Status of petrale sole (*Eopsetta jordani*) along the U.S. west coast in 2019

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Contents

Executive Summary **i**

Stock i
Landings i
Data and Assessment iv
Updated Data iv
Stock Biomass v
Recruitment viii
Exploitation Status x
Ecosystem Considerations xiii
Reference Points xiii
Management Performance xiv
Unresolved Problems and Major Uncertainties xv
Decision Table xvi
Scientific Uncertainty xix
Research and Data Needs xix

1 Introduction **1**

1.1 Basic Information 1
1.2 Life History 2
1.3 Ecosystem Considerations 2
1.4 Historical and Current Fishery Information 2
1.5 Summary of Management History and Performance 4
1.6 Fisheries off Canada and Alaska 5

2 Data 5

2.1 Fishery-Independent Data . . . 6

2.1.1 NWFSC West Coast Groundfish Bottom Trawl Survey . . . 6

2.1.2 AFSC/NWFSC West Coast Triennial Shelf Survey . . . 8

2.2 Fishery-Dependent Data . . . 9

2.2.1 Commercial Fishery Landings . . . 9

2.2.2 Discards . . . 10

2.2.3 Fishery Length and Age Data . . . 11

2.2.4 Historical Commercial Catch-Per-Unit Effort/Logbooks . . . 12

2.2.5 Foreign Landings . . . 12

2.3 Biological Data . . . 13

2.3.1 Natural Mortality . . . 13

2.3.2 Maturation and Fecundity . . . 14

2.3.3 Sex Ratio . . . 14

2.3.4 Length-Weight Relationship . . . 15

2.3.5 Growth (Length-at-Age) . . . 15

2.3.6 Ageing Precision and Bias . . . 15

2.3.7 Environmental and Ecosystem Data . . . 15

3 Assessment Model 16

3.1 Summary of Previous Assessments and Reviews . . . 16

3.1.1 History of Modeling Approaches Used for This Stock . . . 16

3.1.2 Most Recent STAR Panel Recommendations . . . 17

3.1.3 Response to Groundfish Subcommittee Requests . . . 18

3.2 Model Structure and Assumptions . . . 18

3.2.1 Changes Between the 2013, the 2015 Update, and the Current Update Assessment Model . . . 18

3.2.2 Modeling Platform and Bridging Analysis . . . 19

3.2.3 Summary of Fleets and Areas . . . 19

3.2.4 Priors . . . 19

3.2.5 Data Weighting . . . 20

3.2.6 Estimated and Fixed Parameters . . . 20

3.2.7 Key Assumptions and Structural Choices . . . 20

3.3 Base Model Results . . . 21
3.3.1 Parameter Estimates . . . 21
3.3.2 Fits to the Data . . . 22
3.3.3 Population Trajectory . . . 24
3.3.4 Reference Points . . . 24
3.4 Modeling Diagnostics . . . 25
3.4.1 Convergence . . . 25
3.4.2 Sensitivity Analyses . . . 25
3.4.3 Retrospective Analysis . . . 27
3.4.4 Added Data Analysis . . . 27
3.4.5 Historical Analysis . . . 27
3.4.6 Likelihood Profiles . . . 27
3.5 Unresolved Problems and Major Uncertainties . . . 28

4 Harvest Projections and Decision Tables 29

5 Scientific Uncertainty 29

6 Regional Management Considerations 30

7 Research and Data Needs 30
7.1 Items Identified in the Last Assessment . . . 30
7.2 Current Research and Data Needs Identified . . . 31

8 Acknowledgments 32

9 References 33

10 Tables 38

11 Figures 75

12 Appendix A. Detailed Fit to Length Composition Data 192

13 Appendix B. Detailed Fit to Age Composition Data 214

14 Appendix C. List of Auxiliary Files Available 230

Executive Summary

Stock

This assessment reports the status of the petrale sole (*Eopsetta jordani*) off the U.S. coast of California, Oregon, and Washington using data through 2018. While petrale sole are modeled as a single stock, the spatial aspects of the coast-wide population are addressed through geographic separation of data sources/fleets where possible. There is currently no genetic evidence suggesting distinct biological stocks of petrale sole off the U.S. coast. The limited tagging data available to describe adult movement suggests that petrale sole may have some homing ability for deep water spawning sites but also have the ability to move long distances between spawning sites, inter-spawning season, as well as seasonally.

Landings

While records do not exist, the earliest catches of petrale sole are reported in 1876 in California and 1884 in Oregon. In this assessment, fishery removals have been divided among 4 fleets: 1) Winter North trawl, 2) Summer North trawl, 3) Winter South trawl, and 4) Summer South trawl. Landings for the North fleet are defined as fish landed in Washington and Oregon ports. Landings for the South fleet are defined as fish landed in California ports. Recent annual catches between 1981-2018 range between 755 and 3008 mt per year and the most recent year landings are shown in Table a. The landings are summarized into winter and summer fleets where winter is defined as November to February and summer running from March to October. Petrale sole are caught nearly exclusively by trawl fleets; non-trawl gears contribute only a small fraction of the catches across all years.

From the inception of the fishery through the war years, the vast majority of catches occurred between March and October (the summer fishery), when the stock is dispersed over the continental shelf. The post-World War II period witnessed a steady decline in the amount and proportion of annual catches occurring during the summer months (March-October). Conversely, petrale sole catch during the winter season (November-February), when the fishery targets spawning aggregations, has exhibited a steadily increasing trend since the 1940s. From the mid-1980s through the early 2000s, catches during the winter months were roughly equivalent to or exceeded catches throughout the remainder of the year, whereas during the past 10 years, the relative catches during the winter and summer have been more variable across years (Table a). Petrale sole are a desirable market species and discarding has historically been low.

Table a: Landings (mt) and total catch (mt) for the past 10 years for petrale sole by source. The Winter fleets are defined as catches from November - February, Summer fleets from March - October, with the year starting in November (e.g., catches in November and December 2008 were added to the catches occuring in January and February 2009). Total catch reflects the landings plus the model estimated discards based on discard rate data with all discarded fish assumed dead.

Year	Winter (N)	Summer (N)	Winter (S)	Summer (S)	Total Landings	Total Catch
2009	847	642	470	250	2209	2334
2010	264	292	78	121	755	869
2011	224	427	40	78	768	785
2012	410	494	124	108	1135	1153
2013	513	1045	130	280	1967	1995
2014	853	861	273	386	2373	2392
2015	1040	1077	215	354	2686	2704
2016	865	1168	237	235	2506	2523
2017	1142	1271	201	393	3008	3026
2018	957	1262	218	402	2840	2857

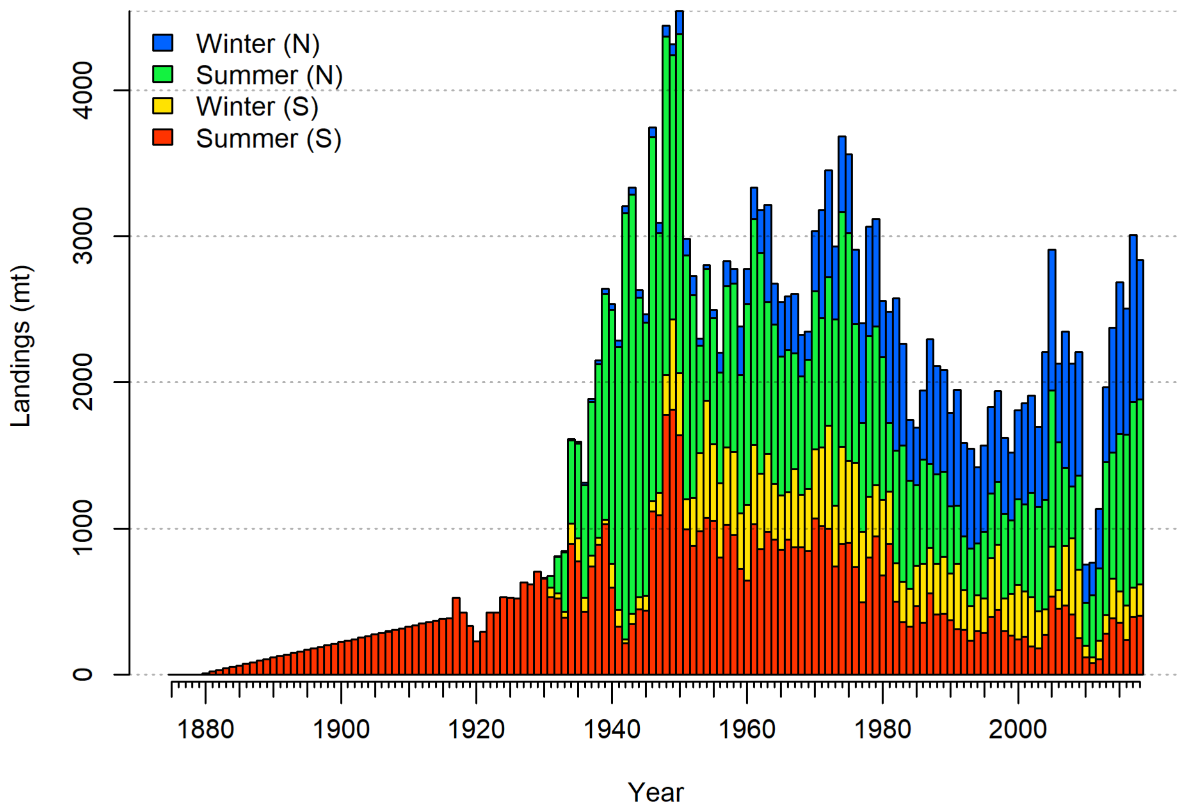

Figure a: Landings of by the Northern and Southern winter and summer fleets off the U.S. west coast. The Winter fleets are defined as catches from November - February, Summer fleets from March - October, with the year starting in November (e.g., catches in November and December 2008 were added to the catches occuring in January and February 2009).

Data and Assessment

This an update assessment for petrale sole, which was last assessed in 2013 and updated in 2015. This update assessment was conducted using the length- and age-structured modeling software Stock Synthesis (version 3.30.13). The coastwide population was modeled allowing separate growth and mortality parameters for each sex (a two-sex model) with the fishing year beginning on November 1 and ending on October 31. The fisheries are structured seasonally based on winter (November to February) and summer (March to October) fishing seasons due to the development and growth of the wintertime fishery, which began in the 1950s. In recent decades, wintertime catches have often exceed summertime catches. The fisheries are modeled as the Winter North and Summer North fleets, where the North includes both Washington and Oregon, and Southern Winter and Southern Summer encompasses California fisheries.

The model includes fishery data in the form of catches, discard rates and average weights, length- and age-frequency data, as well as standardized winter fishery catch-per-unit-effort (CPUE). Biological data are derived from both port and on-board observer sampling programs. The National Marine Fisheries Service (NMFS) AFSC/NWFSC West Coast Triennial Shelf Survey early (1980, 1983, 1986, 1989, 1992) and late period (1995, 1998, 2001, and 2004) and the NWFSC West Coast Groundfish Bottom Trawl Survey (2003-2018) relative biomass indices and biological sampling provide fishery independent information on relative trend and demographics of the petrale sole stock.

Updated Data

The base assessment model structure is consistent with the 2013 assessment and the 2015 update, except as noted here. Modifications from the previous assessment model include:

1. Commercial catches (2015-2018 added);
2. Commercial length and age data (all years reprocessed, 2015-2018 added);
3. Observed discard rates, average weights, and lengths (2002-2017 reprocessed, 2014-2017 added);
4. AFSC/NWFSC West Coast Triennial Shelf Survey early and late indices of abundance and length composition data (1980-2004 reprocessed);
5. NWFSC West Coast Groundfish Bottom Trawl Survey index of abundance, length and age composition data (2003-2018 reprocessed, 2015-2018 added);
6. Model tuning to re-weight data using the McAllister and Iannelli approach (same approach applied in the 2013 assessment);

7. Length-weight relationship parameters estimated outside of the stock assessment model from the NWFSC West Coast Groundfish Bottom Trawl Survey data up to 2018 and input as fixed values;

8. The natural mortality prior for female and male fish was updated; and,

9. Model fitting using latest version of Stock Synthesis (SS v.3.30.13).

Stock Biomass

Petrale sole were lightly exploited during the early 1900s, but by the 1950s, the fishery was well developed with the stock showing declines in biomass and catches (Figures a and b). The rate of decline in spawning biomass accelerated through the 1970s reaching minimums generally around or below 10% of the unexploited levels during the 1980s through the early 2000s (Figure c). The petrale sole spawning stock biomass is estimated to have increased in recent years due to reduced catches during rebuilding and in response to above average recruitment in 2006, 2007, and 2008. The 2019 estimated spawning biomass relative to unfished equilibrium spawning biomass is above the target of 25% of unfished spawning biomass, at 39% (∼ 95% asymptotic interval: ± 28%-50%) (Table b). The standard deviation of the log of the spawning biomass in 2019 is 0.09.

Table b: Recent trend in estimated spawning biomass (mt) and estimated relative spawning biomass.

Year	Spawning Biomass (mt)	~ 95% Confidence Interval	Estimated Relative Spawning Biomass	~ 95% Confidence Interval
2010	4227	3452 - 5002	0.127	0.087 - 0.166
2011	5378	4414 - 6342	0.161	0.111 - 0.211
2012	7205	5958 - 8452	0.216	0.150 - 0.281
2013	9488	7888 - 11087	0.284	0.199 - 0.369
2014	11433	9524 - 13341	0.342	0.241 - 0.443
2015	12691	10603 - 14778	0.380	0.270 - 0.490
2016	13206	11039 - 15374	0.395	0.283 - 0.508
2017	13519	11293 - 15745	0.405	0.292 - 0.518
2018	13365	11077 - 15653	0.400	0.289 - 0.511
2019	13078	10689 - 15467	0.391	0.282 - 0.501

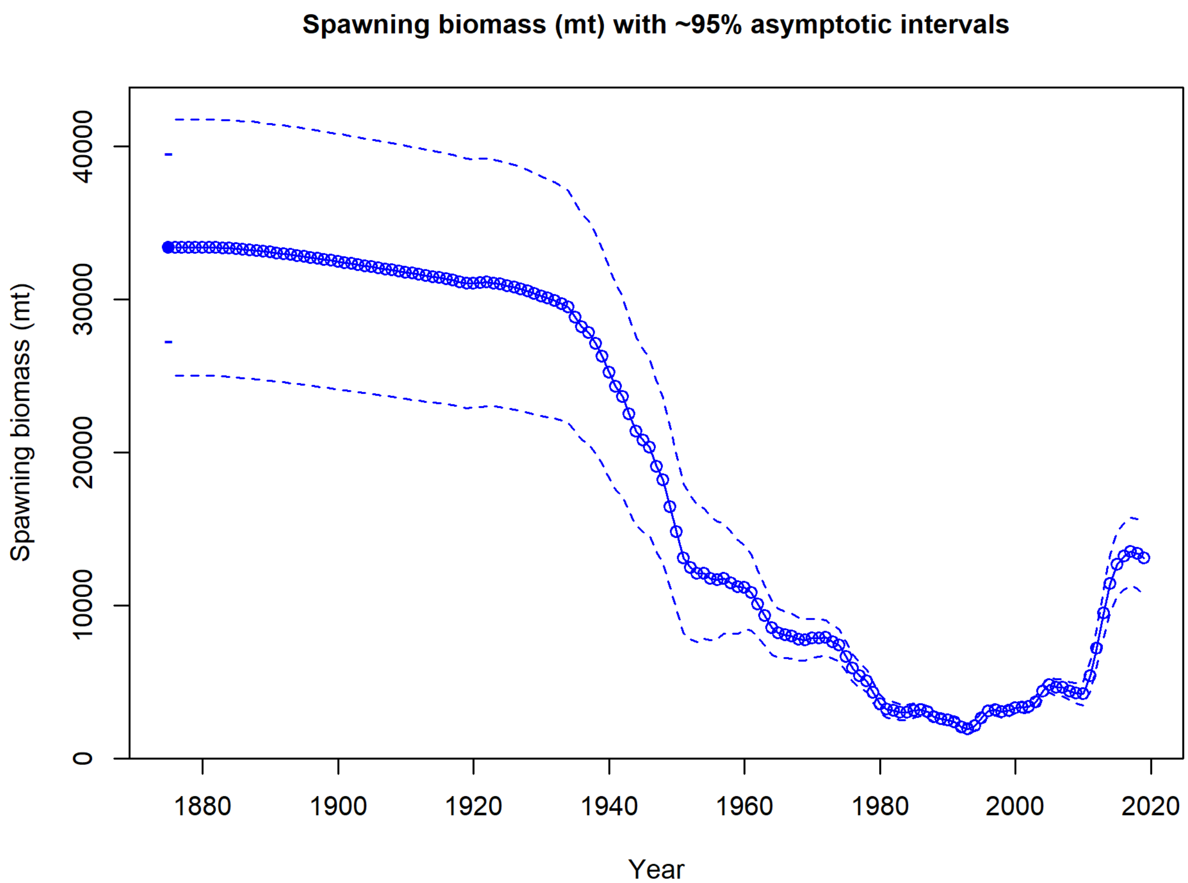

Figure b: Estimated time-series of spawning biomass trajectory (circles and line: median; light broken lines: 95% credibility intervals) for the base assessment model.

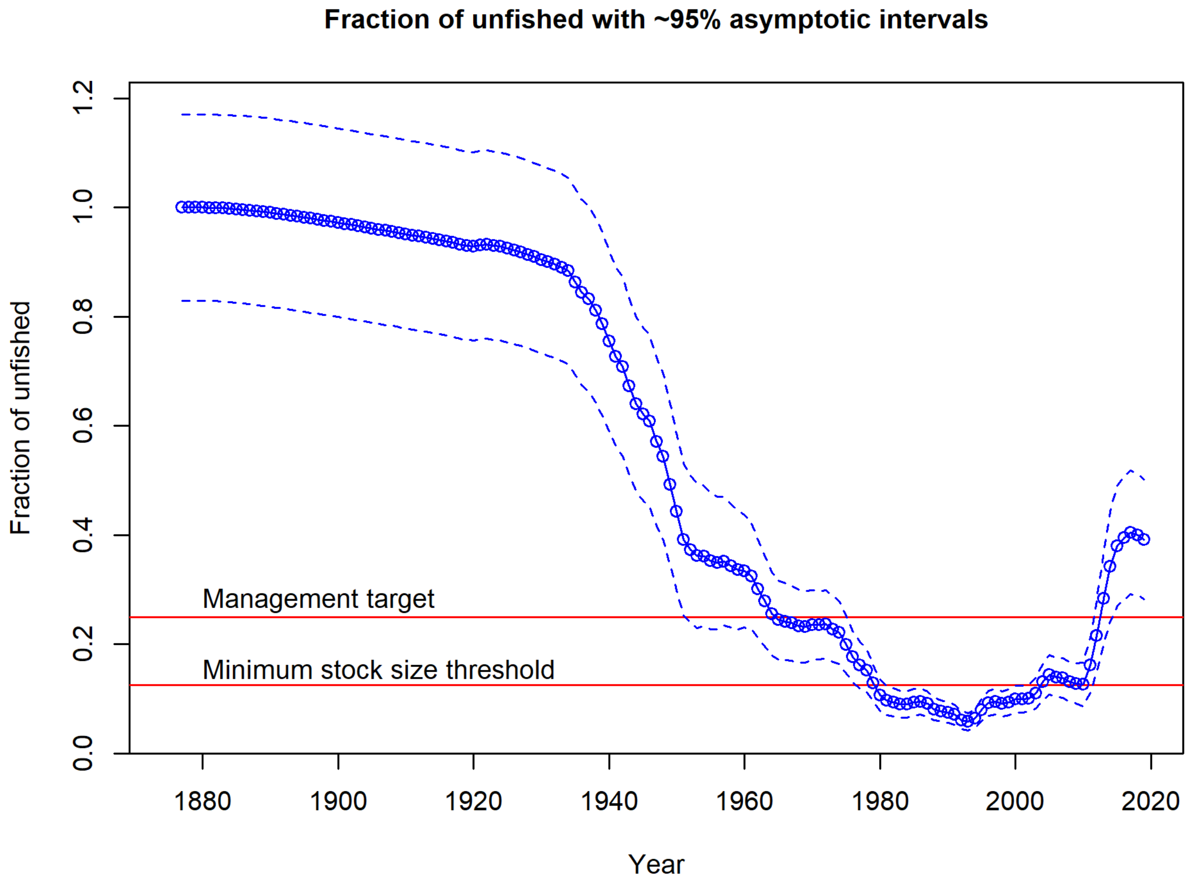

Figure c: Estimated time-series of fraction of unfished spawning biomass (depletion) (circles and line: median; light broken lines: 95% credibility intervals) for the base assessment model.

Recruitment

Annual recruitment was treated as stochastic and estimated as annual deviations from log-mean recruitment, where mean recruitment is the fitted Beverton-Holt stock recruitment curve. The time-series of estimated recruitments shows a relationship with the decline in spawning biomass, punctuated by larger recruitments in 2006, 2007, and 2008 (Figure d). However, recruitment in recent years (2013 - 2017) is estimated to be less than the expected mean recruitment indicating an absence of strong incoming recruitment (Table c).

The five largest estimated recruitments estimated within the model (in ascending order) occurred in 2006, 1998, 1966, 2007, and 2008. The four lowest recruitments estimated within the model (in ascending order) occurred in 1986, 1992, 1987, and 2003.

Table c: Recent estimated trend in recruitment and estimated recruitment deviations determined from the base model. The recruitment deviations for 2018 and 2019 were fixed at zero within the model.

Year	Estimated Recruitment	˜ 95% Confidence Interval	Estimated Recruitment Devs.	˜ 95% Confidence Interval
2010	12637	8002 - 19956	-0.134	-0.446 - 0.177
2011	15344	9888 - 23810	-0.002	-0.288 - 0.283
2012	22946	15296 - 34420	0.339	0.097 - 0.581
2013	13483	8315 - 21863	-0.239	-0.610 - 0.132
2014	13529	8178 - 22379	-0.261	-0.660 - 0.138
2015	12792	7177 - 22801	-0.330	-0.817 - 0.158
2016	16460	8550 - 31688	-0.102	-0.674 - 0.469
2017	16517	7577 - 36006	-0.122	-0.853 - 0.610
2018	19018	8362 - 43254	0.000	-0.784 - 0.784
2019	18972	8346 - 43127	0.000	-0.784 - 0.784

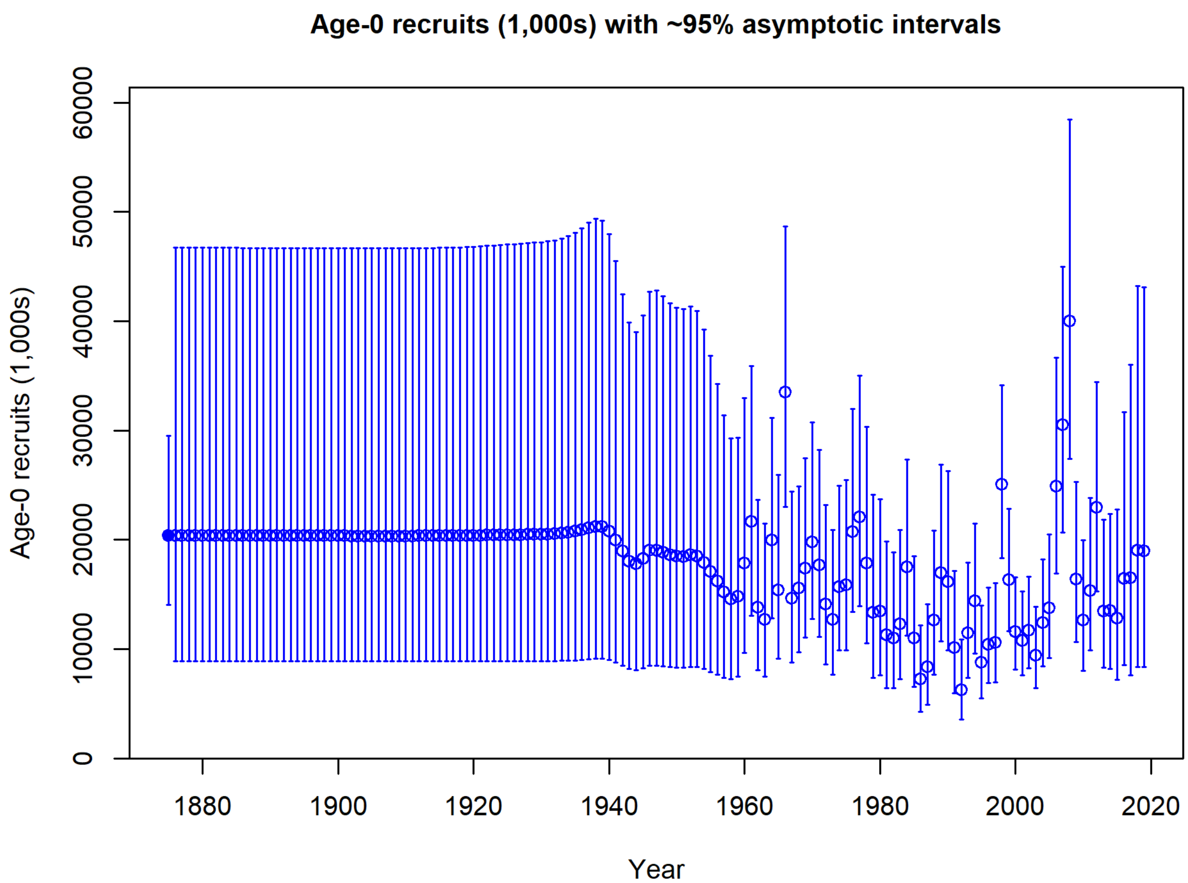

Figure d: Time-series of estimated petrale sole recruitments for the base model with 95% confidence or credibility intervals.

Exploitation Status

The relative spawning biomass of petrale sole was estimated to have dropped below the management target (25%) for the first time in 1965. The stock continued to decline and first fell below the minimum stock size threshold level of 12.5% in 1980 (although, at the time the management target and thresholds were not set at the current values of 25% and 12.5%). The relative spawning biomass reached its lowest level in 1993 at 5.8%, with the stock remaining around the threshold stock size until approximately 2010. In 2009 petrale sole was formally declared overfished. Fishing mortality rates sharply declined during the rebuilding period, relative to rates in previous years, which exceeded the target (Figure e). The 2015 update stock assessment estimated the stock to have rebuilt to the management target (25%) in 2014. This update estimates that the relative spawning biomass exceeded 25% in 2013 with harvest rates in the most recent years remaining under of the target rate (Table d and Figures e and f).

Table d: Recent trend in spawning potential ratio 1-SPR and summary exploitation rate for age 3+ biomass for petrale sole.

Year	1-SPR	~ 95% Confidence Interval	Exploitation Rate	~ 95% Confidence Interval
2009	0.793	0.724 - 0.861	0.232	0.190 - 0.273
2010	0.570	0.469 - 0.670	0.075	0.060 - 0.091
2011	0.498	0.399 - 0.597	0.051	0.041 - 0.061
2012	0.515	0.419 - 0.612	0.061	0.049 - 0.072
2013	0.584	0.491 - 0.677	0.092	0.076 - 0.108
2014	0.578	0.485 - 0.670	0.103	0.085 - 0.120
2015	0.580	0.489 - 0.672	0.110	0.092 - 0.129
2016	0.549	0.458 - 0.640	0.102	0.085 - 0.119
2017	0.584	0.495 - 0.673	0.122	0.102 - 0.143
2018	0.573	0.484 - 0.662	0.119	0.098 - 0.140

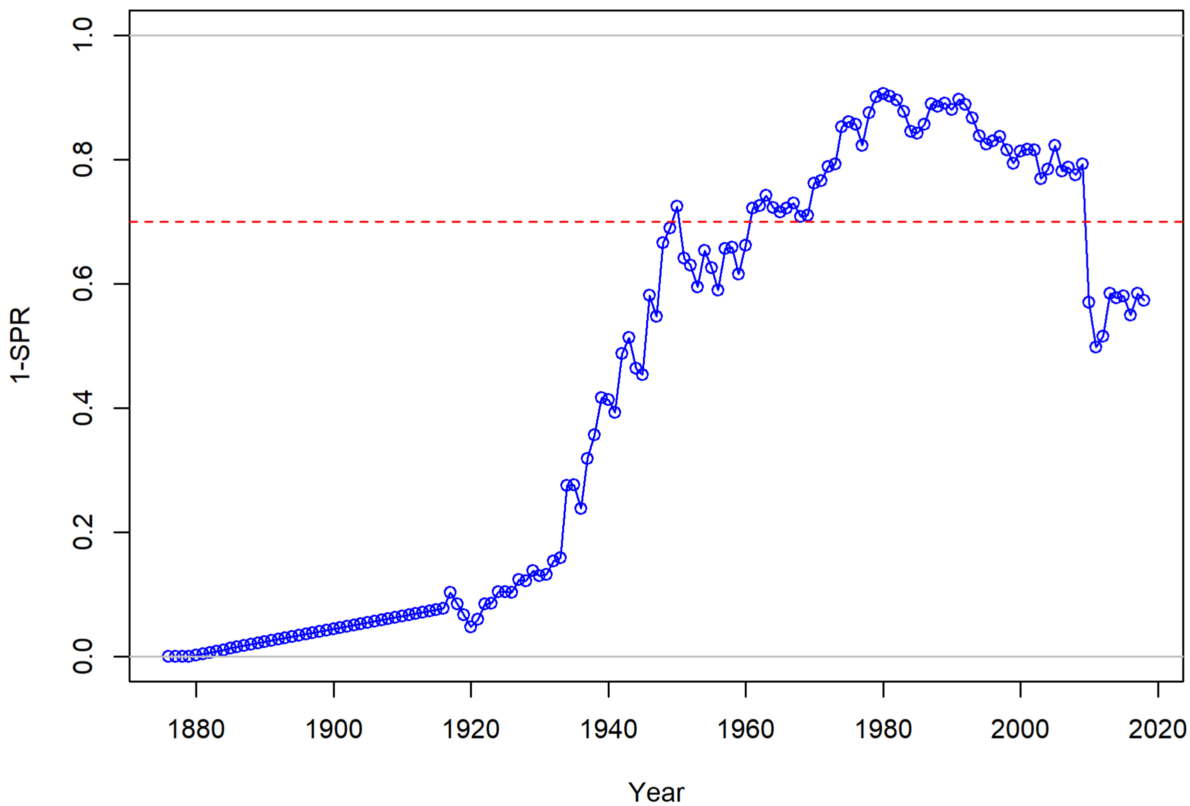

Figure e: Estimated relative spawning potential ratio 1-SPR for the base model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the SPR30% harvest rate. The last year in the time-series is 2018.

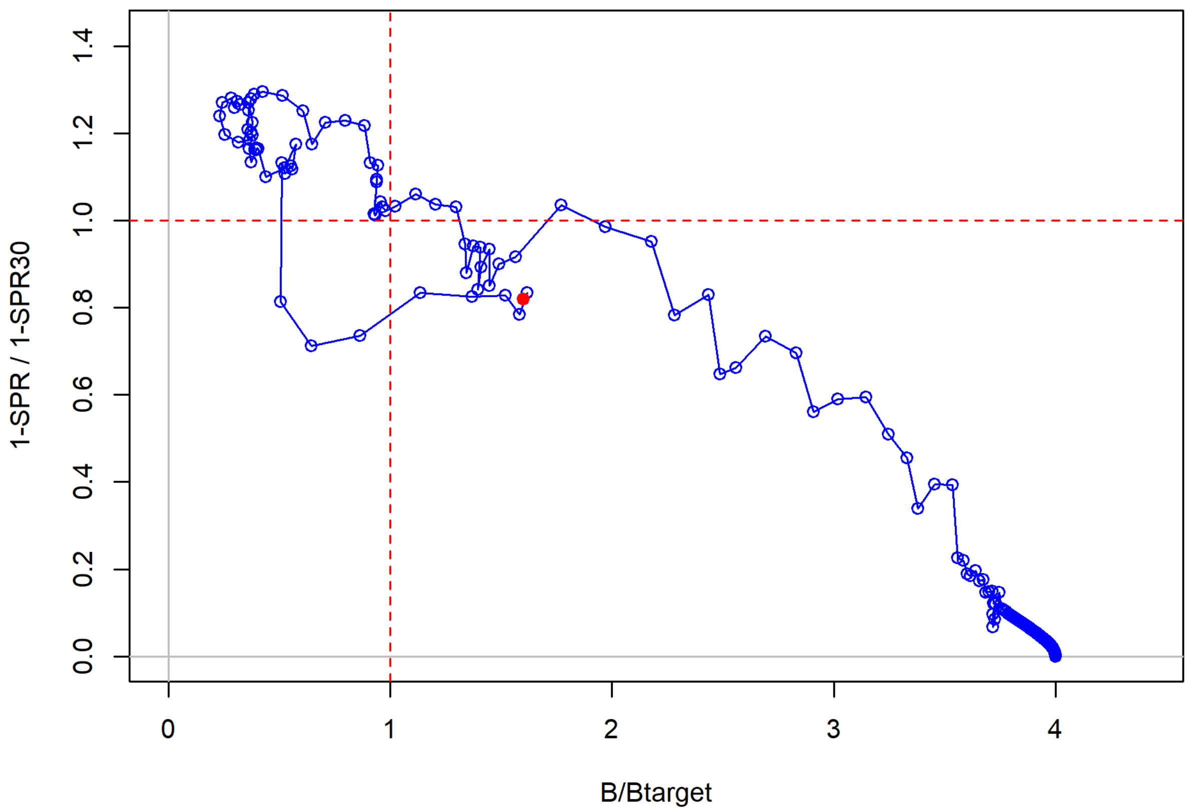

Figure f: Phase plot of estimated 1-SPR(%) vs. relative spawning biomass (B/Btarget) for the base case model. The red circle indicates 2018 estimated status and exploitation for petrale sole.

Ecosystem Considerations

Ecosystem factors have not been explicitly modeled in this assessment, but there are several aspects of the California current ecosystem that may impact petrale sole population dynamics and warrant further research. Castillo (1992) and Castillo et al. (1995) suggest that density-independent survival of early life stages is low and show that offshore Ekman transportation of eggs and larvae may be an important source of variation in year-class strength in the Columbia INPFC area. The effects of the Pacific Decadal Oscillation on California current temperature and productivity (Mantua et al. 1997) may also contribute to non-stationary recruitment dynamics for petrale sole. The prevalence of a strong late 1990s year-class for many West Coast groundfish species suggests that environmentally driven recruitment variation may be correlated among species with relatively diverse life history strategies. Although current research efforts along these lines are limited, a more explicit exploration of ecosystem processes may be possible in future petrale sole stock assessments if resources are available for such investigations.

Reference Points

This update stock assessment estimates that the spawning biomass of petrale sole is above the management target. Due to reduced landings and a series of above average recruitments (2006, 2007, and 2008), an increasing trend in spawning biomass was estimated in the base model from 2011 - 2017, with a decline in biomass in the most recent years (2018 and 2019) as the biomass of the above average cohorts declines. The estimated relative spawning biomass in 2019 is 39% ($\sim$ 95% asymptotic interval: $\pm$ 28%-50%), corresponding to an spawning biomass of 13,078 mt ($\sim$ 95% asymptotic interval: 10,689-15,467 mt) (Table e). Unfished age 3+ biomass was estimated to be 54,086.6 mt in the base model.

The target spawning biomass based on the biomass target ($SB_{25\%}$) is 8,351.5 mt, with an equilibrium catch of 3,148.5 mt (Table e). Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $SPR_{30\%}$ is 3,135.2 mt. Estimated MSY catch is at 3,156.7 spawning biomass of 7,563.3 mt (22.6% relative spawning biomass).

Table e: Summary of reference points and and management quantities, including estimated confidence intervals (CI), for the base case.

Quantity	**Estimate**	**~2.5% CI**	**~97.5% CI**
Unfished spawning biomass (mt)	33405.9	27188.1	39623.7
Unfished age 3+ biomass (mt)	54086.6	45524.9	62648.3
Unfished recruitment (R0, thousands)	20361.1	12720.2	28002
Spawning biomass(2019 mt)	13077.7	10688.8	15466.6
Relative spawning biomass (depletion) (2019)	0.391	0.282	0.501
Reference points based on $\mathbf{SB_{25\%}}$			
Proxy spawning biomass ($B_{25\%}$)	8351.5	6797	9905.9
SPR resulting in $B_{25\%}$ ($SPR_{B25\%}$)	0.285	0.26	0.31
Exploitation rate resulting in $B_{25\%}$	0.182	0.163	0.2
Yield with $SPR_{B25\%}$ at $B_{25\%}$ (mt)	3148.5	2887.6	3409.4
Reference points based on SPR proxy for MSY			
Spawning biomass	8866.2	6954.6	10777.7
$SPR_{30\%}$			
Exploitation rate corresponding to $SPR_{30\%}$	0.173	0.147	0.198
Yield with $SPR_{30\%}$ at SB_{SPR} (mt)	3135.2	2849.4	3420.9
Reference points based on estimated MSY values			
Spawning biomass at MSY (SB_{MSY})	7563.3	5677.6	9448.9
SPR_{MSY}	0.263	0.202	0.323
Exploitation rate at MSY	0.196	0.166	0.227
MSY (mt)	3156.7	2909.6	3403.8

Management Performance

The 2009 stock assessment estimated petrale sole to be at 11.6% of unfished spawning stock biomass. Based on the 2009 stock assessment, the 2010 coast-wide ACL was reduced to 1,200 mt to reflect the overfished status of the stock and the 2011 coast-wide overfishing limit (OFL) and ACL were set at 1,021 mt and 976 mt, respectively (Table f).

Recent coast-wide annual landings have not exceeded the ACL. The 2009, 2011, and 2013 full assessments estimated that petrale sole have been below the management target since the 1960s and below the overfished threshold between the early 1980s and 2009 with fishing mortality rates in excess of the current F-target for flatfish of $SPR_{30\%}$. The 2015 update assessment estimated that the stock had recovered with the relative spawning biomass exceeding the management target.

Table f: Recent trend in total catch and landings (mt) relative to the management guidelines. Estimated total catch reflect the landings plus the model estimated discards based on discard rate data. The catch values shown here may have minimal differences from the West Coast Groundfish Total Mortality Estimates.

Year	OFL (mt; ABC prior to 2011)	ACL (mt; OY prior to 2011)	Total Landings (mt)	Estimated Total Catch (mt)
2009	2811	2433	2209	2334
2010	2751	1200	755	869
2011	1021	976	768	785
2012	1275	1160	1135	1153
2013	2711	2592	1967	1995
2014	2774	2652	2373	2392
2015	3073	2816	2686	2704
2016	3208	2910	2506	2523
2017	3208	3136	3008	3026
2018	3152	3013	2840	2857

Unresolved Problems and Major Uncertainties

Parameter uncertainty is explicitly captured in the asymptotic confidence intervals reported throughout this assessment for key parameters and management quantities. These intervals reflect the uncertainty in the model fit to the data sources included in the assessment, but do not include uncertainty associated with alternative model configurations, weighting of data sources (a combination of input sample sizes and relative weighting of likelihood components), or fixed parameters.

There are a number of major uncertainties regarding model parameters that have been explored via sensitivity analysis. The most notable explorations involved the sensitivity of model estimates to:

1. The stocks rapid increase in biomass since 2010 was driven by reduced catches and three strong year-classes, 2006-2008, entering the population. In recent years, strong recruitments in a single year have been observed leading to sharp increases in biomass in other West Coast groundfish stocks. However, the observation of three subsequent strong recruitments has not been commonly observed in other stocks and the specific mechanisms that led to these three strong-year classes are currently unknown.

2. The value of natural mortality by sex. Natural mortality by sex and steepness are uncertain for petrale sole. Currently, both natural mortality and steepness are estimated within the model and are negatively correlated. This provides information regarding these parameters combined values, but there is large uncertainty regarding the value of each parameter individually.

3. New fecundity data for petrale sole supports a fecundity relationship that differs from the current assumption (fecundity equals body weights) in this update assessment. A

sensitivity to the new data results in a less optimistic estimate of relative spawning biomass, declining to 35

4. Additionally, a reconstructed historical Washington catch history has not been included in the petrale sole stock assessment. Washington state is currently undergoing efforts to determine historical catches for petrale sole and the next stock assessment is likely to incorporate these new historical catch estimates.

Decision Table

The forecast of stock abundance and yield was developed using the base model. The total catches in 2019 and 2020 are set equal to the ACL (e.g., for petrale sole the ACL equals the ABC) each year at 2,908 mt and 2,845 mt, respectively. The exploitation rate for 2021 and beyond is based upon an SPR of 30% and the 25:5 harvest control rule. The average exploitation rates, across recent years, by fleet as provided by the GMT were used to distribute catches during the forecast period.

The catches during the forecasted period are projected from the base model, assuming a P* value of 0.45, start at 4,115 mt in 2021 and decline to 3,093 mt in 2030 as the stock declines towards the target spawning biomass (Table g). The projections assume full ABC removals.

The 2013 assessment and the 2015 update assessment set the axis-of-uncertainty in the decision tables around the uncertainty about female natural mortality. This update assessment also explores the uncertainty in female natural mortality in the decision table. Uncertainty in the forecasts is based upon the uncertainty around the 2019 spawning biomass, $\sigma = 0.09$. The low and high values for female natural mortality, M, were selected to result in a spawning biomass in 2019 that was equal to the 12.5 and 87.5% quantiles of the normal distribution given the maximum likelihood estimate and the asymptotic uncertainty. The female natural mortality values that corresponded with the lower and upper quantiles were 0.105 yr^{-1} and 0.205 yr^{-1}.

Three alternative catch streams were created for the decision table. The first option uses ABC values based on a category 1 σ_y starting at 0.50 and increasing annually combined with a P* value of 0.45. The second option uses the same category σ_y values but applies a P* of 0.40. Both of the first two options assume full attainment of the catch values. The final option, employees a fixed catch approach where catches slowly step down during the 10-year projection period.

Across the low and high states of nature and across alternative future harvest scenarios the relative spawning biomass (depletion) ranges between 0.193 - 0.384 by the end of the 10-year projection period (Table h).

Table g: Projections of potential OFLs (mt), ABCs (mt), estimated spawning biomass and relative spawning biomass. The 2019 and 2020 ABC and OFL values shown are based on current harvest specifications, rather than the updated model estimates. The ABC and buffer values for 2021-2030 were calculated using a P* value of 0.45.

Year	Buffer	OFL	ABC	Removals	Spawning Biomass (mt)	Relative Biomass
2019	1	3042.0	2908.0	2908.0	13078	0.391
2020	1	2976.0	2845.0	2845.0	12558	0.376
2021	0.935	4401.5	4115.4	4115.4	12019	0.360
2022	0.93	3935.7	3660.2	3660.2	10799	0.323
2023	0.926	3633.9	3365.0	3365.0	10038	0.300
2024	0.922	3469.7	3199.0	3199.0	9655	0.289
2025	0.917	3402.3	3119.9	3119.9	9523	0.285
2026	0.913	3392.0	3096.9	3096.9	9527	0.285
2027	0.909	3406.2	3096.3	3096.3	9580	0.287
2028	0.904	3425.5	3096.6	3096.6	9635	0.288
2029	0.9	3441.7	3097.5	3097.5	9677	0.290
2030	0.896	3452.1	3093.1	3093.1	9701	0.290
2019	0.892	3042.0	2908.0	2908.0	13078	0.391

Table h: Decision table summary of 10-year projections beginning in 2021 for alternate states of nature based on an axis of uncertainty about female natural mortality for the base model. Columns range over low, mid, and high states of nature, and rows range over different assumptions of catch levels. The ABC catch stream is based on the equilibrium yield applying the SPR30 harvest rate.

			States of nature					
			M = 0.105		M = 0.159		M = 0.205	
	Year	Catch	Spawning Biomass	Depletion	Spawning Biomass	Depletion	Spawning Biomass	Depletion
ABC P* 0.45	2019	2908.0	11681	0.278	13078	0.391	14524	0.509
	2020	2845.0	11425	0.271	12558	0.376	13729	0.481
	2021	4115.4	11110	0.264	12019	0.360	12963	0.455
	2022	3660.2	10005	0.238	10799	0.323	11614	0.407
	2023	3365.0	9244	0.220	10038	0.300	10820	0.379
	2024	3199.0	8773	0.208	9655	0.289	10462	0.367
	2025	3119.9	8507	0.202	9523	0.285	10381	0.364
	2026	3096.9	8362	0.199	9527	0.285	10434	0.366
	2027	3096.3	8276	0.197	9580	0.287	10520	0.369
	2028	3096.6	8213	0.195	9635	0.288	10588	0.371
	2029	3097.5	8158	0.194	9677	0.290	10624	0.373
	2030	3093.1	8103	0.193	9701	0.290	10633	0.373
ABC P* 0.40	2019	2908.0	11681	0.278	13078	0.391	14524	0.509
	2020	2845.0	11425	0.271	12558	0.376	13729	0.481
	2021	3842.5	11110	0.264	12019	0.360	12963	0.455
	2022	3454.7	10174	0.242	10961	0.328	11772	0.413
	2023	3202.3	9540	0.227	10315	0.309	11081	0.389
	2024	3059.6	9168	0.218	10012	0.300	10791	0.378
	2025	2993.9	8981	0.213	9941	0.298	10755	0.377
	2026	2972.6	8906	0.212	9993	0.299	10841	0.380
	2027	2970.6	8887	0.211	10091	0.302	10958	0.384
	2028	2976.1	8891	0.211	10194	0.305	11058	0.388
	2029	2974.2	8900	0.211	10280	0.308	11126	0.390
	2030	2967.7	8913	0.212	10351	0.310	11168	0.392
Step-down in catch	2019	2908.0	11681	0.278	13078	0.391	14524	0.509
	2020	2845.0	11425	0.271	12558	0.376	13729	0.481
	2021	3600.0	11110	0.264	12019	0.360	12963	0.455
	2022	3600.0	10324	0.245	11105	0.332	11912	0.418
	2023	3300.0	9602	0.228	10369	0.310	11127	0.390
	2024	3300.0	9168	0.218	10008	0.300	10776	0.378
	2025	3100.0	8835	0.210	9803	0.293	10608	0.372
	2026	3100.0	8692	0.207	9804	0.293	10644	0.373
	2027	3000.0	8594	0.204	9846	0.295	10707	0.376
	2028	3000.0	8580	0.204	9951	0.298	10812	0.379
	2029	3000.0	8576	0.204	10046	0.301	10890	0.382
	2030	3000.0	8577	0.204	10124	0.303	10939	0.384

Scientific Uncertainty

The estimated uncertainty in the base model around the 2019 spawning biomass is $\sigma = 0.09$ compared to the uncertainty in the base model around the 2019 OFL of $\sigma = 0.18$.

Research and Data Needs

Progress on a number of research topics and data issues would substantially improve the ability of this assessment to reliably and precisely model petrale sole population dynamics in the future:

1. In the past many assessments have derived historical catches independently. The states of California and Oregon have completed comprehensive historical catch reconstructions. At the time of this assessment, a comprehensive historical catch reconstruction is not available for Washington. Completion of a Washington catch reconstruction would provide the best possible estimated catch series that accounts for all the catch and better resolves historical catch uncertainty for flatfish as a group.

2. Due to limited data, new studies on the maturity at length or age for petrale sole would be beneficial.

3. Where possible, historical otolith samples aged using a combination of surface and break-and-burn methods should be re-aged using the break-and-burn method. Early surface read otoliths should also be re-aged using the break-and-burn method. Historical otoliths aged with a standard method will allow the further evaluation of the potential impacts of consistent under ageing using surface methods, changes in selectivity during early periods of time without any composition information, and potential changes in growth.

4. Studies on stock structure and movement of petrale sole, particularly with regard to the winter-summer spawning migration of petrale sole and the likely trans-boundary movement of petrale sole between U.S. and Canadian waters seasonally.

5. The extent of spatial variability on productivity processes such as growth, recruitment, and maturity is currently unknown and would benefit from further research.

6. The analytical solution for catchability (i.e., observed / predicted biomass) for the NWFSC West Coast Groundfish Bottom Trawl Survey is well above 1.0 in the base model. This was also observed in the 2013 full and the 2015 update assessments. This is not currently well understood and future explorations would be useful to understand the catchability of petrale sole off the West Coast.

Table i: Base model results summary.

Quantity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
OFL (mt)	2751	1021	1275	2711	2774	3073	3208	3208	3152	3042
ACL (mt)	1200	976	1160	2592	2652	2816	2910	3136	3013	2921
Landings (mt)	755	768	1135	1967	2373	2686	2506	3008	2840	
Total Est. Catch (mt)	869	785	1153	1995	2392	2704	2523	3026	2857	
1-SPR	0.570	0.498	0.515	0.584	0.578	0.580	0.549	0.584	0.573	
Exploitation rate	0.075	0.051	0.061	0.092	0.103	0.110	0.102	0.122	0.119	
Age 3+ biomass (mt)	11515.0	15463.3	18960.3	21683.2	23276.7	24487.5	24741.5	24774.1	23996.7	23350.8
Spawning Biomass	4227	5378	7205	9488	11433	12691	13206	13519	13365	13078
95% CI	3452 - 5002	4414 - 6342	5958 - 8452	7888 - 11087	9524 - 13341	10603 - 14778	11039 - 15374	11293 - 15745	11077 - 15653	10689 - 15467
Relative Depletion	0.127	0.161	0.216	0.284	0.342	0.380	0.395	0.405	0.400	0.391
95% CI	0.087 - 0.166	0.111 - 0.211	0.150 - 0.281	0.199 - 0.369	0.241 - 0.443	0.270 - 0.490	0.283 - 0.508	0.292 - 0.518	0.289 - 0.511	0.282 - 0.501
Recruits	12637	15344	22946	13483	13529	12792	16460	16517	19018	18972
95% CI	8002 - 19956	9888 - 23810	15296 - 34420	8315 - 21863	8178 - 22379	7177 - 22801	8550 - 31688	7577 - 36006	8362 - 43254	8346 - 43127

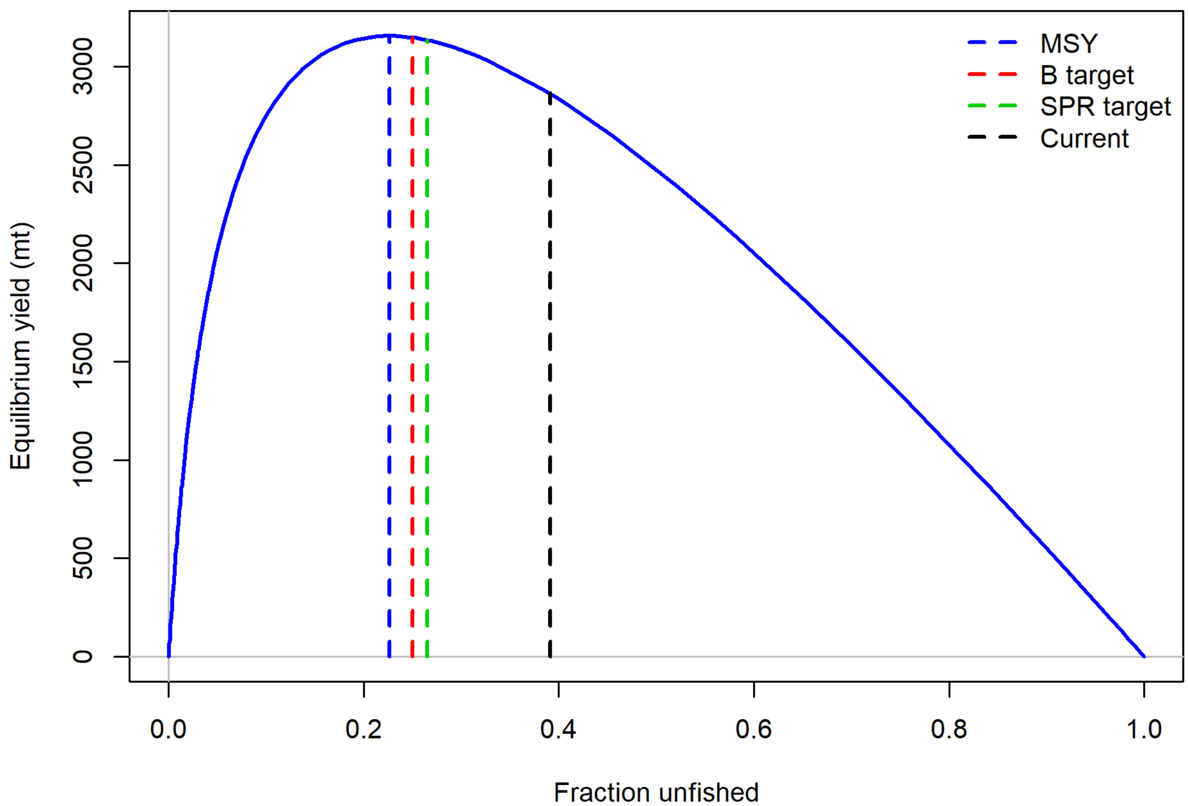

Figure g: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness estimated at 0.84.

1 Introduction

1.1 Basic Information

Petrale sole (*Eopsetta jordani*) is a right-eyed flounder in the family Pleuronectidae ranging from the western Gulf of Alaska to the Coronado Islands, northern Baja California (Kramer et al. 1995, Love et al. 2005) with a preference for soft substrates at depths ranging from 0-550 m (Love et al. 2005). Common names include brill, California sole, Jordan's flounder, cape sole, round nose sole, English sole, soglia, petorau, nameta, and tsubame garei (Smith 1937, Gates and Frey 1974, Eschmeyer and Herald 1983, Love 1996). In northern and central California petrale sole are dominant on the middle and outer continental shelf. PacFIN fishery logbook data show that adults are caught in depths from 18 to 1,280 m off the U.S. West Coast with a majority of the catches of petrale sole being taken between 70-220 m during March through October, and between 290-440 m during November through February.

Past assessments completed by Demory (1984), Turnock et al. (1993), and Sampson and Lee (1999) considered petrale sole in the Columbia and U.S.-Vancouver INPFC areas a single stock. Sampson and Lee (1999) assumed that petrale sole in the Eureka and Monterey INPFC areas represented two additional distinct stocks. The 2005 petrale sole assessment assumed two stocks, northern (U.S.-Vancouver and Columbia INPFC areas) and southern (Eureka, Monterey and Conception INPFC areas), to maintain continuity with previous assessments. Three stocks (West Coast Vancouver Island, Queen Charlotte Sound, and Heceta Strait) are considered for petrale sole in the waters off British Columbia, Canada (Starr and Fargo 2004). The 2009, 2011, 2013, and 2015 assessments integrate the previously separate north-south assessments to provide a coast-wide status evaluation. The decision to conduct a single-area assessment is based on strong evidence of a mixed stock from tagging studies, a lack of genetic studies on stock structure, and a lack of evidence for differences in growth between the 2005 northern and southern assessment areas and from examination of the fishery size-at-age data, as well as confounding differences in data collection between Washington, Oregon, and California. This 2019 update assessment provides a coast-wide status evaluation for petrale sole using data through 2018.

Fishing fleets are separated both geographically and seasonally to account for spatial and seasonal patterns in catch given the coast-wide assessment area. The petrale sole fisheries possess a distinct seasonality, with catches peaking during the winter months, so the fisheries are divided into winter (November-February) and summer (March-October) fisheries. Note that the "fishing year" for this assessment (November 1 to October 31 with catches from November and December being added to the subsequent model year) differs from the standard calendar year. The U.S.-Canadian border is the northern boundary for the assessed stock, although the basis for this choice is due to political and current management needs rather than the population dynamics. Given the lack of clear information regarding the status of distinct biological populations, this assessment treats the U.S. petrale sole resource from the Mexican border to the Canadian border as a single coast-wide stock.

1.2 Life History

Petrale sole spawn during the winter at several discrete deep water sites (270-460 m) off the U.S. West Coast, from November to April, with peak spawning taking place from December to February (Harry 1959, Best 1960, Gregory and Jow 1976, Castillo et al. 1993, Reilly et al. 1994, Love 1996). Females spawn once each year and fecundity varies with fish size, with one large female laying as many as 1.5 million eggs (Porter 1964). Petrale sole eggs are planktonic, ranging in size from 1.2 to 1.3 mm, and are found in deep water habitats at water temperatures of 4-10 °C and salinities of 25-30 ppt (Best 1960, Ketchen and Forrester 1966, Alderdice and Forrest 1971, Gregory and Jow 1976). The duration of the egg stage can range from approximately 6 to 14 days (Alderdice and Forrest 1971, Love 1996). The most favorable conditions for egg incubation and larval growth are 6-7 °C and 27.5-29.5 ppt (Ketchen and Forrester 1966, Alderdice and Forrest 1971, Castillo 1995).

Adult petrale sole achieve a maximum size of around 50 cm and 63 cm for males and females, respectively (Best 1963, Pedersen 1975). The maximum length reported for petrale sole is 70 cm (Eschmeyer and Herald 1983, Love et al. 2005) while the maximum observed break-and-burn age is 34 years (observed in 2003 by the NWFSC West Coast Groundfish Bottom Trawl Survey survey).

1.3 Ecosystem Considerations

Ecosystem factors have not been explicitly modeled in this assessment, but there are several aspects of the California current ecosystem that may impact petrale sole population dynamics and warrant further research. Castillo (1992) and Castillo et al. (1995) suggest that density-independent survival of early life stages is low and show that offshore Ekman transportation of eggs and larvae may be an important source of variation in year-class strength in the Columbia INPFC area. The effects of the Pacific Decadal Oscillation on California current temperature and productivity (Mantua et al. 1997) may also contribute to non-stationary recruitment dynamics for petrale sole. The prevalence of a strong late 1990s year-class for many West Coast groundfish species suggests that environmentally driven recruitment variation may be correlated among species with relatively diverse life history strategies. Although current research efforts along these lines are limited, a more explicit exploration of ecosystem processes may be possible in future petrale sole stock assessments if resources are available for such investigations.

1.4 Historical and Current Fishery Information

Petrale sole have been caught in the flatfish fishery off the U.S. Pacific coast since the late 19th century. The fishery first developed off of California where, prior to 1876, fishing in San Francisco Bay was by hand or set lines and beach seining (Scofield 1948). By 1880 two San

Francisco based trawler companies were running a total of six boats, extending the fishing grounds beyond the Golden Gate Bridge northward to Point Reyes (Scofield 1948). Steam trawlers entered the fishery during 1888 and 1889, and four steam tugs based out of San Francisco were sufficient to flood market with flatfish (Scofield 1948). By 1915 San Francisco and Santa Cruz trawlers were operating at depths of about 45-100 m with catches averaging 10,000 lbs per tow or 3,000 lbs per hour (Scofield 1948). Flatfish comprised approximately 90% of the catch with 20-25% being discarded as unmarketable (Scofield 1948). During 1915 laws were enacted that prohibited dragging in California waters and making it illegal to possess a trawl net from Santa Barbara County southward (Scofield 1948). By 1934 twenty 56-72 foot diesel engine trawlers operated out of San Francisco fishing between about 55 and 185 m (Scofield 1948). From 1944-1947 the number of California trawlers fluctuated between 16 and 46 boats (Scofield 1948). Although the flatfish fishery in California was well developed by the 1950s and 1960s, catch statistics were not reported until 1970 (Heimann and Carlisle 1970). In this early California report petrale sole landings during 1916 to 1930 were not separated from the total flatfish landings.

The earliest trawl fishing off Oregon began during 1884-1885, and the fishery was solidly established by 1937, with the fishery increasing rapidly during WWII (Harry and Morgan, 1961). Initially trawlers stayed close to the fishing grounds adjacent to Newport and Astoria, operating at about 35-90 m between Stonewall Bank and Depoe Bay. Fishing operations gradually extended into deep water. For example, Newport-based trawlers were commonly fishing at about 185 m in 1949, at about 185-365 m by 1952, and at about 550 m by 1953.

Alverson and Chatwin (1957) describe the history of the petrale sole fishery off of Washington and British Columbia with fishing grounds ranging from Cape Flattery to Destruction Island. Petrale sole catches off of Washington were small until the late 1930s with the fishery extending to about 365 m following the development of deep water rockfish fisheries during the 1950s.

By the 1950s the petrale sole fishery was showing signs of depletion with reports suggesting that petrale sole abundance had declined by at least 50% from 1942 to 1947 (Harry 1956). Sampson and Lee (1999) reported that three fishery regulations were implemented during 1957-67: 1) a winter closure off Oregon, Washington and British Columbia, 2) a 3,000 lb per trip limit, and 3) no more than two trips per month during 1957. With the 1977 enactment of the Magnuson Fishery Conservation and Management Act (MFCMA) the large foreign-dominated fishery that had developed since the late 1960s was replaced by the domestic fishery that continues today. Petrale sole are harvested almost exclusively by bottom trawls in the U.S. West Coast groundfish fishery. Recent petrale sole catches exhibit marked seasonal variation, with substantial portions of the annual harvest taken from the spawning grounds during December and January. Evidence suggests that the winter fishery on the deep water spawning grounds developed sporadically during the 1950s and 1960s as fishers discovered new locations (e.g., Alverson and Chatwin (1957); Ketchen and Forrester (1966)). Both historical and current petrale sole fisheries have primarily relied upon trawl fleets.

Historical landings reconstructions show peak catches from the summer fishery occurred during the 1940s and 1950s and subsequently declined, during which time the fleet moved to fishing in deeper waters during the winter. After the period of peak landings during the 1940s and 1950s, total landings were somewhat stable until about the late 1970s, and then generally declined until the mid-2000s. (Table 1 and Figure 1). During 2009 the fishery was declared overfished and during 2010 management restrictions limited the catch to 755 mt (Table 1 and Figure 1). Recent years overfishing limit (OFL), annual catch limit (ACL), landings, and estimated total dead are shown in Table 2.

1.5 Summary of Management History and Performance

Beginning in 1983 the Pacific Fishery Management Council (PFMC) established coast-wide annual catch limits (ACLs) for the annual harvests of petrale sole in the waters off the U.S. West Coast. The first assessment of West Coast petrale sole occurred in 1984 (Demory 1984). Based on the 1999 assessment a coast-wide ACL of 2,762 mt was specified and remained unchanged between 2001 and 2006.

The 2005 assessment of petrale sole stock assessment split the stock into two areas, the northern area that included U.S.-Vancouver and Columbia INPFC areas and the southern area that included the Eureka, Monterey and Conception INPFC areas (Lai et al. 2005). While petrale sole stock structure is not well understood, CPUE and geographical differences between states were used to support the use of two separate assessment areas. In 2005 petrale sole were estimated to be at 34 and 29% of unfished spawning stock biomass in the northern and southern areas, respectively. In spite of different models and data, the biomass trends were qualitatively similar in both areas, providing support for a coast-wide stock. This assessment estimated that petrale sole had historically been below the PFMC's current minimum stock size threshold, 25% of unfished biomass, from the mid-1970s until just prior to the completion of the assessment, with estimated harvest rates in excess of the target fishing mortality rate implemented for petrale sole at that time ($F_{40\%}$). However, the 2005 stock assessment determined that the stock was in the precautionary zone and was not overfished (i.e., the spawning stock biomass was not below 25% of the unfished spawning stock biomass). Based on the 2005 stock assessment results, ACLs were set at 3,025 mt and 2,919 mt for 2007 and 2008, respectively, with an ACT of 2,499 mt for both years.

In comparison to the 1999 assessment of petrale sole, the 2005 assessment represented a significant change in the perception of petrale sole stock status. The stock assessment conducted in 1999 (Washington-Oregon only) estimated the spawning stock biomass in 1998 at 39% of unfished stock biomass. Although the estimates of 1998 spawning-stock biomass were little changed between the 1999 and 2005 (Northern area) assessments, the estimated depletion in the 2005 assessment was much lower. The change in status between the 1999 and 2005 analyses was due to the introduction of a reconstructed catch history in 2005, which spanned the entire period of removals. The 1999 stock assessment used a catch history that started in 1977, after the bulk of the removals from the fishery had already taken place. Thus the 1999 stock assessment produced a more optimistic view of the petrale stock's level of depletion. The stock's estimated decline in status between the 2005 and 2009 assessments was driven primarily by a significant decline in the trawl-survey index over that period. The 2011 assessment concluded that the stock status continued to be below the target of 25% of unfished biomass.

The 2009 coast-wide stock assessment estimated that the petrale sole stock at 11.6% of the unfished spawning stock biomass (Haltuch and Hicks 2009). The petrale sole was declared overfished based on newly adopted management targets (e.g., target spawning biomass for flatfish stocks defined as 25% and overfished threshold of 12.5% of unfished spawning stock biomass) resulting in a rebuilding plan and catch restrictions for petrale sole. The stock was declared rebuilt based on the results of the 2015 update stock assessment which estimated the coastwide biomass at 30.7% of unfished spawning stock output with ACLs of 3,136 and 3,013 in 2017 and 2018 respectively (Stawitz et al. 2015).

For additional information on changes in the petrale sole fishery please see the 2013 stock assessment (Haltuch et al. 2013b).

1.6 Fisheries off Canada and Alaska

The Canadian fishery developed rapidly during the late 1940s to mid-1950s following the discovery of petrale sole spawning aggregations off the West Coast of Vancouver Island (Anon 2001). Annual landings of petrale sole in British Columbia peaked at 4,800 mt in 1948 but declined significantly after the mid-1960s (Anon 2001). By the 1970s, analysis conducted by Pederson (1975) suggested that petrale sole abundance was low and abundance remained low into the 1990s. In the early 1990s vessel trip quotas were established to try to halt the decline in petrale sole abundance (Anon 2001). Winter quarter landings of petrale sole were limited to 44,000 lb per trip during 1985-91; to 10,000 lb per trip during 1991-95; and to 2,000 lb per trip in 1996. Biological data collected during 1980-1996 showed a prolonged decline in the proportion of young fish entering the population (Anon 2001). Therefore, no directed fishing for petrale sole has been permitted in Canada since 1996 due to a continuing decline in long term abundance (Fargo 1997, Anon 2001). As of 2005 petrale sole off of British Columbia were treated as three "stocks" and were still considered to be at low levels. The recent assessments for the Canadian stocks have been based on catch histories and limited biological data.

In Alaska petrale sole are not targeted in the Bering Sea/Aleutian Island fisheries and are managed as a minor species in the "Other Flatfish" stock complex.

2 Data

Data used in the petrale sole assessment are summarized in Figure 2. The data that were added or reprocessed for this assessment are:

1. Commercial catches (2015-2018 added);
2. Commercial length and age data (all years reprocessed, 2015-2018 added);
3. Observed discard rates, average weights, and lengths (2002-2017 reprocessed, 2014-2017 added);
4. AFSC/NWFSC West Coast Triennial Shelf Survey early and late indices of abundance and length composition data (1980-2004 reprocessed); and
5. NWFSC West Coast Groundfish Bottom Trawl Survey index of abundance, length and age composition data (2003-2018 reprocessed, 2015-2018 added).

A description of each data source is provided below.

2.1 Fishery-Independent Data

2.1.1 NWFSC West Coast Groundfish Bottom Trawl Survey

Three sources of information are produced by this survey: an index of relative abundance, length-frequency distributions, and age-frequency distributions which are used in the model at conditional-age-at-length observations. Only years in which the NWFSC West Coast Groundfish Bottom Trawl Survey included the continental shelf (55-183 m) are considered (2003-2018), since the highest percent of positive survey tows with petrale sole are found on the continental shelf.

The NWFSC West Coast Groundfish Bottom Trawl Survey is based on a random-grid design; covering the coastal waters from a depth of 55 m to 1,280 m (Bradburn et al. 2011). This design generally uses four industry chartered vessels per year, assigned to a roughly equal number of randomly selected grid cells and divided into two 'passes' of the coast that are executed from north to south. Two vessels fish during each pass, which are conducted from late May to early October each year. This design therefore incorporates both vessel-to-vessel differences in catchability as well as variance associated with selecting a relatively small number (~700) of possible cells from a very large set of possible cells spread from the Mexican to the Canadian border.

The NWFSC West Coast Groundfish Bottom Trawl Survey commonly encounters petrale sole along the U.S West Coast, except south of Point Conception (Figure 3). The catch-per-unit-effort estimated from the survey is roughly constant north of 38° (Figure 4). The survey does fish shallower than 54 m and the encounter rate of petrale sole declines at waters deeper than 400 m. Figure 5 shows that the positive tows catch rate by depth peaks between 100-200 meters and declines as depth increases. The observed lengths captured across depths by the survey are shown in Figure 6.

The data from the NWFSC West Coast Groundfish Bottom Trawl Survey was analyzed using a spatio-temporal delta model implemented as an R package, VAST (Thorson and Barnett 2017, Thorson 2019), which is publicly available online (https://github.com/James-Thorson/VAST). Spatial and spatio-temporal variation is specifically included in both encounter probability and positive catch rates, a logit-link for encounter probability and a log-link for positive catch rates. Vessel-year effects were included for each unique combination of vessel and year in the data to account for the random selection of commercial vessels used during sampling (Helser et al. 2004, Thorson and Ward 2013). Spatial variation was approximated using 250 knots, and the model used the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016). Further details regarding model structure are available in the user manual (https://github.com/James-Thorson/VAST/blob/master/examples/VAST user manual.pdf).

The gamma distribution with random strata-year and vessel effects was chosen as the final model. The Q-Q plot does not show any departures from the assumed distribution (Figure 7). The Pearson residuals for the encounter and catch rates for gamma distribution model are shown in Figures 8 and 9.

The estimated index of abundance is given in Table 3. For comparison, the 2015 model estimated, the 2019 design based, and the 2019 VAST indices are shown in Figure 10. The spatial density by year estimated by VAST is shown in Figure 11. The index for the NWFSC West Coast Groundfish Bottom Trawl Survey shows an increase in the population between 2009 and 2014 and roughly stable through 2017, and decrease in the index in the most recent year, 2018.

Length bins from 12 to 62 cm in 2 cm increments were used to summarize the length frequency of the survey catches in each year. The first length bin includes all observations less than 14 cm and the last bin includes all fish larger than 62 cm. Table 4 shows the number of lengths taken by the survey. The length frequency distributions for the NWFSC West Coast Groundfish Bottom Trawl Survey from 2003-2018 generally show an increased frequency in observations of smaller fish between 2007 and 2011 (Figure 12). The stratification for length data expansion based on the design-based estimates is provided in Table 5.

Age distributions included bins from age 1 to age 17, with the last bin including all fish of greater age. Table 6 shows the number of ages taken by the survey. The marginal NWFSC West Coast Groundfish Bottom Trawl Survey age-compositions, which allow for easier viewing of strong cohorts, show the strong 1998 cohort ageing from 2003 to 2007, with younger fish appearing between 2008-2011 (Figure 13). The exception to this is the female composition in 2005, where only one female fish estimated to be age 3 was aged from the tow with the largest catch rate.

The input sample sizes for length and marginal age-composition data for all fishery-independent surveys were calculated based on the approach used in the 2013 full and 2015 update assessment as:

$$\text{Input N}_y = (0.138 * (\textstyle\sum^N \text{fish}_y / \sum^N \text{tows}_y) + 1) * \sum^N \text{tows}_y$$

where fish is the number of petrale sole by year y and N the total number of tows by year. The input sample size of conditional-age-at-length data was set at the number of fish at each length by sex and by year. The conditional-age-at-length data were not expanded and were binned according to length, age, sex, and year.

2.1.2 AFSC/NWFSC West Coast Triennial Shelf Survey

The AFSC/NWFSC West Coast Triennial Shelf Survey (referred to as the Triennial Survey for short) was first conducted by the AFSC in 1977 and spanned the time-frame from 1977-2004. The survey's design and sampling methods are most recently described in Weinberg et al. (2002). Its basic design was a series of equally-spaced east to west transects from which searches for tows in a specific depth range were initiated. The survey design has changed slightly over time. In general, all of the surveys were conducted in the mid-summer through early fall: the 1977 survey was conducted from early July through late September; the surveys from 1980 through 1989 ran from mid-July to late September; the 1992 survey spanned from mid-July through early October; the 1995 survey was conducted from early June to late August; the 1998 survey ran from early June through early August; and the 2001 and 2004 surveys were conducted in May-July.

Haul depths ranged from 91-457 m during the 1977 survey with no hauls shallower than 91 m. The surveys in 1980, 1983, and 1986 covered the West Coast south to 36.8° N latitude and a depth range of 55-366 m. The surveys in 1989 and 1992 covered the same depth range but extended the southern range to 34.5° N (near Point Conception). From 1995 through 2004, the surveys covered the depth range 55-500 m and surveyed south to 34.5° N. In the final year of the Triennial Survey series, 2004, the NWFSC's Fishery Resource and Monitoring division (FRAM) conducted the survey and followed very similar protocols as the Alaska Fisheries Science Center (AFSC). Due to haul performance issues and differences in sampling depths, the 1977 are omitted from analysis.

Due to changes in survey timing, the Triennial Survey data have been split into independent early (1980-1992) and late (1995-2004) survey time series. The splitting of this time series was investigated during the 2009 STAR panel due to the changes in survey timing and the expected change in petrale sole catchability because of the stock's seasonal onshore-offshore migrations (Cook et al. 2009). For these reasons, as well as because the split improved fits to the split time series and made small changes to the estimation of the selectivity curves, the 2009 STAR panel supported the split.

The Triennial Survey commonly encounters petrale sole along the U.S West Coast (Figure 14). The catch-per-unit-effort estimated from the survey is roughly constant across the surveyed latitudes (Figure 15). Additionally, petrale sole were captured across the survey depths between 55-500 m (Figure 16). The observed lengths captured across depths by each survey period are shown in Figure 17.

The data from the petrale sole was analyzed using a spatio-temporal delta model implemented as an R package, VAST (Thorson and Barnett 2017, Thorson 2019), described above in NWFSC West Coast Groundfish Bottom Trawl Survey Section. Spatial variation was approximated using 250 knots, and the model used the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016). The index of abundance was estimated using VAST separately for the early and late periods of the survey.

The gamma distribution with random strata-year and vessel effects was chosen as the final model for both the early and late time periods. The Q-Q plots do not show any departures from the assumed distribution (Figures 18 and 19). The Pearson residuals for the encounter and catch rates for the early and late periods are shown in Figures 20, 21, 22, and 23.

The estimated index of abundance is given in Table 3. For comparison, the 2013 model estimated, the 2019 design based, and the 2019 VAST indices are shown in Figure 24. The estimated density of petrale sole is show in Figures 25 and 26. The index for the Triennial Survey across the early and late period shows a slight increase in the population between 1980 and 2001 with a spike in the final year of 2004.

Length bins from 12 to 62 cm in 2 cm increments were used to summarize the length frequency of the survey catches in each year. Table 7 shows the number of lengths taken by the survey. The length frequency distributions for the Triennial Survey from 1980-2004 are shown in Figures 27 and 28. The stratifications for length data expansions are provided in Tables 8 and 9.

There are no petrale sole age data from the Triennial Survey.

The input sample sizes for length data were calculated using the same approach for the NWFSC West Coast Groundfish Bottom Trawl Survey data described in the NWFSC West Coast Groundfish Bottom Trawl Survey Section.

2.2 Fishery-Dependent Data

2.2.1 Commercial Fishery Landings

All landings for this update assessment were summarized by port of landing, where available, as well as for a northern fleet consisting of Washington and Oregon and a southern fleet consisting of California. Landings for Washington and Oregon are summed into a single northern fleet due to the fact that vessels commonly fish and land in each other's waters and ports.

The PacFIN database (1981-2018 for California and Washington; 1987-2018 for Oregon) extracted June 26, 2019. Historical catches were not updated from the previous assessment in 2013. The 2013 assessment historical Washington catches were obtained from WDFW landings reconstruction for 1935, 1939 and 1949- 1969 (pers. comm. T. Tsou and G. Lippert) and the Pacific Marine Fisheries Commission (PMFC) Data Series for 1956-1980 (PFMC 1979). The 2013 assessment historical Oregon landings were obtained from reconstruction for 1932 to 1986 (Karnowski et al. 2014). The 2013 assessment historical California landings used catch reconstruction data extending from 1931-1980 (Ralston et al. 2010) and California Department of Fish and Game (CDFG) Fish Bulletins for 1916-1930 landings (Heimann and Carlisle 1970) as reconstructed by Lai et al. (2005). The California fishery began in 1876 but no landings data are available from 1876-1915. Therefore a linear interpolation between landings of 1 ton in 1876 and the landings recorded for 1916 are used to filling this period.

Fishery removals were divided among 4 fleets: 1) winter North trawl, 2) summer North trawl, 3) winter South trawl, and 4) summer South trawl. Landings for the North fleet are defined as fish landed in Washington and Oregon ports. Landings for the South fleet are defined as fish landed in California ports. Landings for the fishing year, beginning on 1 November, are summarized by fleet in Table 1 and Figure 1. The landings of petrale sole by gear types other than groundfish-trawl have been inconsequential, averaging less than 2.5% of the coast-wide landings. The non-trawl landings, that consist of only a small fraction of the total landings, are included in the trawl landings.

2.2.2 Discards

Data on discards of petrale sole are available from two different data sources. The earliest source is referred to as the Pikitch data and comes from a study organized by Ellen Pikitch that collected trawl discards from 1985-1987 (Pikitch et al. 1988). The northern and southern boundaries of the study were 48°42′ N latitude and 42°60′ N latitude respectively, which is primarily within the Columbia INPFC area (Pikitch et al. 1988, Rogers and Pikitch 1992). Participation in the study was voluntary and included vessels using bottom, midwater, and shrimp trawl gears. Observers of normal fishing operations on commercial vessels collected the data, estimated the total weight of the catch by tow, and recorded the weight of species retained and discarded in the sample. Results of the Pikitch data were obtained from John Wallace (personal communication, NWFSC, NOAA) for the 2013 assessment in the form of ratios of discard weight to retained weight of petrale sole and sex-specific length frequencies. The Pikitch discard estimates were applied to both the summer and winter northern fisheries and are shown in Table 10. These data have not been modified in this update assessment.

The second source is from the West Coast Groundfish Observer Program (WCGOP). This program is part of the NWFSC and has been recording discard observations since 2003. Table 10 shows the discard ratios (discarded/(discarded + retained)) of petrale sole from WCGOP based on observer observations. Since 2011, when the trawl rationalization program was implemented, observer coverage rates increased to nearly 100% for all the limited entry trawl vessels in the program and discard rates declined compared to pre-2011 rates. However, the discarding rate of petrale sole within this data-set has always been relatively low. Discard rates were obtained for both the catch-share and the non-catch share sector for petrale sole.

A single discard rate was calculated by weighting discard rates based on the commercial landings by each sector. Coefficient of variations were calculated for the non-catch shares sector and pre-catch share years by bootstrapping vessels within ports because the observer program randomly chooses vessels within ports to be observed. The coefficient of variation of discarding in the catch share fleet, given nearly 100% observer coverage, was considered low and a value of 0.01 was assumed. The discard rates from WCGOP are shown in Table 10.

Starting in 2015, a small number of vessels switched to electronic monitoring discards at sea rather than a human observer (4, 7, and 8 vessels in 2015, 2016, and 2017 respectively). Discarding rates at sea of petrale sole by these vessels were very low, near zero. This update assessment did not evaluate these data to estimate an electronic monitoring specific discard rate, but rather applied the discard ratio from the observed vessels in the WCGOP database. Future assessments should evaluate this assumption in greater detail.

Discard mean body weight data were obtained from the WCGOP data and used in this update assessment for each of the four fishing fleets. The mean body weight of discarded fish from each fleet are shown in Figures 29 - 32. The summer fisheries, both north and south, had relatively large sample numbers which is reflected in a lower coefficient of variation by year relative to the winter fisheries.

Discard length composition data available from the Pikitch study and WCGOP data were used in this update assessment to estimate retention curves for each of the four fishing fleets. The discard length data from each fleet are shown in Figures 33 and 34.

2.2.3 Fishery Length and Age Data

The PacFIN BDS database contains data from Oregon Department of Fish and Wildlife (ODFW; 1966-present) and Washington Department of Fish and Wildlife (WDFW; 1955-present), but only 1986-present data from California Department of Fish and Game (CDFG). The CDFG data set for the years 1948-1992 was extracted and provided from CalCOM by Brenda Erwin (CDFG) in 2011.

The historical Oregon data for petrale sole has change substantially since 2015. The state identified that samples collected prior to 1987 were not collected according to the state's standardized sampling protocol and were mistakenly included in PacFIN as random samples (pers. comm. Ali Whitman). These samples likely represent samples that were collected for special projects. Oregon had removed some of these samples for petrale sole from PacFIN, but not all, as of June 2019. To remove the remaining non-standard samples, Oregon PacFIN data were filtered to remove samples prior to 1987. Although these samples were removed from the length and age composition data for this update assessment, future assessments should evaluate these data to determine if they can be included within the assessment through alternative means (e.g., external estimates of length-at-age or as conditional-age-at-length data).

Commercial length-frequency distributions based on the fishing year were developed for each state for which observations were available. For each fleet, the raw observations (compiled from the PacFIN and CalCOM data-bases) were expanded to the sample level, to allow for any fish that were not measured, then to the trip level to account for the relative size of the landing from which the sample was obtained. The expanded length observations were then expanded by the landings in each state for the combined Washington and Oregon fleet. Age frequencies were computed in the same manner, except that age observations for Washington and Oregon were not combined due to ageing error considerations.

Length and age data collected from commercial landings for each fleet are summarized by the number of trips and fish sampled by year (Tables 11 and 12). Figures 33, 34, and 35 show plots of the commercial length and age composition data across time for each fishery fleet.

The calculation for input sample sizes for the commercial length and age data was done in the same manner as the 2013 assessment which set the input sample size for commercial lengths and ages equal to the number of trips by year for each fleet.

2.2.4 Historical Commercial Catch-Per-Unit Effort/Logbooks

Commercial logbook data for petrale sole was first used to construct CPUE indices of abundance in the 1999 assessment for Oregon fleets from 1987-1997 (Sampson and Lee 1999). Since the first inclusion in 1999, the commercial CPUE indices were extended and or updated based on management changes and new statistical methods through 2009. For additional information on the use of CPUE indices in the assessment of petrale sole please see the 2013 assessment (Haltuch et al. 2013b).

CPUE calculations for the Winter fishery on aggregations of petrale sole described in the 2013 assessment were retained for this assessment (Haltuch et al. 2013b) (Figures 36 and 37). Two CPUE indices from 1987-2009 with catchability modeled as a power function are used in this update assessment, one each for the north and south winter fisheries. These data have not been re-evaluated for this update assessment.

2.2.5 Foreign Landings

The impact of landings of petrale sole by foreign fishing fleets prior to the institution of the exclusive economic zone (EEZ) of the U.S. West Coast is currently not quantified and remains an area for research.

2.3 Biological Data

2.3.1 Natural Mortality

The instantaneous rate of natural mortality for a wild fish population is notoriously difficult to estimate. One accepted method is to examine the age distribution of an unexploited or lightly exploited stock. This method cannot readily be applied to petrale sole given the long history of exploitation off the U.S. West Coast. Ketchen and Forrester (1966) estimated that the natural mortality coefficients were 0.18-0.26 yr^{-1} for males and 0.19-0.21 yr^{-1} for females based on a catch curve analysis of 1943-1945 Washington trawl data from Swiftsure Bank, off the southwest corner of Vancouver Island. However, petrale sole catches were relatively high during mid-1940s through the 1950s. Starr and Fargo (2004) estimated the instantaneous rate of natural mortality (M) using Hoenig's method (Hoenig 1983) estimating M values of 0.22 and 0.15 yr^{-1} were estimated given maximum ages of 20 and 30 years, respectively.

An archived set of commercial samples, collected from Northern California between the late 1950s and early 1980s, recently found that multiple samples were aged between 20-31 years old, suggesting a similar range of M values for U.S. West Coast petrale sole. U.S. stock assessments prior to 2009 and current British Columbia stock assessments assumed a value of $M = 0.2$ yr^{-1} for both sexes. The 2013 stock assessment used a meta-analysis value produced the following normal prior distributions for females (mean = 0.151, sd = 0.16) and males (0.206, sd = 0.218) based on early research by Owen Hamel (pers. comm.) with maximum age for females and males of 32 and 29 years, respectively.

Hamel (2015) refined and published a method for combining meta-analytic approaches relating the M rate to other life-history parameters such as longevity, size, growth rate, and reproductive effort to provide a prior on M. In that same issue of *ICES Journal of Marine Science*, Then et al. (2015) provided an updated data set of estimates of M and related life history parameters across a large number of fish species from which to develop an M estimator for fish species in general. They concluded by recommending M estimates be based on maximum age alone, based on an updated Hoenig non-linear least squares estimator $M = 4.899 A_{max}^{-0.916}$. The approach of basing M priors on maximum age alone was one that was already being used for West Coast rockfish assessments. However, in fitting the alternative model forms relating M to $A_{\max}$, Then et al. (2015) did not consistently apply their transformation. In particular, in real space, one would expect substantial heteroscedasticity in both the observation and process error associated with the observed relationship of M to $A_{\max}$. Therefore, it would be reasonable to fit all models under a log transformation. This was not done. Re-evaluating the data used in Then et al. (2015) by fitting the one-parameter $A_{\max}$ model under a log-log transformation (such that the slope is forced to be -1 in the transformed space (Hamel 2015)), the point estimate for M is:

$$M = \frac{5.4}{A_{\max}}$$

The above is also the median of the prior. The prior is defined as a lognormal distribution with mean $ln(5.4/A_{\max})$ and SE = 0.438.

The natural mortality prior was updated for this update assessment using the above approach (Figure 38). Maximum age was assumed to be 32 and 29 years for females and males, respectively, the same assumption applied in the 2013 assessment. Using the Hamel et al. approach above, the prior value for females in regular space is 0.169 and for males is 0.186.

2.3.2 Maturation and Fecundity

Petrale sole maturity-at-length information is generally sparse in space and time, has not been collected in a systematic fashion across time, is of varying quality, and does not always agree between studies. It is possible that maturity may have changed over time. However, it is not possible to assess this quantitatively owing to differences in when historical samples on which maturity ogives could be based were taken, and how maturity stage (visual vs. histological) was determined. The 2005 petrale sole assessment used the most recent study for the West Coast of the U.S. that was based on observations collected during 2002 from Oregon and Washington (Hannah et al. 2002). The 50% size-at-maturity was estimated at 33.1 cm with maturity asymptoting to 1.0 for larger fish (Figure 39).

At the time of the last assessment, there had been limited information regarding fecundity at age or length of petrale sole. The 2013 stock assessment assumed that fecundity of female petrale sole was proportional to biomass (Figure 40). However, new research has been done examining the fecundity of petrale sole (Lefebvre et al. n.d.) which is in press at Fisheries Research. The study concluded a difference in fecundity between California and Washington petrale sole where a 40 cm fish in California is more fecund compared to northern fish of the same size (Figure 41). However, northern fish of the largest size were more fecund relative to fish in California. The current petrale sole model is a single area coastwide model, which assumes fish along the U.S. have the same biology (e.g. natural mortality, growth, fecundity). The estimates of fecundity for petrale sole were considered new data and based on the guidelines for update stock assessments, these data were not included in the base model. However, a sensitivity to including these data was provided. The next full assessment should explore and include the new data about fecundity-at-length.

2.3.3 Sex Ratio

Past assessments of petrale sole have assumed a 50% sex ratio at birth between females and males off the U.S West Coast. Similarly, Canadian data from the 2004 published stock assessment also suggests sex ratios of petrale sole in British Columbia are generally 50% males and 50% females (Starr and Fargo 2004). To be consistent with the full assessment this update assessment retains the equal sex ratio assumption. However, examining the NWFSC West Coast Groundfish Bottom Trawl Survey data the proportion of females in the population across the mid-range lengths is approximately 0.40 - 0.45 with the proportion increasing to 1 at the largest lengths due to dimorphic growth (Figure 42). The next full assessment should evaluate the sex ratio across time and space for petrale sole.

2.3.4 Length-Weight Relationship

The length-weight relationship for petrale sole was estimated outside the model using all biological data available from the NWFSC West Coast Groundfish Bottom Trawl Survey data consistent with method applied by the 2013 assessment. The female weight-at-length in grams was estimated at 1.986e-06$L^{3.48}$ and males at 2.983e-06$L^{3.36}$ where L is length in cm (Figure 43). The length-weight relationship estimates from the NWFSC West Coast Groundfish Bottom Trawl Survey data were consistent with the biological observations available from the fishery data.

2.3.5 Growth (Length-at-Age)

The length-at-age was estimated for male and female petrale sole. Figure 44 shows the lengths and ages as well as predicted von Bertalanffy fits to the data from the fishery and the NWFSC West Coast Groundfish Bottom Trawl Survey data. Females grow larger than males and sex-specific growth parameters were estimated at the following values for females $L_\infty = 54$ cm; $k = 0.16$ yr^{-1}, and males $L_\infty = 41$ cm; $k = 0.25$ yr^{-1}. These values were used as starting parameter values within the base model prior to estimating each parameter for male and female petrale sole.

2.3.6 Ageing Precision and Bias

Historically, petrale sole otoliths have been read by multiple ageing labs using surface and break and burn methods. In order to conduct a comprehensive estimation of ageing bias and imprecision, the 2009 assessment compiled and analyzed all of the available double-read data from the Cooperative Aging Project (CAP) and the Washington Department of Fish and Wildlife (WDFW), as well information from a bomb radiocarbon age validation study for petrale sole off the U.S. West Coast (Haltuch and Hicks 2009, Haltuch et al. (2013a)).

The 2013 stock assessment applied read method and lab specific ageing error vectors (Haltuch et al. 2013b). This update assessment did not re-evaluate ageing error and applied the same approach as the 2013 stock assessment. The ageing error vectors are shown in Tables 13 and 14. For a detailed description please see the 2013 stock assessment (Haltuch et al. 2013b).

2.3.7 Environmental and Ecosystem Data

This update assessment did not evaluate potential ecosystem data and methodologies for petrale sole.

3 Assessment Model

3.1 Summary of Previous Assessments and Reviews

3.1.1 History of Modeling Approaches Used for This Stock

Early stock assessments only assessed petrale sole in the combined U.S.-Vancouver and Columbia INPFC areas, i.e., petrale sole in these areas were treated as a unit stock, using time series of data that began during the 1970s (Demory 1984, Turnock et al. 1993). The first assessment used stock reduction analysis and the second assessment used the length-based Stock Synthesis model. The third petrale sole assessment utilized the hybrid length-and-age-based Stock Synthesis 1 model, using data from 1977-1998 (Sampson and Lee 1999). During the 1999 stock assessment an attempt was made to include separate area assessments for the Eureka and Monterey INPFC areas but acceptable models could not be configured due to a lack of data (Sampson and Lee 1999).

The 2005 petrale sole assessment was conducted as two separate stocks, the northern stock encompassing the U.S. Vancouver and Columbia INPFC areas and the southern stock including the Eureka, Monterey and Conception INPFC areas, using Stock Synthesis 2, a length-age structured model. Both the northern- and southern-area models specified the fishing year as beginning on November 1 and continuing through October 31 of the following year, with a November-February winter fishery and a March-October summer fishery. Landings prior to 1957 were assumed to have been taken during the summer season in years where monthly data were not available to split the catches seasonally. The complete catch history was reconstructed for petrale sole for the 2005 stock assessment, with the northern area model starting in 1910 and the southern area model in 1876. In 2005, the STAR panel noted that the petrale sole stock trends were similar in both northern and southern areas, in spite of the different modeling choices made for each area, and that a single coast-wide assessment should be considered.

The 2009 and 2011 assessments treated petrale sole as a single coast-wide stock, with the fleets and landings structured by state (WA, OR, CA) area of catch. During the 2011 STAR panel concerns were raised regarding the difficulty of discriminating landings from Washington and Oregon waters, particularly in light of the Oregon historical landings reconstruction that includes a summary of data by port of landing but not by catch area, due to the fact that the Oregon and Washington vessels commonly fish in each other's waters and land in each other's ports. The availability of the historical comprehensive landings reconstruction for Oregon by port of landing lead the STAR panel to recommend combining the Washington and Oregon fleets within the coast-wide stock assessment using port of landing rather than catch area.

Starting with the 2013 stock assessment, the coast-wide stock assessment now summarizes petrale sole landings by the port of landing and combines Washington and Oregon into a single fleet (Haltuch et al. 2013b). This update assessment assumes the same approach as the 2013 stock assessment.

3.1.2 Most Recent STAR Panel Recommendations

The most recent STAR panel for petrale sole was for the 2013 full assessment. For clarity the petrale sole specific recommendations from the STAR panel are presented here, but given that this was an update assessment which limits model changes, these items have not been formally addressed.

1. The states of California and Oregon have completed comprehensive historical catch reconstructions. Washington historical data are not yet available. Completion of Washington historical catch reconstruction would provide a better catch series.

2. Update both the maturity and fecundity relationships using samples with wider geographic coverage to include California, and from more recent years for petrale sole would be beneficial.

3. Studies on stock structure and movement of petrale sole indicating transboundary movement of petrale sole between U.S. and Canadian waters, particularly with regard to the winter-summer spawning migration. It will be informative to include a time-series plot of fishery catch from Canadian waters in future assessment.

4. Increased collection of commercial fishery age data as well as re-aging any available historical samples from California would help reduce uncertainty. While some recent age data were made available from California, sample sizes could be increased and this data collection needs to continue into the future. Without good age data, the ability to estimate year-class strength and the extent of variation in recruitment is compromised.

5. Where possible, historical otolith samples aged using a combination of surface and break-and-burn methods should be re-aged using the break-and-burn method. Early surface read otoliths should also be re-aged using the break and burn method. Historical otoliths aged with a standard method will allow the further evaluation of the potential impacts of consistent under-aging using surface read methods, changes in selectivity during early periods without any composition information, and potential changes in growth.

6. The effect of the implementation of the IFQ (catch shares) program that began during 2011 on fleet behavior, including impacts on discards, fishery selectivity, and fishing locations, would benefit from further study.

7. The extent of spatial variability on productivity processes such as growth, recruitment, and maturity is currently unknown and would benefit from further research.

8. The Panel appreciated the delta-GLMM approach to derive an index of stock size from commercial CPUE data. However, there may still be factors other than stock size that affect time-trends in the standardized CPUE indices. The panel recommends:

(a) Investigate using effort as an offset in the model. That is, rather than modeling catch/effort = effects, use catch = effort*effects. When a log-link is used then log(effort) can be included as an additive offset, and most GLMM packages include this option. The advantage of this approach is that it is easy to investigate if catch is proportional to effort or not. For example, it may be that CPUE can be higher when effort is low than when effort is high.

(b) Include further consideration of the impacts of trip limits on CPUE. Such limits were gradually introduced since 2006 in the winter fisheries and this may impact CPUE. This consideration should involve consultations with fleet members to understand how their fishing behavior was affected by trip limits.

3.1.3 Response to Groundfish Subcommittee Requests

The 2019 Groundfish Subcommittee meeting was held in Seattle, Washington on August 22-23, 2019. There were no formal requests made during the meeting.

3.2 Model Structure and Assumptions

3.2.1 Changes Between the 2013, the 2015 Update, and the Current Update Assessment Model

This update assessment model retains all parameterization assumed in the 2013 assessment. The only changes between the 2013 and this update assessment were extending and reprocessing data sources. This section linking the two models is intended to clearly identify where substantive changes were made. These changes include:

1. Fitting using SS v.3.30.13.

2. Added commercial fishery catch data (2015-2018).

3. Added composition data from the commercial fishery (length and age data 2015-2018) and reprocessed all data and expanded based upon the current methods.

4. Added recent discard data (2014-2017) and reprocessed all discard rate, average weight, and length composition data.

5. Added 2015-2018 NWFSC West Coast Groundfish Bottom Trawl Survey data and calculated the index of abundance using VAST.

6. Added NWFSC West Coast Groundfish Bottom Trawl Survey length and age data 2015-2018.

7. Triennial Survey early and late indices of abundance were calculated using VAST.
8. Model tuning to re-weight data.
9. Length-weight relationship parameters estimated outside of the stock assessment model from the NWFSC West Coast Groundfish Bottom Trawl Survey data up to 2018 and input as fixed values.
10. Update the natural mortality prior for female and male fish.

The general model set-up is described in Table 15.

3.2.2 Modeling Platform and Bridging Analysis

Stock Synthesis version 3.30.03.13 was used to estimate the parameters in the model (Methot and Wetzel 2013). r4ss, version 1.35.1, along with R version 3.4.3 were used to investigate and plot model fits. The exploration of models began by bridging from the 2015 update assessment to Stock Synthesis version 3.30.03.13, which produced no discernible difference (Figure 45). A more detailed analysis of changes from the 2015 update assessment are shown in the Added Data Analysis Section.

3.2.3 Summary of Fleets and Areas

Fishery removals were divided among 4 fleets: 1) Winter North trawl, 2) Summer North trawl, 3) Winter South trawl, and 4) Summer South trawl. Landings for the North fleet are defined as fish landed in Washington and Oregon ports. Landings for the South fleet are defined as fish landed in California ports. Removals by other gears are very small and are included in the trawl fishery removals. The data available for each fleet are described in Figure 2.

3.2.4 Priors

Priors were applied only to parameters for steepness (h) and natural mortality (M). The steepness prior is based on the Myers (1999) meta-analysis of flatfish steepness and the natural mortality prior is based on a meta-analysis completed by Hamel (2015). The prior for steepness assumed a beta distribution with a mean equal to 0.80 (Figure 46).

The natural mortality prior was updated for this update assessment using the Hamel meta-analysis approach. Maximum age was assumed to be 32 and 29 years for females and male, respectively (Figure 38). The same maximum age assumption was applied in the 2013 assessment.

3.2.5 Data Weighting

Length and conditional-age-at-length compositions from the NWFSC West Coast Groundfish Bottom Trawl Survey were fit along with length and marginal age compositions from the fishery fleets and the Triennial Survey. Length data started with a input sample size determined from the approaches described in the NWFSC West Coast Groundfish Bottom Trawl Survey and Fishery Length and Age Data Sections. It was assumed for conditional-age-at-length data that each age was a random sample within the length bin and the model started with a sample size equal to the number of fish in that length bin.

The update assessment model was weighted using the McAllister and Ianelli (1997) method (Harmonic Mean weighting), consistent with the 2013 full and 2015 update assessments. The McAllister and Ianelli data weight approach looks at the difference between individual observations and predictions. A sensitivity was performed examining the difference between alternative weighting approaches. The weights applied to each length and age data set for the base model are shown in Table 16.

3.2.6 Estimated and Fixed Parameters

There were 304 estimated parameters in the base model. These included parameters for R_0, natural mortality by sex, steepness, growth, selectivity, retention, time blocking of the fleets and the surveys, commercial CPUE catchability, recruitment deviations, and forecast recruitment deviations (Table 17).

Fixed parameters in the model were as follows. The standard deviation of the recruitment deviates was fixed at 0.40. Maturity-at-length and fecundity was fixed as described above in the Maturitation and Fecundity Section. Length-weight parameters were fixed at estimates using all length-weight observations (Figure 43).

3.2.7 Key Assumptions and Structural Choices

All structural choices for stock assessment models are likely to be important under some circumstances. In this update assessment update these choices are generally made to be consistent with the previous assessment (Haltuch et al. 2013b). Major choices in the structuring of this stock assessment model include a coast-wide model with seasonal fleet structure for two regions, north and south, splitting the Triennial Survey into an early and late time period, and estimates of selectivity and retention curves for each fleet.

3.3 Base Model Results

The base model parameter estimates along with approximate asymptotic standard errors are shown in Table 17 and the likelihood components are shown in Table 18. Estimates of derived reference points and approximate 95% asymptotic confidence intervals are shown in Table 19. Estimates of stock size over time are shown in Table 20.

3.3.1 Parameter Estimates

Natural mortality by sex was estimated directly within the model. Natural mortality was estimated to be 0.159 yr^{-1} for female fish and 0.164 yr^{-1} for male fish. In comparison the estimates from the 2015 assessment were 0.145 yr^{-1} and 0.154 yr^{-1} for female and male fish, respectively.

Steepness was also estimated within the model, consistent with the approach applied in the 2013 full and 2015 update assessment. The estimate of steepness from the Beverton-Holt stock recruitment curve was estimated at 0.84. The previous update assessment estimated a steepness of 0.89.

The estimates of maximum length and the von Bertanlaffy growth coefficient, k, were less than the external estimates for males and female but were well within the 95% confidence interval given the estimated uncertainty (Table 17). The estimated k for female and male fish were greater than the values estimated in the 2015 update assessment (0.142 versus 0.134 yr^{-1} for females and 0.238 versus 0.203 yr^{-1} for males). The majority of growth for female and male petrale sole growth occurs at younger ages, reaching near maximum length by age 10-15, depending upon sex, with female petrale sole reaching larger maximum lengths (Figure 47). The spawning output estimated was equal to the spawning weight of female fish (Figure 48).

Selectivity curves were estimated for the fishery and survey fleets. The estimated selectivities for the fishery fleets are shown in Figure 49. All fishery and survey selectivities were fixed to be asymptotic, reaching maximum selectivity for fish between 35 and 40 cm. Shifts in selectivities for each fleet fishery were estimated based on time blocks assumed in the 2013 assessment (Figure 49). The estimated retention curves for each fleet based on the historical time blocks and discarded length composition data are shown in Figure 50. Sex specific survey selectivities were assumed to be asymptotic and are shown in Figure 51.

The catchability for each of the winter CPUE time series were estimated as power functions. The Winter North base catchability value was estimated at 0.001 with the exponent parameter at -0.121. The Winter South base catchability value was estimated at 0.26 with the exponent parameter at -0.853.

The catchability for both surveys, Triennial Survey and NWFSC West Coast Groundfish Bottom Trawl Survey, were analytically solved comparing observed to expected vulnerable biomass across all years. The Triennial Survey had catchability values of 0.423 and 0.65 for the early and late periods, respectively. The NWFSC West Coast Groundfish Bottom Trawl Survey catchability value 2.851.

Additional survey variability, process error added directly to each year's input variability for the Triennial Survey, both early and late, was estimated within the model. The model estimated an added variance of 0.218 for the early time period of and 0.313 for the late period. No additional variance was estimated for the NWFSC West Coast Groundfish Bottom Trawl Survey.

The time-series of estimated recruitments shows a relationship with the decline in spawning output, punctuated by larger recruitments in recent years (2006, 2007, and 2008) (Figures 52 and 53). There is little information regarding recruitment prior to 1960 and the uncertainty in those estimates is expressed in the model. The five largest estimated recruitment estimated with the model (in ascending order) occurred in 2006, 1998, 1966, 2007, and 2008. The four lowest recruitments estimated within the model (in ascending order) occurred in 1986, 1992, 1987, and 2003. However, recruitment in recent years (2013 - 2017) is estimated to be less than the expected mean recruitment indicating an absence of strong incoming recruitment. The recruitment bias adjustment applied within the model across years is shown in Figure 54.

3.3.2 Fits to the Data

There are numerous types of data for which the fits are discussed: fishery CPUE, survey abundance indices, discard data (rates, mean body weights, and length compositions), length-composition data for the fisheries and surveys, marginal age compositions for the fisheries, and conditional age-at-length observations for the NWFSC West Coast Groundfish Bottom Trawl Survey.

The fit to the CPUE for the winter fisheries is show in Figures 55, 56, 57, and 58. The model fits both of the CPUE time-series relatively well. The fits to the survey indices are shown in Figures 59, 60, and 61. In order to fit the early and the late periods of the Triennial Survey extra standard error was required. The trend in the early time-series of the Triennial Survey was generally not consistent with other data within the model. The final year, 2004, in the late period of the Triennial Survey was under fit by the model. The petrale sole survey index from the NWFSC West Coast Groundfish Bottom Trawl Survey was generally fit well. However, the most recent year, 2018 data point which was lower than previous year's indices, was not fit by the model.

The observed WCGOP discard rates (Figures 62 - 65) were fit by each fishery using time blocks. The time blocks on the discard data were based on those defined in the 2013 assessment (Haltuch et al. 2013a) with the final block starting in 2011 being extended through the final model year, 2018. The discard rates for the northern fleets from the Pikitch data collected in 1985-1987 fit the mean of the estimates for the winter fishery (Figure 62) but estimated higher discard rates for the summer fleet (Figure 63). The lack of fit to the summer fleet is consistent to the estimates from the 2015 update assessment. Fits to the WCGOP observed mean body weights are shown in Figures 66 - 69. The fits to the discard mean body weights to the summer fleets were generally better than the data from the winter fisheries which had more variable observations and lower number of observations (hence larger annual uncertainties).

Fits to the length data are shown based on the proportions of lengths observed by year and the Pearson residuals-at-length for all fleets. Detailed fits to the length data by year and fleet are provided in Appendix A. Aggregate fits by fleet are shown in Figure 70. There are a few things that stand out when examining the aggregated length composition data. First, the sexed discard lengths from the Pikitch study appear to be poorly fit by the model but this is related to small sample sizes. However, the unsexed discard lengths from the WCGOP data for each fleet were fit well by the model.

Discard lengths from WCGOP were fit well by the model and show no obvious pattern in the residuals (Figures 71 - 74). The residuals to the fishery lengths clearly showed the growth differential between males and females where the majority of positive residuals at larger sizes were from female fish (Figures 75 - 78). Notably, the Summer North fishery has a large positive residual pattern for male fish between 1966-1980. A similar pattern in the Pearson residuals was observed in the 2013 full and the 2015 update assessment (Haltuch et al. 2013b, Stawitz et al. 2015). The residuals for each of the surveys are shown in Figures 79, 80, and 81. The Pearson residuals from the NWFSC West Coast Groundfish Bottom Trawl Survey shows indications of the 2008 cohort moving through the population. Length data were weighted according to the McAllister Ianelli Harmonic approach and the data weights are shown in Table 16.

Age data were fitted to as marginal age compositions for the fishery fleets.The NWFSC West Coast Groundfish Bottom Trawl Survey ages were treated as conditional age-at-length data to facilitate the estimation of growth within the model. The aggregated fits to the marginal age data are shown in Figure 82. The aggregated age data were fit generally well for the fishery fleets, however, the peaks of the age data were often under fit by the model which was also observed in the 2013 assessment (Haltuch et al. 2013b). Detailed fits to the age data by year and fleet are provided in Appendix B. The Pearson residuals for the fishery fleets are shown in Figures 83 - 86. The age data were weighted using the McAllister Ianelli approach and the data weights are shown in Table 16.

The observed and expected conditional age-at-length fits for NWFSC West Coast Groundfish Bottom Trawl Survey are shown in Figures 87 - 92. The fits generally match the observations. The Pearson residuals are shown in Figure 93 and 94. The age data were also weighted according to the McAllister Ianelli Harmonic mean weights (Table 16).

3.3.3 Population Trajectory

The predicted spawning biomass is given in Table 20 and plotted in Figure 95. The predicted spawning biomass time series shows a strong decline from the late-1930s through the mid-1960s, followed by a small recovery through the mid-1970s, and another decline to its lowest point during the early 1990s. This general pattern of stock decline is coincident with increasing catches and the movement of the fishery from the south to the north, and from summer fishing in shallow waters to winter fishing on spawning aggregations in deeper waters. From the mid-1990s through 2005 the stock increased slightly, then declined through 2010 (Figure 95). The stock has increased strongly since 2010 in response to reduced catches and above average recruitment in 2006, 2007, and 2008. The estimated total biomass follows the same general trend as observed in the spawning biomass (Figure 96). The 2019 estimated spawning biomass relative to unfished equilibrium spawning biomass is above the target of 25% of unfished spawning biomass at 39% (Figure 97). Approximate confidence intervals based on the asymptotic variance estimates show that the uncertainty in the estimated spawning biomass is generally low. The standard deviation of the log of the spawning biomass in 2019 is 0.09.

Recruitment deviations were estimated for the entire time-series that was modeled (Figure 52 and discussed in Section 3.3.1) and provide a realistic portrayal of uncertainty. The time series of estimated recruitments shows a relationship with the decline in spawning output, punctuated by larger recruitments in 2006, 2007, and 2008. The five largest recruitments estimated by the model (in ascending order) occurred in 2006, 1998, 1966, 2007, and 2008. The four lowest recruitments estimated within the model (in ascending order) occurred in 1986, 1992, 1987, and 2003. However, in recent years, 2013 - 2016, based on the data the incoming recruitment has been estimated to be lower than average with negative recruitment deviations (ranging between -0.10 and -0.33) indicating an absence of strong incoming recruitment.

The stock-recruit curve resulting from a value of estimated steepness, 0.84, is shown in Figure 98 with estimated recruitments also shown.

3.3.4 Reference Points

Reference points were calculated using the estimated selectivities and catch distributions among fleets in the most recent year of the model (2018). Sustainable total yields (landings plus discards) were 3,135.2 mt when using an $SPR_{30\%}$ reference harvest rate and with a 95% confidence interval of 2,849.4 mt based on estimates of uncertainty. The spawning biomass equivalent to 25% of the unfished spawning output ($SB_{25\%}$) was 8,351.5.

The predicted spawning biomass from the base model generally showed a decline beginning during the 1950s and reaching a low in spawning biomass in 1993 with the stock declining to 5.8% relative stock size (Figures 95 and 97). Since 2010, the spawning biomass has been increasing due to small catches and above average recruitment. The 2019 spawning biomass relative to unfished equilibrium spawning biomass is above the target of 25% of unfished (Figure 97). The fishing intensity, 1-SPR, exceeded the current harvest rate limit ($SPR_{30\%}$) throughout the late 1970s until approximately 2010 as seen in Figure 99. Recent exploitation rates on petrale sole were estimated to be less than target levels.

Table 19 shows the full suite of estimated reference points for the base model and Figure 100 shows the equilibrium curve based on a steepness value estimated at 0.84.

3.4 Modeling Diagnostics

3.4.1 Convergence

Proper convergence was determined by starting the minimization process from dispersed values of the maximum likelihood estimates to determine if the model found a better minimum. Starting parameters were jittered by 5% and 10%. This was repeated 50 times and a better minimum was not found (Table 21). Jittering showed the model to be sensitive to starting values and there were a number of times where the model resulted in similar likelihood values ($<$ 1 unit difference) to the maximum likelihood estimate. This is likely due to the high correlation between some parameters in the model (i.e., natural mortality and steepness) which allow the model to find similar fits to the data that result in similar estimates.

Through the jittering done as explained above and likelihood profiles, we are confident that the base model as presented represents the best fit to the data given the assumptions made. There were no difficulties in inverting the Hessian to obtain estimates of variability, although much of the early model investigation was done without attempting to estimate a Hessian.

3.4.2 Sensitivity Analyses

A number of sensitivity analyses were conducted. Each of the sensitivities conducted was a single exploration from the base model assumptions and/or data, and were not performed in a cumulative fashion.

1. Fix natural mortality value for female fish at a lower value of 0.125.
2. Fix natural mortality value for female fish at a higher value of 0.180.
3. Use the natural mortality prior for female and male fish used in the 2015 update assessment, natural mortality estimated for both sexes.
4. Use the coastwide fecundity relationship for petrale sole estimated by Lefebvre et al. in press.

5. Estimate the sex ratio at birth between female and male fish within the model. Single parameter estimated for the modeled years. Future explorations may want to explore blocking of this parameter for pre- and post-development of the spawning ground Winter fishery with the assumption that this may disproportionately impact the numbers of female petrale sole.

6. Estimate the sex ratio at birth between female and male fish within the model and assume the coastwide fecundity relationship for petrale sole based on Lefebvre et al. in press. Single parameter for the sex ratio estimated across all modeled years.

7. Data weighting according to the Francis method using the weighting values shown in Table 22.

8. Data weighting according to the Dirichlet method where the estimated parameters are shown in Table 23.

Likelihood values and estimates of key parameters from each sensitivity are available in Table 24. Plots of the estimated time-series of spawning biomass and relative spawning biomass are shown in Figures 101 and 102.

The two sensitivities exploring higher and lower natural mortality for female petrale sole were the two sensitivities that differed the most from the base model. The estimated spawning biomasses and relative stock statuses were higher or lower compared to the base model for each of these runs (Table 24, Figures 101 and 102).

Two sensitivities exploring alternative data weighting approaches were compared to the base model which was weighted using the McAllister-Ianelli data weighting approach. Both data weighting approaches resulted in similar estimates to the base model (Table 22 and Figures 101 and 102). However, the Dirichlet data weighting approach which estimates a parameter for each data source (e.g., length by fleet and ages by fleet), the estimated parameters hit the upper bounds for each data source (Table 23). Converted to real space, this data weighting approach resulted in full weight (approximately 1) for each data set. The Dirichlet method is restricted to data weights less than one, but both the Francis and McAllister and Ianelli approaches estimated data weights greater than one for some data sets. The estimated data weights are linked to the calculation of the input sample sizes which in this model were calculated based on the number of trips for the commercial data and a combination on number of tows and fish samples for the surveys. Future work should be done to better understand the performance of data weighting approaches dependent upon the calculation of input sample sizes.

The final sensitivities that had potentially meaningful differences from the base model were the three runs that explored a skewed sex ratio, potential changes in the fecundity relationship for female petrale sole, and both of these items combined. Each of these sensitivities resulted in slightly more pessimistic estimates of the relative spawning biomass (Table 24). It would be expected that the next full assessment would explore both of these parameter changes.

3.4.3 Retrospective Analysis

A five-year retrospective analysis was conducted by running the model using data only through 2013, 2014, 2015, 2016, 2017 and 2018 (Figures 103, 104, and 105). The initial scale of the spawning biomass trended upward relative to the base model. Overall, no alarming patterns were present in the retrospective analysis.

3.4.4 Added Data Analysis

The changes from the 2015 update assessment based on the addition and reprocessing of data was explored. Each data source was added starting with catches and ending with ages for all fleets within the model where each model run contains the earlier updated data (e.g., + Lengths has data through 2019 for the catches, indices, discard rates and weights, and lengths for all fleets with only the age data through 2014). The estimates of the spawning biomass, relative spawning biomass, and the annual recruitment deviations from each model are shown in Table 25 and Figures 106, 107, and 108.

The time-series when data was added was relatively similar to the estimates from the 2015 update assessment. The one notable difference is the estimates of spawning biomass between the 1950s and 1970s. This update assessment estimates marginally larger spawning biomasses during this period relative to the 2015 estimate. The source of this change was due to two changes; 1) the removal of non-random samples from Oregon from the commercial biological data contained in PacFIN (see Fishery Length and Age Data Section for additional information), and 2) improvements in the processing and expansion of PacFIN data.

3.4.5 Historical Analysis

The estimated summary biomass from previous assessments since 2005 are shown in Figure 109. The current assessment estimated a slight increase in initial spawning biomass compared to previous assessments.

3.4.6 Likelihood Profiles

Likelihood profiles were conducted for R_0, steepness, and female natural mortality values separately. These likelihood profiles were conducted by fixing the parameter at specific values and estimated the remaining parameters based on the fixed parameter value.

For steepness, the negative log-likelihood supported values between 0.70 - 0.95 (Figure 110). Likelihood components by data source show that the age data (primarily the Northern fleets) support a higher steepness value while the length data from the NWFSC West Coast

Groundfish Bottom Trawl Survey support lower values. The surveys generally provide very little information concerning steepness. The relative spawning biomass for petrale sole diverges most during the middle of the time series based on the assumed values of steepness with the final status being above the management target biomass (Figures 111 and 112).

The negative log-likelihood was minimized at a female natural mortality value of 0.159, but the 95% confidence interval extends over values ranging from 0.12 - 0.18. Male natural mortality was estimated in the likelihood profile. The age and length data likelihood contribution was minimized at female natural morality values ranging from 0.15-0.16 (Figure 113). The relative spawning biomass for petrale sole widely varied across alternative values of natural mortality (Figures 114 and 115).

In regards to values of R_0, the negative log-likelihood was minimized at approximately $\log(R_0)$ of 9.92 (Figure 116). The data source with the largest information regarding R_0 was the NWFSC West Coast Groundfish Bottom Trawl Survey.

3.5 Unresolved Problems and Major Uncertainties

Parameter uncertainty is explicitly captured in the asymptotic confidence intervals reported throughout this assessment for key parameters and management quantities. These intervals reflect the uncertainty in the model fit to the data sources included in the assessment, but do not include uncertainty associated with alternative model configurations, weighting of data sources (a combination of input sample sizes and relative weighting of likelihood components), or fixed parameters.

There are a number of major uncertainties regarding model parameters that have been explored via sensitivity analysis. The most notable explorations involved the sensitivity of model estimates to:

1. The stocks rapid increase in biomass since 2010 was driven by reduced catches and three strong year-classes, 2006-2008, entering the population. In recent years, strong recruitments in a single year have been observed leading to sharp increases in biomass in other West Coast groundfish stocks. However, the observation of three subsequent strong recruitments has not been commonly observed in other stocks and the specific mechanisms that led to these three strong-year classes are currently unknown.

2. The value of natural mortality by sex. Natural mortality by sex and steepness are uncertain for petrale sole. Currently, both natural mortality and steepness are estimated within the model and are negatively correlated. This provides information regarding these parameters combined values, but there is large uncertainty regarding the value of each parameter individually.

3. New fecundity data for petrale sole supports a fecundity relationship that differs from the current assumption (fecundity equals body weights) in this update assessment. A sensitivity to the new data results in a less optimistic estimate of relative spawning biomass, declining to 35

4. Additionally, a reconstructed historical Washington catch history has not been included in the petrale sole stock assessment. Washington state is currently undergoing efforts to determine historical catches for petrale sole and the next stock assessment is likely to incorporate these new historical catch estimates.

4 Harvest Projections and Decision Tables

The forecast of stock abundance and yield was developed using the base model. The total catches in 2019 and 2020 are set at values provided by the Groundfish Management Team (GMT) of the PFMC at 2908 and 2845 mt, respectively. The management adopted ACL values for these years are 2921 and 2857 mt. The exploitation rate for 2021 and beyond is based upon an SPR of 30% and the 25:5 harvest control rule. The average exploitation rates, across recent years, by fleet as provided by the GMT were used to distribute catches during the forecast period.

Uncertainty in the forecasts is based upon the uncertainty around the 2019 spawning biomass, $\sigma = 0.09$. The low and high values for female natural mortality, M, were selected to result in a spawning biomass in 2019 that was equal to the 12.5 and 87.5% quantiles of the normal distribution given the maximum likelihood estimate and the asymptotic uncertainty. The female natural mortality values the corresponded with the lower and upper quantiles were 0.105 yr^{-1} and 0.205 yr^{-1}.

The ABC values were estimated using a category 1 σ_y starting at 0.50 and increasing annually combined with a P* value of 0.45. The catches during the projection period were set equal to the year-specific ABC using the current flatfish harvest control rule, 25:5. The catches during the forecasted period are projected from the base model to start at 4115 mt in 2021 and decline to 3093 mt in 2030 as the stock declines towards the target spawning biomass (Table 26). Across the low and high states of nature the relative biomass (depletion) ranges between 0.193 - 0.373 by the end of the 12-year projection period (Table 27).

5 Scientific Uncertainty

The estimated uncertainty in the base model around the 2019 spawning biomass is $\sigma = 0.09$ compared to the uncertainty in the base model around the 2019 OFL of $\sigma = 0.18$.

6 Regional Management Considerations

Currently petrale sole are managed using a coast-wide harvest; therefore this assessment does not provide a recommended method for allocating harvests regionally. The resource is modeled as a single stock. There is currently no genetic evidence that there are distinct biological stocks of petrale sole off the U.S. coast and the limited tagging data that describes adult movement suggests that movement may be significant across depth and latitude.

7 Research and Data Needs

7.1 Items Identified in the Last Assessment

The 2013 full assessment of petrale sole included the following list of research and data needs:

1. In the past many assessments have derived historical catches independently. The states of California and Oregon have completed comprehensive historical catch reconstructions. At the time of this assessment, a comprehensive historical catch reconstruction is not available for Washington. Completion of a Washington catch reconstruction would provide the best possible estimated catch series that accounts for all the catch and better resolves historical catch uncertainty for flatfish as a group.

    (a) Progress: Washington state is currently working on a catch reconstruction for petrale sole that would be included in the next full assessment. Additionally, the next full assessment should confirm that the California and Oregon catch reconstructions are accounting for the location of removals and where catches were landing in a consistent manner (e.g., fish caught in Oregon waters but landed in California and vice versa).

2. Due to limited data, new studies on both the maturity and fecundity relationships for petrale sole would be beneficial.

    (a) Progress: A new analysis of fecundity in petrale sole off the West Coast has been conducted and were included in a sensitivity run in this update assessment.

3. Increased collection of commercial fishery age data as well as re-aging any available historical samples from California would help reduce uncertainty. While some recent age data were made available from California, sample sizes could be increased and this data collection needs to continue into the future. Without good age data, the ability to estimate year-class strength and the extent of variation in recruitment is compromised.

(a) Progress: This is an ongoing concern. The amount of otoliths collected from California are less than the amount being collected in Oregon and Washington combined. Additionally, this update assessment did not include age data from recent years (2015-2018) from California because there were aged in time for inclusion.

4. Where possible, historical otolith samples aged using a combination of surface and break-and-burn methods should be re-aged using the break-and-burn method. Early surface read otoliths should also be re-aged using the break and burn method. Historical otoliths aged with a standard method will allow the further evaluation of the potential impacts of consistent under aging using surface methods, changes in selectivity during early periods of time without any composition information, and potential changes in growth.

   (a) Progress: The re-evaluation of historical otolith samples had not been conducted to date. Given the limited resources (e.g., people, time, and money) for otolith ageing, the will be challenges in carrying out a robust re-evaluation in the foreseeable future.

5. The effect of the implementation of the IFQ (catch shares) program that began during 2011 on fleet behavior, including impacts on discards, fishery selectivity, and fishing locations would benefit from further study.

   (a) Progress: The behavior of the fishery post-IFQ has now better understood relative to the limited data that was available at the time of the last full assessment of petrale sole.

6. Studies on stock structure and movement of petrale sole, particularly with regard to the winter summer spawning migration of petrale sole and the likely trans-boundary movement of petrale sole between U.S. and Canadian waters seasonally.

   (a) Progress: Additional analysis is still needed to better understand stock structure and movement of petrale sole.

7. The extent of spatial variability on productivity processes such as growth, recruitment, and maturity is currently unknown and would benefit from further research.

   (a) Progress: Additional analysis is still needed to better understand growth, recruitment, and maturity of petrale sole along the West Coast.

7.2 Current Research and Data Needs Identified

There are many areas of research that could be improved to benefit the understanding and assessment of petrale sole. Below, are issues that are considered of importance.

1. Due to limited data, new studies on maturity for petrale sole would be beneficial.
2. Studies on stock structure and movement of petrale sole, particularly with regard to the winter-summer spawning migration of petrale sole and the likely trans-boundary movement of petrale sole between U.S. and Canadian waters seasonally.
3. The extent of spatial variability on productivity processes such as growth, recruitment, and maturity is currently unknown and would benefit from further research.

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9 References

Alderdice, D., and Forrest, C. 1971. Effects of salinity and temperature on embryonic development of the petrale sole(*Eopsetta jordani*). Journal of Fisheries Research Board Canada **28**: 727–744.

Alverson, D., and Chatwin, B. 1957. Results from tagging experiments on a spawning stock of petrale sole, *Eopsetta jordani* (Lockington). Journal of Fisheries Research Board Canada **14**: 953–974.

Anon. 2001. Fish stocks of the Pacific coast. Fisheries; Oceans Canada.

Best, E. 1960. Petrale Sole. In: California ocean fishereies resources to the year 1960. California Department of Fish; Game.

Best, E. 1963. Movements of petrale sole, *Eopsetta jordani*, tagged off of California. Pacific Marine Fisheries Commission Bulletin **6**: 24–38.

Bradburn, M., Keller, A., and Horness, B. 2011. The 2003 to 2008 US West Coast bottom trawl surveys of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, length, and age composition. US Department of Commerce, National Oceanic; Atmospheric Administration, National Marine Fisheries Service.

Castillo, G. 1992. Fluctuations of year-class strength of petrale sole (*Eopsetta jordani*) and their relation to environmental factors. Master's thesis, Oregon State University.

Castillo, G. 1995. Latitudinal patterns in reproductive life history traits of northeast Pacific flatfish. *In* Proceedings of the International Symposium on North Pacific Flatfish. Alaska Sea Grant, University of Alaska Fairbanks. pp. 51–72.

Castillo, G., Li, H., and Golden, J. 1993. Environmental induced recruitment variation in petrale sole, *Eopsetta jordani*. Fisheries Bulletin **92**: 481–493.

Cook, R., He, X., Maguire, J., and Tsou, T. 2009. Petrale sole STAR panel report. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Demory, R. 1984. Progress report on the status of petrale sole in the INPFC Columbia-Vancouver areas in 1984. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Eschmeyer, W., and Herald, E. 1983. A field guide of Pacific coaast fishes North America. Houghton Mifflin CO, Boston, MA.

Fargo, J. 1997. Flatfish stock assessments for the West Coast of Canada for 1997 and recommended yield options for 1998. Can. Stock Assess. Sec. Res. Doc.

Gates, D., and Frey, H. 1974. Designated common names of certain marine organisms of California. Fish Buletin **161**: 55–90.

Gregory, P., and Jow, T. 1976. The validity of otoliths as indicators of age of petrale sole from California. California Department of Fish and Game **62**(2): 132–140.

Haltuch, M.A., and Hicks, A.C. 2009. Status of the U.S. petrale sole resource ien 2008. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Haltuch, M.A., Hamel, O.S., Piner, K.R., McDonald, P., Kastelle, C.R., and Field, J.C. 2013a. A California Current bomb radiocarbon reference chronology and petrale sole (*Eopsetta jordani*) age validation. Canadian Journal of Fisheries and Aquatic Sciences **70**(1): 22–31. doi: 10.1139/cjfas-2011-0504.

Haltuch, M.A., Ono, K., and Valero, J.L. 2013b. Status of the U.S. petrale sole resource in 2012. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Hamel, O.S. 2015. A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES Journal of Marine Science: Journal du Conseil **72**(1): 62–69. doi: 10.1093/icesjms/fsu131.

Hannah, R., Parker, S., and Fruth, E. 2002. Length and age at maturity of female petrale sole (*Eopsetta jordani*) determined from samples collected prior to spawning aggregation. U.S. Fish Bulletin **100**: 711–719.

Harry, G. 1956. Analysis and history of the Oregon otter-trawl fishery. PhD Thesis, University of Washington, Seattle, WA.

Harry, G. 1959. Time of spawning, length at maturity, and fecundity of the English, petrale, and dover soles (*Parophrys vetulus*, *Eopsetta jordani*, and *Microstomus pacificus*, respectively). Fisheries Commission of Oregon, Research Briefs **7**(1): 5–13.

Heimann, R., and Carlisle, J. 1970. Pacific Fishes of Canada. California Department of Fish and Game Fish Bulletin **149**.

Helser, T., Punt, A.E., and Methot, R.D. 2004. A generalized linear mixed model analysis of a multi-vessel fishery resource survey. **70**: 251–264.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin **82**: 898–903.

Karnowski, M., Gertseva, V., and Stephens, A. 2014. Historical Reconstruction of Oregon's

Commercial Fisheries Landings. Oregon Department of Fish; Wildlife, Salem, OR.

Ketchen, K., and Forrester, C. 1966. Population dynamics of the petrale sole, *Eopsetta jordani*, in waters off western Canada. Fish. Res. Bd. Canada Bull.

Kramer, D., Barss, W., Paust, B., and Bracken, B. 1995. Guide to northeast Pacific flatfishes: Families Bothidae, Cynoglossidae, and Pleuronectidae. Alaska Sea Grant, University of Alaska Fairbanks.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H.J., and Bell, B. 2016. TMB: Automatic Differentiation and Laplace Approximation. Journal of Statistical Software **70**: 1–21.

Lai, H., Haltuch, M.A., Punt, A.E., and Cope, J. 2005. Stock assessment of petrale sole: 2004. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Lefebvre, L.S., Friedlander, C., and Field, J.C. (n.d.). Reproductive ecology and size-dependent fecundity in the petrale sole, *Eopsetta jordani*, in California, Oregon, and Washington waters. Fishery Bulletin.

Love, M. 1996. Probably more than you want to know about the fishes of the Pacific Coast. Really Big Press, Santa Barbara, California.

Love, M., Mecklenburg, C., Mecklenburg, T., and Thorsteinson, L. 2005. Resource inventory of marine and estuarine fishes of the West Coast and Alaska: A checklist of north Pacific and arctic ocean species from Baja California to the Alsaka-Yukon border. USGS, Seattle, WA.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.R., and Francis, R.C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Meteorol Soc. **78**: 1069–1080.

McAllister, M.K., and Ianelli, J.N. 1997. Bayesian stock assessment using catch-age data and the sampling - importance resampling algorithm. Canadian Journal of Fisheries and Aquatic Sciences **54**: 284–300.

Methot, R.D., and Wetzel, C.R. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research **142**: 86–99. doi: 10.1016/j.fishres.2012.10.012.

Myers, R.A., Bowen, K.G., and Barrowman, N. 1999. Maximum reproductive rate of fish at low population sizes. Canadian Journal of Fisheries and Aquatic Sciences **56**: 2404–2419. Available from http://www.nrcresearchpress.com/doi/pdf/10.1139/f99-201 [accessed 4 October 2016].

Pedersen, M. 1975. Movements and growth of petrale sole (*Eopsetta jordani*) tagged off

Washington and southwest Vancouver Island. Fishery Research Board of Canada Progress Report.

PFMC. 1979. Data series, groundfish section. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Pikitch, E.K., Erikson, D., and Wallace, J.R. 1988. An evaluation of the effectiveness of trip limits as a management tool. NOAA, NMFSC.

Porter, P. 1964. Notes on fecundity, spawning, and early life history of petrale sole (*Eopsetta jordani*) with descriptions of flatfish larvae collected in the Pacific Ocean off Humboldt Bay, California. Master's thesis, Humboldt State College.

Ralston, S., Pearson, D.E., Field, J.C., and Key, M. 2010. Documentation of the California catch reconstruction project. US Department of Commerce, National Oceanic; Atmospheric Adminstration, National Marine.

Reilly, P., Wilson-Vandenberg, D., Lea, R., Wilson, C., and Sullivan, M. 1994. Recreational angler's guide to the common nearshore fishes of Northern and Central California. California Department of Fish; Game.

Rogers, J.B., and Pikitch, E.K. 1992. Numerical definition of groundfish assemblages caught off the coasts of Oregon and Washington using commercial fishing strategies. Canadian Journal of Fisheries and Aquatic Sciences **49**(12): 2648–2656.

Sampson, D., and Lee, Y. 1999. An assessment of the stocks of petrale sole off Washington, Oregon, and Northern California in 1998. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Scofield, W. 1948. Trawling gear in California. California Fish and Game Fish Bulletin **72**: 1–60.

Smith, R. 1937. Report on the Puget Sound otter trawl investigations. Master's thesis, University of Washington.

Starr, P.J., and Fargo, J. 2004. Petrale sole stock assessment for 2003 and recommendations for management in 2004. CSAS Res. Doc 2004/036.

Stawitz, C.C., Hurtado-Ferro, F., Kuriyama, P.T., Trochta, J., Johnson, K.F., Haltuch, M.A., and Hamel, O.S. 2015. Stock assessment update: Status of the U.S. petrale sole resource in 2014. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Then, A.Y., Hoenig, J.M., Hall, N.G., and Hewitt, D.A. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science **72**(1): 82–92. doi: 10.1093/icesjms/fsu136.

Thorson, J.T. 2019. Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. Fisheries Research **210**: 143–161. doi: 10.1016/j.fishres.2018.10.013.

Thorson, J.T., and Barnett, L.A.K. 2017. Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. ICES Journal of Marine Science: Journal du Conseil **74**(5): 1311–1321. doi: 10.1093/icesjms/fsw193.

Thorson, J.T., and Kristensen, K. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fisheries Research **175**: 66–74. doi: 10.1016/j.fishres.2015.11.016.

Thorson, J.T., and Ward, E.J. 2013. Accounting for space–time interactions in index standardization models. Fisheries Research **147**: 426–433. doi: 10.1016/j.fishres.2013.03.012.

Turnock, J., Wilkins, M., Saelens, M., and Wood, C. 1993. Status of West Coast petrale sole in 1993. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Weinberg, K., Wilkins, M., Shaw, F., and Zimmermann, M. 2002. The 2001 Pacific West Coast bottom trawl survey of groundifsh resources: Estimates of distribution, abundance and length and age composition. NOAA Technical Memorandum, U.S. Department of Commerce.

10 Tables

Table 1: Landings (mt) for each fleet for the modeled years.

Year	Winter North	Summer North	Winter South	Summer South
1875	0	0	0	0
1876	0	0	0	1
1877	0	0	0	1
1878	0	0	0	1
1879	0	0	0	1
1880	0	0	0	12
1881	0	0	0	22
1882	0	0	0	33
1883	0	0	0	43
1884	0	0	0	54
1885	0	0	0	64
1886	0	0	0	75
1887	0	0	0	85
1888	0	0	0	96
1889	0	0	0	106
1890	0	0	0	117
1891	0	0	0	128
1892	0	0	0	138
1893	0	0	0	149
1894	0	0	0	159
1895	0	0	0	170
1896	0	0	0	180
1897	0	0	0	191
1898	0	0	0	201
1899	0	0	0	212
1900	0	0	0	223
1901	0	0	0	233
1902	0	0	0	244
1903	0	0	0	254
1904	0	0	0	265
1905	0	0	0	275
1906	0	0	0	286
1907	0	0	0	296
1908	0	0	0	307
1909	0	0	0	318
1910	0	0	0	328
1911	0	0	0	339
1912	0	0	0	349

Continued on next page

Table 1: Landings (mt) for each fleet for the modeled years.

Year	Winter North	Summer North	Winter South	Summer South
1913	0	0	0	360
1914	0	0	0	370
1915	0	0	0	381
1916	0	0	0	386
1917	0	0	0	526
1918	0	0	0	424
1919	0	0	0	333
1920	0	0	0	230
1921	0	0	0	294
1922	0	0	0	425
1923	0	0	0	427
1924	0	0	0	533
1925	0	0	0	528
1926	0	0	0	522
1927	0	0	0	632
1928	0	0	0	620
1929	0	2	0	706
1930	0	1	0	659
1931	0	81	63	531
1932	2	251	36	520
1933	6	408	39	392
1934	10	568	139	896
1935	14	650	155	777
1936	16	770	95	432
1937	20	1051	75	741
1938	27	1187	48	890
1939	35	1545	31	1029
1940	39	1737	162	597
1941	41	1803	111	331
1942	46	2919	24	216
1943	51	2867	72	345
1944	55	2047	86	447
1945	60	1866	102	439
1946	64	2492	72	1116
1947	69	1778	154	1093
1948	74	2315	273	1778
1949	76	1809	617	1812
1950	156	2322	424	1638
1951	118	1666	208	993
1952	131	1390	326	882

Continued on next page

Table 1: Landings (mt) for each fleet for the modeled years.

Year	Winter North	Summer North	Winter South	Summer South
1953	46	737	533	981
1954	27	903	801	1073
1955	57	863	526	1052
1956	137	759	508	801
1957	171	1103	527	1027
1958	99	1152	568	957
1959	332	947	379	723
1960	241	1374	520	644
1961	217	1547	542	1029
1962	295	1512	515	859
1963	663	1038	534	978
1964	282	1090	378	927
1965	370	950	374	853
1966	366	972	325	925
1967	409	793	532	874
1968	284	811	361	871
1969	190	887	421	848
1970	412	1081	472	1071
1971	743	883	540	1016
1972	730	1017	703	1000
1973	497	1272	417	742
1974	517	1611	665	893
1975	539	1559	561	901
1976	506	951	713	737
1977	682	743	484	495
1978	746	1098	419	801
1979	734	1086	353	945
1980	382	976	518	680
1981	761	468	360	895
1982	1041	771	262	502
1983	696	935	273	361
1984	416	739	260	329
1985	392	553	273	471
1986	474	714	403	355
1987	855	573	311	556
1988	743	610	349	411
1989	696	583	393	415
1990	641	460	319	373
1991	793	397	448	310
1992	640	366	272	307

Continued on next page

Table 1: Landings (mt) for each fleet for the modeled years.

Year	Winter North	Summer North	Winter South	Summer South
1993	685	392	237	234
1994	518	355	246	299
1995	591	454	236	287
1996	591	440	406	394
1997	621	430	448	442
1998	522	577	221	300
1999	463	504	287	267
2000	610	586	372	241
2001	691	597	308	260
2002	667	714	335	195
2003	544	713	256	180
2004	1010	750	177	271
2005	964	1069	343	533
2006	537	1012	125	454
2007	931	536	404	475
2008	842	354	519	414
2009	847	642	470	250
2010	264	292	78	121
2011	224	427	40	78
2012	410	494	124	108
2013	513	1045	130	280
2014	853	861	273	386
2015	1040	1077	215	354
2016	865	1168	237	235
2017	1142	1271	201	393
2018	957	1262	218	402

Table 2: Recent trend in estimated total catch relative to management guidelines. The estimated total catch includes the total landings plus the model estimated discard mortality based upon discard rate data. The catch values shown here may have minimal differences from the West Coast Groundfish Total Mortality Estimates.

Year	OFL (mt; ABC prior to 2011)	ACL (mt; OY prior to 2011)	Total landings (mt)	Estimated total catch (mt)
2009	2811	2433	2209	2334
2010	2751	1200	755	869
2011	1021	976	768	785
2012	1275	1160	1135	1153
2013	2711	2592	1967	1995
2014	2774	2652	2373	2392
2015	3073	2816	2686	2704
2016	3208	2910	2506	2523
2017	3208	3136	3008	3026
2018	3152	3013	2840	2857

Table 3: Summary of the fishery-independent biomass/abundance time-series used in the stock assessment. The standard error includes the input annual standard error and model estimated added variance.

	Winter N.		Winter S.		Triennial Early		Triennial Late		NWFSC	
Year	Obs	SE	Obs	SE	Obs	SE	Obs	SE	Obs	SE
1980	-	-	-	-	1416	0.45	-	-	-	-
1983	-	-	-	-	2019	0.40	-	-	-	-
1986	-	-	-	-	2094	0.41	-	-	-	-
1987	1.09	0.28	1.08	0.56	-	-	-	-	-	-
1988	1.16	0.27	0.91	0.33	-	-	-	-	-	-
1989	0.92	0.27	0.53	0.43	3512	0.38	-	-	-	-
1990	0.76	0.28	0.96	0.46	-	-	-	-	-	-
1991	0.86	0.27	0.90	0.36	-	-	-	-	-	-
1992	0.56	0.28	0.59	0.68	2024	0.39	-	-	-	-
1993	0.56	0.27	0.86	0.35	-	-	-	-	-	-
1994	0.50	0.28	0.71	0.30	-	-	-	-	-	-
1995	0.66	0.28	0.90	0.30	-	-	2218	0.39	-	-
1996	0.77	0.29	1.25	0.30	-	-	-	-	-	-
1997	0.85	0.28	0.82	0.28	-	-	-	-	-	-
1998	1.01	0.29	0.93	0.31	-	-	3492	0.38	-	-
1999	0.71	0.29	0.83	0.29	-	-	-	-	-	-
2000	0.67	0.28	0.62	0.29	-	-	-	-	-	-
2001	0.83	0.27	0.66	0.29	-	-	3879	0.39	-	-
2002	0.93	0.28	0.80	0.29	-	-	-	-	-	-
2003	1.02	0.28	0.85	0.29	-	-	-	-	17126	0.11
2004	1.63	0.28	1.71	0.31	-	-	10521	0.39	22842	0.11
2005	1.85	0.28	1.93	0.29	-	-	-	-	23292	0.10
2006	2.01	0.28	1.58	0.29	-	-	-	-	20149	0.10
2007	2.04	0.28	2.07	0.28	-	-	-	-	17102	0.10
2008	1.96	0.27	1.62	0.28	-	-	-	-	14663	0.10
2009	2.12	0.27	1.76	0.28	-	-	-	-	18787	0.10
2010	-	-	-	-	-	-	-	-	24506	0.09
2011	-	-	-	-	-	-	-	-	30070	0.09
2012	-	-	-	-	-	-	-	-	36156	0.10
2013	-	-	-	-	-	-	-	-	52602	0.11
2014	-	-	-	-	-	-	-	-	66738	0.09
2015	-	-	-	-	-	-	-	-	52192	0.09
2016	-	-	-	-	-	-	-	-	61236	0.09
2017	-	-	-	-	-	-	-	-	70052	0.09
2018	-	-	-	-	-	-	-	-	45575	0.09

Table 4: Summary of the number tows, fish sampled, and the calculated input sample size for the length data from the NWFSC West Coast Groundfish Bottom Trawl Survey used in the stock assessment.

Year	Tows	Fish	Input Sample Size
2003	197	2837	589
2004	212	3346	674
2005	278	4555	907
2006	247	3668	753
2007	257	3409	727
2008	257	3047	677
2009	277	3387	744
2010	325	6052	1160
2011	320	6176	1172
2012	295	5372	1036
2013	218	3445	693
2014	332	4822	997
2015	312	4236	897
2016	309	4385	914
2017	314	4261	902
2018	291	3783	813

Table 5: Description of the strata used to create the indices for the NWFSC West Coast Groundfish Bottom Trawl Survey.

Strata	Depth Lower Bound (m)	Depth Upper Bound (m)	Latitude South	Latitude North
Shallow Vancouver	55	100	47.5	49.0
Shallow Columbia	55	100	43.0	47.5
Shallow Eureka	55	100	40.5	43.0
Shallow Monterey	55	100	36.0	40.5
Shallow Conception	55	100	34.5	36.0
Mid Vancouver	100	183	47.5	49.0
Mid Columbia	100	183	43.0	47.5
Mid Eureka	100	183	40.5	43.0
Mid Monterey	100	183	36.0	40.5
Mid Conception	100	183	34.5	36.0
Deep Van/Col/Eur	183	549	40.5	49.0
Deep Montery	183	549	36.0	40.5
Deep Conception	183	549	32.0	36.0

Table 6: Summary of the number tows, fish sampled, and the calculated input sample size for the age data from the NWFSC West Coast Groundfish Bottom Trawl Survey used in the stock assessment.

Year	Tows	Fish	InputSample Size
2003	173	765	279
2004	167	723	267
2005	237	752	341
2006	236	774	343
2007	196	690	291
2008	225	746	328
2009	258	777	365
2010	297	801	408
2011	289	799	399
2012	269	777	376
2013	217	843	333
2014	318	766	424
2015	291	751	395
2016	307	893	430
2017	313	884	435
2018	291	810	403

Table 7: Summary of the number tows, fish sampled, and the calculated input sample size for the length data from the AFSC/NWFSC West Coast Triennial Shelf Survey used in the stock assessment.

Year	Tows	Fish	Input Sample Size
1980	1	16	3
1983	2	30	6
1986	36	540	111
1989	141	1419	337
1992	116	1015	256
1995	145	1369	334
1998	236	2624	598
2001	254	3016	670
2004	239	4676	884

Table 8: Description of the strata used to create the indices for the AFSC/NWFSC West Coast Triennial Shelf Survey Early (1980 - 1992) survey.

Strata	Depth Lower Bound (m)	Depth Upper Bound (m)	Latitude South	Latitude North
Shallow Van/Col	55	100	43.0	49.0
Shallow Eureka	55	100	40.5	43.0
Shallow Mon/Con	55	100	32.0	40.5
Deep Van/Col/Eur	100	400	40.5	49.0
Deep Mon/Con	100	400	32.0	40.5

Table 9: Description of the strata used to create the indices for the AFSC/NWFSC West Coast Triennial Shelf Survey Late (1995-2004) survey.

Strata	Depth Lower Bound (m)	Depth Upper Bound (m)	Latitude South	Latitude North
Shallow Van/Col	55	100	43.0	49.0
Shallow Eureka	55	100	40.5	43.0
Shallow Mon/Con	55	100	32.0	40.5
Deep Van/Col	100	500	43.0	49.0
Deep Eureka	100	500	40.5	43.0
Deep Mon/Con	100	500	36.0	40.5
Deep Con	100	500	32.0	36.0

Table 10: Summary of discard rates used in the model by each data source.

Year	Fleet	Discard Rate	Standard Error	Data Source
1985	WinterN	0.022	0.110	Pikitch
1986	WinterN	0.021	0.116	Pikitch
1987	WinterN	0.027	0.119	Pikitch
2002	WinterN	0.008	0.001	WCGOP
2003	WinterN	0.004	0.002	WCGOP
2004	WinterN	0.003	0.002	WCGOP
2005	WinterN	0.002	0.001	WCGOP
2006	WinterN	0.006	0.003	WCGOP
2007	WinterN	0.012	0.005	WCGOP
2008	WinterN	0.022	0.012	WCGOP
2009	WinterN	0.027	0.014	WCGOP
2010	WinterN	0.119	0.023	WCGOP
2011	WinterN	0.002	0.015	WCGOP
2012	WinterN	0.001	0.015	WCGOP
2013	WinterN	0.001	0.015	WCGOP
2014	WinterN	0.003	0.015	WCGOP
2015	WinterN	0.001	0.015	WCGOP
2016	WinterN	0.001	0.015	WCGOP
2017	WinterN	0.003	0.015	WCGOP
2018	WinterN	0.001	0.015	WCGOP
1985	SummerN	0.035	0.042	Pikitch
1986	SummerN	0.034	0.043	Pikitch
1987	SummerN	0.032	0.045	Pikitch
2002	SummerN	0.186	0.023	WCGOP
2003	SummerN	0.105	0.022	WCGOP
2004	SummerN	0.083	0.023	WCGOP
2005	SummerN	0.042	0.008	WCGOP
2006	SummerN	0.078	0.015	WCGOP
2007	SummerN	0.116	0.021	WCGOP
2008	SummerN	0.051	0.016	WCGOP
2009	SummerN	0.206	0.067	WCGOP
2010	SummerN	0.099	0.029	WCGOP
2011	SummerN	0.037	0.015	WCGOP
2012	SummerN	0.022	0.015	WCGOP
2013	SummerN	0.017	0.015	WCGOP
2014	SummerN	0.026	0.015	WCGOP
2015	SummerN	0.006	0.015	WCGOP
2016	SummerN	0.017	0.015	WCGOP
2017	SummerN	0.007	0.015	WCGOP
2002	WinterS	0.035	0.016	WCGOP

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Table 10: Summary of discard rates used in the model by each data source.

Year	Fleet	Discard Rate	Standard Error	Data Source
2003	WinterS	0.012	0.001	WCGOP
2004	WinterS	0.013	0.033	WCGOP
2005	WinterS	0.033	0.004	WCGOP
2006	WinterS	0.071	0.035	WCGOP
2007	WinterS	0.012	0.003	WCGOP
2008	WinterS	0.013	0.010	WCGOP
2009	WinterS	0.024	0.009	WCGOP
2010	WinterS	0.052	0.031	WCGOP
2011	WinterS	0.001	0.015	WCGOP
2012	WinterS	0.001	0.015	WCGOP
2013	WinterS	0.003	0.015	WCGOP
2014	WinterS	0.001	0.015	WCGOP
2015	WinterS	0.001	0.015	WCGOP
2016	WinterS	0.003	0.015	WCGOP
2017	WinterS	0.006	0.015	WCGOP
2018	WinterS	0.001	0.015	WCGOP
2002	SummerS	0.058	0.016	WCGOP
2003	SummerS	0.033	0.011	WCGOP
2004	SummerS	0.033	0.014	WCGOP
2005	SummerS	0.012	0.003	WCGOP
2006	SummerS	0.038	0.014	WCGOP
2007	SummerS	0.065	0.023	WCGOP
2008	SummerS	0.026	0.014	WCGOP
2009	SummerS	0.023	0.006	WCGOP
2010	SummerS	0.056	0.007	WCGOP
2011	SummerS	0.041	0.015	WCGOP
2012	SummerS	0.013	0.015	WCGOP
2013	SummerS	0.004	0.015	WCGOP
2014	SummerS	0.004	0.015	WCGOP
2015	SummerS	0.010	0.015	WCGOP
2016	SummerS	0.004	0.015	WCGOP
2017	SummerS	0.008	0.015	WCGOP

Table 11: Summary of the number of fishery length samples used in the stock assessment (continued on the next page).

	Winter N.		Summer N.		Winter S.		Summer S.	
Year	Trips	Fish	Trips	Fish	Trips	Fish	Trips	Fish
1948	0	0	0	0	4	202	4	203
1949	0	0	0	0	6	275	4	183
1955	1	507	0	0	0	0	0	0
1956	0	0	1	534	0	0	0	0
1960	0	0	1	644	0	0	0	0
1962	0	0	0	0	0	0	3	150
1964	0	0	0	0	2	73	22	897
1965	0	0	0	0	1	25	14	583
1966	0	0	2	463	20	852	33	1396
1967	0	0	3	485	12	481	44	1815
1968	0	0	7	1842	13	499	87	3414
1969	1	328	4	992	19	705	49	1907
1970	1	237	5	1309	6	226	29	920
1971	3	721	6	1481	12	519	37	1180
1972	2	516	14	3255	21	747	39	1435
1973	2	440	4	829	18	752	40	1460
1974	3	768	25	7196	28	974	35	1133
1975	9	1978	12	3509	8	325	19	873
1976	1	379	4	1054	10	475	26	1255
1977	1	220	2	529	16	739	38	1816
1978	3	678	2	570	9	448	33	1649
1979	2	219	4	400	5	247	13	601
1980	4	573	22	2287	20	999	81	4042
1981	4	400	0	0	31	1522	65	3134
1982	0	0	0	0	30	1496	34	1434
1983	0	0	0	0	17	851	33	1600
1984	0	0	0	0	13	627	19	943
1985	0	0	0	0	8	400	17	825
1986	0	0	0	0	22	1100	32	1602
1987	6	300	16	805	12	600	29	1450
1988	10	499	8	401	10	500	12	532
1989	3	151	13	652	16	783	18	900
1990	5	251	11	552	10	428	2	76
1991	10	356	7	277	22	754	2	82
1992	8	313	11	428	6	176	0	0
1993	8	236	8	296	0	0	0	0
1994	6	258	9	371	1	1	0	0
1995	6	230	2	66	0	0	0	0
1996	2	67	4	168	0	0	0	0

1997	8	284	11	417	0	0	0	0
1998	5	201	22	1004	0	0	0	0
1999	11	413	15	703	0	0	0	0
2000	17	638	24	1012	0	0	0	0
2001	12	468	18	786	10	305	9	289
2002	13	551	31	1259	7	209	10	252
2003	28	872	35	1370	10	254	30	475
2004	22	720	30	1328	10	228	15	431
2005	18	628	35	1493	9	169	36	966
2006	26	1106	51	2639	37	1040	47	1059
2007	42	1680	46	2402	58	1656	103	2971
2008	65	2059	36	2127	66	2023	97	2442
2009	32	1220	66	2860	34	749	62	1597
2010	49	1614	59	1795	29	655	52	1356
2011	26	855	47	2019	33	1170	23	400
2012	32	1059	44	1954	28	1099	40	1125
2013	55	2145	52	2300	40	1753	43	1930
2014	59	2158	64	2421	35	1292	49	1672
2015	61	1929	60	2386	34	1062	62	2026
2016	31	1045	39	1071	34	1311	70	2306
2017	57	1816	74	2790	33	1289	85	2489
2018	50	1386	93	2654	19	823	77	2663

Table 12: Summary of fishery age samples used in the stock assessment (continued on the next page).

	Winter N.		Summer N.		Winter S.		Summer S.	
Year	Trips	Fish	Trips	Fish	Trips	Fish	Trips	Fish
1960	0	0	1	168	0	0	0	0
1966	0	0	2	340	19	441	27	649
1967	0	0	3	482	2	50	11	273
1968	0	0	3	663	4	64	56	1340
1969	1	100	2	192	12	293	31	765
1970	1	116	4	499	5	126	29	709
1971	2	318	5	785	12	294	37	930
1972	2	349	13	1984	21	512	38	962
1973	2	393	4	684	16	425	37	951
1974	3	295	20	2033	27	643	34	837
1975	8	766	10	1012	7	175	18	473
1976	1	99	4	400	10	250	23	575
1977	1	98	1	100	10	241	33	822
1978	3	308	2	387	6	150	32	800
1979	0	0	3	295	4	100	11	270
1980	2	177	16	1569	12	300	50	1244
1981	2	195	0	0	10	250	27	677
1982	0	0	0	0	7	175	18	352
1983	0	0	0	0	9	276	8	191
1984	0	0	0	0	2	49	3	74
1985	0	0	0	0	2	50	4	100
1986	0	0	0	0	11	265	16	396
1987	6	173	16	573	5	125	12	299
1988	10	379	8	256	5	123	6	149
1989	3	144	12	507	0	0	0	0
1990	5	159	11	272	10	294	1	38
1991	10	202	7	151	8	245	0	0
1992	8	313	11	424	0	0	0	0
1993	8	234	8	296	0	0	0	0
1994	6	256	9	371	0	0	0	0
1995	6	228	2	66	0	0	0	0
1996	2	67	4	165	0	0	0	0
1997	8	283	10	375	0	0	0	0
1998	5	201	22	999	0	0	0	0
1999	6	256	14	649	0	0	0	0
2000	6	258	12	560	0	0	0	0
2001	5	250	11	498	0	0	0	0
2002	8	346	20	834	0	0	0	0
2003	20	665	26	1071	2	41	5	55

2004	7	313	24	1059	2	57	4	96
2005	6	294	18	874	3	55	10	217
2006	4	197	14	697	2	51	7	154
2007	14	536	24	1018	4	78	5	97
2008	11	336	26	1079	7	97	18	300
2009	28	400	39	684	0	0	3	78
2010	19	353	34	542	0	0	0	0
2011	24	327	42	845	8	185	8	26
2012	31	385	40	835	4	118	1	34
2013	48	723	46	831	1	39	3	100
2014	29	678	24	616	0	0	0	0
2015	56	584	48	811	0	0	0	0
2016	28	318	36	302	0	0	0	0
2017	49	567	61	779	0	0	0	0
2018	38	534	78	961	0	0	0	0

Table 13: Estimated ageing error vectors applied to ages read by the Cooperative Aging Project lab used in the assessment model.

	Break and Burn		Surface		Combo		Surface Pre-1990	
True Age	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0.5	0.26	0.17	0.16	0.12	0.47	0.13	0.00	0.00
1.5	1.35	0.17	1.27	0.12	1.42	0.13	0.71	0.00
2.5	2.41	0.23	2.35	0.18	2.37	0.25	2.02	0.08
3.5	3.44	0.29	3.41	0.25	3.32	0.38	3.24	0.17
4.5	4.45	0.36	4.43	0.32	4.27	0.51	4.38	0.26
5.5	5.44	0.44	5.42	0.40	5.22	0.64	5.44	0.35
6.5	6.41	0.52	6.39	0.49	6.17	0.76	6.44	0.46
7.5	7.35	0.61	7.33	0.59	7.12	0.89	7.36	0.56
8.5	8.28	0.71	8.25	0.70	8.07	1.02	8.22	0.67
9.5	9.18	0.81	9.14	0.82	9.02	1.14	9.03	0.79
10.5	10.06	0.92	10.01	0.96	9.97	1.27	9.78	0.92
11.5	10.92	1.04	10.85	1.11	10.92	1.40	10.48	1.05
12.5	11.76	1.18	11.67	1.27	11.87	1.53	11.14	1.19
13.5	12.58	1.32	12.47	1.45	12.82	1.65	11.75	1.34
14.5	13.38	1.48	13.24	1.66	13.77	1.78	12.32	1.49
15.5	14.17	1.64	14.00	1.88	14.72	1.91	12.85	1.66
16.5	14.94	1.82	14.73	2.12	15.67	2.03	13.35	1.83
17.5	15.68	2.02	15.45	2.39	16.62	2.16	13.81	2.01

Table 14: Estimated ageing error vectors applied to ages read by Washington Department of Fish and Wildlife used in the assessment model.

	Combo		Surface		Break and Burn	
True Age	Mean	SD	Mean	SD	Mean	SD
0.5	0.49	0.13	0.13	0.10	0.50	0.15
1.5	1.46	0.13	1.32	0.10	1.51	0.15
2.5	2.44	0.27	2.47	0.21	2.52	0.30
3.5	3.42	0.40	3.58	0.31	3.52	0.45
4.5	4.39	0.53	4.64	0.41	4.53	0.60
5.5	5.37	0.67	5.67	0.52	5.53	0.75
6.5	6.35	0.80	6.66	0.62	6.54	0.90
7.5	7.32	0.93	7.62	0.72	7.55	1.05
8.5	8.30	1.07	8.54	0.83	8.55	1.20
9.5	9.28	1.20	9.43	0.93	9.56	1.35
10.5	10.25	1.33	10.28	1.03	10.57	1.51
11.5	11.23	1.47	11.11	1.13	11.57	1.66
12.5	12.21	1.60	11.90	1.24	12.58	1.81
13.5	13.18	1.74	12.67	1.34	13.59	1.96
14.5	14.16	1.87	13.41	1.44	14.59	2.11
15.5	15.14	2.00	14.12	1.55	15.60	2.26
16.5	16.11	2.14	14.81	1.65	16.60	2.41
17.5	17.09	2.27	15.47	1.75	17.61	2.56

Table 15: Specifications of the model for petrale sole.

Model Specification	Base Model
Starting year	1876
Population characteristics	
Maximum age	40
Gender	2
Population lengths	4-78 cm by 2 cm bins
Summary biomass (mt)	Age 3+
Data characteristics	
Data lengths	12-62 cm by 2 cm bins
Data ages	1-17 ages
Minimum age for growth calculations	2
Maximum age for growth calculations	17
First mature age	3
Fishery characteristics	
Fishing mortality method	Hybrid
Maximum F	3
Catchability - Fishery	Power
Catchability - Survey	Analytical estimate
Winter North selectivity	Double Normal
Summer North selectivity	Double Normal
Winter South selectivity	Double Normal
Summer South selectivity	Double Normal
AFSC/NWFSC West Coast Triennial Shelf Survey - early	Double Normal
AFSC/NWFSC West Coast Triennial Shelf Survey - late	Double Normal
NWFSC West Coast Groundfish Bottom Trawl Survey	Double Normal
Fishery time blocks	
Fishery selectivity	1876-1972,1973-1982, 1983-1992, 1993-2002, 2003-2010, 2011-2018
Winter retention	1876-2002, 2003-2009, 2010, 2011-2018
Summer retention	1876-2002, 2003-2008, 2009-2010, 2011-2018

Table 16: Data weights applied when using McAllister Ianelli Harmonic Mean data weighting.

Fleet	Lengths	Ages
Winter North	1.366	2.926
Summer North	1.039	2.45
Winter South	1.017	1.756
Summer South	1.169	1.601
Triennial Early Survey	1.807	-
Triennial Late Survey	1.285	-
NWFSC WCGBT Survey	0.579	0.215

Table 17: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
NatM_p_1_Fem_GP_1	0.158704	2	(0.005, 0.5)	OK	0.02	Log_Norm (-1.7793, 0.438)
L_at_Amin_Fem_GP_1	15.6515	3	(10, 45)	OK	0.42	None
L_at_Amax_Fem_GP_1	53.1167	3	(35, 80)	OK	0.42	None
VonBert_K_Fem_GP_1	0.141731	3	(0.04, 0.5)	OK	0.01	None
SD_young_Fem_GP_1	0.186051	3	(0.01, 1)	OK	0.01	None
SD_old_Fem_GP_1	0.0351949	4	(0.01, 1)	OK	0.01	None
Wtlen_1_Fem_GP_1	0.000001986	-3	(-3, 3)			Normal (0.00000199, 0.8)
Wtlen_2_Fem_GP_1	3.484	-3	(1, 5)			Normal (3.478, 0.8)
Mat50%_Fem_GP_1	33.1	-3	(10, 50)			Normal (33.1, 0.8)
Mat_slope_Fem_GP_1	-0.743	-3	(-3, 3)			Normal (-0.743, 0.8)
Eggs/kg_inter_Fem_GP_1	1	-3	(-3, 3)			Normal (1, 1)
Eggs/kg_slope_wt_Fem_GP_1	0	-3	(-3, 3)			Normal (0, 1)
NatM_p_1_Mal_GP_1	0.164428	2	(0.005, 0.6)	OK	0.02	Log_Norm (-1.6809, 0.438)
L_at_Amin_Mal_GP_1	16.1562	3	(10, 45)	OK	0.35	None
L_at_Amax_Mal_GP_1	40.8281	3	(35, 80)	OK	0.34	None
VonBert_K_Mal_GP_1	0.238	3	(0.04, 0.5)	OK	0.01	None
SD_young_Mal_GP_1	0.136371	3	(0.01, 1)	OK	0.01	None
SD_old_Mal_GP_1	0.06	4	(0.01, 1)	OK	0.00	None
Wtlen_1_Mal_GP_1	0.000002983	-3	(-3, 3)			Normal (0.00000298, 0.8)
Wtlen_2_Mal_GP_1	3.363	-3	(-3, 5)			Normal (3.363, 0.8)
CohortGrowDev	1	-4	(0, 1)			None
FracFemale_GP_1	0.5	-99	(0.01, 0.99)			None
SR_LN(R0)	9.92138	1	(5, 20)	OK	0.19	None
SR_BH_steep	0.841493	5	(0.2, 1)	OK	0.05	Normal (0.8, 0.09)
SR_sigmaR	0.4	-99	(0, 2)			Normal (0.9, 5)
SR_regime	0	-2	(-5, 5)			Normal (0, 0.2)
SR_autocorr	0	-99	(0, 0)			None
Early_InitAge_31	0.000000194064	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_30	0.00000022766	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_29	0.00000026352	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_28	0.000000311448	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_27	0.000000363083	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_26	0.000000420272	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_25	0.000000495381	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_24	0.000000576002	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_23	0.000000673192	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_22	0.000000787185	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_21	0.000000919947	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_20	0.00000107607	3	(-4, 4)	act	0.40	dev (NA, NA)

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Table 17: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Early_InitAge_19	0.00000125601	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_18	0.00000146407	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_17	0.00000170636	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_16	0.00000198596	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_15	0.00000230604	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_14	0.00000268141	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_13	0.00000310519	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_12	0.00000359611	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_11	0.00000415824	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_10	0.0000047992	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_9	0.0000055294	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_8	0.00000635756	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_7	0.00000728903	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_6	0.00000833796	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_5	0.00000951955	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_4	0.0000108453	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_3	0.0000123508	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_2	0.0000140634	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_1	0.0000160097	3	(-4, 4)	act	0.40	dev (NA, NA)
LnQ_base_WinterN(1)	-7.01915	1	(-20, 5)	OK	3.05	None
Q_power_WinterN(1)	-0.120823	3	(-5, 5)	OK	0.39	None
LnQ_base_WinterS(3)	-1.3472	1	(-20, 5)	OK	2.34	None
Q_power_WinterS(3)	-0.852654	3	(-5, 5)	OK	0.29	None
LnQ_base_TriEarly(5)	-0.861191	-1	(-15, 15)			None
Q_extraSD_TriEarly(5)	0.218021	5	(0.001, 2)	OK	0.13	None
LnQ_base_TriLate(6)	-0.430897	-1	(-15, 15)			None
Q_extraSD_TriLate(6)	0.312559	4	(0.001, 2)	OK	0.14	None
LnQ_base_NWFSC(7)	1.0476	-1	(-15, 15)			None
LnQ_base_WinterN(1)_BLK5add_2004	0.490021	3	(-0.99, 0.99)	OK	0.20	Normal (0, 0.5)
LnQ_base_WinterS(3)_BLK5add_2004	0.619915	3	(-0.99, 0.99)	OK	0.23	Normal (0, 0.5)
Size_DblN_peak_WinterN(1)	48.6805	2	(15, 75)	OK	2.27	None
Size_DblN_top_logit_WinterN(1)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_WinterN(1)	4.30771	3	(-4, 12)	OK	0.13	None
Size_DblN_descend_se_WinterN(1)	14	-3	(-2, 15)			None
Size_DblN_start_logit_WinterN(1)	-999	-4	(-15, 5)			None
Size_DblN_end_logit_WinterN(1)	-999	-4	(-5, 5)			None
Retain_L_infl_WinterN(1)	28.0301	2	(10, 40)	OK	1.97	None
Retain_L_width_WinterN(1)	1.8503	4	(0.1, 10)	OK	0.52	None
Retain_L_asymptote_logit_WinterN(1)	8.3732	4	(-10, 10)	OK	29.01	None

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Table 17: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Retain_L_maleoffset_WinterN(1)	0	-2	(-10, 10)			None
SzSel_Male_Peak_WinterN(1)	-11.8861	4	(-15, 15)	OK	0.85	None
SzSel_Male_Ascend_WinterN(1)	-1.45306	4	(-15, 15)	OK	0.20	None
SzSel_Male_Descend_WinterN(1)	0	-4	(-15, 15)			None
SzSel_Male_Final_WinterN(1)	0	-4	(-15, 15)			None
SzSel_Male_Scale_WinterN(1)	1	-4	(-15, 15)			None
Size_DblN_peak_SummerN(2)	48.4299	2	(15, 75)	OK	1.88	None
Size_DblN_top_logit_SummerN(2)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_SummerN(2)	5.29851	3	(-4, 12)	OK	0.11	None
Size_DblN_descend_se_SummerN(2)	14	-3	(-2, 15)			None
Size_DblN_start_logit_SummerN(2)	-999	-4	(-15, 5)			None
Size_DblN_end_logit_SummerN(2)	-999	-4	(-5, 5)			None
Retain_L_infl_SummerN(2)	30.6729	2	(10, 40)	OK	0.40	None
Retain_L_width_SummerN(2)	1.31436	4	(0.1, 10)	OK	0.24	None
Retain_L_asymptote_logit_SummerN(2)	9.37198	4	(-10, 10)	OK	15.63	None
Retain_L_maleoffset_SummerN(2)	0	-2	(-10, 10)			None
SzSel_Male_Peak_SummerN(2)	-12.7368	4	(-20, 15)	OK	1.08	None
SzSel_Male_Ascend_SummerN(2)	-1.89766	4	(-15, 15)	OK	0.24	None
SzSel_Male_Descend_SummerN(2)	0	-4	(-15, 15)			None
SzSel_Male_Final_SummerN(2)	0	-4	(-15, 15)			None
SzSel_Male_Scale_SummerN(2)	1	-4	(-15, 15)			None
Size_DblN_peak_WinterS(3)	38.4882	2	(15, 75)	OK	2.06	None
Size_DblN_top_logit_WinterS(3)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_WinterS(3)	4.41185	3	(-4, 12)	OK	0.28	None
Size_DblN_descend_se_WinterS(3)	14	-3	(-2, 15)			None
Size_DblN_start_logit_WinterS(3)	-999	-4	(-15, 5)			None
Size_DblN_end_logit_WinterS(3)	-999	-4	(-5, 5)			None
Retain_L_infl_WinterS(3)	28.8815	2	(10, 40)	OK	0.50	None
Retain_L_width_WinterS(3)	1.35726	3	(0.1, 10)	OK	0.27	None
Retain_L_asymptote_logit_WinterS(3)	3.97227	4	(-10, 10)	OK	1.66	None
Retain_L_maleoffset_WinterS(3)	0	-2	(-10, 10)			None
SzSel_Male_Peak_WinterS(3)	-12.7221	4	(-15, 15)	OK	1.87	None
SzSel_Male_Ascend_WinterS(3)	-1.86133	4	(-15, 15)	OK	0.51	None
SzSel_Male_Descend_WinterS(3)	0	-4	(-15, 15)			None
SzSel_Male_Final_WinterS(3)	0	-4	(-15, 15)			None
SzSel_Male_Scale_WinterS(3)	1	-4	(-15, 15)			None
Size_DblN_peak_SummerS(4)	40.6429	2	(15, 75)	OK	1.61	None
Size_DblN_top_logit_SummerS(4)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_SummerS(4)	4.89772	3	(-4, 12)	OK	0.17	None

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Table 17: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Size_DblN_descend_se_SummerS(4)	14	-3	(-2, 15)			None
Size_DblN_start_logit_SummerS(4)	-999	-4	(-15, 5)			None
Size_DblN_end_logit_SummerS(4)	-999	-4	(-5, 5)			None
Retain_L_infl_SummerS(4)	28.8753	3	(10, 40)	OK	0.27	None
Retain_L_width_SummerS(4)	1.07128	3	(0.1, 10)	OK	0.15	None
Retain_L_asymptote_logit_SummerS(4)	9.5208	4	(-10, 10)	OK	12.51	None
Retain_L_maleoffset_SummerS(4)	0	-2	(-10, 10)			None
SzSel_Male_Peak_SummerS(4)	-12.548	4	(-15, 15)	OK	1.34	None
SzSel_Male_Ascend_SummerS(4)	-1.89491	4	(-15, 15)	OK	0.28	None
SzSel_Male_Descend_SummerS(4)	0	-4	(-15, 15)			None
SzSel_Male_Final_SummerS(4)	0	-4	(-15, 15)			None
SzSel_Male_Scale_SummerS(4)	1	-4	(-15, 15)			None
Size_DblN_peak_TriEarly(5)	35.3503	2	(15, 61)	OK	1.34	None
Size_DblN_top_logit_TriEarly(5)	3	-2	(-5, 3)			None
Size_DblN_ascend_se_TriEarly(5)	4.21179	2	(-4, 12)	OK	0.22	None
Size_DblN_descend_se_TriEarly(5)	14	-2	(-2, 15)			None
Size_DblN_start_logit_TriEarly(5)	-999	-4	(-15, 5)			None
Size_DblN_end_logit_TriEarly(5)	-999	-4	(-5, 5)			None
SzSel_Male_Peak_TriEarly(5)	-3.88585	3	(-15, 15)	OK	1.19	None
SzSel_Male_Ascend_TriEarly(5)	-0.561008	3	(-15, 15)	OK	0.25	None
SzSel_Male_Descend_TriEarly(5)	0	-3	(-15, 15)			None
SzSel_Male_Final_TriEarly(5)	0	-3	(-15, 15)			None
SzSel_Male_Scale_TriEarly(5)	1	-4	(-15, 15)			None
Size_DblN_peak_TriLate(6)	36.5056	2	(15, 61)	OK	0.91	None
Size_DblN_top_logit_TriLate(6)	3	-2	(-5, 3)			None
Size_DblN_ascend_se_TriLate(6)	4.64265	2	(-4, 12)	OK	0.12	None
Size_DblN_descend_se_TriLate(6)	14	-2	(-2, 15)			None
Size_DblN_start_logit_TriLate(6)	-999	-4	(-15, 5)			None
Size_DblN_end_logit_TriLate(6)	-999	-4	(-5, 5)			None
SzSel_Male_Peak_TriLate(6)	-2.23813	3	(-15, 15)	OK	0.94	None
SzSel_Male_Ascend_TriLate(6)	-0.0352576	3	(-15, 15)	OK	0.14	None
SzSel_Male_Descend_TriLate(6)	0	-3	(-15, 15)			None
SzSel_Male_Final_TriLate(6)	0	-3	(-15, 15)			None
SzSel_Male_Scale_TriLate(6)	1	-4	(-15, 15)			None
Size_DblN_peak_NWFSC(7)	43.0085	2	(15, 61)	OK	0.85	None
Size_DblN_top_logit_NWFSC(7)	3	-2	(-5, 3)			None
Size_DblN_ascend_se_NWFSC(7)	5.14971	2	(-4, 12)	OK	0.07	None
Size_DblN_descend_se_NWFSC(7)	14	-2	(-2, 15)			None
Size_DblN_start_logit_NWFSC(7)	-999	-4	(-15, 5)			None

Continued on next page

Table 17: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Size_DblN_end_logit_NWFSC(7)	-999	-4	(-5, 5)			None
SzSel_Male_Peak_NWFSC(7)	-5.0654	3	(-15, 15)	OK	0.72	None
SzSel_Male_Ascend_NWFSC(7)	-0.410501	3	(-15, 15)	OK	0.08	None
SzSel_Male_Descend_NWFSC(7)	0	-3	(-15, 15)			None
SzSel_Male_Final_NWFSC(7)	0	-3	(-15, 15)			None
SzSel_Male_Scale_NWFSC(7)	1	-4	(-15, 15)			None
Size_DblN_peak_WinterN(1)_BLK1add_1973	2.05549	5	(-31.6, 28.4)	OK	2.40	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_1983	-1.98219	5	(-31.6, 28.4)	OK	2.29	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_1993	-0.790166	5	(-31.6, 28.4)	OK	2.18	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_2003	0.383774	5	(-31.6, 28.4)	OK	2.14	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_2011	0.878534	5	(-31.6, 28.4)	OK	2.14	Normal (0, 14.2)
Retain_L_infl_WinterN(1)_BLK2add_2003	-2.26483	5	(-16.19, 13.81)	OK	3.11	Normal (0, 6.905)
Retain_L_infl_WinterN(1)_BLK2add_2010	1.76566	5	(-16.19, 13.81)	OK	3.39	Normal (0, 6.905)
Retain_L_infl_WinterN(1)_BLK2add_2011	-3.23884	5	(-16.19, 13.81)	OK	2.17	Normal (0, 6.905)
Retain_L_width_WinterN(1)_BLK2add_2003	0.12285	5	(-1.601, 8.299)	OK	0.55	Normal (0, 0.8005)
Retain_L_width_WinterN(1)_BLK2add_2010	0.393503	5	(-1.601, 8.299)	OK	0.76	Normal (0, 0.8005)
Retain_L_width_WinterN(1)_BLK2add_2011	-0.697801	5	(-1.601, 8.299)	OK	0.52	Normal (0, 0.8005)
Retain_L_asymptote_logit_WinterN(1)_BLK2repl_2003	6.63678	5	(-10, 10)	OK	1.32	None
Retain_L_asymptote_logit_WinterN(1)_BLK2repl_2010	2.11235	5	(-10, 10)	OK	0.44	None
Retain_L_asymptote_logit_WinterN(1)_BLK2repl_2011	9.9881	5	(-10, 10)	HI	0.37	None
Size_DblN_peak_SummerN(2)_BLK1add_1973	1.9558	5	(-38.8, 21.2)	OK	1.86	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_1983	-0.399466	5	(-38.8, 21.2)	OK	1.85	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_1993	-2.38392	5	(-38.8, 21.2)	OK	1.80	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_2003	-0.0936437	5	(-38.8, 21.2)	OK	1.61	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_2011	3.26642	5	(-38.8, 21.2)	OK	1.58	Normal (0, 10.6)
Retain_L_infl_SummerN(2)_BLK3add_2003	-0.419922	5	(-20.679, 9.321)	OK	0.62	Normal (0, 4.6605)
Retain_L_infl_SummerN(2)_BLK3add_2009	1.29282	5	(-20.679, 9.321)	OK	0.64	Normal (0, 4.6605)
Retain_L_infl_SummerN(2)_BLK3add_2011	-1.92562	5	(-20.679, 9.321)	OK	0.67	Normal (0, 4.6605)
Retain_L_width_SummerN(2)_BLK3add_2003	0.161789	5	(-1.0278, 8.8722)	OK	0.30	Normal (0, 0.5139)
Retain_L_width_SummerN(2)_BLK3add_2009	0.138985	5	(-1.0278, 8.8722)	OK	0.30	Normal (0, 0.5139)
Retain_L_width_SummerN(2)_BLK3add_2011	0.21153	5	(-1.0278, 8.8722)	OK	0.25	Normal (0, 0.5139)
Retain_L_asymptote_logit_SummerN(2)_BLK3repl_2003	5.45846	5	(-10, 10)	OK	1.10	None
Retain_L_asymptote_logit_SummerN(2)_BLK3repl_2009	7.55883	5	(-10, 10)	OK	13.67	None
Retain_L_asymptote_logit_SummerN(2)_BLK3repl_2011	6.15877	5	(-10, 10)	OK	0.42	None
Size_DblN_peak_WinterS(3)_BLK1add_1973	-15.0996	5	(-25.422, 34.578)	OK	6.68	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_1983	5.08526	5	(-25.422, 34.578)	OK	2.21	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_1993	9.18368	5	(-25.422, 34.578)	OK	2.59	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_2003	6.98535	5	(-25.422, 34.578)	OK	2.13	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_2011	8.30205	5	(-25.422, 34.578)	OK	2.13	Normal (0, 12.711)

Continued on next page

Table 17: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Retain_L_infl_WinterS(3)_BLK2add_2003	-2.0172	5	(-18.816, 11.184)	OK	1.31	Normal (0, 5.592)
Retain_L_infl_WinterS(3)_BLK2add_2010	1.52688	5	(-18.816, 11.184)	OK	1.64	Normal (0, 5.592)
Retain_L_infl_WinterS(3)_BLK2add_2011	-4.29967	5	(-18.816, 11.184)	OK	2.30	Normal (0, 5.592)
Retain_L_width_WinterS(3)_BLK2add_2003	0.366784	5	(-1.0443, 8.8557)	OK	0.37	Normal (0, 0.52215)
Retain_L_width_WinterS(3)_BLK2add_2010	0.13891	5	(-1.0443, 8.8557)	OK	0.45	Normal (0, 0.52215)
Retain_L_width_WinterS(3)_BLK2add_2011	-0.0497998	5	(-1.0443, 8.8557)	OK	0.35	Normal (0, 0.52215)
Retain_L_asymptote_logit_WinterS(3)_BLK2repl_2003	7.80958	5	(-10, 10)	OK	5.65	None
Retain_L_asymptote_logit_WinterS(3)_BLK2repl_2010	5.53053	5	(-10, 10)	OK	7.47	None
Retain_L_asymptote_logit_WinterS(3)_BLK2repl_2011	7.87413	5	(-10, 10)	OK	1.52	None
Size_DblN_peak_SummerS(4)_BLK1add_1973	-5.16048	5	(-28.0793, 31.9207)	OK	2.31	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_1983	-6.38506	5	(-28.0793, 31.9207)	OK	4.33	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_1993	3.57295	5	(-28.0793, 31.9207)	OK	2.06	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_2003	6.2503	5	(-28.0793, 31.9207)	OK	1.72	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_2011	6.03167	5	(-28.0793, 31.9207)	OK	1.70	Normal (0, 14.0397)
Retain_L_infl_SummerS(4)_BLK3add_2003	-1.40609	5	(-19.055, 10.945)	OK	0.88	Normal (0, 5.4725)
Retain_L_infl_SummerS(4)_BLK3add_2009	-1.68655	5	(-19.055, 10.945)	OK	1.29	Normal (0, 5.4725)
Retain_L_infl_SummerS(4)_BLK3add_2011	-2.0893	5	(-19.055, 10.945)	OK	1.06	Normal (0, 5.4725)
Retain_L_width_SummerS(4)_BLK3add_2003	0.604487	5	(-0.876, 9.024)	OK	0.23	Normal (0, 0.438)
Retain_L_width_SummerS(4)_BLK3add_2009	0.47059	5	(-0.876, 9.024)	OK	0.25	Normal (0, 0.438)
Retain_L_width_SummerS(4)_BLK3add_2011	0.581508	5	(-0.876, 9.024)	OK	0.20	Normal (0, 0.438)
Retain_L_asymptote_logit_SummerS(4)_BLK3repl_2003	7.55833	5	(-10, 10)	OK	3.64	None
Retain_L_asymptote_logit_SummerS(4)_BLK3repl_2009	8.89461	5	(-10, 10)	OK	15.05	None
Retain_L_asymptote_logit_SummerS(4)_BLK3repl_2011	7.68067	5	(-10, 10)	OK	1.30	None

Table 18: Likelihood components from the base model

Likelihood Component	Value
Total	1383.6
Survey	-74.63
Discard	-228.76
Mean-body weight data	-161.16
Length-frequency data	769.45
Age-frequency data	1093.47
Recruitment	-22.45
Forecast Recruitment	0.05
Parameter Priors	7.59
Parameter Softbounds	0.04

Table 19: Summary of reference points and management quantities for the base model.

Quantity	**Estimate**	**~2.5% Confidence Interval**	**~97.5% Confidence Interval**
Unfished spawning biomass (mt)	33405.9	27188.1	39623.7
Unfished age 3+ biomass (mt)	54086.6	45524.9	62648.3
Unfished recruitment (R0, thousands)	20361.1	14037.4	29533.5
Spawning biomass(2019 mt)	13077.7	10688.8	15466.6
Depletion (2019)	0.391	0.282	0.501
Reference points based on $\mathbf{SB_{40\%}}$			
Proxy spawning biomass ($B_{25\%}$)	8351.5	6797	9905.9
SPR resulting in $B_{25\%}$ ($SPR_{B25\%}$)	0.285	0.26	0.31
Exploitation rate resulting in $B_{25\%}$	0.182	0.163	0.2
Yield with $SPR_{B25\%}$ at $B_{25\%}$ (mt)	3148.5	2887.6	3409.4
Reference points based on SPR proxy for MSY			
Spawning biomass	8866.2	6954.6	10777.7
SPR_{proxy}			
Exploitation rate corresponding to SPR_{proxy}	0.173	0.147	0.198
Yield with SPR_{proxy} at SB_{SPR} (mt)	3135.2	2849.4	3420.9
Reference points based on estimated MSY values			
Spawning bioamss at MSY (SB_{MSY})	7563.3	5677.6	9448.9
SPR_{MSY}	0.263	0.202	0.323
Exploitation rate at MSY	0.196	0.166	0.227
MSY (mt)	3156.7	2909.6	3403.8

Table 20: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning biomass (million eggs)	Summary biomass 3+ (mt)	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1876	54,744	33,406	54,087	1.00	20,362	1	0	0
1877	54,742	33,405	54,086	1.00	20,362	1	0	0
1878	54,742	33,405	54,085	1.00	20,362	1	0	0
1879	54,741	33,404	54,084	1.00	20,362	1	0	0
1880	54,740	33,404	54,083	1.00	20,362	12	0	0
1881	54,729	33,397	54,072	1.00	20,362	23	0	0
1882	54,708	33,383	54,051	1.00	20,361	34	0.01	0.001
1883	54,678	33,363	54,021	1.00	20,361	45	0.01	0.001
1884	54,640	33,337	53,983	1.00	20,360	56	0.01	0.001
1885	54,593	33,307	53,937	1.00	20,360	66	0.01	0.001
1886	54,540	33,271	53,884	1.00	20,359	77	0.01	0.001
1887	54,481	33,231	53,825	0.99	20,358	88	0.02	0.002
1888	54,416	33,188	53,760	0.99	20,357	99	0.02	0.002
1889	54,347	33,141	53,690	0.99	20,355	110	0.02	0.002
1890	54,273	33,091	53,616	0.99	20,354	121	0.02	0.002
1891	54,195	33,038	53,538	0.99	20,353	132	0.03	0.002
1892	54,114	32,982	53,457	0.99	20,352	143	0.03	0.003
1893	54,029	32,925	53,373	0.99	20,350	154	0.03	0.003
1894	53,942	32,865	53,286	0.98	20,349	165	0.03	0.003
1895	53,853	32,804	53,196	0.98	20,348	176	0.03	0.003
1896	53,761	32,741	53,105	0.98	20,347	187	0.04	0.004
1897	53,668	32,677	53,012	0.98	20,345	198	0.04	0.004
1898	53,573	32,612	52,917	0.98	20,344	208	0.04	0.004
1899	53,477	32,546	52,820	0.97	20,343	219	0.04	0.004
1900	53,379	32,479	52,723	0.97	20,342	230	0.04	0.004
1901	53,280	32,411	52,625	0.97	20,341	241	0.05	0.005
1902	53,181	32,342	52,525	0.97	20,340	252	0.05	0.005
1903	53,081	32,273	52,425	0.97	20,339	263	0.05	0.005
1904	52,980	32,204	52,324	0.96	20,338	274	0.05	0.005
1905	52,879	32,134	52,223	0.96	20,338	285	0.05	0.005
1906	52,777	32,063	52,121	0.96	20,338	296	0.06	0.006
1907	52,674	31,992	52,018	0.96	20,338	307	0.06	0.006
1908	52,572	31,921	51,916	0.96	20,338	318	0.06	0.006
1909	52,469	31,850	51,813	0.95	20,338	329	0.06	0.006
1910	52,366	31,779	51,710	0.95	20,339	340	0.06	0.007
1911	52,263	31,707	51,607	0.95	20,340	351	0.07	0.007
1912	52,160	31,635	51,504	0.95	20,342	361	0.07	0.007
1913	52,056	31,564	51,400	0.94	20,344	372	0.07	0.007
1914	51,954	31,492	51,298	0.94	20,347	383	0.07	0.007
1915	51,851	31,420	51,195	0.94	20,350	394	0.08	0.008
1916	51,748	31,349	51,092	0.94	20,354	400	0.08	0.008
1917	51,651	31,281	50,995	0.94	20,359	545	0.1	0.011
1918	51,425	31,129	50,769	0.93	20,361	439	0.08	0.009
1919	51,319	31,054	50,662	0.93	20,367	345	0.07	0.007
1920	51,316	31,044	50,659	0.93	20,376	239	0.05	0.005
1921	51,422	31,107	50,765	0.93	20,388	304	0.06	0.006
1922	51,465	31,132	50,808	0.93	20,400	440	0.08	0.009
1923	51,379	31,074	50,722	0.93	20,410	443	0.08	0.009
1924	51,298	31,017	50,640	0.93	20,421	552	0.1	0.011
1925	51,119	30,897	50,461	0.92	20,430	547	0.1	0.011
1926	50,958	30,787	50,300	0.92	20,441	540	0.1	0.011

Continued on next page

Table 20: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning biomass (million eggs)	Summary biomass 3+ (mt)	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1927	50,819	30,690	50,160	0.92	20,454	655	0.12	0.013
1928	50,585	30,531	49,926	0.91	20,465	643	0.12	0.013
1929	50,383	30,392	49,723	0.91	20,478	733	0.14	0.015
1930	50,115	30,209	49,455	0.90	20,492	684	0.13	0.014
1931	49,919	30,071	49,258	0.90	20,513	701	0.13	0.014
1932	49,731	29,936	49,070	0.90	20,543	836	0.15	0.017
1933	49,441	29,732	48,780	0.89	20,589	871	0.16	0.018
1934	49,155	29,524	48,492	0.88	20,664	1669	0.28	0.034
1935	48,143	28,847	47,478	0.86	20,761	1651	0.28	0.035
1936	47,228	28,220	46,561	0.84	20,902	1354	0.24	0.029
1937	46,688	27,822	46,018	0.83	21,078	1946	0.32	0.042
1938	45,663	27,104	44,988	0.81	21,207	2221	0.36	0.049
1939	44,487	26,278	43,806	0.79	21,167	2724	0.42	0.062
1940	42,960	25,213	42,277	0.75	20,775	2618	0.41	0.062
1941	41,689	24,300	41,010	0.73	19,980	2359	0.39	0.058
1942	40,800	23,642	40,137	0.71	18,955	3300	0.49	0.082
1943	39,124	22,492	38,487	0.67	18,052	3442	0.51	0.089
1944	37,409	21,369	36,804	0.64	17,762	2727	0.46	0.074
1945	36,420	20,776	35,840	0.62	18,287	2555	0.45	0.071
1946	35,587	20,325	35,010	0.61	18,996	3882	0.58	0.111
1947	33,480	19,064	32,885	0.57	19,027	3215	0.55	0.098
1948	32,063	18,188	31,450	0.54	18,838	4627	0.67	0.147
1949	29,373	16,440	28,761	0.49	18,621	4532	0.69	0.158
1950	26,903	14,790	26,297	0.44	18,497	4772	0.72	0.181
1951	24,369	13,076	23,770	0.39	18,449	3144	0.64	0.132
1952	23,551	12,452	22,955	0.37	18,588	2890	0.63	0.126
1953	23,083	12,094	22,487	0.36	18,469	2461	0.6	0.109
1954	23,076	12,073	22,478	0.36	17,903	3010	0.65	0.134
1955	22,567	11,766	21,976	0.35	17,072	2671	0.63	0.122
1956	22,391	11,659	21,820	0.35	16,199	2356	0.59	0.108
1957	22,504	11,752	21,960	0.35	15,184	3013	0.66	0.137
1958	21,938	11,476	21,423	0.34	14,552	2961	0.66	0.138
1959	21,339	11,215	20,854	0.34	14,828	2518	0.62	0.121
1960	21,084	11,172	20,611	0.33	17,846	2939	0.66	0.143
1961	20,365	10,829	19,865	0.32	21,665	3530	0.72	0.178
1962	19,094	10,062	18,498	0.30	13,814	3368	0.73	0.182
1963	18,090	9,310	17,445	0.28	12,694	3414	0.74	0.196
1964	17,147	8,531	16,704	0.26	19,968	2882	0.72	0.173
1965	16,725	8,170	16,270	0.24	15,367	2742	0.71	0.169
1966	16,473	8,061	15,849	0.24	33,481	2769	0.72	0.175
1967	16,312	7,974	15,707	0.24	14,607	2807	0.73	0.179
1968	16,358	7,783	15,404	0.23	15,535	2517	0.71	0.163
1969	16,892	7,748	16,414	0.23	17,403	2586	0.71	0.158
1970	17,393	7,844	16,878	0.23	19,796	3332	0.76	0.197
1971	17,133	7,845	16,557	0.23	17,690	3434	0.77	0.207
1972	16,719	7,892	16,097	0.24	14,127	3716	0.79	0.231
1973	15,973	7,602	15,427	0.23	12,674	3230	0.79	0.209
1974	15,535	7,385	15,096	0.22	15,687	4095	0.85	0.271
1975	14,050	6,645	13,633	0.20	15,867	3926	0.86	0.288
1976	12,534	5,906	12,038	0.18	20,698	3258	0.86	0.271
1977	11,538	5,402	11,013	0.16	22,092	2668	0.82	0.242

Continued on next page

Table 20: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning biomass (million eggs)	Summary biomass 3+ (mt)	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1978	11,202	5,065	10,547	0.15	17,849	3436	0.88	0.326
1979	10,335	4,296	9,674	0.13	13,331	3600	0.9	0.372
1980	9,426	3,540	8,897	0.11	13,427	3100	0.91	0.348
1981	8,897	3,224	8,487	0.10	11,286	2959	0.9	0.349
1982	8,345	3,109	7,941	0.09	11,010	2891	0.9	0.364
1983	7,774	3,002	7,420	0.09	12,310	2524	0.88	0.34
1984	7,387	2,993	7,021	0.09	17,514	1949	0.85	0.278
1985	7,463	3,108	7,036	0.09	10,978	1906	0.84	0.271
1986	7,608	3,166	7,092	0.09	7,223	2174	0.86	0.307
1987	7,544	3,022	7,215	0.09	8,333	2605	0.89	0.361
1988	6,989	2,702	6,747	0.08	12,634	2387	0.89	0.354
1989	6,498	2,577	6,199	0.08	16,947	2329	0.89	0.376
1990	6,000	2,479	5,566	0.07	16,145	1989	0.88	0.357
1991	5,892	2,366	5,357	0.07	10,105	2175	0.9	0.406
1992	5,792	2,021	5,316	0.06	6,230	1848	0.89	0.348
1993	6,062	1,927	5,760	0.06	11,479	1721	0.87	0.299
1994	6,469	2,121	6,231	0.06	14,370	1572	0.84	0.252
1995	6,954	2,633	6,568	0.08	8,763	1702	0.82	0.259
1996	7,294	3,070	6,867	0.09	10,406	1950	0.83	0.284
1997	7,377	3,160	7,083	0.09	10,573	2071	0.84	0.292
1998	7,313	3,030	6,968	0.09	25,032	1763	0.82	0.253
1999	7,560	3,109	7,128	0.09	16,297	1641	0.79	0.23
2000	8,132	3,302	7,387	0.10	11,595	1941	0.81	0.263
2001	8,709	3,322	8,216	0.10	10,761	2013	0.82	0.245
2002	9,354	3,363	8,985	0.10	11,690	2116	0.82	0.235
2003	9,885	3,662	9,533	0.11	9,430	1797	0.77	0.188
2004	10,589	4,360	10,225	0.13	12,378	2299	0.78	0.225
2005	10,701	4,809	10,376	0.14	13,730	3019	0.82	0.291
2006	10,009	4,641	9,594	0.14	24,871	2218	0.78	0.231
2007	10,016	4,615	9,496	0.14	30,482	2408	0.79	0.254
2008	10,159	4,379	9,314	0.13	40,004	2183	0.78	0.234
2009	11,102	4,260	10,070	0.13	16,393	2334	0.79	0.232
2010	12,644	4,227	11,515	0.13	12,637	869	0.57	0.075
2011	15,968	5,378	15,463	0.16	15,344	785	0.5	0.051
2012	19,391	7,205	18,960	0.22	22,946	1153	0.52	0.061
2013	22,223	9,488	21,683	0.28	13,483	1995	0.58	0.092
2014	23,953	11,433	23,277	0.34	13,529	2392	0.58	0.103
2015	24,922	12,691	24,488	0.38	12,792	2704	0.58	0.11
2016	25,175	13,206	24,742	0.40	16,460	2523	0.55	0.102
2017	25,211	13,519	24,774	0.40	16,517	3026	0.58	0.122
2018	24,529	13,365	23,997	0.40	19,018	2857	0.57	0.119
2019	23,900	13,078	23,351	0.39	18,972	-	-	-

Table 21: Results from 50 jitters from the base model.

Status	Jitter = 0.05	Jitter = 0.10
Returned to base case	2	2
Found local minimum	48	48
Likelihood Diff. < 0.5	9	5
Found better solution	0	0
Gradient > 1	42	45
Total	50	50

Table 22: Data weights applied when using Francis data weighting in the base model. The data weights were acquired after a single model weighting iteration.

Fleet	Lengths	Ages
Winter North	1.132	2.937
Summer North	1.001	1.1684
Winter South	1.092	0.9932
Summer South	0.487	0.7214
Triennial Early Survey	0.230	-
Triennial Late Survey	0.960	-
NWFSC WCGBT Survey	0.258	0.0755

Table 23: Data weights applied when using Dirichlet data weighting. SS estimates these parameters in log-space. The estimated parameter values in log-space, converted to real-space, and the resulting theta values, the adjustment factor to the input sample sizes, are provided

Fleet	log(Lengths Parm)	log(Ages Parm)	Lengths	Ages	Lengths Theta	Ages Theta
Winter North	6.999	6.99629	1095	1093	1	1
Summer North	6.999	6.99596	1095	1092	1	1
Winter South	9.998	6.99547	21993	1092	1	1
Summer South	6.998	6.99493	1095	1091	1	1
Triennial Early Survey	6.973	-	1068	-	1	-
Triennial Late Survey	6.970	-	1064	-	1	-
NWFSC WCGBT Survey	6.994	6.99985	1090	1096	1	1

Table 24: Sensitivity runs compared to the base model.

Label	Base	Low M (female)	High M (female)	Old M Prior	Fecundity	Sex Ratio	Sex Ratio Fecundity	Francis	Dirichlet
Total Likelihood	1383.600	1390.010	1387.460	1383.790	1394.590	1382.630	1393.630	627.466	1391.400
Survey Likelihood	-74.627	-73.247	-74.205	-74.631	-74.682	-74.746	-74.758	-75.430	-74.644
Discard Likelihood	-228.761	-229.067	-228.395	-228.759	-228.770	-228.486	-228.485	-229.180	-228.767
Discard Mean Body Wt.	-161.155	-161.300	-161.005	-161.153	-161.168	-161.120	-161.125	-162.310	-161.173
Length Likelihood	769.450	773.790	767.134	769.378	770.135	769.764	769.737	480.251	772.946
Age Likelihood	1093.470	1091.240	1097.250	1093.550	1093.440	1092.350	1092.400	633.841	1098.340
Recruitment Likelihood	-22.449	-21.460	-21.563	-22.434	-22.578	-22.584	-22.635	-25.480	-22.533
Forecast Recruitment Likelihood	0.046	0.039	0.046	0.046	0.046	0.045	0.045	0.020	0.000
Parameter Priors Likelihood	7.587	9.973	8.160	7.751	18.126	7.365	18.410	5.714	7.111
log(R0)	9.921	9.265	10.403	9.934	9.900	9.906	9.914	9.878	9.884
SB Virgin	33405.900	42089.200	28513.700	33273.400	34042.400	35308.900	36065.400	33437.300	33537.900
SB 2019	13077.700	11680.900	14524.300	13117.900	11970.800	13114.900	12123.000	12483.700	13004.900
Depletion 2019	0.391	0.278	0.509	0.394	0.352	0.371	0.336	0.373	0.388
Total Yield - SPR 30	3135.150	2840.980	3232.440	3138.060	3043.360	3097.490	3029.910	3081.350	3097.050
Steepness	0.841	0.965	0.756	0.839	0.868	0.857	0.880	0.849	0.845
Natural Mortality - Female	0.159	0.105	0.205	0.160	0.158	0.147	0.148	0.157	0.156
Length at Amin - Female	15.652	15.795	15.464	15.649	15.654	15.681	15.676	15.690	15.661
Length at Amax - Female	53.117	52.819	53.327	53.122	53.113	52.956	52.956	53.490	53.094
Von Bert. k - Female	0.142	0.146	0.139	0.142	0.142	0.144	0.144	0.138	0.142
CV young - Female	0.186	0.183	0.189	0.186	0.186	0.185	0.185	0.184	0.186
CV old - Female	0.035	0.037	0.034	0.035	0.035	0.036	0.036	0.028	0.035
Natural Mortality - Male	0.164	0.106	0.215	0.166	0.163	0.175	0.176	0.162	0.161
Length at Amin - Male	16.156	16.188	16.111	16.154	16.155	16.155	16.155	16.429	16.154
Length at Amax - Male	40.828	40.642	40.972	40.832	40.815	40.962	40.963	41.346	40.806
Von Bert. k - Male	0.238	0.245	0.233	0.238	0.239	0.234	0.234	0.226	0.239
CV young - Male	0.136	0.136	0.137	0.136	0.136	0.137	0.137	0.127	0.136
CV old - Male	0.060	0.060	0.060	0.060	0.060	0.059	0.059	0.059	0.060

Table 25: Data analysis runs where incremental changes were made to the 2015 model.

Parameters	2015	Conversion + Priors	+ Catch	+ Survey	+ Discard	+ Length	+ Age	2019
log(R0)	9.647	9.677	9.675	9.693	9.693	10.143	9.840	9.921
SB Virgin	33476.300	33998.900	34029.900	33791.400	33840.800	29431.500	33590.600	33405.900
SB 2015	10289.900	10605.700	10595.100	11485.800	11403.000	12323.000	12030.800	12690.800
Depletion 2015	0.307	0.312	0.311	0.340	0.337	0.419	0.358	0.380
Steepness	0.901	0.889	0.890	0.889	0.890	0.813	0.857	0.841
Natural Mortality - Female	0.146	0.146	0.146	0.148	0.148	0.186	0.153	0.159
Length at Amin - Female	15.723	15.715	15.716	15.686	15.680	15.691	15.797	15.652
Length at Amax - Female	54.411	54.433	54.434	54.440	54.415	54.063	53.218	53.117
Von Bert. k - Female	0.134	0.134	0.134	0.134	0.135	0.134	0.139	0.142
CV young - Female	0.191	0.190	0.190	0.191	0.190	0.188	0.183	0.186
CV old - Female	0.026	0.026	0.026	0.026	0.026	0.027	0.036	0.035
Natural Mortality - Male	0.154	0.155	0.155	0.157	0.158	0.198	0.157	0.164
Length at Amin - Male	16.502	16.560	16.560	16.550	16.514	16.419	16.249	16.156
Length at Amax - Male	43.203	43.181	43.182	43.189	43.175	41.555	41.155	40.828
Von Bert. k - Male	0.203	0.203	0.203	0.203	0.203	0.225	0.230	0.238
CV young - Male	0.138	0.136	0.136	0.136	0.136	0.130	0.132	0.136
CV old - Male	0.046	0.047	0.047	0.047	0.047	0.058	0.061	0.060

Table 26: Projections of potential OFLs (mt), ABCs (mt), estimated spawning biomass and relative spawning biomass. The 2019 and 2020 ABC and OFL values shown are based on current harvest specifications, rather than the updated model estimates. The ABC and buffer values for 2021-2030 were calculated using a P* value of 0.45.

Year	Buffer	OFL	ABC	Removals	Spawning Biomass (mt)	Relative Biomass
2019	1	3042.0	2908.0	2908.0	13078	0.391
2020	1	2976.0	2845.0	2845.0	12558	0.376
2021	0.935	4401.5	4115.4	4115.4	12019	0.360
2022	0.93	3935.7	3660.2	3660.2	10799	0.323
2023	0.926	3633.9	3365.0	3365.0	10038	0.300
2024	0.922	3469.7	3199.0	3199.0	9655	0.289
2025	0.917	3402.3	3119.9	3119.9	9523	0.285
2026	0.913	3392.0	3096.9	3096.9	9527	0.285
2027	0.909	3406.2	3096.3	3096.3	9580	0.287
2028	0.904	3425.5	3096.6	3096.6	9635	0.288
2029	0.9	3441.7	3097.5	3097.5	9677	0.290
2030	0.896	3452.1	3093.1	3093.1	9701	0.290
2019	0.892	3042.0	2908.0	2908.0	13078	0.391

Table 27: Decision table summary of 10-year projections beginning in 2021 for alternate states of nature based on an axis of uncertainty about female natural mortality for the base model. Columns range over low, mid, and high states of nature, and rows range over different assumptions of catch levels. The ABC catch streams are based on the equilibrium yield applying the SPR30 harvest rate.

			States of nature					
			M = 0.105		M = 0.159		M = 0.205	
	Year	Catch	Spawning Biomass	Depletion	Spawning Biomass	Depletion	Spawning Biomass	Depletion
ABC P* 0.45	2019	2908.0	11681	0.278	13078	0.391	14524	0.509
	2020	2845.0	11425	0.271	12558	0.376	13729	0.481
	2021	4115.4	11110	0.264	12019	0.360	12963	0.455
	2022	3660.2	10005	0.238	10799	0.323	11614	0.407
	2023	3365.0	9244	0.220	10038	0.300	10820	0.379
	2024	3199.0	8773	0.208	9655	0.289	10462	0.367
	2025	3119.9	8507	0.202	9523	0.285	10381	0.364
	2026	3096.9	8362	0.199	9527	0.285	10434	0.366
	2027	3096.3	8276	0.197	9580	0.287	10520	0.369
	2028	3096.6	8213	0.195	9635	0.288	10588	0.371
	2029	3097.5	8158	0.194	9677	0.290	10624	0.373
	2030	3093.1	8103	0.193	9701	0.290	10633	0.373
ABC P* 0.40	2019	2908.0	11681	0.278	13078	0.391	14524	0.509
	2020	2845.0	11425	0.271	12558	0.376	13729	0.481
	2021	3842.5	11110	0.264	12019	0.360	12963	0.455
	2022	3454.7	10174	0.242	10961	0.328	11772	0.413
	2023	3202.3	9540	0.227	10315	0.309	11081	0.389
	2024	3059.6	9168	0.218	10012	0.300	10791	0.378
	2025	2993.9	8981	0.213	9941	0.298	10755	0.377
	2026	2972.6	8906	0.212	9993	0.299	10841	0.380
	2027	2970.6	8887	0.211	10091	0.302	10958	0.384
	2028	2976.1	8891	0.211	10194	0.305	11058	0.388
	2029	2974.2	8900	0.211	10280	0.308	11126	0.390
	2030	2967.7	8913	0.212	10351	0.310	11168	0.392
Step-down in catch	2019	2908.0	11681	0.278	13078	0.391	14524	0.509
	2020	2845.0	11425	0.271	12558	0.376	13729	0.481
	2021	3600.0	11110	0.264	12019	0.360	12963	0.455
	2022	3600.0	10324	0.245	11105	0.332	11912	0.418
	2023	3300.0	9602	0.228	10369	0.310	11127	0.390
	2024	3300.0	9168	0.218	10008	0.300	10776	0.378
	2025	3100.0	8835	0.210	9803	0.293	10608	0.372
	2026	3100.0	8692	0.207	9804	0.293	10644	0.373
	2027	3000.0	8594	0.204	9846	0.295	10707	0.376
	2028	3000.0	8580	0.204	9951	0.298	10812	0.379
	2029	3000.0	8576	0.204	10046	0.301	10890	0.382
	2030	3000.0	8577	0.204	10124	0.303	10939	0.384

11 Figures

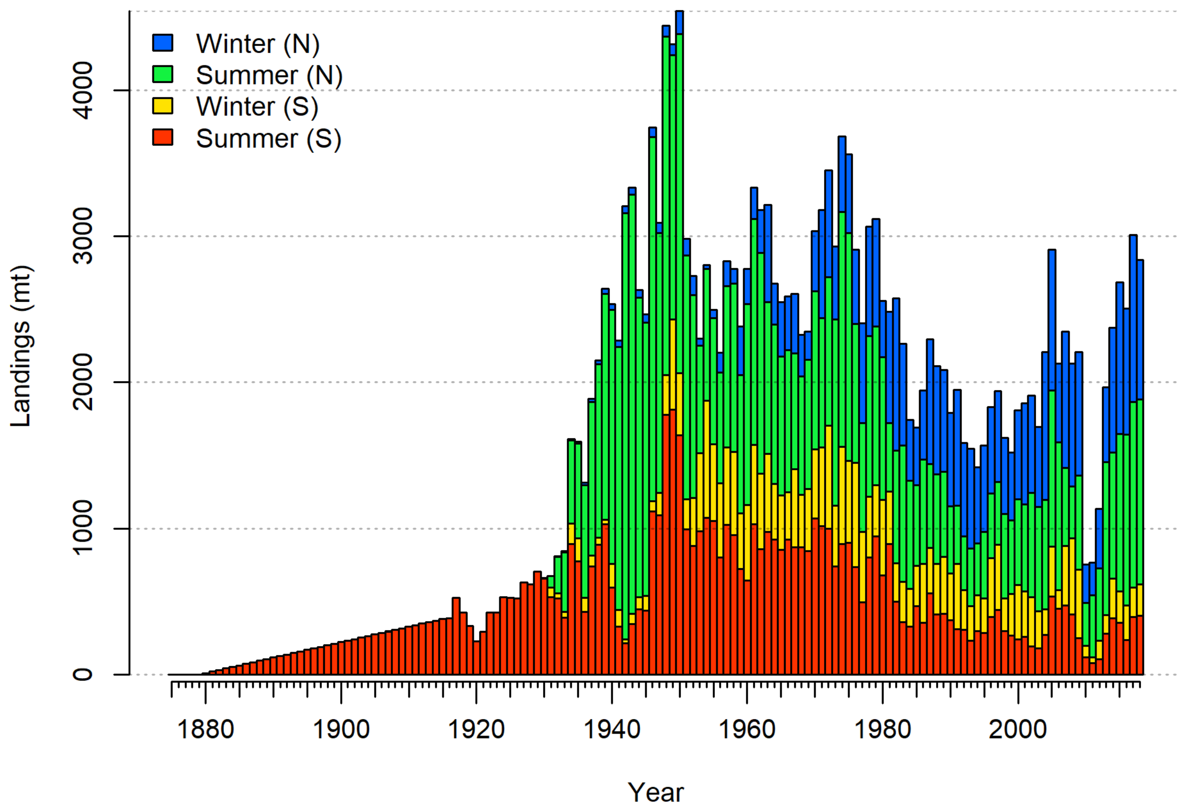


Figure 1: Total landings of petrale sole.

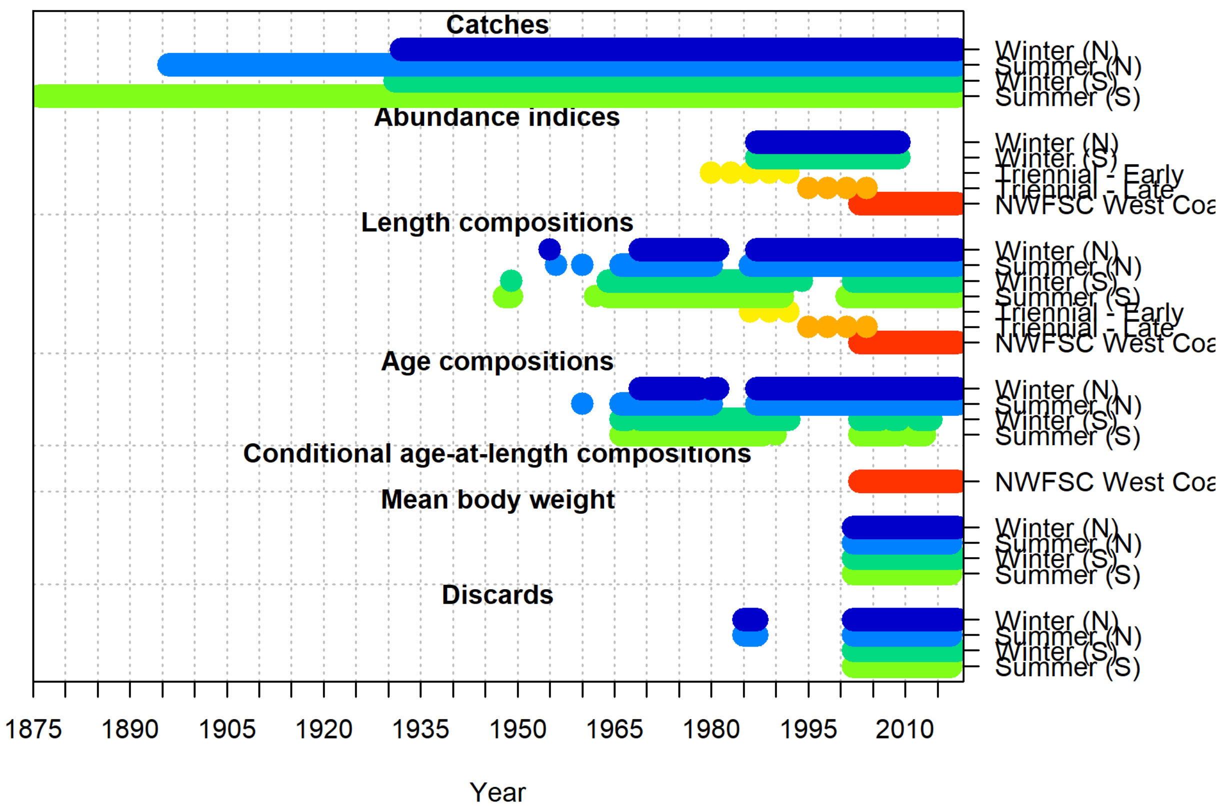


Figure 2: Summary of data sources used in the base model.

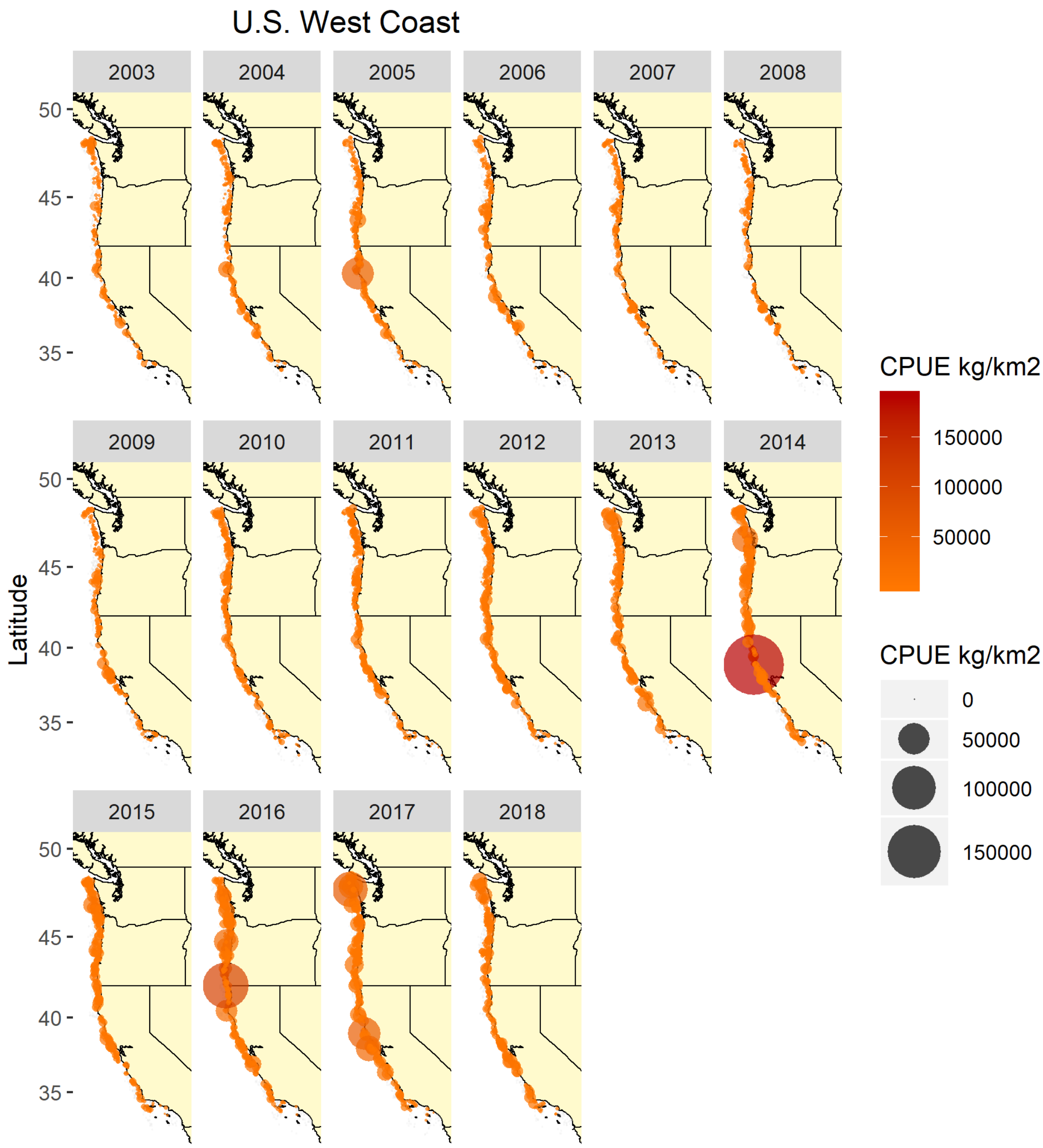


Figure 3: Map of the catch-per-unit-effort across by year for the NWFSC West Coast Groundfish Bottom Trawl Survey data.

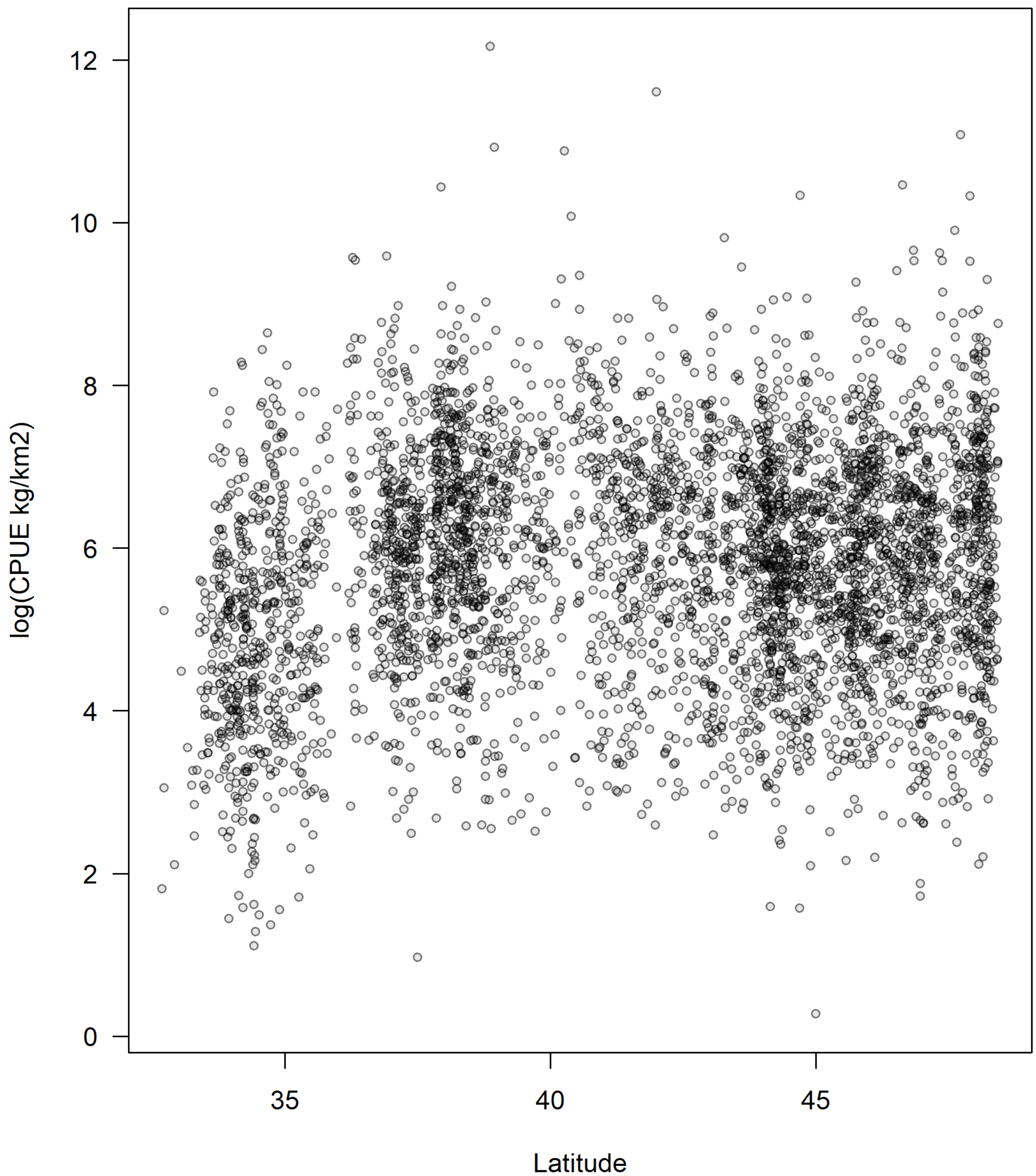


Figure 4: Catch-per-unit-effort (in log space) by latitude for the NWFSC West Coast Groundfish Bottom Trawl Survey data.

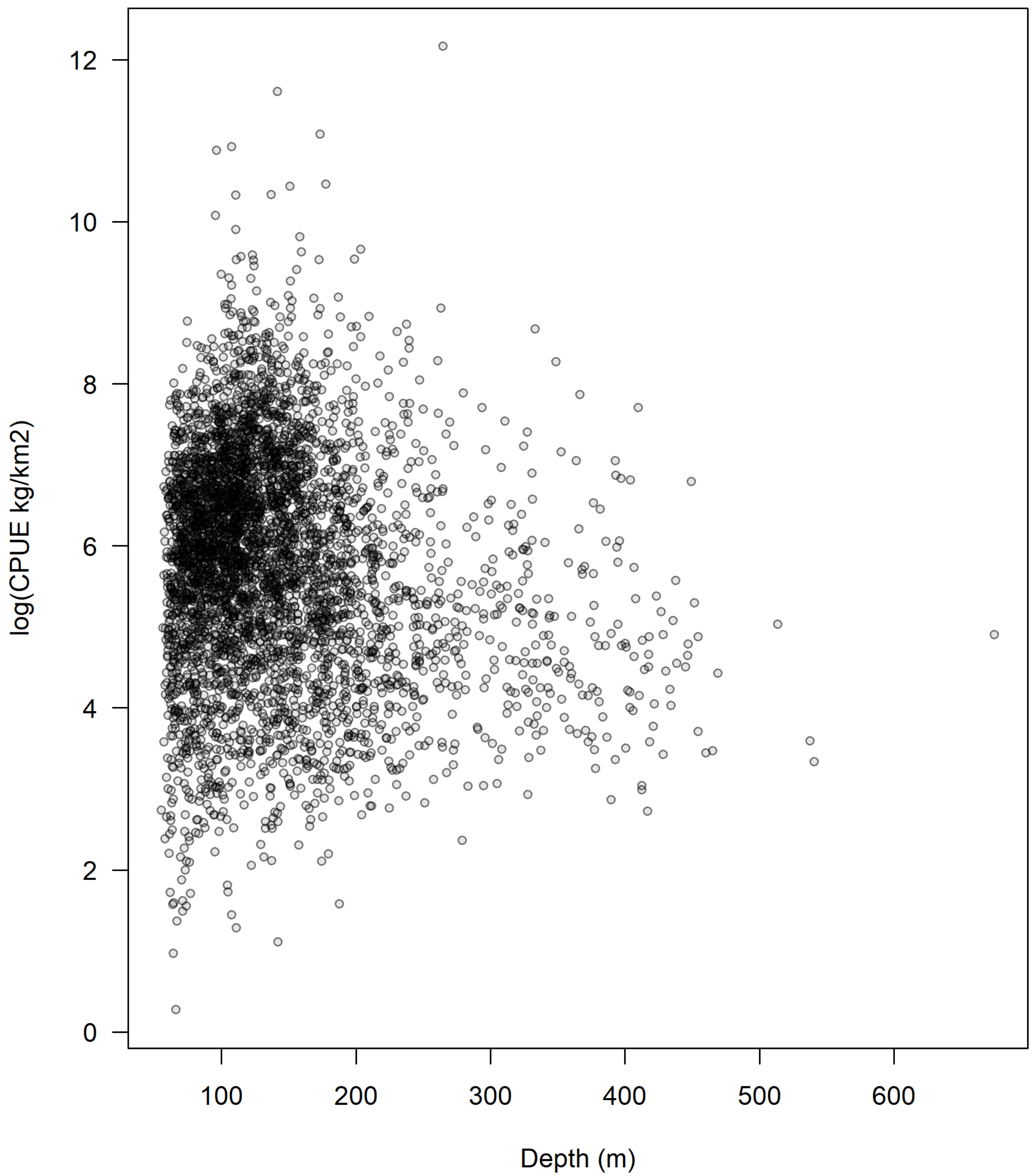


Figure 5: Catch-per-unit-effort (in log space) by depth for the NWFSC West Coast Groundfish Bottom Trawl Survey data.

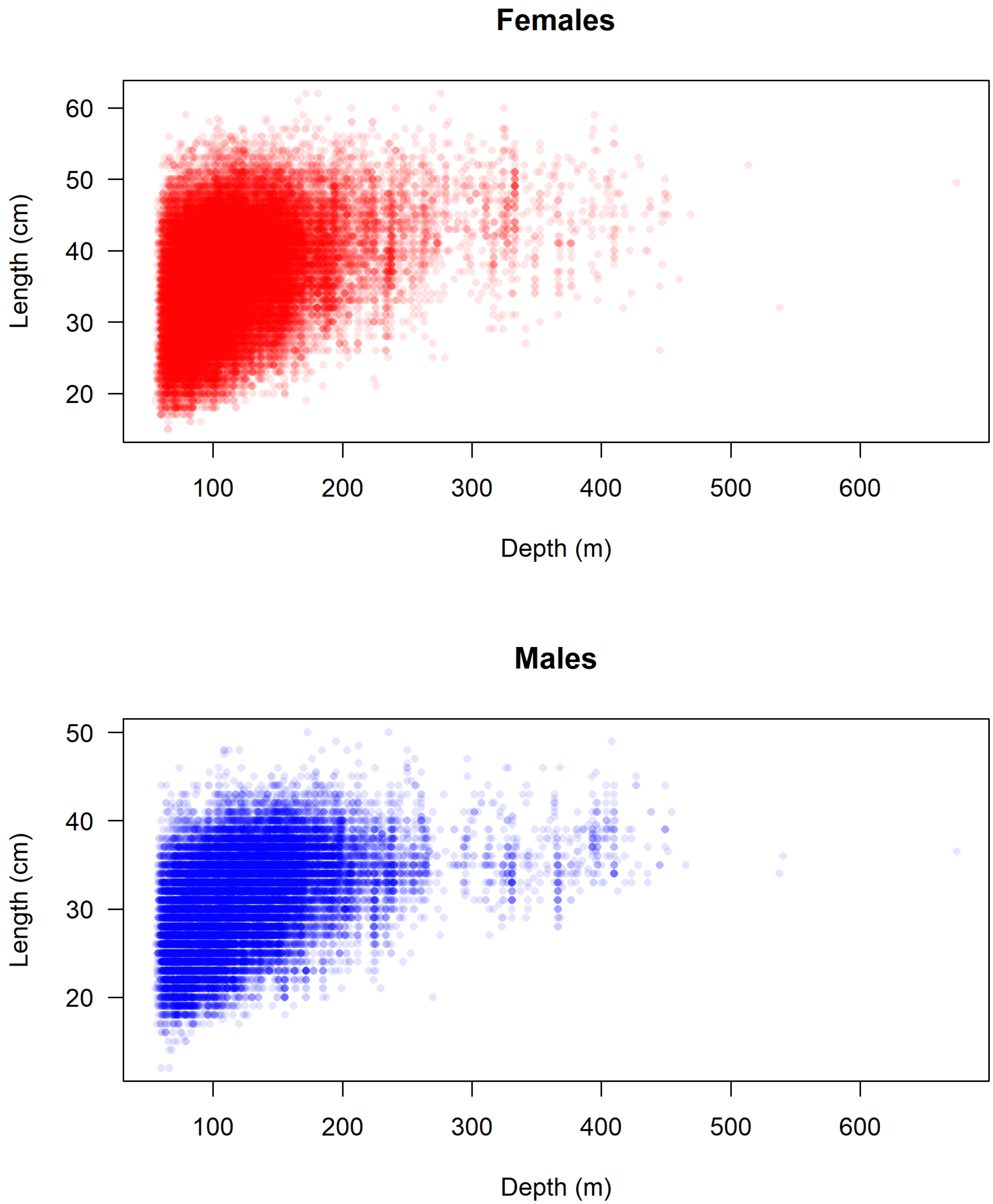


Figure 6: Length (cm) by depth (m) for the NWFSC West Coast Groundfish Bottom Trawl Survey data.

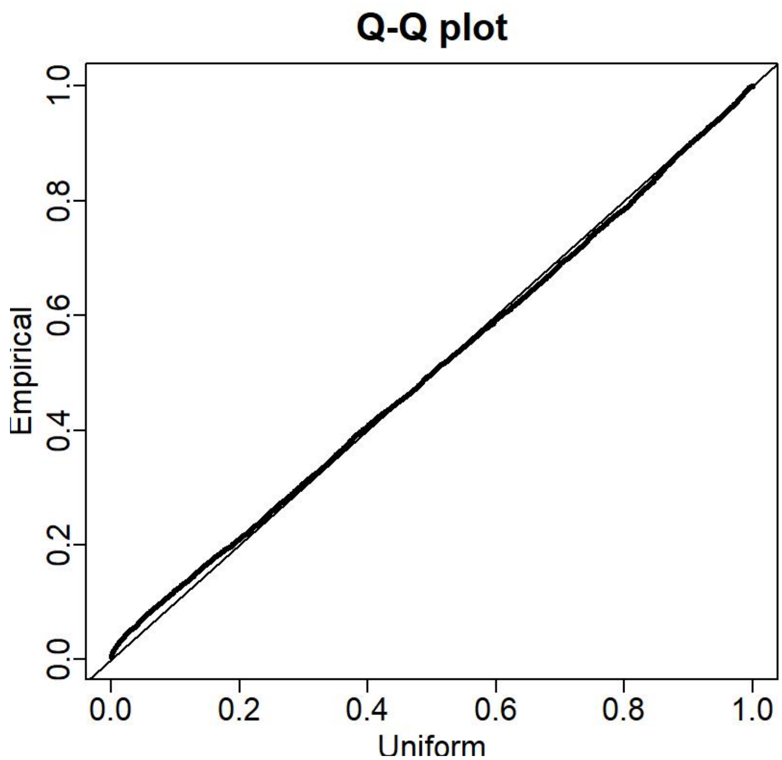


Figure 7: QQ plot for the NWFSC West Coast Groundfish Bottom Trawl Survey data.

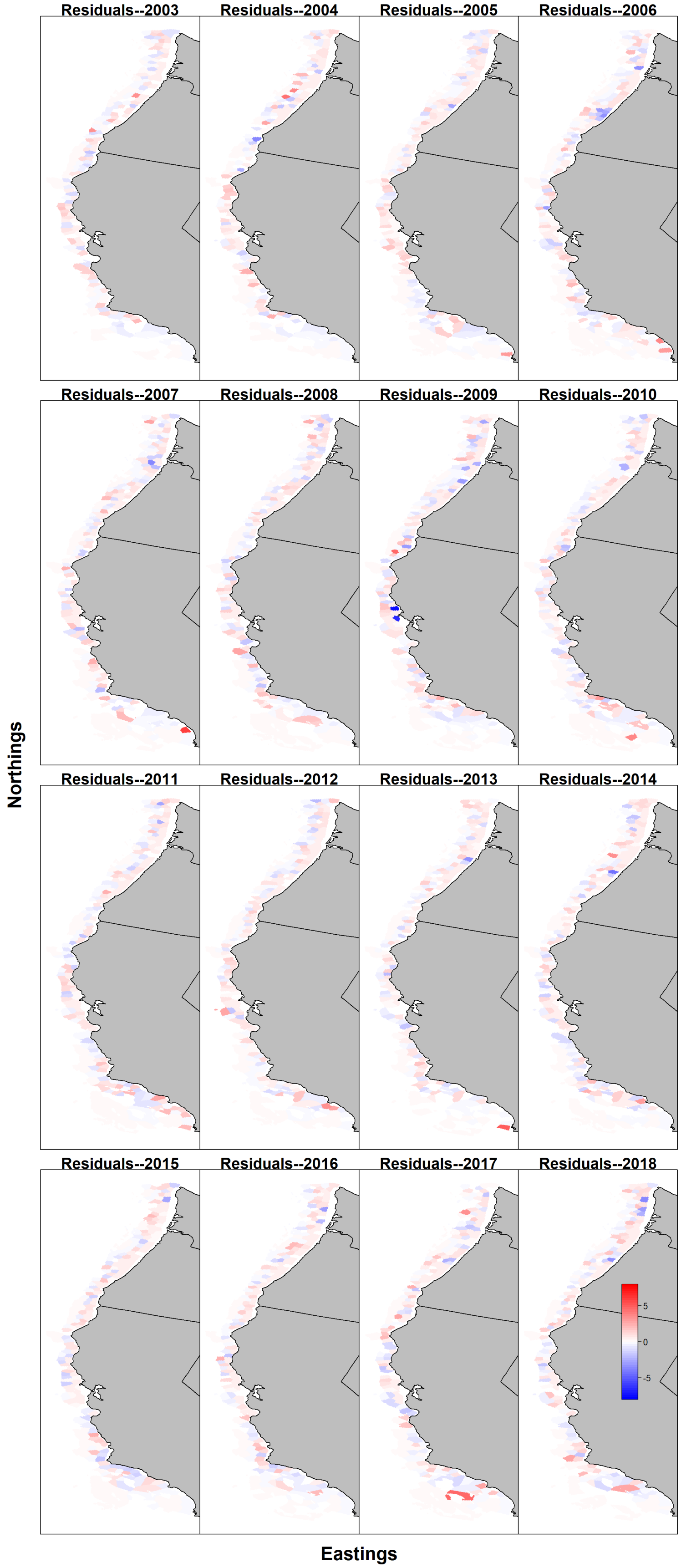


Figure 8: Pearson residuals for the encounter rate for the NWFSC West Coast Groundfish Bottom Trawl Survey by VAST.

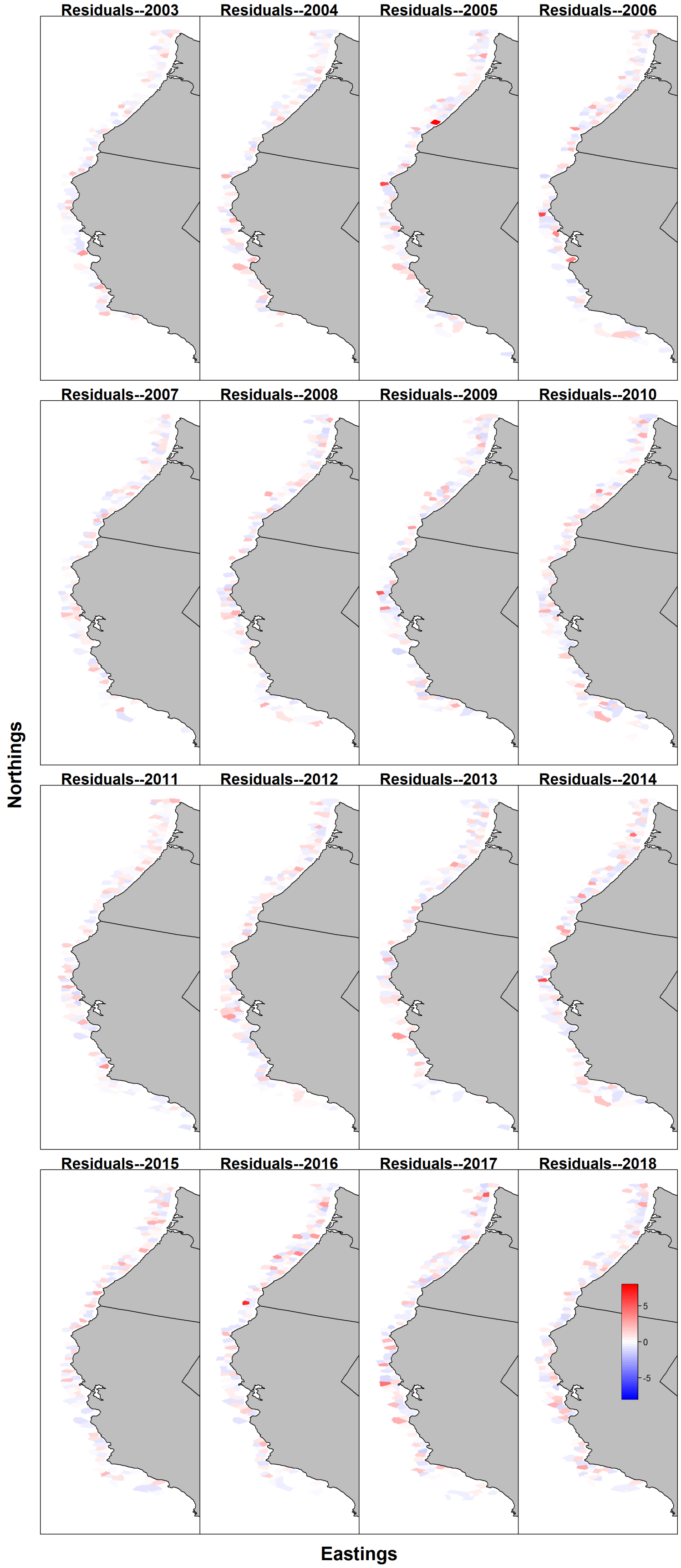


Figure 9: Pearson residuals for the estimated catch rate for the NWFSC West Coast Groundfish Bottom Trawl Survey by VAST.

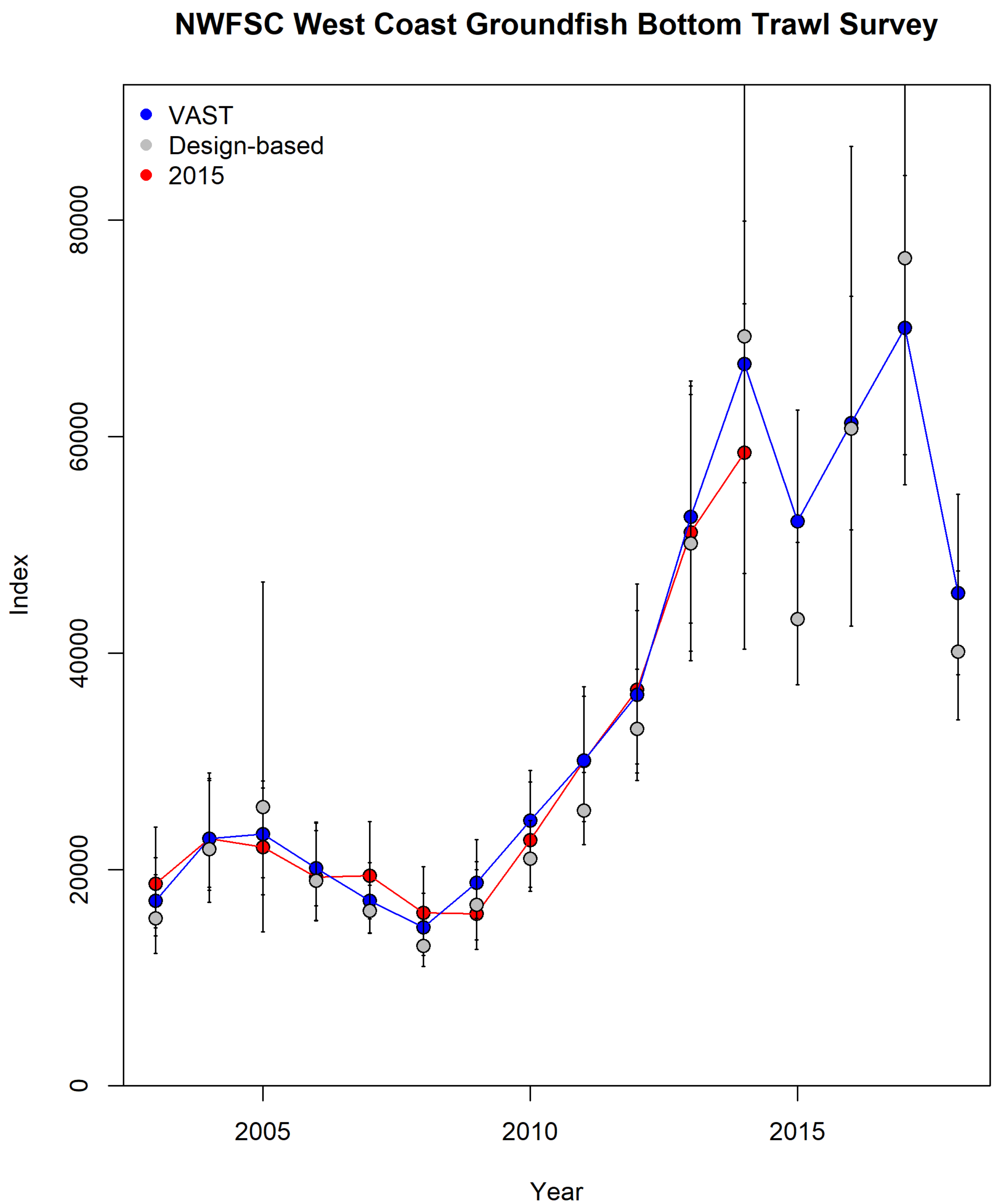


Figure 10: Estimated index of abundance from the NWFSC West Coast Groundfish Bottom Trawl Survey data compared to the design-based index and the index from the 2015 update assessment.

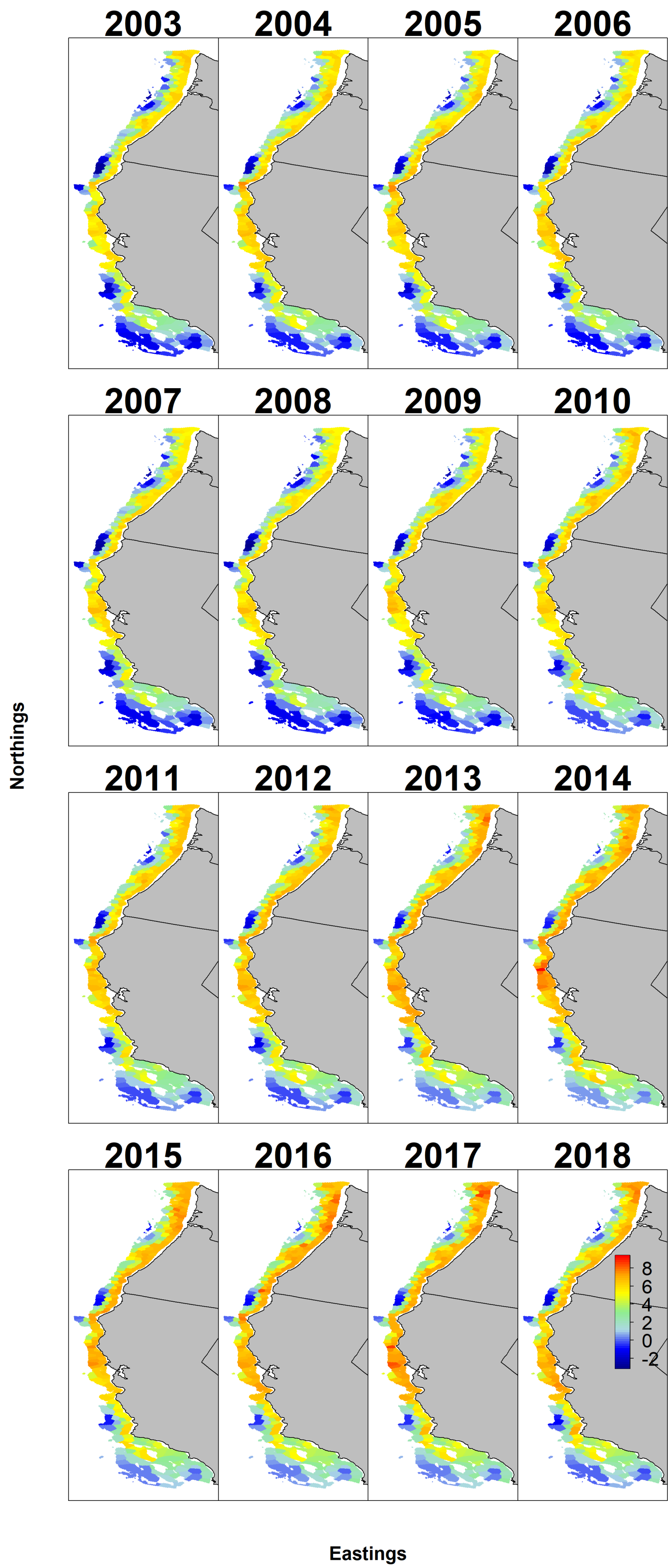


Figure 11: Estimated density of abundance from the NWFSC West Coast Groundfish Bottom Trawl Survey data by VAST.

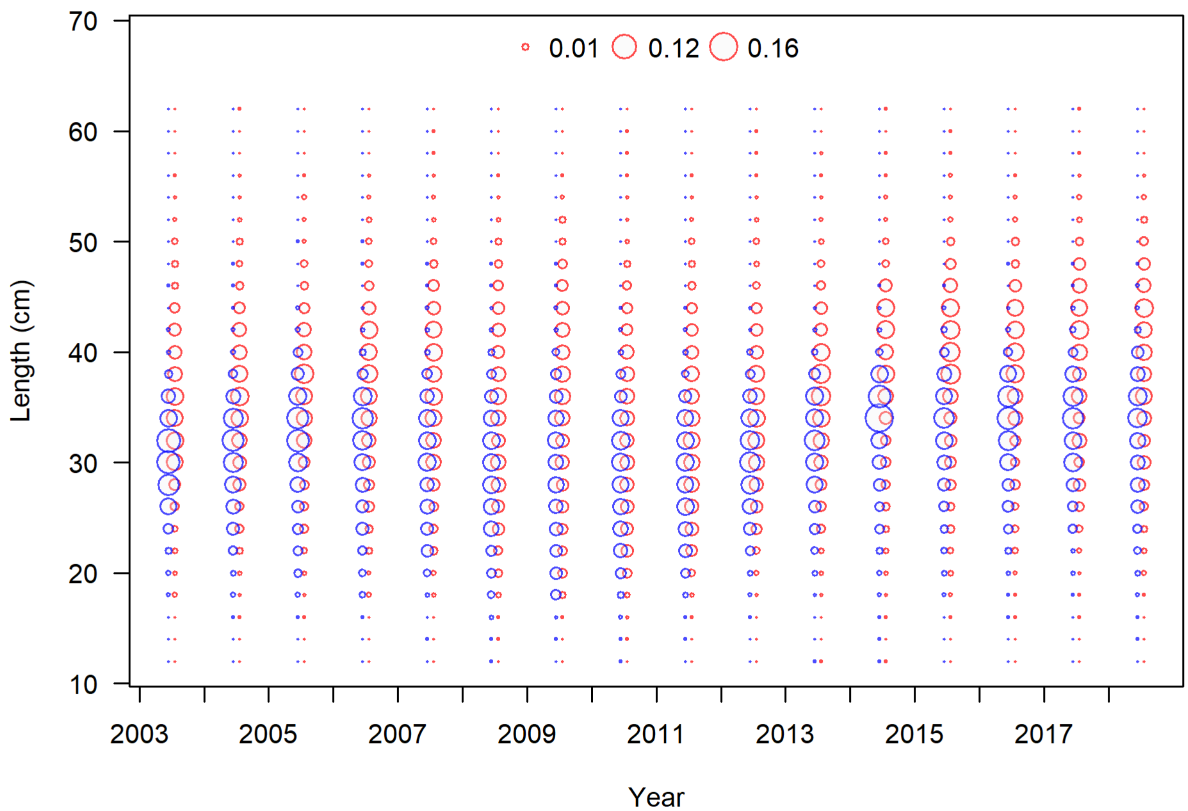


Figure 12: Length frequency by sex for the NWFSC West Coast Groundfish Bottom Trawl Survey data.

Figure 13: Age frequency by sex for the NWFSC West Coast Groundfish Bottom Trawl Survey data.

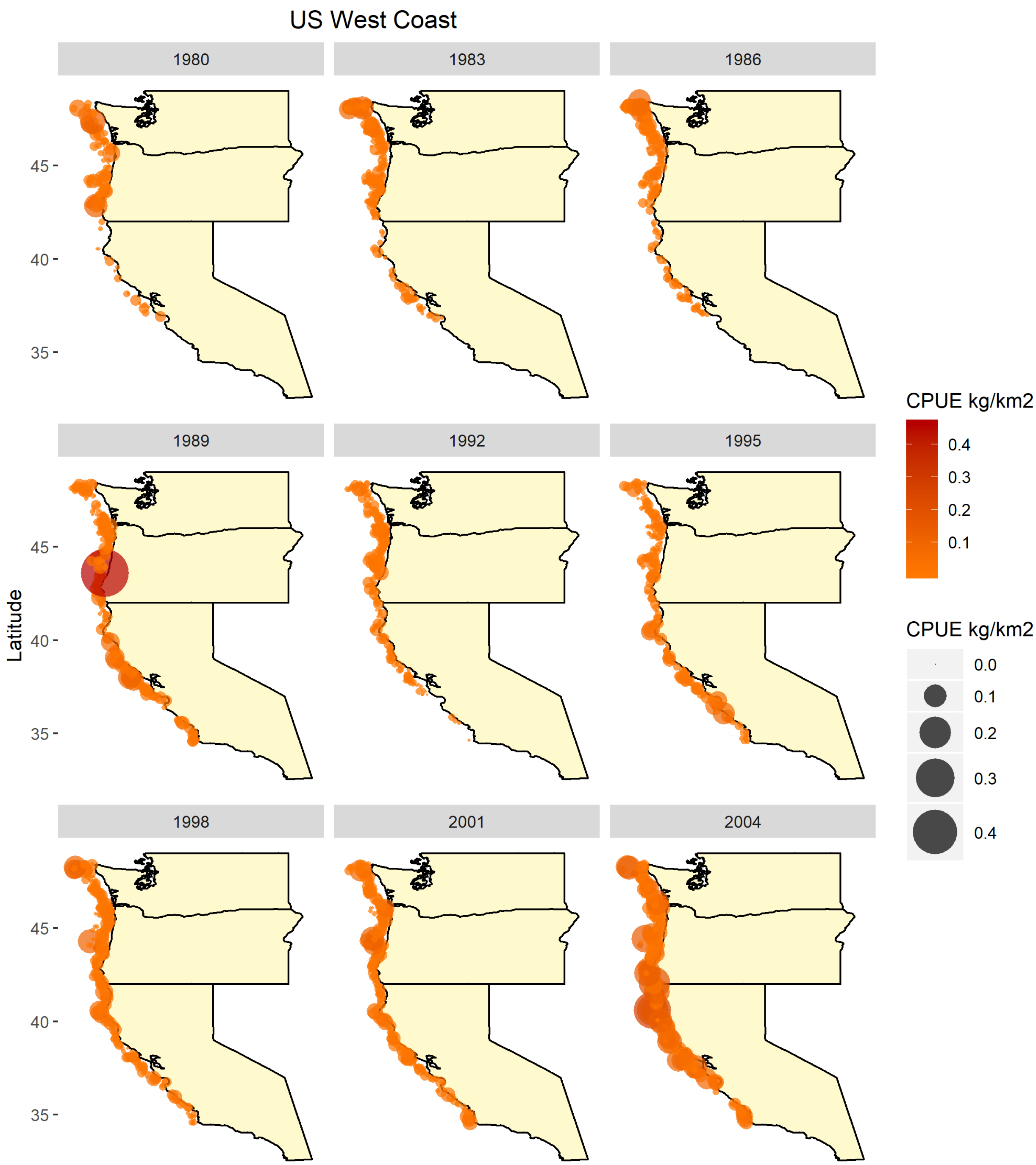


Figure 14: Map of the catch-per-unit-effort across by year for the Triennial Survey data.

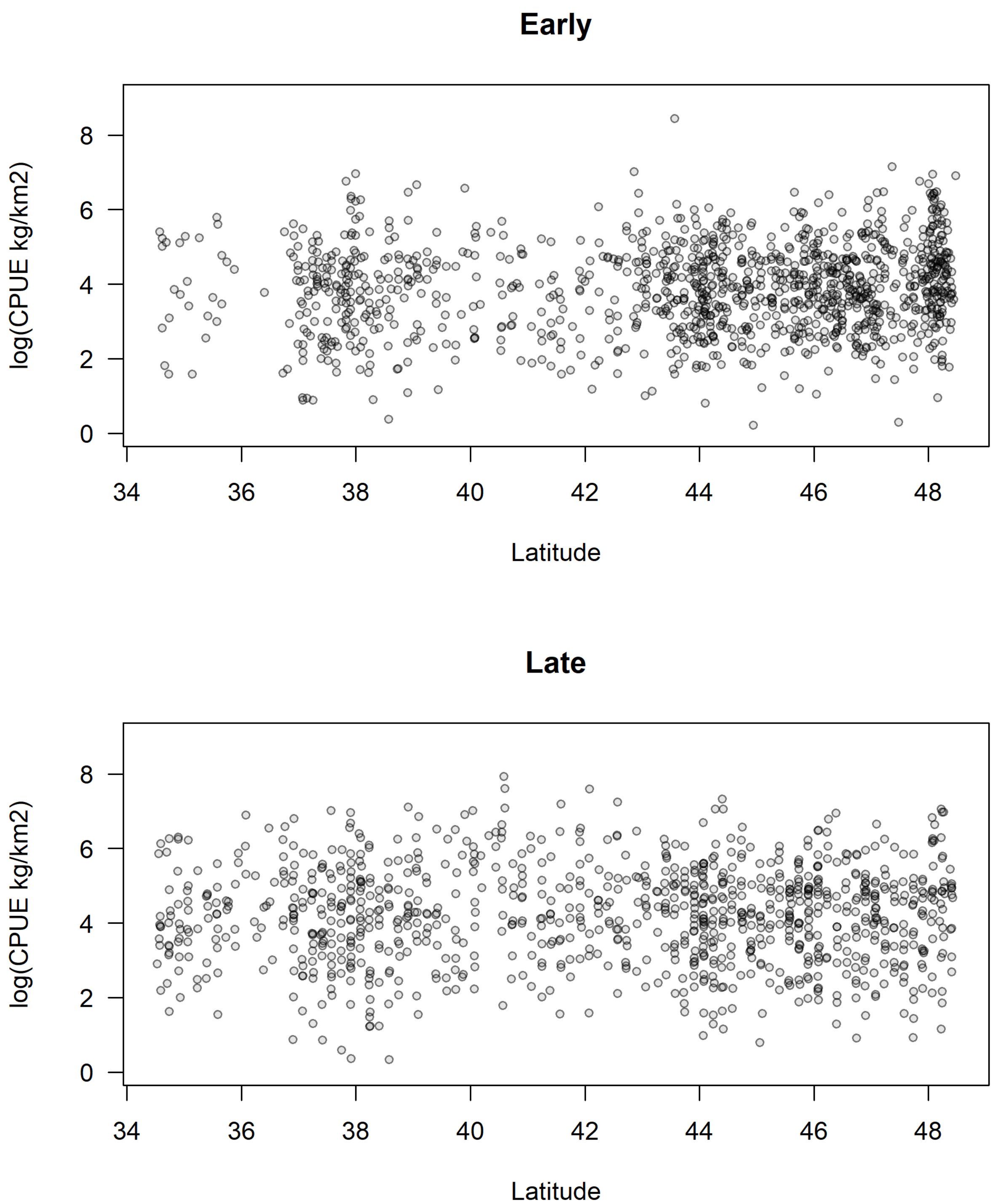


Figure 15: Catch-per-unit-effort (in log space) by latitude for the Triennial Survey data.

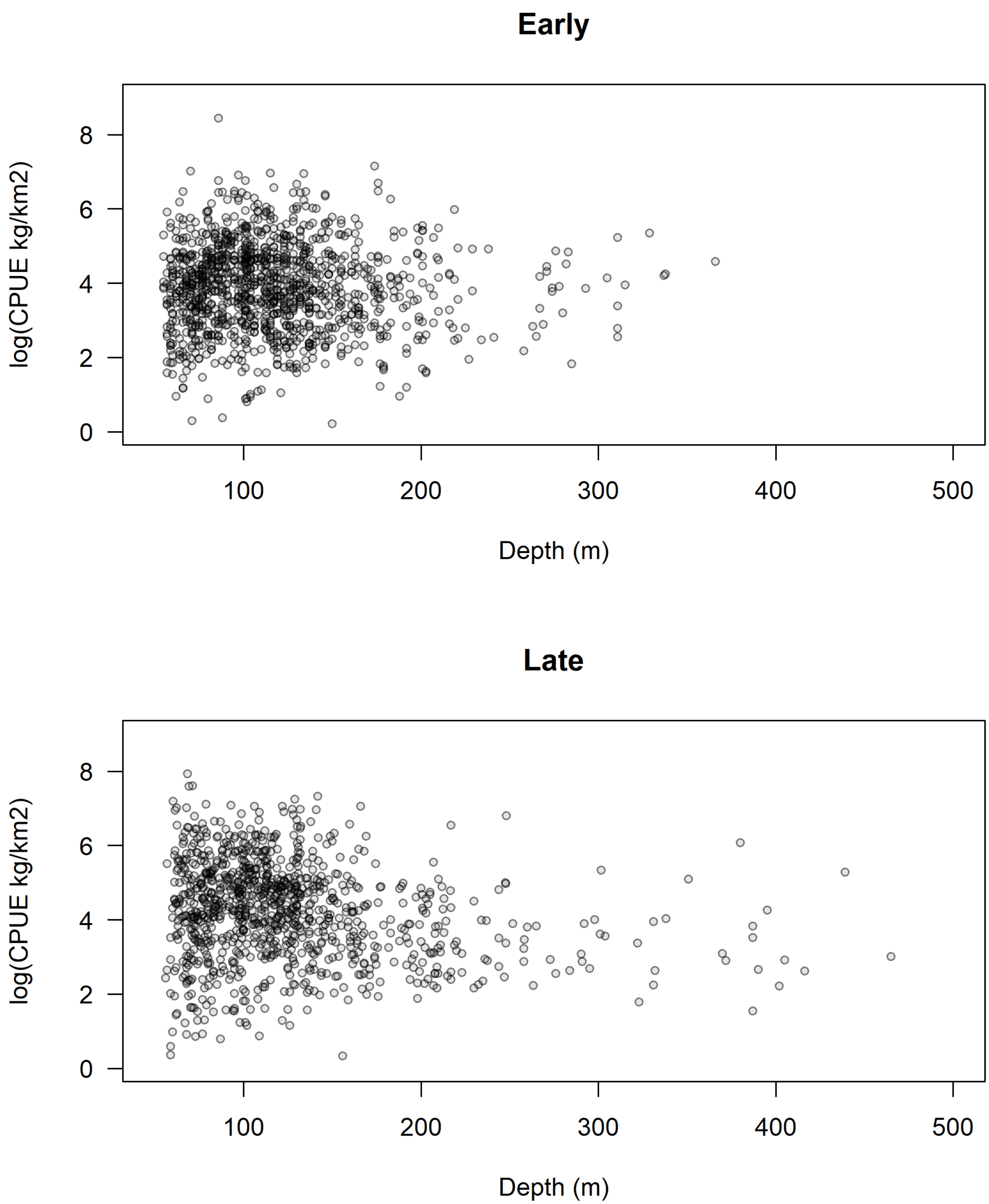


Figure 16: Catch-per-unit-effort (in log space) by depth (m) for the Triennial Survey data.

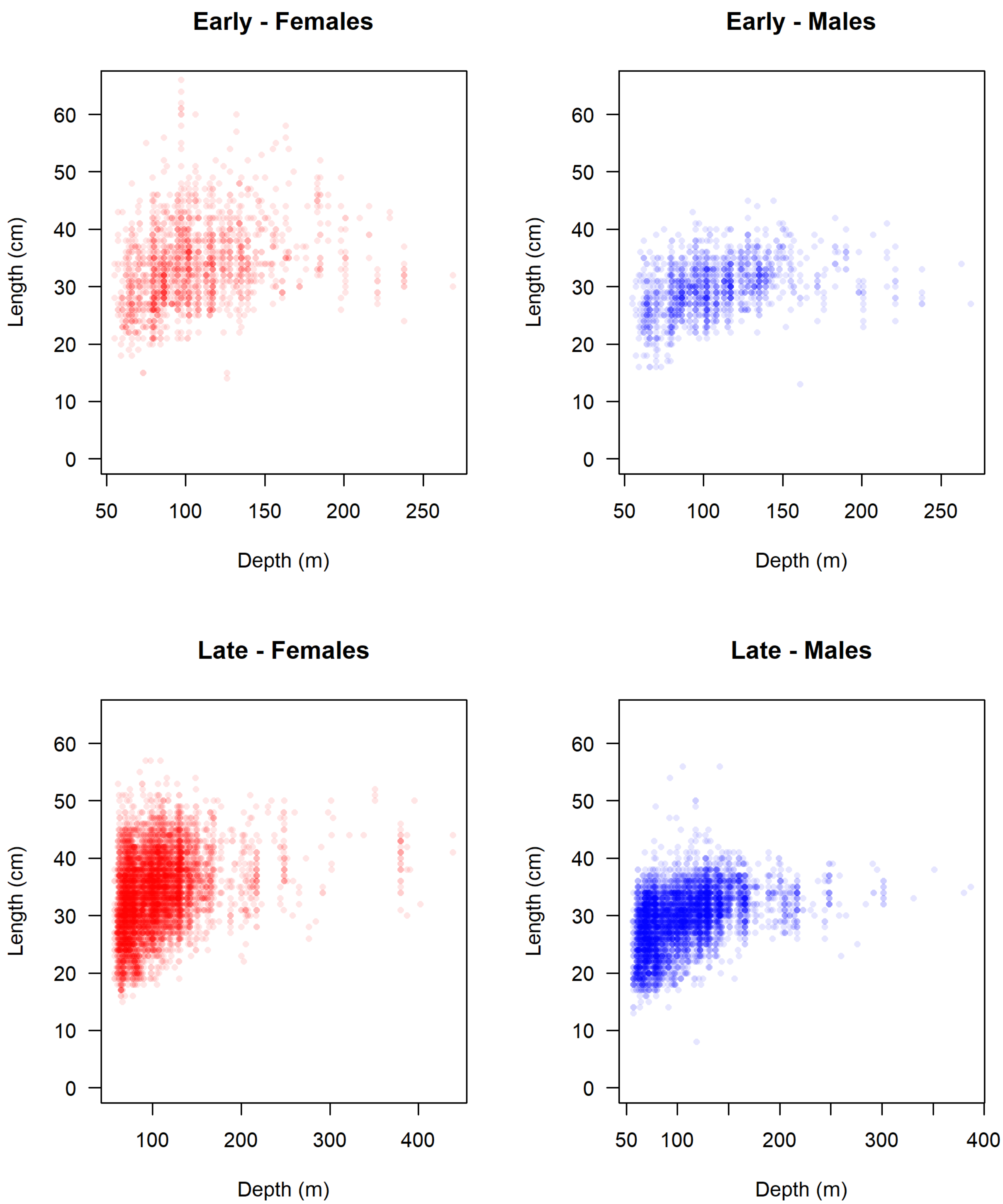


Figure 17: Length (cm) by depth (m) for the Triennial Survey data.

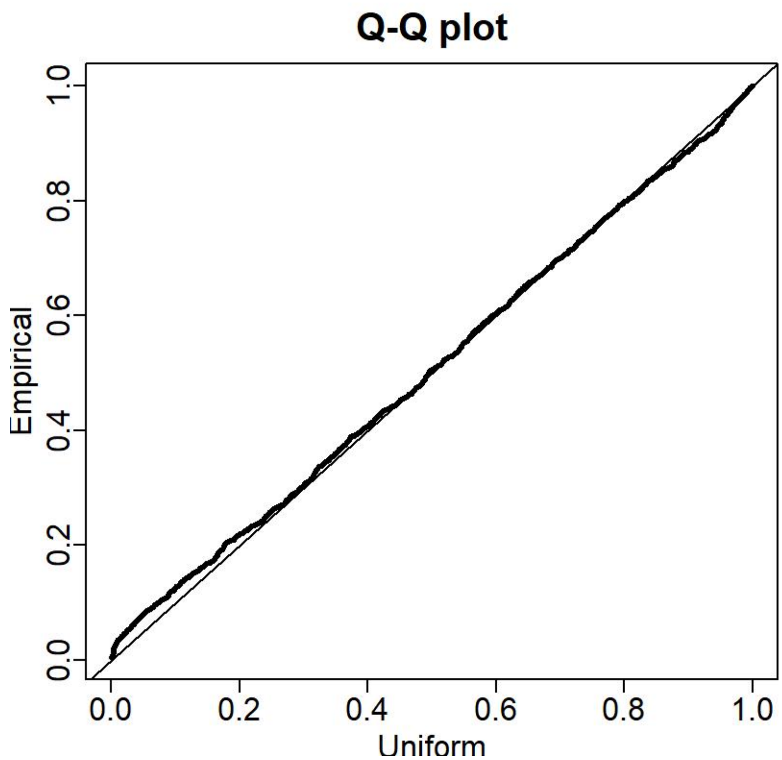


Figure 18: QQ plot for the Triennial Early Survey data.

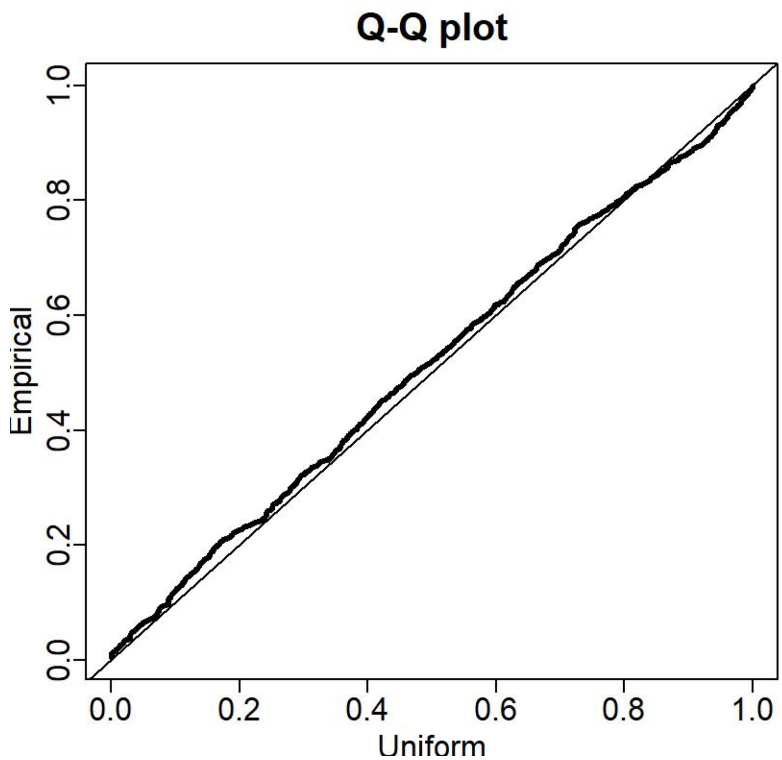


Figure 19: QQ plot for the Triennial Late Survey data.

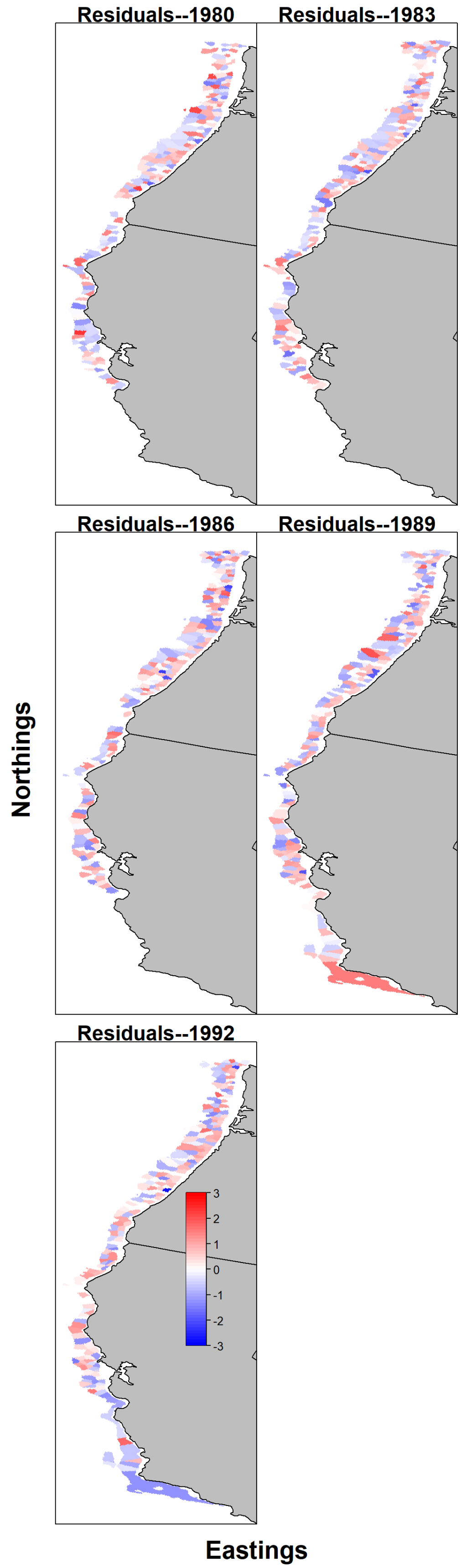


Figure 20: Pearson residuals for the encounter rate for the Triennial Early Survey by VAST.

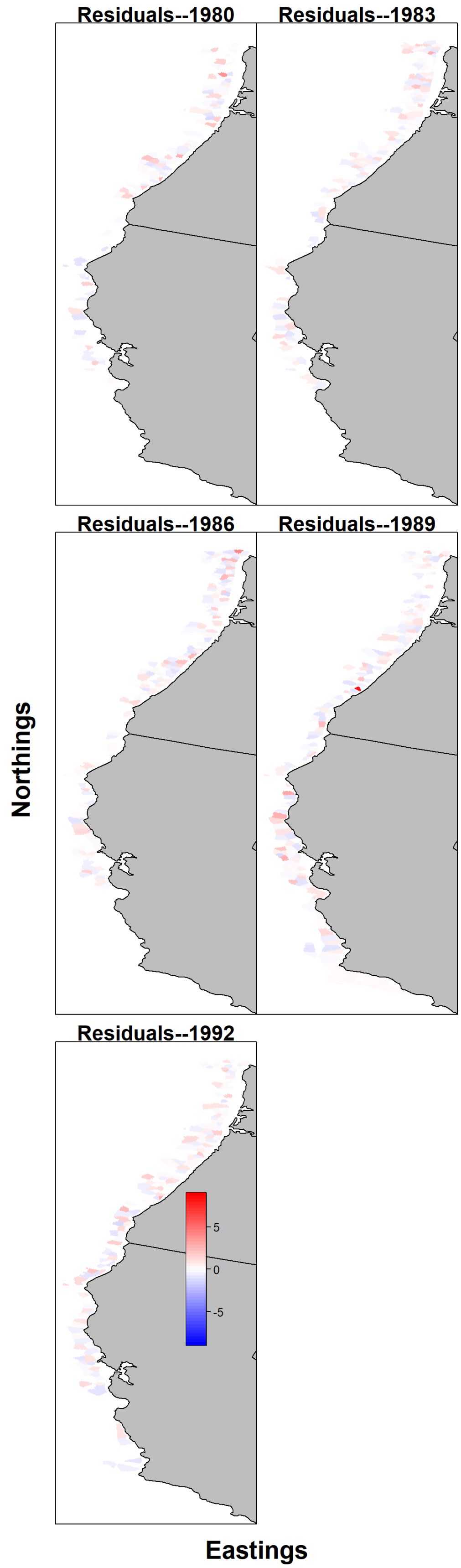


Figure 21: Pearson residuals for the estimated catch rate for the Triennial Early Survey by VAST.

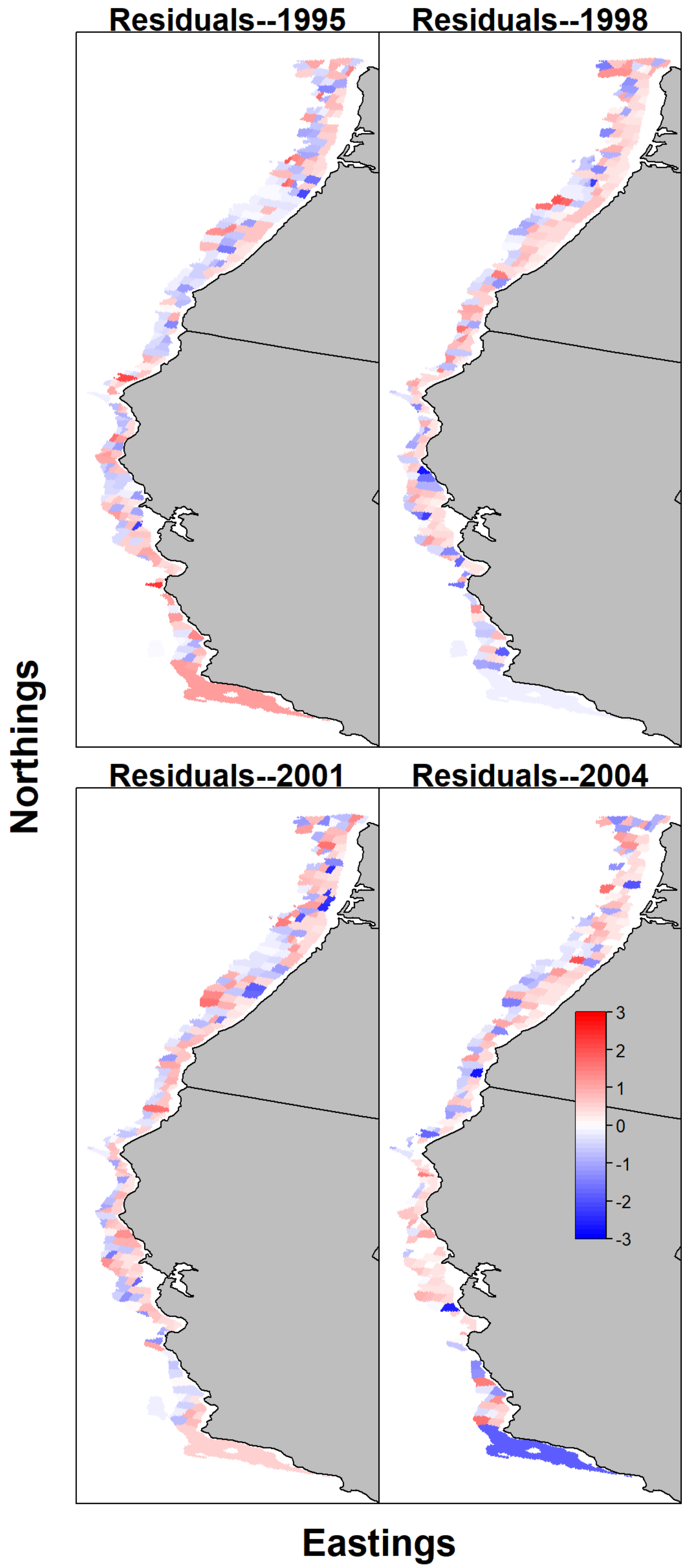


Figure 22: Pearson residuals for the encounter rate for the Triennial Late Survey by VAST.

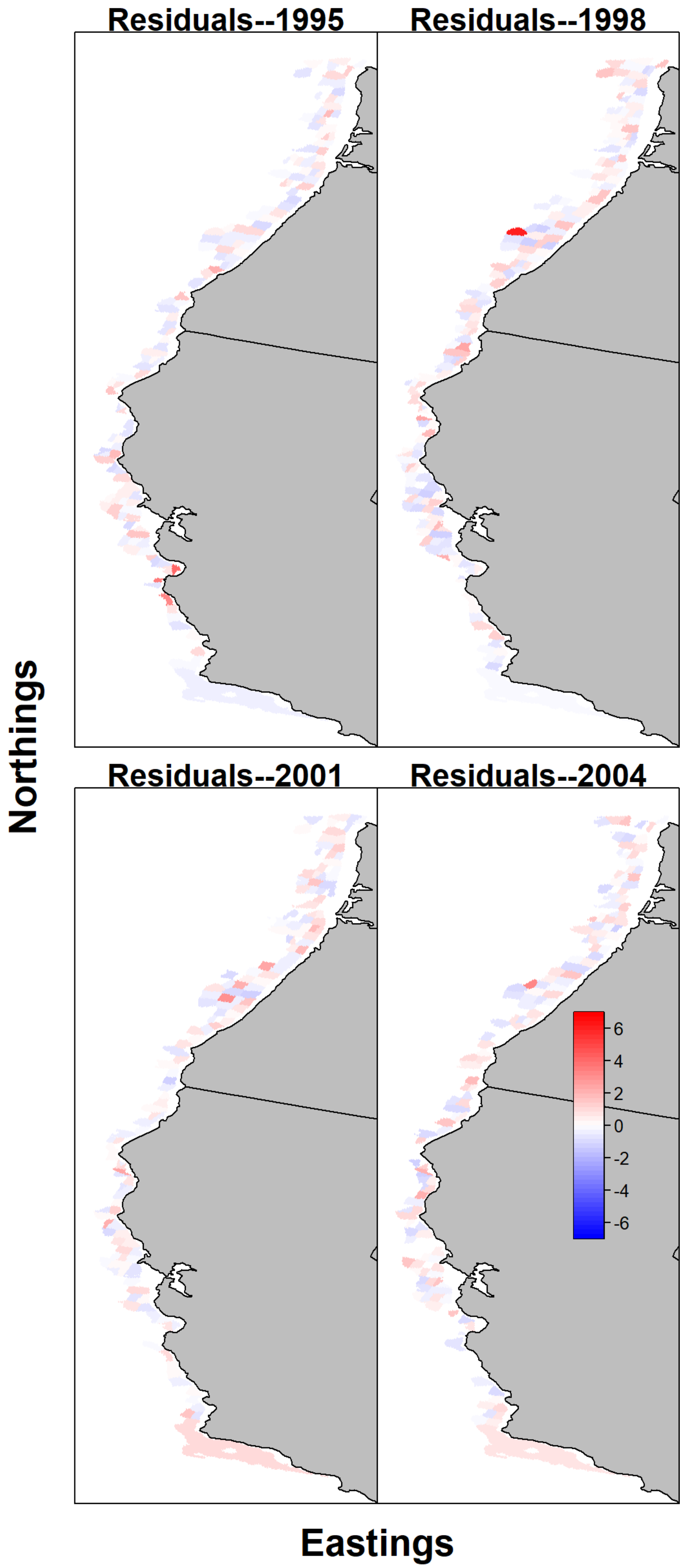


Figure 23: Pearson residuals for the estimated catch rate for the Triennial Late Survey by VAST.

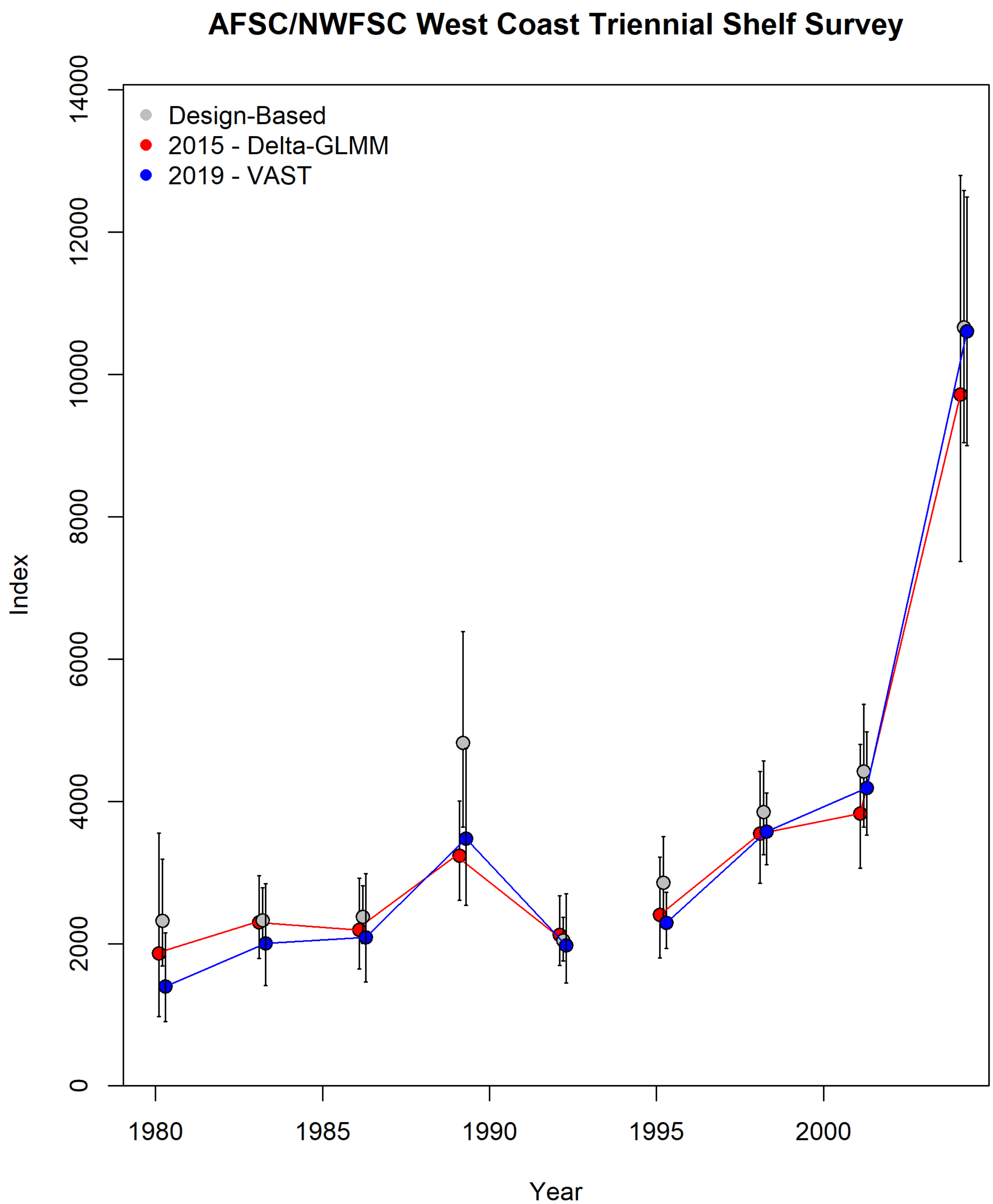


Figure 24: Estimated index of abundance from the Triennial Survey data compared to the design-based index and the index from the 2015 update assessment.

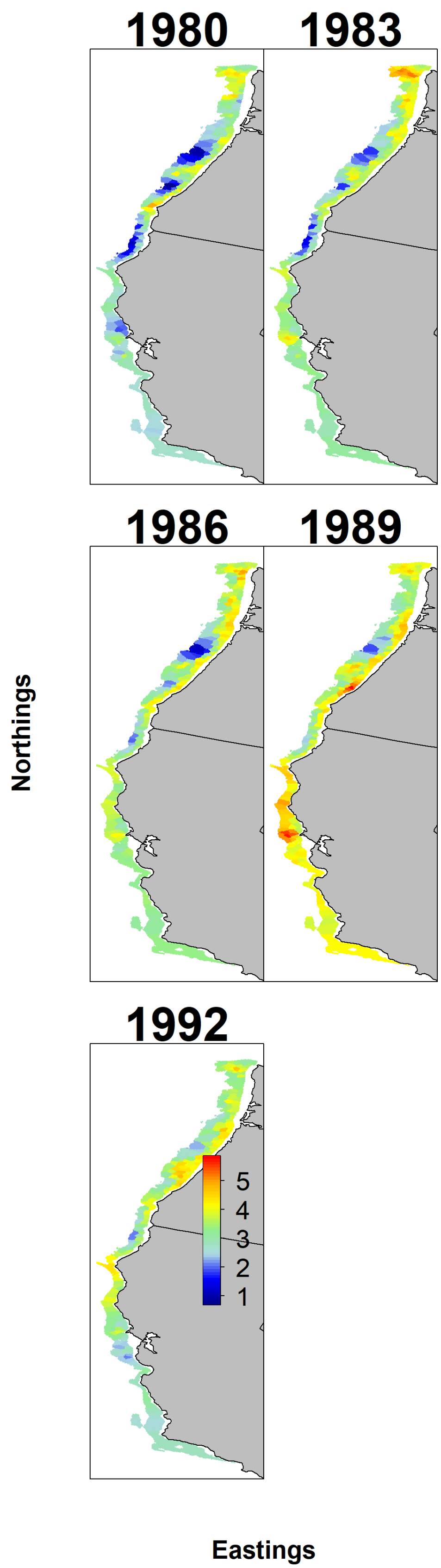


Figure 25: Estimated density of abundance from the Triennial Early Survey data by VAST.

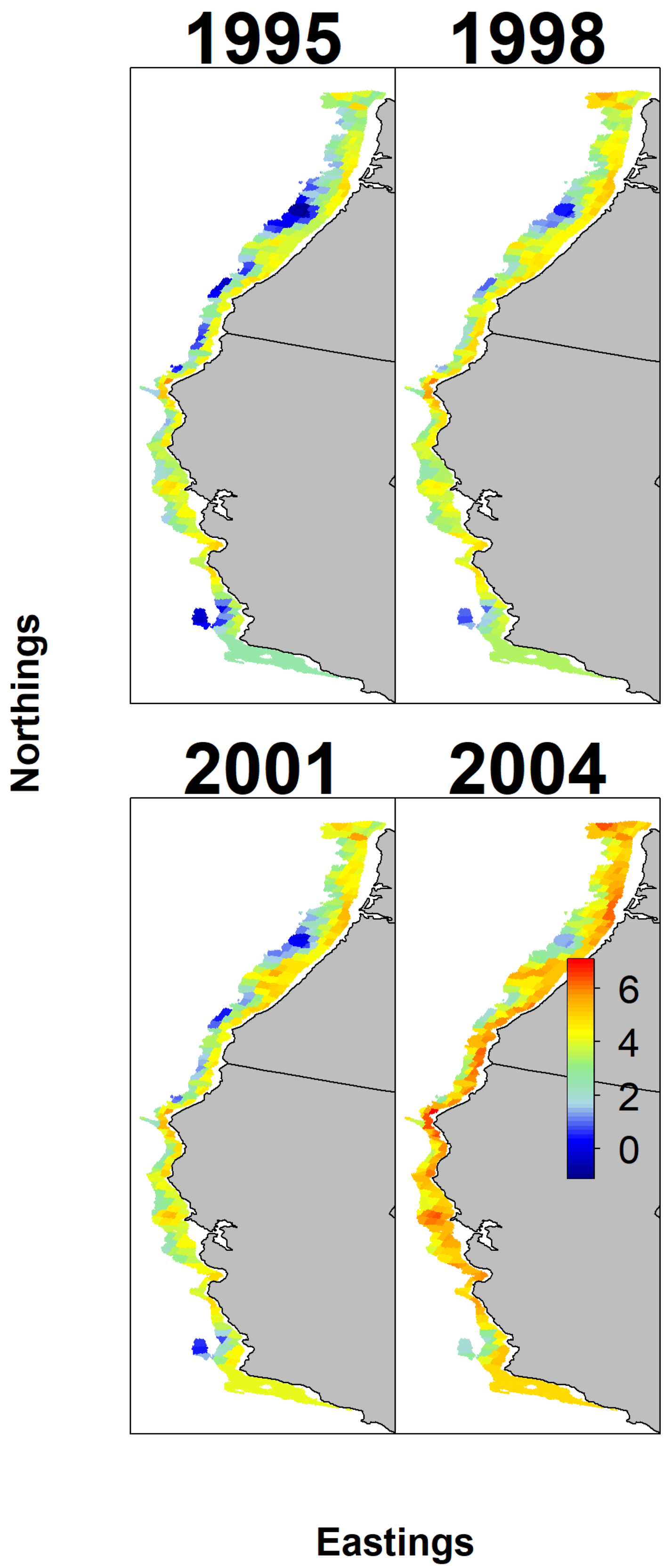


Figure 26: Estimated density of abundance from the Triennial Late Survey data by VAST.

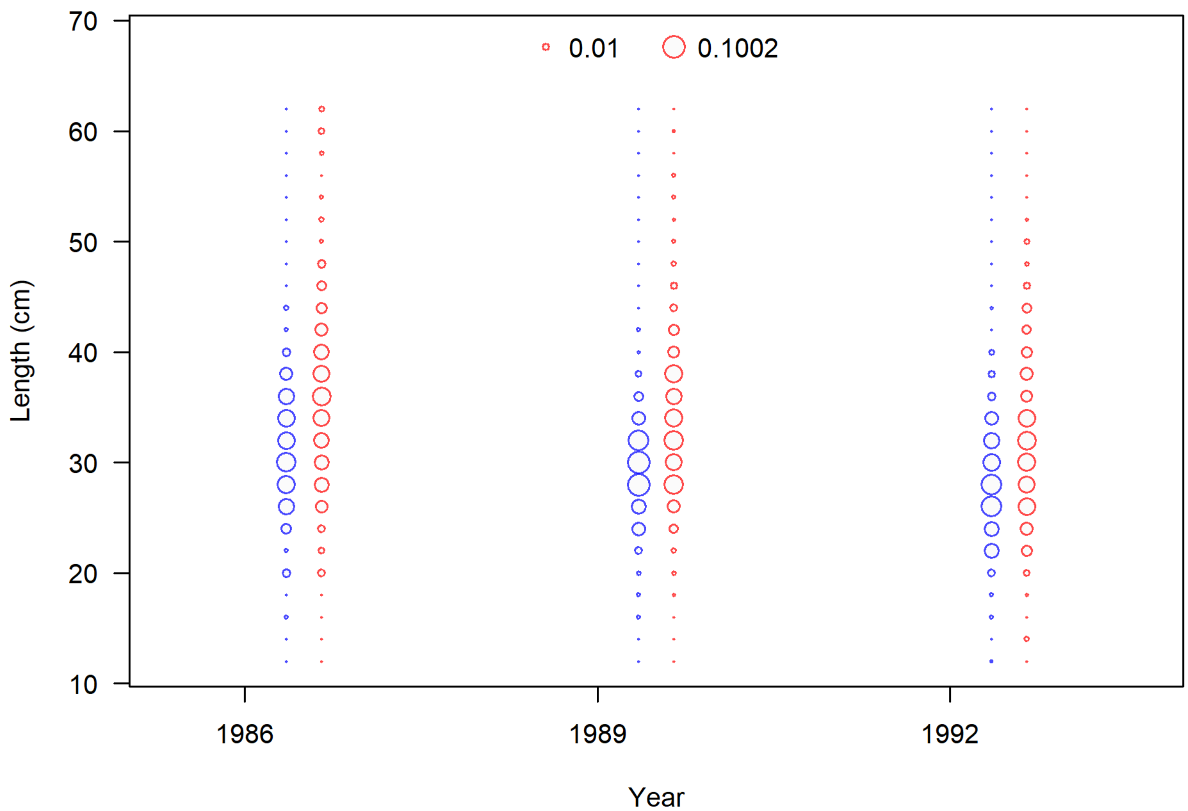


Figure 27: Length frequency by sex for the Triennial Early Survey data.

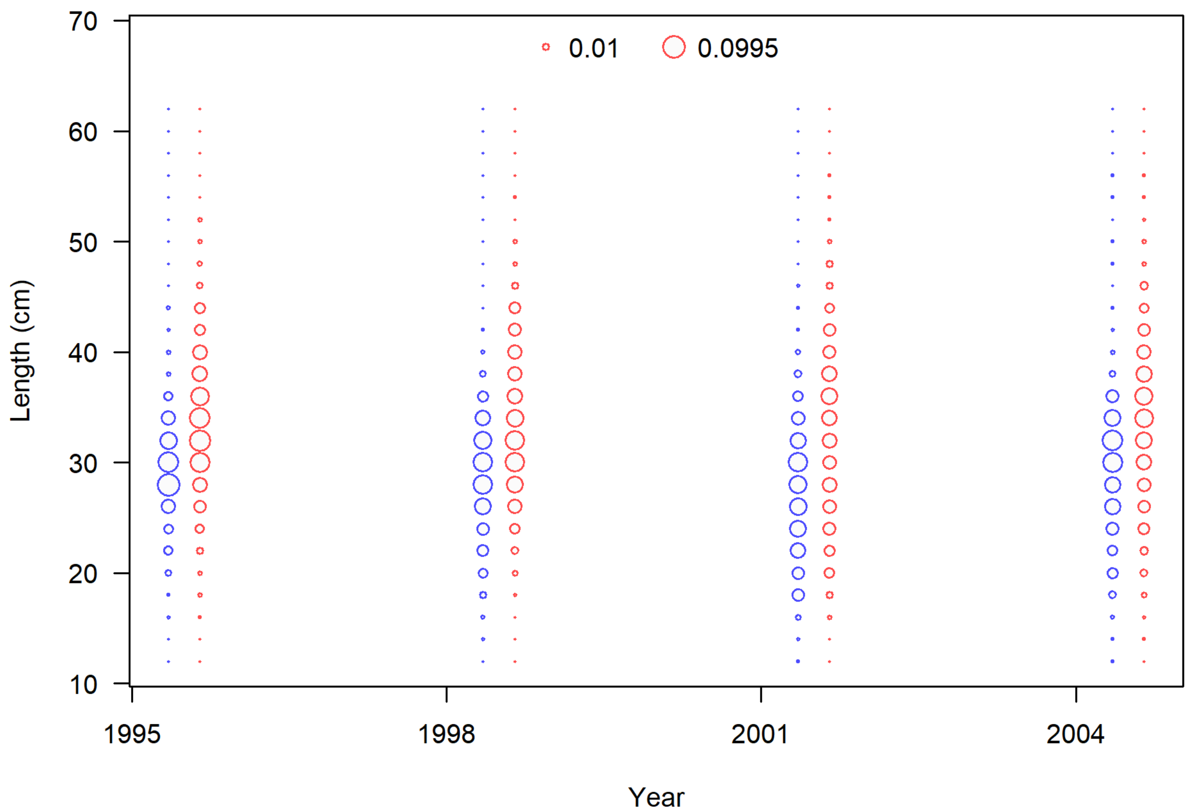


Figure 28: Length frequency by sex for the Triennial Late Survey data.

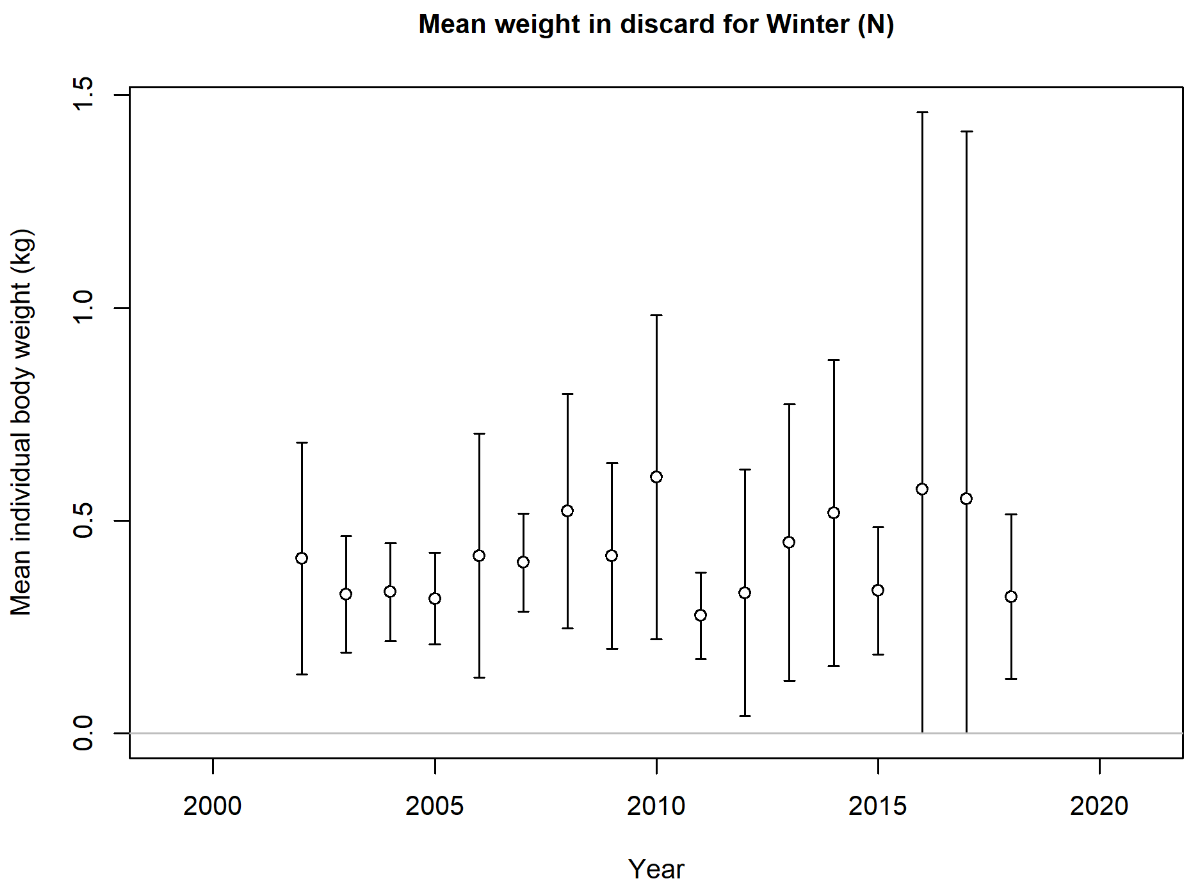


Figure 29: Northern winter fishery mean body weights of discarded fish for petrale sole.

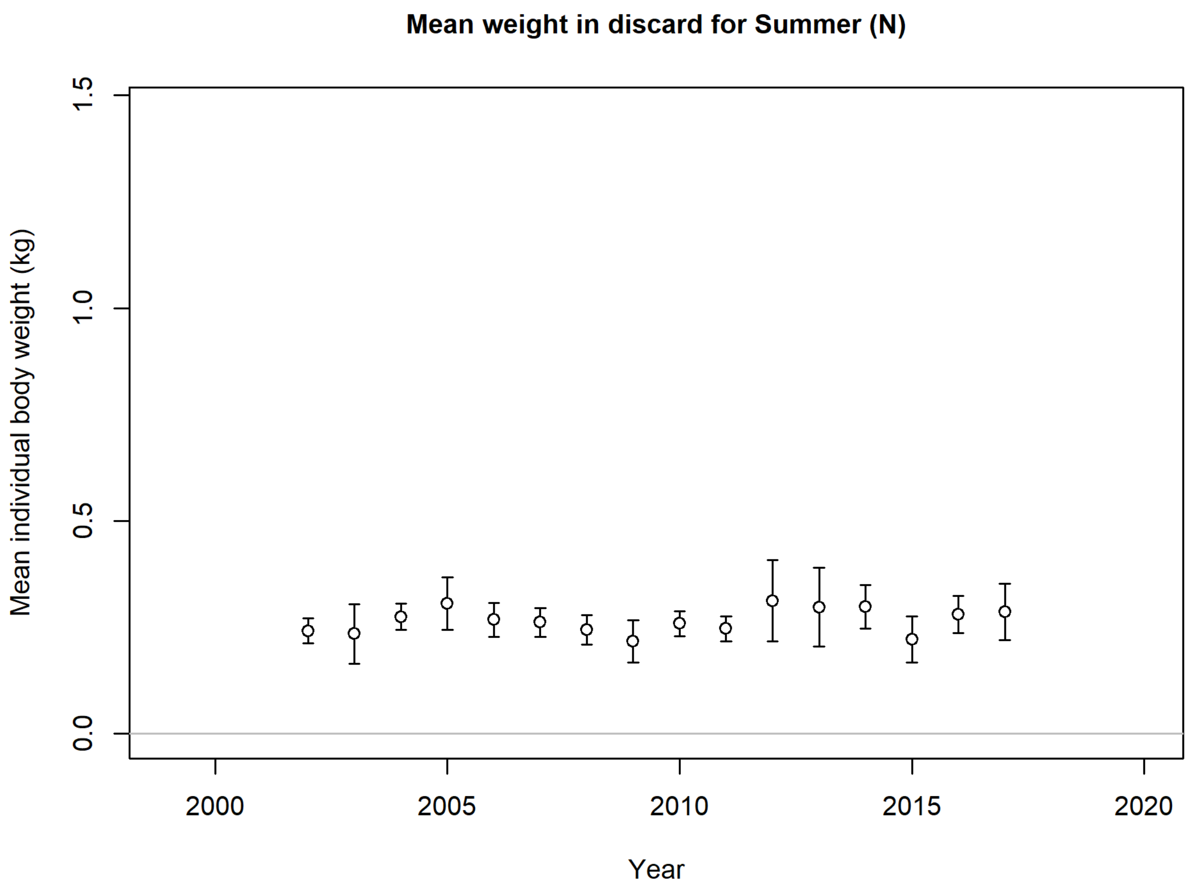


Figure 30: Northern summer fishery mean body weights of discarded fish for petrale sole.

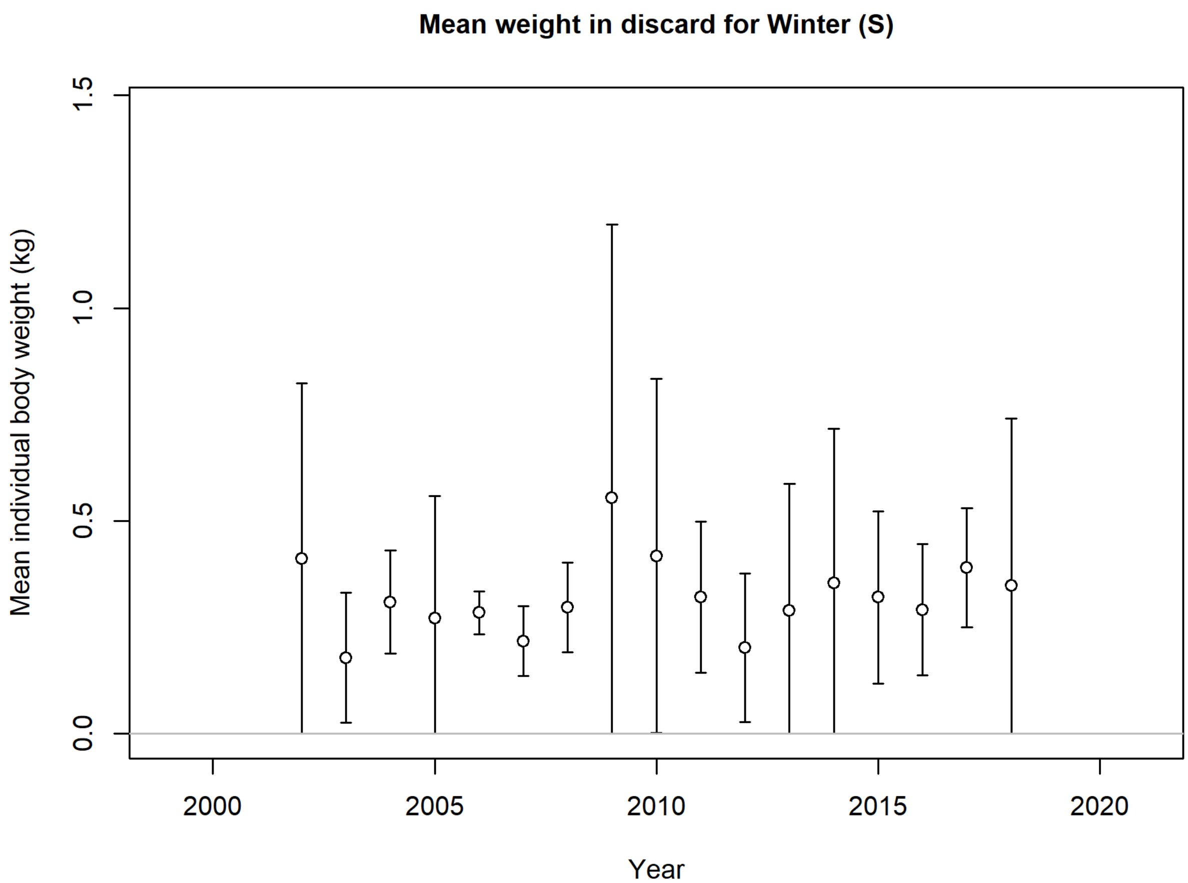


Figure 31: Southern winter fishery mean body weights of discarded fish for petrale sole.

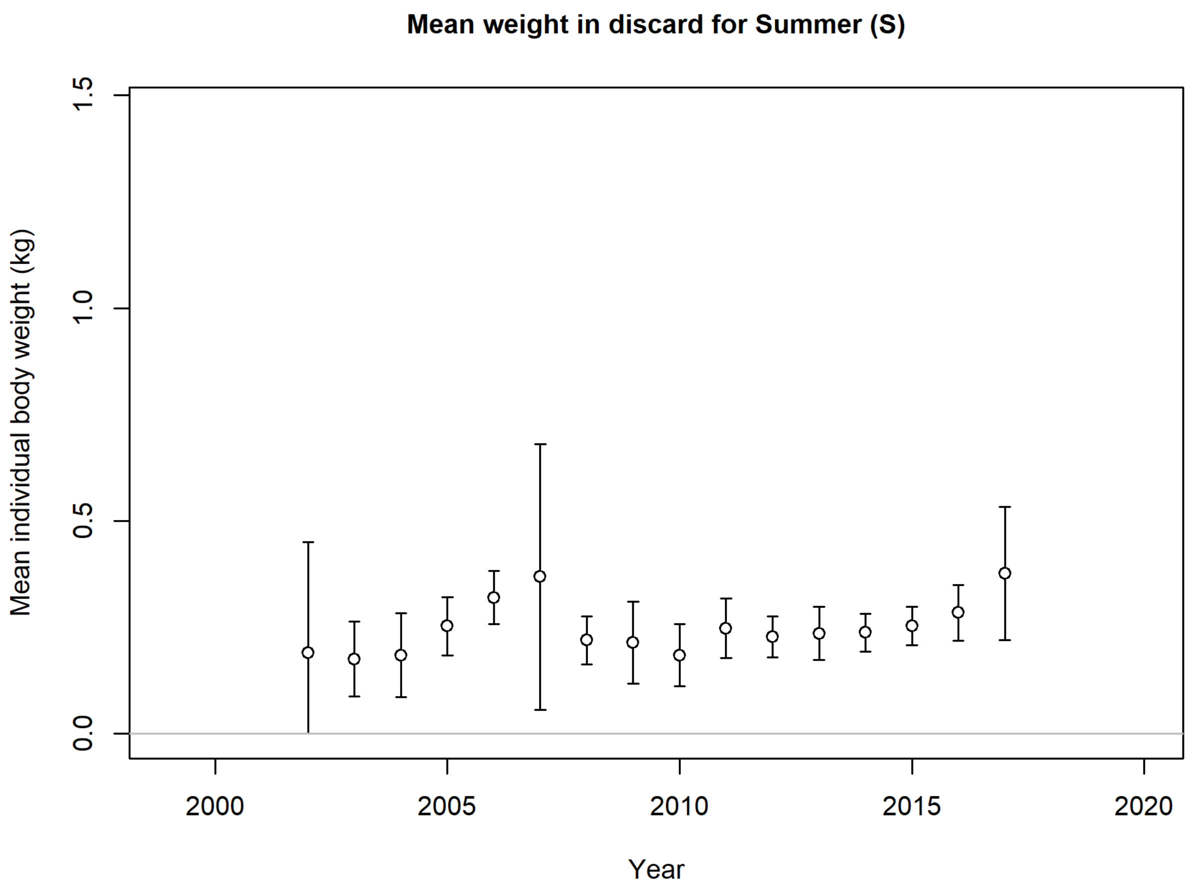


Figure 32: Southern summer fishery mean body weights of discarded fish for petrale sole.

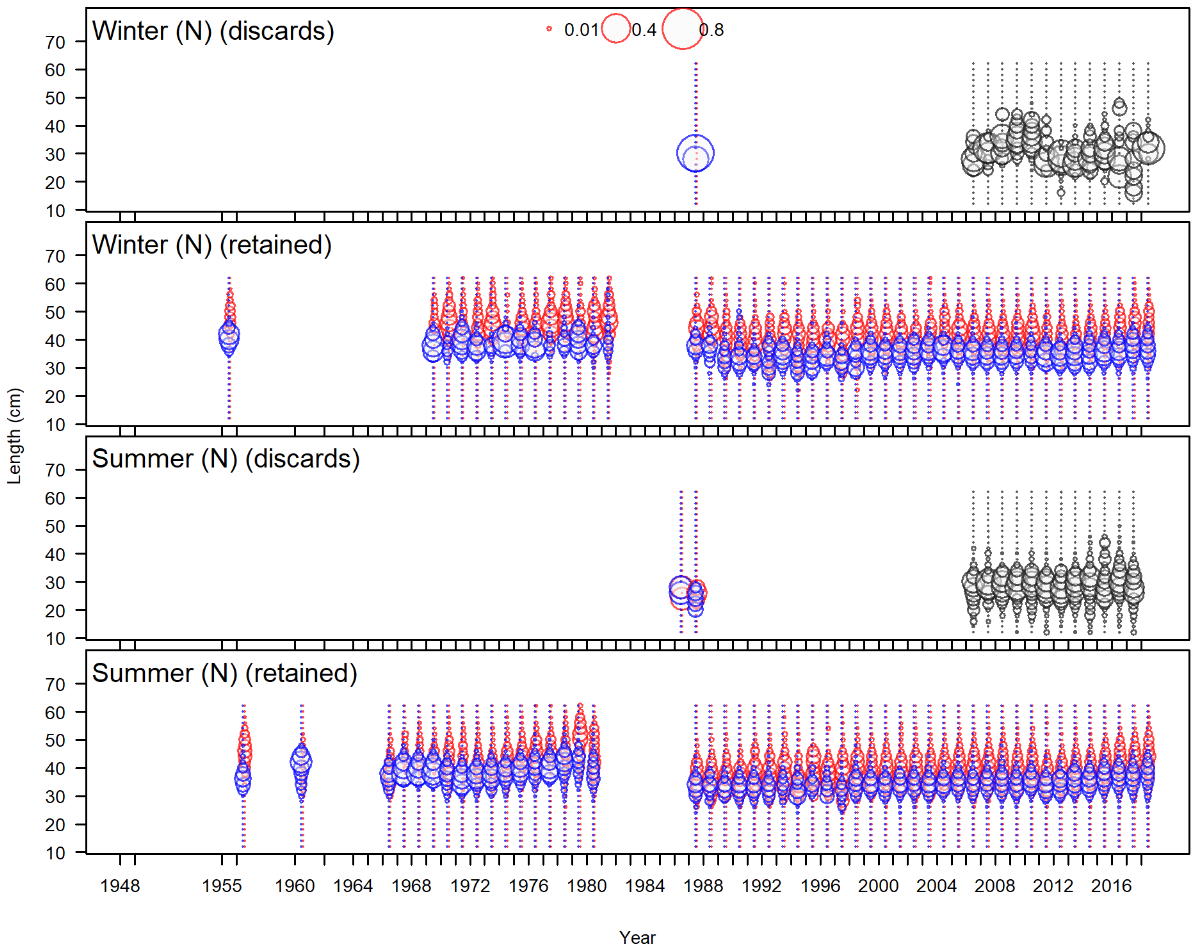


Figure 33: Northern, winter and summer fleets, retained and discarded length frequency distributions for petrale sole.

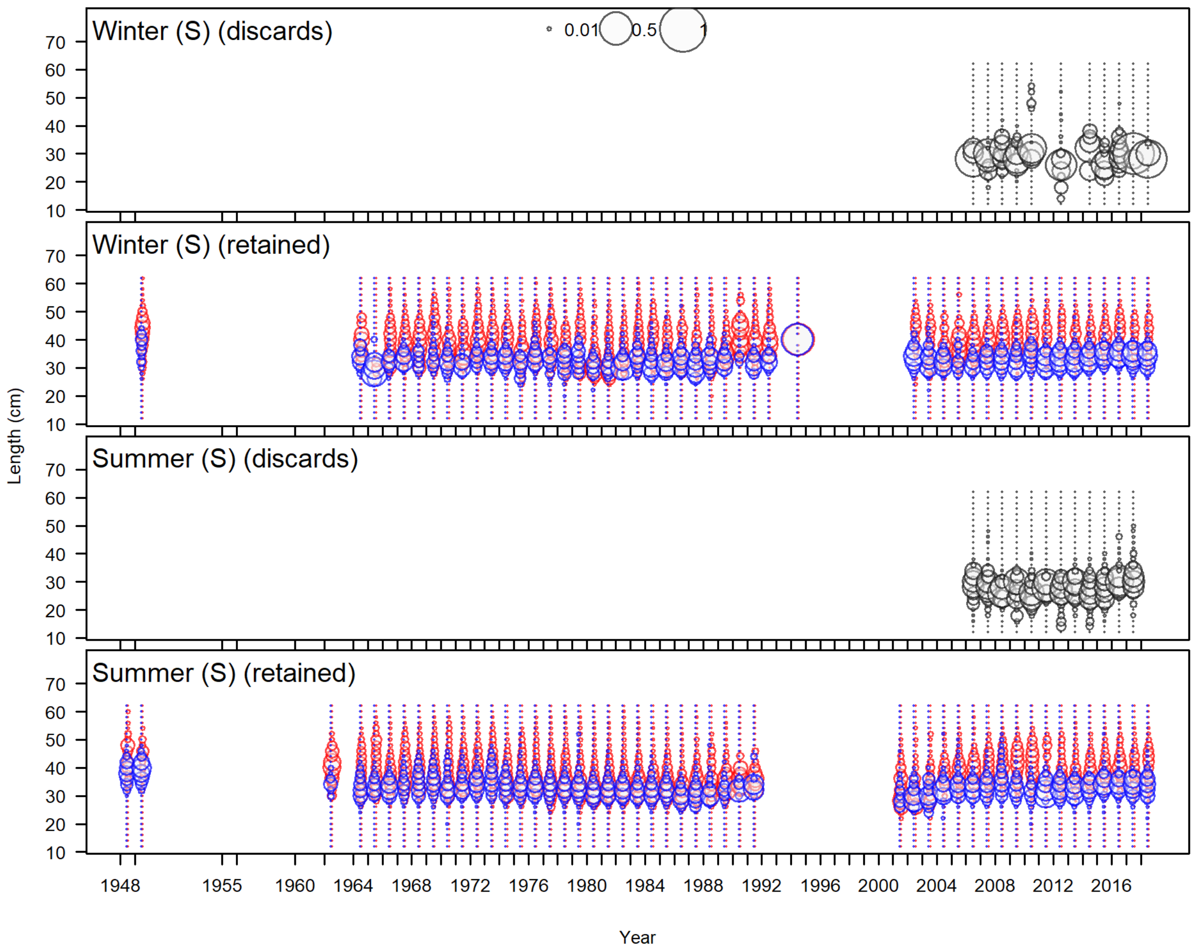


Figure 34: Northern, winter and summer fleets, retained and discarded length frequency distributions for petrale sole.

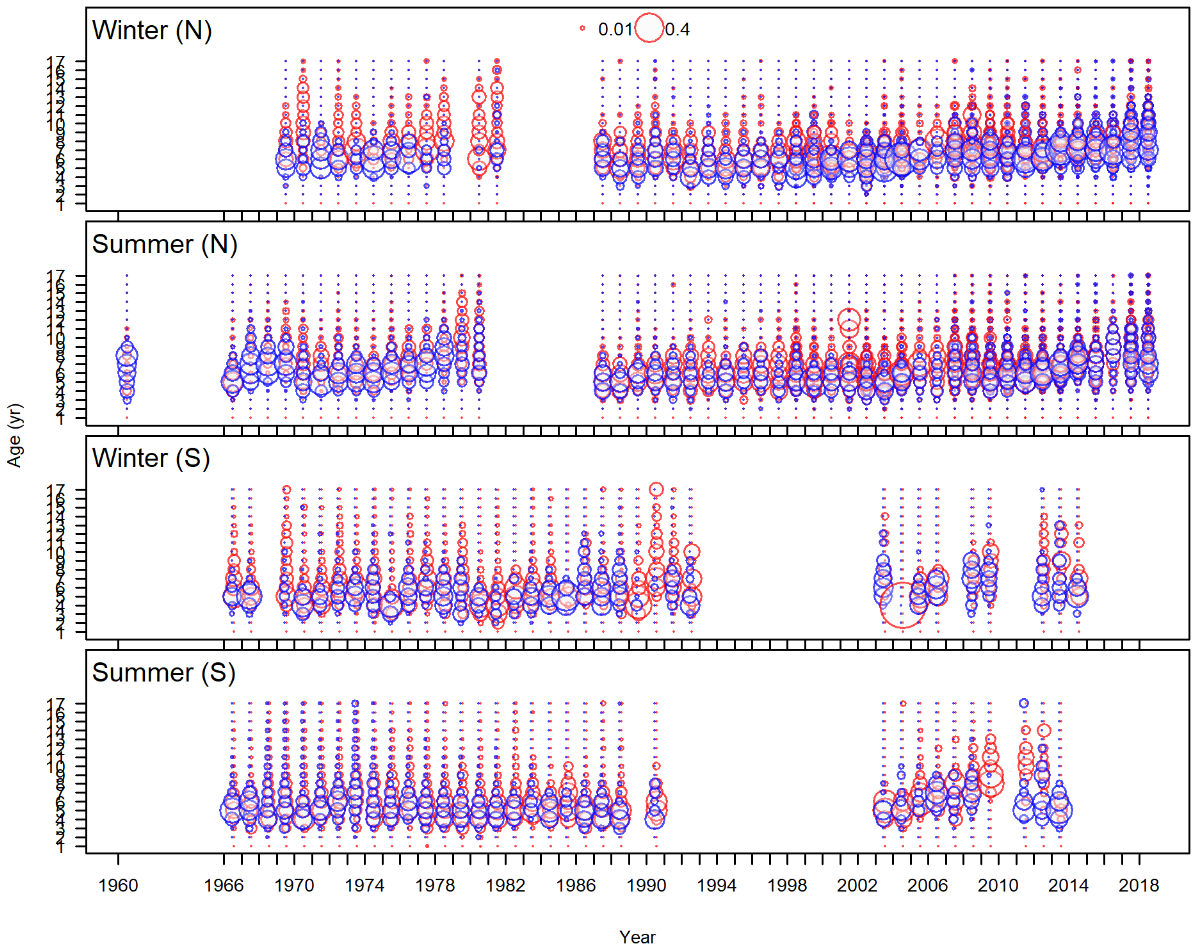


Figure 35: Commercial fishery age frequency distributions for petrale sole.

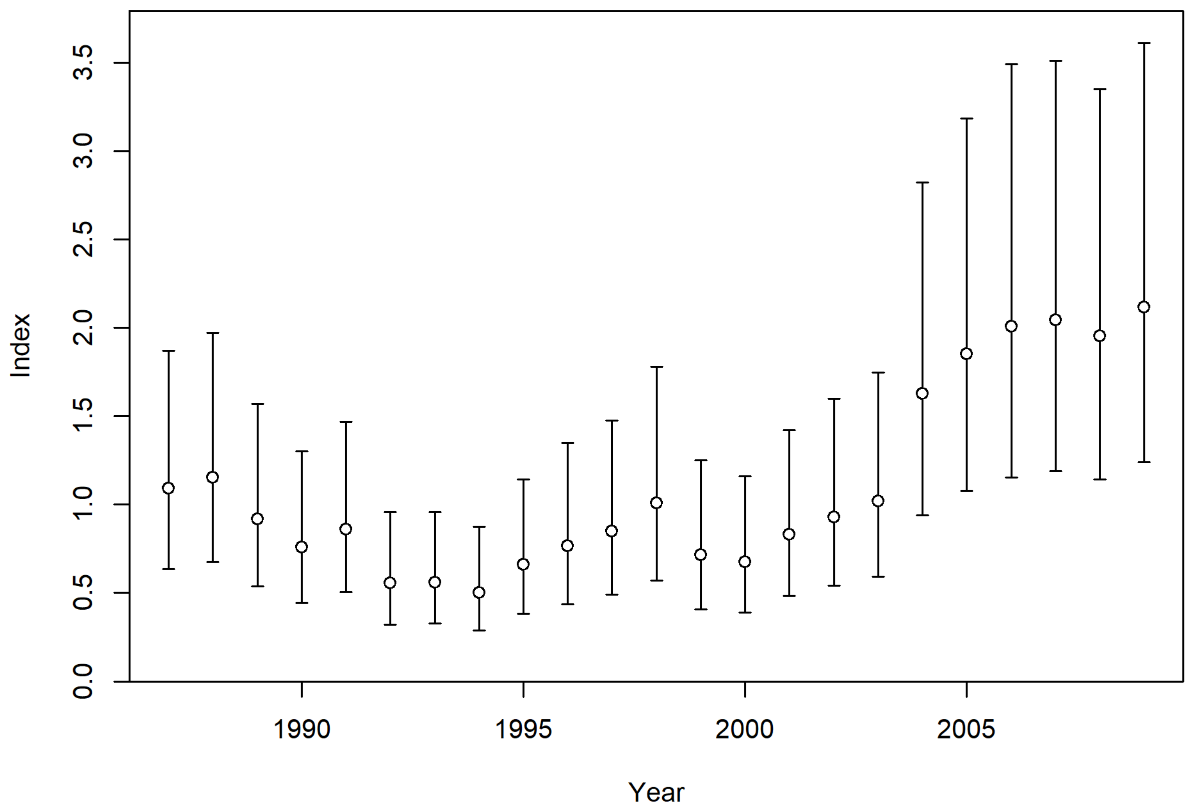


Figure 36: The Northern Winter fishery catch-per-unit-effort based on logbook data for petrale sole.

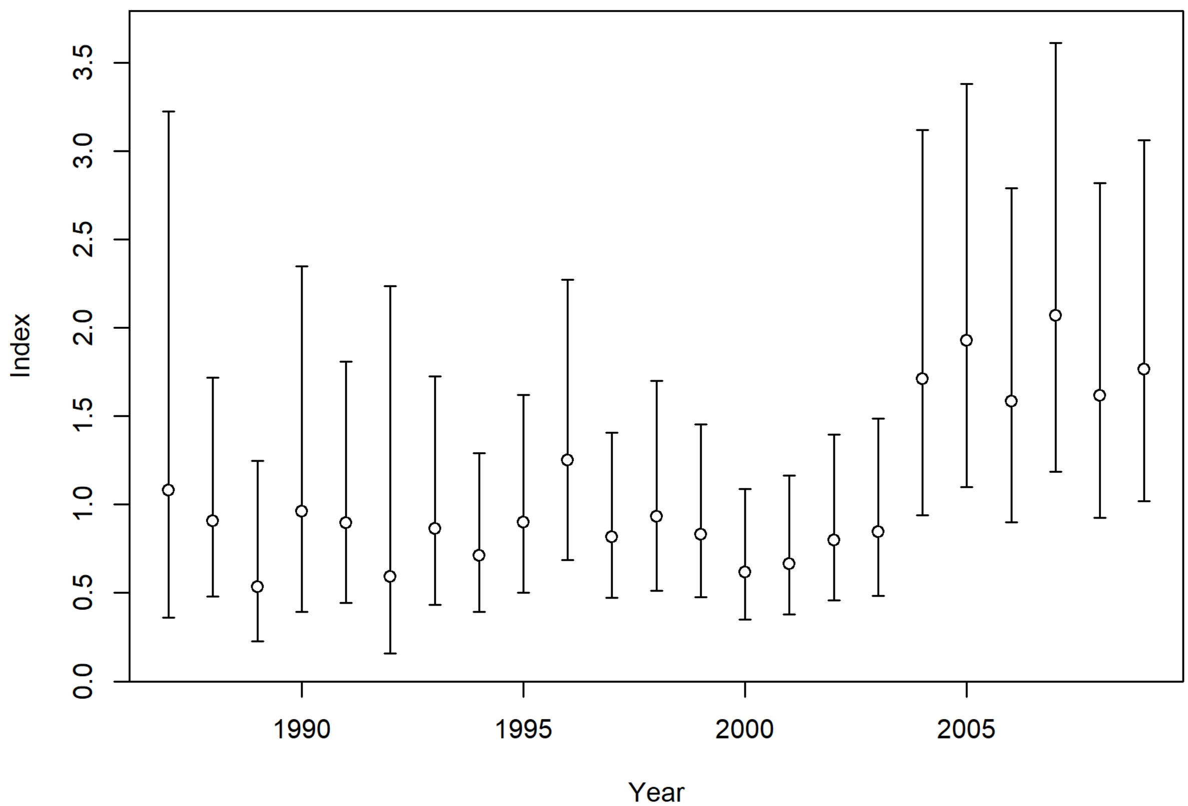


Figure 37: The Southern Winter fishery catch-per-unit-effort based on logbook data for petrale sole.

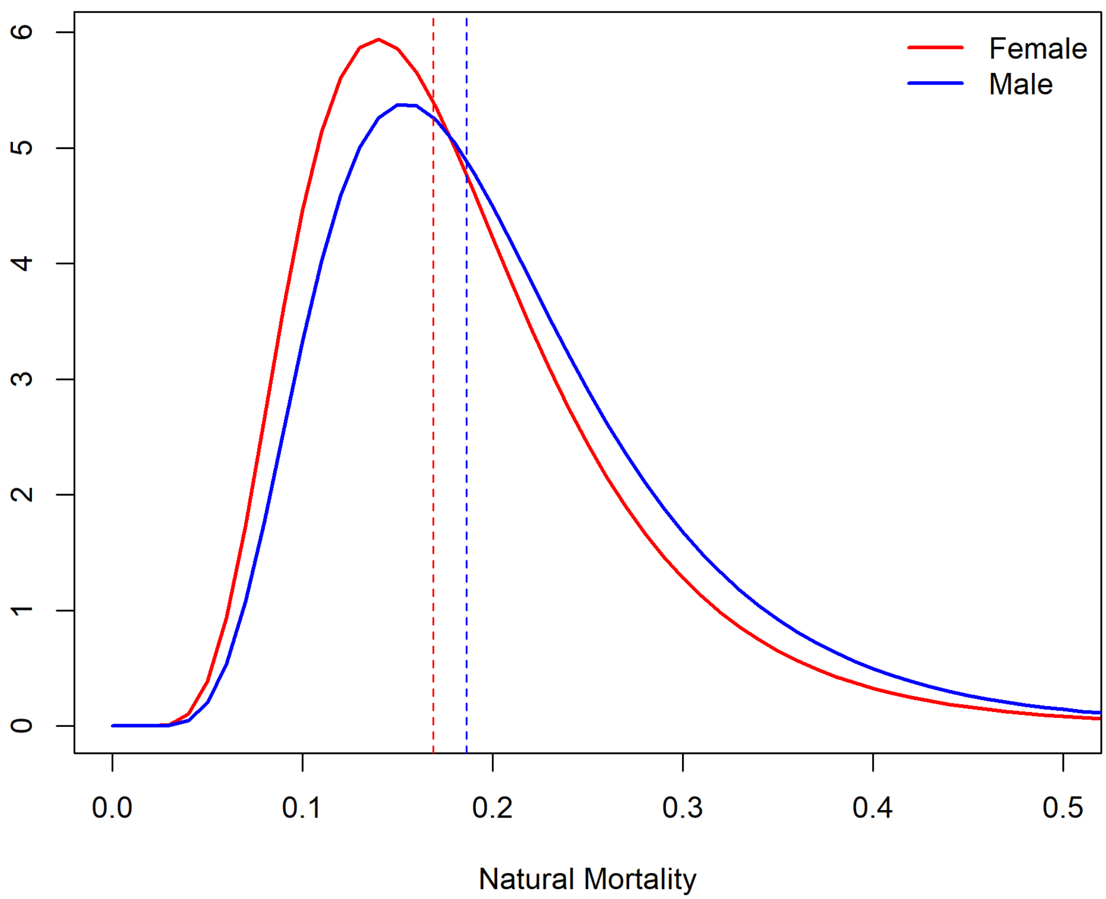


Figure 38: Prior distribution for natural mortality for female and male petrale sole.

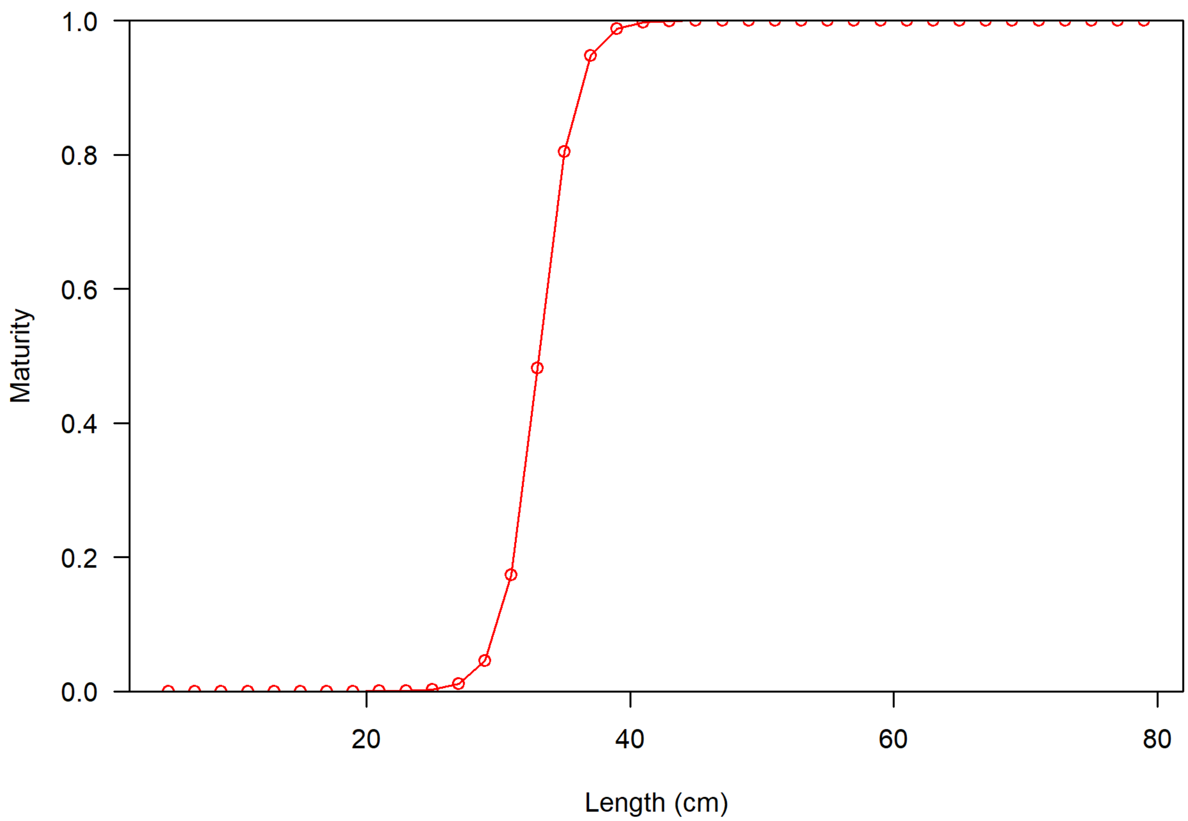


Figure 39: Assumed maturity-at-length for petrale sole.

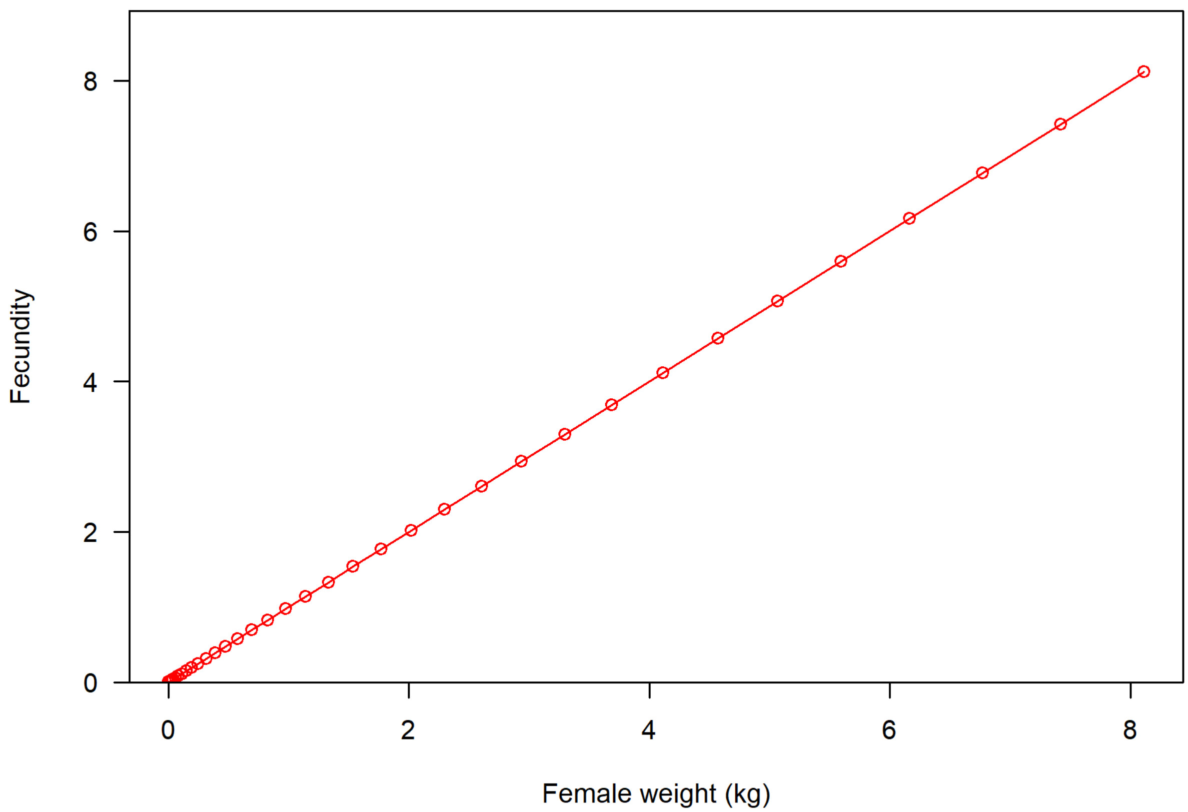


Figure 40: Fecundity-at-length assumed in the model for petrale sole.

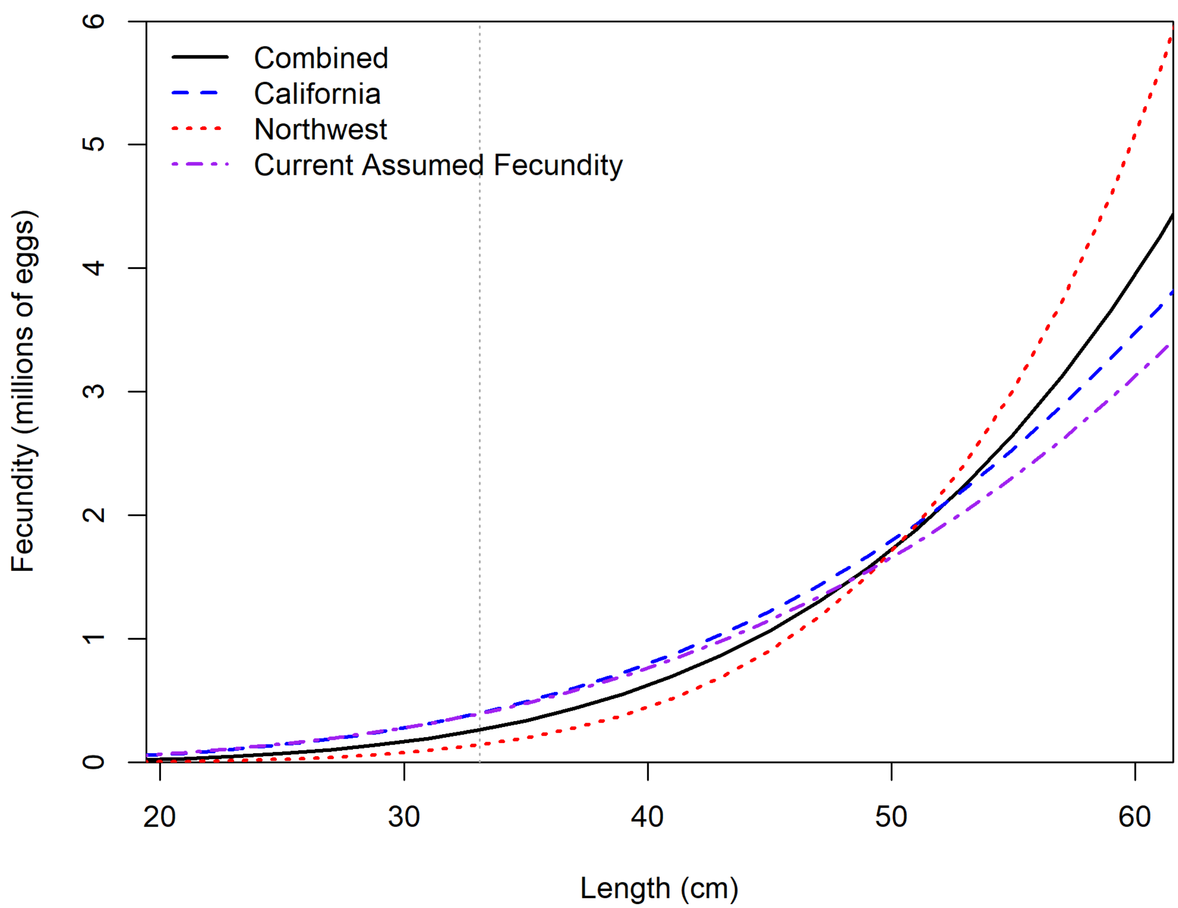


Figure 41: Estimated fecundity-at-length for petrale sole based on Lefebvre et al. (in press).

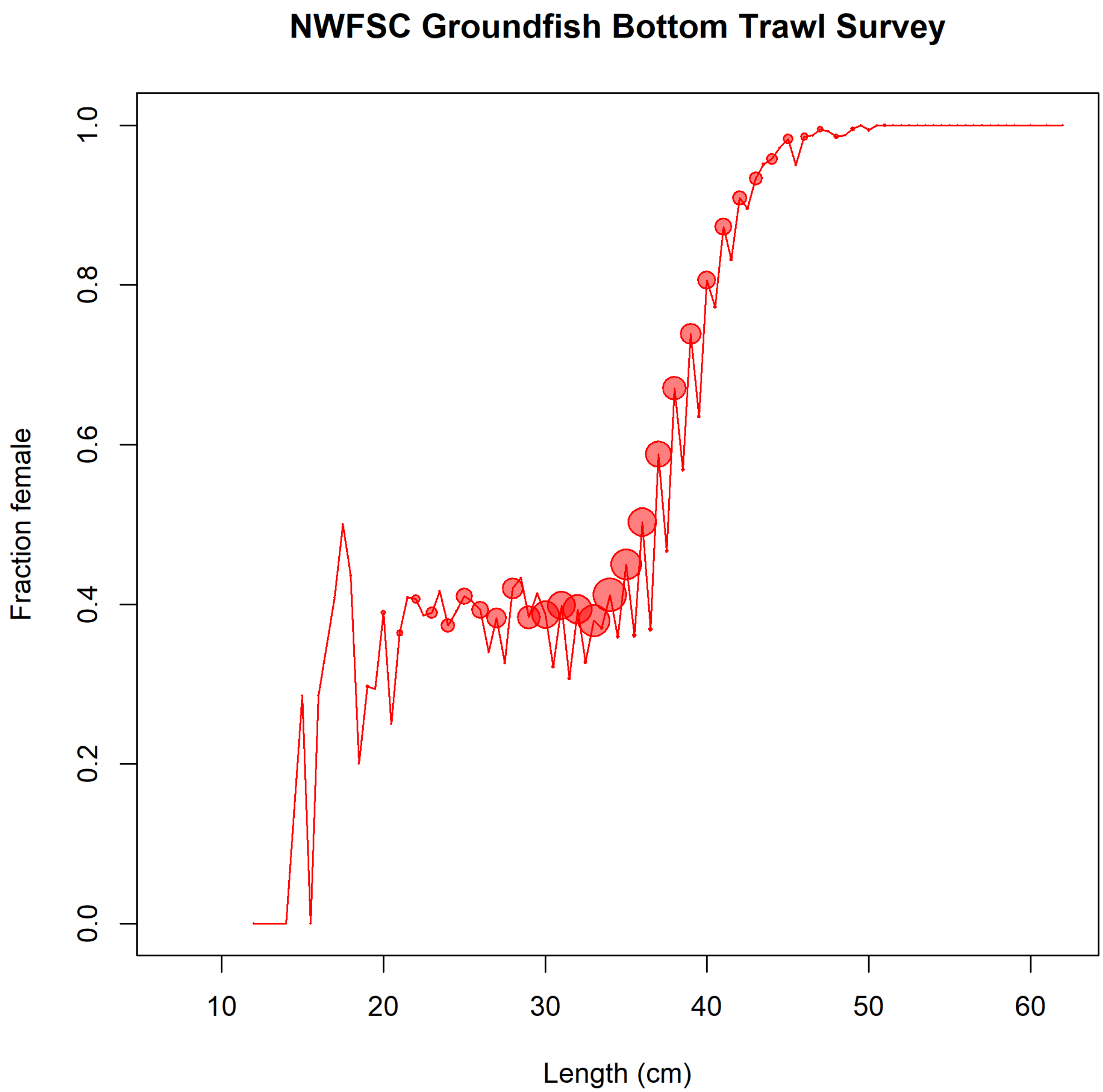


Figure 42: Estimated proportion of female fish collected by the NWFSC West Coast Groundfish Bottom Trawl Survey across all years for petrale sole.

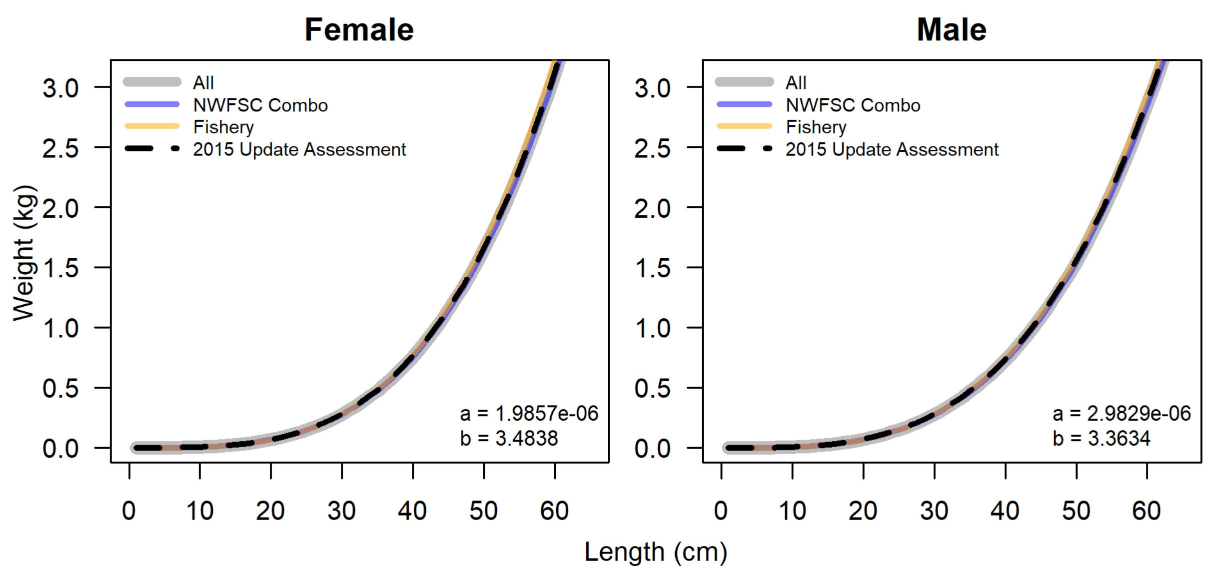


Figure 43: Estimated weight-at-length for female and male petrale sole.

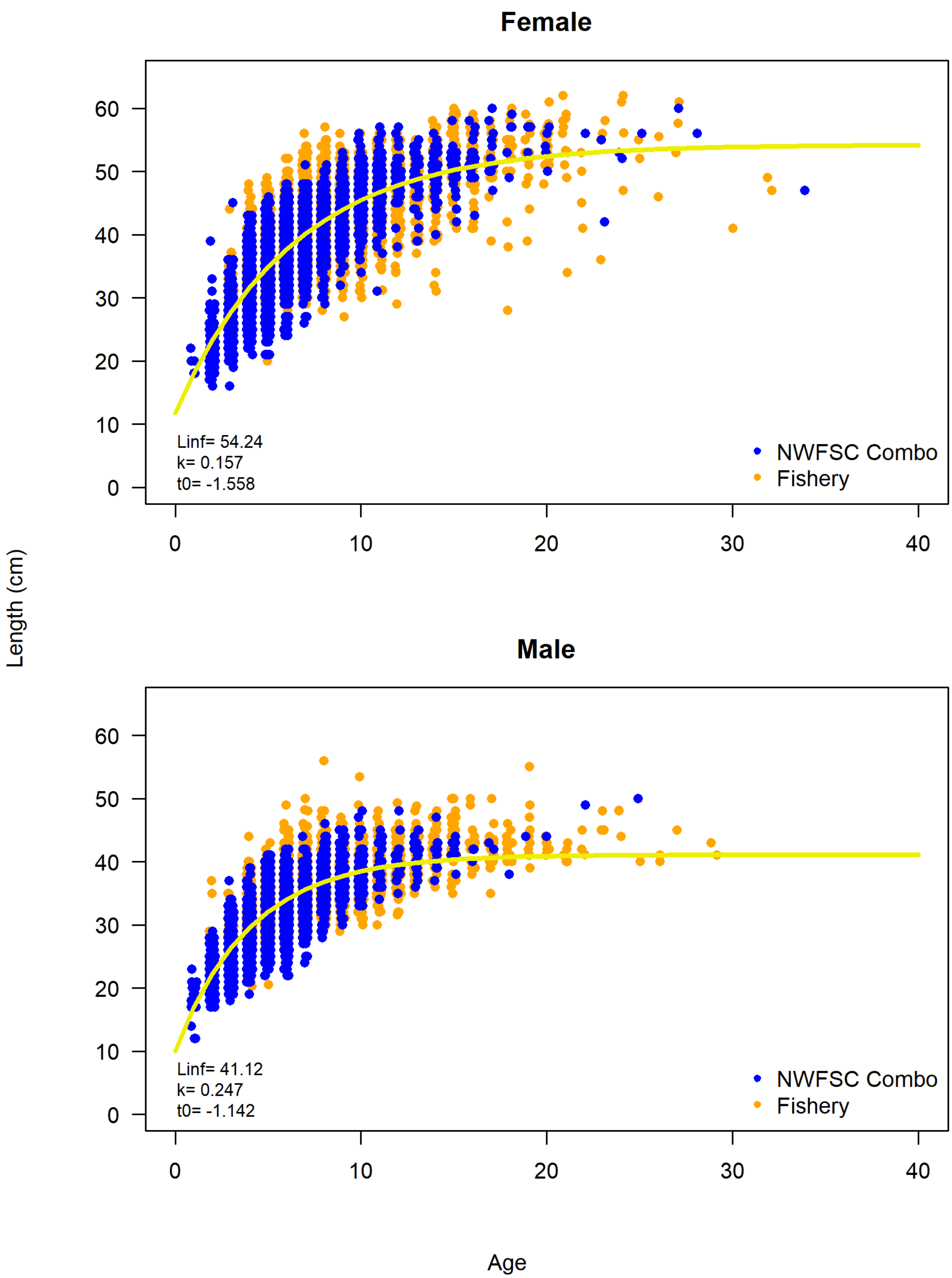


Figure 44: Length-at-age across data sources for female and male petrale sole.

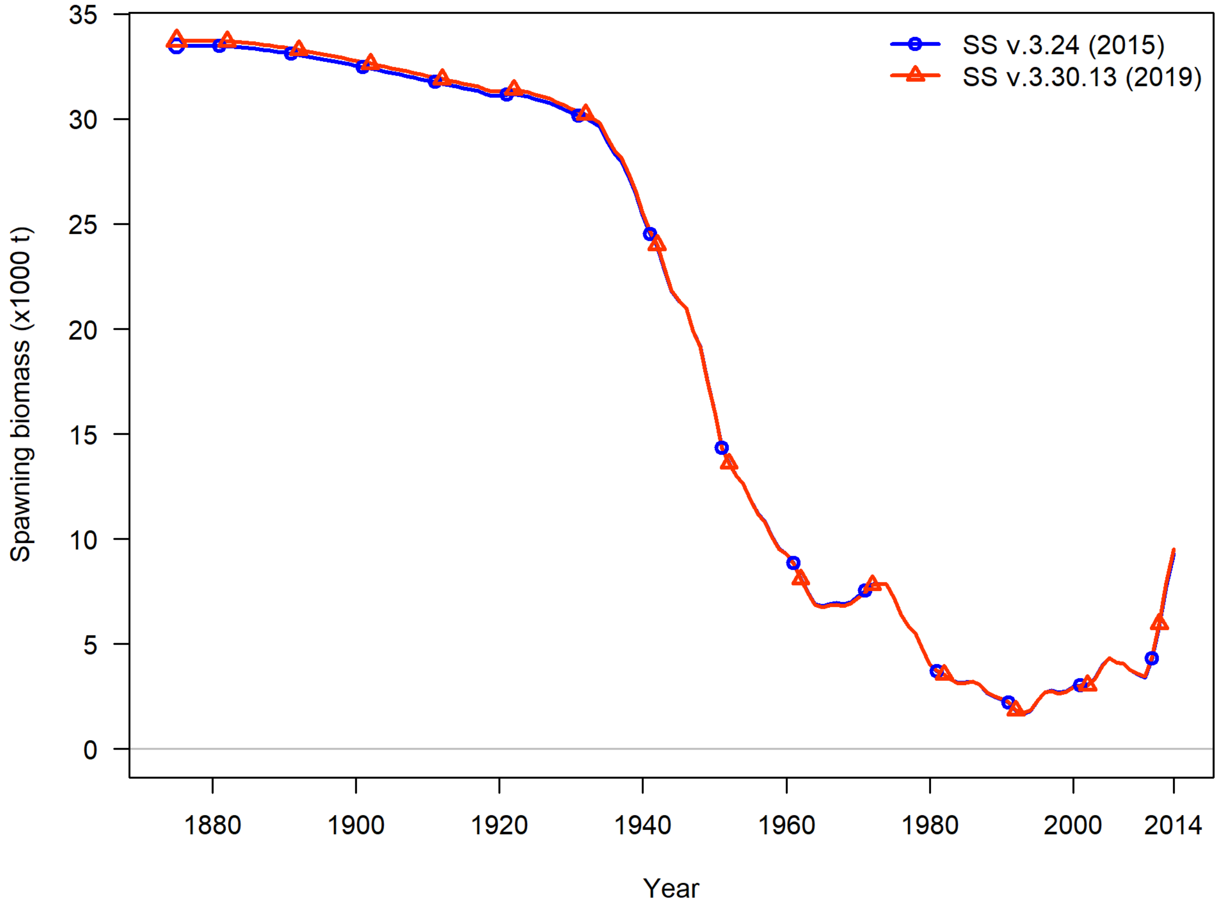


Figure 45: Comparison of model bridging estimates from Stock Synthesis version 3.30.13 and 3.24U for petrale sole for the 2015 assessment.

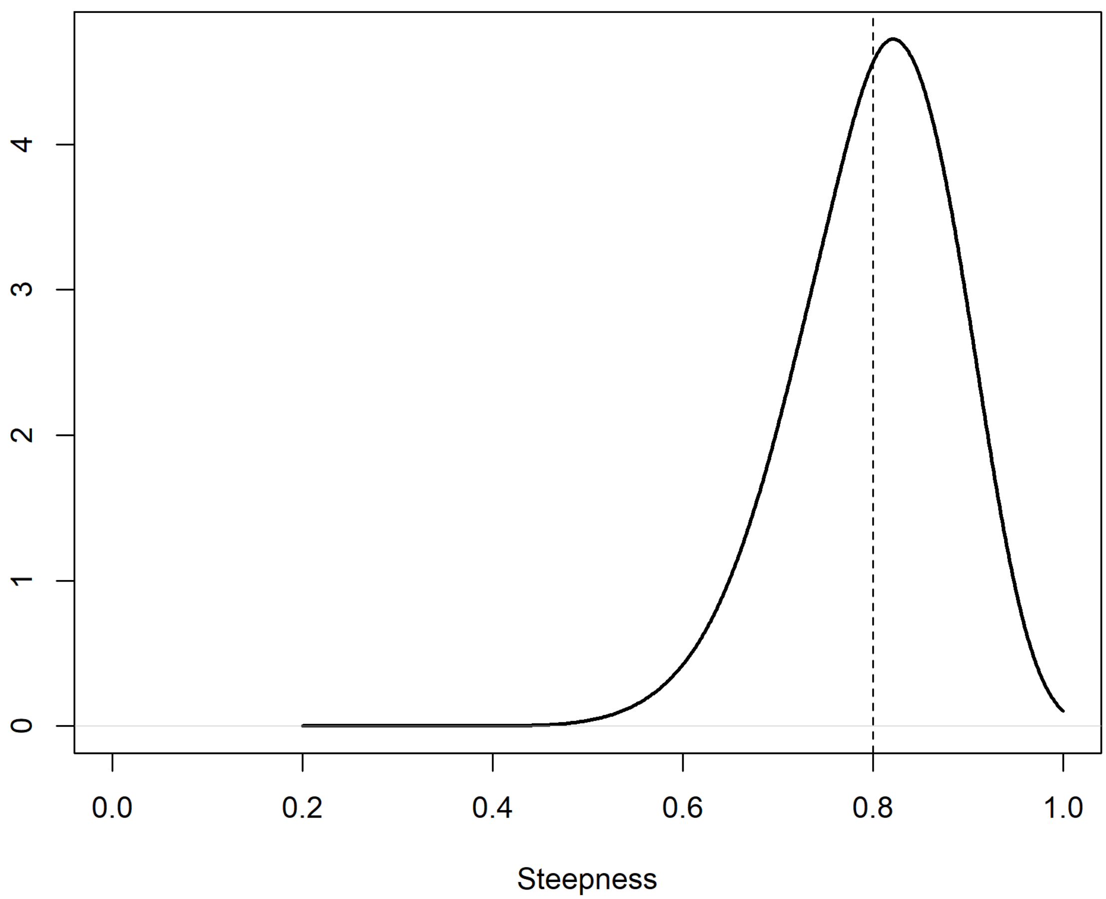


Figure 46: Prior distribution for steepness petrale sole.

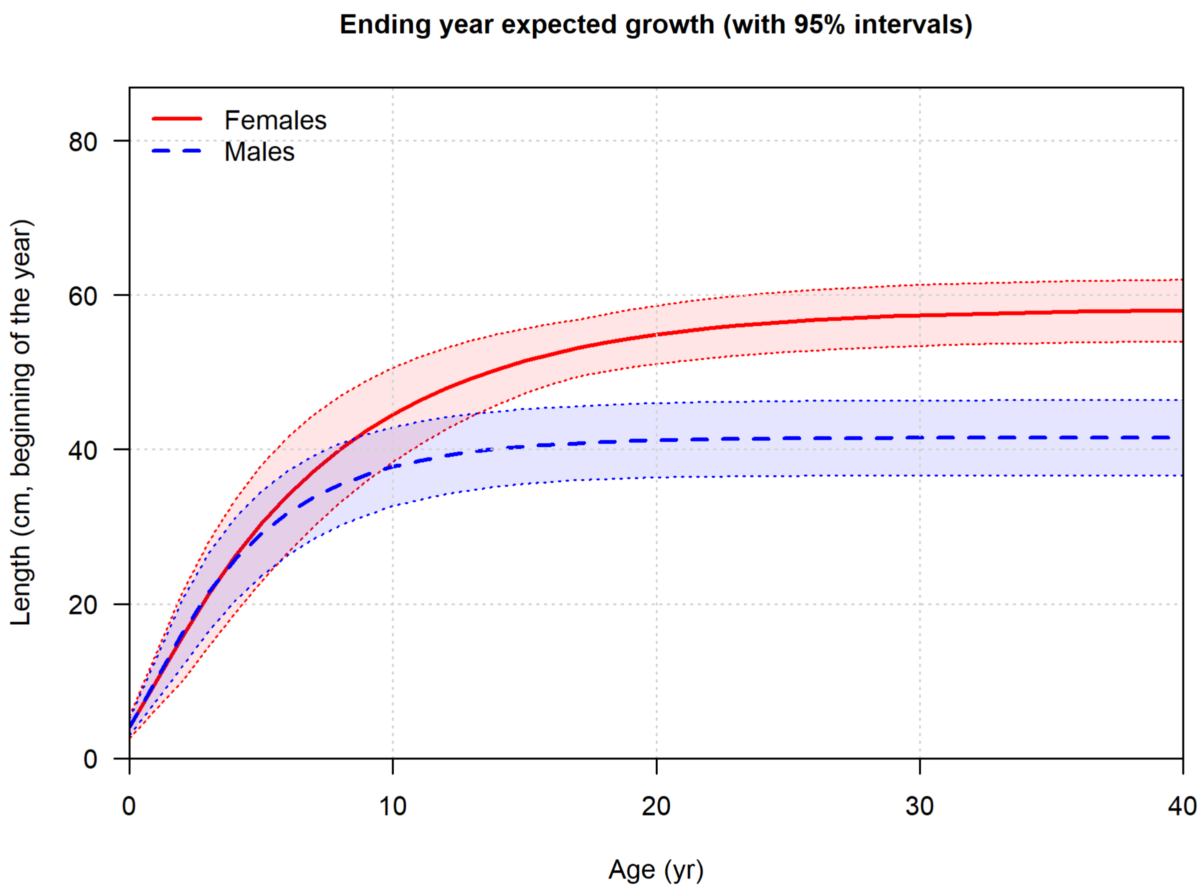


Figure 47: Estimated length-at-age for male and female for petrale sole with estimated CV.

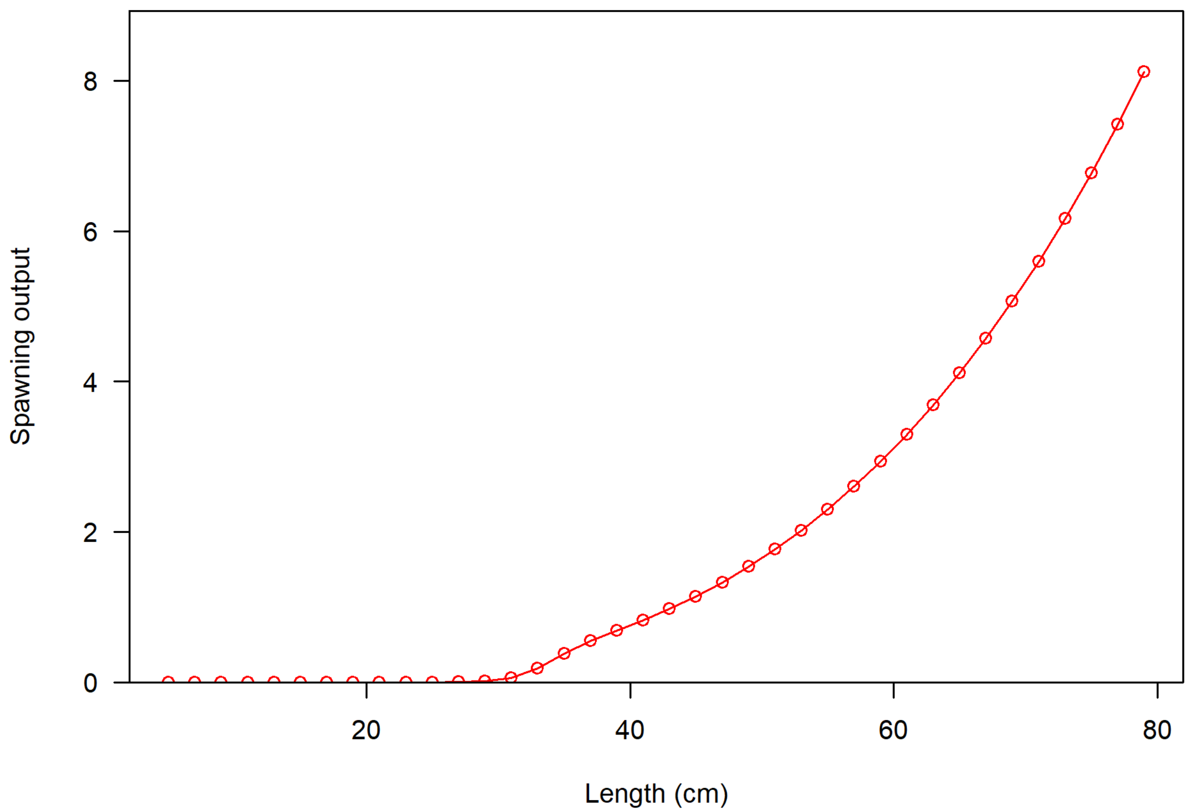


Figure 48: Estimated spawning output-at-length for female petrale sole.

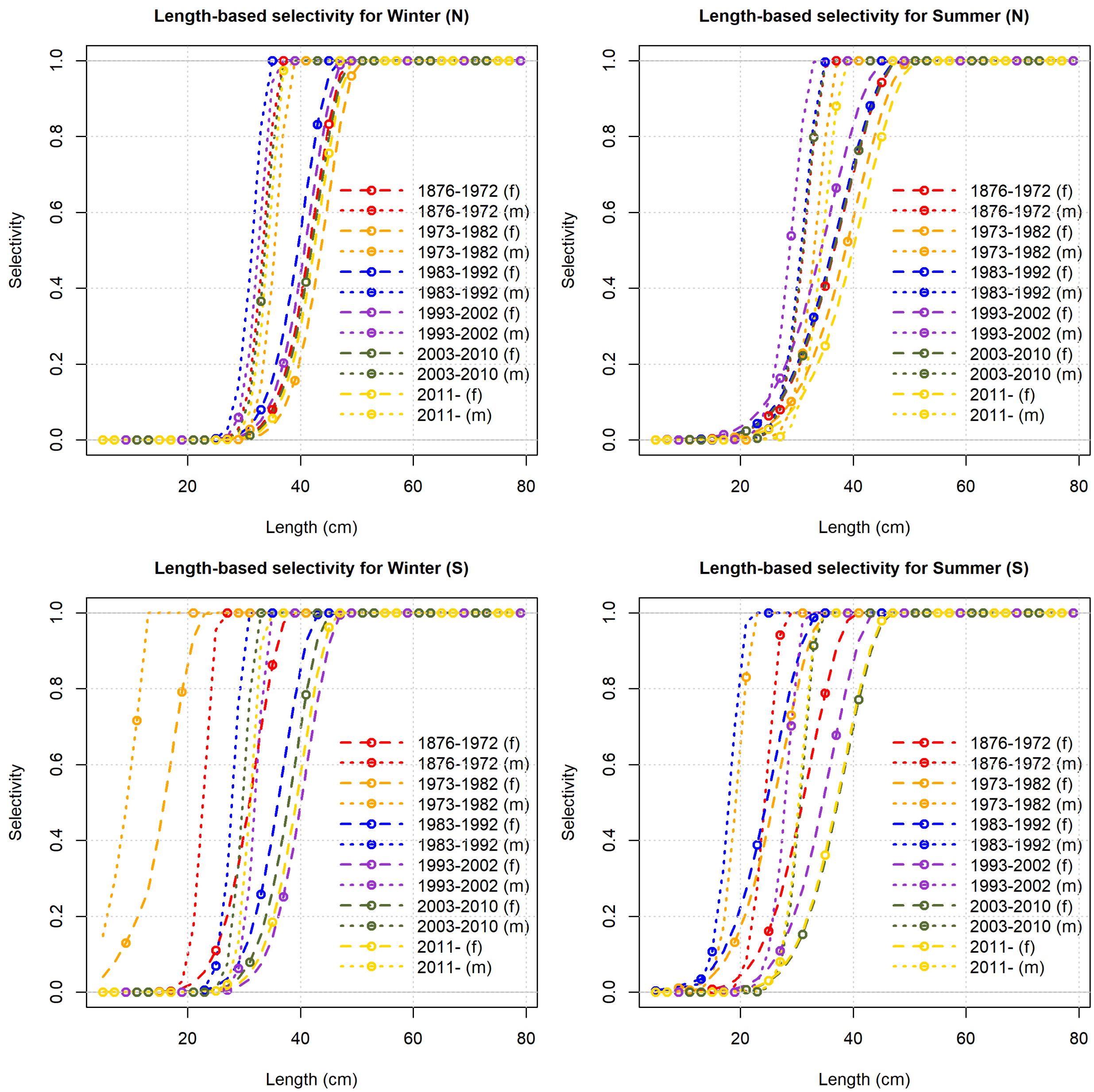


Figure 49: Estimated selectivity for each commerical fleet over the assessment period for female and male petrale sole.

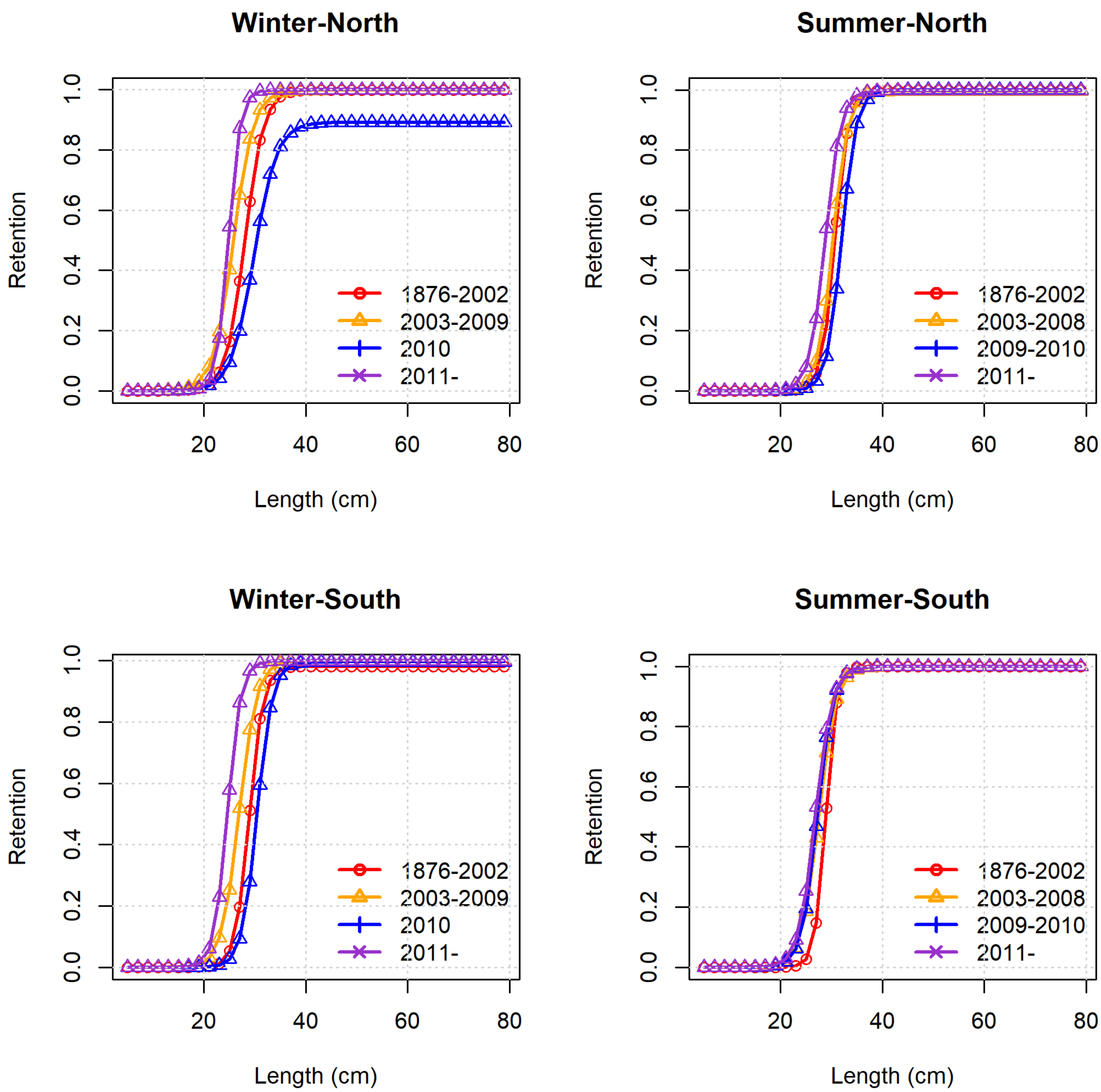


Figure 50: Estimated retention for each commerical fleet over the assessment period for petrale sole. Retention was not estimated to be sex-specific.

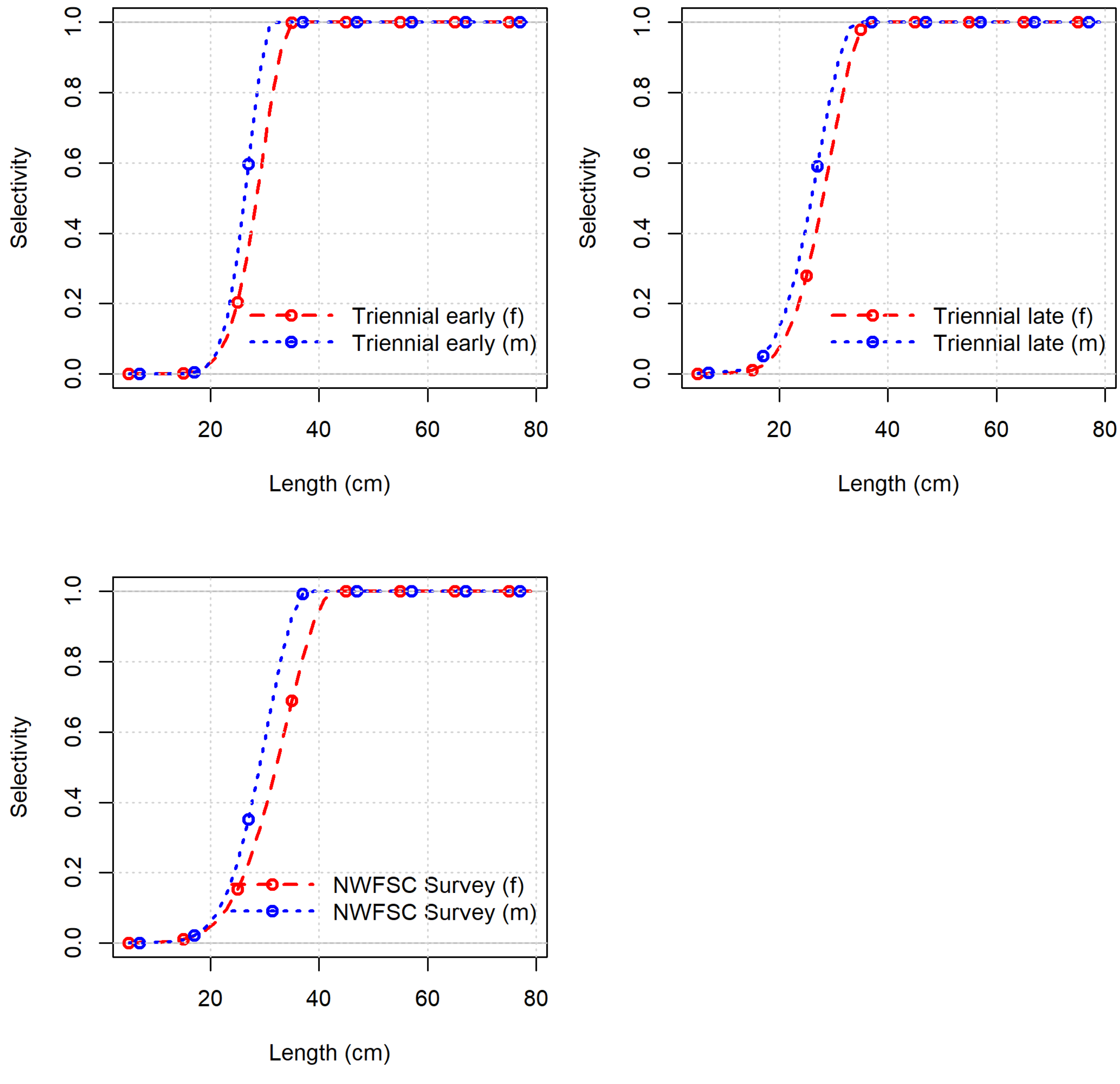


Figure 51: Estimated selectivity for each survey over the assessment period for female and male petrale sole.

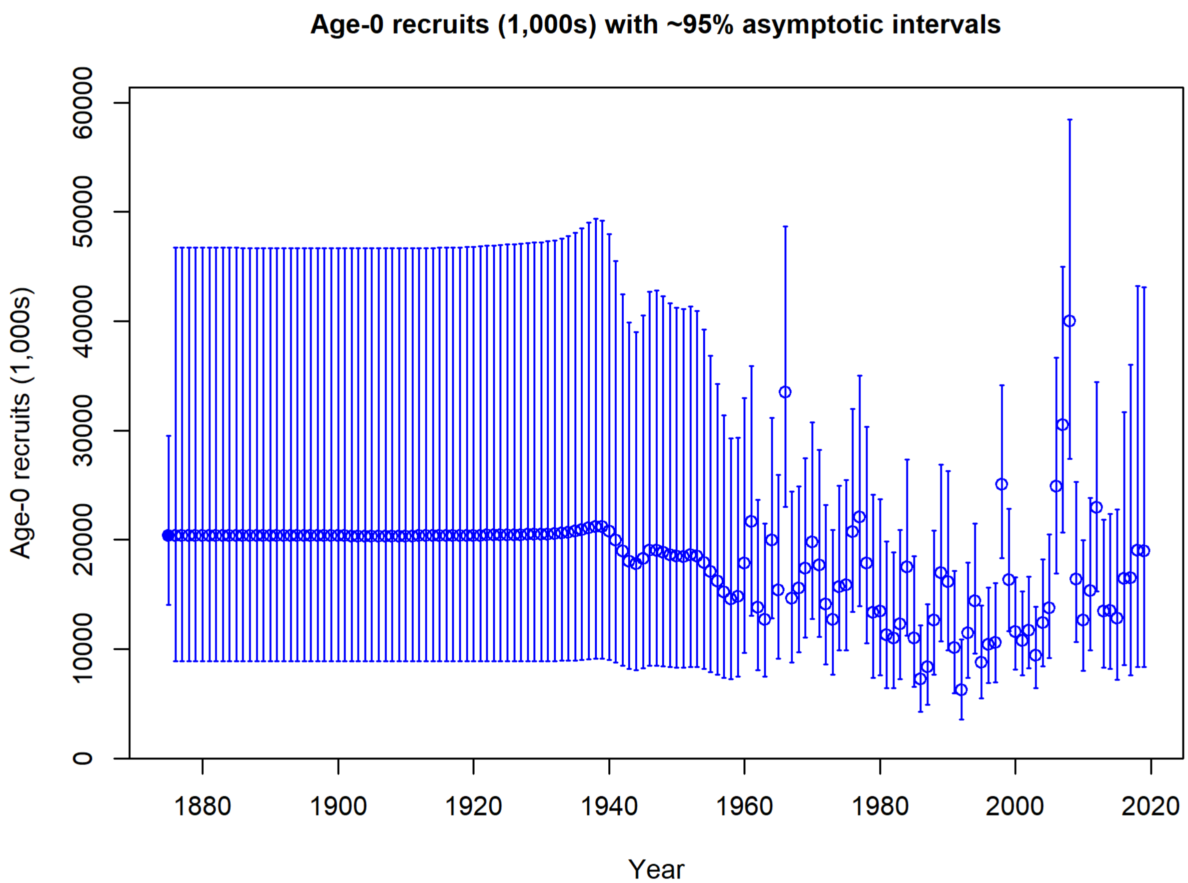


Figure 52: Estimated time-series of recruitment for petrale sole.

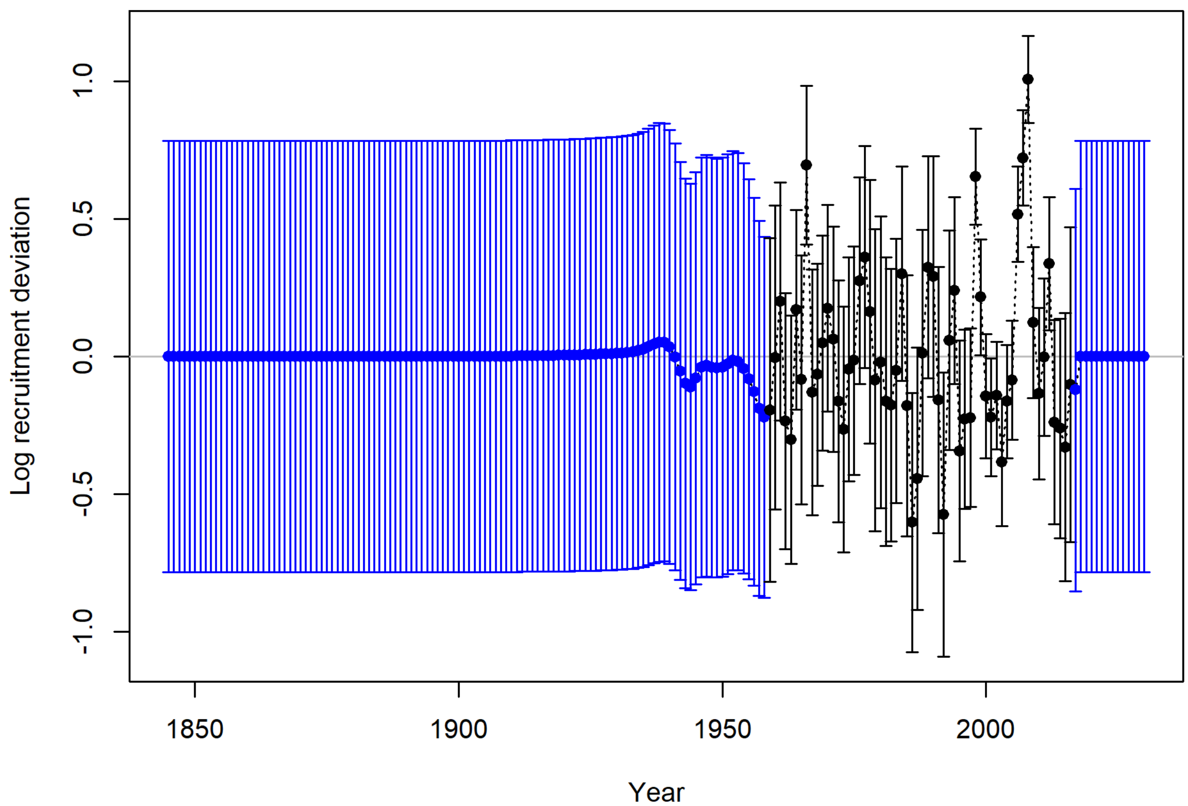


Figure 53: Estimated time-series of recruitment deviations for petrale sole.

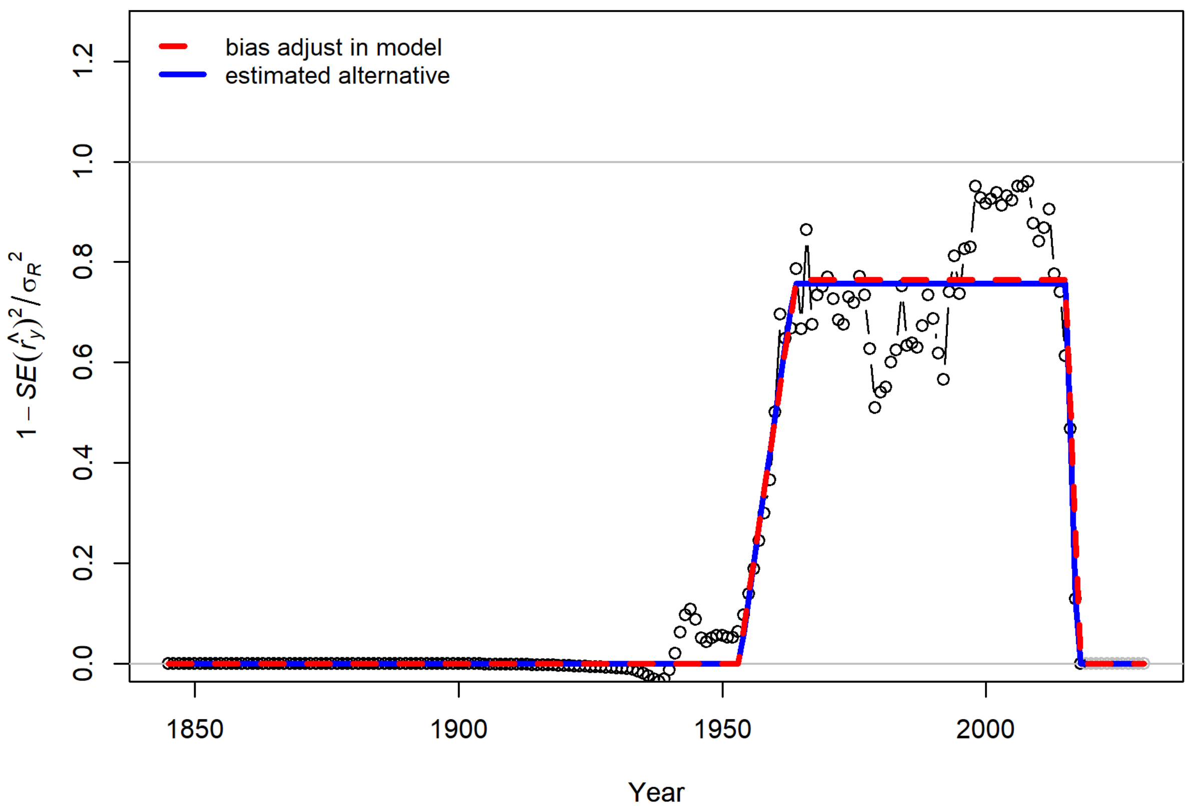


Figure 54: Recruitment bias adjustment in the model.

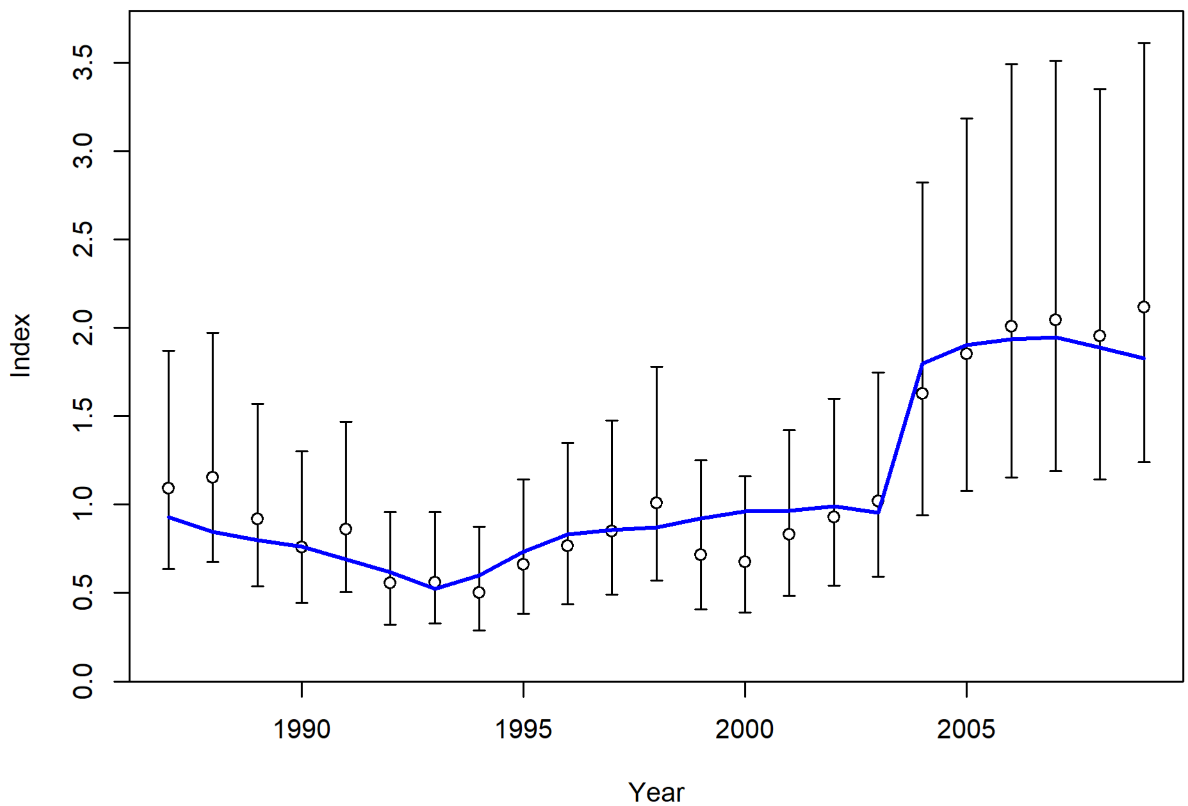


Figure 55: Fit to the Winter North catch-per-unit-effort time series for petrale sole.

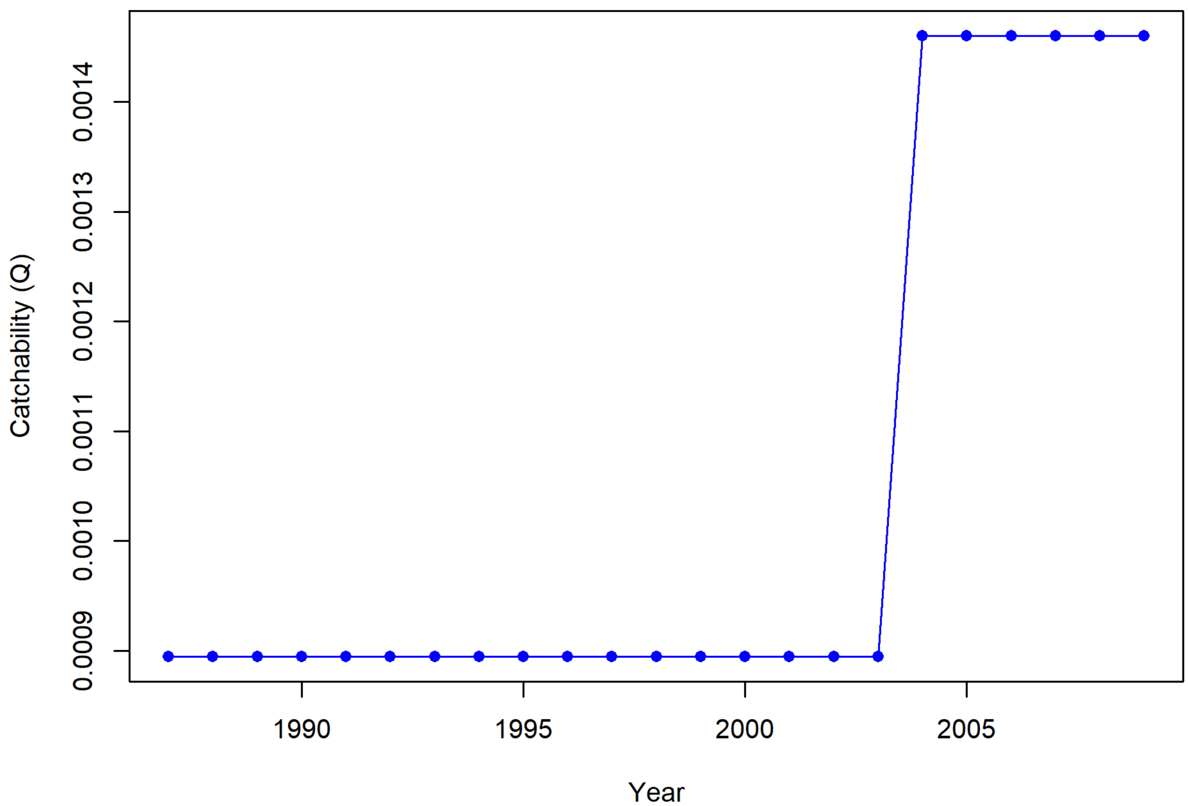


Figure 56: Catchability to the Winter North catch-per-unit-effort time series.

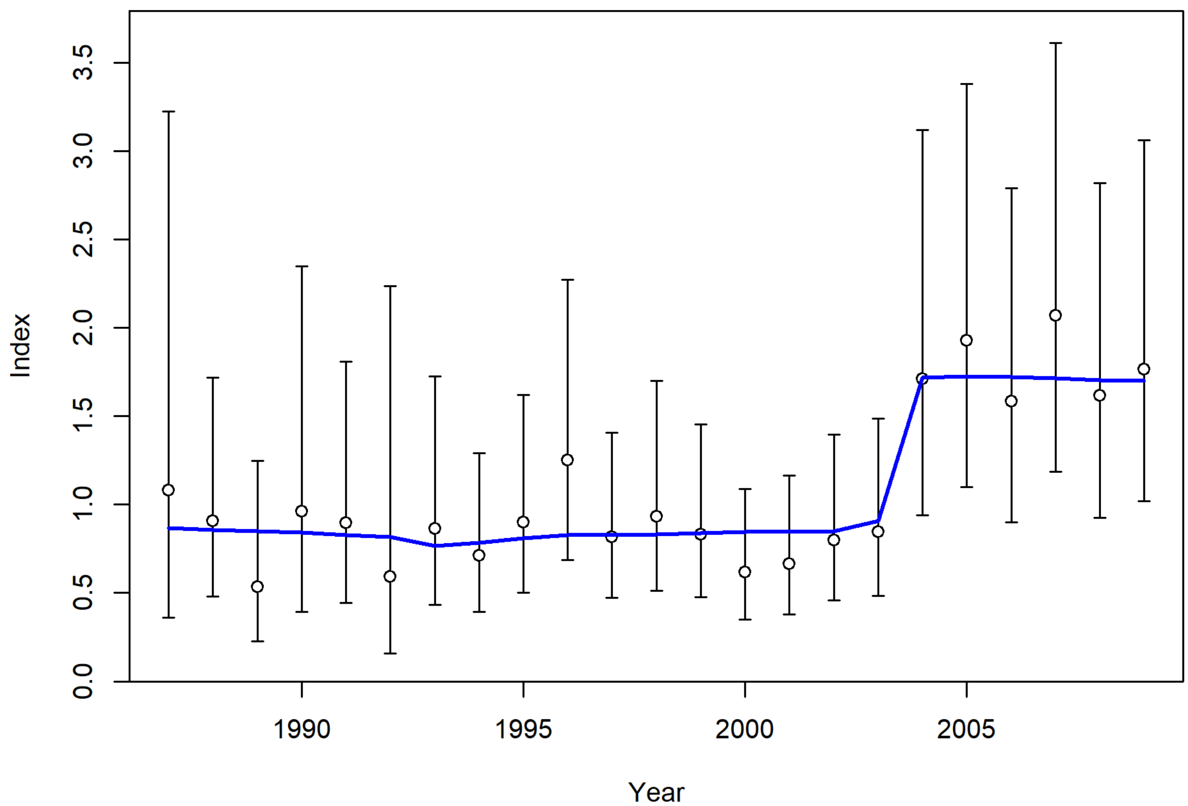


Figure 57: Fit to the Winter South catch-per-unit-effort time series for petrale sole.

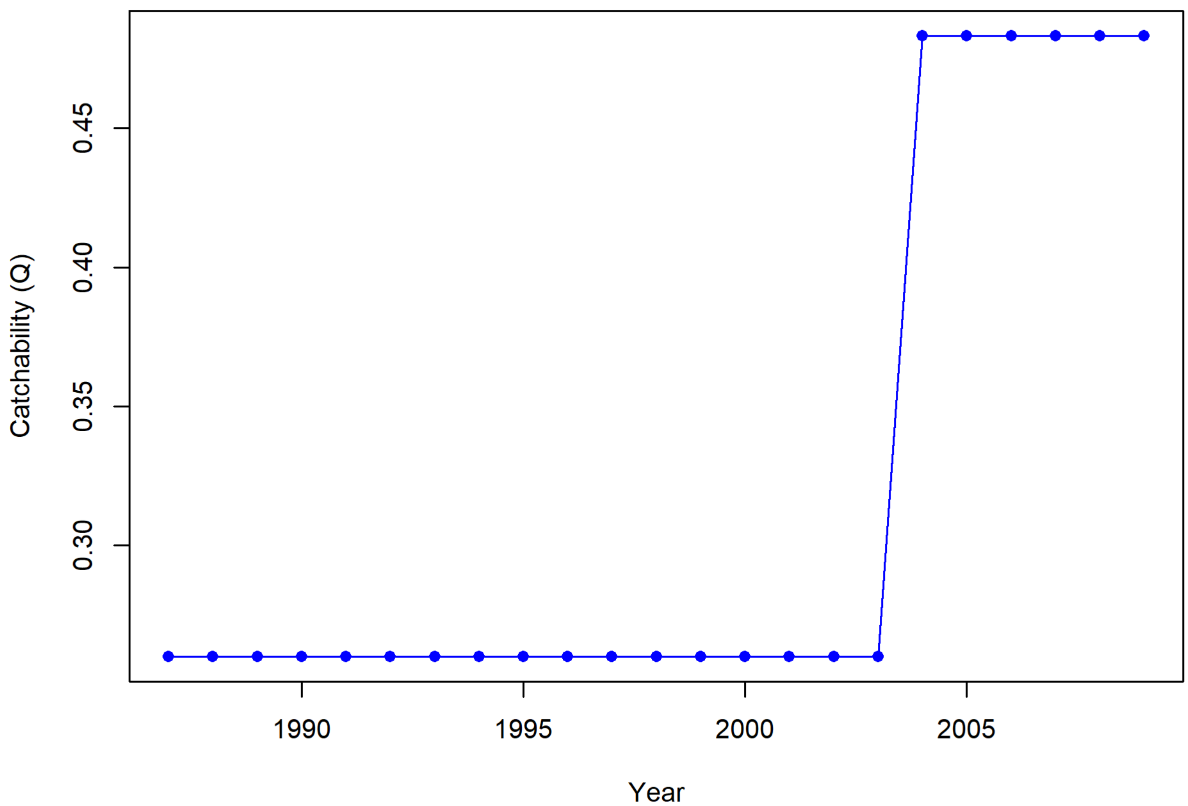


Figure 58: Catchability to the Winter South catch-per-unit-effort time series.

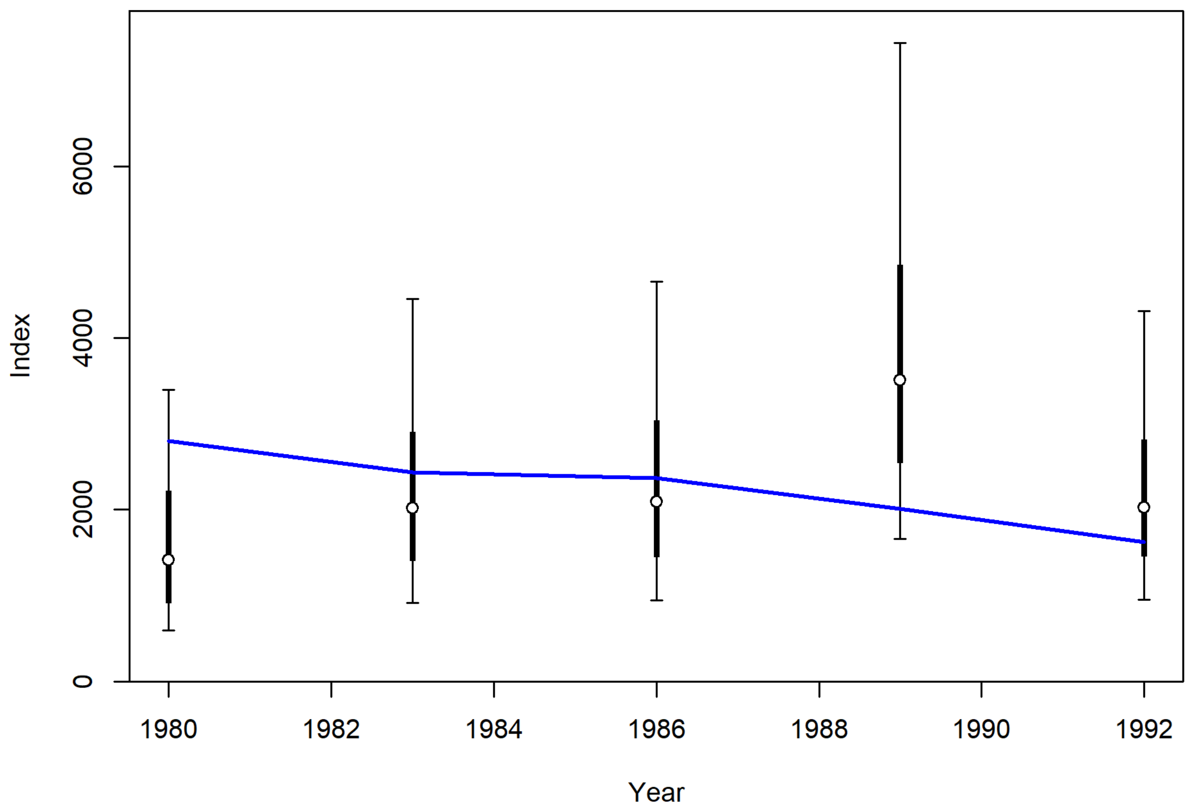


Figure 59: Fit to the Triennial Survey Early time series for petrale sole.

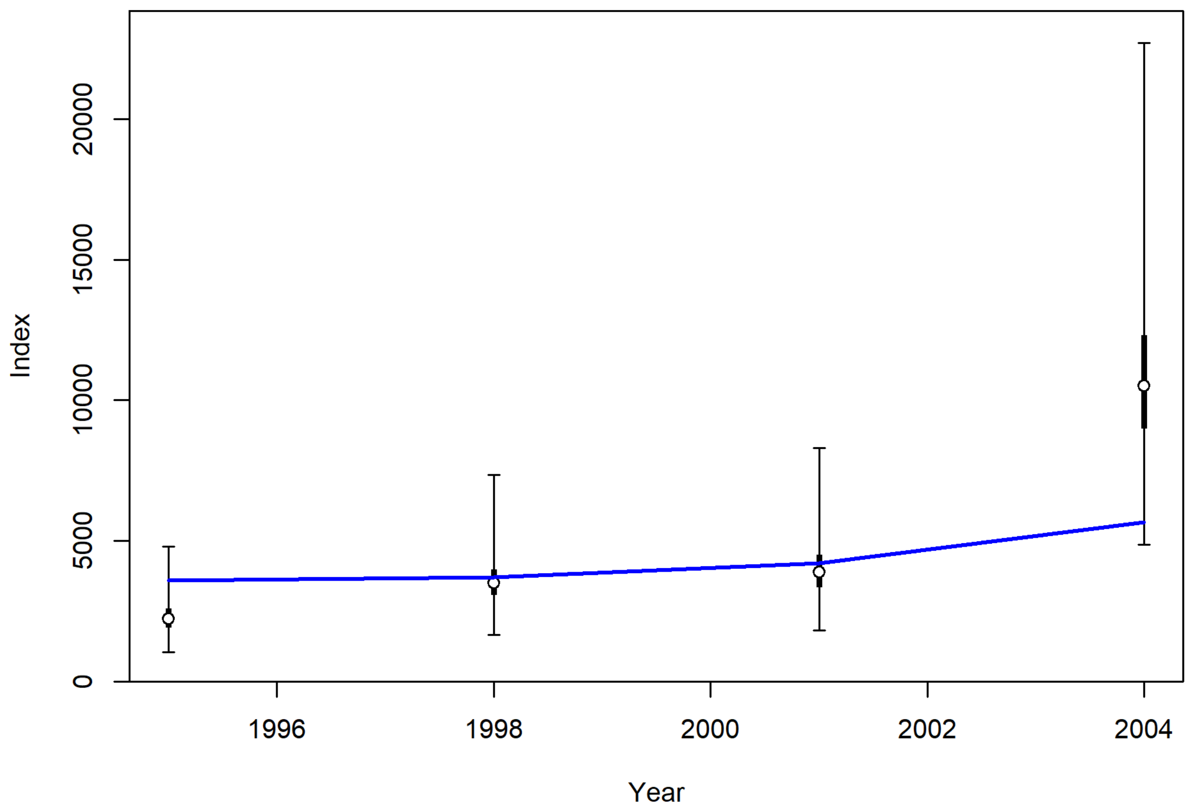


Figure 60: Fit to the Triennial Survey Late time series for petrale sole.

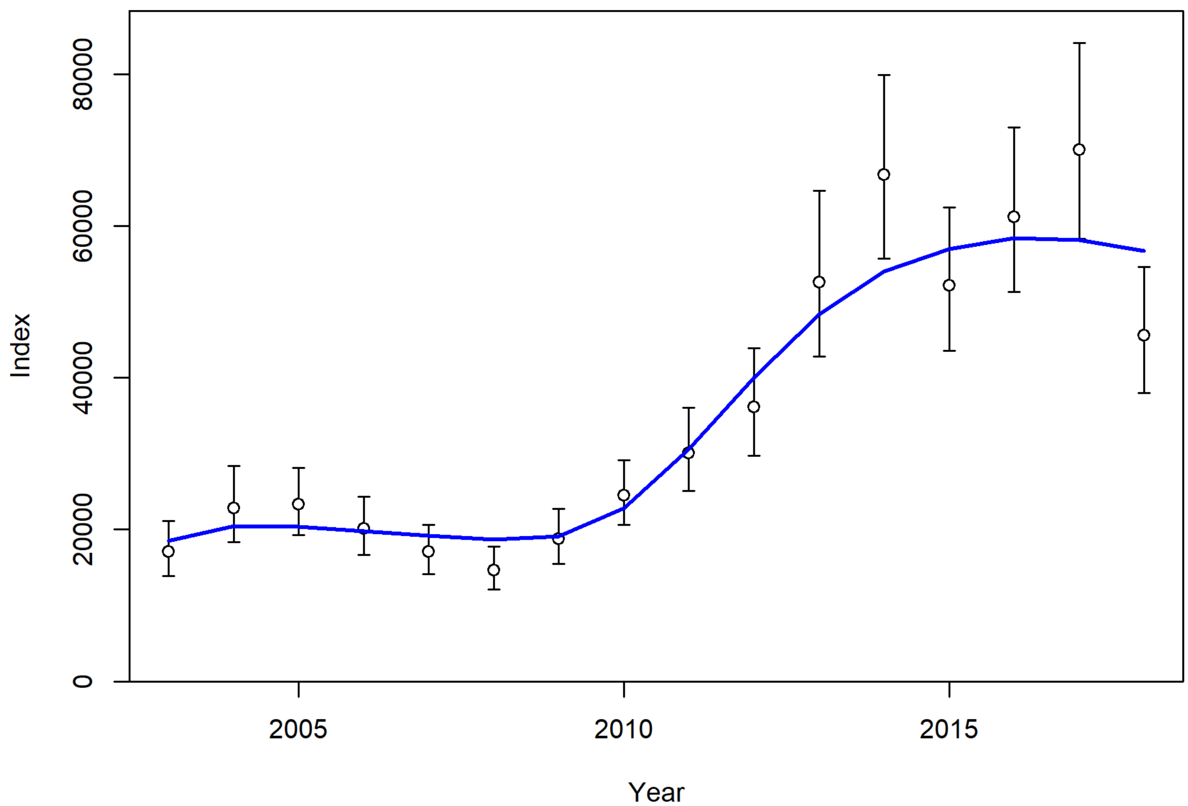


Figure 61: Fit to the NWFSC West Coast Groundfish Bottom Trawl Survey time series for petrale sole.

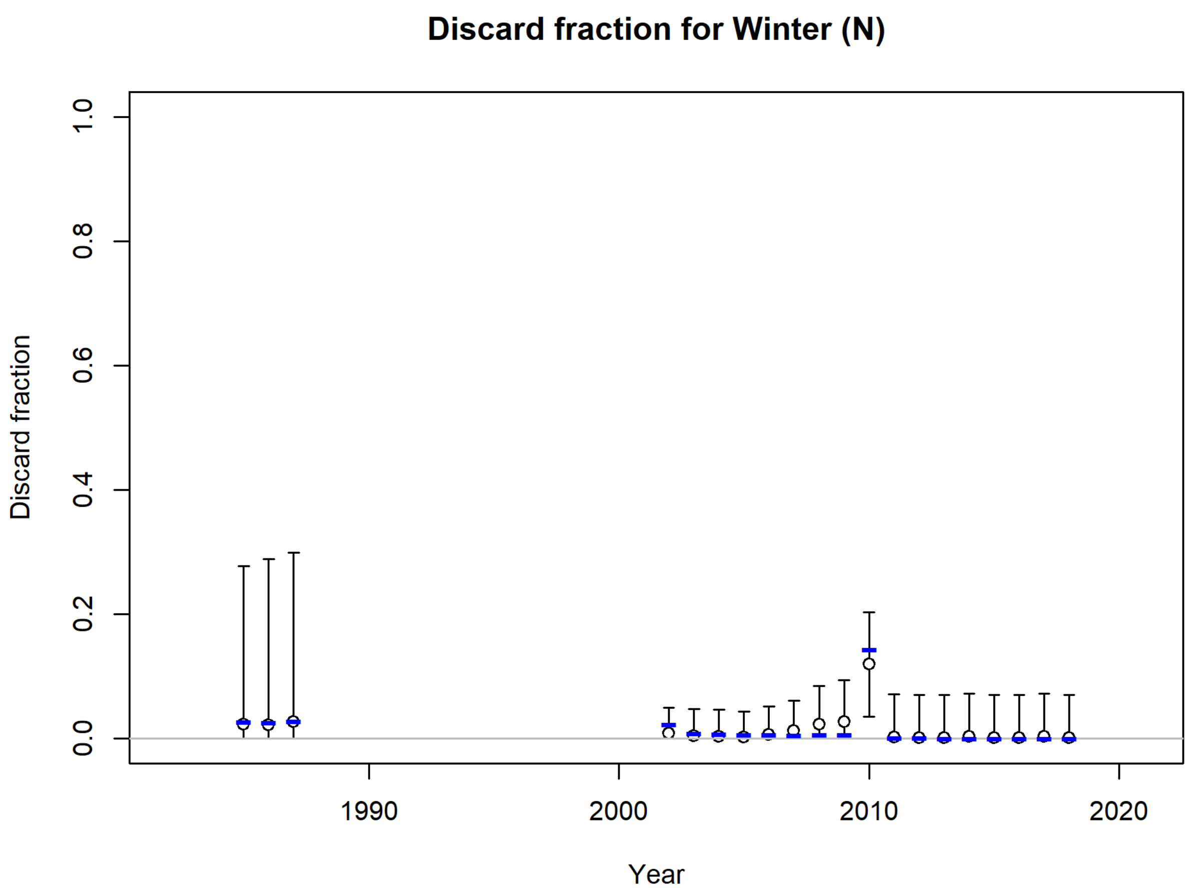


Figure 62: Fit to the discard rates for the Winter North fleet for petrale sole.

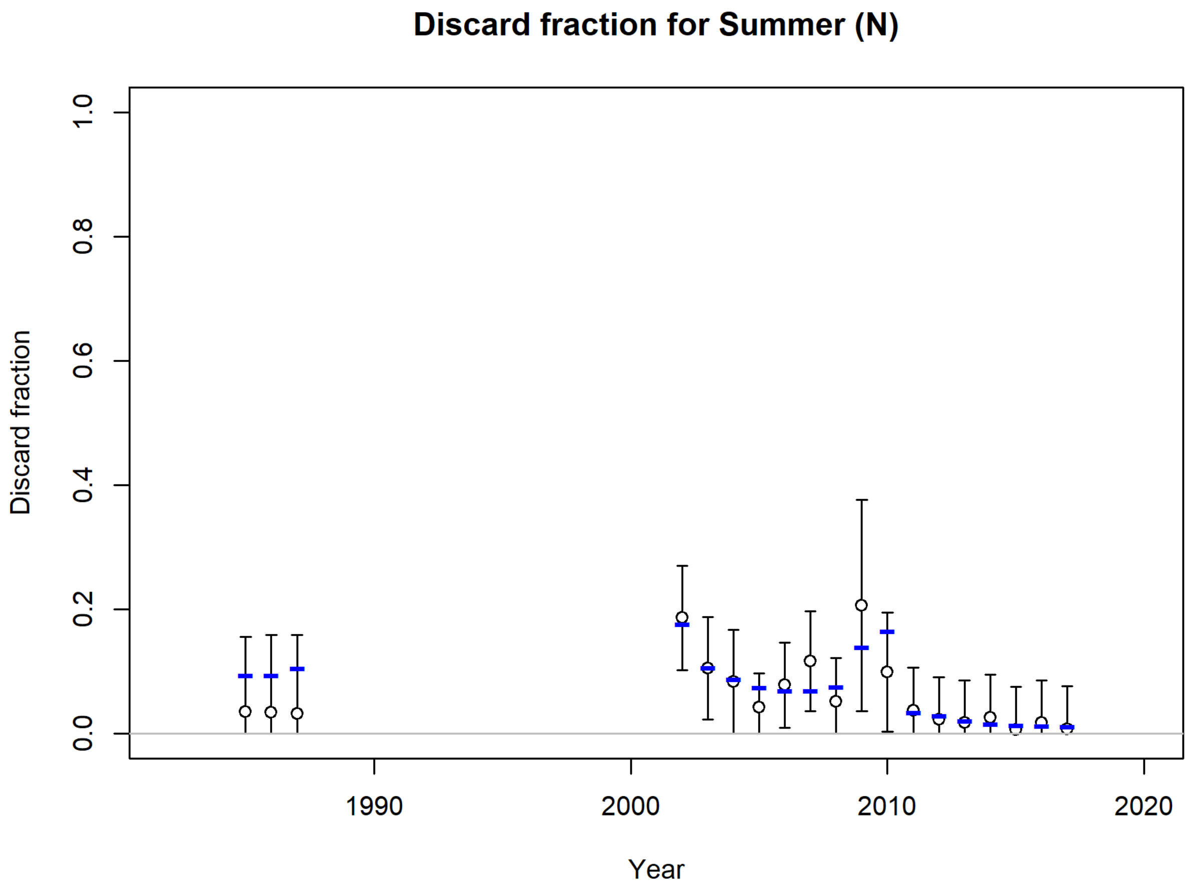


Figure 63: Fit to the discard rates for the Summer North fleet for petrale sole.

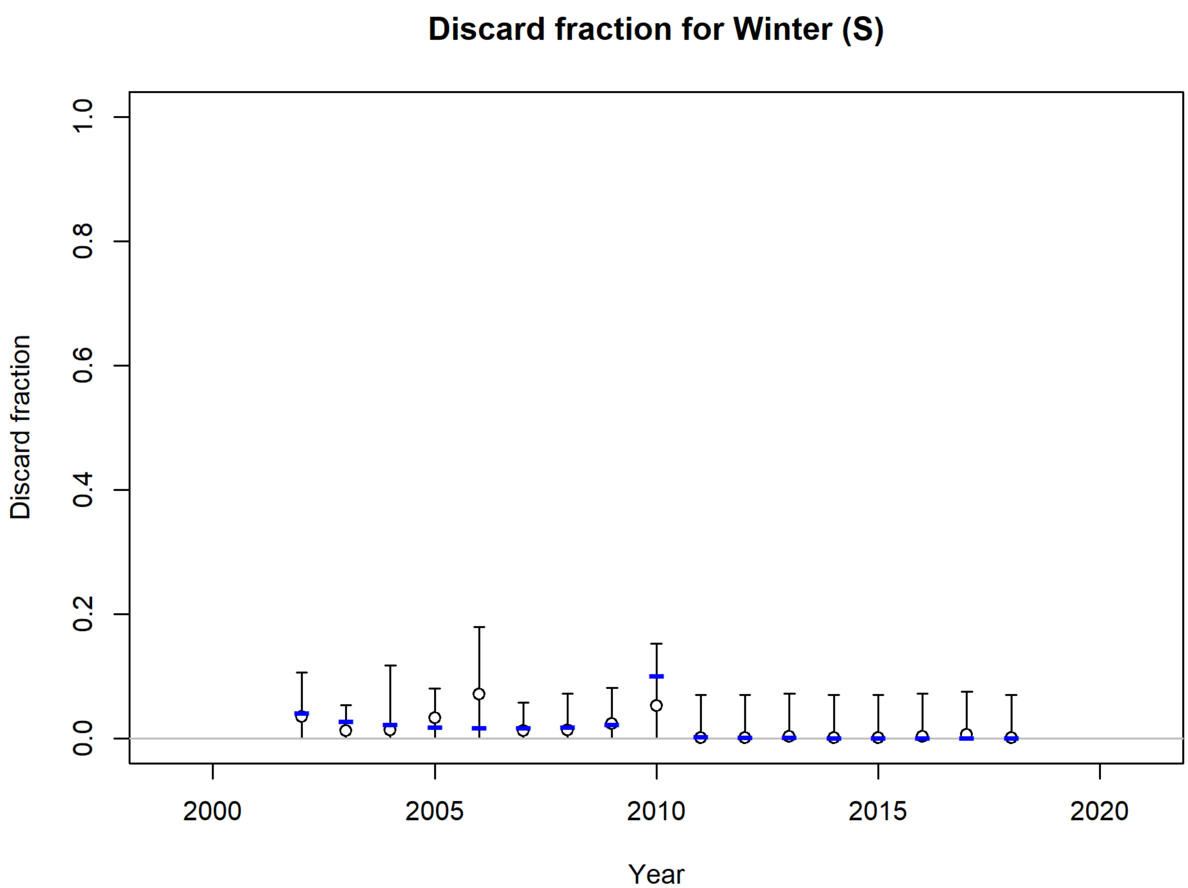


Figure 64: Fit to the discard rates for the Winter South fleet for petrale sole.

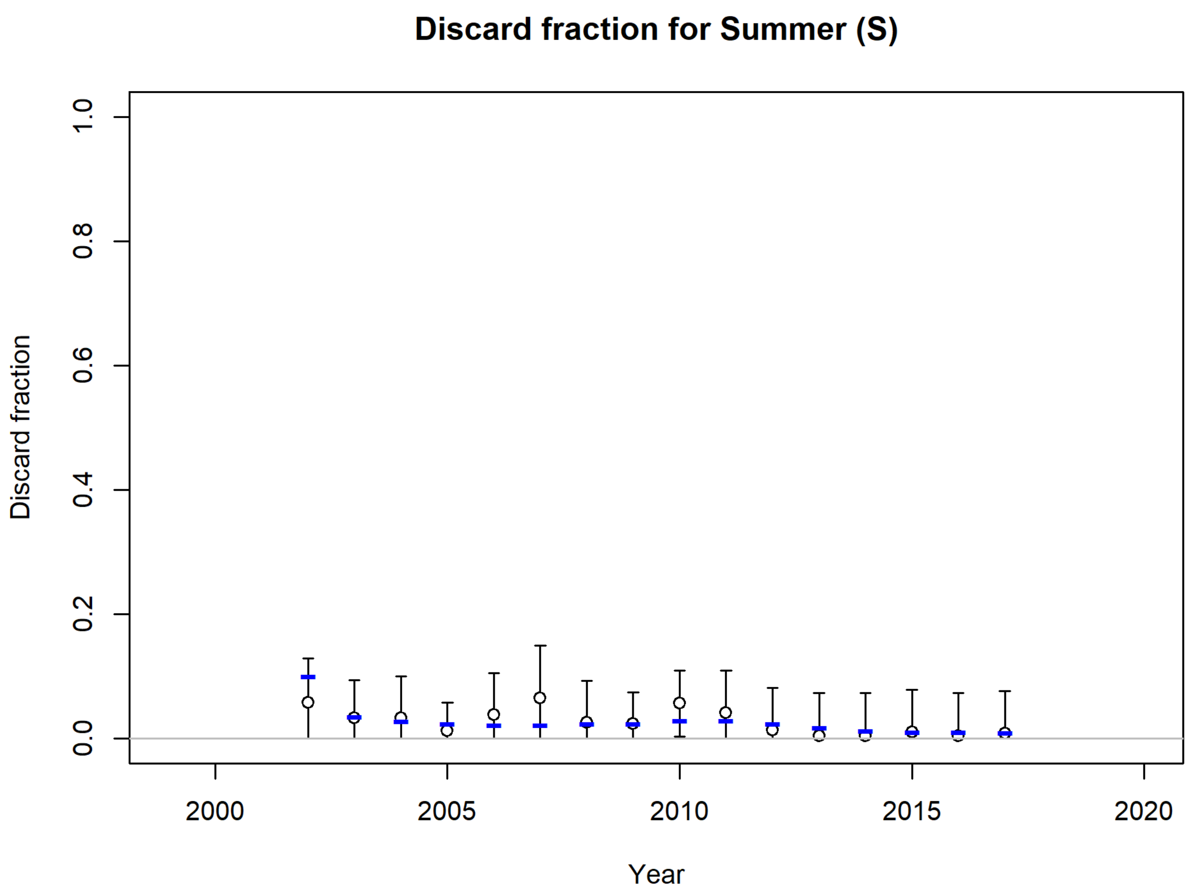


Figure 65: Fit to the discard rates for the Summer South fleet for petrale sole.

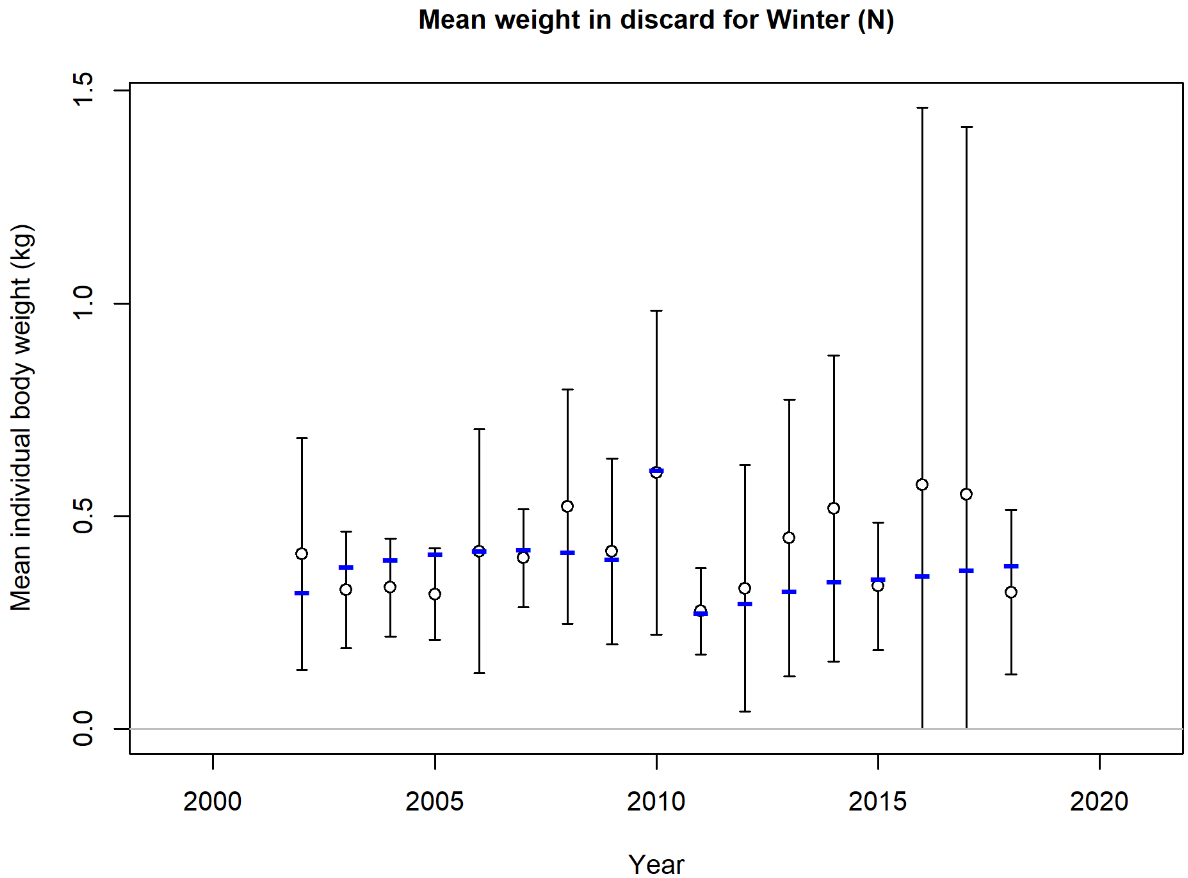


Figure 66: Fit to the Northern winter fishery mean body weights of discarded fish for petrale sole.

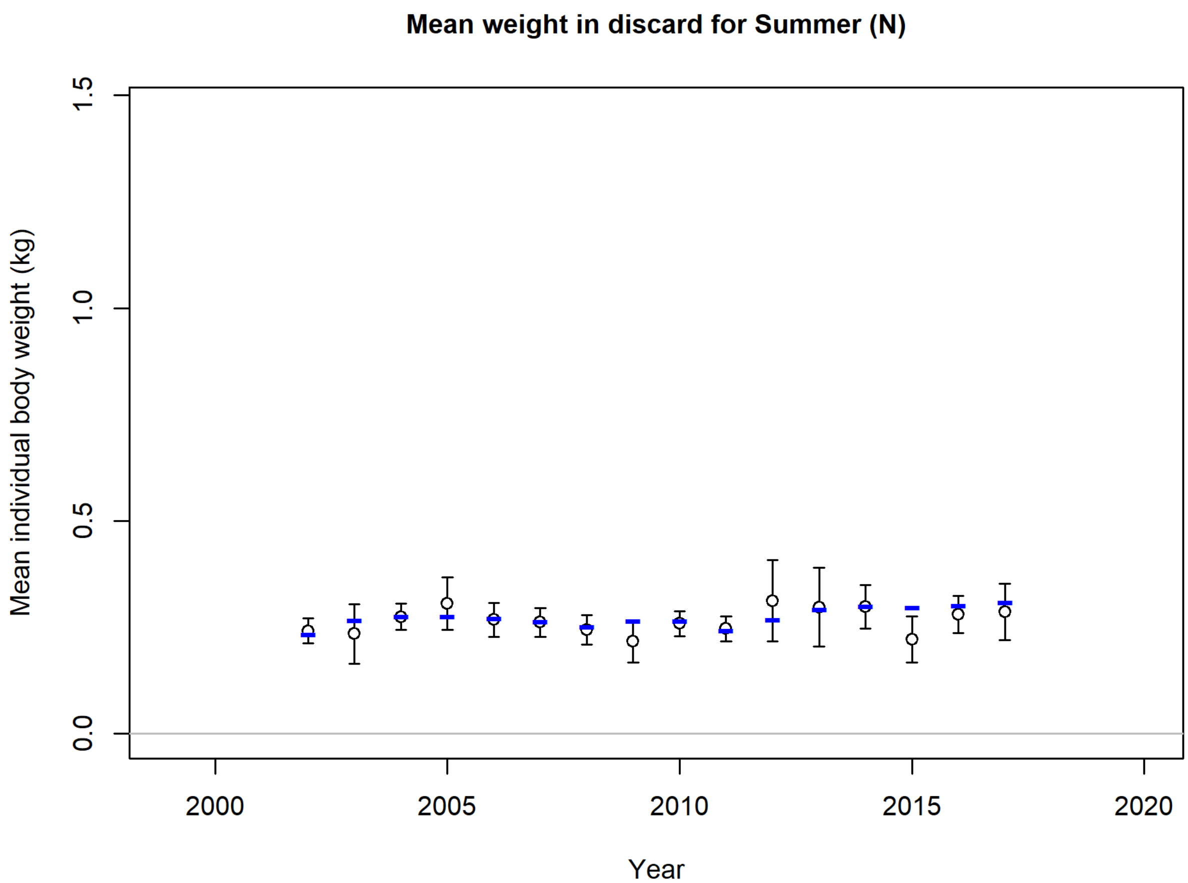


Figure 67: Fit to the Northern summer fishery mean body weights of discarded fish for petrale sole.

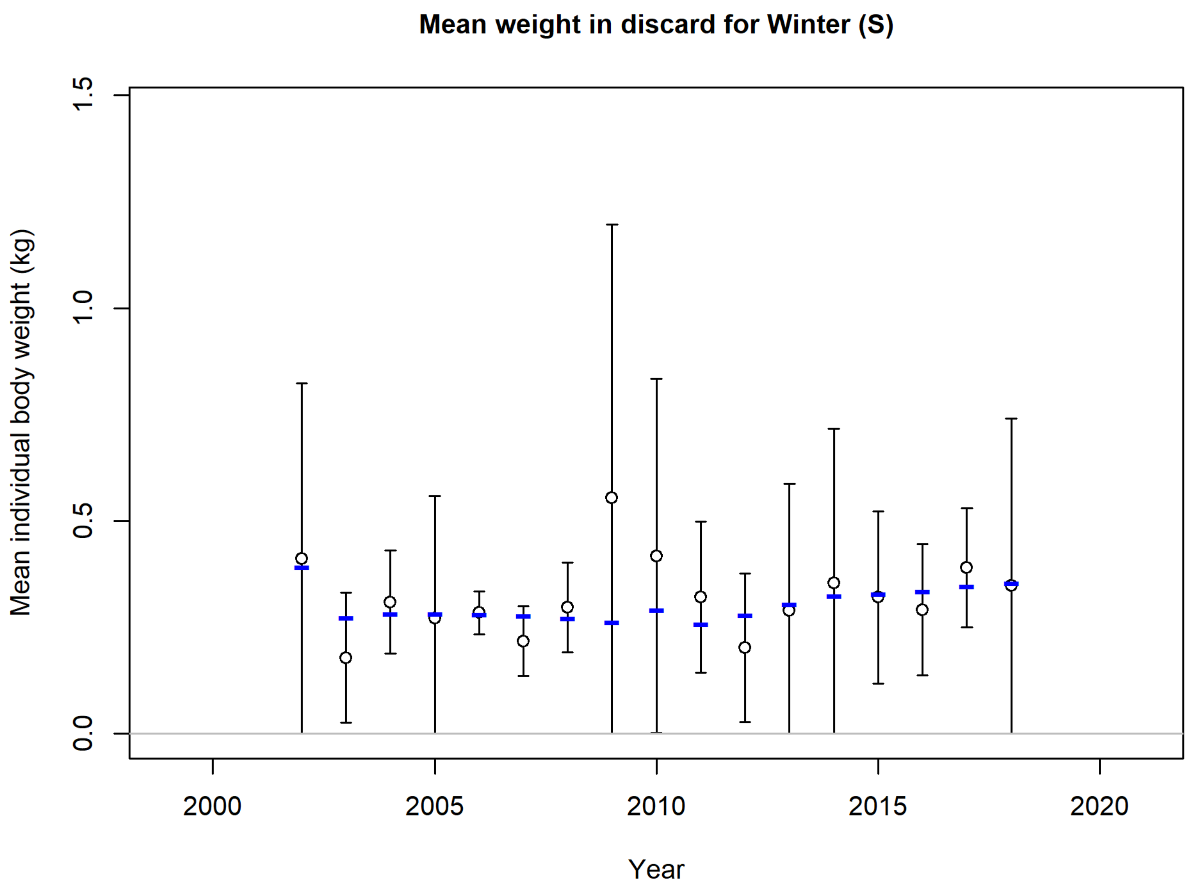


Figure 68: Fit to the Southern winter fishery mean body weights of discarded fish for petrale sole.

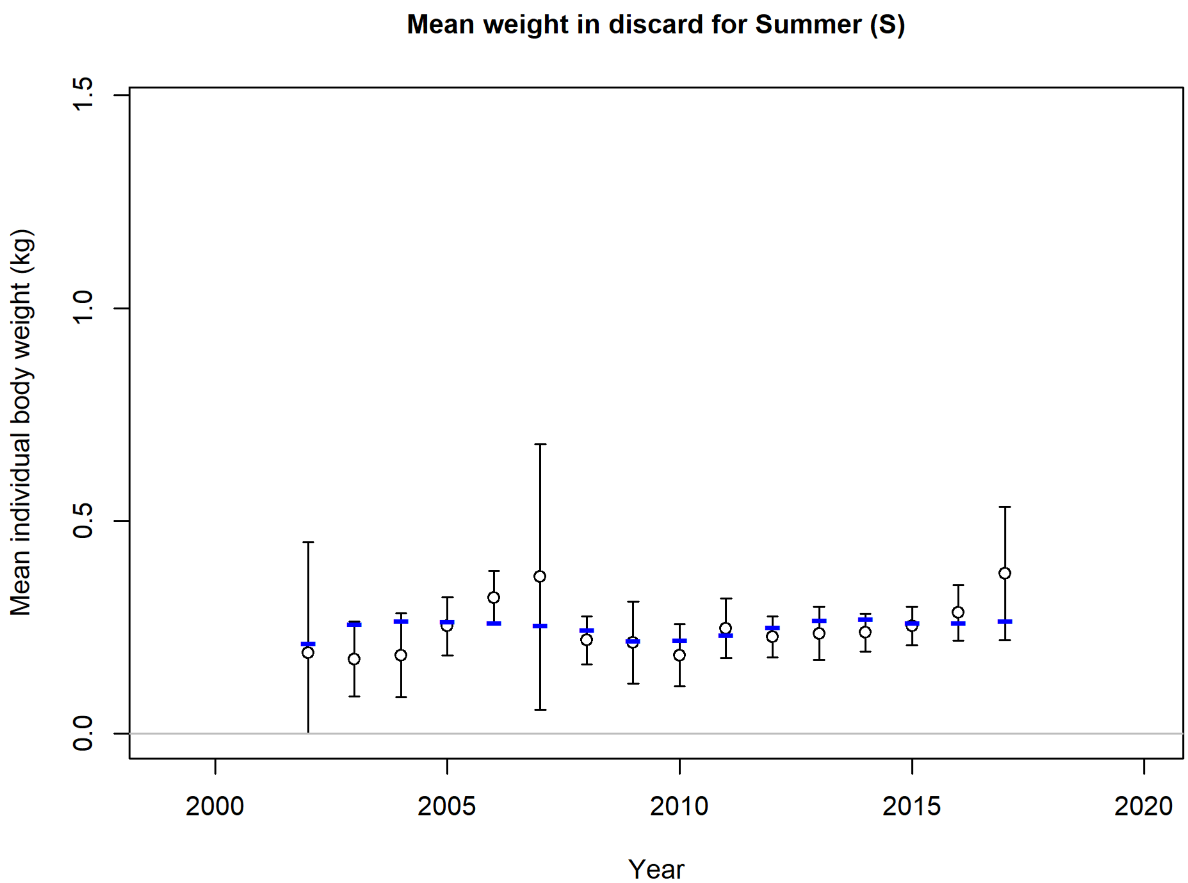


Figure 69: Fit to the Southern summer fishery mean body weights of discarded fish for petrale sole.

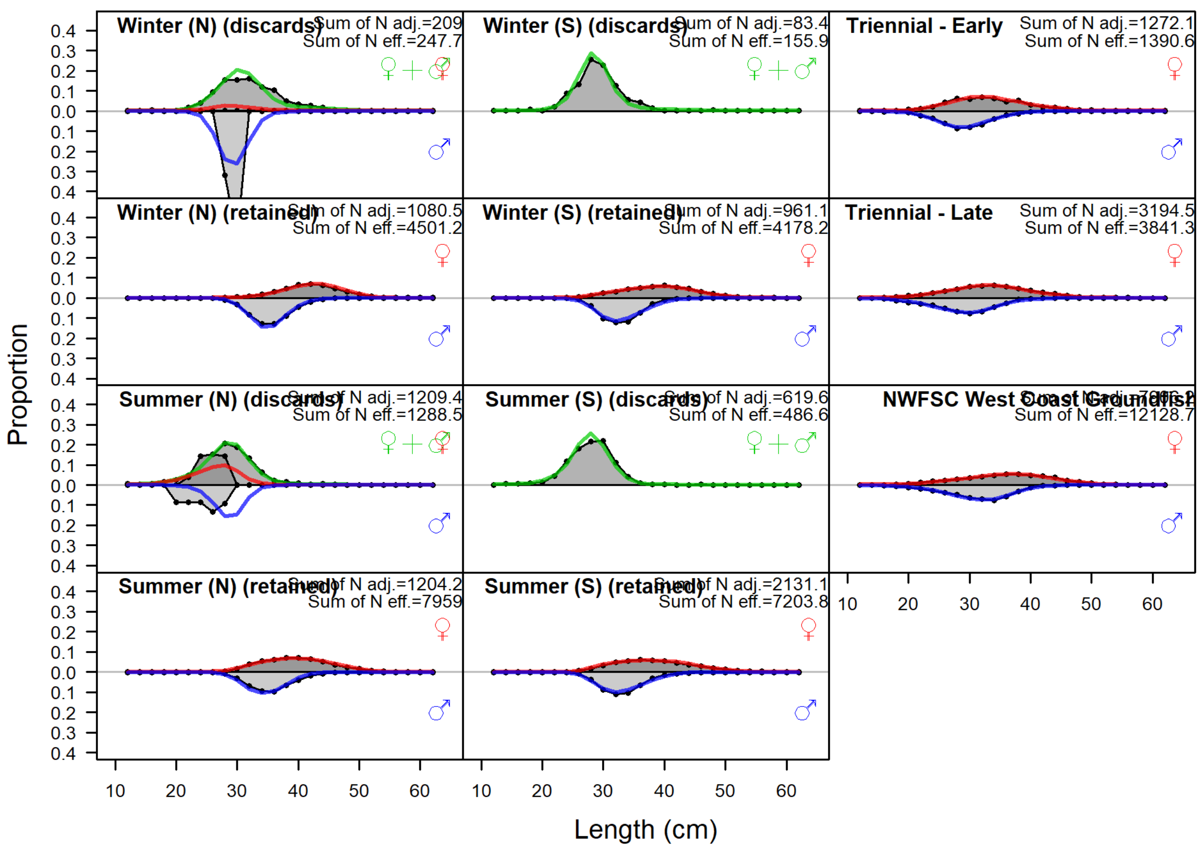


Figure 70: Length compositions aggregated across time by fleet. Labels 'retained' and 'discard' indicate retained or discarded samples for each fleet. Panels without this designation represent the whole catch.

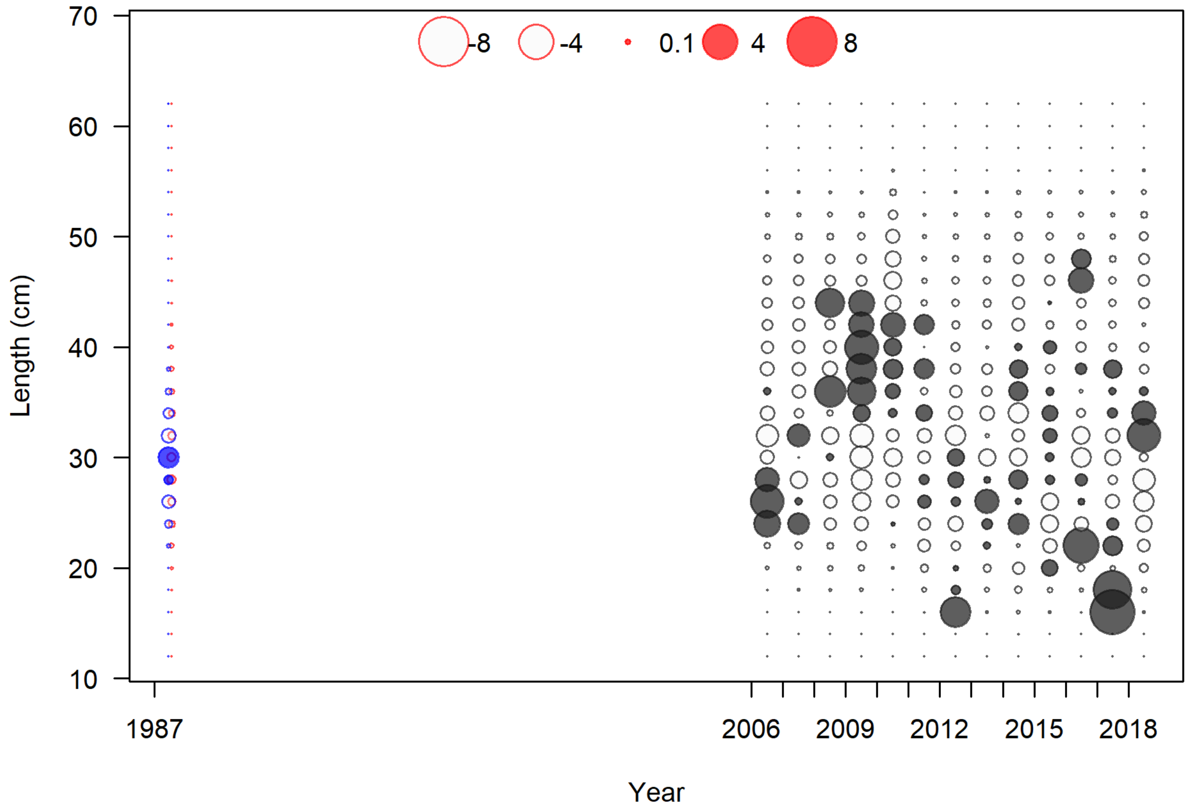


Figure 71: Pearson residuals, discard, Winter (N) (max=6.35)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

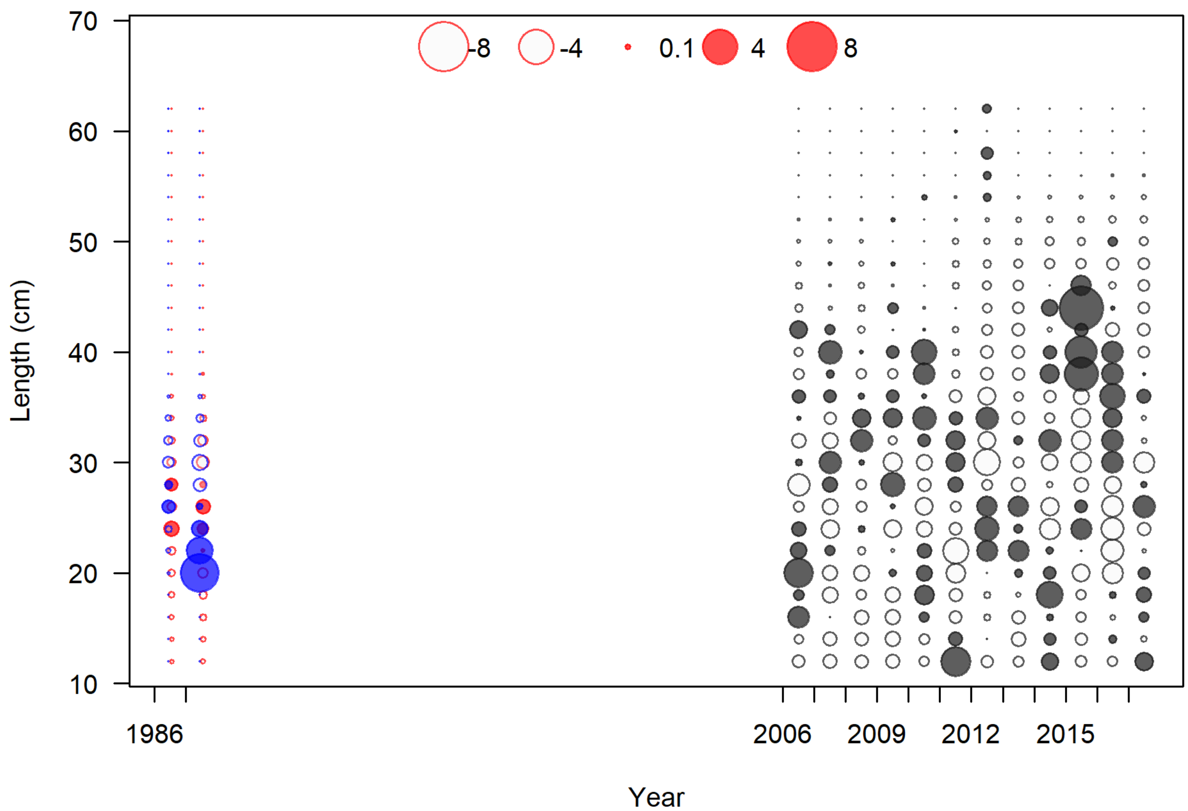


Figure 72: Pearson residuals, discard, Summer (N) (max=6.21)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

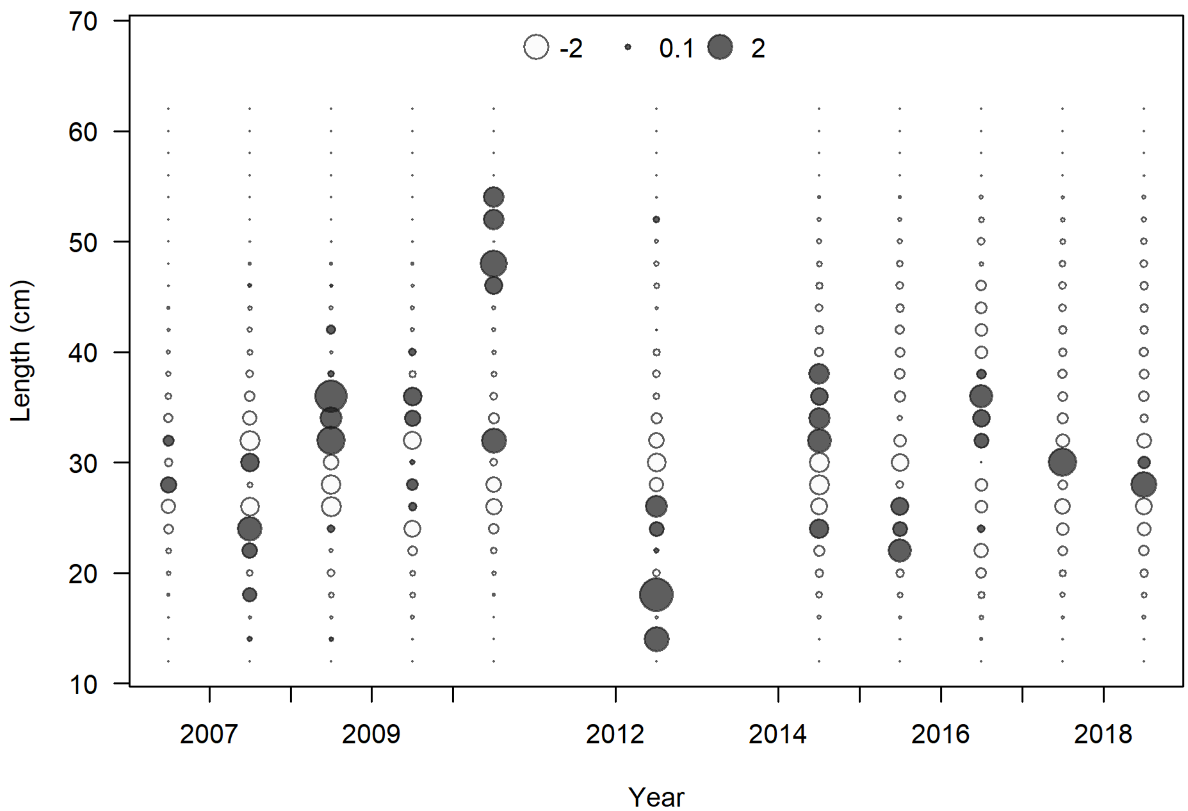


Figure 73: Pearson residuals, discard, Winter (S) (max=3.58)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

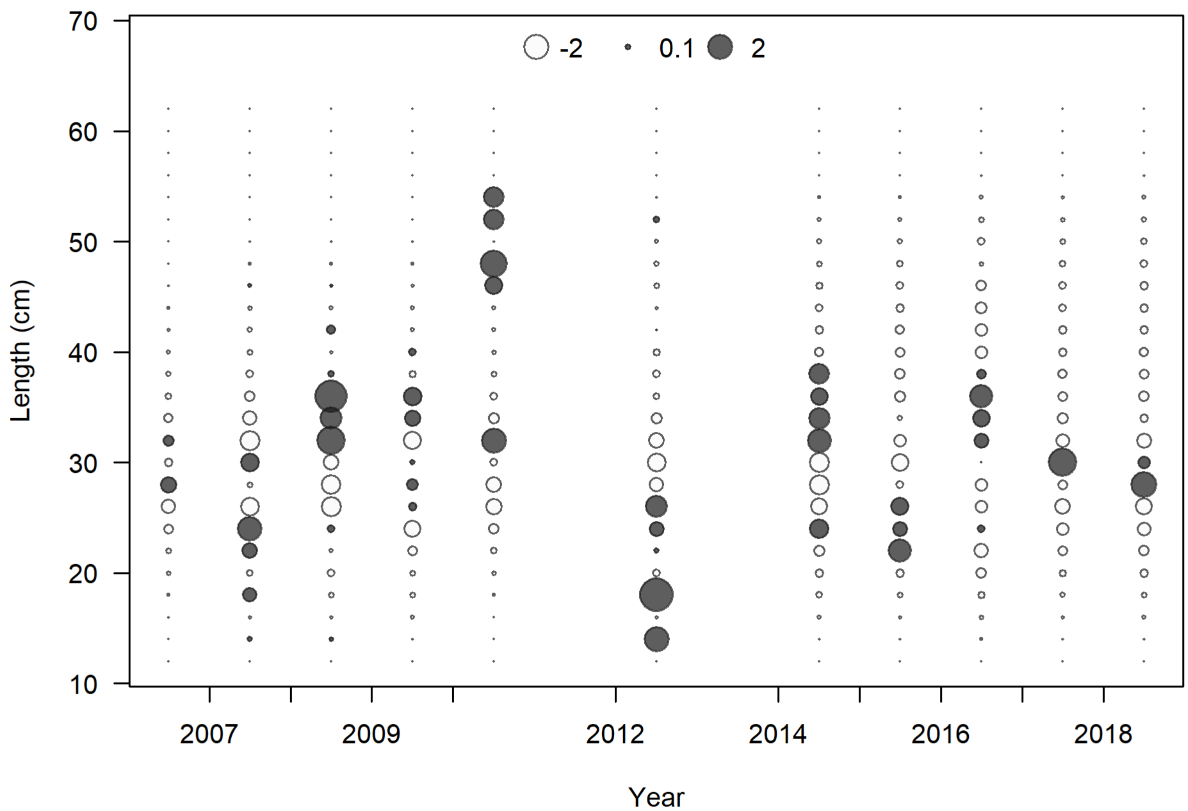


Figure 74: Pearson residuals, discard, Winter (S) (max=3.58)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

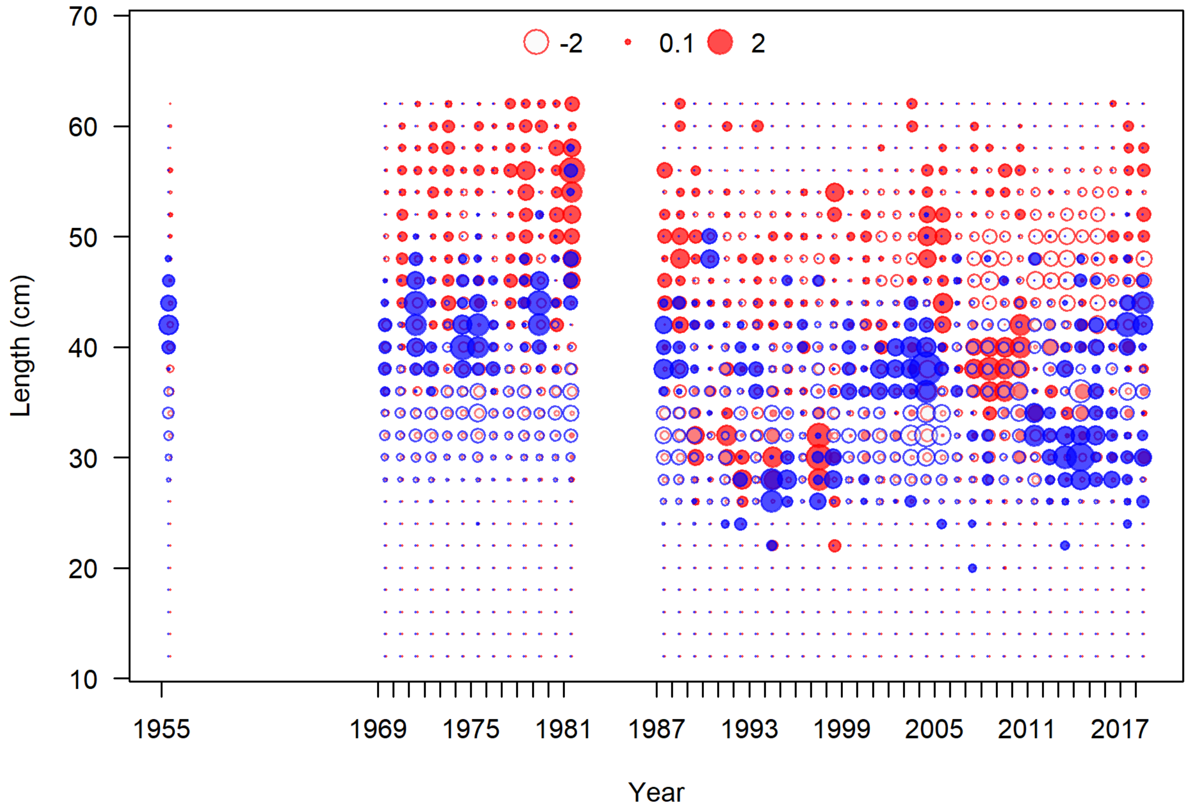


Figure 75: Pearson residuals, retained, Winter (N) (max=3.47) (plot 3 of 3)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

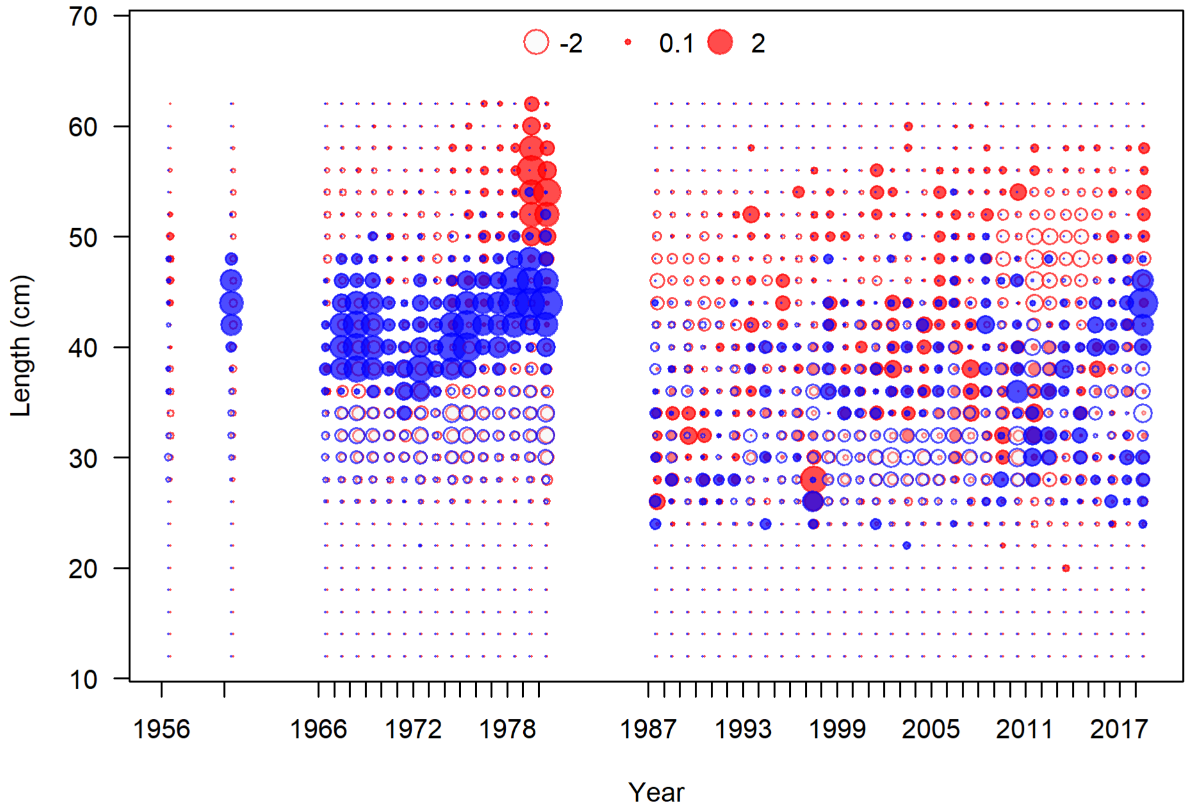


Figure 76: Pearson residuals, retained, Summer (N) (max=3.37) (plot 4 of 4)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

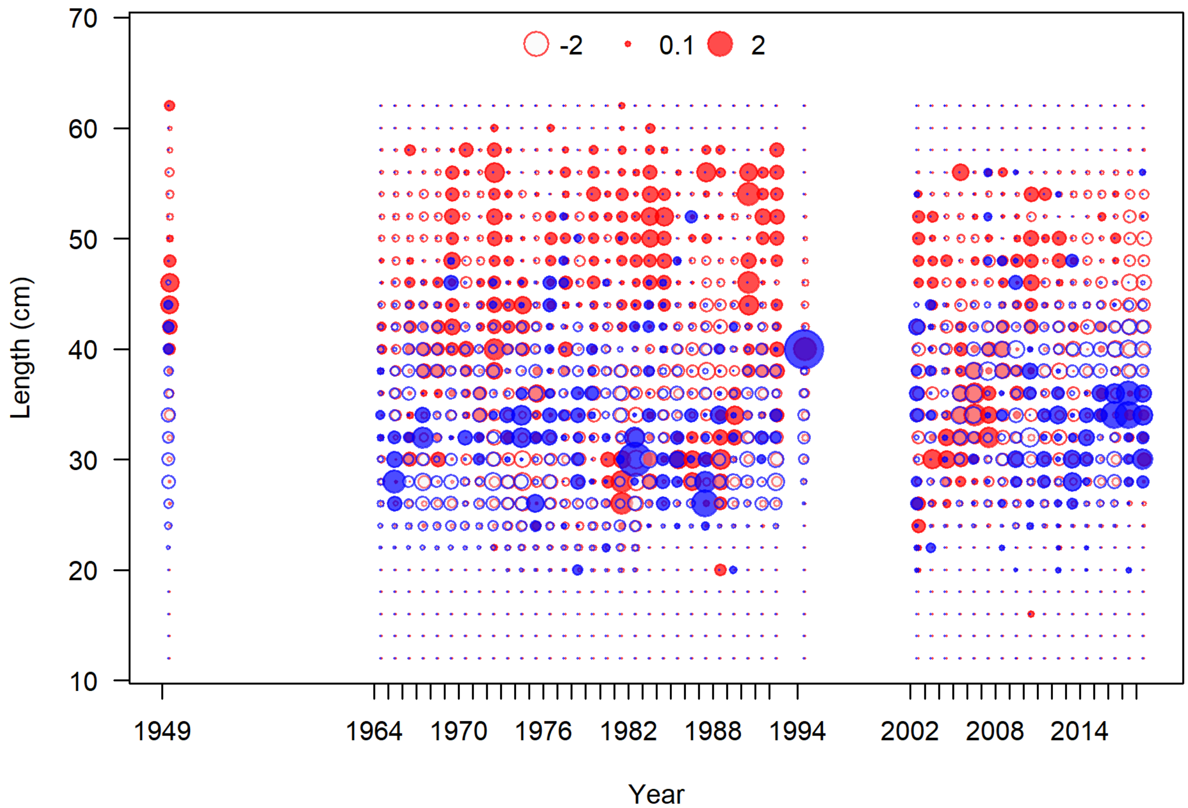


Figure 77: Pearson residuals, retained, Winter (S) (max=4.93) (plot 3 of 3)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

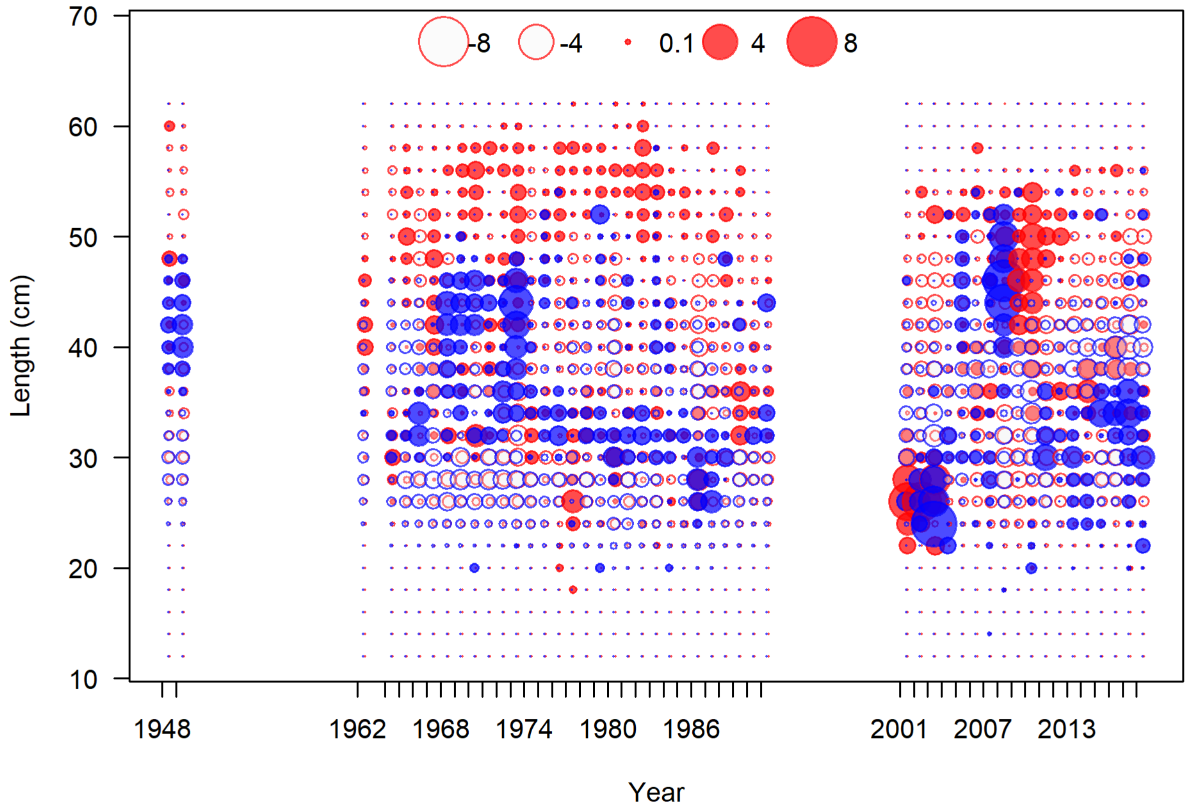


Figure 78: Pearson residuals, retained, Summer (S) (max=6.55) (plot 4 of 4)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

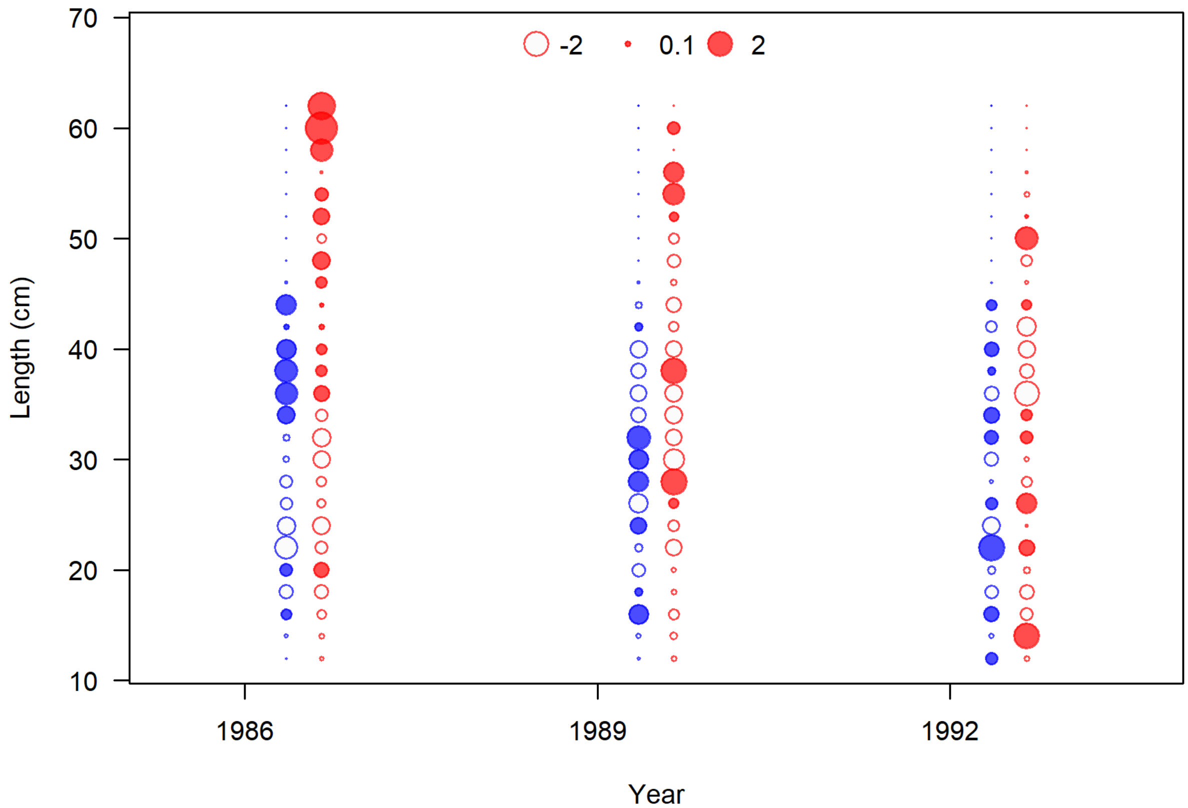


Figure 79: Pearson residuals, whole catch, Triennial _ Early (max=3.22)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

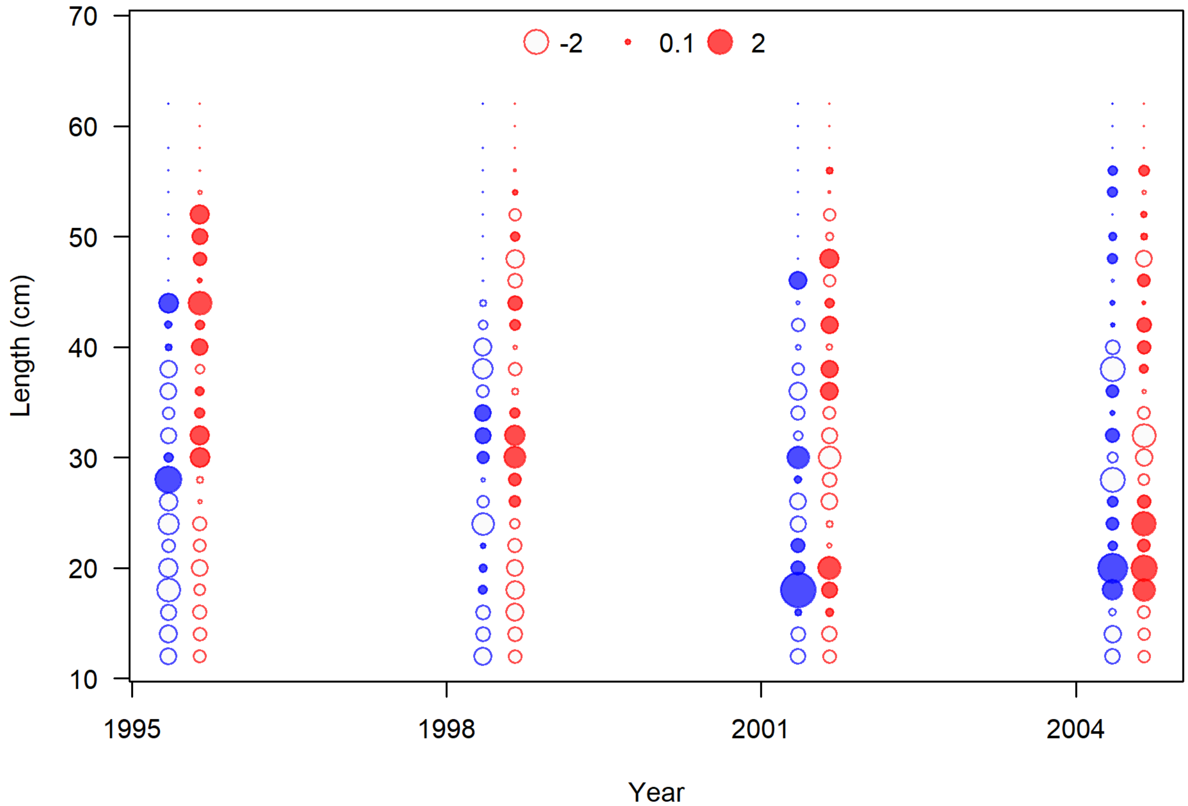


Figure 80: Pearson residuals, whole catch, Triennial _ Late (max=3.9)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

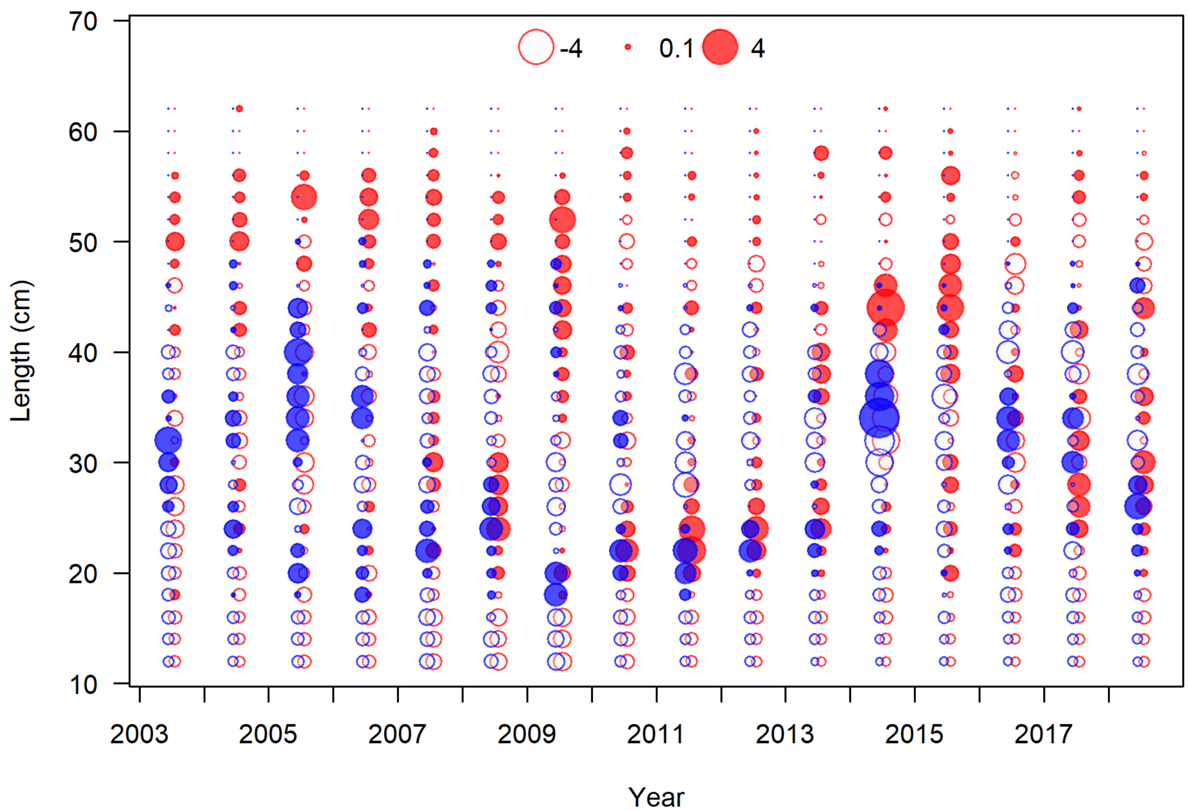


Figure 81: Pearson residuals, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (max=5.08)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

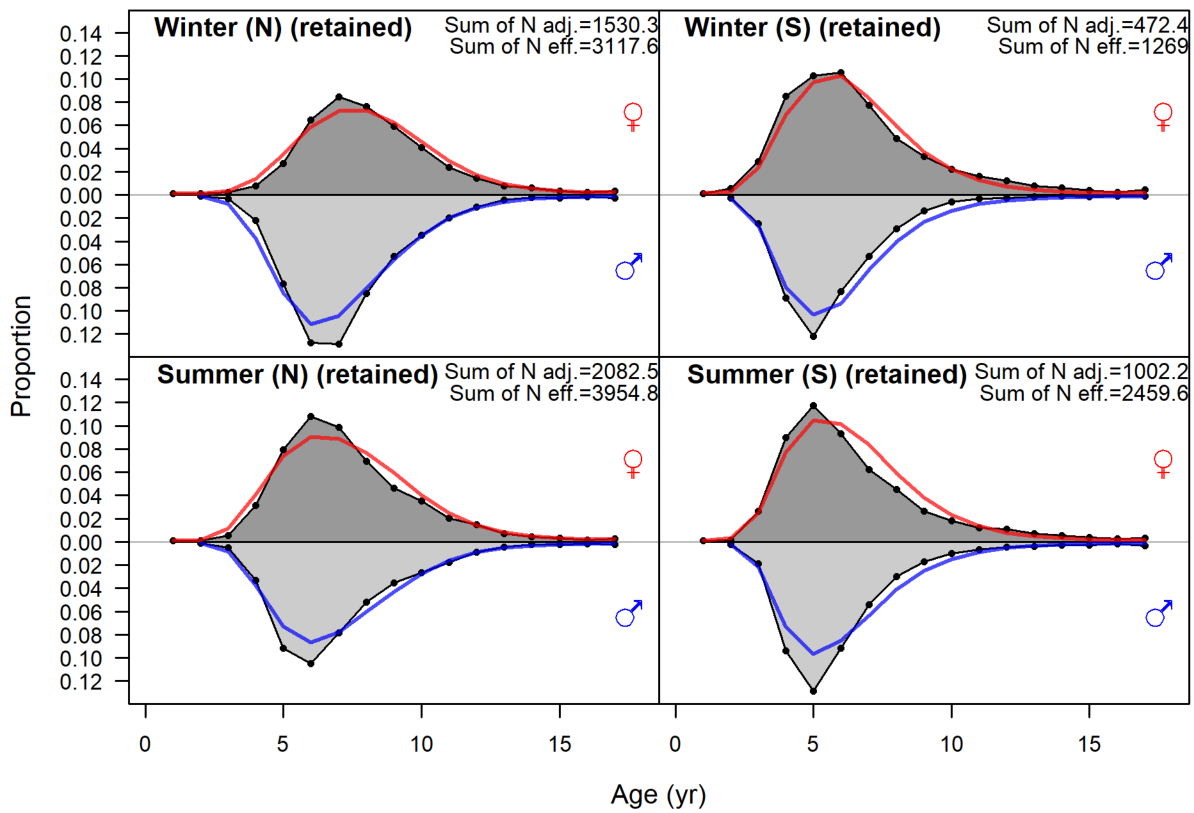


Figure 82: Age compositions aggregated across time for each fishery fleet.

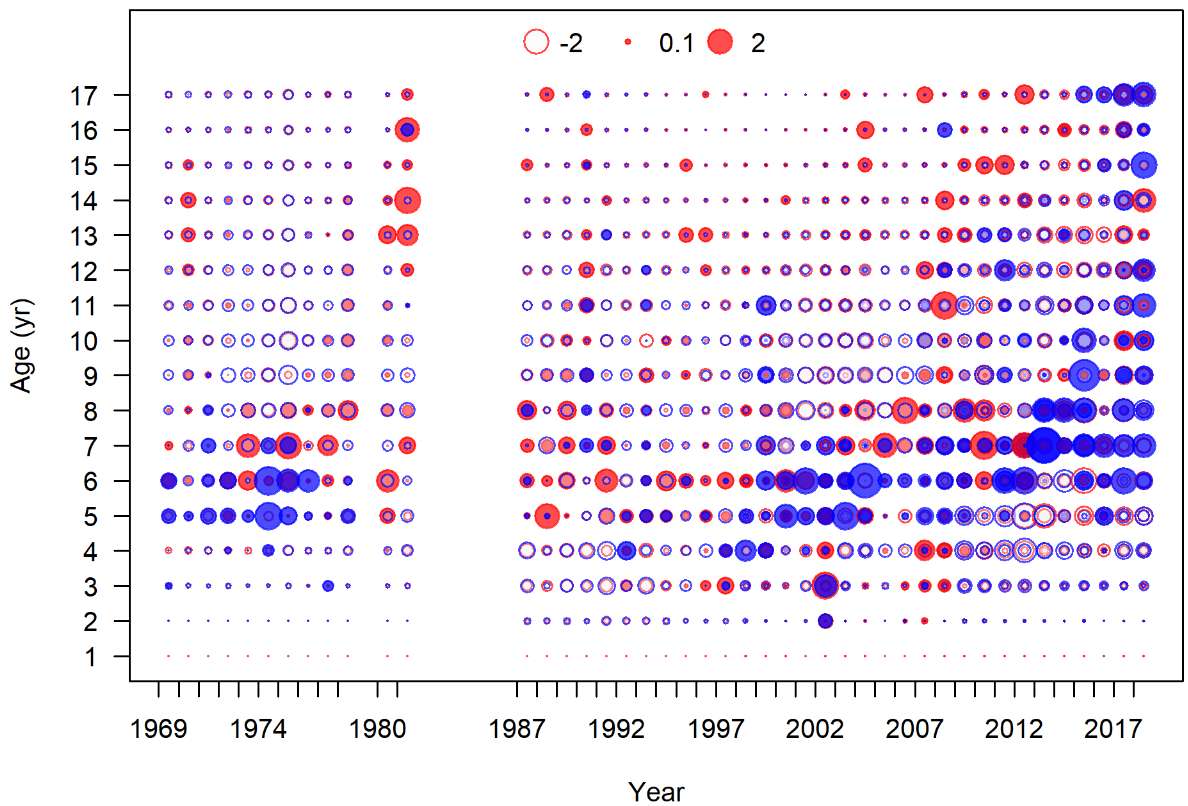


Figure 83: Pearson residuals, retained, Winter (N) (max=4.05) (plot 4 of 4)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

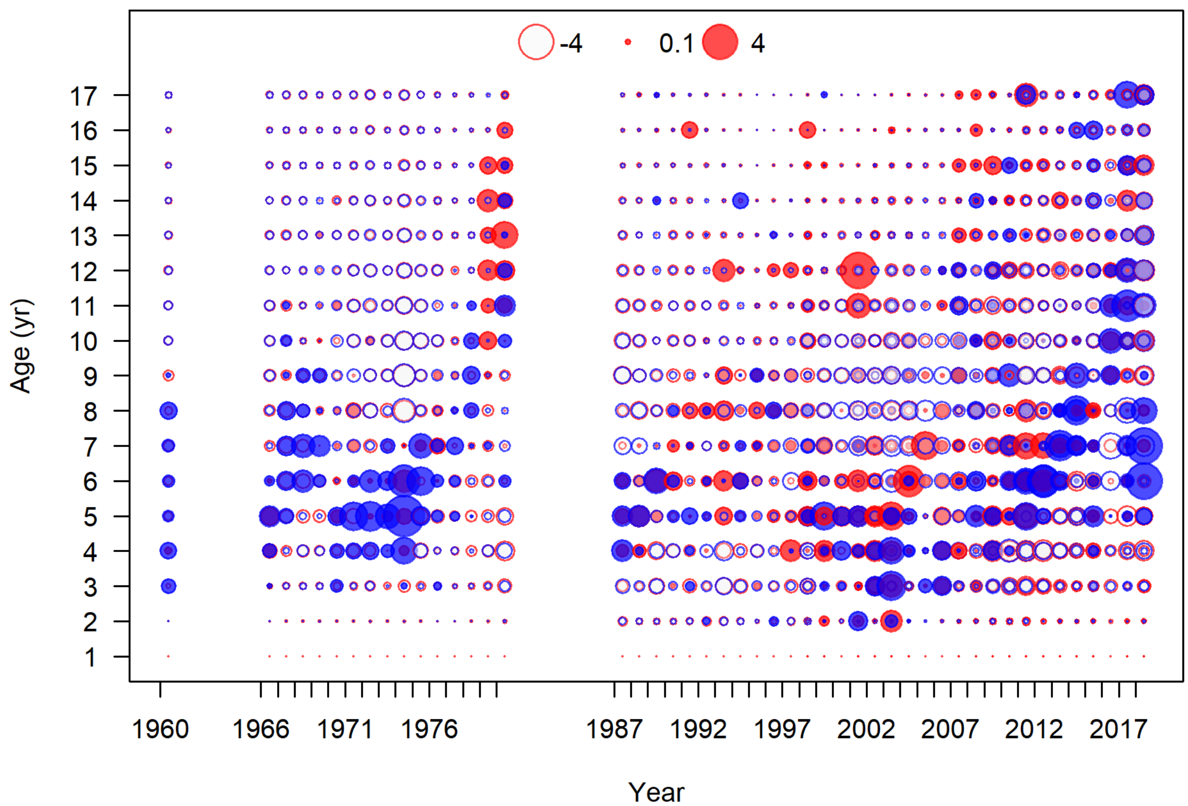


Figure 84: Pearson residuals, retained, Summer (N) (max=5.4) (plot 5 of 5)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

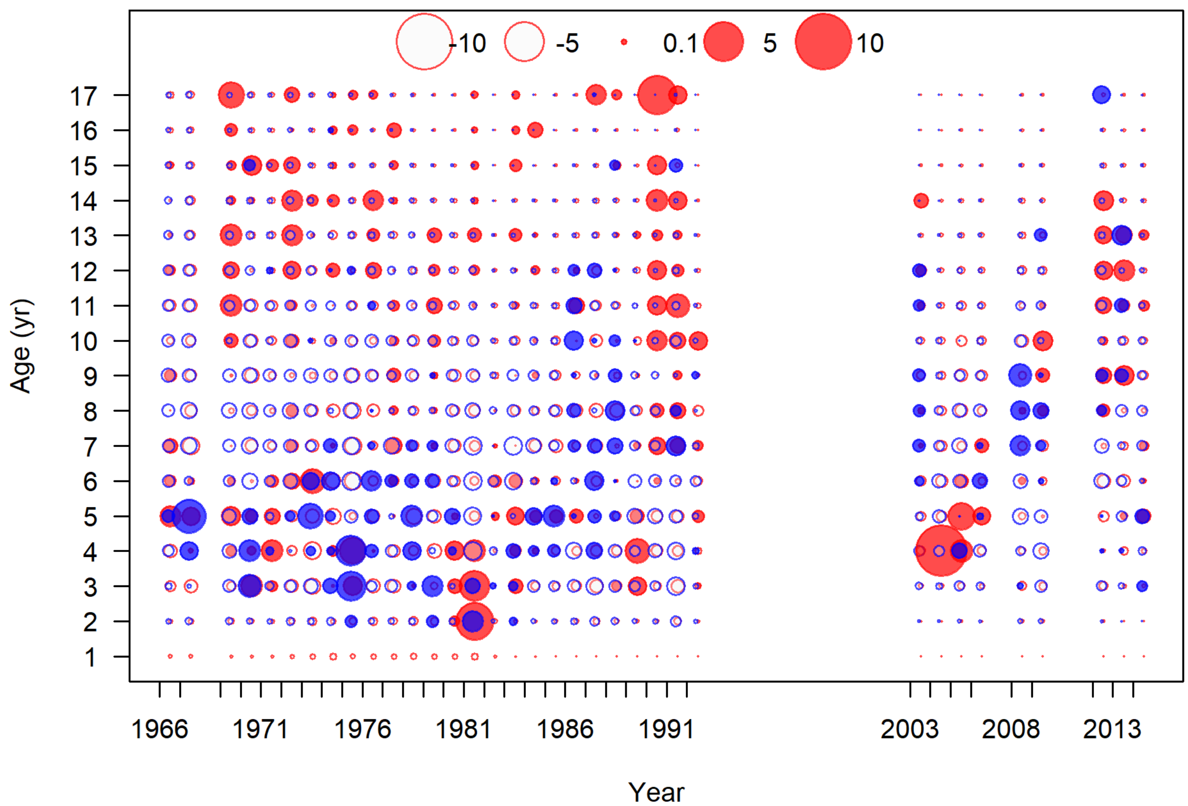


Figure 85: Pearson residuals, retained, Winter (S) (max=8.32) (plot 3 of 3)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

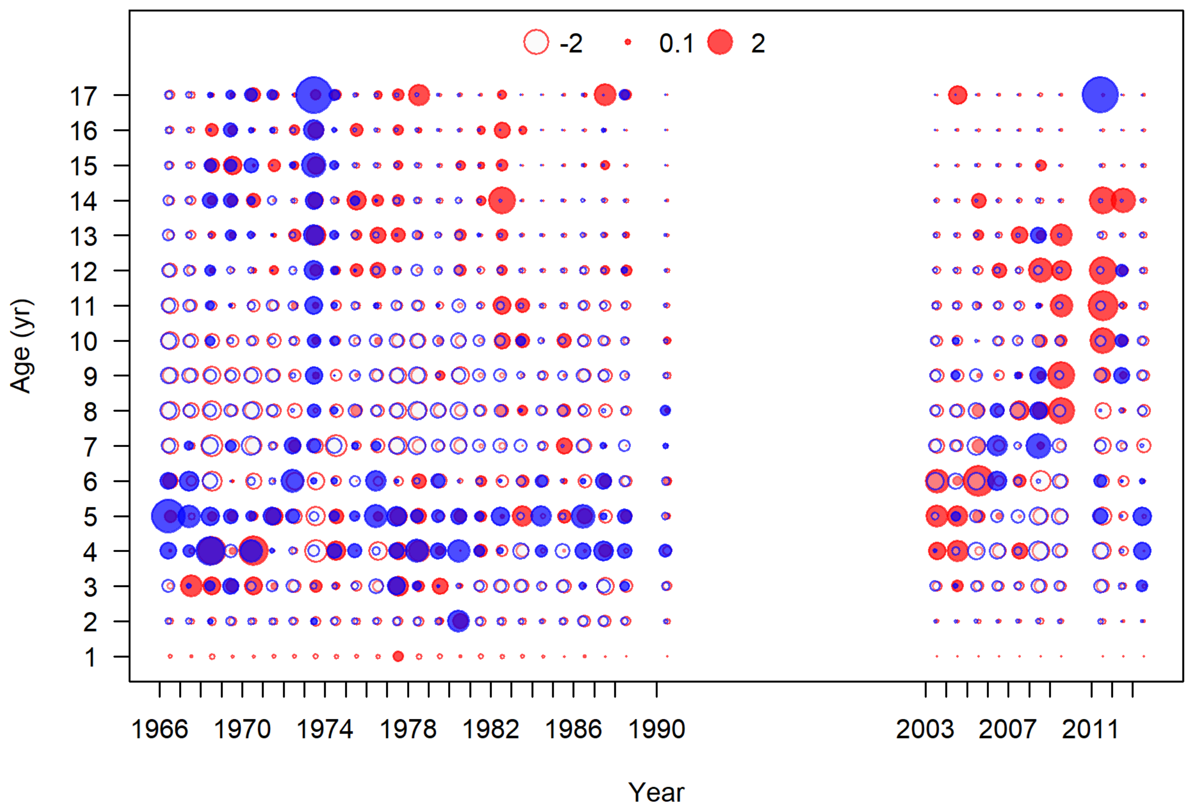


Figure 86: Pearson residuals, retained, Summer (S) (max=4.26) (plot 3 of 3)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

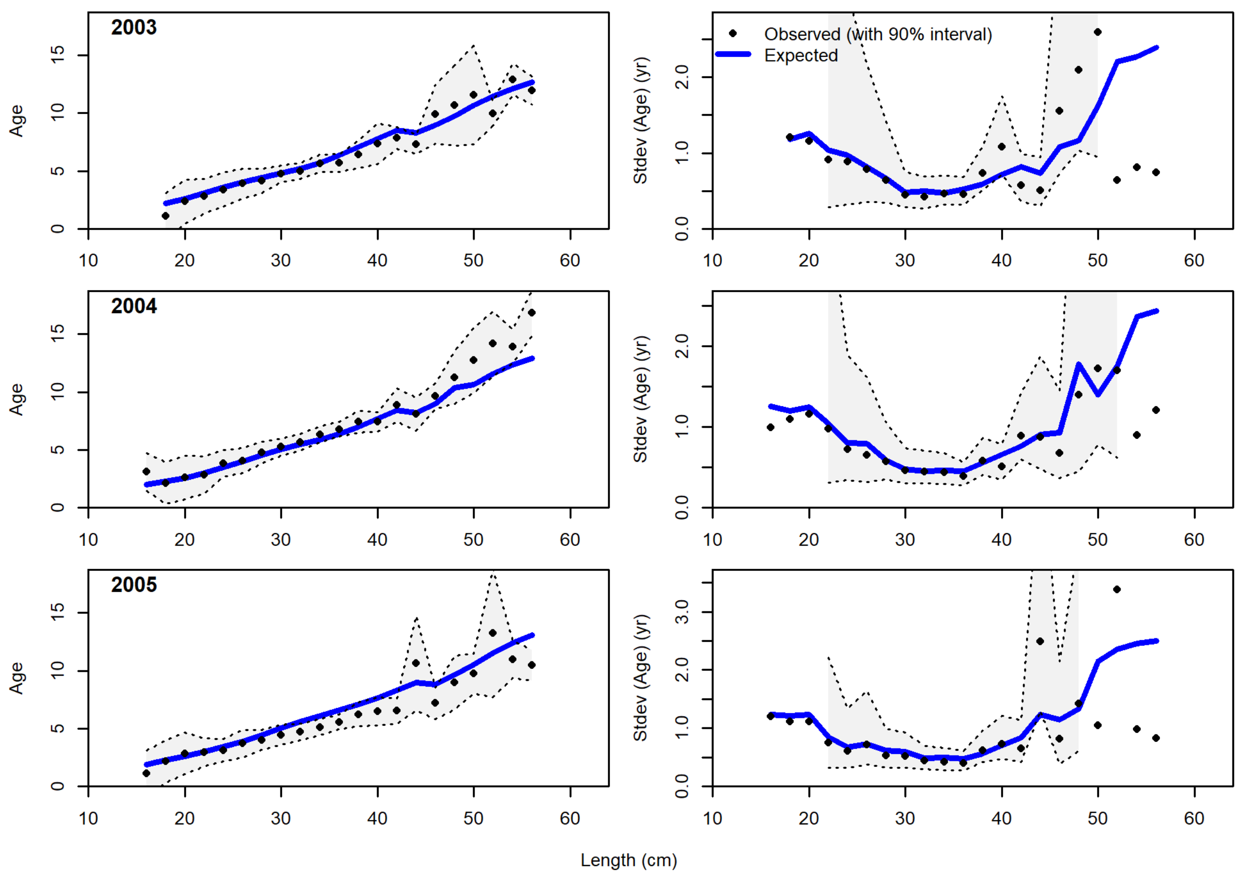


Figure 87: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 1 of 6) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution.

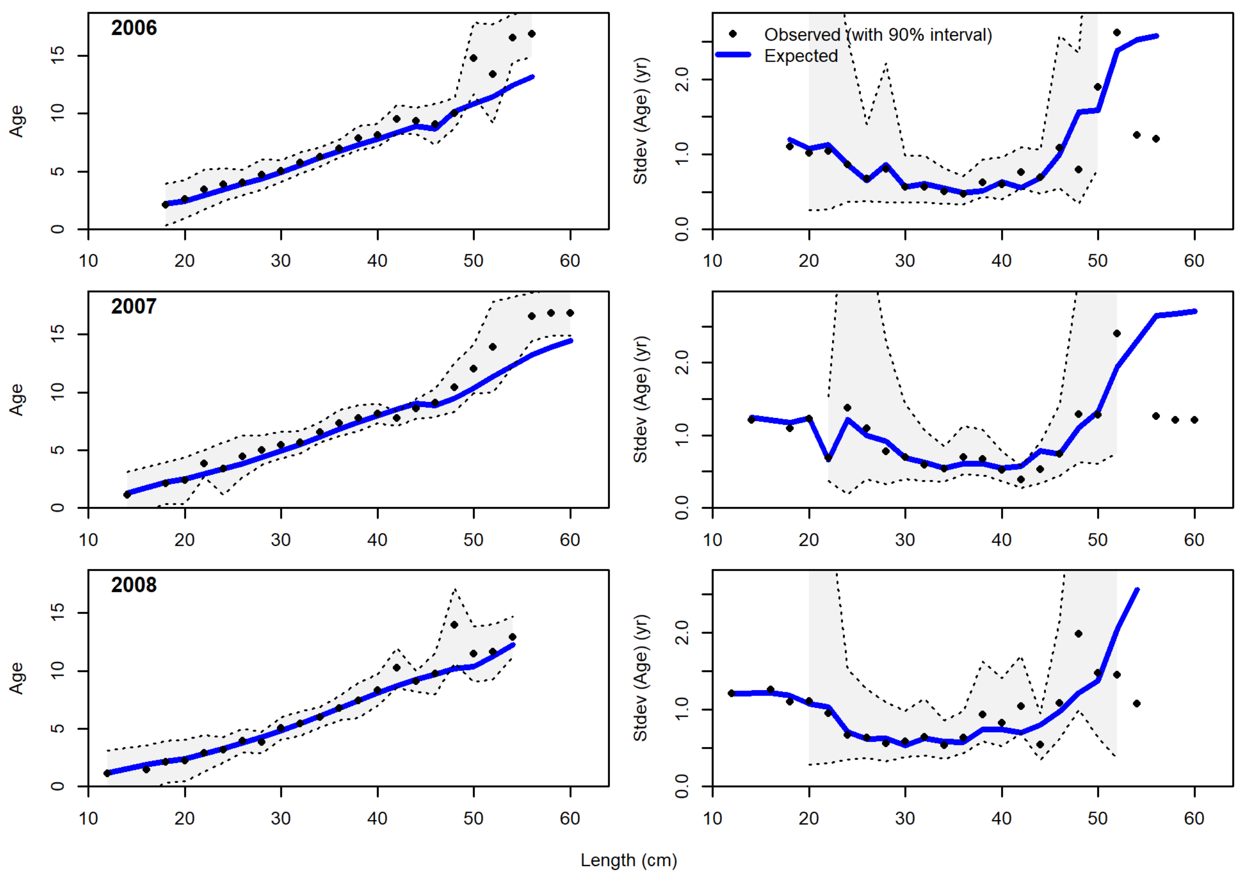


Figure 88: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 2 of 6)

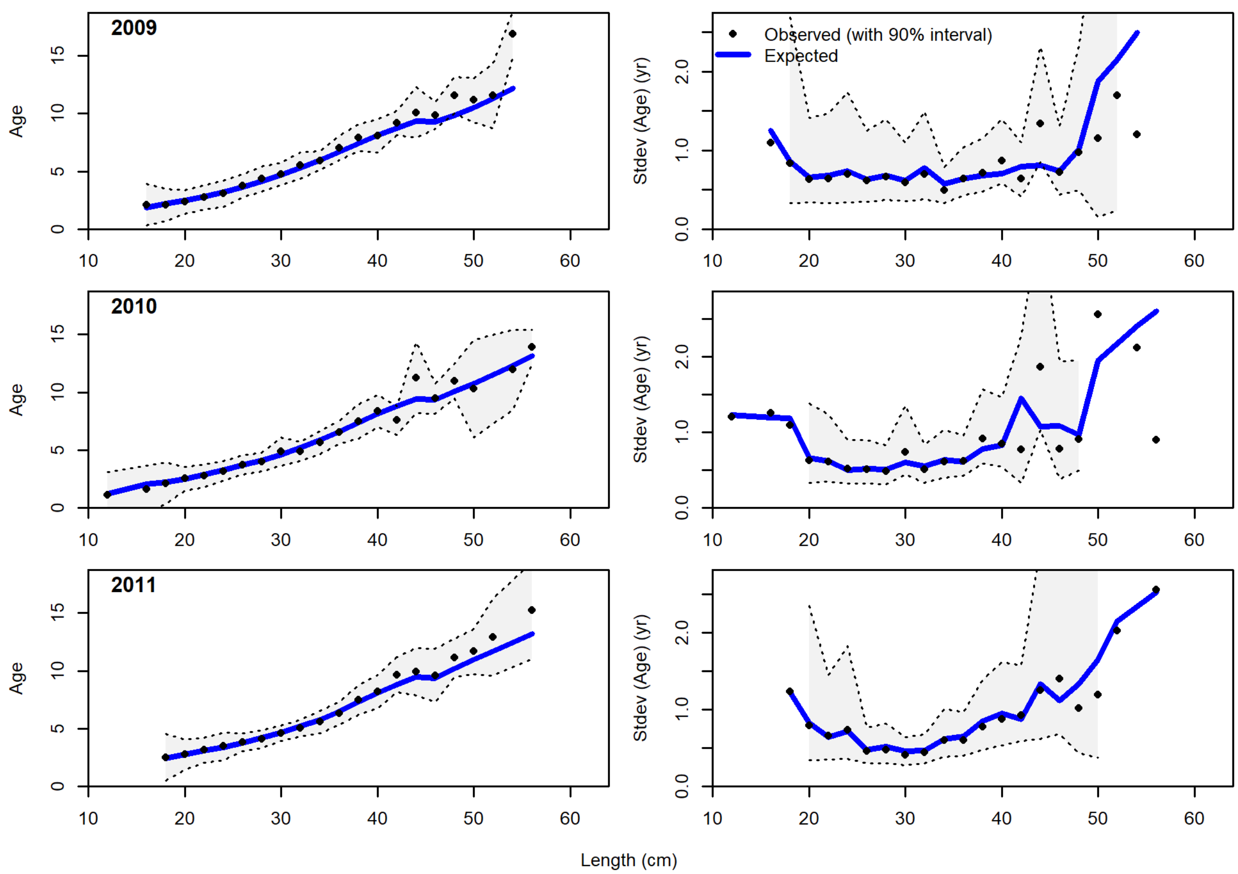


Figure 89: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 3 of 6)

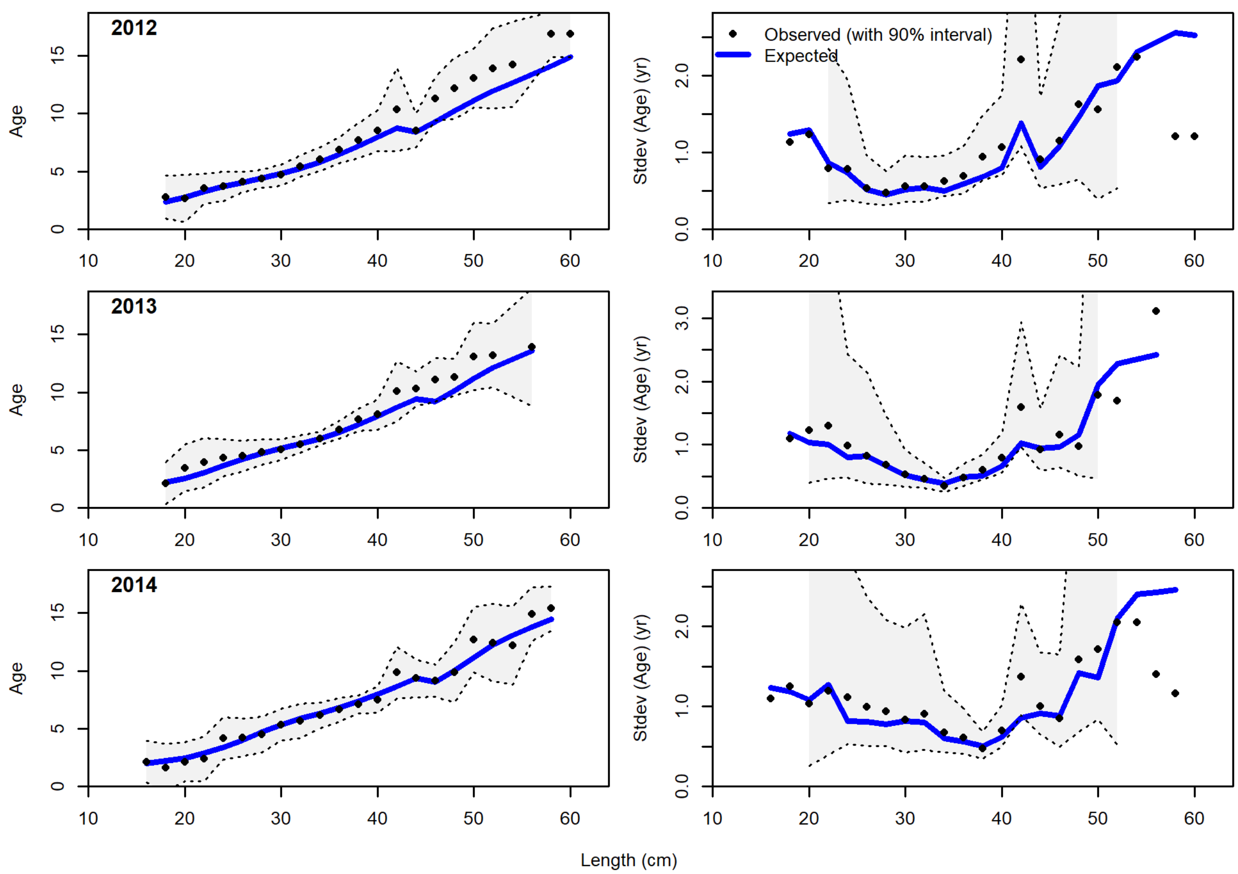


Figure 90: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 4 of 6)

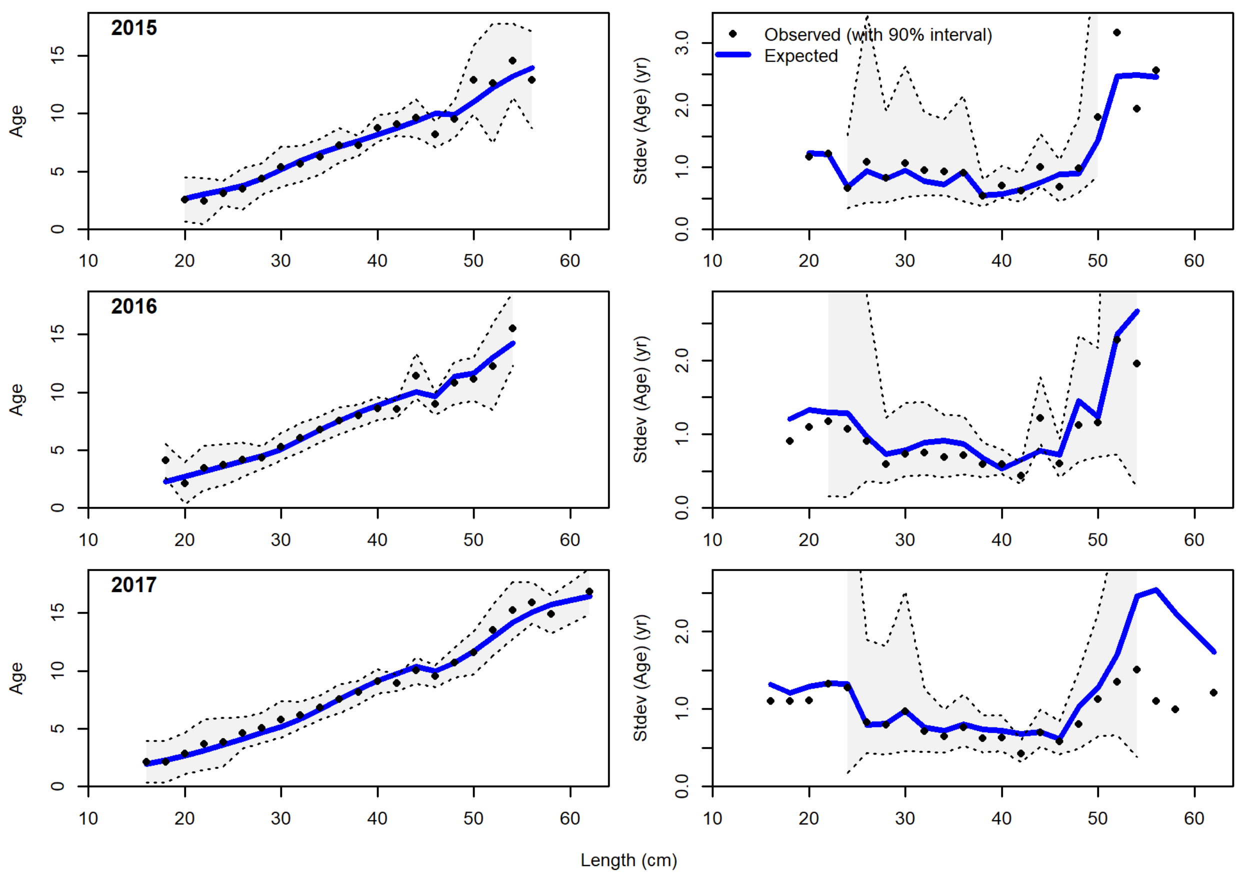


Figure 91: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 5 of 6)

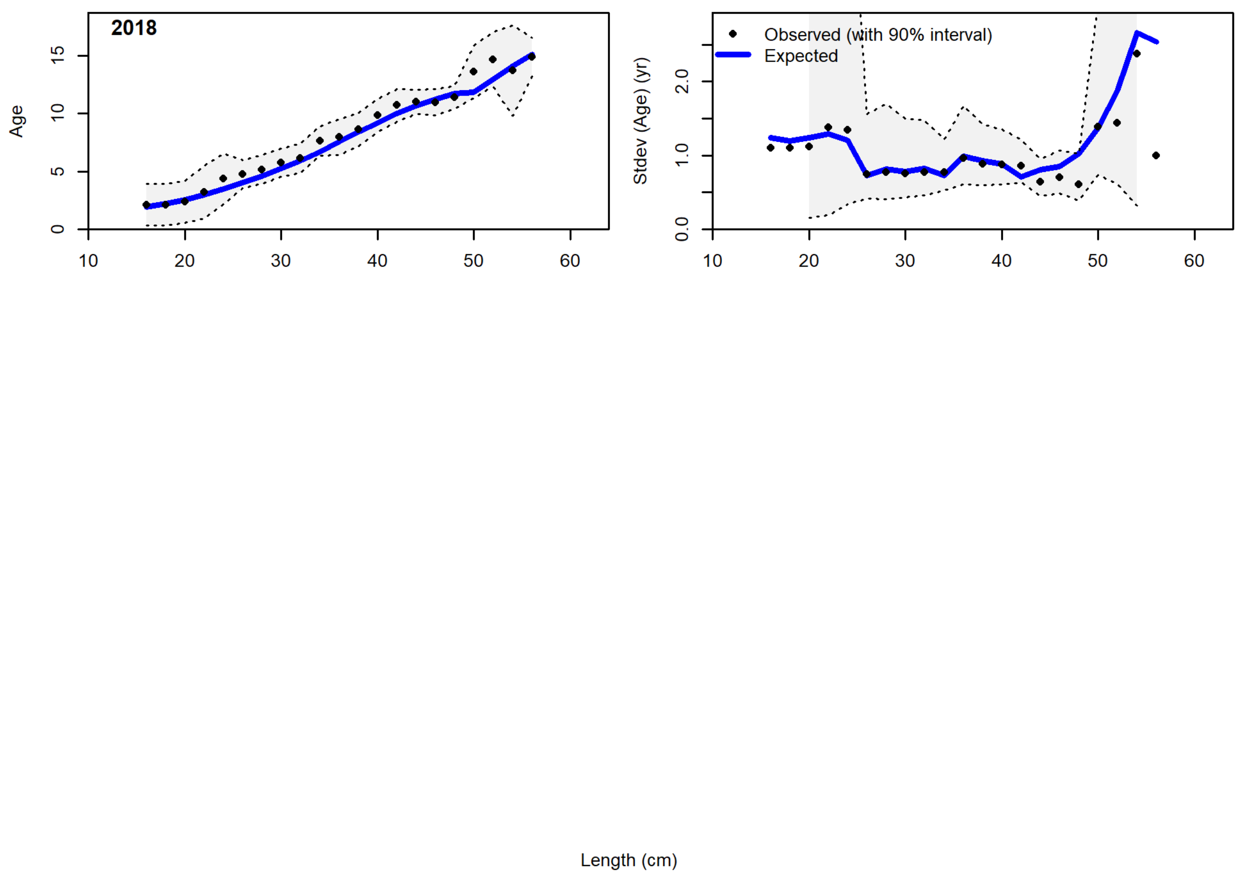


Figure 92: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 6 of 6)

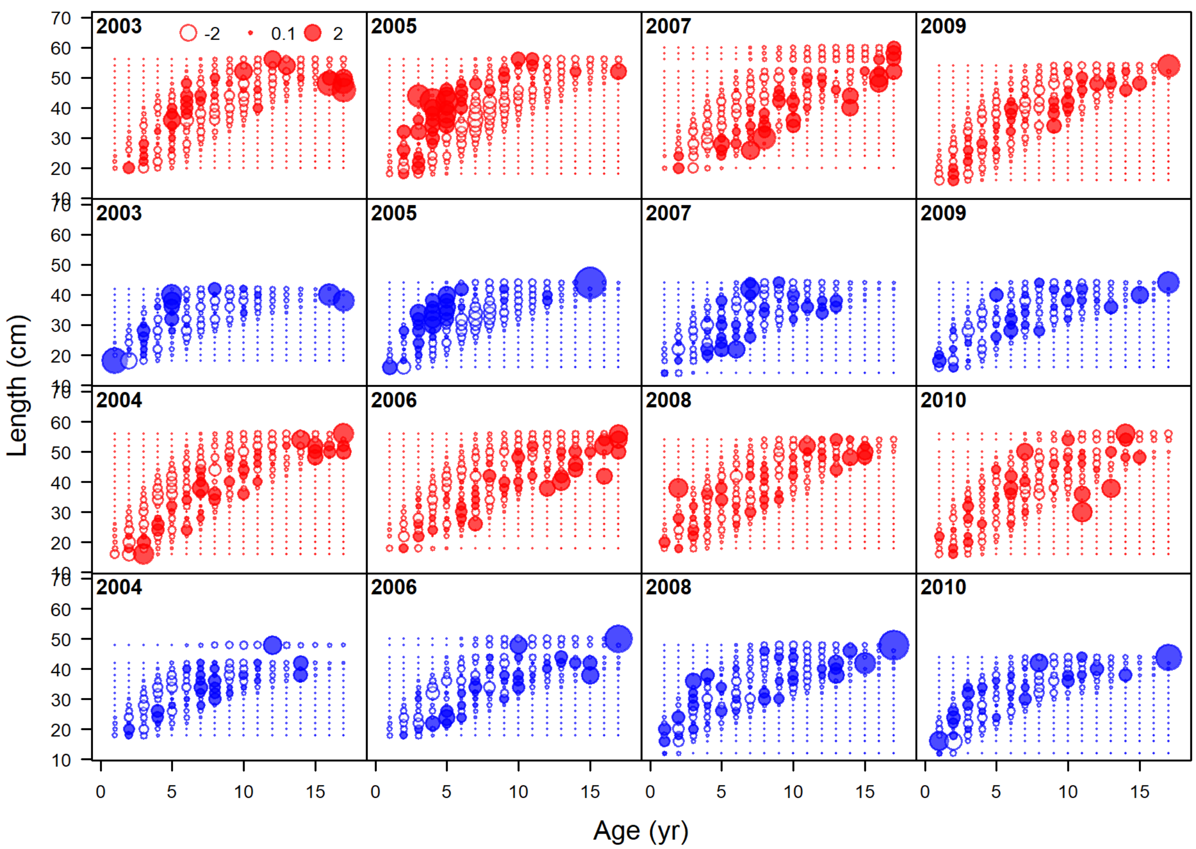


Figure 93: Pearson residuals, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (max=7.1) (plot 1 of 2)

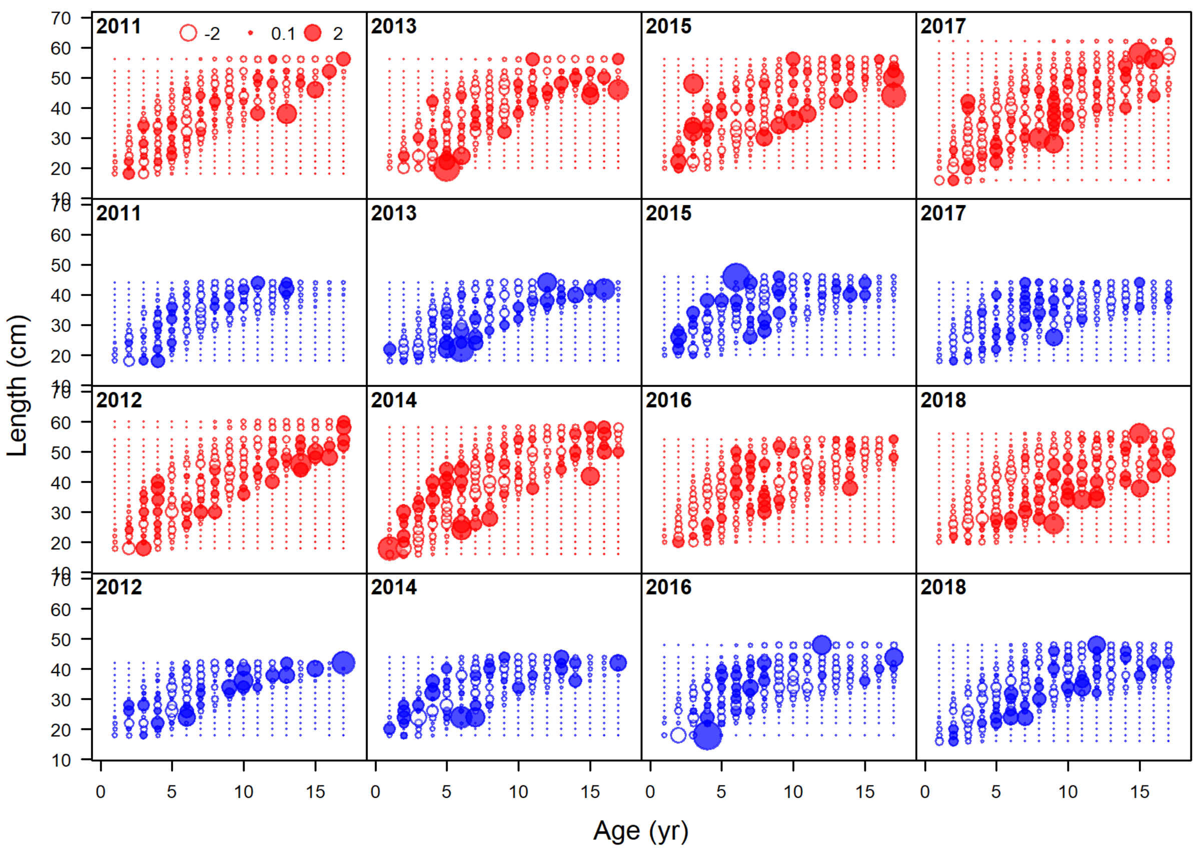


Figure 94: Pearson residuals, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (max=7.1) (plot 1 of 2) (plot 2 of 2)

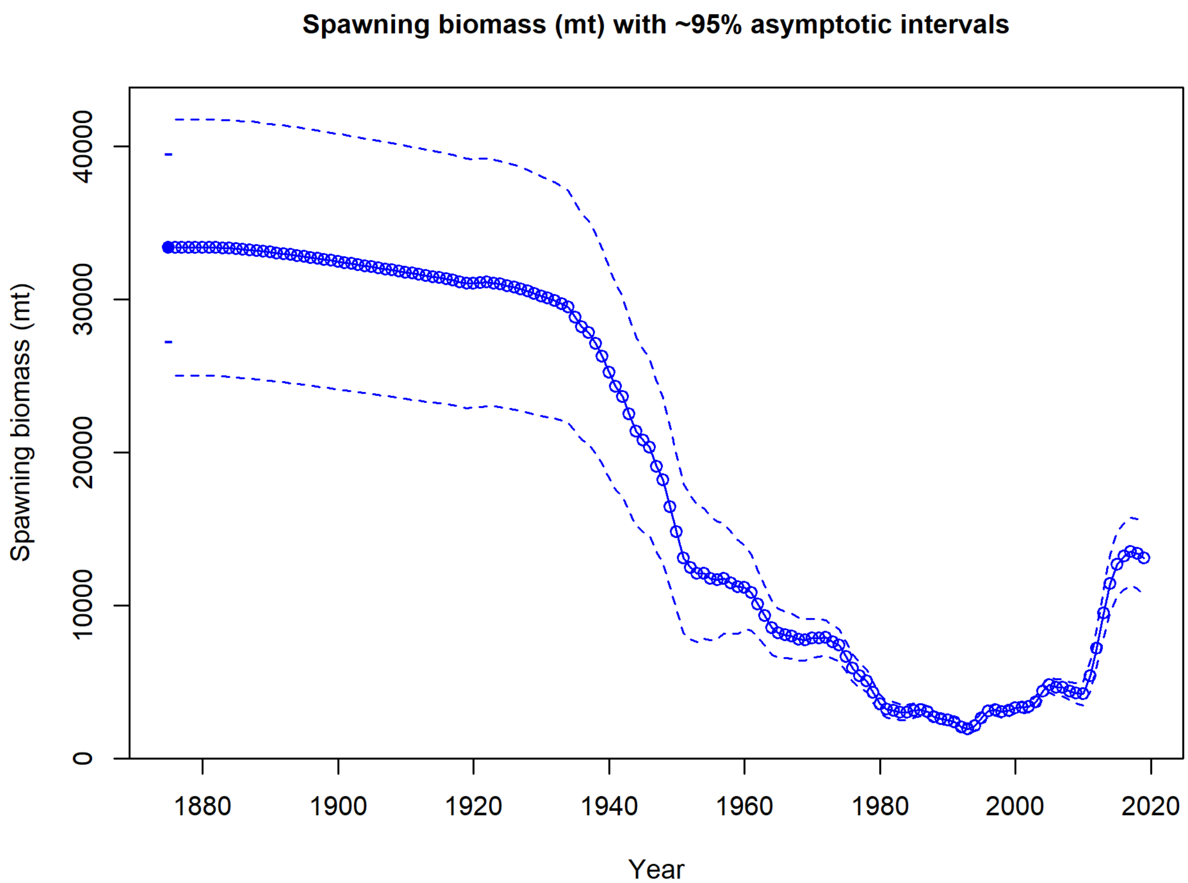


Figure 95: Estimated time-series of spawning biomass trajectory (circles and line: median; light broken lines: 95% credibility intervals) for petrale sole.

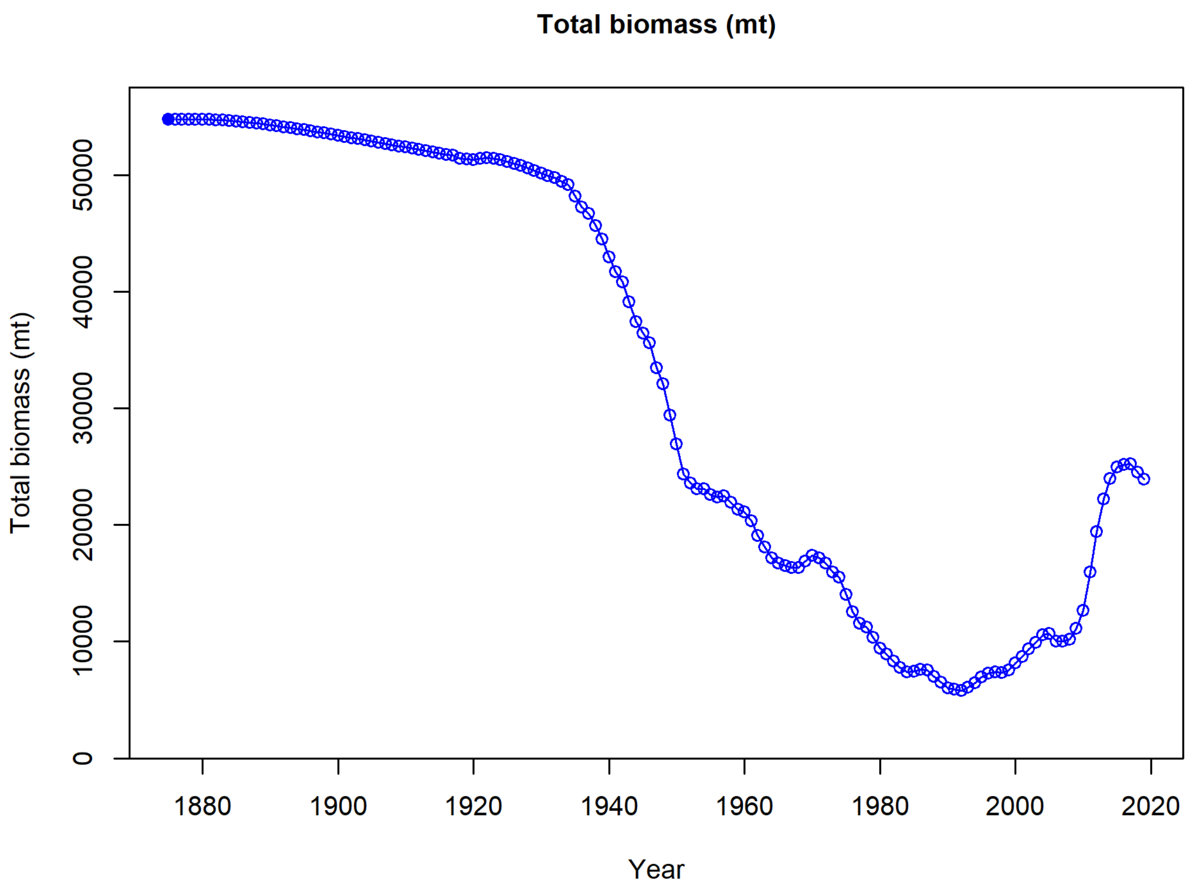


Figure 96: Estimated time-series of total biomass for petrale sole.

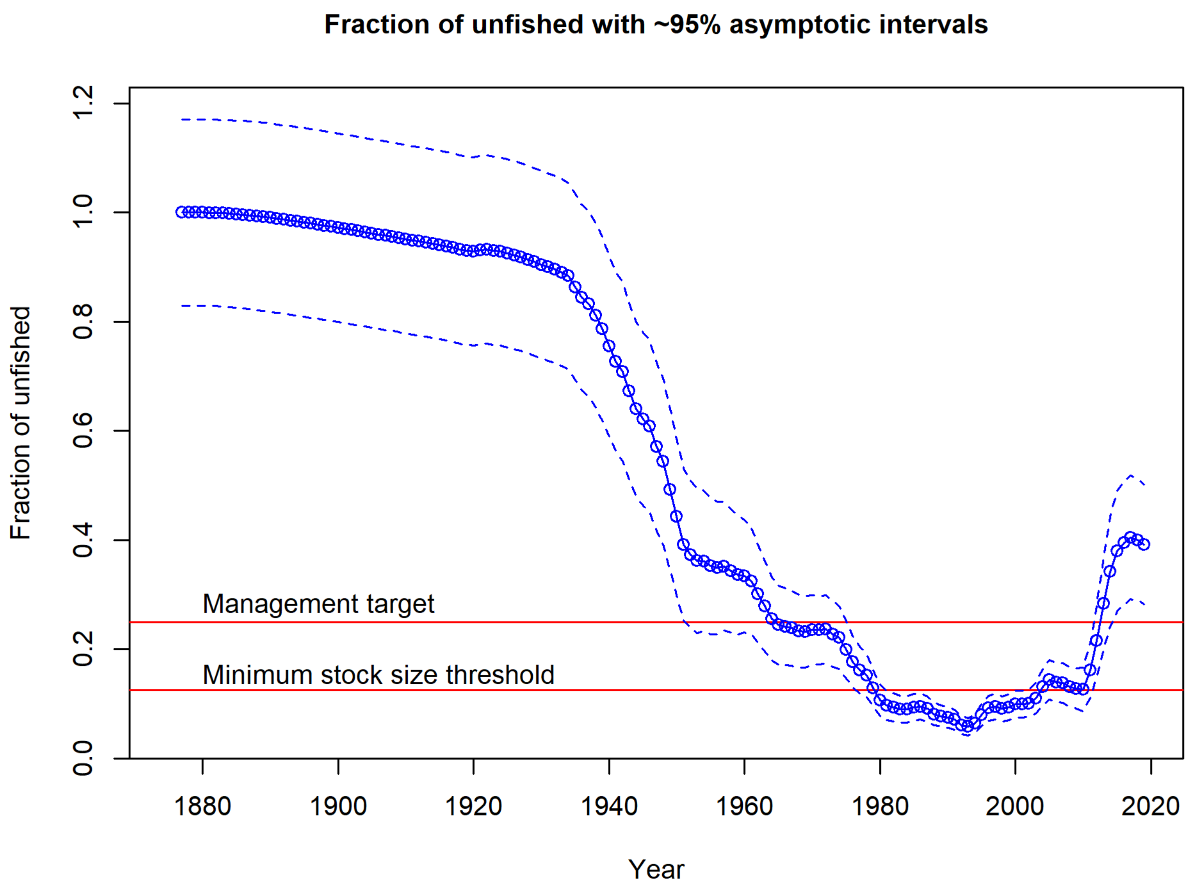


Figure 97: Estimated time-series of fraction of unfished spawning biomass (depletion) (circles and line: median; light broken lines: 95% credibility intervals) for petrale sole.

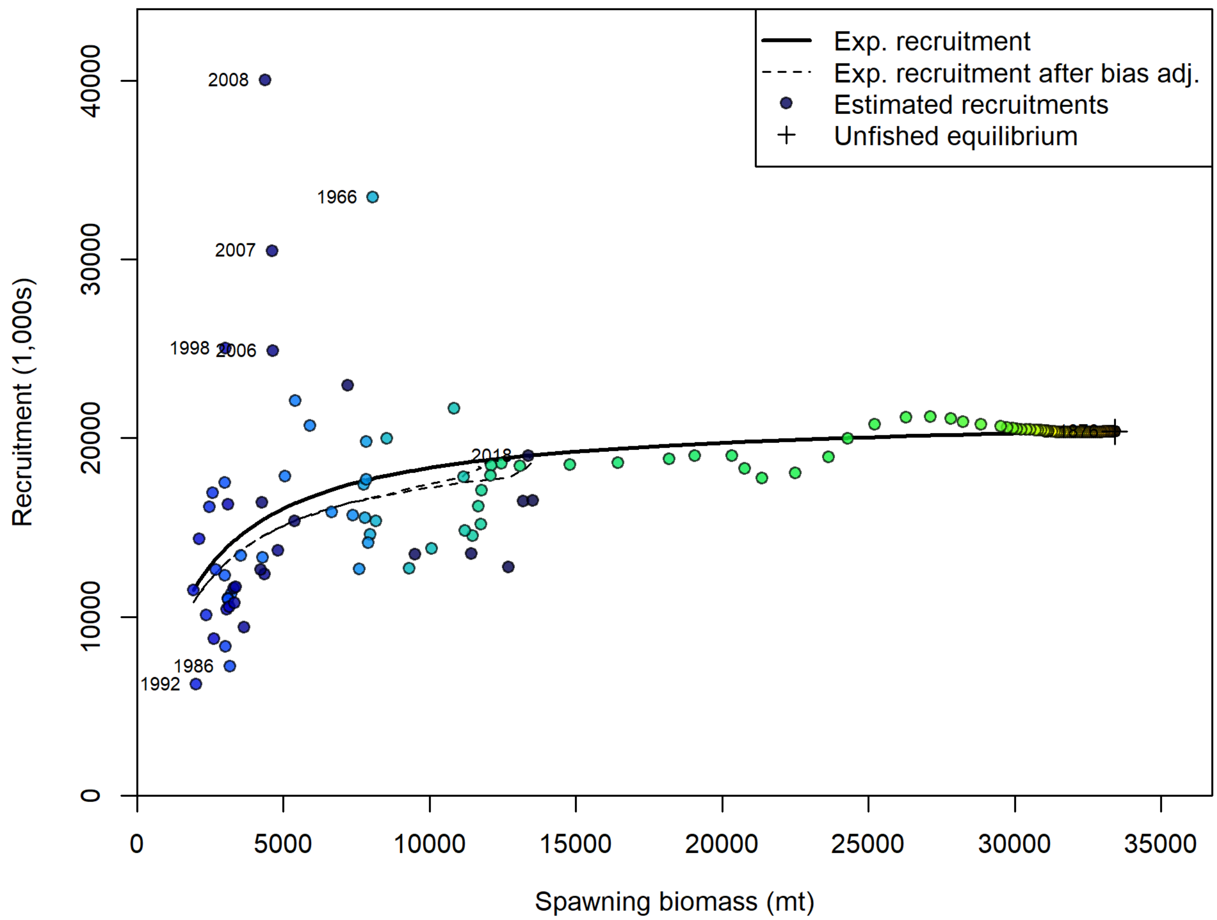


Figure 98: Estimated recruitment (colored circles) and the assumed stock-recruit relationship (solid black line). The dashed line shows the effect of the bias correction for the lognormal distribution.

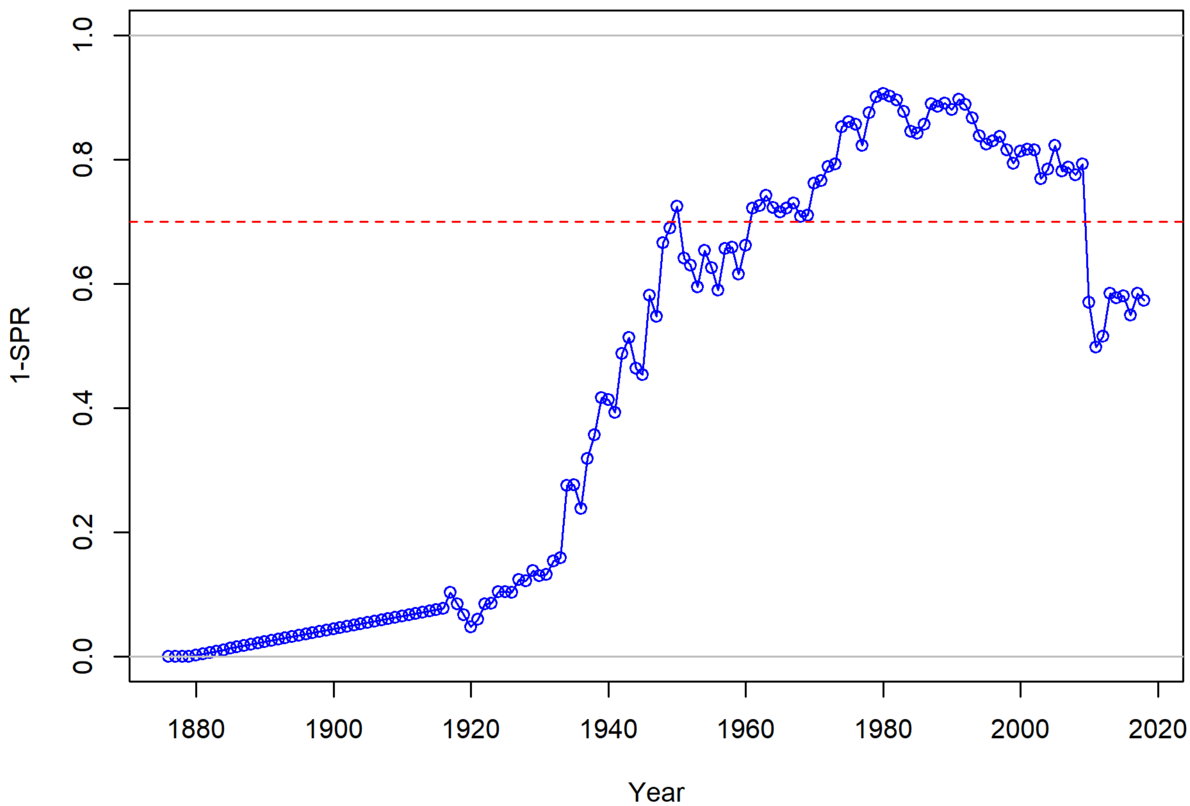


Figure 99: Estimated relative spawning potential ratio 1-SPR for the base model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the SPR30% harvest rate. The last year in the time-series is 2018.

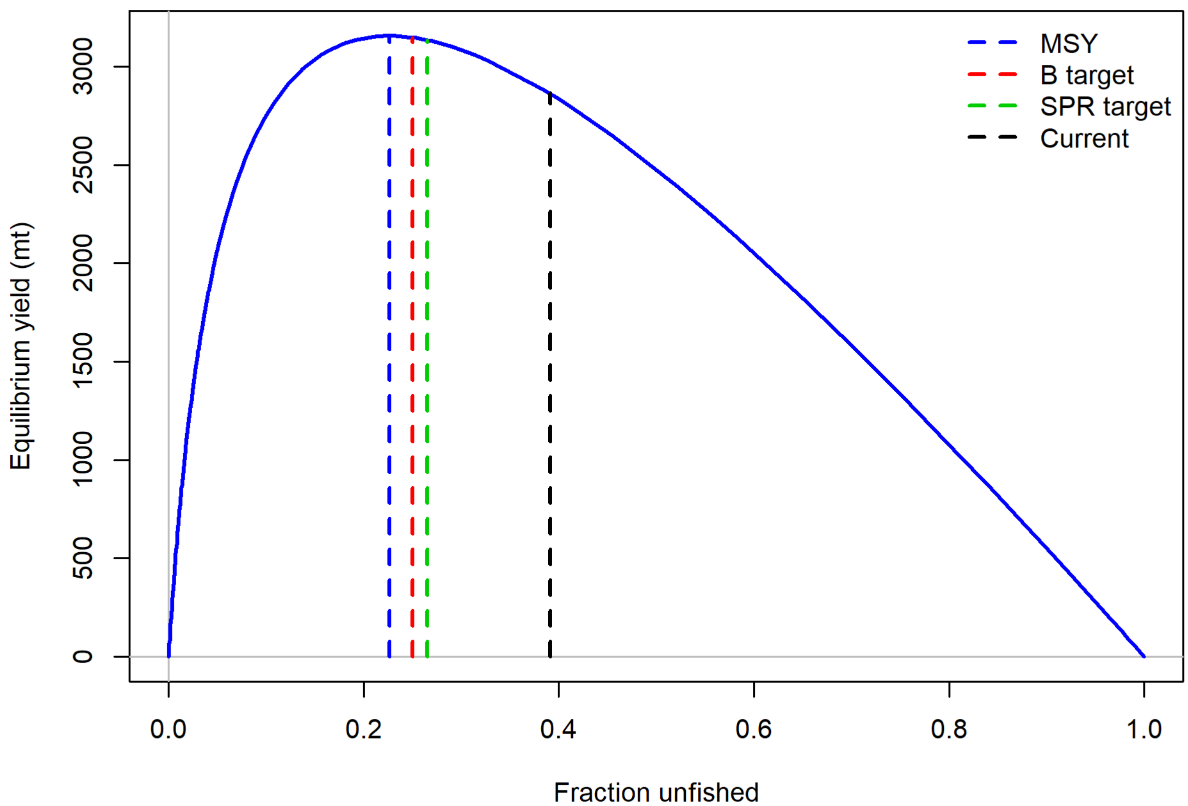


Figure 100: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness estimated at 0.84.

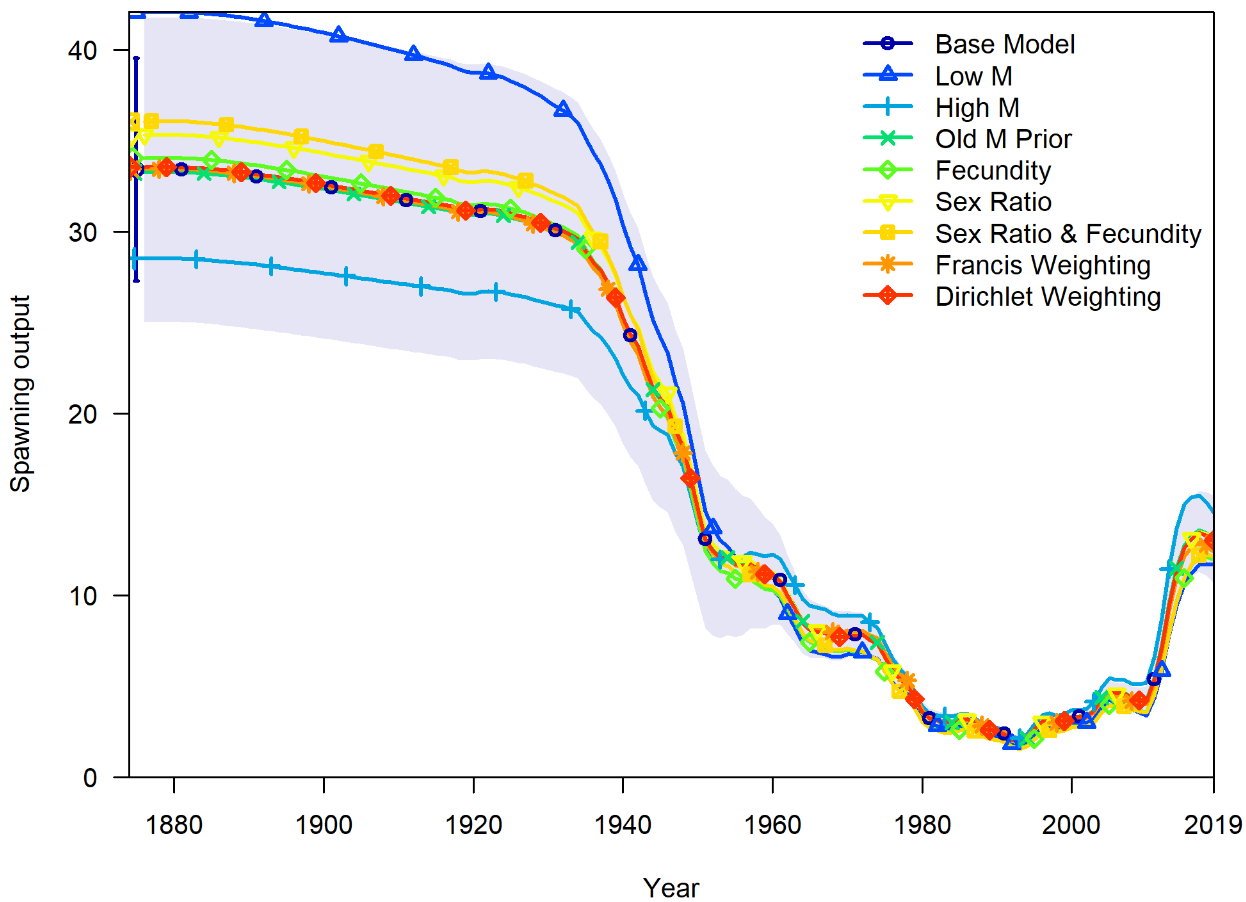


Figure 101: Estimated spawning biomass for the base model and each sensitivity.

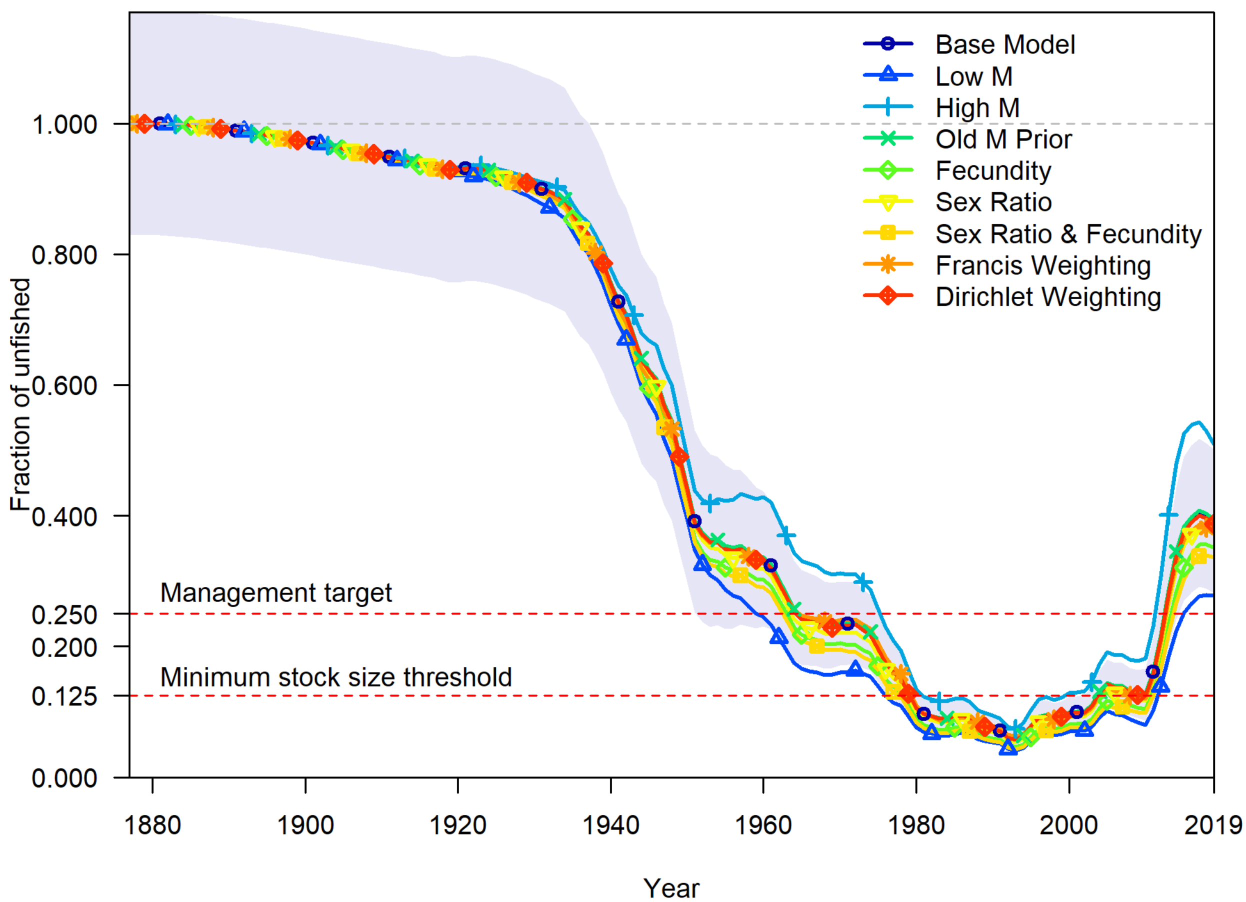


Figure 102: Estimated relative spawning biomass for the base model and each sensitivity.

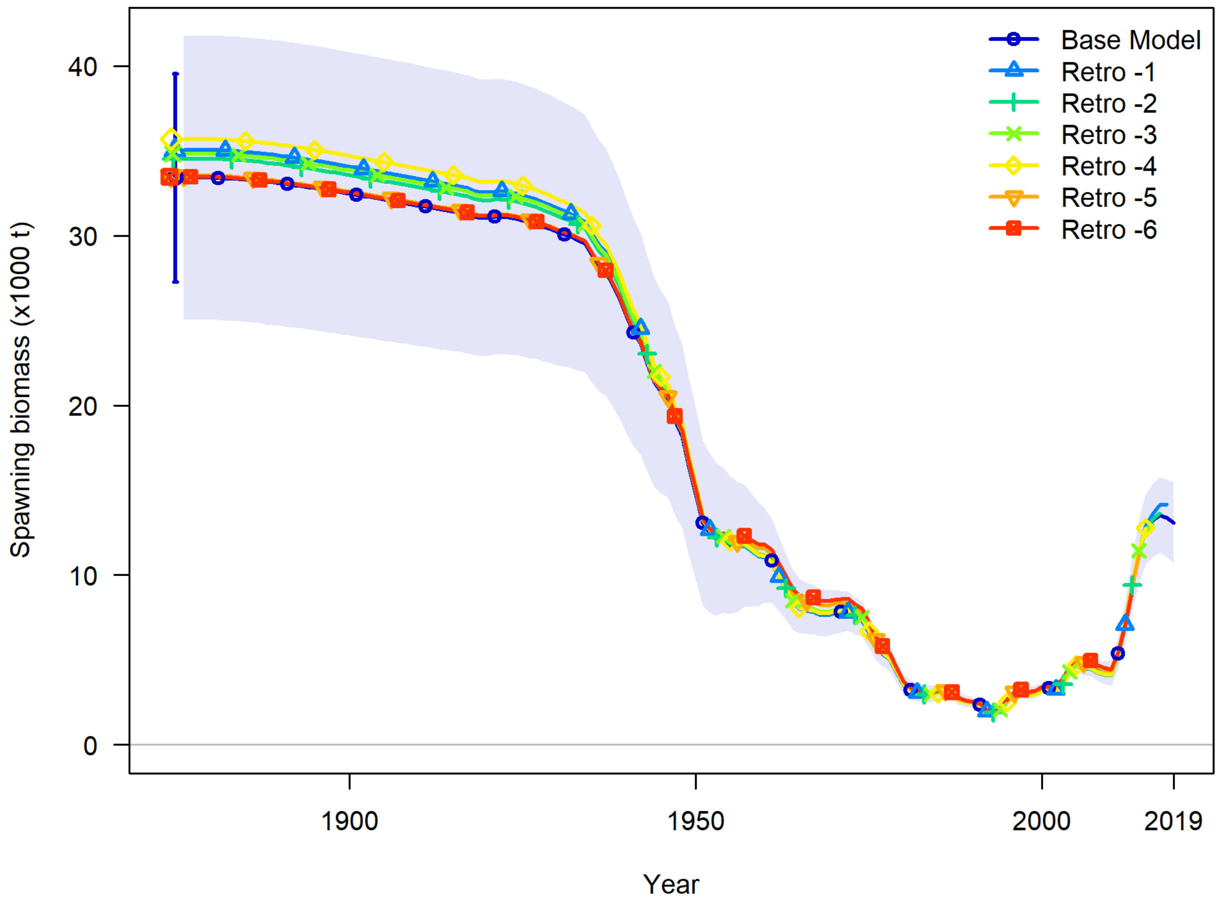


Figure 103: Retrospective pattern for spawning biomass.

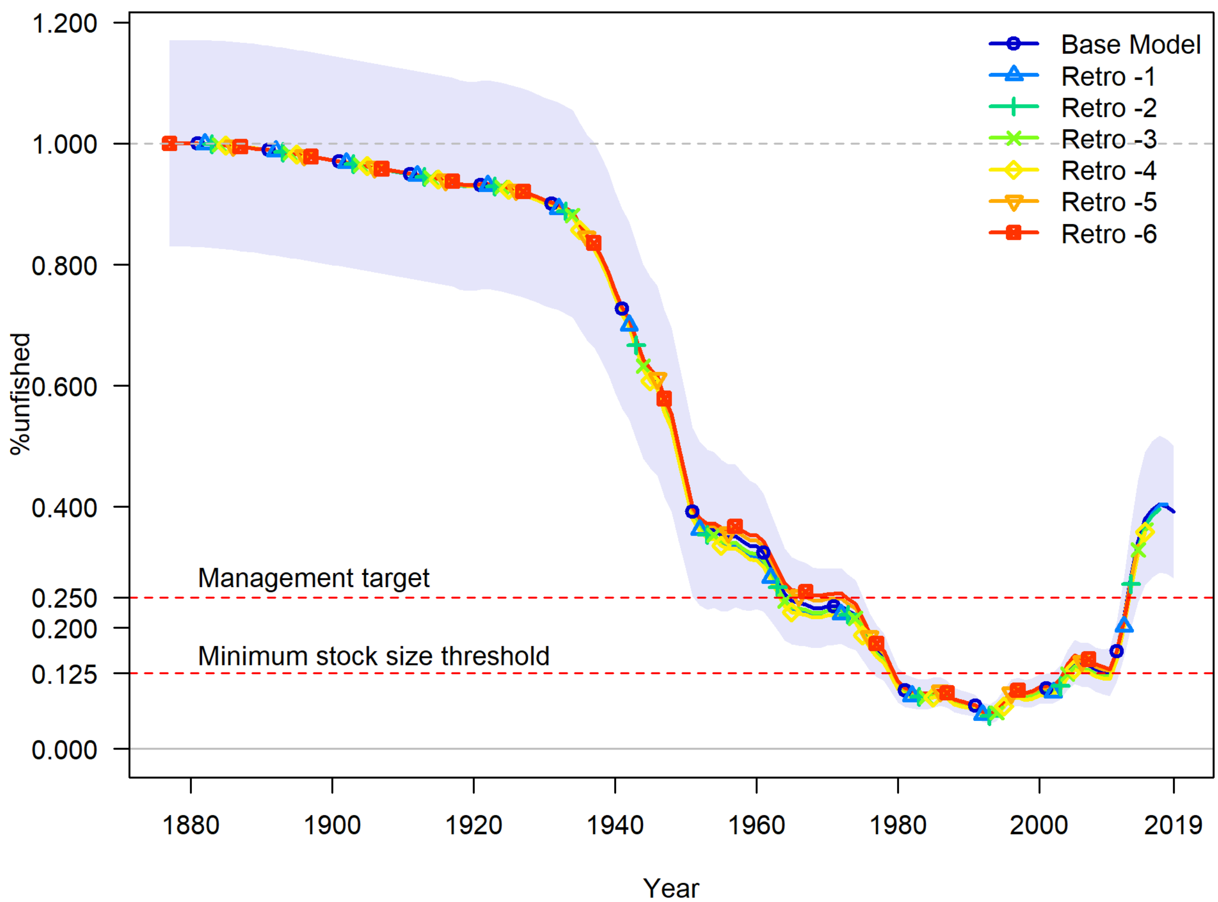


Figure 104: Retrospective pattern for relative spawning biomass.

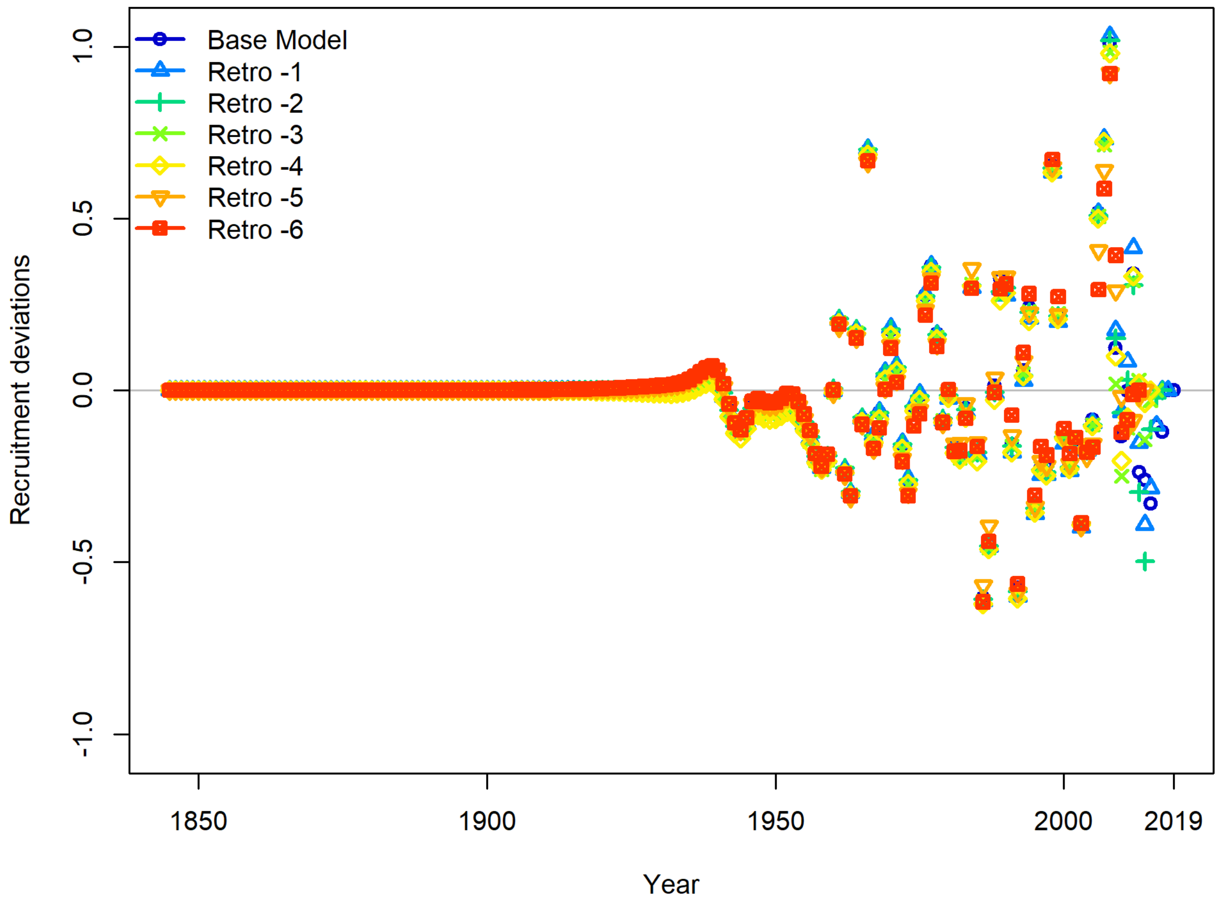


Figure 105: Retrospective pattern for estimated recruitment deviations.

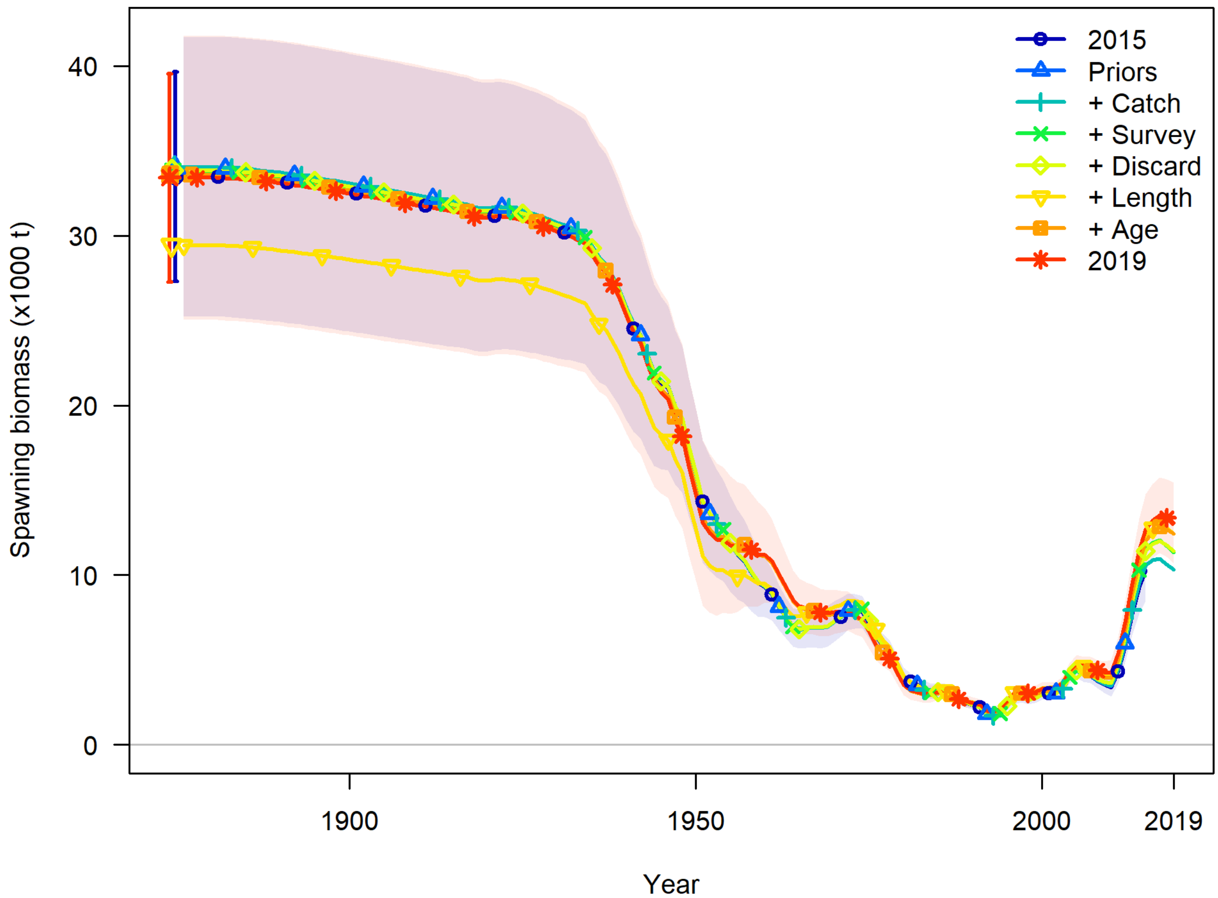


Figure 106: The estimated spawning output trajectory as each data source was updated relative to the 2015 update assessment.

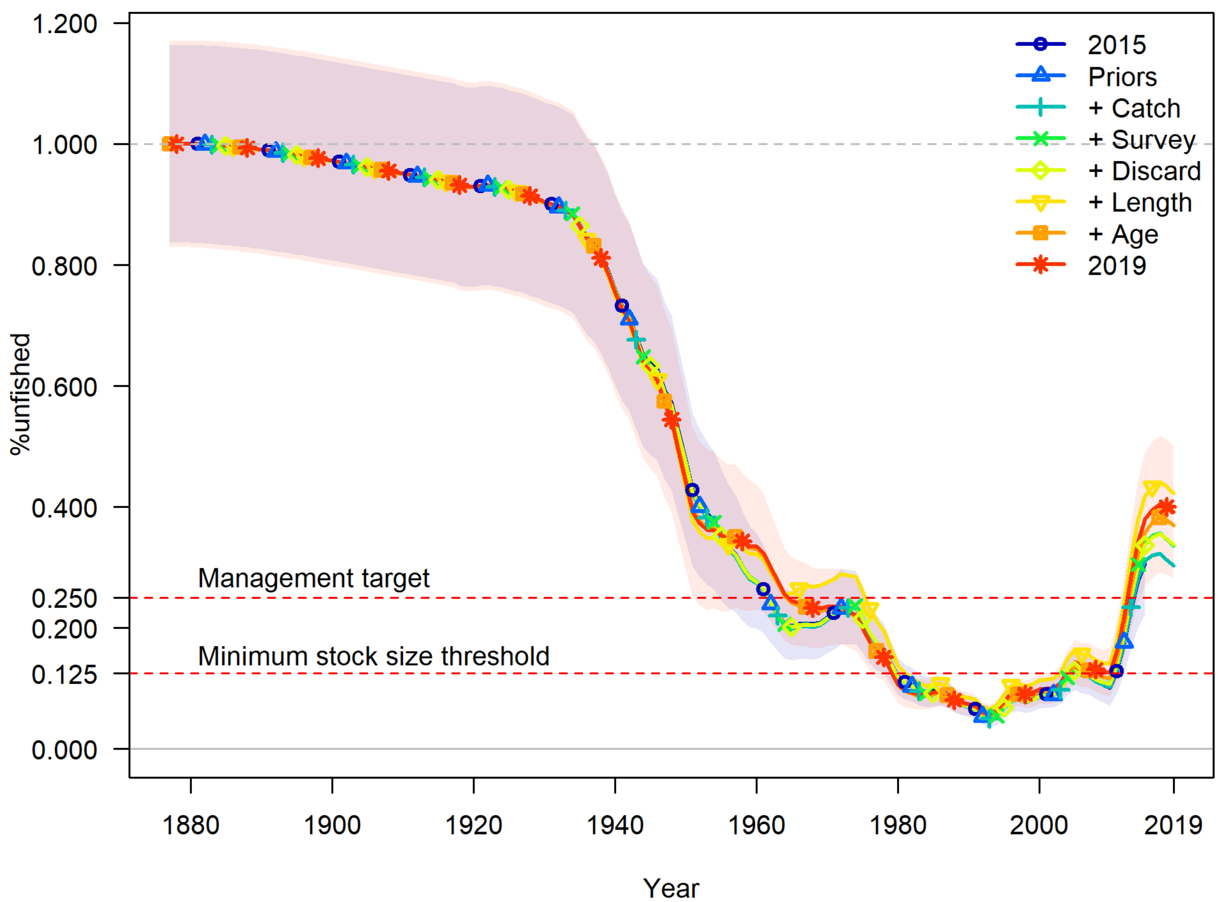


Figure 107: The estimated relative spawning output trajectory as each data source was updated relative to the 2015 update assessment.

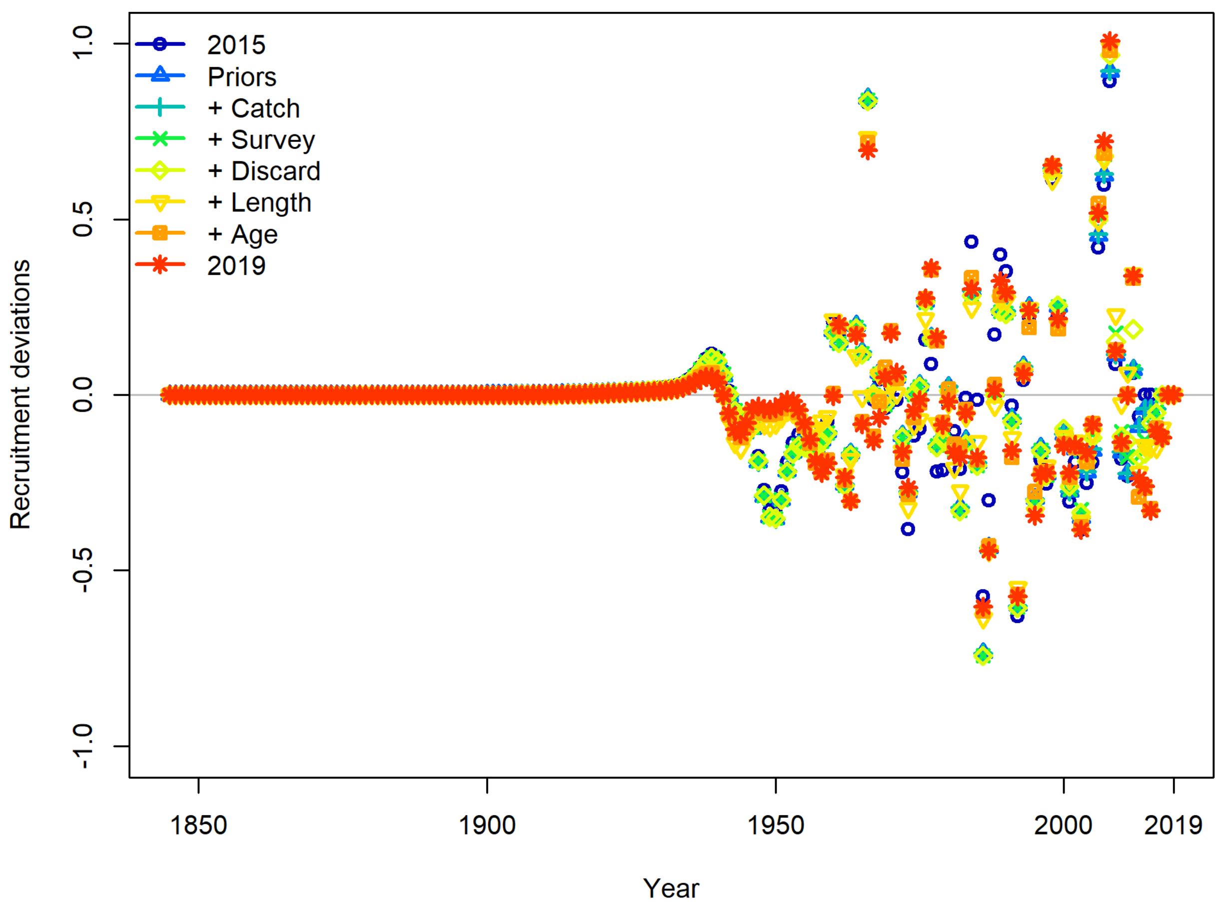


Figure 108: The estimated annual recruitment deviations as each data source was updated relative to the 2015 update assessment.

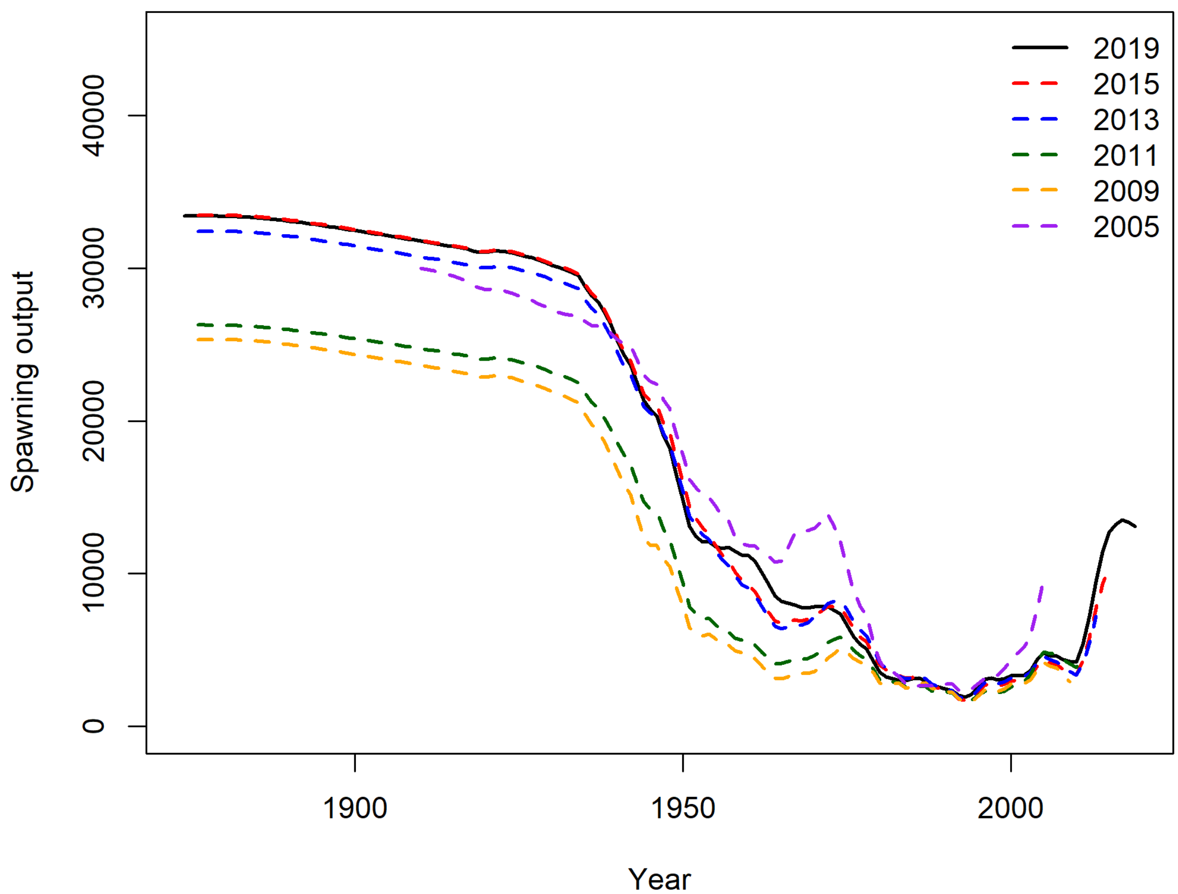


Figure 109: The estimated spawning output from each assessment since 2005.

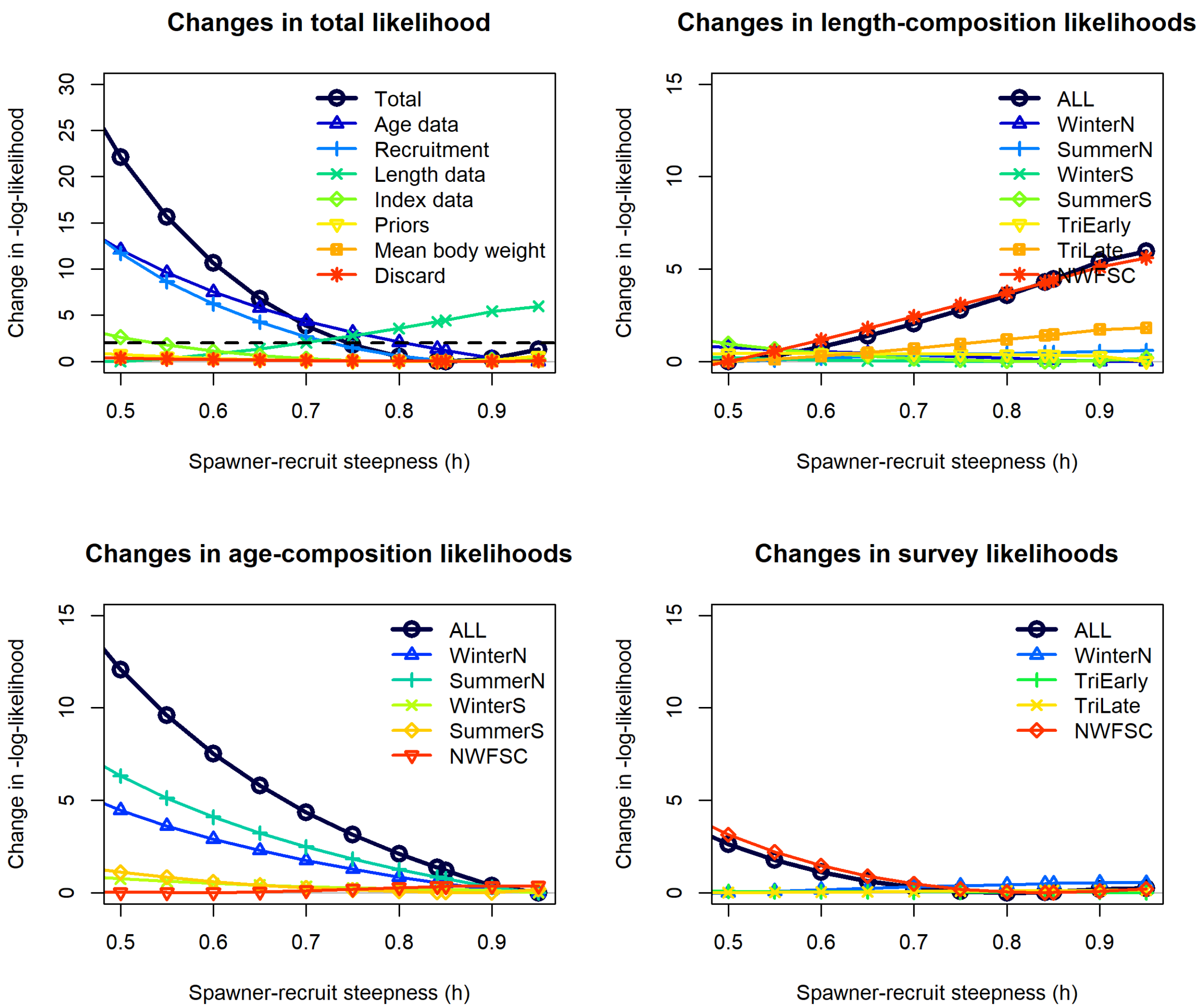


Figure 110: Likelihood profile across steepness values.

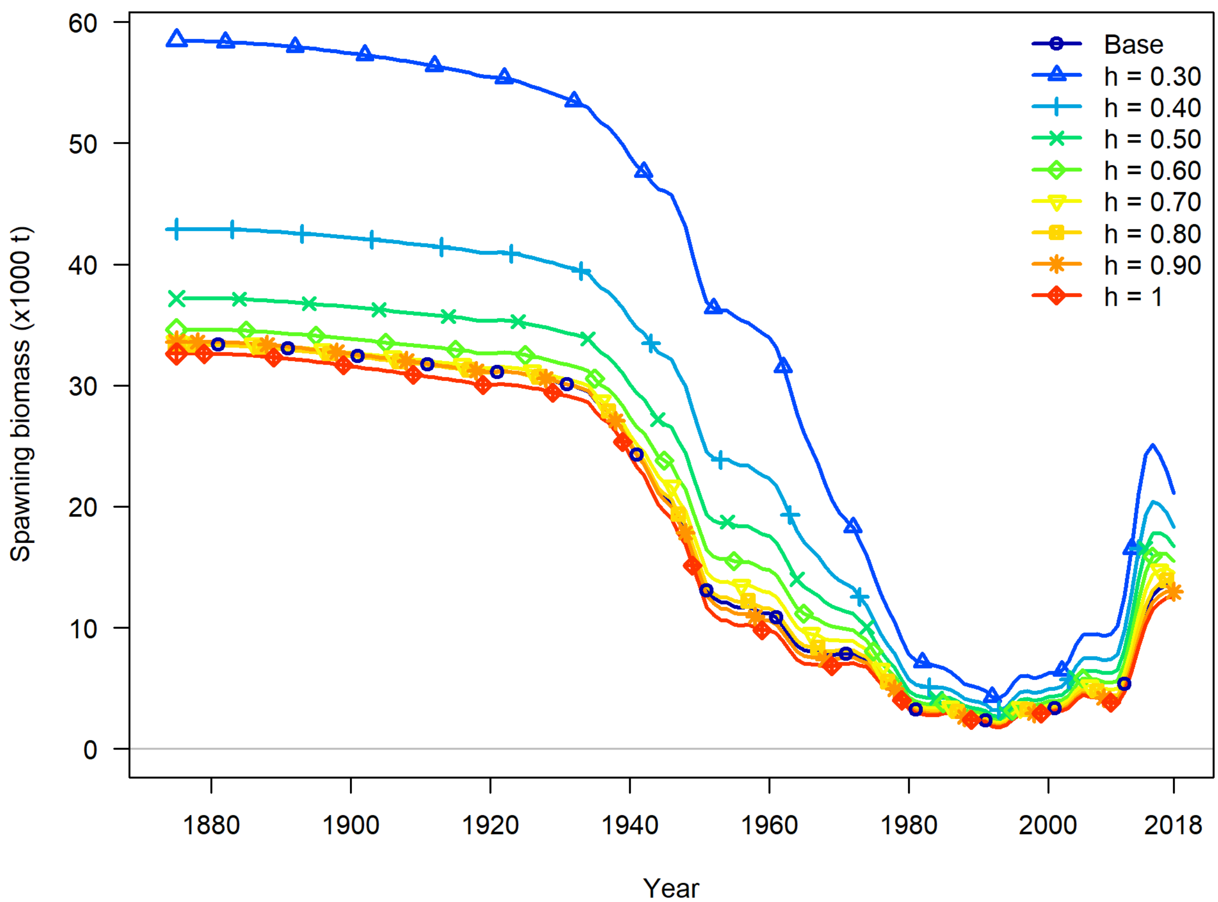


Figure 111: Trajectories of spawning output across values of steepness.

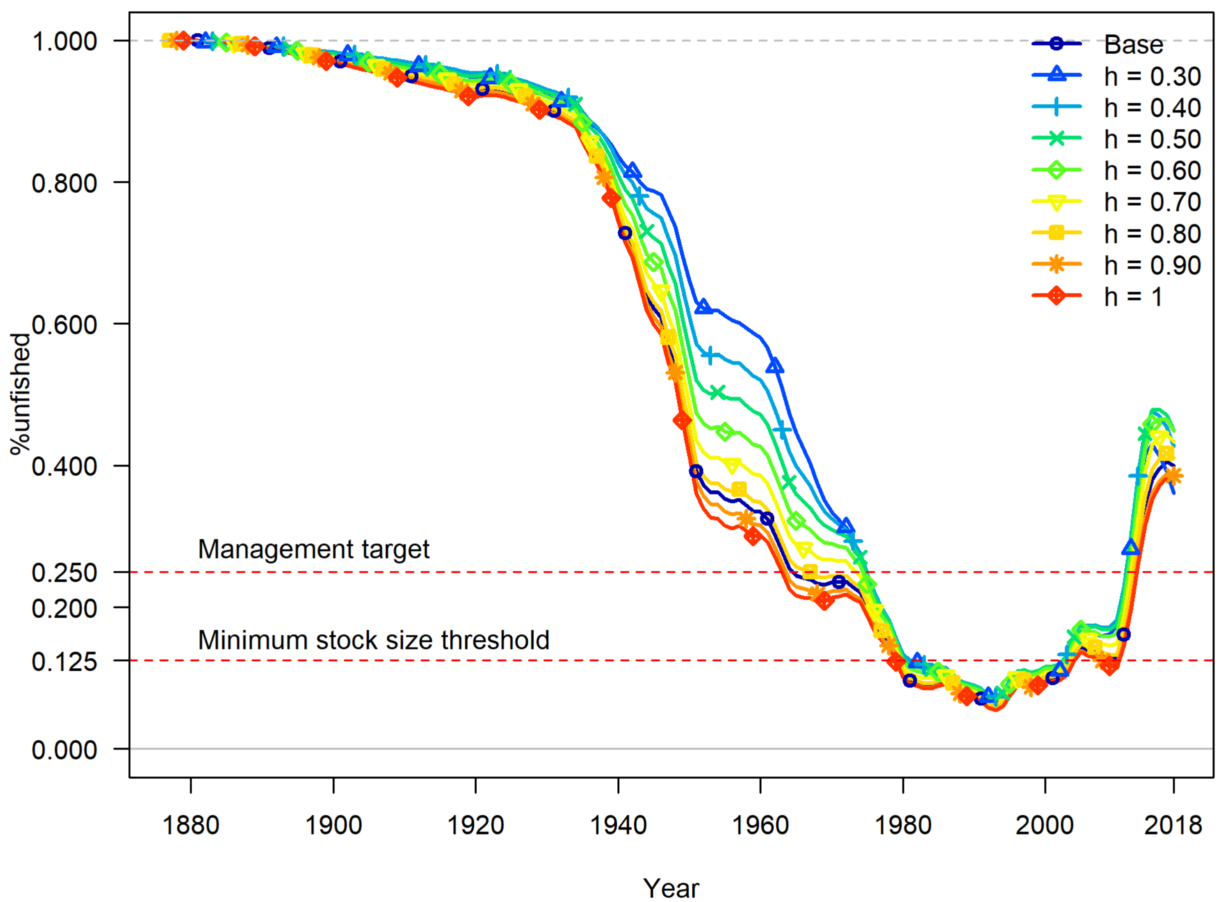


Figure 112: Trajectories of relative spawning output across values of steepness.

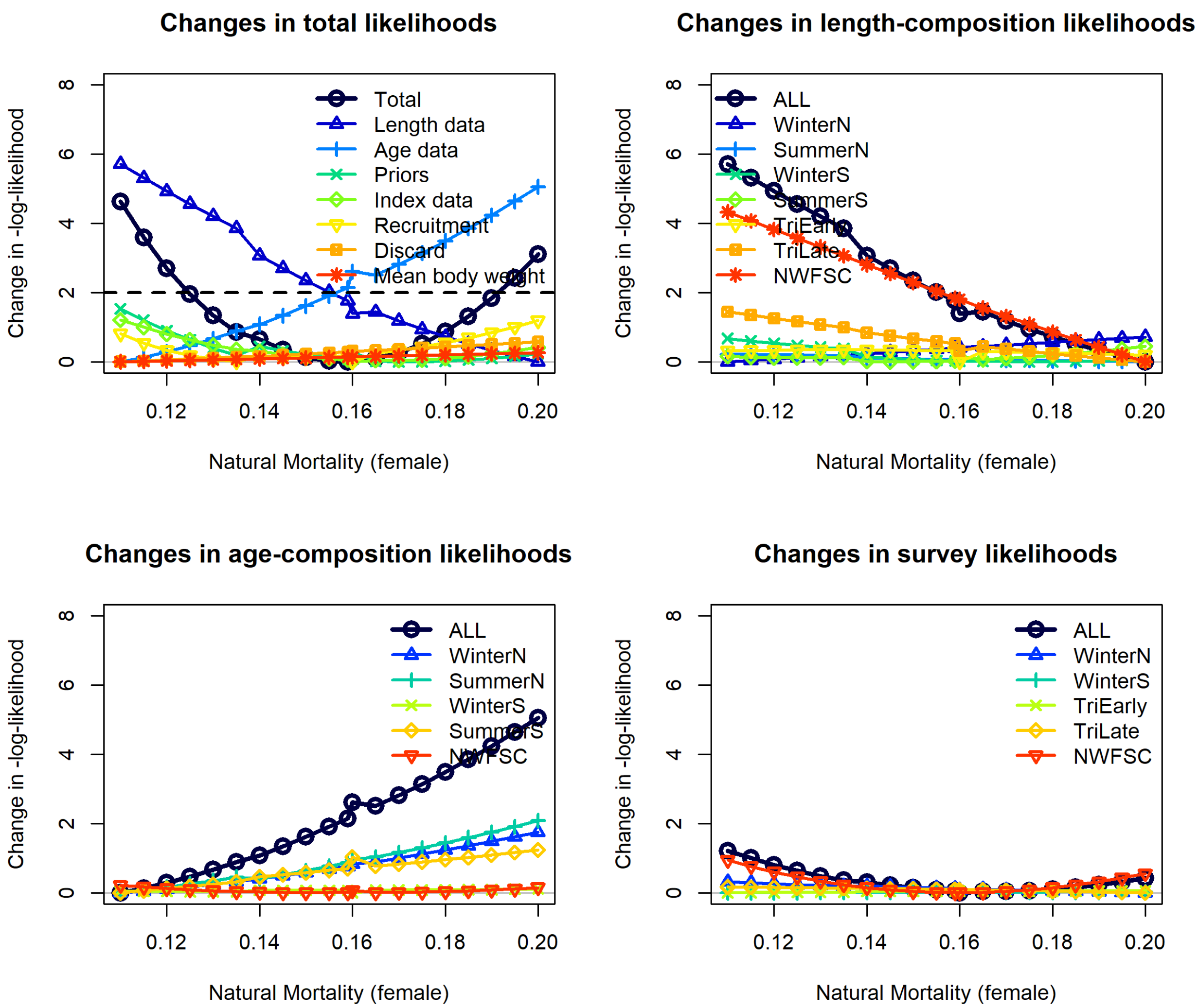


Figure 113: Likelihood profile across female natural mortality values. Male natural mortality was estimated.

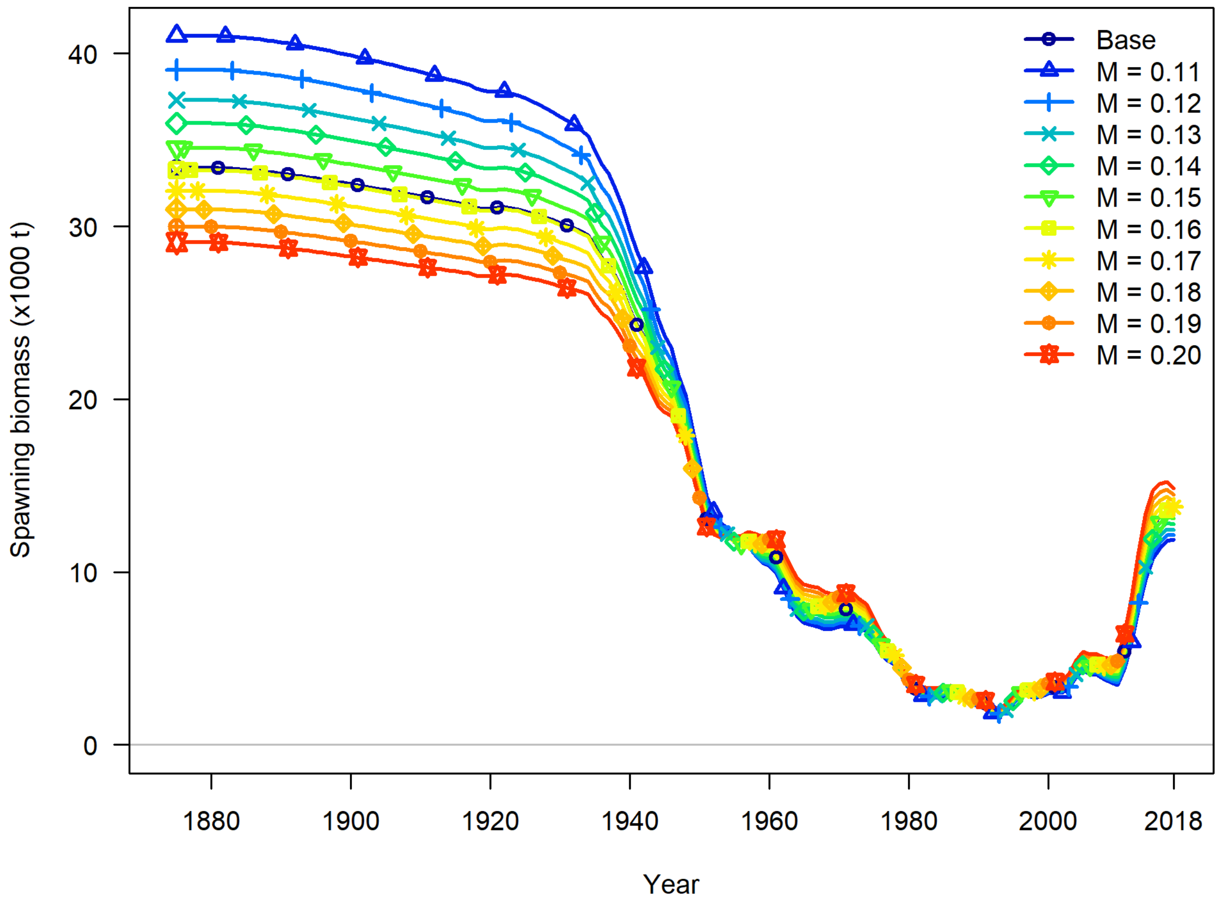


Figure 114: Trajectories of spawning output across values of natural mortality.

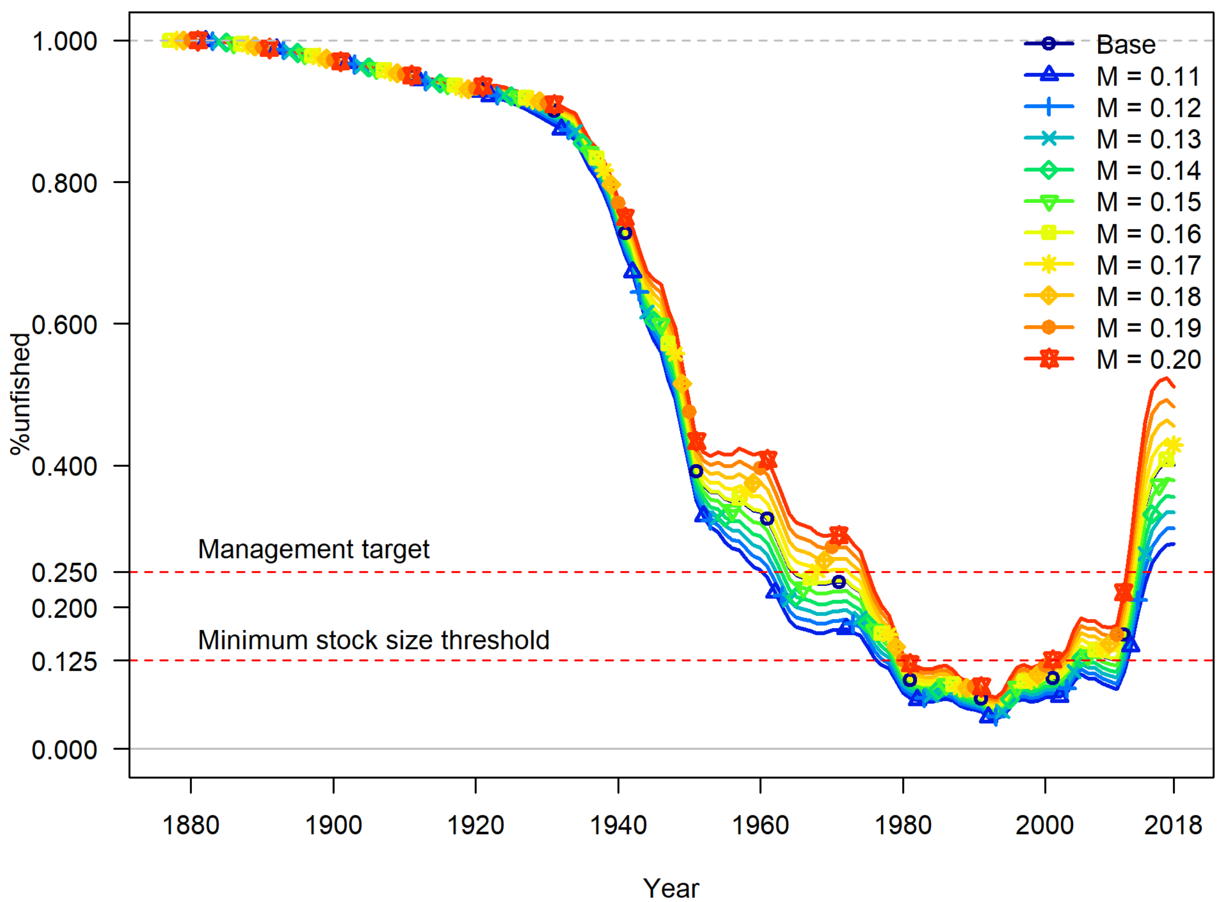


Figure 115: Trajectories of relative spawning output across values of natural mortality.

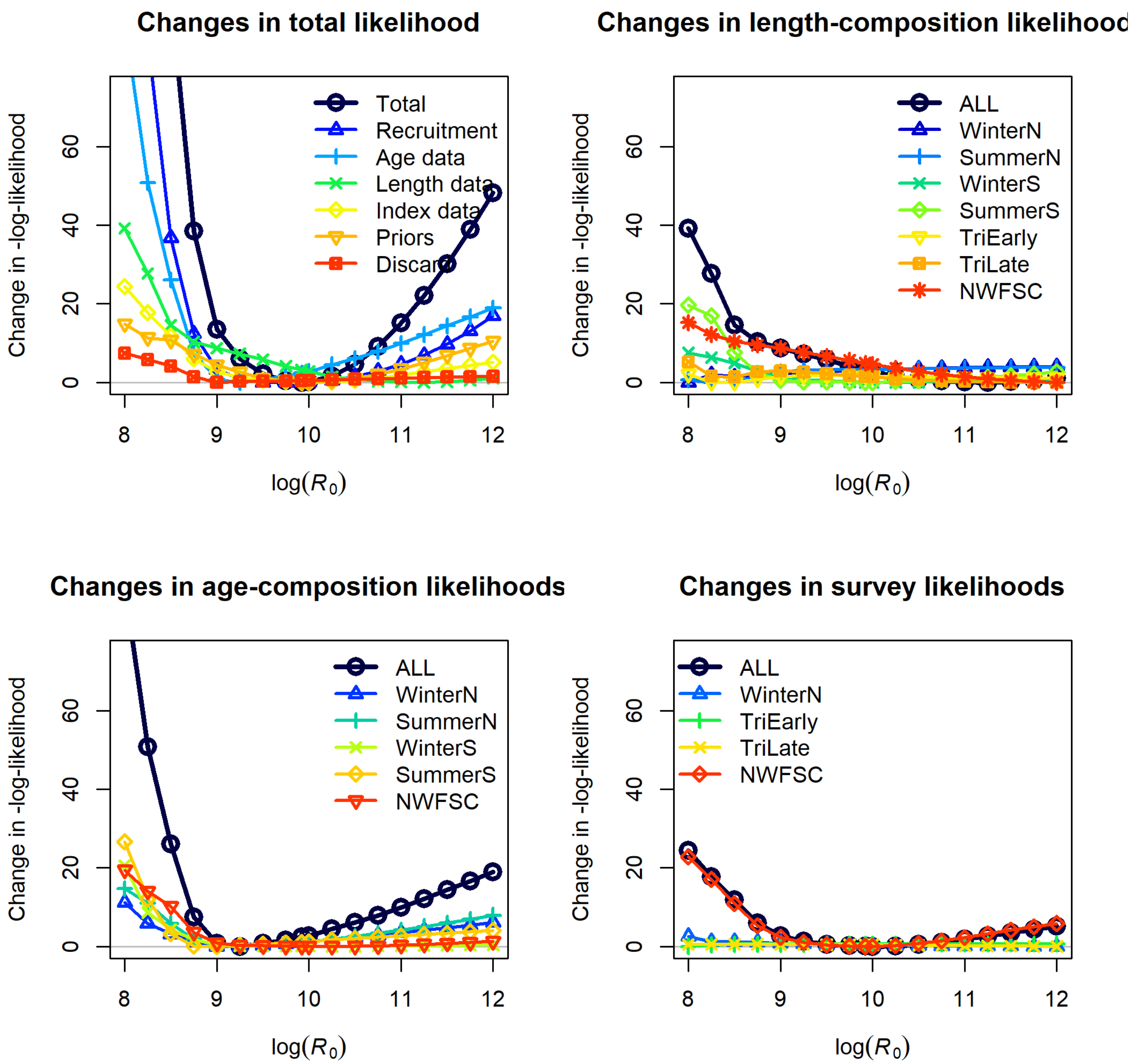


Figure 116: Likelihood profile across R_0 values.

12 Appendix A. Detailed Fit to Length Composition Data

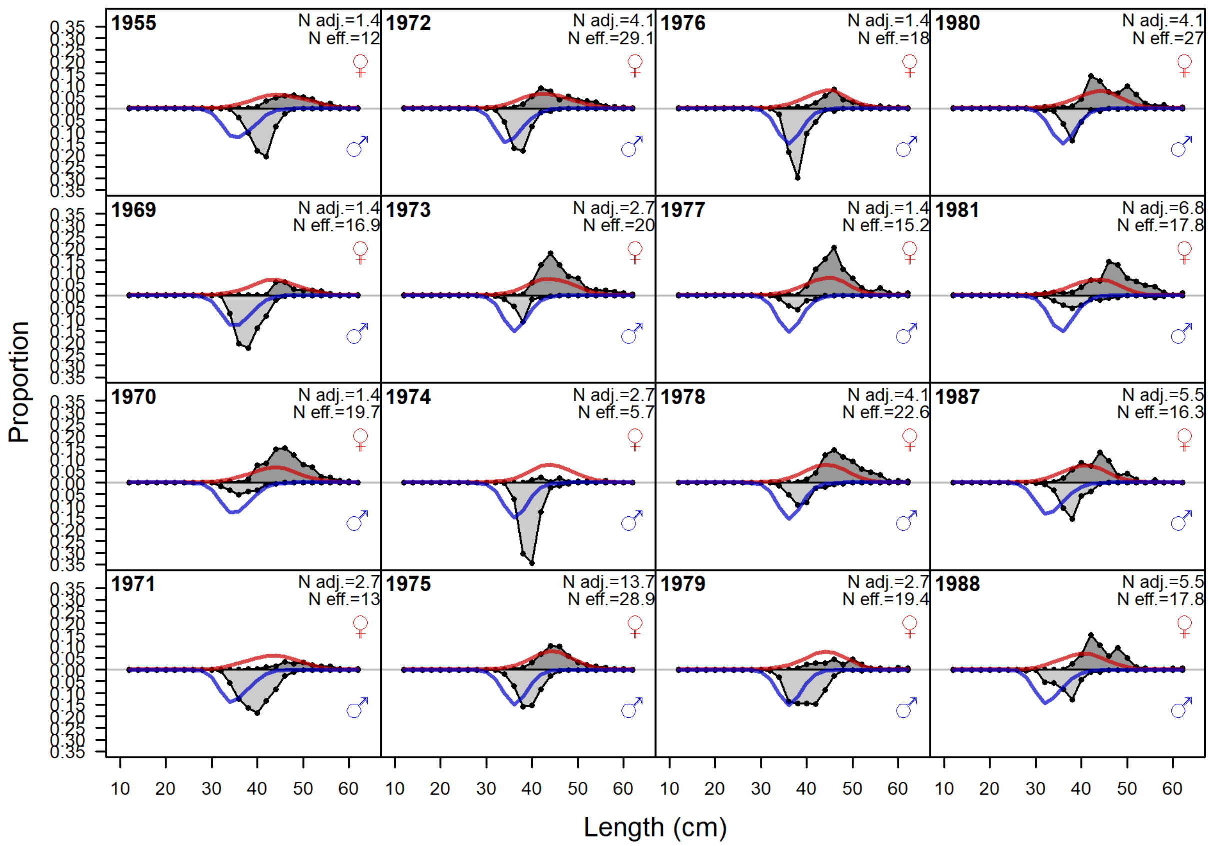


Figure 117: Length comps, retained, Winter (N) (plot 1 of 3). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

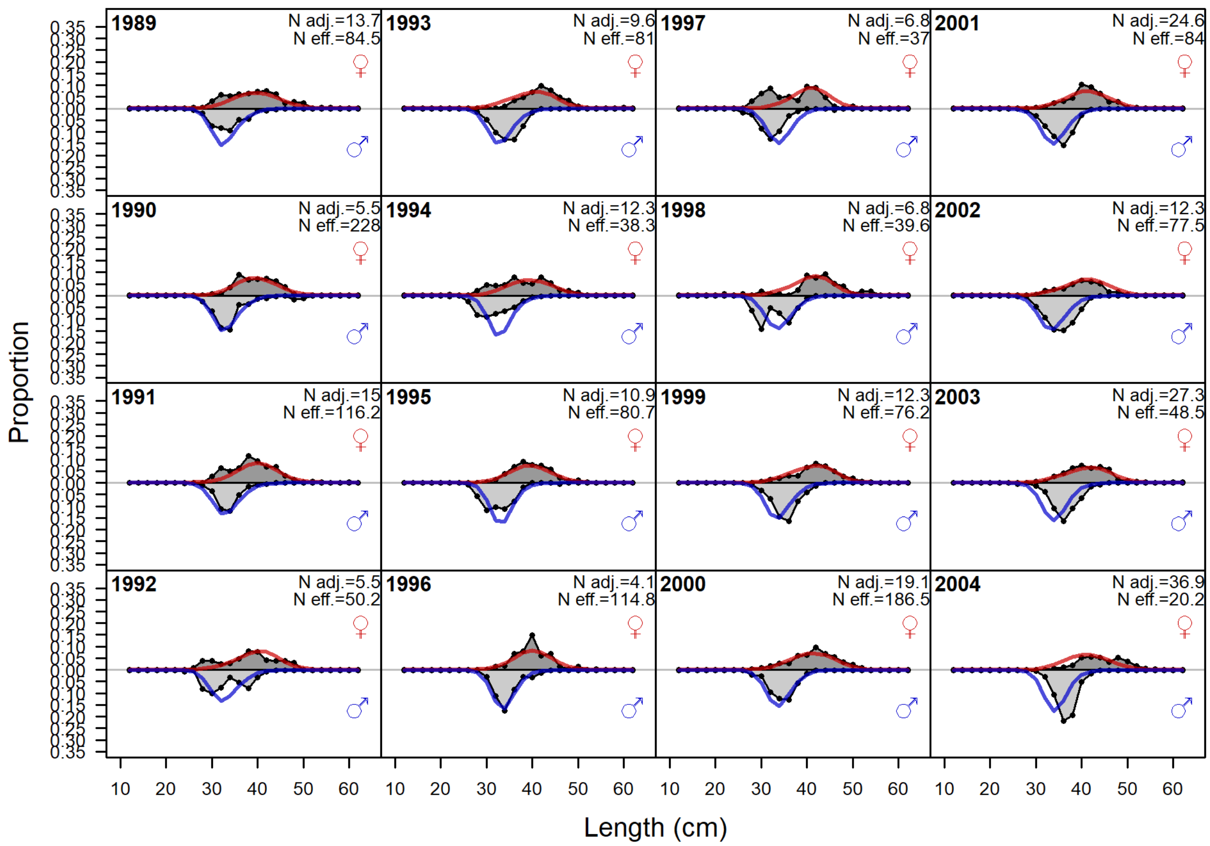


Figure 118: Length comps, retained, Winter (N) (plot 2 of 3)

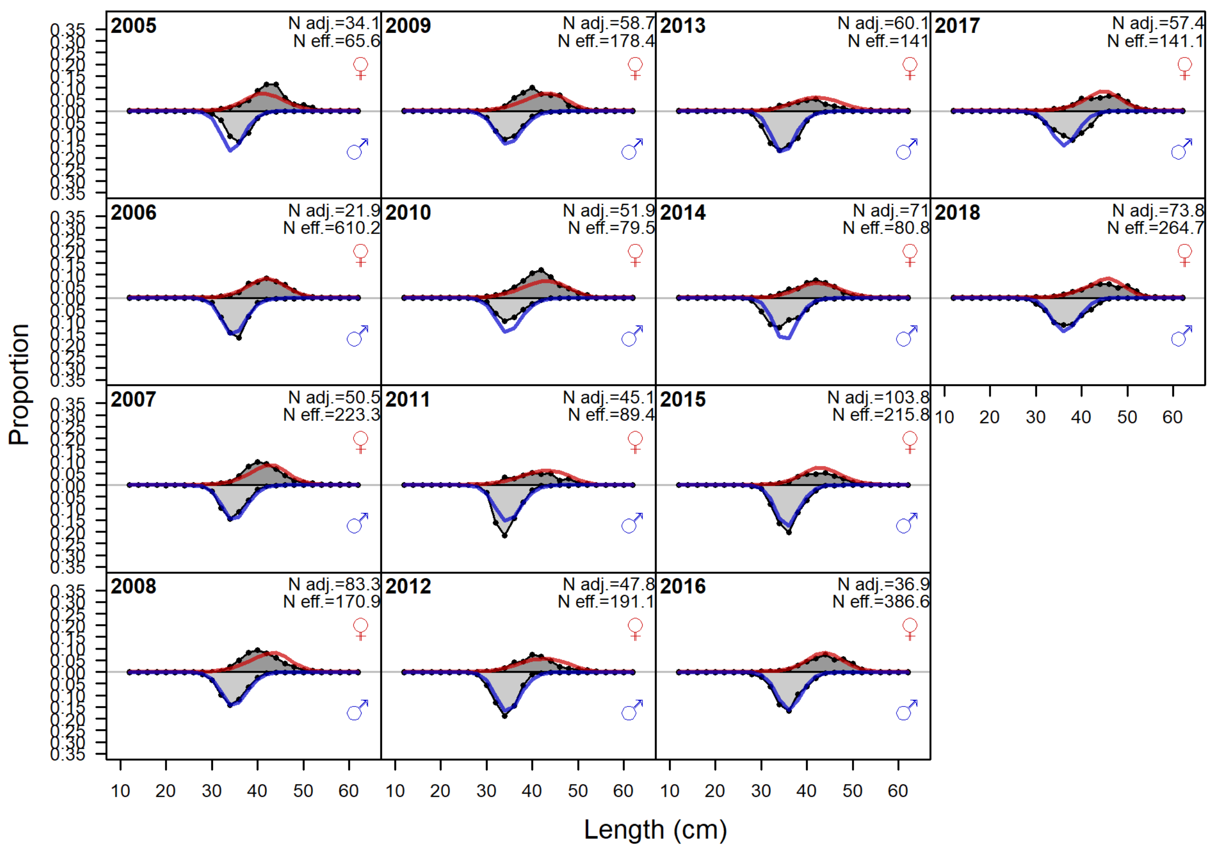


Figure 119: Length comps, retained, Winter (N) (plot 3 of 3)

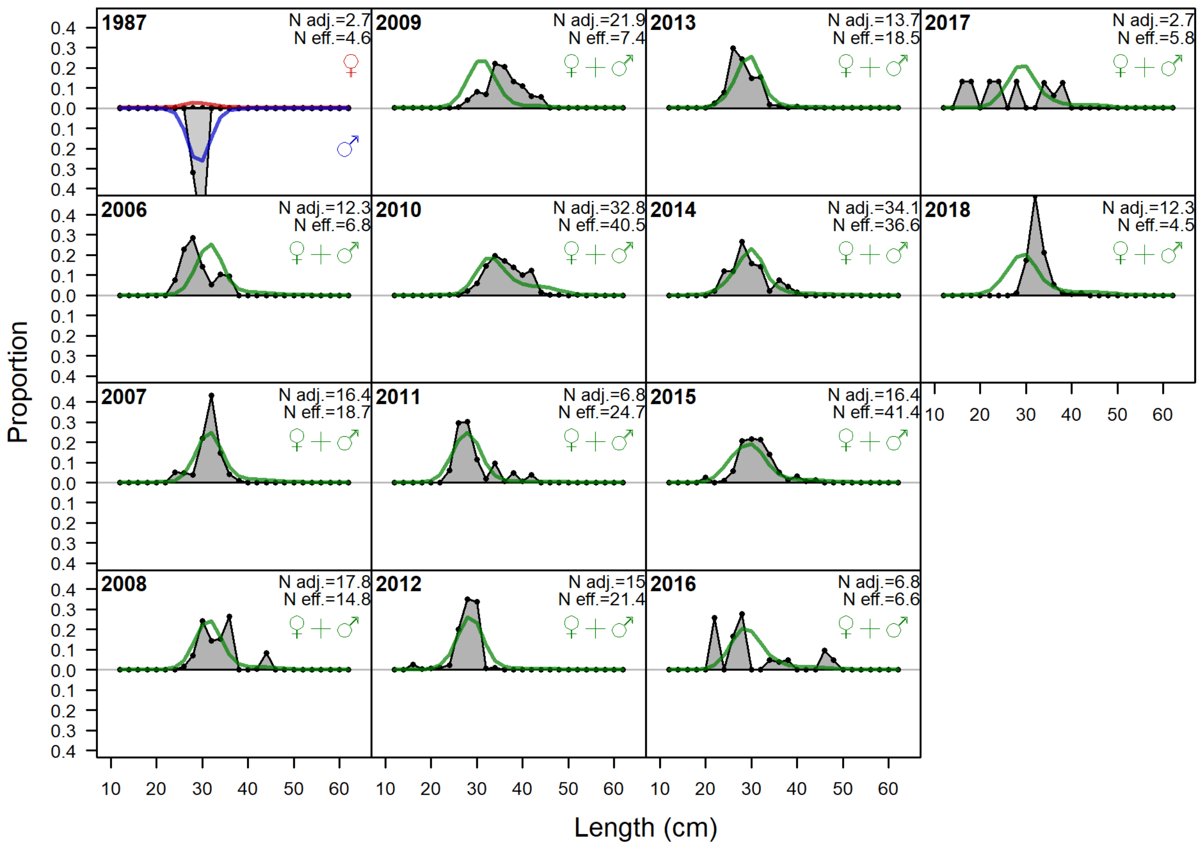


Figure 120: Length comps, discard, Winter (N). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

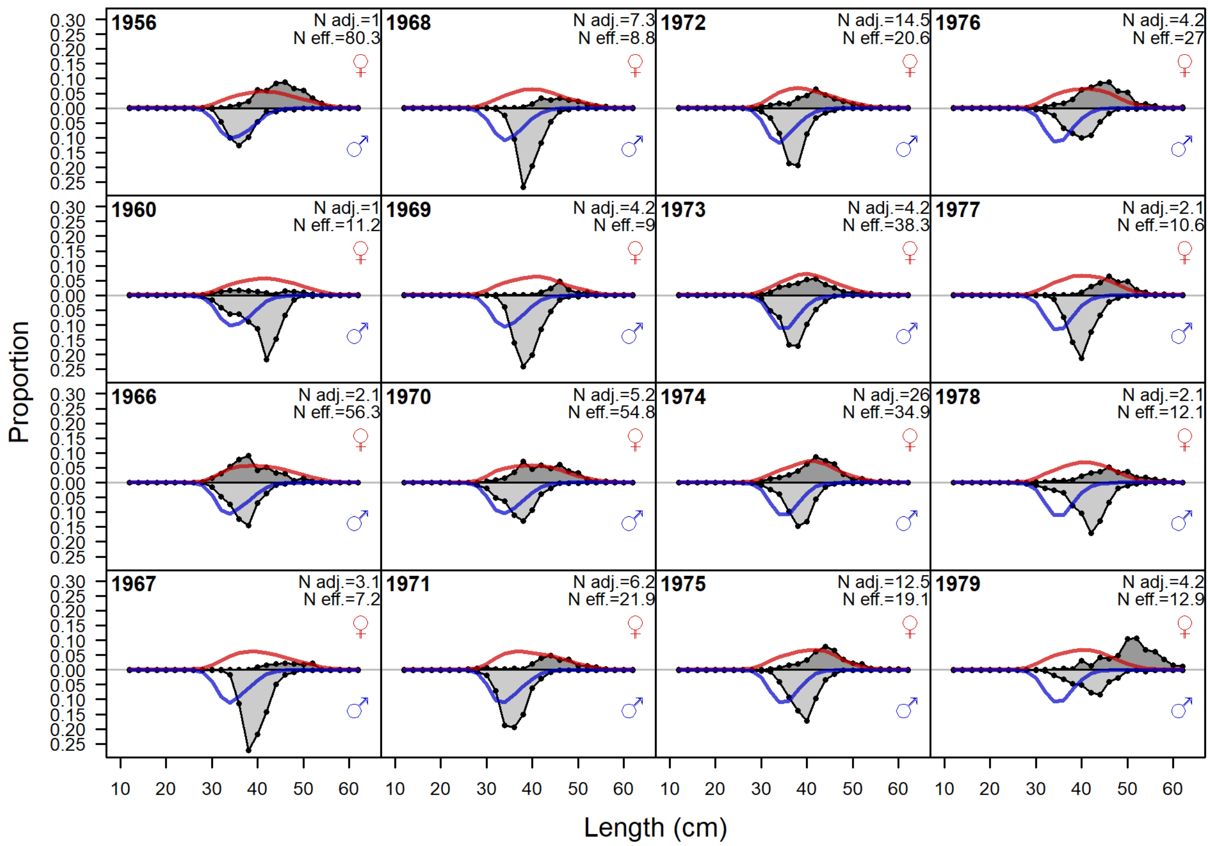


Figure 121: Length comps, retained, Summer (N) (plot 1 of 4). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

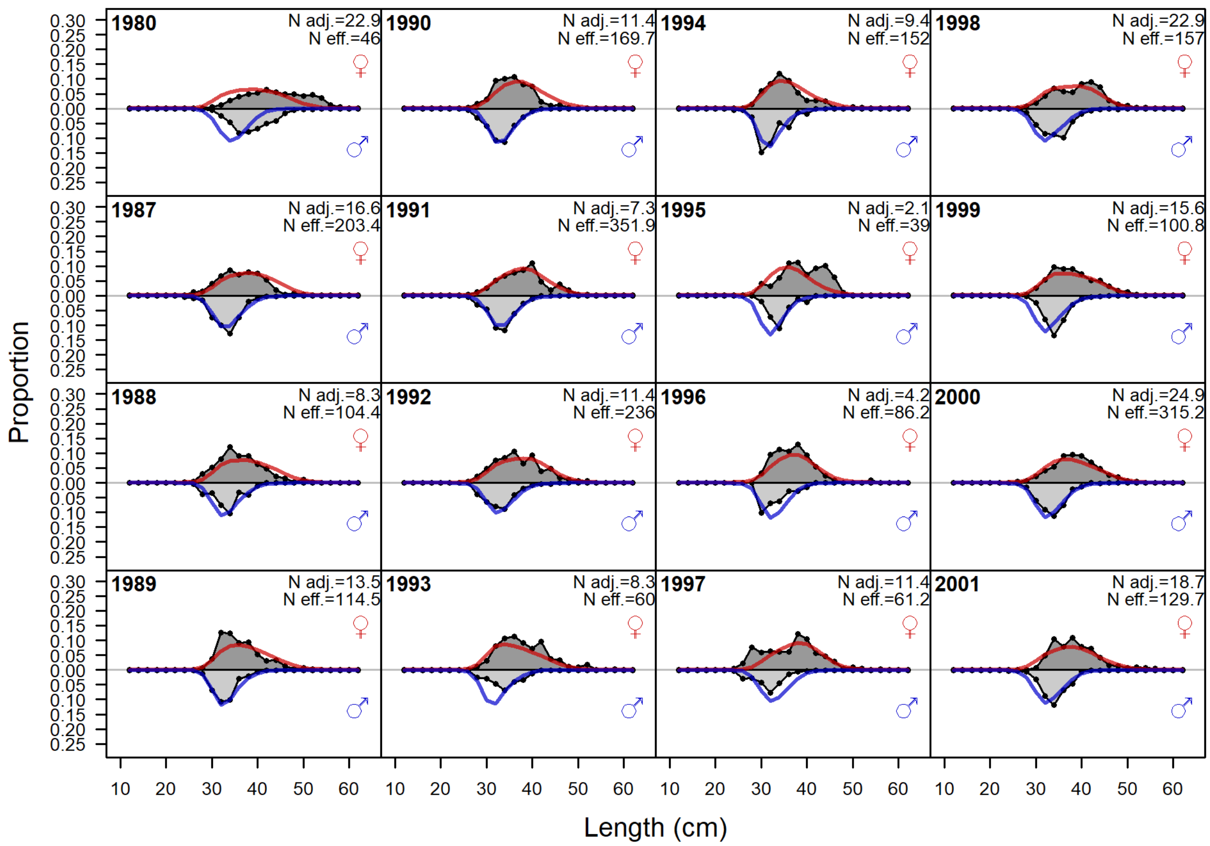


Figure 122: Length comps, retained, Summer (N) (plot 2 of 4)

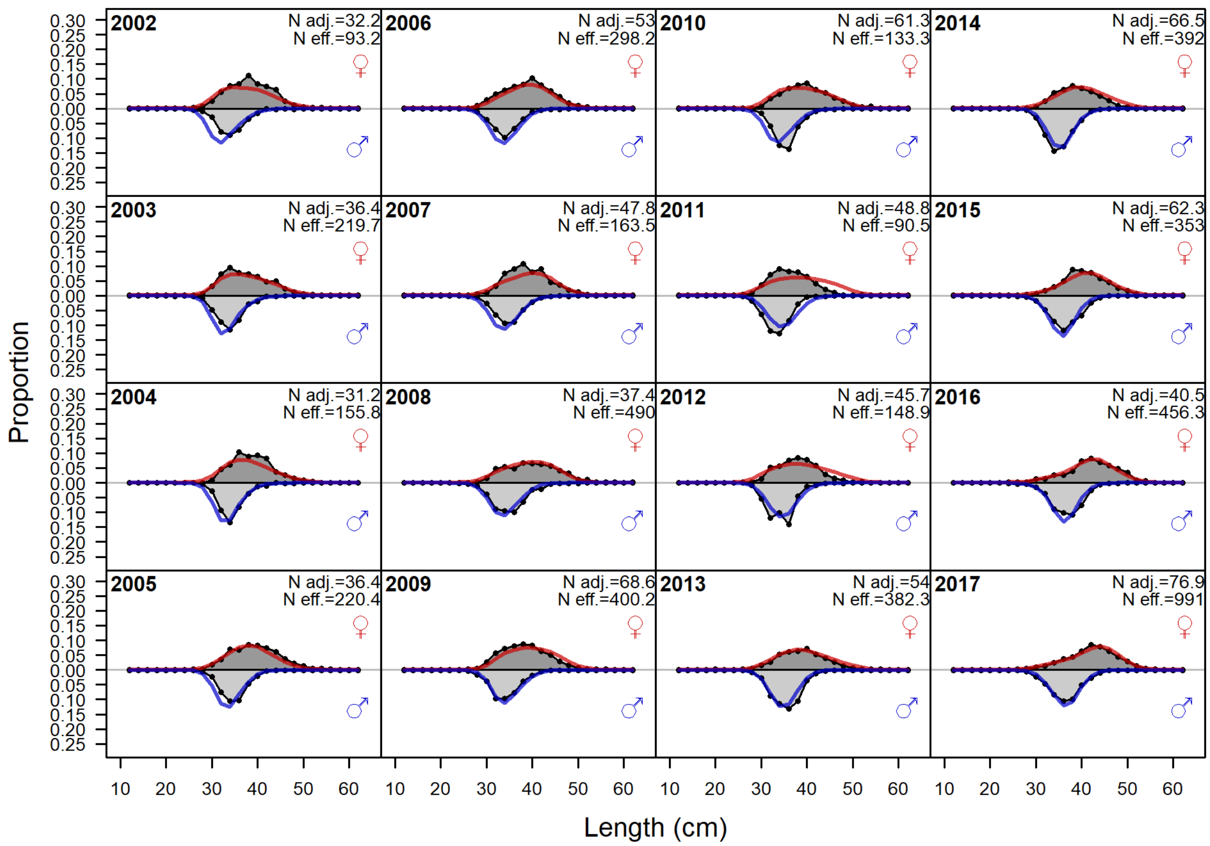


Figure 123: Length comps, retained, Summer (N) (plot 3 of 4)

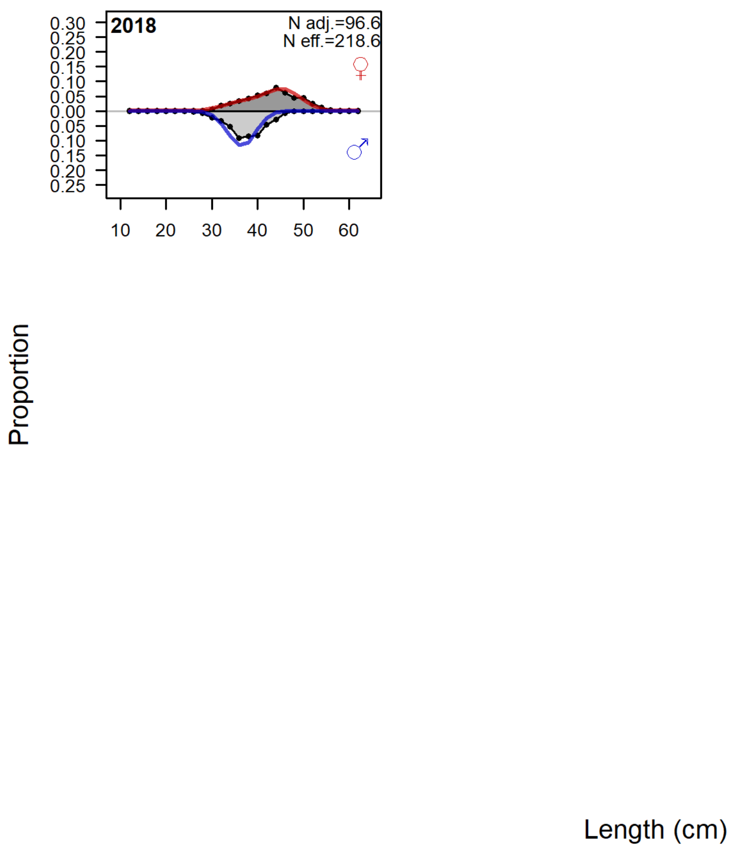


Figure 124: Length comps, retained, Summer (N) (plot 4 of 4)

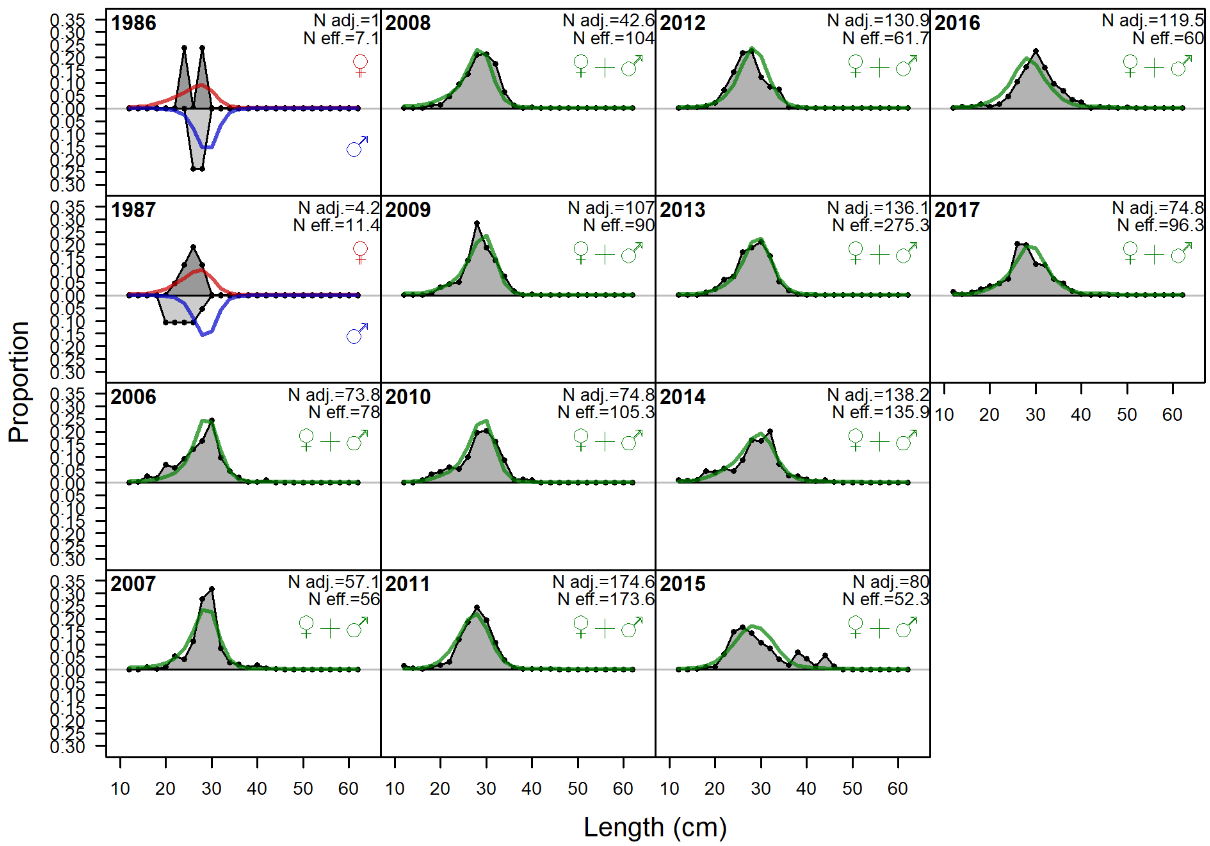


Figure 125: Length comps, discard, Summer (N). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

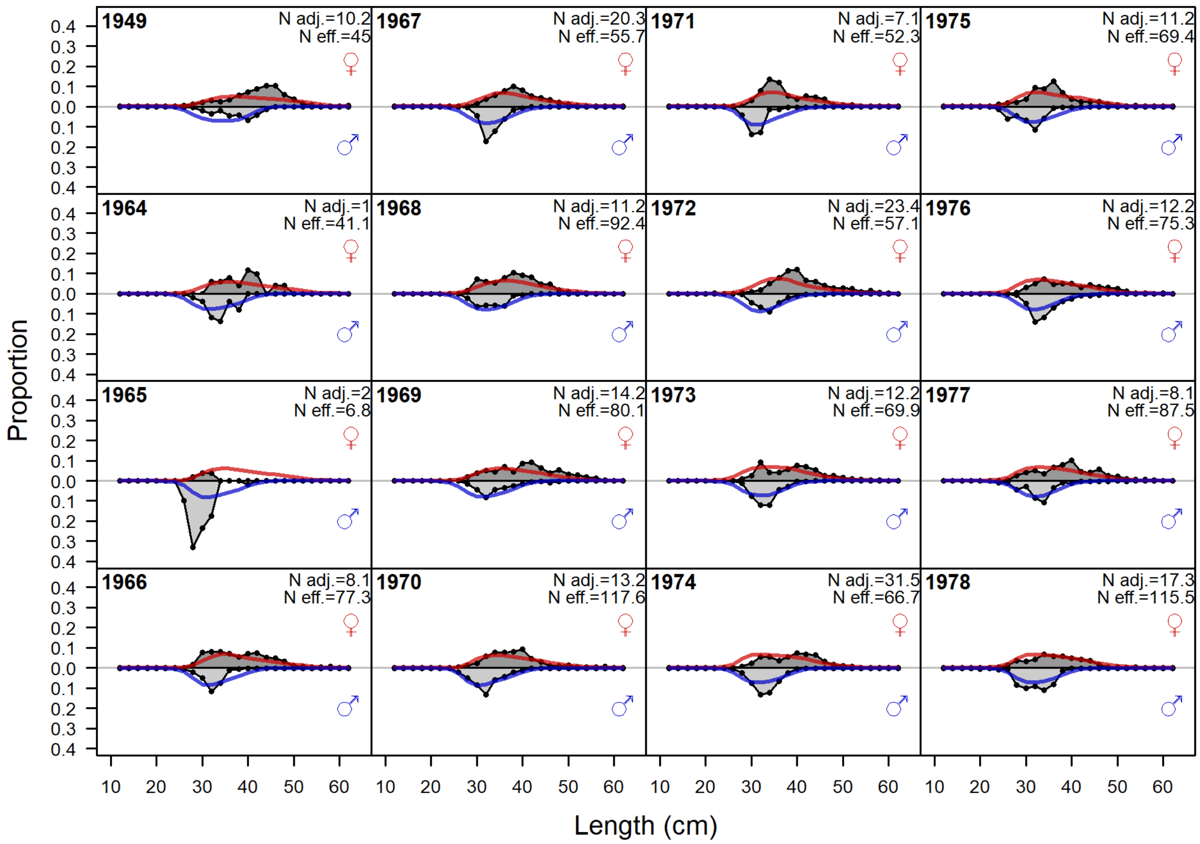


Figure 126: Length comps, retained, Winter (S) (plot 1 of 3). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

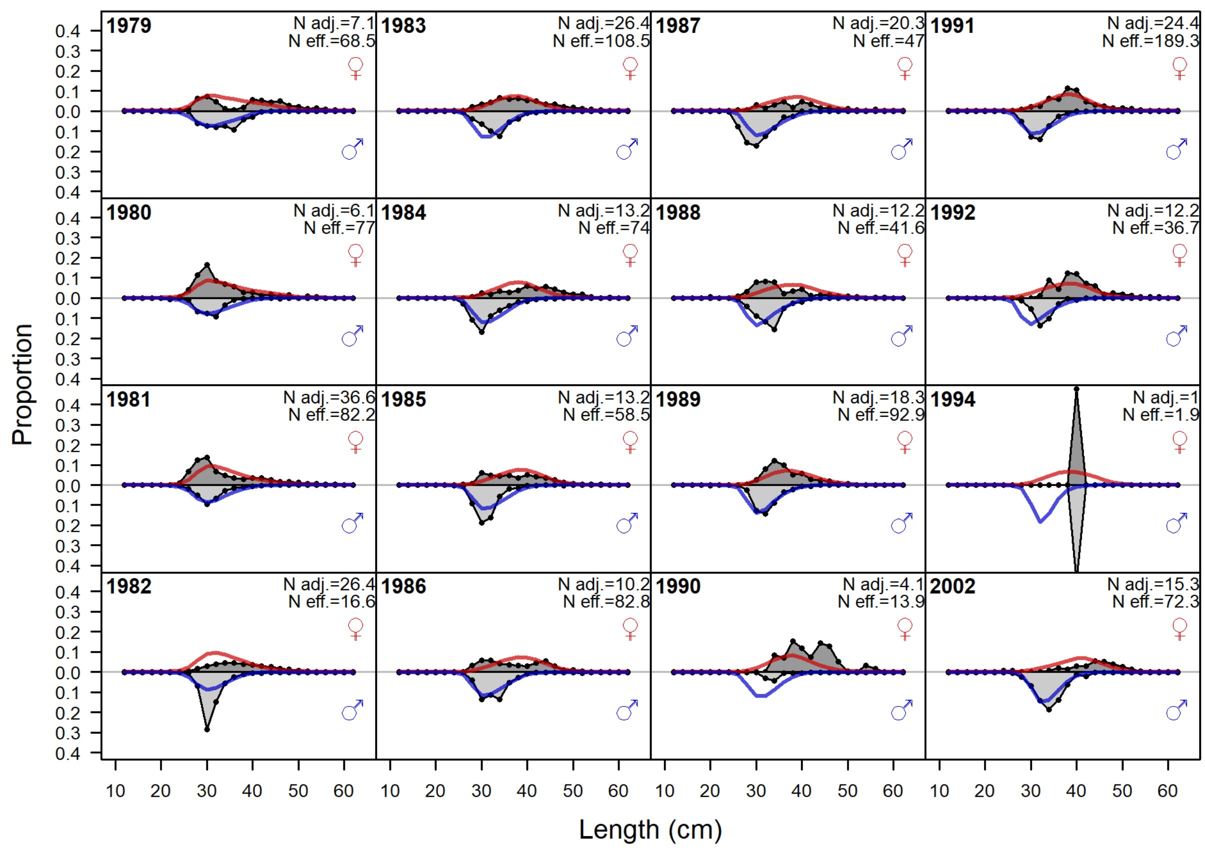


Figure 127: Length comps, retained, Winter (S) (plot 2 of 3)

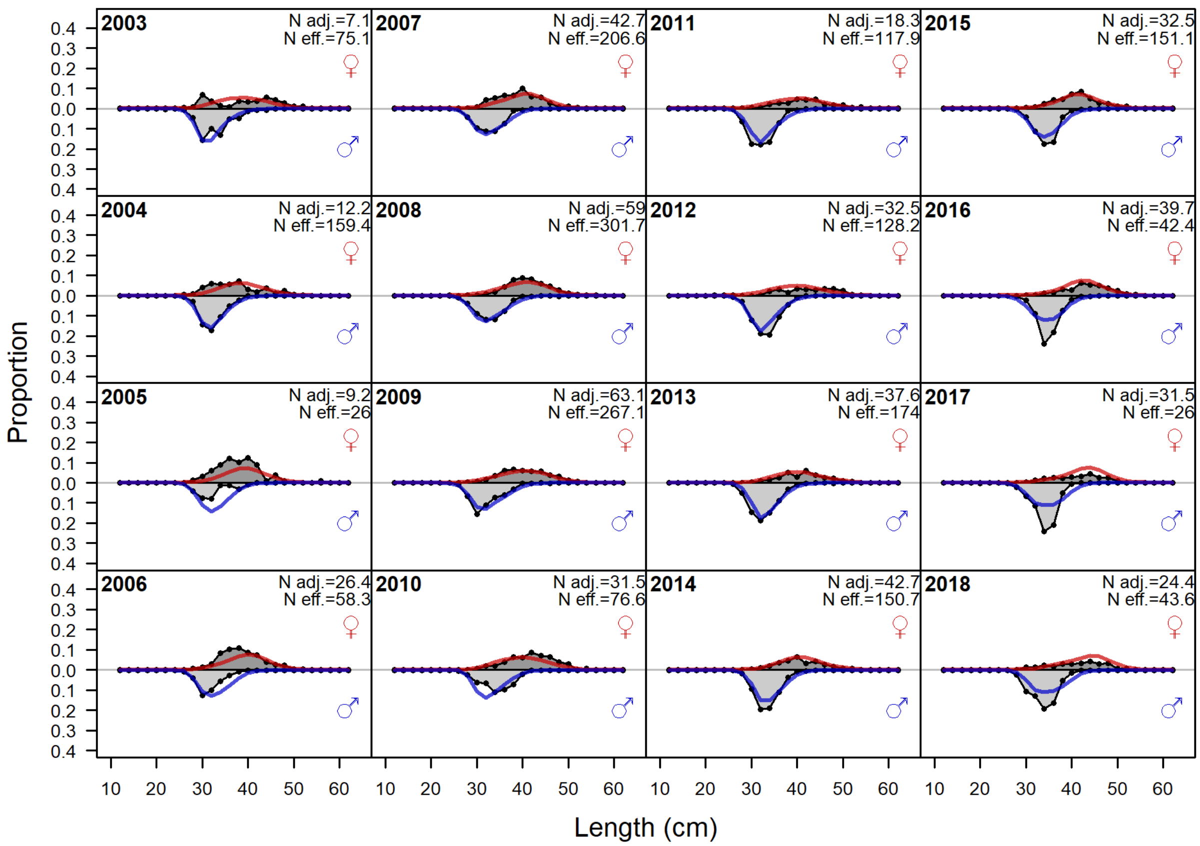


Figure 128: Length comps, retained, Winter (S) (plot 3 of 3)

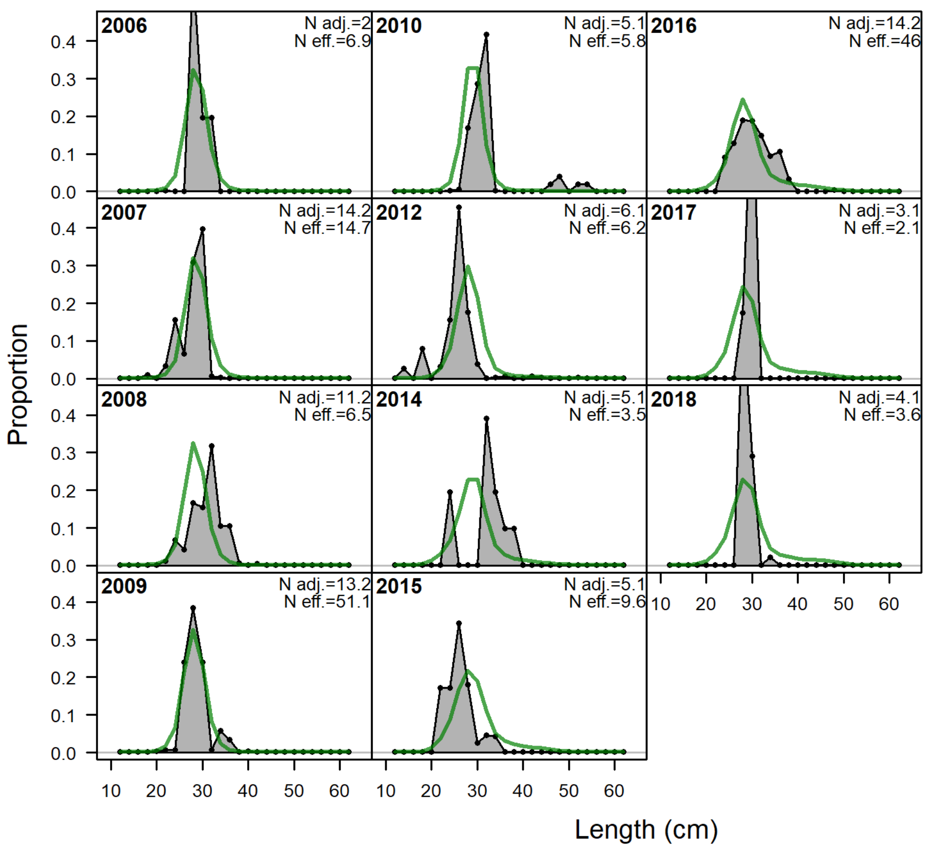


Figure 129: Length comps, discard, Winter (S). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

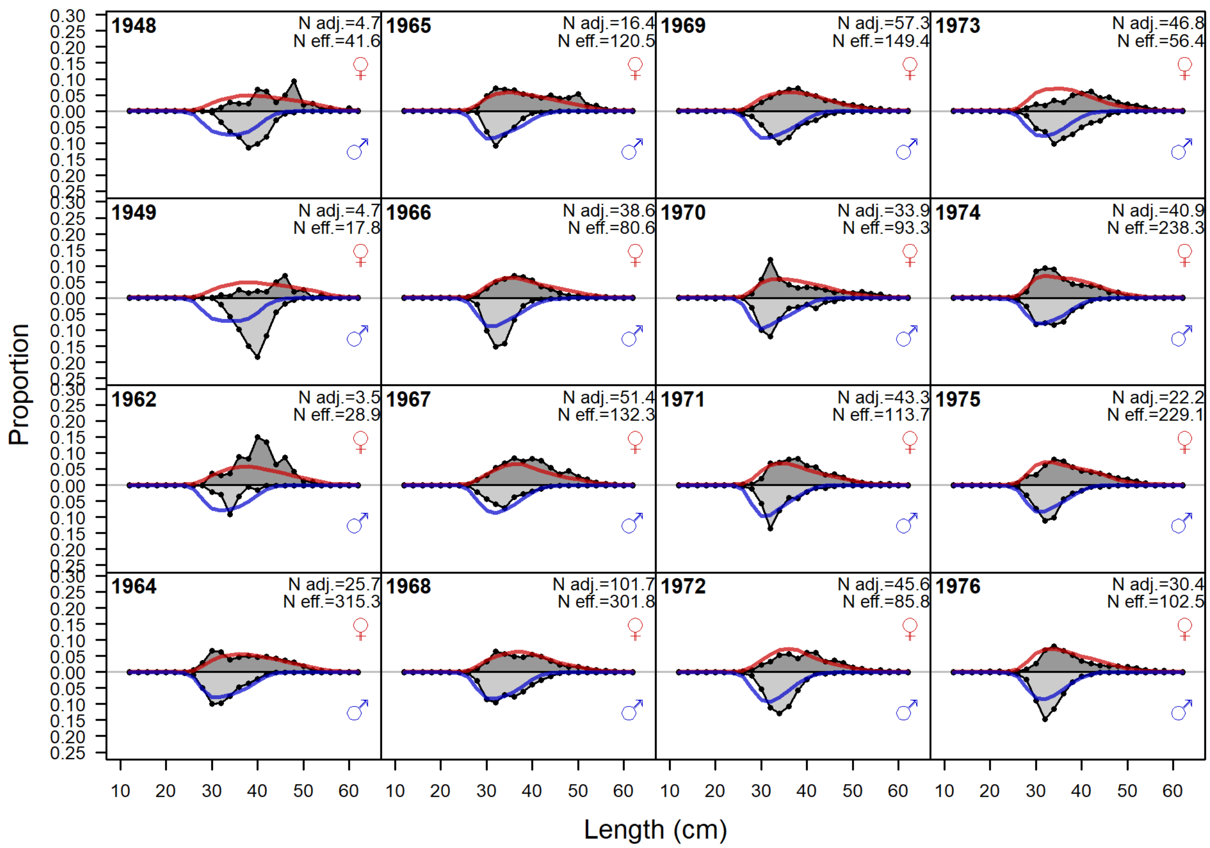


Figure 130: Length comps, retained, Summer (S) (plot 1 of 4). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

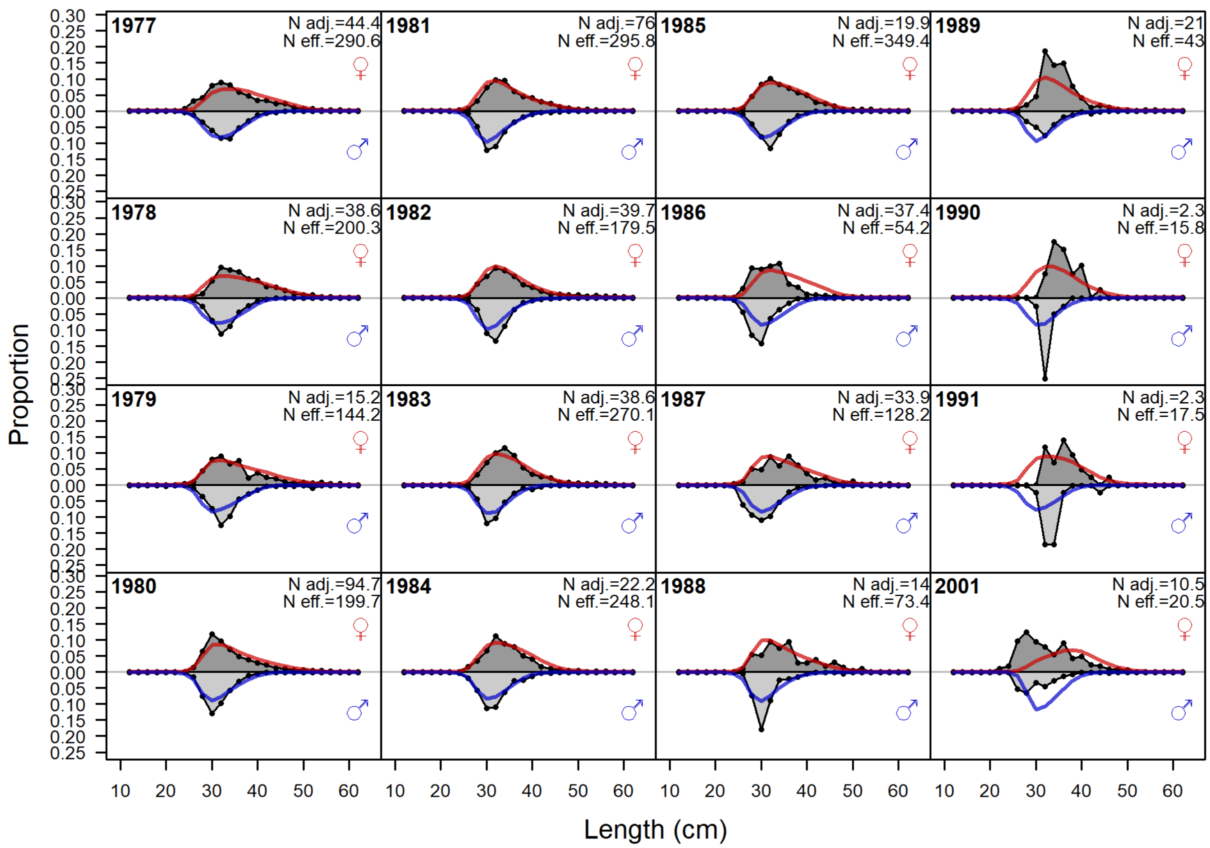


Figure 131: Length comps, retained, Summer (S) (plot 2 of 4)

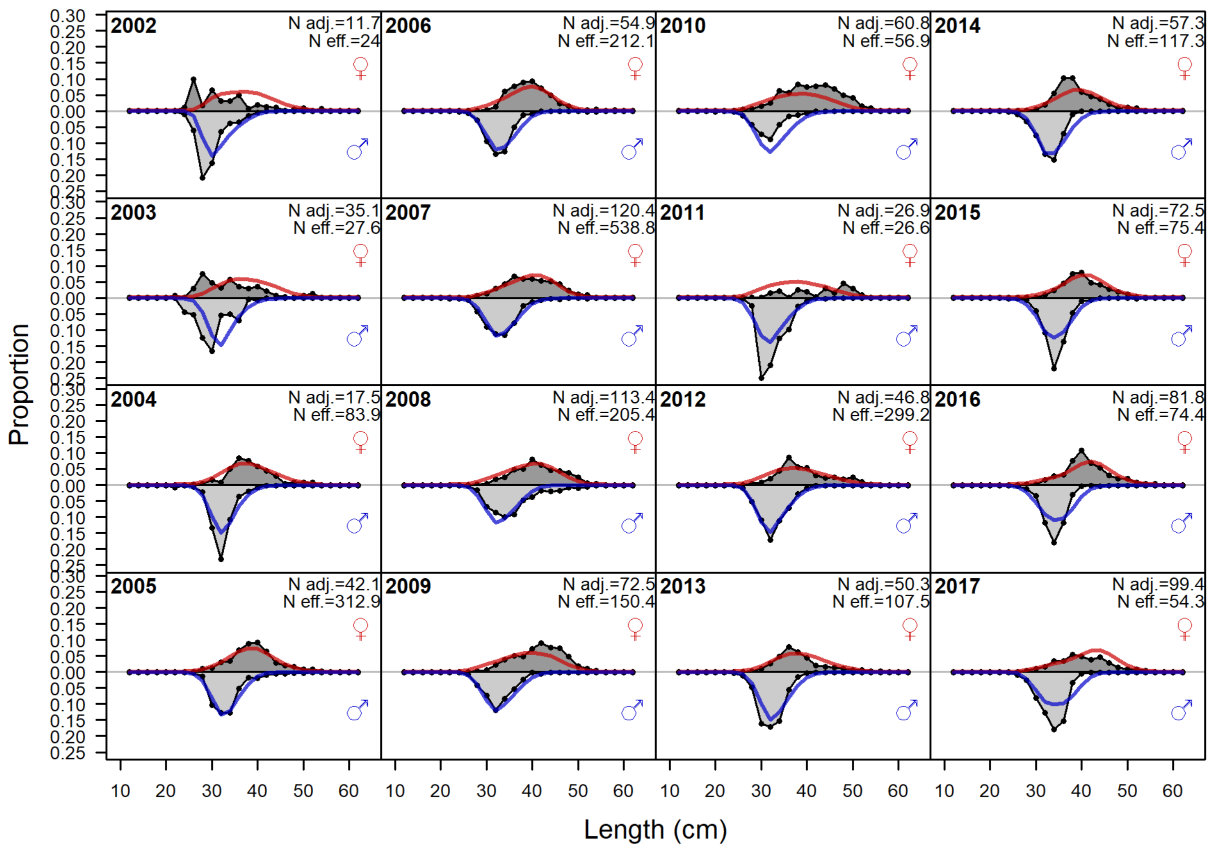


Figure 132: Length comps, retained, Summer (S) (plot 3 of 4)

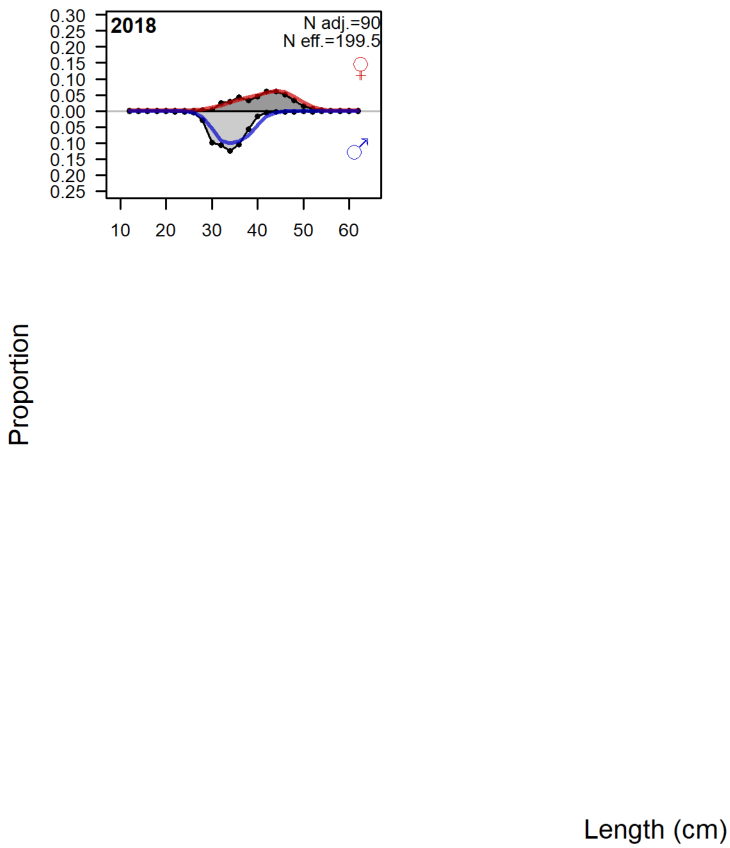


Figure 133: Length comps, retained, Summer (S) (plot 4 of 4)

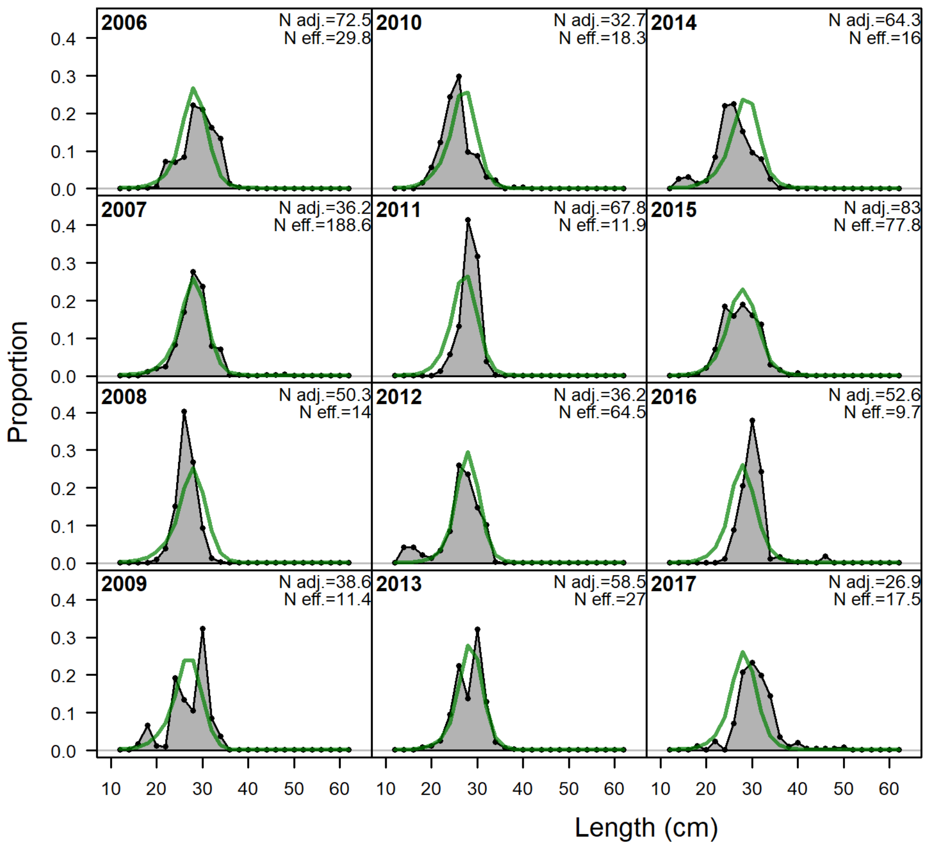


Figure 134: Length comps, discard, Summer (S). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

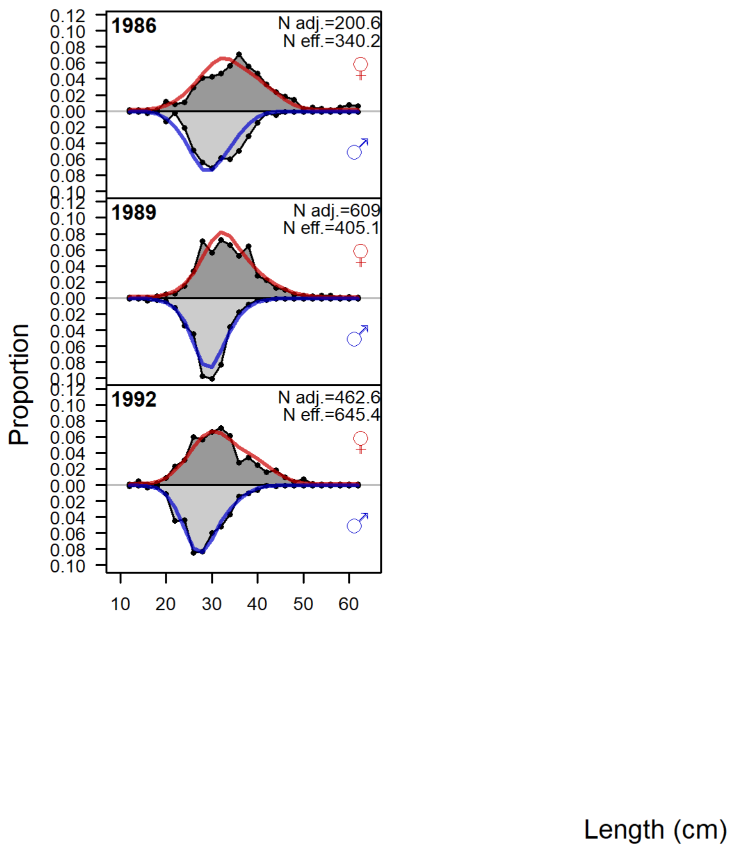


Figure 135: Length comps, whole catch, Triennial _ Early. 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

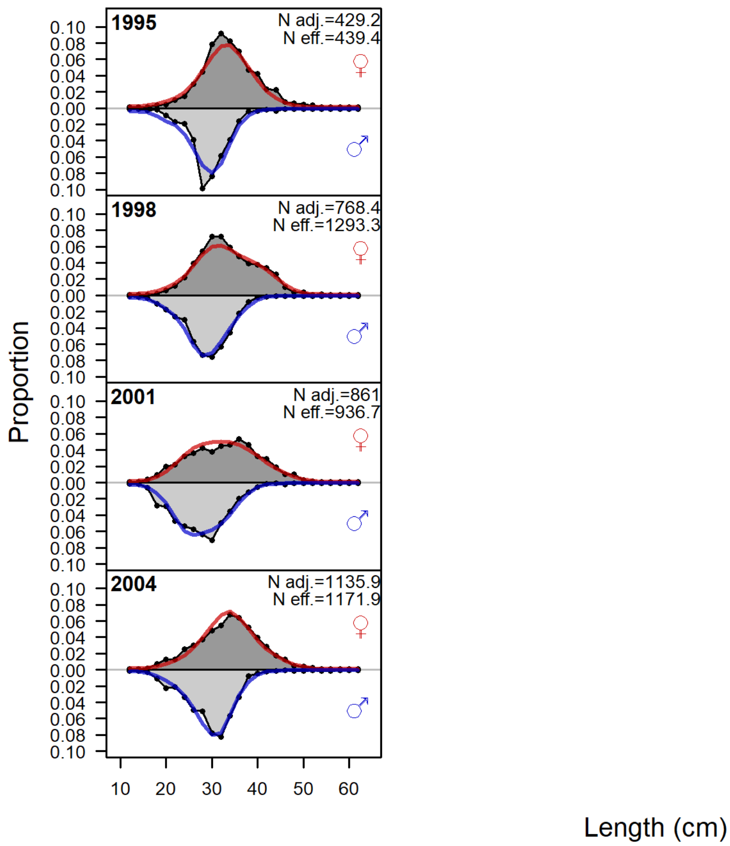


Figure 136: Length comps, whole catch, Triennial _ Late. 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

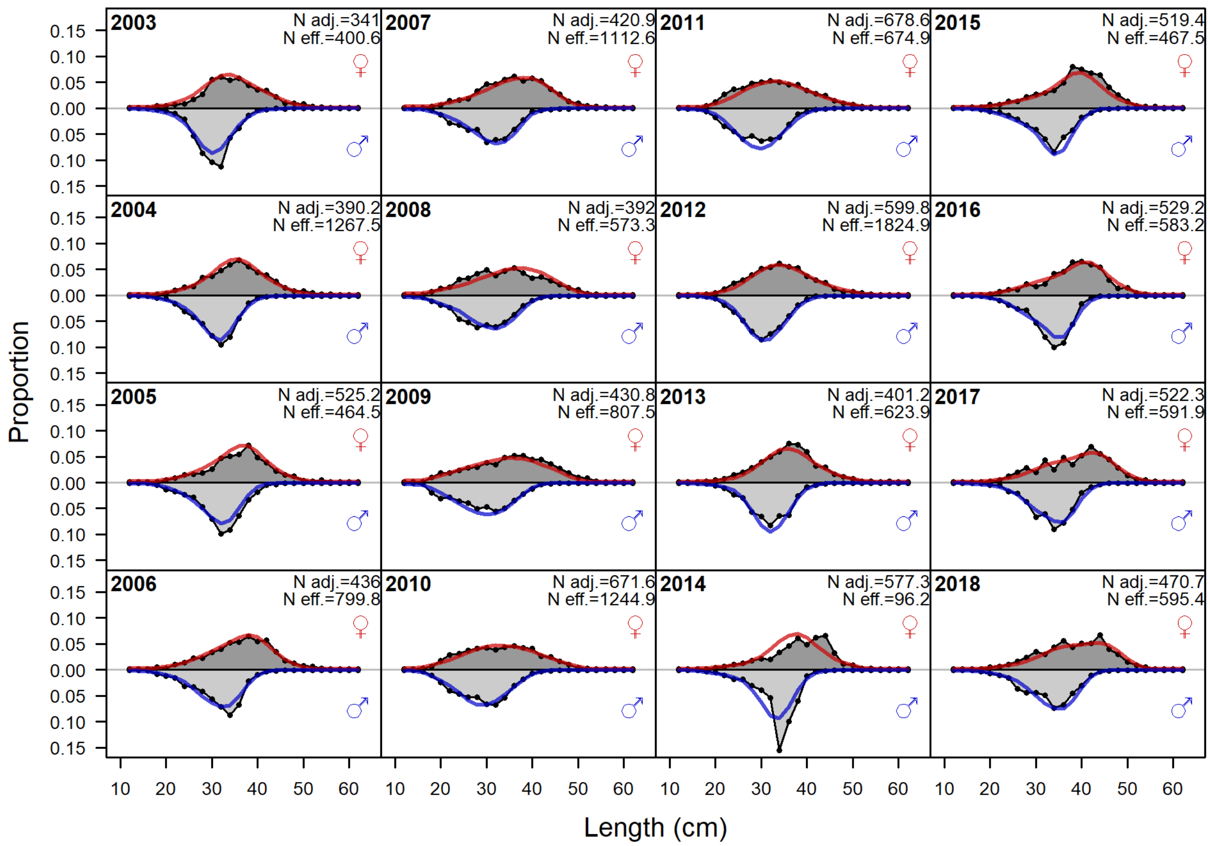


Figure 137: Length comps, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey. 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

13 Appendix B. Detailed Fit to Age Composition Data

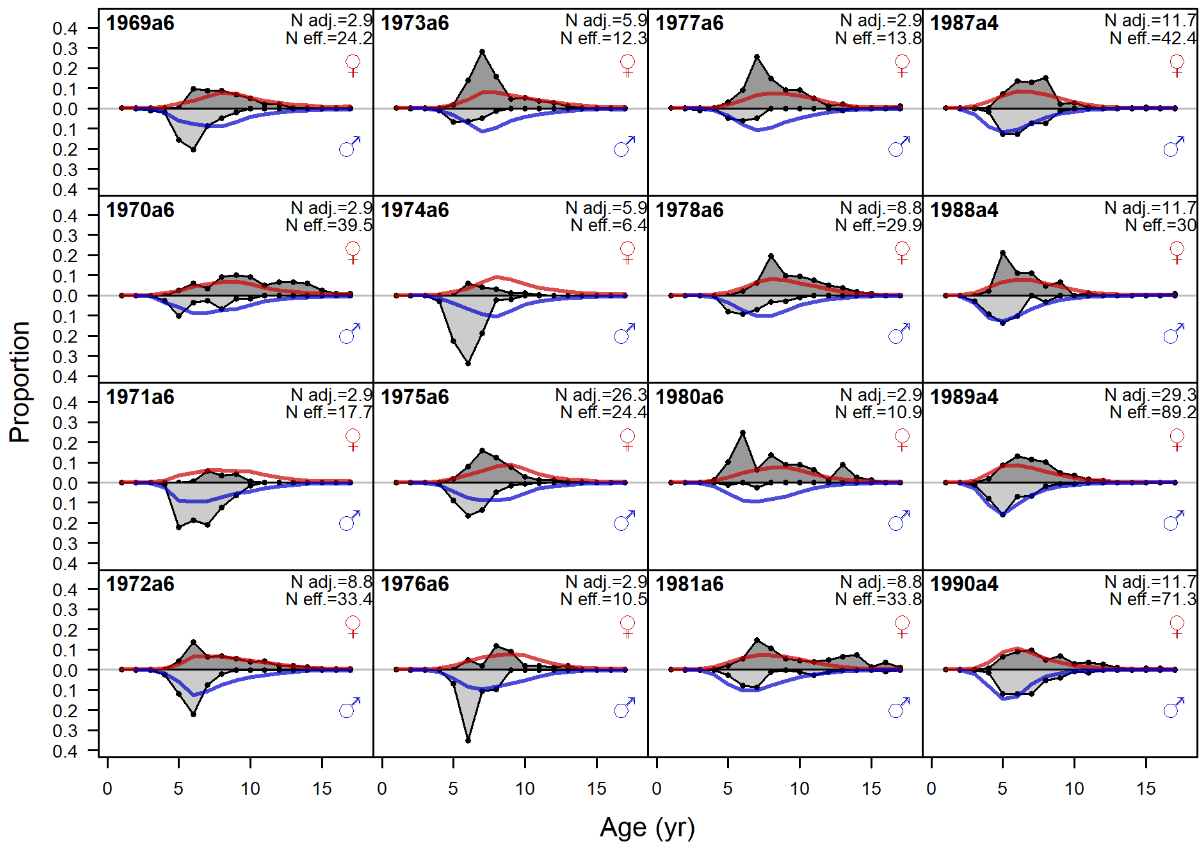


Figure 138: Age comps, retained, Winter (N) (plot 1 of 4). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

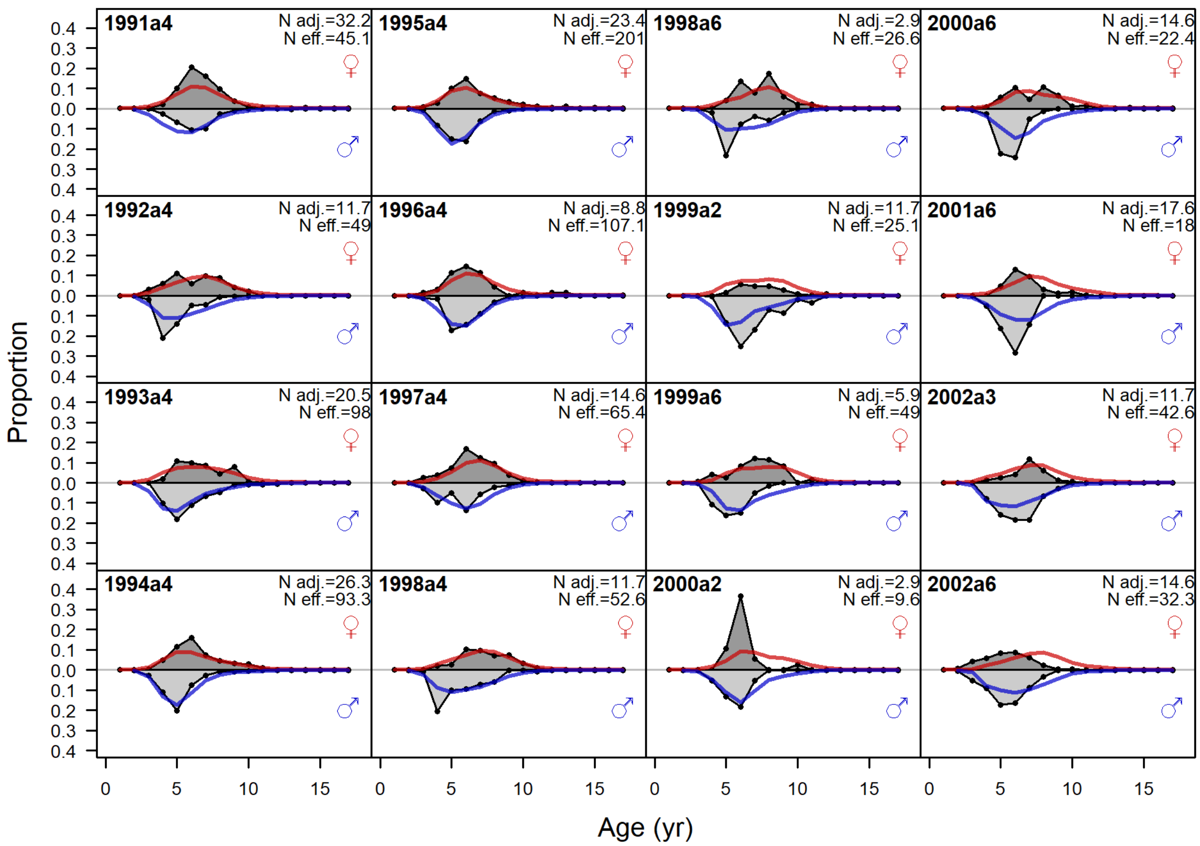


Figure 139: Age comps, retained, Winter (N) (plot 2 of 4)

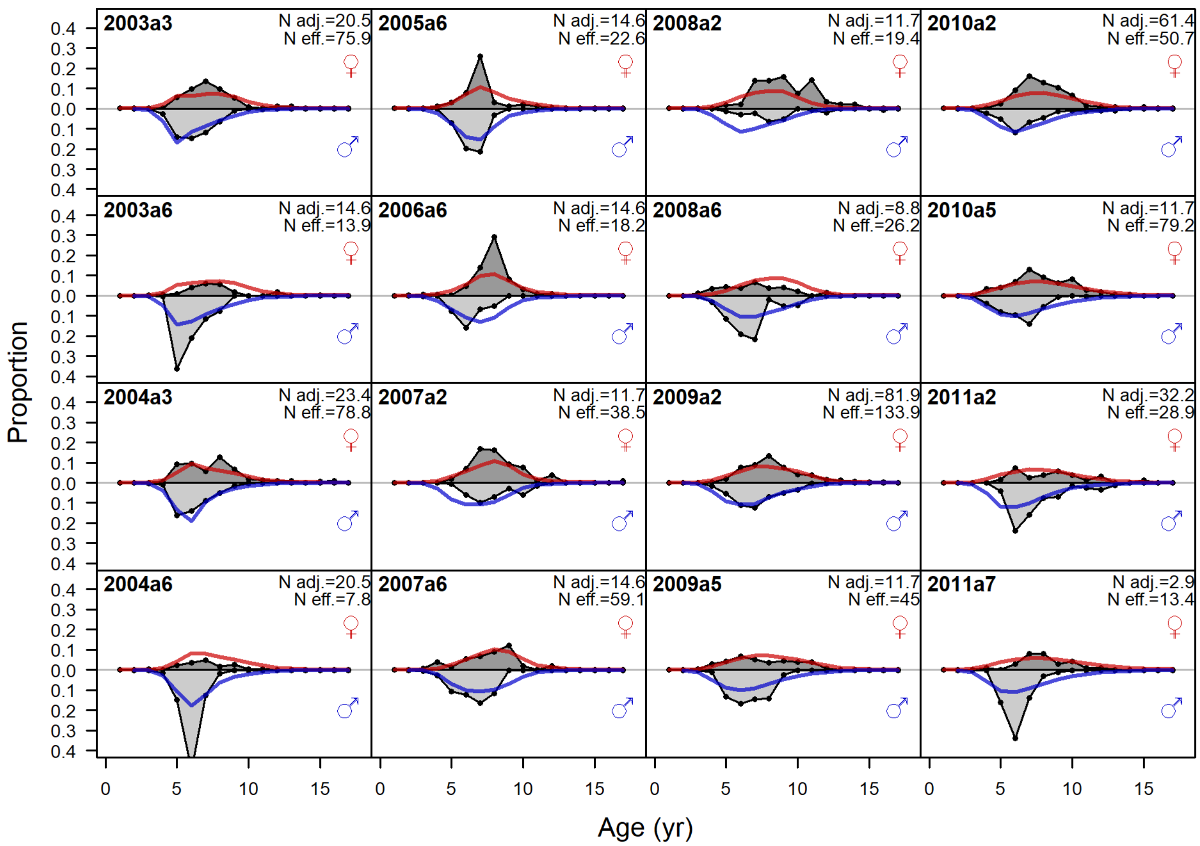


Figure 140: Age comps, retained, Winter (N) (plot 3 of 4)

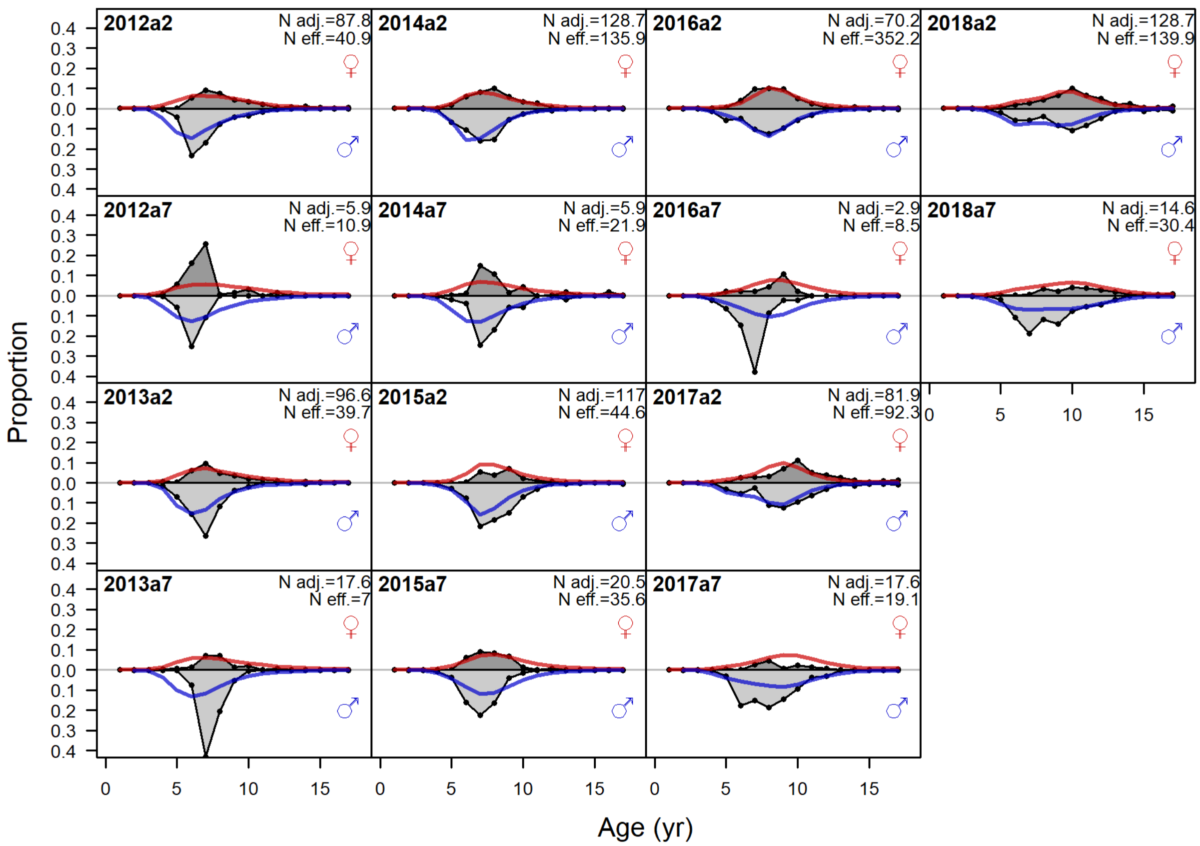


Figure 141: Age comps, retained, Winter (N) (plot 4 of 4)

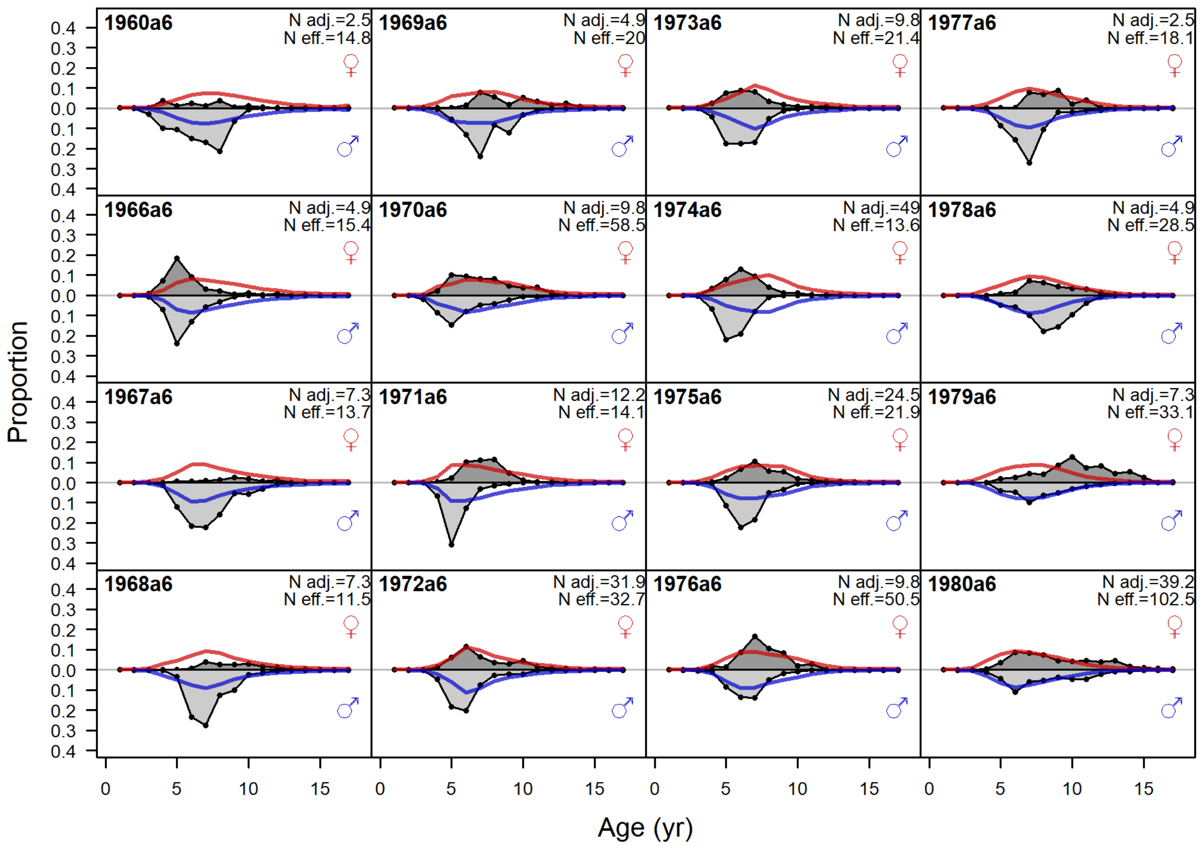


Figure 142: Age comps, retained, Summer (N) (plot 1 of 5). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

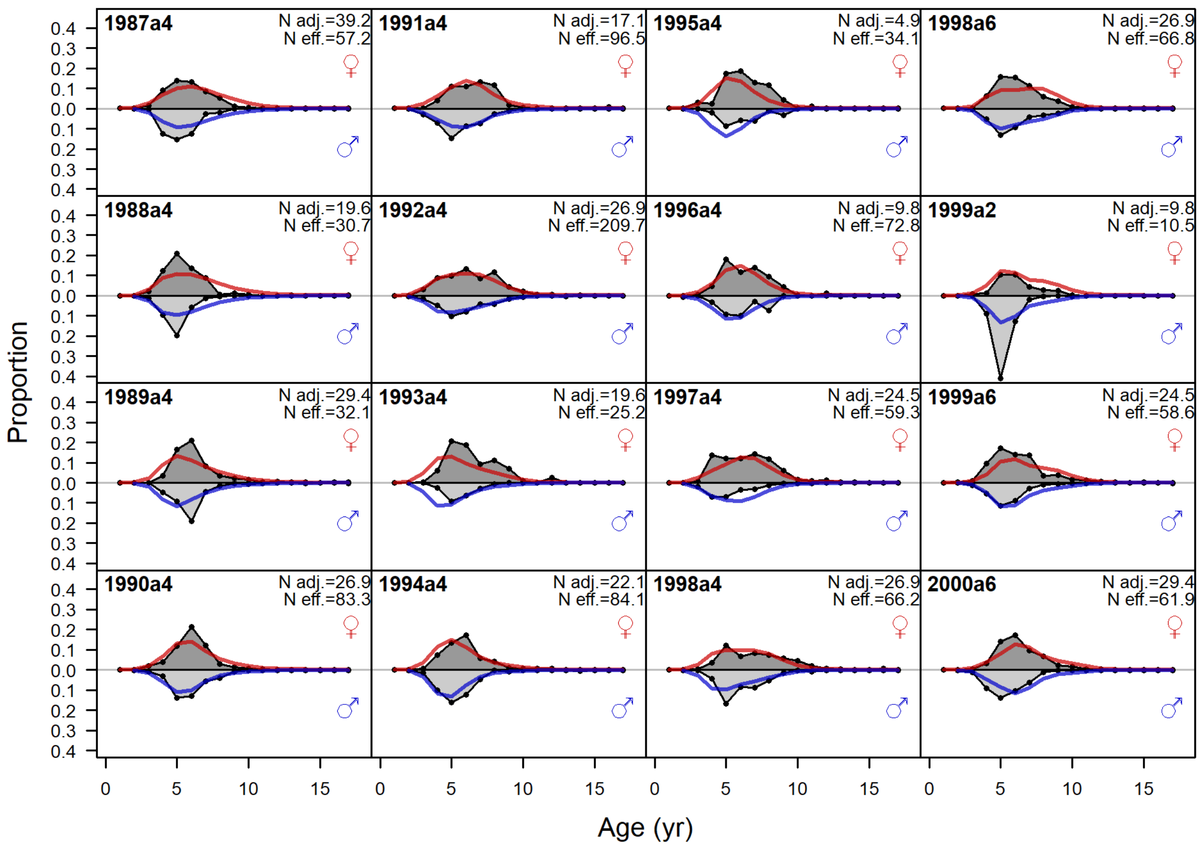


Figure 143: Age comps, retained, Summer (N) (plot 2 of 5)

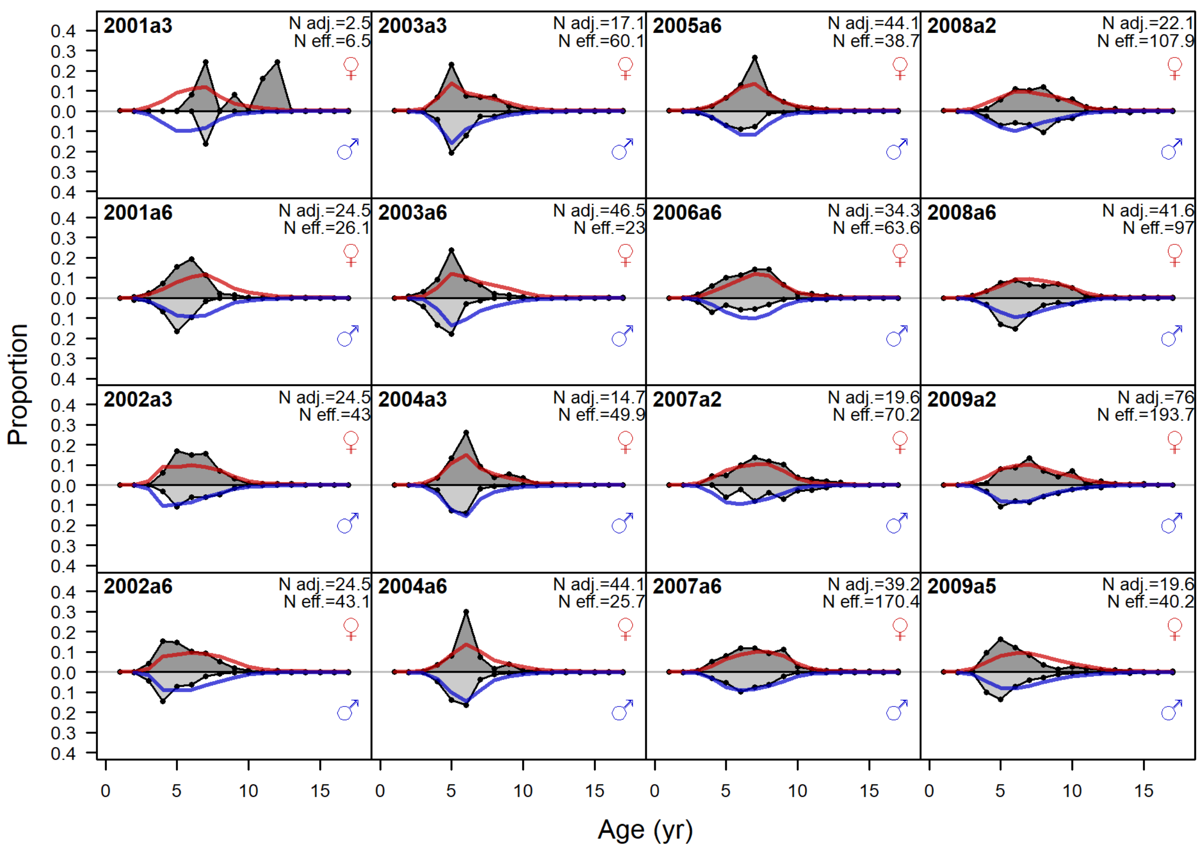


Figure 144: Age comps, retained, Summer (N) (plot 3 of 5)

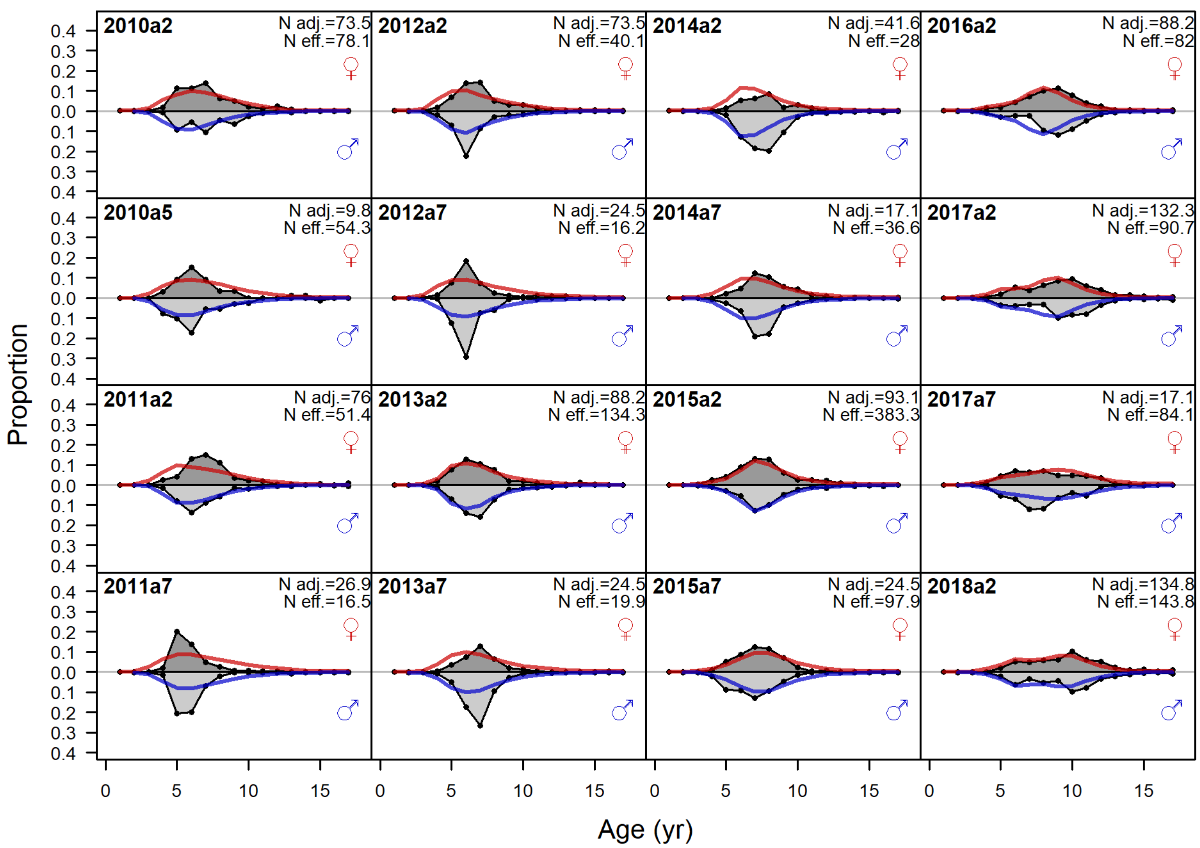
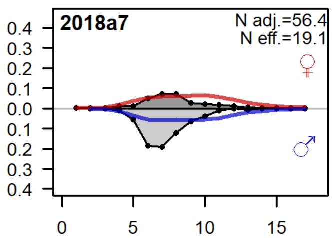


Figure 145: Age comps, retained, Summer (N) (plot 4 of 5)



Proportion

Age (yr)

Figure 146: Age comps, retained, Summer (N) (plot 5 of 5)

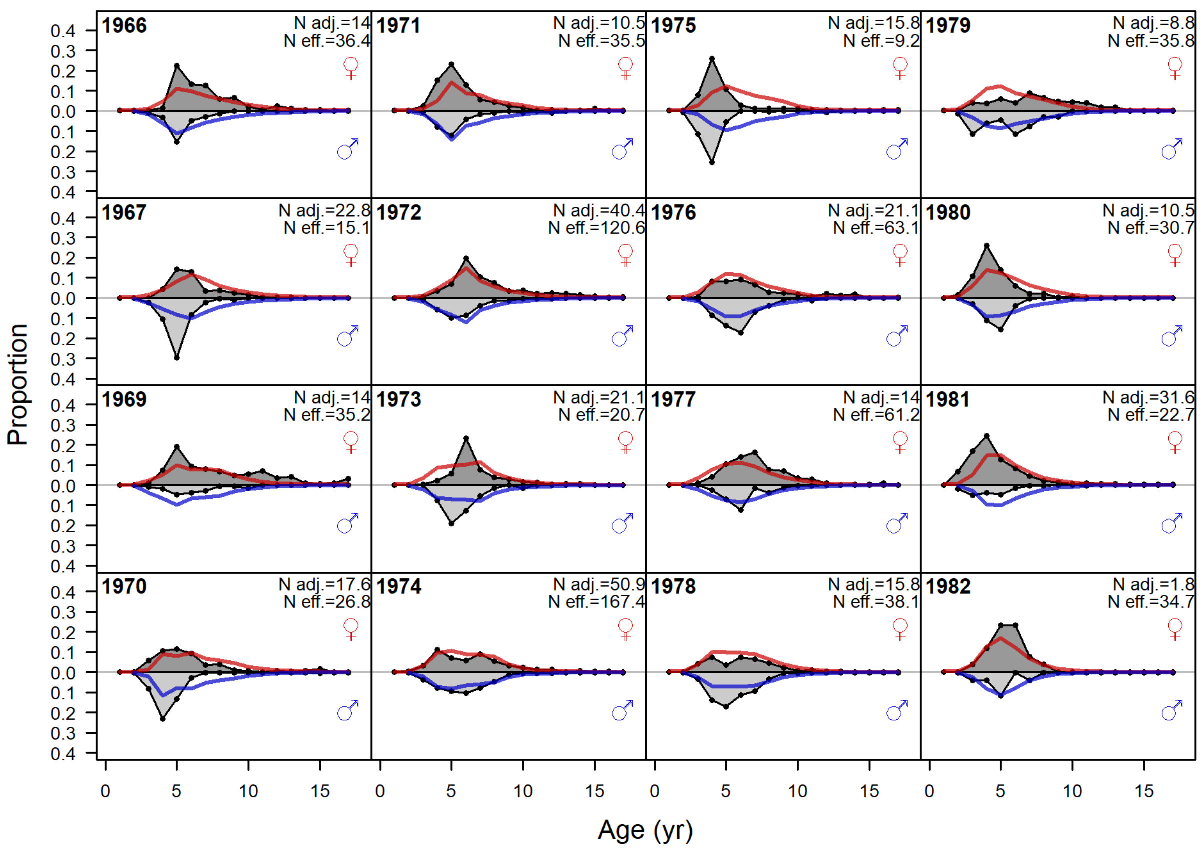


Figure 147: Age comps, retained, Winter (S) (plot 1 of 3). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

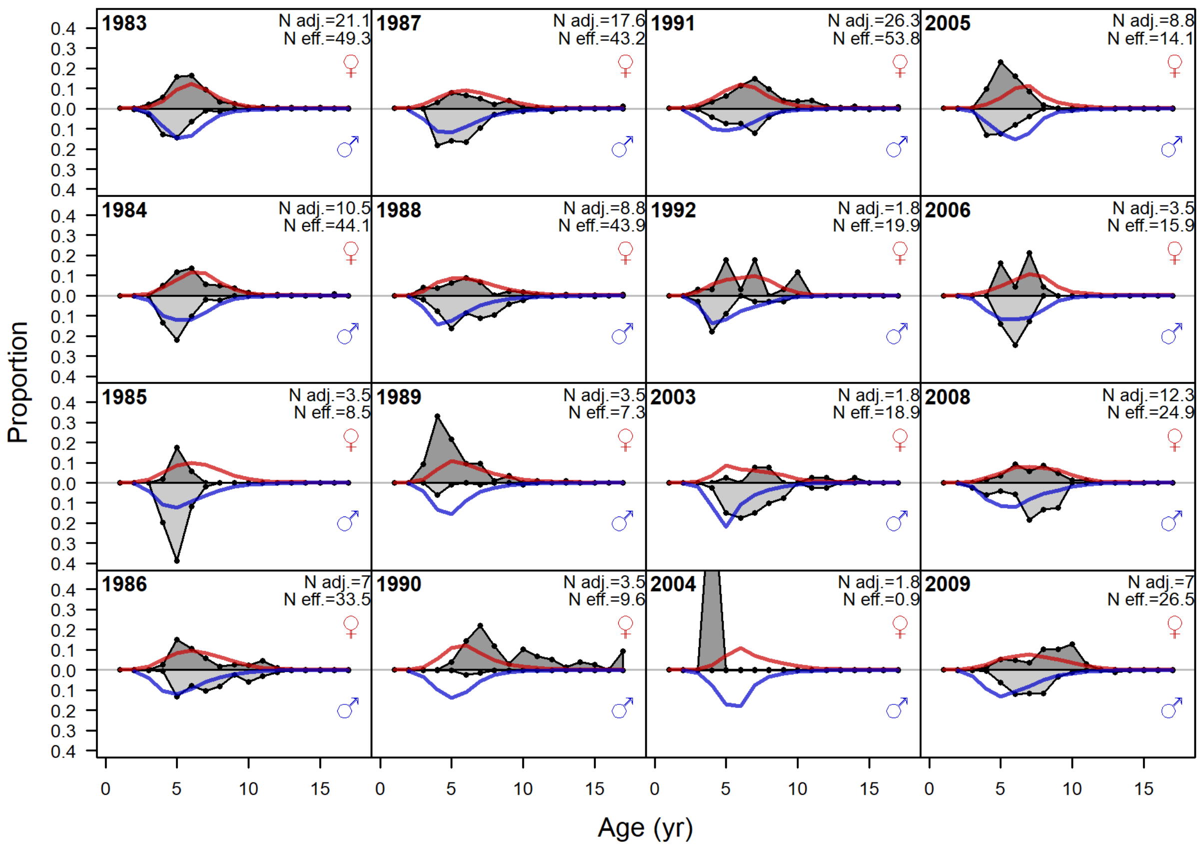


Figure 148: Age comps, retained, Winter (S) (plot 2 of 3)

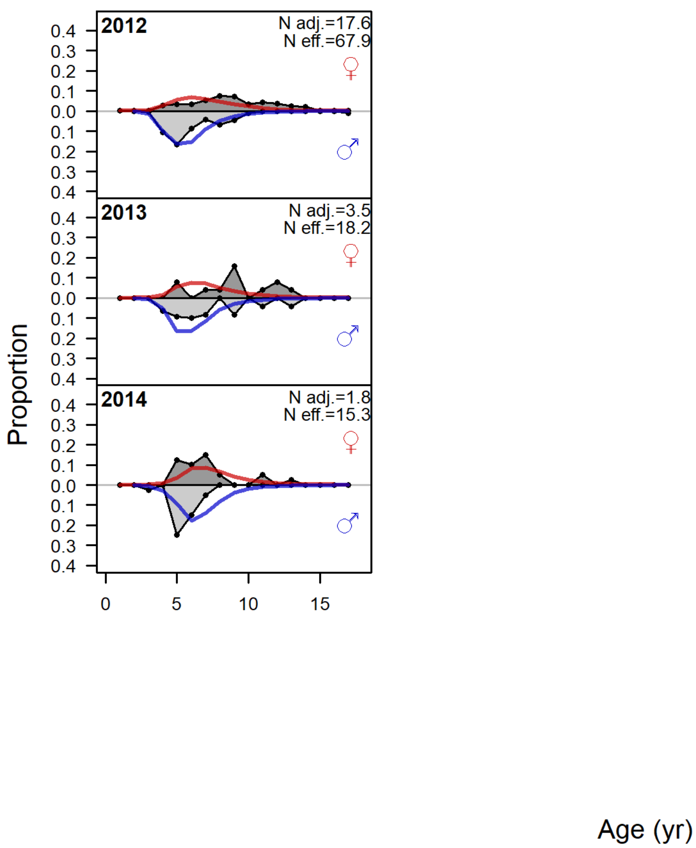


Figure 149: Age comps, retained, Winter (S) (plot 3 of 3)

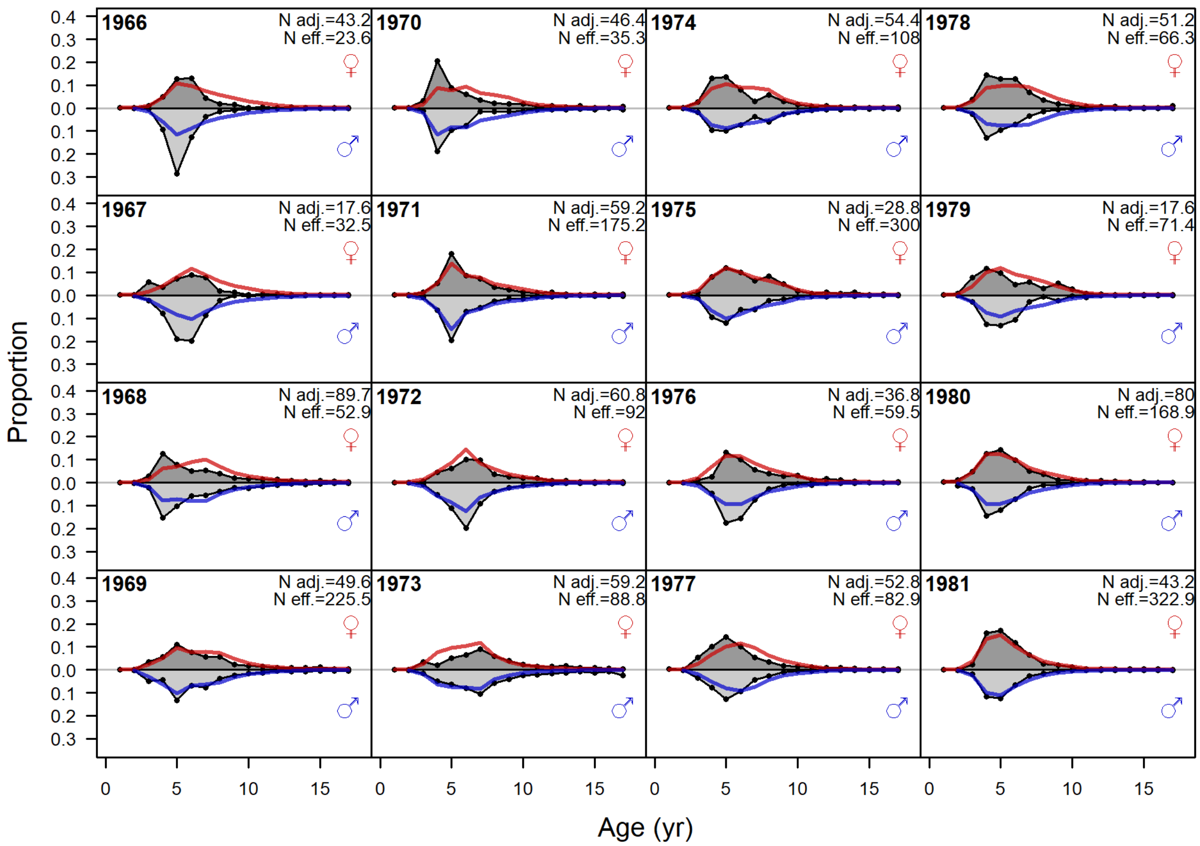


Figure 150: Age comps, retained, Summer (S) (plot 1 of 3). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method.

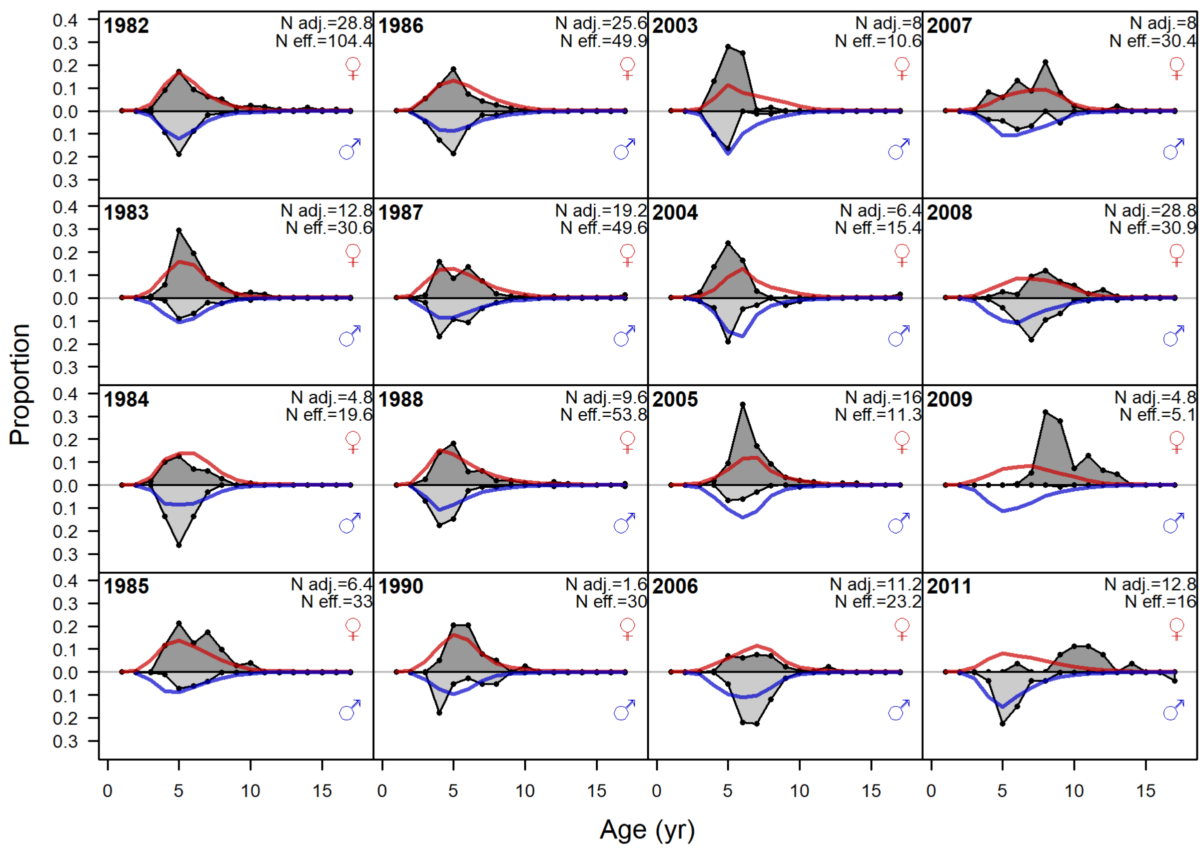


Figure 151: Age comps, retained, Summer (S) (plot 2 of 3)

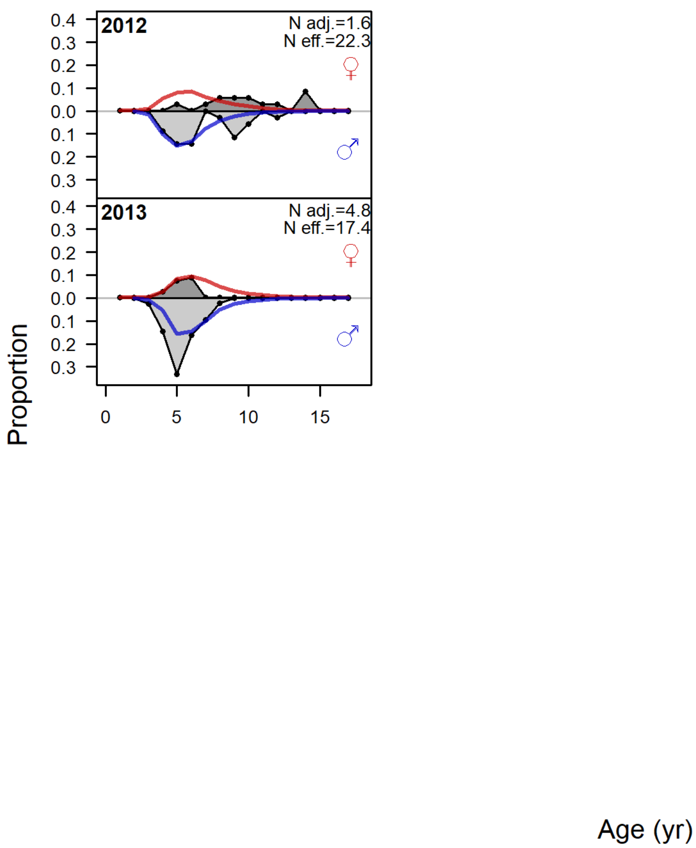


Figure 152: Age comps, retained, Summer (S) (plot 3 of 3)

14 Appendix C. List of Auxiliary Files Available

The listed files are also available as auxiliary files to accompany the assessment document:

1. Numbers at age for female and male petrale sole (Petrale natagef.csv and Petrale natagem.csv)
2. The petrale sole Stock Synthesis 3.30.13 model files
   (a) 2019petrale.dat
   (b) 2019petrale.ctl
   (c) forecast.ss
   (d) starter.ss