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

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June 2019

This report may be cited as:
Wetzel, C.R. 2019. Status of petrale sole (*Eopsetta jordani*) along the U.S. west coast in 2019. Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

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Contents

Executive Summary

executive-summary

Stock

stock

This assessment reports the status of the petrale sole (*Eopsetta jordani*) off 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

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 landing are shown in Table a. Petrale sole are caught nearly exclusively by trawl fleets; non-trawl gears contribute less than 3% of the catches. Based on the 2005 assessment, annual catch limits (ACLs) were reduced to 2499 mt for 2007-2008. Following the 2009 assessment ACLs were further reduced to a low of 976 mt for 2011 and have subsequently increased to a high value of 3,136 for 2017. 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 (a). petrale sole are a desirable market species and discarding has historically been low.

Table a: Landings (mt) for the past 10 years for petrale sole by source.
tab:Exec_catch

Year	Winter (N)	Summer (N)	Winter (S)	Summer (S)	Total Landings
2009	846.71	641.75	469.66	250.38	2208.49
2010	258.09	292.34	77.60	120.95	748.98
2011	221.60	423.11	39.59	77.70	762.00
2012	406.05	477.71	124.46	107.63	1115.85
2013	509.04	1007.26	130.10	278.35	1924.74
2014	852.90	860.31	273.40	354.19	2340.80

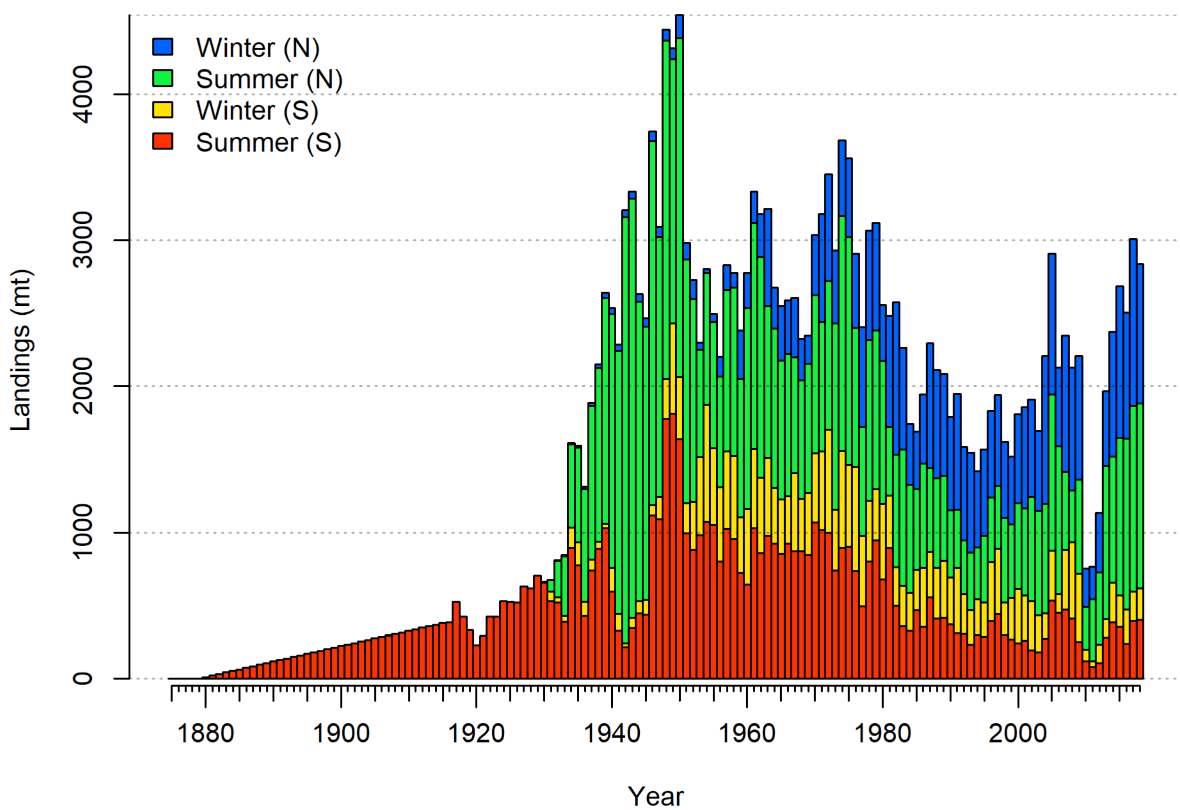

Figure a: 'Landings of by the Northern and Southern winter and summer fleets of the US west coast. fig:Exec_catch1

Data and Assessment

data-and-assessment

This an update assessment for petrale sole, which was last assessed in 2013 and updated in 2015. The 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 modeled as the North Winter and North Summer, where the north includes both Washington and Oregon, and South Winter and South Summer encompasses California fisheries.

The model includes catch, length- and age-frequency data from the trawl fleets as well as standardized winter fishery catch-per-unit-effort (CPUE) indices. 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

updated-data

The base stock 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. Model fitting using latest version of Stock Synthesis (SS v.3.30.13).
2. Added commercial fishery catch data (2015-2018).
3. Updated historical composition data from the commercial fishery (length and age data) and new data (2015 - 2018) expanded to trip and catch based on current best practices.
4. Updated discard rate, average weight, and discard length composition data (2014-2017).
5. NWFSC West Coast Groundfish Bottom Trawl Survey index of abundance was calculated using VAST.
6. Updated NWFSC West Coast Groundfish Bottom Trawl Survey length and age data (2015-2018) with all years data expanded to the tow and strata.
7. AFSC/NWFSC West Coast Triennial Shelf Survey early and late index 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.

Stock Biomass

stock-biomass

Petrale sole were lightly exploited during the early 1900s, but by the 1950s the fishery was well developed and showing clear signs of depletion and declines in catches and biomass (Figures a and b). The rate of decline in spawning biomass accelerated through the 1930s-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 year 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 37.7% ($\sim$ 95% asymptotic interval: $\pm$ 27.0%-48.5%).

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

tab:SpawningDeplete_mod1

Year	Spawning Biomass (mt)	˜ 95% Confidence Interval	Estimated Relative Spawning Biomass	˜ 95% Confidence Interval
2010	4102	3339 - 4865	0.118	0.080 - 0.156
2011	5237	4286 - 6187	0.151	0.103 - 0.199
2012	7058	5826 - 8290	0.203	0.140 - 0.266
2013	9334	7754 - 10914	0.269	0.186 - 0.351
2014	11305	9417 - 13194	0.325	0.227 - 0.424
2015	12586	10516 - 14657	0.362	0.255 - 0.470
2016	13139	10984 - 15295	0.378	0.268 - 0.488
2017	13486	11267 - 15705	0.388	0.277 - 0.499
2018	13367	11080 - 15654	0.385	0.276 - 0.494
2019	13114	10722 - 15506	0.377	0.270 - 0.485

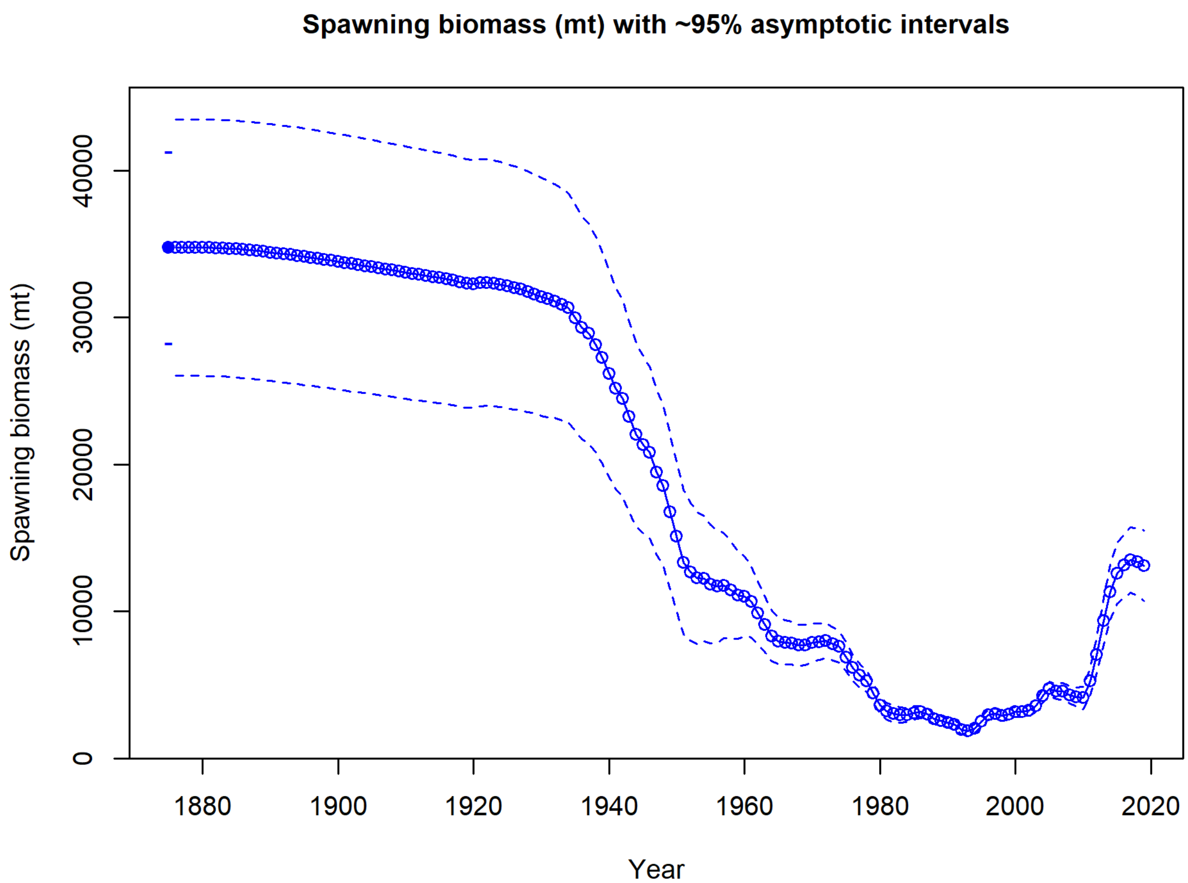

Figure b: Estimated time-series of spawning biomass trajectory (circles and line: median; light broken lines: 95% credibility intervals) for the base assessment model. fig:Spawnbio_all

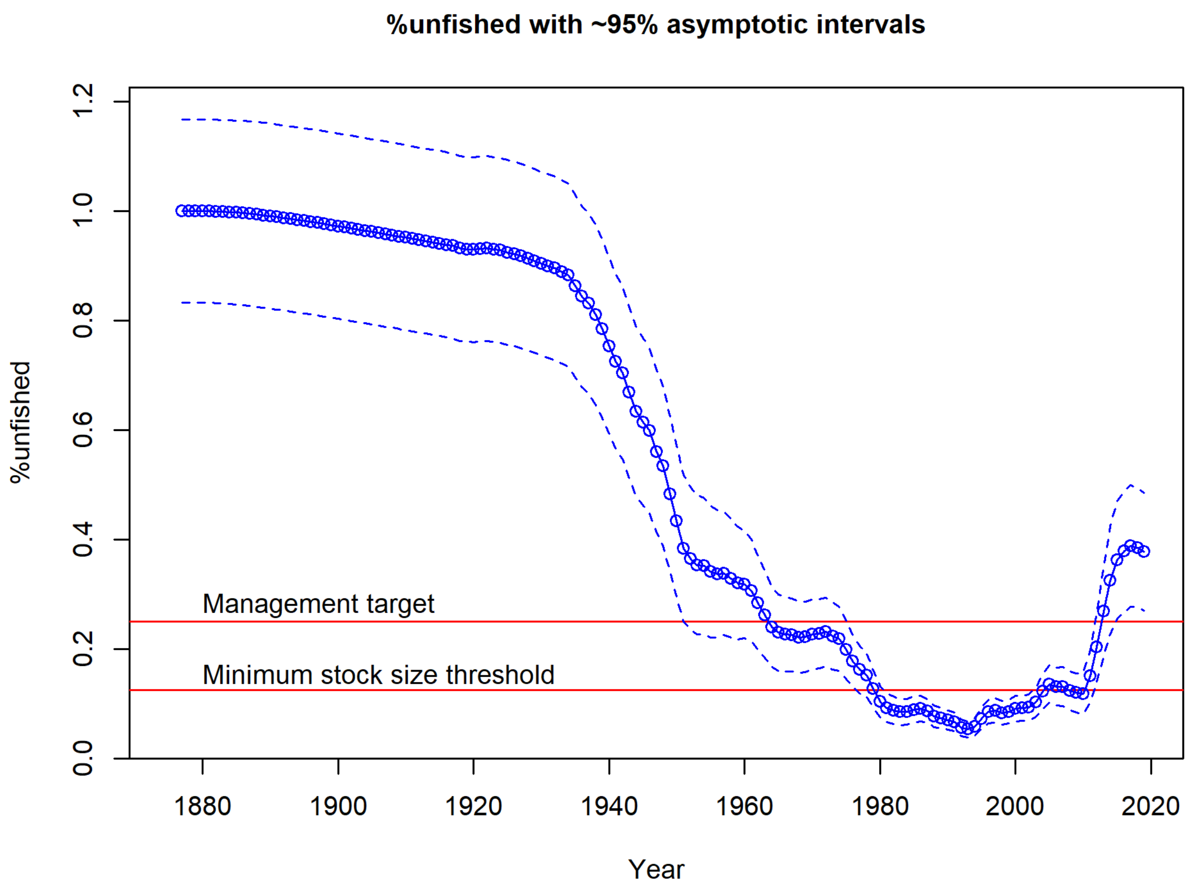

Figure c: Estimated time-series of relative spawning biomass (depletion) (circles and line: median; light broken lines: 95% credibility intervals) for the base assessment model. fig:RelDeplete_all

Recruitment

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

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.

tab:Recruit_mod1

Year	Estimated Recruitment	˜ 95% Confidence Interval	Estimated Recruitment Devs.	˜ 95% Confidence Interval
2010	11804	7471 - 18650	-0.148	-0.462 - 0.166
2011	14333	9229 - 22260	-0.012	-0.299 - 0.275
2012	21430	14273 - 32176	0.333	0.089 - 0.577
2013	12557	7721 - 20424	-0.244	-0.618 - 0.130
2014	12654	7627 - 20995	-0.260	-0.662 - 0.142
2015	11960	6676 - 21426	-0.328	-0.821 - 0.165
2016	15556	8041 - 30096	-0.091	-0.667 - 0.486
2017	15507	7097 - 33881	-0.118	-0.851 - 0.616
2018	17806	7823 - 40532	0.000	-0.784 - 0.784
2019	17773	7812 - 40436	0.000	-0.784 - 0.784

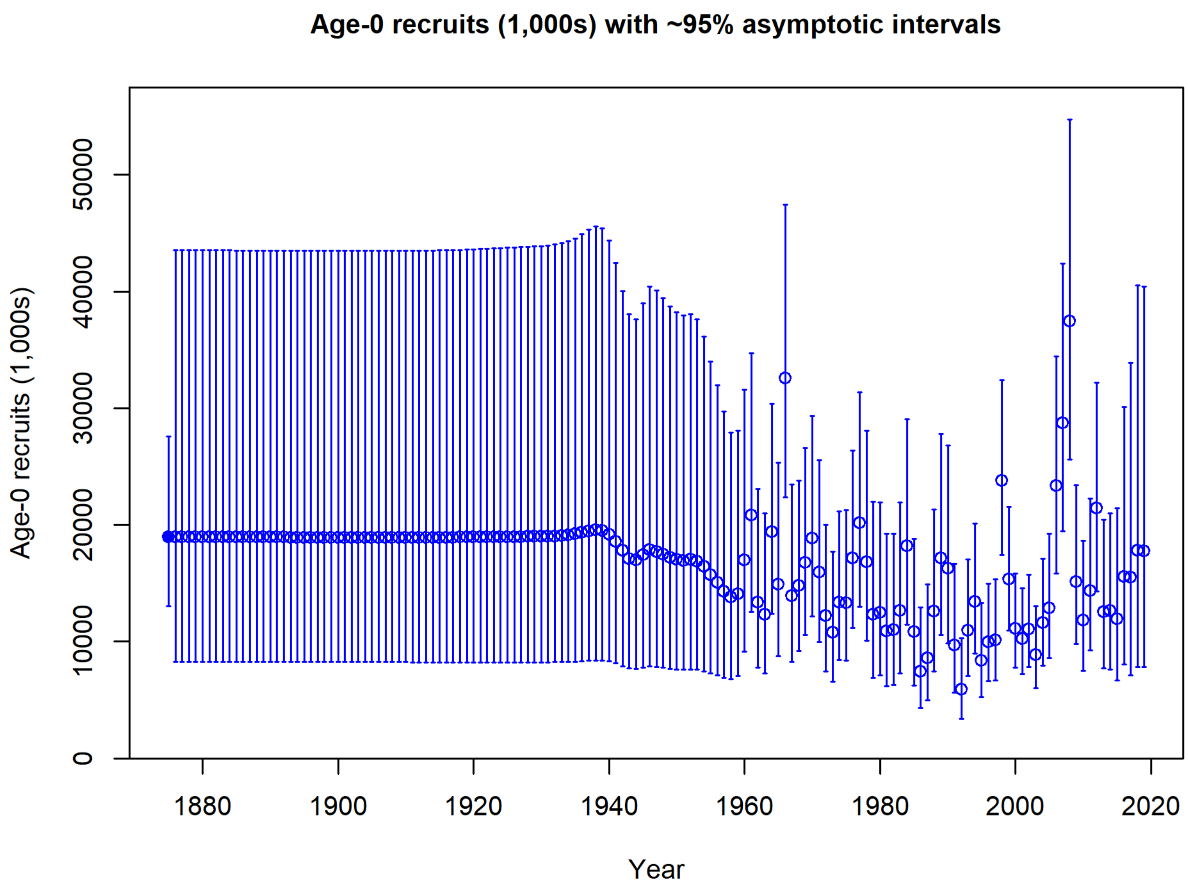

Figure d: Time-series of estimated petrale sole recruitments for the base model with 95% confidence or credibility intervals. fig:Recruits_all

Exploitation Status

exploitation-status

The relative spawning biomass of of petrale sole was estimated to have dropped below the management target (25%) for the first time in 1964. The stock continued to decline and first fell below the minimum stock size threshold level of 12.5% in 1980. The relative spawning biomass remained around the threshold stock size until approximately 2010, with the stock reaching its lowest relative spawning biomass level in 1993 at 5.3%. In 2009 petrale sole was formally declared overfished. Fishing mortality rates sharply declined during the rebuilding period relative to previous year rates which exceeded the target (Figure e). After reduced harvests, 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 exceed 25% in 2013 with harvest rates in the most recent years remaining just under of the target rate (Figure e).

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

tab:SPR_Exploit_mod1

Year	1-SPR	~ 95% Confidence Interval	Exploitation Rate	~ 95% Confidence Interval
2009	0.812	0.745 - 0.878	0.238	0.195 - 0.281
2010	0.588	0.485 - 0.690	0.078	0.061 - 0.094
2011	0.506	0.404 - 0.607	0.052	0.041 - 0.063
2012	0.528	0.428 - 0.627	0.062	0.050 - 0.074
2013	0.594	0.498 - 0.689	0.094	0.077 - 0.111
2014	0.593	0.498 - 0.687	0.105	0.087 - 0.123
2015	0.595	0.501 - 0.688	0.112	0.093 - 0.131
2016	0.564	0.470 - 0.657	0.103	0.086 - 0.121
2017	0.599	0.509 - 0.690	0.124	0.103 - 0.144
2018	0.589	0.498 - 0.679	0.120	0.099 - 0.141

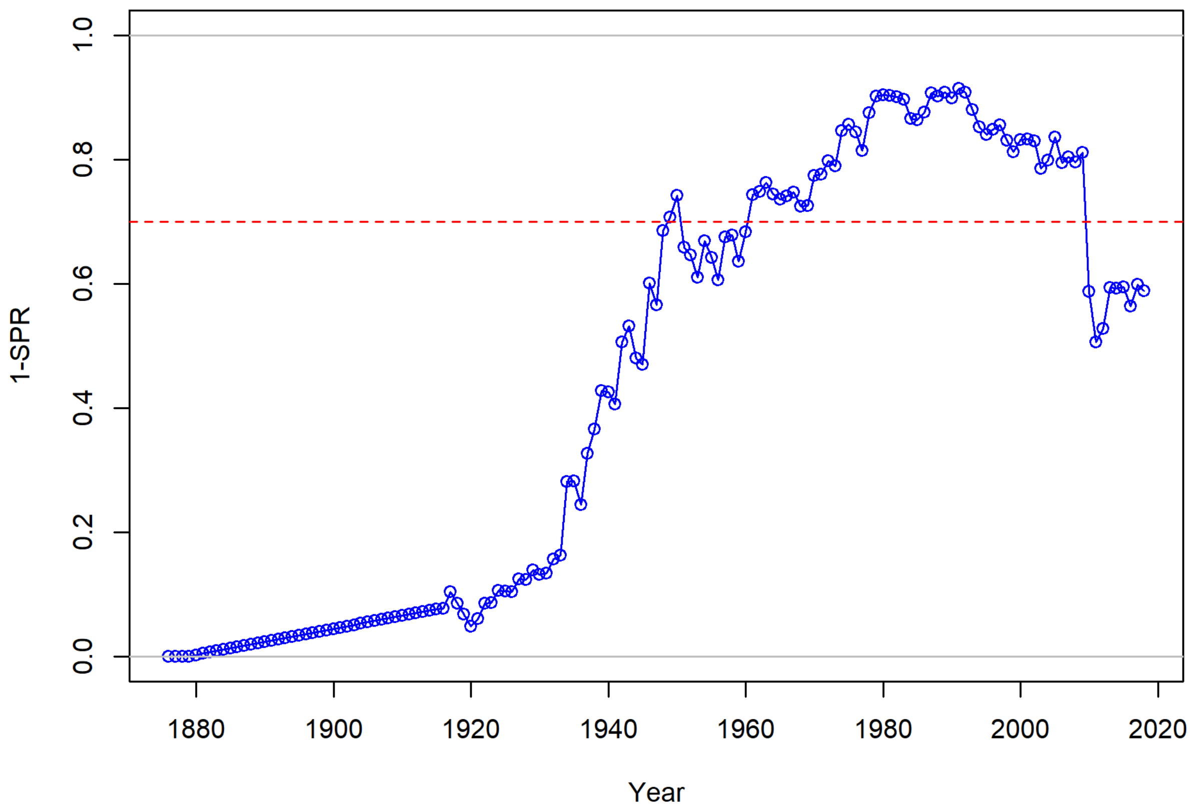

Figure e: Estimated relative spawning potential ratio 1-SPR for the base model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing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

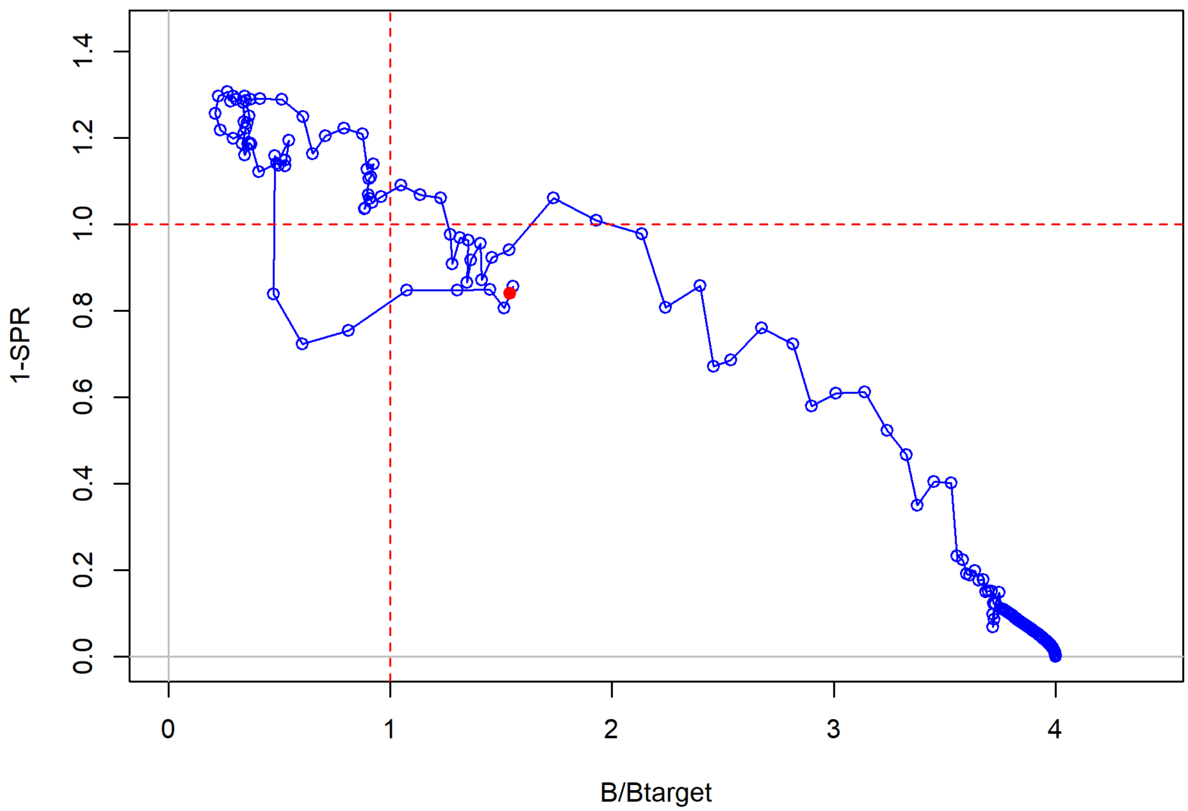

Figure f: Phase plot of estimated 1-SPR(%) vs. relative spawning biomass (B/Btarget) for the base case model. The red circle indicates 2018 estimated status and exploitation for petrale sole. fig:Phase_all

Ecosystem Considerations

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

reference-points

This stock assessment estimates that the spawning biomass of petrale sole is above the management target. Due to reduced landings and the large 2008 year-class, an increasing trend in spawning biomass was estimated in the base model. The estimated depletion in 2019 is 37.7% ($\sim$ 95% asymptotic interval: $\pm$ 27.0%-48.5%), corresponding to an spawning biomass of 13,114 mt ($\sim$ 95% asymptotic interval: 10,722-15,506 mt). Unfished age 3+ biomass was estimated to be 55,563.4 mt in the base model. The target spawning biomass based on the biomass target ($SB_{25\%}$) is 8,687.4 mt, with an equilibrium catch of 3,169.4 mt. Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $SPR_{30\%}$ is 3,145.7 mt. Estimated MSY catch is at a 3,184.6 spawning biomass of 7,564.2 mt (21.8% relative spawning biomass).

Table e: Summary of reference points and management quantities for the base case.

tab:Ref_pts_mod1

Quantity	**Estimate**	**~2.5% Confidence Interval**	**~97.5% Confidence Interval**
Unfished spawning biomass (mt)	34749.5	28140.3	41358.7
Unfished age 3+ biomass (mt)	55563.4	46647.3	64479.5
Unfished recruitment (R0, thousands)	18943.9	11771.9	26115.9
Spawning biomass(2019 mt)	13114.1	10722.3	15505.9
Relative spawning biomass (depletion) (2019)	0.377	0.27	0.485
Reference points based on $\mathbf{SB_{25\%}}$			
Proxy spawning biomass ($B_{25\%}$)	8687.4	7035.1	10339.7
SPR resulting in $B_{25\%}$ ($SPR_{B25\%}$)	0.28	0.257	0.303
Exploitation rate resulting in $B_{25\%}$	0.179	0.16	0.199
Yield with $SPR_{B25\%}$ at $B_{25\%}$ (mt)	3169.4	2902.2	3436.7
Reference points based on SPR proxy for MSY			
Spawning biomass $SPR_{30\%}$	9412.8	7349.3	11476.3
Exploitation rate corresponding to $SPR_{30\%}$	0.167	0.141	0.193
Yield with $SPR_{30\%}$ at SB_{SPR} (mt)	3145.7	2847.5	3443.8
Reference points based on estimated MSY values			
Spawning biomass at MSY (SB_{MSY})	7564.2	5628.4	9500.1
SPR_{MSY}	0.249	0.188	0.31
Exploitation rate at MSY	0.201	0.168	0.233
MSY (mt)	3184.6	2935.8	3433.4

Management Performance

management-performance

The 2009 stock assessment estimated petrale sole to be at 11.6% of unfished spawning stock biomass in 2010. 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 the early 2000s with fishing mortality rates in excess of the current F-target for flatfish of SPR30%. 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 discarded biomass based on discard rate data.

tab:mnmgt_perform

Year	OFL (mt; ABC prior to 2011)	ACL (mt; OY prior to 2011)	Total Landings (mt)	Estimated Total Catch (mt)
2009	2811	2433	2209	2340
2010	2751	1200	755	870
2011	1021	976	768	782
2012	1275	1160	1135	1150
2013	2711	2592	1967	1990
2014	2774	2652	2373	2390
2015	3073	2816	2686	2702
2016	3208	2910	2506	2520
2017	3208	3136	3008	3024
2018	3152	3013	2840	2855

Unresolved Problems and Major Uncertainties

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. Value of female natural mortality.
2. Sex ratio between female and male petrale sole.
3. Changes in estimated based on alternative data weighting approaches.

Additionally, to date 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.

Decision Table

decision-table

Model uncertainty has been described by the estimated uncertainty within the base model and by the sensitivities to different model structure.

Table g: Projections of potential OFL (mt) and ABC (mt) and the estimated spawning biomass and relative depletion based on ABC removals. The 2019 and 2020 removals are set at the harvest limits currently set by management of XXX mt per year.

tab:OFL_projection

Year	OFL	ABC	Spawning Biomass (mt)	Relative Depletion
2019	4494	2908	13114	0.377
2020	4327	2845	12630	0.363
2021	4154	3884	12115	0.349
2022	3770	3506	11040	0.318
2023	3523	3262	10367	0.298
2024	3391	3126	10032	0.289
2025	3341	3064	9925	0.286
2026	3341	3050	9945	0.286
2027	3361	3055	10011	0.288
2028	3385	3060	10082	0.290
2029	3407	3066	10142	0.292
2030	3423	3067	10185	0.293

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. The removals in 2019 and 2020 were set at the defined management specification of 2908 and 2845 mt, respectively, assuming full attainment. Columns range over low, mid, and high states of nature, and rows range over different assumptions of catch levels. The SPR30 catch stream is based on the equilibrium yield applying the SPR30 harvest rate.

`tab:Decision_table_mod1`

			States of nature					
			M = 0.12		M = 0.151		M = 0.18	
	Year	Catch	Spawning Biomass	Depletion	Spawning Biomass	Depletion	Spawning Biomass	Depletion
ABC	2021	3884	11559	0.3	12115	0.3	14446	0.5
	2022	3506	10560	0.3	11040	0.3	13168	0.4
	2023	3262	9895	0.2	10367	0.3	12401	0.4
	2024	3126	9517	0.2	10032	0.3	12021	0.4
	2025	3064	9341	0.2	9925	0.3	11877	0.4
	2026	3050	9284	0.2	9945	0.3	11850	0.4
	2027	3055	9279	0.2	10011	0.3	11863	0.4
	2028	3060	9291	0.2	10082	0.3	11874	0.4
	2029	3066	9303	0.2	10142	0.3	11872	0.4
	2030	3067	9309	0.2	10185	0.3	11856	0.4
SPR target = 0.34	2021	3262	11559	0.3	12115	0.3	14446	0.5
	2022	3050	10944	0.3	11416	0.3	13534	0.4
	2023	2916	10558	0.3	11003	0.3	13010	0.4
	2024	2850	10381	0.3	10845	0.3	12785	0.4
	2025	2830	10352	0.3	10860	0.3	12742	0.4
	2026	2841	10409	0.3	10967	0.3	12783	0.4
	2027	2863	10498	0.3	11101	0.3	12843	0.4
	2028	2882	10592	0.3	11230	0.3	12892	0.4
	2029	2901	10679	0.3	11342	0.3	12922	0.4
	2030	2913	10753	0.3	11434	0.3	12933	0.4
SPR target = 0.4	2021	2549	11559	0.3	12115	0.3	14446	0.5
	2022	2478	11385	0.3	11847	0.3	13954	0.5
	2023	2445	11349	0.3	11764	0.3	13737	0.4
	2024	2447	11449	0.3	11854	0.3	13733	0.4
	2025	2471	11643	0.3	12058	0.3	13851	0.4
	2026	2511	11882	0.3	12312	0.4	14011	0.5
	2027	2554	12128	0.3	12567	0.4	14165	0.5
	2028	2590	12360	0.3	12800	0.4	14290	0.5
	2029	2623	12571	0.3	13004	0.4	14385	0.5
	2030	2649	12758	0.3	13178	0.4	14452	0.5

Research and Data Needs

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 relationships 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.

Table i: Base model results summary.

tab:base_summary

Quantity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
OFL (mt)	2751	1021	1275	2711	2774	3073	3208	3208	3152	1
ACL (mt)	1200	976	1160	2592	2652	2816	2910	3136	3013	1
Landings (mt)	755	768	1135	1967	2373	2686	2506	3008	2840	
Total Est. Catch (mt)	870	782	1150	1990	2390	2702	2520	3024	2855	
1-SPR	0.588	0.506	0.528	0.594	0.593	0.594	0.564	0.599	0.589	
Exploitation rate	0.078	0.052	0.062	0.094	0.105	0.112	0.103	0.124	0.120	
Age 3+ biomass (mt)	11195.5	15026.7	18471.1	21200.3	22827.3	24065.6	24368.7	24459.8	23743.7	23154.4
Spawning Biomass	4102	5237	7058	9334	11305	12586	13139	13486	13367	13114
95% CI	3339 - 4865	4286 - 6187	5826 - 8290	7754 - 10914	9417 - 13194	10516 - 14657	10984 - 15295	11267 - 15705	11080 - 15654	10722 - 15506
Relative Depletion	0.118	0.151	0.203	0.269	0.325	0.362	0.378	0.388	0.385	0.377
95% CI	0.080 - 0.156	0.103 - 0.199	0.140 - 0.266	0.186 - 0.351	0.227 - 0.424	0.255 - 0.470	0.268 - 0.488	0.277 - 0.499	0.276 - 0.494	0.270 - 0.485
Recruits	11804	14333	21430	12557	12654	11960	15556	15507	17806	17773
95% CI	7471 - 18650	9229 - 22260	14273 - 32176	7721 - 20424	7627 - 20995	6676 - 21426	8041 - 30096	7097 - 33881	7823 - 40532	7812 - 40436

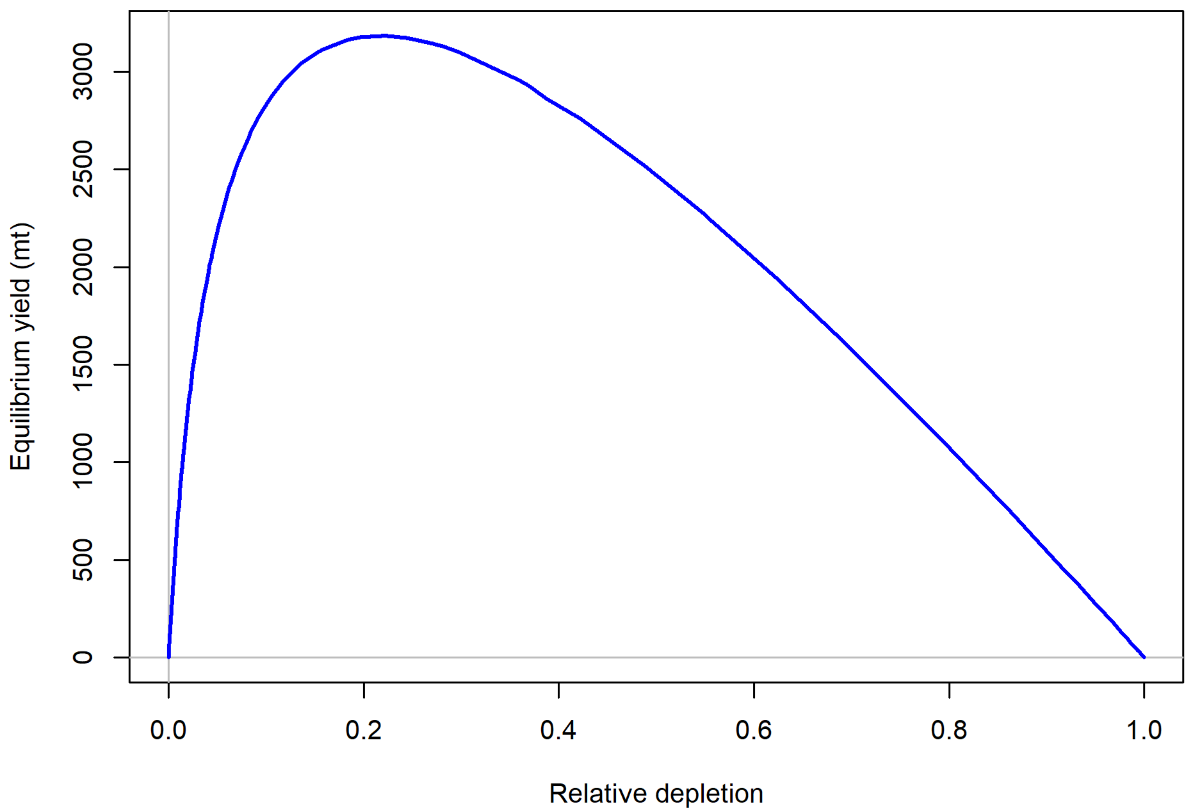

Figure g: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness fixed at 0.86. fig:Yield_all

1 Introduction

introduction

This updated assessment does not attempt to reiterate all background information for petrale sole presented in the 2013 assessment document. Instead, only a few key assumptions are restated, along with a detailed description of changes made during the course of the update. Those interested in a more complete description of petrale sole life-history and the details of previous assessments should refer to the 2013 assessment (Haltuch et al. 2013b).

1.1 Basic Information

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 socks. 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) 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

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 degrees 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 degrees 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 31 years (Haltuch et al. 2013b).

1.3 Historical and Current Fishery Information

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. 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.

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, Figure 1). During 2009 the fishery was declared overfished and during 2010 management restrictions limited the catch to 755 mt (Table 1, Figure 1). Recent years overfishing limit (OFL), annual catch limit (ACL), landings, and estimated total dead are shown in Table 2.

1.4 Summary of Management History and Performance

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 Pacific Council's minimum stock size threshold of 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 (F40%). 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 had declined from its 2005 high to 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).

1.5 Fisheries off Canada and Alaska

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

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

`fishery-independent-data`

2.1.1 NWFSC West Coast Groundfish Bottom Trawl Survey

`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. 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 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 no petrale sole were caught deeper than 550 m. Figure 5 shows that the postie tows catch rate by depth peaks between 100-200 meters and declines as depth increases.

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 stratification is provided in Table 3.

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 6). The Pearson residuals for the encounter and catch rates for gamma distribution model are shown in Figures 7 and 8.

The estimated index of abundance is shown in Table 4. For contrast, the 2015 model estimated, the 2019 design based, and the 2019 VAST indices are shown in Figure 9 and the spatial density by year estimated by VAST are shown in Figure 10. 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 most recent year.

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 5 shows the number of lengths taken by the survey. The first bin includes all observations less than 14 cm and the last bin includes all fish larger than 62 cm. The length frequency distributions for the NWFSC West Coast Groundfish Bottom Trawl Survey from 2003-2018 generally show a strong cohort growing through 2005 and smaller fish entering the population beginning in 2007 rows with a large 2014 cohort entering the populations (Figure 11).

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 2008-2014 (Figure 12). The exception to this is the female composition in 2005, where only one female fish was aged from the tow with the largest catch rate. The expansion of numbers to tow can greatly affect the marginal age distribution, but does not have as much effect on the conditional age-at-length data.

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:

$$N = (0.138 * (\sum^N fish_y / \sum^N tows_y) + 1) * \sum^N tows_y$$

where fish is the number of petrale sole by year y and the total number of tows by year. The effective 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 by according to length, age, sex, and year.

2.1.2 AFSC/NWFSC West Coast Triennial Shelf Survey

`afscnwfsc-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 transects from which searches for tows in a specific depth range were initiated. The survey design has changed slightly over the period of 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 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 13). The catch-per-unit-effort estimated from the survey is roughly constant across the surveyed latitudes (Figure 14). Additionally, petrale sole were captured across the survey depths between 55-500 m (Figure 15).

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 Section 2.1.1. 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 seperately for the early and late periods of the survey. The stratifications are provided in Tables 7 and 8.

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 17 and 20). The Pearson residuals for the encounter and catch rate for the early and late periods are shown in Figures 18, 19, 21, and 22.

The estimated index of abundance is shown in Table 4. For contrast, the 2015 model estimated, the 2019 design based, and the 2019 VAST indices are shown in Figure 23 and the estimated density of petrale sole is show in Figures 24 and 25. The index for the Triennial Survey across the early and late period shows an 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 9 shows the number of lengths taken by the survey. The first bin includes all observations less than 14 cm and the last bin includes all fish larger than 62 cm. The length frequency distributions for the Triennial Survey from 1980-2004 are shown in Figures 26 and 27.

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 Section 2.1.1.

2.2 Fishery-Dependent Data

`fishery-dependent-data`

2.2.1 Commercial Fishery Landings

`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 XXX ADD DATE XXX. 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.

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 are included in the trawl landings.

2.2.2 Discards

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) 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.

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. 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. 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 discard rates from WCGOP are shown in Table 10.

Starting in 2015 a small number of vessels switched to electronic monitoring discards at sea (4, 7, and 8 vessels in 2015, 2016, and 2017 respectively) rather than a human observer and as of this update assessment only 3 years of data are available. 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 assessmet for each of the four fishing fleets. The mean body weight of discarded fish from each fleet are shown in Figures 28 - 31. The summer fisheries, both north and south, had relatively large sample numbers which is reflected in a lower CV by year relative to the winter fisheries.

Discard length composition data were obtained from the WCGOP data and 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 32 and 33.

The data, historical and current, provided by the WCGOP are updated annually based on the most recent standards of QA/QC methods. Hence, these data can have minor changes over time. To ensure the data from the years since the last update assessment (2014-2018) were consistent with the earlier data, data from all years were replaced based to reflect the current standings of the WCGOP data.

2.2.3 Foreign Landings

`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.

2.2.4 Historical Commercial Catch-Per-Unit Effort/Logbooks

`historical-commercial-catch-per-unit-effortlogbooks`

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 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 35 and 36). Two CPUE indices from 1987-2009 with catchability modeled as a power function are used in this update assessment, one for the north and south winter fisheries.

2.2.5 Fishery Length and Age Data

`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 has identified samples across years that were not collected according to the state's standardized sampling protocal that were included in PacFIN due to error. These samples likely represent samples that were collected for special projects. Oregon has removed some of these samples for petrale sole from PacFIN, but not all as of 2019. To remove the remaining non-standard samples, Oregon PacFIN data was filtered according to the "Sample Quality" based on directions from Ali Whitman at ODFW where samples with a sample quality code of 63 represent non-standardized samples. Filtering out these records removed all Oregon samples from 1966-1970 and 1972-1975 and a portion of samples from 1971.

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 databases) 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 aging 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 32, 33, and 34 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 to be consistent with the 2015 update assessment. The input sample size for commercial lengths and ages were set equal to the number of trips by year for each fleet.

2.3 Biological Data

biological-data

2.3.1 Natural Mortality

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 $M = 4.899A_{max}^{-0.916}$. 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. 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

`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 37).

To date, there has been limited information regarding fecundity at age or length of petrale sole. The 2013 stock assessment assumed that fecundity of female petrale sole was equal to biomass (Figure 38). Since the last full assessment, new research has been done examining the fecundity of petrale sole (Lefebvre et al. n.d.). 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 39). 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 include the new data about fecundity at length.

2.3.3 Sex Ratio

`sex-ratio`

Past assessments of petrale sole have assumed a 50% sex ratio 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 with the proportion increasing to 1 at the largest lengths due to dimorphic growth (Figure 40). The next full assessment should evaluate the sex ratio for petrale sole.

2.3.4 Length-Weight Relationship

`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, where 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 (Figures 41).

2.3.5 Growth (Length-at-Age)

`growth-length-at-age`

The length-at-age was estimated for male and female petrale sole. Figure 42 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:

XXX DOUBLE CHECK THESE VALUES WHEN AGES ARRIVE XXX

$$\text{Females } L_\infty = 54;\ k = 0.16$$

$$\text{Males } L_\infty = 41;\ k = 0.25$$

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

`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 state of Oregon, 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). The same approach to ageing error based on data source are age reading method applied in the 2013 assessment was applied in this update 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

`environmental-and-ecosystem-data`

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

3 Assessment Model

assessment-model

3.1 History of Modeling Approaches Used for This Stock

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). The 2015 this 2019 update assessment assumes the same approach as the 2013 stock assessment.

3.2 General Model Specifications and Assumptions

general-model-specifications-and-assumptions

Stock Synthesis version 3.30.03.13 was used to estimate the parameters in the model (Methot and Wetzel 2013). R4SS, version 1.33.2, along with R version 3.4.3 were used to investigate and plot model fits. A summary of the data sources used in the model (details discussed above) is shown in Figure 2.

3.2.1 Changes Between the 2015 Update and Current Assessment Model

changes-between-the-2015-update-and-current-assessment-model

As with the 2013 petrale sole stock assessment, the current model is implemented as a single-area model. The current update assessment has been upgraded to a new version of SS (3.30.13). A thorough description of the 2013 assessment model, which is used in this update assessment, is presented separately below; 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 recalculated data expansions based upon the current methods.
4. Reprocessed all discard data sources and added discard rate, average weight, and length composition data (2014-2017).
5. Added 2015-2018 NWFSC West Coast Groundfish Bottom Trawl Survey data and calculated the index of abundance 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 Summary of Fleets and Areas

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. Other removals are very small and are included in the trawl fishery removals. The data available for each fleet are described in Figure 2.

3.2.3 Priors

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 44).

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 males (Figure 43), respectively, the same assumption regarding maximum age as applied in the 2013 assessment.

3.2.4 Data Weighting

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 and the Triennial Survey. Length data started with a input sample size determined from the equation listed in Sections 2.1.1 (survey data) and 2.2.5 (fishery data). 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 2015 update assessment. 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.

3.2.5 Estimated and Fixed Parameters

estimated-and-fixed-parameters

There were 304 estimated parameters in the base model. These included one parameters for R_0, natural mortality, 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 recruitment deviates was fixed at 0.40. Maturity-at-length was fixed as described above in Section 2.3.2. Length-weight parameters were fixed at estimates using all length-weight observations (Figure 41).

3.2.6 Key Assumptions and Structural Choices

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.

3.2.7 Bridging Analysis

bridging-analysis

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).

3.2.8 Convergence

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 10%. This was repeated 50 times and a better minimum was not found (Table 18). The model did not experience convergence issues when provided reasonable starting values. 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.

3.3 Base Model Results

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 19. Estimates of derived reference points and approximate 95% asymptotic confidence intervals are shown in Table 20. Estimates of stock size over time are shown in Table 21.

3.3.1 Parameter Estimates

`parameter-estimates`

Natural mortality be sex was estimated directly within the model. Natural mortality was estimated to be 0.151 for female fish and 0.157 for male fish. In comparison the estimates from the 2015 assesment were 0.145 and 0.154 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 0.86. 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 fish was consistent with the value estimated in the 2015 update assessment (0.142 versus 0.134), but the estimated k for male fish was higher than the value estimated in 2015 (0.234 versus 0.203). 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 46). The spawning output estimated was equal to the spawning weight of female fish (Figure 47).

Selectivity curves were estimated for the fishery and survey fleets. The estimated selectivities for the fishery fleets are shown in Figure 48. All fishery selectivities were estimated to be asymptotic, reaching maximum selectivity for fish between 35 and 40 cm. Shifts in selectivities for were estimated for each fleet fishery were estimated based on time blocks assumed in the 2013 assessment (Figure 48). The estimated retention curves for each fleet based on the historical time blocks and discarded length composition data are shown in Figure 49. Sex specific survey selectivities were assumed to be asymptotic and are shown in Figure 50.

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 -0.079. The Winter South base catchability value was estimated at 0.185 with the exponent parameter at -0.814.

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 a added variance of 0.21 for the early time period of and 0.307 for the late period.

The time-series of estimated recruitments shows a relationship with the decline in spawning output, punctuated by larger recruitments (Figures 51 and 52) in recent years (2006, 2007, and 2008). 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, 2007, 1966, and 2008. The four lowest recruitments estimated within the model (in ascending order) occurred in 1992, 1986, 2003, and 1987.

3.3.2 Fits to the Data

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 54, 55, 56, and 57. The model fits both of the CPUE time-series relatively well. The fits to the survey indices are shown in Figures 58, 59, and 60. 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 was over fit by the model.

The observed WCGOP discard rates (Figures 61 - 64) were fit by each fishery using time blocks. The time blocks on the discard data was based on those define in the 2013 assessment (Haltuch et al. 2013a) with the final block starting in 2011 being extended through the final model year. The discarding rates over time by each fleet are shown in Figure 65. Fits to the discard rates for the northern fleets from the Pikitch data in 1985-1987 were either under (Figure 61) or over fit (Figure 62) which 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, section 11. 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 mean weights. The relationship between the observed (input) sample size to the effective sample sizes after weighting are shown in Figures 85 - 88.

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 89. The aggregated age data were general fit well for the fishery fleets, however, the peaks of each 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, section 12. The Pearson residuals for the fishery fleets are shown in Figures 90 - **??**.

The observed and expected conditional age-at-length fits for NWFSC West Coast Groundfish Bottom Trawl Survey are shown in Figures 94 - **??**. The fits generally match the observations. The Pearson residuals are shown in Figure 98 and 99.

The age data were also weighted according to the McAllister Ianelli Harmonic mean weights. The relationship betwen the observed (input) sample size to the effective sample sizes after weighting are shown in Figures 103 - 103.

3.3.3 Population Trajectory

`population-trajectory`

The predicted spawning biomass is given in Table 21 and plotted in Figure 104. 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 104). The stock has increased strongly since 2010 in response to reduced catches and in response to above average recruitment in 2006, 2007, and 2008. The estimated total biomass follows the same genera trend as observed in the spawning biomass (Figure 105). The 2019 estimated spawning biomass relative to unfished equilibrium spawning biomass is above the target of 25% of unfished spawning biomass at 37.7% (Figure 106). Approximate confidence intervals based on the asymptotic variance estimates show that the uncertainty in the estimated spawning biomass is generaly low. The standard deviation of the log of the spawning output in 2019 is 0.09.

Recruitment deviations were estimated for the entire time-series that was modeled (Figure 51 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 estimated recruitment estimated with the model (in ascending order) occurred in 2006, 1998, 2007, 1966, and 2008. The four lowest recruitments estimated within the model (in ascending order) occurred in 1992, 1986, 2003, and 1987. The stock-recruit curve resulting from a value of estimated steepness, 0.86, is shown in Figure 107 with estimated recruitments also shown.

3.3.4 Sensitivity Analyses

`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 ??.
2. Fix natural mortality value for female fish at a higher value of ??.
3. Use the natural mortality prior for female and male fish used in the 2015 update assessment, natural mortality estimated.
4. Use the coastwide fecundity relationship for petrale sole estimated by Lefebvre et al. (in press).
5. Estimate the sex ratio between female and male fish within the model.
6. Data weight according to the Francis method using the weighting values shown in Table 23.
7. Data weight according to the Dirichlet method where the estimated parameters are shown in Table 24.

Likelihood values and estimates of key parameters from each sensitivity are available in Table 22. Plots of the estimated time-series of spawning biomass and relative spawning biomass are shown in Figures 108 and 109

3.3.5 Retrospective Analysis

retrospective-analysis

A five-year retrospective analysis was conducted by running the model using data only through 2014, 2015, 2016, 2017 and 2018 (Figures 110, 111, and 112). he initial scale of the spawning biomass trended upward relative to the base model. Overall, no alarming patterns were present in the retrospective analysis.

3.3.6 Historical Analysis

historical-analysis

The estimated summary biomass from previous assessments since 2005 are shown in Figure 113. The current assessment estimated a slight increase in initial spawning biomass compared to previous assessments.

3.3.7 Likelihood Profiles

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 114). Likelihood components by data source show that the age data support a higher steepness value. The surveys generally provide very little information concerning steepness. The relative spawning biomass for petrale sole diverges most during the middel of the time series based on the assumed values of steepness with the final status generally being above the management target biomass (Figure 115).

The negative log-likelihood was minimized at a female natural mortality value of ??, but the 95% confidence interval extends over values ranging from ?? - ??. Male natural mortality was estimated in the likelihood profile. The age and length data likelihood contribution was minimized at natural morality values ranging from ??-?? (Figure **??**). The relative spawning biomass for petrale sole widely varied across alternative values of natural mortality (Figure 117).

In regards to values of R_0, the negative log-likelihood was minimized at approximately $\log(R_0)$ of 9.85 (Figure 118).

3.3.8 Reference Points

reference-points-1

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 3,145.7 mt when using an $SPR_{30\%}$ reference harvest rate and with a 95% confidence interval of 2,847.5 mt based on estimates of uncertainty. The spawning biomass equivalent to 25% of the unfished spawning output ($SB_{25\%}$) was 8,687.4.

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 5.3% relative stock size (Figures 104 and 106). Since 20010, 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 106). The fishing intensity, 1-SPR, exceeded the current harvest rate limit ($SPR_{30\%}$) throughout the late 1970s until approximately 2010 as seen in Figure 119. Recent exploitation rates on petrale sole were estimated to be less than target levels.

Table 20 shows the full suite of estimated reference points for the base model and Figure 120 shows the equilibrium curve based on a steepness value estimated at 0.86.

4 Harvest Projections and Decision Tables

`harvest-projections-and-decision-tables`

5 Regional Management Considerations

`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.

6 Research Needs

`research-needs`

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. 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 both the maturity and fecundity relationships for petrale sole would be beneficial.

3. 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.

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.

7 Acknowledgments

`acknowledgments`

Many people were instrumental in the successful completion of this assessment and their contribution is greatly appreciated.

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9 Tables

`tables`

Table 1: Landings for each fleet for the modeled years.

tab:Comm_Catch

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
1913	0	0	0	360
1914	0	0	0	370

Year	Winter North	Summer North	Winter South	Summer South
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
1953	46	737	533	981
1954	27	903	801	1073

Year	Winter North	Summer North	Winter South	Summer South
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
1993	685	392	237	234
1994	518	355	246	299

Year	Winter North	Summer North	Winter South	Summer South
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
1953	46	737	533	981
1954	27	903	801	1073

Year	Winter North	Summer North	Winter South	Summer South
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.

tab:mnmgt_perform_tables

Year	OFL (mt; ABC prior to 2011)	ACL (mt; OY prior to 2011)	Total landings (mt)	Estimated total catch (mt)
2009	2811	2433	2209	2340
2010	2751	1200	755	870
2011	1021	976	768	782
2012	1275	1160	1135	1150
2013	2711	2592	1967	1990
2014	2774	2652	2373	2390
2015	3073	2816	2686	2702
2016	3208	2910	2506	2520
2017	3208	3136	3008	3024
2018	3152	3013	2840	2855

Table 3: Description of the strata used to create the indices for the NWFSC Shelf-Slope survey.

tab:strata_nwfsc

Strata	Depth Lower Bound	Depth Upper Bound	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 4: 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.

tab:Index_Summary

	Winter N.		Winter S.		Triennial Early		Triennial Late		NWFSC Combo	
Year	Obs	SE	Obs	SE	Obs	SE	Obs	SE	Obs	SE
1980	-	-	-	-	1416	0.44	-	-	-	-
1983	-	-	-	-	2019	0.40	-	-	-	-
1986	-	-	-	-	2094	0.40	-	-	-	-
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	0.38	-	-	-	-
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	0.37	-	-
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	0.38	-	-
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 5: Summary of NWFSC shelf-slope survey length samples used in the stock assessment. tab:NWcombo_Lengths

Year	Tows	Fish	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 6: Summary of NWFSC shelf-slope survey age samples used in the stock assessment.

tab:NWcombo_Ages

Year	Tows	Fish	Sample 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: Description of the strata used to create the indices for the Triennial Early (1980 - 1992) survey.

tab:strata_tri_early

Strata	Depth Lower Bound	Depth Upper Bound	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 8: Description of the strata used to create the indices for the Triennial Late (1995-2004) survey.

tab:strata_tri_late

Strata	Depth Lower Bound	Depth Upper Bound	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 9: Summary of Triennial survey length samples used in the stock assessment.
tab:Triennial_Lengths

Year	Tows	Fish	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 10: Summary of discard rates used in the model by each data source (continued on next page).

tab:Discard

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	WGCOP
2003	WinterN	0.004	0.002	WGCOP
2004	WinterN	0.003	0.002	WGCOP
2005	WinterN	0.002	0.001	WGCOP
2006	WinterN	0.006	0.003	WGCOP
2007	WinterN	0.012	0.005	WGCOP
2008	WinterN	0.022	0.012	WGCOP
2009	WinterN	0.027	0.014	WGCOP
2010	WinterN	0.119	0.023	WGCOP
2011	WinterN	0.002	0.015	WGCOP
2012	WinterN	0.001	0.015	WGCOP
2013	WinterN	0.001	0.015	WGCOP
2014	WinterN	0.003	0.015	WGCOP
2015	WinterN	0.001	0.015	WGCOP
2016	WinterN	0.001	0.015	WGCOP
2017	WinterN	0.003	0.015	WGCOP
2018	WinterN	0.001	0.015	WGCOP
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	WGCOP
2003	SummerN	0.105	0.022	WGCOP
2004	SummerN	0.083	0.023	WGCOP
2005	SummerN	0.042	0.008	WGCOP
2006	SummerN	0.078	0.015	WGCOP
2007	SummerN	0.116	0.021	WGCOP
2008	SummerN	0.051	0.016	WGCOP
2009	SummerN	0.206	0.067	WGCOP
2010	SummerN	0.099	0.029	WGCOP
2011	SummerN	0.037	0.015	WGCOP
2012	SummerN	0.022	0.015	WGCOP
2013	SummerN	0.017	0.015	WGCOP
2014	SummerN	0.026	0.015	WGCOP
2015	SummerN	0.006	0.015	WGCOP
2016	SummerN	0.017	0.015	WGCOP
2017	SummerN	0.007	0.015	WGCOP

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

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

tab:Fishery_Lengths

	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

	Winter N.		Summer N.		Winter S.		Summer S.	
Year	Trips	Fish	Trips	Fish	Trips	Fish	Trips	Fish
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 next page).

tab:Fishery_Ages

	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

	Winter N.		Summer N.		Winter S.		Summer S.	
Year	Trips	Fish	Trips	Fish	Trips	Fish	Trips	Fish
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.

tab:age_error1

	Break and Burn		Surface		Combo		Surface Pre-1990	
True Age	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0	0.26	0.17	0.16	0.12	0.47	0.13	0.00	0.00
1	1.35	0.17	1.27	0.12	1.42	0.13	0.71	0.00
2	2.41	0.23	2.35	0.18	2.37	0.25	2.02	0.08
3	3.44	0.29	3.41	0.25	3.32	0.38	3.24	0.17
4	4.45	0.36	4.43	0.32	4.27	0.51	4.38	0.26
5	5.44	0.44	5.42	0.40	5.22	0.64	5.44	0.35
6	6.41	0.52	6.39	0.49	6.17	0.76	6.44	0.46
7	7.35	0.61	7.33	0.59	7.12	0.89	7.36	0.56
8	8.28	0.71	8.25	0.70	8.07	1.02	8.22	0.67
9	9.18	0.81	9.14	0.82	9.02	1.14	9.03	0.79
10	10.06	0.92	10.01	0.96	9.97	1.27	9.78	0.92
11	10.92	1.04	10.85	1.11	10.92	1.40	10.48	1.05
12	11.76	1.18	11.67	1.27	11.87	1.53	11.14	1.19
13	12.58	1.32	12.47	1.45	12.82	1.65	11.75	1.34
14	13.38	1.48	13.24	1.66	13.77	1.78	12.32	1.49
15	14.17	1.64	14.00	1.88	14.72	1.91	12.85	1.66
16	14.94	1.82	14.73	2.12	15.67	2.03	13.35	1.83
17	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.

tab:age_error2

	Combo		Surface		Break and Burn	
True Age	Mean	SD	Mean	SD	Mean	SD
0	0.49	0.13	0.13	0.10	0.50	0.15
1	1.46	0.13	1.32	0.10	1.51	0.15
2	2.44	0.27	2.47	0.21	2.52	0.30
3	3.42	0.40	3.58	0.31	3.52	0.45
4	4.39	0.53	4.64	0.41	4.53	0.60
5	5.37	0.67	5.67	0.52	5.53	0.75
6	6.35	0.80	6.66	0.62	6.54	0.90
7	7.32	0.93	7.62	0.72	7.55	1.05
8	8.30	1.07	8.54	0.83	8.55	1.20
9	9.28	1.20	9.43	0.93	9.56	1.35
10	10.25	1.33	10.28	1.03	10.57	1.51
11	11.23	1.47	11.11	1.13	11.57	1.66
12	12.21	1.60	11.90	1.24	12.58	1.81
13	13.18	1.74	12.67	1.34	13.59	1.96
14	14.16	1.87	13.41	1.44	14.59	2.11
15	15.14	2.00	14.12	1.55	15.60	2.26
16	16.11	2.14	14.81	1.65	16.60	2.41
17	17.09	2.27	15.47	1.75	17.61	2.56

Table 15: Specifications of the model for petrale sole.

tab:Model_setup

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 harmonic data weighting.

tab:harm

Fleet	Lengths	Ages
Winter North	1.377	2.904
Summer North	0.940	2.421
Winter South	0.897	1.744
Summer South	1.157	1.583
Triennial Early survey	1.822	-
Triennial Late survey	1.270	-
NWFSC shelf-slope survey	0.568	0.216

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	0.151334	6	(0.005, 0.5)	OK	0.02	Log_Norm (-1.7793, 0.438)
L_at_Amin_Fem_GP_1	15.4987	2	(10, 45)	OK	0.42	None
L_at_Amax_Fem_GP_1	53.1287	3	(35, 80)	OK	0.40	None
VonBert_K_Fem_GP_1	0.142492	2	(0.04, 0.5)	OK	0.01	None
SD_young_Fem_GP_1	0.188679	3	(0.01, 1)	OK	0.01	None
SD_old_Fem_GP_1	0.0344042	4	(0.01, 1)	OK	0.01	None
Wtlen_1_Fem_GP_1	0.000001986	-3	(-3, 3)			Normal (0.000001986, 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	0.156867	6	(0.005, 0.6)	OK	0.02	Log_Norm (-1.6809, 0.438)
L_at_Amin_Mal_GP_1	16.2205	2	(10, 45)	OK	0.34	None
L_at_Amax_Mal_GP_1	40.8739	3	(35, 80)	OK	0.34	None
VonBert_K_Mal_GP_1	0.234	2	(0.04, 0.5)	OK	0.01	None
SD_young_Mal_GP_1	0.135122	3	(0.01, 1)	OK	0.01	None
SD_old_Mal_GP_1	0.059	4	(0.01, 1)	OK	0.00	None
Wtlen_1_Mal_GP_1	0.000002983	-3	(-3, 3)			Normal (0.000002983, 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)	9.84924	1	(5, 20)	OK	0.19	None
SR_BH_steep	0.862234	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	0.000000179961	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_30	0.000000209323	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_29	0.000000243446	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_28	0.000000283075	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_27	0.000000329104	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_26	0.000000382525	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_25	0.000000444513	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_24	0.0000005164	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_23	0.000000599721	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_22	0.000000696226	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_21	0.000000807918	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_20	0.000000937085	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	0.00000108631	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_18	0.00000125853	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_17	0.00000145702	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_16	0.00000168554	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_15	0.00000194822	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_14	0.00000224969	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_13	0.00000259503	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_12	0.0000029899	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_11	0.00000344047	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_10	0.00000395345	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_9	0.00000453609	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_8	0.00000519584	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_7	0.00000593993	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_6	0.00000677576	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_5	0.00000771393	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_4	0.00000877183	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_3	0.00000997084	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_2	0.0000113314	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_1	0.0000128747	3	(-4, 4)	act	0.40	dev (NA, NA)
LnQ_base_WinterN(1)	-7.33661	1	(-20, 5)	OK	2.90	None
Q_power_WinterN(1)	-0.078707	3	(-5, 5)	OK	0.37	None
LnQ_base_WinterS(3)	-1.68912	1	(-20, 5)	OK	3.34	None
Q_power_WinterS(3)	-0.813913	3	(-5, 5)	OK	0.41	None
LnQ_base_TriEarly(5)	-0.845251	-1	(-15, 15)			None
Q_extraSD_TriEarly(5)	0.210369	5	(0.001, 2)	OK	0.13	None
LnQ_base_TriLate(6)	-0.397712	-1	(-15, 15)			None
Q_extraSD_TriLate(6)	0.306846	4	(0.001, 2)	OK	0.14	None
LnQ_base_NWFSC(7)	1.0575	-1	(-15, 15)			None
LnQ_base_WinterN(1)_BLK5add_2004	0.479235	3	(-0.99, 0.99)	OK	0.20	Normal (0, 0.5)
LnQ_base_WinterS(3)_BLK5add_2004	0.637066	3	(-0.99, 0.99)	OK	0.21	Normal (0, 0.5)
Size_DblN_peak_WinterN(1)	48.6913	1	(15, 75)	OK	2.35	None
Size_DblN_top_logit_WinterN(1)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_WinterN(1)	4.32519	2	(-4, 12)	OK	0.16	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)	28.1513	1	(10, 40)	OK	1.80	None
Retain_L_width_WinterN(1)	1.84909	2	(0.1, 10)	OK	0.52	None
Retain_L_asymptote_logit_WinterN(1)	9.03653	4	(-10, 10)	OK	21.70	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)	-12.0716	3	(-15, 15)	OK	0.99	None
SzSel_Male_Ascend_WinterN(1)	-1.48626	4	(-15, 15)	OK	0.22	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)	45.3007	1	(15, 75)	OK	1.64	None
Size_DblN_top_logit_SummerN(2)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_SummerN(2)	5.15775	2	(-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)	29.211	1	(10, 40)	OK	0.56	None
Retain_L_width_SummerN(2)	1.57764	2	(0.1, 10)	OK	0.29	None
Retain_L_asymptote_logit_SummerN(2)	4.53507	4	(-10, 10)	OK	1.97	None
Retain_L_maleoffset_SummerN(2)	0	-2	(-10, 10)			None
SzSel_Male_Peak_SummerN(2)	-13.2585	3	(-20, 15)	OK	1.05	None
SzSel_Male_Ascend_SummerN(2)	-2.17725	4	(-15, 15)	OK	0.28	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)	38.7137	1	(15, 75)	OK	2.49	None
Size_DblN_top_logit_WinterS(3)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_WinterS(3)	4.41461	2	(-4, 12)	OK	0.24	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)	29.4209	1	(10, 40)	OK	0.77	None
Retain_L_width_WinterS(3)	1.61088	2	(0.1, 10)	OK	0.33	None
Retain_L_asymptote_logit_WinterS(3)	8.67923	4	(-10, 10)	OK	27.81	None
Retain_L_maleoffset_WinterS(3)	0	-2	(-10, 10)			None
SzSel_Male_Peak_WinterS(3)	-7.48802	3	(-15, 15)	OK	1.53	None
SzSel_Male_Ascend_WinterS(3)	-1.26686	4	(-15, 15)	OK	0.37	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)	40.6087	1	(15, 75)	OK	1.68	None
Size_DblN_top_logit_SummerS(4)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_SummerS(4)	4.923	2	(-4, 12)	OK	0.17	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_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)	28.936	1	(10, 40)	OK	0.26	None
Retain_L_width_SummerS(4)	1.04009	2	(0.1, 10)	OK	0.14	None
Retain_L_asymptote_logit_SummerS(4)	9.52099	4	(-10, 10)	OK	12.50	None
Retain_L_maleoffset_SummerS(4)	0	-2	(-10, 10)			None
SzSel_Male_Peak_SummerS(4)	-12.8125	3	(-15, 15)	OK	1.36	None
SzSel_Male_Ascend_SummerS(4)	-1.93303	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)	34.9276	1	(15, 61)	OK	1.15	None
Size_DblN_top_logit_TriEarly(5)	3	-2	(-5, 3)			None
Size_DblN_ascend_se_TriEarly(5)	4.14085	1	(-4, 12)	OK	0.20	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)	-3.4918	2	(-15, 15)	OK	1.09	None
SzSel_Male_Ascend_TriEarly(5)	-0.491136	2	(-15, 15)	OK	0.24	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)	36.5552	1	(15, 61)	OK	0.92	None
Size_DblN_top_logit_TriLate(6)	3	-2	(-5, 3)			None
Size_DblN_ascend_se_TriLate(6)	4.64973	1	(-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)	-2.11797	2	(-15, 15)	OK	0.95	None
SzSel_Male_Ascend_TriLate(6)	-0.0242089	2	(-15, 15)	OK	0.15	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)	42.7668	1	(15, 61)	OK	0.90	None
Size_DblN_top_logit_NWFSC(7)	3	-2	(-5, 3)			None
Size_DblN_ascend_se_NWFSC(7)	5.13924	1	(-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)	-4.91699	2	(-15, 15)	OK	0.75	None
SzSel_Male_Ascend_NWFSC(7)	-0.4041	2	(-15, 15)	OK	0.09	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	1.9551	4	(-31.6, 28.4)	OK	2.40	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_1983	-1.97291	4	(-31.6, 28.4)	OK	2.30	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_1993	-0.789171	4	(-31.6, 28.4)	OK	2.20	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_2003	0.485316	4	(-31.6, 28.4)	OK	2.17	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_2011	0.916987	4	(-31.6, 28.4)	OK	2.17	Normal (0, 14.2)
Retain_L_infl_WinterN(1)_BLK2add_2003	-2.40321	4	(-16.19, 13.81)	OK	3.02	Normal (0, 6.905)
Retain_L_infl_WinterN(1)_BLK2add_2010	1.52172	4	(-16.19, 13.81)	OK	3.34	Normal (0, 6.905)
Retain_L_infl_WinterN(1)_BLK2add_2011	-3.39699	4	(-16.19, 13.81)	OK	2.22	Normal (0, 6.905)
Retain_L_width_WinterN(1)_BLK2add_2003	0.116126	4	(-1.601, 8.299)	OK	0.54	Normal (0, 0.8005)
Retain_L_width_WinterN(1)_BLK2add_2010	0.384528	4	(-1.601, 8.299)	OK	0.77	Normal (0, 0.8005)
Retain_L_width_WinterN(1)_BLK2add_2011	-0.690633	4	(-1.601, 8.299)	OK	0.51	Normal (0, 0.8005)
Retain_L_asymptote_logit_WinterN(1)_BLK2repl_2003	6.61377	4	(-10, 10)	OK	1.31	None
Retain_L_asymptote_logit_WinterN(1)_BLK2repl_2010	2.10248	4	(-10, 10)	OK	0.43	None
Retain_L_asymptote_logit_WinterN(1)_BLK2repl_2011	9.96042	4	(-10, 10)	HI	1.00	None
Size_DblN_peak_SummerN(2)_BLK1add_1973	-0.4095	4	(-38.8, 21.2)	OK	1.74	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_1983	0.981231	4	(-38.8, 21.2)	OK	1.60	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_1993	-0.0735326	4	(-38.8, 21.2)	OK	1.70	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_2003	1.07942	4	(-38.8, 21.2)	OK	1.49	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_2011	4.35803	4	(-38.8, 21.2)	OK	1.50	Normal (0, 10.6)
Retain_L_infl_SummerN(2)_BLK3add_2003	-0.198357	4	(-20.679, 9.321)	OK	0.85	Normal (0, 4.6605)
Retain_L_infl_SummerN(2)_BLK3add_2009	1.94573	4	(-20.679, 9.321)	OK	0.83	Normal (0, 4.6605)
Retain_L_infl_SummerN(2)_BLK3add_2011	-1.45955	4	(-20.679, 9.321)	OK	0.88	Normal (0, 4.6605)
Retain_L_width_SummerN(2)_BLK3add_2003	0.319789	4	(-1.0278, 8.8722)	OK	0.34	Normal (0, 0.5139)
Retain_L_width_SummerN(2)_BLK3add_2009	0.267803	4	(-1.0278, 8.8722)	OK	0.33	Normal (0, 0.5139)
Retain_L_width_SummerN(2)_BLK3add_2011	-0.0105716	4	(-1.0278, 8.8722)	OK	0.31	Normal (0, 0.5139)
Retain_L_asymptote_logit_SummerN(2)_BLK3repl_2003	5.68752	4	(-10, 10)	OK	1.52	None
Retain_L_asymptote_logit_SummerN(2)_BLK3repl_2009	9.55626	4	(-10, 10)	OK	11.68	None
Retain_L_asymptote_logit_SummerN(2)_BLK3repl_2011	6.25184	4	(-10, 10)	OK	0.45	None
Size_DblN_peak_WinterS(3)_BLK1add_1973	-4.28962	4	(-25.422, 34.578)	OK	4.20	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_1983	2.78231	4	(-25.422, 34.578)	OK	2.47	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_1993	4.57917	4	(-25.422, 34.578)	OK	2.36	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_2003	5.27907	4	(-25.422, 34.578)	OK	2.30	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_2011	6.22985	4	(-25.422, 34.578)	OK	2.30	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	-0.767558	4	(-18.816, 11.184)	OK	1.28	Normal (0, 5.592)
Retain_L_infl_WinterS(3)_BLK2add_2010	2.26849	4	(-18.816, 11.184)	OK	1.57	Normal (0, 5.592)
Retain_L_infl_WinterS(3)_BLK2add_2011	-3.01204	4	(-18.816, 11.184)	OK	2.09	Normal (0, 5.592)
Retain_L_width_WinterS(3)_BLK2add_2003	-0.176178	4	(-1.0443, 8.8557)	OK	0.36	Normal (0, 0.52215)
Retain_L_width_WinterS(3)_BLK2add_2010	-0.172343	4	(-1.0443, 8.8557)	OK	0.50	Normal (0, 0.52215)
Retain_L_width_WinterS(3)_BLK2add_2011	-0.0975636	4	(-1.0443, 8.8557)	OK	0.38	Normal (0, 0.52215)
Retain_L_asymptote_logit_WinterS(3)_BLK2repl_2003	9.80678	4	(-10, 10)	HI	5.52	None
Retain_L_asymptote_logit_WinterS(3)_BLK2repl_2010	5.57119	4	(-10, 10)	OK	6.53	None
Retain_L_asymptote_logit_WinterS(3)_BLK2repl_2011	7.34024	4	(-10, 10)	OK	1.39	None
Size_DblN_peak_SummerS(4)_BLK1add_1973	-4.81708	4	(-28.0793, 31.9207)	OK	2.42	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_1983	-11.3425	4	(-28.0793, 31.9207)	OK	6.54	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_1993	3.92846	4	(-28.0793, 31.9207)	OK	2.07	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_2003	6.48698	4	(-28.0793, 31.9207)	OK	1.75	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_2011	6.27675	4	(-28.0793, 31.9207)	OK	1.75	Normal (0, 14.0397)
Retain_L_infl_SummerS(4)_BLK3add_2003	-1.45406	4	(-19.055, 10.945)	OK	0.87	Normal (0, 5.4725)
Retain_L_infl_SummerS(4)_BLK3add_2009	-1.70934	4	(-19.055, 10.945)	OK	1.27	Normal (0, 5.4725)
Retain_L_infl_SummerS(4)_BLK3add_2011	-2.14155	4	(-19.055, 10.945)	OK	1.05	Normal (0, 5.4725)
Retain_L_width_SummerS(4)_BLK3add_2003	0.627828	4	(-0.876, 9.024)	OK	0.23	Normal (0, 0.438)
Retain_L_width_SummerS(4)_BLK3add_2009	0.488692	4	(-0.876, 9.024)	OK	0.25	Normal (0, 0.438)
Retain_L_width_SummerS(4)_BLK3add_2011	0.609335	4	(-0.876, 9.024)	OK	0.20	Normal (0, 0.438)
Retain_L_asymptote_logit_SummerS(4)_BLK3repl_2003	7.41647	4	(-10, 10)	OK	3.28	None
Retain_L_asymptote_logit_SummerS(4)_BLK3repl_2009	8.69003	4	(-10, 10)	OK	13.86	None
Retain_L_asymptote_logit_SummerS(4)_BLK3repl_2011	7.65847	4	(-10, 10)	OK	1.28	None

tab:model_params

Table 18: Results from 50 jitters from the base model.

tab:jitter

Status	Base.Model..jitter.0.05.
Returned to base case	8
Found local minimum	42
Found better solution	0
Total	50

Table 19: Likelihood components from the base model

tab:like

Likelihood Component	Value
Total	1397.46
Survey	-75.07
Discard	-228.29
Mean-body weight data	-160.93
Length-frequency data	785.85
Age-frequency data	1096.58
Recruitment	-27.8
Forecast Recruitment	0.04
Parameter Priors	7.04
Parameter Softbounds	0.04

Table 20: Summary of reference points and management quantities for the base case.

tab:Ref_pts

Quantity	**Estimate**	**~2.5% Confidence Interval**	**~97.5% Confidence Interval**
Unfished spawning biomass (mt)	34749.5	28140.3	41358.7
Unfished age 3+ biomass (mt)	55563.4	46647.3	64479.5
Unfished recruitment (R0, thousands)	18943.9	13018.3	27566.8
Spawning biomass(2019 mt)	13114.1	10722.3	15505.9
Depletion (2019)	0.377	0.27	0.485
Reference points based on $\mathbf{SB_{40\%}}$			
Proxy spawning biomass ($B_{25\%}$)	8687.4	7035.1	10339.7
SPR resulting in $B_{25\%}$ ($SPR_{B25\%}$)	0.28	0.257	0.303
Exploitation rate resulting in $B_{25\%}$	0.179	0.16	0.199
Yield with $SPR_{B25\%}$ at $B_{25\%}$ (mt)	3169.4	2902.2	3436.7
Reference points based on SPR proxy for MSY			
Spawning biomass	9412.8	7349.3	11476.3
SPR_{proxy}			
Exploitation rate corresponding to SPR_{proxy}	0.167	0.141	0.193
Yield with SPR_{proxy} at SB_{SPR} (mt)	3145.7	2847.5	3443.8
Reference points based on estimated MSY values			
Spawning bioamss at MSY (SB_{MSY})	7564.2	5628.4	9500.1
SPR_{MSY}	0.249	0.188	0.31
Exploitation rate at MSY	0.201	0.168	0.233
MSY (mt)	3184.6	2935.8	3433.4

Table 21: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning biomass (million eggs)	Summary biomass 3+	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1876	56,178	34,750	55,564	1.00	18,944	1	0	0
1877	56,177	34,749	55,563	1.00	18,944	1	0	0
1878	56,176	34,748	55,562	1.00	18,944	1	0	0
1879	56,175	34,748	55,561	1.00	18,944	1	0	0
1880	56,175	34,747	55,560	1.00	18,944	12	0	0
1881	56,164	34,740	55,549	1.00	18,944	23	0	0
1882	56,142	34,726	55,528	1.00	18,944	34	0.003	0.001
1883	56,112	34,706	55,498	1.00	18,944	45	0.003	0.001
1884	56,073	34,680	55,459	1.00	18,943	56	0.003	0.001
1885	56,027	34,649	55,412	1.00	18,943	66	0.003	0.001
1886	55,973	34,613	55,358	1.00	18,942	77	0.003	0.001
1887	55,913	34,572	55,298	0.99	18,941	88	0.006	0.002
1888	55,847	34,527	55,232	0.99	18,940	99	0.006	0.002
1889	55,776	34,479	55,161	0.99	18,939	110	0.006	0.002
1890	55,700	34,427	55,086	0.99	18,939	121	0.006	0.002
1891	55,620	34,373	55,006	0.99	18,938	132	0.009	0.002
1892	55,537	34,316	54,922	0.99	18,937	143	0.009	0.003
1893	55,450	34,256	54,836	0.99	18,935	154	0.009	0.003
1894	55,361	34,195	54,746	0.98	18,934	165	0.009	0.003
1895	55,269	34,131	54,654	0.98	18,933	175	0.009	0.003
1896	55,174	34,066	54,560	0.98	18,932	187	0.012	0.003
1897	55,078	34,000	54,464	0.98	18,931	198	0.012	0.004
1898	54,980	33,932	54,366	0.98	18,930	208	0.012	0.004
1899	54,880	33,863	54,266	0.97	18,929	219	0.012	0.004
1900	54,780	33,794	54,166	0.97	18,928	230	0.012	0.004
1901	54,678	33,723	54,064	0.97	18,927	241	0.015	0.004
1902	54,575	33,652	53,961	0.97	18,926	252	0.015	0.005
1903	54,471	33,580	53,857	0.97	18,926	263	0.015	0.005
1904	54,366	33,507	53,752	0.96	18,925	274	0.015	0.005
1905	54,261	33,434	53,647	0.96	18,925	285	0.018	0.005
1906	54,155	33,360	53,541	0.96	18,924	296	0.018	0.006
1907	54,049	33,287	53,435	0.96	18,924	307	0.018	0.006
1908	53,942	33,212	53,328	0.96	18,924	318	0.018	0.006
1909	53,835	33,138	53,221	0.95	18,924	328	0.018	0.006
1910	53,727	33,063	53,113	0.95	18,924	339	0.021	0.006
1911	53,620	32,988	53,006	0.95	18,925	350	0.021	0.007
1912	53,512	32,913	52,898	0.95	18,926	361	0.021	0.007
1913	53,404	32,838	52,790	0.94	18,927	372	0.021	0.007
1914	53,296	32,762	52,682	0.94	18,929	383	0.021	0.007
1915	53,188	32,687	52,574	0.94	18,930	394	0.024	0.007
1916	53,081	32,612	52,467	0.94	18,933	400	0.024	0.008
1917	52,978	32,540	52,364	0.94	18,935	545	0.03	0.01
1918	52,746	32,383	52,132	0.93	18,936	439	0.027	0.008
1919	52,634	32,303	52,019	0.93	18,940	345	0.021	0.007
1920	52,624	32,290	52,010	0.93	18,945	239	0.015	0.005
1921	52,724	32,350	52,110	0.93	18,953	304	0.018	0.006
1922	52,762	32,371	52,147	0.93	18,961	440	0.027	0.008
1923	52,670	32,309	52,055	0.93	18,966	442	0.027	0.008
1924	52,583	32,249	51,968	0.93	18,973	552	0.033	0.011
1925	52,397	32,125	51,782	0.92	18,978	547	0.033	0.011
1926	52,229	32,009	51,614	0.92	18,983	540	0.03	0.01
1927	52,081	31,907	51,466	0.92	18,990	654	0.036	0.013

Table 21: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning biomass (million eggs)	Summary biomass 3+	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1928	51,837	31,741	51,221	0.91	18,995	642	0.036	0.013
1929	51,624	31,595	51,008	0.91	19,002	733	0.042	0.014
1930	51,343	31,403	50,727	0.90	19,009	684	0.039	0.013
1931	51,133	31,256	50,517	0.90	19,022	700	0.039	0.014
1932	50,931	31,112	50,314	0.90	19,042	838	0.048	0.017
1933	50,620	30,896	50,003	0.89	19,076	875	0.048	0.017
1934	50,306	30,674	49,688	0.88	19,136	1671	0.084	0.034
1935	49,261	29,974	48,642	0.86	19,214	1654	0.084	0.034
1936	48,307	29,322	47,686	0.84	19,326	1360	0.072	0.029
1937	47,717	28,896	47,093	0.83	19,464	1956	0.099	0.042
1938	46,629	28,142	46,001	0.81	19,561	2233	0.111	0.049
1939	45,376	27,274	44,744	0.78	19,523	2742	0.129	0.061
1940	43,755	26,155	43,121	0.75	19,208	2633	0.129	0.061
1941	42,380	25,185	41,750	0.72	18,582	2377	0.123	0.057
1942	41,381	24,463	40,762	0.70	17,789	3335	0.153	0.082
1943	39,564	23,236	38,967	0.67	17,114	3475	0.159	0.089
1944	37,712	22,023	37,140	0.63	16,970	2749	0.144	0.074
1945	36,624	21,342	36,069	0.61	17,424	2574	0.141	0.071
1946	35,726	20,815	35,172	0.60	17,843	3911	0.18	0.111
1947	33,561	19,478	32,993	0.56	17,707	3234	0.171	0.098
1948	32,118	18,552	31,540	0.53	17,480	4650	0.207	0.147
1949	29,392	16,761	28,820	0.48	17,232	4536	0.213	0.157
1950	26,901	15,081	26,336	0.43	17,060	4788	0.222	0.182
1951	24,308	13,336	23,750	0.38	16,958	3159	0.198	0.133
1952	23,416	12,680	22,863	0.36	17,034	2895	0.195	0.127
1953	22,874	12,279	22,324	0.35	16,903	2448	0.183	0.11
1954	22,816	12,210	22,265	0.35	16,422	2989	0.201	0.134
1955	22,266	11,853	21,722	0.34	15,716	2662	0.192	0.123
1956	22,039	11,699	21,512	0.34	15,073	2346	0.183	0.109
1957	22,107	11,746	21,602	0.34	14,293	3008	0.201	0.139
1958	21,497	11,421	21,014	0.33	13,784	2955	0.204	0.141
1959	20,867	11,112	20,407	0.32	14,088	2518	0.192	0.123
1960	20,596	11,027	20,145	0.32	16,983	2940	0.204	0.146
1961	19,874	10,653	19,395	0.31	20,853	3535	0.222	0.182
1962	18,603	9,865	18,031	0.28	13,388	3373	0.225	0.187
1963	17,608	9,104	16,982	0.26	12,344	3411	0.228	0.201
1964	16,699	8,323	16,267	0.24	19,380	2889	0.222	0.178
1965	16,323	7,975	15,878	0.23	14,897	2749	0.222	0.173
1966	16,131	7,889	15,522	0.23	32,559	2778	0.222	0.179
1967	16,031	7,838	15,440	0.23	13,935	2801	0.225	0.181
1968	16,157	7,688	15,226	0.22	14,767	2520	0.219	0.166
1969	16,767	7,703	16,308	0.22	16,779	2583	0.219	0.158
1970	17,354	7,856	16,860	0.23	18,873	3335	0.231	0.198
1971	17,168	7,918	16,611	0.23	15,968	3428	0.234	0.206
1972	16,815	8,018	16,225	0.23	12,193	3700	0.24	0.228
1973	16,105	7,768	15,614	0.22	10,760	3233	0.237	0.207
1974	15,638	7,592	15,251	0.22	13,364	4085	0.255	0.268
1975	14,103	6,884	13,738	0.20	13,323	3922	0.258	0.285
1976	12,493	6,154	12,059	0.18	17,163	3203	0.252	0.266
1977	11,454	5,631	10,995	0.16	20,189	2625	0.243	0.239
1978	11,051	5,261	10,476	0.15	16,838	3402	0.261	0.325
1979	10,096	4,432	9,468	0.13	12,327	3569	0.27	0.377

Table 21: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning biomass (million eggs)	Summary biomass 3+	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1980	9,128	3,595	8,614	0.10	12,489	3059	0.27	0.355
1981	8,636	3,206	8,237	0.09	10,903	2958	0.27	0.359
1982	8,146	3,038	7,753	0.09	11,007	2921	0.27	0.377
1983	7,617	2,939	7,262	0.08	12,654	2545	0.27	0.35
1984	7,284	2,954	6,920	0.09	18,222	1965	0.261	0.284
1985	7,403	3,090	6,968	0.09	10,829	1934	0.258	0.278
1986	7,566	3,148	7,043	0.09	7,454	2189	0.264	0.311
1987	7,517	2,994	7,195	0.09	8,597	2637	0.273	0.367
1988	6,940	2,667	6,696	0.08	12,615	2396	0.27	0.358
1989	6,443	2,539	6,142	0.07	17,129	2339	0.273	0.381
1990	5,933	2,430	5,506	0.07	16,266	2010	0.27	0.365
1991	5,794	2,303	5,264	0.07	9,694	2197	0.273	0.417
1992	5,645	1,943	5,178	0.06	5,920	1875	0.273	0.362
1993	5,846	1,837	5,563	0.05	10,952	1697	0.264	0.305
1994	6,239	2,021	6,012	0.06	13,441	1553	0.255	0.258
1995	6,720	2,523	6,351	0.07	8,364	1683	0.252	0.265
1996	7,059	2,960	6,656	0.09	9,953	1937	0.255	0.291
1997	7,132	3,034	6,850	0.09	10,124	2059	0.258	0.301
1998	7,057	2,888	6,725	0.08	23,771	1742	0.249	0.259
1999	7,311	2,971	6,896	0.09	15,357	1625	0.243	0.236
2000	7,881	3,164	7,169	0.09	11,105	1923	0.249	0.268
2001	8,447	3,183	7,978	0.09	10,249	1992	0.249	0.25
2002	9,092	3,233	8,737	0.09	11,074	2081	0.249	0.238
2003	9,648	3,545	9,312	0.10	8,876	1791	0.237	0.192
2004	10,364	4,248	10,018	0.12	11,622	2295	0.24	0.229
2005	10,492	4,714	10,185	0.14	12,879	3016	0.252	0.296
2006	9,808	4,555	9,416	0.13	23,363	2216	0.24	0.235
2007	9,807	4,552	9,315	0.13	28,717	2406	0.24	0.258
2008	9,921	4,307	9,122	0.12	37,445	2181	0.24	0.239
2009	10,809	4,162	9,833	0.12	15,143	2340	0.243	0.238
2010	12,258	4,102	11,196	0.12	11,804	870	0.177	0.078
2011	15,497	5,237	15,027	0.15	14,333	782	0.153	0.052
2012	18,875	7,058	18,471	0.20	21,430	1150	0.159	0.062
2013	21,708	9,334	21,200	0.27	12,557	1990	0.177	0.094
2014	23,463	11,305	22,827	0.33	12,654	2390	0.177	0.105
2015	24,473	12,586	24,066	0.36	11,960	2702	0.177	0.112
2016	24,777	13,139	24,369	0.38	15,556	2520	0.168	0.103
2017	24,872	13,486	24,460	0.39	15,507	3024	0.18	0.124
2018	24,249	13,367	23,744	0.38	17,806	2855	0.177	0.12
2019	23,673	13,114	23,154	0.38	17,773	-	-	-

tab:Timeseries_mod1

Table 22: Sensitivity of the base model.

tab:sens_table

Label	Base	Low M	High M	Old M Prior	Fecundity	Sex Ratio	Francis	Dirichlet	NA
Total Likelihood	1397.460	1399.700	1641.010	1397.720	1408.490	1396.340	1407.380	1397.460	3067.230
Survey Likelihood	-75.071	-74.367	-69.484	-75.030	-75.085	-75.101	-75.112	-75.069	-75.049
Discard Likelihood	-228.290	-228.458	-189.705	-228.323	-228.291	-227.963	-227.962	-228.288	-228.711
Discard Mean Body Wt.	-160.927	-161.049	-160.482	-160.933	-160.926	-160.858	-160.858	-160.936	-161.187
Length Likelihood	785.852	787.493	929.400	786.289	785.863	785.938	785.957	785.843	881.219
Age Likelihood	1096.580	1095.280	1148.630	1096.290	1096.600	1094.780	1094.780	1096.580	2669.450
Recruitment Likelihood	-27.797	-27.500	-26.131	-27.577	-27.834	-27.819	-27.879	-27.795	-24.307
Forecast Recruitment Likelihood	0.043	0.041	0.021	0.044	0.043	0.044	0.043	0.043	0.000
Parameter Priors Likelihood	7.038	8.217	8.717	6.926	18.081	7.285	18.364	7.042	5.780
Convergence Gradient	0.000	0.280	0.651	0.633	0.008	0.059	0.280	1.263	1408.380
log(R0)	9.849	9.478	10.168	9.862	9.856	9.890	9.894	9.848	9.781
SB Virgin	34749.500	39864.800	30936.200	34717.000	35578.900	36771.800	37802.600	34781.300	36377.800
SB 2019	13114.100	12261.200	16234.700	13107.400	12141.300	13340.300	12371.100	13128.700	13735.500
Depletion 2019	0.377	0.308	0.525	0.378	0.341	0.363	0.327	0.377	0.378
Total Yield - SPR 30	3145.650	2981.340	3248.460	3130.850	3077.190	3156.070	3075.860	3145.640	3056.970
Steepness	0.862	0.928	0.811	0.853	0.885	0.873	0.895	0.862	0.847
Natural Mortality - Female	0.151	0.120	0.180	0.152	0.152	0.143	0.144	0.151	0.142
Length at Amin - Female	15.499	15.625	14.948	15.524	15.495	15.506	15.501	15.498	15.459
Length at Amax - Female	53.129	52.971	52.535	53.142	53.127	52.963	52.961	53.129	52.447
Von Bert. k - Female	0.142	0.144	0.155	0.142	0.143	0.145	0.145	0.142	0.149
SD young - Female	0.189	0.187	0.188	0.188	0.189	0.187	0.187	0.189	0.194
SD old - Female	0.034	0.035	0.039	0.034	0.034	0.036	0.036	0.034	0.036
Natural Mortality - Male	0.151	0.120	0.180	0.152	0.152	0.143	0.144	0.151	0.142
Length at Amin - Male	15.499	15.625	14.948	15.524	15.495	15.506	15.501	15.498	15.459
Length at Amax - Male	53.129	52.971	52.535	53.142	53.127	52.963	52.961	53.129	52.447
Von Bert. k - Male	0.142	0.144	0.155	0.142	0.143	0.145	0.145	0.142	0.149
SD young - Male	0.189	0.187	0.188	0.188	0.189	0.187	0.187	0.189	0.194
SD old - Male	0.034	0.035	0.039	0.034	0.034	0.036	0.036	0.034	0.036

Table 23: Data weights applied when using Francis data weighting in the base model. The data weights were acquired after a single model weighting iteration.

tab:francis

Fleet	Lengths	Ages
Winter North	1.127	3.077
Summer North	0.823	1.243
Winter South	1.024	0.671
Summer South	0.490	0.716
Triennial Early survey	0.230	-
Triennial Late survey	0.956	-
NWFSC shelf-slope survey	0.256	0.076

Table 24: Data weights applied when using Dirichlet data weighting.

tab:dirichlet

Fleet	Lengths	Ages
Winter North	16.725	14.373
Summer North	18.812	14.373
Winter South	19.324	13.6679
Summer South	14.202	14.0375
Triennial Early survey	13.947	-
Triennial Late survey	15.798	-
NWFSC shelf-slope survey	19.498	16.3388

Table 25: Projection of potential OFL, spawning biomass, and depletion for the base case model. The removals in 2017 and 2018 were set at the defined management specification of XXX mt for each year assuming full attainment.

tab:Forecast_mod1

Year	OFL (mt)	ACL (mt)	Spawning Biomass	Depletion (%)
2019	4753	4340	5741	83.3
2020	4632	4229	5745	83.4
2021	4499	4108	5723	83.1
2022	4364	3984	5666	82.2
2023	4230	3862	5586	81.1
2024	4105	3748	5494	79.8
2025	3991	3644	5395	78.3
2026	3889	3551	5292	76.8
2027	3797	3467	5188	75.3
2028	3712	3389	5084	73.8

Table 26: 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. The removals in 2019 and 2020 were set at the defined management specification of 2908 and 2845 mt, respectively, assuming full attainment. Columns range over low, mid, and high states of nature, and rows range over different assumptions of catch levels. The SPR30 catch stream is based on the equilibrium yield applying the SPR30 harvest rate.

`tab:Decision_table_mod1`

			States of nature					
			M = 0.12		M = 0.151		M = 0.18	
	Year	Catch	Spawning Biomass	Depletion	Spawning Biomass	Depletion	Spawning Biomass	Depletion
ABC	2021	3884	11559	0.3	12115	0.3	14446	0.5
	2022	3506	10560	0.3	11040	0.3	13168	0.4
	2023	3262	9895	0.2	10367	0.3	12401	0.4
	2024	3126	9517	0.2	10032	0.3	12021	0.4
	2025	3064	9341	0.2	9925	0.3	11877	0.4
	2026	3050	9284	0.2	9945	0.3	11850	0.4
	2027	3055	9279	0.2	10011	0.3	11863	0.4
	2028	3060	9291	0.2	10082	0.3	11874	0.4
	2029	3066	9303	0.2	10142	0.3	11872	0.4
	2030	3067	9309	0.2	10185	0.3	11856	0.4
SPR target = 0.34	2021	3262	11559	0.3	12115	0.3	14446	0.5
	2022	3050	10944	0.3	11416	0.3	13534	0.4
	2023	2916	10558	0.3	11003	0.3	13010	0.4
	2024	2850	10381	0.3	10845	0.3	12785	0.4
	2025	2830	10352	0.3	10860	0.3	12742	0.4
	2026	2841	10409	0.3	10967	0.3	12783	0.4
	2027	2863	10498	0.3	11101	0.3	12843	0.4
	2028	2882	10592	0.3	11230	0.3	12892	0.4
	2029	2901	10679	0.3	11342	0.3	12922	0.4
	2030	2913	10753	0.3	11434	0.3	12933	0.4
SPR target = 0.4	2021	2549	11559	0.3	12115	0.3	14446	0.5
	2022	2478	11385	0.3	11847	0.3	13954	0.5
	2023	2445	11349	0.3	11764	0.3	13737	0.4
	2024	2447	11449	0.3	11854	0.3	13733	0.4
	2025	2471	11643	0.3	12058	0.3	13851	0.4
	2026	2511	11882	0.3	12312	0.4	14011	0.5
	2027	2554	12128	0.3	12567	0.4	14165	0.5
	2028	2590	12360	0.3	12800	0.4	14290	0.5
	2029	2623	12571	0.3	13004	0.4	14385	0.5
	2030	2649	12758	0.3	13178	0.4	14452	0.5

10 Figures

figures

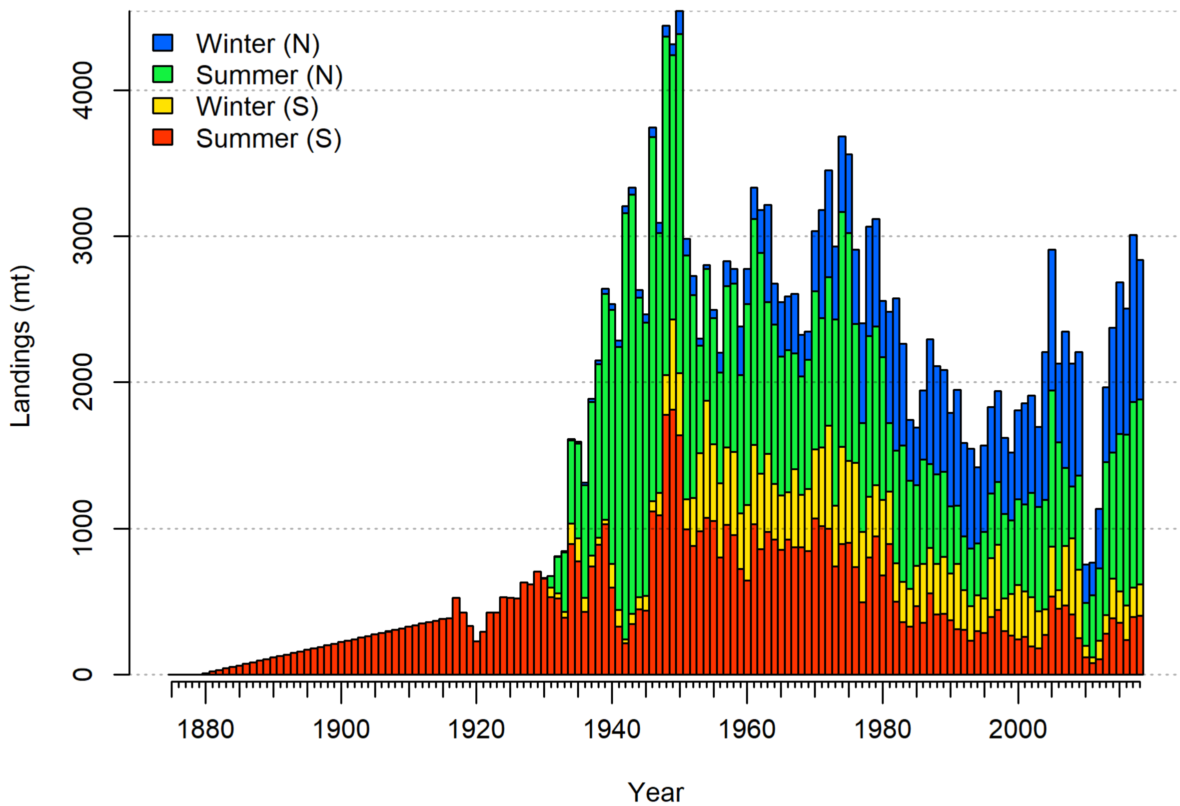

Figure 1: Total catches petrale sole. fig:Catch

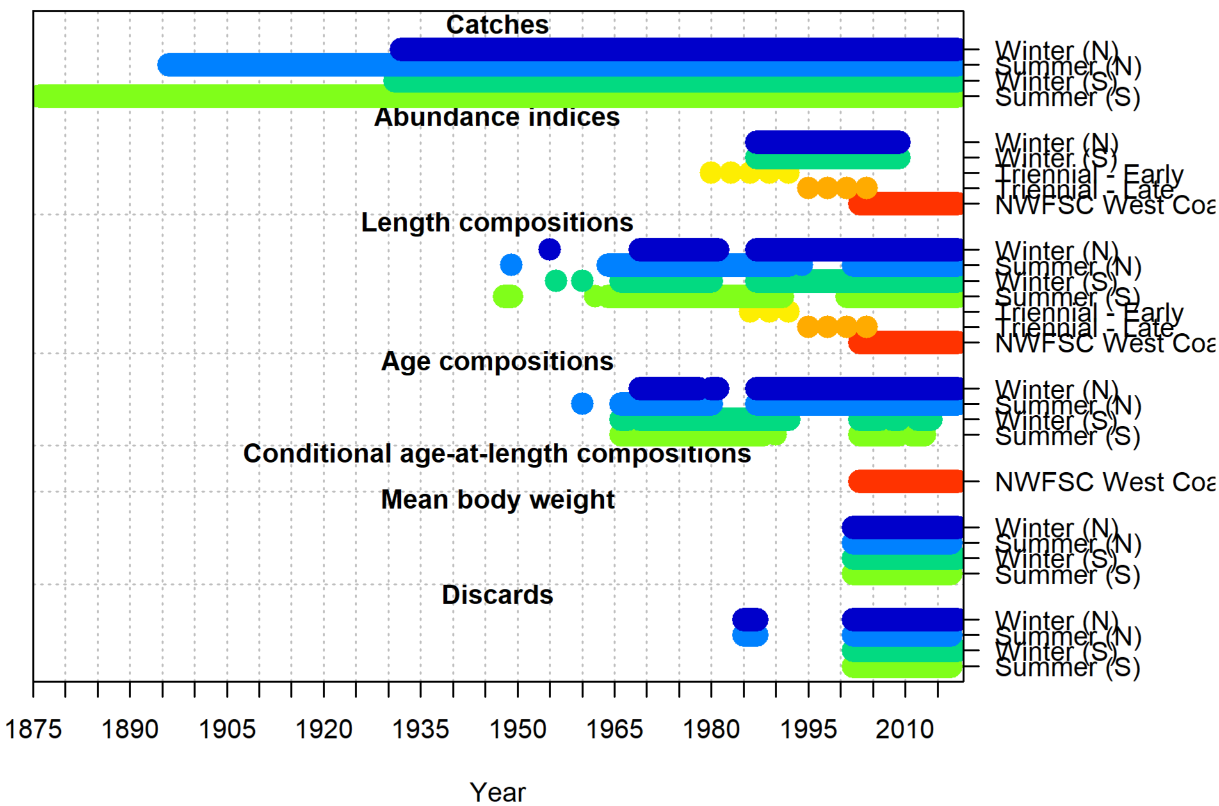

Figure 2: Summary of data sources used in the base model. fig:data_plot

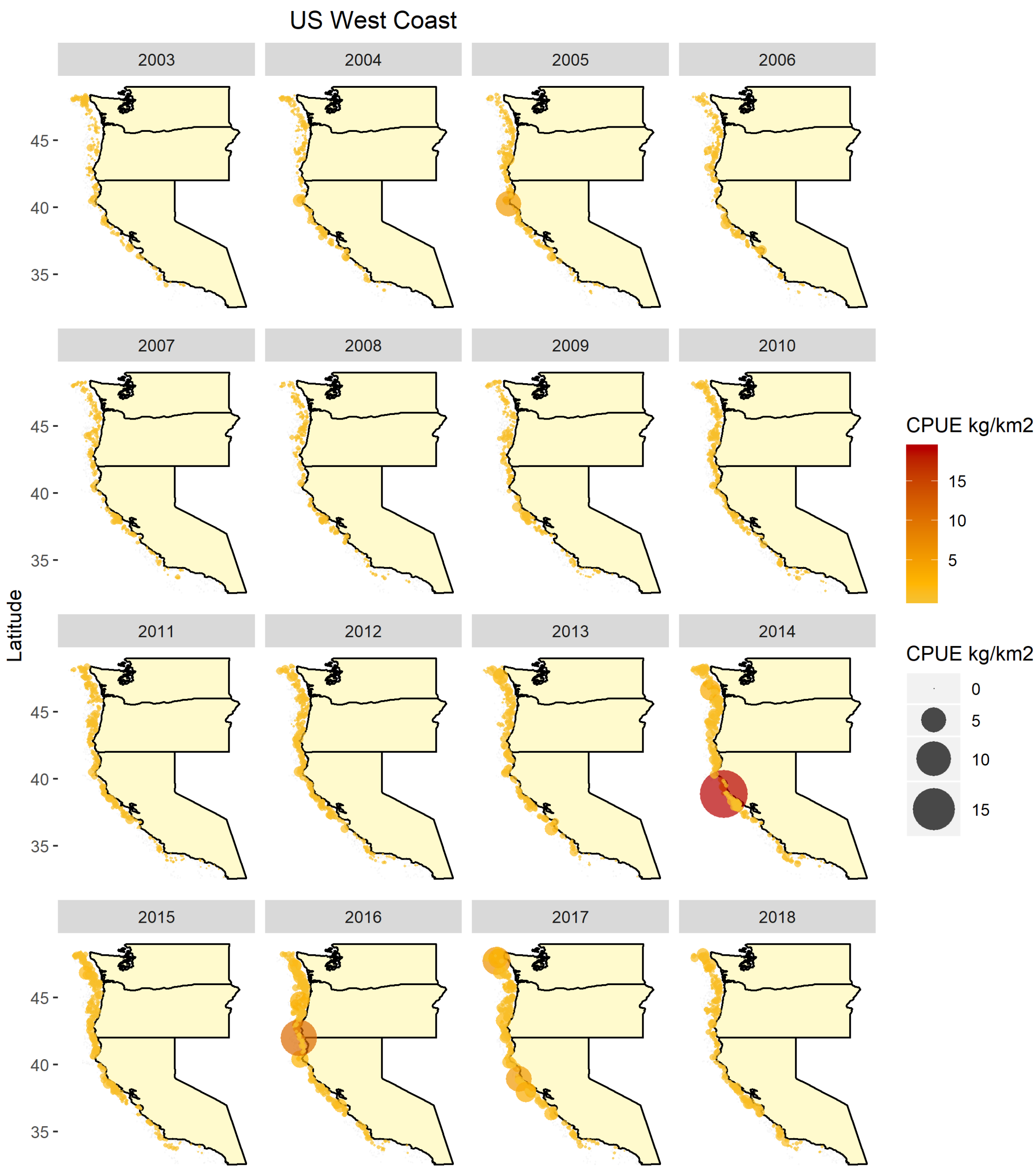

Figure 3: Map of the catch-per-unit-effort across by year for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_map

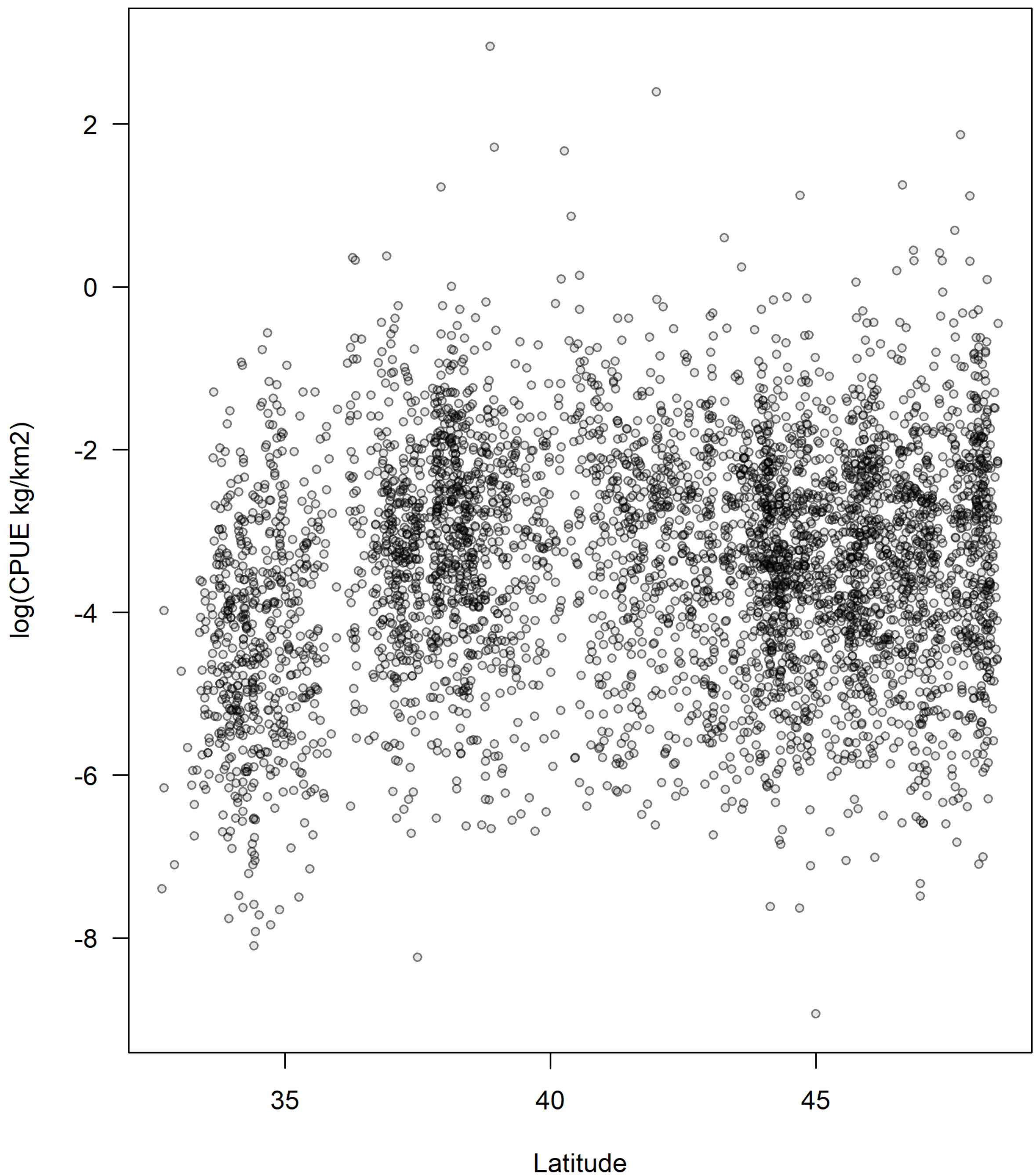

Figure 4: Catch-per-unit-effort (in log space) by latitude for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_cpue_lat

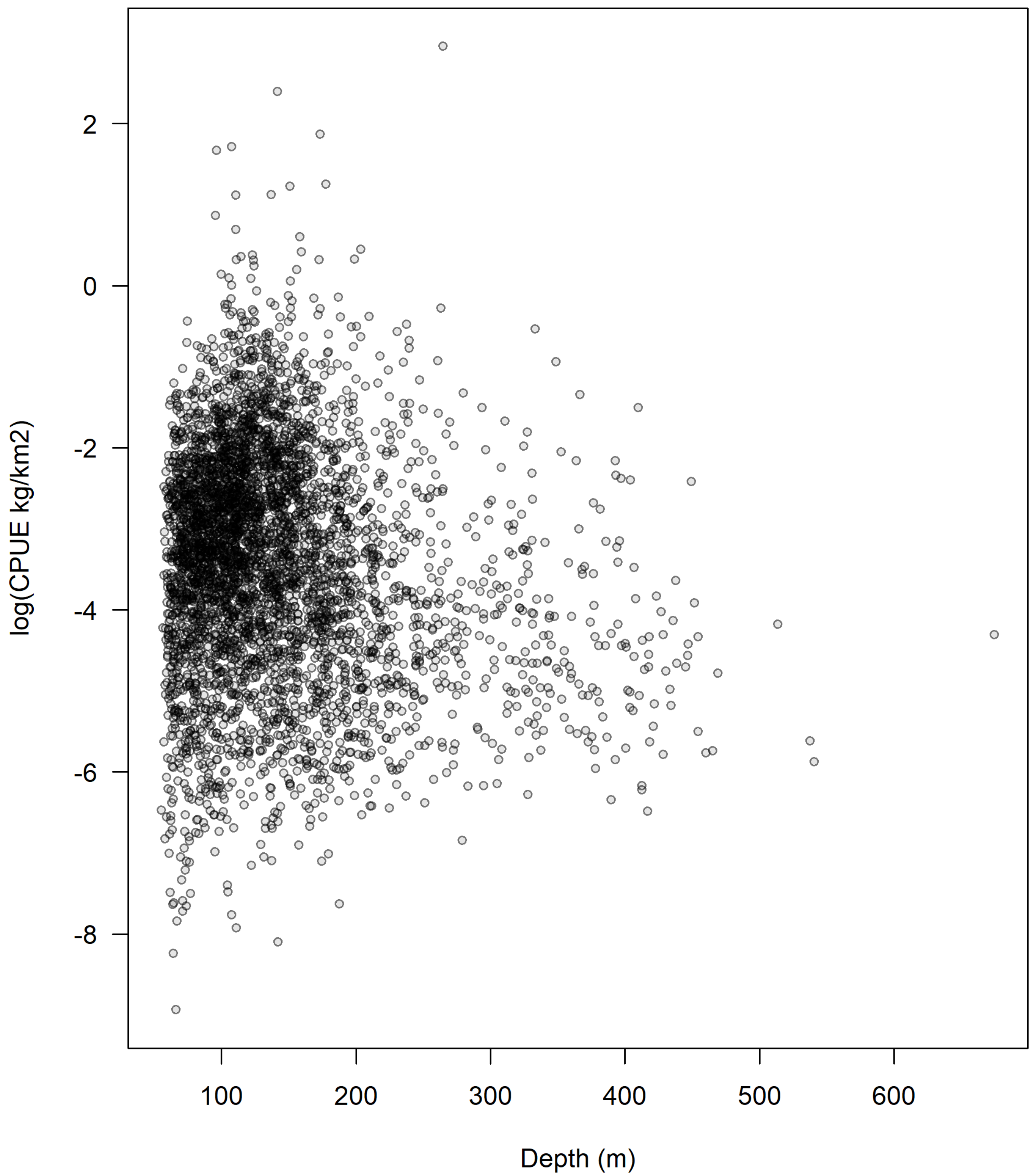

Figure 5: Catch-per-unit-effort (in log space) by depth for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_cpue_depth

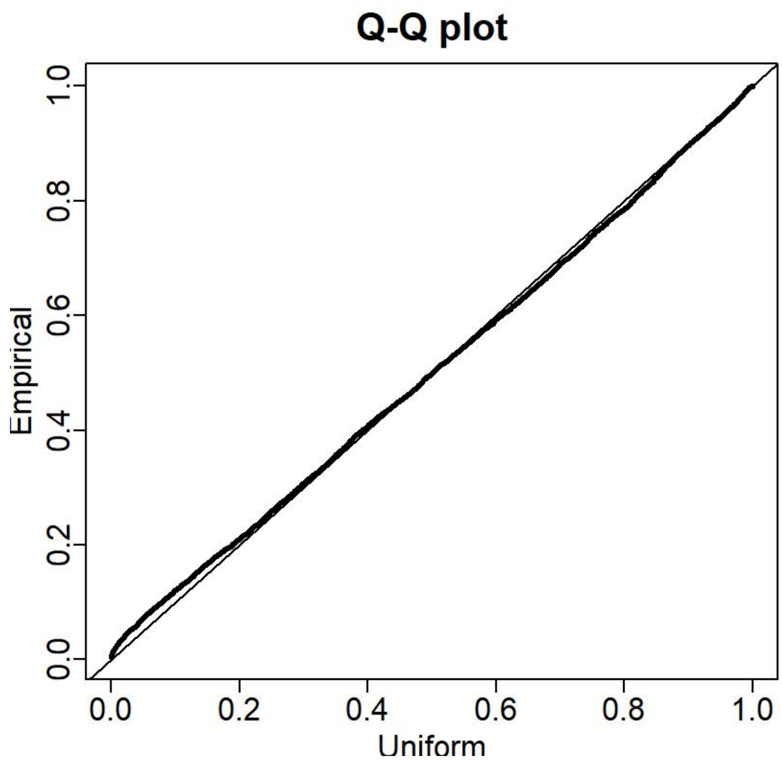

Figure 6: QQ plot for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_qq

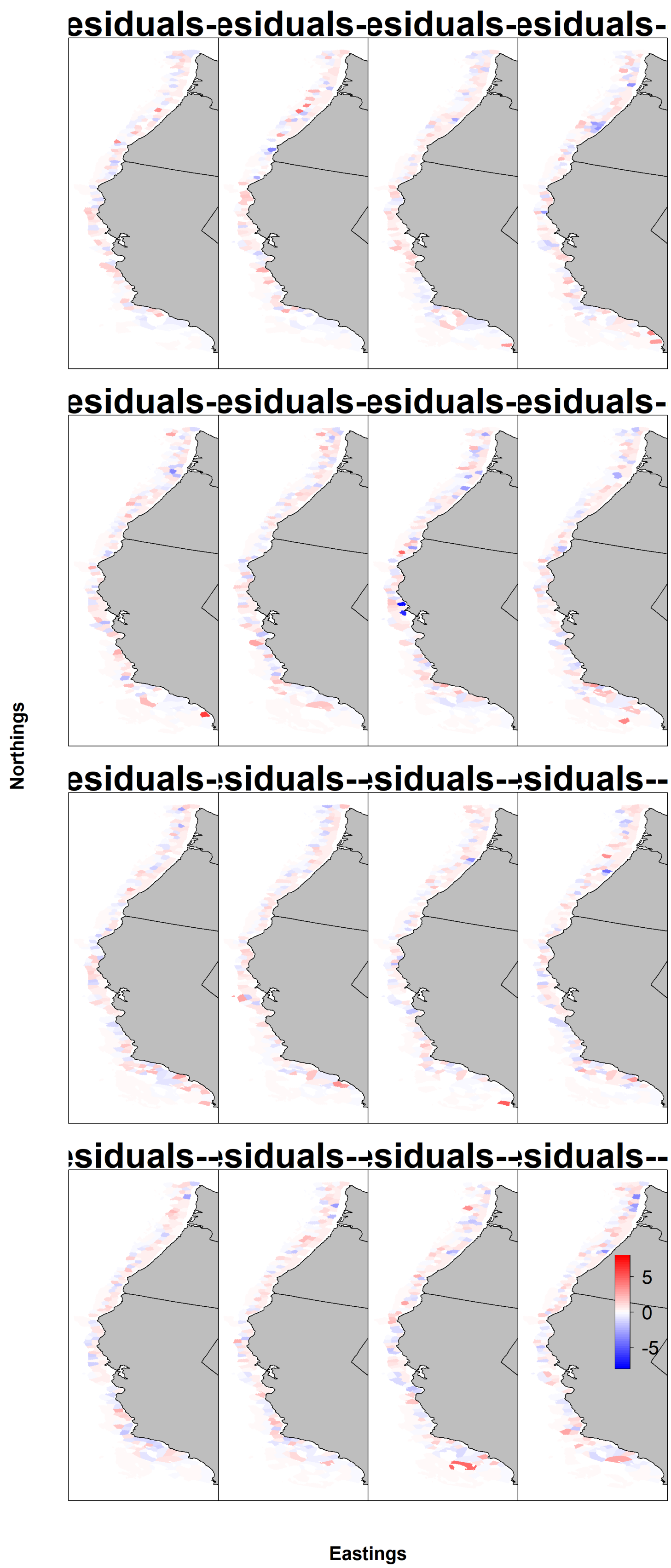

Figure 7: Pearson residuals for the encounter rate for the NWFSC West Coast Groundfish Bottom Trawl Survey by VAST. fig:nw_enc_rate

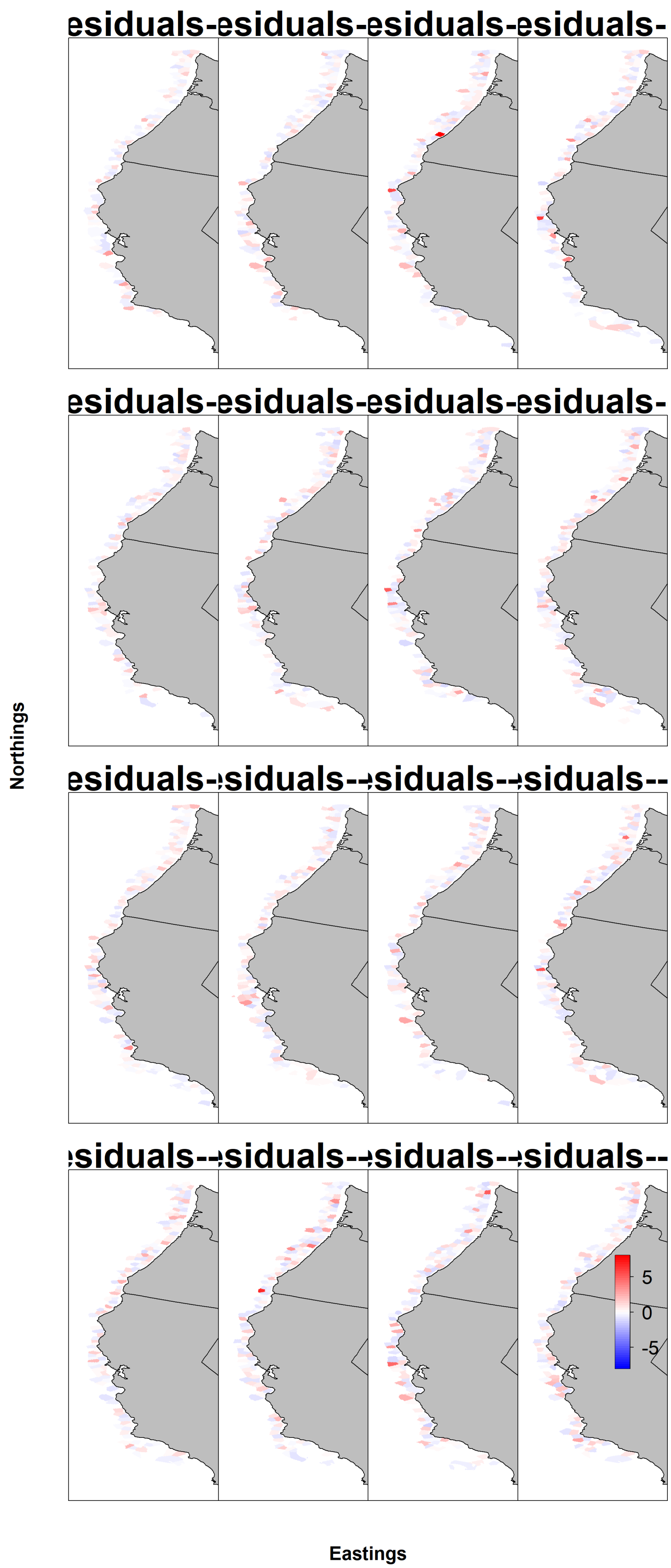

Figure 8: Pearson residuals for the estimated catch rate for the NWFSC West Coast Groundfish Bottom Trawl Survey by VAST. fig:nw_catch_rate

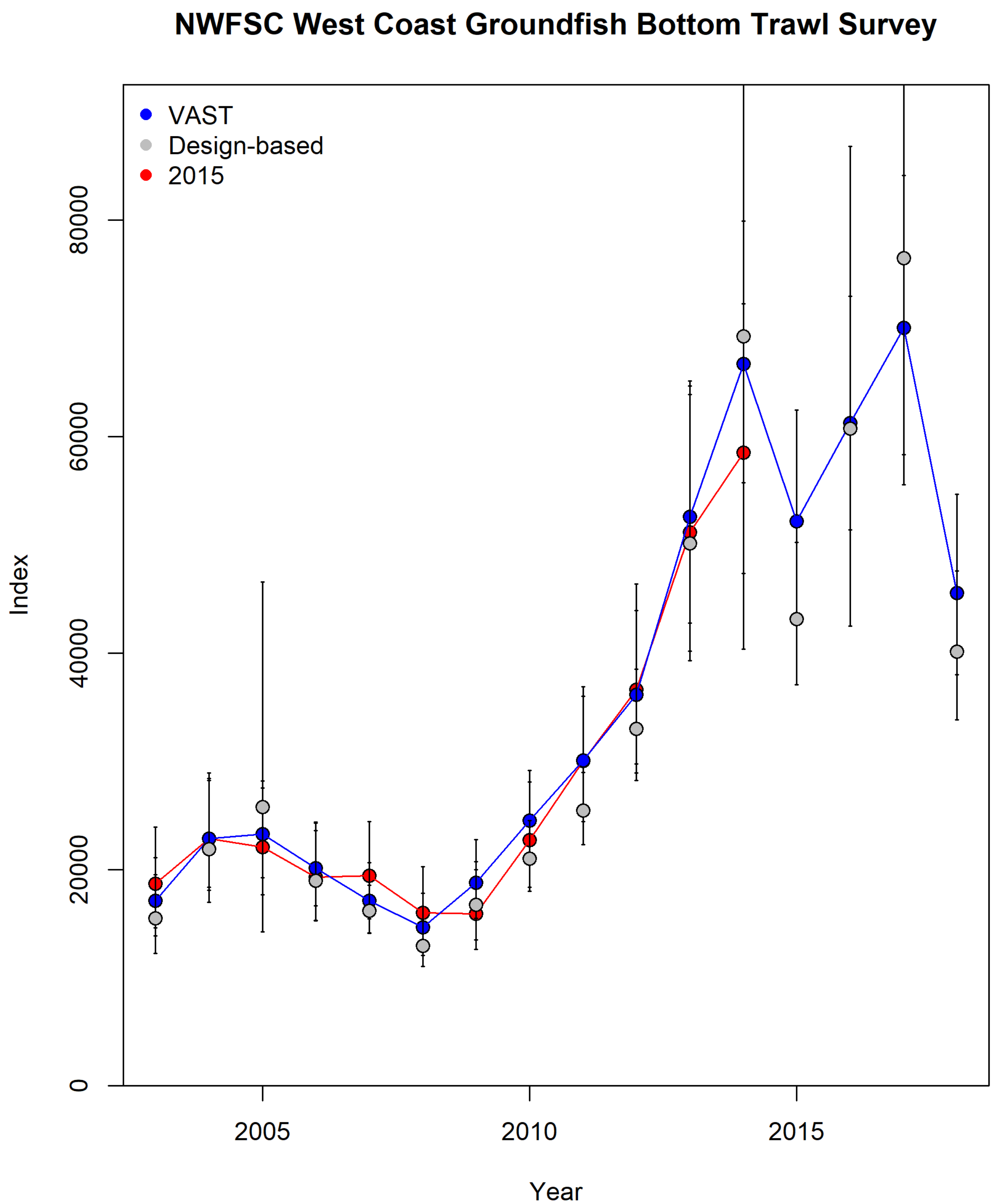

Figure 9: Estimated index of abundance from the NWFSC West Coast Groundfish Bottom Trawl Survey data compared to the design-based index and the index from the 2015 update assessment. fig:nw_index

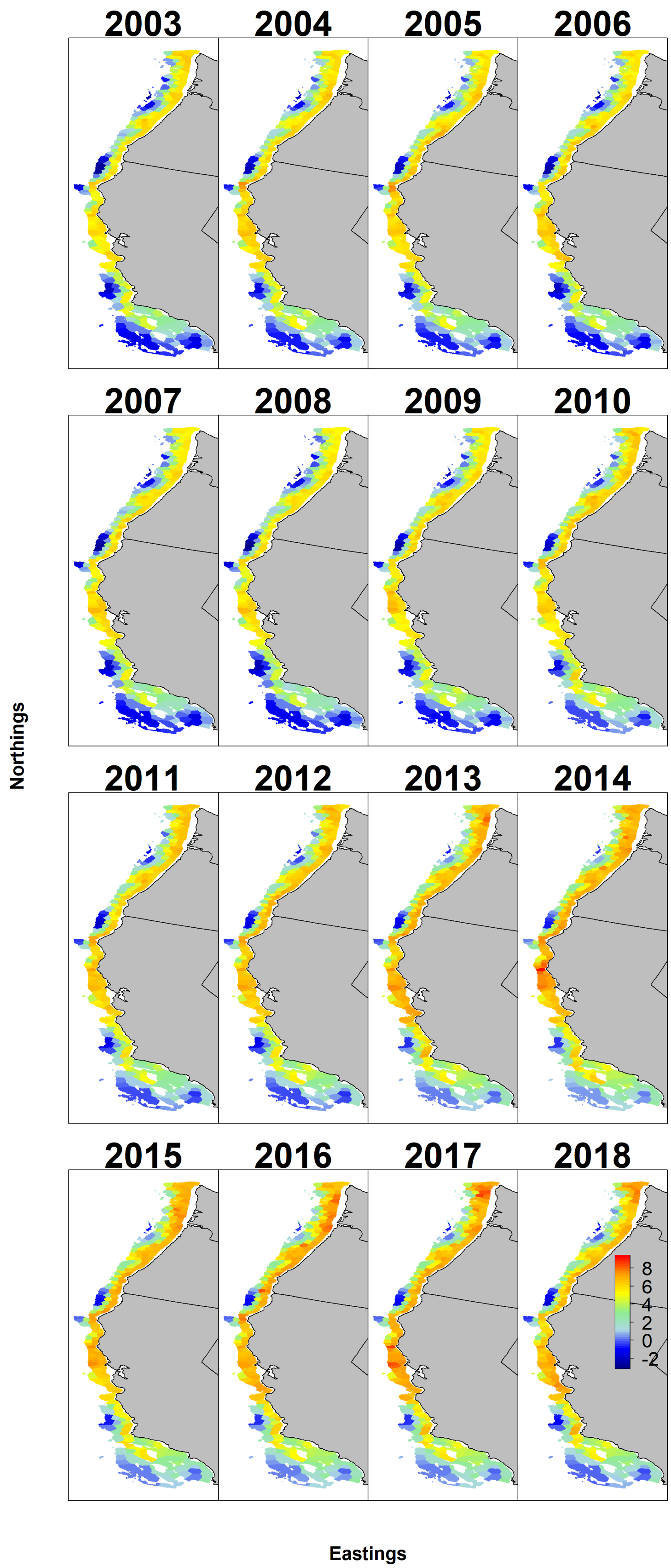

Figure 10: Estimated density of abundance from the NWFSC West Coast Groundfish Bottom Trawl Survey data by VAST. fig:nw_density

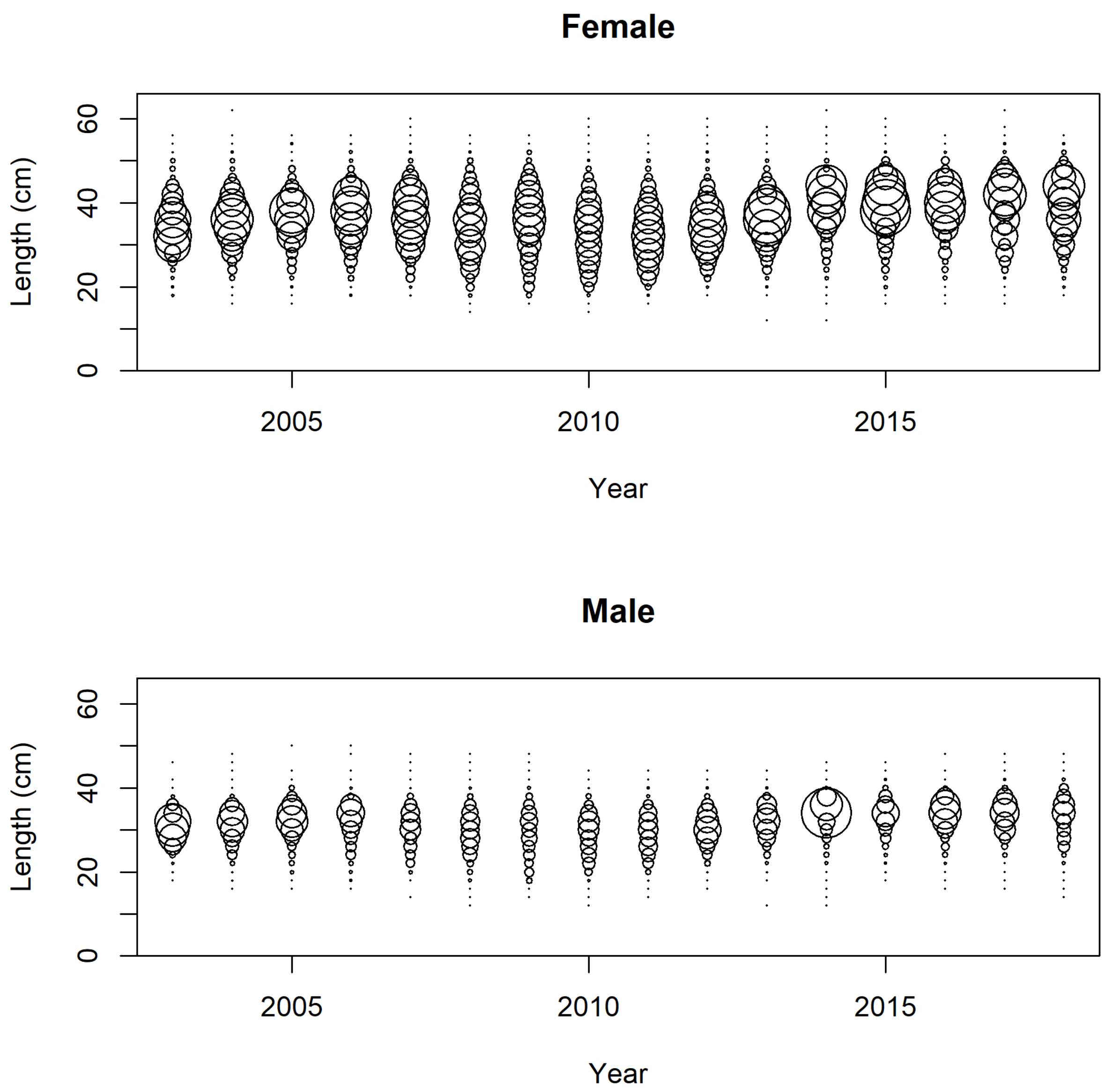

Figure 11: Length frequency by sex for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_len_freq

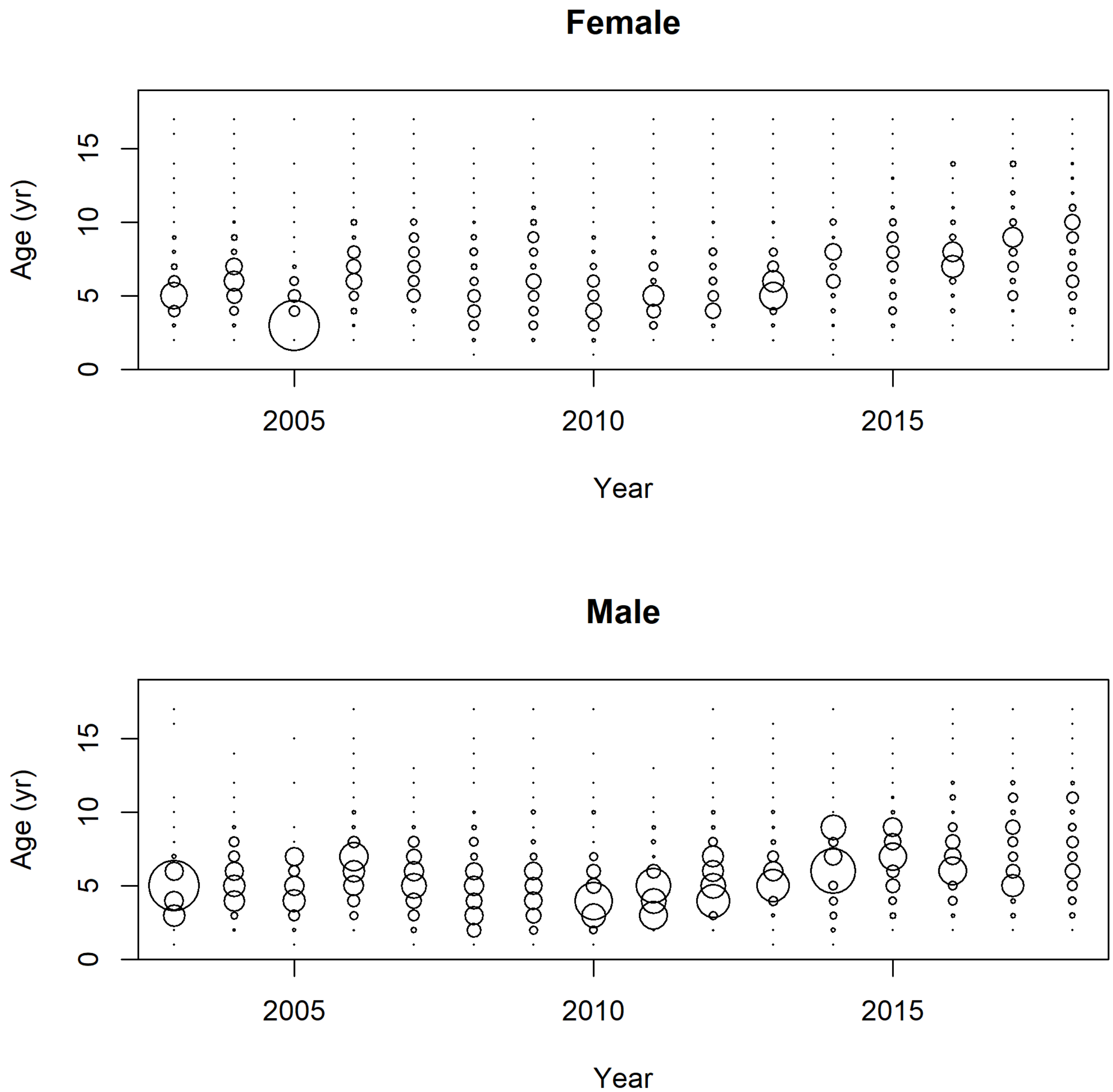

Figure 12: Age frequency by sex for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_age_freq

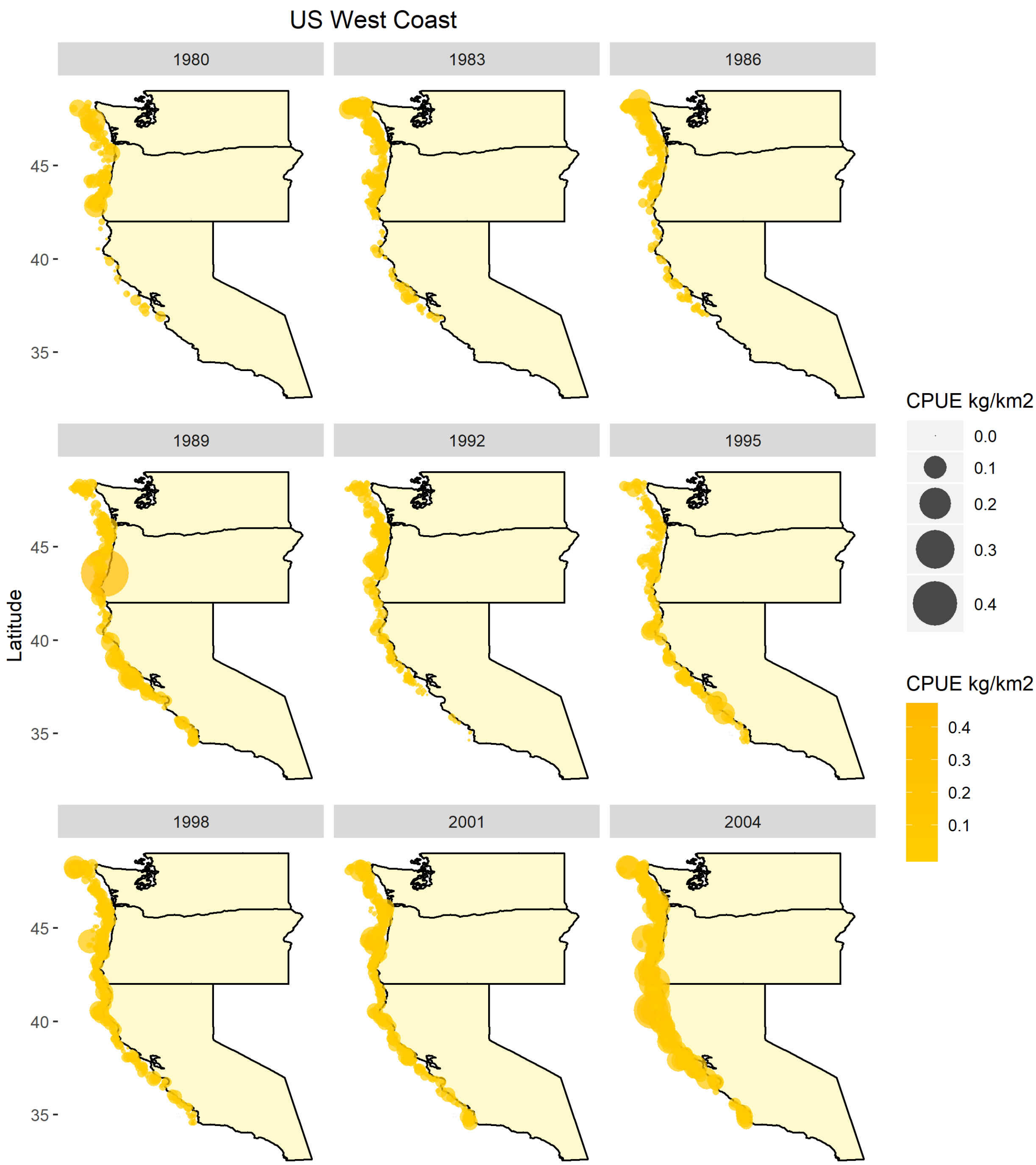

Figure 13: Map of the catch-per-unit-effort across by year for the Triennial Survey data. fig:tri_map

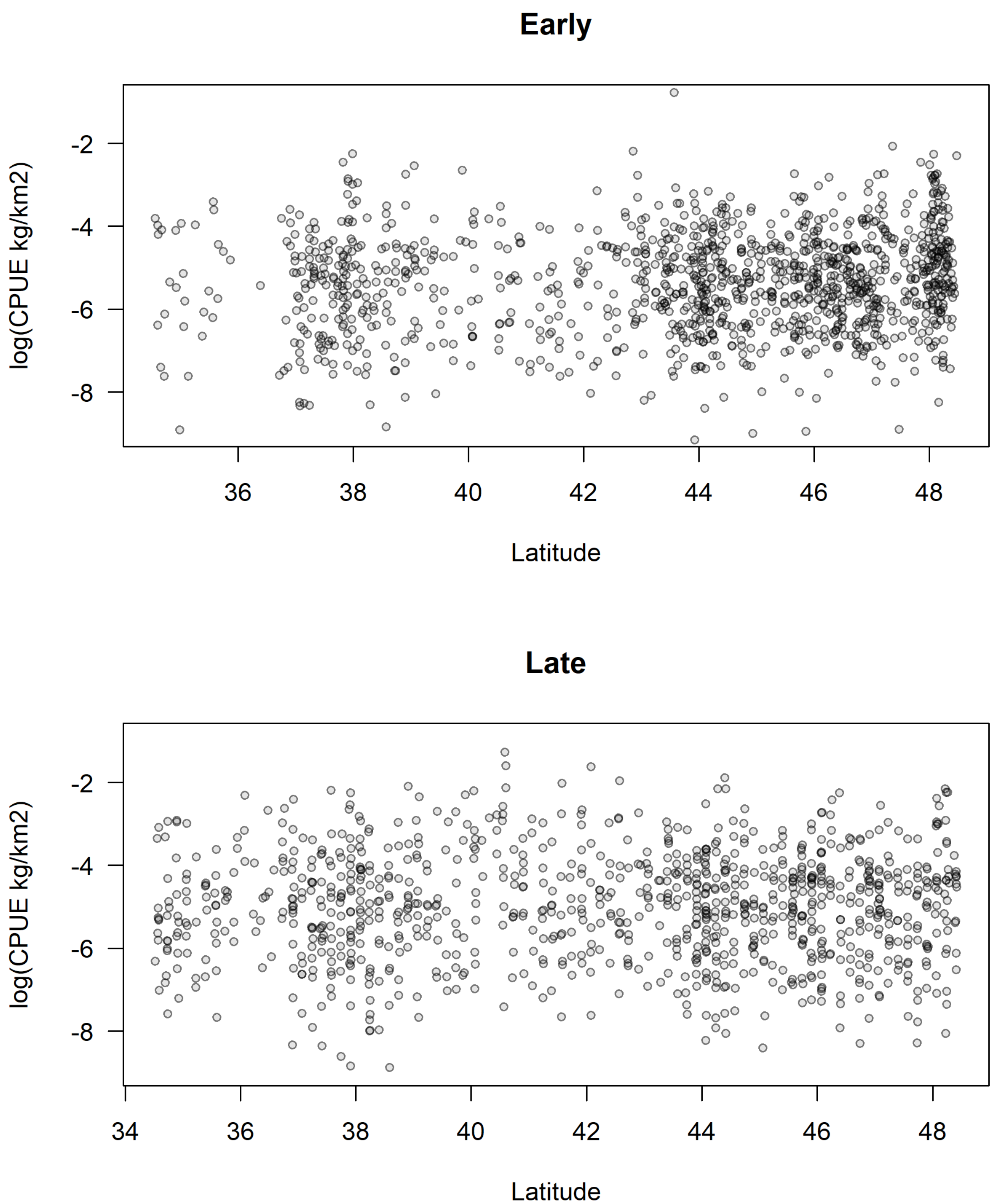

Figure 14: Catch-per-unit-effort (in log space) by latitude for the Triennial Survey data. fig:tri_cpue_l

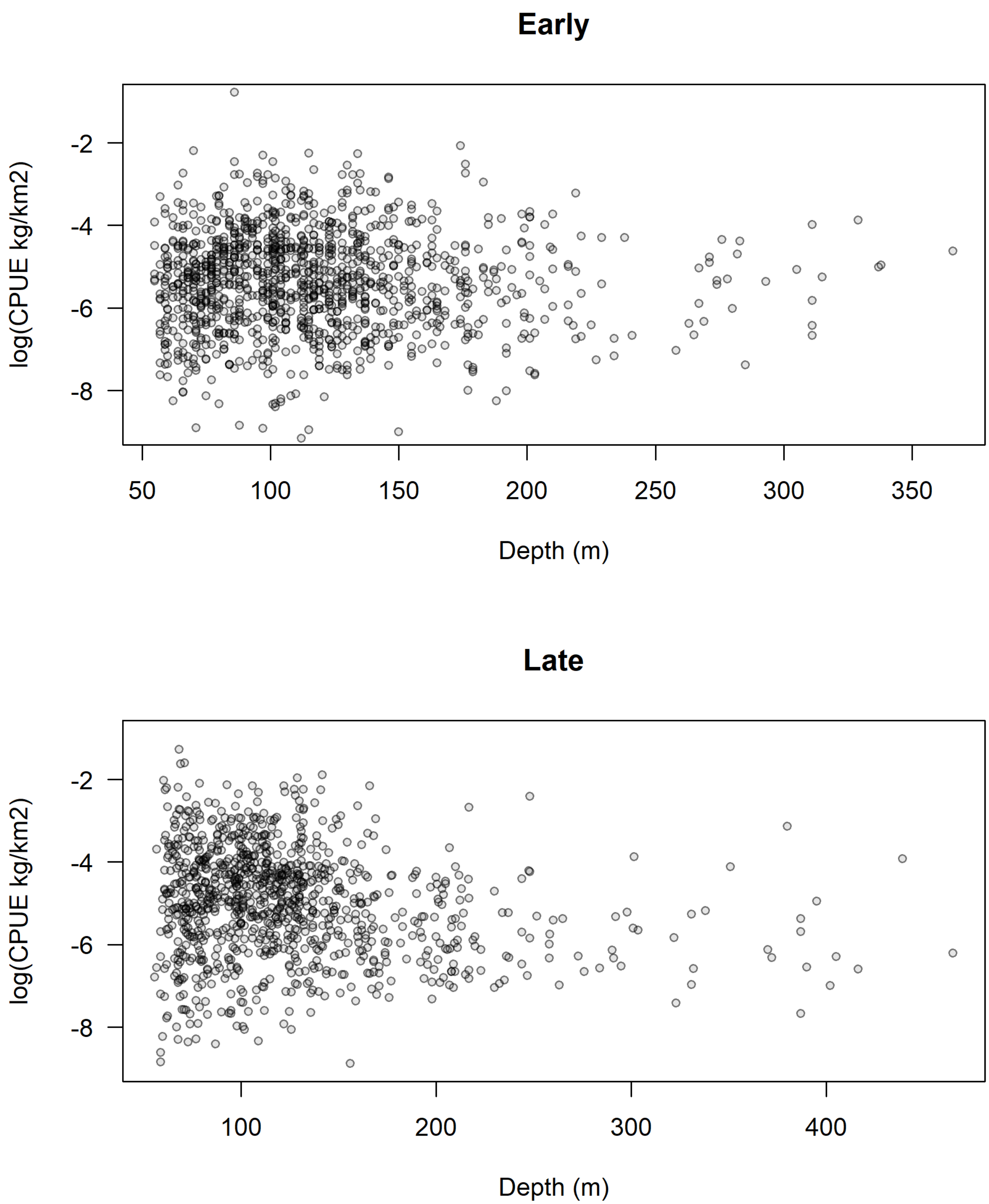

Figure 15: Catch-per-unit-effort (in log space) by depth (m) for the Triennial Survey data. fig:tri_cpue_

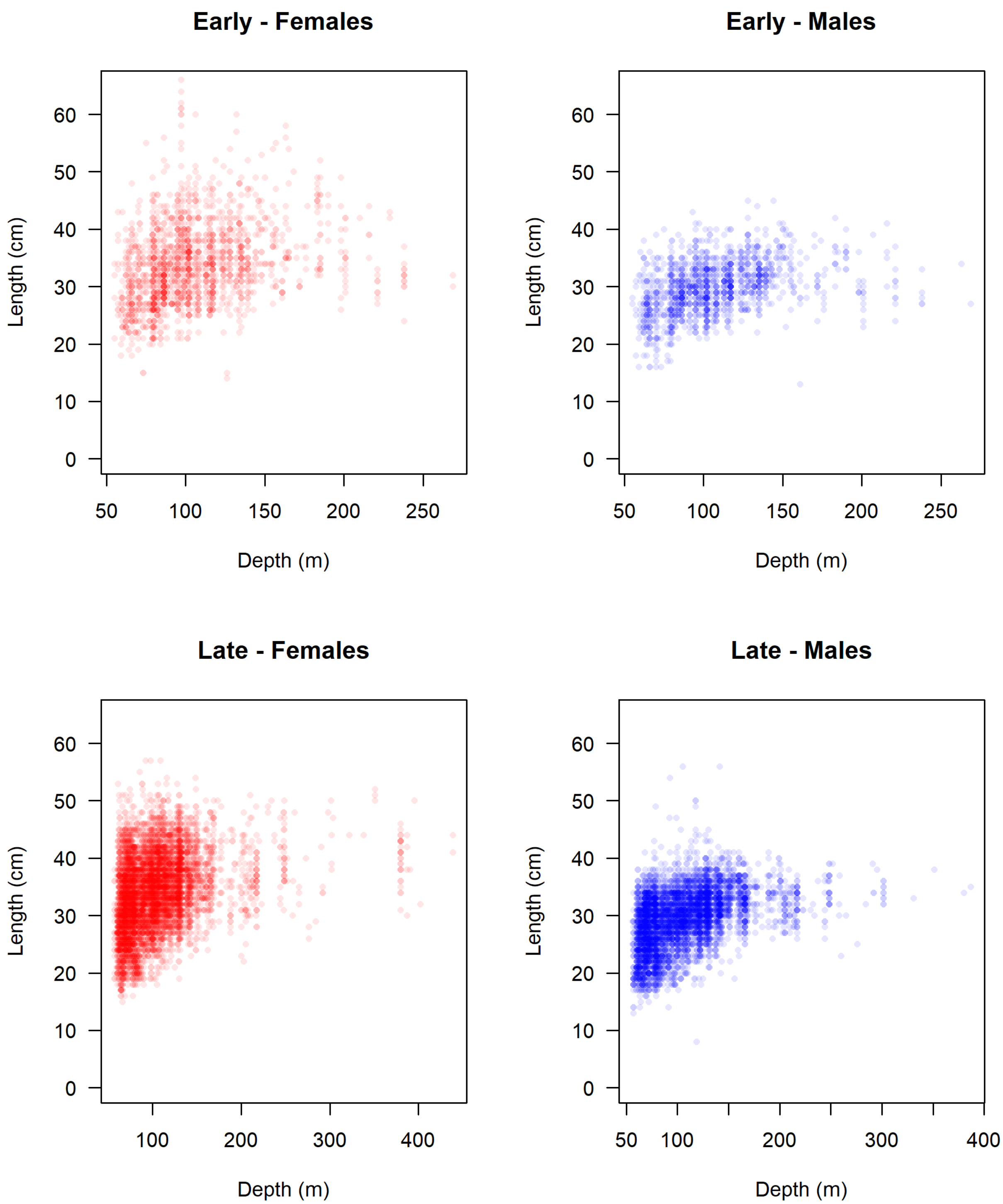

Figure 16: Length (cm) by depth (m) for the Triennial Survey data. fig:tri_size_depth

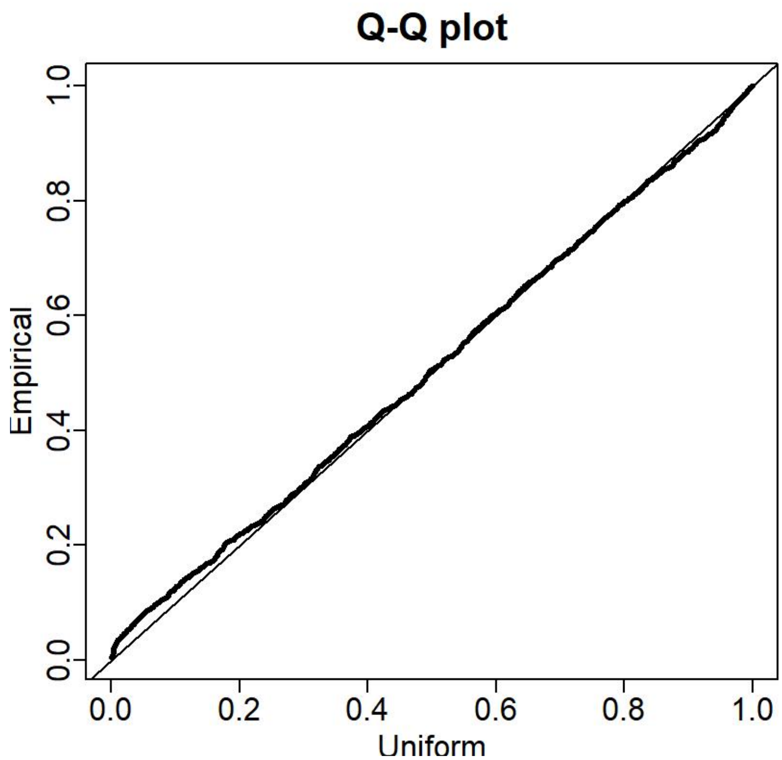

Figure 17: QQ plot for the Triennial Early Survey data. fig:tri_early_qq

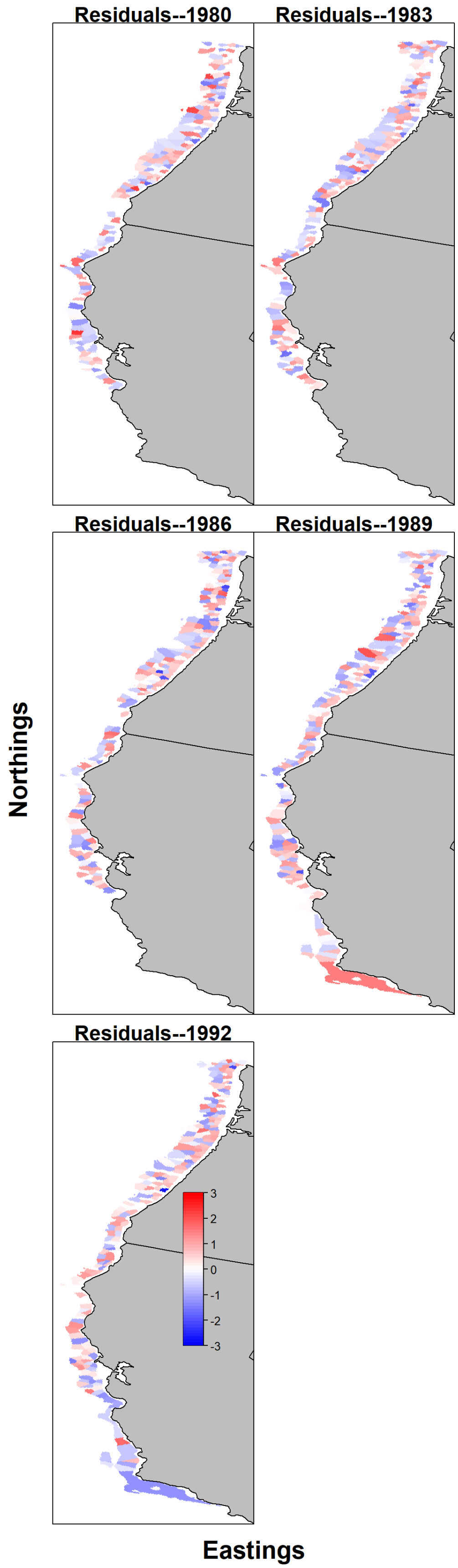

Figure 18: Pearson residuals for the encounter rate for the Triennial Early Survey by VAST. fig:tri_early

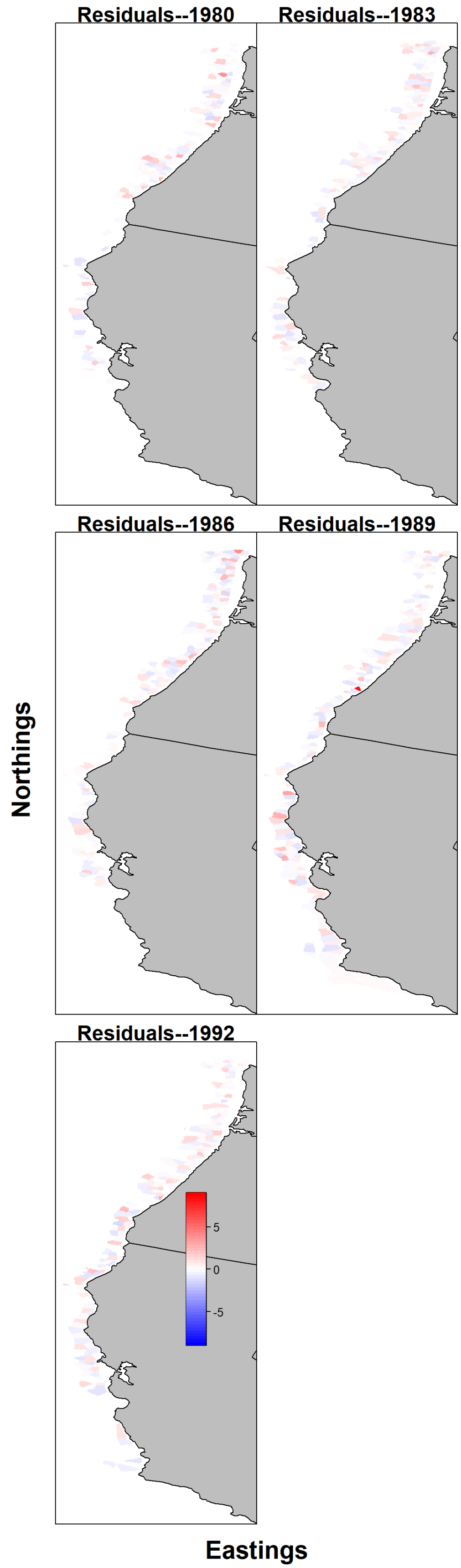

Figure 19: Pearson residuals for the estimated catch rate for the Triennial Early Survey by VAST. fig:tri_early_catch_rate

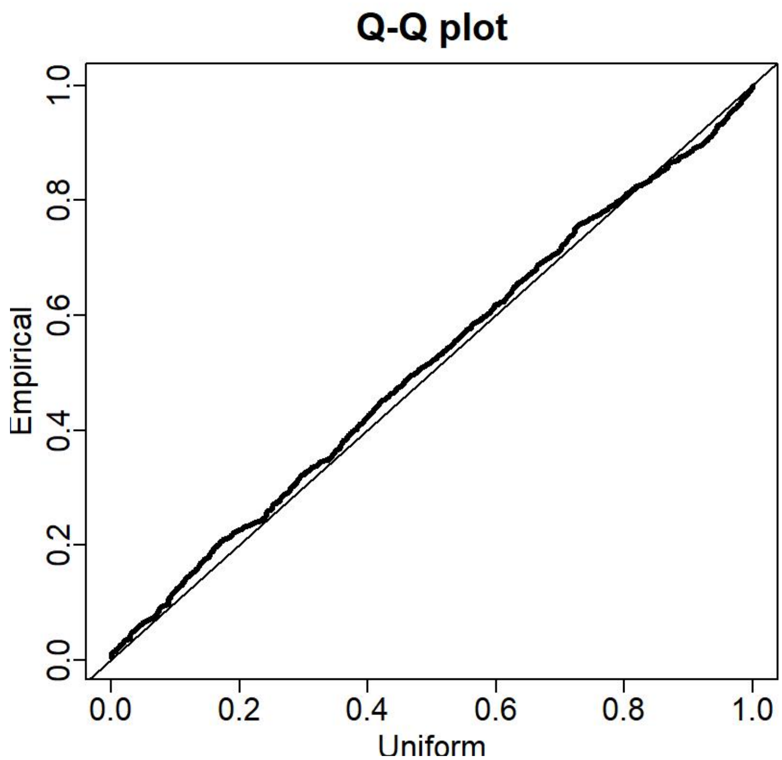

Figure 20: QQ plot for the Triennial Late Survey data. fig:tri_late_qq

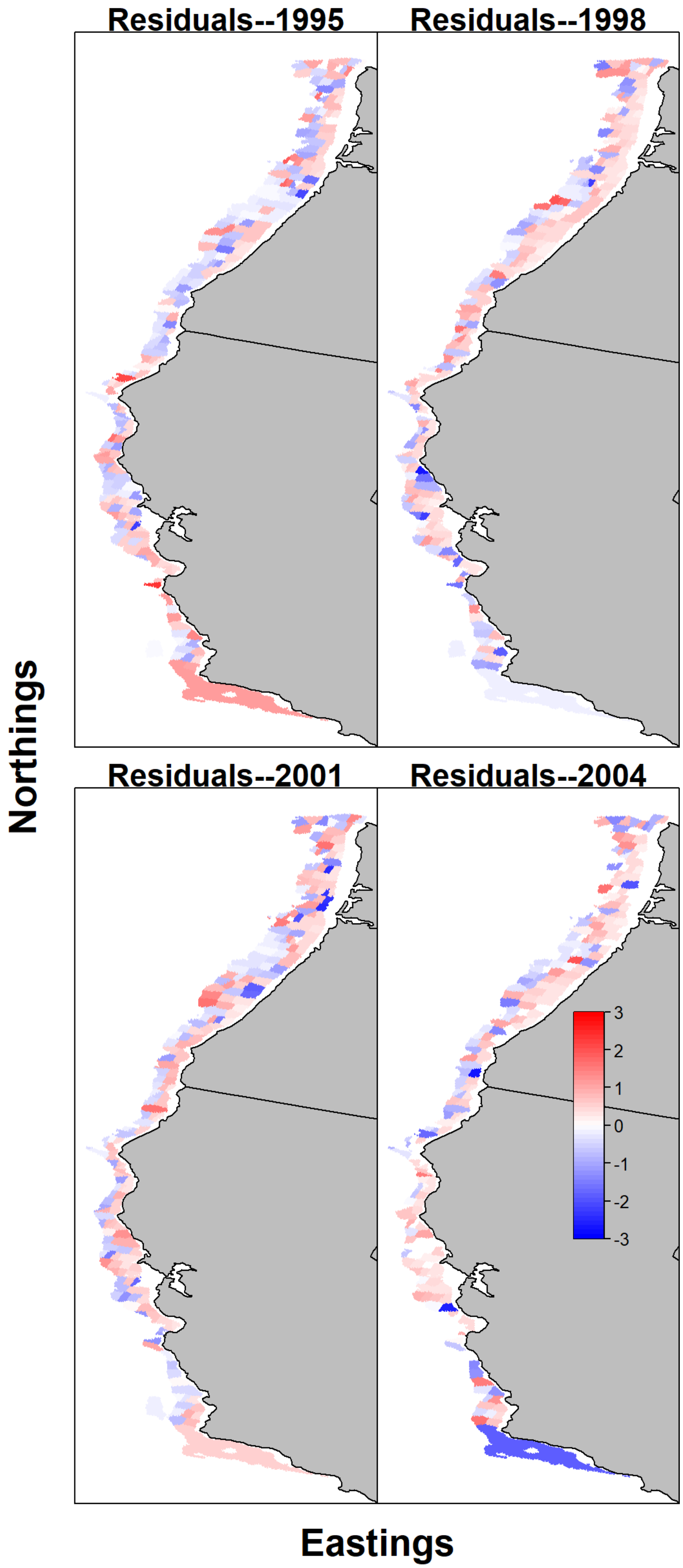

Figure 21: Pearson residuals for the encounter rate for the Triennial Late Survey by VAST. fig:tri_late_

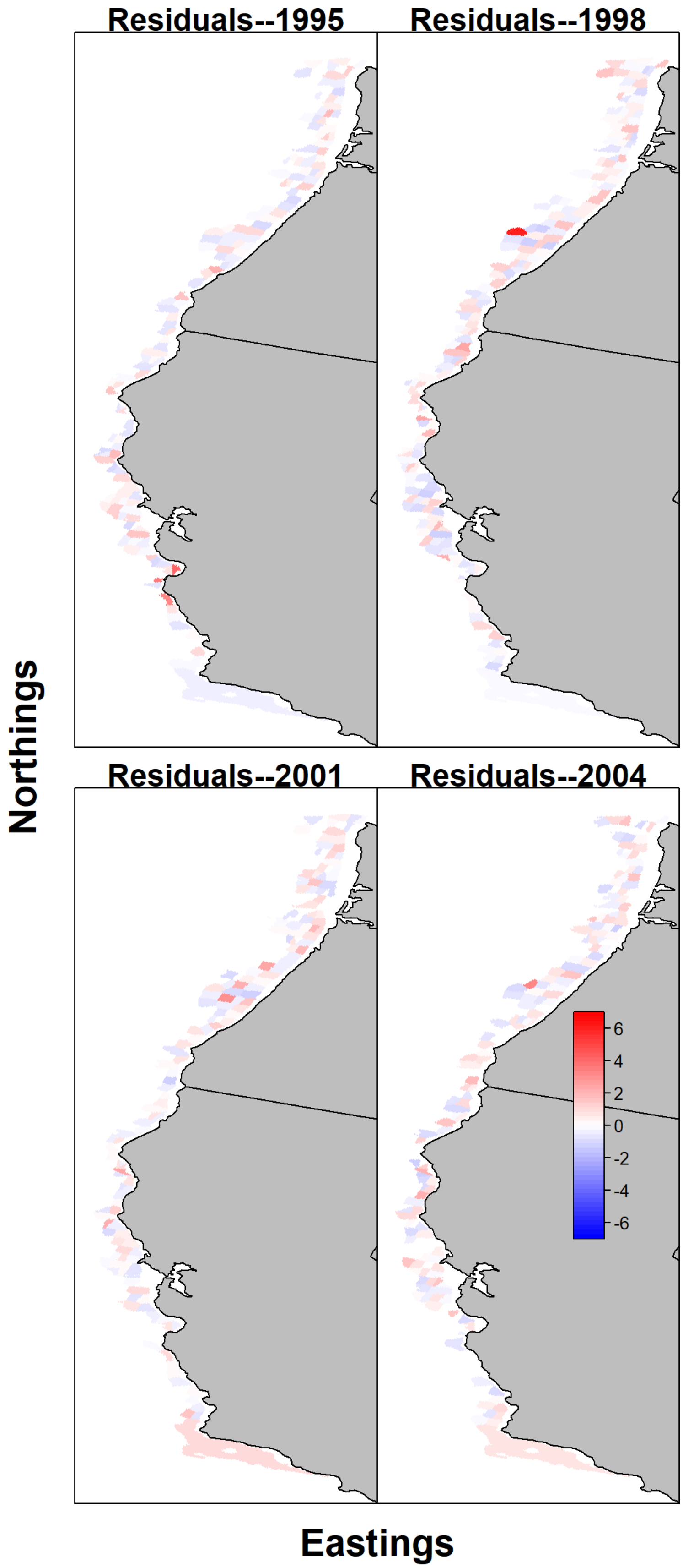

Figure 22: Pearson residuals for the estimated catch rate for the Triennial Late Survey by VAST. fig:tri_late_catch_rate

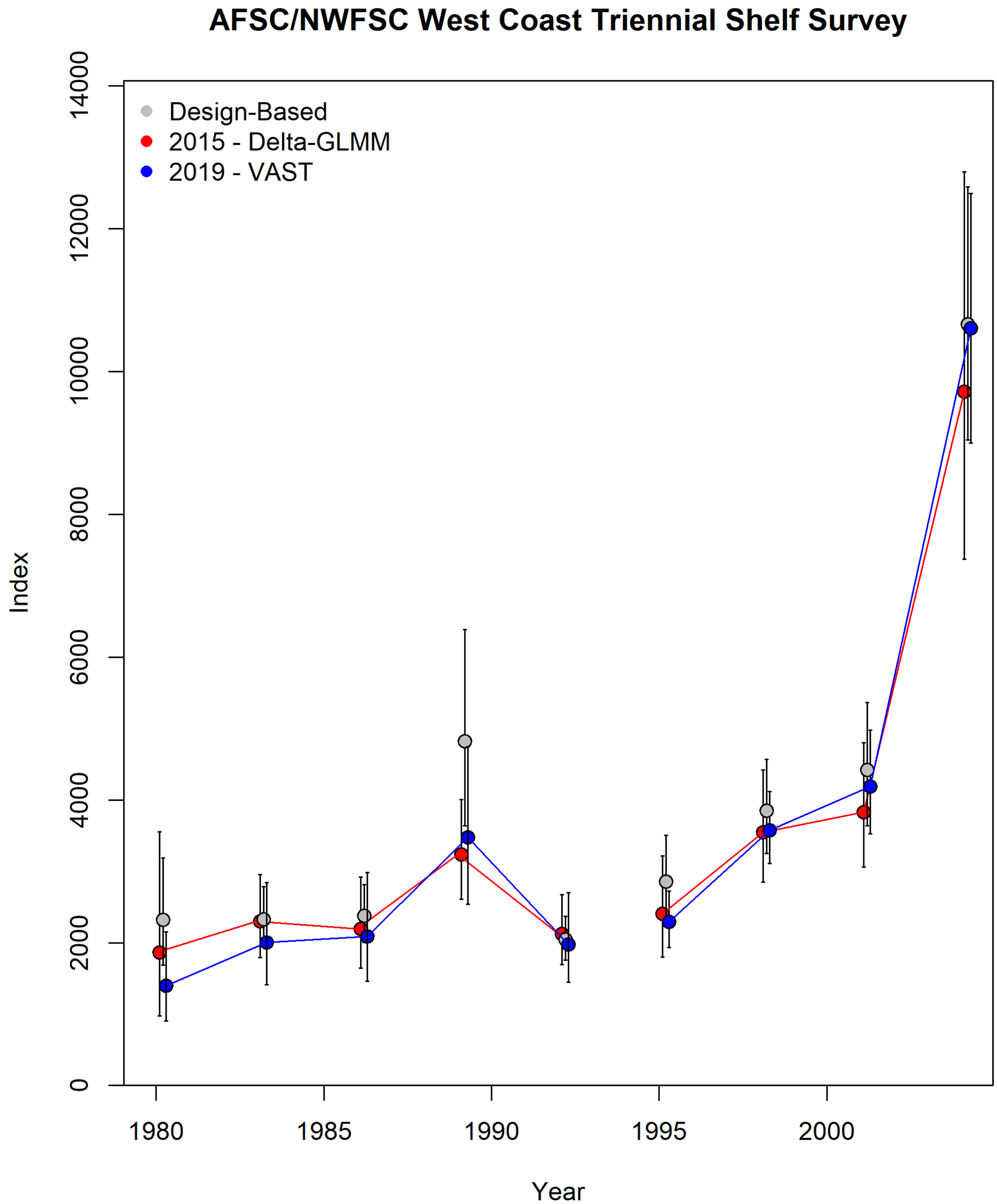

Figure 23: Estimated index of abundance from the Triennial Survey data compared to the design-based index and the index from the 2015 update assessment. fig:tri_index

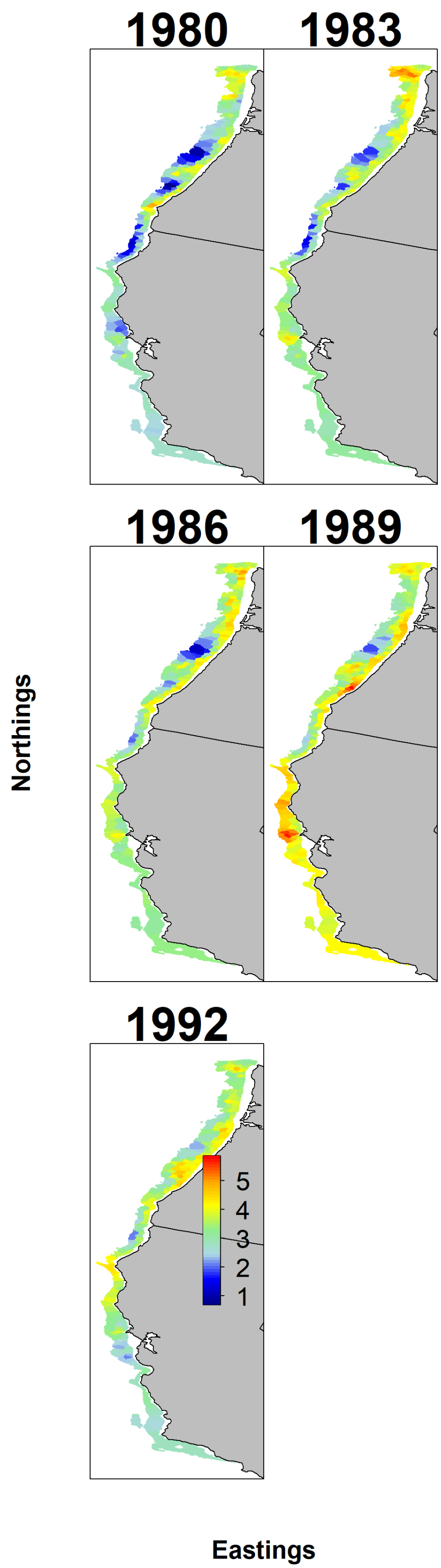

Figure 24: Estimated density of abundance from the Triennial Early Survey data by VAST. fig:tri_early

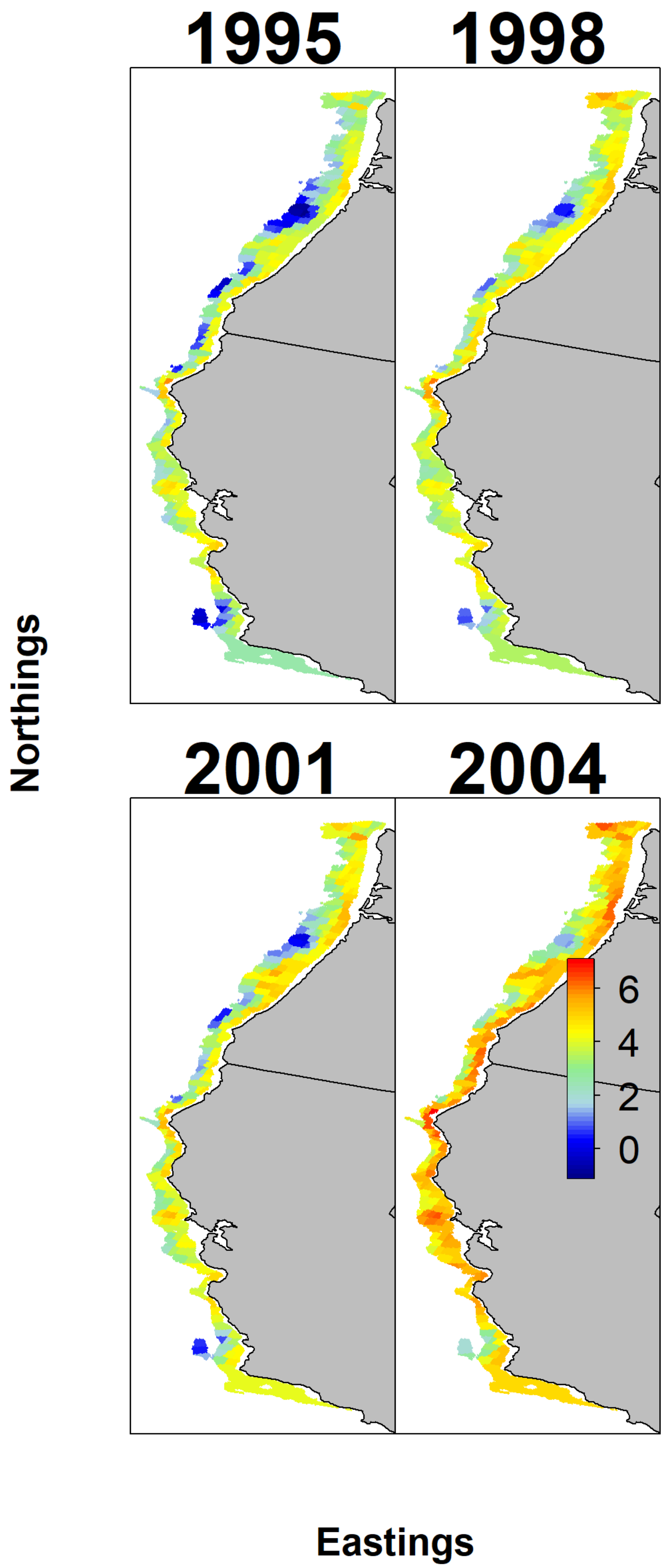

Figure 25: Estimated density of abundance from the Triennial Late Survey data by VAST. fig:tri_late_

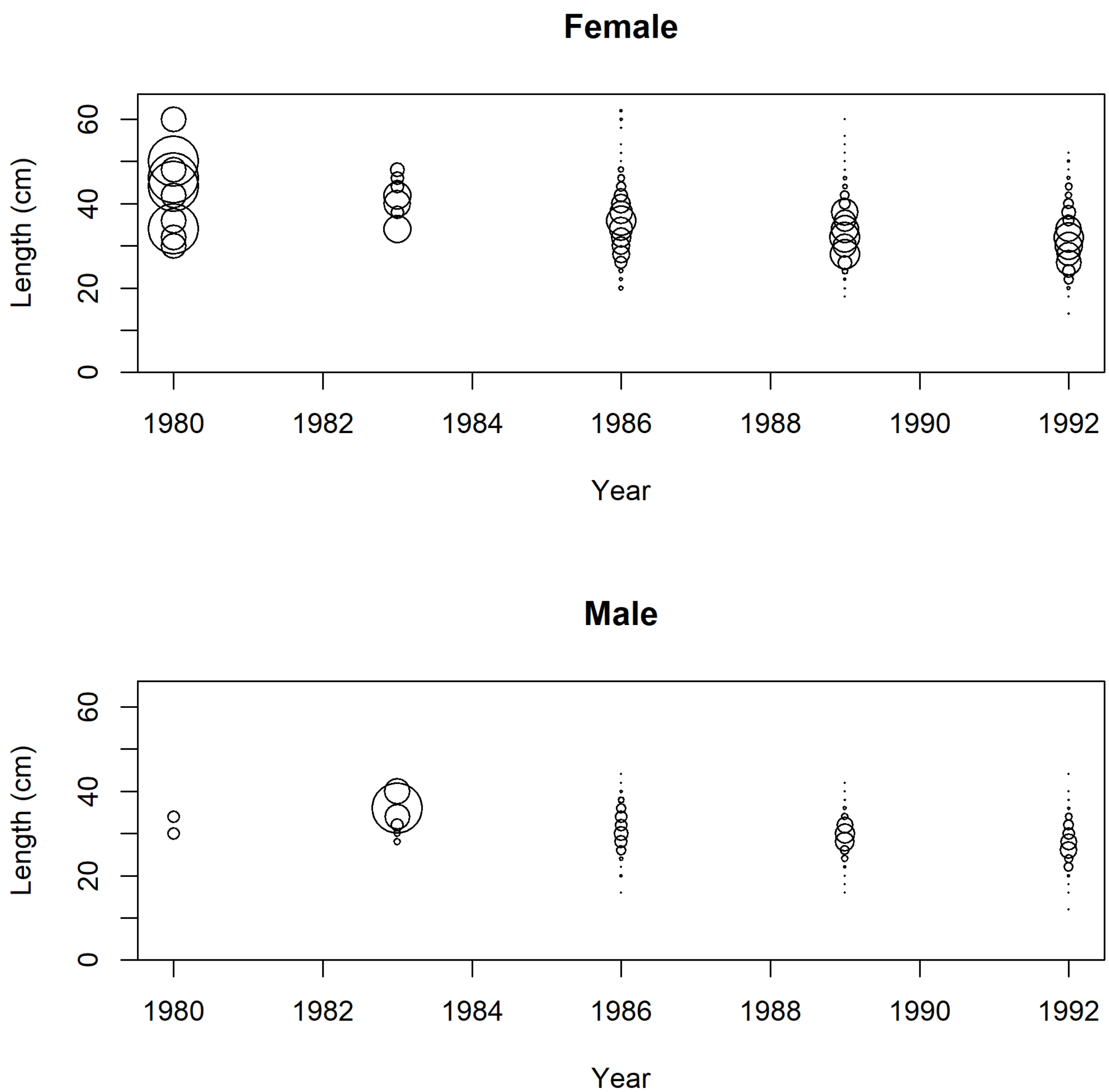

Figure 26: Length frequency by sex for the Triennial Early Survey data. fig:tri_early_len_fre

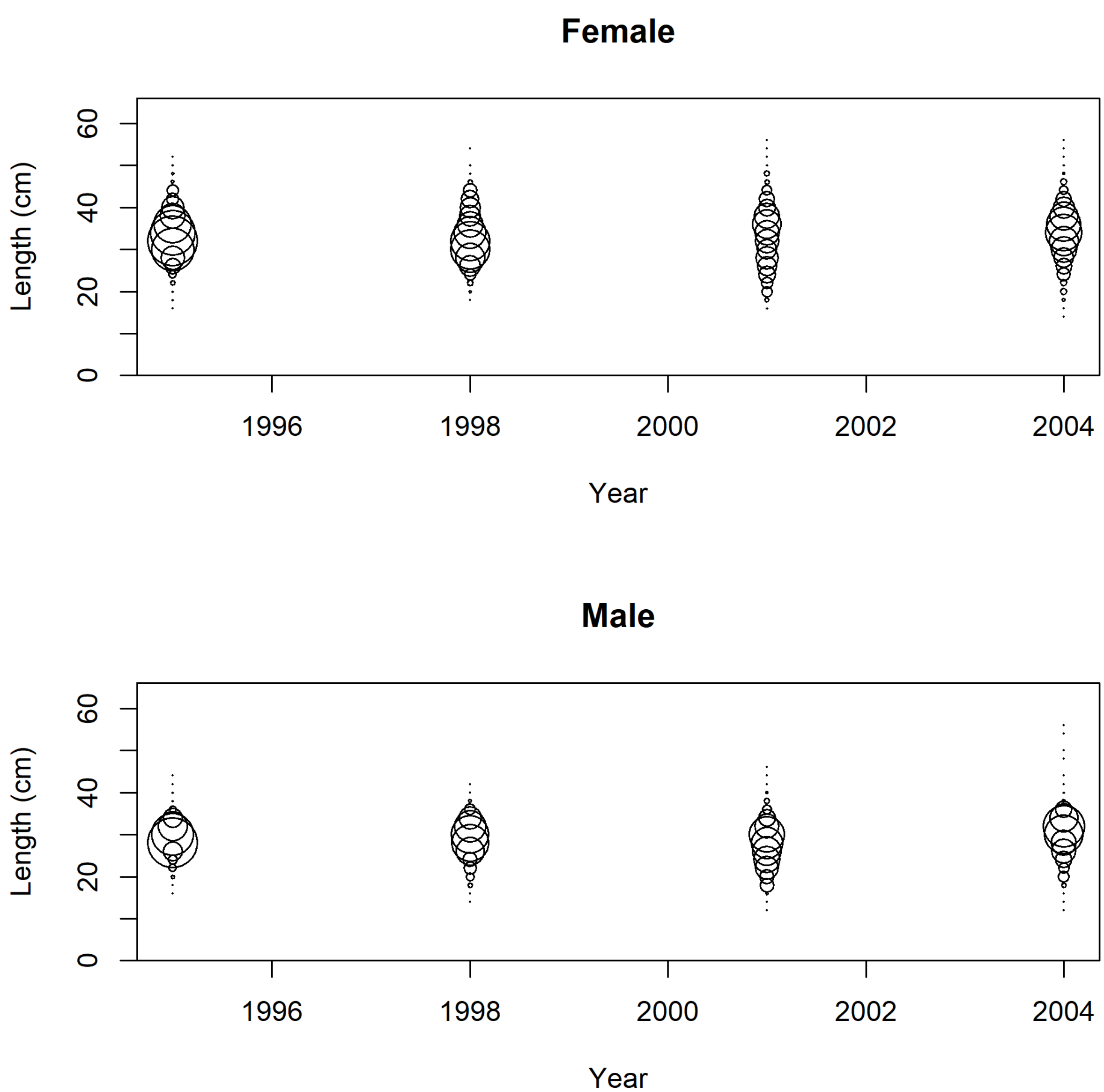

Figure 27: Length frequency by sex for the Triennial Late Survey data. fig:tri_late_len_freq

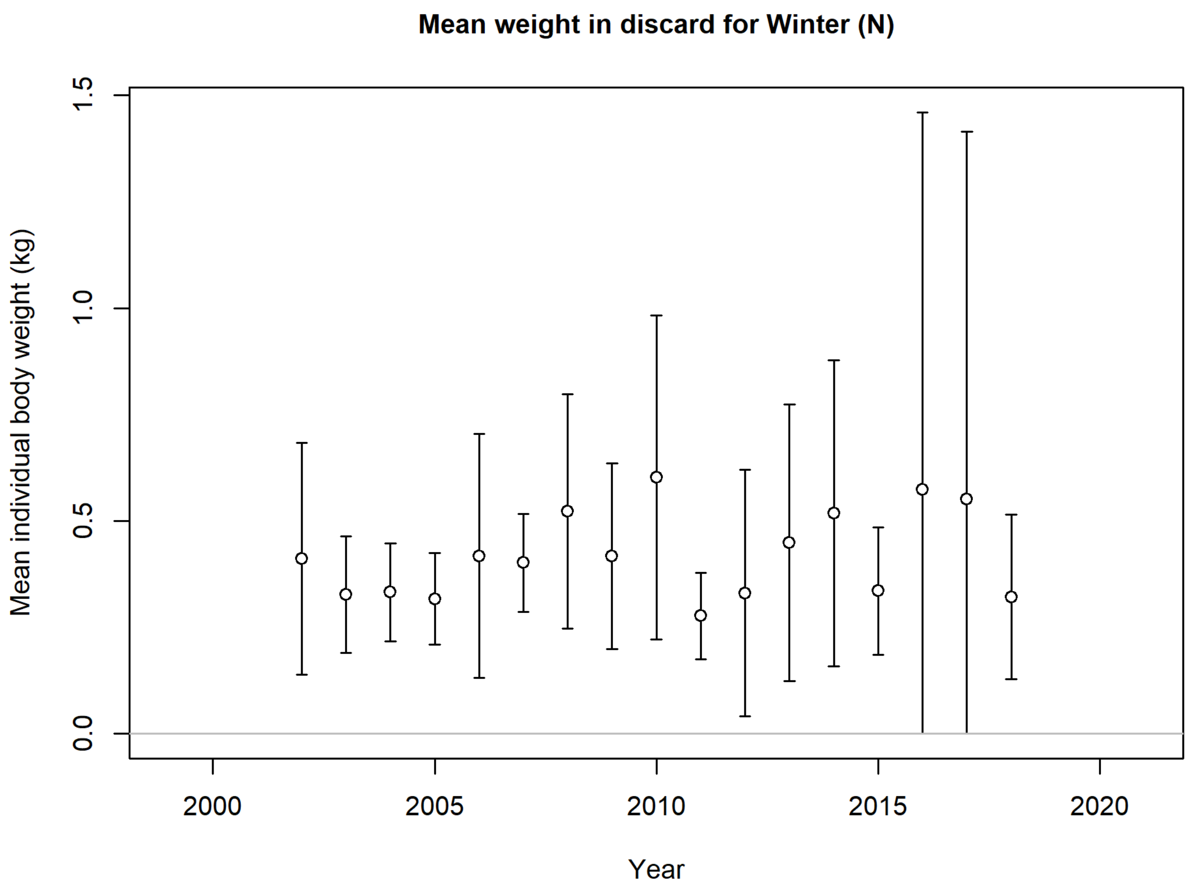

Figure 28: Northern winter fishery mean body weights of discarded fish for petrale sole. fig:nw_bodywt

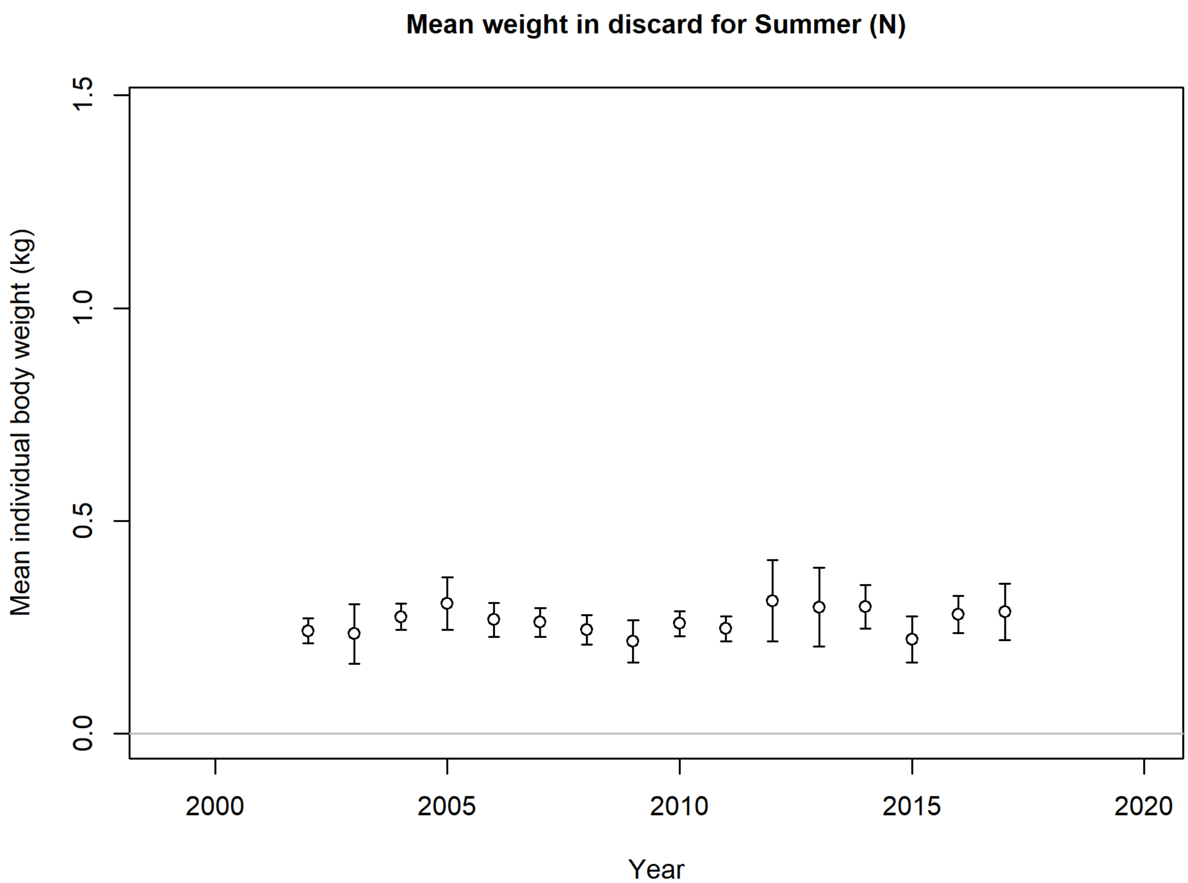

Figure 29: Northern summer fishery mean body weights of discarded fish for petrale sole. fig:ns_bodywt

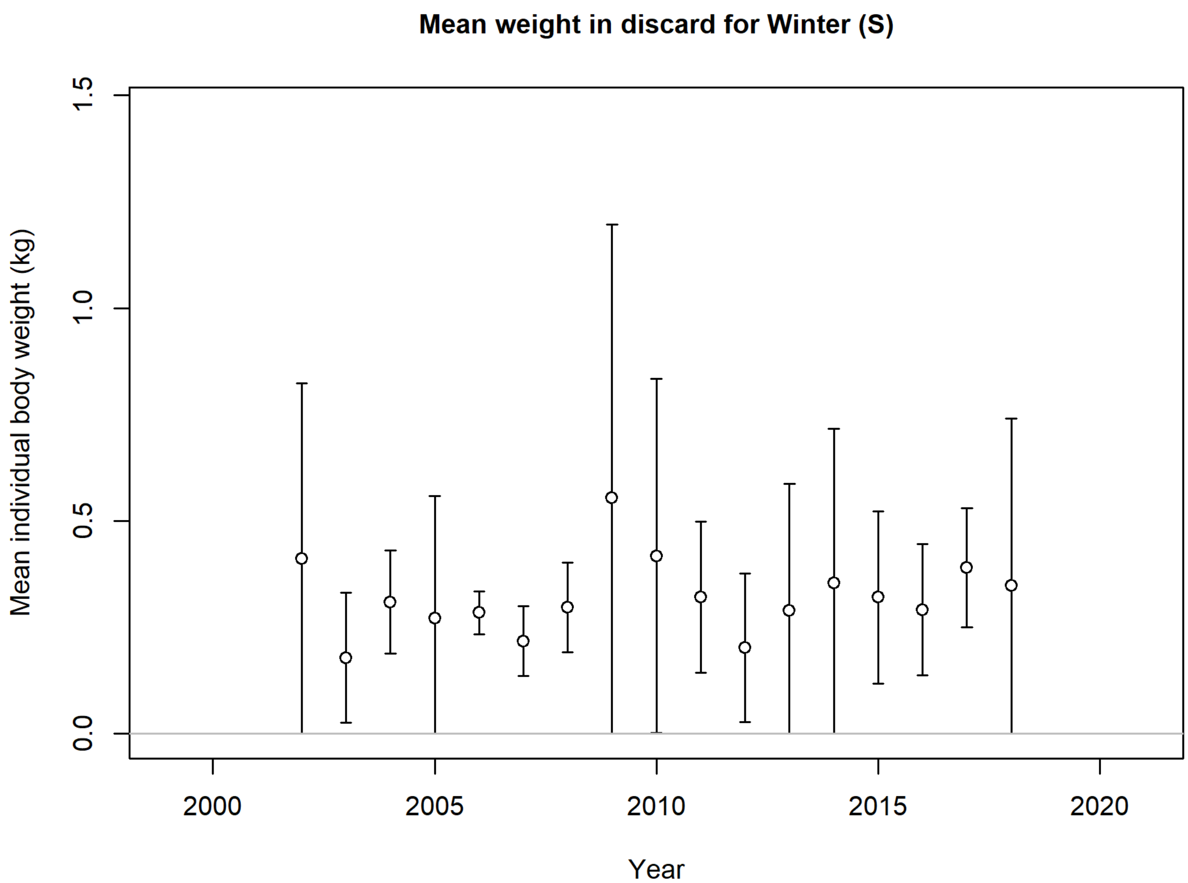

Figure 30: Southern winter fishery mean body weights of discarded fish for petrale sole. fig:sw_bodywt

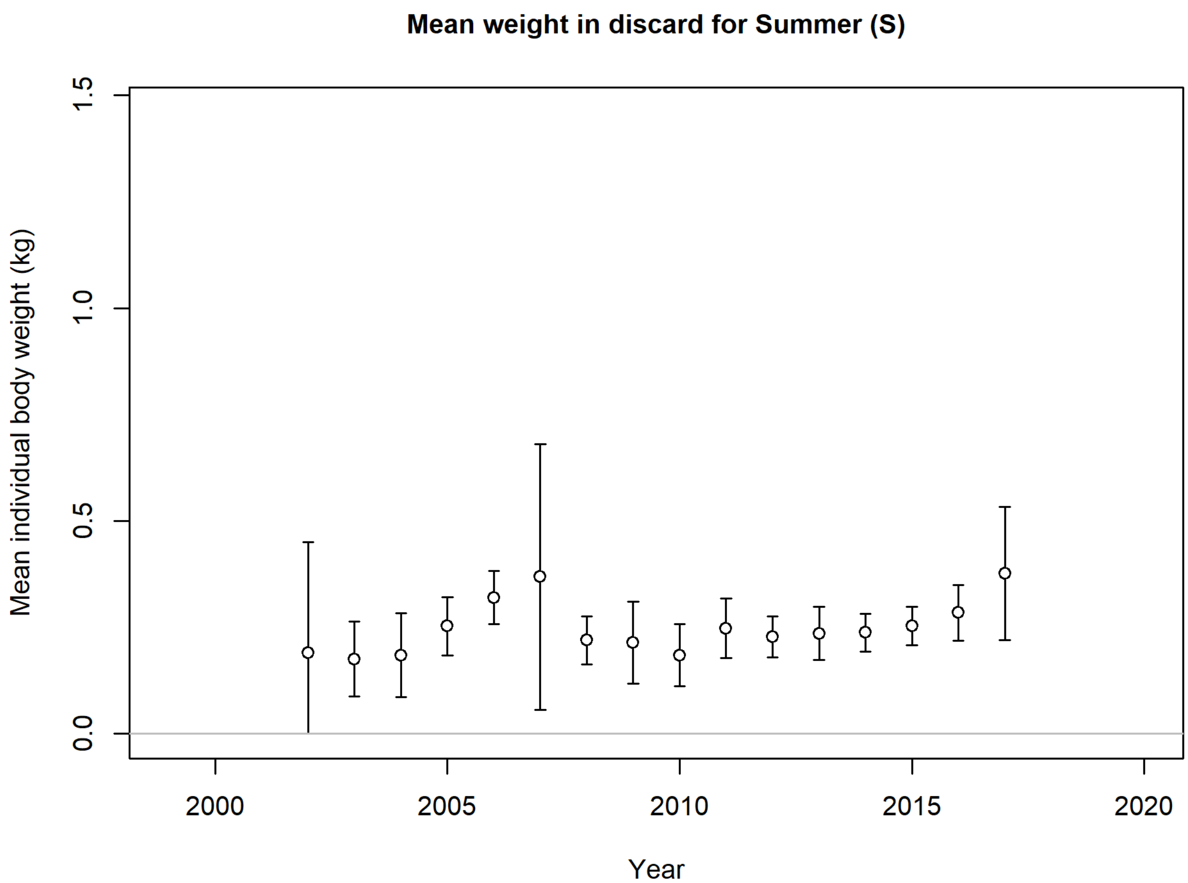

Figure 31: Southern summer fishery mean body weights of discarded fish for petrale sole. fig:ss_bodywt

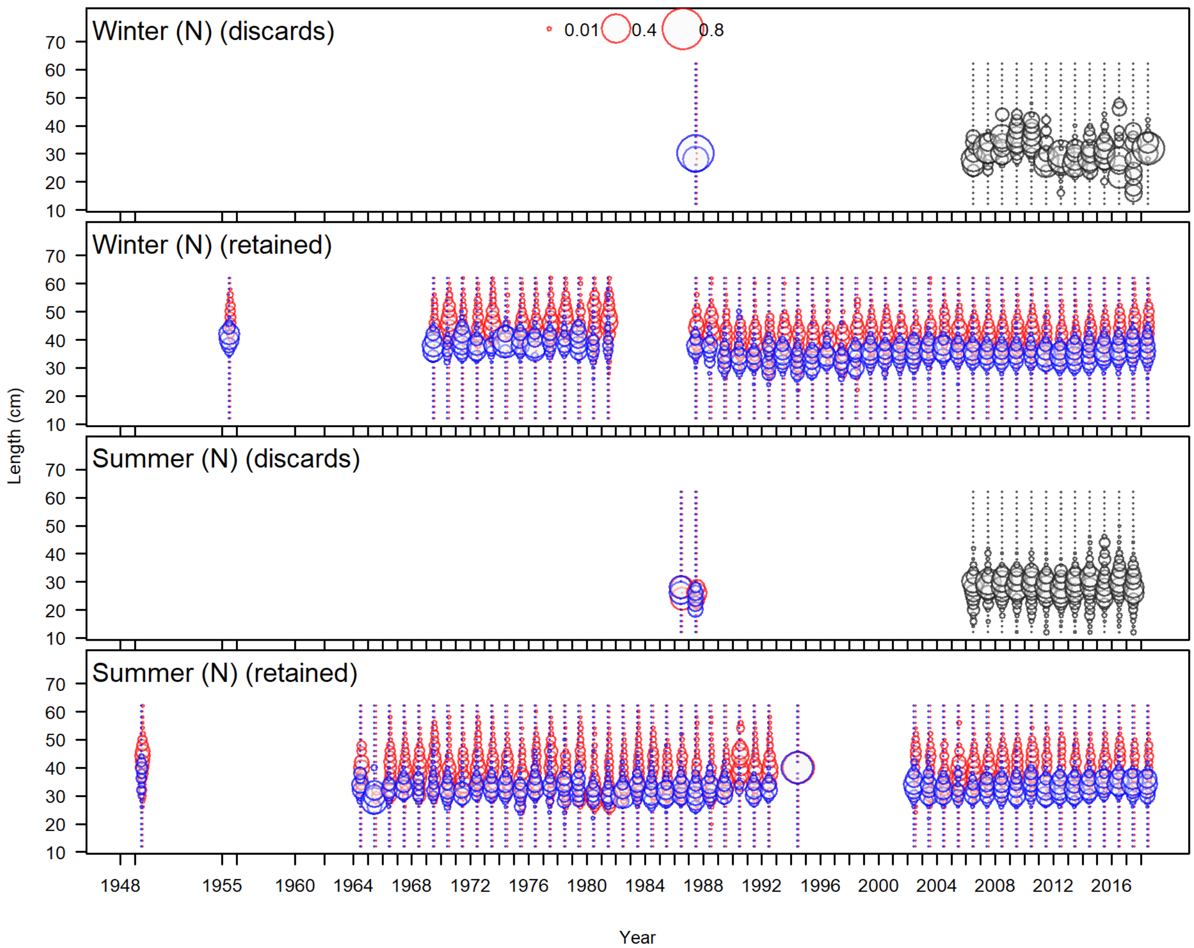

Figure 32: Northern fishery, winter and summer, retained and discarded length frequency distributions for petrale sole. fig:north_lengths

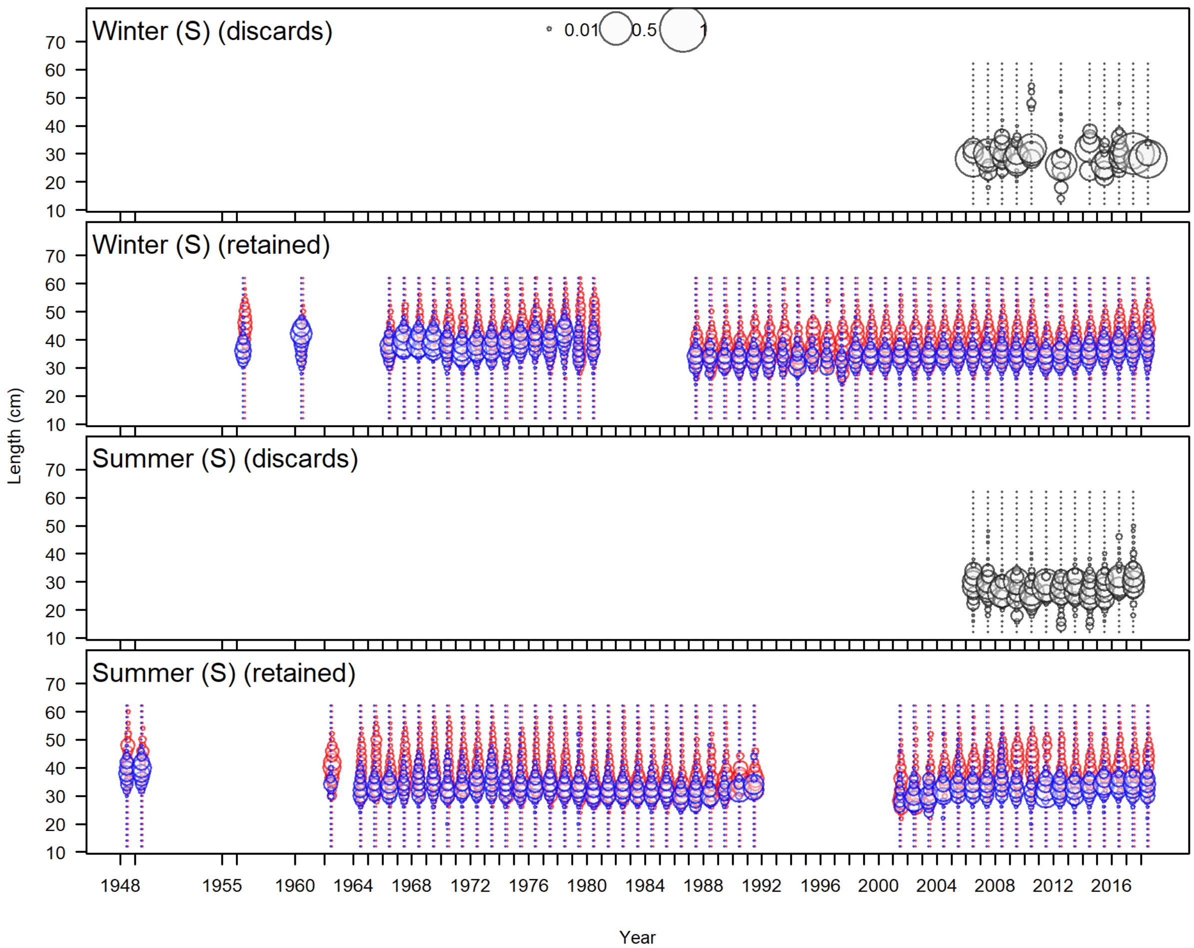

Figure 33: Southern fishery, winter and summer, retained and discarded length frequency distributions for petrale sole. fig:south_lengths

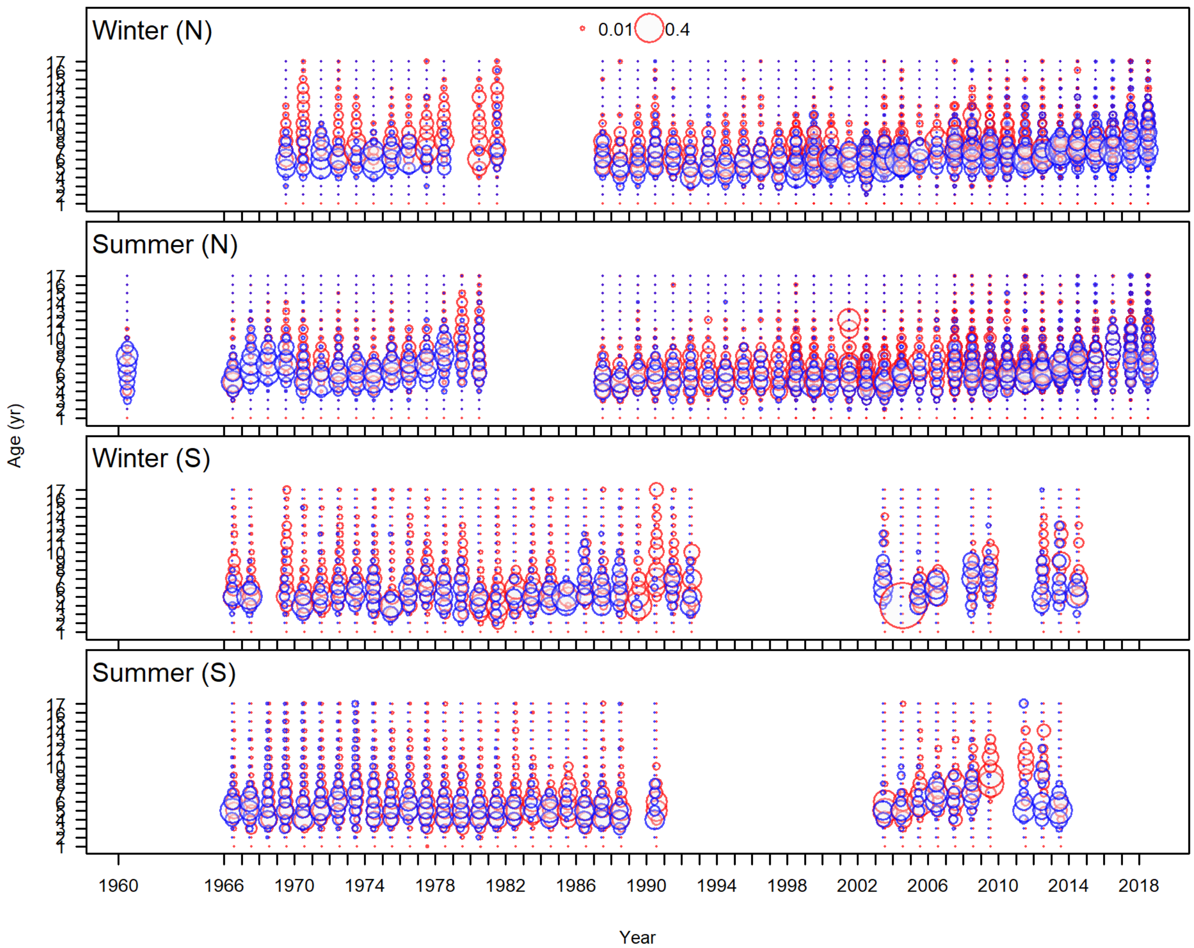

Figure 34: Commercial fishery age frequency distributions for petrale sole. fig:comm_ages

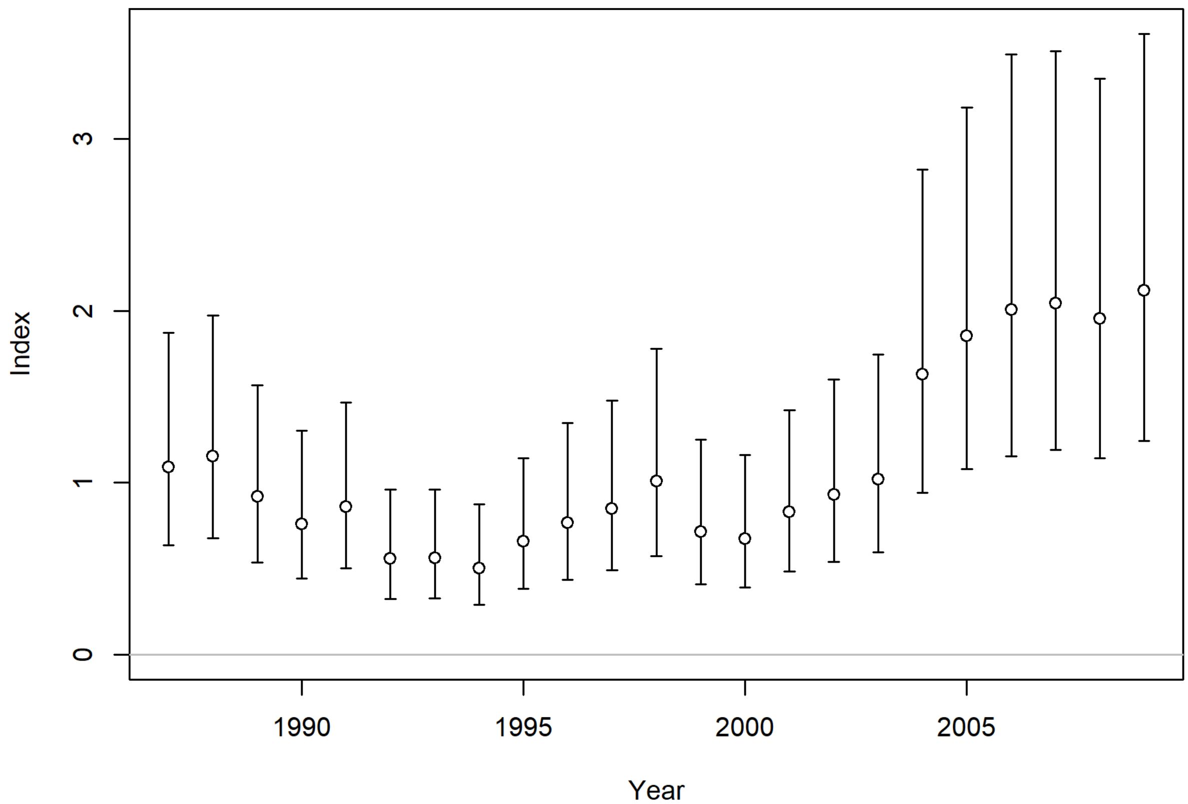

Figure 35: The Northern Winter fishery catch-per-unit-effort based on logbook data for petrale sole. fig:north_cpue

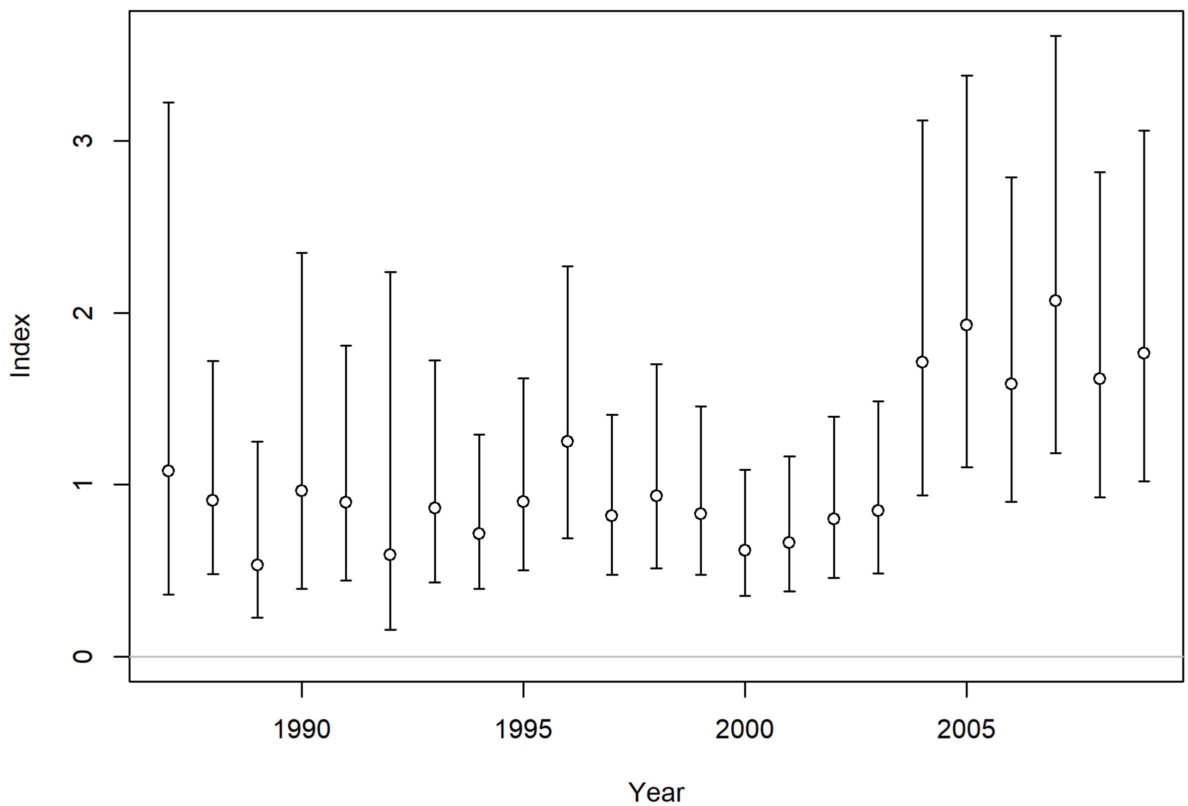

Figure 36: The Southern Winter fishery catch-per-unit-effort based on logbook data for petrale sole. fig:south_cpue

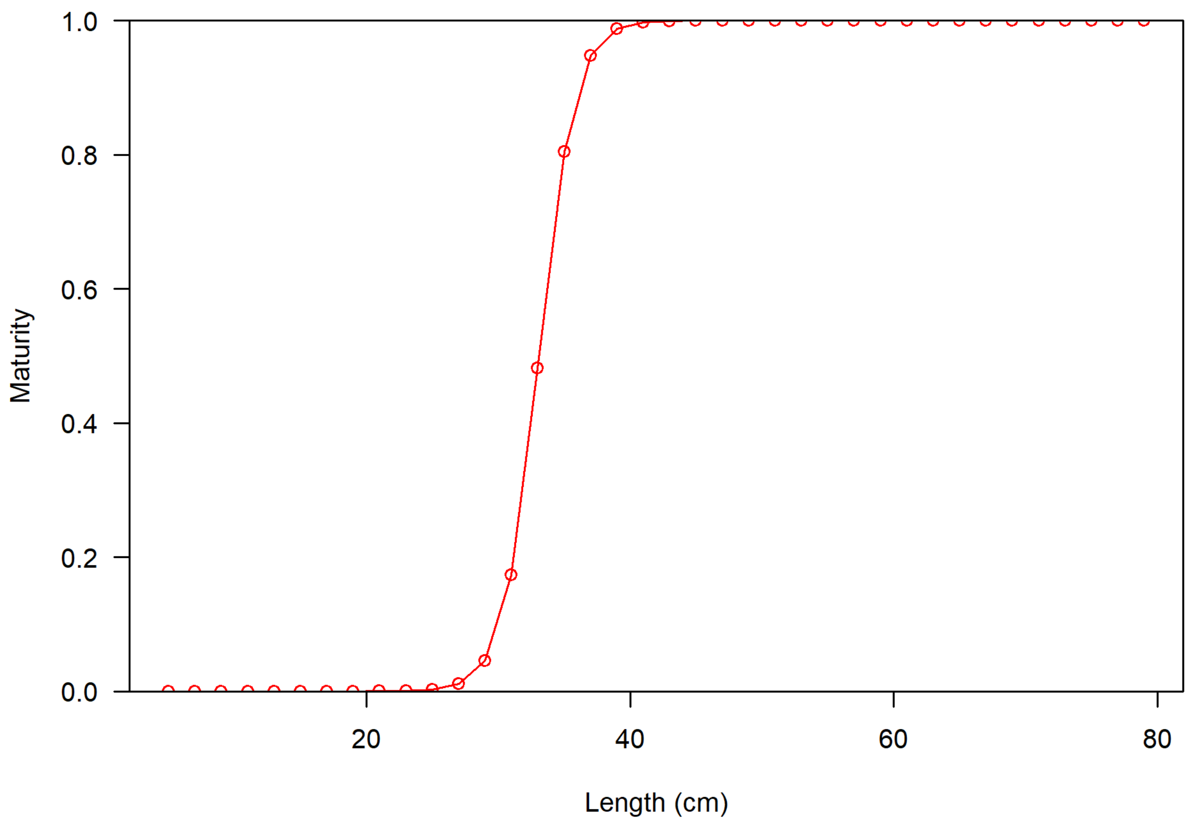

Figure 37: Estimated maturity-at-length for petrale sole. fig:maturity

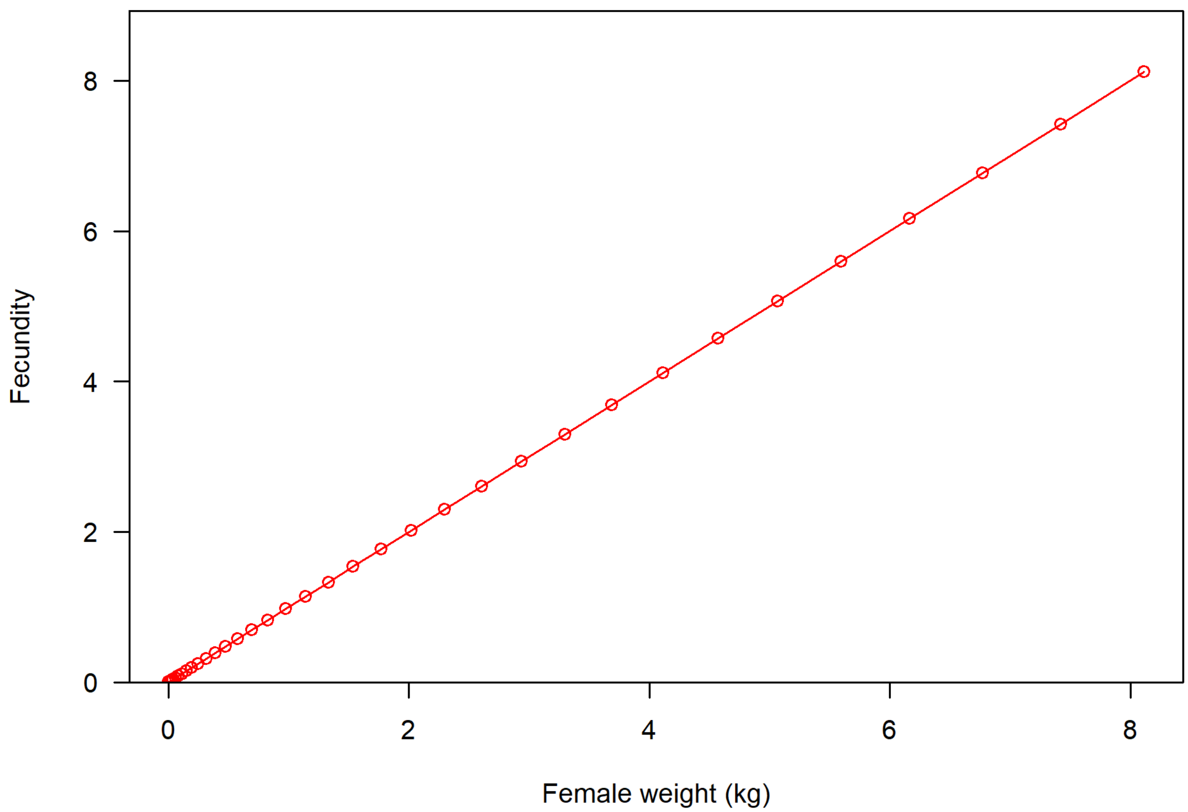

Figure 38: Fecundity-at-length assumed in the model for petrale sole. fig:fecundity_model

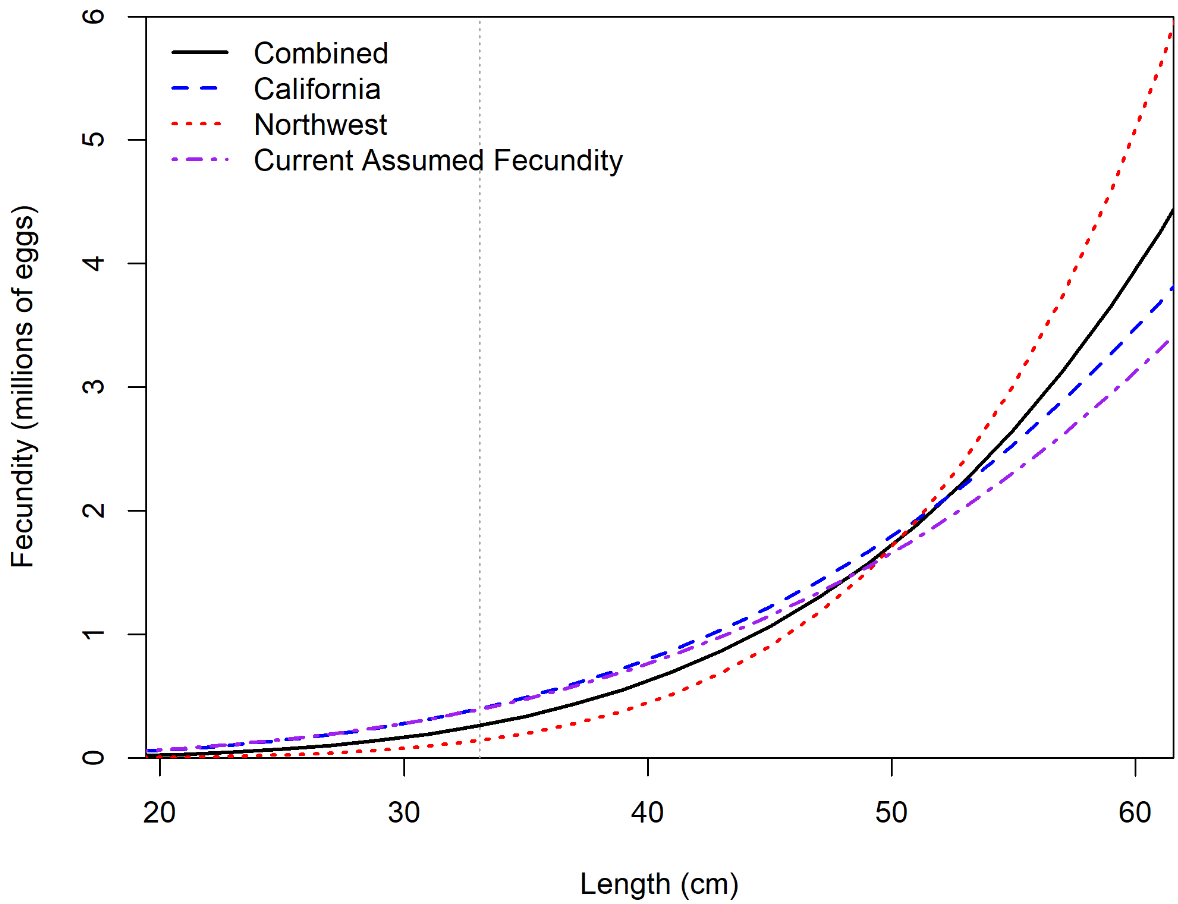

Figure 39: Estimated fecundity-at-length for petrale sole based on Lefebvre et al. (in press). fig:fecundity

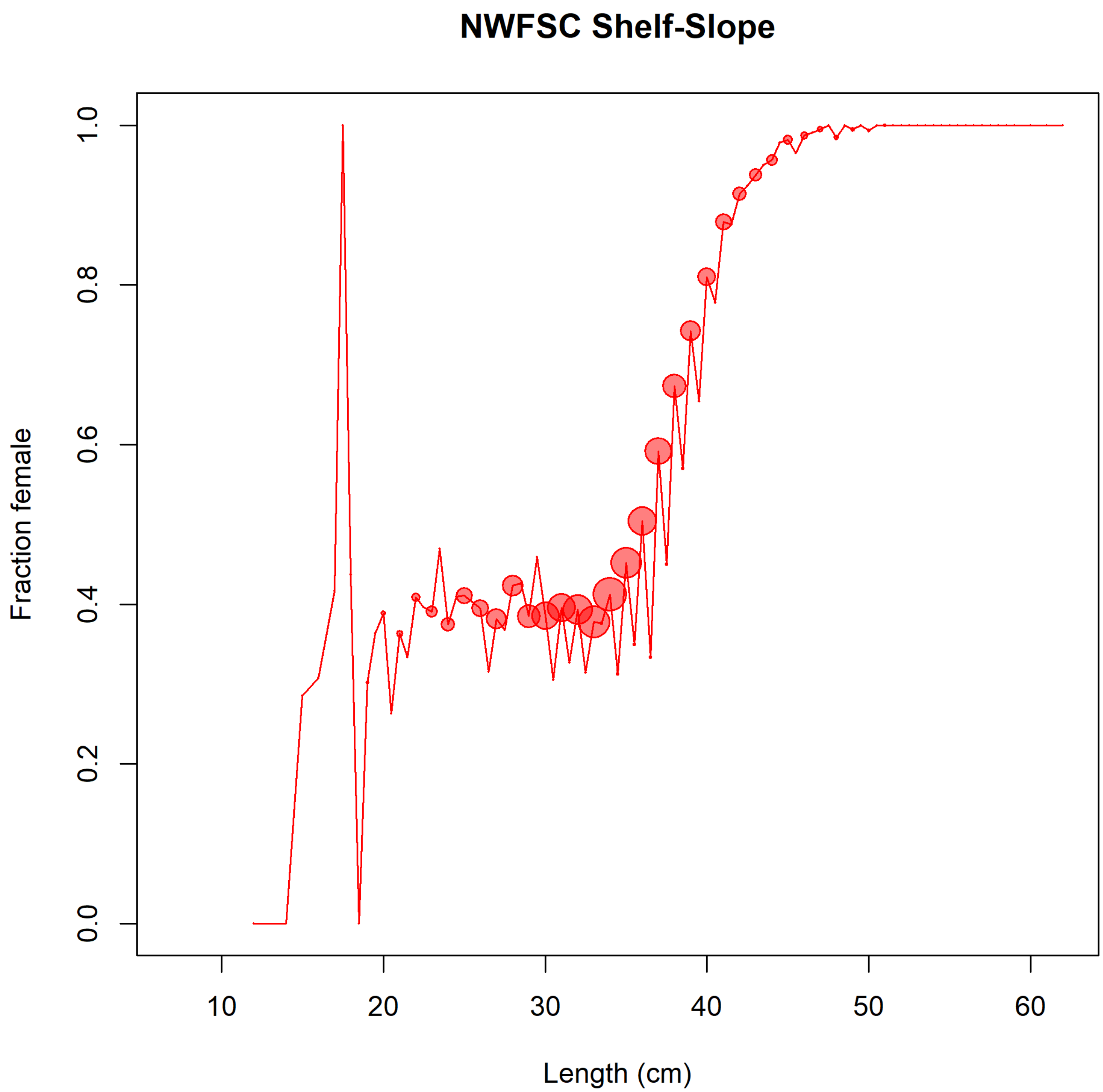

Figure 40: Estimated proportion of female fish collected by the NWFSC shelf-slope survey across all years for petrale sole. fig:sex_ratio

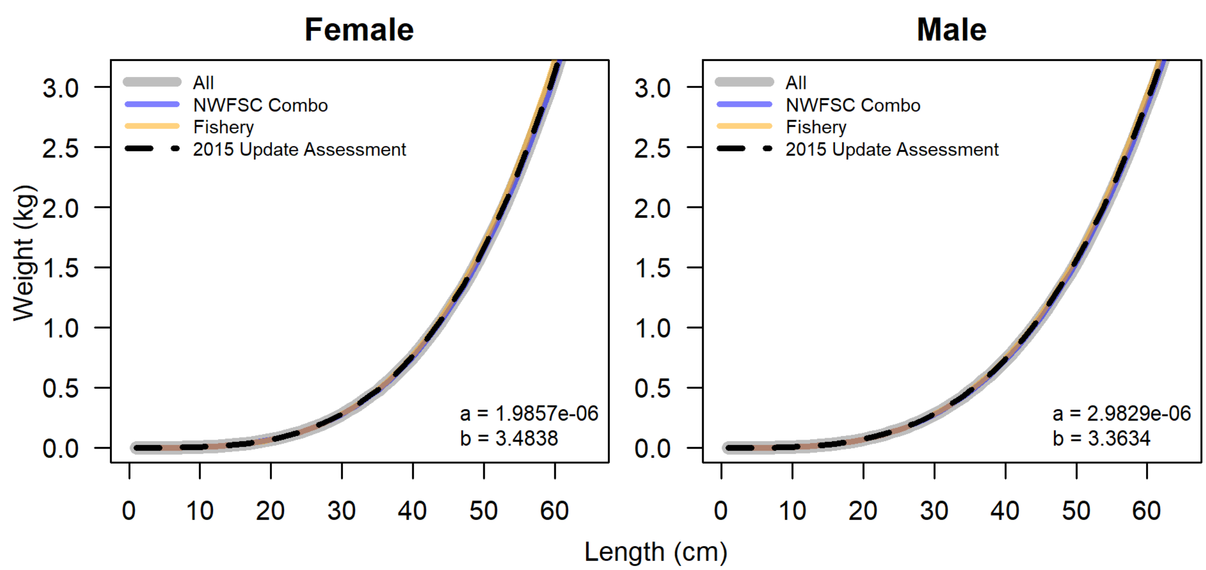

Figure 41: Estimated weight-at-length for female and male petrale sole. fig:wt_length

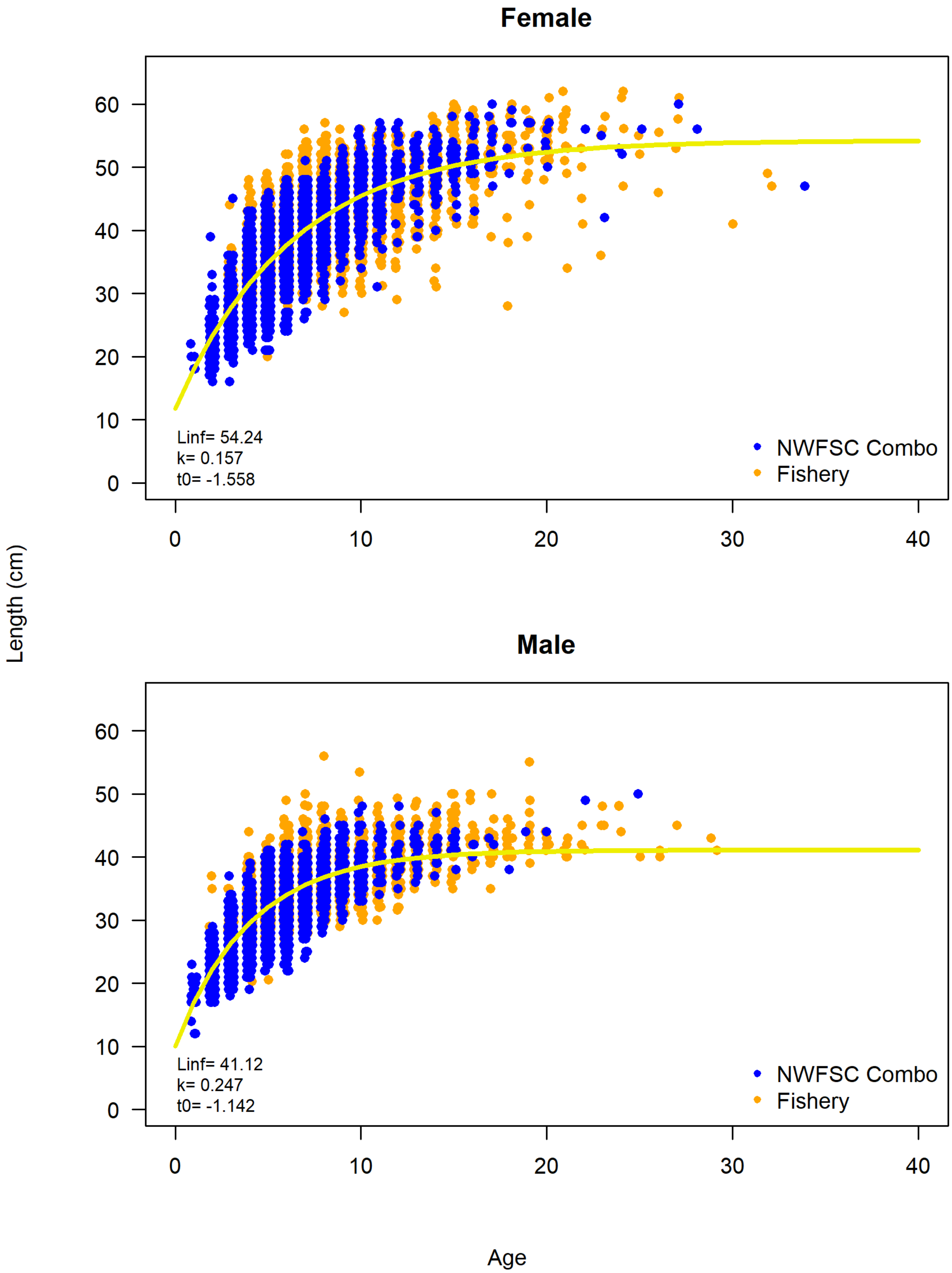

Figure 42: Length-at-age across data sources for female and male petrale sole. fig:length_age

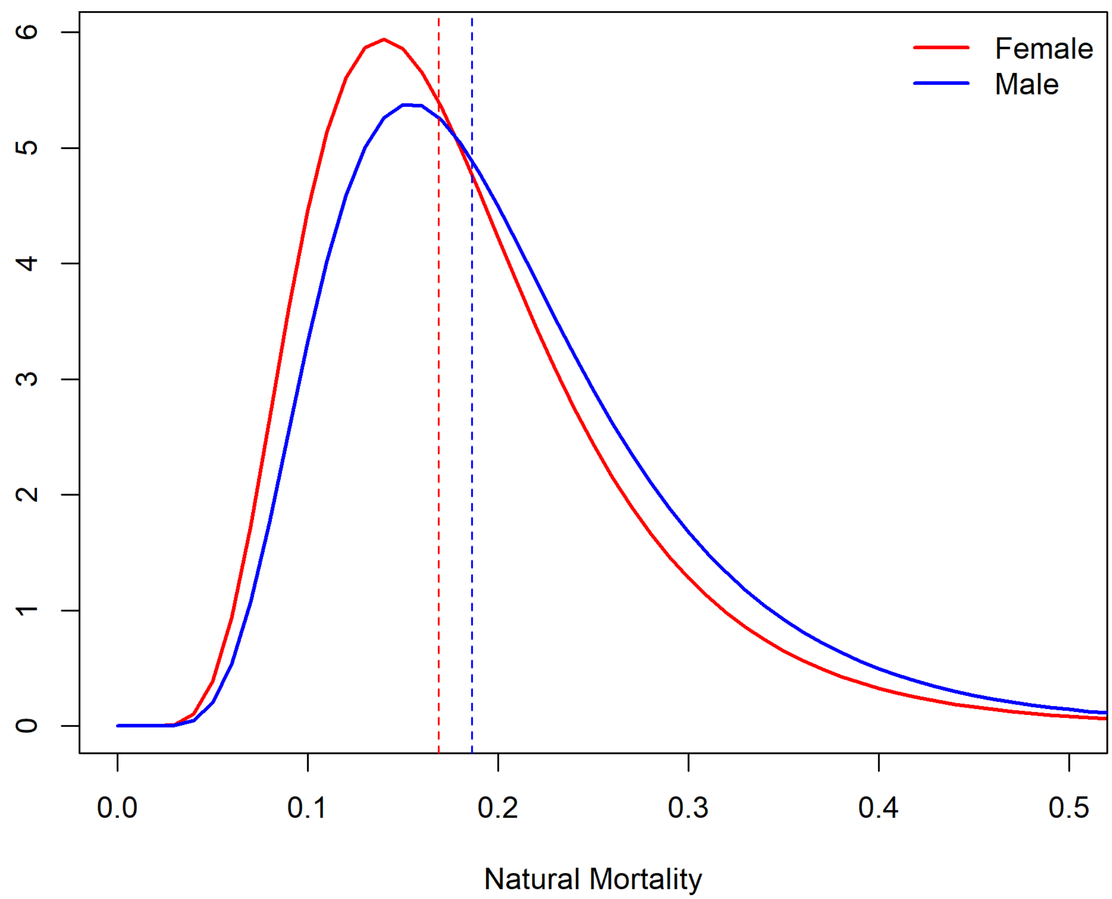

Figure 43: Prior distribution for natural mortality for female and male petrale sole. fig:m_prior

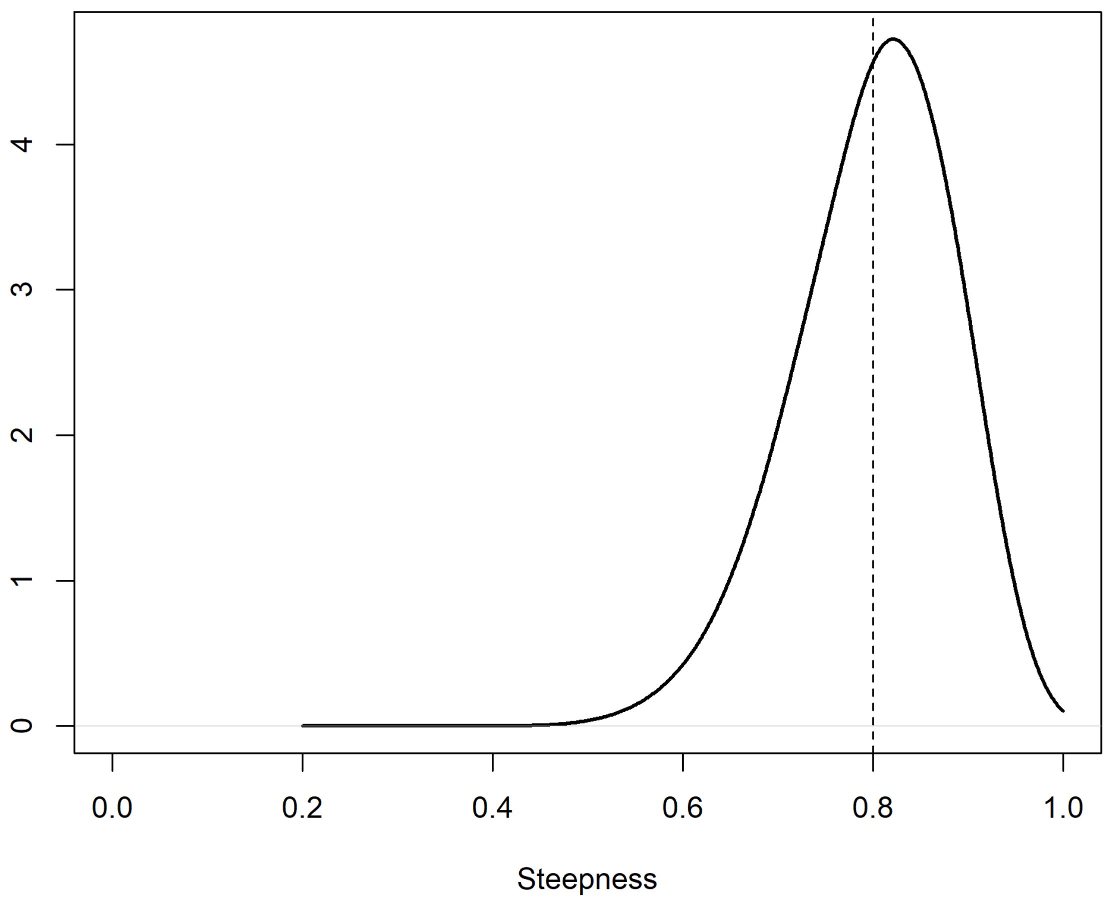

Figure 44: Prior distribution for steepness petrale sole. fig:h_prior

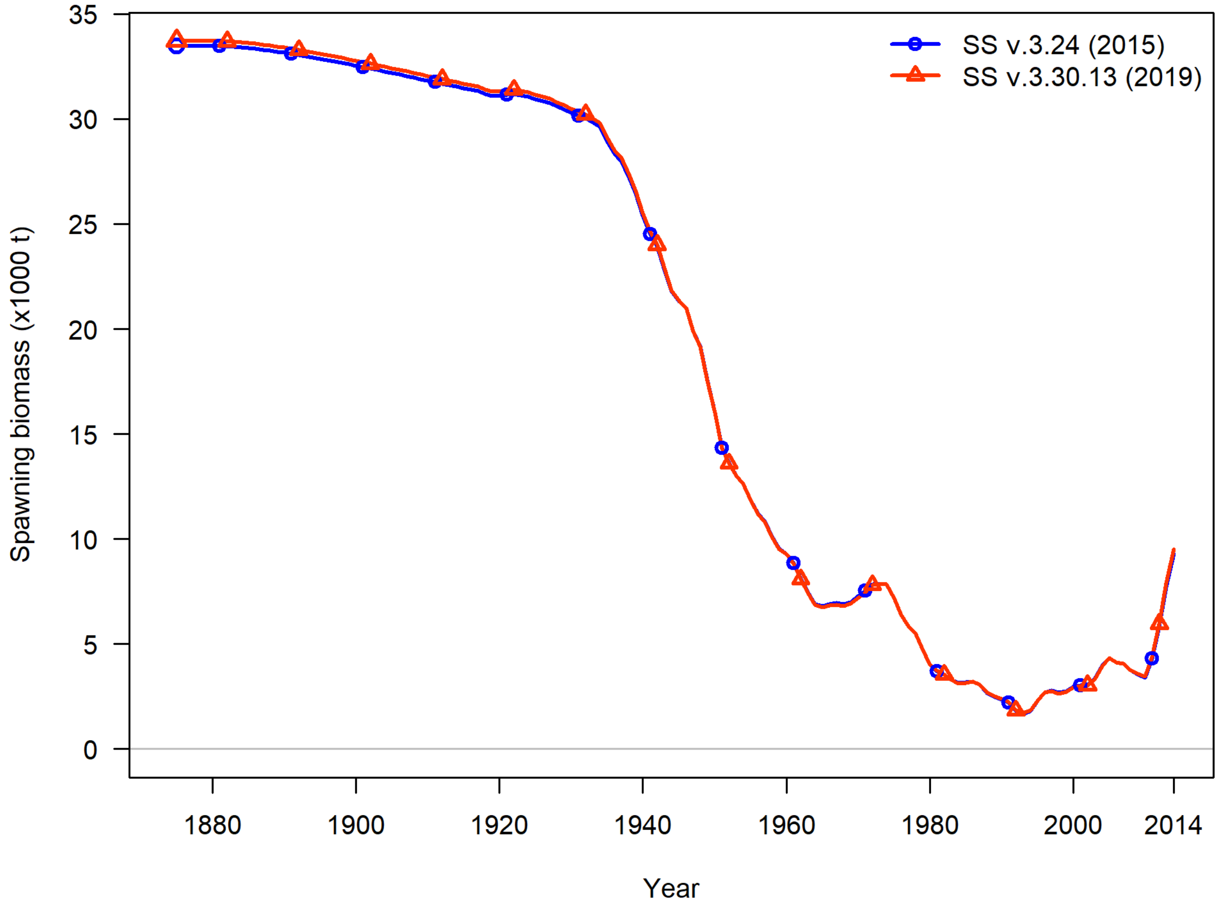

Figure 45: Comparison of model bridging estimates from Stock Synthesis version 3.30.13 and 3.24U for petrale sole for the 2015 assessment. fig:bridge

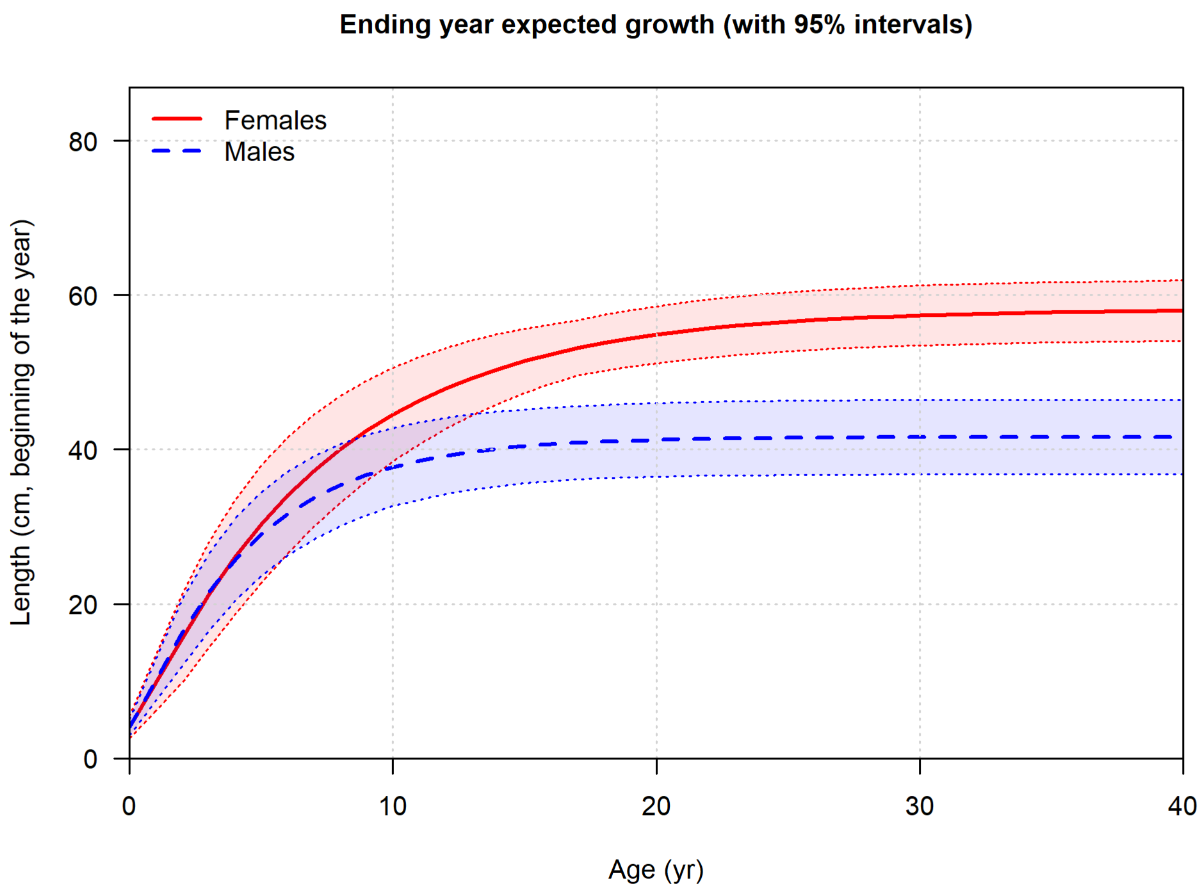

Figure 46: Estimated length-at-age for male and female for petrale sole with estimated CV. fig:sizeatage

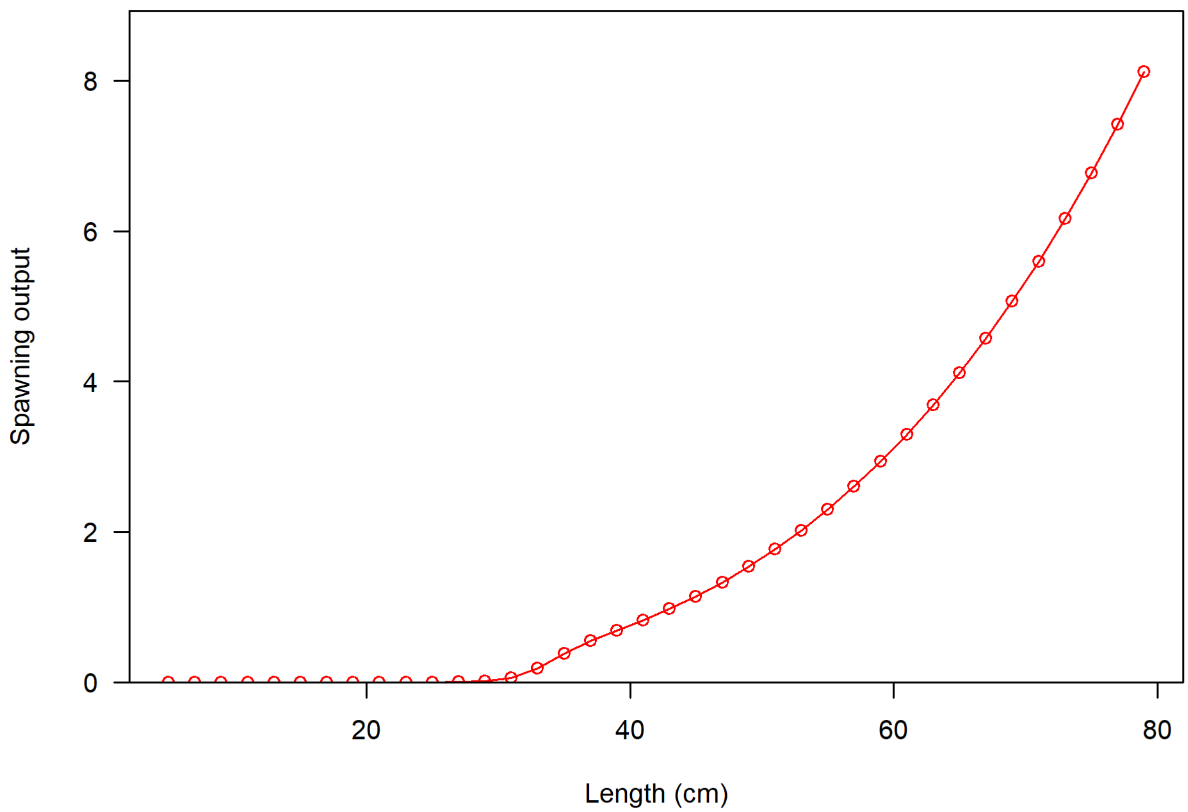

Figure 47: Estimated spawning output-at-length for female petrale sole. fig:spawnoutlen

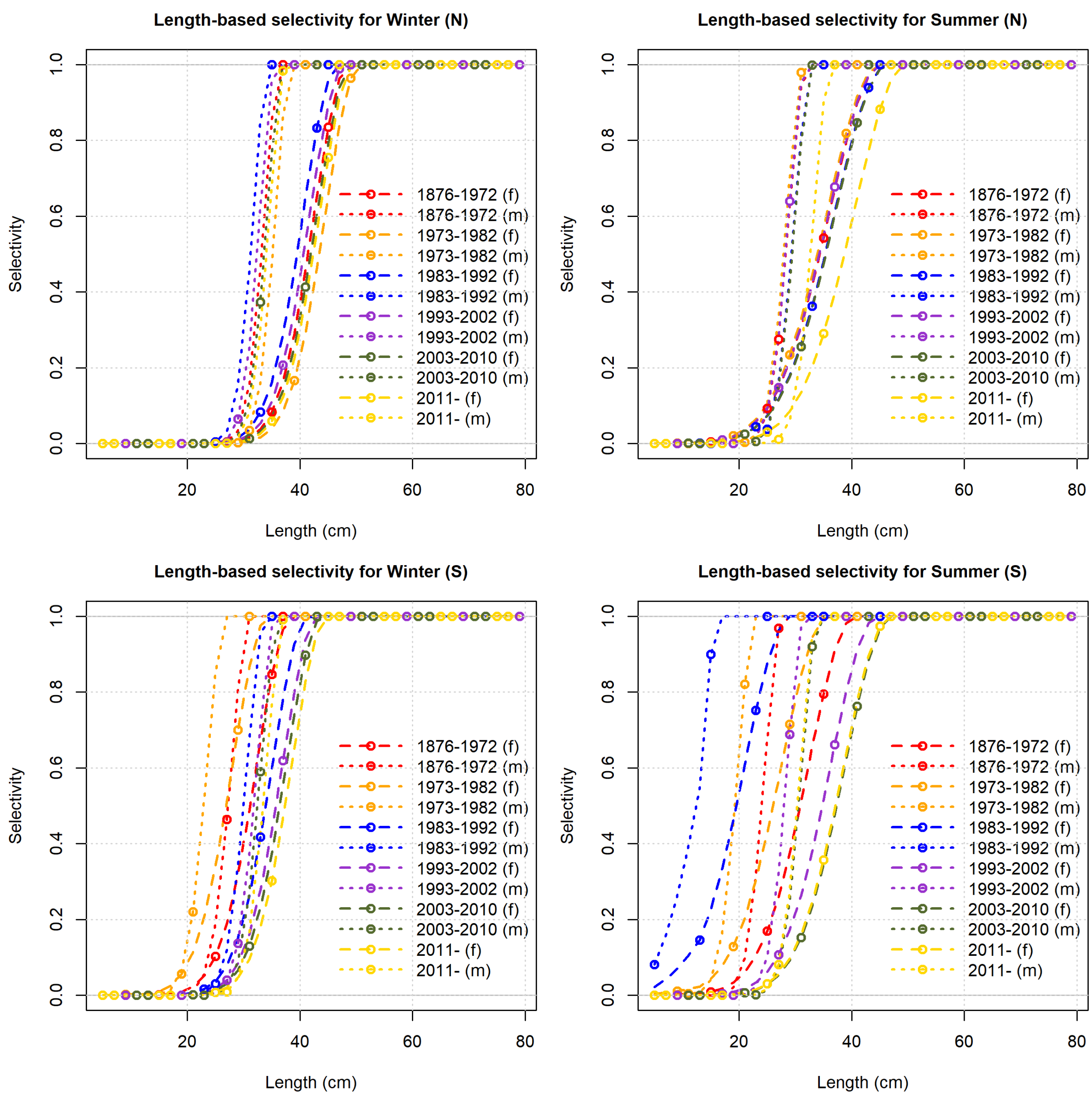

Figure 48: Estimated selectivity for each commerical fleet over the assessment period for female and male petrale sole. [fig:fish_selex]

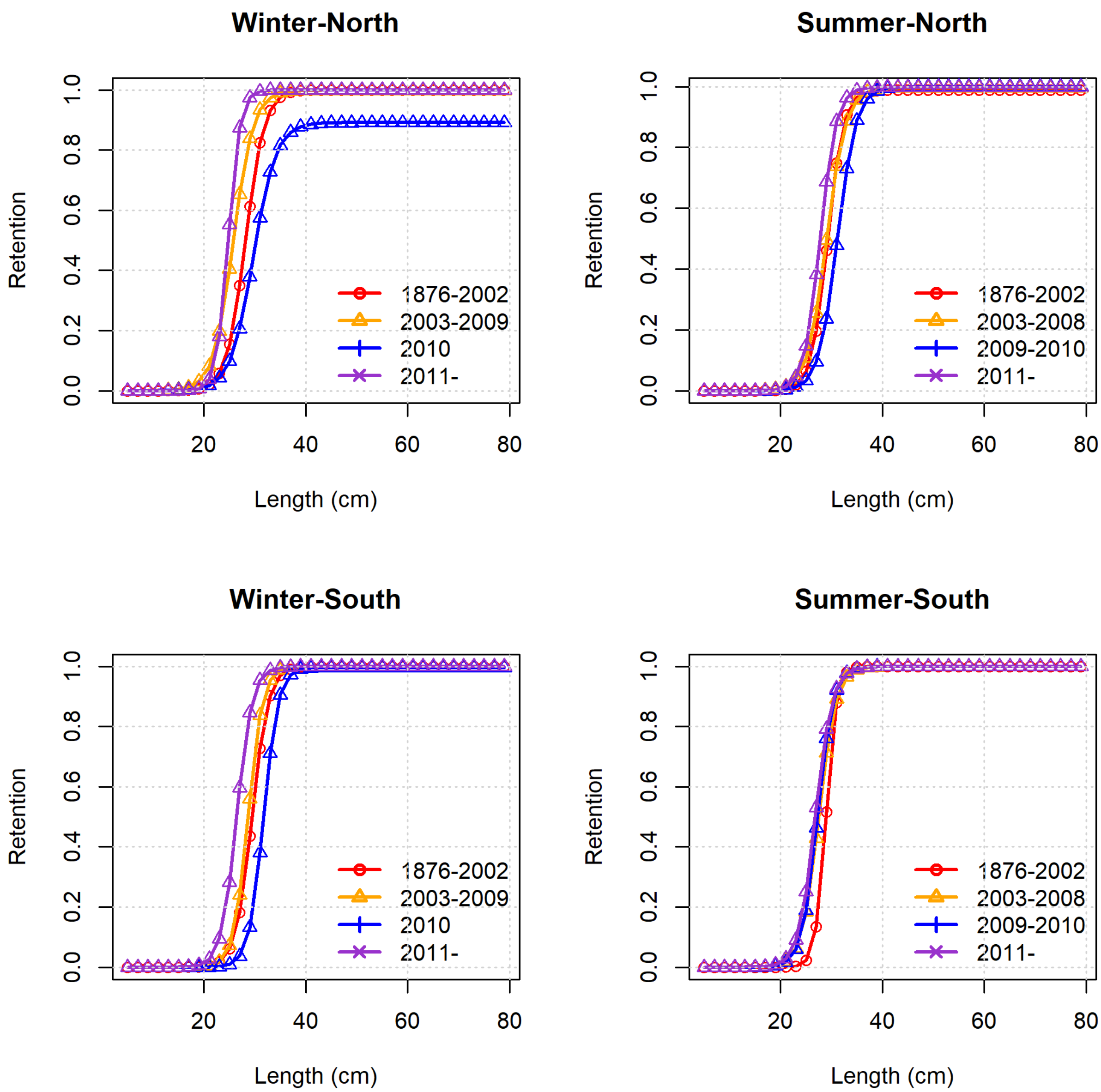

Figure 49: Estimated retention for each commerical fleet over the assessment period for petrale sole. Retention was not estimated to be sex-specific. fig:fish_reten

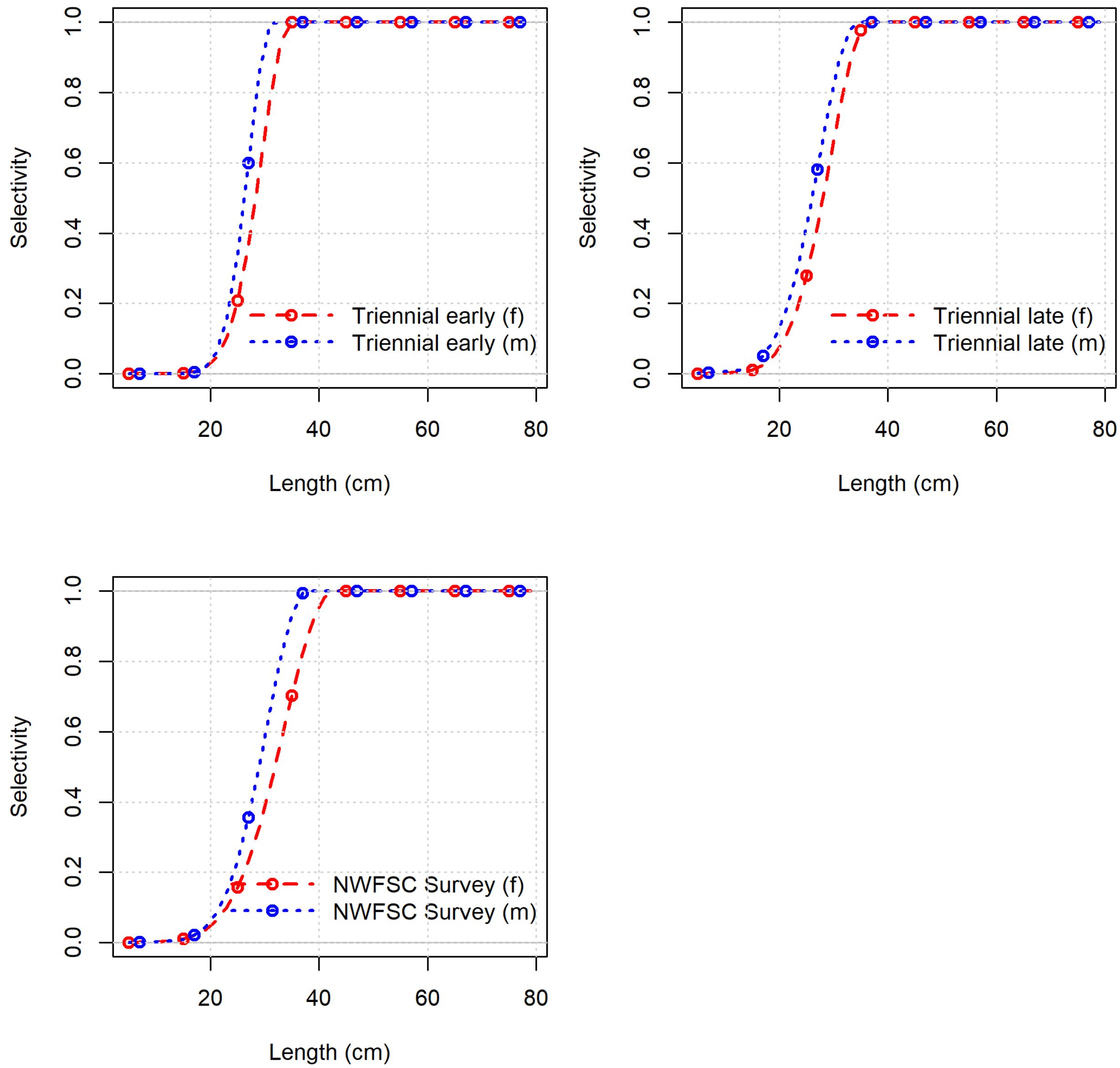

Figure 50: Estimated selectivity for each survey over the assessment period for female and male petrale sole. fig:survey_selex

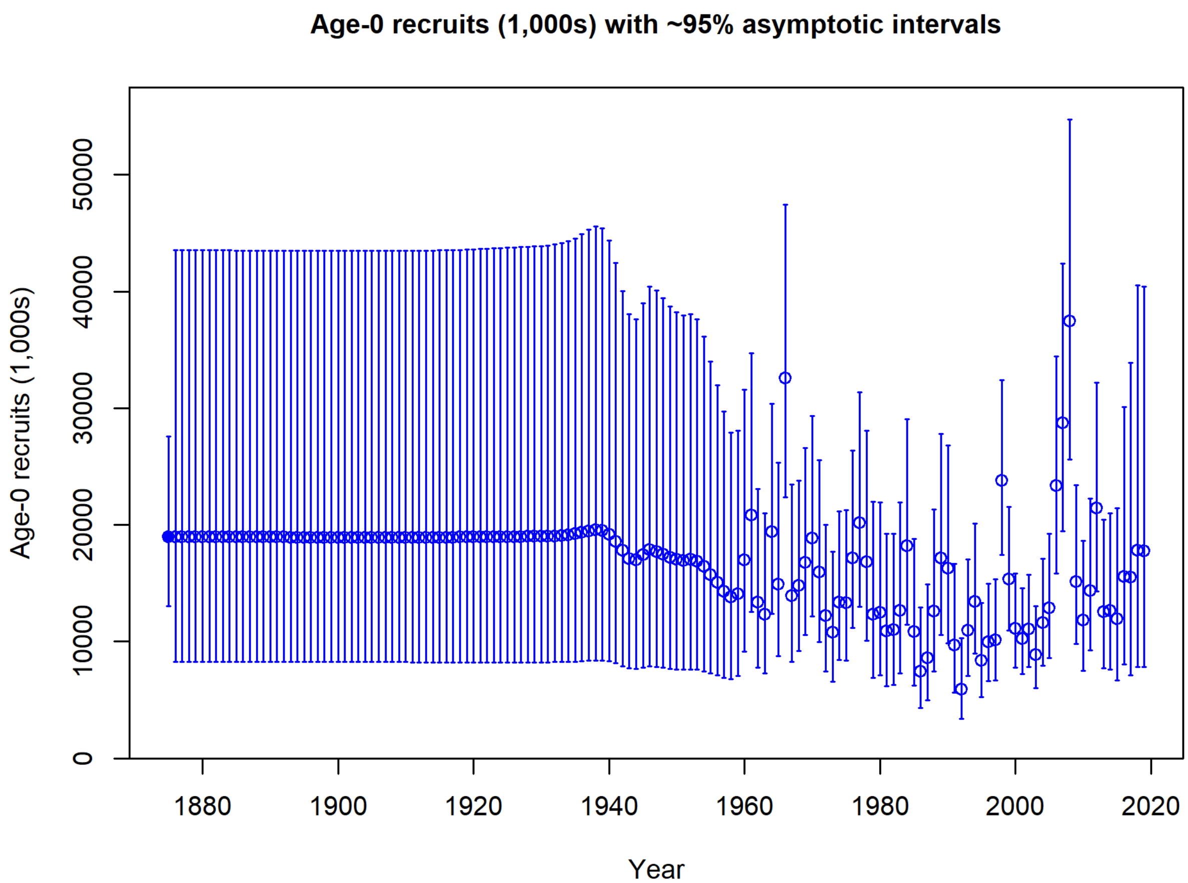

Figure 51: Estimated time-series of recruitment for petrale sole. fig:recruits

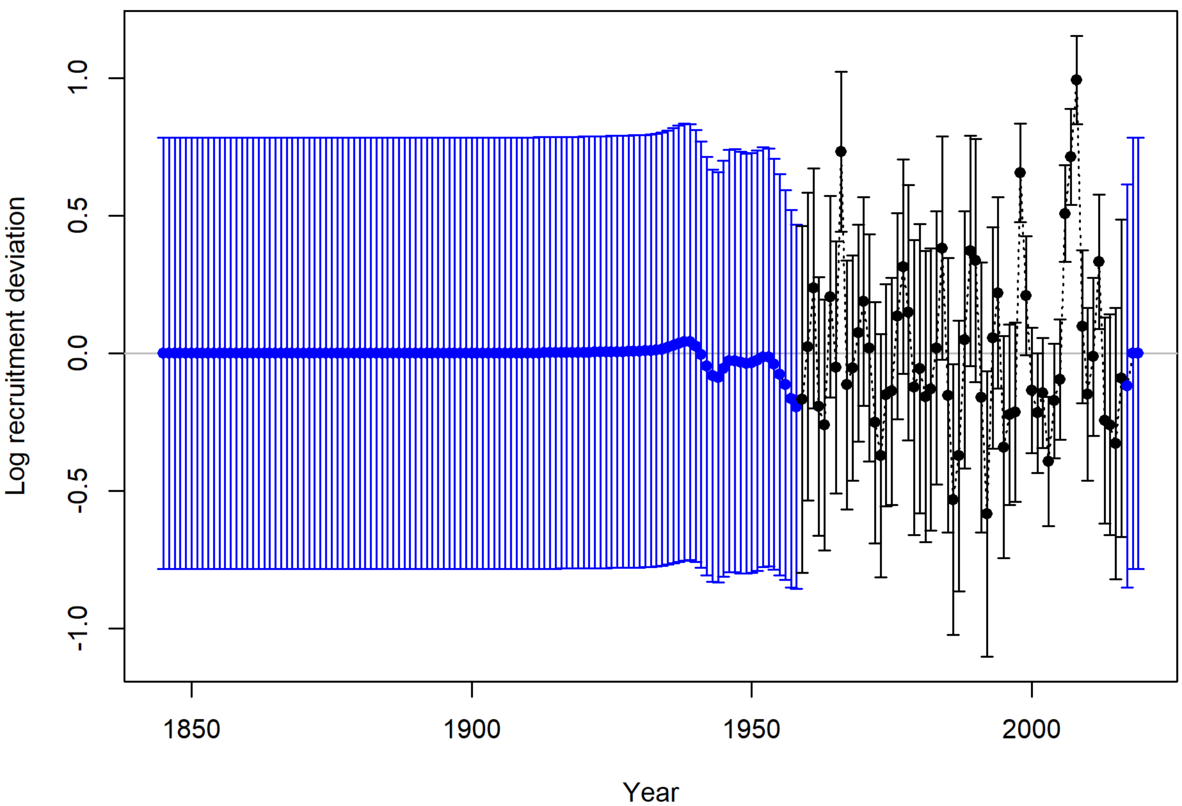

Figure 52: Estimated time-series of recruitment deviations for petrale sole. fig:recdevs

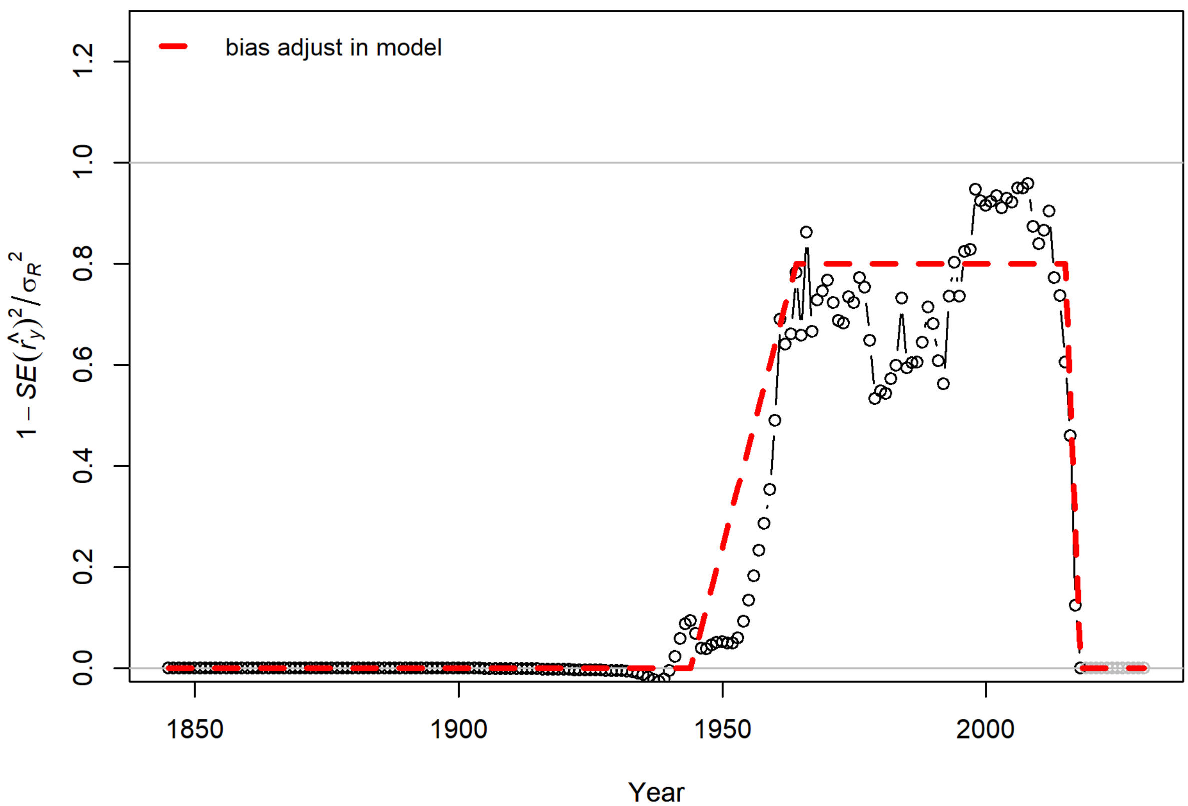

Figure 53: Recruitment bias adjustment in the model. fig:bias_adjust

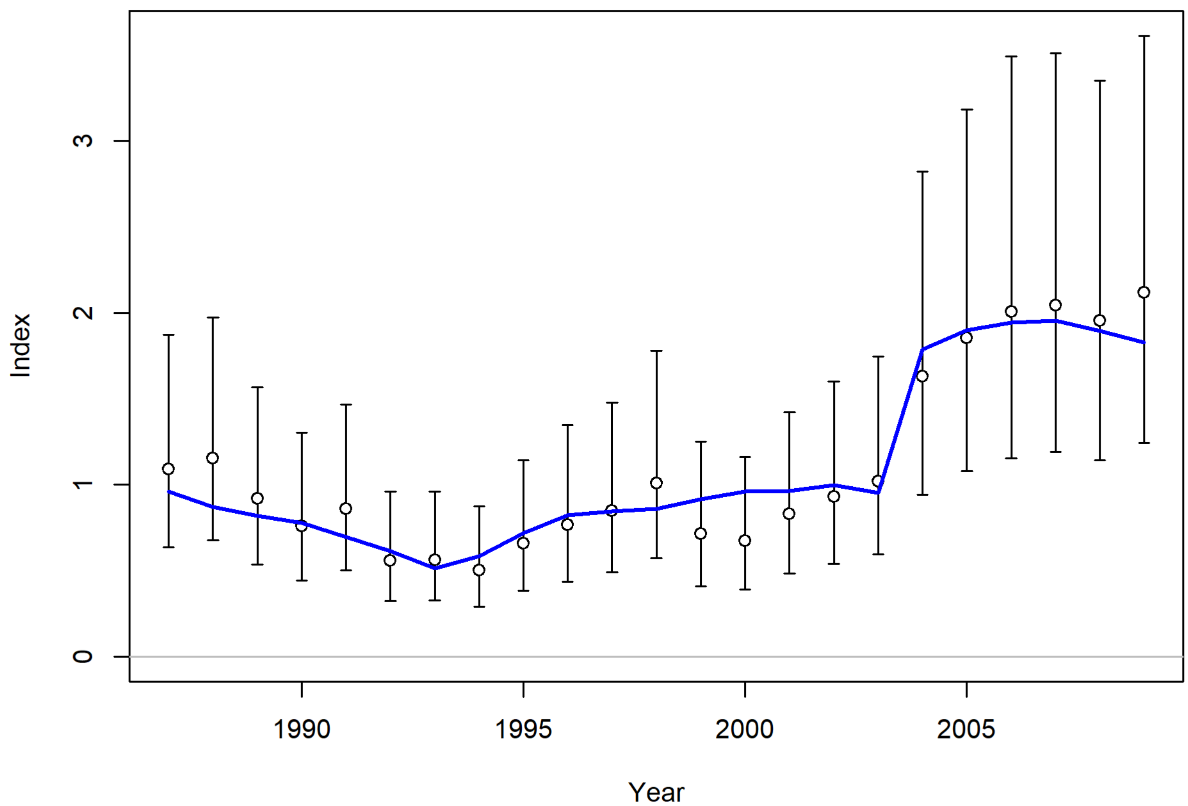

Figure 54: Fit to the Winter North catch-per-unit-effort time series for petrale sole. fig:fit_wn_cpue

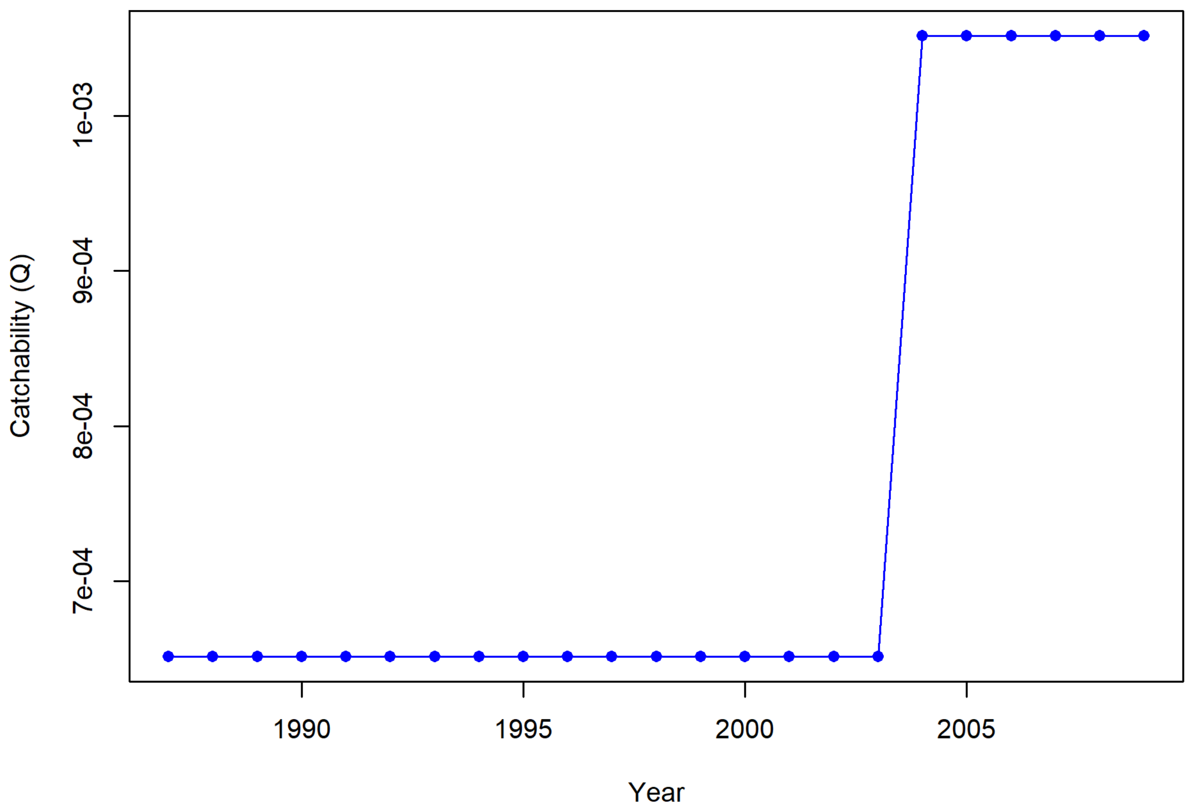

Figure 55: Catchability to the Winter North catch-per-unit-effort time series. fig:q_north

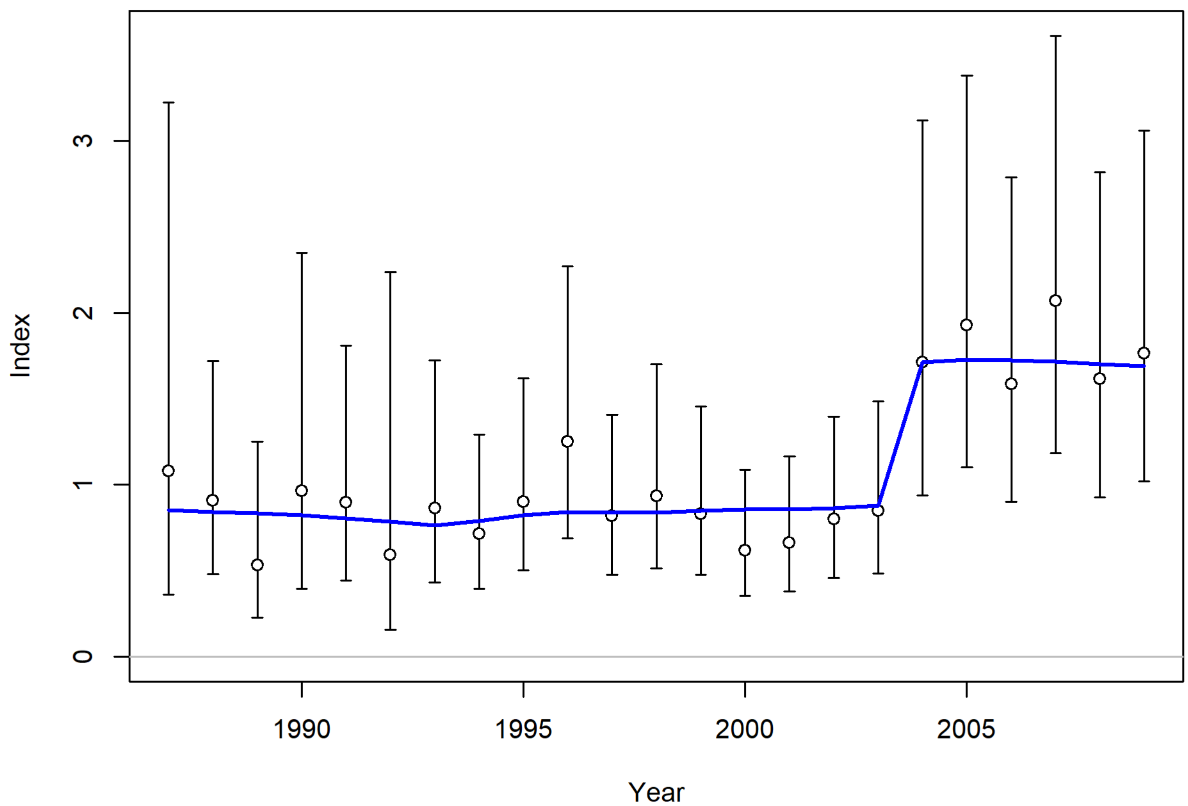

Figure 56: Fit to the Winter South catch-per-unit-effort time series for petrale sole. fig:fit_ws_cpue

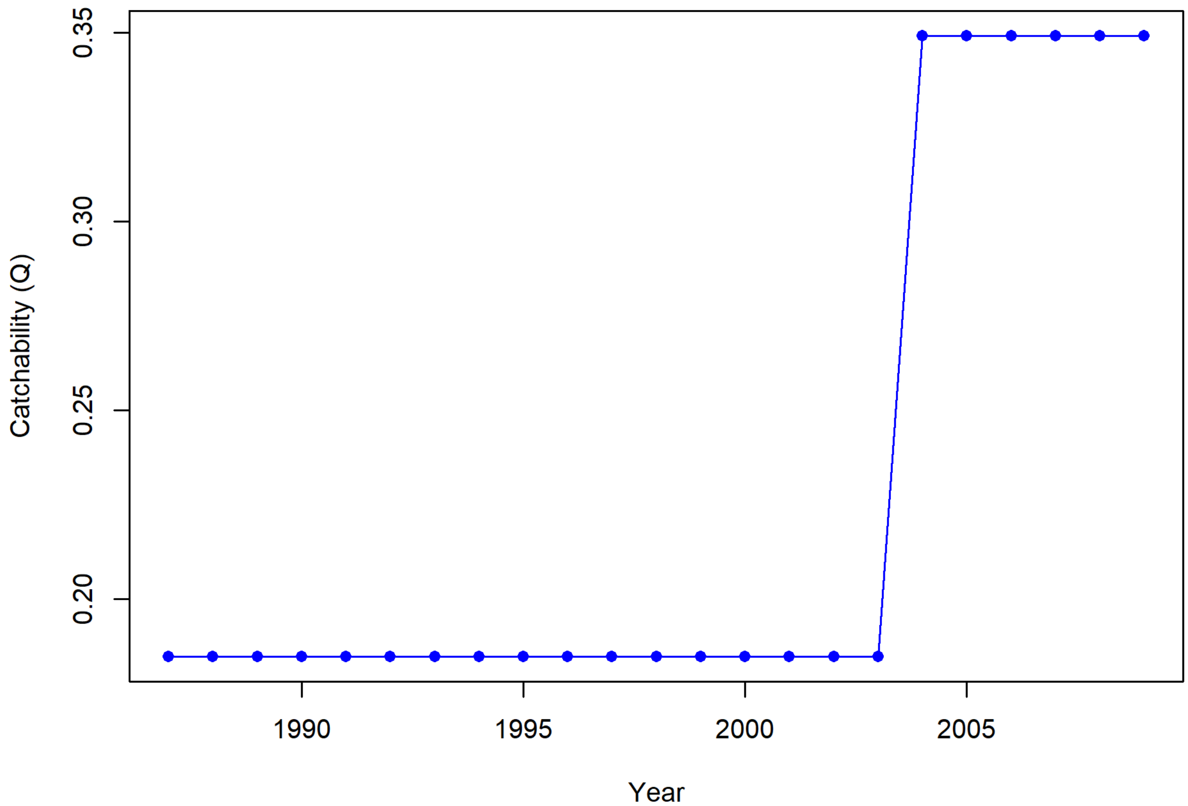

Figure 57: Catchability to the Winter South catch-per-unit-effort time series. fig:q_south

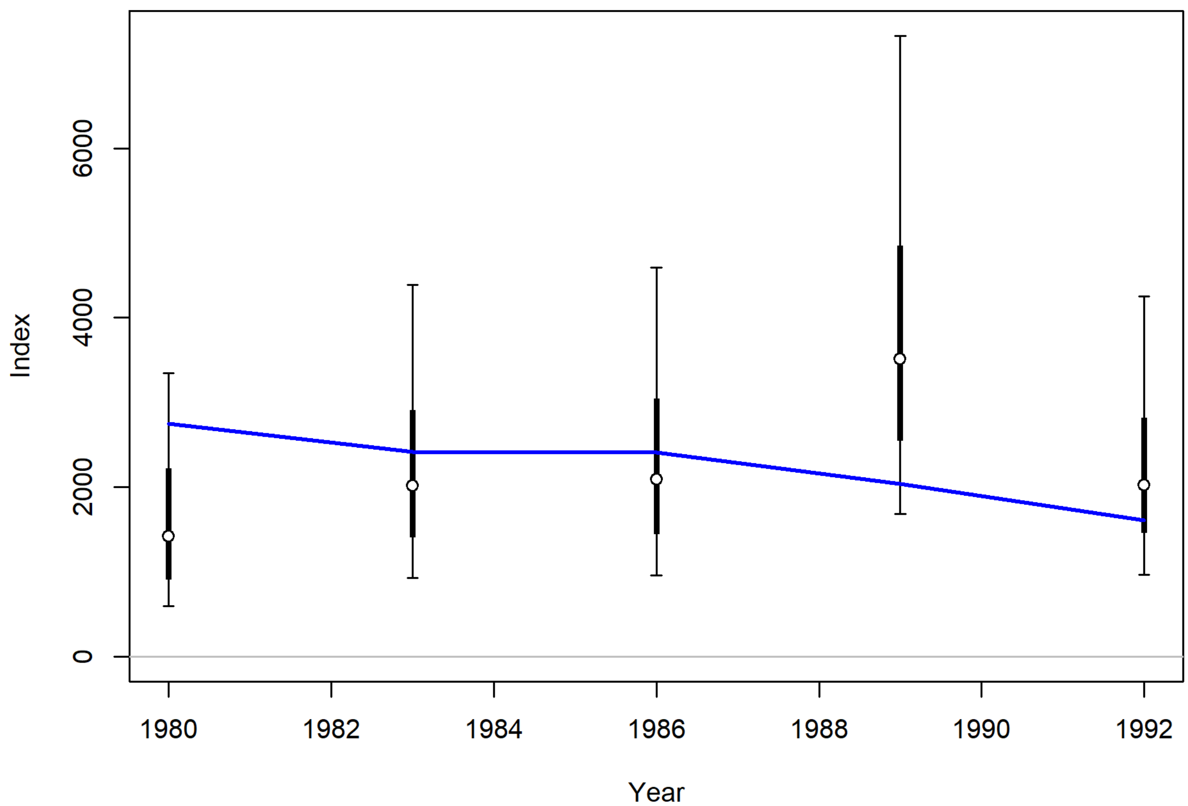

Figure 58: Fit to the Triennial Survey Early time series for petrale sole. fig:fit_tri_early

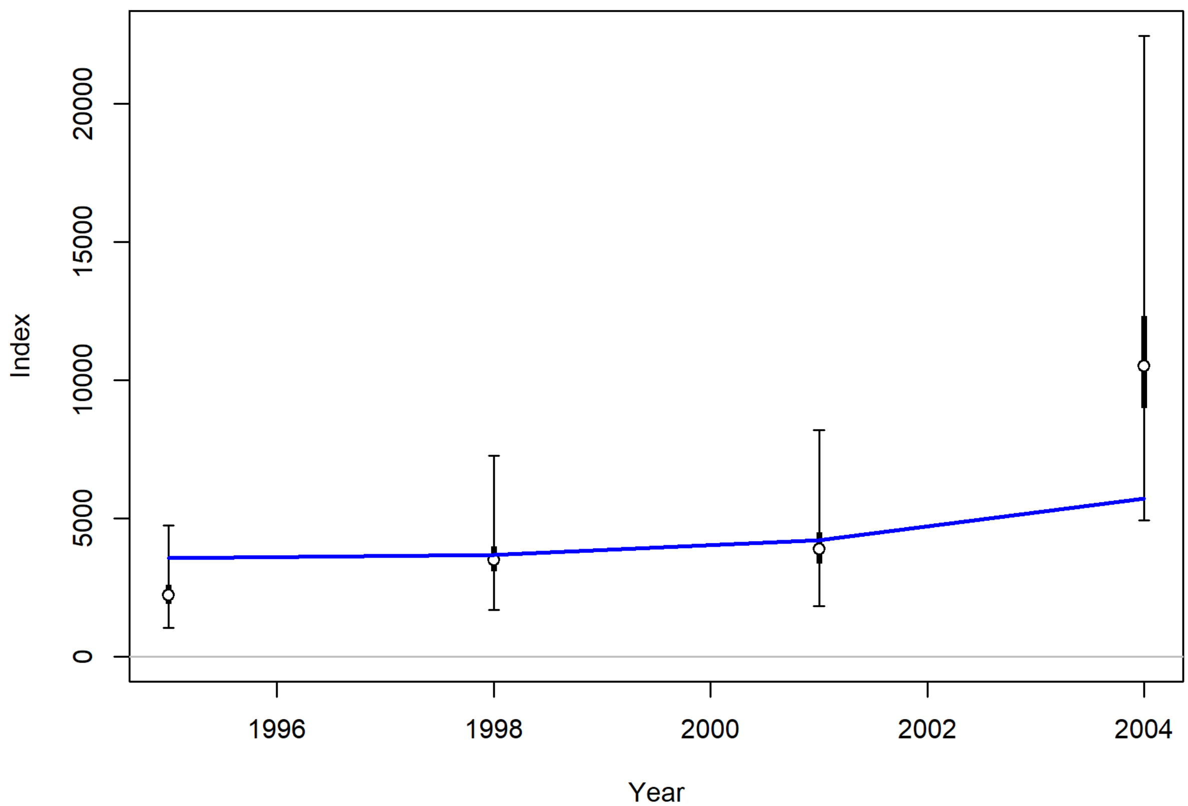

Figure 59: Fit to the Triennial Survey Late time series for petrale sole. fig:fit_tri_late

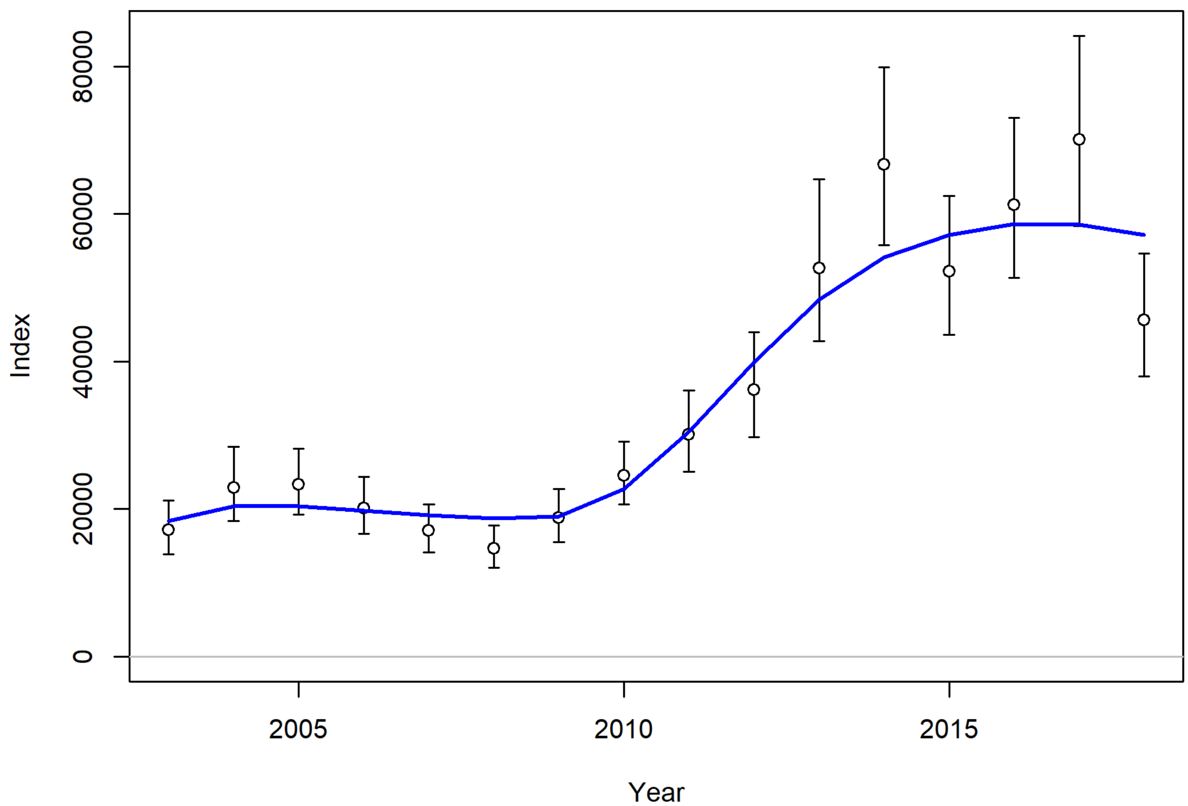

Figure 60: Fit to the NWFSC West Coast Groundfish Bottom Trawl Survey time series for petrale sole. fig:fit_nwfsc_survey

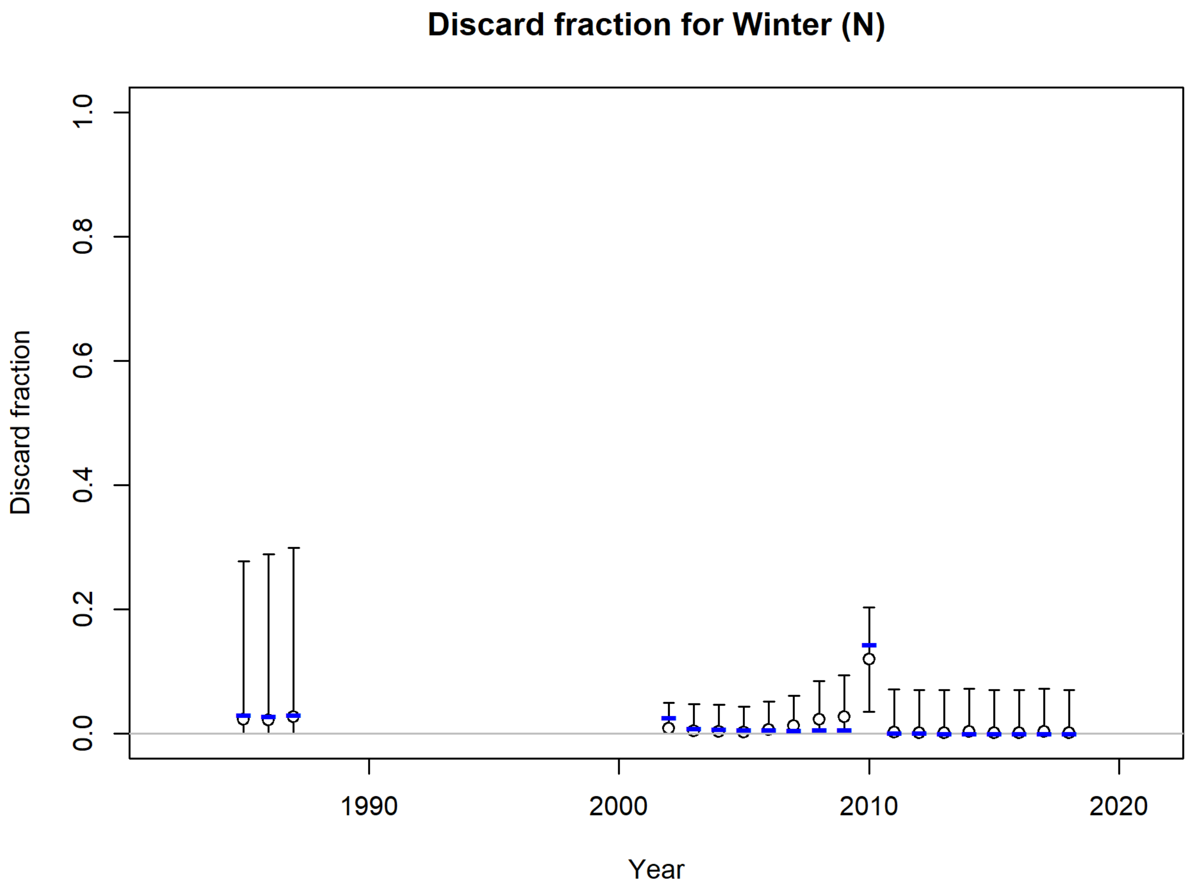

Figure 61: Fit to the discard rates for the Winter North fleet for petrale sole. fig:fit_wn_discard

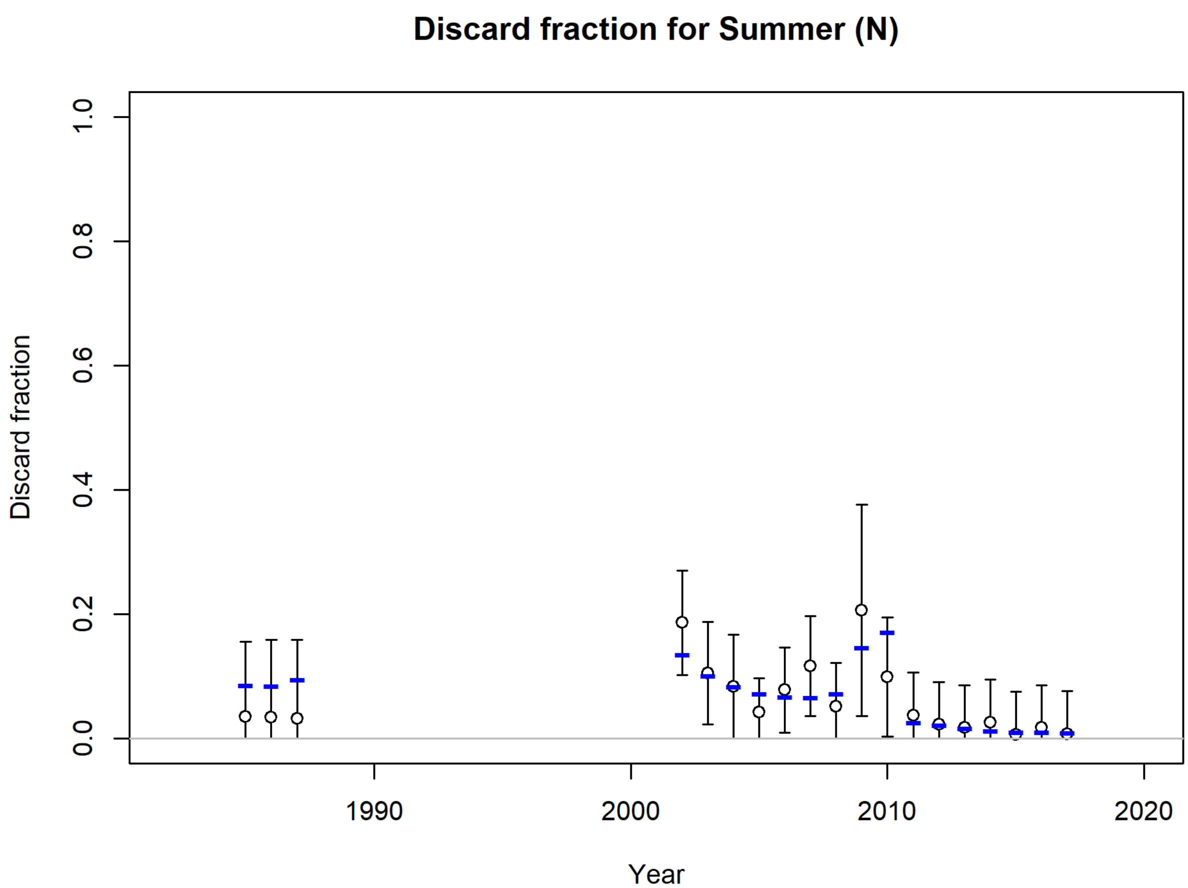

Figure 62: Fit to the discard rates for the Summer North fleet for petrale sole. fig:fit_sn_discard

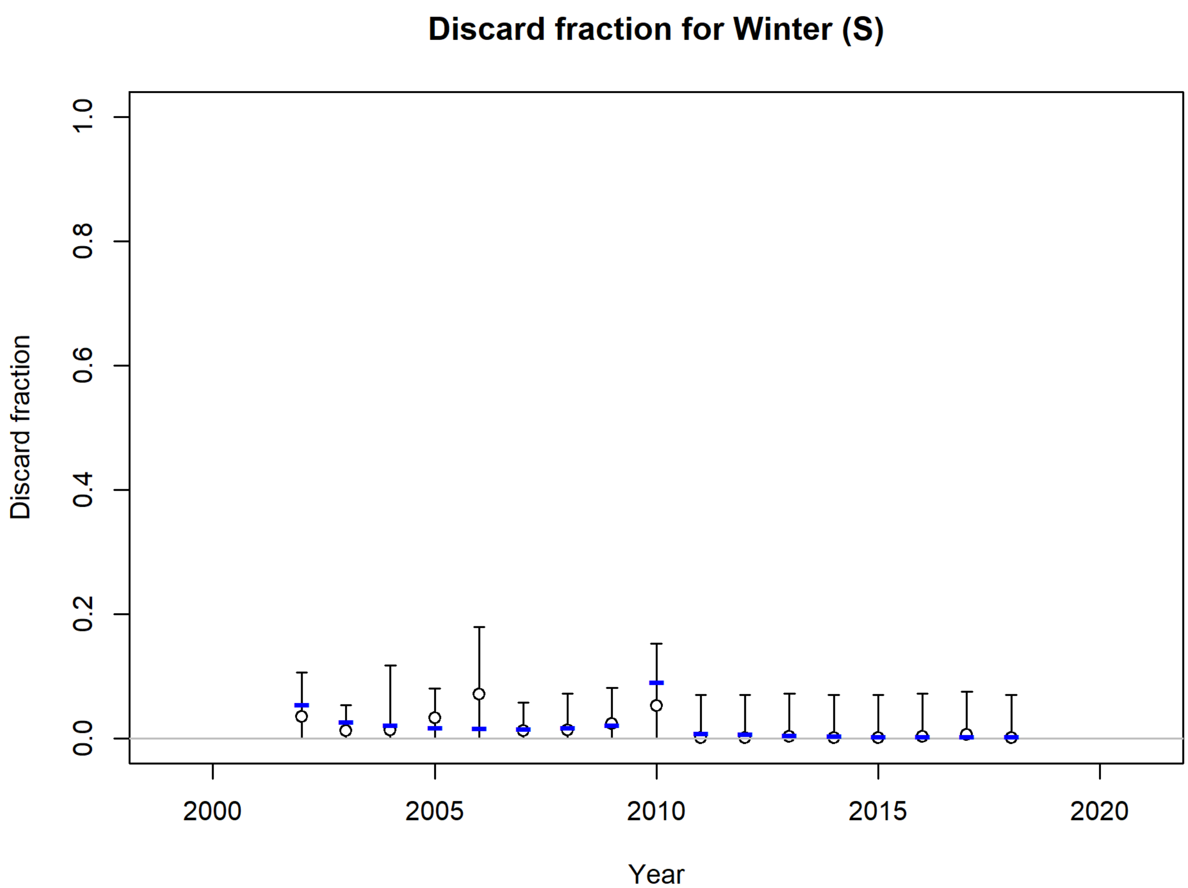

Figure 63: Fit to the discard rates for the Winter South fleet for petrale sole. fig:fit_ws_discard

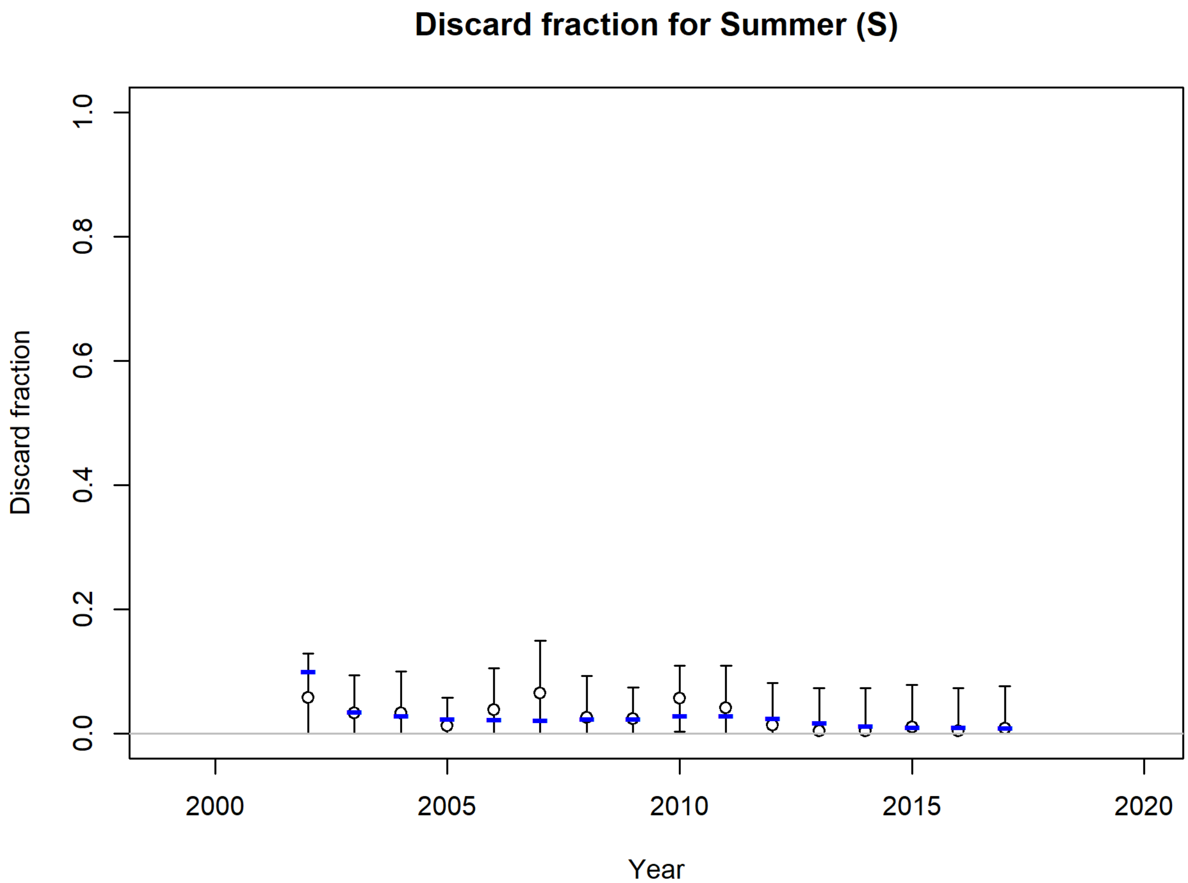

Figure 64: Fit to the discard rates for the Summer South fleet for petrale sole. fig:fit_ss_discard

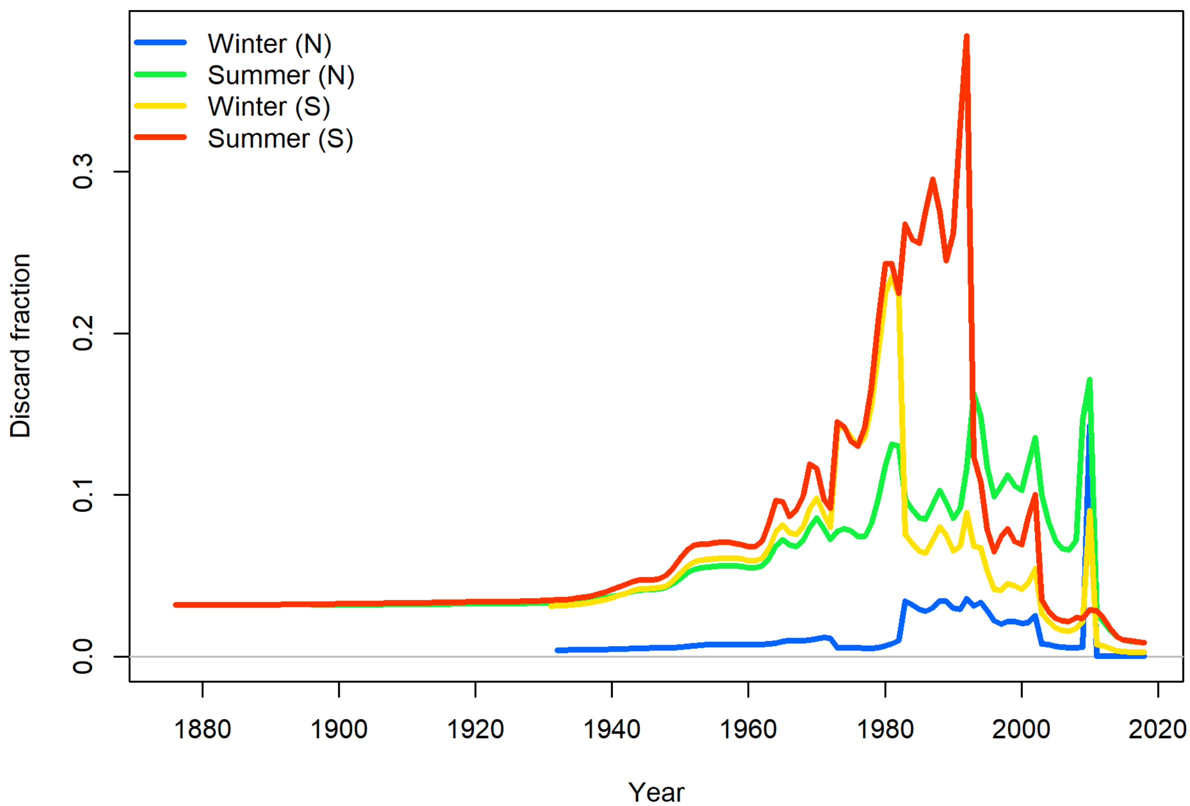

Figure 65: Discard rates by fleet for petrale sole. fig:Discard

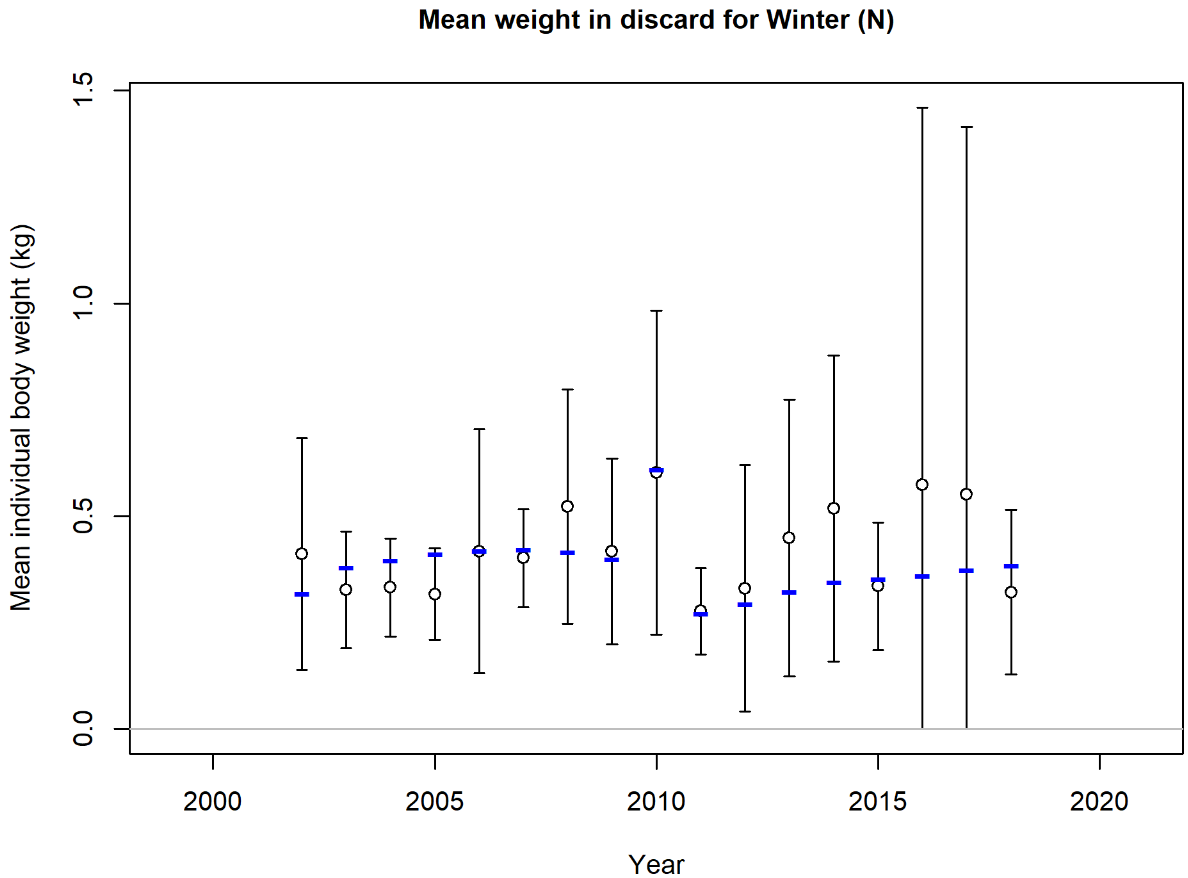

Figure 66: Fit to the Northern winter fishery mean body weights of discarded fish for petrale sole. fig:nw_bodywt_fit

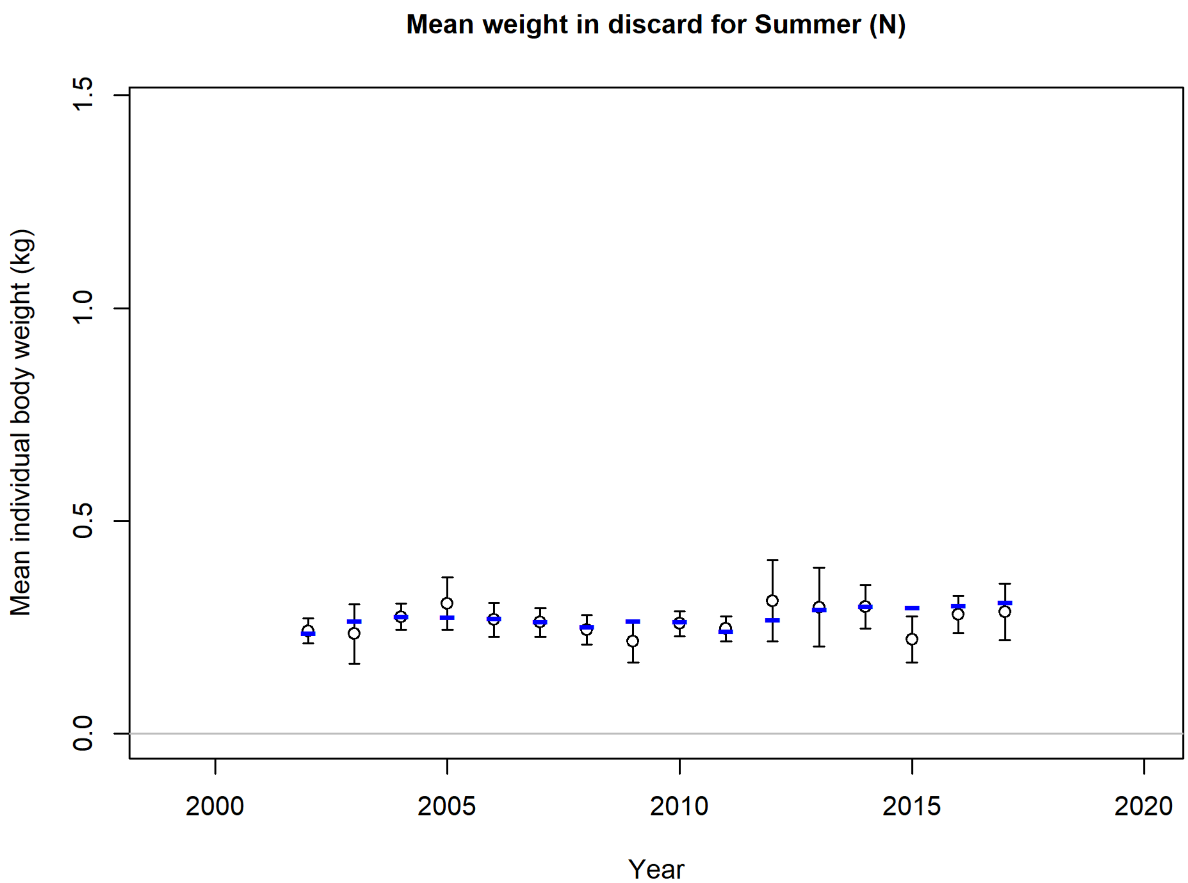

Figure 67: Fit to the Northern summer fishery mean body weights of discarded fish for petrale sole. fig:ns_bodywt_fit

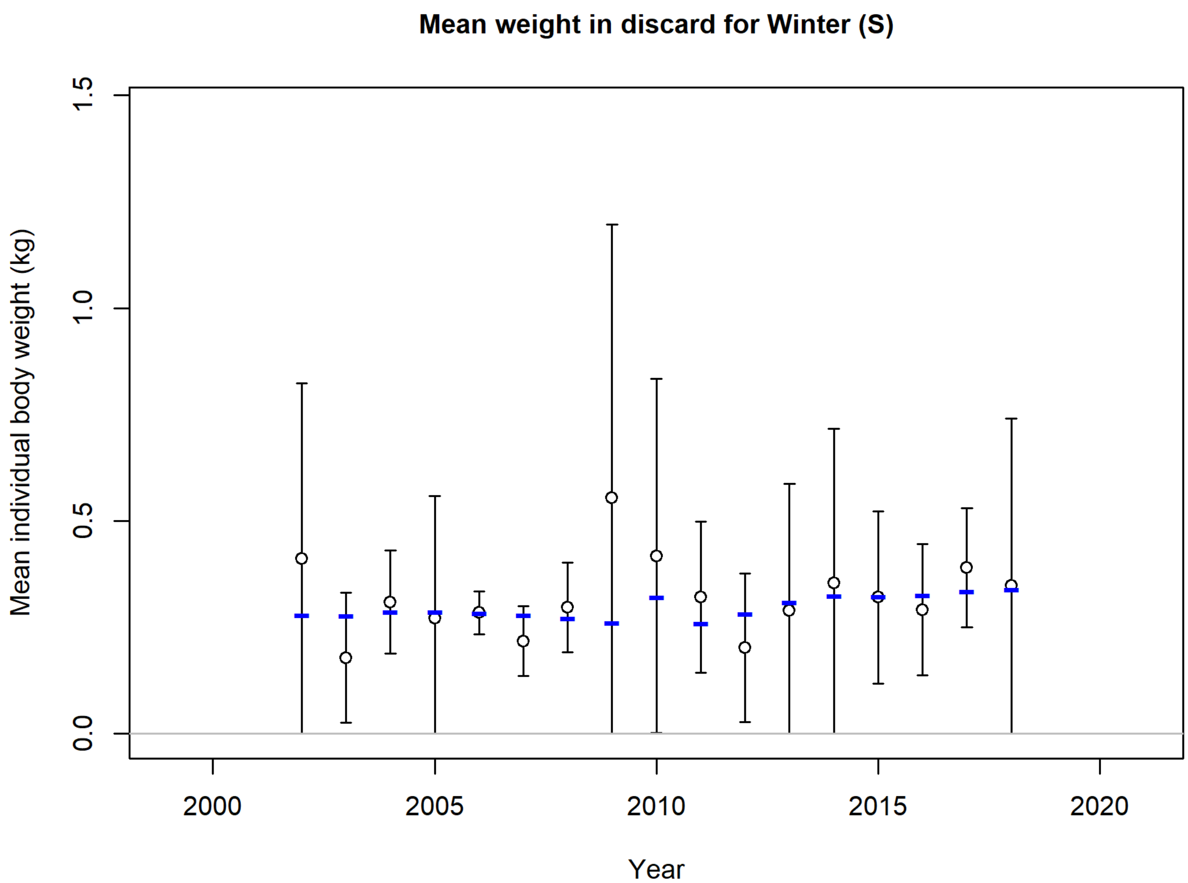

Figure 68: Fit to the Southern winter fishery mean body weights of discarded fish for petrale sole. fig:sw_bodywt_fit

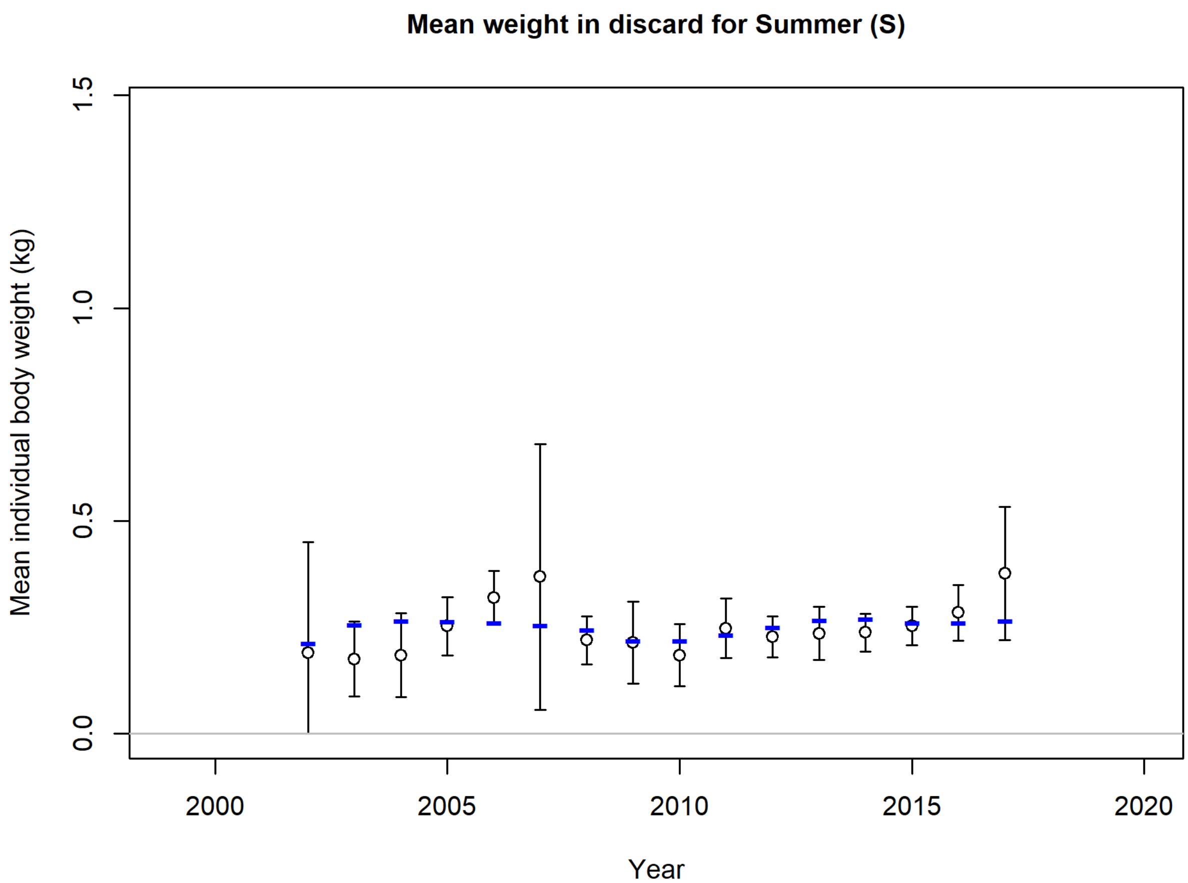

Figure 69: Fit to the Southern summer fishery mean body weights of discarded fish for petrale sole. fig:ss_bodywt_fit

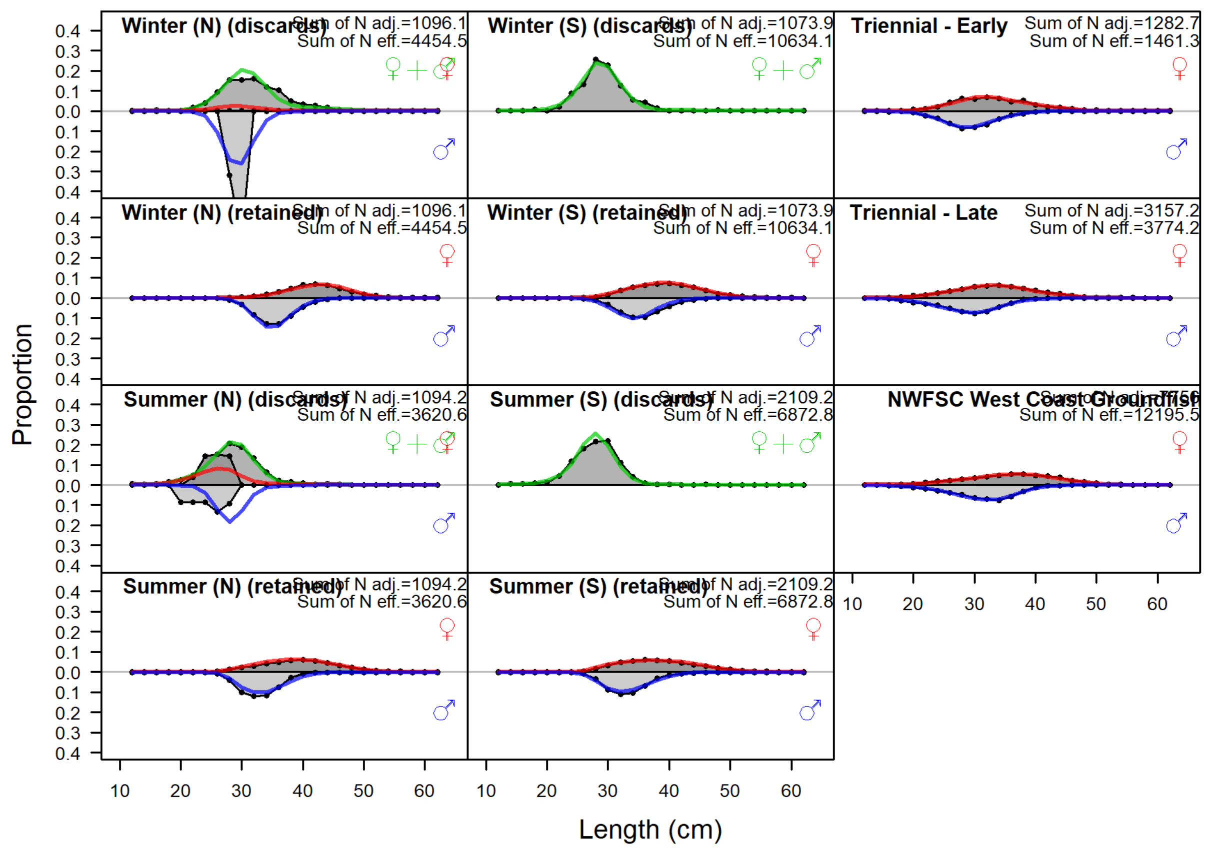

Figure 70: Length compositions aggregated across time by fleet. Labels 'retained' and 'discard' indicate retained or discarded samples for each fleet. Panels without this designation represent the whole catch. fig:length_agg

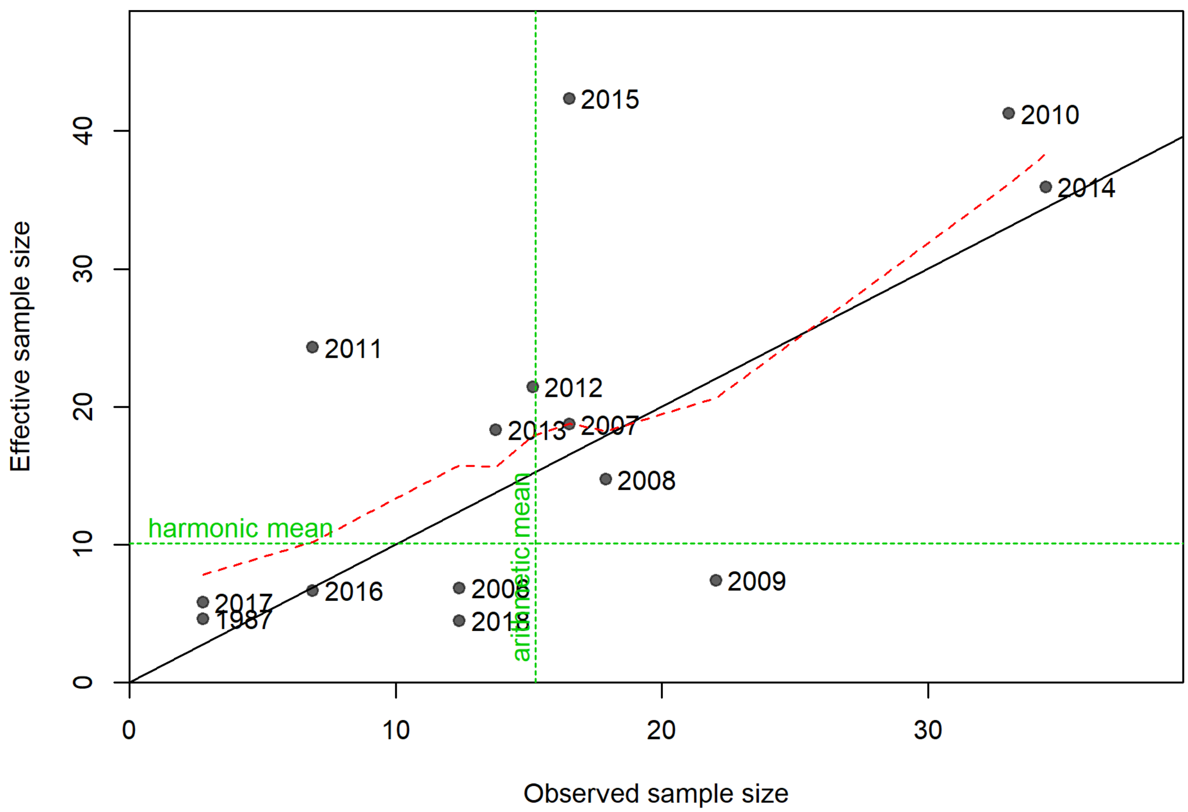

Figure 71: N_EffN comparison, Length comps, discard, Winter (N) fig:discard_wn_len_pears

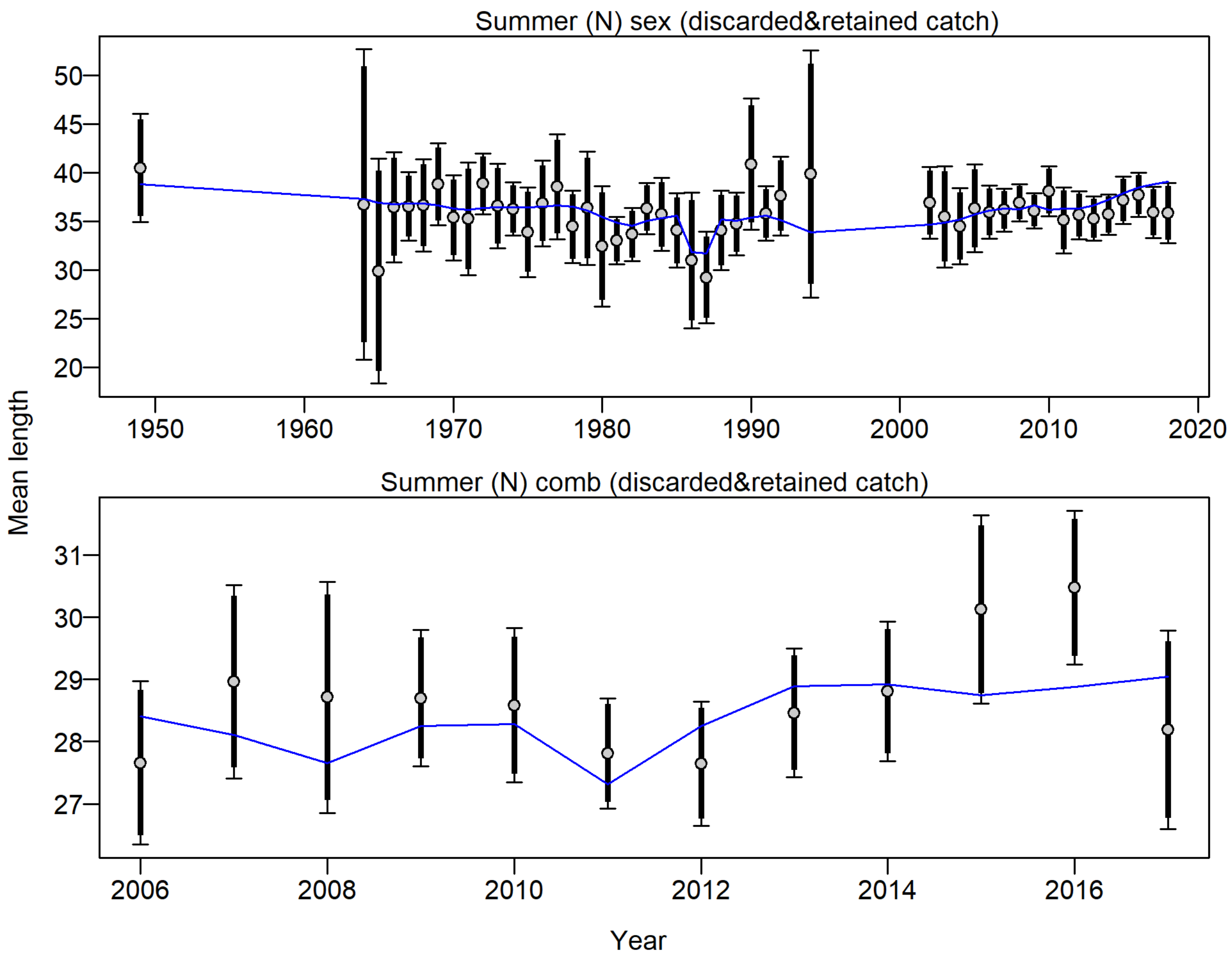

Figure 72: Mean length for Summer (N) with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for len data from Summer (N): 0.7932 (0.5984_1.1773) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. https://doi.org/10.1139/f2011_025 fig:discard_sn_len_pearson

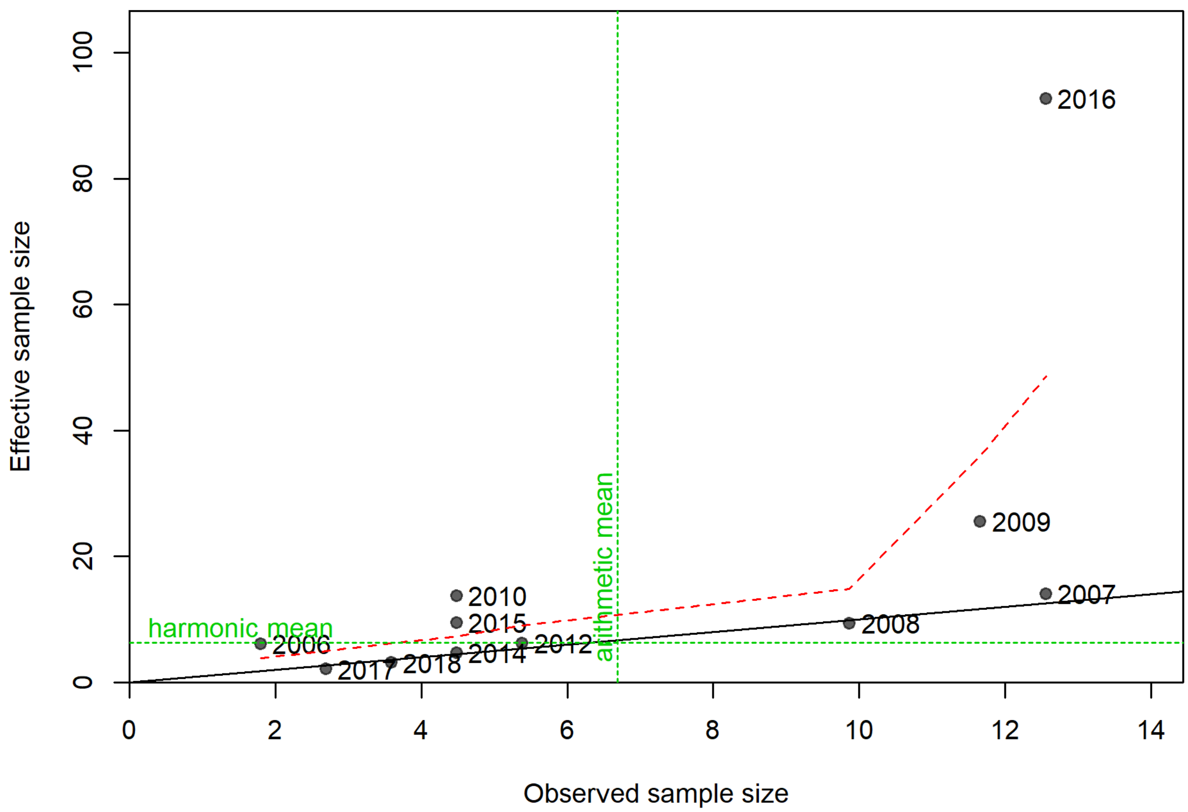

Figure 73: N_EffN comparison, Length comps, discard, Winter (S) fig:discard_ws_len_pears

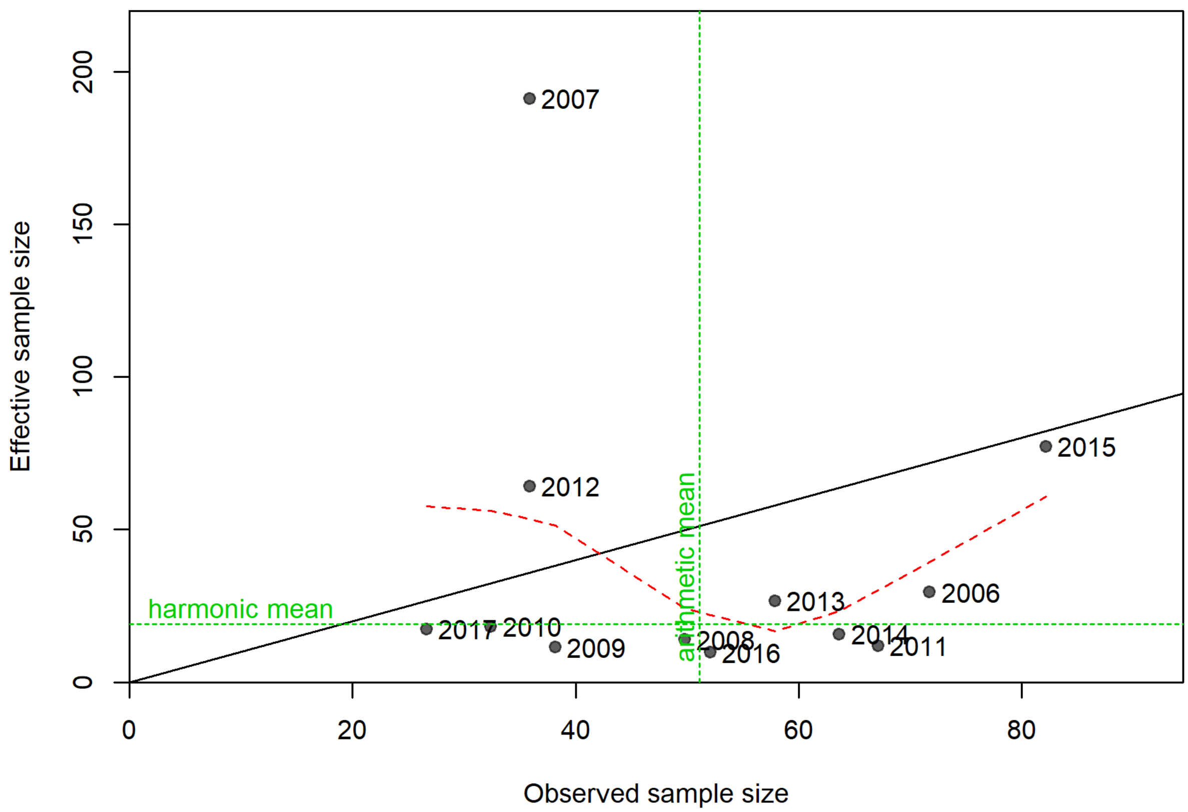

Figure 74: N_EffN comparison, Length comps, discard, Summer (S) fig:discard_ss_len_pear

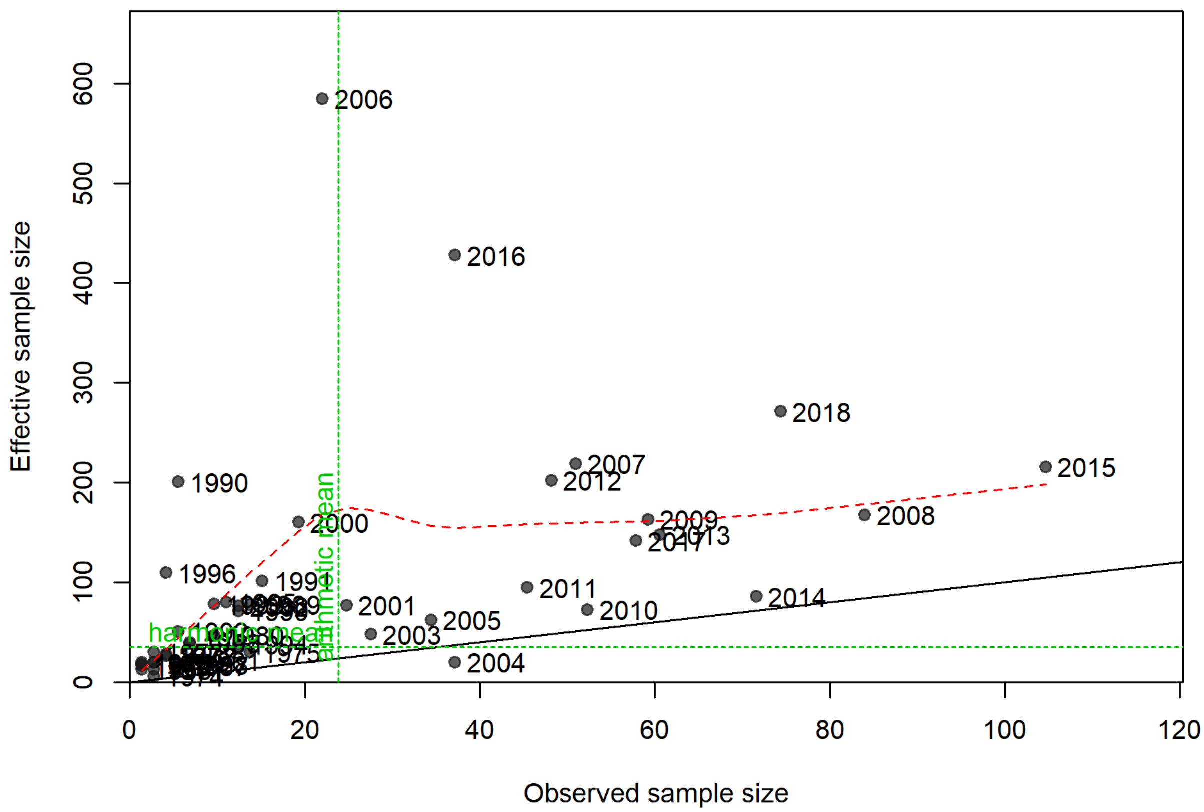

Figure 75: N_EffN comparison, Length comps, retained, Winter (N) fig:wn_len_pearson

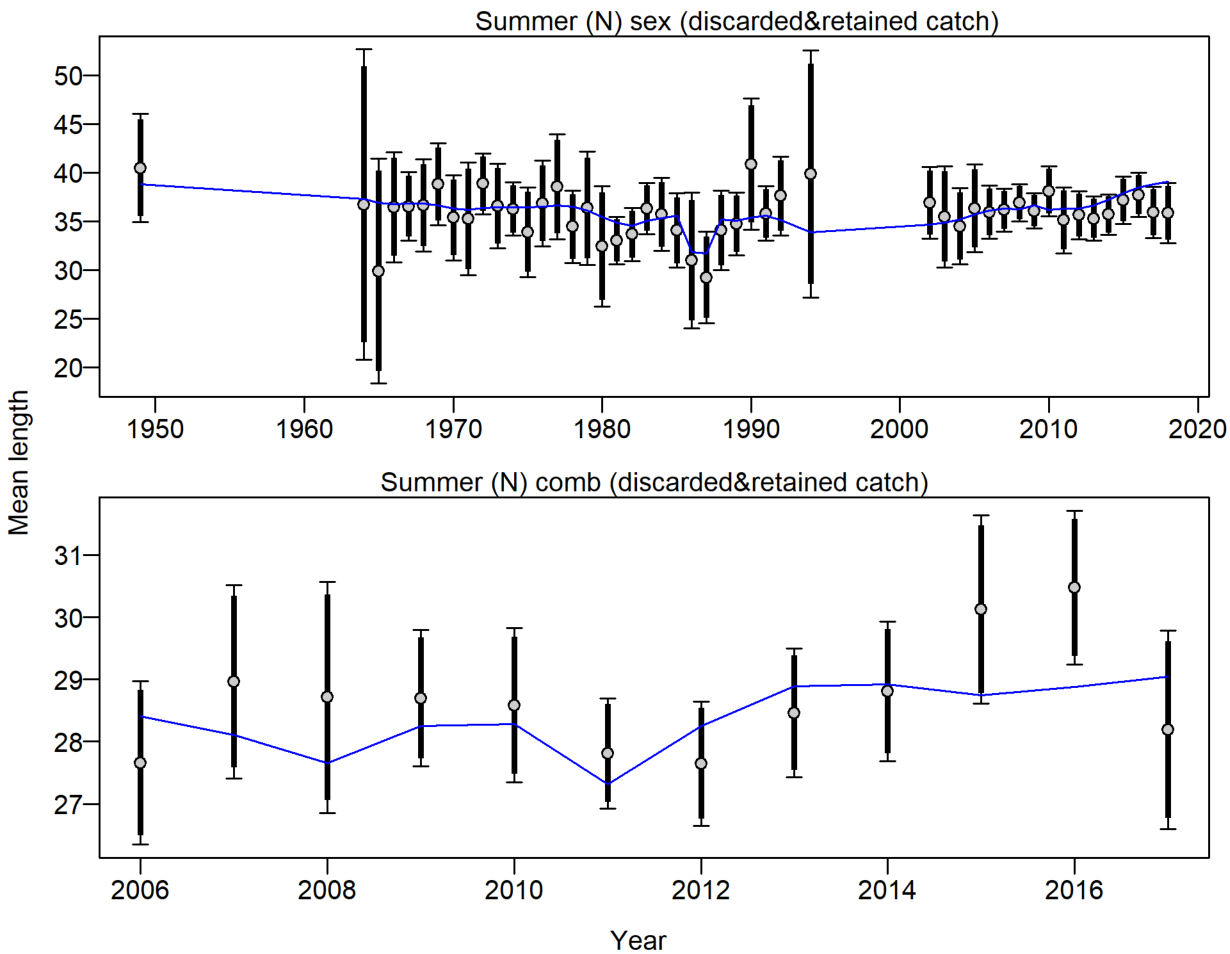

Figure 76: Mean length for Summer (N) with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for len data from Summer (N): 0.7932 (0.5979_1.1834) For more info, see Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124_1138. https://doi.org/10.1139/f2011_025 fig:sn_len_pearson

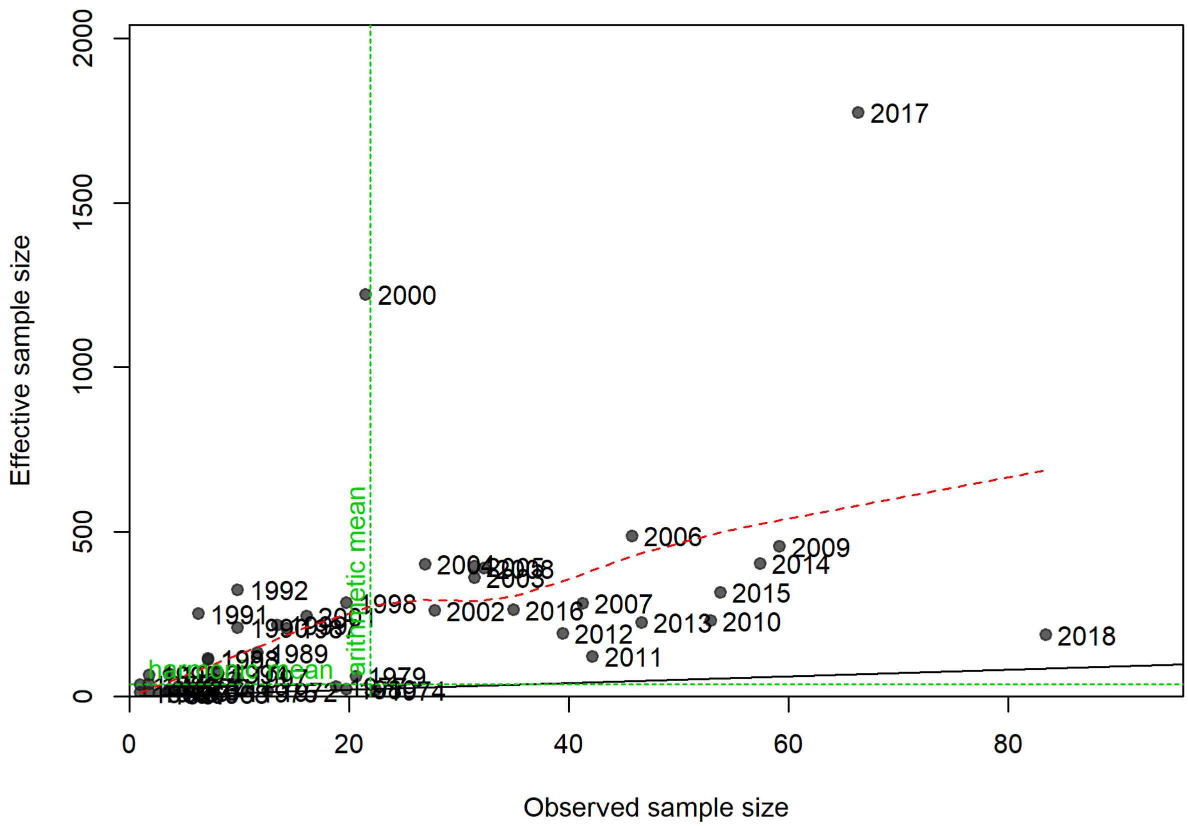

Figure 77: N_EffN comparison, Length comps, retained, Winter (S) fig:ws_len_pearson

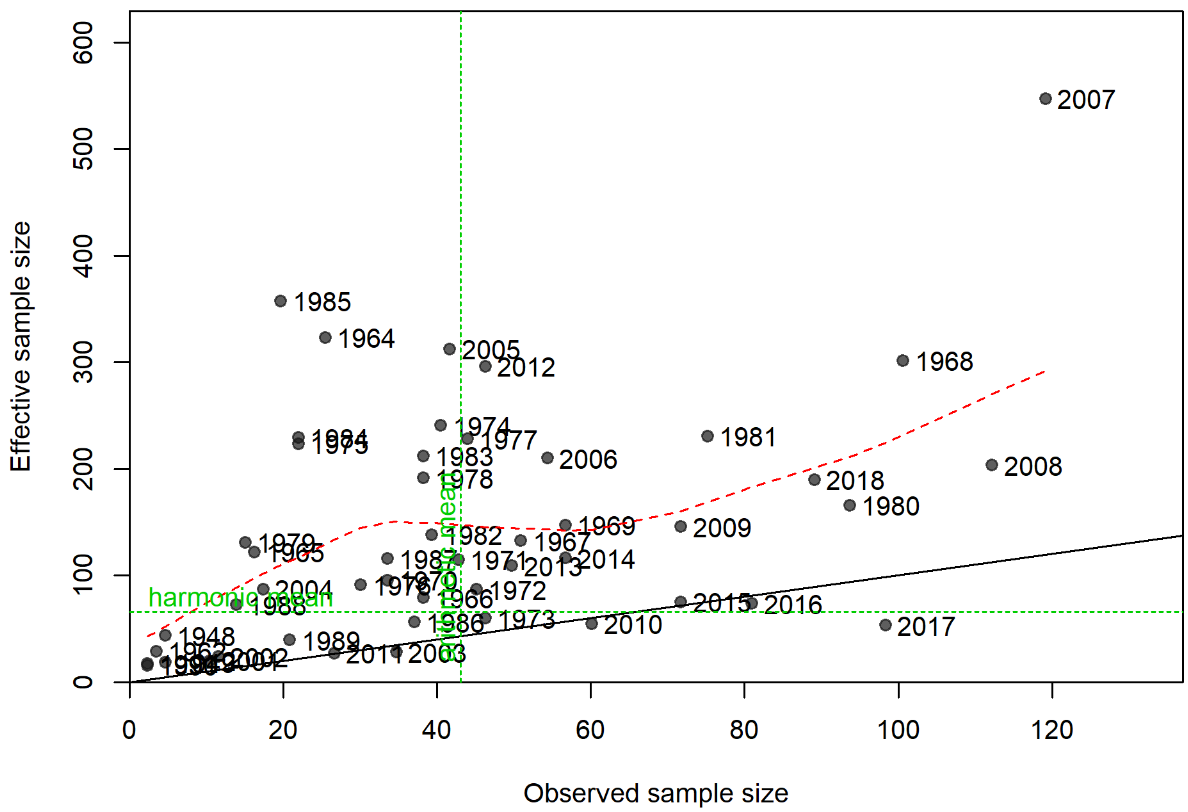

Figure 78: N_EffN comparison, Length comps, retained, Summer (S) fig:ss_len_pearson

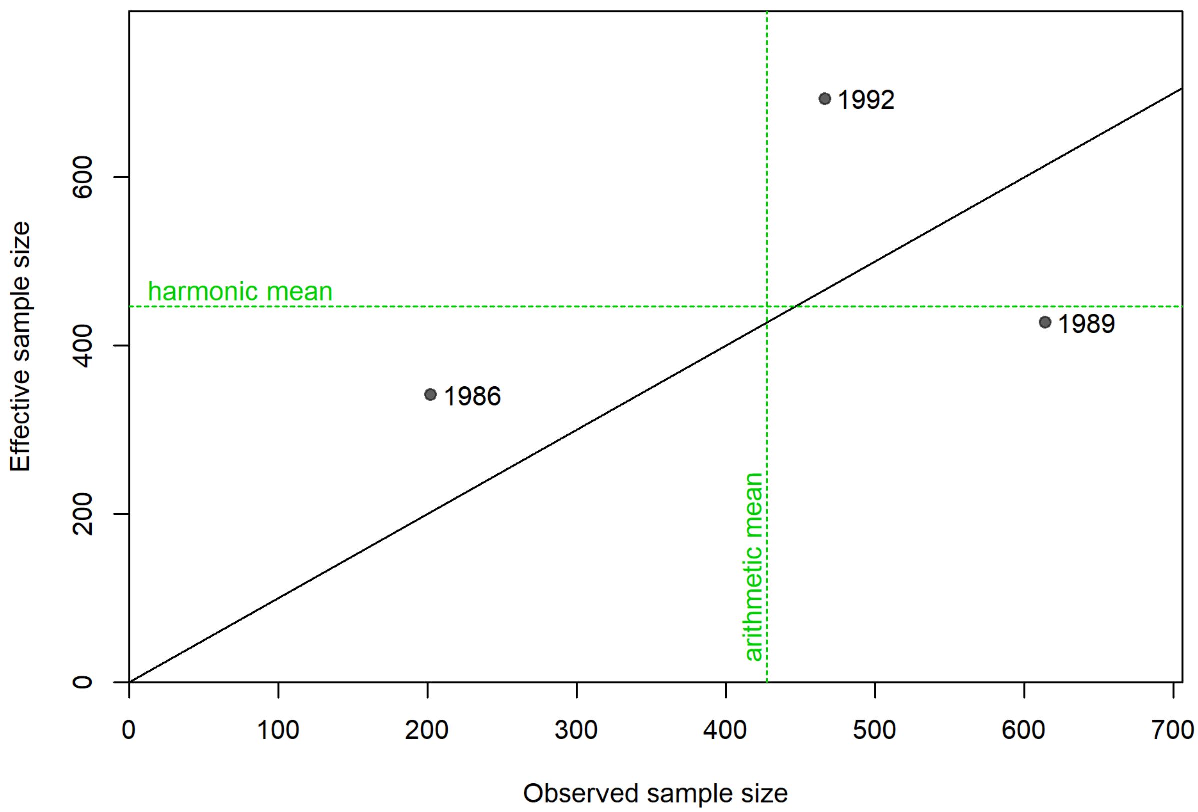

Figure 79: N_EffN comparison, Length comps, whole catch, Triennial _ Early [fig:tri_early_len_p

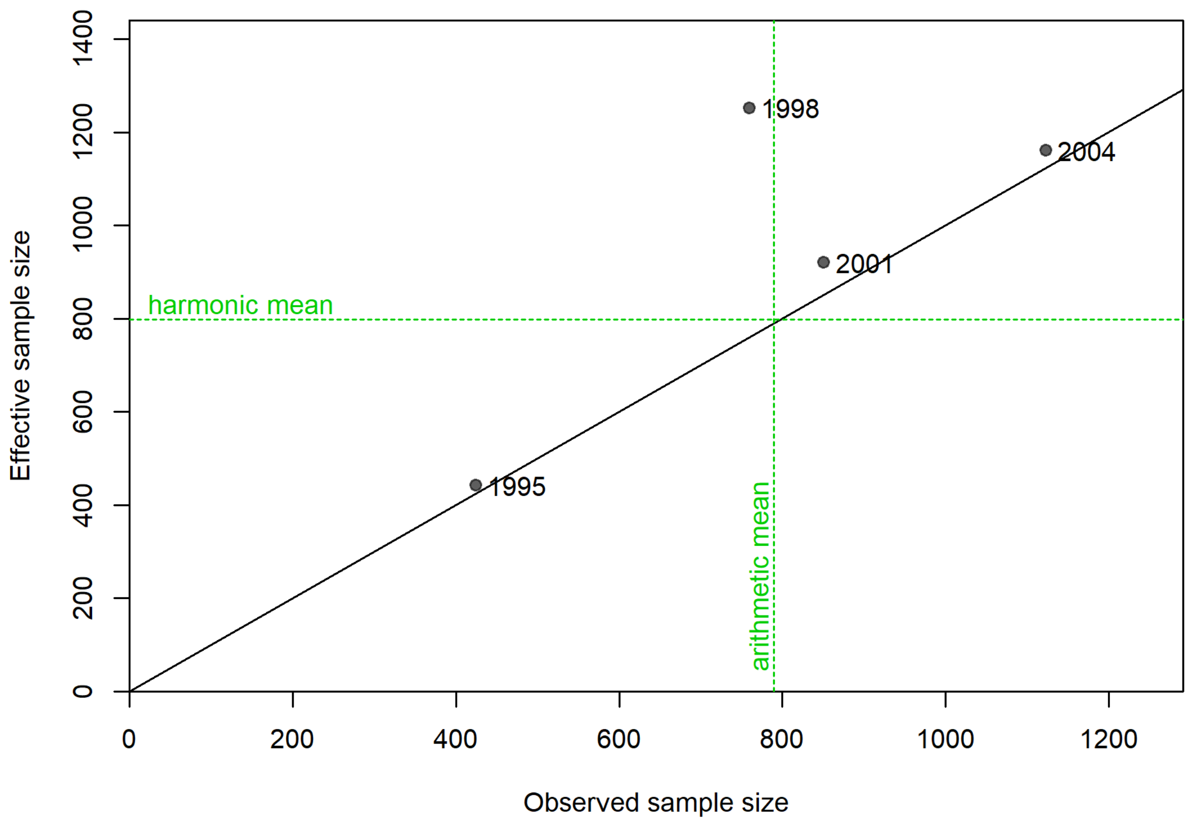

Figure 80: N_EffN comparison, Length comps, whole catch, Triennial _ Late fig:tri_late_len_pe

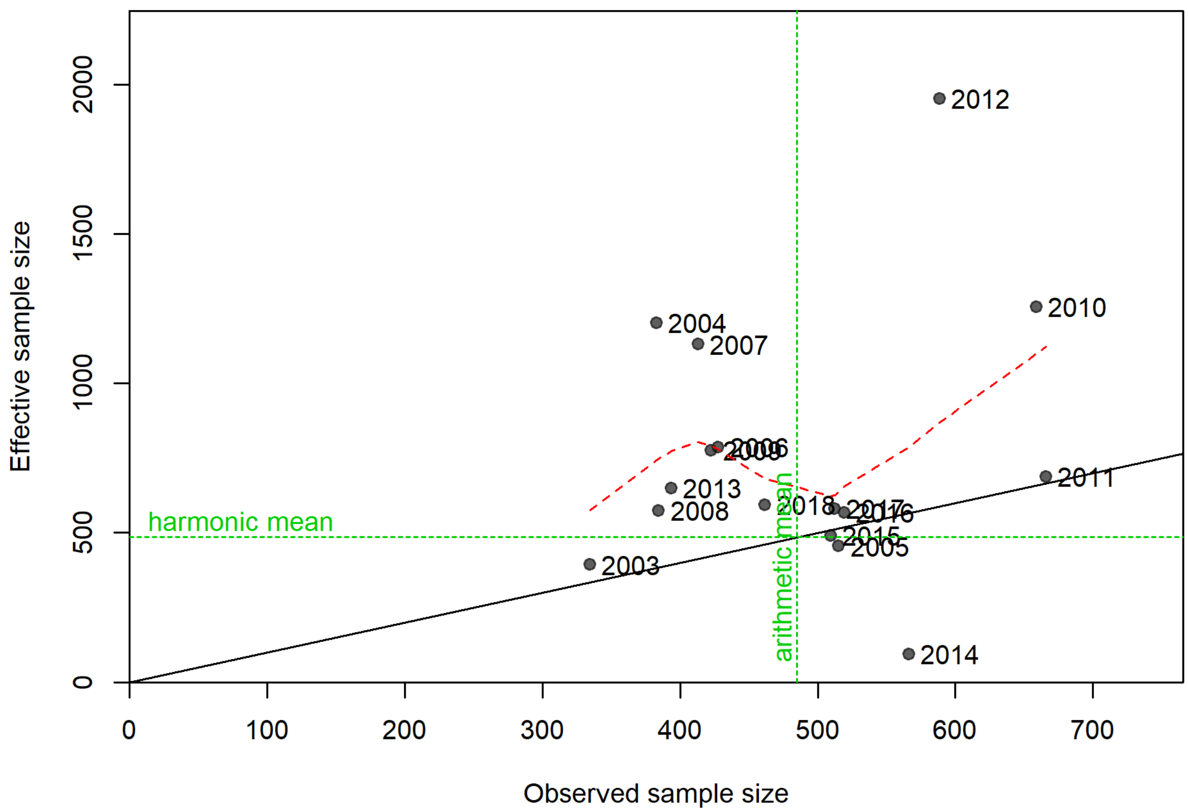

Figure 81: N_EffN comparison, Length comps, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey fig:nwfsc_combo_len_pearson

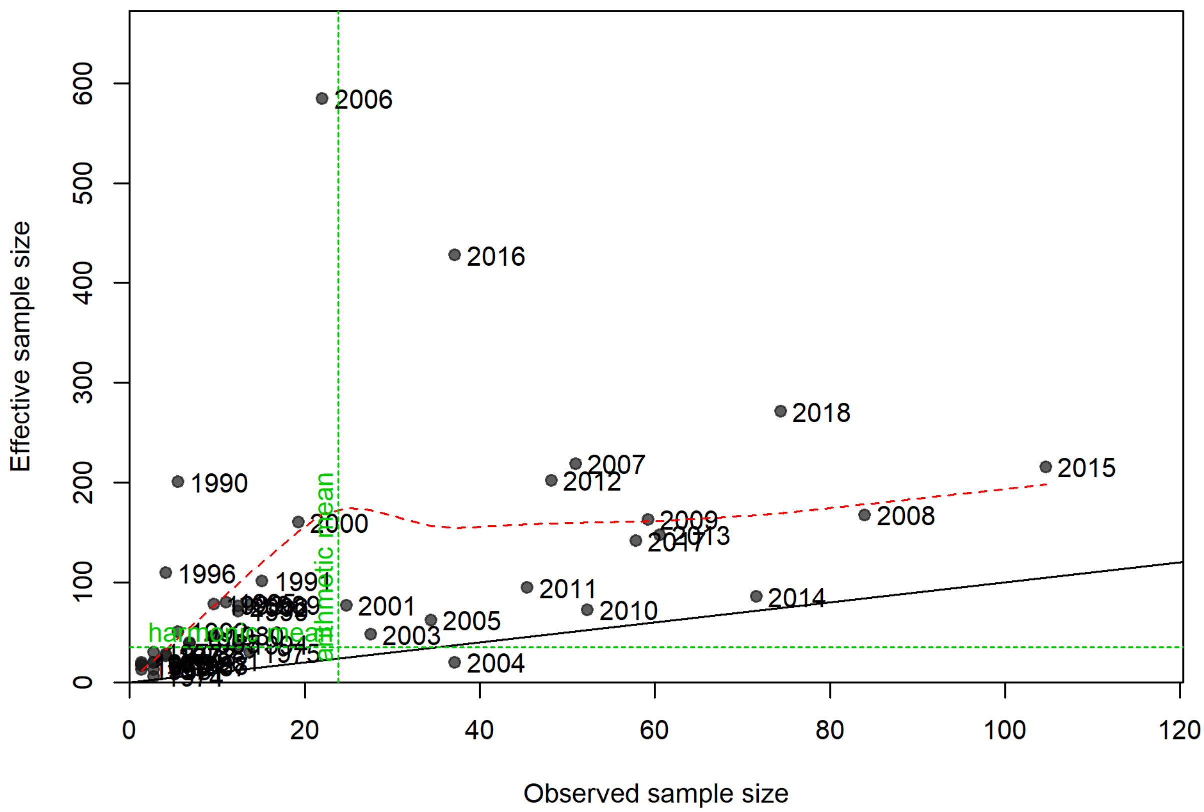

Figure 82: McAllister and Ianelli (harmonic mean) weighting for the Winter North fishery length data. fig:harm_mean_wn

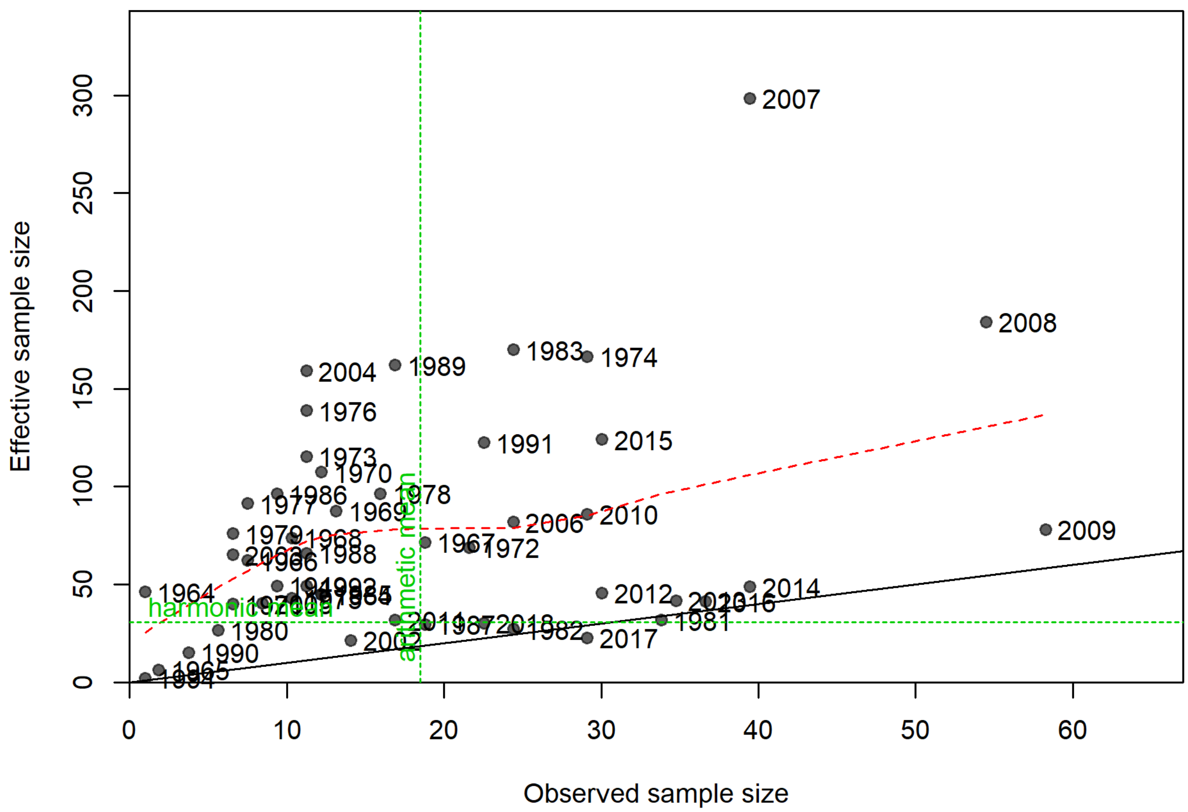

Figure 83: McAllister and Ianelli (harmonic mean) weighting for the Summer North fishery length data. fig:harm_mean_sn

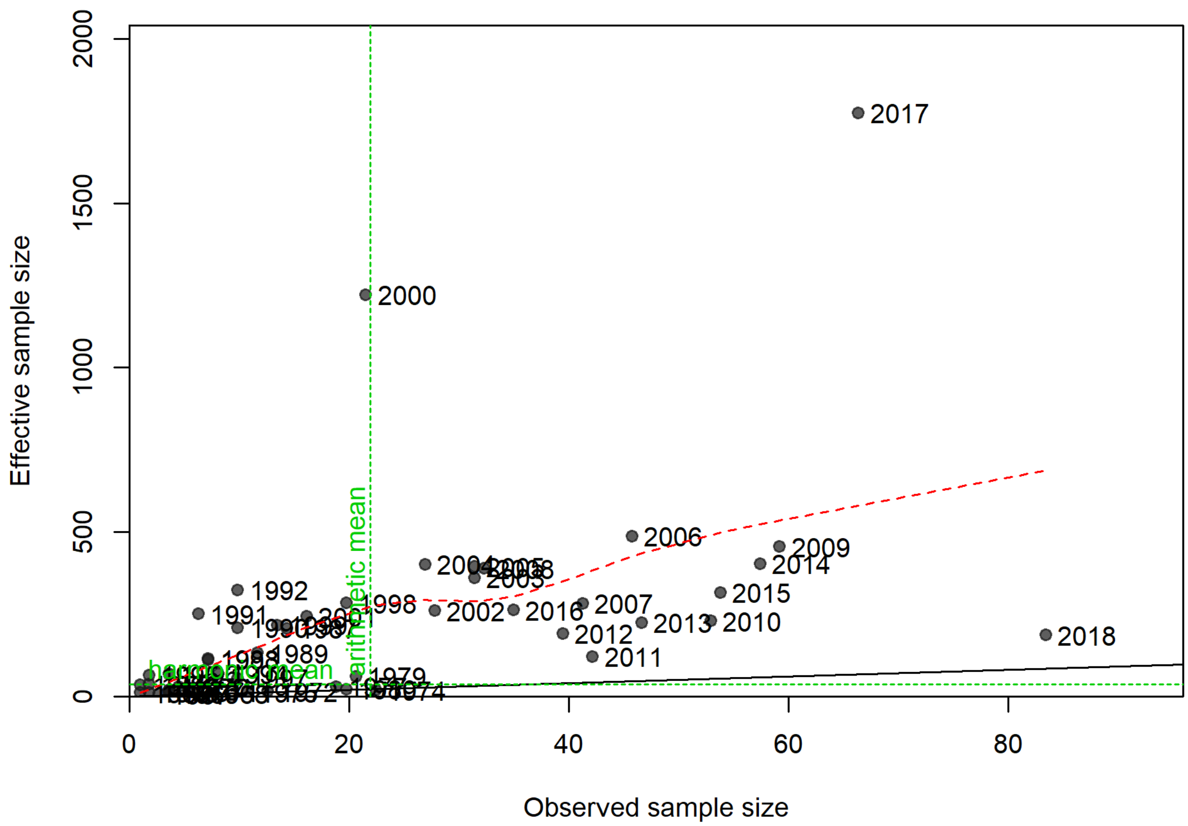

Figure 84: McAllister and Ianelli (harmonic mean) weighting for the Winter South fishery length data. fig:harm_mean_ws

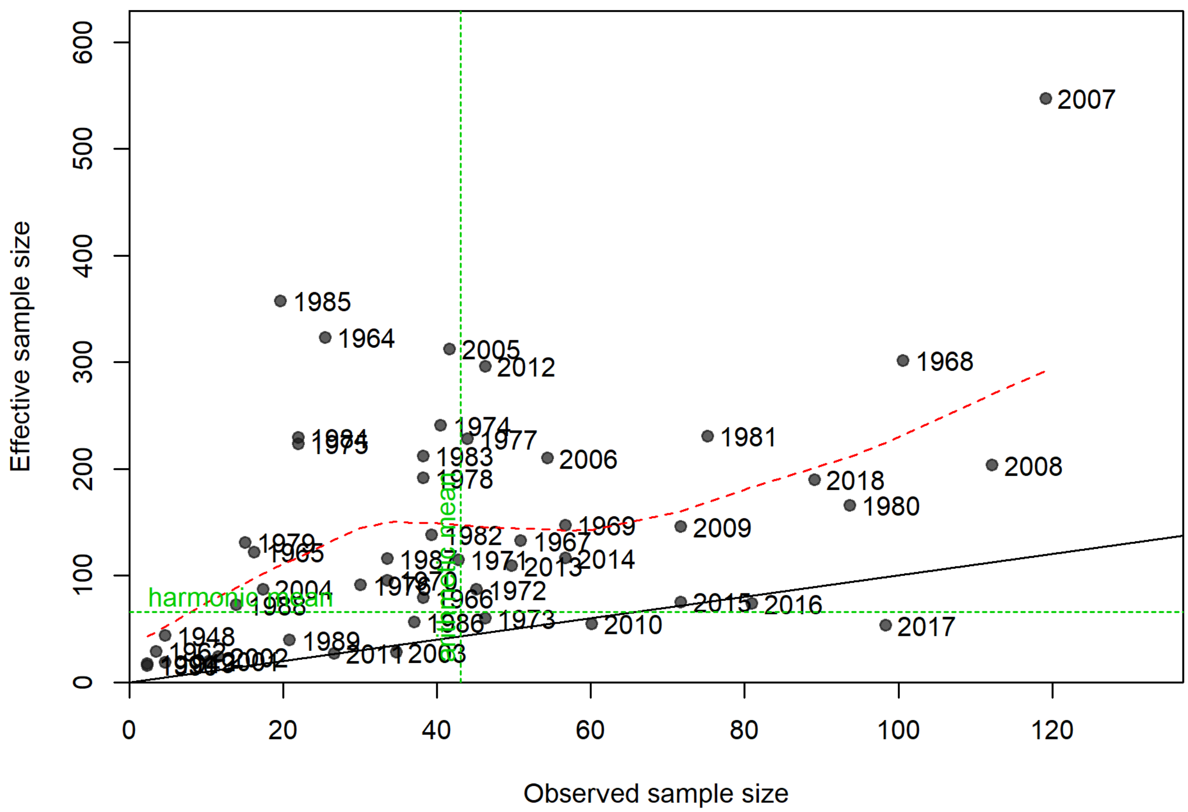

Figure 85: McAllister and Ianelli (harmonic mean) weighting for the Summer South fishery length data. fig:harm_mean_wn

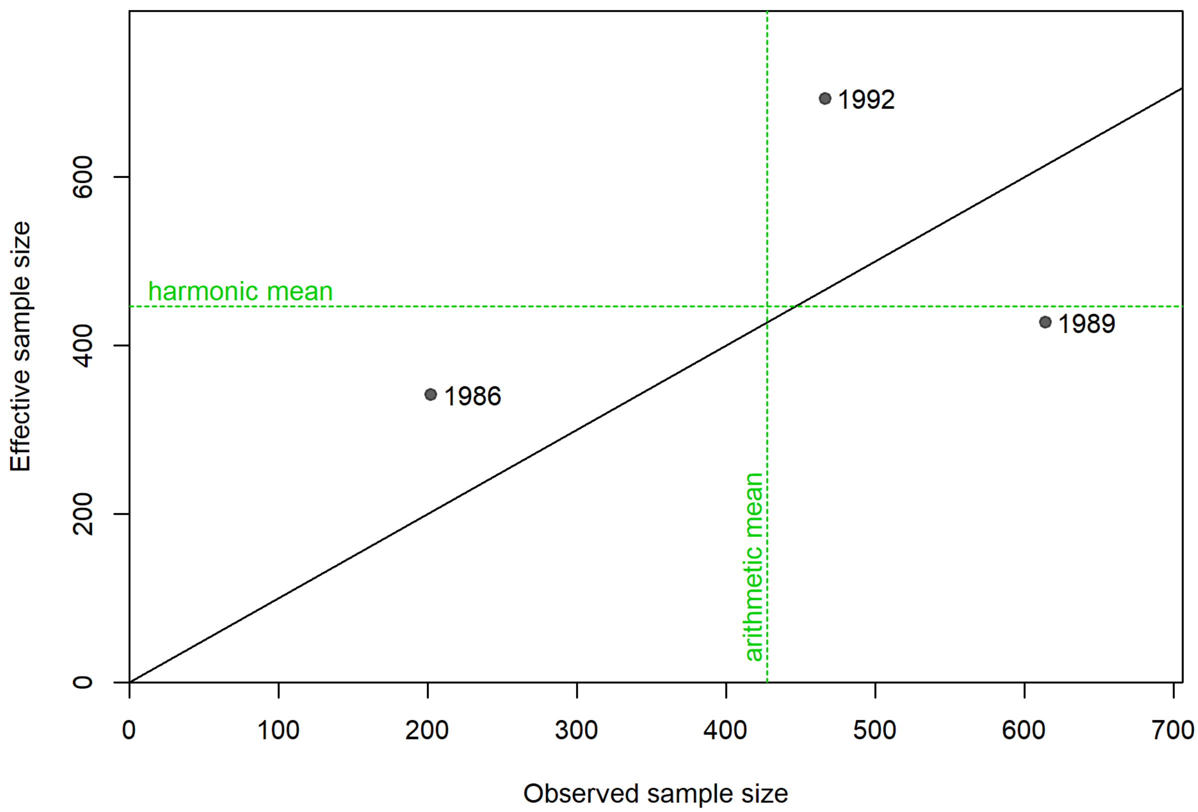

Figure 86: McAllister and Ianelli (harmonic mean) weighting for the Triennial Survey - early length data. fig:harm_mean_tri_early

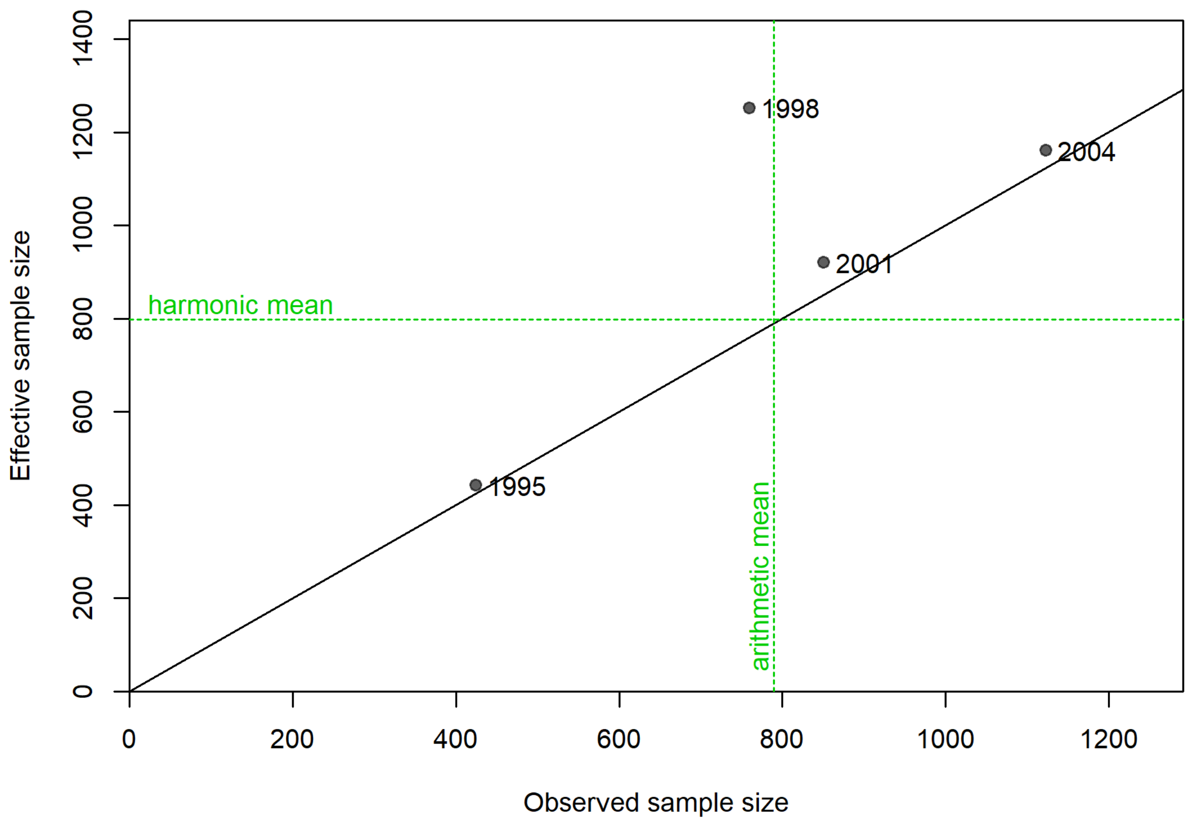

Figure 87: McAllister and Ianelli (harmonic mean) weighting for the Triennial Survey - late length data. fig:harm_mean_tri_late

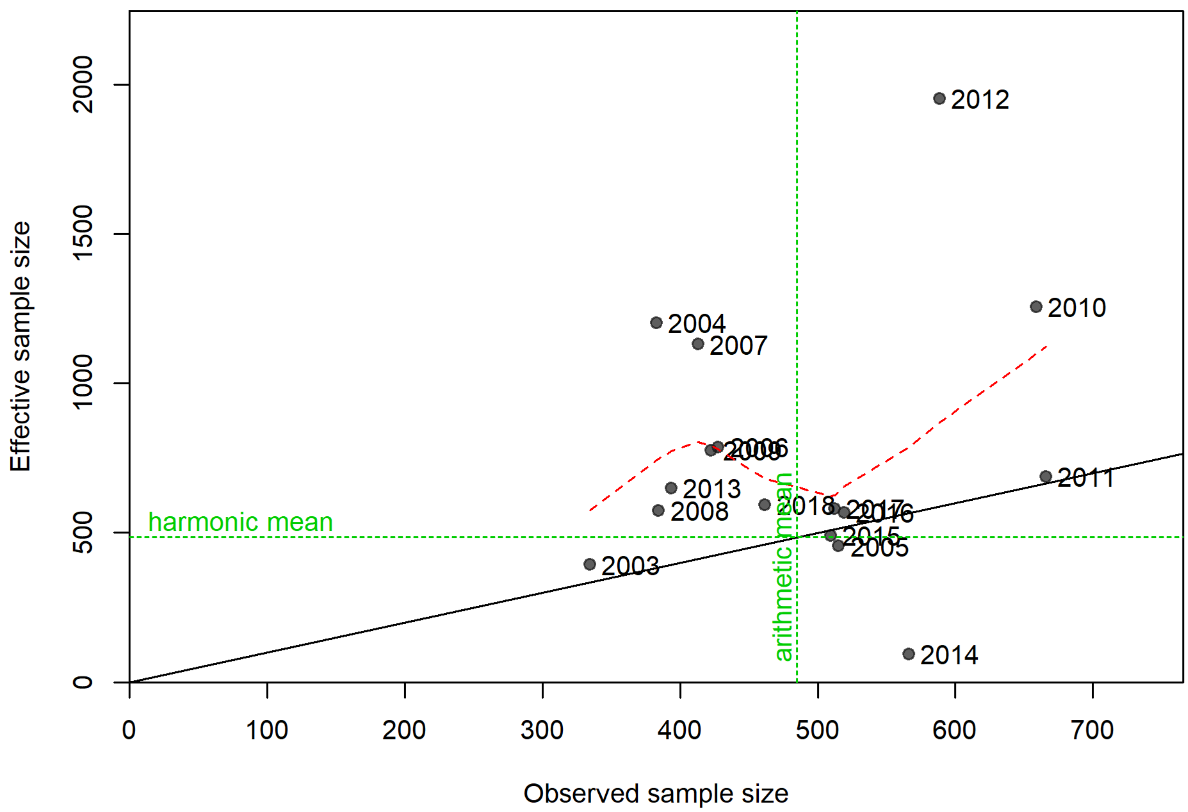

Figure 88: McAllister and Ianelli (harmonic mean) weighting for the NWFSC West Coast Groundfish Bottom Trawl Survey length data. fig:harm_mean_nwfsc

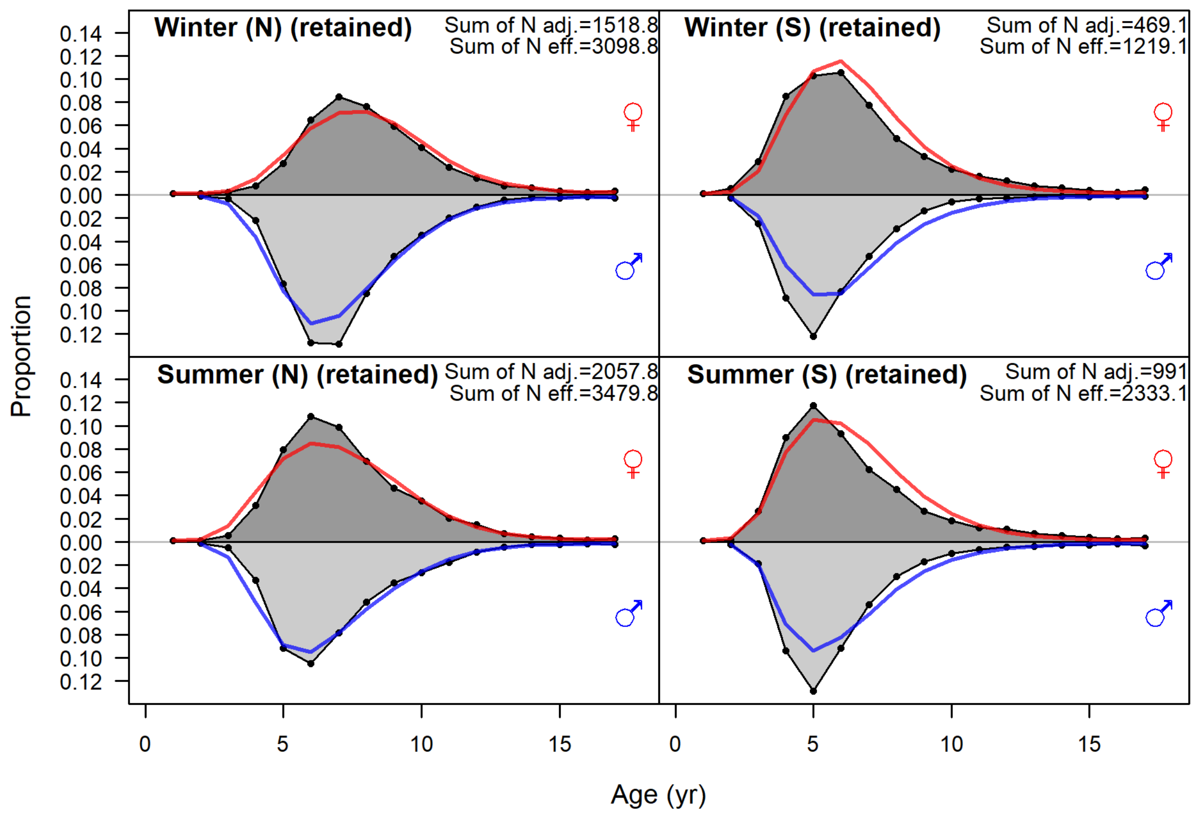

Figure 89: Age compositions aggregated across time for each fishery fleet. fig:age_agg

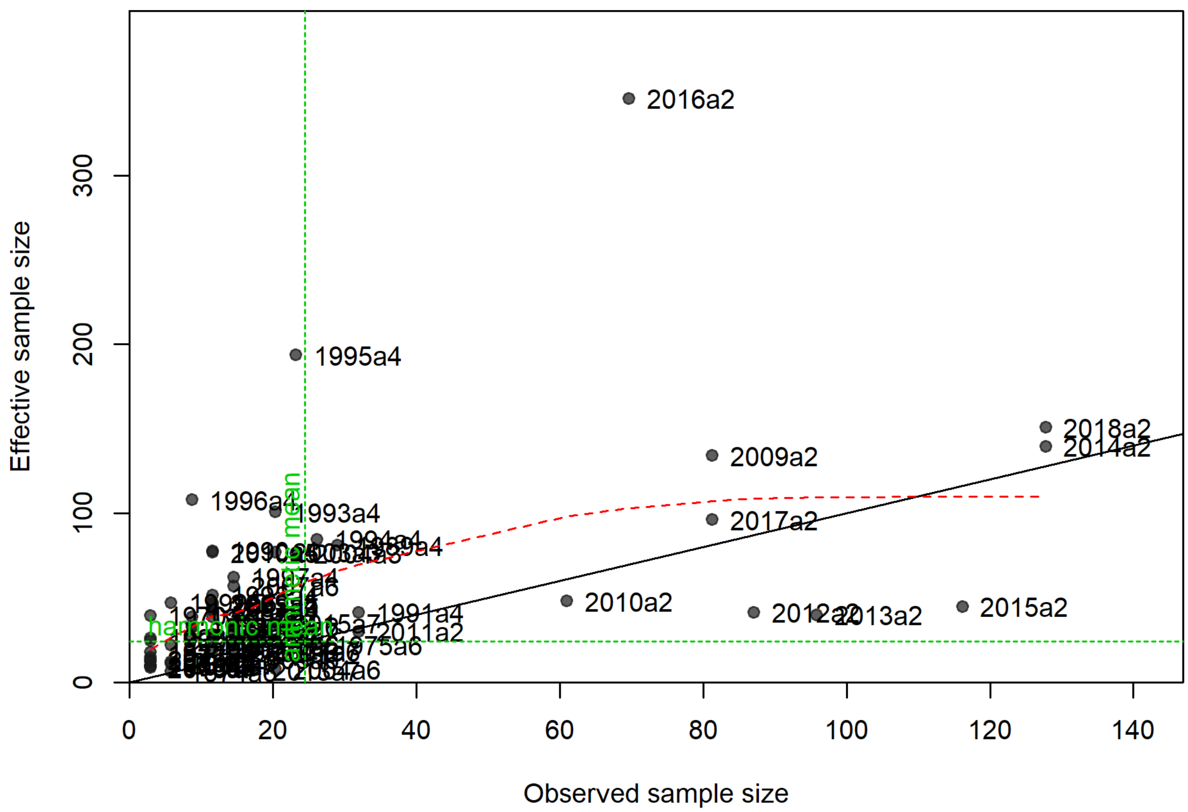

Figure 90: N_EffN comparison, Age comps, retained, Winter (N) fig:wn_age_pearson

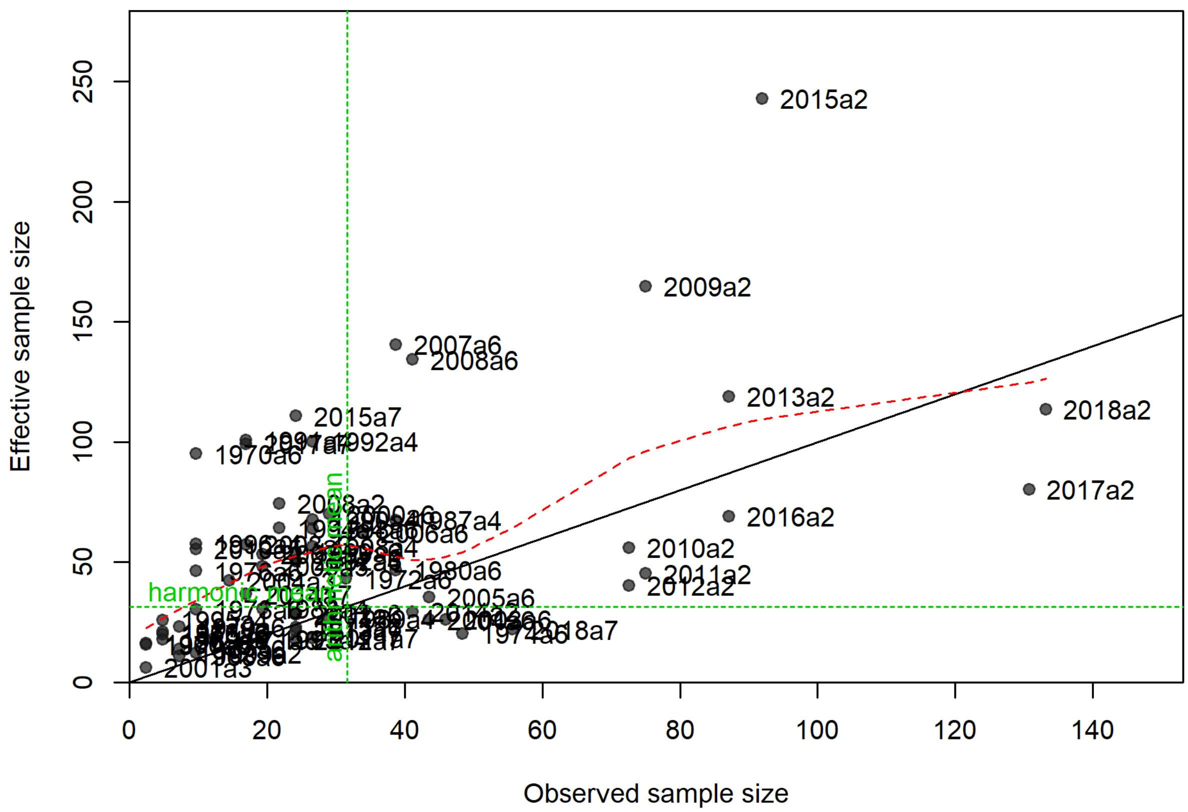

Figure 91: N_EffN comparison, Age comps, retained, Summer (N) fig:sn_age_pearson

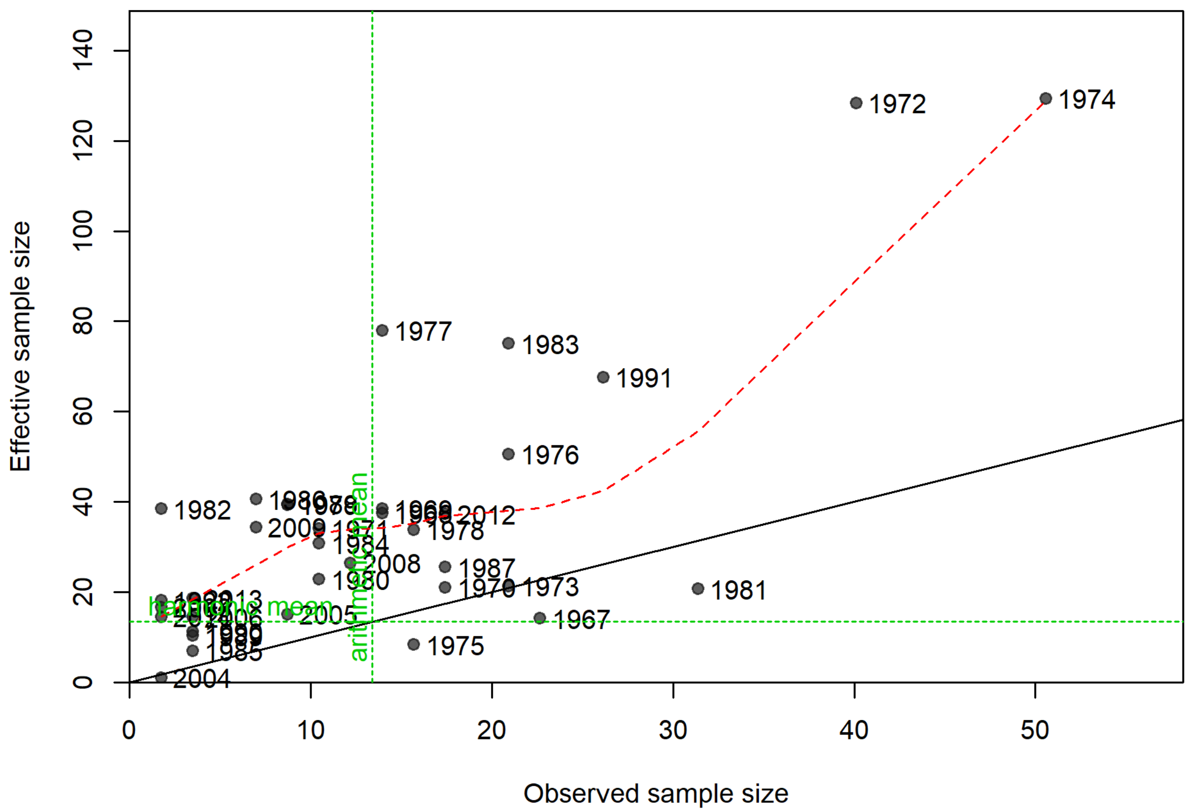

Figure 92: N_EffN comparison, Age comps, retained, Winter (S) fig:ws_age_pearson

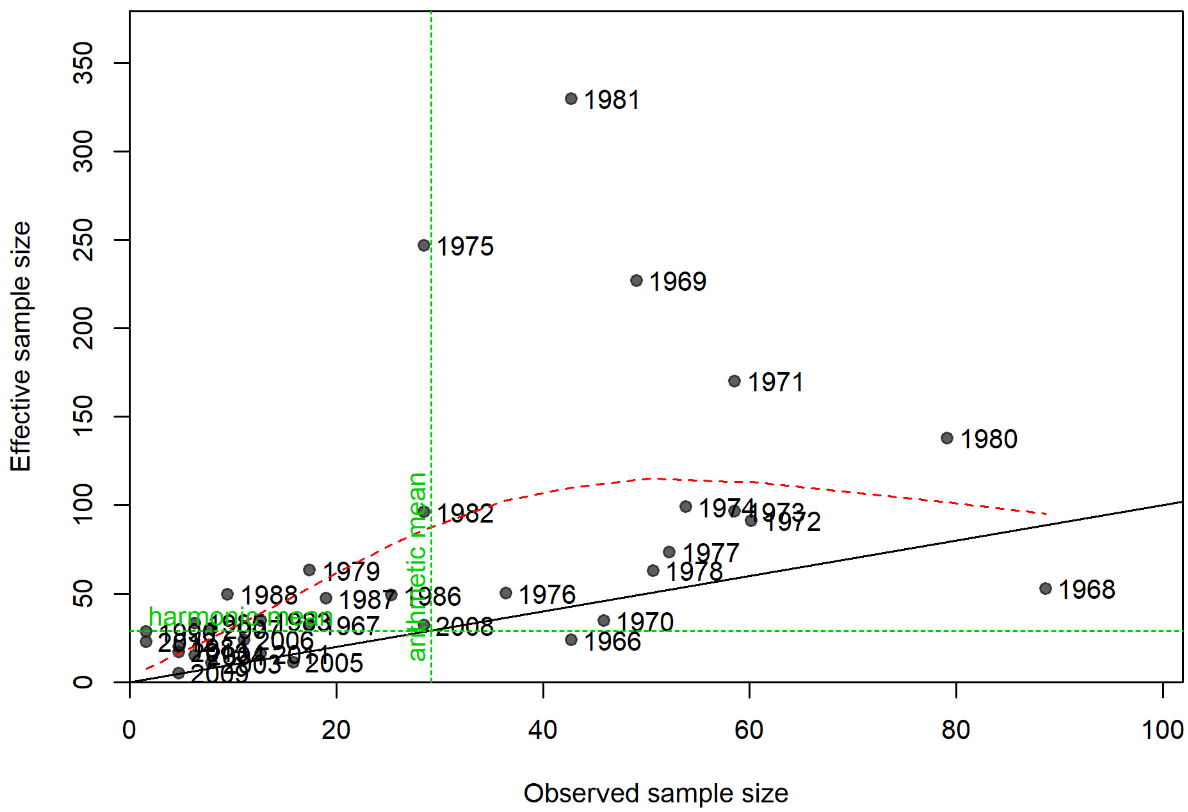

Figure 93: N_EffN comparison, Age comps, retained, Summer (S) fig:ss_age_pearson

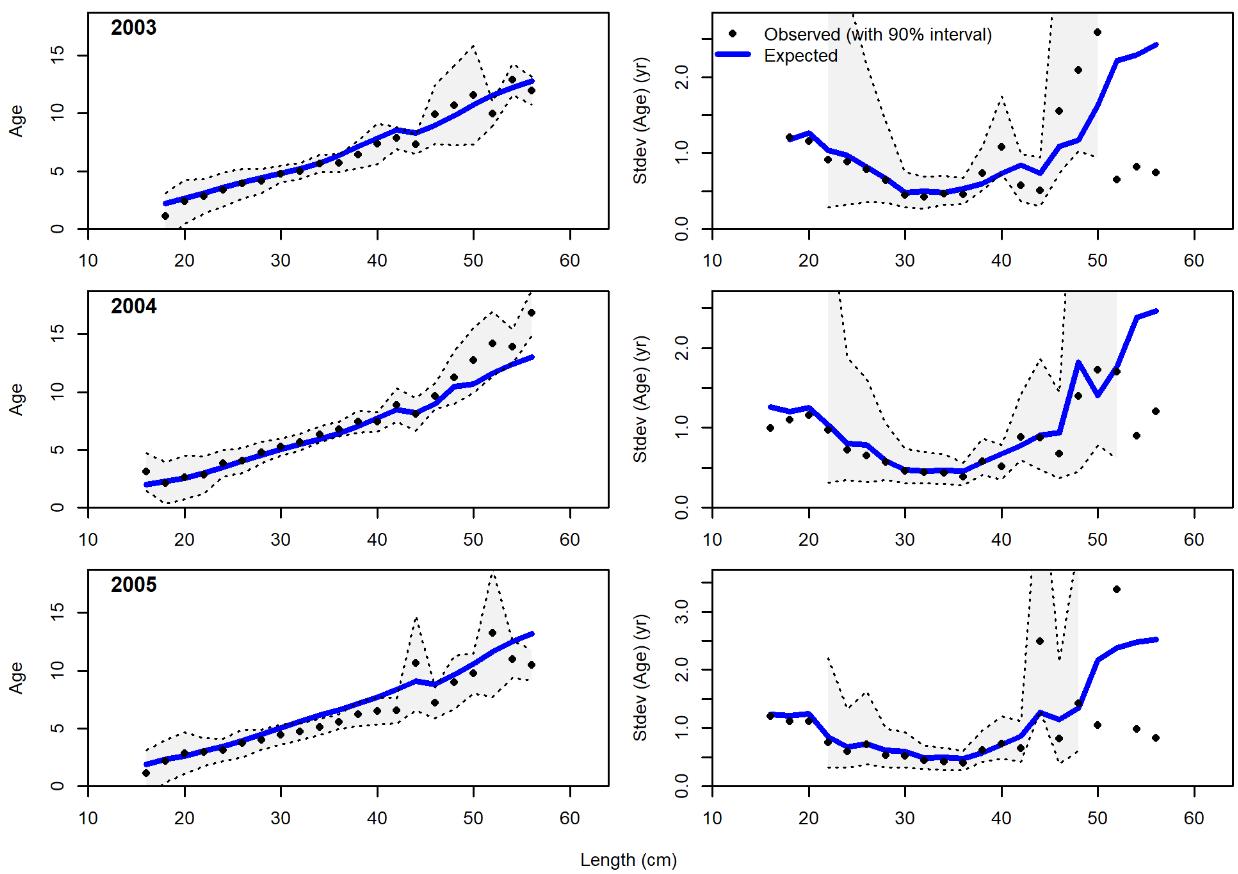

Figure 94: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 1 of 6) These plots show mean age and std. dev. in conditional AAL. Left plots are mean AAL by size_class (obs. and pred.) with 90% CIs based on adding 1.64 SE of mean to the data. Right plots in each pair are SE of mean AAL (obs. and pred.) with 90% CIs based on the chi_square distribution. fig:nwfsc_combo_andre_1

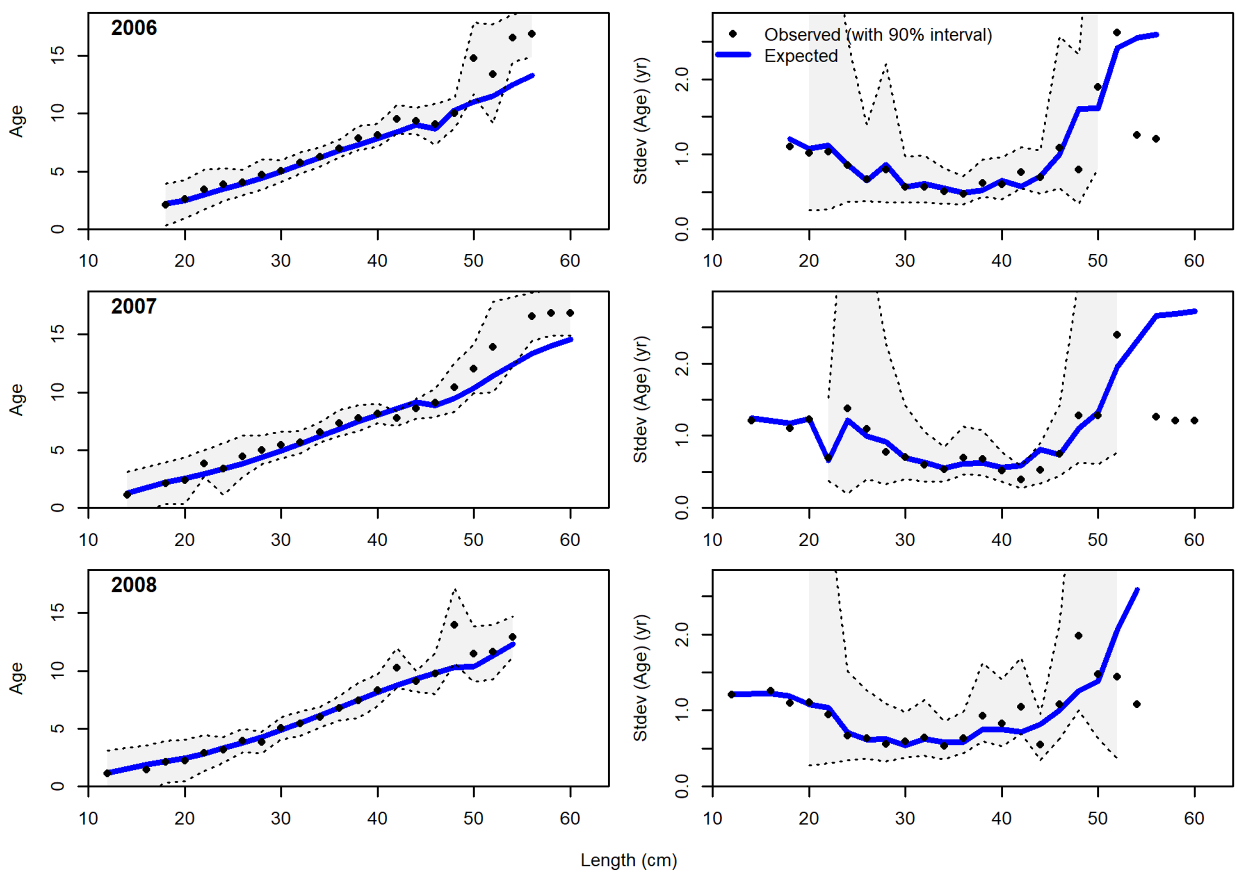

Figure 95: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 2 of 6) fig:nwfsc_combo_andre_2

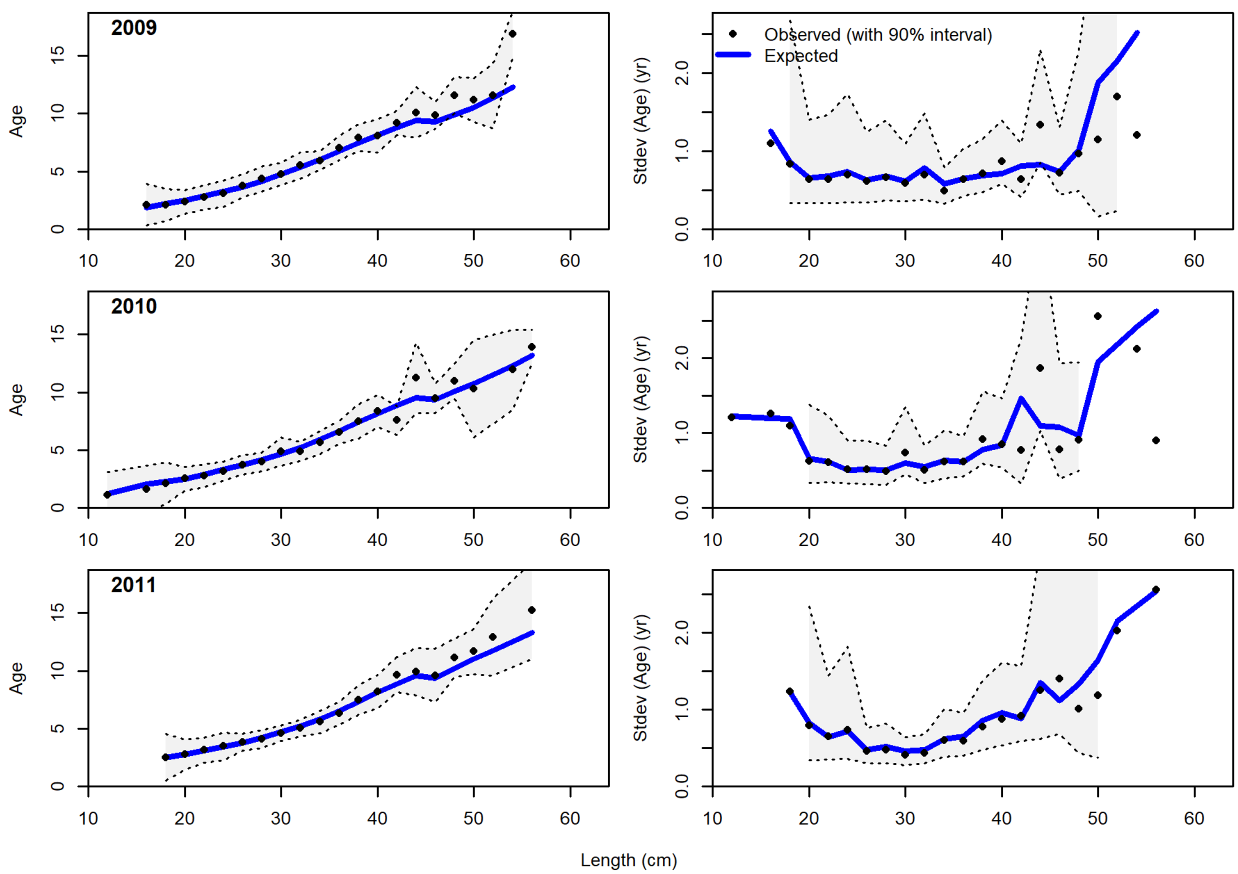

Figure 96: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 3 of 6) fig:nwfsc_combo_andre_3

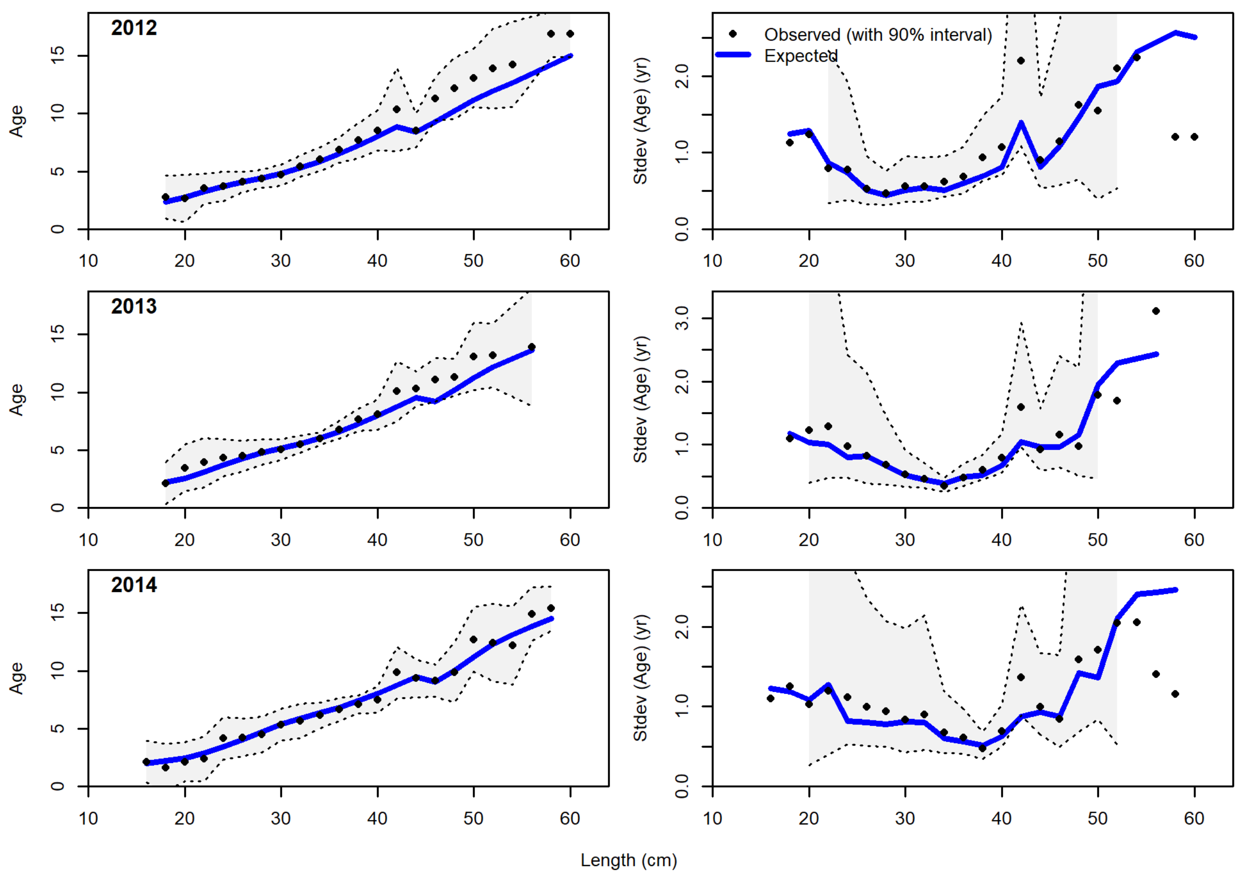

Figure 97: Conditional AAL plot, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (plot 4 of 6) fig:nwfsc_combo_andre_4

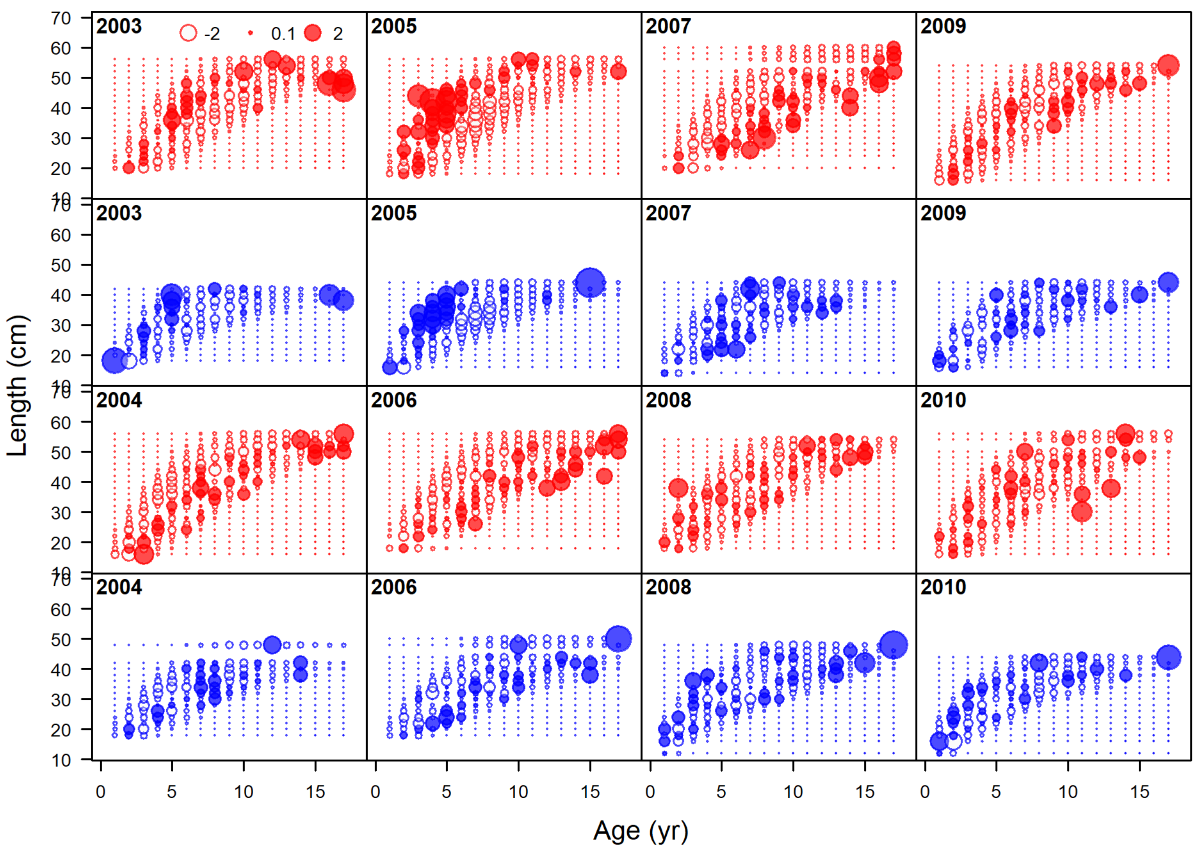

Figure 98: Pearson residuals, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (max=6.52) (plot 1 of 2) fig:nwfsc_combo_pearson_1

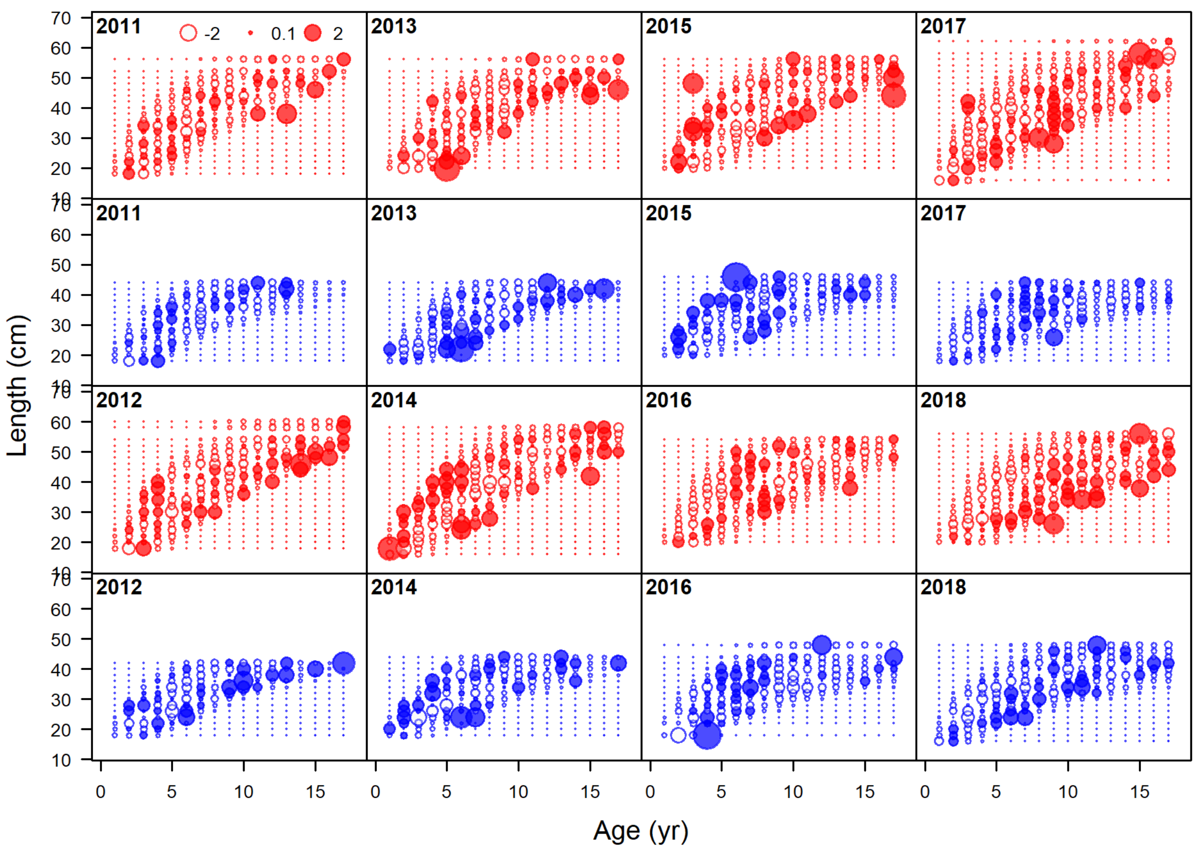

Figure 99: Pearson residuals, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (max=6.52) (plot 1 of 2) (plot 2 of 2) fig:nwfsc_combo_pearson_2

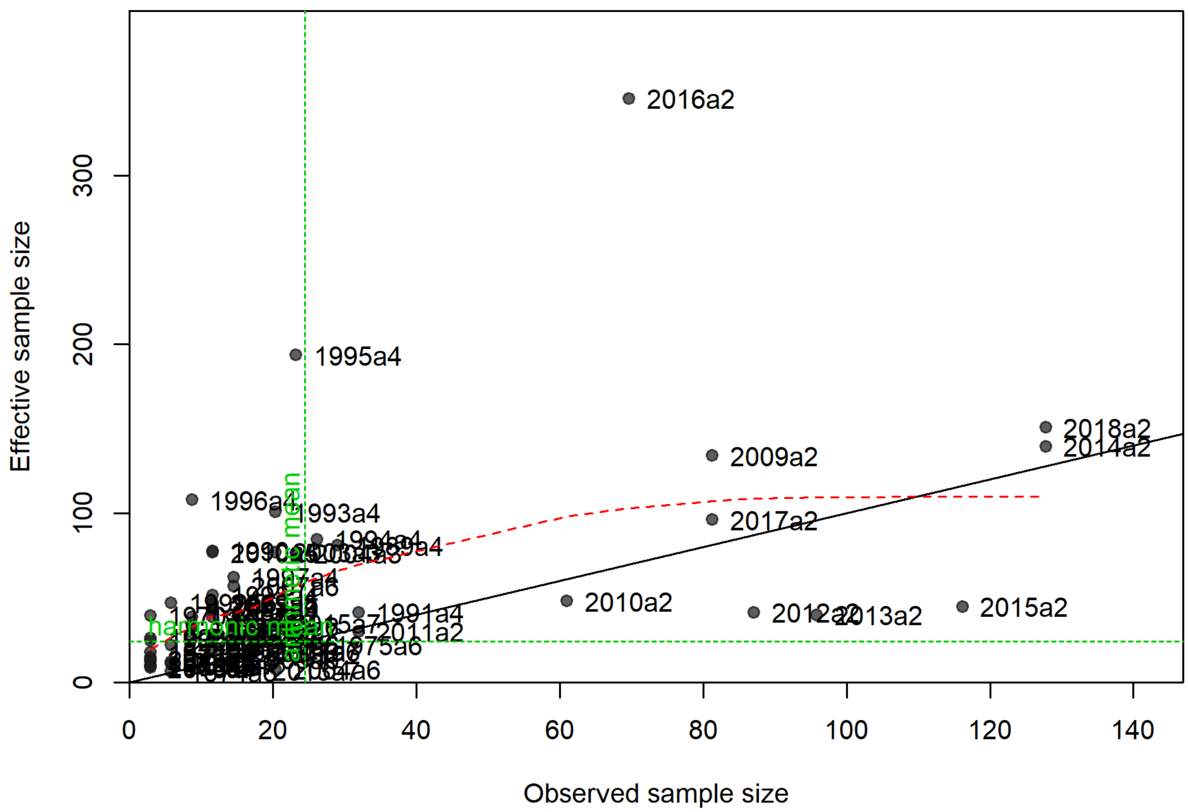

Figure 100: McAllister and Ianelli (harmonic mean) weighting for the Winter North fishery age data. fig:harm_mean_wn_age

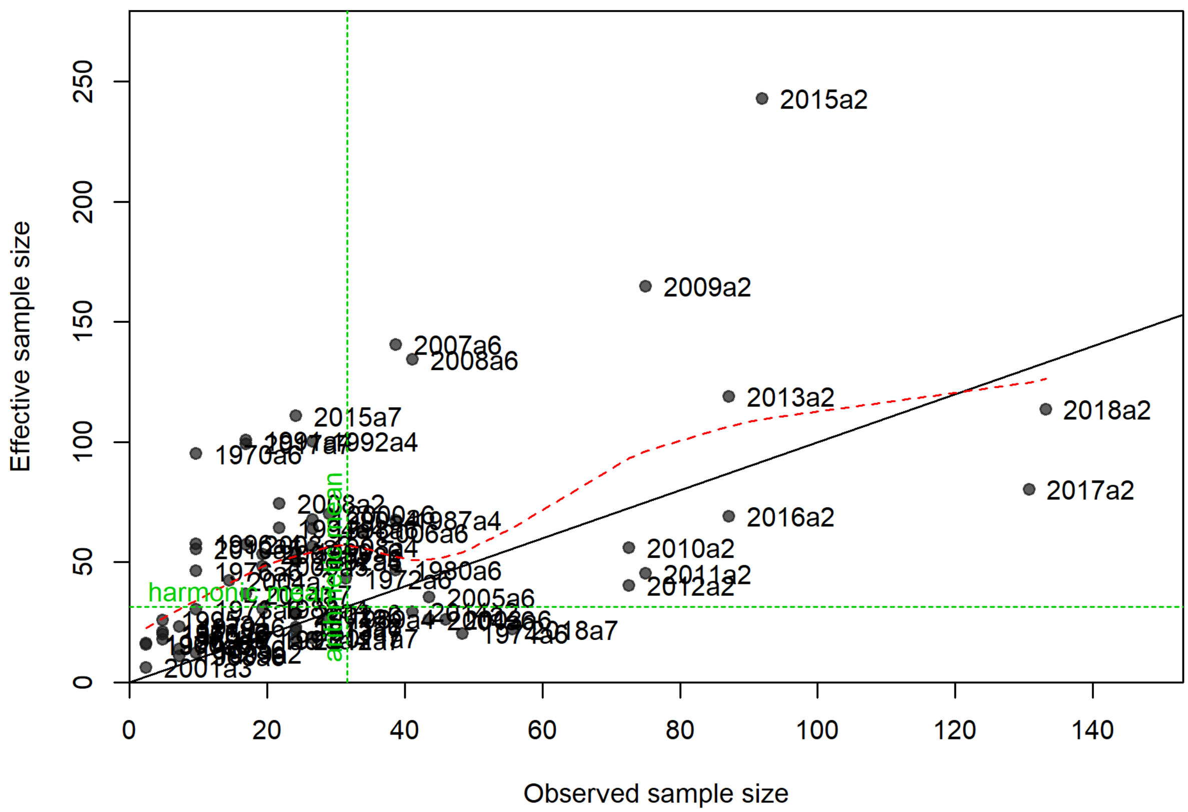

Figure 101: McAllister and Ianelli (harmonic mean) weighting for the Summer North fishery age data. fig:harm_mean_sn_age

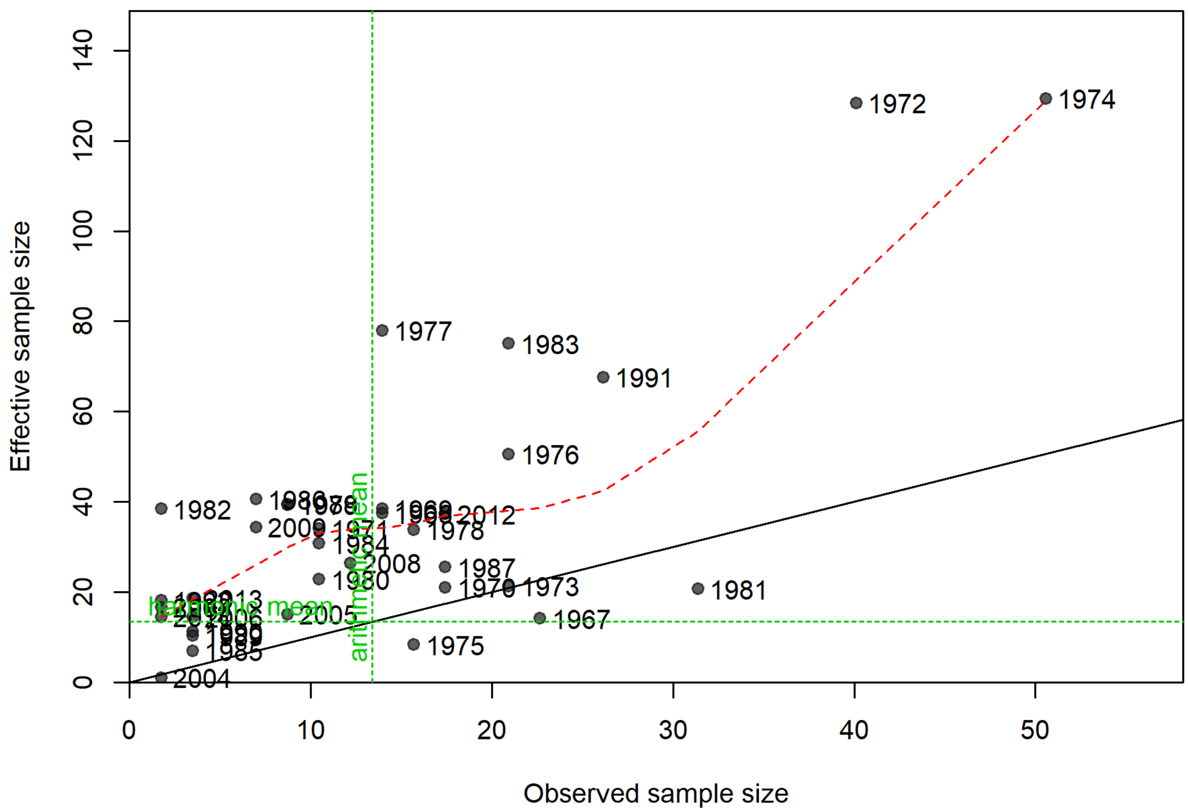

Figure 102: McAllister and Ianelli (harmonic mean) weighting for the Winter South fishery age data. fig:harm_mean_ws_age

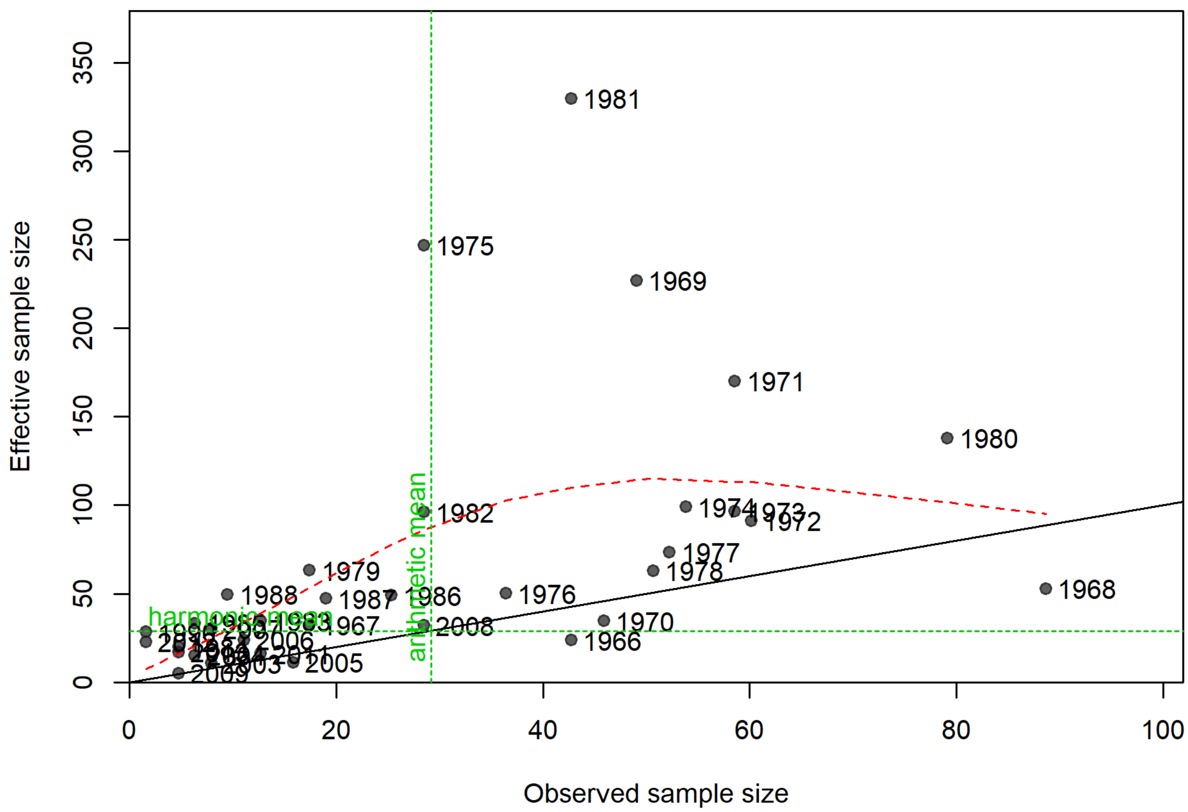

Figure 103: McAllister and Ianelli (harmonic mean) weighting for the Summer South fishery age data. fig:harm_mean_wn_age

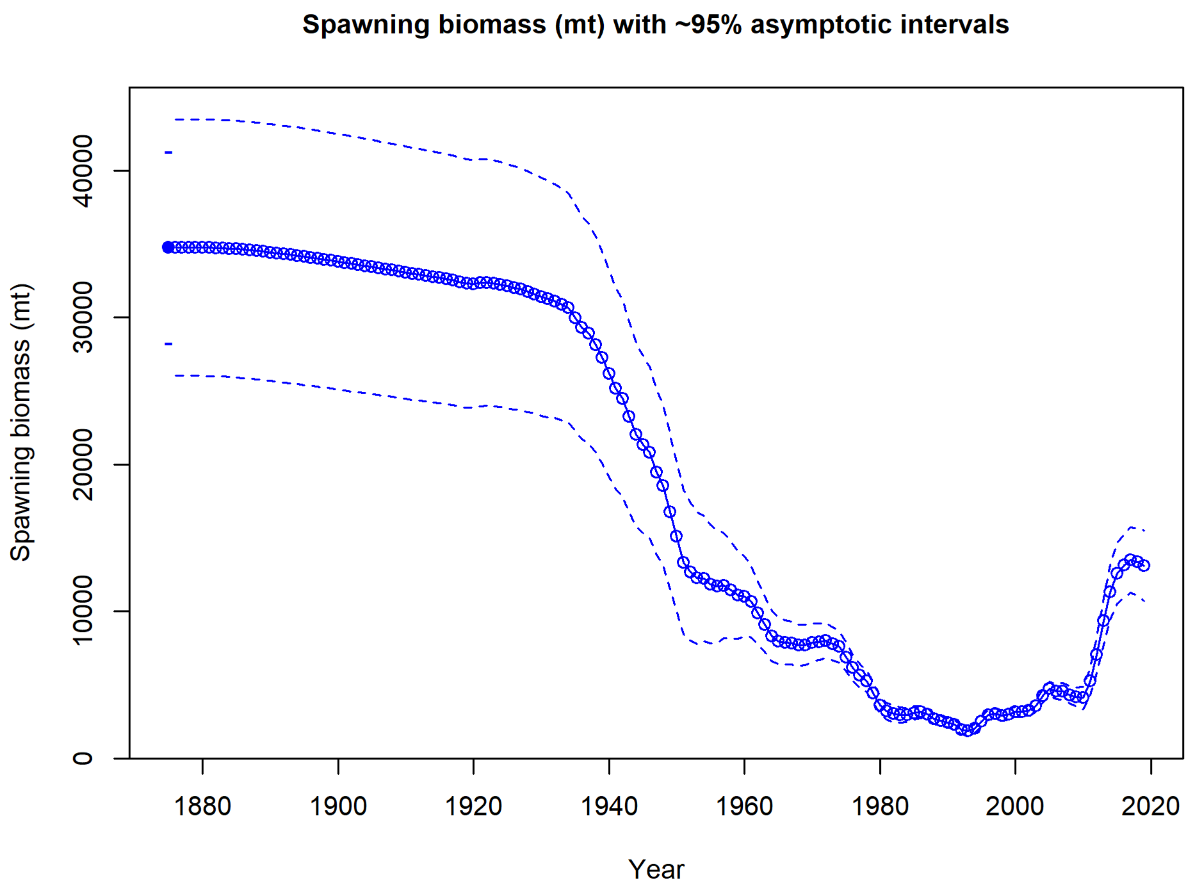

Figure 104: Estimated time-series of spawning biomass trajectory (circles and line: median; light broken lines: 95% credibility intervals) for petrale sole. fig:ssb

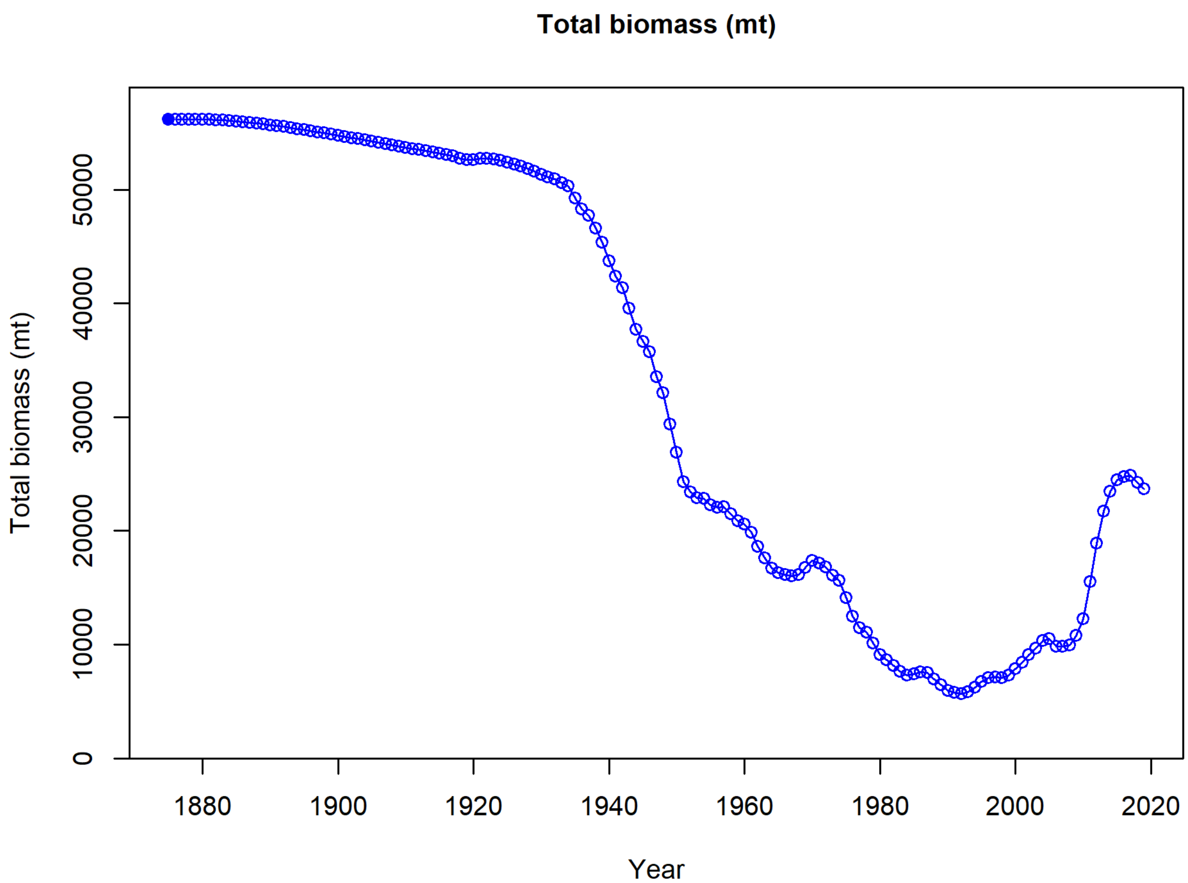

Figure 105: Estimated time-series of total biomass for petrale sole. fig:total_bio

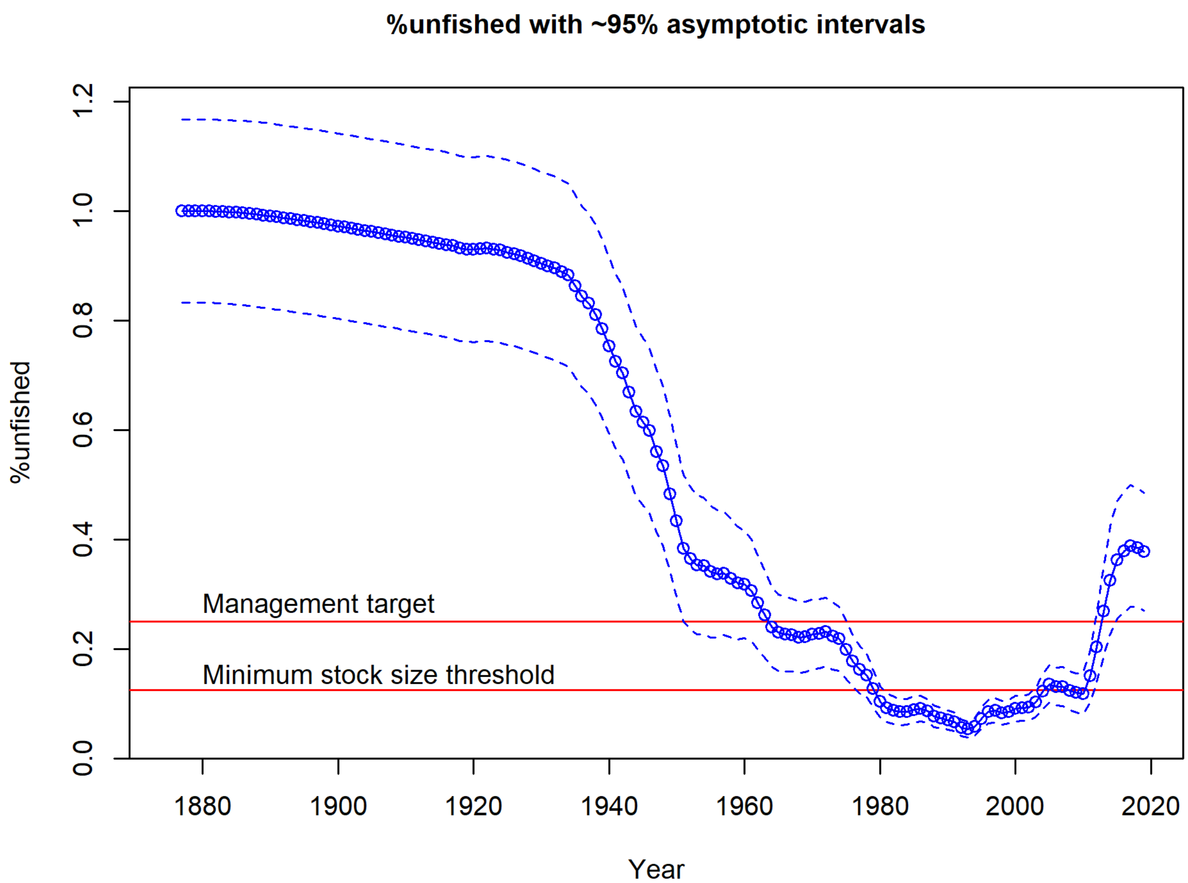

Figure 106: Estimated time-series of relative spawning biomass (depletion) (circles and line: median; light broken lines: 95% credibility intervals) for petrale sole. fig:depl

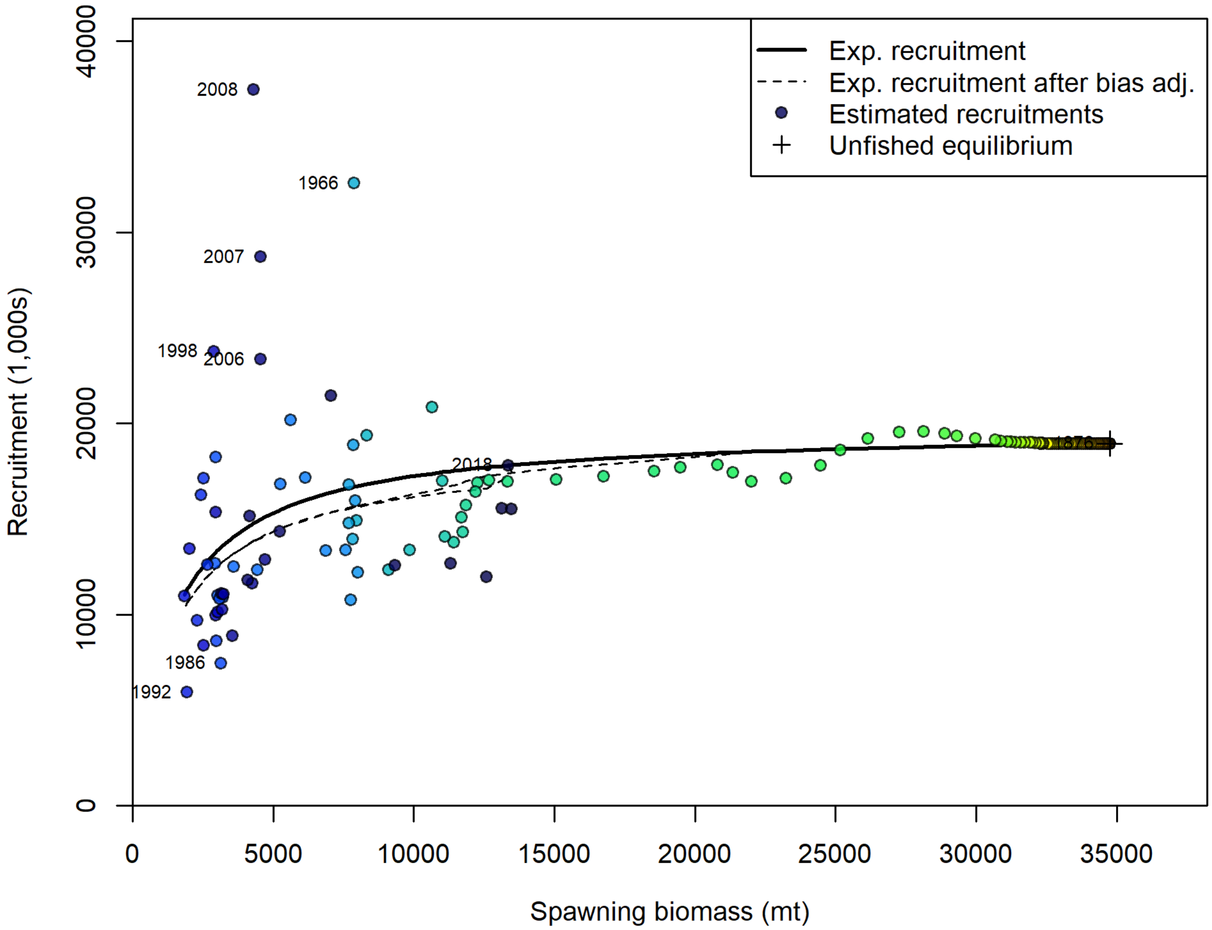

Figure 107: Estimated recruitment (colored circles) and the assumed stock-recruit relationship (solid black line). The dashed line shows the effect of the bias correction for the lognormal distribution. fig:stock_recruit_curve

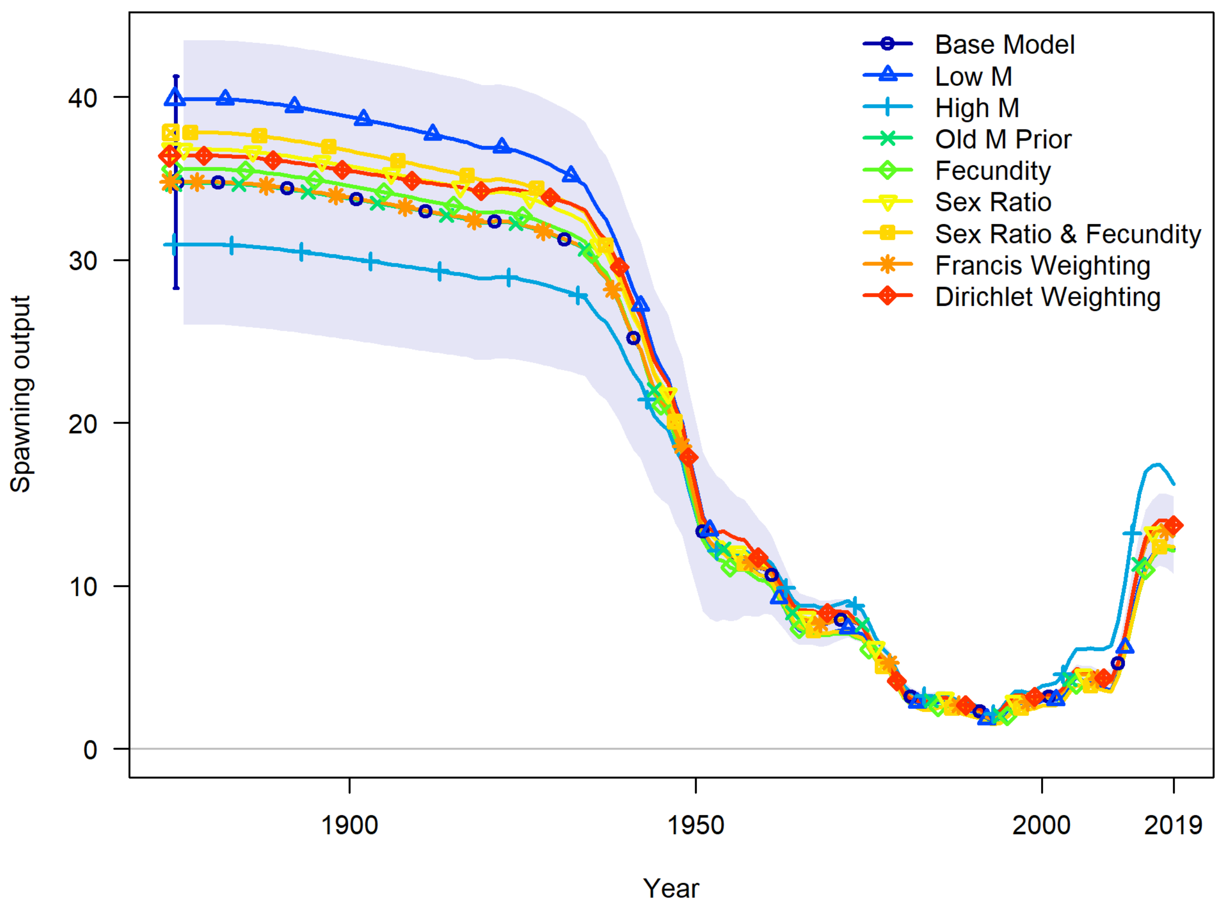

Figure 108: Estimate spawning biomass for the base model and each sensitivity. fig:sens_ssb

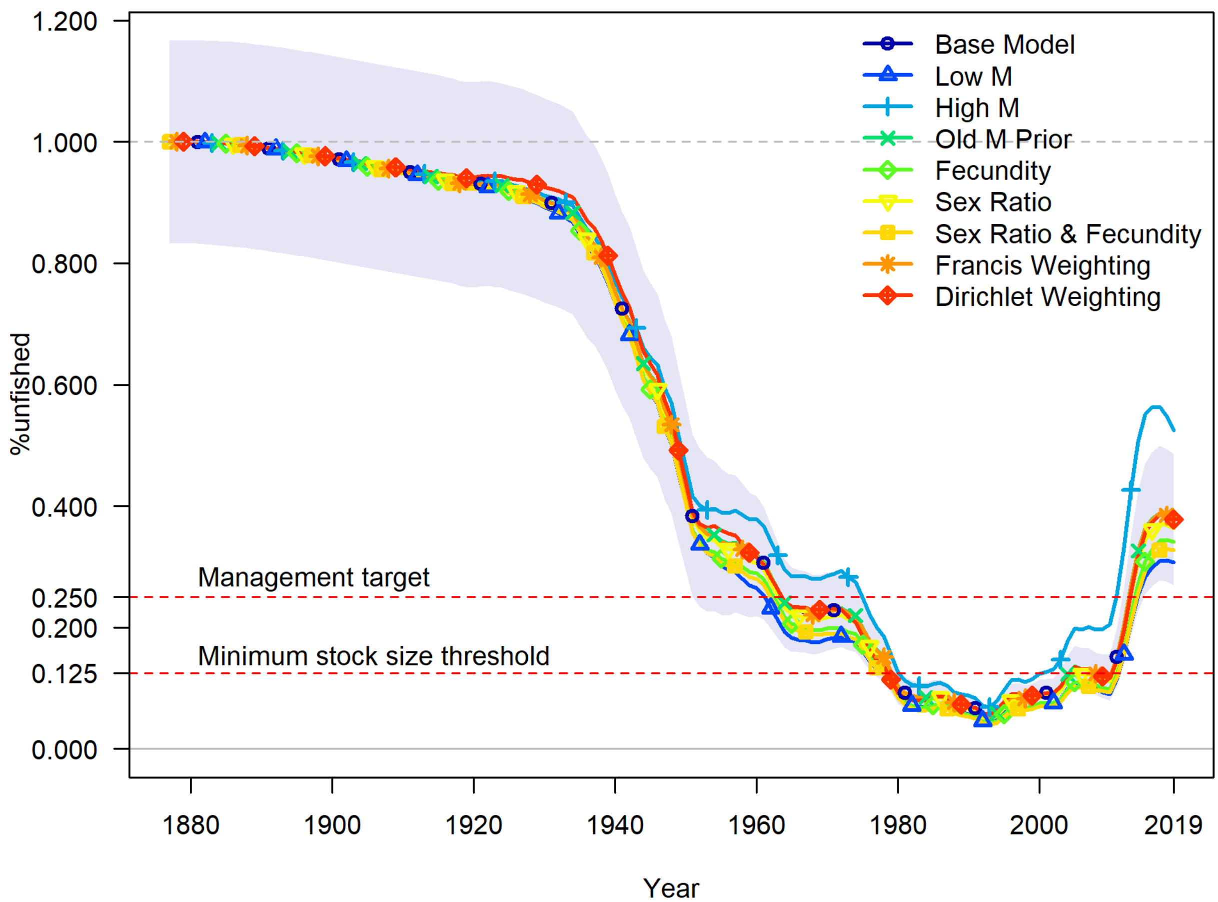

Figure 109: Estimate relative spawning biomass for the base model and each sensitivity. fig:sens_depl

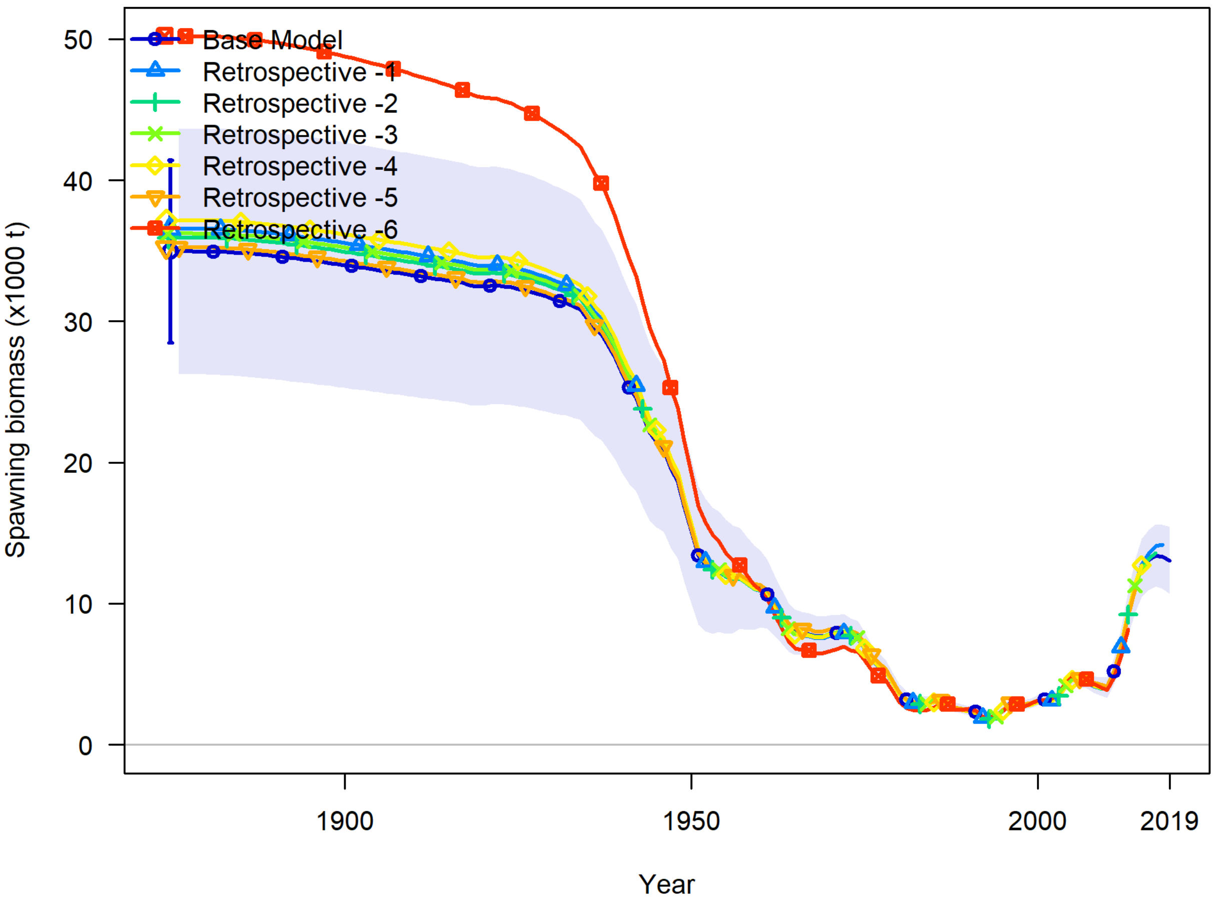

Figure 110: Retrospective pattern for spawning biomass. fig:retro_ssb

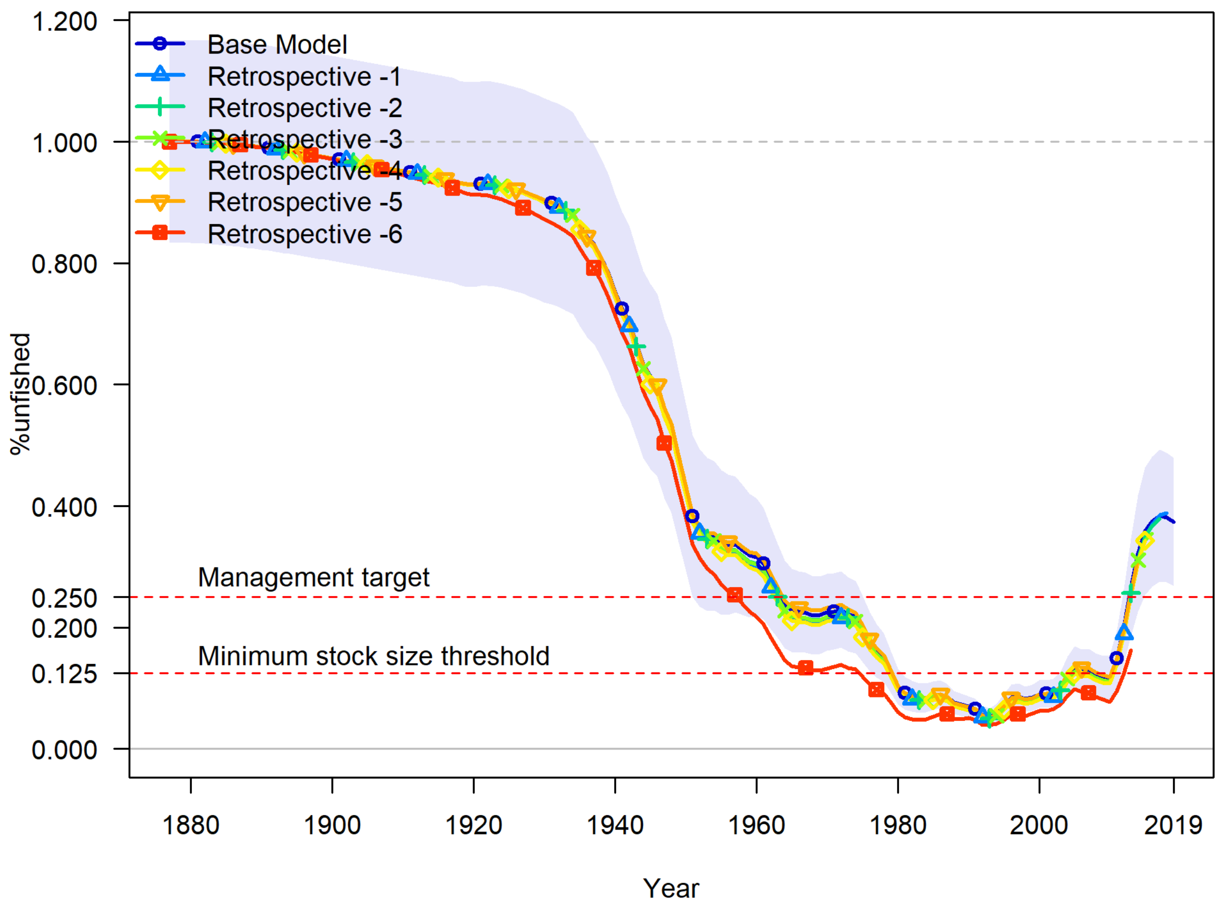

Figure 111: Retrospective pattern for relative spawning biomass. fig:retro_depl

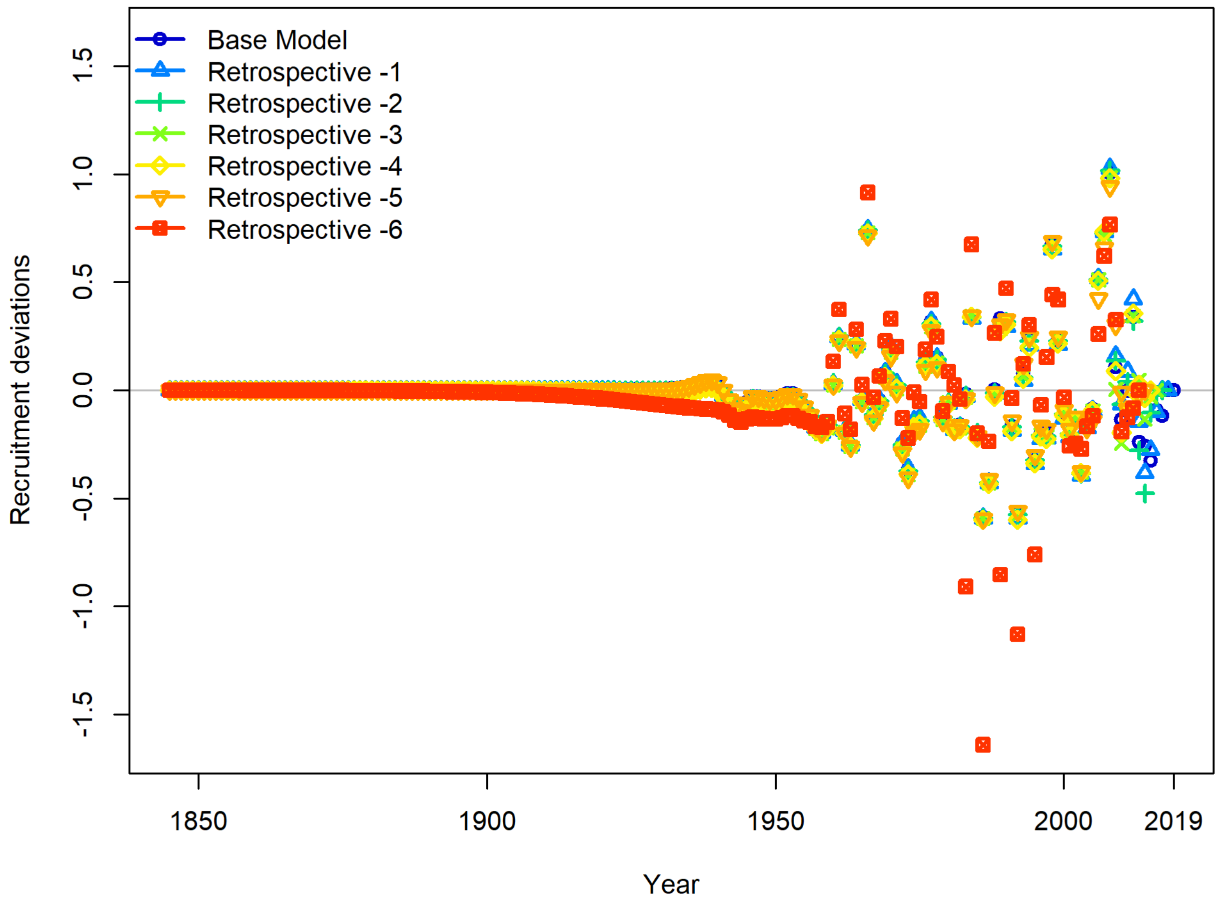

Figure 112: Retrospective pattern for estimated recruitment deviations. fig:retro_recdev

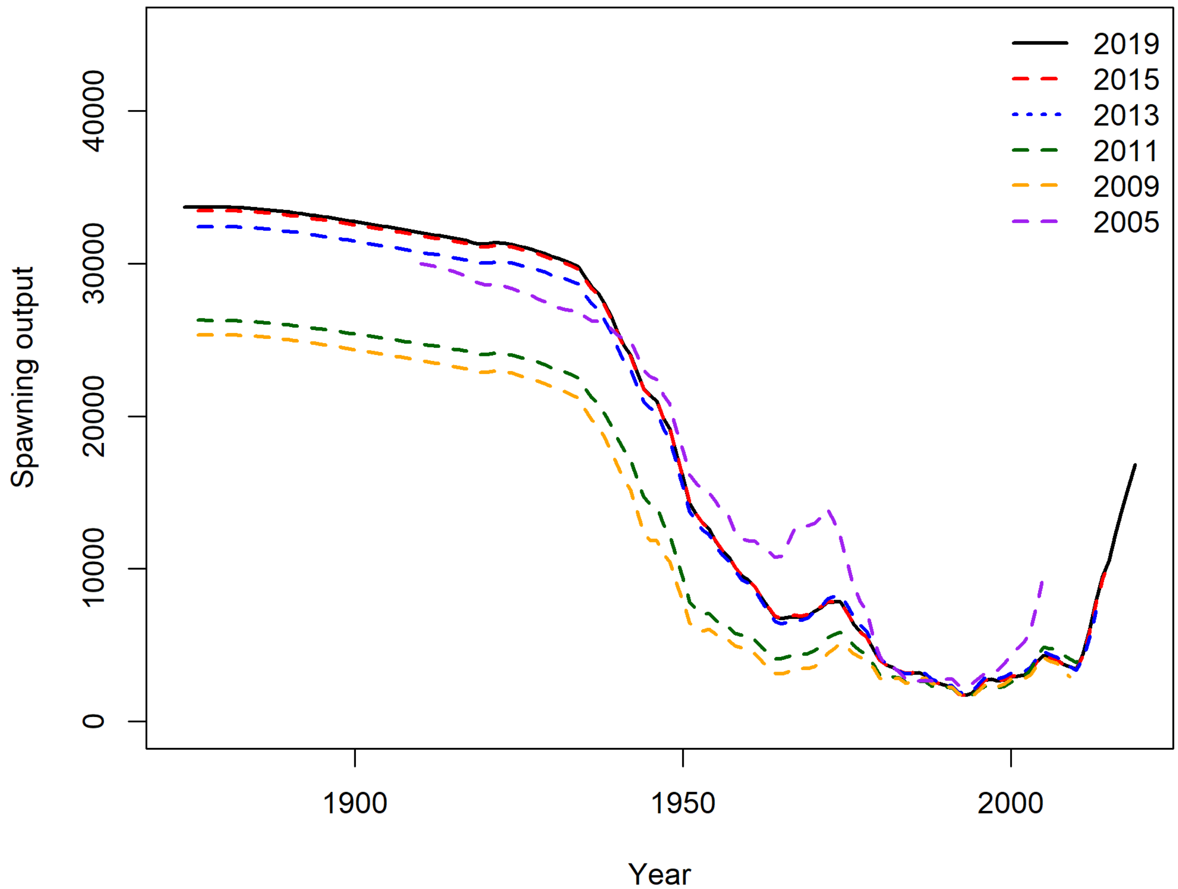

Figure 113: Pattern for estimated spawning biomass from each assessment since 2005. fig:historical_

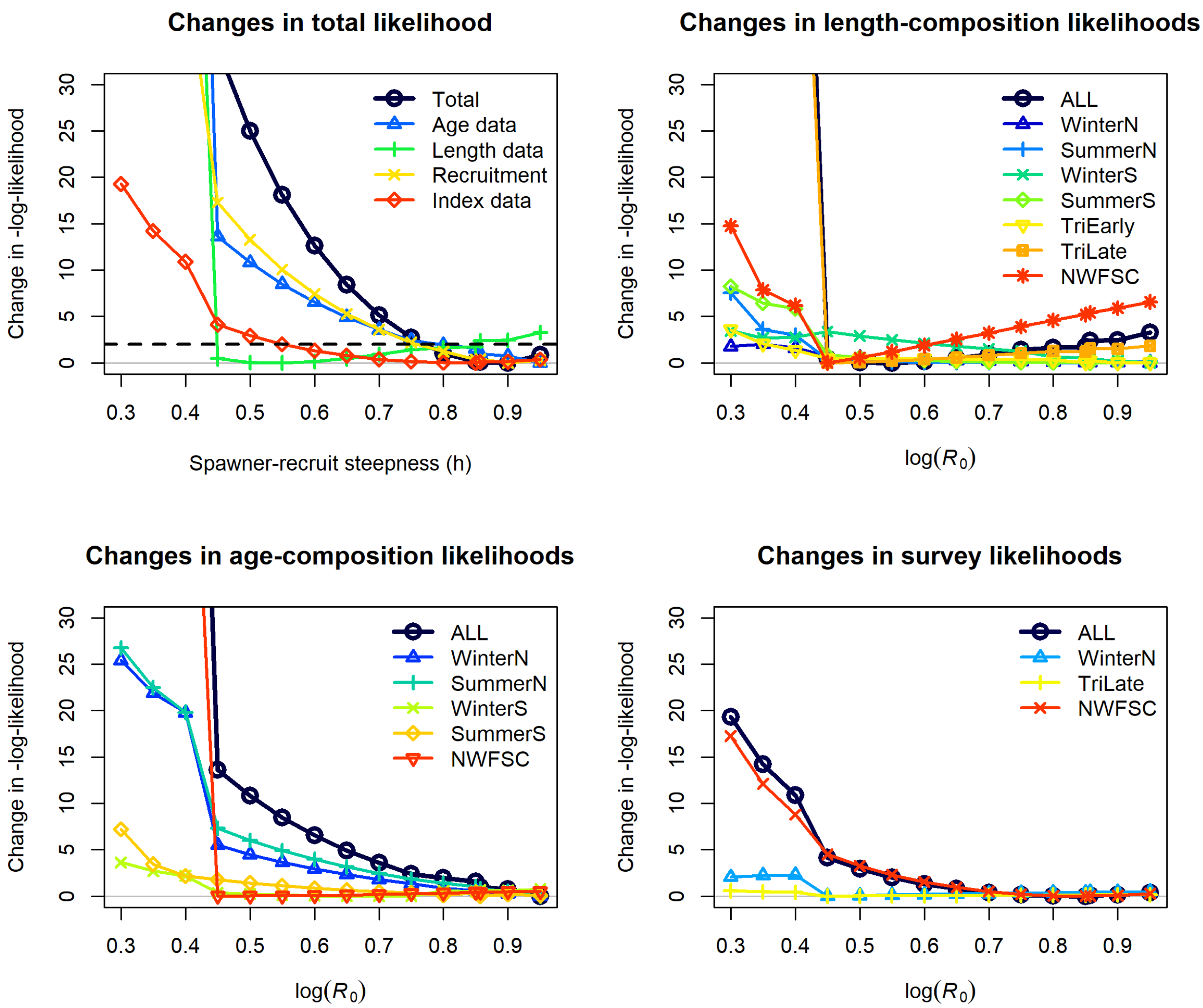

Figure 114: Likelihood profile across steepness values. fig:piner_h

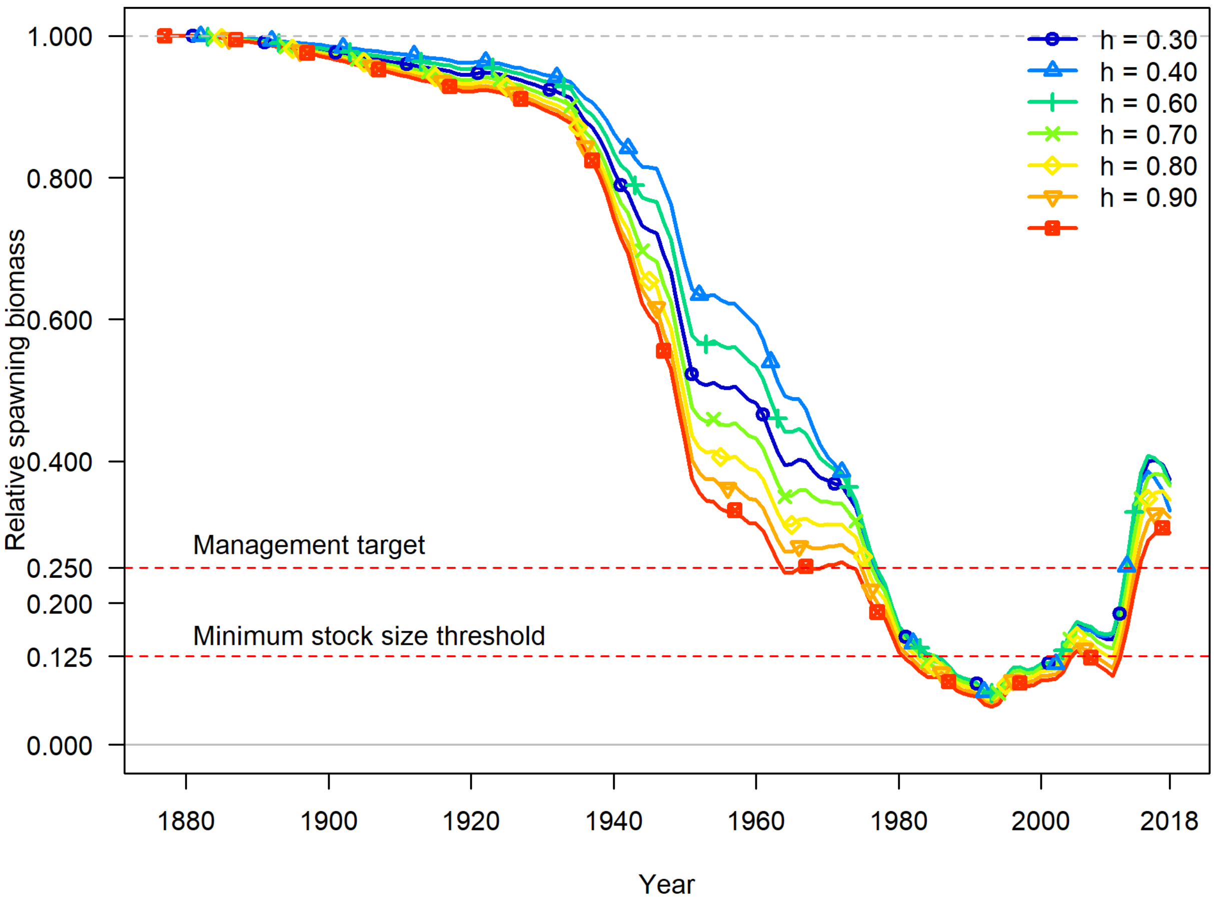

Figure 115: Trajectories of relative spawning biomass across values of steepness. fig:h_trajectory

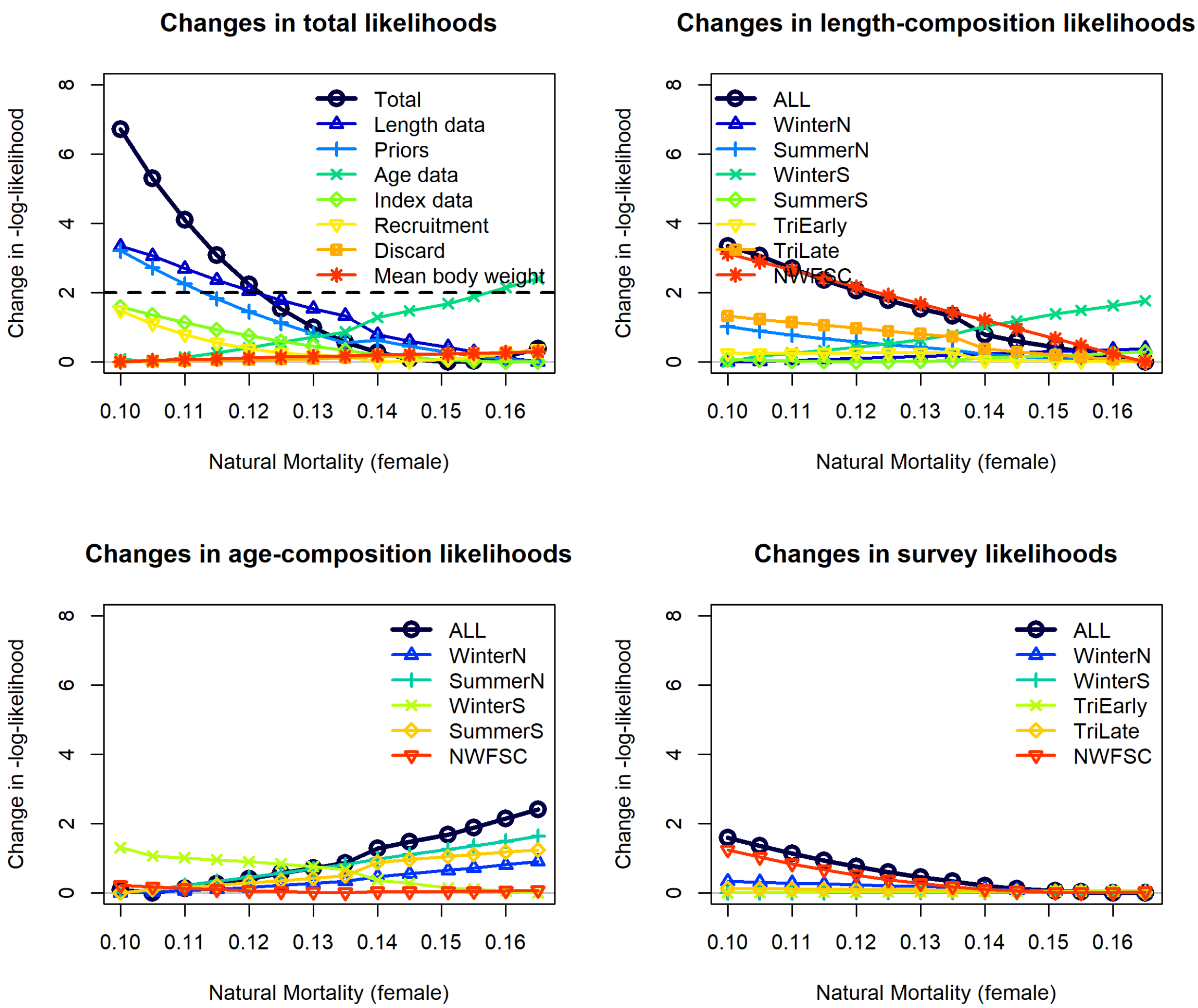

Figure 116: Likelihood profile across female natural mortality values. Male natural mortality was estimated. fig:m_like

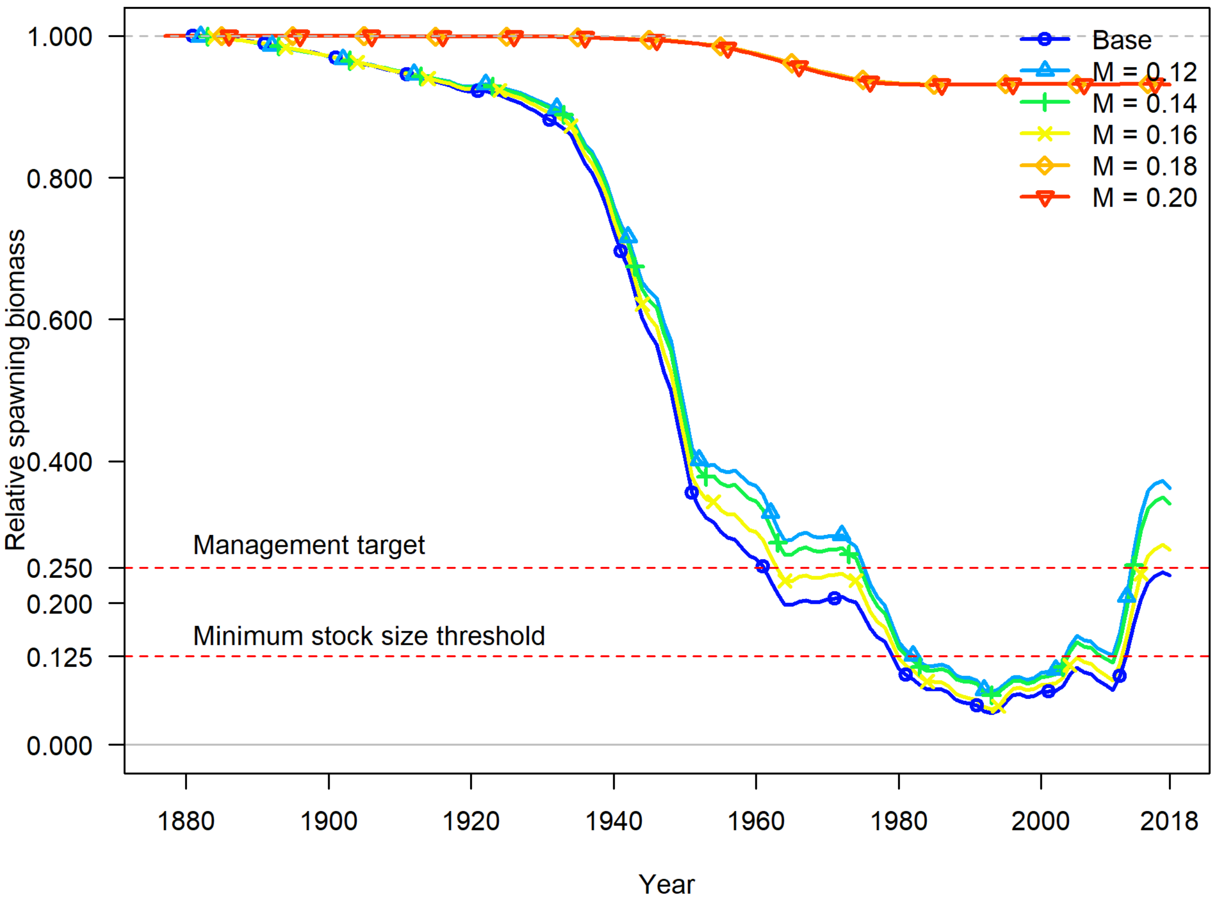

Figure 117: Trajectories of relative spawning biomass across values of natural mortality. fig:m_trajecto

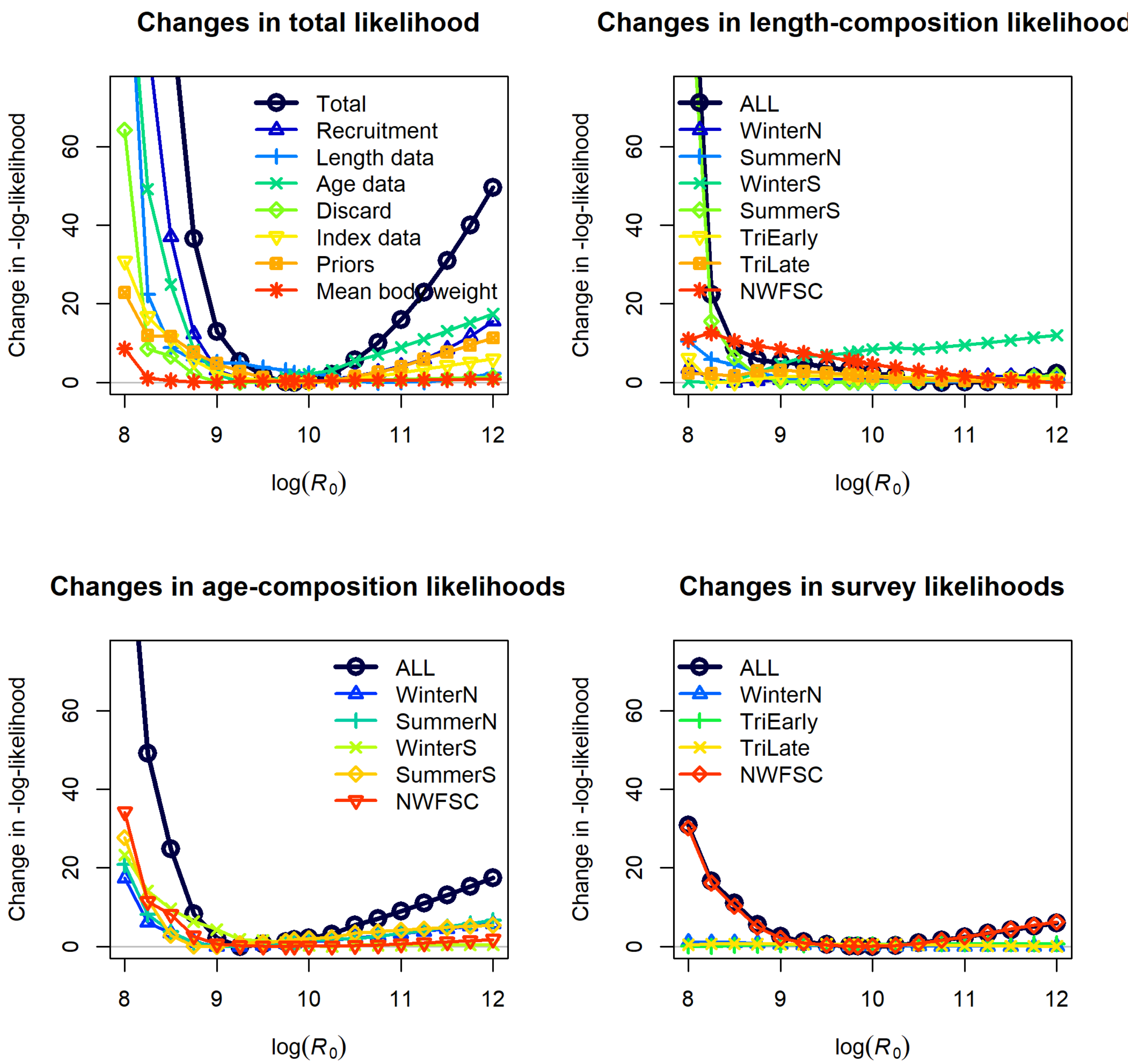

Figure 118: Likelihood profile across R_0 values. fig:piner_R0

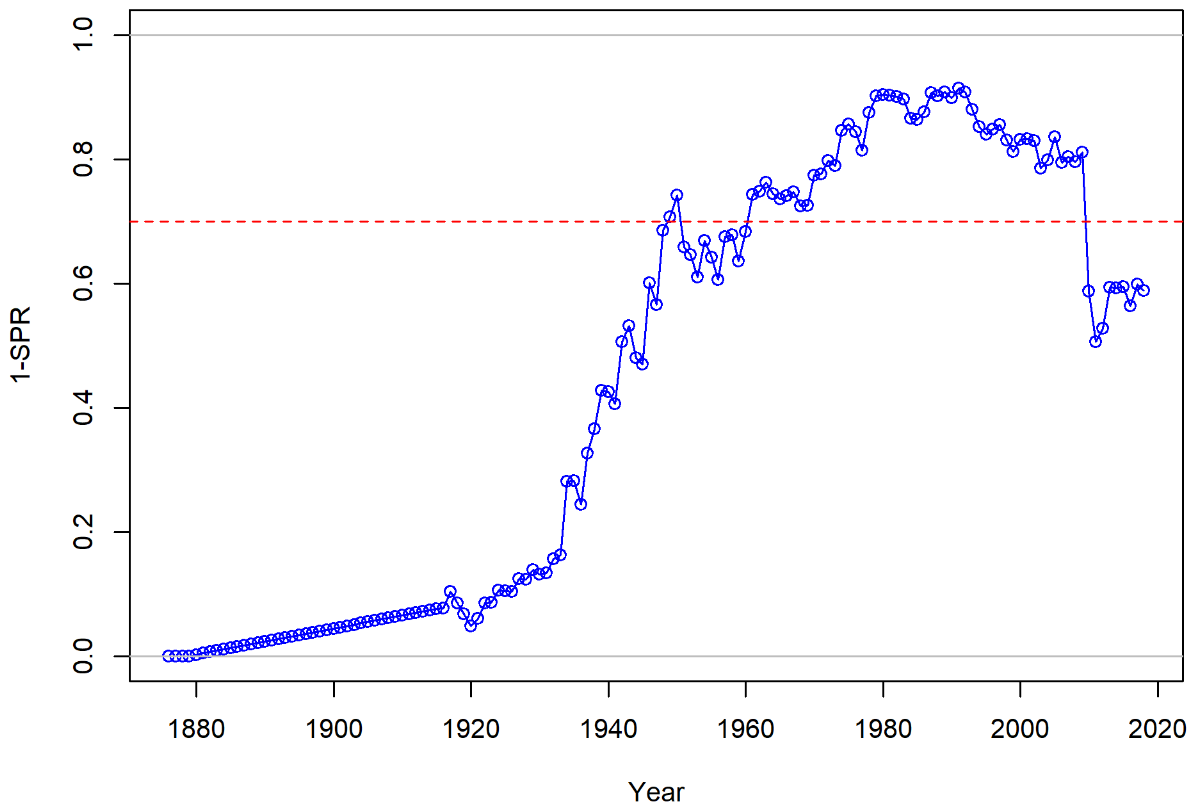

Figure 119: Estimated relative spawning potential ratio 1-SPR for the base model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the SPR30% harvest rate. The last year in the time-series is 2018. fig:SPR_all_fig

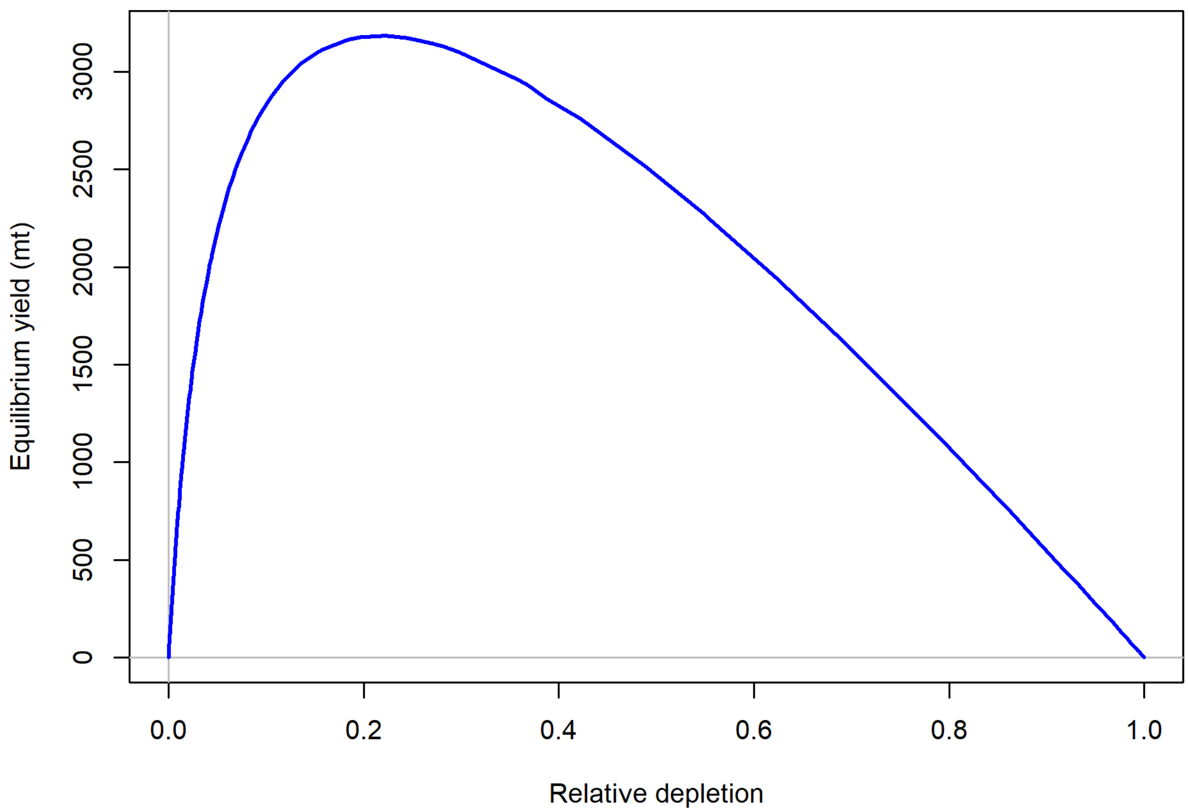

Figure 120: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness estimated at 0.86. fig:yield

11 Appendix A. Detailed Fit to Length Composition Data

appendix-a.-detailed-fit-to-length-composition-data

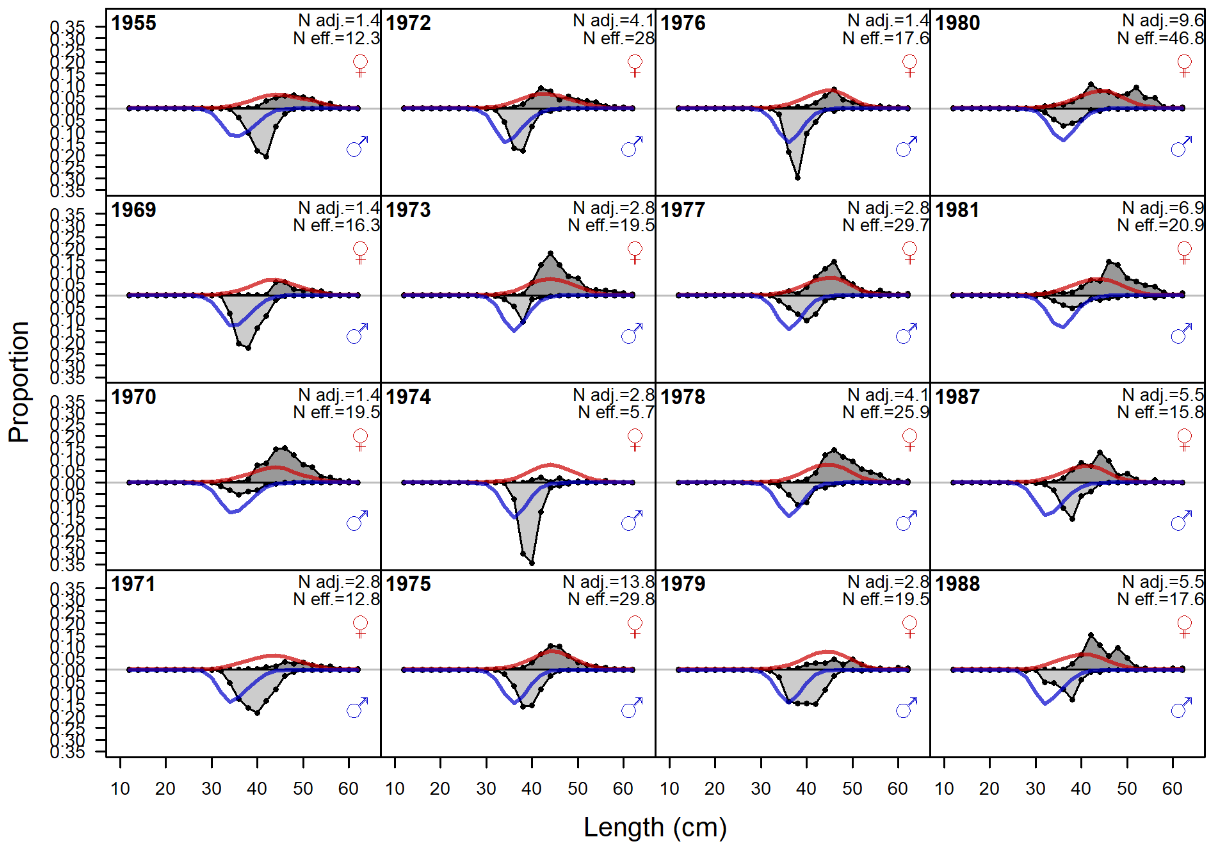

Figure 121: Length comps, retained, Winter (N) (plot 1 of 3). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method. fig:length_fits

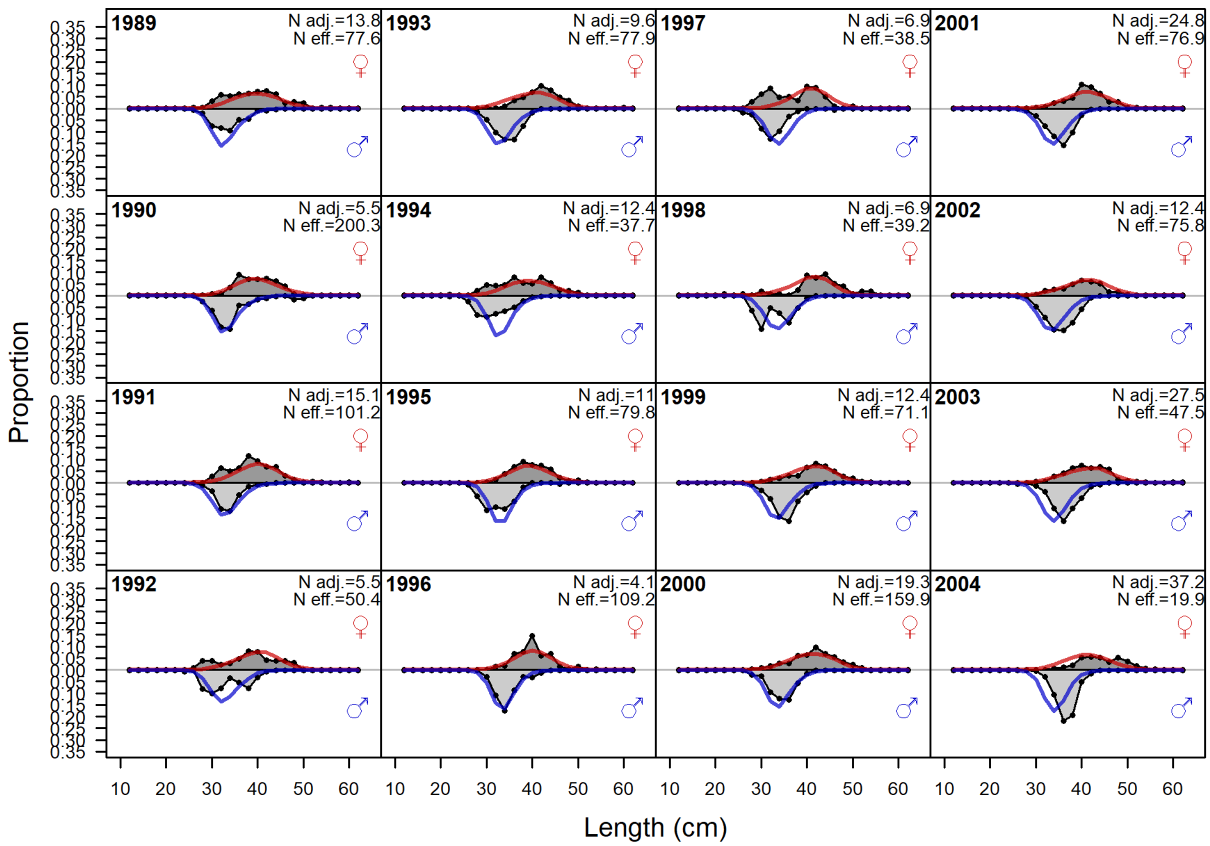

Figure 122: Length comps, retained, Winter (N) (plot 2 of 3) fig:length_fits

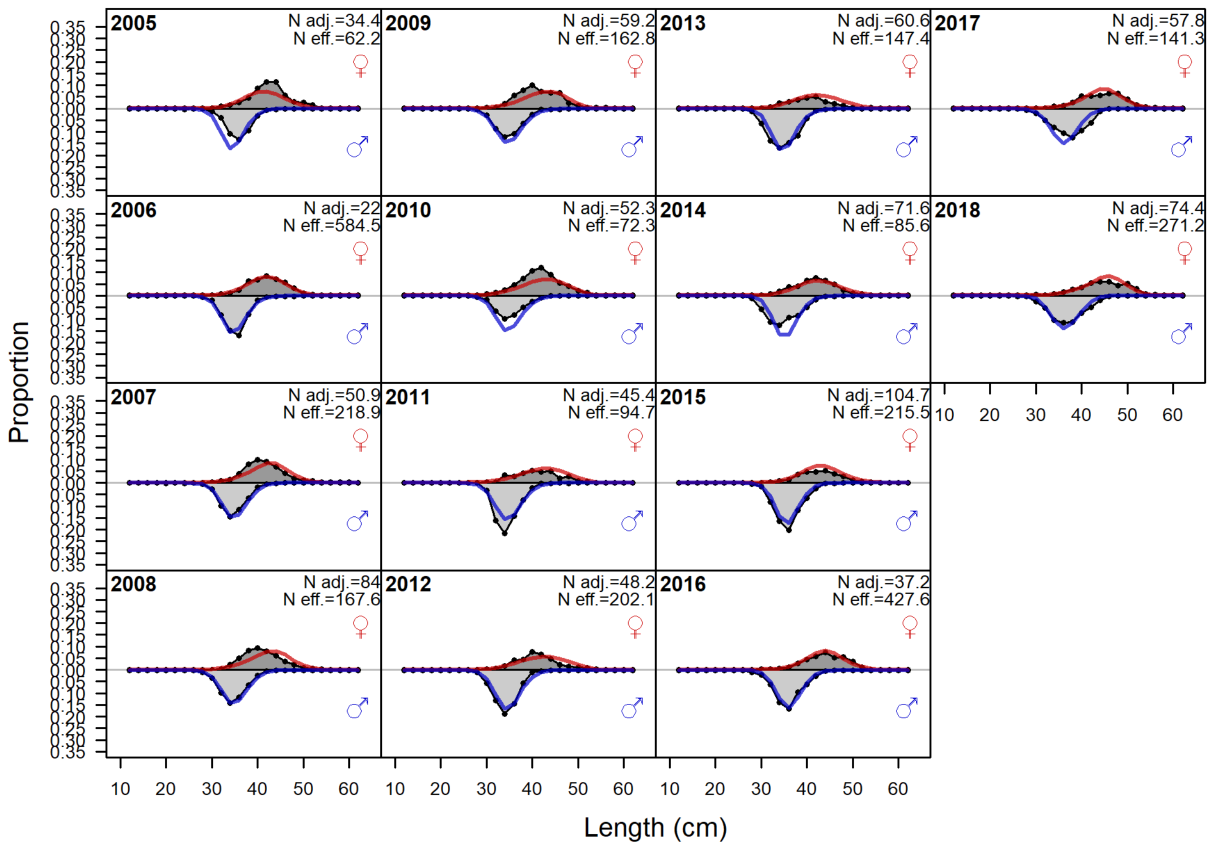

Figure 123: Length comps, retained, Winter (N) (plot 3 of 3) fig:length_fits

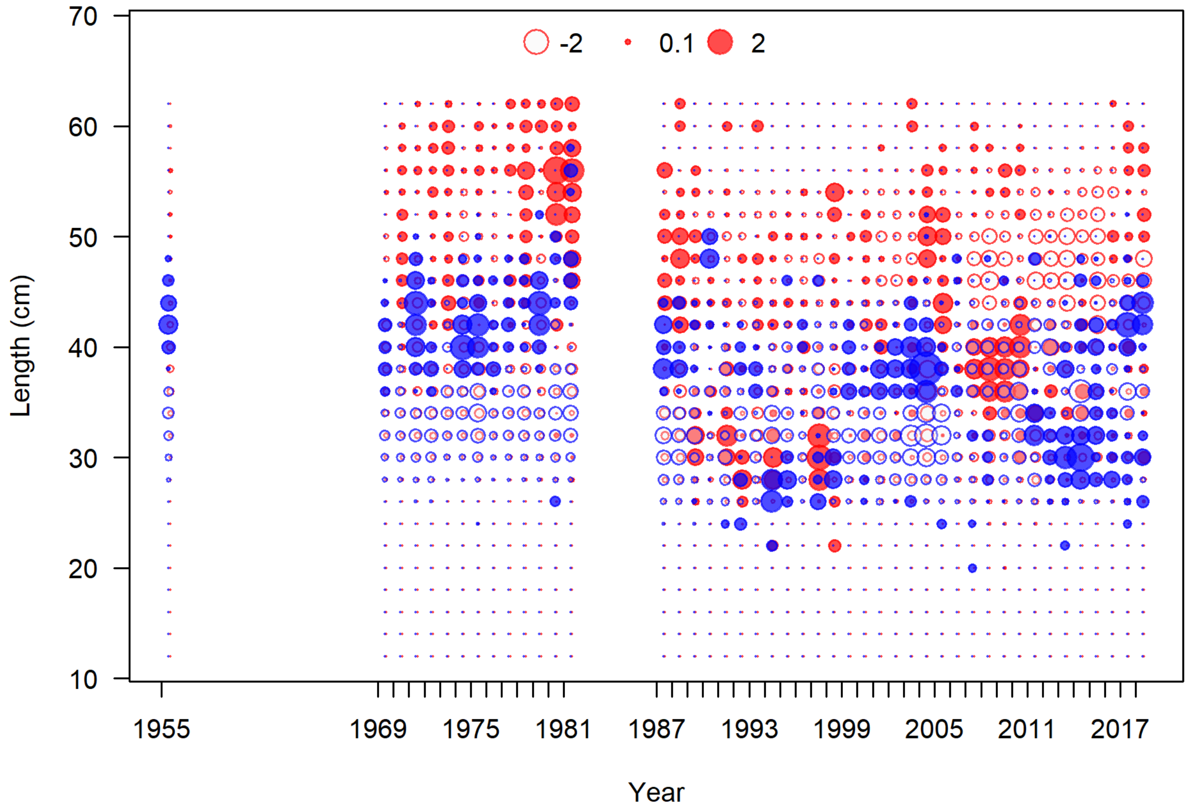

Figure 124: Pearson residuals, retained, Winter (N) (max=3.47) (plot 3 of 3)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

Figure 125: Pearson residuals, discard, Winter (N) (max=6.3)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

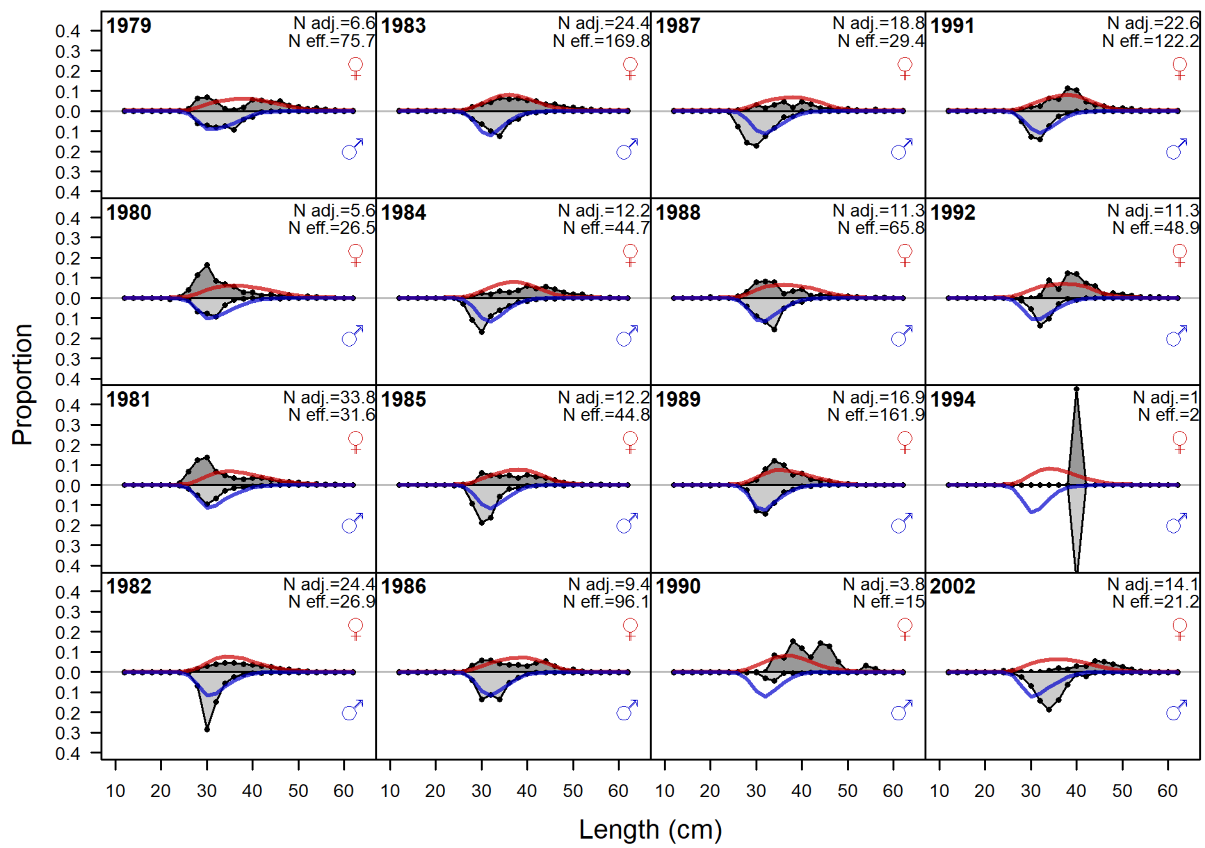

Figure 126: Length comps, retained, Summer (N) (plot 2 of 3) fig:length_fits

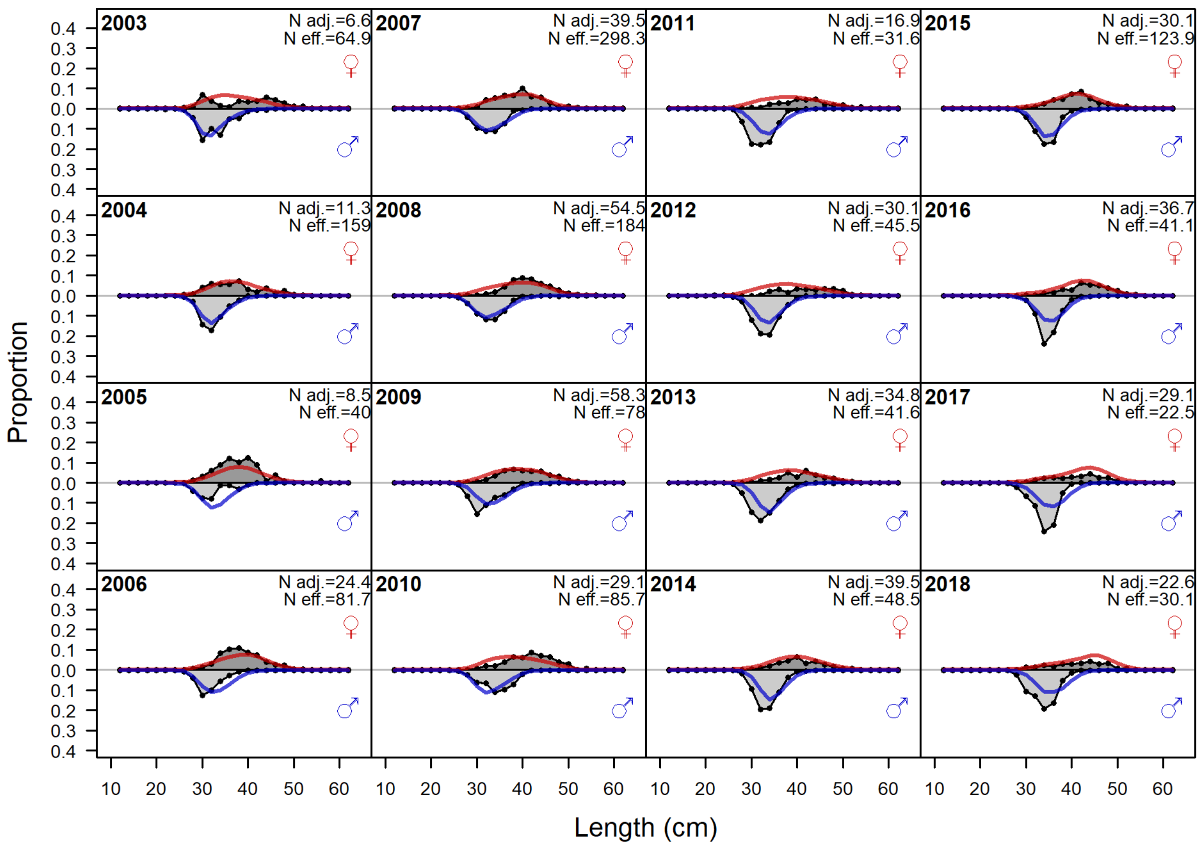

Figure 127: Length comps, retained, Summer (N) (plot 3 of 3) fig:length_fits

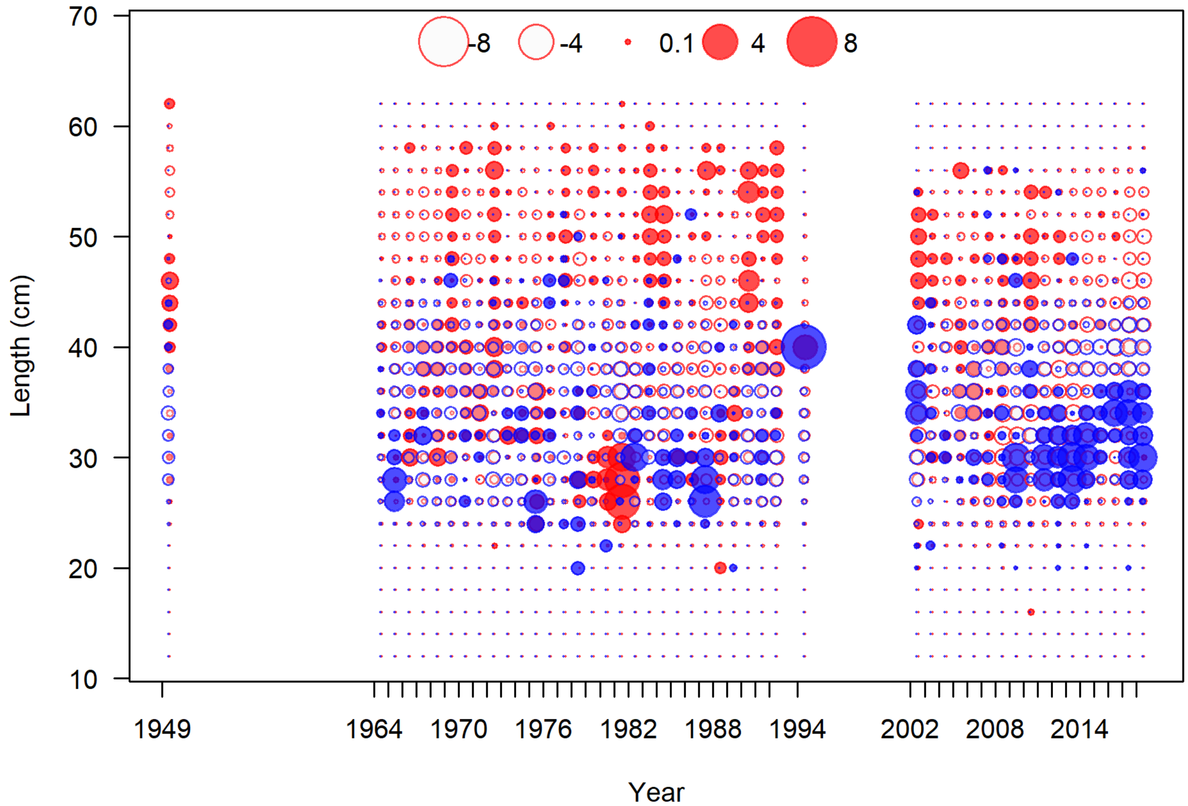

Figure 128: Pearson residuals, retained, Summer (N) (max=6.45) (plot 3 of 3)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

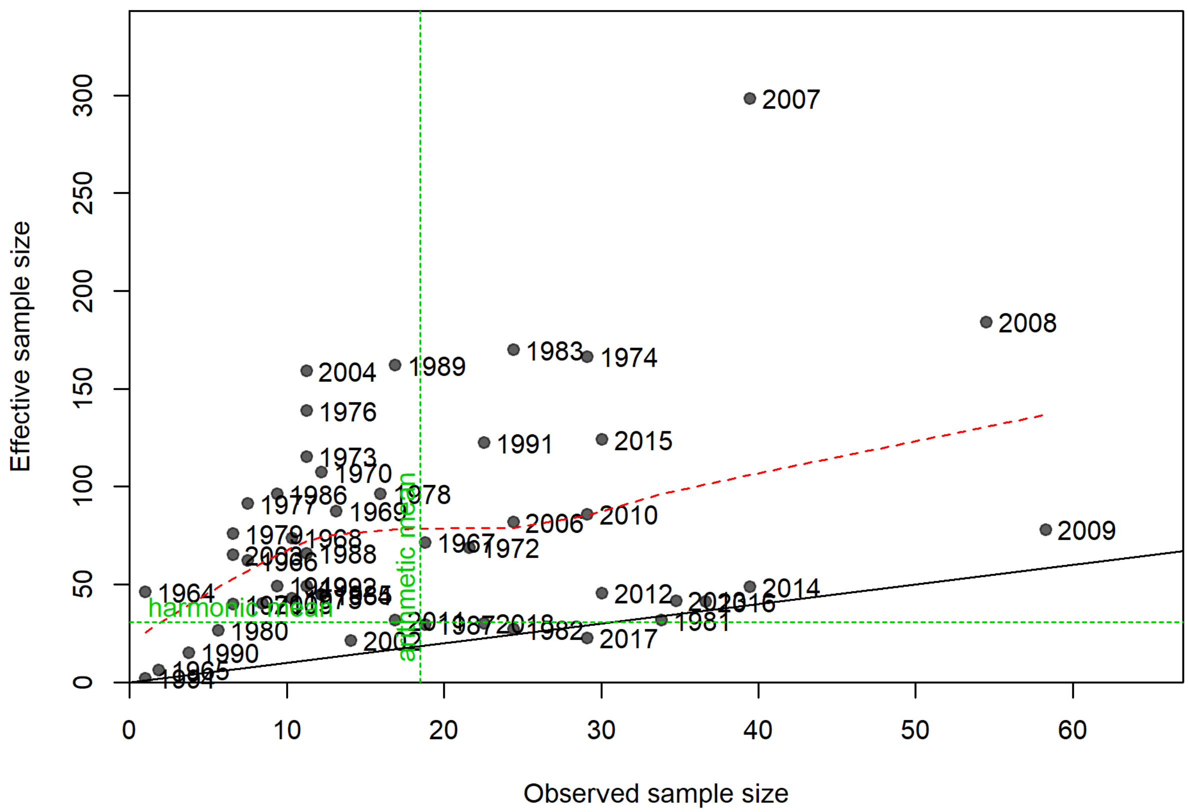

Figure 129: N_EffN comparison, Length comps, retained, Summer (N) fig:length_fits

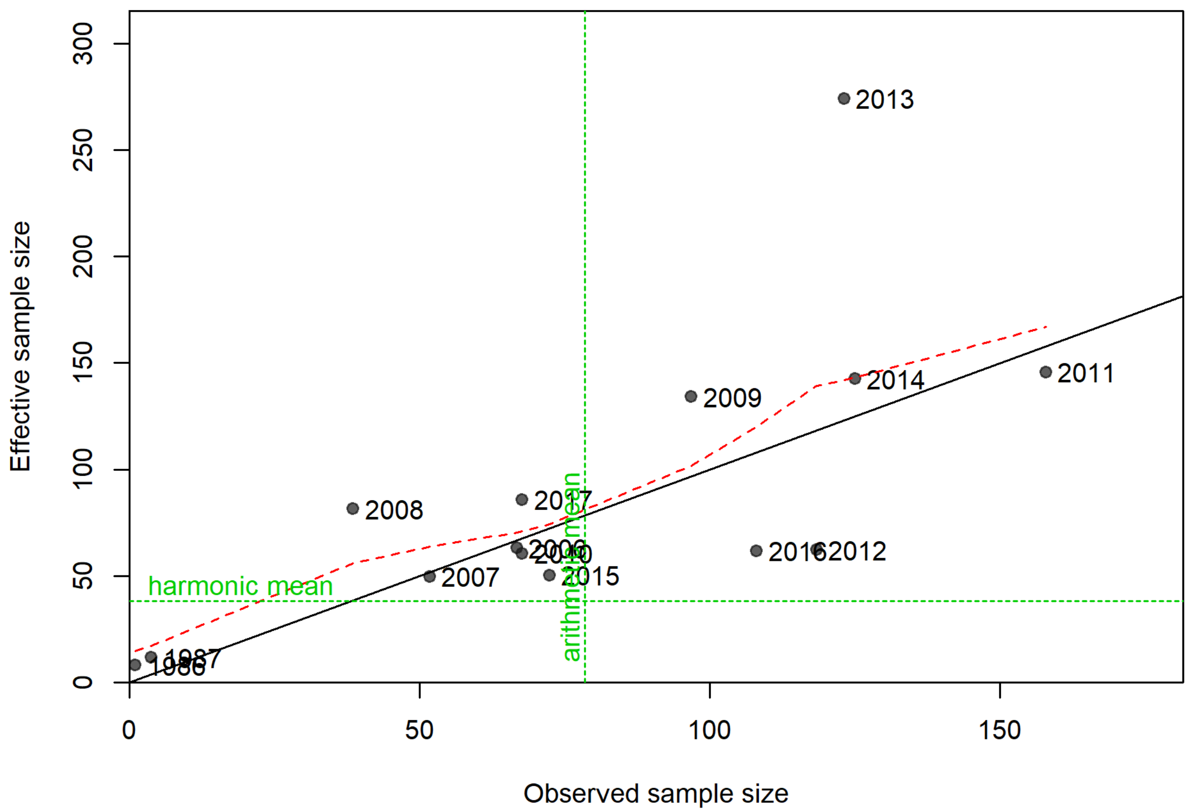

Figure 130: N_EffN comparison, Length comps, discard, Summer (N) fig:length_fits

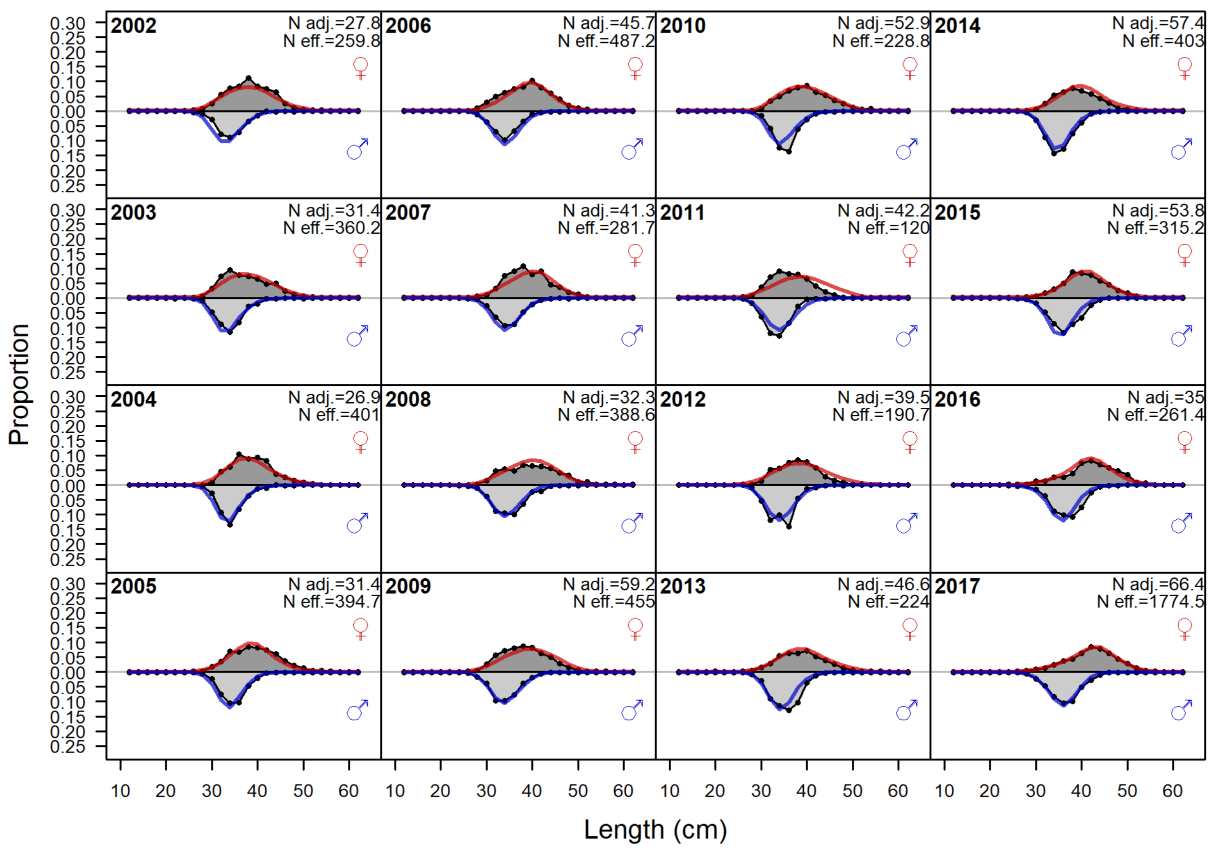

Figure 131: Length comps, retained, Winter (S) (plot 3 of 4) fig:length_fits

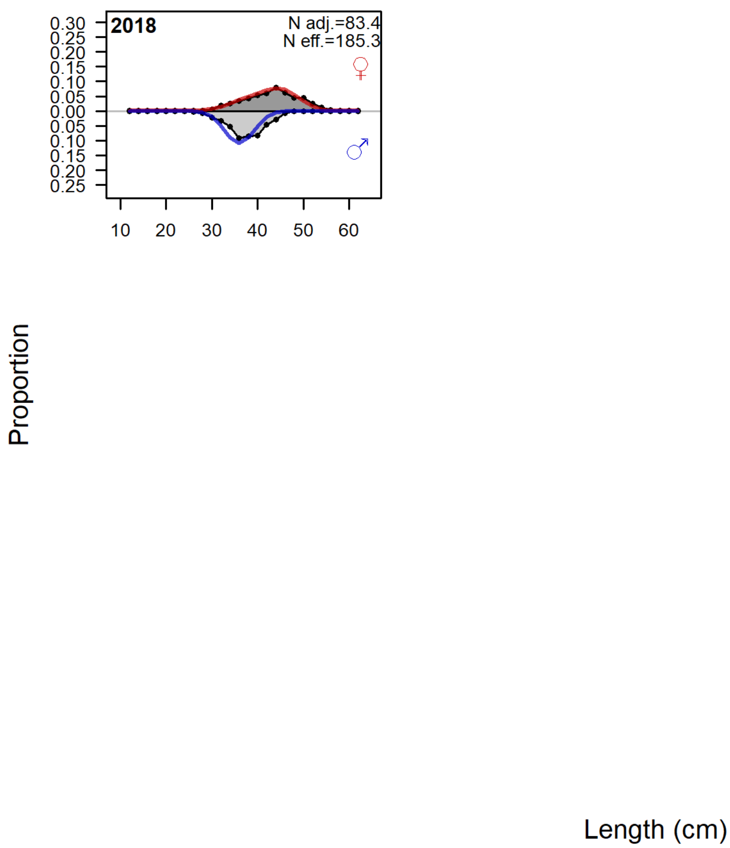

Figure 132: Length comps, retained, Winter (S) (plot 4 of 4) fig:length_fits

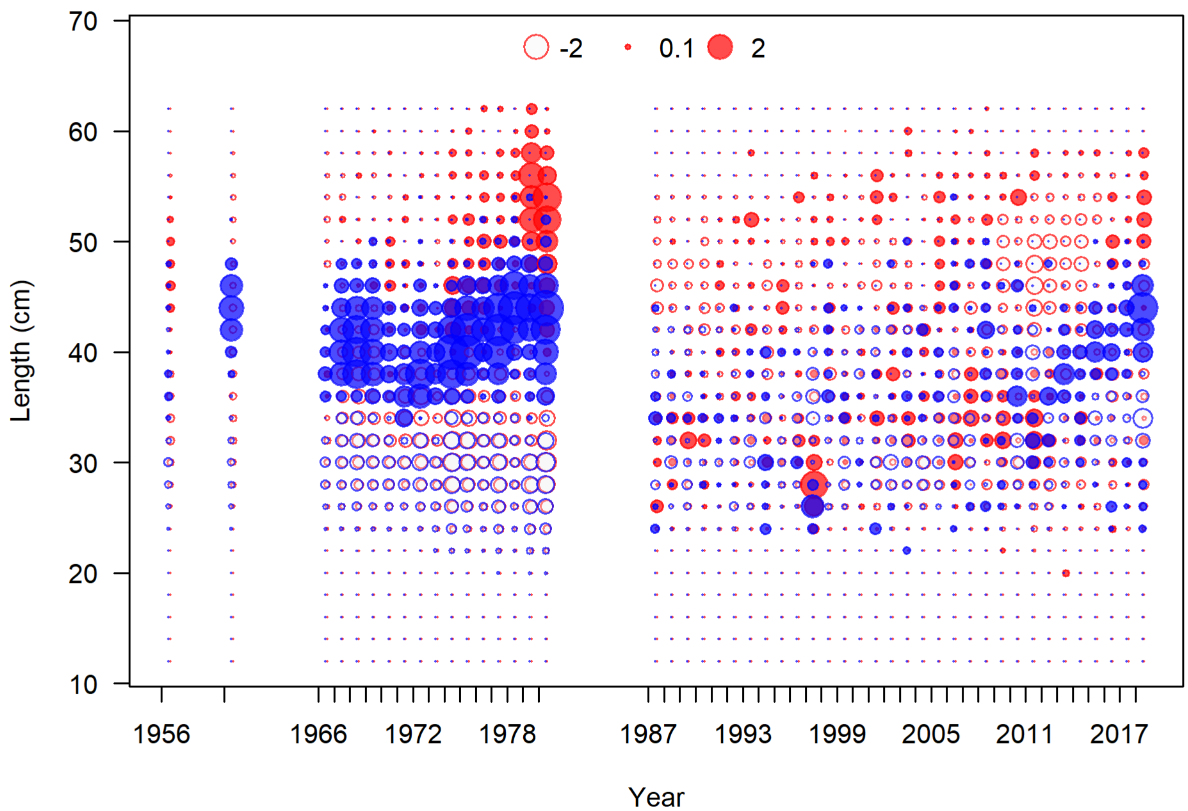

Figure 133: Pearson residuals, retained, Winter (S) (max=3.92) (plot 4 of 4)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

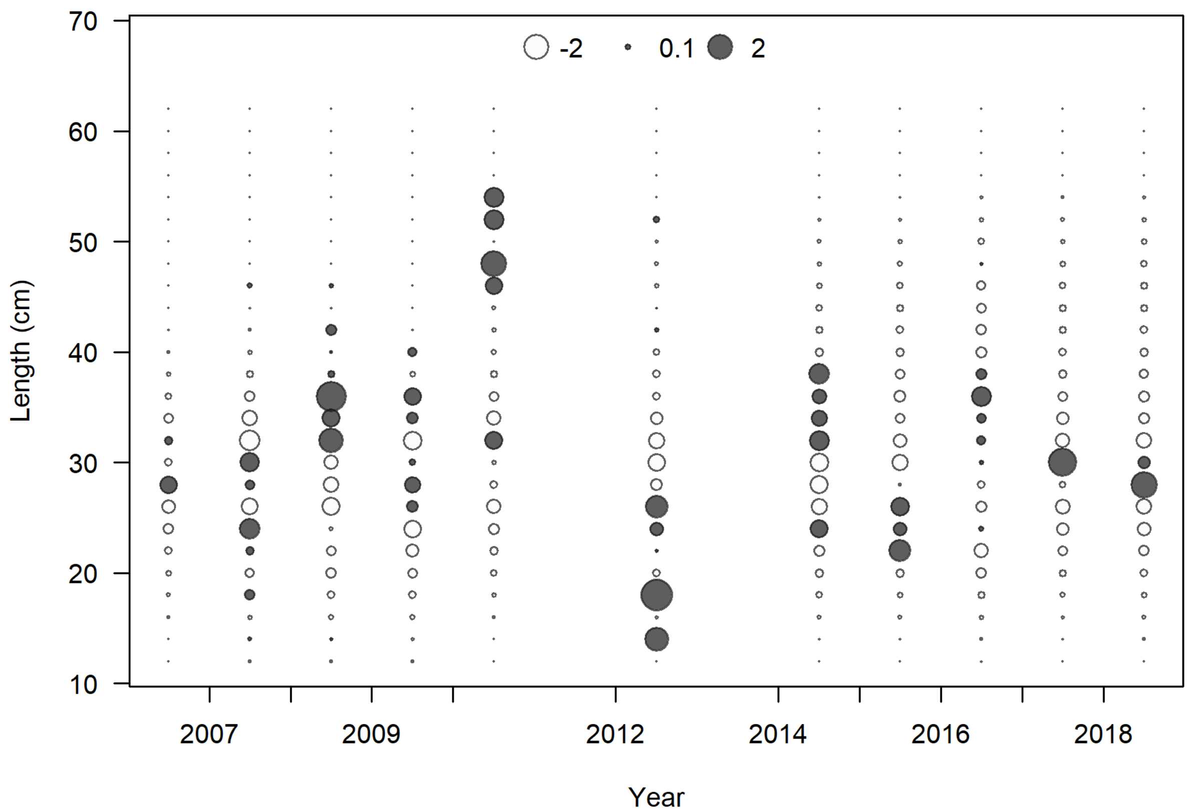

Figure 134: Pearson residuals, discard, Winter (S) (max=3.19)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

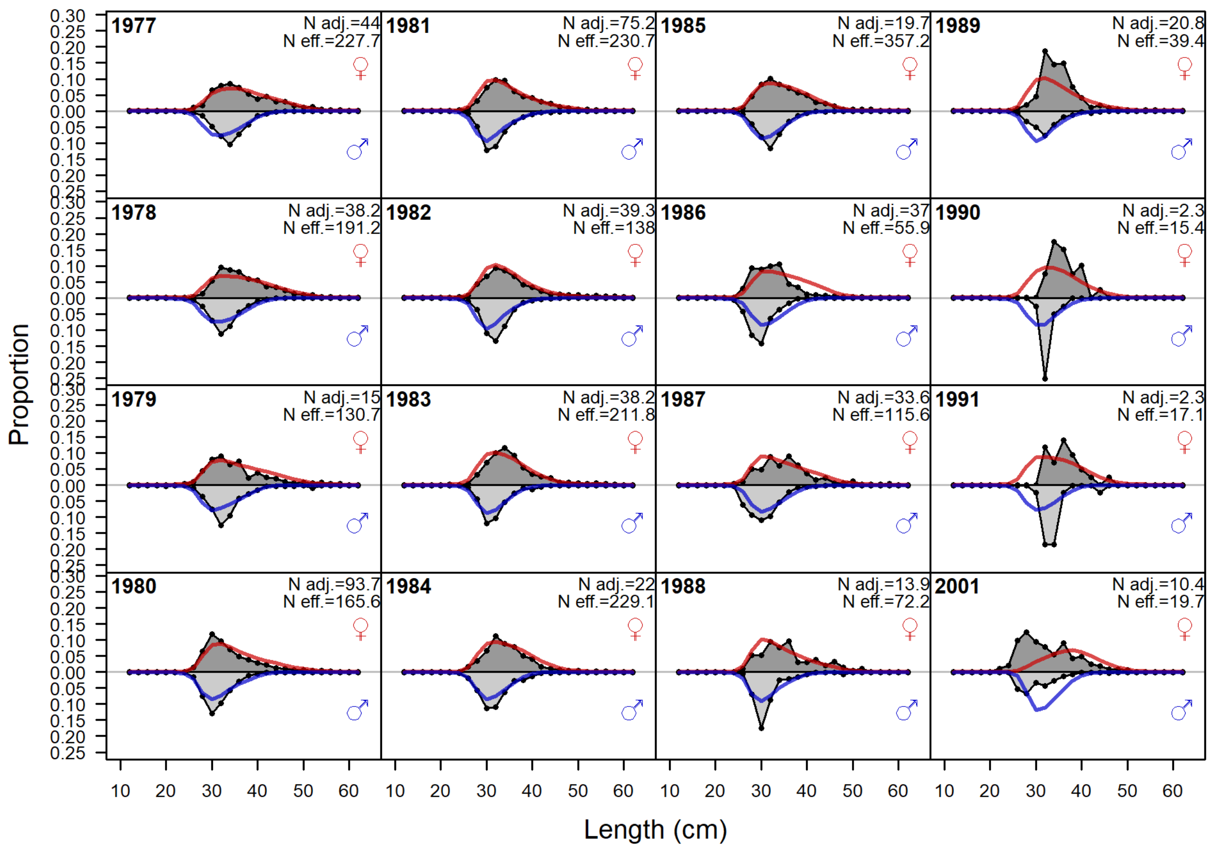

Figure 135: Length comps, retained, Summer (S) (plot 2 of 4) fig:length_fits

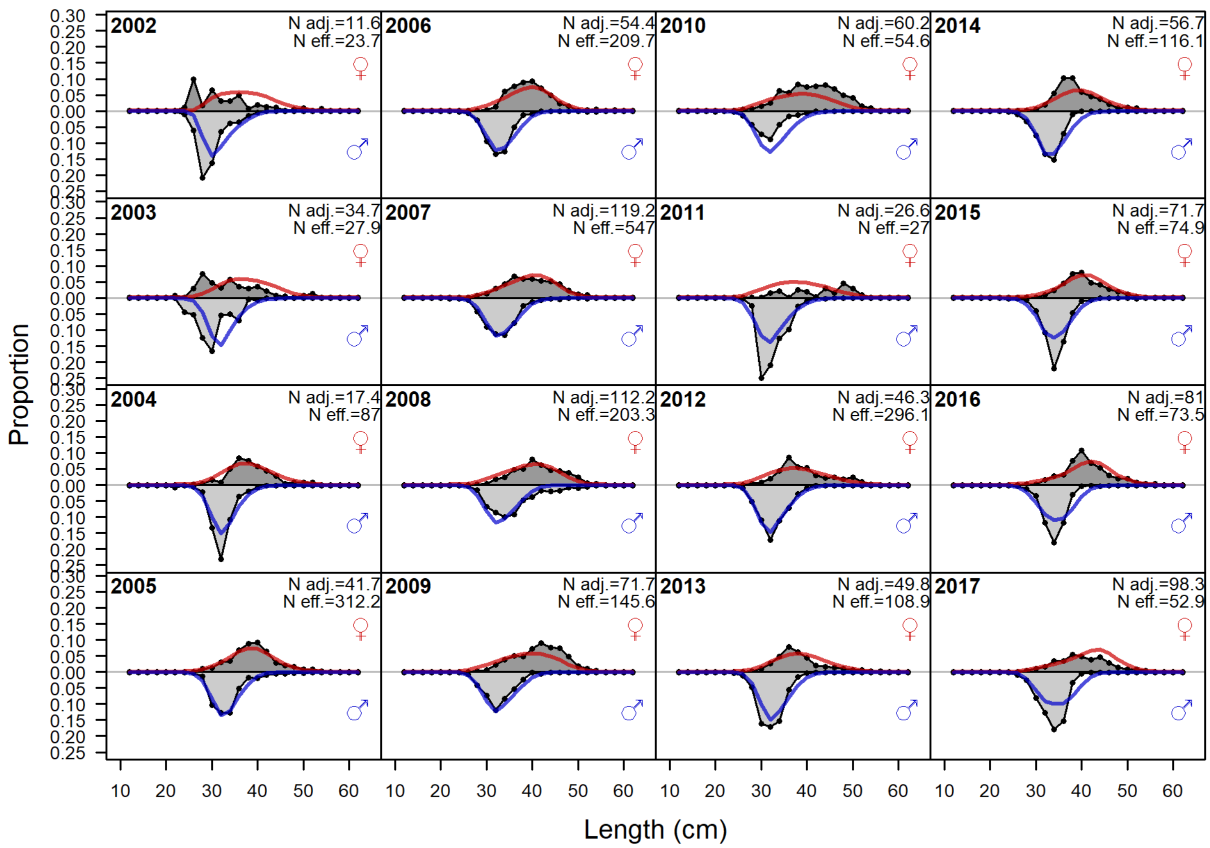

Figure 136: Length comps, retained, Summer (S) (plot 3 of 4) fig:length_fits

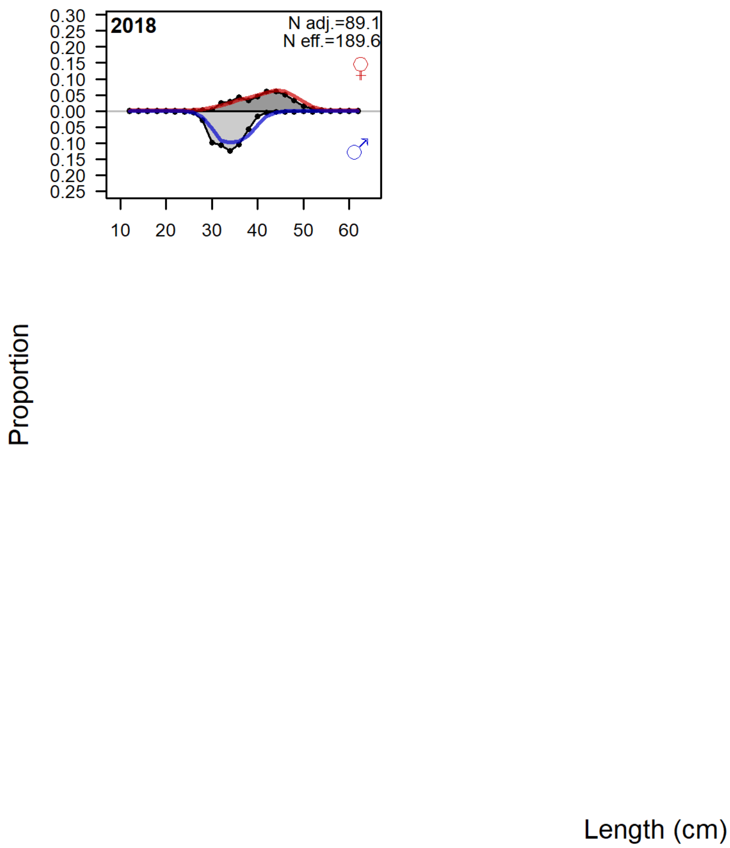

Figure 137: Length comps, retained, Summer (S) (plot 4 of 4) fig:length_fits

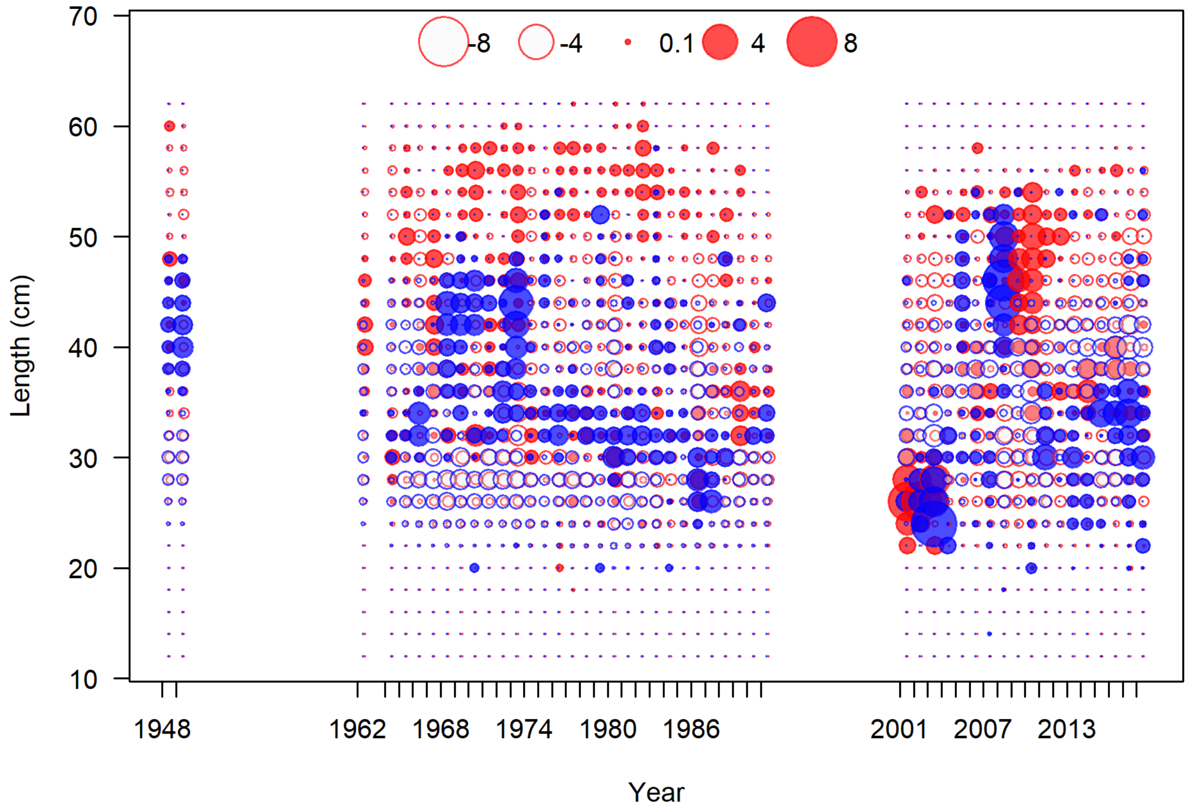

Figure 138: Pearson residuals, retained, Summer (S) (max=6.51) (plot 4 of 4)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

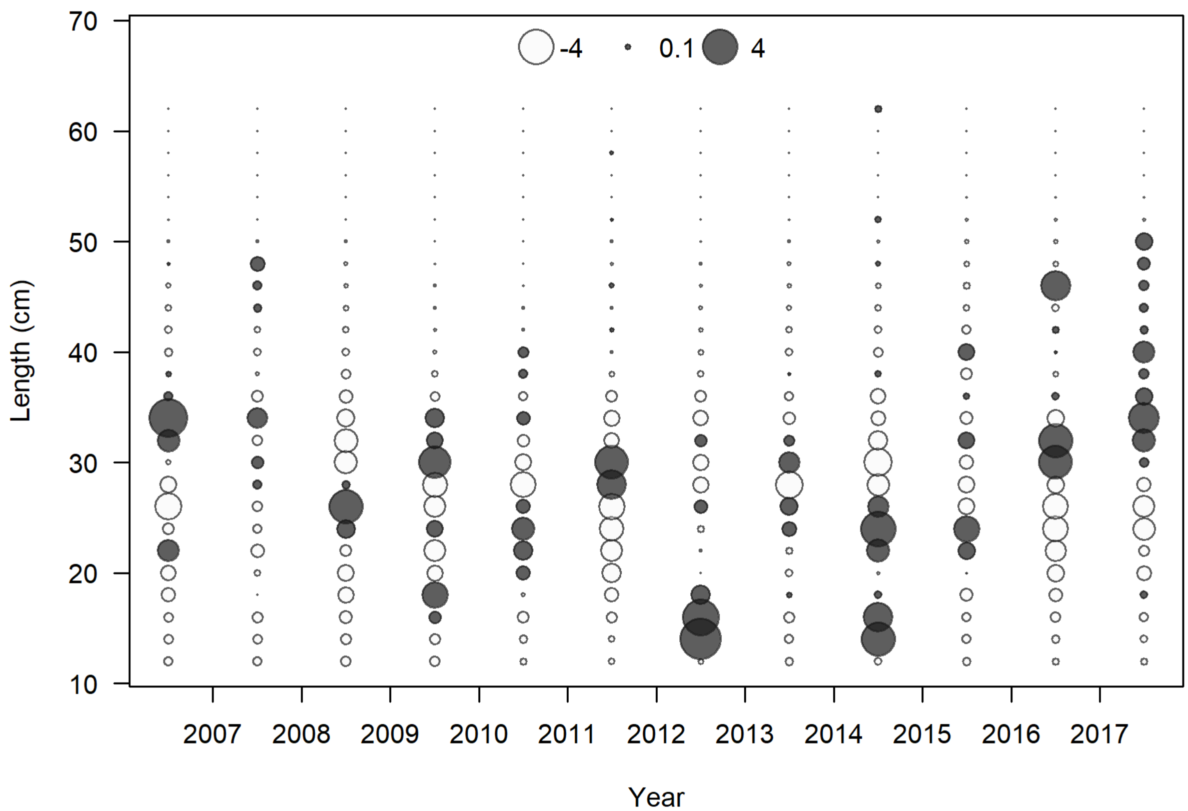

Figure 139: Pearson residuals, discard, Summer (S) (max=5.31)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

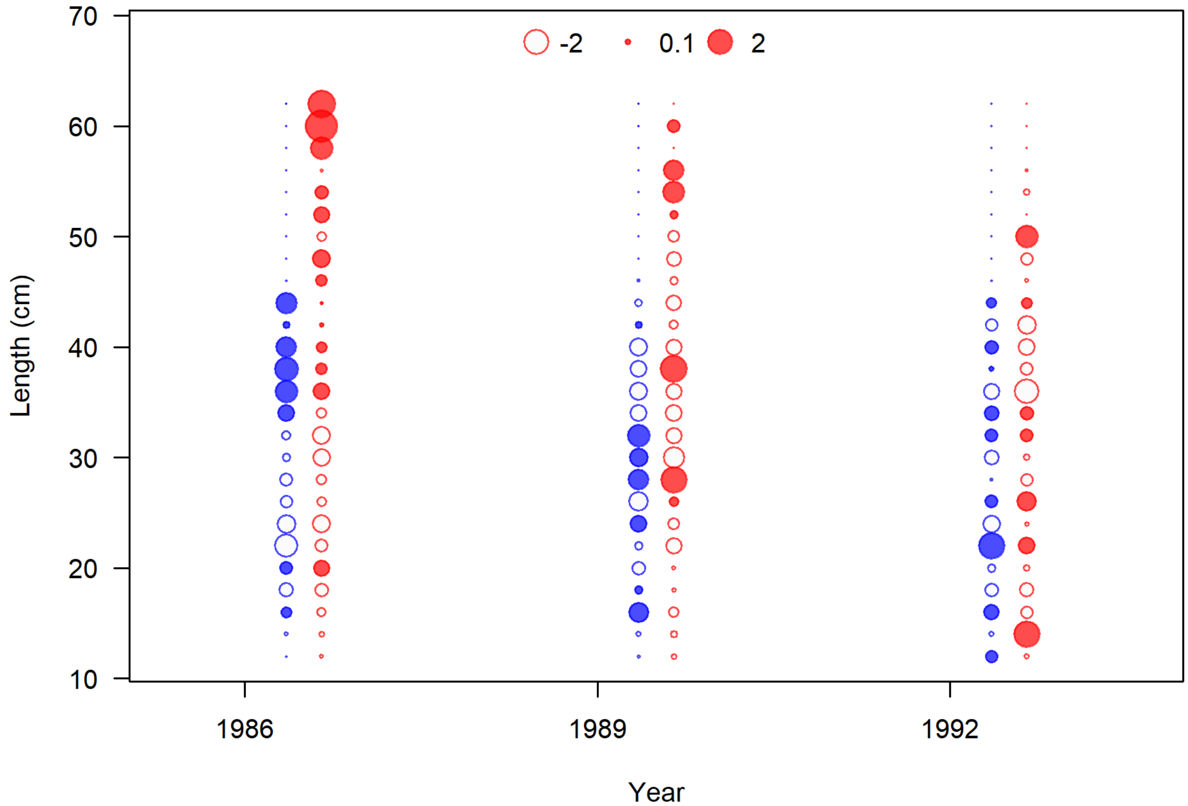

Figure 140: Pearson residuals, whole catch, Triennial _ Early (max=3.23)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

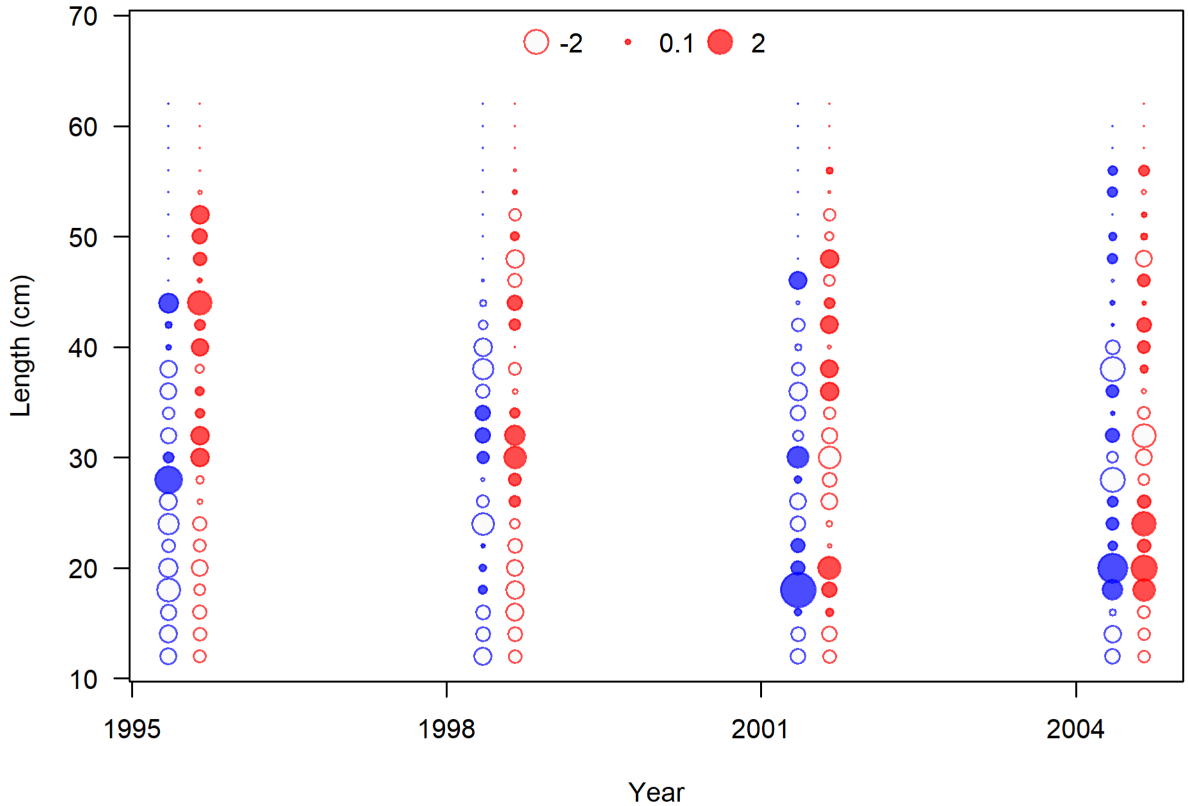

Figure 141: Pearson residuals, whole catch, Triennial _ Late (max=3.91)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

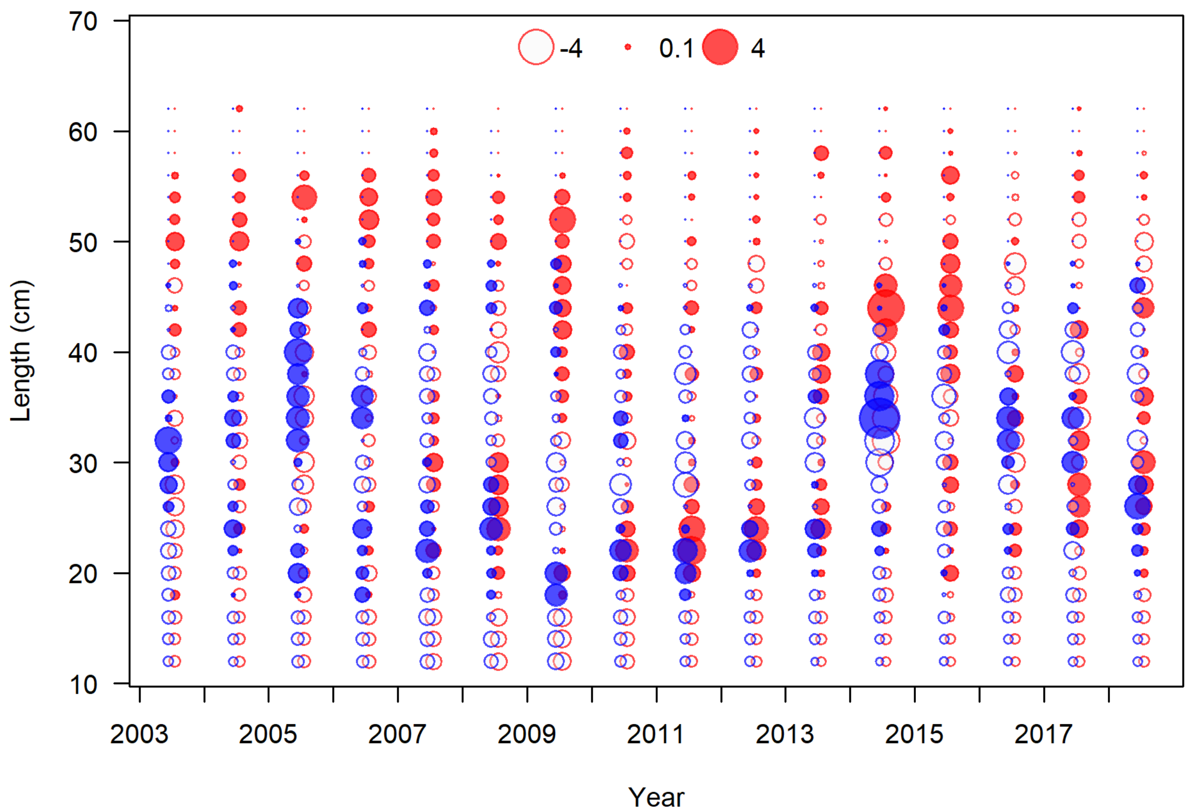

Figure 142: Pearson residuals, whole catch, NWFSC West Coast Groundfish Bottom Trawl Survey (max=5.12)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:length_fits

12 Appendix B. Detailed Fit to Age Composition Data

appendix-b.-detailed-fit-to-age-composition-data

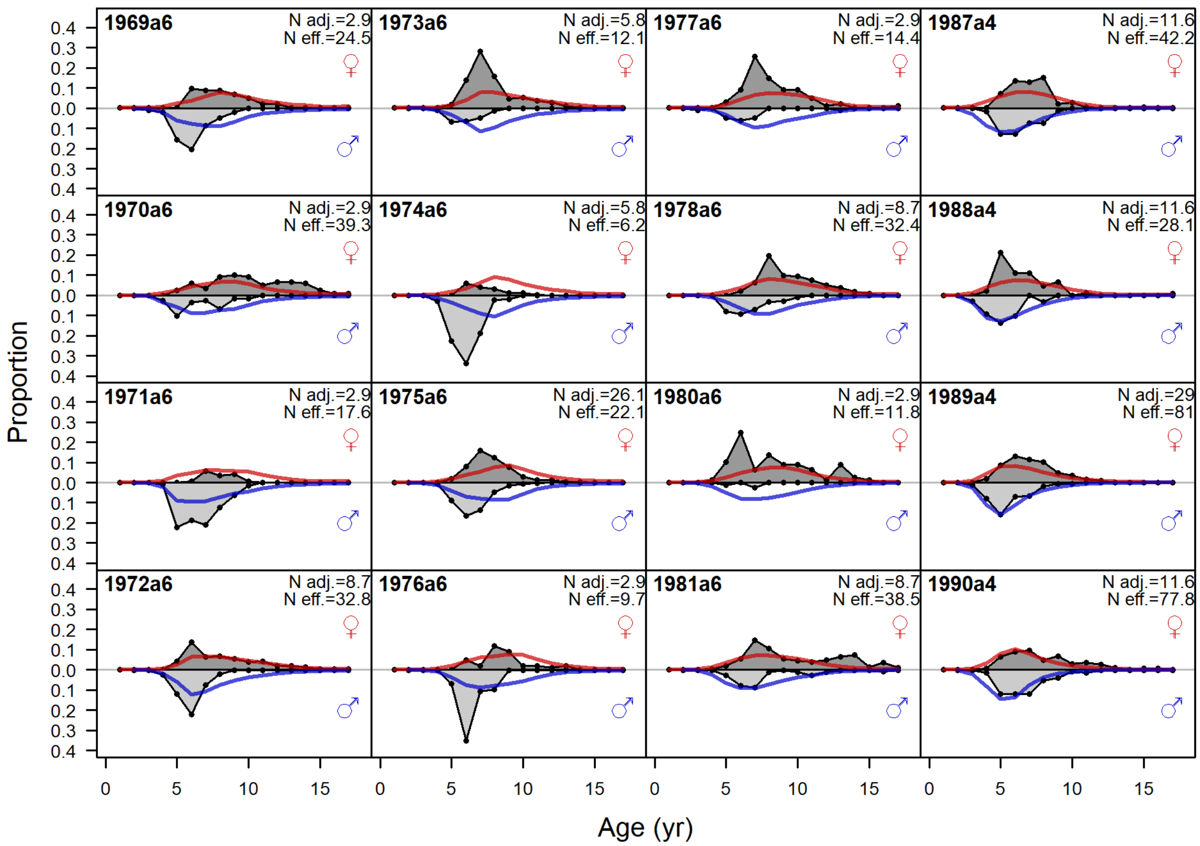

Figure 143: Age comps, retained, Winter (N) (plot 1 of 4). 'N adj.' is the input sample size after data_weighting adjustment. N eff. is the calculated effective sample size used in the McAllister_Iannelli tuning method. fig:age_fits

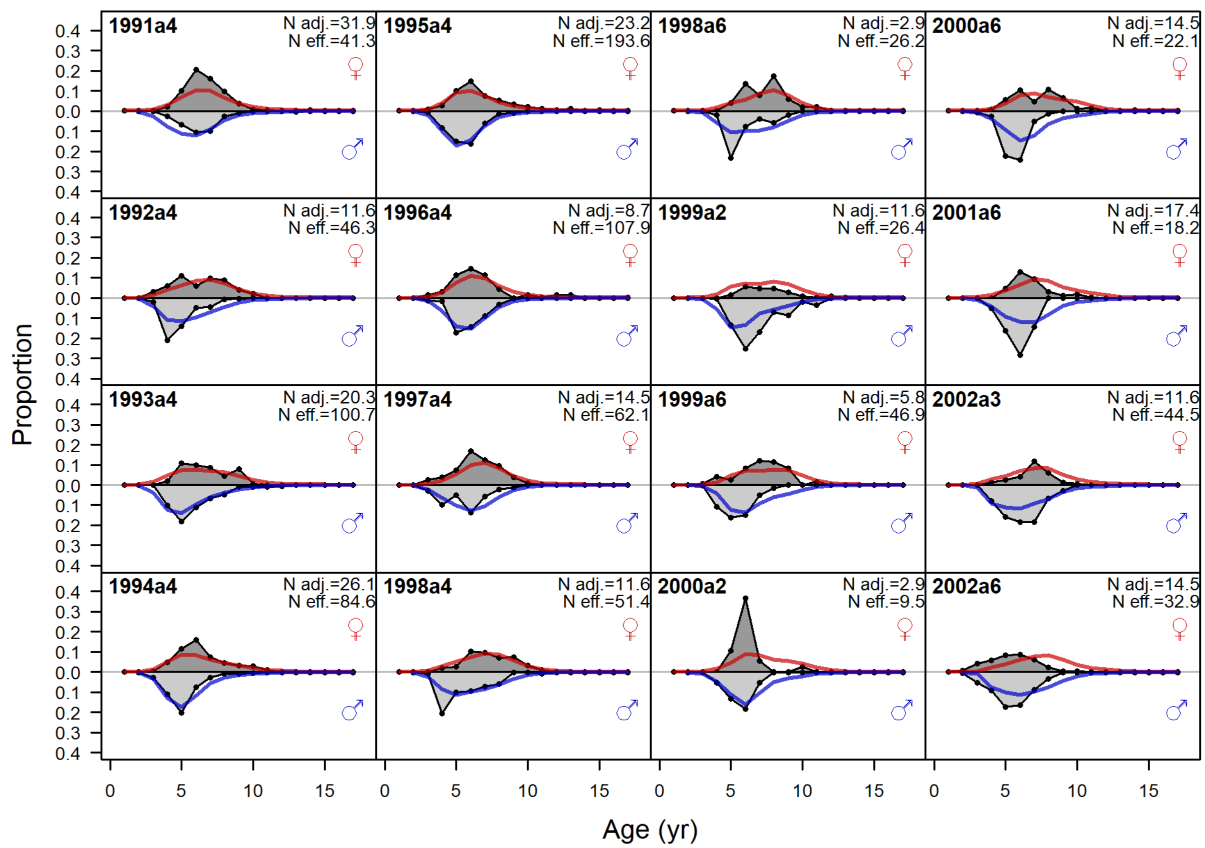

Figure 144: Age comps, retained, Winter (N) (plot 2 of 4) fig:age_fits

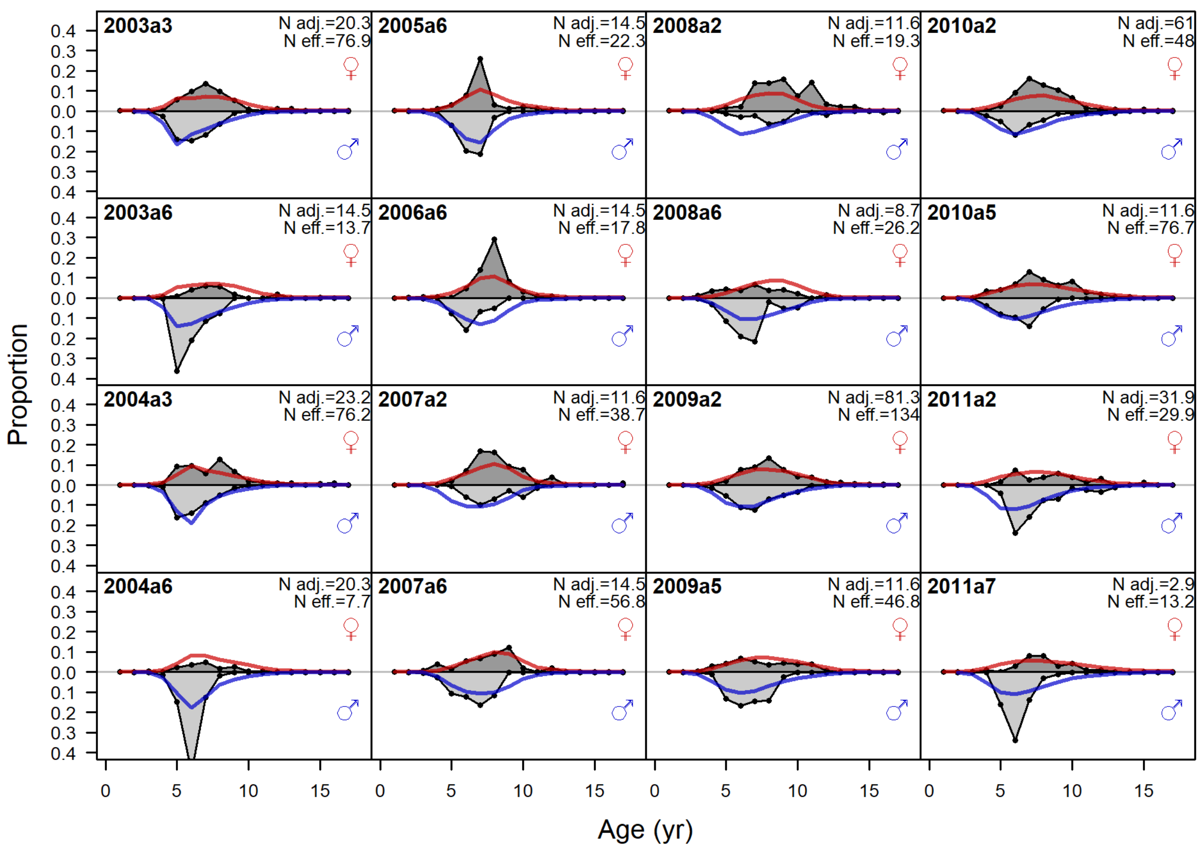

Figure 145: Age comps, retained, Winter (N) (plot 3 of 4) fig:age_fits

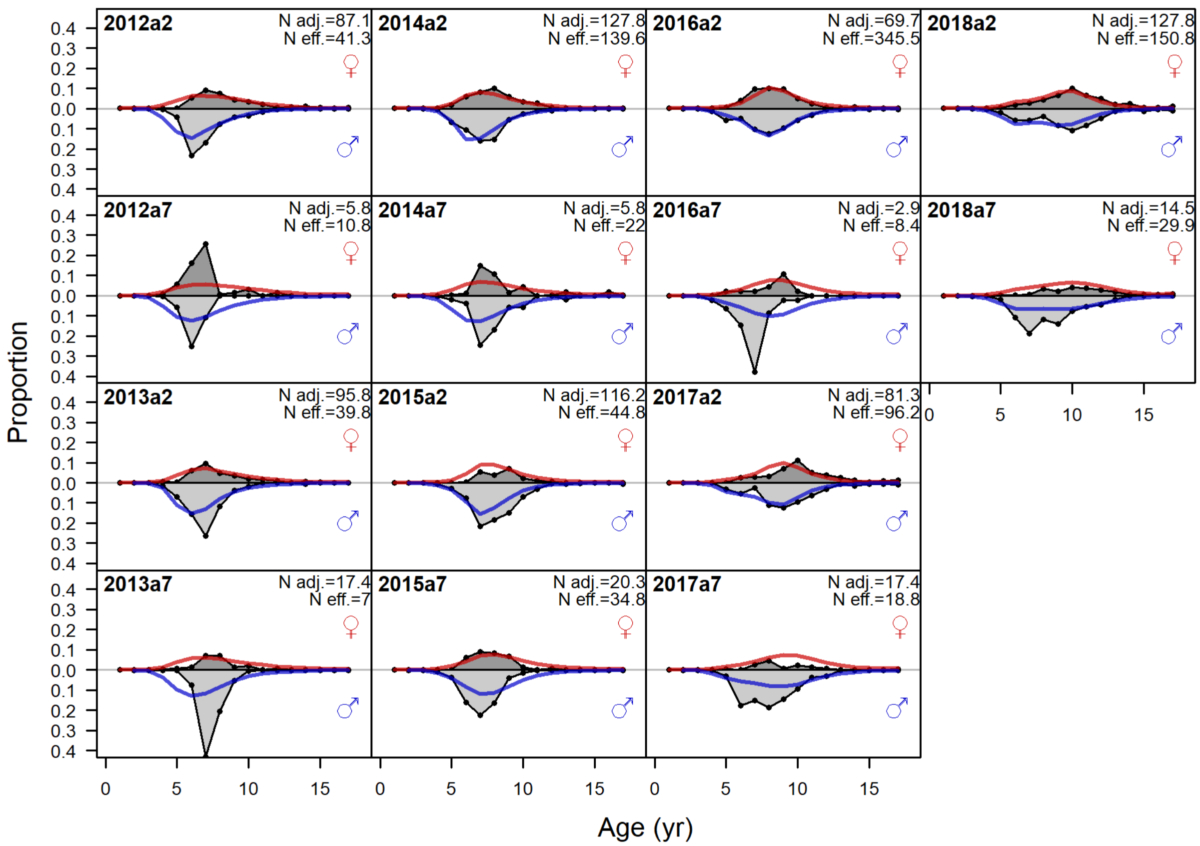

Figure 146: Age comps, retained, Winter (N) (plot 4 of 4) fig:age_fits

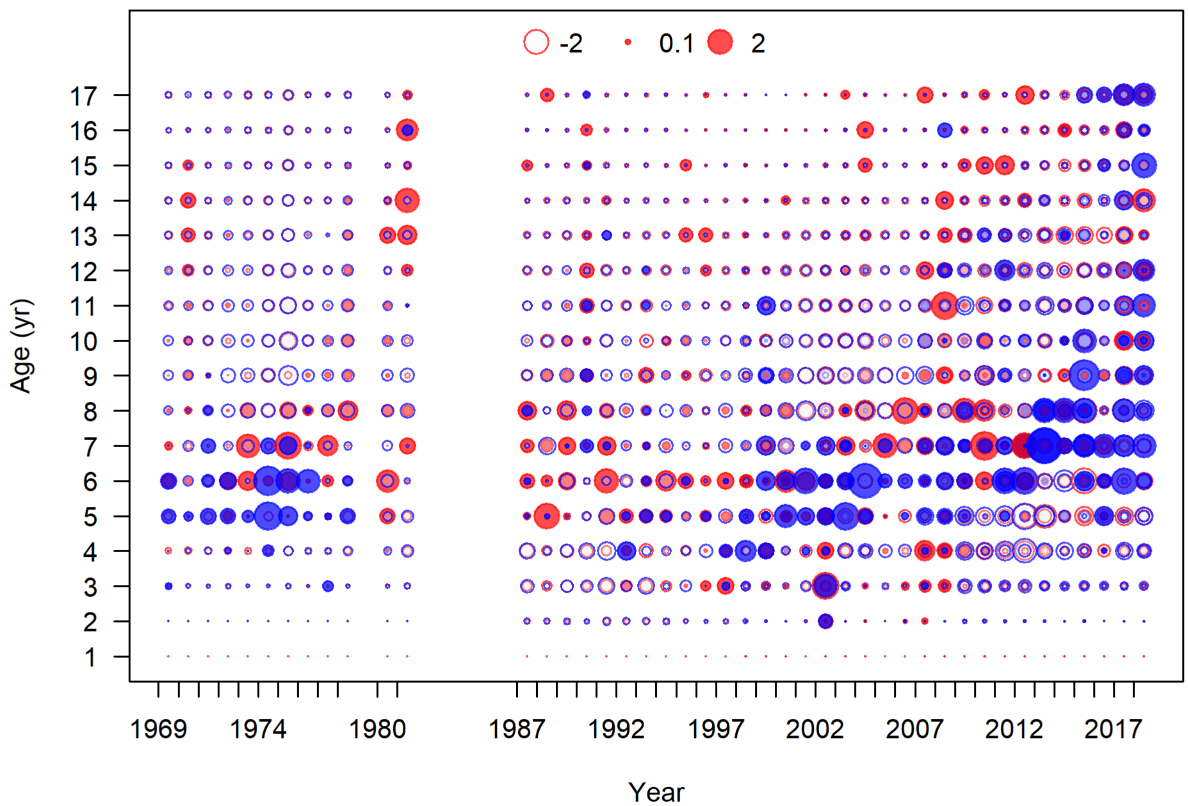

Figure 147: Pearson residuals, retained, Winter (N) (max=4.05) (plot 4 of 4)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:age_fits

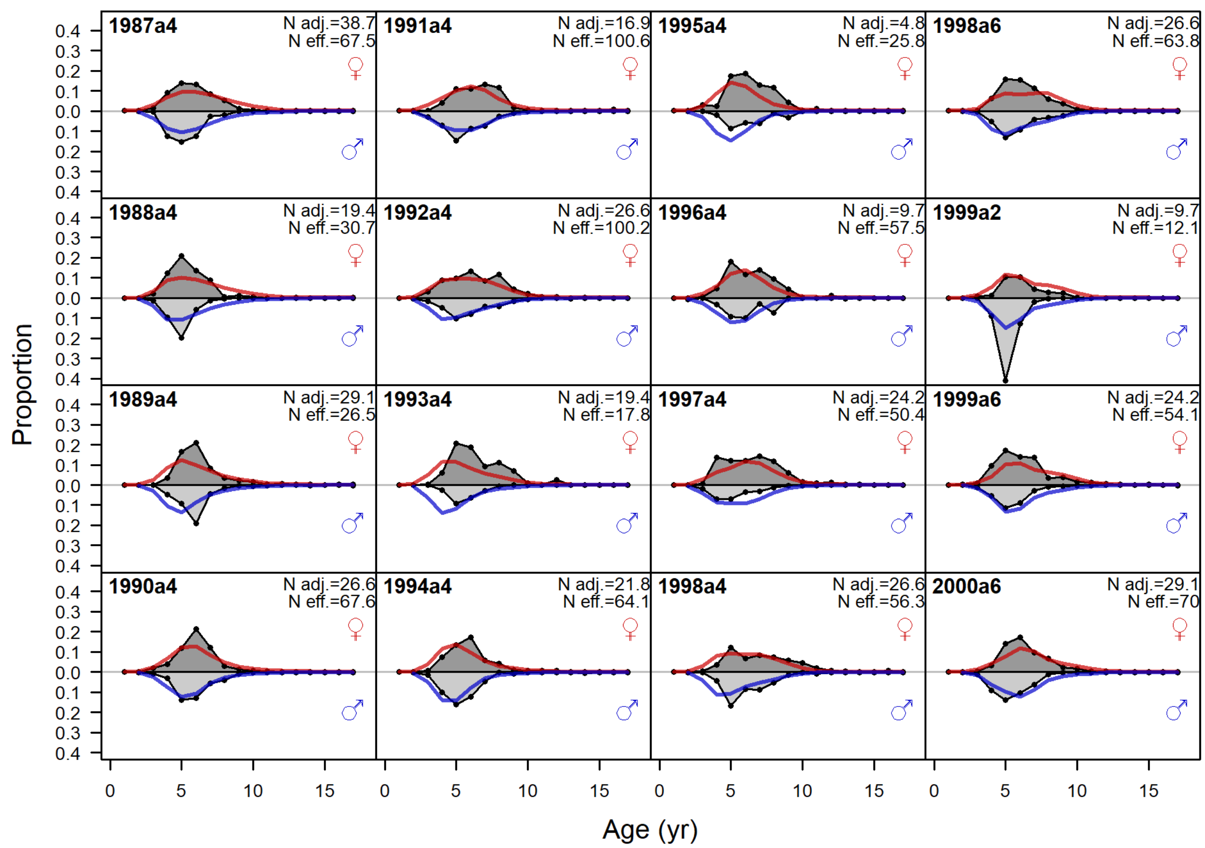

Figure 148: Age comps, retained, Summer (N) (plot 2 of 5) fig:age_fits

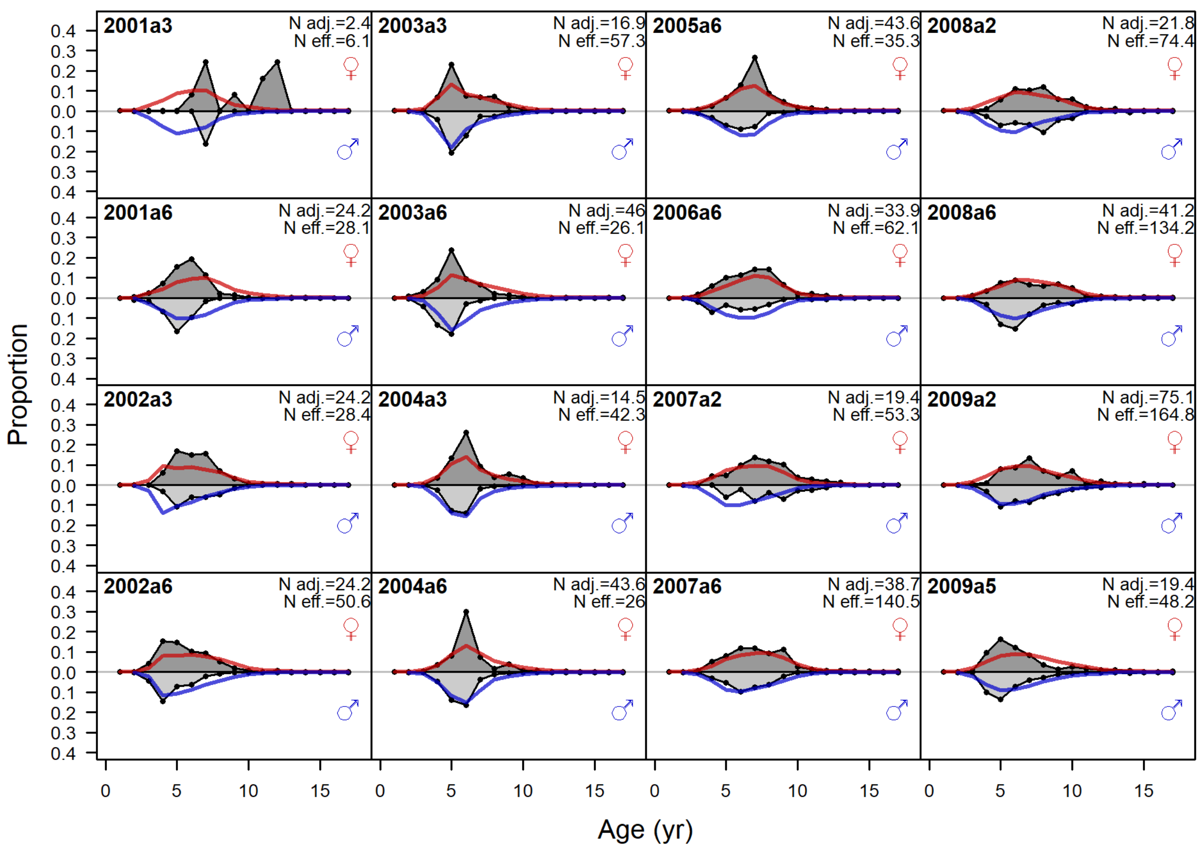

Figure 149: Age comps, retained, Summer (N) (plot 3 of 5) fig:age_fits

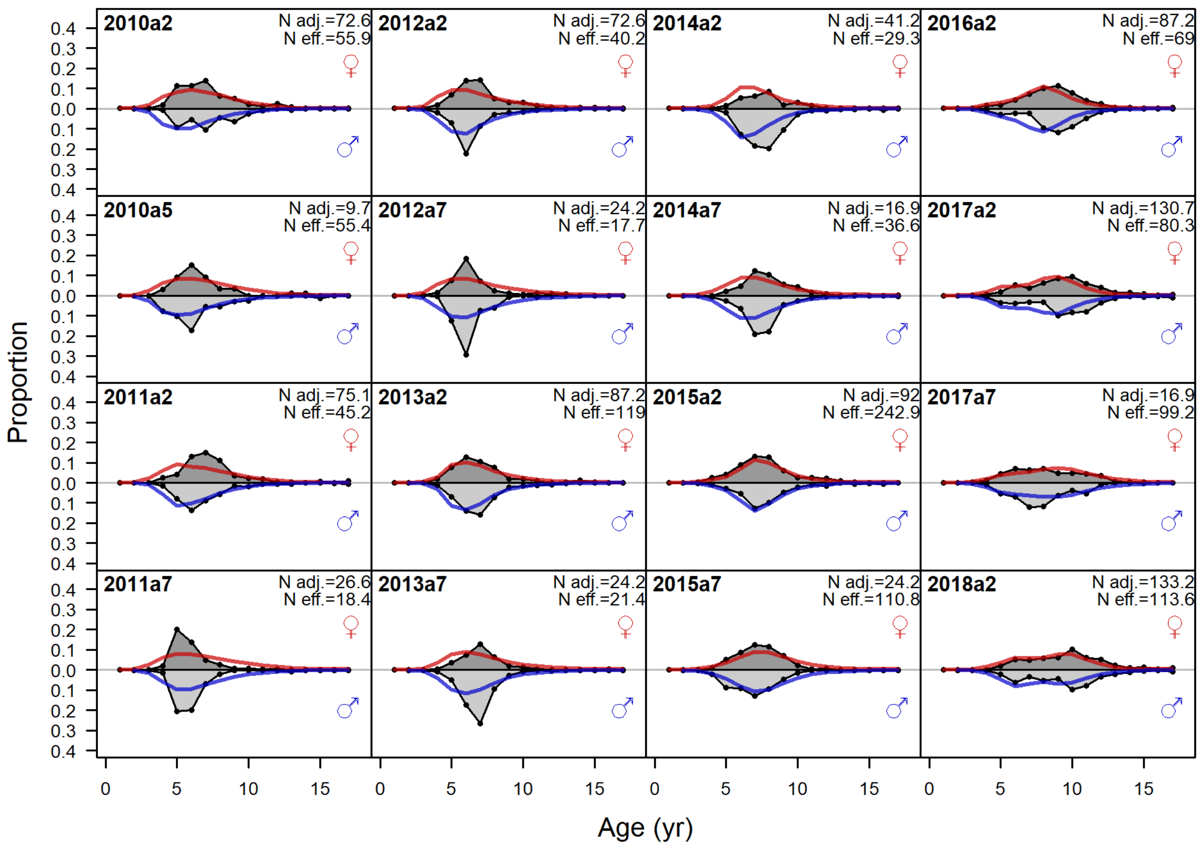

Figure 150: Age comps, retained, Summer (N) (plot 4 of 5) fig:age_fits

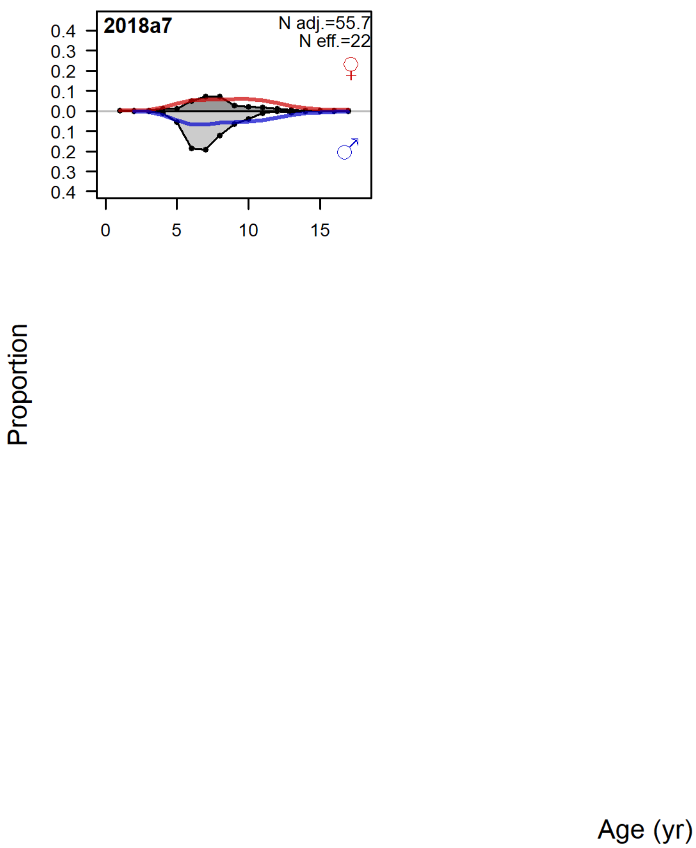

Figure 151: Age comps, retained, Summer (N) (plot 5 of 5) fig:age_fits

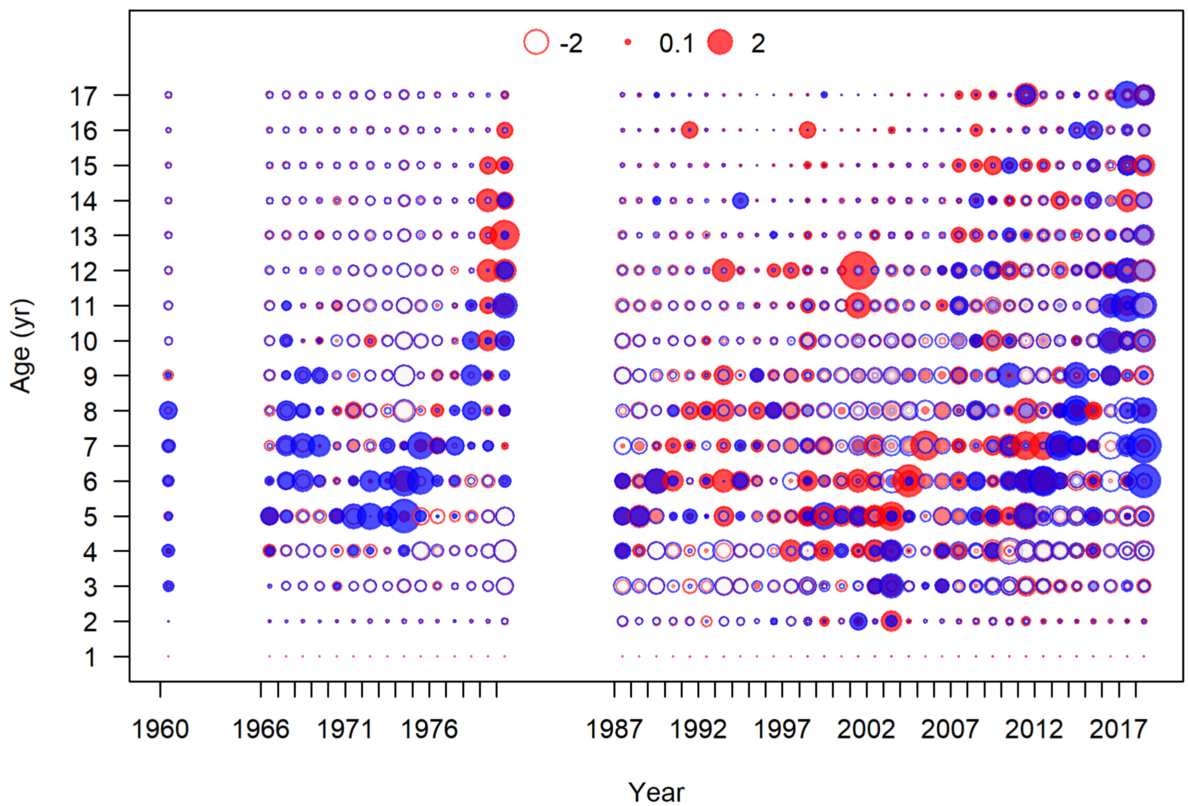

Figure 152: Pearson residuals, retained, Summer (N) (max=4.53) (plot 5 of 5)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:age_fits

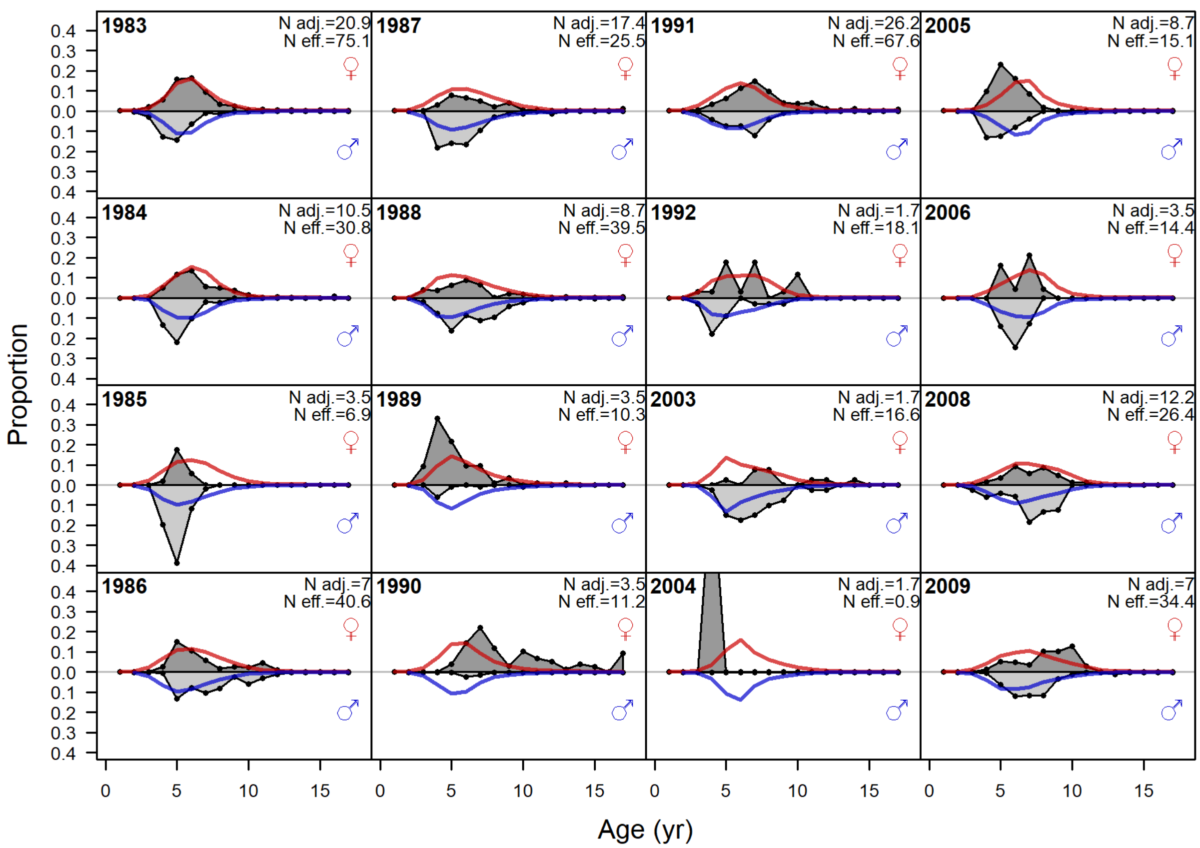

Figure 153: Age comps, retained, Winter (S) (plot 2 of 3) fig:age_fits

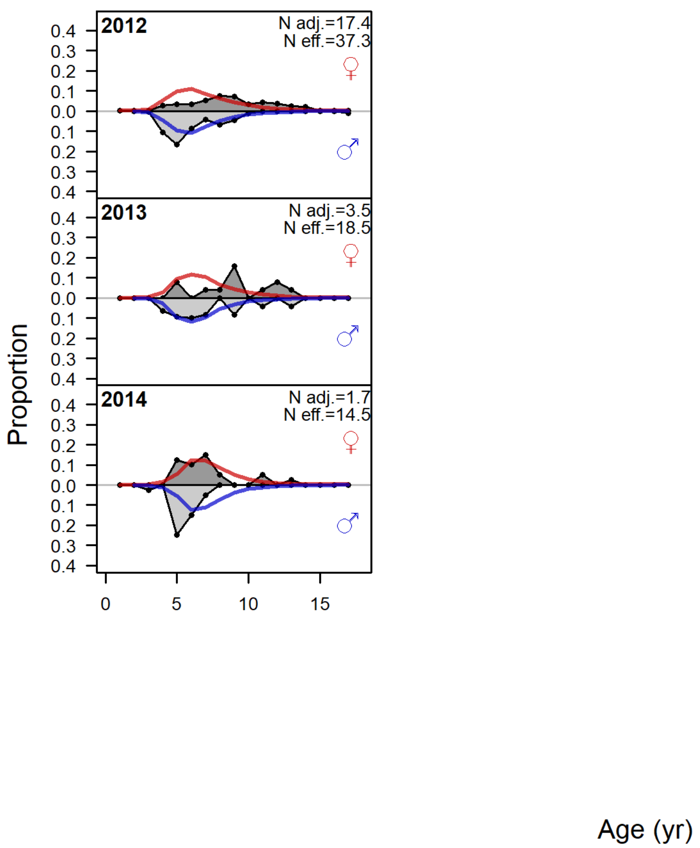

Figure 154: Age comps, retained, Winter (S) (plot 3 of 3) fig:age_fits

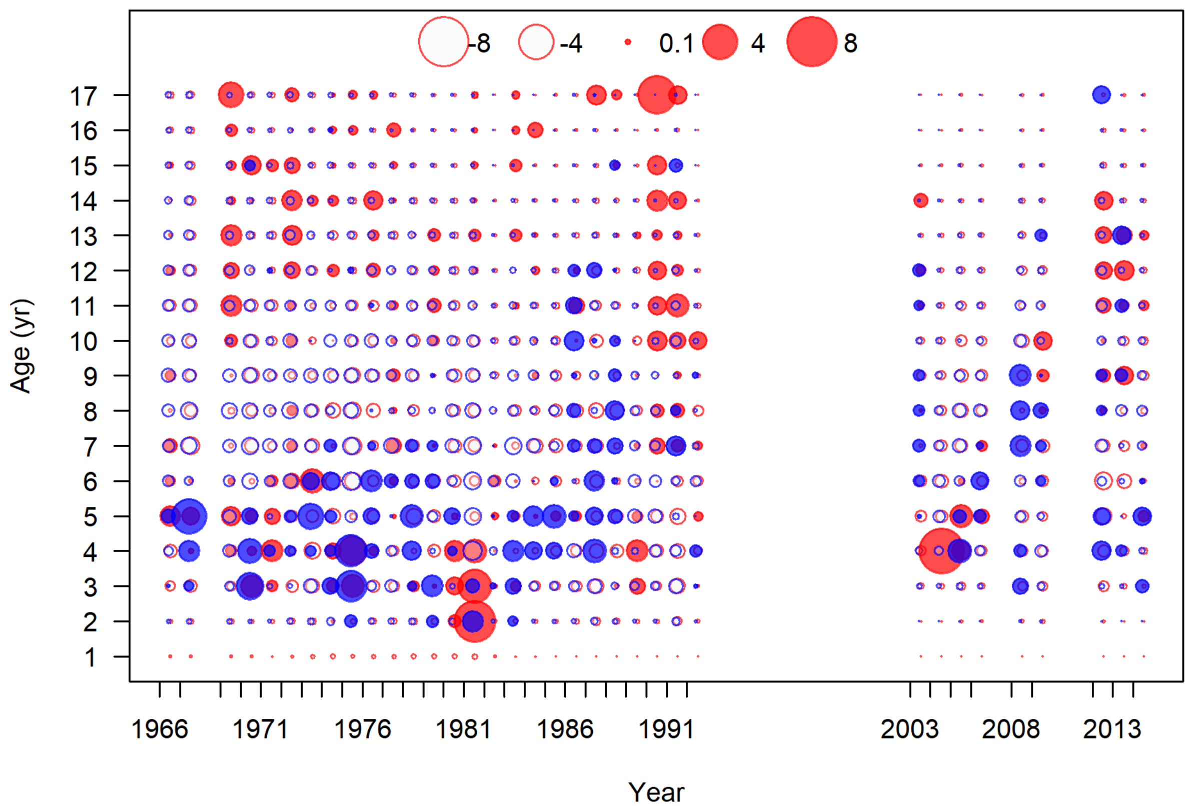

Figure 155: Pearson residuals, retained, Winter (S) (max=6.55) (plot 3 of 3)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:age_fits

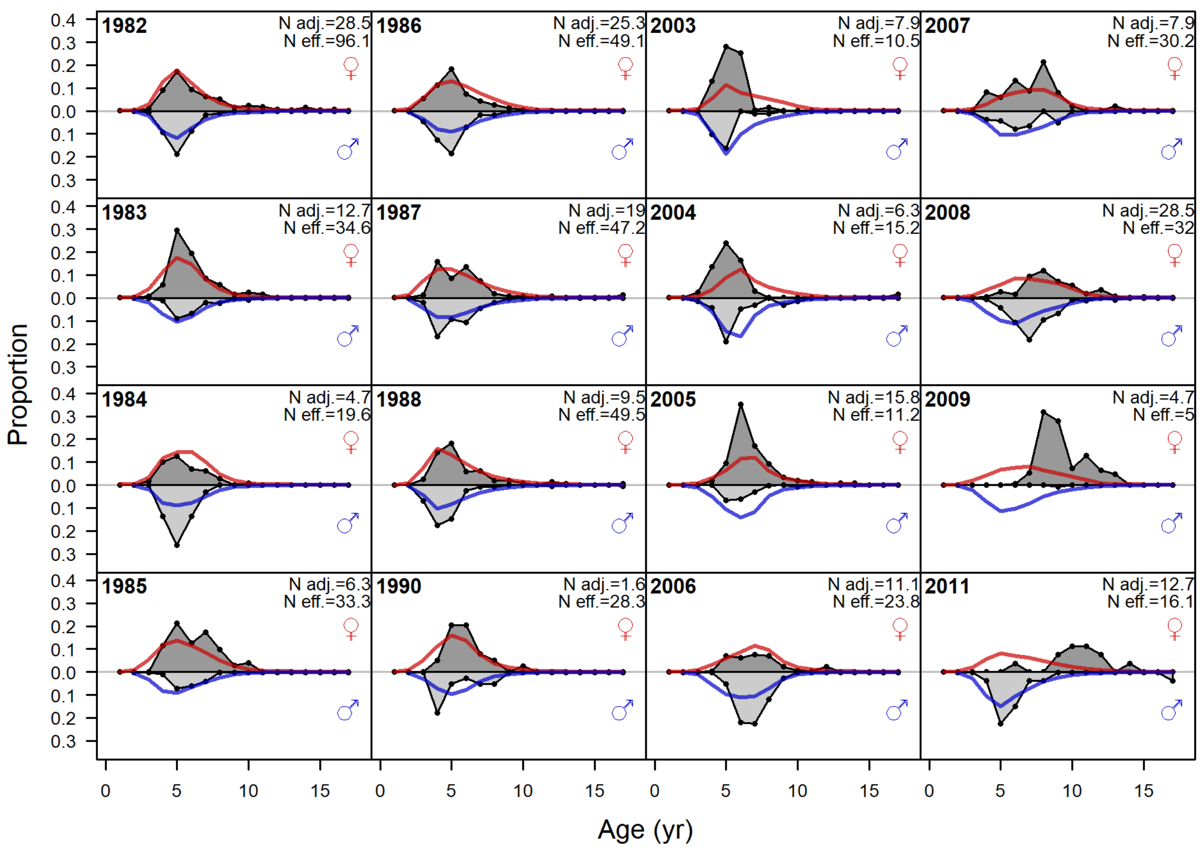

Figure 156: Age comps, retained, Summer (S) (plot 2 of 3) fig:age_fits

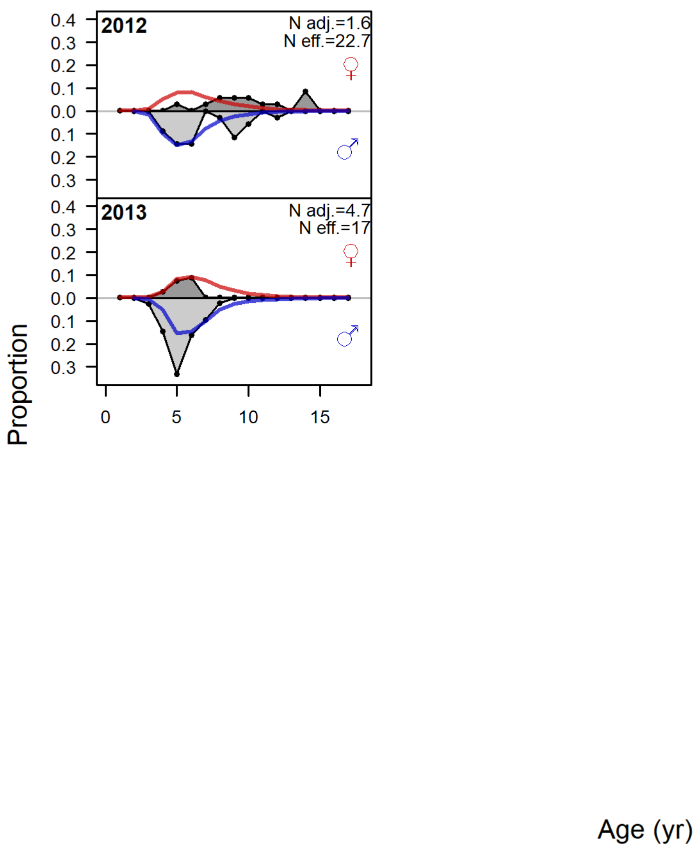

Figure 157: Age comps, retained, Summer (S) (plot 3 of 3) fig:age_fits

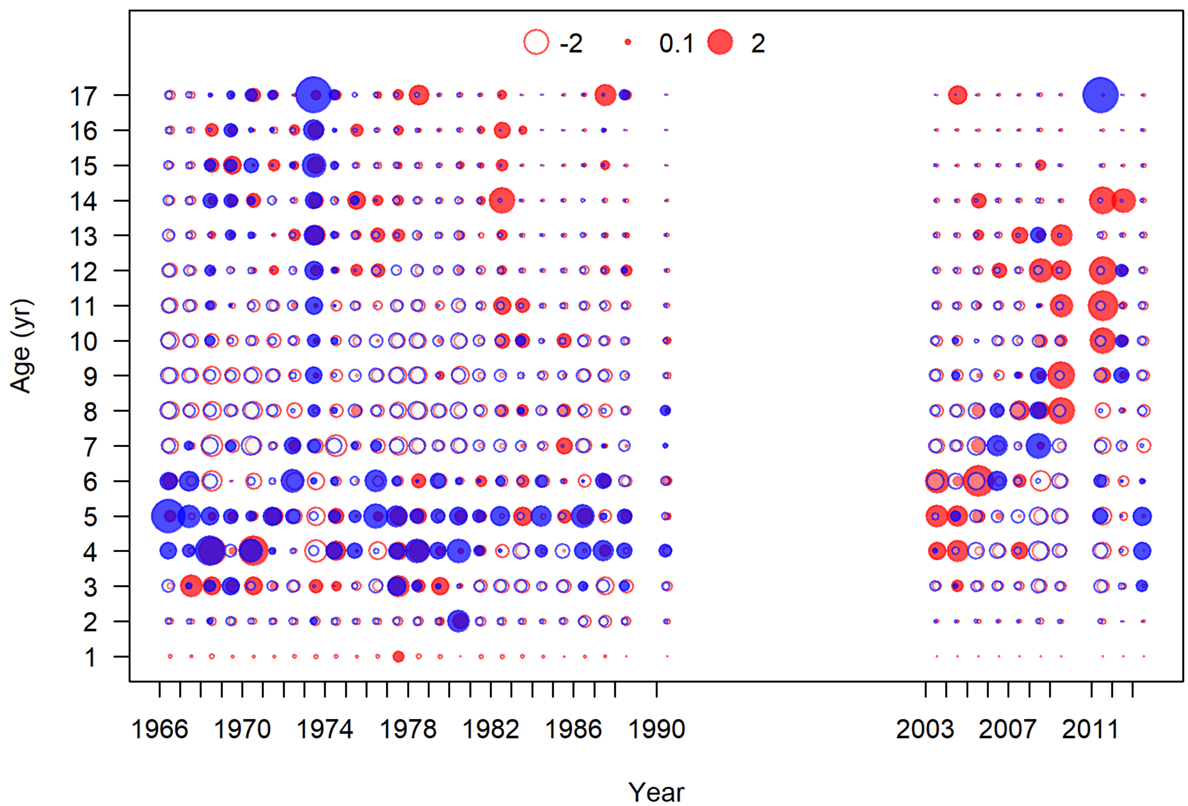

Figure 158: Pearson residuals, retained, Summer (S) (max=4.06) (plot 3 of 3)
Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). fig:age_fits

13 Appendix C. List of Auxiliary Files Available

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

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