Status of petrale sole (*Eopsetta jordani*) along the U.S. west coast in 2018

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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

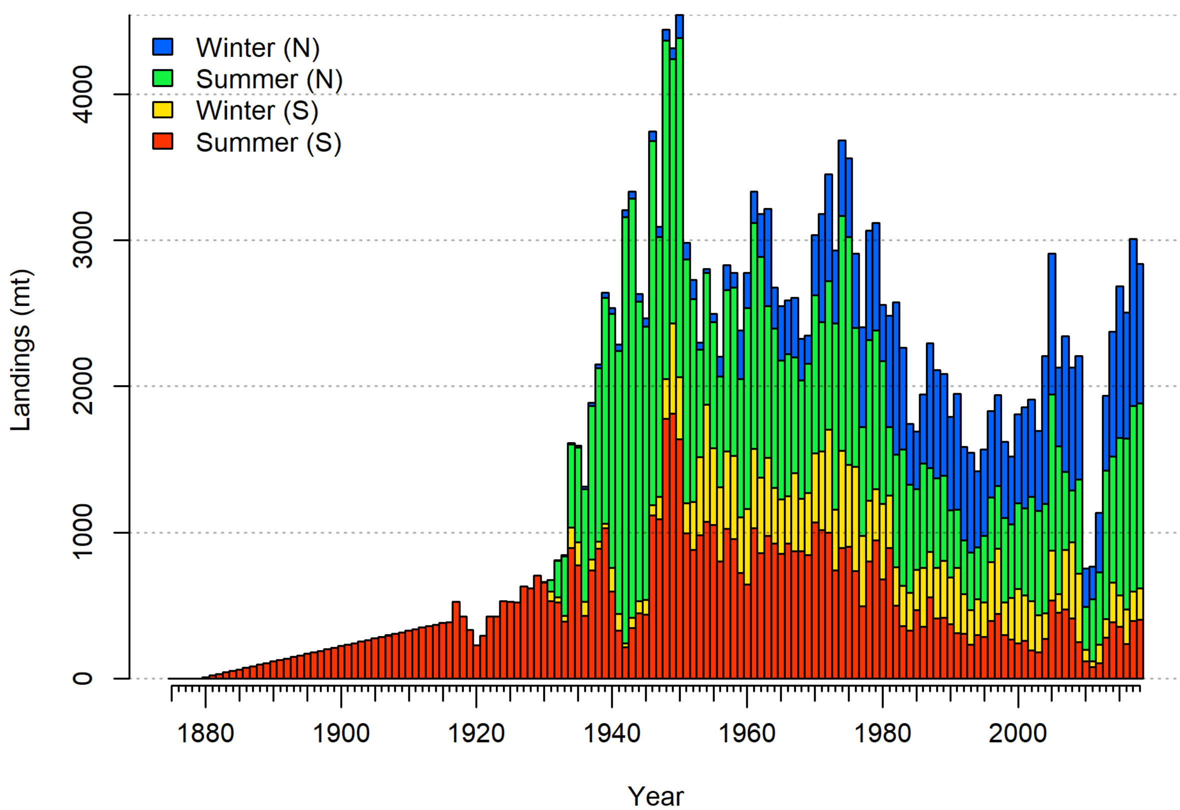

Figure a: 'Landings of by the Northern and Southern winter and summer fleets of the US west coast. fig:Exec_catch1

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 output 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 output relative to unfished equilibrium spawning output is above the target of 25% of unfished spawning output at 32.3% (∼ 95% asymptotic interval: ± 21.9%-42.6%).

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

tab:SpawningDeplete_mod1

Year	Spawning Output (mt)	˜ 95% Confidence Interval	Estimated Relative Spawning Output	˜ 95% Confidence Interval
2010	3494	2845 - 4143	0.114	0.077 - 0.152
2011	4414	3606 - 5222	0.144	0.098 - 0.191
2012	5904	4858 - 6950	0.193	0.132 - 0.255
2013	7751	6410 - 9091	0.254	0.174 - 0.333
2014	9284	7682 - 10886	0.304	0.209 - 0.398
2015	10202	8441 - 11962	0.334	0.231 - 0.436
2016	10439	8593 - 12284	0.342	0.237 - 0.446
2017	10531	8606 - 12457	0.345	0.240 - 0.449
2018	10213	8186 - 12240	0.334	0.231 - 0.437
2019	9867	7682 - 12052	0.323	0.219 - 0.426

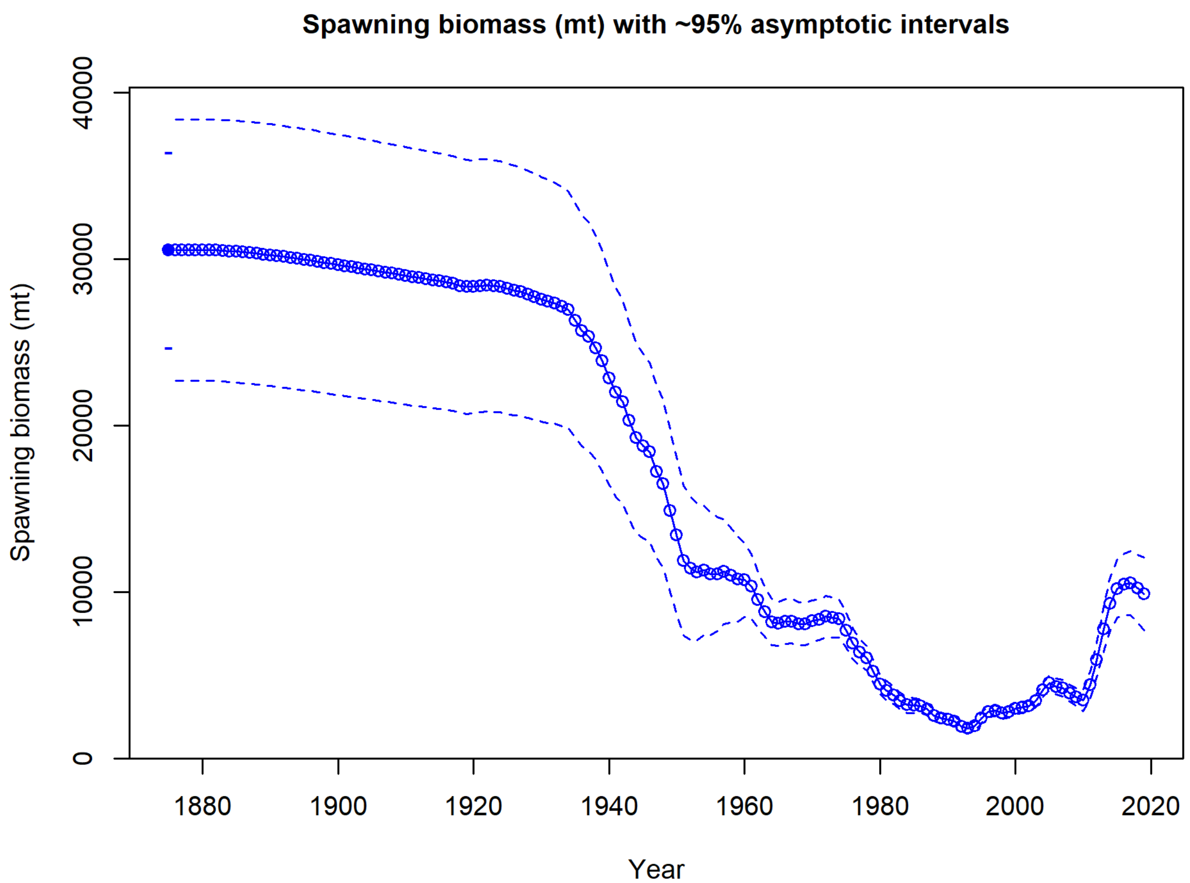

Figure b: Estimated time-series of spawning output trajectory (circles and line: median; light broken lines: 95% credibility intervals) for the base assessment model. fig:Spawnbio_all

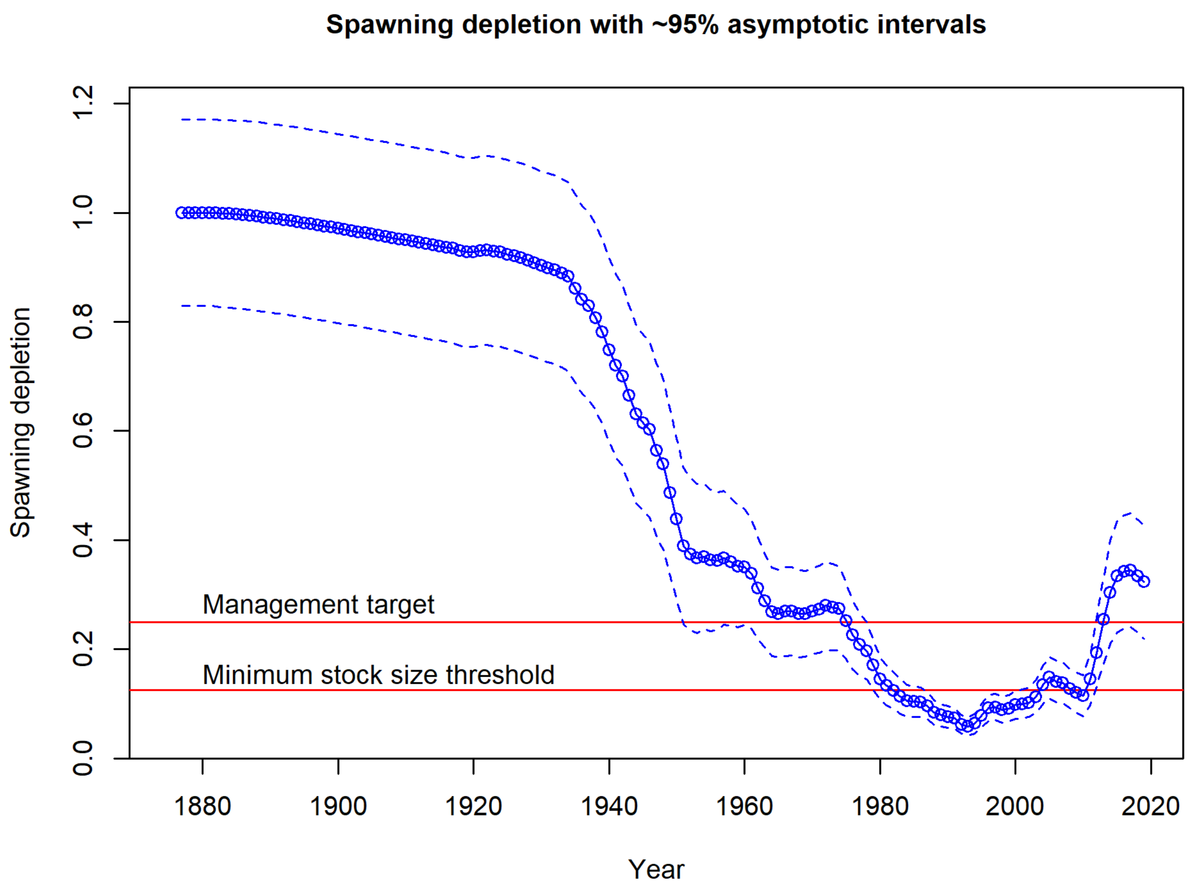

Figure c: Estimated time-series of relative spawning output (depletion) (circles and line: median; light broken lines: 95% credibility intervals) for the base assessment model. fig:RelDeplete_all

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 output, 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, 2007, 1998, 1966, and 1966. The four lowest recruitments estimated within the model (in ascending order) occurred in 1986, 1992, 1973, 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	11740	7281 - 18929	-0.083	-0.411 - 0.244
2011	13434	8205 - 21994	-0.014	-0.358 - 0.330
2012	19781	12473 - 31372	0.306	0.002 - 0.609
2013	12763	7331 - 22221	-0.183	-0.631 - 0.265
2014	13826	7883 - 24251	-0.130	-0.586 - 0.325
2015	13751	7464 - 25334	-0.149	-0.664 - 0.366
2016	13924	6927 - 27992	-0.160	-0.771 - 0.451
2017	15071	6851 - 33154	-0.104	-0.837 - 0.630
2018	17012	7437 - 38914	0.000	-0.784 - 0.784
2019	16935	7409 - 38710	0.000	-0.784 - 0.784

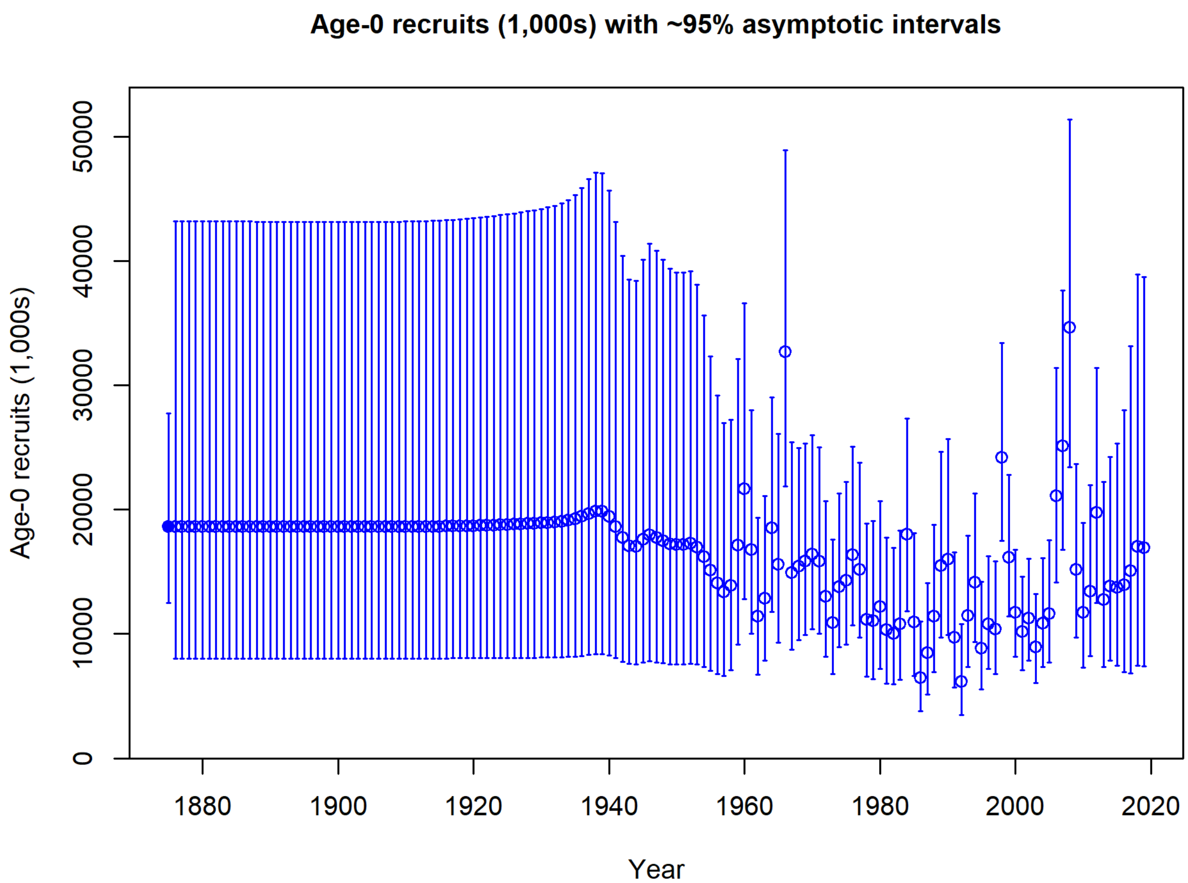

Figure d: Time-series of estimated petrale sole recruitments for the base model with 95% confidence or credibility intervals. fig:Recruits_all

Exploitation Status

exploitation-status

The relative spawning output of of petrale sole was estimated to have dropped below the managment target (25%) for the first time in 1976. The stock continued to decline and first fell below the minimum stock size threshold level of 12.5% in 1982. The relative spawning output remained around the threshold stock size until approximately 2010, with the stock reaching its lowest relative spawning output level in 1993 at 5.8%. 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 assesssment estimated the stock to have rebuilt to the management target (25%) in 2014. This update estimates that the relative spawning output 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	0.822	0.757 - 0.888	0.271	0.223 - 0.318
2010	0.625	0.521 - 0.728	0.091	0.072 - 0.111
2011	0.552	0.446 - 0.658	0.062	0.049 - 0.075
2012	0.568	0.466 - 0.671	0.074	0.060 - 0.089
2013	0.632	0.535 - 0.730	0.111	0.090 - 0.131
2014	0.633	0.537 - 0.729	0.126	0.104 - 0.149
2015	0.644	0.549 - 0.738	0.138	0.113 - 0.163
2016	0.618	0.521 - 0.714	0.129	0.105 - 0.153
2017	0.654	0.561 - 0.747	0.155	0.126 - 0.185
2018	0.649	0.555 - 0.743	0.152	0.121 - 0.183

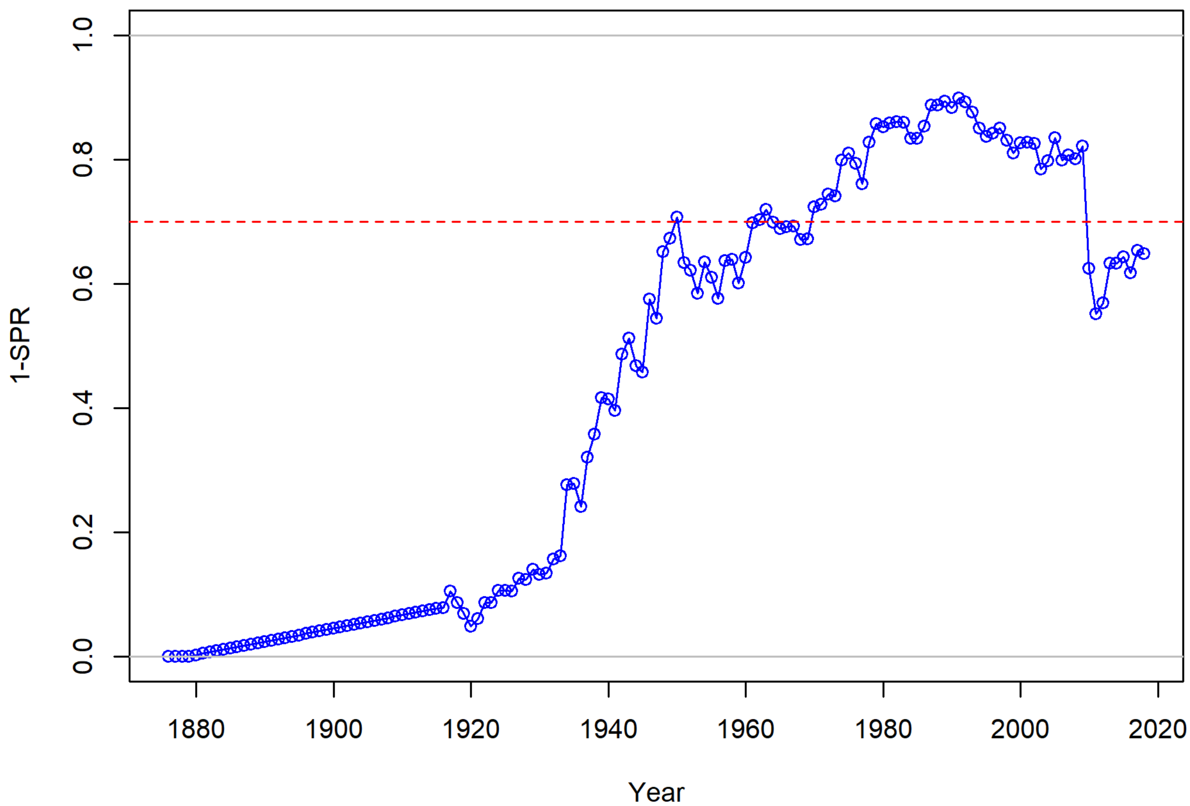

Figure e: Estimated relative spawning potential ratio 1-SPR for the base model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing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

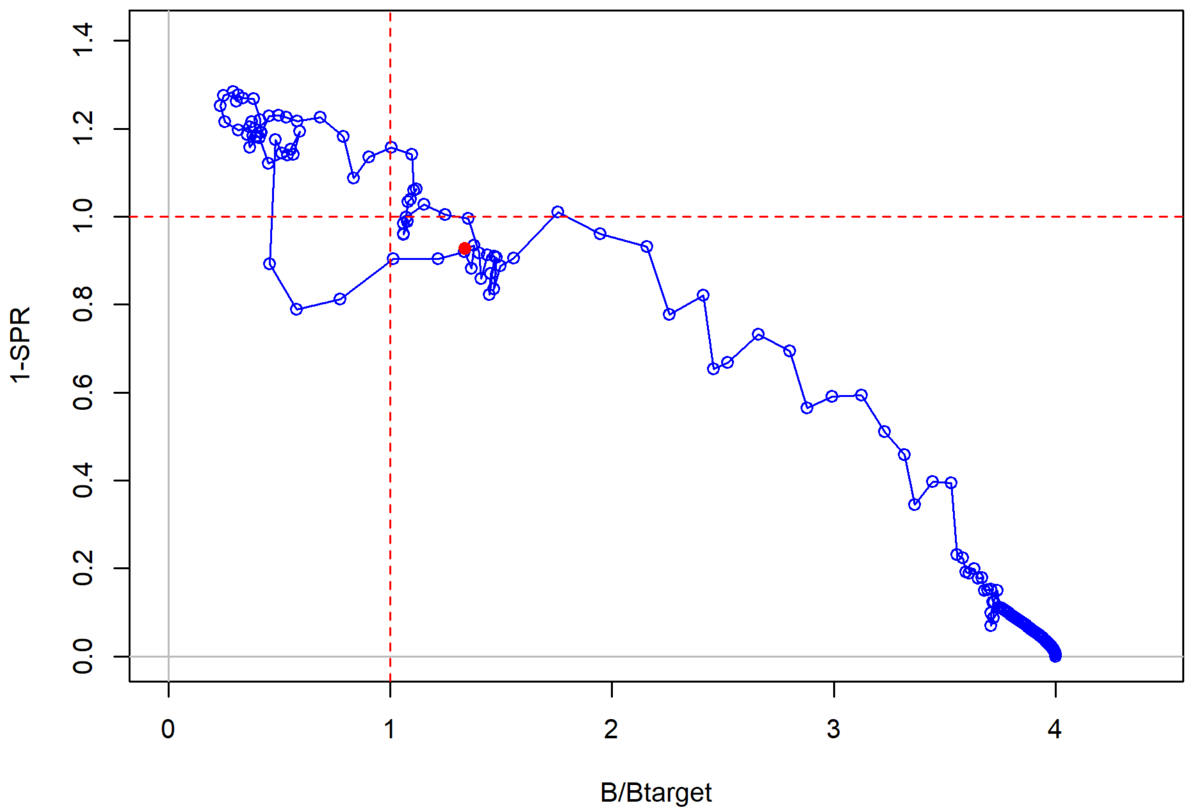

Figure f: Phase plot of estimated 1-SPR(%) vs. relative spawning output (B/Btarget) for the base case model. The red circle indicates 2018 estimated status and exploitation for petrale sole. fig:Phase_all

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 output of petrale sole is above the management target. Due to reduced landings and the large 2008 year-class, an increasing trend in spawning output was estimated in the base model. The estimated depletion in 2019 is 32.3% ($\sim$ 95% asymptotic interval: $\pm$ 21.9%-42.6%), corresponding to an spawning output of 9,867 mt ($\sim$ 95% asymptotic interval: 7,682-12,052 mt). Unfished age 3+ biomass was estimated to be 49,439.6 mt in the base model. The target spawning output based on the biomass target ($SB_{25\%}$) is 7,638.7 mt, with an equilibrium catch of 2,830.3 mt. Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $SPR_{30\%}$ is 2,819.8 mt. Estimated MSY catch is at a 2,835.9 spawning output of 7,005.9 mt (22.9% depletion).

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 output (mt)	30554.7	24634.6	36474.8
Unfished age 3+ biomass (mt)	49439.6	41597	57282.2
Unfished recruitment (R0, thousands)	18626.7	11147.4	26106
Spawning output(2019 mt)	9867.3	7682.4	12052.2
Relative spawning output (depletion) (2019)	0.323	0.219	0.426
Reference points based on $\mathbf{SB_{25\%}}$			
Proxy spawning output ($B_{25\%}$)	7638.7	6158.7	9118.7
SPR resulting in $B_{25\%}$ ($SPR_{B25\%}$)	0.286	0.258	0.313
Exploitation rate resulting in $B_{25\%}$	0.182	0.163	0.2
Yield with $SPR_{B25\%}$ at $B_{25\%}$ (mt)	2830.3	2624.2	3036.4
Reference points based on SPR proxy for MSY			
Spawning output $SPR_{30\%}$	8096.3	6199.3	9993.3
Exploitation rate corresponding to $SPR_{30\%}$	0.173	0.145	0.2
Yield with $SPR_{30\%}$ at SB_{SPR} (mt)	2819.8	2590.1	3049.5
Reference points based on estimated MSY values			
Spawning output at MSY (SB_{MSY})	7005.9	5242.2	8769.6
SPR_{MSY}	0.266	0.201	0.331
Exploitation rate at MSY	0.195	0.164	0.225
MSY (mt)	2835.9	2641.9	3029.9

Management Performance

management-performance

Exploitation rates on petrale sole…

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	2329
2010	2751	1200	755	867
2011	1021	976	768	791
2012	1275	1160	1135	1159
2013	2711	2592	1936	1973
2014	2774	2652	2373	2398
2015	3073	2816	2686	2727
2016	3208	2910	2506	2543
2017	3208	3136	3008	3050
2018	3152	3013	2840	2882

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 output 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 Output (mt)	Relative Depletion
2019	3436	3301	9867	0.323
2020	3189	3065	9191	0.301
2021	2987	2870	8630	0.282
2022	2843	2731	8235	0.270
2023	2764	2655	8035	0.263
2024	2742	2633	8009	0.262
2025	2757	2648	8087	0.265
2026	2790	2680	8201	0.268
2027	2824	2713	8304	0.272
2028	2851	2738	8379	0.274
2029	2869	2756	8427	0.276
2030	2880	2766	8455	0.277

Table h: Decision table summary of 10-year projections beginning in 2021 for alternate states of nature based on an axis of uncertainty for the base model. The removals in 2019 and 2020 were set at the defined management specification of XXX mt for each year assuming full attainment. The range of natural mortality values corresponded to the 12.5 and 87.5th quantile from the uncertainty around final spawning biomass. 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					
			Low State		Base		High State	
	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
ABC	2021							
	2022							
	2023							
	2024							
	2025							
	2026							
	2027							
	2028							
	2029							
	2030							
SPR target = 0.34	2021							
	2022							
	2023							
	2024							
	2025							
	2026							
	2027							
	2028							
	2029							
	2030							

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	1936	2373	2686	2506	3008	2840	
Total Est. Catch (mt)	867	791	1159	1973	2398	2727	2543	3050	2882	
1-SPR	0.625	0.552	0.568	0.632	0.633	0.644	0.618	0.654	0.649	
Exploitation rate	0.091	0.062	0.074	0.111	0.126	0.138	0.129	0.155	0.152	
Age 3+ biomass (mt)	9487.05	12726.80	15602.80	17806.70	18973.00	19748.50	19715.50	19637.00	18918.70	18265.30
Spawning Output	3494	4414	5904	7751	9284	10202	10439	10531	10213	9867
95% CI	2845 - 4143	3606 - 5222	4858 - 6950	6410 - 9091	7682 - 10886	8441 - 11962	8593 - 12284	8606 - 12457	8186 - 12240	7682 - 12052
Relative Depletion	0.114	0.144	0.193	0.254	0.304	0.334	0.342	0.345	0.334	0.323
95% CI	0.077 - 0.152	0.098 - 0.191	0.132 - 0.255	0.174 - 0.333	0.209 - 0.398	0.231 - 0.436	0.237 - 0.446	0.240 - 0.449	0.231 - 0.437	0.219 - 0.426
Recruits	11740	13434	19781	12763	13826	13751	13924	15071	17012	16935
95% CI	7281 - 18929	8205 - 21994	12473 - 31372	7331 - 22221	7883 - 24251	7464 - 25334	6927 - 27992	6851 - 33154	7437 - 38914	7409 - 38710

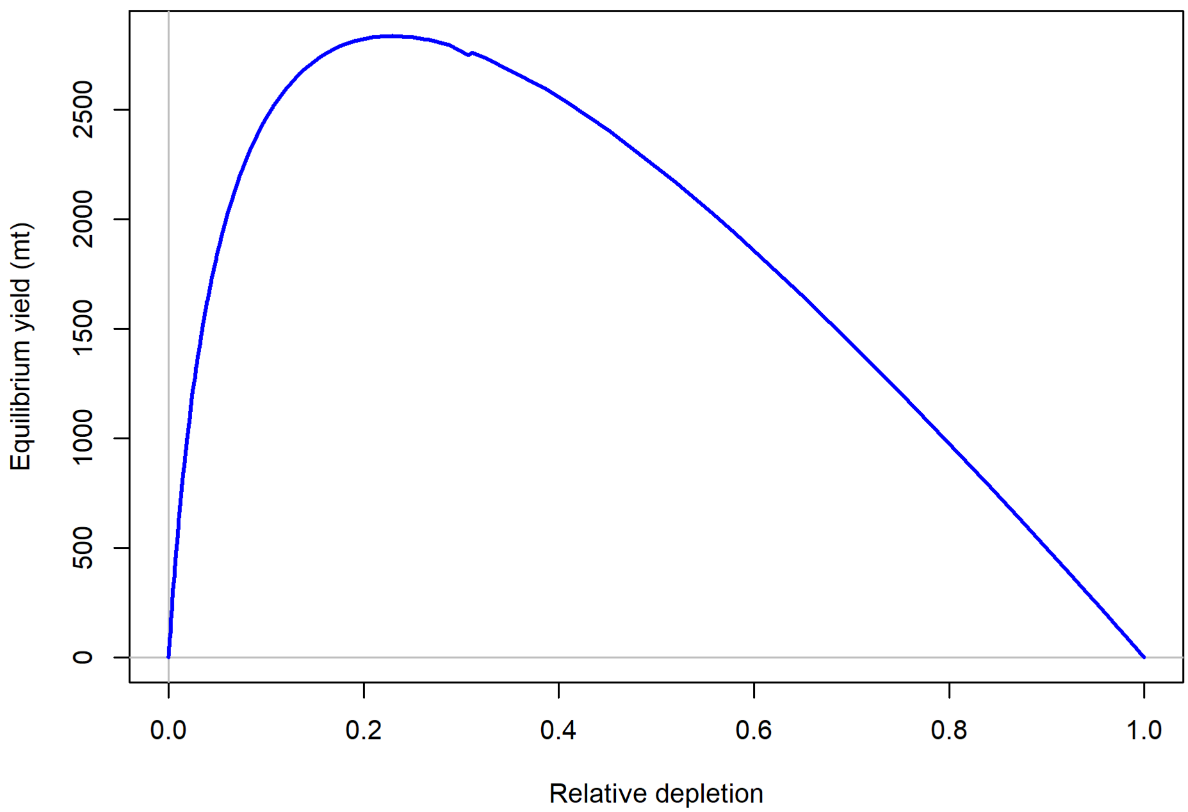

Figure g: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness fixed at 0.84. fig:Yield_all

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 deepwater sites (270-460 m) off the U.S. West Coast, from November to April, with peak spawning taking place from December to February (Harry 1956, Best 1960, Gregory and Jow 1976, Castillo et al. 1993, Reilly et al. 1994, Castillo 1995, 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).

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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 deepwater 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 deepwater 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 **??**.

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 3. The data that were added or reprocessed for this assessment are:

1. Commerical catches (2015-2018);
2. Observed discard rates, average weights, and lengths (2002-2017); and
3. NWFSC West Coast Groundfish Bottom Trawl Survey (2015-2018).

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 data from the NWFSC shelf-slope survey was analyzed using a spatio-temporal delta model implemented as an R package, VAST (Thorson and Barnett 2017), 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 1,000 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 and modeling configuration are provided in Tables 3 and XXX.

The NWFSC West Coast Groundfish Bottom Trawl Survey commonly encounters petrale sole along the U.S West Coast, except south of Point Conception (Figure 4). The catch-per-unit-effort estimated from the survey is roughly constant north of 38° (Figure 5). The survey does fish shallower than 54 m and no petrale sole were caught deeper than 550 m. Figure 6 shows that the postive tows catch rate by depth peaks between 100-200 meters and declines as depth increases.

ADD INFORMATION ON THE DATA USED FOR PETRALE

Figure 7 Figure 9

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 4 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 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 9).

Age distributions included bins from age 1 to age 17, with the last bin including all fish of greater age. Table 5 shows the number of ages taken by the survey. These data show the growth trajectory of females reaching a maximum size near 60 cm and males reaching a maximum size of about 54 cm (Figure XX). 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 in 2008-2014 (Figure 10). 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 was set equal to the number of tows that sampled petrale sole by year to be consistent with the 2015 update assessment. 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. (**???**). 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 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.

An analysis of the mean length by depth also showed evidence of an ontogenetic movement of petrale to deeper water (Figure XX 18), and depth stratification similar to the strata used for the NWFSC survey was used for the early and late Triennial Survey (Table 6 and 8).Strata were determined based on having an adequate sample size in each year-strata combination.

DESCRIBE VAST AND THE INDICES

Table 9

Size distributions were calculated following the same procedures as the NWFSC survey. The numbers of fish and number of hauls represented in each year of the survey are presented in Table 7. The length frequency distributions generally show little trend, although there is evidence of small fish in 1992 and large fish in 2004 (Figure XX).

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

The input sample sizes for length data were based on the number of tows that sampled petrale sole by year.

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) extacted 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 but do not include discarded petrale sole (Table 10).

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. Post-ITQ, all catch-share vessels have 100% observer coverage and discarding is assumed to be known. 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, and were not included in this update assessment.

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

Commerical 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). In West Coast assessments since the first inclusion 1999 the commercial CPUE indices have been extended and or updated based on management changes and new statistical methods. For additional information on the use of CPUE indices in the assessmnet 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). 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 ODFW (1966-present) and WDFW (1955-present), but only 1985-present data from CDFG. The CDFG dataset for the years 1948-1922 was extracted and provided from CALCOM by Brenda Erwin (CDFG) in 2011.

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 Wasington 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 tows (Table XX -Table XX). Figures 11, 12, and 13 show plots of the commercial length and age composition data.

The input sample size for commercial lengths and ages were calculated based on the number of tows by years.

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 $ln(5.4/A_{\text{max}})$ 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.

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 19).

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 consistant with the full assessment this update assessment retains the equal sex ratio assumption. However, examining the NWFSC West Coast Groundfish Bottom Trawl Survey data there appears to be a higher proportion of males in the population across the mid-range lengths with the proportion rising to 1 at the largest lengths due to dimorphic growth (Figure 15). 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 2.08e-06$L^{3.47}$ and males at 3.05e-06$L^{3.36}$ where L is length in cm (Figures 16).

2.3.5 Growth (Length-at-Age)

growth-length-at-age

The length-at-age was estimated for male and female petrale sole. Figure ?? shows the lengths and ages as well as predicted von Bertalanffy fits to the data to 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:

$$\text{Females } L_\infty = 54.4;\ k = 0.13$$

$$\text{Males } L_\infty = 43.2;\ k = 0.20$$

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 19 and 20. 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 was unable to generate new analyses to evaluate potential ecosystem data and methodologies for this stock assessment for consistency with the last full assessment.

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 3.

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. NWFSC West Coast Groundfish Bottom Trawl Survey index was calculated using VAST.
4. Added composition data from the commercial fishery (length and age data 2015-2018) and NWFSC West Coast Groundfish Bottom Trawl Survey (length and age data 2015-2018).
5. Corrected NWFSC West Coast Groundfish Bottom Trawl Survey length and age composition data expansion (2003-2018).
6. Discard rate, average weight, and length composition data (2014-2017).
7. Model tuning to re-weight data.
8. 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.
9. Update the natural mortality prior for female and male fish.

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 3.

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 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, respectively, the same assumption regarding maximum age as applied in the 2013 assessment.

3.2.4 Data Weighting

data-weighting

Length and 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 other survey fleets. Length data started with a sample size determined from the equation listed in Sections 2.1.1 (survey data) and 2.2.5 (fishery data). It was assumed for 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.

XXX - I think they may have done Harmonic Mean Weighting - check The update assessment model was weighted using the "Francis method", which was based on equation TA1.8 in Francis (2011). This formulation looks at the mean length or age and the variance of the mean to determine if across years, the variability is explained by the model. If the variability around the mean does not encompass the model predictions, then that data source should be down-weighted. This method accounts for correlation in the data (i.e., the multinomial distribution) as opposed to the McAllister and Ianelli (1997) method (Harmonic Mean weighting) of looking at the difference between individual observations and predictions. A sensitivity was performed examining the difference between the weighting approaches. The weights applied to each length and age data set for the base model are shown in Table 22.

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 23).

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 **??**).

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 (**???**). 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 17).

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 24). 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 23 and the likelihood components are shown in Table 25. Estimates of derived reference points and approximate 95% asymptotic confidence intervals are shown in Table 26. Estimates of stock size over time are shown in Table 27.

3.3.1 Parameter Estimates

parameter-estimates

3.3.2 Fits to the Data

fits-to-the-data

3.3.3 Population Trajectory

population-trajectory

3.3.4 Uncertainty and Sensitivity Analyses

uncertainty-and-sensitivity-analyses

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 (Figure **??**).

3.3.6 Historical Analysis

historical-analysis

3.3.7 Likelihood Profiles

likelihood-profiles

3.3.8 Reference Points

reference-points-1

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.

8 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	930	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	1013	130	280
2014	853	860	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	2329
2010	2751	1200	755	867
2011	1021	976	768	791
2012	1275	1160	1135	1159
2013	2711	2592	1936	1973
2014	2774	2652	2373	2398
2015	3073	2816	2686	2727
2016	3208	2910	2506	2543
2017	3208	3136	3008	3050
2018	3152	3013	2840	2882

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 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	254	3037	673
2009	273	3375	739
2010	322	6018	1152
2011	320	6176	1172
2012	295	5372	1036
2013	218	3445	693
2014	332	4822	997
2015	312	4236	897
2016	309	4385	914
2017	314	4261	902
2018	291	3783	813

Table 5: 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	222	736	324
2009	255	766	361
2010	295	794	405
2011	289	799	399
2012	269	777	376
2013	217	843	333
2014	318	766	424
2015	291	751	395

Table 6: 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 7: 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 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 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	-	-	-	-	1512	0.49	-	-	-	-
1983	-	-	-	-	2380	0.45	-	-	-	-
1986	-	-	-	-	2249	0.46	-	-	-	-
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	3569	0.43	-	-	-	-
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	2226	0.43	-	-	-	-
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	-	-	2636	0.33	-	-
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	-	-	3836	0.32	-	-
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	-	-	4362	0.33	-	-
2002	0.93	0.28	0.80	0.29	-	-	-	-	-	-
2003	1.02	0.28	0.85	0.29	-	-	-	-	19970	0.13
2004	1.63	0.28	1.71	0.31	-	-	10662	0.33	26767	0.14
2005	1.85	0.28	1.93	0.29	-	-	-	-	26795	0.12
2006	2.01	0.28	1.58	0.29	-	-	-	-	22288	0.12
2007	2.04	0.28	2.07	0.28	-	-	-	-	21003	0.13
2008	1.96	0.27	1.62	0.28	-	-	-	-	17597	0.12
2009	2.12	0.27	1.76	0.28	-	-	-	-	18270	0.12
2010	-	-	-	-	-	-	-	-	26860	0.12
2011	-	-	-	-	-	-	-	-	36324	0.12
2012	-	-	-	-	-	-	-	-	42005	0.12
2013	-	-	-	-	-	-	-	-	58743	0.13
2014	-	-	-	-	-	-	-	-	65532	0.12
2015	-	-	-	-	-	-	-	-	59015	0.12
2016	-	-	-	-	-	-	-	-	64522	0.12
2017	-	-	-	-	-	-	-	-	66101	0.12
2018	-	-	-	-	-	-	-	-	46594	0.12

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
2019	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
2019	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 Winter North fishery length samples used in the stock assessment (continued on next page). Sample sizes were calculated according to method described above in Section 2.2.5.

tab:WN_Lengths

Year	Trips	Fish	Sample Size
1966	1	238	7
1967	5	1020	35
1968	3	912	21
1969	4	1213	28
1970	13	1830	92
1971	22	4698	155
1972	23	4561	162
1973	17	4134	120
1974	20	4806	141
1975	19	3637	134
1976	21	3677	148
1977	32	4846	226
1978	52	7715	367
1979	34	3414	240
1980	55	5425	388
1981	40	3921	282
1982	48	4824	339
1983	39	3944	275
1984	31	3102	219
1985	45	4508	318
1986	40	4002	282
1987	43	3053	304
1988	9	601	64
1989	16	798	113
1990	12	599	85
1991	8	216	38
1994	43	2608	304
1995	49	3161	346
1996	64	3085	452
1997	76	3570	537
1998	56	3450	395
1999	58	2812	409
2000	49	2004	326
2001	59	1696	293
2002	50	1666	280
2003	67	1661	296
2004	53	1202	219
2005	51	1277	227
2006	59	1486	264
2007	81	2248	391
2008	101	3058	523
2009	107	3207	550
2010	134	2872	530
2011	100	1943	368
2012	97	1873	355
2013	117	2167	416
2014	140	2850	533
2015	110	2504	456
2016	131	2158	429

Table 12: Summary of Summer North fishery length samples used in the stock assessment (continued on next page). Sample sizes were calculated according to method described above in Section 2.2.5.

tab:SN_Lengths

Year	Trips	Fish	Sample Size
1966	1	238	7
1967	5	1020	35
1968	3	912	21
1969	4	1213	28
1970	13	1830	92
1971	22	4698	155
1972	23	4561	162
1973	17	4134	120
1974	20	4806	141
1975	19	3637	134
1976	21	3677	148
1977	32	4846	226
1978	52	7715	367
1979	34	3414	240
1980	55	5425	388
1981	40	3921	282
1982	48	4824	339
1983	39	3944	275
1984	31	3102	219
1985	45	4508	318
1986	40	4002	282
1987	43	3053	304
1988	9	601	64
1989	16	798	113
1990	12	599	85
1991	8	216	38
1994	43	2608	304
1995	49	3161	346
1996	64	3085	452
1997	76	3570	537
1998	56	3450	395
1999	58	2812	409
2000	49	2004	326
2001	59	1696	293
2002	50	1666	280
2003	67	1661	296
2004	53	1202	219
2005	51	1277	227
2006	59	1486	264
2007	81	2248	391
2008	101	3058	523
2009	107	3207	550
2010	134	2872	530
2011	100	1943	368
2012	97	1873	355
2013	117	2167	416
2014	140	2850	533
2015	110	2504	456
2016	131	2158	429

Table 13: Summary of Winter South fishery length samples used in the stock assessment (continued on next page). Sample sizes were calculated according to method described above in Section 2.2.5.

tab:WS_Lengths

Year	Trips	Fish	Sample Size
1966	1	238	7
1967	5	1020	35
1968	3	912	21
1969	4	1213	28
1970	13	1830	92
1971	22	4698	155
1972	23	4561	162
1973	17	4134	120
1974	20	4806	141
1975	19	3637	134
1976	21	3677	148
1977	32	4846	226
1978	52	7715	367
1979	34	3414	240
1980	55	5425	388
1981	40	3921	282
1982	48	4824	339
1983	39	3944	275
1984	31	3102	219
1985	45	4508	318
1986	40	4002	282
1987	43	3053	304
1988	9	601	64
1989	16	798	113
1990	12	599	85
1991	8	216	38
1994	43	2608	304
1995	49	3161	346
1996	64	3085	452
1997	76	3570	537
1998	56	3450	395
1999	58	2812	409
2000	49	2004	326
2001	59	1696	293
2002	50	1666	280
2003	67	1661	296
2004	53	1202	219
2005	51	1277	227
2006	59	1486	264
2007	81	2248	391
2008	101	3058	523
2009	107	3207	550
2010	134	2872	530
2011	100	1943	368
2012	97	1873	355
2013	117	2167	416
2014	140	2850	533
2015	110	2504	456
2016	131	2158	429

Table 14: Summary of Summer South fishery length samples used in the stock assessment (continued on next page). Sample sizes were calculated according to method described above in Section 2.2.5.

tab:SS_Lengths

Year	Trips	Fish	Sample Size
1966	1	238	7
1967	5	1020	35
1968	3	912	21
1969	4	1213	28
1970	13	1830	92
1971	22	4698	155
1972	23	4561	162
1973	17	4134	120
1974	20	4806	141
1975	19	3637	134
1976	21	3677	148
1977	32	4846	226
1978	52	7715	367
1979	34	3414	240
1980	55	5425	388
1981	40	3921	282
1982	48	4824	339
1983	39	3944	275
1984	31	3102	219
1985	45	4508	318
1986	40	4002	282
1987	43	3053	304
1988	9	601	64
1989	16	798	113
1990	12	599	85
1991	8	216	38
1994	43	2608	304
1995	49	3161	346
1996	64	3085	452
1997	76	3570	537
1998	56	3450	395
1999	58	2812	409
2000	49	2004	326
2001	59	1696	293
2002	50	1666	280
2003	67	1661	296
2004	53	1202	219
2005	51	1277	227
2006	59	1486	264
2007	81	2248	391
2008	101	3058	523
2009	107	3207	550
2010	134	2872	530
2011	100	1943	368
2012	97	1873	355
2013	117	2167	416
2014	140	2850	533
2015	110	2504	456
2016	131	2158	429

Table 15: Summary of Winter North fishery age samples used in the stock assessment. Sample sizes were calculated according to method described above in Section 2.2.5.

tab:WN_Ages

Year	Trips	Fish	Sample Size
1981	20	1901	141
1982	40	2776	282
1983	33	3317	233
1984	27	2625	191
1985	21	2096	148
1986	17	1693	120
1987	24	1193	169
1988	4	199	28
1994	8	238	41
1999	18	863	127
2000	14	677	99
2001	40	1349	226
2002	38	1414	233
2003	40	1309	221
2004	30	854	148
2005	37	1018	177
2006	49	1258	223
2007	63	1825	315
2008	44	1129	200
2009	75	1548	289
2010	54	1264	228
2011	85	1230	255
2012	7	331	49
2013	10	265	47
2014	91	587	172
2015	78	513	149
2016	21	254	56

Table 16: Summary of Summer North fishery age samples used in the stock assessment. Sample sizes were calculated according to method described above in Section 2.2.5.

tab:SN_Ages

Year	Trips	Fish	Sample Size
1981	20	1901	141
1982	40	2776	282
1983	33	3317	233
1984	27	2625	191
1985	21	2096	148
1986	17	1693	120
1987	24	1193	169
1988	4	199	28
1994	8	238	41
1999	18	863	127
2000	14	677	99
2001	40	1349	226
2002	38	1414	233
2003	40	1309	221
2004	30	854	148
2005	37	1018	177
2006	49	1258	223
2007	63	1825	315
2008	44	1129	200
2009	75	1548	289
2010	54	1264	228
2011	85	1230	255
2012	7	331	49
2013	10	265	47
2014	91	587	172
2015	78	513	149
2016	21	254	56

Table 17: Summary of Winter South fishery age samples used in the stock assessment. Sample sizes were calculated according to method described above in Section 2.2.5.

tab:WS_Ages

Year	Trips	Fish	Sample Size
1981	20	1901	141
1982	40	2776	282
1983	33	3317	233
1984	27	2625	191
1985	21	2096	148
1986	17	1693	120
1987	24	1193	169
1988	4	199	28
1994	8	238	41
1999	18	863	127
2000	14	677	99
2001	40	1349	226
2002	38	1414	233
2003	40	1309	221
2004	30	854	148
2005	37	1018	177
2006	49	1258	223
2007	63	1825	315
2008	44	1129	200
2009	75	1548	289
2010	54	1264	228
2011	85	1230	255
2012	7	331	49
2013	10	265	47
2014	91	587	172
2015	78	513	149
2016	21	254	56

Table 18: Summary of Summer South fishery age samples used in the stock assessment. Sample sizes were calculated according to method described above in Section 2.2.5.

tab:SS_Ages

Year	Trips	Fish	Sample Size
1981	20	1901	141
1982	40	2776	282
1983	33	3317	233
1984	27	2625	191
1985	21	2096	148
1986	17	1693	120
1987	24	1193	169
1988	4	199	28
1994	8	238	41
1999	18	863	127
2000	14	677	99
2001	40	1349	226
2002	38	1414	233
2003	40	1309	221
2004	30	854	148
2005	37	1018	177
2006	49	1258	223
2007	63	1825	315
2008	44	1129	200
2009	75	1548	289
2010	54	1264	228
2011	85	1230	255
2012	7	331	49
2013	10	265	47
2014	91	587	172
2015	78	513	149
2016	21	254	56

Table 19: 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 20: 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 21: 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
Starting year of estimated recruitment	1959
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
Triennial Early survey	Double Normal
Triennial Late survey	Double Normal
NWFSC shelf-slope 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 22: 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		
Summer North		
Winter South		
Summer South		
Triennial Early survey		-
Triennial Late survey		-
NWFSC shelf-slope survey		

Table 23: 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	0.161992	6	(0.005, 0.5)	OK	0.02	Log_Norm (-1.7793, 0.438)
L_at_Amin_Fem_GP_1	15.8915	2	(10, 45)	OK	0.42	None
L_at_Amax_Fem_GP_1	53.9424	3	(35, 80)	OK	0.40	None
VonBert_K_Fem_GP_1	0.135371	2	(0.04, 0.5)	OK	0.01	None
SD_young_Fem_GP_1	0.189896	3	(0.01, 1)	OK	0.01	None
SD_old_Fem_GP_1	0.0250563	4	(0.01, 1)	OK	0.01	None
Wtlen_1_Fem_GP_1	0.00000208	-3	(-3, 3)			Normal (0.00000208, 0.8)
Wtlen_2_Fem_GP_1	3.4737	-3	(1, 5)			Normal (3.4737, 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	0.174411	6	(0.005, 0.6)	OK	0.02	Log_Norm (-1.6809, 0.438)
L_at_Amin_Mal_GP_1	16.4779	2	(10, 45)	OK	0.33	None
L_at_Amax_Mal_GP_1	42.1411	3	(35, 80)	OK	0.41	None
VonBert_K_Mal_GP_1	0.216	2	(0.04, 0.5)	OK	0.01	None
SD_young_Mal_GP_1	0.134634	3	(0.01, 1)	OK	0.01	None
SD_old_Mal_GP_1	0.053	4	(0.01, 1)	OK	0.01	None
Wtlen_1_Mal_GP_1	0.00000305	-3	(-3, 3)			Normal (0.00000305, 0.8)
Wtlen_2_Mal_GP_1	3.36054	-3	(-3, 5)			Normal (3.36054, 0.8)
CohortGrowDev	1	-4	(0, 1)			None
FracFemale_GP_1	0.5	-99	(0.01, 0.99)			None
SR_LN(R0)	9.83235	1	(5, 20)	OK	0.20	None
SR_BH_steep	0.839916	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	0.000000278911	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_30	0.000000327699	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_29	0.000000384942	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_28	0.000000452078	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_27	0.000000530781	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_26	0.000000622998	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_25	0.000000730985	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_24	0.000000857355	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_23	0.00000100513	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_22	0.00000117777	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_21	0.00000137929	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_20	0.00000161425	3	(-4, 4)	act	0.40	dev (NA, NA)

Continued on next page

Table 23: 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	0.00000188786	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_18	0.00000220604	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_17	0.00000257549	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_16	0.00000300378	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_15	0.00000349937	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_14	0.00000407165	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_13	0.00000473103	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_12	0.00000548896	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_11	0.00000635795	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_10	0.00000735162	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_9	0.00000848451	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_8	0.00000977139	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_7	0.0000112258	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_6	0.0000128609	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_5	0.0000146966	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_4	0.0000167694	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_3	0.0000191253	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_2	0.0000218083	3	(-4, 4)	act	0.40	dev (NA, NA)
Early_InitAge_1	0.0000248635	3	(-4, 4)	act	0.40	dev (NA, NA)
LnQ_base_WinterN(1)	-5.11324	1	(-20, 5)	OK	3.14	None
Q_power_WinterN(1)	-0.353898	3	(-5, 5)	OK	0.41	None
LnQ_base_WinterS(3)	-1.36603	1	(-20, 5)	OK	2.34	None
Q_power_WinterS(3)	-0.849303	3	(-5, 5)	OK	0.30	None
LnQ_base_TriEarly(5)	-0.803067	-1	(-15, 15)			None
Q_extraSD_TriEarly(5)	0.340847	5	(0.001, 2)	OK	0.15	None
LnQ_base_TriLate(6)	-0.254844	-1	(-15, 15)			None
Q_extraSD_TriLate(6)	0.236348	4	(0.001, 2)	OK	0.12	None
LnQ_base_NWFSC(7)	1.33092	-1	(-15, 15)			None
LnQ_base_WinterN(1)_BLK5add_2004	0.547816	3	(-0.99, 0.99)	OK	0.22	Normal (0, 0.5)
LnQ_base_WinterS(3)_BLK5add_2004	0.623155	3	(-0.99, 0.99)	OK	0.22	Normal (0, 0.5)
Size_DblN_peak_WinterN(1)	49.1595	1	(15, 75)	OK	0.92	None
Size_DblN_top_logit_WinterN(1)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_WinterN(1)	4.28513	2	(-4, 12)	OK	0.13	None
Size_DblN_descend_se_WinterN(1)	14	-3	(-2, 15)			None
Size_DblN_start_logit_WinterN(1)	-999	-4	(-15, 5)			None
Size_DblN_end_logit_WinterN(1)	-999	-4	(-5, 5)			None
Retain_L_infl_WinterN(1)	24.2848	1	(10, 40)	OK	1.42	None
Retain_L_width_WinterN(1)	1.44101	2	(0.1, 10)	OK	0.19	None
Retain_L_asymptote_logit_WinterN(1)	9.99652	4	(-10, 10)	HI	0.11	None

Continued on next page

Table 23: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Retain_L_maleoffset_WinterN(1)	0	-2	(-10, 10)			None
SzSel_Male_Peak_WinterN(1)	-11.5865	3	(-15, 15)	OK	0.78	None
SzSel_Male_Ascend_WinterN(1)	-1.51838	4	(-15, 15)	OK	0.18	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)	54.4414	1	(15, 75)	OK	1.27	None
Size_DblN_top_logit_SummerN(2)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_SummerN(2)	5.43766	2	(-4, 12)	OK	0.10	None
Size_DblN_descend_se_SummerN(2)	14	-3	(-2, 15)			None
Size_DblN_start_logit_SummerN(2)	-999	-4	(-15, 5)			None
Size_DblN_end_logit_SummerN(2)	-999	-4	(-5, 5)			None
Retain_L_infl_SummerN(2)	30.2865	1	(10, 40)	OK	0.36	None
Retain_L_width_SummerN(2)	1.30185	2	(0.1, 10)	OK	0.11	None
Retain_L_asymptote_logit_SummerN(2)	5.74848	4	(-10, 10)	OK	0.35	None
Retain_L_maleoffset_SummerN(2)	0	-2	(-10, 10)			None
SzSel_Male_Peak_SummerN(2)	-14.0633	3	(-20, 15)	OK	0.97	None
SzSel_Male_Ascend_SummerN(2)	-1.9821	4	(-15, 15)	OK	0.18	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)	44.2878	1	(15, 75)	OK	1.74	None
Size_DblN_top_logit_WinterS(3)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_WinterS(3)	4.4519	2	(-4, 12)	OK	0.27	None
Size_DblN_descend_se_WinterS(3)	14	-3	(-2, 15)			None
Size_DblN_start_logit_WinterS(3)	-999	-4	(-15, 5)			None
Size_DblN_end_logit_WinterS(3)	-999	-4	(-5, 5)			None
Retain_L_infl_WinterS(3)	28.9561	1	(10, 40)	OK	0.57	None
Retain_L_width_WinterS(3)	1.44014	2	(0.1, 10)	OK	0.29	None
Retain_L_asymptote_logit_WinterS(3)	4.86774	4	(-10, 10)	OK	0.94	None
Retain_L_maleoffset_WinterS(3)	0	-2	(-10, 10)			None
SzSel_Male_Peak_WinterS(3)	-12.2823	3	(-15, 15)	OK	1.77	None
SzSel_Male_Ascend_WinterS(3)	-1.8526	4	(-15, 15)	OK	0.50	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)	45.2206	1	(15, 75)	OK	1.29	None
Size_DblN_top_logit_SummerS(4)	3	-3	(-5, 3)			None
Size_DblN_ascend_se_SummerS(4)	4.89214	2	(-4, 12)	OK	0.15	None

Continued on next page

Table 23: 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)	29.2437	1	(10, 40)	OK	0.33	None
Retain_L_width_SummerS(4)	1.4909	2	(0.1, 10)	OK	0.12	None
Retain_L_asymptote_logit_SummerS(4)	5.79317	4	(-10, 10)	OK	0.89	None
Retain_L_maleoffset_SummerS(4)	0	-2	(-10, 10)			None
SzSel_Male_Peak_SummerS(4)	-11.8309	3	(-15, 15)	OK	1.28	None
SzSel_Male_Ascend_SummerS(4)	-1.83638	4	(-15, 15)	OK	0.29	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)	34.4179	1	(15, 61)	OK	1.10	None
Size_DblN_top_logit_TriEarly(5)	3	-2	(-5, 3)			None
Size_DblN_ascend_se_TriEarly(5)	4.05668	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)	-3.30159	2	(-15, 15)	OK	1.07	None
SzSel_Male_Ascend_TriEarly(5)	-0.488328	2	(-15, 15)	OK	0.25	None
SzSel_Male_Descend_TriEarly(5)	0	-3	(-15, 15)			None
SzSel_Male_Final_TriEarly(5)	0	-3	(-15, 15)			None
SzSel_Male_Scale_TriEarly(5)	1	-4	(-15, 15)			None
Size_DblN_peak_TriLate(6)	36.7376	1	(15, 61)	OK	0.90	None
Size_DblN_top_logit_TriLate(6)	3	-2	(-5, 3)			None
Size_DblN_ascend_se_TriLate(6)	4.65333	1	(-4, 12)	OK	0.11	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)	-2.59651	2	(-15, 15)	OK	0.92	None
SzSel_Male_Ascend_TriLate(6)	-0.0842824	2	(-15, 15)	OK	0.14	None
SzSel_Male_Descend_TriLate(6)	0	-3	(-15, 15)			None
SzSel_Male_Final_TriLate(6)	0	-3	(-15, 15)			None
SzSel_Male_Scale_TriLate(6)	1	-4	(-15, 15)			None
Size_DblN_peak_NWFSC(7)	43.5751	1	(15, 61)	OK	0.83	None
Size_DblN_top_logit_NWFSC(7)	3	-2	(-5, 3)			None
Size_DblN_ascend_se_NWFSC(7)	5.18139	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 23: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Size_DblN_end_logit_NWFSC(7)	-999	-4	(-5, 5)			None
SzSel_Male_Peak_NWFSC(7)	-5.93554	2	(-15, 15)	OK	0.71	None
SzSel_Male_Ascend_NWFSC(7)	-0.502877	2	(-15, 15)	OK	0.08	None
SzSel_Male_Descend_NWFSC(7)	0	-3	(-15, 15)			None
SzSel_Male_Final_NWFSC(7)	0	-3	(-15, 15)			None
SzSel_Male_Scale_NWFSC(7)	1	-4	(-15, 15)			None
Size_DblN_peak_WinterN(1)_BLK1add_1973	-0.201894	4	(-31.6, 28.4)	OK	0.88	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_1983	-1.23738	4	(-31.6, 28.4)	OK	0.81	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_1993	-1.32607	4	(-31.6, 28.4)	OK	0.63	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_2003	-0.388152	4	(-31.6, 28.4)	OK	0.46	Normal (0, 14.2)
Size_DblN_peak_WinterN(1)_BLK1add_2011	-0.119181	4	(-31.6, 28.4)	OK	0.48	Normal (0, 14.2)
Retain_L_infl_WinterN(1)_BLK2add_2003	0.477145	4	(-16.19, 13.81)	OK	3.61	Normal (0, 6.905)
Retain_L_infl_WinterN(1)_BLK2add_2010	5.78079	4	(-16.19, 13.81)	OK	2.87	Normal (0, 6.905)
Retain_L_infl_WinterN(1)_BLK2add_2011	2.22632	4	(-16.19, 13.81)	OK	1.73	Normal (0, 6.905)
Retain_L_width_WinterN(1)_BLK2add_2003	0.437634	4	(-1.601, 8.299)	OK	0.33	Normal (0, 0.8005)
Retain_L_width_WinterN(1)_BLK2add_2010	0.571584	4	(-1.601, 8.299)	OK	0.74	Normal (0, 0.8005)
Retain_L_width_WinterN(1)_BLK2add_2011	-0.510919	4	(-1.601, 8.299)	OK	0.20	Normal (0, 0.8005)
Retain_L_asymptote_logit_WinterN(1)_BLK2repl_2003	7.37374	4	(-10, 10)	OK	1.70	None
Retain_L_asymptote_logit_WinterN(1)_BLK2repl_2010	2.08428	4	(-10, 10)	OK	0.40	None
Retain_L_asymptote_logit_WinterN(1)_BLK2repl_2011	9.02851	4	(-10, 10)	OK	1.02	None
Size_DblN_peak_SummerN(2)_BLK1add_1973	-2.75604	4	(-38.8, 21.2)	OK	0.85	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_1983	-4.93864	4	(-38.8, 21.2)	OK	1.12	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_1993	-5.7762	4	(-38.8, 21.2)	OK	1.16	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_2003	-4.12696	4	(-38.8, 21.2)	OK	0.67	Normal (0, 10.6)
Size_DblN_peak_SummerN(2)_BLK1add_2011	-1.53447	4	(-38.8, 21.2)	OK	0.62	Normal (0, 10.6)
Retain_L_infl_SummerN(2)_BLK3add_2003	0.15738	4	(-20.679, 9.321)	OK	0.52	Normal (0, 4.6605)
Retain_L_infl_SummerN(2)_BLK3add_2009	1.77908	4	(-20.679, 9.321)	OK	0.55	Normal (0, 4.6605)
Retain_L_infl_SummerN(2)_BLK3add_2011	-1.06712	4	(-20.679, 9.321)	OK	0.51	Normal (0, 4.6605)
Retain_L_width_SummerN(2)_BLK3add_2003	0.106445	4	(-1.0278, 8.8722)	OK	0.22	Normal (0, 0.5139)
Retain_L_width_SummerN(2)_BLK3add_2009	0.142802	4	(-1.0278, 8.8722)	OK	0.23	Normal (0, 0.5139)
Retain_L_width_SummerN(2)_BLK3add_2011	0.228908	4	(-1.0278, 8.8722)	OK	0.16	Normal (0, 0.5139)
Retain_L_asymptote_logit_SummerN(2)_BLK3repl_2003	5.51708	4	(-10, 10)	OK	0.97	None
Retain_L_asymptote_logit_SummerN(2)_BLK3repl_2009	6.86695	4	(-10, 10)	OK	6.44	None
Retain_L_asymptote_logit_SummerN(2)_BLK3repl_2011	5.96198	4	(-10, 10)	OK	0.58	None
Size_DblN_peak_WinterS(3)_BLK1add_1973	-6.07356	4	(-25.422, 34.578)	OK	2.15	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_1983	-0.393954	4	(-25.422, 34.578)	OK	1.18	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_1993	2.96858	4	(-25.422, 34.578)	OK	1.66	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_2003	0.859894	4	(-25.422, 34.578)	OK	0.85	Normal (0, 12.711)
Size_DblN_peak_WinterS(3)_BLK1add_2011	1.91596	4	(-25.422, 34.578)	OK	0.99	Normal (0, 12.711)

Continued on next page

Table 23: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values indicate not estimated), status (indicates if parameters are near bounds, and prior type information (mean, SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Retain_L_infl_WinterS(3)_BLK2add_2003	-2.31652	4	(-18.816, 11.184)	OK	1.34	Normal (0, 5.592)
Retain_L_infl_WinterS(3)_BLK2add_2010	1.40756	4	(-18.816, 11.184)	OK	1.65	Normal (0, 5.592)
Retain_L_infl_WinterS(3)_BLK2add_2011	-3.95341	4	(-18.816, 11.184)	OK	2.49	Normal (0, 5.592)
Retain_L_width_WinterS(3)_BLK2add_2003	0.34367	4	(-1.0443, 8.8557)	OK	0.37	Normal (0, 0.52215)
Retain_L_width_WinterS(3)_BLK2add_2010	0.118141	4	(-1.0443, 8.8557)	OK	0.46	Normal (0, 0.52215)
Retain_L_width_WinterS(3)_BLK2add_2011	-0.387615	4	(-1.0443, 8.8557)	OK	0.48	Normal (0, 0.52215)
Retain_L_asymptote_logit_WinterS(3)_BLK2repl_2003	8.47752	4	(-10, 10)	OK	9.50	None
Retain_L_asymptote_logit_WinterS(3)_BLK2repl_2010	5.69214	4	(-10, 10)	OK	8.51	None
Retain_L_asymptote_logit_WinterS(3)_BLK2repl_2011	6.98104	4	(-10, 10)	OK	1.60	None
Size_DblN_peak_SummerS(4)_BLK1add_1973	-8.19143	4	(-28.0793, 31.9207)	OK	2.13	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_1983	-8.6809	4	(-28.0793, 31.9207)	OK	2.90	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_1993	-0.797364	4	(-28.0793, 31.9207)	OK	1.39	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_2003	0.932051	4	(-28.0793, 31.9207)	OK	0.74	Normal (0, 14.0397)
Size_DblN_peak_SummerS(4)_BLK1add_2011	0.680221	4	(-28.0793, 31.9207)	OK	0.85	Normal (0, 14.0397)
Retain_L_infl_SummerS(4)_BLK3add_2003	-1.86903	4	(-19.055, 10.945)	OK	0.84	Normal (0, 5.4725)
Retain_L_infl_SummerS(4)_BLK3add_2009	-2.00786	4	(-19.055, 10.945)	OK	1.14	Normal (0, 5.4725)
Retain_L_infl_SummerS(4)_BLK3add_2011	-2.12954	4	(-19.055, 10.945)	OK	0.90	Normal (0, 5.4725)
Retain_L_width_SummerS(4)_BLK3add_2003	0.305622	4	(-0.876, 9.024)	OK	0.22	Normal (0, 0.438)
Retain_L_width_SummerS(4)_BLK3add_2009	0.176878	4	(-0.876, 9.024)	OK	0.26	Normal (0, 0.438)
Retain_L_width_SummerS(4)_BLK3add_2011	0.0539534	4	(-0.876, 9.024)	OK	0.21	Normal (0, 0.438)
Retain_L_asymptote_logit_SummerS(4)_BLK3repl_2003	9.13443	4	(-10, 10)	OK	12.97	None
Retain_L_asymptote_logit_SummerS(4)_BLK3repl_2009	9.7475	4	(-10, 10)	OK	7.09	None
Retain_L_asymptote_logit_SummerS(4)_BLK3repl_2011	9.9577	4	(-10, 10)	HI	1.31	None

tab:model_params

Table 24: Results from 50 jitters from the base model.

tab:jitter

Status	Base.Model
Returned to base case	
Found local minimum	
Found better solution	
Total	50

Table 25: Likelihood components from the base model

tab:like

Likelihood Component	Value
Total	1455.79
Survey	-77.56
Discard	-225.63
Mean-body weight data	-158.25
Length-frequency data	904.37
Age-frequency data	1036.37
Recruitment	-28.68
Forecast Recruitment	0.03
Parameter Priors	5.09
Parameter Softbounds	0.04

Table 26: 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 output (mt)	30554.7	24634.6	36474.8
Unfished age 3+ biomass (mt)	49439.6	41597	57282.2
Unfished recruitment (R0, thousands)	18626.7	12518.1	27716.1
Spawning output(2019 mt)	9867.3	7682.4	12052.2
Depletion (2019)	0.323	0.219	0.426
Reference points based on $\mathbf{SB_{40\%}}$			
Proxy spawning output ($B_{25\%}$)	7638.7	6158.7	9118.7
SPR resulting in $B_{25\%}$ ($SPR_{B25\%}$)	0.286	0.258	0.313
Exploitation rate resulting in $B_{25\%}$	0.182	0.163	0.2
Yield with $SPR_{B25\%}$ at $B_{25\%}$ (mt)	2830.3	2624.2	3036.4
Reference points based on SPR proxy for MSY			
Spawning output	8096.3	6199.3	9993.3
SPR_{proxy}			
Exploitation rate corresponding to SPR_{proxy}	0.173	0.145	0.2
Yield with SPR_{proxy} at SB_{SPR} (mt)	2819.8	2590.1	3049.5
Reference points based on estimated MSY values			
Spawning output at MSY (SB_{MSY})	7005.9	5242.2	8769.6
SPR_{MSY}	0.266	0.201	0.331
Exploitation rate at MSY	0.195	0.164	0.225
MSY (mt)	2835.9	2641.9	3029.9

Table 27: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning output (million eggs)	Summary biomass 3+	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1876	49,440	30,555	48,800	1.00	18,627	1	0	0
1877	49,439	30,554	48,800	1.00	18,627	1	0	0
1878	49,438	30,554	48,799	1.00	18,627	1	0	0
1879	49,437	30,553	48,798	1.00	18,628	1	0	0
1880	49,437	30,553	48,797	1.00	18,628	12	0	0
1881	49,426	30,545	48,786	1.00	18,628	23	0	0
1882	49,406	30,532	48,766	1.00	18,627	33	0.003	0.001
1883	49,377	30,512	48,738	1.00	18,627	44	0.003	0.001
1884	49,341	30,487	48,701	1.00	18,626	55	0.003	0.001
1885	49,298	30,457	48,658	1.00	18,626	65	0.003	0.001
1886	49,248	30,422	48,608	1.00	18,625	76	0.006	0.002
1887	49,193	30,384	48,553	0.99	18,624	87	0.006	0.002
1888	49,132	30,342	48,493	0.99	18,623	98	0.006	0.002
1889	49,068	30,297	48,429	0.99	18,622	108	0.006	0.002
1890	49,000	30,248	48,360	0.99	18,621	119	0.006	0.002
1891	48,928	30,198	48,288	0.99	18,620	130	0.009	0.003

Table 27: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning output (million eggs)	Summary biomass 3+	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1892	48,853	30,145	48,214	0.99	18,619	141	0.009	0.003
1893	48,776	30,090	48,136	0.98	18,618	151	0.009	0.003
1894	48,696	30,034	48,057	0.98	18,617	162	0.009	0.003
1895	48,614	29,976	47,975	0.98	18,616	173	0.009	0.004
1896	48,531	29,916	47,892	0.98	18,615	184	0.012	0.004
1897	48,446	29,856	47,806	0.98	18,614	195	0.012	0.004
1898	48,359	29,794	47,720	0.98	18,613	205	0.012	0.004
1899	48,272	29,732	47,633	0.97	18,613	216	0.012	0.005
1900	48,183	29,669	47,544	0.97	18,612	227	0.012	0.005
1901	48,094	29,605	47,455	0.97	18,612	238	0.015	0.005
1902	48,004	29,540	47,365	0.97	18,611	248	0.015	0.005
1903	47,913	29,476	47,274	0.96	18,611	259	0.015	0.005
1904	47,822	29,410	47,183	0.96	18,612	270	0.015	0.006
1905	47,731	29,345	47,092	0.96	18,612	281	0.018	0.006
1906	47,639	29,279	47,000	0.96	18,613	291	0.018	0.006
1907	47,547	29,213	46,908	0.96	18,614	302	0.018	0.006
1908	47,455	29,146	46,816	0.95	18,616	313	0.018	0.007
1909	47,363	29,080	46,724	0.95	18,618	324	0.018	0.007
1910	47,271	29,014	46,632	0.95	18,621	334	0.021	0.007
1911	47,179	28,947	46,540	0.95	18,624	345	0.021	0.007
1912	47,088	28,881	46,448	0.95	18,628	356	0.021	0.008
1913	46,996	28,814	46,357	0.94	18,633	367	0.021	0.008
1914	46,906	28,748	46,266	0.94	18,638	377	0.024	0.008
1915	46,815	28,682	46,175	0.94	18,645	388	0.024	0.008
1916	46,725	28,617	46,085	0.94	18,652	394	0.024	0.009
1917	46,641	28,555	46,001	0.93	18,661	537	0.03	0.012
1918	46,433	28,409	45,792	0.93	18,668	432	0.027	0.009
1919	46,343	28,341	45,702	0.93	18,679	340	0.021	0.007
1920	46,352	28,341	45,711	0.93	18,694	235	0.015	0.005
1921	46,467	28,411	45,825	0.93	18,712	299	0.018	0.007
1922	46,518	28,441	45,876	0.93	18,731	433	0.027	0.009
1923	46,443	28,387	45,800	0.93	18,749	436	0.027	0.01
1924	46,374	28,336	45,730	0.93	18,768	543	0.033	0.012
1925	46,212	28,222	45,568	0.92	18,787	539	0.033	0.012
1926	46,072	28,120	45,427	0.92	18,808	532	0.033	0.012
1927	45,954	28,032	45,309	0.92	18,832	644	0.039	0.014
1928	45,747	27,884	45,101	0.91	18,856	632	0.036	0.014
1929	45,574	27,757	44,928	0.91	18,882	721	0.042	0.016
1930	45,340	27,588	44,692	0.90	18,910	673	0.039	0.015
1931	45,179	27,467	44,530	0.90	18,946	688	0.039	0.015
1932	45,029	27,350	44,379	0.90	18,989	822	0.048	0.019
1933	44,781	27,163	44,130	0.89	19,042	857	0.048	0.019
1934	44,539	26,973	43,887	0.88	19,131	1640	0.084	0.037
1935	43,600	26,312	42,946	0.86	19,259	1622	0.084	0.038
1936	42,770	25,713	42,112	0.84	19,445	1331	0.072	0.032
1937	42,310	25,351	41,648	0.83	19,678	1914	0.096	0.046
1938	41,384	24,665	40,715	0.81	19,869	2184	0.108	0.054
1939	40,324	23,878	39,647	0.78	19,860	2678	0.126	0.068
1940	38,938	22,855	38,257	0.75	19,434	2569	0.123	0.067
1941	37,821	22,000	37,143	0.72	18,623	2315	0.12	0.062
1942	37,080	21,408	36,420	0.70	17,727	3242	0.147	0.089
1943	35,577	20,317	34,944	0.66	17,085	3377	0.153	0.097

Table 27: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning output (million eggs)	Summary biomass 3+	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1944	34,051	19,271	33,447	0.63	17,050	2672	0.141	0.08
1945	33,239	18,772	32,653	0.61	17,582	2503	0.138	0.077
1946	32,584	18,413	31,995	0.60	17,963	3805	0.171	0.119
1947	30,712	17,244	30,106	0.56	17,751	3148	0.162	0.105
1948	29,524	16,484	28,909	0.54	17,503	4525	0.195	0.157
1949	27,115	14,878	26,508	0.49	17,257	4412	0.201	0.166
1950	24,942	13,412	24,343	0.44	17,160	4643	0.213	0.191
1951	22,705	11,885	22,113	0.39	17,164	3054	0.189	0.138
1952	22,093	11,425	21,503	0.37	17,273	2797	0.186	0.13
1953	21,790	11,202	21,201	0.37	16,951	2367	0.174	0.112
1954	21,912	11,295	21,322	0.37	16,181	2888	0.189	0.135
1955	21,541	11,088	20,965	0.36	15,105	2570	0.183	0.123
1956	21,451	11,063	20,904	0.36	14,068	2267	0.174	0.108
1957	21,592	11,219	21,082	0.37	13,386	2904	0.192	0.138
1958	21,048	10,988	20,570	0.36	13,872	2851	0.192	0.139
1959	20,457	10,756	19,992	0.35	17,137	2435	0.18	0.122
1960	20,192	10,709	19,690	0.35	21,658	2840	0.192	0.144
1961	19,576	10,334	18,959	0.34	16,766	3413	0.21	0.18
1962	18,561	9,536	17,856	0.31	11,393	3257	0.21	0.182
1963	17,840	8,807	17,301	0.29	12,855	3299	0.216	0.191
1964	17,126	8,186	16,721	0.27	18,499	2765	0.21	0.165
1965	16,893	8,096	16,414	0.26	15,563	2627	0.207	0.16
1966	16,798	8,220	16,173	0.27	32,710	2661	0.207	0.165
1967	16,768	8,233	16,123	0.27	14,915	2682	0.207	0.166
1968	16,972	8,087	15,975	0.26	15,421	2398	0.201	0.15
1969	17,638	8,085	17,122	0.26	15,854	2432	0.201	0.142
1970	18,321	8,242	17,788	0.27	16,417	3153	0.216	0.177
1971	18,290	8,336	17,742	0.27	15,835	3288	0.219	0.185
1972	18,038	8,541	17,480	0.28	13,025	3555	0.222	0.203
1973	17,407	8,459	16,885	0.28	10,902	3132	0.222	0.186
1974	16,897	8,390	16,463	0.27	13,807	3949	0.24	0.24
1975	15,362	7,679	14,967	0.25	14,283	3808	0.243	0.254
1976	13,780	6,899	13,302	0.23	16,377	3122	0.237	0.235
1977	12,768	6,368	12,264	0.21	15,187	2561	0.228	0.209
1978	12,345	6,021	11,794	0.20	11,138	3302	0.249	0.28
1979	11,294	5,226	10,802	0.17	11,032	3423	0.258	0.317
1980	10,128	4,435	9,747	0.15	12,172	2855	0.255	0.293
1981	9,419	4,068	9,033	0.13	10,311	2765	0.258	0.306
1982	8,704	3,803	8,300	0.12	10,034	2770	0.258	0.334
1983	7,955	3,454	7,602	0.11	10,772	2454	0.258	0.323
1984	7,429	3,199	7,075	0.10	17,986	1911	0.249	0.27
1985	7,385	3,170	6,968	0.10	10,962	1871	0.249	0.269
1986	7,448	3,142	6,884	0.10	6,464	2133	0.255	0.31
1987	7,330	2,937	6,985	0.10	8,491	2563	0.267	0.367
1988	6,756	2,558	6,518	0.08	11,405	2360	0.267	0.362
1989	6,260	2,409	5,946	0.08	15,485	2304	0.267	0.387
1990	5,762	2,326	5,342	0.08	15,973	1961	0.264	0.367
1991	5,636	2,230	5,106	0.07	9,723	2133	0.27	0.418
1992	5,511	1,894	5,010	0.06	6,145	1807	0.267	0.361
1993	5,742	1,785	5,431	0.06	11,468	1681	0.264	0.309
1994	6,105	1,943	5,855	0.06	14,126	1544	0.255	0.264
1995	6,556	2,405	6,147	0.08	8,861	1674	0.252	0.272

Table 27: Time-series of population estimates from the base model.

Year	Total biomass (mt)	Spawning output (million eggs)	Summary biomass 3+	Relative biomass	Age-0 recruits	Estimated total catch (mt)	1-SPR	Exploit. rate
1996	6,877	2,801	6,428	0.09	10,797	1929	0.252	0.3
1997	6,936	2,863	6,618	0.09	10,373	2051	0.255	0.31
1998	6,865	2,718	6,489	0.09	24,170	1739	0.249	0.268
1999	7,128	2,797	6,679	0.09	16,132	1621	0.243	0.243
2000	7,720	3,002	6,950	0.10	11,710	1915	0.249	0.275
2001	8,292	3,050	7,771	0.10	10,177	1980	0.249	0.255
2002	8,917	3,122	8,525	0.10	11,236	2067	0.249	0.242
2003	9,434	3,434	9,078	0.11	8,955	1795	0.234	0.198
2004	10,066	4,110	9,695	0.13	10,870	2294	0.24	0.237
2005	10,088	4,523	9,766	0.15	11,630	3015	0.252	0.309
2006	9,275	4,306	8,890	0.14	21,088	2215	0.24	0.249
2007	9,107	4,222	8,638	0.14	25,131	2404	0.243	0.278
2008	8,985	3,906	8,227	0.13	34,665	2180	0.24	0.265
2009	9,529	3,681	8,610	0.12	15,169	2329	0.246	0.271
2010	10,536	3,494	9,487	0.11	11,740	867	0.186	0.091
2011	13,224	4,414	12,727	0.14	13,434	791	0.165	0.062
2012	16,022	5,904	15,603	0.19	19,781	1159	0.171	0.074
2013	18,309	7,751	17,807	0.25	12,763	1973	0.189	0.111
2014	19,603	9,284	18,973	0.30	13,826	2398	0.189	0.126
2015	20,194	10,202	19,748	0.33	13,751	2727	0.192	0.138
2016	20,190	10,439	19,716	0.34	13,924	2543	0.186	0.129
2017	20,111	10,531	19,637	0.34	15,071	3050	0.195	0.155
2018	19,406	10,213	18,919	0.33	17,012	2882	0.195	0.152
2019	18,796	9,867	18,265	0.32	16,935	-	-	-

tab:Timeseries_mod1

Table 28: Sensitivity of the base model.

tab:Sensitivity1

Label	Base	Low M	High M	Harmonic weights	Dirichlet weights	NA
Total Likelihood						
Survey Likelihood						
Discard Likelihood						
Length Likelihood						
Age Likelihood						
Recruitment Likelihood						
Forecast Recruitment Likelihood						
Parameter Priors Likelihood						
Parameter Deviation Likelihood						
log(R0)						
SB Virgin						
SB 2017						
Depletion 2017						
Total Yield - SPR 50						
Steepness						
Natural Mortality - Female						
Length at Amin - Female						
Length at Amax - Female						
Von Bert. k - Female						
SD young - Female						
SD old - Female						
Natural Mortality - Male						
Length at Amin - Male						
Length at Amax - Male						
Von Bert. k - Male						
SD young - Male						
SD old - Male						

Table 29: Data weights applied when using harmonic data weighting.

tab:harm

Fleet	Lengths	Ages
Winter North		
Summer North		
Winter South		
Summer South		
Triennial Early survey		-
Triennial Late survey		-
NWFSC shelf-slope survey		

Table 30: Data weights applied when using Dirichlet data weighting.

tab:dirichlet

Fleet	Lengths	Ages
Winter North		
Summer North		
Winter South		
Summer South		
Triennial Early survey		-
Triennial Late survey		-
NWFSC shelf-slope survey		

Table 31: 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 Output	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 32: Decision table summary of 10-year projections beginning in 2021 for alternate states of nature based on an axis of uncertainty for the base model. The removals in 2017 and 2018 were set at the defined management specification of 281 mt for each year assuming full attainment. Columns range over low, mid, and high states of nature over natural mortality, and rows range over different assumptions of catch levels. An entry of "–" indicates that the stock is driven to very low abundance under the particular scenario.

tab:Decision_table_mod1_back

			States of nature					
			M = 0.04725		M = 0.054		M = 0.0595	
	Year	Catch	Spawning Output	Depletion (%)	Spawning Output	Depletion (%)	Spawning Output	Depletion (%)
	2021							
	2022							
	2023							
ABC	2024							
	2025							
	2026							
	2027							
	2028							
	2029							
	2030							
	2021							
	2022							
	2023							
SPR target = 0.34	2024							
	2025							
	2026							
	2027							
	2028							
	2029							
	2030							

9 Figures

`figures`

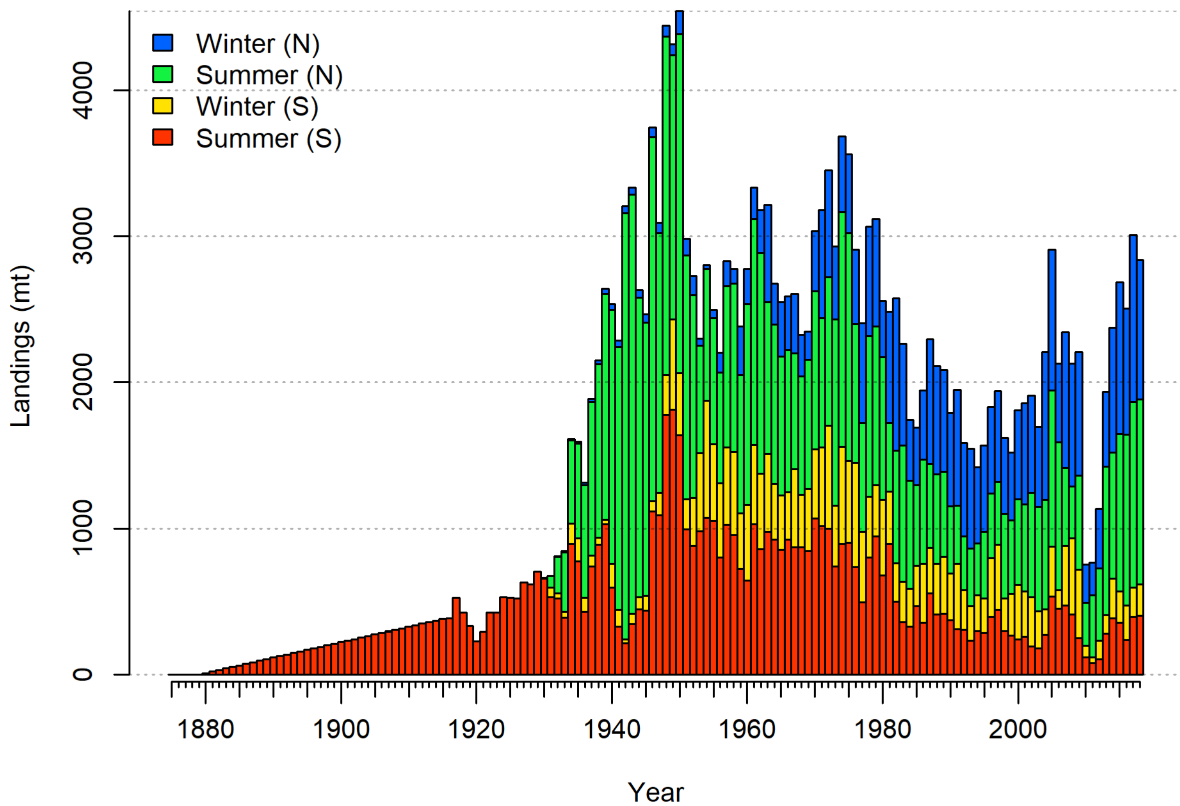

Figure 1: Total catches petrale sole. fig:Catch

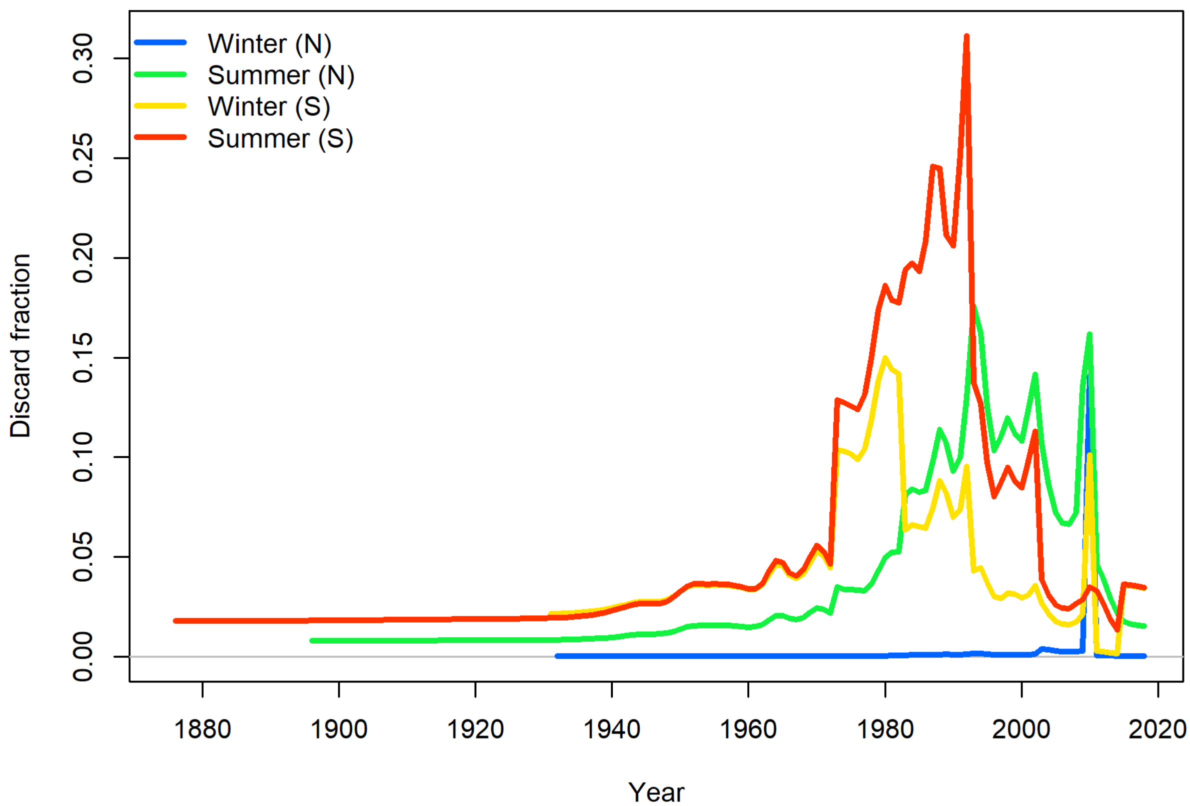

Figure 2: Discard rates by fleet for petrale sole. fig:Discard

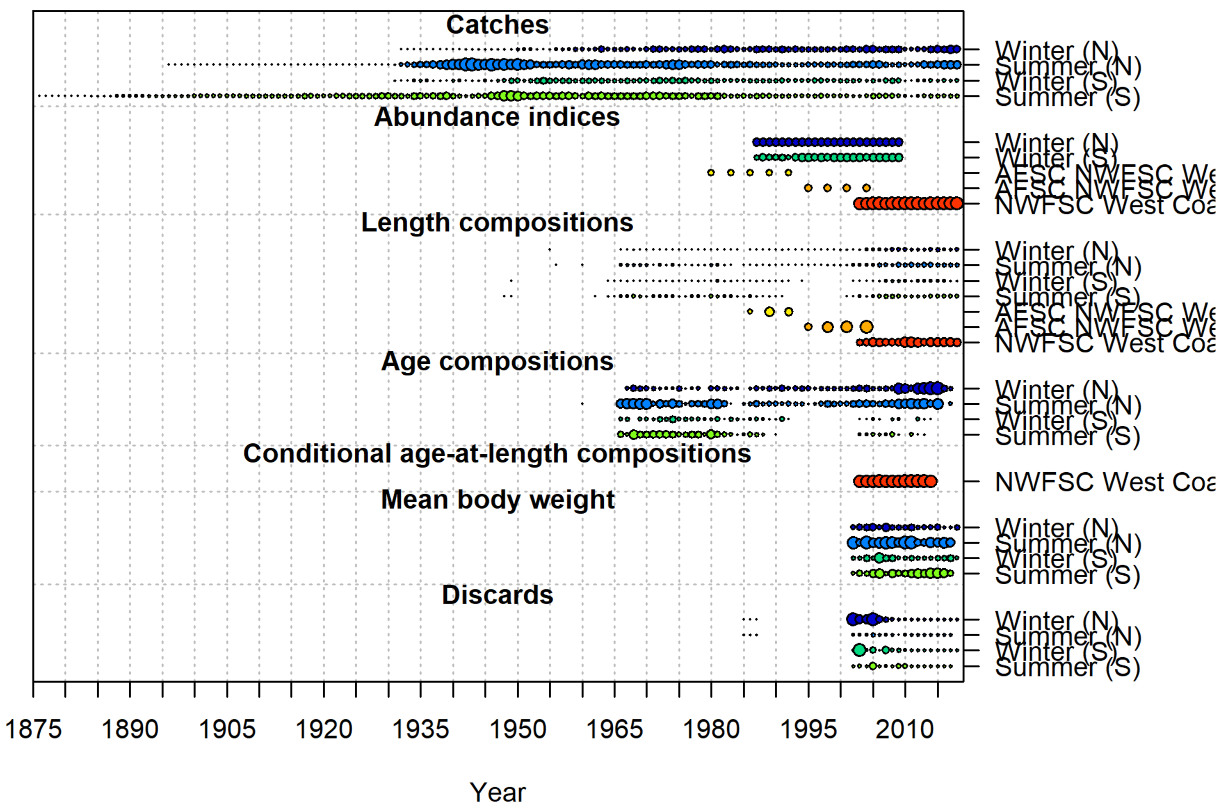

Figure 3: Summary of data sources used in the base model. fig:data_plot

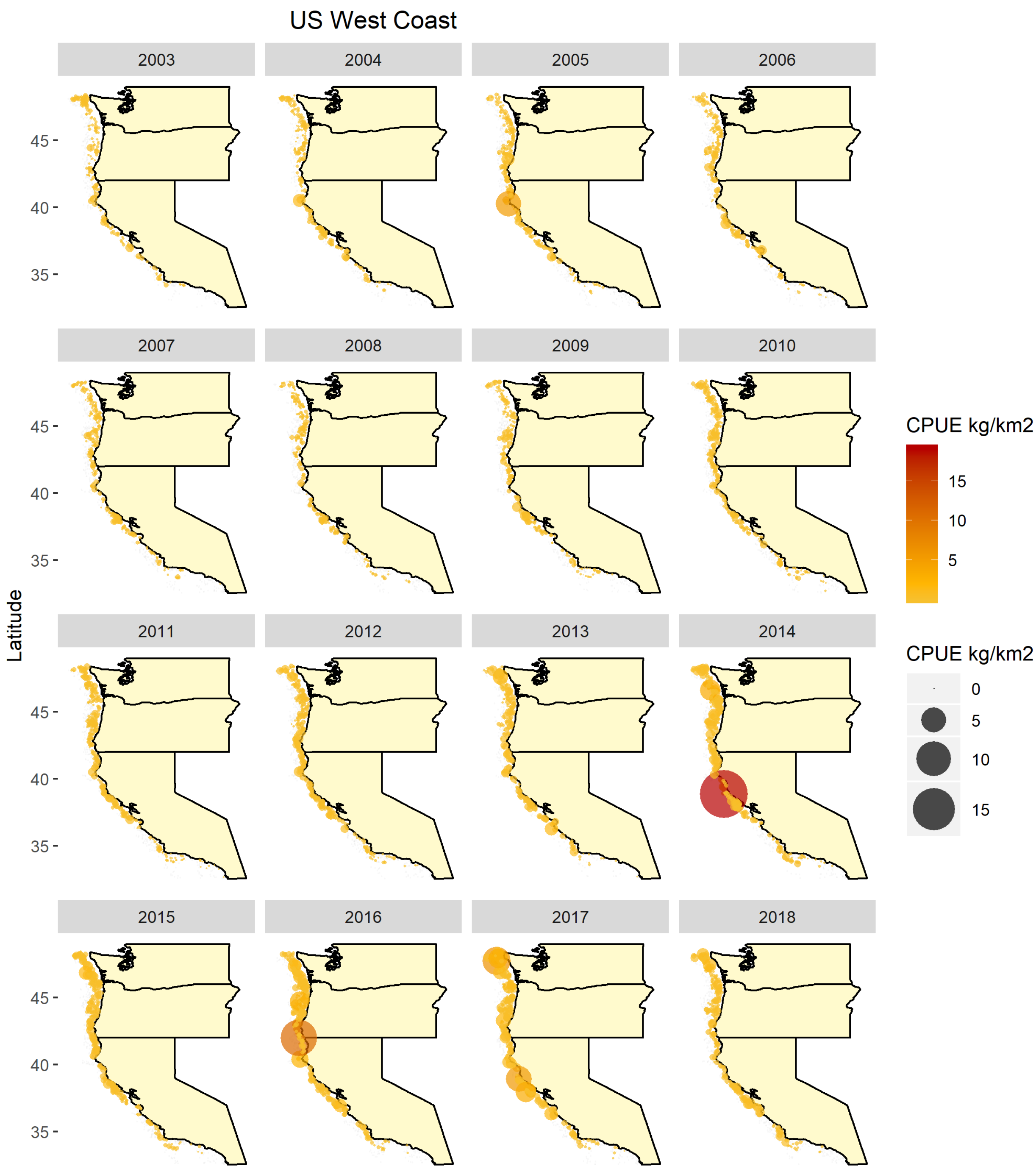

Figure 4: Map of the catch-per-unit-effort across by year for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_map

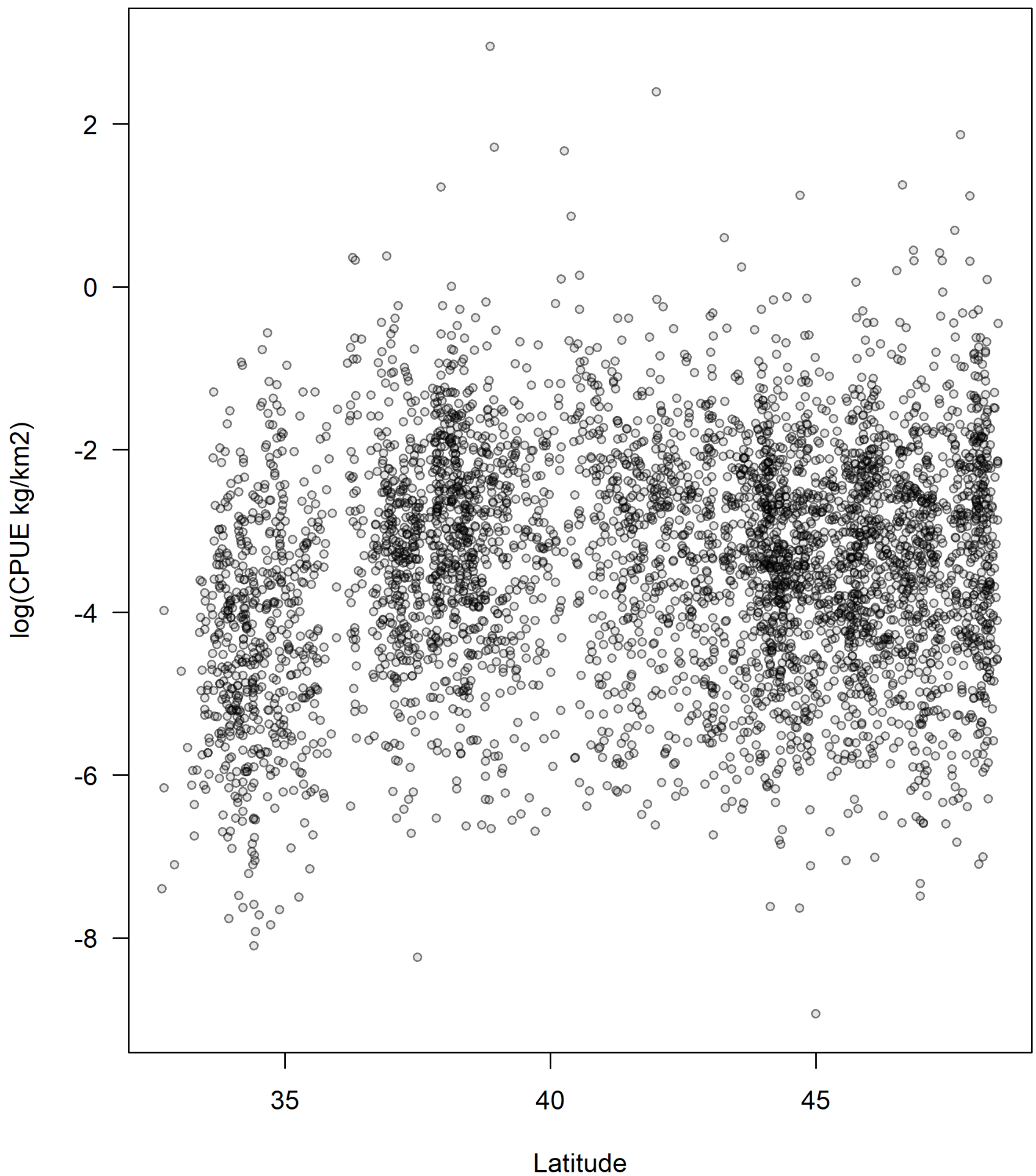

Figure 5: Catch-per-unit-effort (in log space) by latitude for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_cpue_lat

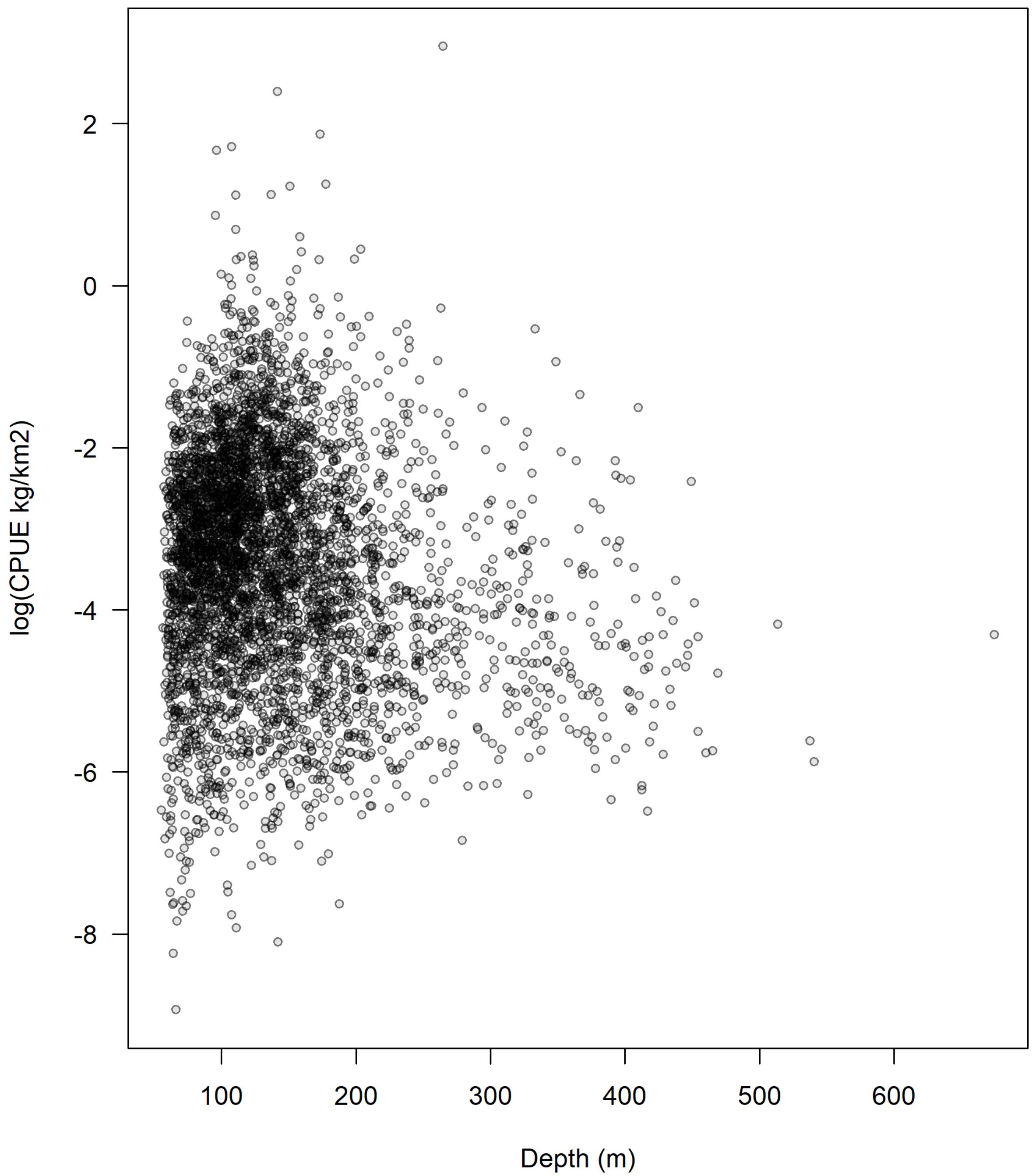

Figure 6: Catch-per-unit-effort (in log space) by depth for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_cpue_depth

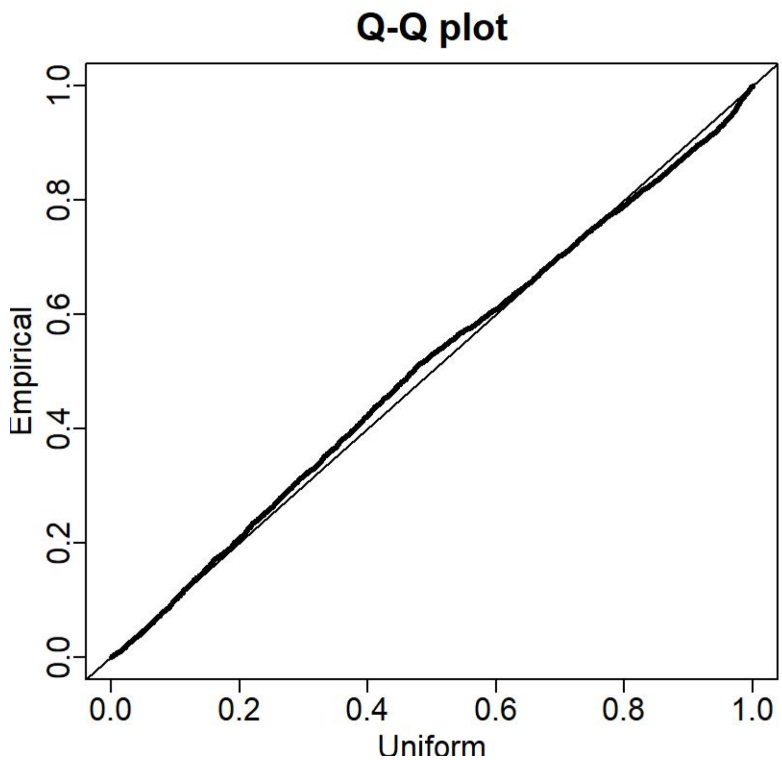

Figure 7: QQ plot for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_qq

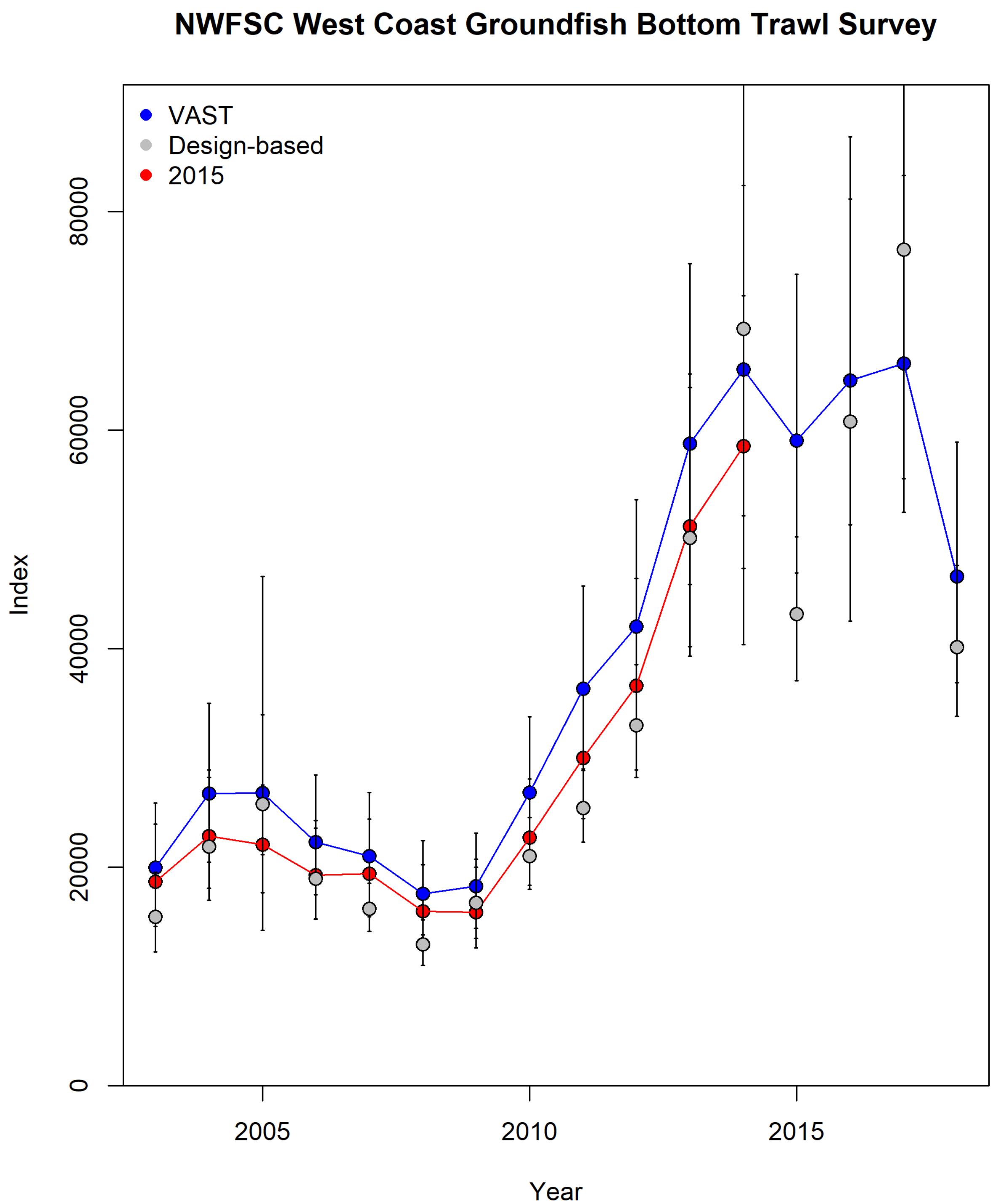

Figure 8: Estimated index of abundance from the NWFSC West Coast Groundfish Bottom Trawl Survey data compared to the design-based index and the index from the 2015 update assessment. fig:nw_index

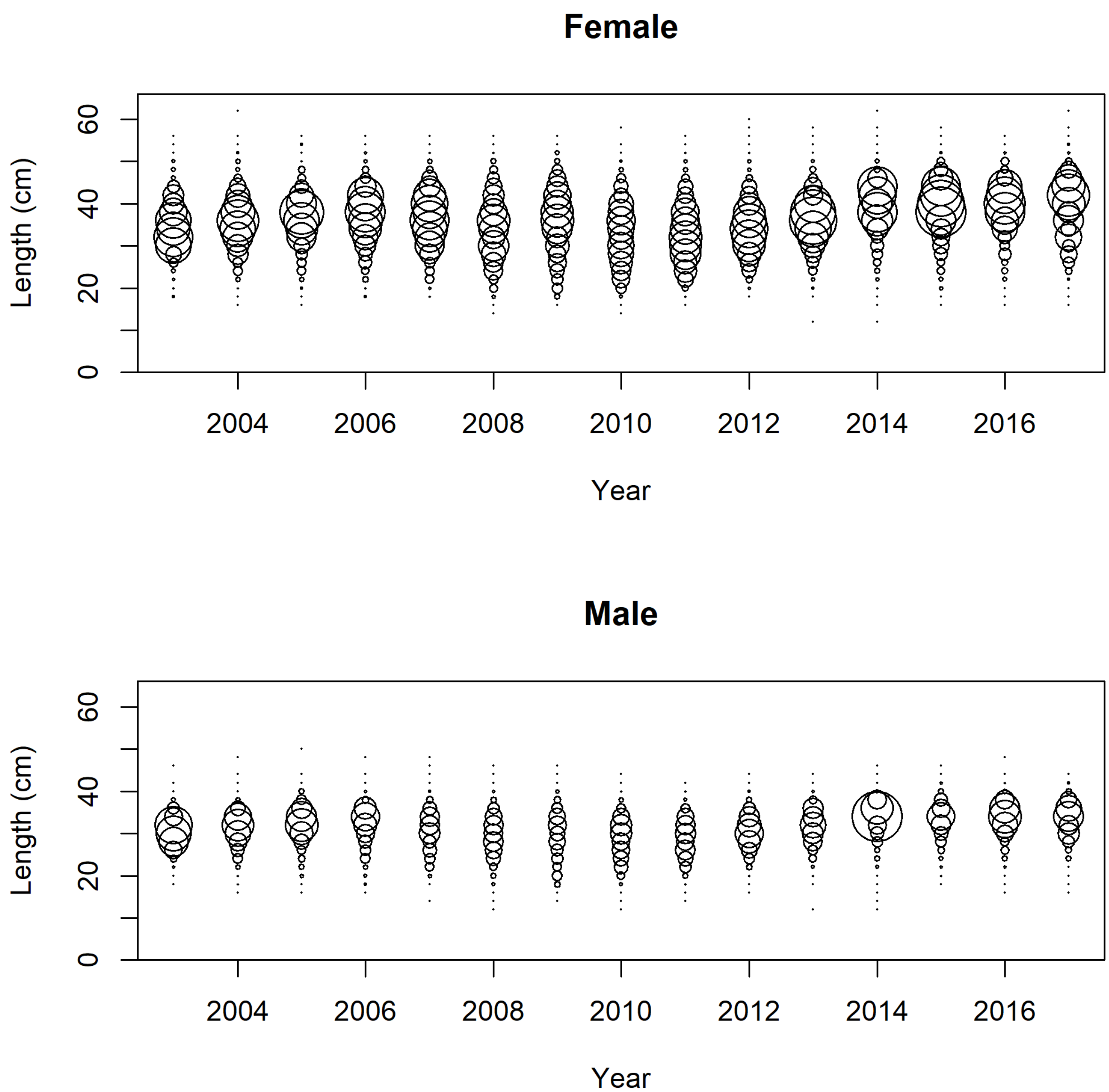

Figure 9: Length frequency by sex for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_len_freq

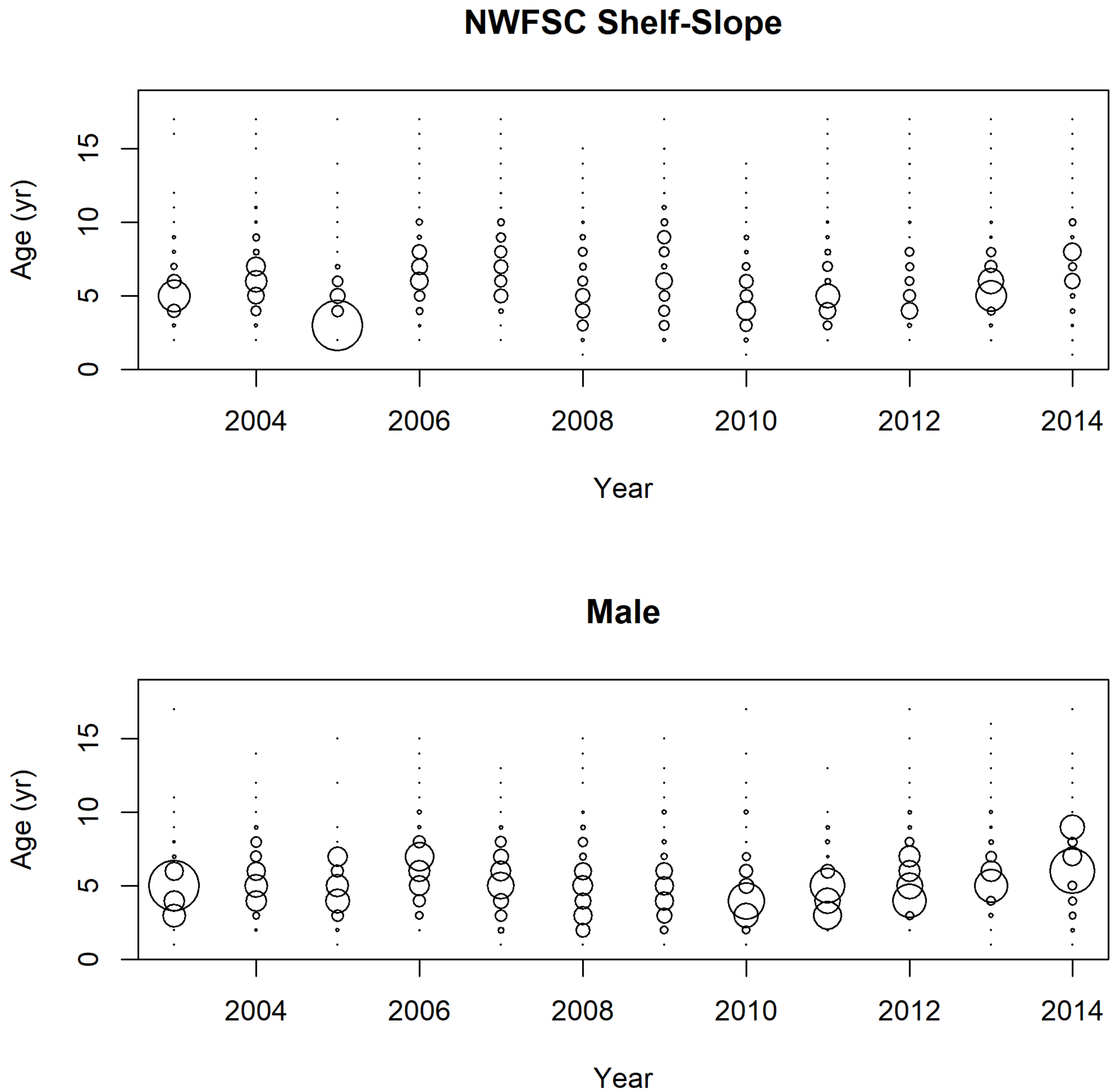

Figure 10: Age frequency by sex for the NWFSC West Coast Groundfish Bottom Trawl Survey data. fig:nw_age_freq

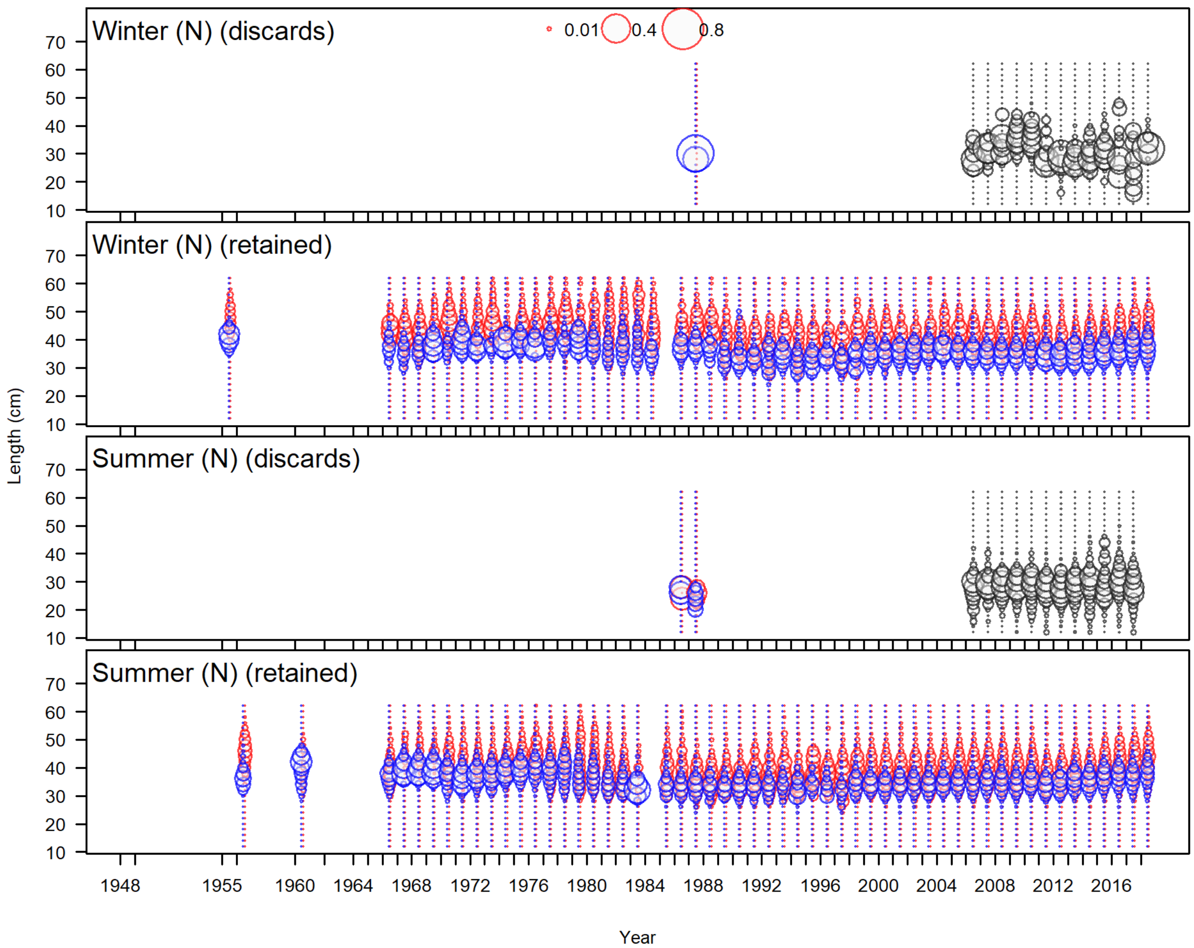

Figure 11: Northern fishery, winter and summer, retained and discarded length frequency distributions for petrale sole. fig:north_lengths

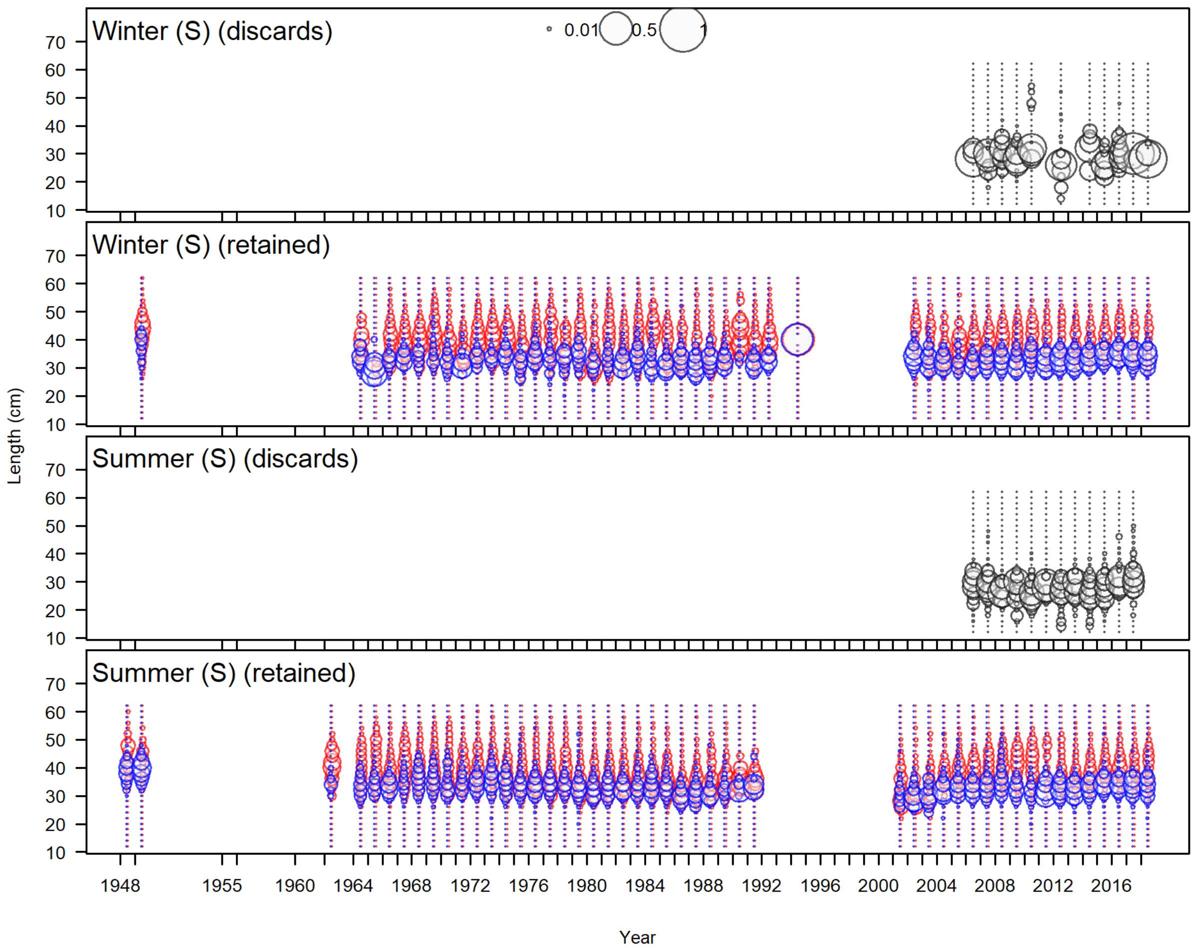

Figure 12: Southern fishery, winter and summer, retained and discarded length frequency distributions for petrale sole. fig:south_lengths

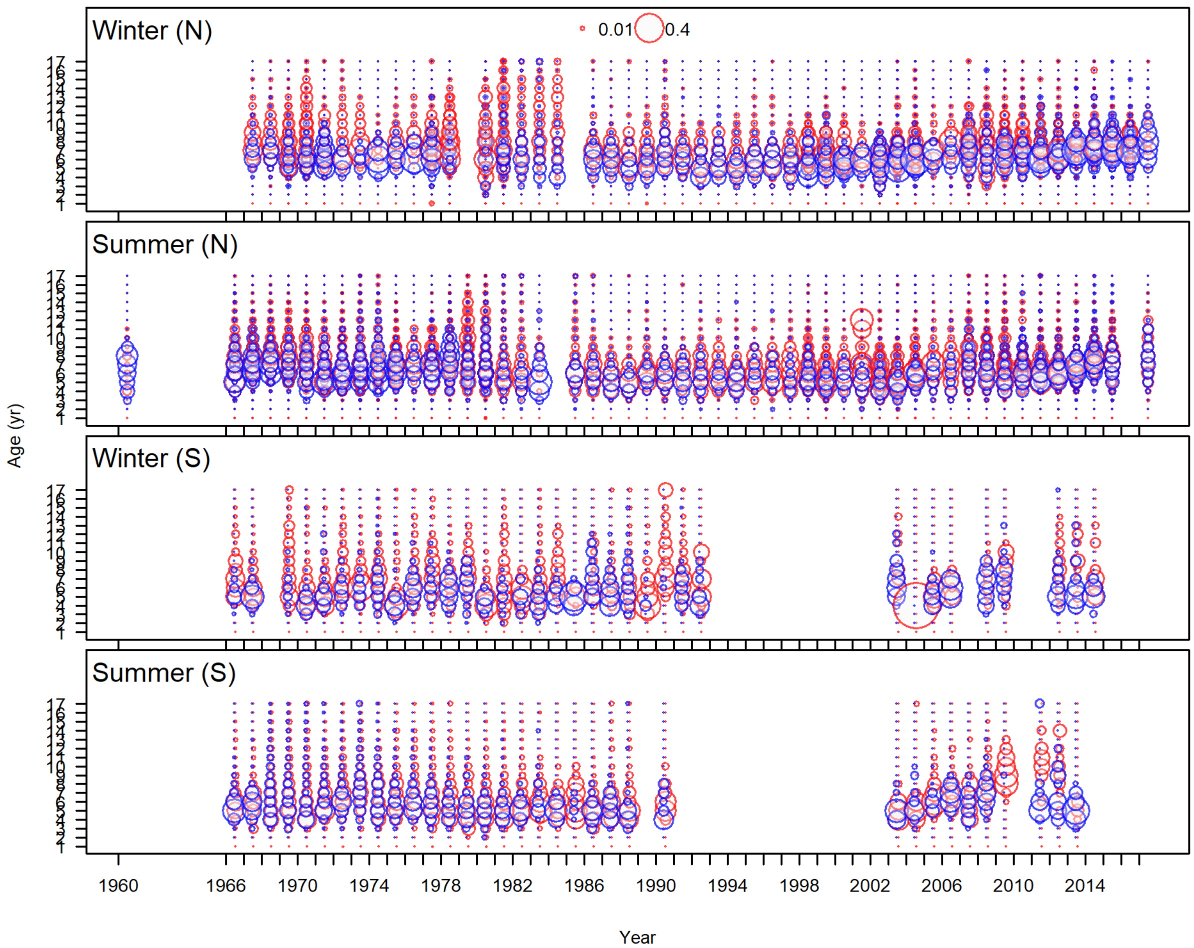

Figure 13: Commercial fishery age frequency distributions for petrale sole. fig:comm_ages

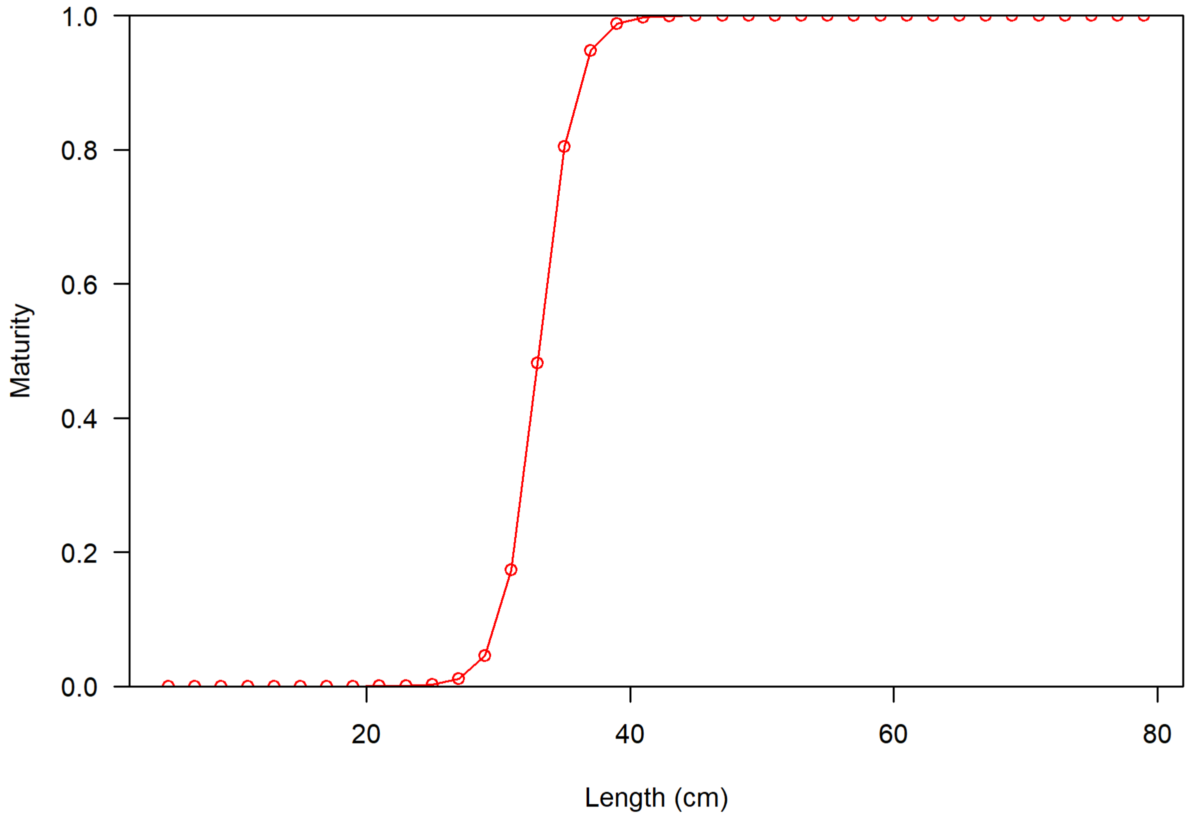

Figure 14: Estimated maturity-at-length for petrale sole. fig:maturity

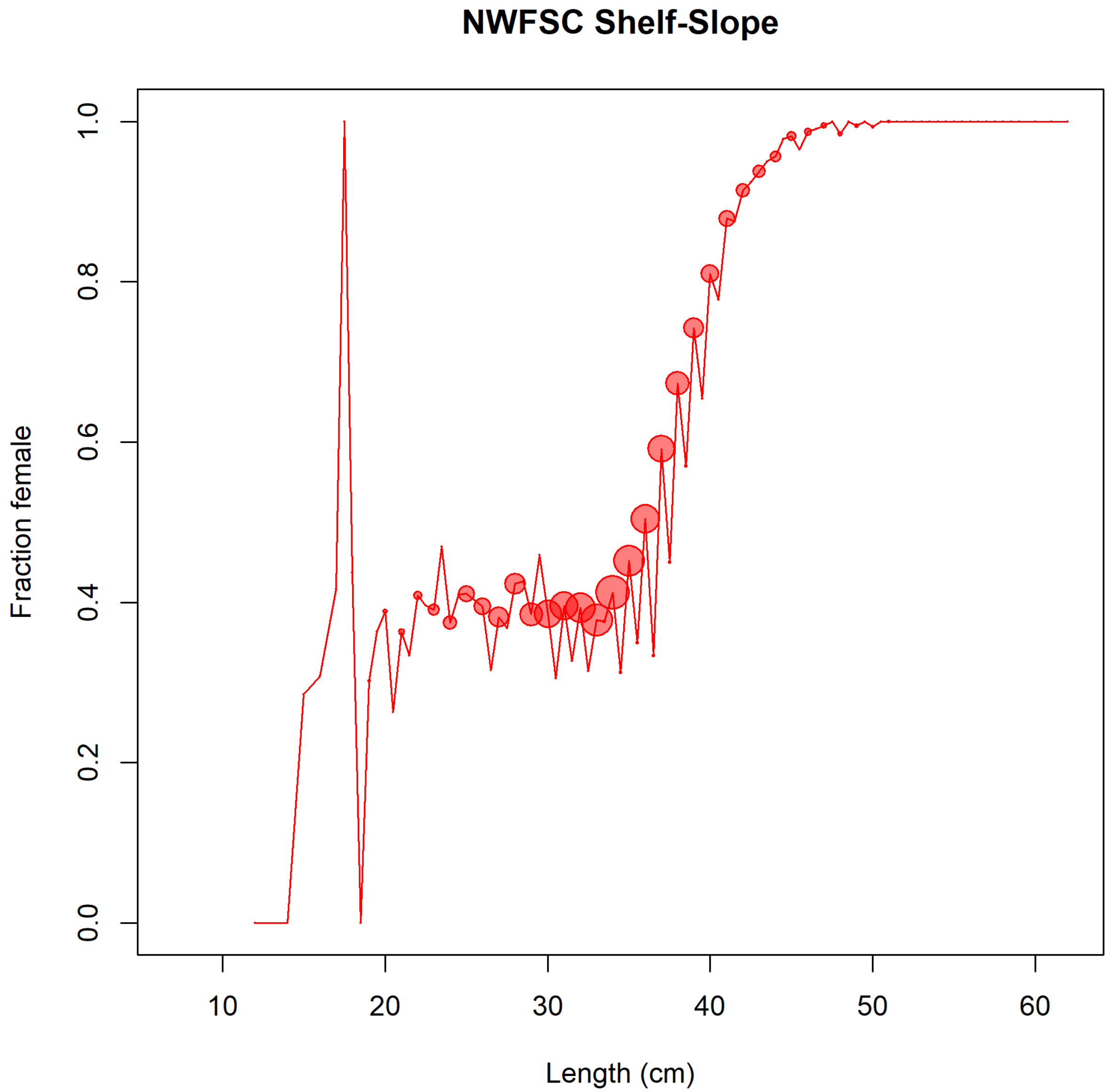

Figure 15: Estimated proportion of female fish collected by the NWFSC shelf-slope survey across all years for petrale sole. fig:sex_ratio

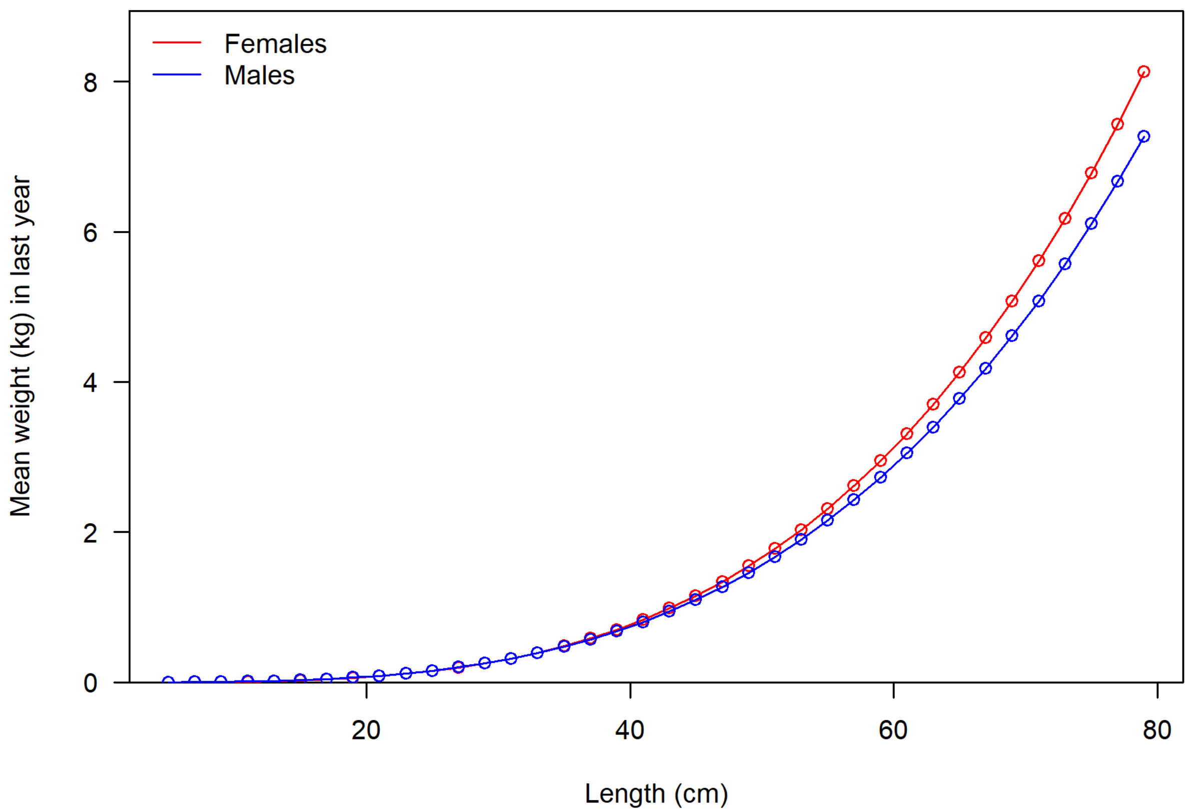

Figure 16: Estimated weight-at-length for female and male petrale sole. fig:mod_wt_length

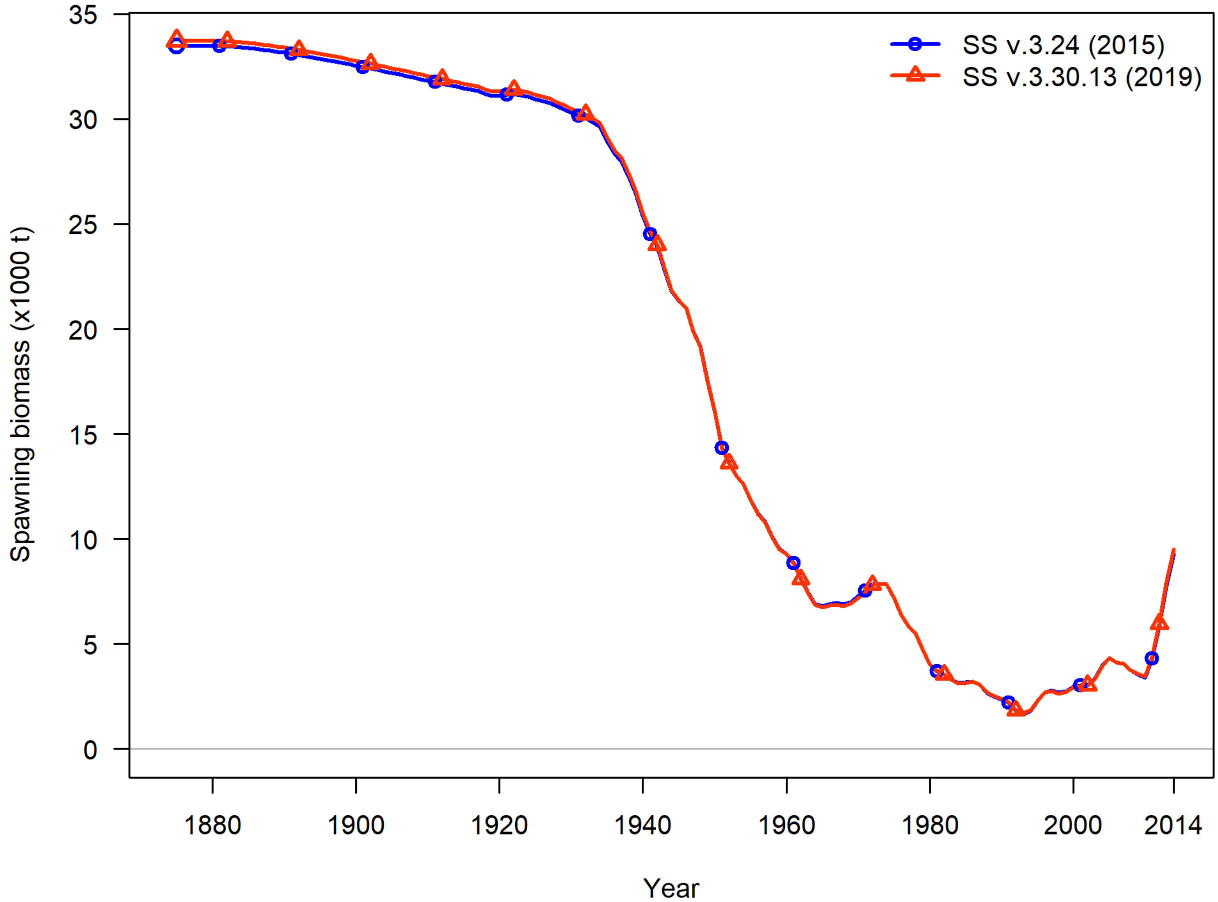

Figure 17: Comparison of model bridging estimates from Stock Synthesis version 3.30.13 and 3.24U for petrale sole for the 2015 assessment. fig:bridge

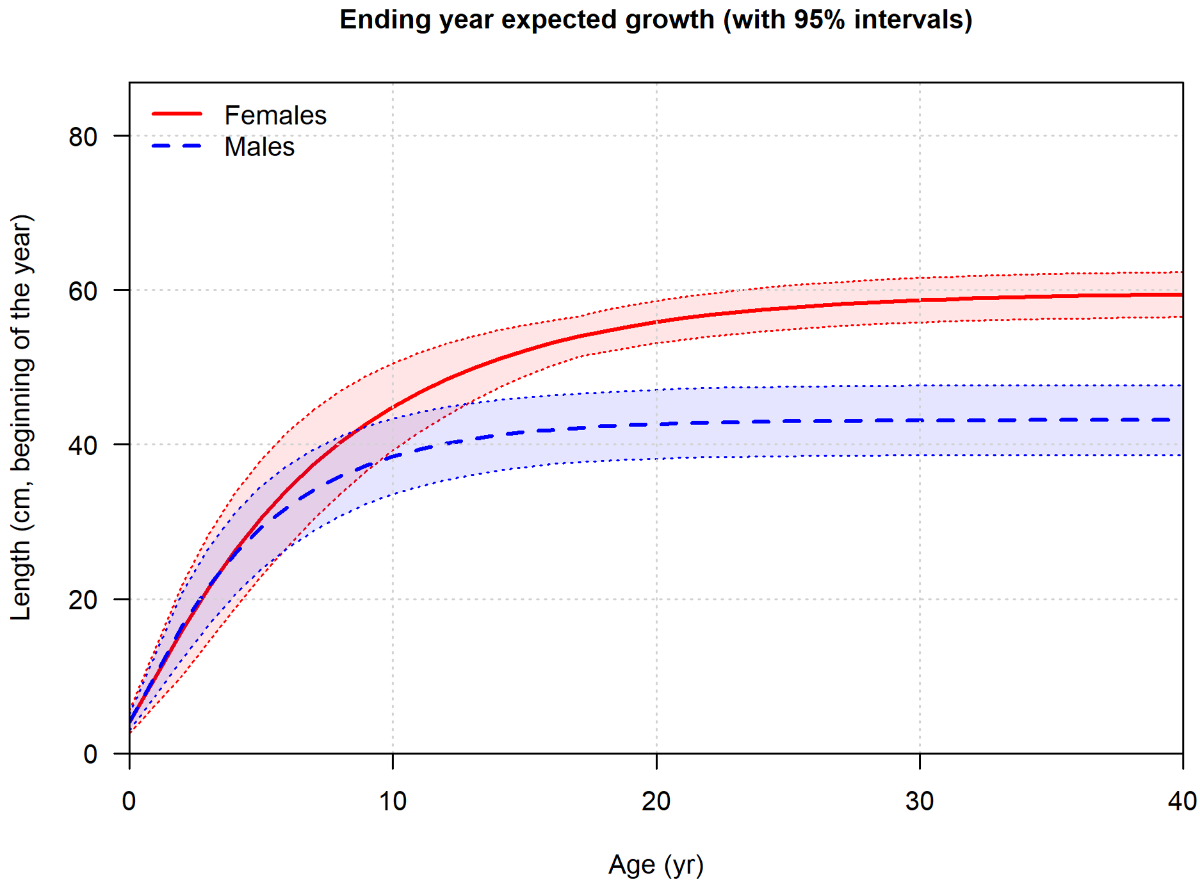

Figure 18: Estimated length-at-age for male and female for petrale sole with estimated CV. fig:sizeatage

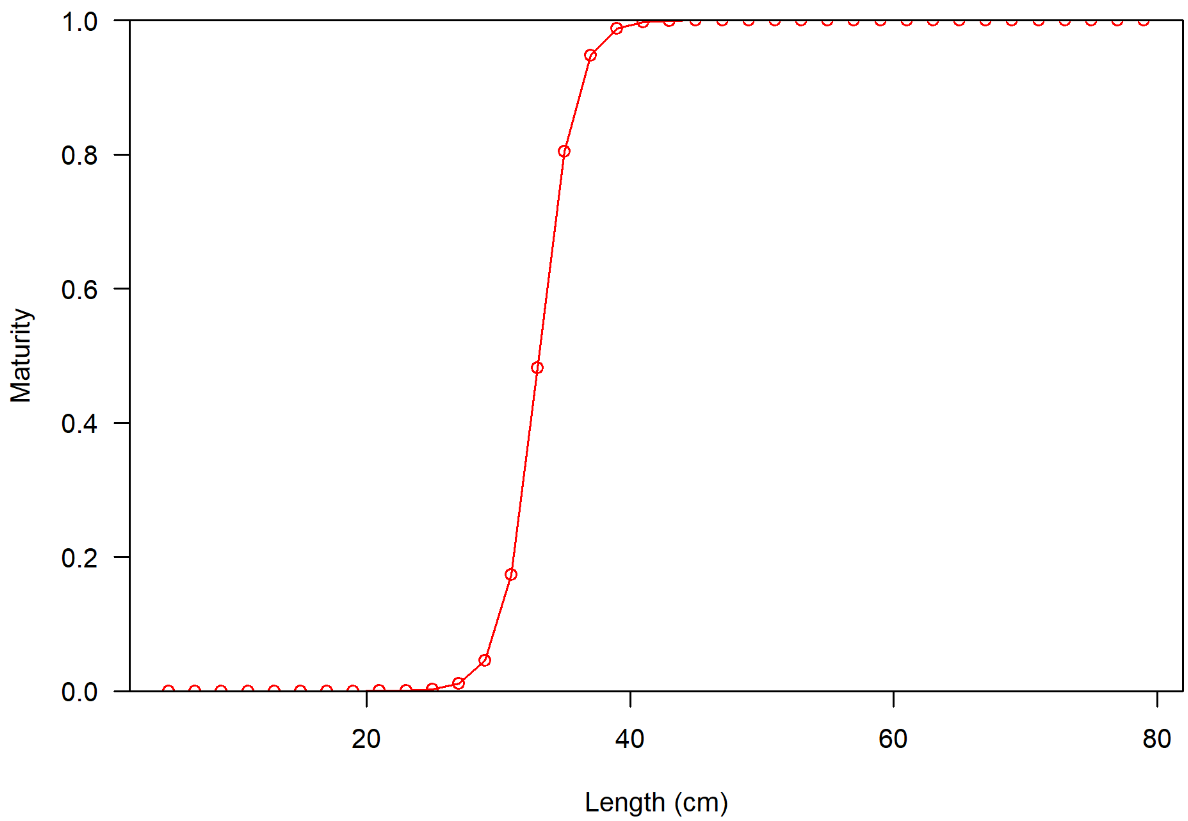

Figure 19: Estimated maturity-at-length for petrale sole. fig:maturity

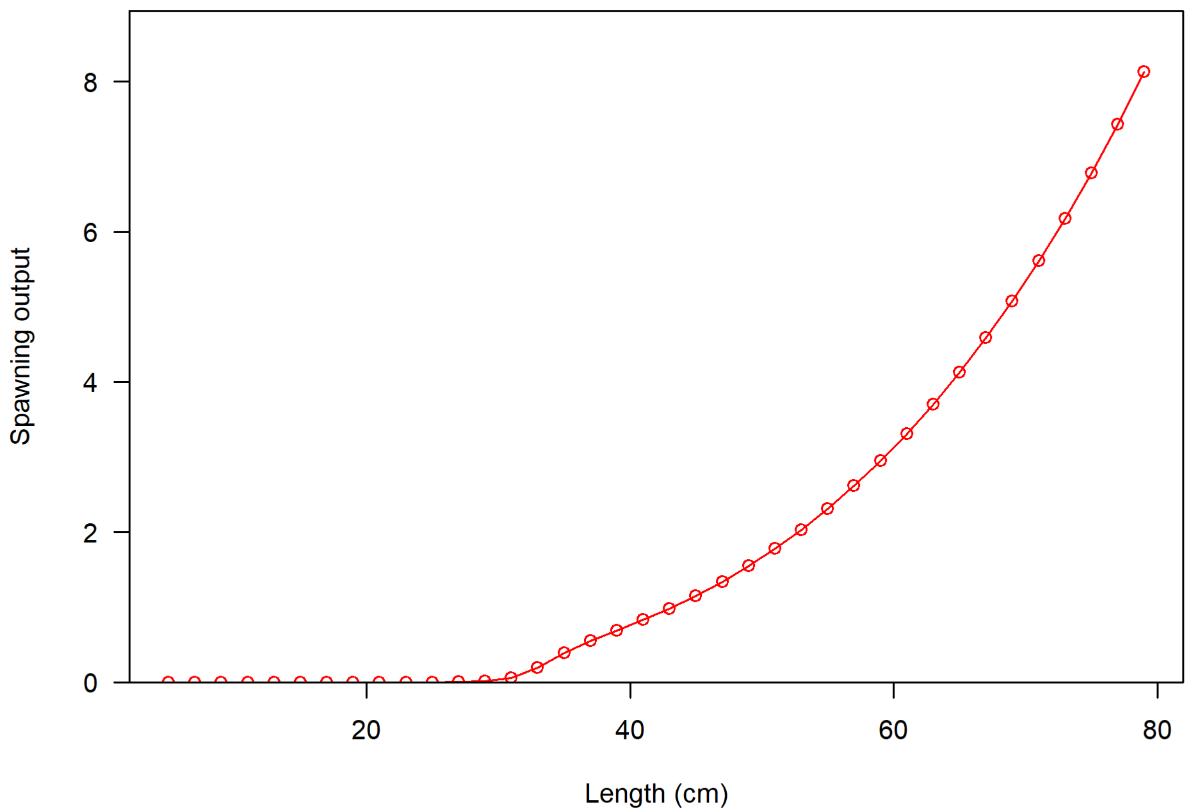

Figure 20: Estimated spawning output-at-length for female petrale sole. fig:spawnoutlen

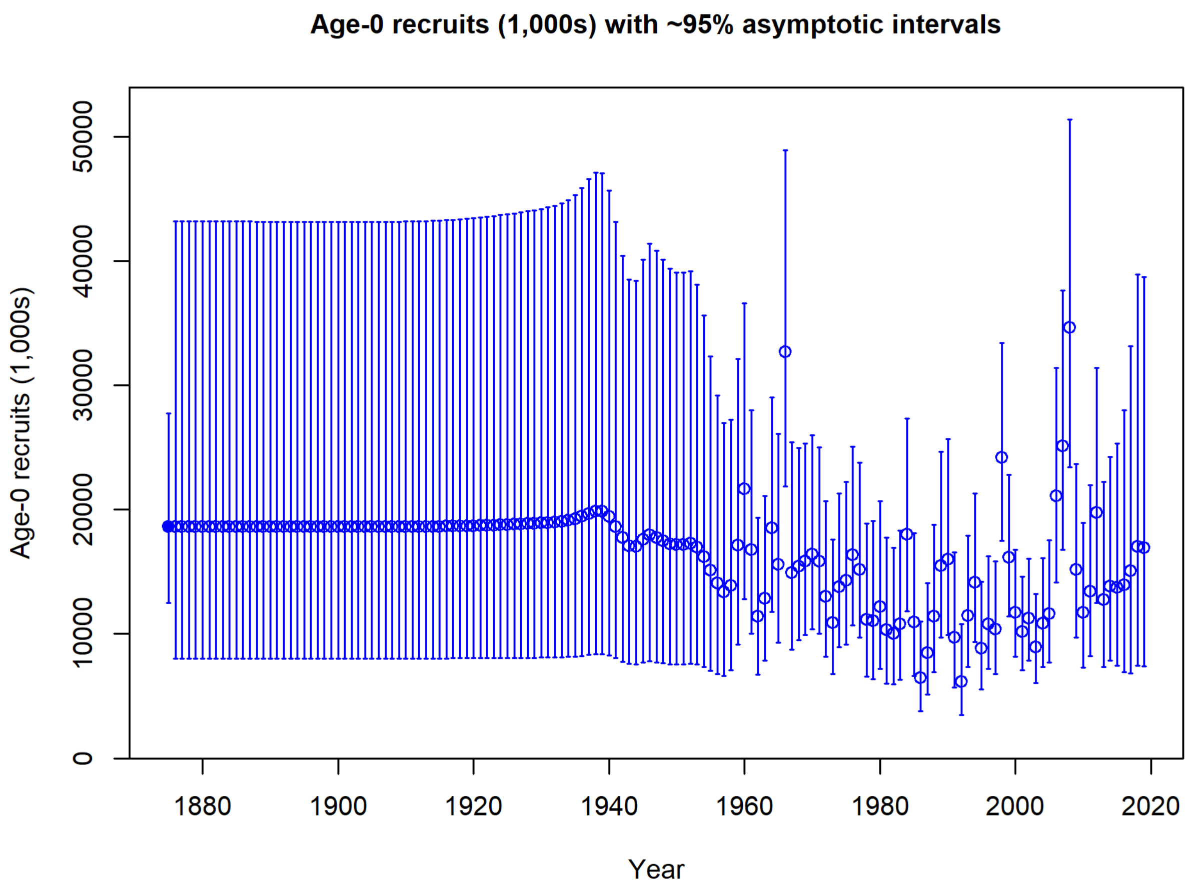

Figure 21: Estimated time-series of recruitment for petrale sole. fig:recruits

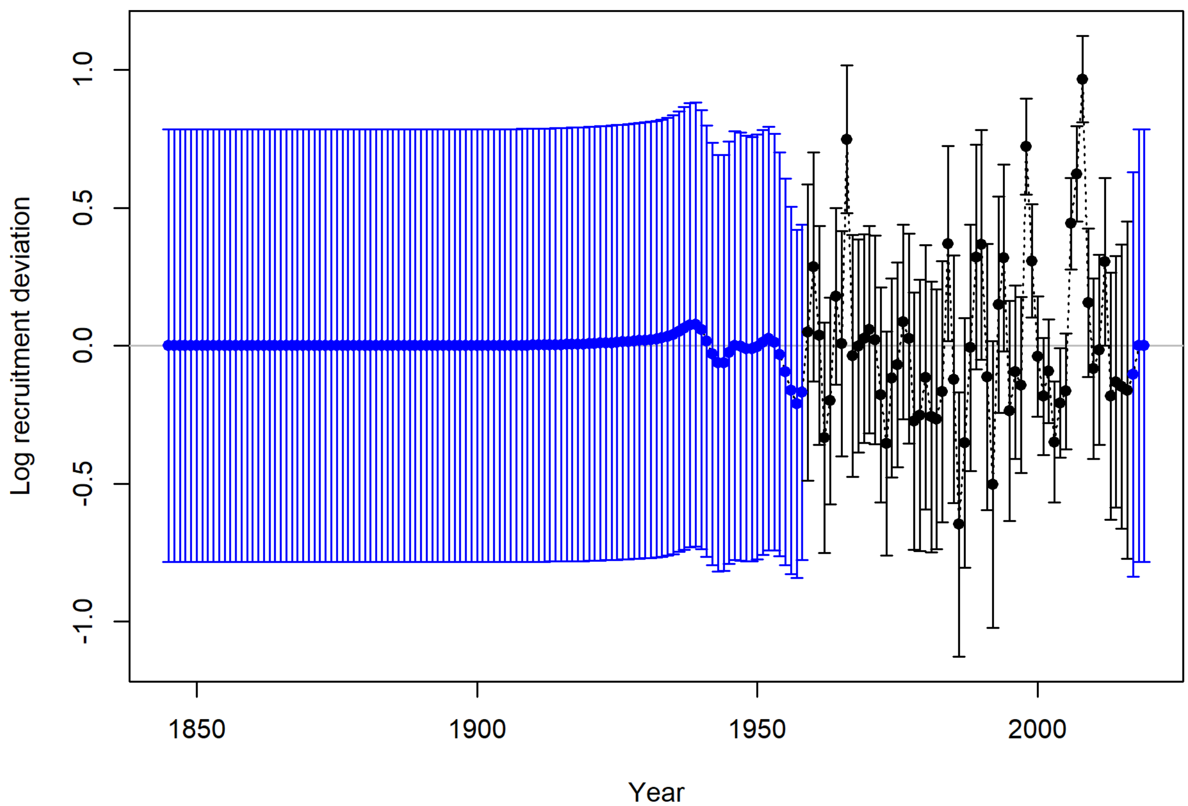

Figure 22: Estimated time-series of recruitment deviations for petrale sole. fig:recdevs

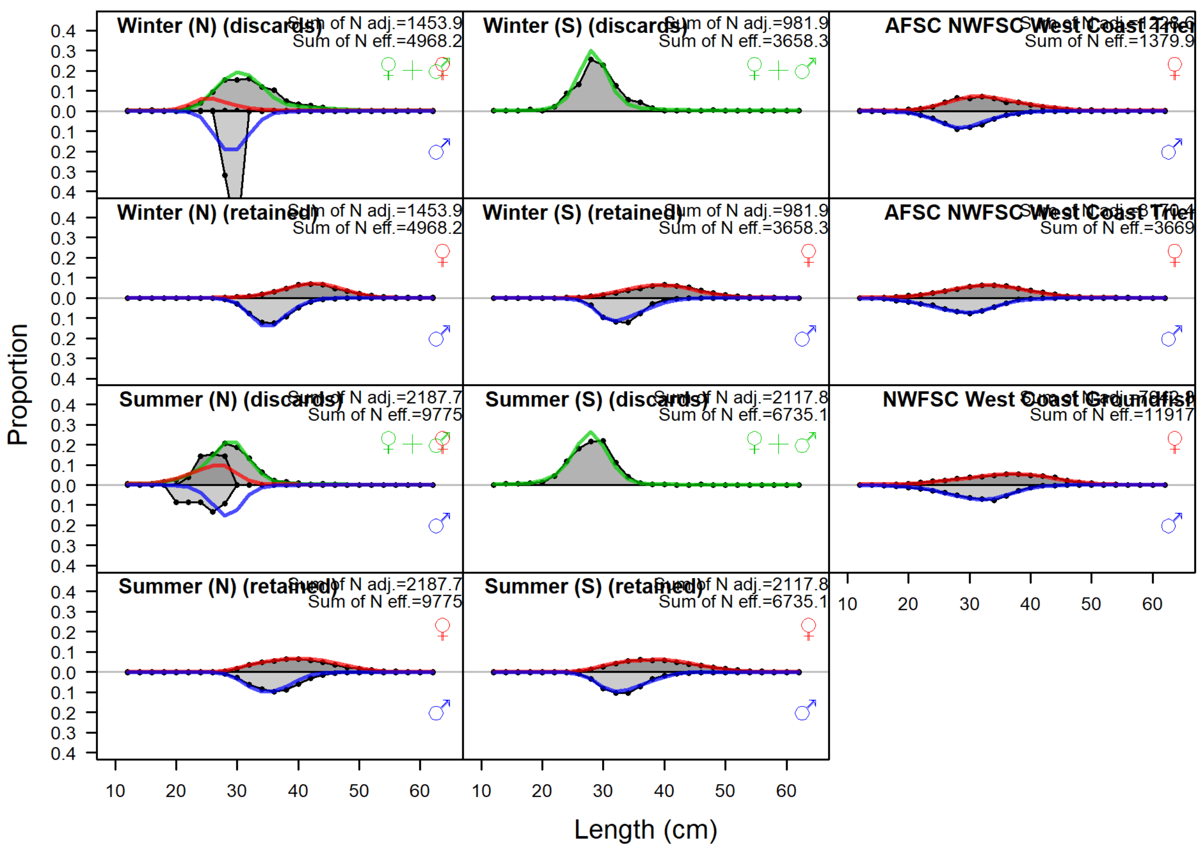

Figure 23: Length compositions aggregated across time by fleet. Labels ‘retained’ and ‘discard’ indicate retained or discarded samples for each fleet. Panels without this designation represent the whole catch. The Triennial shelf survey length data were not used in the final model, but the implied model fits are shown. fig:length_agg

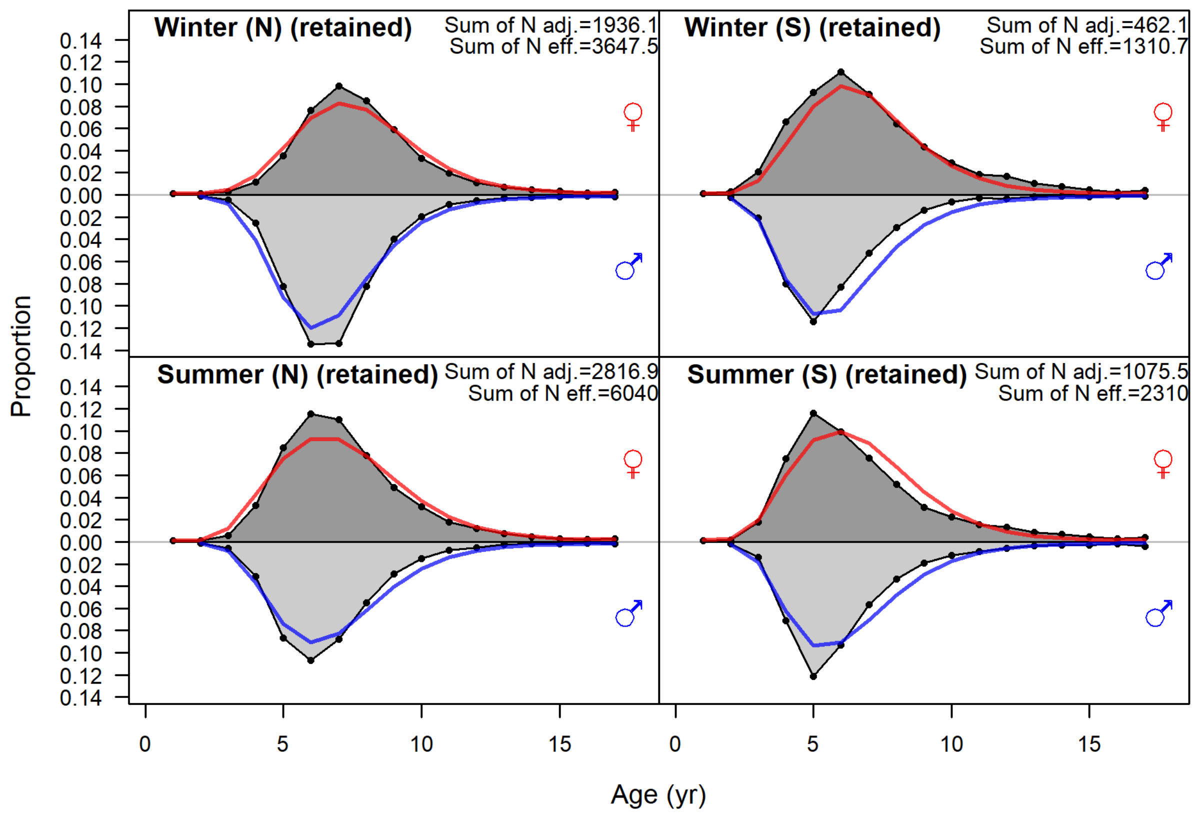

Figure 24: Age compositions aggregated across time by fleet. The Triennial shelf survey age data were not used in the final model, but the implied model fits are shown. fig:age_agg

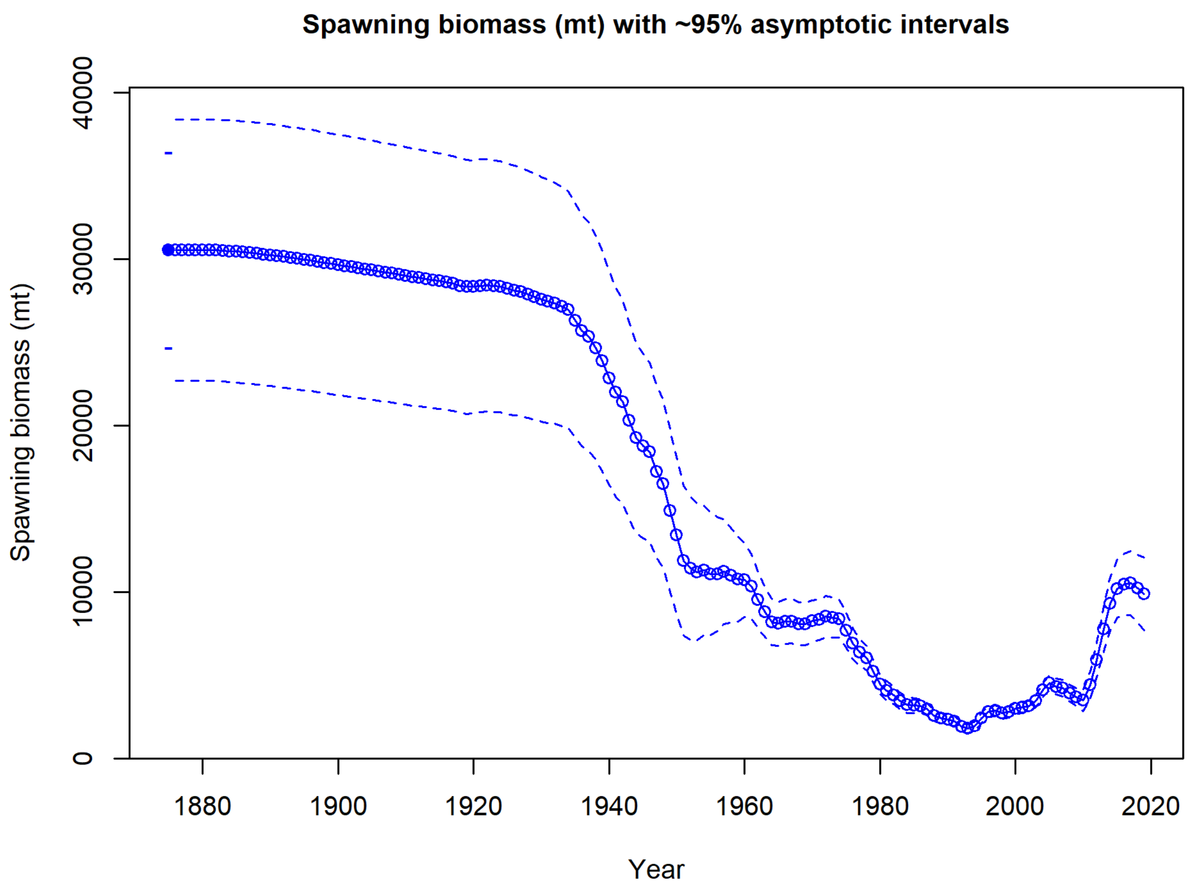

Figure 25: Estimated time-series of spawning output trajectory (circles and line: median; light broken lines: 95% credibility intervals) for petrale sole. fig:ssb

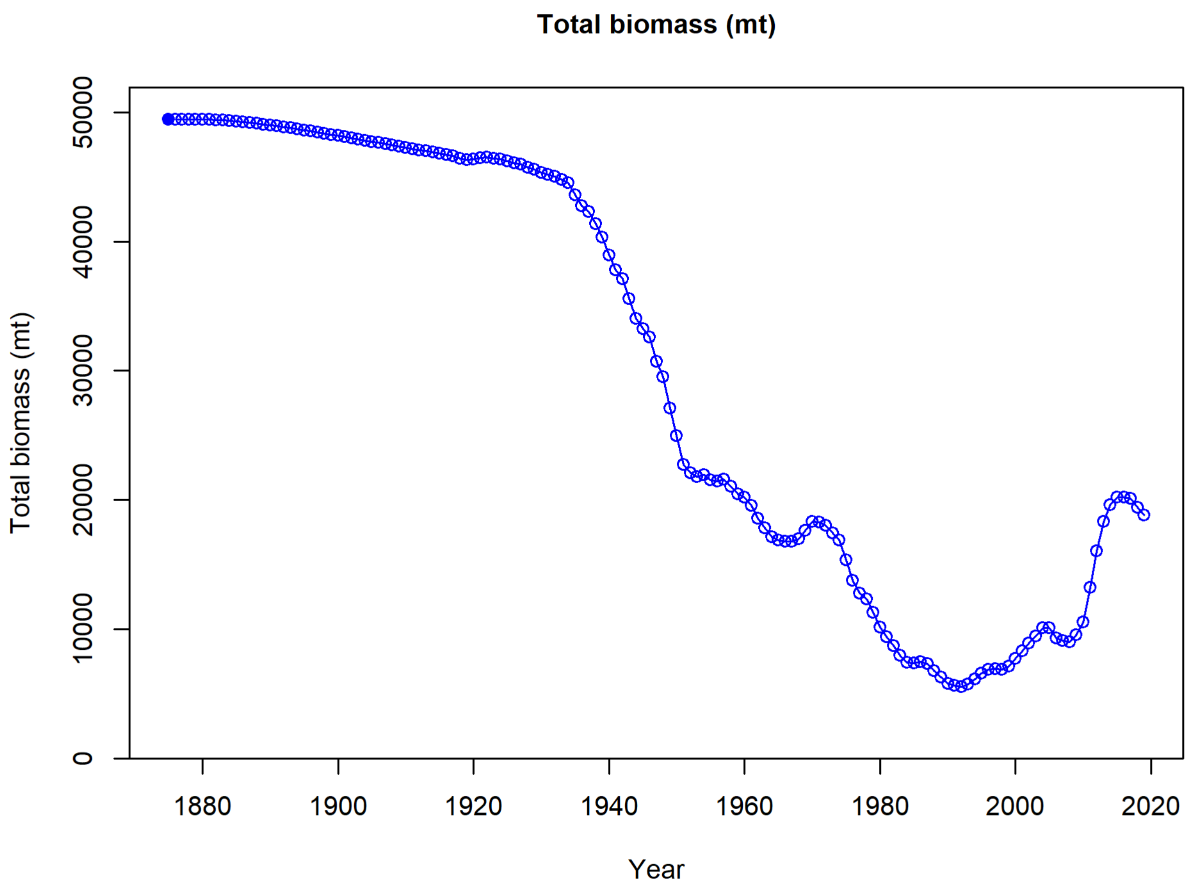

Figure 26: Estimated time-series of total biomass for petrale sole. fig:total_bio

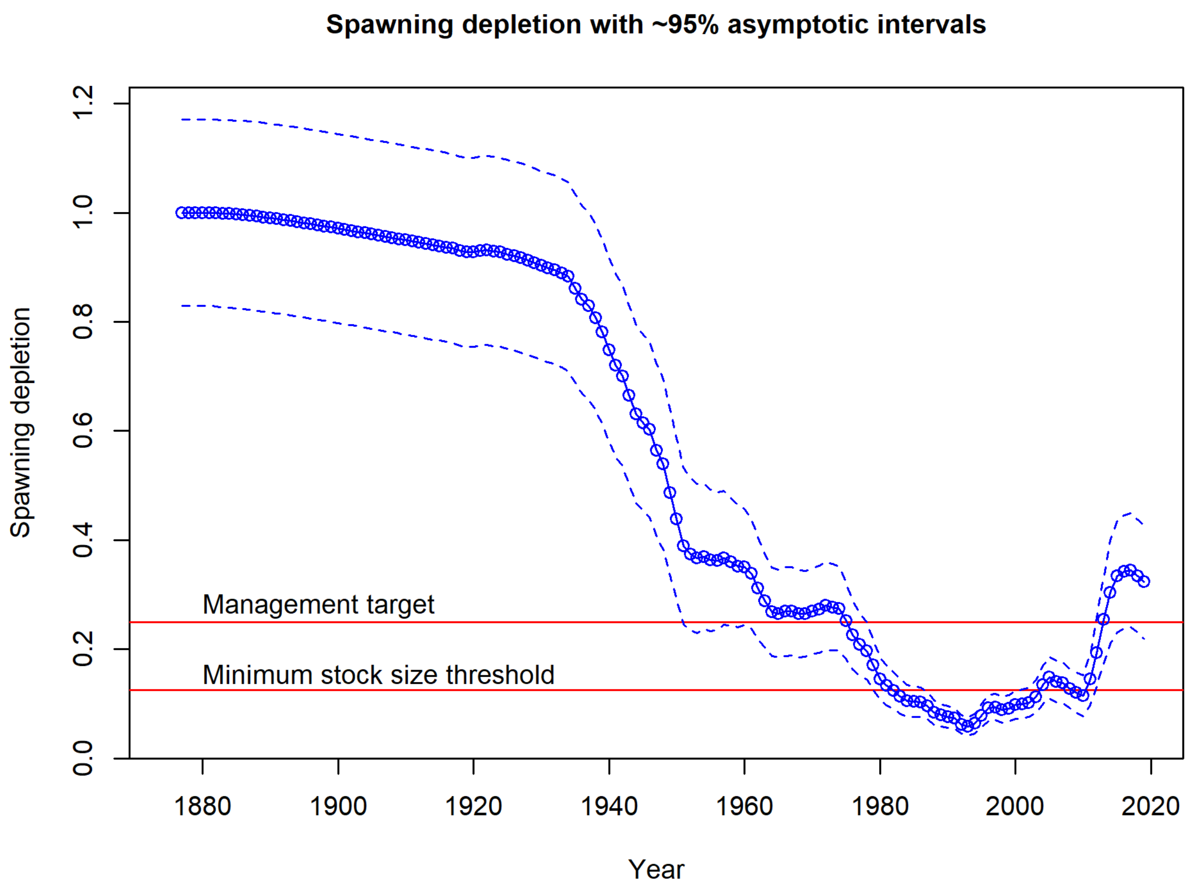

Figure 27: Estimated time-series of relative spawning output (depletion) (circles and line: median; light broken lines: 95% credibility intervals) for petrale sole. fig:depl

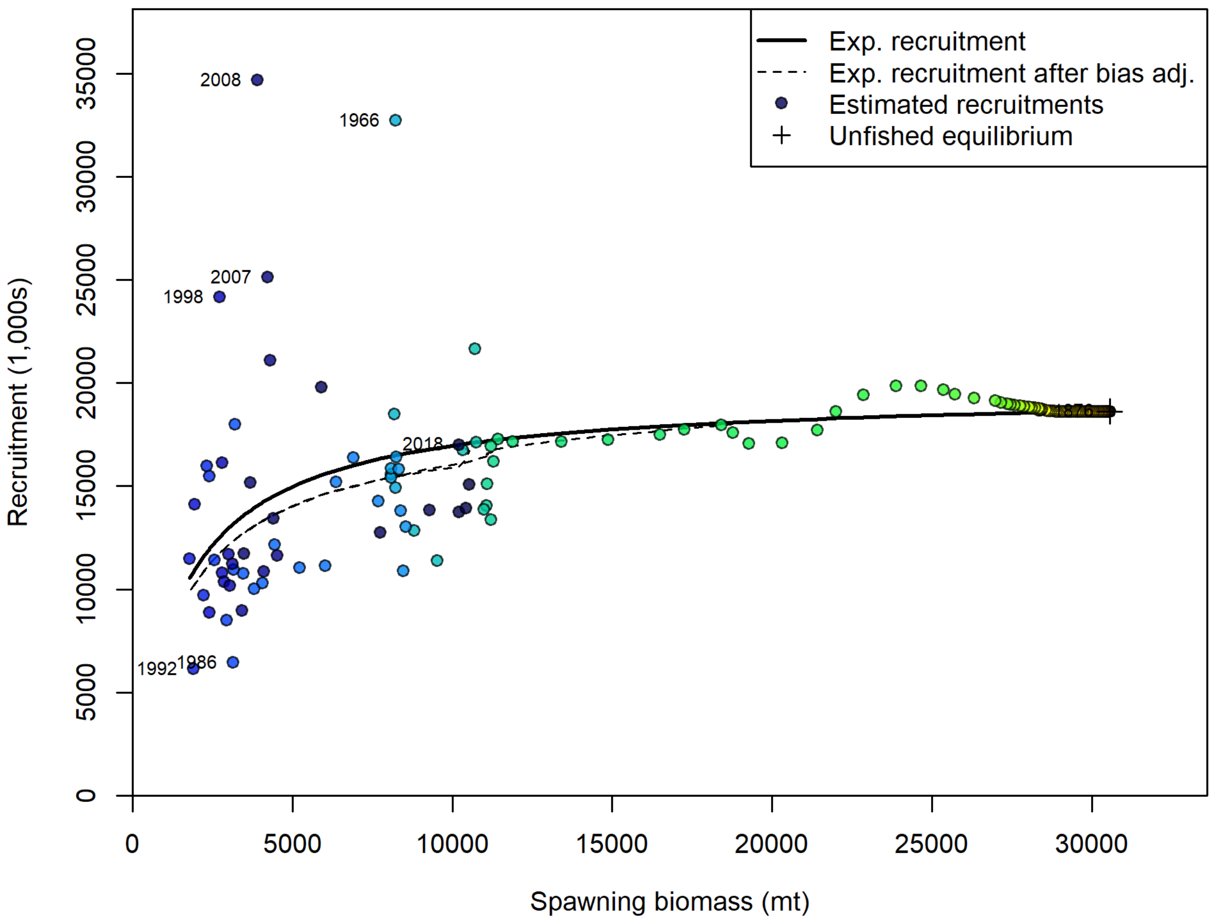

Figure 28: Estimated recruitment (red circles) and the assumed stock-recruit relationship (black line). The green line shows the effect of the bias correction for the lognormal distribution
fig:stock_recruit_curve

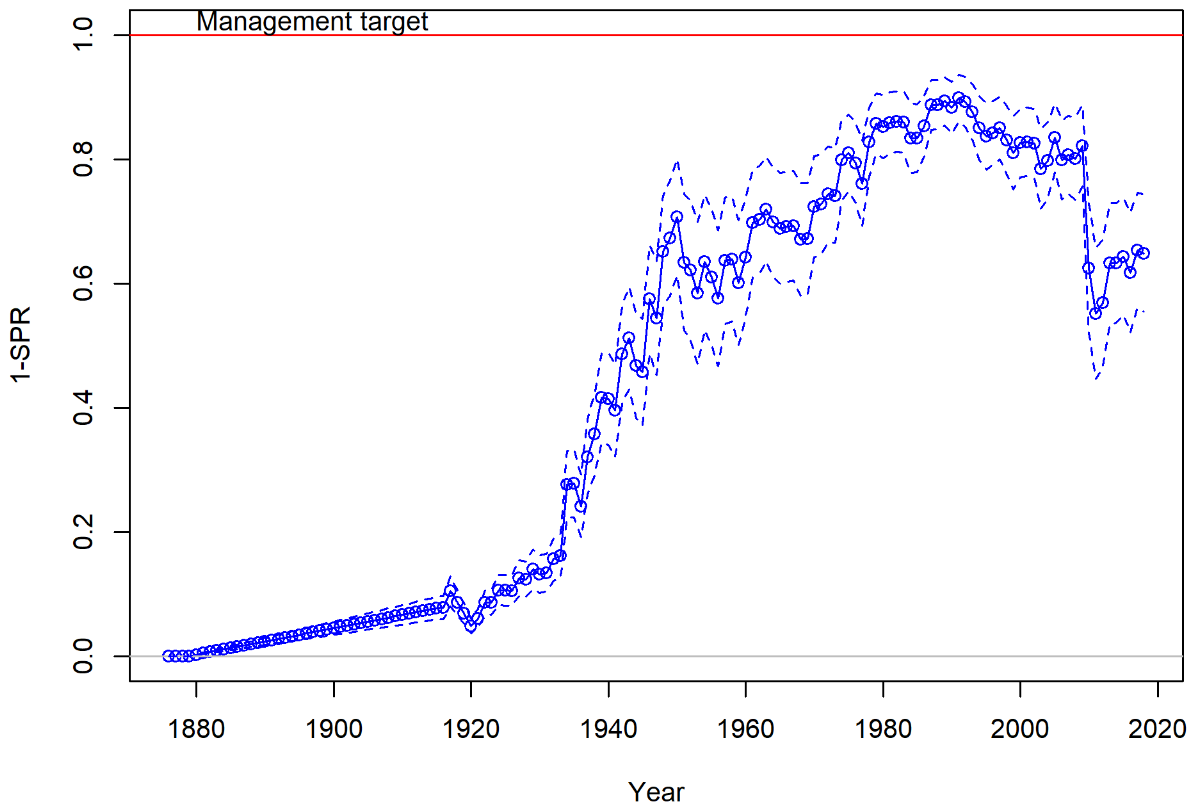

Figure 29: Estimated spawning potential ratio (1-SPR)/(1-SPR30%) for the base-case model. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as a red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the SPR30% harvest rate. The last year in the time series is 2018. fig:SPR

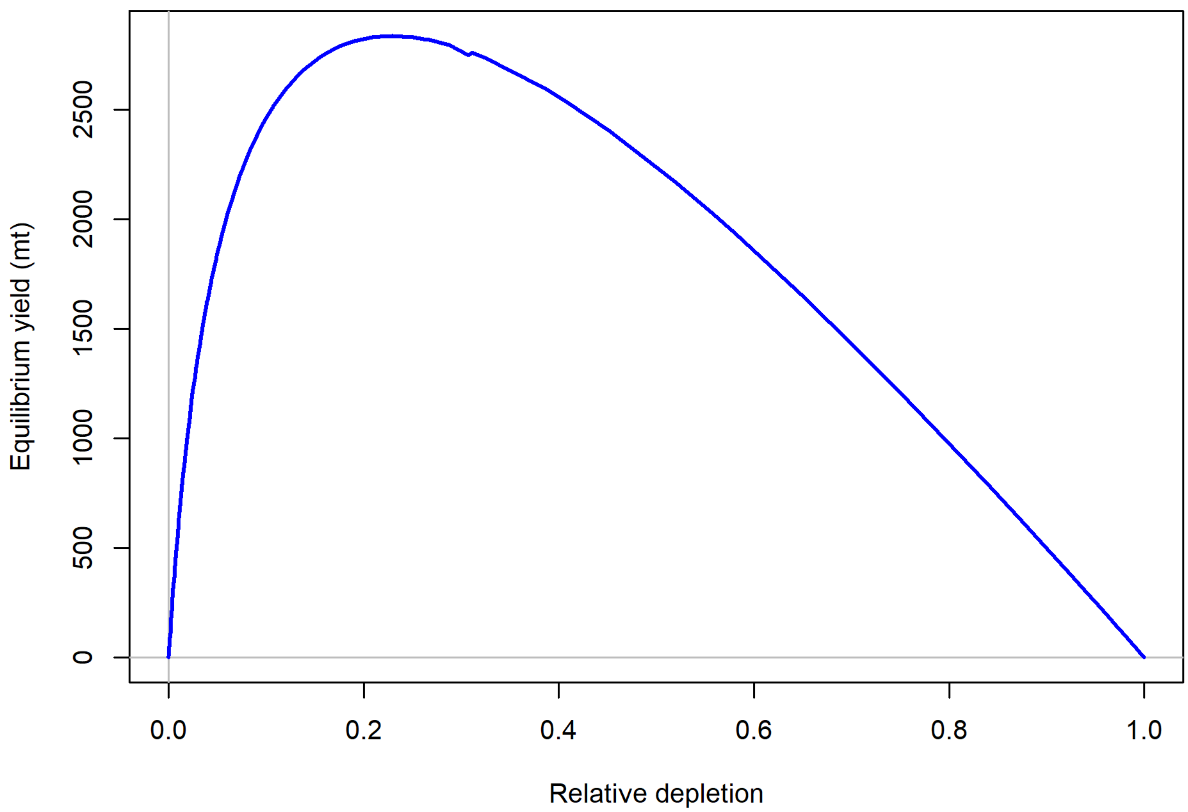

Figure 30: Equilibrium yield curve for the base case model. Values are based on the 2018 fishery selectivity and with steepness fixed at 0.84. fig:yield

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