Status of the darkblotched rockfish resource off the continental U.S. Pacific Coast in 2017

(Update of 2015 assessment model)

by

John R. Wallace and Vladlena Gertseva

Fishery Resource Analysis and Monitoring Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East, Seattle, WA 98112

January 2018

This report may be cited as:

Wallace, J.W., Gertseva, V., 2017. Status of the darkblotched rockfish resource off the continental U.S. Pacific Coast in 2017 (Update of 2015 assessment model). Pacific Fishery Management Council, Portland, OR. Available from http://www.pcouncil.org/groundfish/stock-assessments/

Table of Contents

Executive Summary

Stock

Darkblotched rockfish (*Sebastes crameri*) in the Northeast Pacific Ocean occur from the southeastern Bering Sea and Aleutian Islands to near Santa Catalina Island in southern California. This species is most abundant from off British Columbia to Central California. Commercially important concentrations are found from the Canadian border through Northern California. This update assessment focuses on the portion of the population that occurs in coastal waters of the western contiguous United States, off Washington, Oregon and California, the area bounded by the U.S.-Canada border on the north and U.S.-Mexico border on the south. The population within this area is treated as a single coast wide stock, due to the lack of biological and genetic data supporting the presence of multiple stocks.

Catches

Darkblotched rockfish is caught primarily with commercial trawl gear, as part of a complex of slope rockfish, which includes Pacific ocean perch (*Sebastes alutus*), splitnose rockfish (*Sebastes diploproa*), yellowmouth rockfish (*Sebastes reedi*), and sharpchin rockfish (*Sebastes zacentrus*). The species is managed with stock-specific harvest specifications (not within the current slope rockfish complexes). Catches taken with non-trawl gear over the years comprised 2% of the total coast wide shoreside catch. This species has not been taken recreationally.

Catch of darkblotched rockfish first became significant in the mid-1940s when balloon trawl nets (efficient in taking rockfish) were introduced, and due to increased demand during World War II. The largest removals of the species occurred in the 1960s, when foreign trawl fleets from the former Soviet Union, Japan, Poland, Bulgaria and East Germany came to the Northeast Pacific Ocean to target large aggregations of Pacific ocean perch, a species that co-occurs with darkblotched rockfish. In 1966 the removals of darkblotched rockfish reached 4,220 metric tons. By the late-1960s, the foreign fleet had more or less abandoned the fishery. Shoreside landings of darkblotched rockfish rose again between the late-1970s and the late-1980s, peaking in 1987 with landings of 2,415 metric tons. In 2000, the species was declared overfished, and landings substantially decreased due to management regulations. During the last decade the average annual landings of darkblotched rockfish made by the shoreside fishery was around 120 metric tons. Since the mid-1970s, a small amount of darkblotched rockfish has been also taken as bycatch in the at-sea Pacific hake fishery, with a maximum annual removal of 49 metric tons that occurred in 1995.

In this update assessment, removals are divided between three fleets, which include the shoreside commercial fishery (that included removals by all gear types), bycatch removals in foreign Pacific ocean perch and bycatch removals in at-sea Pacific hake fisheries. Reconstructed removals of darkblotched rockfish bycatch in the Pacific ocean perch and at-sea hake fisheries represent total catch that includes both retained and discarded catch. Discards in the shoreside fishery were explicitly modeled in the assessment; total catches were estimated simultaneously with other model parameters and derived quantities of management interest.

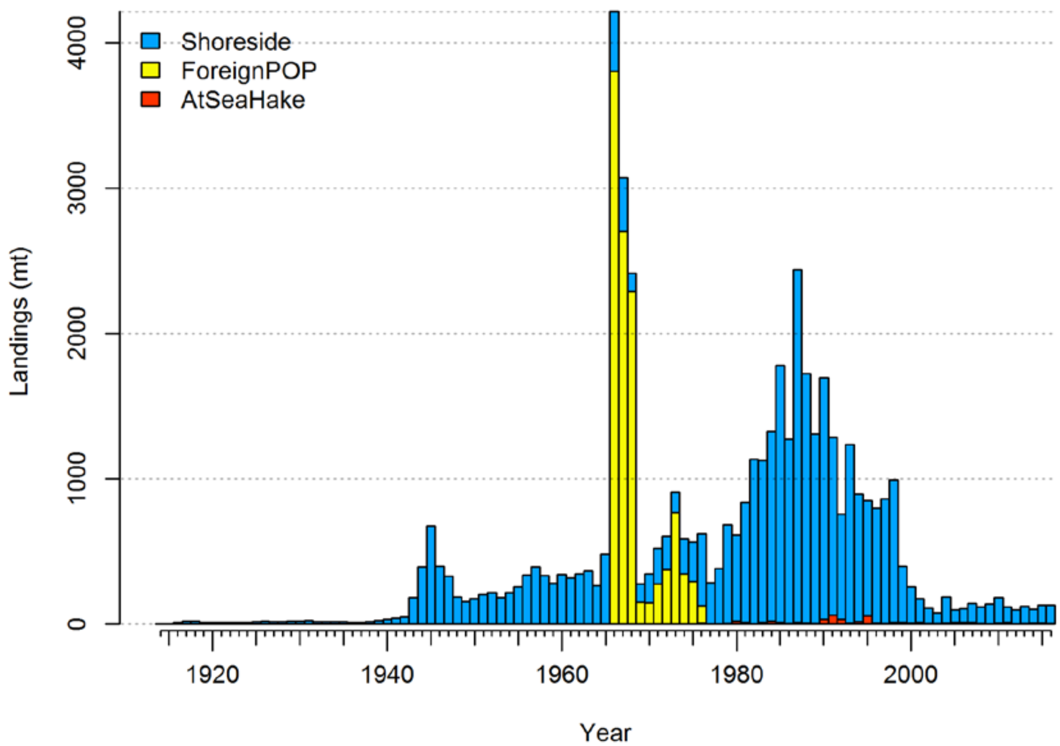

Figure ES-1: Darkblotched rockfish landings history between 1915 and 2016 by fleet.

Table ES-1: Recent darkblotched rockfish landings (mt) by component that comprised three fleets used in the assessment (removals by California, Oregon and Washington were combined into a Shoreside fleet). The third fleet (foreign vessels fishing for POP) did not operate in the fishery beyond 1976.

Year	California landings	Oregon landings	Washington landings	Bycatch in at-sea hake fishery	Total
2007	41	87	3	12	144
2008	34	74	3	6	117
2009	47	89	2	0	138
2010	17	152	7	8	184
2011	3	87	14	12	117
2012	7	70	20	3	99
2013	4	103	11	6	124
2014	4	77	11	11	103
2015	8	103	11	8	131
2016	10	108	6	5	129

Data and assessment

The last full assessment of darkblotched rockfish was conducted in 2015. This update assessment used the most recent version of Stock Synthesis (SSv3.30.01.12; Dr. Richard Methot; NMFS, NWFSC) available when this assessment was undertaken. This version included improvements in the output statistics for producing assessment results and several corrections to older versions.

The data used in the assessment include landings, length and age compositions of the retained commercial catch from Pacific Fisheries Information Network (PacFIN). It includes discard ratios, length and age compositions of the discards from West Coast Groundfish Observer Program (WCGOP). The assessment also includes bycatch data within the at-sea hake fishery and, for the first time, length and age compositions of darkblotched rockfish bycatch from the At-Sea Hake Observer Program (ASHOP). Data from four National Marine Fisheries Service (NMFS) bottom trawl surveys are used to estimate indices of stock abundance and generate length and age frequency distributions for each survey. The Northwest Fisheries Science Center (NWFSC) shelf-slope survey covers the period between 2003 and 2016 and provides information on the current trend of the stock. Three other surveys (which are discontinued) include the NWFSC slope survey (1999- 2002), the AFSC slope survey (1997-2001), and the AFSC shelf Triennial survey (1980-2004).

The modeling period in the assessment begins in 1916, assuming that in 1915 the stock was in an unfished equilibrium condition. Females and males are treated separately to account for sexual dimorphism in growth exhibited by the species. Growth is assumed to follow the von Bertalanffy growth model, and the assessment explicitly estimates most parameters describing growth for both sexes. Externally estimated life history parameters, included those defining the weight-length relationship, female fecundity and maturity schedule. Recruitment dynamics are assumed to follow the Beverton-Holt stock-recruit function. As in 2015 full assessment, natural mortality in this update assessment was fixed at the value of 0.054 yr^{-1} for females and estimated for males with a flat prior.

Stock spawning output

The darkblotched rockfish assessment uses a non-proportional egg-to-weight relationship, and the spawning output is reported in the number of eggs. The unexploited level of spawning stock output is estimated to be 3,544 million eggs (95% confidence interval: 2,711-4,377 million eggs). At the beginning of 2017, the spawning stock output is estimated to be 1,419 million eggs (95% confidence interval: 611-2,226 million eggs), which represents 40.03% of the unfished spawning output level, just over the 40% management target.

The spawning output of darkblotched rockfish started to decline in the 1940s, during World War II, but exhibited a sharp decline in the 1960s during the time of the intense foreign fishery targeting Pacific ocean perch. Between 1965 and 1976, spawning output dropped from 90% to 64% of its unfished level. Spawning output continued to decline throughout the 1980s and 1990s and in 2000 reached its lowest estimated level of 17% of its unfished state. Since 2000, the spawning output has been slowly increasing, which corresponds to decreased removals due to management regulations.

Table ES-2: Recent trends in estimated darkblotched rockfish spawning biomass and relative depletion.

Year	Spawning stock output (millions of eggs)	~95% confidence interval	Estimated depletion	~95% confidence interval
2008	917	418–1,415	25.9%	14.6–37.1%
2009	970	437–1,503	27.4%	15.3–39.4%
2010	1,014	449–1,578	28.6%	15.8–41.4%
2011	1,051	455–1,647	29.7%	16.1–43.2%
2012	1,105	478–1,732	31.2%	16.9–45.4%
2013	1,161	502–1,820	32.8%	17.8–47.7%
2014	1,222	528–1,916	34.5%	18.7–50.2%
2015	1,289	557–2,021	36.4%	19.8–53.0%
2016	1,355	585–2,125	38.2%	20.7–55.7%
2017	1,419	611–2,226	40.0%	21.7–58.4%

Table ES-3: Recent trends in estimated darkblotched rockfish recruitment and recruitment deviations.

Year	Estimated recruitment (1000s)	~95% confidence interval	Recruitment Deviations	95% Asymptotic Interval
2008	6,048	3,548–10,311	1.194	0.851–1.536
2009	874	456–1,673	-0.758	-1.284 – -0.231
2010	2,456	1,389–4,342	0.264	-0.140–0.668
2011	2,447	1,366–4,383	0.251	-0.173–0.674
2012	1,482	780–2,817	-0.264	-0.780–0.252
2013	13,767	7,827–24,215	1.952	1.552–2.352
2014	1,227	567–2,655	-0.504	-1.204–0.196
2015	2,565	1,095–6,009	0.195	-0.614–1.003
2016	2,598	1,970–3,427	NA	NA
2017	2,624	1,994–3,454	NA	NA

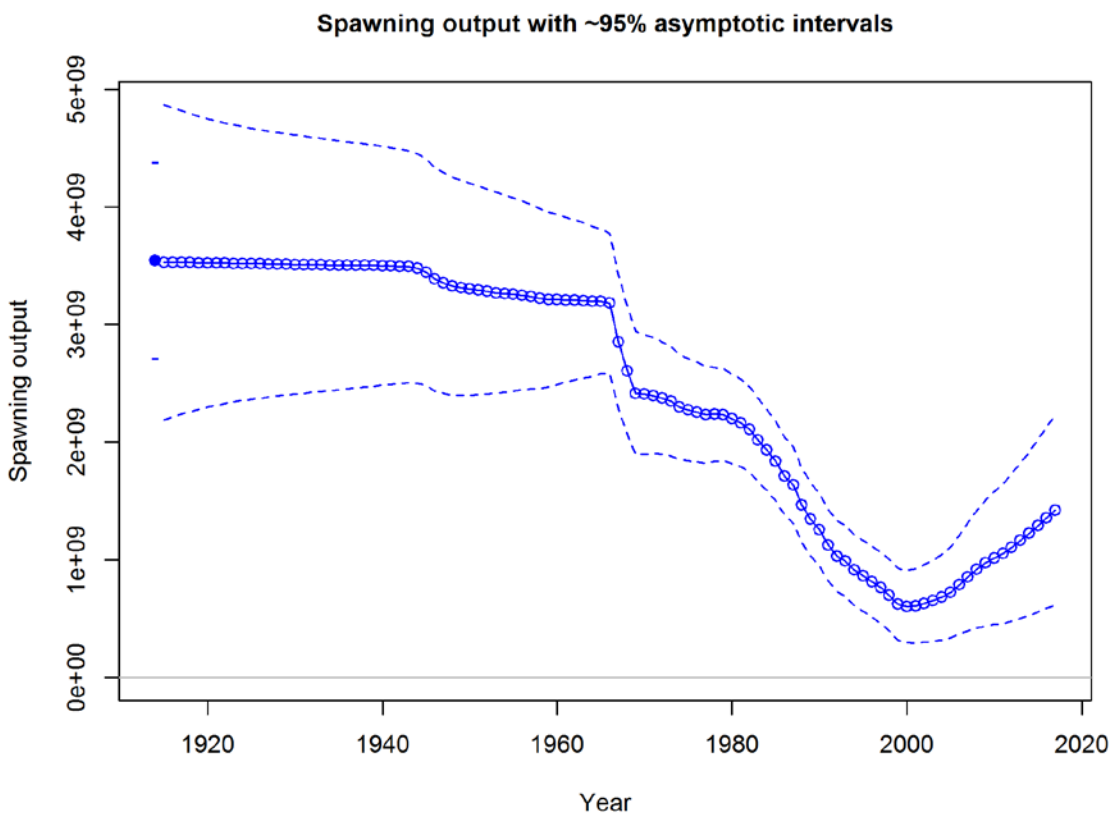

Figure ES-2: Estimated spawning biomass time-series (1915-2017) for the base-case model (circles) with ~ 95% interval (dashed lines). Spawning output is expressed in the number of eggs.

Recruitment

Recruitment dynamics are assumed to follow a Beverton-Holt stock-recruit function. The level of virgin recruitment is estimated in order to assess the magnitude of the initial stock size. 'Main' recruitment deviations were estimated for modeled years that had information about recruitment, between 1960 and 2013 (as determined from the bias-correction ramp in 2015). We additionally estimated 'early' deviations between 1870 and 1959 so that age-structure in the initial modeled year (1915) could deviate from the stable age-structure. The Beverton-Holt recruitment compensation steepness parameter (*h*) is fixed in the assessment at the value of 0.720 (down from 0.773 in 2015), which is the mean of steepness prior probability distribution, derived from this year's meta-analysis of Category 1 rockfish assessments.

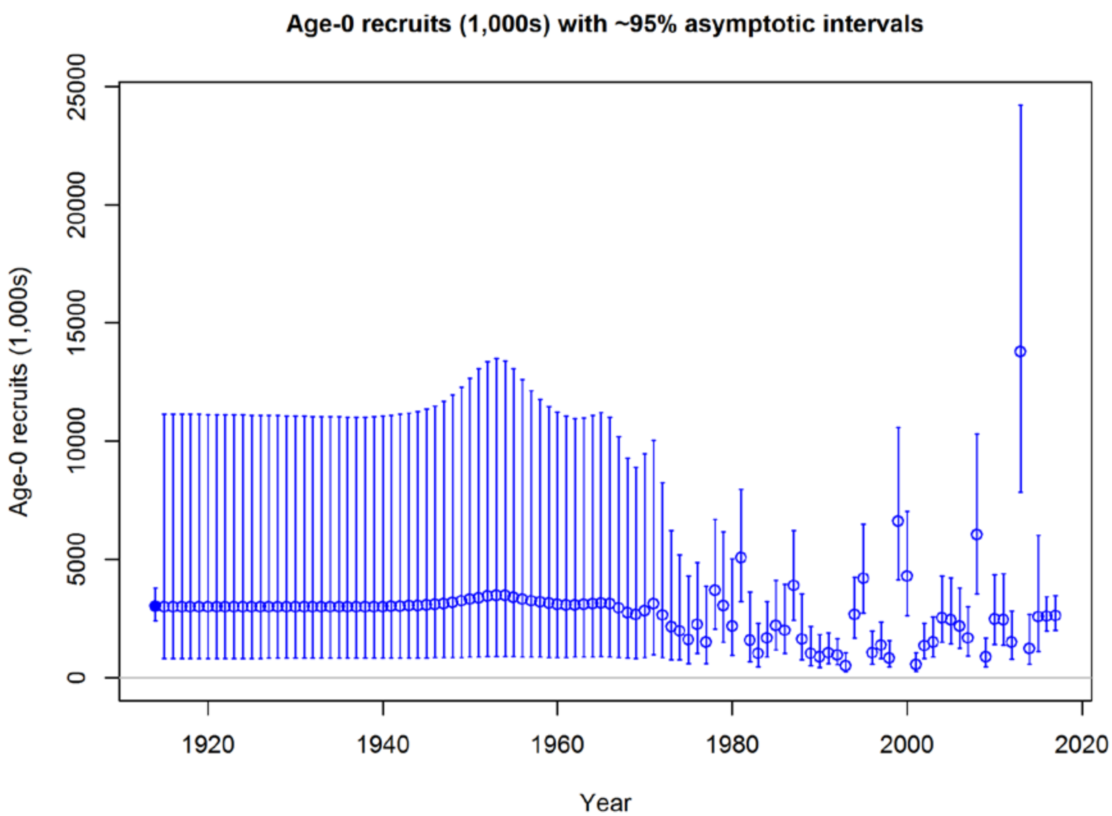

Figure ES-3: Time series of estimated darkblotched rockfish recruitments for the base-case model (solid line) with ~95% intervals (vertical lines).

Reference points

Unfished spawning stock output for darkblotched rockfish was estimated to be 3,544 million eggs (95% confidence interval: 2,711-4,377 million eggs). The stock is declared overfished if the current spawning output is estimated to be below 25% of unfished level. The management target for darkblotched rockfish is defined as 40% of the unfished spawning output ($SB_{40\%}$), which is estimated by the model to be 1,418 million eggs (95% confidence interval: 1,084-1,751), which corresponds to an exploitation rate of 0.037.

This harvest rate provides an equilibrium yield of 639 mt at $SB_{40\%}$ (95% confidence interval: 495-783 mt). The model estimate of maximum sustainable yield (MSY) is 670 mt (95% confidence interval: 518-821 mt). The estimated spawning stock output at MSY is 1,018 million eggs (95% confidence interval: 778-1,259 million of eggs). The exploitation rate corresponding to the estimated SPR_{MSY} of $F_{36\%}$ is 0.052.

Table ES-4. Summary of reference points for the base case model.

Quantity	Estimate	~95% Confidence Interval
Unfished Spawning output (million eggs)	3,544	2,7118–4,377
Unfished Age 1+ Biomass (mt)	39,932	30,971–48,893
Spawning output (million eggs, 2017)	1,419	611–2,226
Unfished Recruitment (R0)	3,006	2,304–3,709
Depletion (2017)	40.03	21.68–58.38
Reference Points Based SB40%		
Proxy spawning output ($B_{40\%}$, million eggs)	1,418	1,084–1,751
SPR resulting in $B40_{\%}$ ($SPR_{B40\%}$)	0.458	0.458–0.458
Exploitation rate resulting in $B_{40\%}$	0.037	0.036–0.038
Yield with *SPR* at $B_{40\%}$ (mt)	639	495–783
Reference Points based on SPR proxy for MSY		
Proxy spawning biomass (SPR_{50}, million eggs)	2,166	1,657–2,675
SPR_{50}	0.649	NA
Exploitation rate corresponding to SPR_{50}	0.019	0.018–0.020
Yield with SPR_{50} at SB_{SPR} (mt)	477	370–584
Reference points based on estimated MSY values		
Spawning biomass at MSY (SB_{MSY})	1,018	778–1,259
SPR_{MSY}	0.357	0.351–0.362
Exploitation rate corresponding to SPR_{MSY}	0.052	0.050–0.054
MSY (mt)	670	518–821

Exploitation status

The assessment shows that the stock of darkblotched rockfish off the continental U.S. Pacific Coast is currently at 40% of its unexploited level. This is above the overfished threshold of $SB_{25\%}$, but just at the management target of $SB_{40\%}$ of unfished spawning biomass. Historically, the spawning output of darkblotched rockfish dropped below the $SB_{40\%}$ target for the first time in 1989, as a result of intense fishing by foreign and domestic fleets. It continued to decline and reached the level of 16% of its unfished output in 2000. The same year, the stock was declared overfished. Since then, the spawning output was slowly increasing primarily due to management regulations instituted for the species and the continued sporadic appearance of strong year-classes.

This assessment estimates that the 2016 SPR is 86%. The SPR used for setting the OFL is 50%, while the SPR-based management fishing mortality target, specified in the current rebuilding plan and used to determine the ACL, is 64.9%. Historically, the darkblotched rockfish was fished beyond the relative SPR ratio [calculated as (1-SPR)/(1-$SPR_{Target=0.5}$)]

between 1966 and 1968, during the peak years of the Pacific ocean perch fishery, in 1973, and for a prolonged period between from 1981 and 2000.

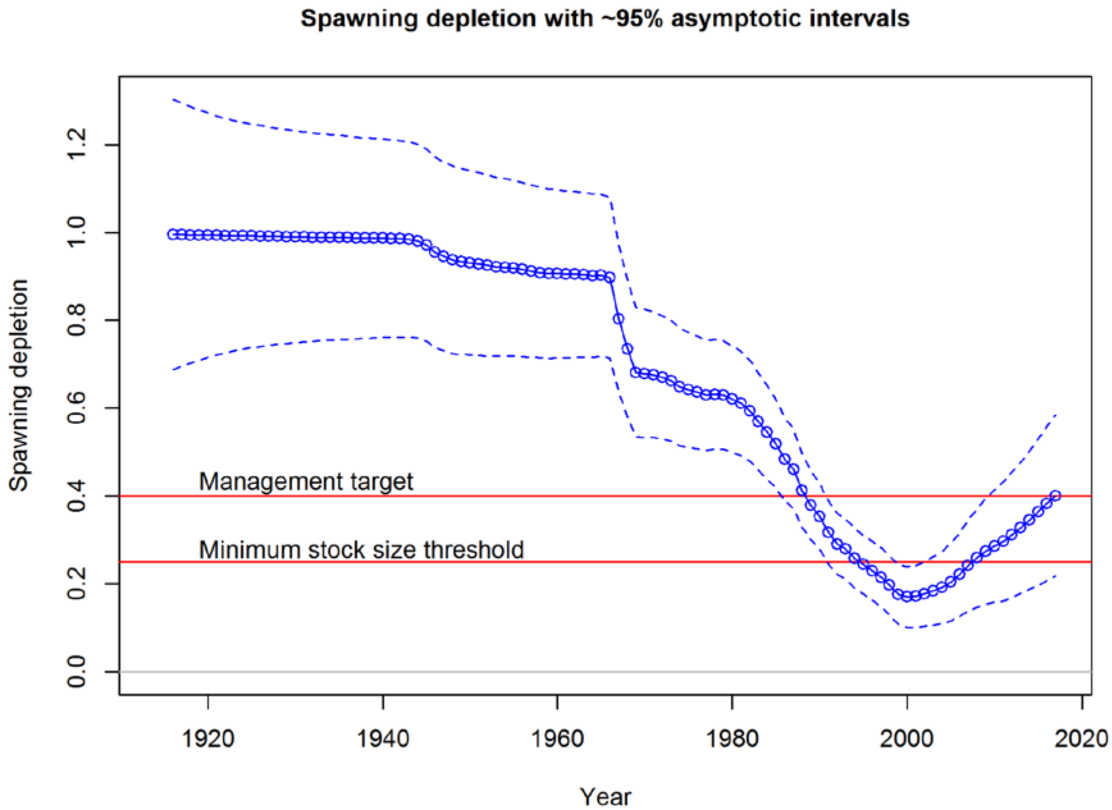

Figure ES-4. Estimated relative depletion with approximate 95% asymptotic confidence intervals (dashed lines) for the base case assessment model.

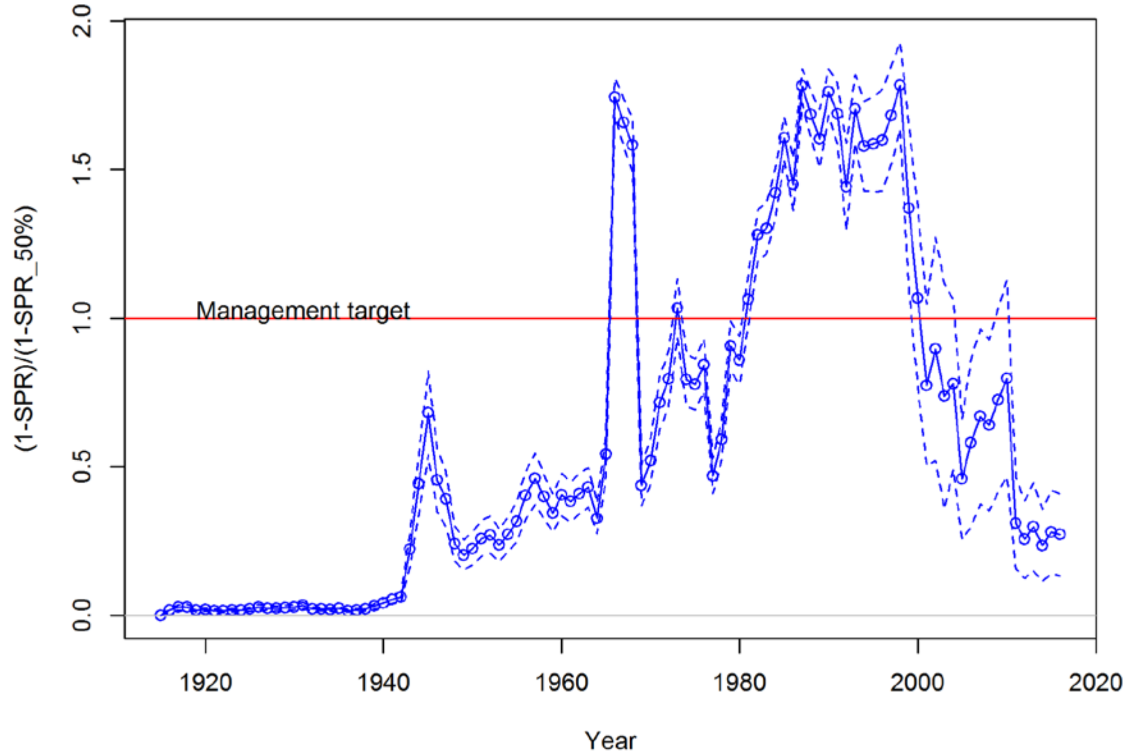

Figure ES-5. Time series of estimated relative spawning potential ratio [(1-SPR)/(1-$SPR_{Target=0.5}$)] for the base-case model (round points) with ~95% intervals (dashed lines). Values of relative SPR above 1.0 reflect harvests in excess of the current overfishing proxy.

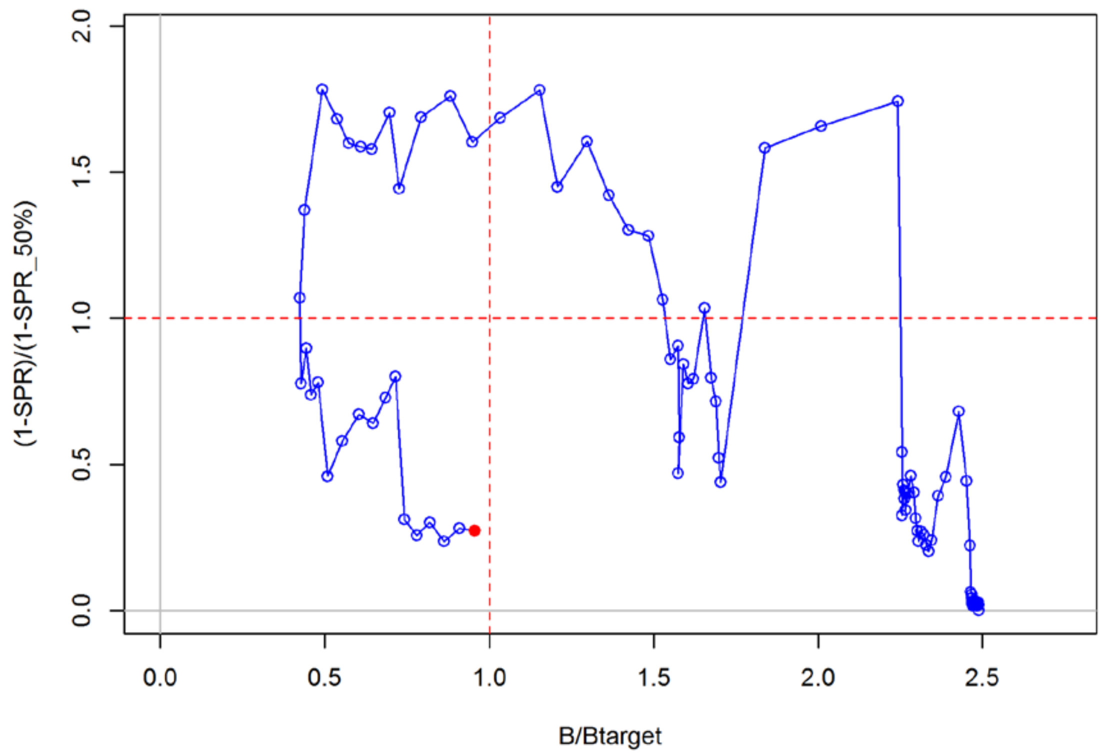

Figure ES-6. Phase plot of estimated relative (1-SPR) vs. relative spawning biomass for the base case model. The relative (1-SPR) is (1-SPR) divided by 0.5 (the SPR target). Relative depletion is the annual spawning biomass divided by the spawning biomass corresponding to 40% of the unfished spawning biomass. The red point indicates the year 2016.

Table ES-5. Recent trend in spawning potential ratio (SPR) and harvest rate.

Year	(1-SPR)/ (1-SPR_50%)	95% Asymptotic Interval	Harvest rate (proportion)	95% Asymptotic Interval
2007	67.09%	37.64–96.55%	0.020	0.009–0.032
2008	64.07%	35.23–92.91%	0.019	0.008–0.029
2009	72.75%	41.88–103.62%	0.021	0.009–0.033
2010	79.95%	46.81–113.08%	0.024	0.010–0.037
2011	31.18%	15.68–46.67%	0.008	0.004–0.013
2012	25.61%	12.59–38.64%	0.007	0.003–0.010
2013	30.04%	14.99–45.09%	0.008	0.004–0.012
2014	23.57%	11.45–35.70%	0.006	0.003–0.010
2015	27.98%	13.77–42.18%	0.008	0.003–0.012
2016	27.18%	13.29–41.07%	0.007	0.003–0.011

Ecosystem considerations

Darkblotched rockfish is most abundant from off British Columbia to Central California. This slope species occurs at depths between 25 and 600m, with the majority of fish inhabiting depths between 100 and 400 meters. Darkblotched rockfish co-occurs with an assemblage of slope rockfish, including Pacific ocean perch (*Sebastes alutus*), splitnose rockfish (*Sebastes diploproa*), yellowmouth rockfish (*Sebastes reedi*), and sharpchin rockfish (*Sebastes zacentrus*). Pacific ocean perch and darkblotched rockfish are the most abundant members of that assemblage off the coasts of Oregon and Washington, but splitnose rockfish and darkblotched rockfish dominate off the northern coast of California. Adults typically are observed resting on mud near cobble or boulders. They feed primarily in the midwater on large planktonic organisms such as krill, gammarid amphipods, copepods and salps, and less frequently on fishes and octopi. King salmon and albacore eat young darkblotched rockfish.

In this assessment, ecosystem considerations were not explicitly included in the analysis. This is primarily due to a lack of relevant data and results of analyses (conducted elsewhere) that could contribute ecosystem-related quantitative information for the assessment. It may be worth noting however, that we used the recently developed geostatistical VAST approach to estimate an abundance index from NWFSC shelf-slope survey data. VAST explicitly uses information on the location of samples to estimate local densities at a far smaller scale than the strata used in the past for GLMM or design-based estimates. This use of the data better reflects the spatial complexity of the species distribution, which is determined in large part by habitat suitability and other ecological factors, along with fishing history.

Management performance

The stock has historically been managed with bimonthly cumulative landings limit (a.k.a. "trip limits") as most of the catch came from the limited entry bottom trawl fishery. However, since 2011, that allocation has been managed as a catch share fishery, using Individual Fishing Quotas (IFQ), where each permit holder has an annual quota. Darkblotched rockfish has been managed using species-specific harvest specifications since 2001. Over the last 10 years, the total catch (as estimated in this assessment) exceeded the Annual Catch Limit (ACL) in two years: 2009 and 2010. The total catch has not exceeded the Overfishing Limit (OFL) during the last decade. Note that the assessment assumes that no discards survive (i.e., total catch = total dead catch).

Table ES-6. Recent trend in total catch and commercial landings (mt) relative to the management guidelines. Estimated total catch consists of commercial landings, plus the model-estimated discarded biomass. This table also includes total catch by year reported by the West Coast Groundfish Observer Program (WCGOP), for comparison.

Year	OFL (mt)	ACL (mt)	Commercial Landings (mt)	Estimated Total Catch (mt)*	Total catch (mt) reported by WCGOP
2007	456	260	143.6	256.1	277.9
2008	456	260	117.4	243.8	254.4
2009	437	282	138.4	290.7	299.6
2010	437	282	184.3	337.9	335.0
2011	508	298	116.9	121.3	124.6
2012	508	298	99.0	102.5	108.0
2013	541	317	124.1	127.8	130.6
2014	541	317	103.2	106.5	138.2
2015	574	338	130.7	136.8	139.8
2016	580	346	129.1	136.6	

Unresolved problems and major uncertainties

Uncertainty in the model was explored though asymptotic variance and sensitivity analyses. Asymptotic confidence intervals were estimated within the model and reported throughout the assessment for key model parameters and management quantities. To explore uncertainty associated with alternative model configurations and evaluate the responsiveness of model outputs to changes in key model assumptions, a variety of sensitivity runs were performed, including an increase and decrease of fishery removals, runs with different assumptions regarding life-history parameters, shape of selectivity curves, stock-recruitment parameters, and many others. The uncertainty regarding natural mortality, stock-recruit steepness and the unfished recruitment level was also explored through likelihood profile analysis. Additionally, a retrospective analysis was conducted where the model was re-run after successively removing data from recent years, one year at a time.

Main life history parameters, such as natural mortality and stock-recruit curve steepness, continue to be a major source of uncertainty. These quantities, which the model is unable to estimate reliably, are essential for understanding the dynamics of the stock. In the model, female natural mortality is fixed at the value estimated outside the model using other life history characteristics of the species, while male natural mortality is estimated within the model, with a flat prior. Stock-recruit steepness is fixed at the value estimated outside the model using meta-analysis of species with similar life history characteristics.

Historically, darkblotched rockfish landings have not been sorted at the discrete species level; therefore, the time series of catch remained a source of uncertainty. Although significant progress has been made in reconstructing historical landings in California, Oregon and Washington, the lack of early species composition data does not allow the reconstruction to account for a gradual shift of fishing effort towards deeper areas, which can cause the potential to overestimate the historical contribution of slope species (including darkblotched rockfish) to overall landings of the mixed-species market category (i.e. “unspecified rockfish”). Also, it is known that the shoreside fishery has discarded a portion of the catch at sea. Previous to 2002, when the West Coast Groundfish Observer Program was established, only the Pikitch et al. study exists (Wallace, in review) that informs pre-2002 discarding practices of darkblotched rockfish.

Decision table

The base model estimate for 2017 spawning depletion is 40.03%. The primary axis of uncertainty about this estimate used in the decision table was based on female natural mortality. In this update assessment, we used the same natural mortality values to describe low and high states of nature, as in 2015 assessment. This update assessment assumed the same value for female natural mortality as the previous assessment. The value for the male natural mortality was re-estimated, but did not change from the 2015 assessment. The alternative female natural mortality values in 2015 were selected following a multi-step algorithm. These values corresponded to alternative depletion levels calculated using a normal approximation to the prior distribution for stock-recruit steepness (Gertseva, et al., 2016). The multi-step algorithm was necessary since natural mortality was thought by the STAR panel to be the main axis of uncertainty but no prior (i.e. only a flat prior) for natural mortality was used in the model.

A variety of different catch streams were developed to use in the decision table and projections. In one, twelve-year forecasts for each state of nature were calculated based on average catch for the period between 2013 and 2016 using a SPR of 0.50. They were also produced with future catches fixed at the 2018 darkblotched rockfish ACL. Also, forecasts for each state of nature were calculated based on removals at a current rebuilding SPR of 64.9% for the base model. Finally, a mixture approach was used with the average 2013-2016 catch assumed for 2017-2020 and 2018 ACL catch for 2021-2028 at an SPR of 0.50.

Under the middle state of nature (which corresponds to the base model), the spawning output and depletion are projected to increase under all three considered catch streams. Under the low state of nature, spawning depletion mostly stays below the $SB_{40\%}$ target during the next 12 years. Under the high state of nature, the spawning output remains above the 40% target level throughout the 12-year projection period.

Research and data needs

The following research could improve the ability of future stock assessments to determine the current status and productivity of the darkblotched rockfish population:

1) Additional population genetics research to elucidate potential spatial stock structure would be valuable for assessment and management, to ensure prevention of local depletion and preserve genetic diversity.

2) Additional research on darkblotched rockfish movement including migration patterns by latitude and depth, diurnal migration patterns through the water column, relative time spent off-bottom versus midwater, relating movements to size, age and sex would be valuable for further understanding this rockfish's ecological niche, stock structure, and lend insight to catchability and gear selectivity patterns.

3) Given that the population range extends north to the border with Canada, it is important that future research would evaluate the impact of not accounting for any Canadian portion of population abundance. Such an analysis would require evaluation of movement of darkblotched rockfish along the coast; such information is currently lacking. There also appears to be no published Canadian assessment available for darkblotched that includes recruitment trends by year to see if there is any synchrony in recruitment on either side of the border.

4) Continuing collection of maturity and fecundity data on darkblotched rockfish would allow further research into latitudinal variability in life history parameters that again would advance understanding this species stock structure. Multi-year data would also allow evaluation of temporal changes in darkblotched rockfish maturity and fecundity.

5) Additional research into natural mortality, as it relates to length and age would be valuable to enable more realistic and accurate modeling of this parameter, which is a common source of uncertainty in assessment of this, and other rockfish species.

6) Future research could also improve existing meta-analyses for natural mortality and steepness, which both contribute to the implied yield curve. Directions for improvements could include (1) weighting methods in natural mortality prior estimates included in the Hamel meta-analysis, and (2) developing a larger database of species for estimating steepness, perhaps by including species from other regions, e.g., Canada and Alaska.

7) Research into establishing optimum methods for more precise modeling of selectivity patterns is needed. Either asymptotic or dome-shaped selectivity curves are frequently used in stock assessments, when neither may be the best available representation of selectivity. A dome shape selection can suggest a "cryptic" biomass, or create confounding with natural mortality assumptions, potentially inflating abundance indices (Crone et al. 2013). Assumptions of asymptotic shape may also not be realistic.

8) Research assessing the effects of the unprecedented warm ocean conditions off the West Coast of the U.S., first detected in late 2013 and persisting into 2016, on rockfish populations is needed. Specifically, investigations are needed that focus on how temperature and other water conditions at depth, in rockfish habitat correspond to high sea-surface temperatures recorded throughout those years, and how the fish respond to those changing conditions. Research is needed that examines whether fish move in response to changing temperatures, where, and how they move, as well as whether the conditions influence life history parameters and aspects such as mortality, feeding, fecundity and other reproductive considerations. What oceanographic and climatic forces are responsible and how long these conditions are expected to persist are also critical pieces of knowledge.

Table ES-7. 12-year projections for alternate states of nature defined based on female natural mortality. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels.*

			State of nature					
			Low *Female M=0.0412*		Base case Female M=0.054		High *Female M=0.059*	
Management decision	Year	Catch (mt)	Spawning output (million eggs)	Depletion	Spawning output (million eggs)	Depletion	Spawning output (million eggs)	Depletion
Average catch for the period between 2013 and 2016 with SPR = 0.50	2017	122	863	25%	1,419	40%	1,691	46%
	2018	122	914	26%	1,489	42%	1,767	48%
	2019	122	979	28%	1,579	45%	1,867	51%
	2020	122	1,060	30%	1,693	48%	1,994	54%
	2021	122	1,146	33%	1,813	51%	2,127	58%
	2022	122	1,228	35%	1,924	54%	2,249	61%
	2023	122	1,302	37%	2,020	57%	2,353	64%
	2024	122	1,367	39%	2,102	59%	2,440	67%
	2025	122	1,426	41%	2,173	61%	2,513	69%
	2026	122	1,479	43%	2,233	63%	2,575	70%
	2027	122	1,528	44%	2,287	65%	2,628	72%
	2028	122	1,574	45%	2,334	66%	2,673	73%
2018 ACL catch assumed for years between 2018 and 2028 with SPR = 0.50	2017	641	863	25%	1,419	40%	1,691	46%
	2018	653	883	25%	1,458	41%	1,737	47%
	2019	653	914	26%	1,516	43%	1,804	49%
	2020	653	958	28%	1,593	45%	1,895	52%
	2021	653	1,001	29%	1,671	47%	1,987	54%
	2022	653	1,033	30%	1,736	49%	2,063	56%
	2023	653	1,055	30%	1,783	50%	2,120	58%
	2024	653	1,068	31%	1,817	51%	2,160	59%
	2025	653	1,074	31%	1,840	52%	2,187	60%
	2026	653	1,075	31%	1,855	52%	2,204	60%
	2027	653	1,072	31%	1,863	53%	2,214	60%
	2028	653	1,066	31%	1,866	53%	2,218	61%
Projections based on target SPR of 50%, under the ACL = ABC (P*=0.45) harvest control rule For 2017 – 2020, the adopted ACLs are used.	2017	641	863	25%	1,419	40%	1,691	46%
	2018	653	883	25%	1,458	41%	1,737	47%
	2019	765	914	26%	1,516	43%	1,804	49%
	2020	815	952	27%	1,587	45%	1,889	52%
	2021	794	984	28%	1,655	47%	1,971	54%
	2022	751	1,005	29%	1,708	48%	2,036	56%
	2023	714	1,017	29%	1,746	49%	2,084	57%
	2024	687	1,022	29%	1,773	50%	2,117	58%
	2025	668	1,023	29%	1,791	51%	2,140	58%
	2026	656	1,020	29%	1,802	51%	2,154	59%
	2027	648	1,014	29%	1,809	51%	2,163	59%
	2028	642	1,006	29%	1,811	51%	2,166	59%

Table ES-7 (continued). 12-year projections for alternate states of nature defined based on female natural mortality. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels.*

			State of nature					
			Low *Female M=0.0412*		Base case Female M=0.054		High *Female M=0.059*	
Management decision	Year	Catch (mt)	Spawning output (million eggs)	Depletion	Spawning output (million eggs)	Depletion	Spawning output (million eggs)	Depletion
Average 2013-2016 catch assumed for 2017-2020 and 2018 ACL catch for 2021-2028 with SPR = 0.50	2017	122	863	25%	1,419	40%	1,691	46%
	2018	122	914	26%	1,489	42%	1,767	48%
	2019	122	979	28%	1,579	45%	1,867	51%
	2020	122	1,060	30%	1,693	48%	1,994	54%
	2021	653	1,146	33%	1,813	51%	2,127	58%
	2022	653	1,196	34%	1,892	53%	2,217	61%
	2023	653	1,232	35%	1,952	55%	2,285	62%
	2024	653	1,257	36%	1,994	56%	2,333	64%
	2025	653	1,273	37%	2,024	57%	2,366	65%
	2026	653	1,281	37%	2,042	58%	2,386	65%
	2027	653	1,283	37%	2,052	58%	2,397	65%
	2028	653	1,281	37%	2,056	58%	2,400	66%

* The percent change in the ratio of estimated male to fixed female natural mortality changes from the base case very little. From 5.4% for the low state of nature to 1.2% for the high state of nature. There is only a change across states of nature (columns) but no change over management decisions (rows). As stated in the text, the estimated male natural mortality for the base case is essentially unchanged from the 2015 base (0.0693 vs. 0.0695).

Table ES-8. Summary of recent trends in estimated darkblotched rockfish exploitation and stock level from the assessment model.

	2007	2008	2009	2010	20011	2012	2013	2014	2015	2016	2017
Landings (mt)	144	117	138	184	117	99	124	103	131	129	NA
Estimated Total catch (mt)	256	243	291	338	121	102	128	107	137	137	NA
OFL (mt)	456	456	437	437	508	508	541	541	574	580	671
ACL (mt)	260	260	282	282	298	298	317	317	338	346	641
1-SPR	0.67	0.64	0.73	0.80	0.31	0.26	0.30	0.24	0.28	0.27	NA
Exploitation_Rate (catch/ age 1+ biomass)	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	NA
Age 1+ Biomass (mt)	12,648	13,177	13,735	14,284	14,826	15,576	16,313	17,138	18,190	19,426	20,713
Spawning output (million eggs)	855	917	970	1,014	1,051	1,105	1,161	1,222	1,289	1,355	1,419
~95% Confidence Interval	395–1,315	419–1,415	437–1,503	449–1,578	455–1,647	4789–1,732	502–1,820	528–1,916	557–2,021	585–2,125	611–2,226
Recruitment	1,657	6,048	874	2,456	2,447	1,482	13,767	1,227	2,565	2,598	2,624
~95% Confidence Interval	917–2,993	3,548–10,311	456–1,673	1,389–4,342	1,366–4,383	780–2,817	7,827–24,215	567–2,655	1,095–6,009	1,970–3,427	1,994–3,454
Depletion (%)	24.1	25.9	27.4	28.6	29.7	31.2	32.8	34.5	36.4	38.2	40.0
~95% Confidence Interval	13.7–34.5	14.6–37.1	15.3–39.4	15.8–41.4	16.1–43.2	16.9–45.4	17.8–47.7	18.7–50.2	19.8–53.0	20.7–55.7	21.7–58.4

Table ES-9. 10-year projections of predicted OFL, maximum potential ACL, estimated summary biomass (age-1 and older), spawning output, and depletion based on target SPR of 50%, under the ACL = ABC (P*=0.45) harvest control rule. Projections assume total catches of 641, 653, 765, and 815 mt (the Council's adopted ACLs) for 2017 - 2020, respectively.

Year	Predicted OFL (mt)	Potential ACL (mt)	Summary biomass (mt)	Spawning output (million eggs)	Depletion (%)
2017	675	641	20,713	1,419	40%
2018	700	653	21,423	1,458	41%
2019	800	765	22,005	1,516	43%
2020	853	815	22,334	1,587	45%
2021	830	794	22,454	1,655	47%
2022	785	751	22,464	1,708	48%
2023	746	714	22,424	1,746	49%
2024	718	687	22,356	1,773	50%
2025	698	668	22,273	1,791	51%
2026	686	656	22,179	1,802	51%
2027	677	648	22,078	1,809	51%
2028	671	642	21,974	1,811	51%

Table ES-10. 10-year projections of predicted OFL, estimated summary biomass (age-1 and older), spawning output, and depletion under a constant ACL catch of 653 mt. Projections assume total catch of 641 and 653 mt (the Council's adopted ACLs) for 2017 and 2018, respectively.

Year	Predicted OFL (mt)	ACL (mt)	Summary biomass (mt)	Spawning output (million eggs)	Depletion (%)
2017	675	641	20,713	1,419	40%
2018	700	653	21,423	1,458	41%
2019	800	653	22,005	1,516	43%
2020	859	653	22,449	1,593	45%
2021	843	653	22,742	1,671	47%
2022	803	653	22,909	1,736	49%
2023	767	653	22,979	1,783	50%
2024	739	653	22,981	1,817	51%
2025	720	653	22,933	1,840	52%
2026	706	653	22,851	1,855	52%
2027	696	653	22,745	1,863	53%
2028	689	653	22,624	1,866	53%

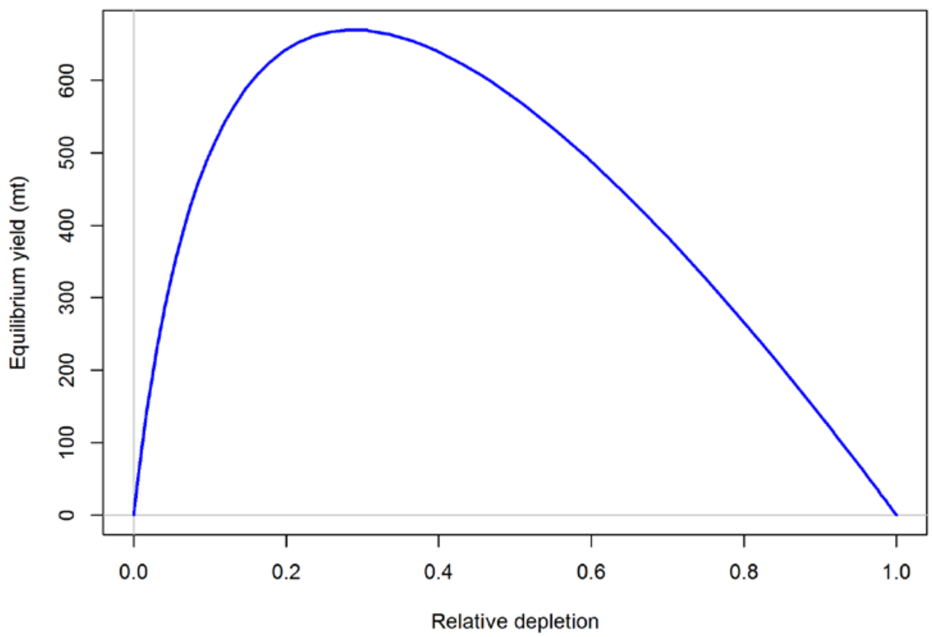

Figure ES-7. Equilibrium yield curve (derived from reference point values reported in Table ES-5) for the base case model. Values are based on 2016 fishery selectivity and distribution with steepness fixed at 0.72. The depletion is relative to unfished spawning biomass.

1 Introduction

This updated assessment does not attempt to reiterate all background information for darkblotched rockfish presented in the 2015 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 darkblotched rockfish life history and the details of previous assessments should refer to the 2015 assessment (Gertseva et al. 2016), the last full assessment for this stock.

1.1 Basic Information and Life History

Darkblotched rockfish (*Sebastes crameri*) are found in the Northeast Pacific Ocean from the southeastern Bering Sea and Aleutian Islands to near Santa Catalina Island in southern California. This species is most abundant from off British Columbia to Central California. Darkblotched rockfish occur at depths between 25 m and 900 m (Love et al., 2002), with the majority of fish inhabiting depths between 100 m and 600 m. Commercially important concentrations are found from the Canadian border through Northern California, on or near the bottom, at depths between 183 m and 366 m.

This species co-occurs with an assemblage of slope rockfish, including Pacific ocean perch (*Sebastes alutus*), splitnose rockfish (*Sebastes diploproa*), yellowmouth rockfish (*Sebastes reedi*), and sharpchin rockfish (*Sebastes zacentrus*) (Rogers and Pikitch, 1992; Rogers, 1994). Pacific ocean perch and darkblotched rockfish are the most abundant members of that assemblage off the coasts of Oregon and Washington, but splitnose rockfish and darkblotched rockfish dominate off the northern coast of California.

There are no clear stock delineations for darkblotched rockfish in the waters of the United States. There are no distinct breaks in the catch distribution (Figure 1) or landings. Survey catches exhibit a continuous distribution of fish over most of the species range (Figure 2), with areas of higher abundance present in the Columbia, Eureka, and Monterey International North Pacific Fisheries Commission (INPFC) areas.

Microsatellite analyses of spatial genetic structure in darkblotched rockfish (Gomez-Uchida and Banks, 2005) suggested a possibility of some genetic differentiation in the stock along the coast, but the level of differentiation was low, it was indicated only in a few of the loci examined. No distinct breaks in the stock were identified. This is the most recent and perhaps the only population genetic study performed for this stock to date.

Darkblotched rockfish are among the longer living rockfish; the data used in this assessment includes individuals that have been aged to be 98 years old. In the literature, the maximum darkblotched rockfish age is reported to be 105 years (Love et al., 2002). As with many other *Sebastes* species, darkblotched rockfish exhibit sexually dimorphic growth; females reach larger sizes than males, while males approach their asymptotic length more rapidly than females (Love et al., 2002; Nichol, 1990; Rogers et al., 2000).

Darkblotched rockfish mate from August to December, eggs are fertilized from October through March, and larvae are released from November through April (Love et al., 2002). Fecundity increases with fish size, and all larvae are released in one batch. Pelagic juveniles settle at 4 to 6 cm in length in about 55 to 200 m (Love et al., 2002). As in many other *Sebastes*, this species exhibits ontogenetic movement, with fish migrating to deeper waters as they mature and increase in size and age (Lenarz, 1993; Nichol, 1990).

It was suggested that the maturity schedule of darkblotched rockfish might vary with latitude. Maturity parameters of fish collected in waters off California (Echeverria, 1987; Phillips, 1964) were found to be smaller than those of fish collected off Oregon (Nichol, 1990). However, Nichol (1990) argued that these differences are rather attributed to different criteria used to determine maturity in the two studies. Also, Westrheim (1975) determined that the size at 50% maturity for darkblotched rockfish decreased, rather than increased, with increasing latitude from Oregon to Alaska. New biological (physiological based) maturity estimates (Melissa Head, personal communication) that included two new years of data were used in an investigational run. Little change in the maturity schedule was seen, with almost no change in L50. Overall, this resulted in a slightly higher spawning output but almost no change in relative spawning output. The next full assessment author will need to decide whether to incorporate the new functional (potential spawner based) maturity schedule in concert with a new look at the model and data.

Size-at-age parameters reported for darkblotched rockfish in the literature vary widely. Substantially smaller size-at-age was estimated for darkblotched rockfish off British Columbia, Canada, than for fish off Oregon (Hamel, 2008). Gertseva et al. (2015) evaluated darkblotched rockfish size at-age data collected within the NMFS Northwest Fisheries Science Center shelf-slope survey, and did not find evidence of differences in growth among states.

For the purpose of this assessment, the species is treated as a single stock from the U.S.-Canadian border in the north to the U.S.-Mexican border in the south, due to the lack of biological and genetic data supporting the presence of multiple stocks. A map depicting the spatial scope of the assessment is shown in Figure 3.

No study has been conducted to evaluate movement patterns of darkblotched rockfish within the assessment area. Adults of darkblotched rockfish typically are observed resting on mud near cobble or boulders (Love et al., 2002). However, this species is among few other rockfish species that are bycaught within the at-sea hake fishery, which operates in the mid-water. This suggests that darkblotched rockfish spend time off the bottom.

1.2 Ecosystem Considerations

Darkblotched rockfish belong to groundfish of the California Current Large Marine Ecosystem. They interact with many other species throughout their long lives (Figure 4). Larvae and juvenile darkblotched rockfish are pelagic. They are also often found perched on the highest bit of structure in the benthic habitat. Juveniles occasionally are seen around the bottoms of deep-water oil platforms. Older larvae and pelagic juvenile darkblotched rockfish are found closer to the surface than many other rockfish species. They feed on plankton, and are vulnerable to predation by other fish and seabirds. Young darkblotched rockfish are eaten by king salmon and albacore (Love et al., 2002). As they grow and mature, they feed on variety of invertebrates and fishes. Occasionally, darkblotched rockfish take octopi. Large fishes and marine mammals prey upon them. Competition for prey and habitat may exist within and among groundfish, and many groundfish species prey upon other groundfish.

Basin-scale forces ultimately affect local production and the quality of the habitat types that groundfish use over the course of their lives. Circulation patterns and upwelling affect patchiness of food and retention of pelagic larvae and juveniles, and upwelling promotes spring/summer production. Temperature affects metabolic rates and growth. In some areas, strong productivity may produce excess phytoplankton, which settles to the bottom and can lead to hypoxia due to high microbial respiration (Figure 5).

Groundfish support extensive and valuable fisheries on the U.S. West Coast. Fisheries that operate with bottom trawl gear may degrade groundfish habitat. Conservation measures and precautionary fisheries management practices are implemented to sustain groundfish populations and their habitat. In addition, habitat qualities and fishery opportunities may be affected by non-fishing activities related to various industrial, shipping, energy development, and land-use practices. Such activities can contribute to nutrient loading, changes in delivery of sediments, pollution and other forms of habitat alteration (Figure 6).

In this assessment, ecosystem considerations were not explicitly included in the analysis. This is primarily due to lack of relevant data and results of analyses (conducted elsewhere) that could contribute ecosystem-related quantitative information for the assessment.

1.3 Fishery Information and Summary of Management History

Darkblotched rockfish has always been caught primarily with commercial trawl gear, as part of a complex of slope rockfish, which includes Pacific ocean perch (*Sebastes alutus*), splitnose rockfish (*Sebastes diploproa*), yellowmouth rockfish (*Sebastes reedi*), and sharpchin rockfish (*Sebastes zacentrus*) (Rogers and Pikitch, 1992; Rogers, 1994). Over the years, catches with non-trawl gear comprised 2% of the total coast wide shoreside landings (Figure 7). This species has not been taken recreationally as evident from RecFIN (www.recfin.com), a regional source of recreational data managed by the Pacific States Marine Fisheries Commission (PSMFC).

Catch of darkblotched rockfish first became significant in the mid-1940s when balloon trawl nets (efficient in taking rockfish) were introduced and World War II increased demand. The largest removals of the species occurred in the 1960s, when foreign trawl fleets from the former Soviet Union, Japan, Poland, Bulgaria and East Germany came to the Northeast Pacific Ocean to target large aggregations of Pacific ocean perch, a species that co-occurs with darkblotched rockfish. In 1966 the removals of darkblotched rockfish reached 4,220 metric tons. By the late-1960s, the foreign fleet had more or less abandoned the fishery. Shoreside landings of darkblotched rockfish rose again between the late-1970s and the late-1980s, peaking in 1987 with landings of 2,415 metric tons. In 2000, the species was declared overfished, and landings substantially decreased due to management regulations. During the last decade the average annual landings of darkblotched rockfish made by the shoreside fishery was around 120 metric tons. Since the mid-1970s, a small amount of darkblotched rockfish has been also taken as bycatch in the at-sea Pacific hake fishery, with a maximum annual removal of 49 metric tons that occurred in 1995.

1.4 Management Performance

Table 1 present a summary of management performance for darkblotched rockfish over the last 10 years, which include a comparison of darkblotched rockfish Overfishing Limits (OFLs), Annual Catch Limits (ACLs), landings, and catch (i.e., landings plus discard). The stock has historically been managed with bimonthly cumulative landings limit (a.k.a. “trip limits”) as most of the catch came from the limited entry bottom trawl fishery. However, since 2011, that allocation has been managed as a catch share fishery, using Individual Fishing Quotas (IFQ), where each permit holder has an annual quota. Darkblotched rockfish has been managed using species-specific harvest specifications since 2001. Over the last 10 years, the total dead catch (as estimated in this assessment) exceeded the Annual Catch Limit (ACL) in two years: 2009 and 2010. The total dead catch has not exceeded the Overfishing Limit (OFL) during last decade.

1.5 Fisheries off Canada, Alaska, and/or Mexico

Darkblotched rockfish have a widespread distribution through the Canadian West Coast Exclusive Economic Zone; however, the highest concentrations occur along the shelf northwest of Vancouver Island and in Moresby Gully southeast of the Queen Charlotte Islands. Similarly to the Unites States, the Canadian commercial trawl fleet captures this species in a slope rockfish assemblage and as a bycatch to the important Pacific ocean perch fishery, but in much lower numbers than in the United States. A formal stock assessment of darkblotched rockfish in Canada has not been conducted. However, a review of darkblotched rockfish biology, distribution, and abundance trends along the Pacific coast of Canada was completed by Haigh and Starr (2008). In this review Haigh and Starr (2008) use values for natural mortality and individual growth drawn from the contemporaneous U.S. assessments. This review was not intended to advise fisheries managers on harvest policy and, therefore did not yield a conclusion on status and long-term trends of the stock. In the future, this review could serve as a basis for a stock assessment.

In the Gulf of Alaska and the Bering Sea-Aleutian Islands, darkblotched rockfish are rare but still occur in fishery catches. The catch of darkblotched rockfish is managed within the other rockfish complex, with management measures set based on area-swept biomass estimates and natural mortality assumptions. The range of darkblotched rockfish does not extend beyond southern California.

2 Assessment

2.1 Data

The darkblotched rockfish data used in the assessment are summarized in Figure 9. These data include both fishery-dependent and fishery-independent sources.

2.1.1 Fishery-dependent data

The fishery removals in the assessment are divided among three fleets: which include a shoreside fishery that contains catches from all gear types, historical catch in the foreign Pacific ocean perch (POP) fishery and bycatch in the at-sea Pacific hake fishery.

Landings of darkblotched rockfish were reconstructed back to 1916, and the assessment assumes a zero catch and equilibrium unfished biomass in 1915. The reconstructed time series of darkblotched rockfish landings by the shoreside fishery and removals by bycatch fleets are presented in Figure 7 and Table 2. Figure 1 shows the spatial distribution of darkblotched rockfish catch in the shoreside fishery, as observed by the WCGOP between 2002 and 2008.

2.1.1.1 Shoreside landings

Shoreside landings were updated for this assessment, as new Washington catch reconstruction became available. Washington darkblotched rockfish landings were provided by Washington Department of Fish and Wildlife (WDFW) for the entire time period covered by the assessment (between 1916 and 2016). These time series are presented in Table 2.

Estimates of recent shoreside landings (between 1981 and 2016) of darkblotched rockfish in Oregon and California were obtained from PacFIN (extracted on March 17, 2017). These recent PacFIN landings in Oregon for the period between 1987 and 1999 were supplemented with the estimates of darkblotched rockfish landed within unspecified categories (i.e., URCK and POP1) provided by the ODWF. Rockfish landings in these unspecified categories were not accounted for in stock assessments previously. These annual landings ranged between 5 and 155 mt with a mean of 80 mt with no trend over the years. The percent increase on a yearly basis ranged from 32% to 305% with an average over the 13 years of 166%. The issue of speciation of unspecified rockfish landings in Oregon was presented to the Council by the ODFW and discussed at the March 2017 Council meeting.

Historical landings in Oregon were based on Karnowski et al. (2014), as in 2015 assessment. California historical landings (between 1916 and 1980) were obtained from CalCOM. These landings were identical to ones used in 2015 assessment. The apparent problem in the darkblotched rockfish historical landings in California, identified during the Historical Groundfish Catch Reconstruction Workshop, was a result of an error in the CalCOM database and not in catch estimates used in the 2015 assessment. The landings used in this assessment are summarized in Table 2. Comparison of shoreside landings from 2015 assessment and landings used in this update assessment is presented in Figure 8.

2.1.1.2 Discard

As in the 2015 assessment, discard ratios for 1985 and 1987 were estimated from observations of retained and discarded catch collected in the Pikitch study (Pikitch et al., 1988) and Wallace (in review) For the period between 2002 and 2015 estimates of the discard ratios of darkblotched rockfish were provided by the WCGOP.

2.1.1.3 Bycatch in the foreign POP and the at-sea Pacific hake fishery

As in the 2015 assessment, we used estimates of darkblotched rockfish bycatch in the foreign POP fishery between 1966 and 1976 as reported in Rogers (2003). The annual amounts of darkblotched rockfish bycatch in the at-sea hake fishery were obtained from the North Pacific Database Program (NORPAC).

2.1.1.4 Fishery biological data

Biological information on shoreside landings was obtained from PacFIN (date of data extraction: April 25, 2017) and on commercial discard from the WCGOP and the Pikitch study. The fishery biological data were also obtained from NORPAC for darkblotched rockfish removals in the at-sea hake fishery. The fishery biological data included sex, length and age of individual fish. The amount of data available varied by source, year and state. These biological data were used to generate length and age frequency distributions by sex (when possible), which were then used in the assessment to inform selectivity and retention of the shoreside fleet. The summary of sampling efforts, which include number of sampled trips, hauls (when available) and fish by source, year and state is provided in Table 3 and Table 4. No biological information was available on darkblotched rockfish removals in the foreign POP fishery.

2.1.1.4.1 Length composition data

Length composition data from commercial fisheries were compiled into 30 length bins, ranging from 4 to 62 cm. Most of the length data from PacFIN were reported for females and males separately; therefore, length frequency distributions of darkblotched rockfish in commercial landings were generated by year and sex. We did not include limited amounts of unsexed fish while constructing these compositions. We also excluded samples that were not taken as part of the three states' regular commercial fishery sampling programs.

The number of fish sampled by port samplers from different trips has not been proportional to the amount of landed catch in these trips. Sampling effort also has varied among states. To account for non-proportional sampling of darkblotched rockfish among trips and states, and to generate length frequency distributions that would be more representative of coast wide species landings, the observed length composition data were expanded using the following algorithm:

1. Length composition data were acquired at the trip level by year, state and sex;
2. For each trip, raw length observations were scaled up to represent darkblotched rockfish landings for the entire trip:

    a. An expansion factor was calculated by dividing the total weight of trip landings by the total weight of darkblotched rockfish sampled for length within the same trip;
    b. The observed raw length composition data within each trip were multiplied by the expansion factor and then summed up by state.
3. The expanded and summed lengths in each state were then expanded again to account for differences in species landings among states:
    a. The expansion factor was computed by dividing the total weight of state landings by the total weight of organisms sampled for length within this state;
    b. The length frequency distributions for each state (from step 2 of this algorithm) were multiplied by the expansion factor (from step 3.a) and then summed up to determine the coast wide sex-specific length frequency distributions by year.

The coast wide length frequency distributions of darkblotched rockfish (generated as described above) landed in the shoreside fishery by year and sex are shown in Figure 10 and Figure 11.

Length frequencies distributions were developed for the period between 1977 and 2016. However, as in the 2015 assessment, length distributions between 1977 and 1979 were not used in the assessment, as those distributions were substantially different from distributions in the other years. Most likely, length data during these years mainly represented catches in the midwater trawl fishery targeting widow rockfish, the dominant rockfish fishery in the late-1970s on the U.S. West Coast, or pink shrimp trawl fishery. Landings of that period, however, were not distinguished between bottom midwater or shrimp trawls; therefore, we were unable to confirm our assumption regarding the reason for the observed difference.

Length-frequency distributions of darkblotched rockfish that were discarded at sea were obtained from the WCGOP for the period between 2003 and 2015, and from the Pikitch study for 1985-1987, the aggregate amounts were entered in the assessment model only under 1986. The WCGOP discard length composition data were analyzed using a weighting method consistent with that applied to the port samples of landed catch described above. The Pikitch study length compositions were obtained from Wallace (In review). Length frequency distributions of discarded fish were developed for both sexes combined, since the vast majority of data did now have sex information associated with length measurements. The length frequency distributions of darkblotched rockfish discarded at sea by year are shown in Figure 11.

Length-frequency distributions of darkblotched rockfish bycaught in the at-sea hake fishery were available by sex for the period between 2003 and 2016. Again, these length composition data were analyzed using a weighting method consistent with the one applied to data from other sources. The length frequency distributions of darkblotched rockfish in the at-sea hake fishery by sex and year are shown in Figure 12.

The initial input sample sizes for length frequency distributions of darkblotched rockfish landings by year were calculated as a function of the number of trips and number of fish sampled using the method developed by Stewart and Hamel (2014):

$$N_{input} = N_{trips} + 0.138N_{fish} \quad \text{when} \quad \frac{N_{fish}}{N_{trips}} < 44$$

$$N_{input} = 7.06N_{trips} \quad \text{when} \quad \frac{N_{fish}}{N_{trips}} \geq 44$$

The method was developed based on analysis of the input and model-derived effective sample sizes from west coast groundfish stock assessments. A step-wise linear regression was used to estimate the increase in effective sample size per sample based on fish-per-sample and the maximum effective sample size for large numbers of individual fish. The estimates of the effect sample sizes were taken from a set of stock assessments that had been tuned to derive "acceptable" estimates of the effective sample sizes.

2.1.1.4.2 Age composition data

Age composition data from commercial fisheries were compiled into 36 age bins, ranging from age 0 to age 35 fish. Age estimates for darkblotched rockfish are available between 1980 and 2016. The amount of age data sampled from commercial landings varied among states (Table 4). Age data on discarded fish were available from the WCGOP for 2004 and 2005. Age data from at-sea hake fishery were available for the period between 2003 and 2015.

The age data from the fisheries were used to derive marginal age compositions using the same weighting methods as used for the length frequency distributions. The marginal composition approach was preferred over the conditional age-at-length compositions (used for fishery-independent data) because the commercial fishery often operates over a more protracted season than the surveys (making age-at-length less stationary during a single year) and in order to speed the computation time of model runs. The marginal age compositions for commercial landings and discards, and removals in the at-sea hake fishery used in the assessment are presented in Figure 13, Figure 14 and Figure 15.

Since 2005, darkblotched rockfish age structures (otoliths) were read by a single reader (Reader 1) from the Ageing Laboratory in the Hatfield Marine Science Center in Newport (Oregon) using the break and burn method, with few other readers producing double-reads of the same age structures. Prior to 2005, several age readers were involved in ageing darkblotched rockfish, who used the same method (break and burn) and same criteria to estimate ages from darkblotched rockfish otoliths as the current age reader for this species. To account for the change in age readers in 2005, a separate pattern for ageing error was used in an “early” (prior to and including data aged in 2004) and “late” (after and including data aged in 2005) periods of age data.

2.1.2 Fishery-independent data

2.1.2.1 Surveys used in the assessment

The assessment utilizes fishery-independent data from four bottom trawl surveys conducted on the continental shelf and slope of the Northeast Pacific Ocean by NWFSC and Alaska Fisheries Science Centers (AFSC), including: 1) the AFSC shelf survey (often called “Triennial”, since it was conducted every third year), 2) the AFSC slope survey, 3) the NWFSC slope survey, and 4) the NWFSC shelf-slope survey (often referred to as the “combo” survey). Details on latitudinal and depth coverage of these surveys by year are presented in Table 5.

The AFSC Triennial survey was conducted every third year between 1977 and 2004 (in 2004 this survey was conducted by the NWFSC using the same protocols). Survey methods are most recently described in Weinberg et al. (2002). The basic design was a series of equally spaced transects from which searches for tows in a specific depth range were initiated. Over the years, the survey area varied in depth and latitudinal range (Table 5). Prior to 1995, the maximum depth was limited to 366 m (200 fm) and the surveyed area included four INPFC areas (Monterey, Eureka, Columbia and U.S. Vancouver). After 1995, the depth coverage was expanded to 500 m (275 fm) and the latitudinal range included not only the four INPFC areas covered in the earlier years, but also part of the Conception area with a southern border of 34º50’ N. latitude. For all years, except 1977, the shallower surveyed depth was 55 m (30 fm); in 1977, no tows were conducted shallower than 91 m (50 fm). The data from the 1977 survey were not used in the assessment, because of the differences in depths surveyed and the large number of “water hauls”, when the trawl footrope apparently failed to maintain contact with the bottom (Zimmermann et al., 2001). The tows conducted in Canadian and Mexican waters were also excluded. In the assessment, the Triennial survey was divided into two periods: 1980- 1992, and 1995-2004; separate catchability coefficients (Q) were estimated for each time period. This was done to account for differences in spatial coverage before and after 1995 (Table 5) and to reflect a change in the timing of the survey. The survey was conducted from mid-summer to early fall in the earlier time period, and was conducted at least a full month earlier in the later time period (Figure 16).

The AFSC slope survey was initiated in 1984. The survey methods are described in Lauth (2000). Prior to 1997, the survey was conducted in different latitudinal ranges each year (Table 5). In this assessment, only data from 1997, 1999, 2000 and 2001 were used – these years were consistent in latitudinal range (from 34º30’ N. latitude to the U.S.-Canada border) and depth coverage (183-1280 m; 100-700 fm).

The NWFSC slope survey was conducted annually from 1999 to 2002 (Keller et al., 2007). The surveyed area ranged between 34º50’ and 48º07’ N. latitude, encompassing the U.S. Vancouver, Columbia, Eureka, Monterey INPFC areas, and a portion of the Conception area, and consistently covered depths from 100 to 700 fm (183-1280 m) (Table 5).

The NWFSC shelf-slope (combo) survey has been conducted annually since 2003, and the data between 2003 and 2016 were used in the assessment. The survey consistently covered depths between 55 and 1280 m (30 and 700 fm) and the latitudinal range between $32^{o}34'$ and $48^{o}22'$ N. latitude, the extent of all five INPFC areas on the U.S. west coast (Table 5). The survey is based on a random-grid design, and four industry chartered vessels per year are assigned an approximately equal number of randomly selected grid cells. The survey is conducted from late May to early October, and is divided into two passes, with two vessels operating during each pass. The survey methods are most recently described in detail in Bradburn et al. (2011).

2.1.2.2 Survey abundance indices

Time series of relative abundance indices and uncertainty (CVs) around estimated values for four bottom trawl surveys used in the assessment are provided in Table 6. Indices of abundance for three out of four surveys (that include AFSC shelf, AFSC slope and NWFSC slope surveys) were retained from the 2015 assessment (Gertseva and Thorson, 2013). These indices were derived using a delta-generalized linear mixed model, or delta-GLMM (Maunder and Punt, 2004), implemented using the software from Thorson and Ward (2014).

Abundance index for the NWFSC shelf-slope survey re-analyzed using a spatio-temporal delta-model (Thorson et al. 2015), implemented as the R package *VAST* (Thorson and Barnett, in press; publicly available online (https://github.com/James-Thorson/VAST). We specifically included spatial and spatio-temporal variation in both encounter probability and positive catch rates, a logit-link for encounter probability with assumed Bernoulli error distribution, and a log-link for positive catch rates with an assumed gamma error distribution. We also include vessel-year effects for each unique combination of vessel and year in the database, to account for the random selection of commercial vessels used during sampling (Helser et al. 2004, Thorson and Ward 2014). We approximated spatial variation using 250 knots, and 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). To confirm convergence of the model estimation algorithm, we verified that the Hessian matrix is positive definite and that the absolute value of the final gradient of the log-likelihood with respect to each fixed effect was <0.0001.

Following advice from the Science and Statistical Committee, we used the following three diagnostics for model fit:

1. The Quantile-Quantile plot, generated by comparing each observed datum with its predicted distribution under the fitted model, calculating the quantile of that datum, and comparing the distribution of quantiles with its expectation under a null model (i.e., a uniform distribution). This Q-Q plot showed no evidence that the model failed to capture the shape of dispersion shown in the positive catch rate data (Figure 20).

2. A comparison of predicted and observed proportion encountered when binning observations by their predicted encounter probability. This comparison shows no evidence that encounter probabilities are over-estimated for low-encounter-probability observations, or vice versa.

3. A visualization of Pearson residuals for encounter probability and positive catch rates associated with each knot. This comparison shows no evidence of residual spatial patterns for either model component.

Comparison of VAST abundance indices used in the assessment with estimates calculated using the designed-based area swept approach are provided in Figure 21.

2.1.2.3 Length composition data

Length composition data collected by the surveys were used to derive length frequency distributions by survey, year and sex. The amount of length composition data available for the assessment varied by survey and year. A summary of sampling efforts in all surveys is provided in Table 7, Table 8, Table 9 and Table 10. Length composition data were compiled into 30 length bins, ranging from 4 to 62 cm. The observed length compositions were expanded to account for differences in catches among tows and spatial strata. To generate coast wide length frequency distributions the following algorithm was used:

1. For a specific year and survey, length data by sex were acquired at the tow level;
2. For each tow, the raw length observations were expanded to represent the entire tow:
    a. An expansion factor was calculated by dividing the total weight of darkblotched rockfish within the tow by the total weight of darkblotched rockfish in this tow measured for length;
    b. The observed length frequencies were multiplied by the expansion factor and then summed up within a spatial stratum.
3. The expanded and summed length frequencies in each spatial stratum were then expanded again to account for differences in catches among spatial strata:
    a. The expansion factor was computed by dividing the total weight of darkblotched rockfish within a stratum by the total weight of darkblotched rockfish within this stratum measured for length;
    b. The length frequency distributions within each stratum (calculated via step 2 above) were multiplied by the second expansion factor (from step 3.a) and then summed up to produce annual sex-specific length frequency distributions for the entire survey area.

Spatial strata used to generate annual length frequency distributions were consistent with the strata used to compute the survey abundance indices (Table 6). The coast-wide length frequency distributions of female and male darkblotched rockfish by survey, year and sex are shown in Figure 22 through Figure 25.

The initial input sample sizes for the survey length frequency distribution data were calculated as a function of both the number of fish and number of tows sampled using the method developed by Stewart and Hamel (2014):

$$N_{input} = N_{tows} + 0.0707 N_{fish} \qquad \text{when } \frac{N_{fish}}{N_{tows}} < 55$$

$$N_{input} = 4.89 N_{tows} \qquad \text{when } \frac{N_{fish}}{N_{tows}} \geq 55$$

2.1.2.4 Age composition data

Age composition data were collected for all the surveys, but the amount of data varied by survey and year. A summary of age data available for the assessment is presented in Table 7, Table 8, Table 9 and Table 10.

Age composition data from the surveys were compiled as conditional distributions of ages at length by survey, year and sex. Prior to that, the observed age compositions were expanded to account for differences in catches among tows and spatial strata, using the same approach as described for length composition data above. The conditional ages at length approach uses an age-length matrix, in which columns correspond to ages and rows to length bins. The distribution of ages in each column then is treated as a separate observation, conditioned on the corresponding length bin (row). The conditional ages at length approach has been used in most recent stock assessments on the West Coast of the United States, since it has several advantages over the use of marginal age frequency distributions. Age structures are usually collected from the individuals that have been measured for length. If the standard age compositions are used along with length frequency distributions in the assessment, the information on sex ratio and year class strength may be double-counted since the same fish are contributing to likelihood components that are assumed to be independent. The use of conditional age distributions within each length bin allows avoiding such double-counting. Also, the use of conditional ages at length distributions allows the reliable estimation of growth parameters within the assessment model.

The number of ages within each length bin was used as the initial input sample sizes for conditional ages and length distributions. Conditional ages at length compositions generated and used in the assessment are shown in Figure 26 through Figure 29.

2.1.3 Biological parameters

A number of biological parameters were kept at the values used in the 2015 assessment, which were the result of estimates outside of the assessment model (Table 11). The 2015 assessment document provides a description of the data and methods upon which these parameters are based. These parameters included the weight-length relationship, the maturity-at-length relationship, and the fecundity-at-weight relationship. Values for these relationships are treated as fixed and therefore uncertainty reported for the stock assessment results does not include any uncertainty associated with these quantities. The ageing imprecision and bias estimates used for this update are also the same as those used in 2015. The female natural mortality was fixed at the same value as in the 2015 assessment (0.054 yr^{-1}), while male natural mortality rate was estimated in this update (as in the 2015 assessment) with a flat prior.

2.2 History of Modeling Approaches Used for this Stock

2.2.1 Previous assessments

The 2015 assessment document contains a detailed description of the history of darkblotched rockfish assessments. In aggregate, these assessments have largely drawn the same conclusions regarding historical trends in stock dynamics (Figure 104). The darkblotched rockfish abundance declined rapidly in the 1960s and 1970s due to high fishing intensity, and continued to decline in the 1980s and 1990s reaching the lowest point around 2000. For the last decade, the stock has been slowly increasing, primarily due to management efforts toward rebuilding of the stock.

2.2.2 Responses to STAR Panel recommendations in 2015

The STAR panel report from the 2015 review provided recommendations for future full assessments of darkblotched rockfish and other rockfish. As this is an update assessment, we did not have an opportunity to address these recommendations. These recommendations are available from the 2015 STAR Panel report at the PFMC website (http://www.pcouncil.org).

2.3 Model Description

2.3.1 Link from the 2015 to the updated assessment model

The bridge from the 2015 stock assessment model to the current base case followed two steps: 1) upgrade to the newest version of SS, and 2) add all new data inputs, including the new Washington catch reconstruction and updated 1987-1999 Oregon catch, recent catch for each fleet, biological data, and extended and re-analyzed NWFSC shelf-slope survey abundance index. The detailed systematic transition from the last assessment is presented in Table 14, which includes values for selected likelihood components, key parameters and key derived quantities.

2.3.2 Modeling software

This assessment used the most recent version of Stock Synthesis (SSv3.30.01.12; Dr. Richard Methot; NMFS, NWFSC) available at the time this assessment was undertaken. Relative spawning biomass of the models to move from the 2015 base (using SSv3.24U) to the current 2017 base model, including a fit with the new base using the old steepness (0.773) is shown in Figure 99.

2.3.3 General model specifications

This assessment focuses on a portion of a population of darkblotched rockfish that occurs in coastal waters of the western United States, off Washington, Oregon and California, the area bounded by the U.S.-Canada border on the north and U.S.-Mexico border on the south. Following the 2015 full assessment, which points to the lack of data suggesting the presence of multiple stocks, the population within this area is treated as a single coast wide stock. The modeling period begins in 1916, assuming that in 1915 the stock was in an unfished equilibrium condition.

Fishery removals are divided among three fleets: 1) the shoreside fishery, 2) bycatch in the historical foreign POP fishery, and 3) bycatch in the at-sea Pacific hake fishery. The shoreside fleet was treated separately to account for differences in handling and reporting the discards. The shoreside fishery is associated with a particular amount of catch discarded at sea. The foreign POP fishery is known not to discard fish (based on their size or species), while the at-sea hake fishery is managed under maximized retention regulations and accounts for all catch of darkblotched rockfish. The time series of discards, therefore, are estimated for the shoreside fleet only, and no discard is assumed for the two bycatch fleets. As dictated by the last full assessment modeling choices, the bycatch fleets were treated separately, since they operate with different gear types; historical foreign POP fishery used bottom trawl gear, while at-sea hake fishery operates with midwater trawl gear.

Historical catches for the shoreside fishery were reconstructed by state, and then combined into the coast wide fleet. Selectivity and retention parameters are estimated for the shoreside fleet and at-sea hake fishery bycatch fleet, while selectivity of the POP fishery bycatch fleet is mirrored to that of the shoreside fishery. Each survey is treated as a separate fleet with independently estimated selectivity and catchability parameters reflecting differences in depth and latitudinal coverage, design and methods among them. No seasons are used to structure removals or biological predictions; data collection is assumed relatively continuous throughout the year.

This is a sex-specific model. The sex-ratio at birth is assumed to be 1:1. Growth of darkblotched rockfish is assumed to follow the von Bertalanffy growth model, and separate growth parameters are estimated for females and males. Females and males also have separate weight-at-length parameters.

Recruitment dynamics are assumed to be governed by a Beverton-Holt stock-recruit function. 'Main' recruitment deviations were estimated for modeled years that had information about recruitment, between 1960 and 2015 (as determined from the bias-correction ramp). We additionally estimated 'early' deviations between 1870 and 1959 so that age-structure in the initial modeled year (1915) would deviate from the stable age-structure that is consistent with estimated variability in recruitment. This resulted in an estimate of B_0 that is also consistent with estimated variability in recruitment given the assumption that initial catch was negligible.

The length composition data are summarized into thirty 2-cm bins, ranging between 4 and 62 cm. Population length bins are defined at a finer, 1-cm scale. The age data are summarized into 36 bins, ranging being age 0 and age 35. Age data beyond age 35 comprise less than 5% of all the age data available for the assessment. For the internal population dynamics, ages 0-45 are individually tracked, with the accumulator age of 45 determining when the 'plus-group' calculations are applied. This accumulator age is selected since little growth is predicted to occur at and beyond this age. The model does not allow growth to continue in the plus-group.

Following the 2015 full assessment's approach, the iterative re-weighting using the McAllister-Ianelli approach (McAllister and Ianelli 1997) as implemented in the R4SS software was used in the assessment to achieve consistency between the input sample sizes and the effective sample sizes for length and age composition samples based on model fit. This reduces the potential for particular data sources to have a disproportionate effect on total model fit. A series of iteration runs using the Francis weighting method was tried, but the length comps became down weighted excessively, which resulted in an unrealistic high depletion level compared to the 2015 full assessment's McAllister-Ianelli approach.

2.3.4 Estimated and fixed parameters

A full list of all parameters used in the assessment is provided in Table 11; this parameter estimation framework remains unchanged from the 2015 assessment.

2.3.4.1 Life history parameters

Life history parameters that were fixed in the model included weight-at-length parameters for females and males, female maturity-at-length and fecundity-at-length and natural mortality. These parameters were retained from the 2015 assessment.

The von Bertalanffy growth function (von Bertalanffy, 1938) was used to model the relationship between length and age in darkblotched rockfish. The Stock Synthesis modeling framework uses the following version of the von Bertalanffy function:

$$L_A = L_\infty + (L_1 - L_\infty)e^{-k(A-A_1)}$$

Where asymptotic length, L_∞, is calculated as:

$$L_\infty = L_1 + \frac{L_2 - L_1}{1 - e^{-k(A_2-A_1)}}$$

In these equations, L_A is length (cm) at age A, k is the growth coefficient, L_∞ is asymptotic length, and L_1 and L_2 are the sizes associated with a minimum A_1 and maximum A_2 reference ages.

Ages A_1 and A_2 were set to be 2 and 30 years, respectively. Female parameters L_1, L_2, growth coefficient k and standard deviations associated with L_1 estimates were estimated in the model. The male L_2 and growth coefficient k were estimated in the model while L_1 and standard deviation associated with L_1 were set to be identical to those of for females (the suggested default setting).

The fixed estimate of female natural mortality (M) used in this assessment was based on the classical Hoenig linear regression model but with recently updated parameters based on an improved database (Then et al, 2015; Gertseva, et al., 2016)

2.3.4.2 Stock recruitment parameters

Recruitment dynamics are assumed in the assessment to be governed by a Beverton-Holt stock-recruit function. This relationship is parameterized to include two estimated quantities: the log of unexploited equilibrium recruitment (R_0) and steepness (h).

In this assessment the log of R_0 was estimated, while h was fixed at its prior mean of 0.720, from the most recent likelihood profile approximation to a maximum marginal likelihood mixed-effect model for steepness from ten Category-1 rockfish species off the U.S. West Coast (Thorson, J, pers. com.). This likelihood profile model is intended to synthesize observation-level data from assessed species, while avoiding the use of model output and thus improving upon previous meta-analyses (Dorn, 2002; Forrest et al., 2010). This methodology has been simulation tested, and has been recommended by the PFMC's SSC for use in stock assessments.

We estimate lognormal deviations from the standard Beverton-Holt stock-recruit relationship for the period between 1870 and 2015. 'Main' recruitment deviations were estimated for modeled years that had information about recruitment (as determined from the bias-correction ramp), i.e., 1960-2015. We additionally estimated 'early' deviations between 1870 and 1959 so that age-structure in the initial modeled year (1915) would deviate from the stable age-structure to a degree that is consistent with estimated variability in recruitment. This resulted in an estimate of B_0 that is also consistent with estimated variability in recruitment given the assumption that initial catch was negligible.

Recruitment deviations were also bias-corrected following Methot and Taylor (2011), by providing a proportion of the total bias correction for year y that varies depending upon how informative the data are about r_y. Specifically, we used R4SS (Taylor et al., 2012) to estimate a five-parameter bias-correction ramp (Figure 32).

2.3.4.3 Selectivity parameters

Gear selectivity parameters used in this assessment were specified as a function of length. Separate length-based selectivity curves were fit to each fishery fleet and survey, for which length composition data were available. Age-based selectivity was assumed to be 1.0 for all ages beginning at age-0.

A double-normal selectivity curve was used for all fleets. The foreign POP fishery was "mirrored" to that of the shoreside fleet. The double-normal selectivity curve has six parameters, including: 1) peak, which is the length at which selectivity is fully selected, 2) width of the plateau on the top, 3) width of the ascending part of the curve, 4) width of the descending part of the curve, 5) selectivity at the first size bin, and 6) selectivity at the last size bin.

For the shoreside fleet, five of the six parameters of the double-normal selectivity curve were estimated (the second parameter was fixed at -6). It also was allowed to be time-varying, to reflect changes associated with implementation of the IFQ fishery. To accomplish this, a time block on selectivity parameters was created for the period of

2011-2016. (There is bug in SSv3.30.01.12 that requires 2016 to be 2017 to achieve correct forecasts.) A separate retention curve was estimated for the shoreside fleet. This retention curve is defined as a logistic function of size. It is controlled by four parameters including 1) inflection, 2) slope, 3) asymptotic retention, and 4) male offset to inflection. Male offset to retention was fixed at 0 (i.e. no male offset was applied). Asymptotic retention was set as a time-varying quantity to match the observed amount of discard between 2002 and 2010. The base value of asymptotic retention used for the period prior to 2002 and after 2010 was assumed to be 1, since only a small portion of the catch was discarded prior to 2000, and since implementation of the IFQ fishery. Inflection and the slope of the retention curve were also allowed to change in 2011 (the beginning of the IFQ fishery) since analysis of length composition data of retain catch indicated a change relative to the pre-IFQ years, with smaller fish being retained. The time-varying parameters were set via use of time blocks.

For bycatch in the at-sea hake fishery, five out of six selectivity parameters were estimated, and only one parameter, selectivity at the first size bin, was assumed zero, since no fish at the smallest size bin were selected within this fleet. The selectivity curves of both fishery fleets were estimated to be of varying degrees of selectivity between dome-shaped and asymptotic.

The selectivity curves for the AFSC shelf, AFSC slope and NWFS slope surveys were set up similarly to that of at-sea hake bycatch fleet, and estimated to be dome-shaped. The NWFSC shelf-slope survey selectivity curve had more complex settings. In initial runs within 2015 assessment, the selectivity for this survey was fully estimated, when selectivity for shoreside fleet was fixed as asymptotic. Later, five of the six parameters (all, but selectivity at the final bin) were fixed at the estimated values. In later runs, when fishery selectivity was allowed to be dome-shaped, the selectivity at the last bin was estimated to be above its minimum value (indicating that survey is catching a portion of the largest fish), making the entire selection curve less dome-shaped. For the 2015 base model, the parameter controlling selection for the last length-bin (parameter 6) was fixed at that estimated value. These settings, although requiring a complicated algorithm to achieve, were retained for the base model in 2015 assessment because they resulted in the best fit to length composition data of the shoreside fleet, while producing a reasonable picture of stock dynamics.

2.4 Model Selection and Evaluation

2.4.1 Key assumptions and structural choices

A large number of alternative model configurations of different levels of complexity were explored in 2015 assessment in order to formulate a base model that would realistically describe the population dynamics of this stock and would balance realism and parsimony. Following the terms of reference for an updated assessment, all assumptions and structural choices remained unchanged, and were not reevaluated the 2017 update assessment.

2.5 Base-Model Results

The list of the all the parameters used in the assessment model and their values (either fixed or estimated) is provided in Table 11. The life history parameters estimated within the model are reasonable and consistent with what we know about the species. Both sexes follow the same trajectory in their grow until around age 6. Males grow slightly faster than females, but females reach larger sizes (Figure 33). The estimated growth parameters for females and males are very close to the values used in previous assessments. Figure 34 through Figure 37 show weight-at-length relationships by sex, female maturity-at-length, fecundity-at-weight and spawning output-at-length generated based on fixed parameters that were derived outside the model. Female fecundity and spawning output in the assessment are expressed in number of eggs.

The base model was able to capture general trends for indices in all the surveys (Figure 38, Figure 40, Figure 42 and Figure 44). Fits to index data on a log scale are presented in Figure 39, Figure 41, Figure 43 and Figure 45. With time-varying catchability incorporated into the model for the AFSC Triennial survey (to reflect a change in survey timing in 1995), the predicted survey values fit the AFSC shelf survey abundance index well (Figure 38). This survey had the lowest index values in 1995 and highest estimate in 1983. The expected index values from the base model showed a slow decline from 1980–1995 and an increase over the period 1995–2004. The model was unable to fit the first point of this survey time series (1980), and accommodate a large difference between index value in 1980 and 1983, which is the highest value in the entire index time series. The model expectations for all other indices fell within the 95% intervals of all observations. Fit to the NWFSC slope and AFSC slope surveys was generally flat, as might be expected for such short time-series. We additionally explored including an extra standard deviation parameter for these two slope surveys, but it was estimated to be zero for both of them. The NWFSC shelf-slope survey was generally flat, but exhibited a slight decrease in the last two years but the overall trend is mostly slowly increasing with flattening in the last two years. The expected index values from the base model showed a relatively flat trend between 2003 and 2014 and is estimated to increase for 2015-2016. For the AFSC Triennial and NWFSC shelf-slope surveys, the model estimated non-zero extra SD parameters (0.0176 and 0.082 for the AFSC shelf and NWFSC shelf-slope survey, respectively).

The model fit to length and age frequency distributions, by year and aggregated across year, and Pearson residuals for the fits by fleet, year and sex are shown in Figure 46 through Figure 67. The quality of fit varies among years and fleets, which reflects the differences in the quantity and quality of the data. The Pearson residuals, which reflect the noise in the data both within and among years, did not exhibit any strong trends.

Plots of observed and expected length composition for the shoreside landings aggregated across all years (Figure 60) shows that the model was able to replicate the length composition pretty well. Similarly, the model is able to largely match the observed length composition data for the surveys, which incorporates differences in selectivity at length for these fleets. The survey length composition generally exhibits smaller average length than the fishery, and hence is more likely to pick out individual cohorts. Finally, the model is able to predict the changes in length composition of discards, including a noticeable decline in average length of discards following implementation of the IFQ fishery in 2011 (Figure 48).

The fits to conditional ages at length and Pearson residuals for the fits by survey are shown in Figure 68 through Figure 75). These plots show that predicted average age at length is generally within predicted error bars around the observed average age at length, which provides support for the assumption that length at age is adequately approximated by the base model, as is necessary to model size at age internally to Stock Synthesis. For visual interpretation of fit to survey age composition data, we included the "ghost" marginal survey age compositions. These age compositions do not contribute to the likelihood and do not affect model fit in any way (Figure 76 through Figure 79).

Selectivity curves for fisheries and surveys are shown in Figure 80 through Figure 87. Both fisheries were estimated to be dome-shaped (with selection for the large fish greater than zero), which is reasonable given that we do observe large fish in the fishery landings. Such selectivity curve allowed better fit to fishery length composition data. The retention function, as expected shows changes in asymptote with changes in discard ratios as well as changes in slope and inflection of the curve at the start of the IFQ fishery. Estimated values for selectivity and retention parameters are provided in Table 11.The AFSC shelf has peak selectivity at length for slightly smaller fishes than other surveys, as is plausible for a species that has ontogenetic movement offshore. It is also estimated to be dome-shaped, which is reasonable since the AFSC shelf survey also would be expected to take fewer larger fish due to limited coverage of the depth range of the species. Selectivity curves for the slope surveys are broadly similar, which is reasonable given that they had similar coverage, and estimated to be dome-shaped (Figure 80). It is not clear why the slope surveys, which include deep waters in which larger darkblotched rockfish occur, would be dome-shaped. However, the footrope and roller gear used by this survey may play a role in the catchability of darkblotched rockfish. The length compositions observed for these three fleets with strongly dome-shaped selectivity show a smaller proportion of large fish than the fisheries.

Discard ratios for the shoreside fishery, as estimated from WCGOP and the Pikitch study data, were fit by the model well (Figure 88). Based on these data, year-specific discard fractions and discard amounts were estimated within the model (Figure 89, Figure 90). These estimates follow the assumption that discard amounts were minimal until 2000, when the species was declared overfished, and more restrictive management measures were implemented. Discard ratios increased following the implementation of management measures in the 2000s but decreased after the implementation of IFQ fishery. The retention curve is similarly estimated to shift to smaller fishes following IFQ implementation, as fishers are encouraged to retain broader sizes of fish.

The deviations from the estimated stock-recruitment function had very large uncertainty prior to the mid-1960s, when the data first become informative about incoming cohort strengths (Figure 91). Therefore, the relative bias adjustment was ramped to the maximum value during this period. Recruitment of darkblotched rockfish was estimated to be quite variable over the historical record, and the estimated stock-recruit function predicts a wide range of cohort sizes over the observed range of spawning biomass (Figure 92).

The estimated time series of total and summary biomass, spawning output, spawning depletion (relative to B_0), recruitment and fishing mortality are presented in Figure 93 through Figure 98 and Table 12. Trends in total and summary biomass, spawning output and spawning depletion track one another very closely. The spawning output of darkblotched rockfish started to decline in the 1940s, during World War II, but exhibited a sharp decline in the 1960s during the time of the intense foreign fishery targeting Pacific ocean perch. Between 1965 and 1976, spawning output dropped from 95% to less than 65% of its unfished level. Spawning output continued to decline throughout the 1980s and 1990s and in 2000 reached its lowest estimated level of 16% of its unfished state. Since 2000, the spawning output has been slowly increasing, which corresponds to decreased removals due to management regulations. Currently, the spawning output is estimated to be 40% of its unfished level (Figure 96).

2.6 Uncertainty and Sensitivity Analyses

As in 2015, parameter uncertainty in the assessment is explicitly captured in the asymptotic confidence intervals estimated within the model and reported throughout this assessment for key parameters and management quantities (Figure 95, Figure 96 and Figure 97). These intervals reflect the uncertainty in the model fits to the data sources in the assessment, but do not include the uncertainty associated with alternative model configurations and fixed parameters.

2.6.1 Retrospective analysis

A retrospective analysis was conducted, where the model is fitted to a series of shortened input data sets, with the most recent years of input data sequentially being dropped. A 5-year retrospective analysis was conducted by running the model using data only from 2011-2015 (Figure 100 through Figure 103 and Table 13). No systematic pattern is apparent through any of these removals, indicating that the new data is consistent with previous values or the sample sizes are too small to have any impact.

The second type of retrospective analysis addresses assessment error, or at least the historical context of the current result given previous analyses. Figure 104 shows the spawning depletion time series for all assessments (full and update assessment) conducted since 2000. In aggregate, these assessments have largely drawn the same conclusions regarding historical trends: that the darkblotched rockfish resource declined rapidly due to high fishing intensity in the 1960s and 1970s, with continued decline in the 1980s and 1990s reaching the lowest point around 2000. For the last decade, the stock was slowly increasing due to management efforts toward rebuilding of the stock. The 2003, 2005, 2007, 2009, 2011 and 2013 assessments estimated spawning depletion at terminal year of each assessment to be 13%, 17%, 22%, 28%, 30%, 36% and 39% respectively. This assessment estimates the stock to be at 40.03% of its unfished state.

2.6.2 Likelihood profile analyses

The base model included several key parameters, including female natural mortality and stock-recruit steepness, which were fixed at the values determined outside the assessment model. Likelihood profiles were performed to look at the sensitivity of the model to assumptions about natural mortality (M) and steepness (h). Also, likelihood profile analysis over the $\ln(R_0)$ parameter was conducted to explore the influence of different data sources on the scale of the population and stock status.

A likelihood profile analysis conducted over a range of values for female natural mortality shows that the negative log-likelihood for the base model is minimized at a value of around 0.06 (Figure 105). However, as described in Section 2.1.3.4, we only fixed female natural mortality, while male natural mortality is estimated in the base model (0.069 yr^{-1}) and in the likelihood profile analyses. Dimorphic growth is often accompanied by different rates of natural mortality. Although the data are insufficient to estimate natural mortality for both males and females, when female M is fixed, the compositional data should be informative about the difference in natural mortality between the sexes. Estimating natural mortality for at least one sex would capture more of the uncertainty in the model results. Time series of spawning depletion associated with different values of natural mortality ranging from 0.04 to 0.1 are shown in Figure 106.

When estimated with a meta-analytical prior, stock-recruit steepness was 0.720. Which corresponds well with a likelihood profile of the base model indicated that the negative log-likelihood is the lowest with steepness value around 0.7 (Figure 107). Profile analysis also indicated that there is tension between length and age composition likelihoods, when length composition likelihoods for all fleets have the lowest values (negative) associated with higher steepness and age composition likelihoods, on the contrary, with lower steepness. The model run associated with steepness of 0.7 produces reasonable output (Figure 108).

A likelihood profile analysis for $\ln(R_0)$ is shown in Figure 109. All the runs for the $\ln(R_0)$ profile analysis converged. The primary source of information about $\ln(R_0)$ is in the recruitment penalties, and none of the likelihood components based on actual observed data provide appreciable information on the scale $\ln(R_0)$ of this stock. Different values of $\ln(R_0)$ scale the recruitment deviations up or downward from the mean value of 0, with low values of $\ln(R_0)$ having high recruitment deviations and vice-versa Additionally, recruitment scales with $\ln(R_0)$; high values of $\ln(R_0)$ coincide with higher recruitment, and low values of $\ln(R_0)$ coincide with lower recruitment (Figure 110; Figure 111). Such interplay between spawning output and recruitment transmits backward to the virgin state of the stock and $\ln(R_0)$. The available data cause the model to seek a particular value for recruitment, and changes in $\ln(R_0)$ cause the model to compensate by changing recruitment deviations in order to continue achieving that desired level of recruitment, which in turn causes recruitment deviations to contribute the greatest change in log-likelihood to $\ln(R_0)$.

3 Reference Points

Unfished spawning stock output for darkblotched rockfish was estimated to be 3,544 million eggs (95% confidence interval: 2,711-4,377 million eggs, see Table 15). The stock is declared overfished if the current spawning output is estimated to be below 25% of unfished level. The management target for darkblotched rockfish is defined as 40% of the unfished spawning output ($SB_{40\%}$), which is estimated by the model to be 1,418 million eggs (95% confidence interval: 1,084-1,751), which corresponds to an exploitation rate of 0.037. This harvest rate provides an equilibrium yield of 639 mt at $SB_{40\%}$ (95% confidence interval: 495-783 mt). The model estimate of maximum sustainable yield (MSY) is 670 mt (95% confidence interval: 518-821 mt). The estimated spawning stock output at MSY is 1,018 million eggs (95% confidence interval: 778-1,259 million of eggs). The exploitation rate corresponding to the estimated SPR_{MSY} of $F_{36\%}$ is 0.052.

The assessment shows that the stock of darkblotched rockfish off the continental U.S. Pacific Coast is currently at 40% of its unexploited level. This is above the overfished threshold of $SB_{25\%}$, but just at the management target of $SB_{40\%}$ of unfished spawning biomass. Historically, the spawning output of darkblotched rockfish dropped below the $SB_{40\%}$ target for the first time in 1989, as a result of intense fishing by foreign and domestic fleets. It continued to decline and reached the level of 16% of its unfished output in 2000. The same year, the stock was declared overfished. Since then, the spawning output was slowly increasing primarily due to management regulations instituted for the species. (Figure 96).

This assessment estimates that the 2016 SPR is 86%. The SPR used for setting the OFL is 50%, while the SPR-based management fishing mortality target, specified in the current rebuilding plan and used to determine the ACL, and is 64.9%. Historically, the darkblotched rockfish was fished beyond the relative SPR ratio (calculated as 1-SPR/1-$SPR_{Target=0.5}$) between 1966 and 1968, during the peak years of the Pacific ocean perch fishery, in 1973, and for a prolonged period between from 1981 and 2000. (Figure 112). The phase plot of estimated relative (1-SPR) vs. relative spawning biomass for the base case model is shown in Figure 113.

A summary of reference points for the base model is provided in Table 15. A summary of recent trends in estimated darkblotched rockfish exploitation and stock level from the assessment model are given in Table 16.

4 Harvest Projections and Decision Table

The base model estimate for 2017 spawning depletion is 40.03%. The primary axis of uncertainty about this estimate used in the decision table was based on female natural mortality. As in the 2015 assessment, female natural mortality of 0.0412 and 0.059 were used to define low and high states of nature respectively and to construct the decision table (Table 17). The value for the male natural mortality was re-estimated, but did not change from the 2015 assessment. The alternative female natural mortality values were selected following a multi-step algorithm, and they corresponded to alternative depletion levels, calculated using a normal approximation to the prior distribution for stock-recruit steepness (Gertseva et al. 2016). The multi-step algorithm was necessary since natural mortality was thought by the STAR panel to be the main axis of uncertainty but no prior (i.e. only a flat prior) for natural mortality was used in the model. The value of sigma (CV method), calculated from the base model's estimate of 2017 spawning output and its standard deviation, is 0.2903 (which is less than the 0.36 value that the PFMC uses as the minimum acceptable value for scientific uncertainty).

Twelve-year forecasts for each state of nature were calculated based on average catch for the period between 2013 and 2016 using a SPR of 0.50. They were also produced with future catches fixed at the 2018-darkblotched rockfish ACL. In addition, forecasts for each state of nature were calculated based on removals at a current rebuilding SPR of 64.9% for the base model. Finally, a mixture of approaches was used with the average 2013-2016 catch assumed for 2017-2020 and 2018 ACL catch for 2021-2028 at an SPR of 0.50.

Under the middle state of nature (which corresponds to the base model), the spawning output and depletion are projected to increase under all three considered catch streams. Under the low state of nature, spawning depletion mostly stays below the $SB_{40\%}$ target during the next 12 years. Under the high state of nature, the spawning output remains above the 40% target level throughout the 12-year projection period.

5 Regional Management Considerations

In the waters of the western United States, off California, Oregon and Washington, this species is managed coast wide, with coast wide ACLs determined for management purposes. The population within the assessed area is treated as a single coast wide stock, due to the lack of biological and genetic data indicating the presence of multiple stocks. Analysis conducted within this assessment did not find support for regional management considerations as well. However, below we identify several of areas of research that may aid evidence for regional management considerations for the future.

6 Research Needs

The following research could improve the ability of future stock assessments to determine the status and productivity of the darkblotched rockfish population:

1) Additional population genetics research to elucidate potential spatial stock structure would be valuable for assessment and management, to ensure prevention of local depletion and preserve genetic diversity.

2) Additional research on darkblotched rockfish movement including migration patterns by latitude and depth, diurnal migration patterns through the water column, relative time spent off-bottom versus midwater, relating movements to size, age and sex would be valuable for further understanding this rockfish’s ecological niche, stock structure, and lend insight to catchability and gear selectivity patterns.

3) Given that the population range extends north to the border with Canada, it is important that future research would evaluate the impact of not accounting for any Canadian portion of population abundance. Such an analysis would require evaluation of movement of darkblotched rockfish along the coast; such information is currently lacking. There also appears to be no published Canadian assessment available for darkblotched rockfish that includes recruitment trends by year to see if there is any synchrony in recruitment on either side of the border.

4) Continuing collection of maturity and fecundity data on darkblotched rockfish would allow further research into latitudinal variability in life history parameters that again would advance understanding this species stock structure. Multi-year data would also allow evaluation of temporal changes in darkblotched rockfish maturity and fecundity.

5) Additional research into natural mortality, as it relates to length and age would be valuable to enable more realistic and accurate modeling of this parameter, which is a common source of uncertainty in assessment of this, and other rockfish species.

6) Future research could also improve existing meta-analyses for natural mortality and steepness, which both contribute to the implied yield curve. Directions for improvements could include (1) weighting methods in natural mortality prior estimates included in the Hamel meta-analysis, and (2) developing a larger database of species for estimating steepness, perhaps by including species from other regions, e.g., Canada and Alaska.

7) Research into establishing optimum methods for more precise modeling of selectivity patterns is needed. Either asymptotic or dome-shaped selectivity assumptions are frequently used in stock assessments, when neither may be the best available representation of selectivity. Assumptions of a dome shape can suggest a “cryptic” biomass, or create confounding with natural mortality assumptions, potentially inflating abundance indices (Crone et al 2013). Assumptions of asymptotic shape may also not be realistic. Simulation studies could be performed to empirically evaluate varying degrees of intermediate selectivity shapes, and how best to effectively implement them in existing stock assessment software platforms.

8) Research assessing the effects of the unprecedented warm ocean conditions off the West Coast of the U.S. during 2014 and 2015, on rockfish populations is needed. Specifically, investigations are needed that focus on how temperature and other water conditions at depth, in rockfish habitat correspond to high sea-surface temperatures recorded throughout those years, and how the fish respond to those changing conditions. Research is needed that examines whether fish move in response to changing temperatures, where, and how they move, as well as whether the conditions influence life history parameters and aspects such as mortality, feeding, fecundity and other reproductive considerations. What

oceanographic and climatic forces are responsible and how long these conditions are expected to persist are also critical pieces of knowledge.

7 Acknowledgments

First, we would like to thank Richard Methot for continuing to improve Stock Synthesis. We would also like to thank Jason Cope for discussions that helped to successfully navigate the complexity of Stock Synthesis and Ian Taylor for his continuing efforts in refining r4ss, which makes diagnosis and reporting of alternate model runs a much easier process.

Many people assisted with assembling the data included in this assessment, and we are grateful to everyone who was directly or indirectly involved in providing and processing the data. Specifically, we thank Beth Horness for generating the NWFSC shelf-slope survey data packages; to Vanessa Tuttle for providing data from the at-sea hake observer program; to Patrick McDonald and the team of age readers who have worked on ageing darkblotched rockfish throughout the years; to Kayleigh Somers, and Chantel Wetzel for providing details and data from the West Coast Groundfish Observer Program (WCGOP); to Melissa Head for new maturity data; to Andi Stephens for data processing software; to Alison Whitman, and Theresa Tsou for providing details on state specific fishery data and valuable background on state sampling programs and fishery data processing.

8 Literature Cited

Alverson, D.L., Pruter, A.T., Ronholt, L.L., 1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. Institute of Fisheries, University of British Columbia.

Barss, W.H., Niska, E.L. 1978. Pacific Ocean perch (Sebastes alutus) and other rockfish (Scorpaenidae) trawl landings in Oregon 1963-1977. Oregon Department of Fish and Wildlife, Informational Report 78-6.

Bradburn, M. J., Keller, A. Horness, B. H. 2011. The 2003 to 2008 U.S. West Coast bottom trawl surveys of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, length, and age composition. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-NWFSC-114.

Crone, P., Maunder, M. Valero, J., McDaniel, J., Semmens, B. 2013. Selectivity: theory, estimation, and application in fishery stock assessment models. Workshop Report 1. Center for the Advancement of Population Assessment Methodology (CAPAM), La Jolla, CA.

Dorn, M.W. 2002. Advice on West Coast rockfish harvest rates from Bayesian meta-analysis of stock- recruit relationships. North American Journal of Fisheries Management 22: 280–300.

Douglas, D.A., 1998. Species composition of rockfish in catches by Oregon trawlers, 1963-93. Marine Program Data Series Report, Oregon Department of Fish and Wildlife.

Echeverria, T.W., 1987. Thirty-four species of California rockfishes: Maturity and seasonality of reproduction. Fishery Bulletin 85: 229-250.

Forrest, R.E., McAllister, M.K., Dorn, M.W., Martell, S.J.D., Stanley, R.D. 2010. Hierarchical Bayesian estimation of recruitment parameters and reference points for Pacific rockfishes (Sebastes spp.) under alternative assumptions about the stock-recruit function. Canadian Journal of Fisheries and Aquatic Sciences 67: 1611–1634.

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A., Sibert, J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software 27: 1–17.

Gertseva, V. V., S. E. Matson, E. Councill. 2016. Status of the Darkblotched Rockfish Resource off the Continental U.S. Pacific Coast in 2015. *In* Status of the Pacific Coast Groundfish Fishery through 2015, Stock Assessment and Fishery Evaluation: Stock Assessments, STAR Panel Reports, and Rebuilding Analyses. Pacific Fishery Management Council, Portland, Oregon, 238 pp.

Gertseva, V. V., J. M. Cope, S. E. Matson. 2010. Growth Variability of the Splitnose Rockfish (Sebastes diploproa) in the Northeast Pacific Ocean: pattern revisited. Marine Ecology Progress Series, 413:125-136.

Gomez-Uchida, D., Banks, M.A. 2005. Microsatellite analyses of spatial genetic structure in darkblotched rockfish (S ebastes crameri): Is pooling samples safe? Canadian Journal of Fisheries and Aquatic Sciences 62: 1874-1886.

Gunderson, D.R., Zimmerman, M, Nichol, D.G., Pearson, K. 2003. Indirect estimates of natural mortality rate for arrowtooth flounder (*Atheresthes stomias*) and darkblotched rockfish (*Sebastes crameri*). Fishery Bulletin 101:175-182.

Haddon, M. 2001 Modelling and Quantitative Methods in Fisheries. CRC Press.
Haigh, R., Starr, P. 2008. A review of darkblotched rockfish Sebastes crameri along the Pacific coast of Canada: biology, distribution, and abundance trends. Fisheries and Oceans Canada, Science.
Hamel, O.S. 2008. Status and future prospects for the darkblotched rockfish resource in waters off Washington, Oregon and California as assessed in 2007. Pacific Fishery Management Council, Portland, OR.
Harry, G., Morgan, A.R. 1961. History of the trawl fishery, 1884-1961. Oregon Fish Commission Research Briefs 19: 5-26.
Helser, T.E., Punt, A.E., Methot, R.D. 2004. A generalized linear mixed model analysis of a multi-vessel fishery resources survey. Fisheries Research 70: 251-264.
Karnowski, M., Gertseva, V.V., Stephens, A. 2014. Historical Reconstruction of Oregon's Commercial Fisheries Landings. 2014-02, Oregon Department of Fish and Wildlife, Newport, Oregon, 56 pp.
Keller, A.A., Horness, B.H., Simon, V.H., Tuttle, V.J., Wallace, J.R., Fruh, E.L., Bosley, K.L., Kamikawa, D.J., Buchanan, J.C. 2007. The U.S. West Coast trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition in 2004. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC.
Keller, A. A., K. J. Molton, A. C. Hicks, M. A. Haltuch, C. R. Wetzel. 2012. Variation in age and growth of greenstriped rockfish (sebastes elongatus) along the U.S. West Coast (Washington to California). Fisheries Research 119: 80-88.
Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., and Bell, B.M. 2016. TMB: Automatic Differentiation and Laplace Approximation. J. Stat. Softw. **70**(5): 1–21.
Lauth, R.R. 2000. The 2000 Pacific west coast upper continental slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. NTIS No. PB2001-105327.
Lenarz, W.H. 1993. An initial examination of the status of the darkblotched rockfish fishery off the coasts of California, Oregon, and Washington. Appendix C in Appendices to the status of the Pacific coast groundfish through 1993 and recommended acceptable biological catches for 1994. 22 p. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97201.
Love, M.S., Yoklavich, M.M., Thorsteinson, L.K., 2002. The rockfishes of the northeast Pacific. University of California Press.
Maunder, M.N., Punt, A.E., 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research 70: 141-159.
Methot, R.D.J., Taylor, I.G. 2011. Adjusting for bias due to variability of estimated recruitments in fishery assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68: 1744-1760.
McAllister, M.K. and Ianelli, J.N., 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Canadian Journal of Fisheries and Aquatic Sciences, 54(2): 284-300.

McDermott, S.F. 1994. Reproductive Biology of Rougheye and Shortraker Rockfish, Sebastes aleutianus and Sebastes borealis. M.S. Thesis, University of Washington, Seattle.
Nichol, D.G. 1990. Life history examination of darkblotched rockfish (Sebastes crameri) off the Oregon coast. M.S. Thesis, Oregon State University, Corvallis.
Niska, E.L., 1976. Species composition of rockfish in catches by Oregon trawlers 1963-1971. Oregon Department of Fish and Wildlife, Informational Report 76-7.
Pikitch, E.K., Erickson, D.L., Wallace, J.R., 1988. An evaluation of the effectiveness of trip limits as a management tool. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, US Department of Commerce.
Rogers, J.B. 1994. Assemblages of groundfish caught using commercial fishing strategies off the coasts of Oregon and Washington from 1985-1987. Ph.D. Dissertation, Oregon State University, Oregon.
Rogers, J.B. 2003. Species allocation of Sebastes and Sebastolobus sp. caught by foreign countries from 1965 through 1976 off Washington, Oregon, and California, USA. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.
Rogers, J.B., Methot, R.D., Builder, T.L., Piner, K., and Wilkins, M. 2000. Status of the Darkblotched Rockfish (*Sebastes crameri*) Resource in 2000, appendix to Status of the Pacific coast groundfish fishery through 2000 and recommended acceptable biological catches for 2001. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97201.
Rogers, J.B., Pikitch, E.K., 1992. Numerical definition of groundfish assemblages caught off the coasts of Oregon and Washington using commercial fishing strategies. Canadian Journal of Fisheries and Aquatic Sciences 49: 2648-2656.
Scofield, W.L. 1948. Trawling gear in California. Fishery Bulletin 72.
Stephens, A., Hamel, O., Taylor, I., Welzel, C. 2011. Status and Future Prospects for the Darkblotched Rockfish Resource in Waters off Washington, Oregon, and California in 2011. In: Status of the Pacific Coast Groundfish Fishery through 2011, Stock Assessment and Fishery Evaluation: Stock Assessments, STAR Panel Reports, and Rebuilding Analyses. Pacific Fishery Management Council, Portland, OR.
Stewart, I.J., and Hamel, O.S. 2014. Bootstrapping of sample sizes for length- or age composition data used in stock assessments. Canadian Journal of Fisheries and Aquatic Sciences 71(4): 581-588.
Stewart, I.J., Thorson, J.T., Wetzel, C. 2011. Status of the US Sablefish resource in 2011. In: Status of the Pacific Coast Groundfish Fishery through 2011, Stock Assessment and Fishery Evaluation: Stock Assessments, STAR Panel Reports, and Rebuilding Analyses. Pacific Fishery Management Council, Portland, OR.
Tagart, J., Kimura, D.K. 1982. Review of Washington's Coastal Trawl Rockfish Fishery. Technical report 68, State of Washington Department of Fisheries.
Taylor, I., Stewart, I., Hicks, A., Garrison, T., Punt, A., Wallace, J., Wetzel, C. 2012. r4ss: R code for Stock Synthesis.
Then, A.Y., Hoenig, J. M., Hall, N.G., Hewitt, D.A. In press. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES J. Mar. Sci.

Thorson, J.T., and Barnett, L.A.K. 2017. Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. ICES J. Mar. Sci. Volume 74, Issue 5:1311-1321, 2017.
Thorson, J.T., Kristensen, K. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fish. Res. 175: 66–74.
Thorson, J.T., Shelton, A.O., Ward, E.J., and Skaug, H. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES J. Mar. Sci. Vol 72, Issue 5: 1297-1310, 2015.
Thorson, J.T., Stewart, I., Punt, A. 2011. Accounting for fish shoals in single- and multi-species survey data using mixture distribution models. Canadian Journal of Fisheries and Aquatic Sciences 68: 1681–1693.
Thorson, J.T., Stewart, I.J., Punt, A.E. 2012. Development and application of an agent-based model to evaluate methods for estimating relative abundance indices for shoaling fish such as Pacific rockfish (*Sebastes* spp.). Ices Journal of Marine Sciences 69: 635-647.
Thorson, J.T., Ward, E. 2014. Accounting for space-time interactions in index standardization models. Fisheries Research 155: 168-176
von Bertalanffy, L. 1938. A quantitative theory of organic growth (inquiries on growth laws II). Human Biology 10: 181-213.
Wallace, J.R. In review. Applying information from the U.S. West Coast's first major trawl bycatch and mesh size studies to fishery data using post-hoc fishing strategies and geographical area.
Wallace, J., Hamel, O. 2009. Status and Future Prospects for the Darkblotched Rockfish Resource in Waters off Washington, Oregon, and California as Updated in 2009. In: Status of the Pacific Coast Groundfish Fishery through 2009, Stock Assessment and Fishery Evaluation: Stock Assessments, STAR Panel Reports, and Rebuilding Analyses. Pacific Fishery Management Council, Portland, OR.
Westrheim, S.J. 1975. Reproduction, maturation, and identification of larvae of some Sebastes (Scorpaenidae) species in the northeast Pacific Ocean. Journal of the Fisheries Research Board of Canada 32: 2399-2411.
Weinberg, K.L., Wilkins, M. E., Shaw, F. R., Zimmermann, M. 2002. The 2001 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, and length and age composition. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-128.
Wilberg, M.J., Thorson, J.T., Linton, B.C., and Berkson, J. 2010. Incorporating time-varying catchability into population dynamic stock assessment models. Reviews in Fisheries Science 18: 7-24.
Wilkins, M.E. Golden, J.T. 1983. Condition of the Pacific ocean perch resource off Washington and Oregon during 1979: Results of a cooperative trawl survey. North American Journal of Fisheries Management 3: 103-122.
Zimmerman, M. 2001. Retrospective analysis of suspiciously small catches in the National Marine Fisheries Service West Coast Triennial bottom trawl survey. AFSC Processed Rep. 2001-03, AFSC/NMFS, Seattle.

9 Auxiliary Files Provided

9.1 Pacific Fisheries Management Council for Archiving

- SS Starter file
- SS Forecast file
- SS Data file
- SS Control file
- Predicted numbers-at-age by sex

9.2 Species Information System (SIS) for Federal Government Accounting

- SS SIS file

10 Tables

Table 1: Recent darkblotched rockfish Overfishing Limits (OFLs) and Annual Catch Limits (ACLs) relative to recent total landings and total dead catch estimated in this assessment. This table also includes total catch by year reported by the West Coast Groundfish Observer Program (WCGOP), for comparison.

Year	OFL (mt)	ACL (mt)	Commercial Landings (mt)	Estimated Total Catch (mt)*	Total catch (mt) reported by WCGOP
2007	456	260	143.6	256.1	277.9
2008	456	260	117.4	243.8	254.4
2009	437	282	138.4	290.7	299.6
2010	437	282	184.3	337.9	335.0
2011	508	298	116.9	121.3	124.6
2012	508	298	99.0	102.5	108.0
2013	541	317	124.1	127.8	130.6
2014	541	317	103.2	106.5	138.2
2015	574	338	130.7	136.8	139.8
2016	580	346	129.1	136.6	

*Includes discards estimated within the stock assessment and therefore may differ from total mortality reports used by management.

Table 2: Total landings (mt) of darkblotched rockfish for the shoreside fleet (provided here by state) and bycatch fleet (separated here as bycatch in foreign POP and in at-sea Pacific hake fisheries).

Year	Shoreside California	Shoreside Oregon	Shoreside Washington	Bycatch in foreign POP fishery	Bycatch in at-sea hake fishery	Total
1915	0	0	0	0	0	0
1916	13	0	0	0	0	13
1917	21	0	0	0	0	21
1918	21	0	0.24	0	0	22
1919	14	0	0.08	0	0	14
1920	14	0	0.07	0	0	15
1921	12	0	0.06	0	0	12
1922	11	0	0.03	0	0	11
1923	14	0	0.04	0	0	14
1924	14	0	0.10	0	0	14
1925	16	0	0.13	0	0	16
1926	21	0	0.22	0	0	22
1927	18	0	0.29	0	0	19
1928	18	0	0.26	0	0	18
1929	19	0	0.15	0	0	19
1930	21	0	0.19	0	0	21
1931	26	0	0.09	0	0	26
1932	16	0	0.08	0	0	17
1933	16	0	0.11	0	0	16
1934	15	0	0.14	0	0	15
1935	17	0	0.12	0	0	18
1936	11	0	0.15	0	0	12
1937	13	1	0.11	0	0	14
1938	16	0	0.14	0	0	17
1939	23	1	0.12	0	0	24
1940	20	13	0.14	0	0	33
1941	22	19	0.24	0	0	42
1942	12	36	0.24	0	0	48
1943	57	125	1	0	0	183
1944	177	218	2	0	0	397
1945	334	337	4	0	0	675
1946	189	209	2	0	0	399
1947	199	130	1	0	0	331
1948	99	89	1	0	0	189
1949	70	86	1	0	0	157

Year	Shoreside California	Shoreside Oregon	Shoreside Washington	Bycatch in foreign POP fishery	Bycatch in at-sea hake fishery	Total
1950	73	101	2	0	0	176
1951	106	96	2	0	0	204
1952	78	136	1	0	0	215
1953	87	96	1	0	0	184
1954	79	136	1	0	0	216
1955	131	123	1	0	0	256
1956	149	189	1	0	0	339
1957	190	205	1	0	0	396
1958	180	153	1	0	0	335
1959	139	142	1	0	0	282
1960	151	189	2	0	0	343
1961	120	197	3	0	0	320
1962	107	235	4	0	0	346
1963	136	225	5	0	0	366
1964	85	175	4	0	0	264
1965	97	380	5	0	0	481
1966	84	320	4	3807	0	4216
1967	102	262	4	2706	0	3074
1968	110	17	0	2288	0	2415
1969	43	80	2	153	0	278
1970	49	145	2	149	0	345
1971	65	174	6	278	0	523
1972	84	148	2	374	0	607
1973	67	67	5	768	0	907
1974	95	144	2	346	0	587
1975	106	102	64	293	0	565
1976	121	322	54	118	11	625
1977	123	130	31	0	2	287
1978	60	156	167	0	1	384
1979	148	497	37	0	4	686
1980	166	334	94	0	21	615
1981	522	266	37	0	12	837
1982	170	941	25	0	2	1137
1983	510	582	23	0	12	1126
1984	596	625	85	0	20	1325
1985	802	848	121	0	13	1783
1986	417	622	231	0	6	1274
1987	1641	710	75	0	14	2440
1988	750	789	123	0	10	1725

Year	Shoreside California	Shoreside Oregon	Shoreside Washington	Bycatch in foreign POP fishery	Bycatch in at-sea hake fishery	Total
1989	441	768	96	0	5	1311
1990	871	774	19	0	33	1696
1991	333	832	59	0	60	1284
1992	187	516	22	0	33	758
1993	285	930	14	0	9	1238
1994	292	572	10	0	19	893
1995	366	393	32	0	58	849
1996	408	359	22	0	7	796
1997	453	382	24	0	4	863
1998	497	461	21	0	15	994
1999	113	263	14	0	11	401
2000	114	129	8	0	8	259
2001	87	66	10	0	12	175
2002	50	52	7	0	3	112
2003	11	62	2	0	4	80
2004	39	136	7	0	7	189
2005	18	68	1	0	11	98
2006	23	71	2	0	11	107
2007	41	87	3	0	12	144
2008	34	74	3	0	6	117
2009	47	89	2	0	0	138
2010	17	152	7	0	8	184
2011	3	87	14	0	12	117
2012	7	70	20	0	3	99
2013	4	103	11	0	6	124
2014	4	77	11	0	11	103
2015	8	103	11	0	8	131
2016	10	108	6	0	5	129

Table 3: Summary of fishery sampling effort (number of trips, hauls and fish sampled) used to create length frequency distributions of the shoreside fishery.

Year	Lengths from retained catch						Lengths from discarded catch		
	California		Oregon		Washington				
	# Trips	# Fish	# Trips	# Fish	# Trips	# Fish	# Trips	#Hauls	# Fish
1980	31	206	0	0	0	0	0	0	0
1981	29	195	0	0	0	0	0	0	0
1982	55	444	2	300	0	0	0	0	0
1983	115	792	0	0	0	0	0	0	0
1984	161	1925	1	70	0	0	0	0	0
1985	206	2985	0	0	0	0	0	0	0
1986	145	2436	0	0	0	0	5	0	145
1987	119	2644	0	0	0	0	0	0	0
1988	93	1339	0	0	0	0	0	0	0
1989	91	1098	0	0	0	0	0	0	0
1990	89	862	1	100	0	0	0	0	0
1991	72	756	2	200	0	0	0	0	0
1992	45	421	0	0	0	0	0	0	0
1993	42	509	0	0	0	0	0	0	0
1994	39	436	2	200	0	0	0	0	0
1995	40	745	7	188	0	0	0	0	0
1996	72	1003	23	833	0	0	0	0	0
1997	52	909	22	802	0	0	0	0	0
1998	70	1232	13	541	24	317	0	0	0
1999	37	712	9	430	24	332	0	0	0
2000	50	869	7	224	20	652	0	0	0
2001	39	692	30	1005	20	660	0	0	0
2002	39	861	21	611	47	1124	0	0	0
2003	27	436	59	1398	28	580	5	18	408
2004	29	526	58	1305	19	605	106	408	3440
2005	33	567	54	1275	9	117	147	354	2228
2006	62	1129	62	1457	10	397	127	303	1175
2007	74	1520	79	2155	22	529	171	338	1230
2008	81	1795	102	2689	12	350	184	401	1506
2009	52	1214	136	2828	11	350	258	476	1805
2010	44	746	136	2855	5	206	195	415	1675
2011	53	559	148	2570	17	869	258	682	3205
2012	56	697	125	2309	17	729	269	659	2968
2013	46	380	120	2320	8	701	256	499	2216
2014	40	405	143	2469	11	372	310	711	3119
2015	44	364	161	3189	21	522	301	651	2046
2016	49	848	151	2467	32	487			

Table 4: Summary of fishery sampling effort (number of trips, hauls and fish sampled) used to create age frequency distributions of the shoreside fishery.

Year	Ages from retained catch						Ages from discarded catch		
	California		Oregon		Washington				
	# Trips	# Fish	# Trips	# Fish	# Trips	# Fish	# Trips	#Hauls	# Fish
1980	30	196	0	0	0	0	0	0	0
1981	30	198	0	0	0	0	0	0	0
1982	53	403	0	0	0	0	0	0	0
1983	78	523	0	0	0	0	0	0	0
1985	1	1	0	0	0	0	0	0	0
1986	199	2877	0	0	0	0	0	0	0
1987	17	169	0	0	0	0	0	0	0
1988	48	1070	0	0	0	0	0	0	0
1990	29	375	0	0	0	0	0	0	0
1991	74	798	0	0	0	0	0	0	0
1993	35	354	0	0	0	0	0	0	0
1994	35	466	0	0	0	0	0	0	0
1995	35	420	0	0	0	0	0	0	0
1996	17	353	0	0	0	0	0	0	0
1997	58	779	1	33	0	0	0	0	0
1998	47	810	0	0	0	0	0	0	0
1999	53	855	1	24	0	0	0	0	0
2000	23	500	6	183	0	0	0	0	0
2001	30	564	25	841	0	0	0	0	0
2002	30	622	20	608	12	388	0	0	0
2003	31	643	52	1209	11	369	0	0	0
2004	22	314	27	753	11	415	66	113	387
2005	15	249	42	912	6	103	114	222	619
2006	31	494	54	1218	8	292	0	0	0
2007	46	857	66	1771	18	423	0	0	0
2008	30	559	87	2348	9	243	0	0	0
2009	21	310	126	2620	11	281	0	0	0
2010	19	447	115	2296	4	120	0	0	0
2011	13	237	138	2436	15	535	0	0	0
2012	41	368	119	2262	10	456	0	0	0
2013	39	425	37	927	6	400	0	0	0
2014	0	0	134	2356	6	200	0	0	0
2015	0	0	119	1403	16	340	0	0	0
2016	0	0	14	109	0	0	0	0	0

Table 5: Latitudinal and depth ranges by year of four NMFS groundfish trawl surveys used in the assessment.

Survey	Year	Latitudes	Depths (fm)
AFSC shelf	1977	34° 00'- Canadian border	50-250
	1980	36° 48'- 49° 15'	30-200
	1983	36° 48'- 49° 15'	30-200
	1986	36° 48'- Border	30-200
	1989	34° 30'- 49° 40'	30-200
	1992	34° 30'- 49° 40'	30-200
	1995	34° 30'- 49° 40'	30-275
	1998	34° 30'- 49° 40'	30-275
	2001	34° 30'- 49° 40'	30-275
	2004	34° 30'- Canadian border	30-275
AFSC slope	1988	44° 05'- 45° 30'	100-700
	1990	44° 30'- 40° 30'	100-700
	1991	38° 20'- 40° 30'	100-700
	1992	45° 30'- Border	100-700
	1993	43° 00'- 45° 30'	100-700
	1995	40° 30'- 43° 00'	100-700
	1996	43° 00'- Canadian border	100-700
	1997	34° 00'- Canadian border	100-700
	1999	34° 00'- Canadian border	100-700
	2000	34° 00'- Canadian border	100-700
	2001	34° 00'- Canadian border	100-700
NWFSC slope	1999	34° 50'- 48° 10'	100-700
	2000	34° 50'- 48° 10'	100-700
	2001	34° 50'- 48° 10'	100-700
	2002	34° 50'- 48° 10'	100-700
NWFSC shelf-slope	2003	32° 34'- 48° 27'	30-700
	2004	32° 34'- 48° 27'	30-700
	2005	32° 34'- 48° 27'	30-700
	2006	32° 34'- 48° 27'	30-700
	2007	32° 34'- 48° 27'	30-700
	2008	32° 34'- 48° 27'	30-700
	2009	32° 34'- 48° 27'	30-700
	2010	32° 34'- 48° 27'	30-700
	2011	32° 34'- 48° 27'	30-700
	2012	32° 34'- 48° 27'	30-700
	2013	32° 34'- 48° 27'	30-700
	2014	32° 34'- 48° 27'	30-700
	2015	32° 34'- 48° 27'	30-700
	2016	32° 34'- 48° 27'	30-700

Table 6: Time series of relative abundance indices and uncertainty (CVs) for the fishery-independent surveys used in this assessment.

	AFSC Triennial		AFSC Slope		NWFSC Slope		NWFSC Shelf-Slope	
Year	Index	CV	Index	CV	Index	CV	Index	CV
1980	4,330	33%	-	-	-	-	-	-
1983	11,307	19%	-	-	-	-	-	-
1986	5,626	25%	-	-	-	-	-	-
1989	7,001	32%	-	-	-	-	-	-
1992	6,185	29%	-	-	-	-	-	-
1995	3,574	30%	-	-	-	-	-	-
1997	-	-	1,655	56%	-	-	-	-
1998	4,153	35%	-	-	-	-	-	-
1999	-	-	1,918	61%	3,467	55%	-	-
2000	-	-	1,633	56%	5,715	42%	-	-
2001	3,409	33%	2,180	88%	2,917	45%	-	-
2002	-	-	-	-	2,342	45%	-	-
2003	-	-	-	-	-	-	16,175	31%
2004	7,329	32%	-	-	-	-	7,599	31%
2005	-	-	-	-	-	-	9,521	30%
2006	-	-	-	-	-	-	6,894	26%
2007	-	-	-	-	-	-	6,999	26%
2008	-	-	-	-	-	-	6,378	27%
2009	-	-	-	-	-	-	9,208	26%
2010	-	-	-	-	-	-	8,005	27%
2011	-	-	-	-	-	-	9,091	28%
2012	-	-	-	-	-	-	9,308	30%
2013	-	-	-	-	-	-	8,855	30%
2014	-	-	-	-	-	-	5,002	28%
2015	-	-	-	-	-	-	12,795	29%
2016	-	-	-	-	-	-	21,668	31%

Table 7: Summary of sampling effort used to produce AFSC shelf survey biomass index and generate length and age frequency distributions.

Year	Number of hauls	Number of positive hauls	Number of hauls with lengths	Number of lengths	Number of hauls with ages	Numbers of ages
1980	349	126	12	656	2	96
1983	521	232	44	4483	1	117
1986	484	188	39	1839	8	219
1989	505	198	91	3056	0	0
1992	482	159	43	1614	0	0
1995	512	172	163	2897	45	626
1998	528	169	169	3396	62	467
2001	506	186	186	2935	115	1030
2004	383	152	152	3578	148	1134

Table 8: Summary of sampling effort used to produce AFSC slope survey biomass index and generate length and age frequency distributions.

Year	Number of hauls	Number of positive hauls	Number of hauls with lengths	Number of lengths	Number of hauls with ages	Numbers of ages
1997	182	27	25	314	0	0
1999	199	32	32	259	0	0
2000	208	27	27	236	24	128
2001	207	22	22	363	18	191

Table 9: Summary of sampling effort used to produce NWFSC slope survey biomass index and generate length and age frequency distributions.

Year	Number of hauls	Number of positive hauls	Number of hauls with lengths	Number of lengths	Number of hauls with ages	Numbers of ages
1999	149	53	0	0	0	0
2000	153	52	25	296	25	137
2001	165	54	45	494	45	184
2002	205	55	54	1027	54	301

Table 10: Summary of sampling effort used to produce NWFSC shelf-slope survey biomass index and generate length and age frequency distributions.

Year	Number of hauls	Number of positive hauls	Number of hauls with lengths	Number of lengths	Number of hauls with ages	Numbers of ages
2003	542	101	100	2375	100	748
2004	471	92	90	1062	90	594
2005	637	112	110	1983	110	804
2006	641	130	130	1925	130	940
2007	687	132	132	2086	132	987
2008	679	111	111	1647	111	762
2009	681	126	126	2298	126	1159
2010	714	117	117	2239	117	912
2011	695	110	108	1828	108	796
2012	698	102	102	2205	102	791
2013	469	89	89	1548	89	687
2014	682	116	114	1517	114	767
2015	668	132	132	2458	131	1066
2016	542	119	115	2097	117	713

Table 11: List of parameter values used in the base model.

Parameter	Value	Phase	Low bound	High bound	Initial value	Estimated or fixed	Parameter SD
Females							
Natural mortality (M)	0.054	-3	0.01	0.15	0.054	Fixed	_
Individual growth							
Length at A1	15.32	2	1	20	15.324	Estimated	0.109
Length at A2	42.88	2	20	60	42.880	Estimated	0.220
von Bertalanffy K	0.19	2	0.05	0.3	0.195	Estimated	0.004
CV of length at A1	1.81	5	0.5	15	1.814	Estimated	0.057
CV of length at A2	2.16	5	0.5	15	2.160	Estimated	0.115
Weight at length							
Coefficient	0.000011486	-3	0	1	1.1E-05	Fixed	_
Exponent	3.13	-3	2	4	3.12536	Fixed	_
Maturity at length							
Inflection	34.59	-3	0	60	34.59	Fixed	_
Slope	-0.64	-3	-3	3	-0.6429	Fixed	_
Fecundity at length							
Inflection	101100	-3	-3	150000	101100	Fixed	_
Slope	44800	-3	0	50000	44800	Fixed	_
Males							
Natural mortality (M)	0.069	3	0.01	0.15	0.06932	Estimated	0.003
Individual growth							
Length at A1	0	-3	-3	3	0	Fixed	_
Length at A2	38.43	2	20	60	38.430	Estimated	0.172
von Bertalanffy K	0.24	2	0.05	0.3	0.242	Estimated	0.005
CV of length at A1	0	-3	-3	3	0	Fixed	_
CV of length at A2	1.67	5	0.5	15	1.665	Estimated	0.096
Weight at length							
Coefficient	0.000012238	-3	0	1	1.2E-05	Fixed	_
Exponent	3.11	-3	2	4	3.106	Fixed	_
Stock and recruitment							
Ln(R0)	8.01	1	5	12	8.01	Estimated	0.119
Steepness (h)	0.72	-2	0.2	1	0.72	Fixed	_
Recruitment SD (σr)	0.75	-1	0	2	0.75	Fixed	_
Recrutiment deviations							
Early period							
1915	-0.0045	3	-5	5	0	Estimated	0.748
1916	-0.0046	3	-5	5	0	Estimated	0.748
1917	-0.0047	3	-5	5	0	Estimated	0.748
1918	-0.0048	3	-5	5	0	Estimated	0.748
1919	-0.0048	3	-5	5	0	Estimated	0.748
1920	-0.0049	3	-5	5	0	Estimated	0.748
1921	-0.0049	3	-5	5	0	Estimated	0.748
1922	-0.0050	3	-5	5	0	Estimated	0.748

Parameter	Value	Phase	Low bound	High bound	Initial value	Estimated or fixed	Parameter SD
1923	-0.0050	3	-5	5	0	Estimated	0.748
1924	-0.0050	3	-5	5	0	Estimated	0.747
1925	-0.0051	3	-5	5	0	Estimated	0.747
1926	-0.0051	3	-5	5	0	Estimated	0.747
1927	-0.0051	3	-5	5	0	Estimated	0.747
1928	-0.0051	3	-5	5	0	Estimated	0.747
1929	-0.0051	3	-5	5	0	Estimated	0.747
1930	-0.0050	3	-5	5	0	Estimated	0.747
1931	-0.0050	3	-5	5	0	Estimated	0.747
1932	-0.0050	3	-5	5	0	Estimated	0.747
1933	-0.0049	3	-5	5	0	Estimated	0.747
1934	-0.0049	3	-5	5	0	Estimated	0.747
1935	-0.0047	3	-5	5	0	Estimated	0.746
1936	-0.0045	3	-5	5	0	Estimated	0.746
1937	-0.0041	3	-5	5	0	Estimated	0.746
1938	-0.0034	3	-5	5	0	Estimated	0.746
1939	-0.0020	3	-5	5	0	Estimated	0.747
1940	-0.0002	3	-5	5	0	Estimated	0.747
1941	0.0026	3	-5	5	0	Estimated	0.748
1942	0.0059	3	-5	5	0	Estimated	0.749
1943	0.0100	3	-5	5	0	Estimated	0.750
1944	0.0155	3	-5	5	0	Estimated	0.752
1945	0.0228	3	-5	5	0	Estimated	0.754
1946	0.0325	3	-5	5	0	Estimated	0.758
1947	0.0452	3	-5	5	0	Estimated	0.762
1948	0.0612	3	-5	5	0	Estimated	0.767
1949	0.0804	3	-5	5	0	Estimated	0.774
1950	0.1021	3	-5	5	0	Estimated	0.781
1951	0.1238	3	-5	5	0	Estimated	0.788
1952	0.1420	3	-5	5	0	Estimated	0.793
1953	0.1516	3	-5	5	0	Estimated	0.794
1954	0.1478	3	-5	5	0	Estimated	0.791
1955	0.1325	3	-5	5	0	Estimated	0.783
1956	0.1100	3	-5	5	0	Estimated	0.774
1957	0.0863	3	-5	5	0	Estimated	0.764
1958	0.0662	3	-5	5	0	Estimated	0.756
1959	0.0506	3	-5	5	0	Estimated	0.749
Main period							
1960	0.0391	3	-5	5	0	Estimated	0.742
1961	0.0320	3	-5	5	0	Estimated	0.735
1962	0.0313	3	-5	5	0	Estimated	0.730
1963	0.0401	3	-5	5	0	Estimated	0.727

Parameter	Value	Phase	Low bound	High bound	Initial value	Estimated or fixed	Parameter SD
1964	0.0590	3	-5	5	0	Estimated	0.729
1965	0.0790	3	-5	5	0	Estimated	0.729
1966	0.0786	3	-5	5	0	Estimated	0.724
1967	0.0448	3	-5	5	0	Estimated	0.710
1968	-0.0016	3	-5	5	0	Estimated	0.692
1969	-0.0120	3	-5	5	0	Estimated	0.683
1970	0.0561	3	-5	5	0	Estimated	0.688
1971	0.1672	3	-5	5	0	Estimated	0.661
1972	0.0164	3	-5	5	0	Estimated	0.637
1973	-0.1834	3	-5	5	0	Estimated	0.590
1974	-0.2574	3	-5	5	0	Estimated	0.535
1975	-0.4494	3	-5	5	0	Estimated	0.541
1976	-0.1053	3	-5	5	0	Estimated	0.422
1977	-0.4921	3	-5	5	0	Estimated	0.513
1978	0.4197	3	-5	5	0	Estimated	0.321
1979	0.2336	3	-5	5	0	Estimated	0.382
1980	-0.0902	3	-5	5	0	Estimated	0.451
1981	0.7698	3	-5	5	0	Estimated	0.247
1982	-0.3903	3	-5	5	0	Estimated	0.452
1983	-0.8103	3	-5	5	0	Estimated	0.436
1984	-0.2905	3	-5	5	0	Estimated	0.348
1985	0.0026	3	-5	5	0	Estimated	0.332
1986	-0.0672	3	-5	5	0	Estimated	0.356
1987	0.6112	3	-5	5	0	Estimated	0.243
1988	-0.2450	3	-5	5	0	Estimated	0.414
1989	-0.6737	3	-5	5	0	Estimated	0.388
1990	-0.8282	3	-5	5	0	Estimated	0.380
1991	-0.6113	3	-5	5	0	Estimated	0.293
1992	-0.6907	3	-5	5	0	Estimated	0.261
1993	-1.3133	3	-5	5	0	Estimated	0.370
1994	0.3731	3	-5	5	0	Estimated	0.195
1995	0.8468	3	-5	5	0	Estimated	0.163
1996	-0.5194	3	-5	5	0	Estimated	0.287
1997	-0.2328	3	-5	5	0	Estimated	0.222
1998	-0.7077	3	-5	5	0	Estimated	0.284
1999	1.4140	3	-5	5	0	Estimated	0.140
2000	0.9942	3	-5	5	0	Estimated	0.152
2001	-1.0836	3	-5	5	0	Estimated	0.286
2002	-0.1855	3	-5	5	0	Estimated	0.183
2003	-0.0916	3	-5	5	0	Estimated	0.187
2004	0.4188	3	-5	5	0	Estimated	0.170
2005	0.3656	3	-5	5	0	Estimated	0.180

Parameter	Value	Phase	Low bound	High bound	Initial value	Estimated or fixed	Parameter SD
2006	0.2153	3	-5	5	0	Estimated	0.196
2007	-0.0801	3	-5	5	0	Estimated	0.223
2008	1.1937	3	-5	5	0	Estimated	0.175
2009	-0.7575	3	-5	5	0	Estimated	0.268
2010	0.2639	3	-5	5	0	Estimated	0.206
2011	0.2505	3	-5	5	0	Estimated	0.216
2012	-0.2638	3	-5	5	0	Estimated	0.263
2013	1.9523	3	-5	5	0	Estimated	0.204
2014	-0.5040	3	-5	5	0	Estimated	0.357
2015	0.1946	3	-5	5	0	Estimated	0.413
Catchability and variability							
Ln(Q) – AFSC shelf survey	0.521	1	-10	2	0.52051	Estimated	0.176
Extra additive SD for AFSC shelf survey	0.013	3	0	1	0.01331	Estimated	0.068
Ln(Q) – AFSC slope survey	-0.172	1	-10	2	-0.1716	Estimated	0.397
Ln(Q) – NWFSC slope survey	0.026	1	-10	2	0.02627	Estimated	0.351
Ln(Q) – NWFSC shelf-slope survey	0.478	1	-10	2	0.47828	Estimated	0.281
Extra additive SD for NWFSC shelf-slope	0.038	3	0	1	0.03792	Estimated	0.062
Selectivity and discard							
Shoreside fishery							
Peak	33.693	3	20	45	33.6932	Estimated	0.812
Top: width of plateau	-6.000	-4	-6	4	-6	Fixed	_
Ascending slope	2.246	3	1	9	2.24563	Estimated	0.547
Descending slope base	1.807	3	-1	9	1.80732	Estimated	0.946
Selectivity at first bin	-1.407	2	-5	9	-1.4072	Estimated	0.143
Selectivity at last bin	0.010	3	-5	9	0.01004	Estimated	0.210
Shoreside fishery discard							
Retention parameter 1	27.295	2	15	70	27.2946	Estimated	0.761
Retention parameter 2	1.947	2	0.1	10	1.94682	Estimated	0.486
Retention parameter 3	10	-3	-10	10	10	Fixed	_
Retention parameter 4	0	-3	0	0	0	Fixed	_
At-sea hake bycatch fleet							
Peak	32.316	2	20	45	32.3164	Estimated	1.053
Top: width of plateau	-5.817	3	-6	4	-5.8167	Estimated	5.278
Ascending slope	3.550	2	-1	9	3.55029	Estimated	0.305
Descending slope base	2.244	3	-1	9	2.244	Estimated	1.054
Selectivity at first bin	-999	-2	-999	9	-999	Fixed	_
Selectivity at last bin	-0.151	3	-5	9	-0.1513	Estimated	0.317
AFSC triennial shelf survey							
Peak	22.2698	2	10	45	22.2697	Estimated	0.704
Top: width of plateau	-6	-2	-6	4	-6	Fixed	_
Ascending slope	3.46718	3	-1	9	3.46718	Estimated	0.240
Descending slope base	4.86243	4	-1	9	4.86243	Estimated	0.138

Parameter	Value	Phase	Low bound	High bound	Initial value	Estimated or fixed	Parameter SD
Selectivity at first bin	-999	-2	-999	9	-999	Fixed	_
Selectivity at last bin	-999	-3	-999	9	-999	Fixed	_
AFSC slope survey							
Peak	22.241	2	10	45	22.2411	Estimated	1.423
Top: width of plateau	-1.688	2	-6	4	-1.6878	Estimated	0.601
Ascending slope	1.860	3	-1	9	1.8599	Estimated	0.968
Descending slope base	3.277	3	-1	9	3.27663	Estimated	0.805
Selectivity at first bin	-999	-4	-999	9	-999	Fixed	_
Selectivity at last bin	-999	-3	-999	9	-999	Fixed	_
NWFSC slope survey						Estimated	
Peak	24.69	2	10	45	24.69	Estimated	1.079
Top: width of plateau	-6	-5	-6	4	-6	Fixed	_
Ascending slope	3.111	4	-1	9	3.11051	Estimated	0.422
Descending slope base	4.820	4	-1	9	4.81968	Estimated	0.295
Selectivity at first bin	-999	-5	-999	9	-999	Fixed	_
Selectivity at last bin	-999	-4	-999	9	-999	Fixed	_
NWFSC shelf-slope survey							
Peak	24.473	-2	8	45	24.4731	Fixed	_
Top: width of plateau	-6	-3	-6	4	-6	Fixed	_
Ascending slope	4.138	-3	-1	9	4.13751	Fixed	_
Descending slope base	3	-4	-1	9	3	Fixed	_
Selectivity at first bin	-999	-4	-999	9	-999	Fixed	_
Selectivity at last bin	-0.842	-3	-5	9	-0.8419	Fixed	_
Shoresidefishery (2011 forward)							
Peak	31.500	2	20	45	31.5	Estimated	0.232
Top: width of plateau	-3.070	3	-6	4	-3.0698	Estimated	0.932
Ascending slope	-2.243	2	-4	9	-2.2425	Estimated	15.124
Descending slope base	2.246	3	-1	9	2.24597	Estimated	0.744
Selectivity at last bin	-1.502	3	-5	9	-1.5024	Estimated	0.283

Table 12: Time series of total biomass, summary biomass, spawning output, depletion relative to B_0, recruitment, and exploitation rate estimated in the base model.

Year	Total biomass (mt)	Summary biomass (mt)	Spawning output (million eggs)	Depletion (%)	Age-0 Recruits (1000's)	Exploitation rate (catch/ age 1+ biomass)
1915	39,766	39,760	3,528	100.00%	2,991	0.00000
1916	39,767	39,761	3,528	99.54%	2,991	0.00034
1917	39,754	39,748	3,527	99.51%	2,991	0.00053
1918	39,734	39,728	3,525	99.46%	2,991	0.00056
1919	39,712	39,706	3,524	99.41%	2,990	0.00036
1920	39,698	39,692	3,522	99.38%	2,990	0.00037
1921	39,684	39,678	3,521	99.35%	2,990	0.00032
1922	39,673	39,667	3,520	99.32%	2,989	0.00029
1923	39,662	39,656	3,519	99.30%	2,989	0.00035
1924	39,650	39,644	3,518	99.27%	2,989	0.00036
1925	39,637	39,631	3,517	99.24%	2,989	0.00041
1926	39,623	39,617	3,516	99.20%	2,989	0.00056
1927	39,604	39,598	3,514	99.15%	2,989	0.00048
1928	39,588	39,582	3,513	99.11%	2,989	0.00048
1929	39,573	39,567	3,511	99.07%	2,988	0.00050
1930	39,557	39,551	3,510	99.03%	2,988	0.00055
1931	39,540	39,534	3,508	98.98%	2,988	0.00068
1932	39,519	39,513	3,506	98.93%	2,988	0.00043
1933	39,508	39,502	3,505	98.90%	2,988	0.00042
1934	39,498	39,492	3,504	98.87%	2,989	0.00040
1935	39,490	39,484	3,503	98.84%	2,989	0.00046
1936	39,480	39,474	3,502	98.81%	2,990	0.00031
1937	39,476	39,470	3,502	98.80%	2,991	0.00035
1938	39,471	39,465	3,501	98.78%	2,992	0.00043
1939	39,464	39,458	3,500	98.76%	2,997	0.00062
1940	39,449	39,443	3,499	98.72%	3,002	0.00085
1941	39,427	39,421	3,497	98.66%	3,010	0.00109
1942	39,397	39,391	3,494	98.58%	3,020	0.00125
1943	39,363	39,357	3,491	98.48%	3,032	0.00477
1944	39,193	39,186	3,476	98.06%	3,047	0.01038
1945	38,809	38,803	3,442	97.13%	3,067	0.01786
1946	38,149	38,143	3,385	95.51%	3,092	0.01074
1947	37,792	37,786	3,352	94.57%	3,128	0.00898
1948	37,523	37,517	3,325	93.81%	3,176	0.00517
1949	37,420	37,414	3,311	93.41%	3,236	0.00431
1950	37,371	37,364	3,301	93.13%	3,306	0.00483

Year	Total biomass (mt)	Summary biomass (mt)	Spawning output (million eggs)	Depletion (%)	Age-0 Recruits (1000's)	Exploitation rate (catch/ age 1+ biomass)
1951	37,326	37,319	3,291	92.84%	3,377	0.00563
1952	37,277	37,270	3,279	92.52%	3,438	0.00592
1953	37,247	37,240	3,269	92.22%	3,470	0.00508
1954	37,280	37,273	3,262	92.04%	3,456	0.00597
1955	37,310	37,303	3,255	91.84%	3,403	0.00705
1956	37,326	37,320	3,247	91.61%	3,326	0.00934
1957	37,278	37,271	3,234	91.26%	3,247	0.01094
1958	37,183	37,176	3,220	90.84%	3,181	0.00927
1959	37,155	37,148	3,212	90.63%	3,131	0.00781
1960	37,176	37,170	3,212	90.62%	3,095	0.00948
1961	37,122	37,115	3,208	90.51%	3,073	0.00886
1962	37,075	37,069	3,207	90.48%	3,071	0.00961
1963	36,982	36,976	3,203	90.38%	3,088	0.01017
1964	36,852	36,846	3,197	90.21%	3,113	0.00737
1965	36,814	36,807	3,198	90.24%	3,143	0.01343
1966	36,541	36,535	3,179	89.70%	3,108	0.11571
1967	32,515	32,509	2,849	80.37%	2,937	0.09490
1968	29,680	29,674	2,605	73.51%	2,744	0.08152
1969	27,554	27,549	2,416	68.16%	2,661	0.01023
1970	27,610	27,605	2,406	67.89%	2,818	0.01271
1971	27,613	27,606	2,396	67.59%	3,114	0.01921
1972	27,450	27,444	2,374	66.97%	2,647	0.02240
1973	27,219	27,215	2,347	66.22%	2,142	0.03349
1974	26,698	26,694	2,298	64.83%	1,962	0.02228
1975	26,479	26,476	2,275	64.18%	1,601	0.02166
1976	26,241	26,236	2,255	63.61%	2,232	0.02439
1977	25,878	25,875	2,231	62.94%	1,498	0.01139
1978	25,808	25,801	2,236	63.09%	3,691	0.01527
1979	25,602	25,596	2,232	62.97%	3,031	0.02751
1980	25,094	25,090	2,198	62.02%	2,165	0.02518
1981	24,709	24,699	2,164	61.06%	5,052	0.03489
1982	24,158	24,155	2,105	59.40%	1,561	0.04863
1983	23,380	23,378	2,018	56.93%	1,008	0.04991
1984	22,662	22,659	1,933	54.54%	1,666	0.06067
1985	21,716	21,711	1,838	51.86%	2,192	0.08514
1986	20,243	20,239	1,712	48.29%	1,997	0.06509
1987	19,267	19,259	1,635	46.12%	3,879	0.13085
1988	17,076	17,073	1,464	41.29%	1,612	0.10447
1989	15,652	15,650	1,344	37.93%	1,031	0.08685

Year	Total biomass (mt)	Summary biomass (mt)	Spawning output (million eggs)	Depletion (%)	Age-0 Recruits (1000's)	Exploitation rate (catch/ age 1+ biomass)
1990	14,686	14,684	1,252	35.31%	869	0.12019
1991	13,303	13,301	1,122	31.66%	1,051	0.10044
1992	12,317	12,315	1,030	29.05%	949	0.06389
1993	11,833	11,832	988	27.89%	504	0.10836
1994	10,799	10,794	913	25.75%	2,659	0.08545
1995	10,089	10,081	864	24.37%	4,199	0.08673
1996	9,460	9,458	813	22.94%	1,051	0.08727
1997	8,982	8,979	760	21.45%	1,370	0.10080
1998	8,512	8,510	697	19.68%	827	0.12385
1999	7,938	7,924	622	17.54%	6,615	0.05385
2000	8,057	8,049	602	16.99%	4,294	0.03429
2001	8,483	8,482	606	17.11%	539	0.02209
2002	9,178	9,175	628	17.72%	1,341	0.02764
2003	9,890	9,887	650	18.35%	1,493	0.02031
2004	10,641	10,636	681	19.20%	2,529	0.02186
2005	11,309	11,304	721	20.34%	2,447	0.01177
2006	12,030	12,026	785	22.15%	2,167	0.01666
2007	12,651	12,648	855	24.11%	1,657	0.02025
2008	13,189	13,177	917	25.86%	6,048	0.01850
2009	13,737	13,735	970	27.37%	874	0.02117
2010	14,289	14,284	1,014	28.60%	2,456	0.02366
2011	14,831	14,826	1,051	29.65%	2,447	0.00818
2012	15,580	15,576	1,105	31.17%	1,482	0.00658
2013	16,340	16,313	1,161	32.77%	13,767	0.00784
2014	17,140	17,138	1,222	34.48%	1,227	0.00622
2015	18,195	18,190	1,289	36.38%	2,565	0.00752
2016	19,431	19,426	1,355	38.23%	2,598	0.00703
2017	20,718	20,713	1,419	40.03%	2,624	NA

Table 13: Comparison across retrospective analysis runs. Likelihoods in italics are not comparable across rows. Note that for space issues, the 2017 base model with the 2015 steepness of 0.773 is listed here. (See Table 14.)

Model	Base	Base - 1 year	Base - 2 years	Base - 3 years	Base - 4 years	Base - 5 years	2015 steepness
Negative log-likelihood							
Total	1911.24	*1830.88*	*1747.82*	*1635.74*	*1569.78*	*1465.43*	1911.23
Indices	-18.10	*-18.29*	*-16.78*	*-18.89*	*-17.68*	*-16.73*	-18.07
Length frequencies	579.38	*558.7*	*526.84*	*492.95*	*466.61*	*434.09*	579.29
Age frequencies	1,381.4	*1,322.9*	*1,265.7*	*1,197.7*	*1,147.5*	*1,075.9*	1,381.4
Selected parameters							
Ln(R_0)	8.008	7.984	7.968	7.987	7.982	7.983	8.003
Steepness (*h*)	0.72	0.72	0.72	0.72	0.72	0.72	0.773
Female *M*	0.054	0.054	0.054	0.054	0.054	0.054	0.054
Male *M*	0.069	0.069	0.068	0.068	0.069	0.068	0.069
Female L at A_1	15.324	15.336	15.247	15.102	15.064	15.128	15.324
Female L at A_2	42.880	42.901	42.724	42.603	42.596	42.578	42.883
Male L at A_1	15.324	15.336	15.247	15.102	15.064	15.128	15.324
Male L at A_2	38.430	38.447	38.328	38.237	38.197	38.178	38.429
Female von Bert *K*	0.195	0.195	0.197	0.202	0.203	0.204	0.195
Male von Bert *K*	0.242	0.242	0.245	0.250	0.252	0.253	0.242
Management quantities							
Equilibrium spawning output (10^6 eggs)	3,544	3,469	3,356	3,396	3,383	3,394	3,526
2017 Spawning depletion	0.4003	0.3576	0.3375	0.3891	0.4030	0.3825	0.4260

Table 14: Model comparisons for the transition from the 2015 base to the new 2017 base. Likelihoods of only a few pairs of columns are comparable. Note that for space issues, the 2017 base model with the 2015 steepness of 0.773 is listed in Table 13. (Cf. Figure 99.)

Model	2015 Base	2015 Base SSv3.30	+ All Catch	+Steepness = 0.72	+WCGOP Rates & Comps	+WCGBTS VAST Index	+WCGBTS VAST Length Comps	+ Rest of Comps & Tuning = New Base
Negative log-likelihood								
Total	1854.24	1856.47	1855.07	1855.54	1891.6	1889.91	1908.51	1911.24
Indices	-18.67	-18.77	-17.95	-18.07	-16.74	-18.12	-18.18	-18.10
Length frequencies	540.81	541.95	540.79	541.57	575.28	574.28	592.25	579.38
Age frequencies	1,357.5	1,358	1,357.4	1,357.3	1,365.6	1,366.2	1,366.7	1,381.4
Selected parameters								
Ln(R_0)	7.928	7.933	7.948	7.948	7.958	7.966	7.991	8.008
Steepness (*h*)	0.773	0.773	0.773	0.72	0.72	0.72	0.72	0.72
Female *M*	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
Male *M*	0.069	0.069	0.070	0.070	0.069	0.069	0.070	0.069
Female L at A_1	15.187	15.193	15.194	15.192	15.277	15.272	15.317	15.324
Female L at A_2	42.662	42.659	42.670	42.657	42.708	42.715	42.872	42.880
Male L at A_1	15.187	15.193	15.194	15.192	15.277	15.272	15.317	15.324
Male L at A_2	38.347	38.330	38.358	38.348	38.383	38.390	38.457	38.430
Female von Bert *K*	0.198	0.198	0.198	0.198	0.196	0.196	0.194	0.195
Male von Bert *K*	0.245	0.245	0.245	0.245	0.243	0.243	0.241	0.242
Management quantities								
Equilibrium spawning output (10^6 eggs)	3,203	3,220	3,271	3,267	3,310	3,339	3,475	3,544
2017 Spawning depletion	0.4137	0.4218	0.4530	0.4179	0.3404	0.3378	0.3940	0.4003

Table 15: Summary of reference points for the base model.

Quantity	**Estimate**	**~95% Confidence Interval**
Unfished Spawning output (million eggs)	3,544	2,7118–4,377
Unfished Age 1+ Biomass (mt)	39,932	30,971–48,893
Spawning output (million eggs, 2017)	1,419	611–2,226
Unfished Recruitment (R0)	3,006	2,304–3,709
Depletion (2017)	40.03	21.68–58.38
Reference Points Based SB40%		
Proxy spawning output ($B_{40\%}$, million eggs)	1,418	1,084–1,751
SPR resulting in $B40_{\%}$ ($SPR_{B40\%}$)	0.458	0.458–0.458
Exploitation rate resulting in $B_{40\%}$	0.037	0.036–0.038
Yield with *SPR* at $B_{40\%}$ (mt)	639	495–783
Reference Points based on SPR proxy for MSY		
Proxy spawning biomass (SPR_{50}, million eggs)	2,166	1,657–2,675
SPR_{50}	0.649	NA
Exploitation rate corresponding to SPR_{50}	0.019	0.018–0.020
Yield with SPR_{50} at SB_{SPR} (mt)	477	370–584
Reference points based on estimated MSY values		
Spawning biomass at MSY (SB_{MSY})	1,018	778–1,259
SPR_{MSY}	0.357	0.351–0.362
Exploitation rate corresponding to SPR_{MSY}	0.052	0.050–0.054
MSY (mt)	670	518–821

Table 16: Summary of recent trends in estimated darkblotched rockfish exploitation and stock level from the base model.

	2007	2008	2009	2010	20011	2012	2013	2014	2015	2016	2017
Landings (mt)	144	117	138	184	117	99	124	103	131	129	NA
Estimated Total catch (mt)	256	243	291	338	121	102	128	107	137	137	NA
OFL (mt)	456	456	437	437	508	508	541	541	574	580	671
ACL (mt)	260	260	282	282	298	298	317	317	338	346	641
1-SPR	0.67	0.64	0.73	0.80	0.31	0.26	0.30	0.24	0.28	0.27	NA
Exploitation_Rate (catch/ age 1+ biomass)	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	NA
Age 1+ Biomass (mt)	12,648	13,177	13,735	14,284	14,826	15,576	16,313	17,138	18,190	19,426	20,713
Spawning output (million eggs)	855	917	970	1,014	1,051	1,105	1,161	1,222	1,289	1,355	1,419
~95% Confidence Interval	395–1,315	419–1,415	437–1,503	449–1,578	455–1,647	4789–1,732	502–1,820	528–1,916	557–2,021	585–2,125	611–2,226
Recruitment	1,657	6,048	874	2,456	2,447	1,482	13,767	1,227	2,565	2,598	2,624
~95% Confidence Interval	917–2,993	3,548–10,311	456–1,673	1,389–4,342	1,366–4,383	780–2,817	7,827–24,215	567–2,655	1,095–6,009	1,970–3,427	1,994–3,454
Depletion (%)	24.1	25.9	27.4	28.6	29.7	31.2	32.8	34.5	36.4	38.2	40.0
~95% Confidence Interval	13.7–34.5	14.6–37.1	15.3–39.4	15.8–41.4	16.1–43.2	16.9–45.4	17.8–47.7	18.7–50.2	19.8–53.0	20.7–55.7	21.7–58.4

Table 17: 12-year projections for alternate states of nature defined based on female natural mortality. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels.*

			State of nature					
			Low *Female M=0.0412*		Base case Female M=0.054		High *Female M=0.059*	
Management decision	Year	Catch (mt)	Spawning output (million eggs)	Depletion	Spawning output (million eggs)	Depletion	Spawning output (million eggs)	Depletion
Average catch for the period between 2013 and 2016 with SPR = 0.50	2017	122	863	25%	1,419	40%	1,691	46%
	2018	122	914	26%	1,489	42%	1,767	48%
	2019	122	979	28%	1,579	45%	1,867	51%
	2020	122	1,060	30%	1,693	48%	1,994	54%
	2021	122	1,146	33%	1,813	51%	2,127	58%
	2022	122	1,228	35%	1,924	54%	2,249	61%
	2023	122	1,302	37%	2,020	57%	2,353	64%
	2024	122	1,367	39%	2,102	59%	2,440	67%
	2025	122	1,426	41%	2,173	61%	2,513	69%
	2026	122	1,479	43%	2,233	63%	2,575	70%
	2027	122	1,528	44%	2,287	65%	2,628	72%
	2028	122	1,574	45%	2,334	66%	2,673	73%
2018 ACL catch assumed for years between 2018 and 2028 with SPR = 0.50	2017	641	863	25%	1,419	40%	1,691	46%
	2018	653	883	25%	1,458	41%	1,737	47%
	2019	653	914	26%	1,516	43%	1,804	49%
	2020	653	958	28%	1,593	45%	1,895	52%
	2021	653	1,001	29%	1,671	47%	1,987	54%
	2022	653	1,033	30%	1,736	49%	2,063	56%
	2023	653	1,055	30%	1,783	50%	2,120	58%
	2024	653	1,068	31%	1,817	51%	2,160	59%
	2025	653	1,074	31%	1,840	52%	2,187	60%
	2026	653	1,075	31%	1,855	52%	2,204	60%
	2027	653	1,072	31%	1,863	53%	2,214	60%
	2028	653	1,066	31%	1,866	53%	2,218	61%
Projections based on current rebuilding SPR of 64.9% applied to the base model For 2017 and 2018, adopted ACLs are used.	2017	641	863	25%	1,419	40%	1,691	46%
	2018	653	883	25%	1,458	41%	1,737	47%
	2019	490	914	26%	1,516	43%	1,804	49%
	2020	531	967	28%	1,602	45%	1,904	52%
	2021	525	1,018	29%	1,689	48%	2,005	55%
	2022	503	1,062	31%	1,763	50%	2,091	57%
	2023	484	1,096	32%	1,823	51%	2,159	59%
	2024	470	1,124	32%	1,871	53%	2,213	60%
	2025	462	1,146	33%	1,909	54%	2,255	62%
	2026	457	1,164	33%	1,939	55%	2,287	62%
	2027	454	1,179	34%	1,963	55%	2,313	63%
	2028	453	1,192	34%	1,983	56%	2,332	64%

			State of nature					
			Low *Female M=0.0412*		Base case Female M=0.054		High *Female M=0.059*	
Management decision	Year	Catch (mt)	Spawning output (million eggs)	Depletion	Spawning output (million eggs)	Depletion	Spawning output (million eggs)	Depletion
Average 2013-2016 catch assumed for 2017-2020 and 2018 ACL catch for 2021-2028 with SPR = 0.50	2017	122	863	25%	1,419	40%	1,691	46%
	2018	122	914	26%	1,489	42%	1,767	48%
	2019	122	979	28%	1,579	45%	1,867	51%
	2020	122	1,060	30%	1,693	48%	1,994	54%
	2021	653	1,146	33%	1,813	51%	2,127	58%
	2022	653	1,196	34%	1,892	53%	2,217	61%
	2023	653	1,232	35%	1,952	55%	2,285	62%
	2024	653	1,257	36%	1,994	56%	2,333	64%
	2025	653	1,273	37%	2,024	57%	2,366	65%
	2026	653	1,281	37%	2,042	58%	2,386	65%
	2027	653	1,283	37%	2,052	58%	2,397	65%
	2028	653	1,281	37%	2,056	58%	2,400	66%

* The percent change in the ratio of estimated male to fixed female natural mortality changes from the base case very little. From 5.4% for the low state of nature to 1.2% for the high state of nature. There is only a change across states of nature (columns) but no change over management decisions (rows). As stated in the text, the estimated male natural mortality for the base case is essentially unchanged from the 2015 base (0.0693 vs. 0.0695).

11 Figures

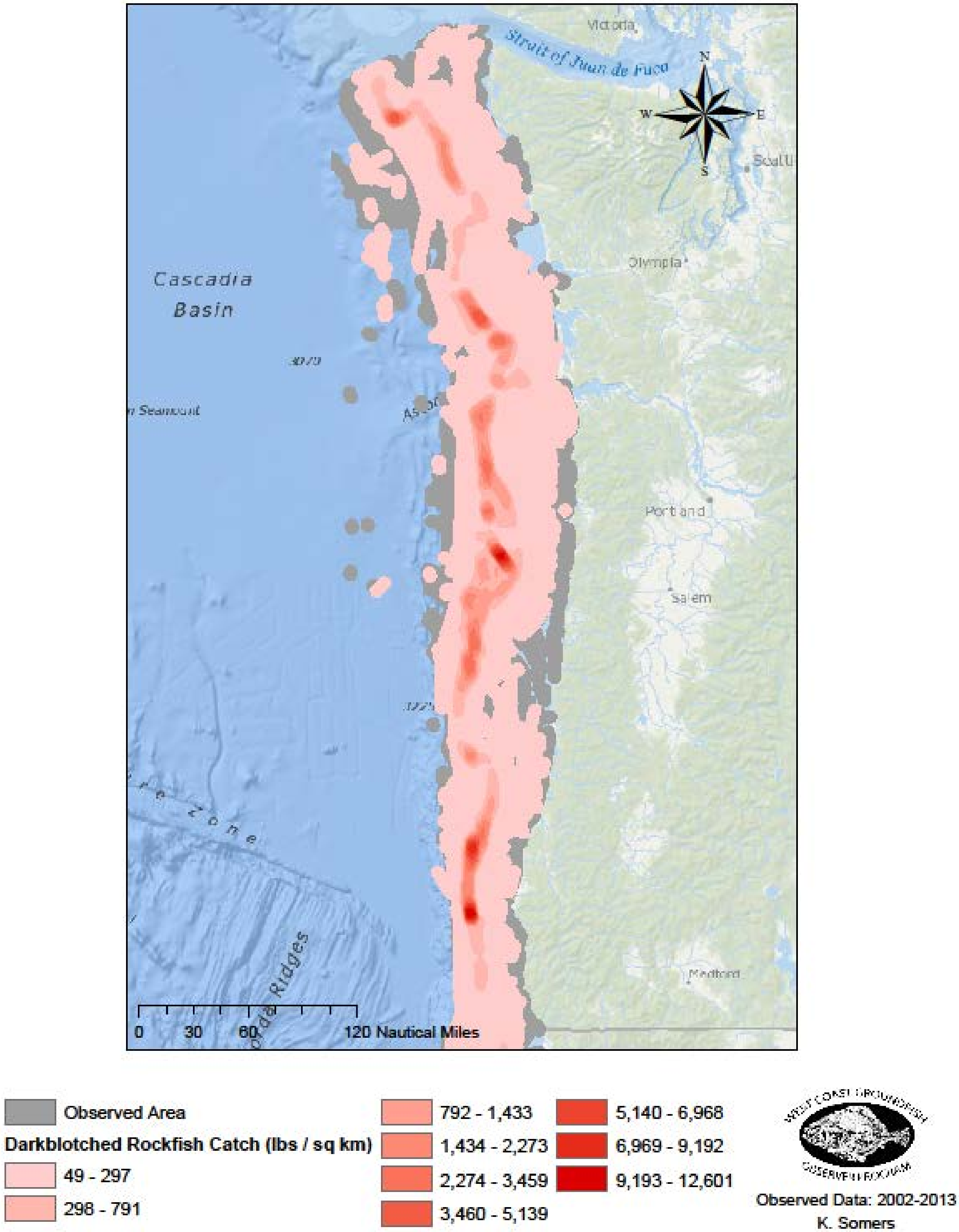

Figure 1: Spatial distribution of darkblotched rockfish catch observed by the West Coast Groundfish Observer Program and the summary area of all observed fishing events.

Figure 1 (continued): Spatial distribution of darkblotched rockfish catch observed by the West Coast Groundfish Observer Program and the summary area of all observed fishing events.

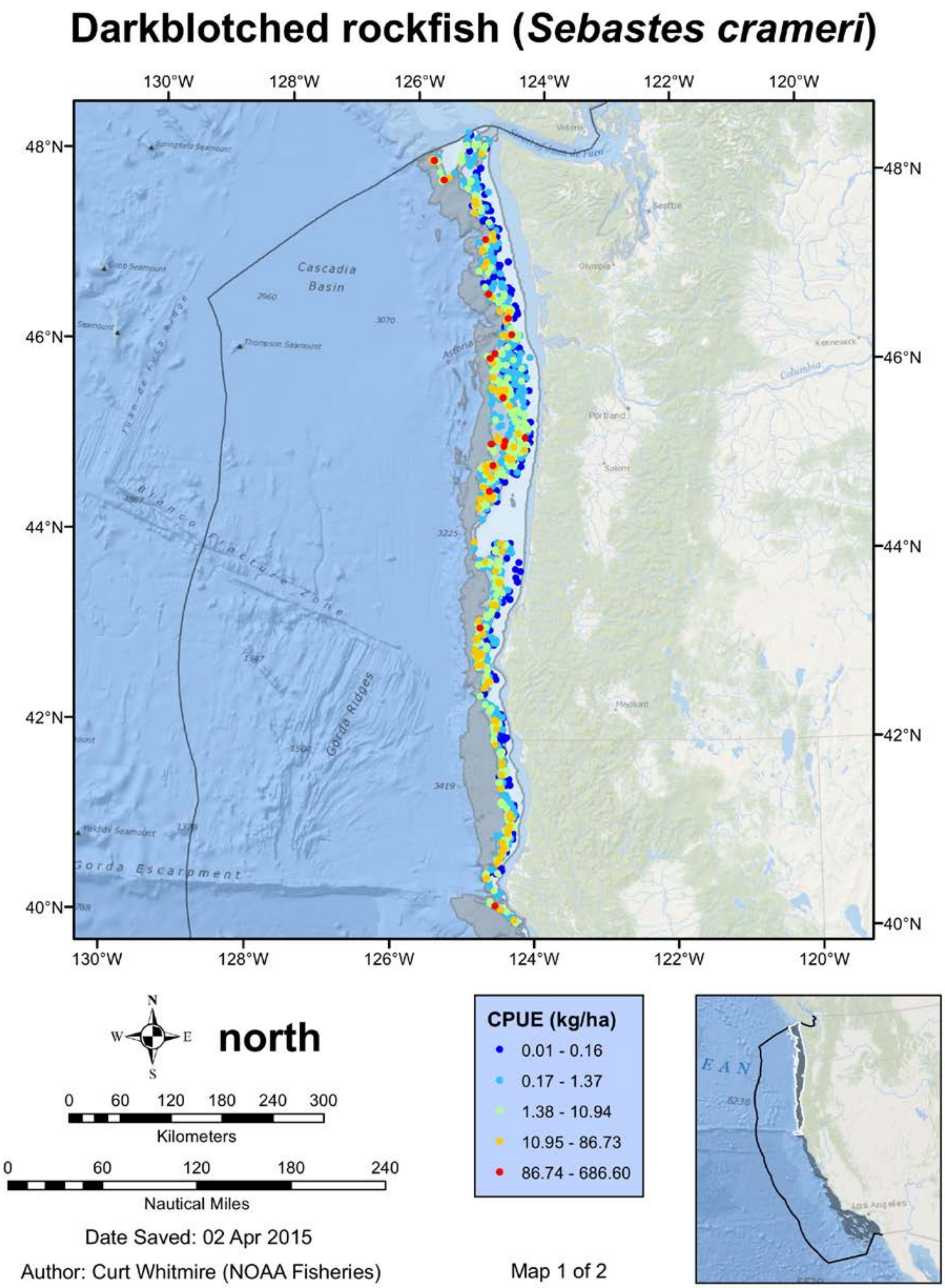

Figure 2: Spatial distribution of darkblotched rockfish (*Sebastes crameri*) catch in the NWFSC groundfish survey (2003-2012) by INPFC area.

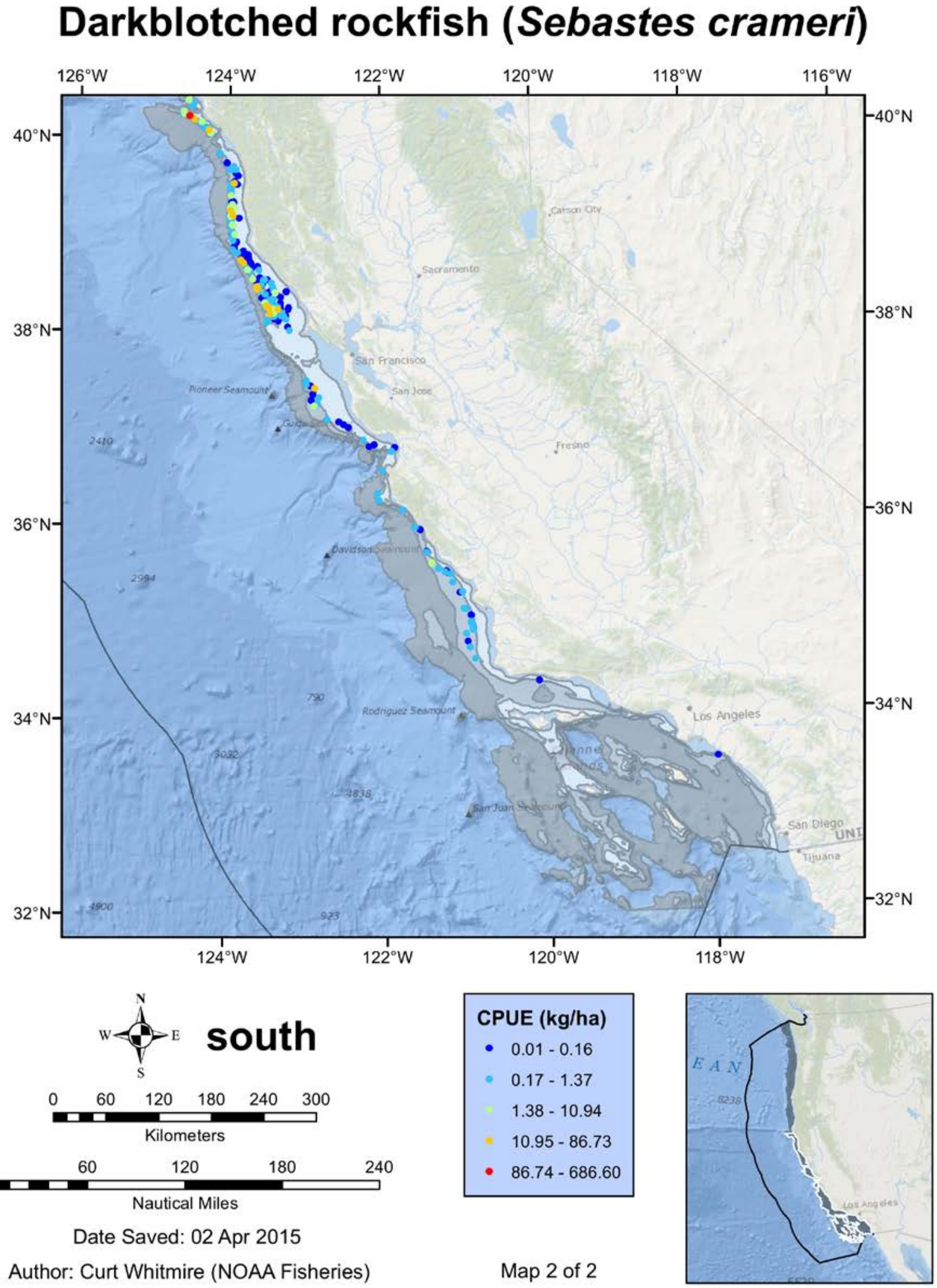

Figure 2 (continued): Spatial distribution of darkblotched rockfish (*Sebastes crameri*) catch in the NWFSC groundfish survey (2003-2012) by INPFC area.

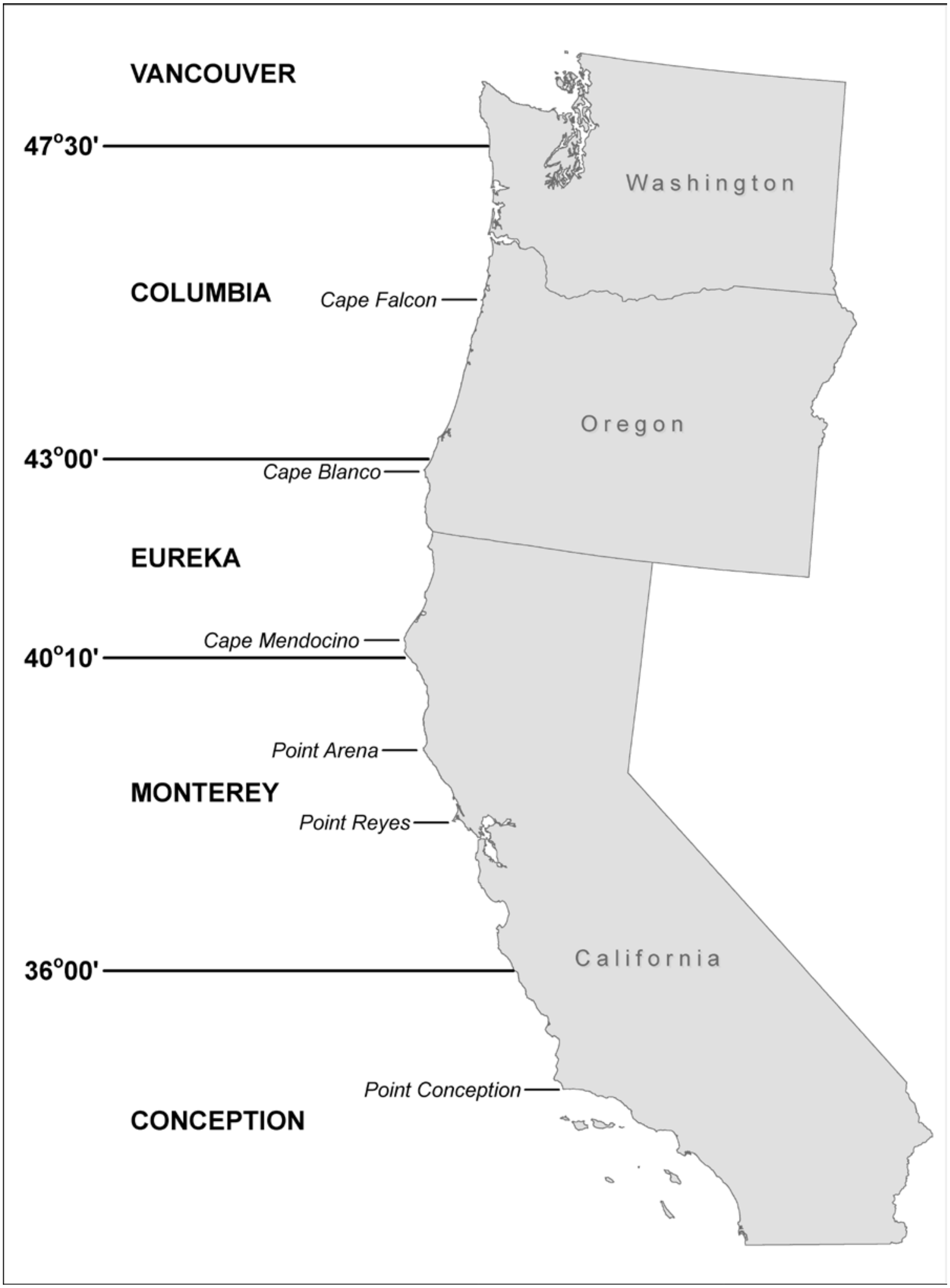

Figure 3: A map of the assessment area that includes coastal waters off three U.S. west coast states and five International North Pacific Fisheries Commission (INPFC) areas.

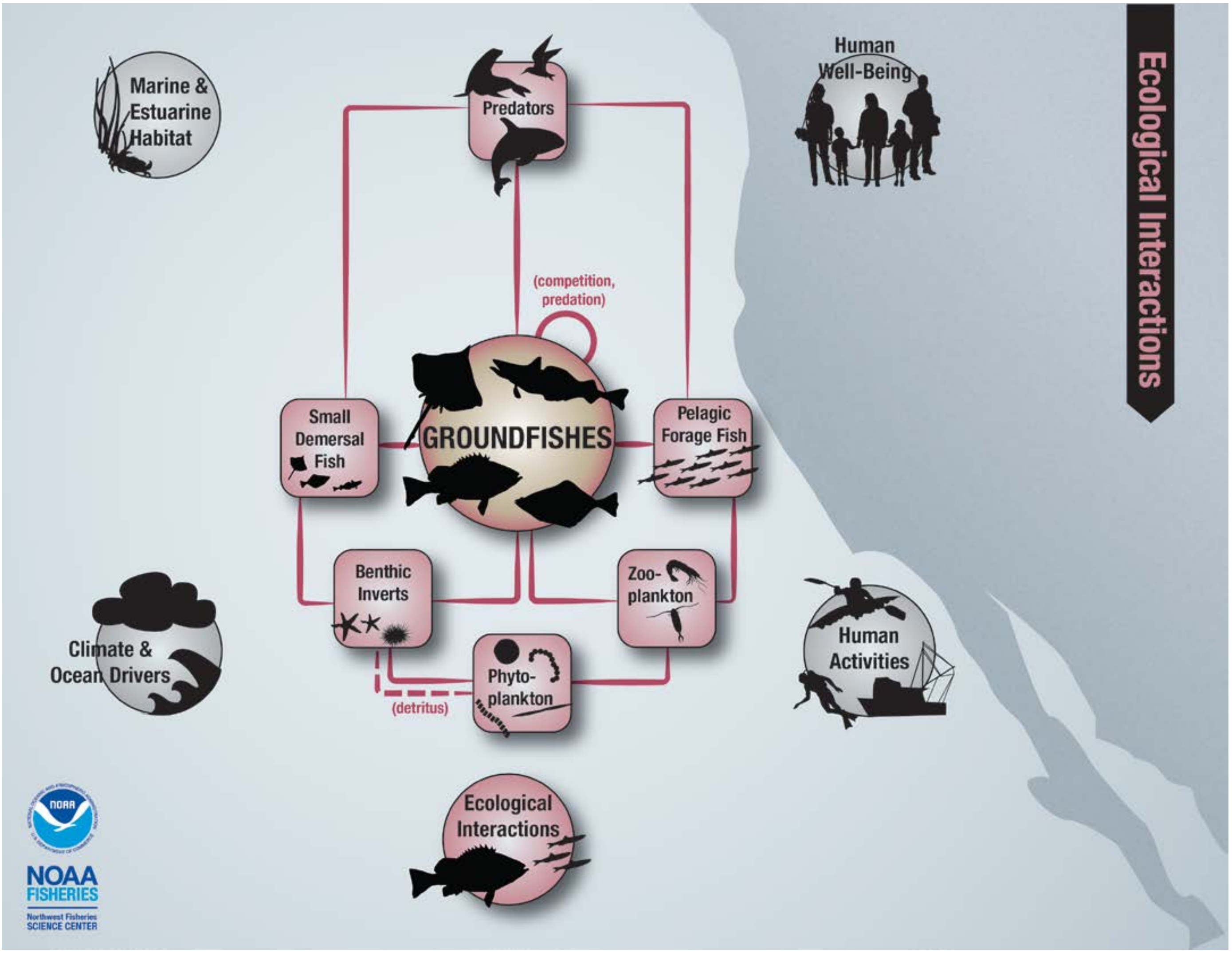

Figure 4: Conceptual diagram of ecological interactions of groundfish species in California Current large marine ecosystem.

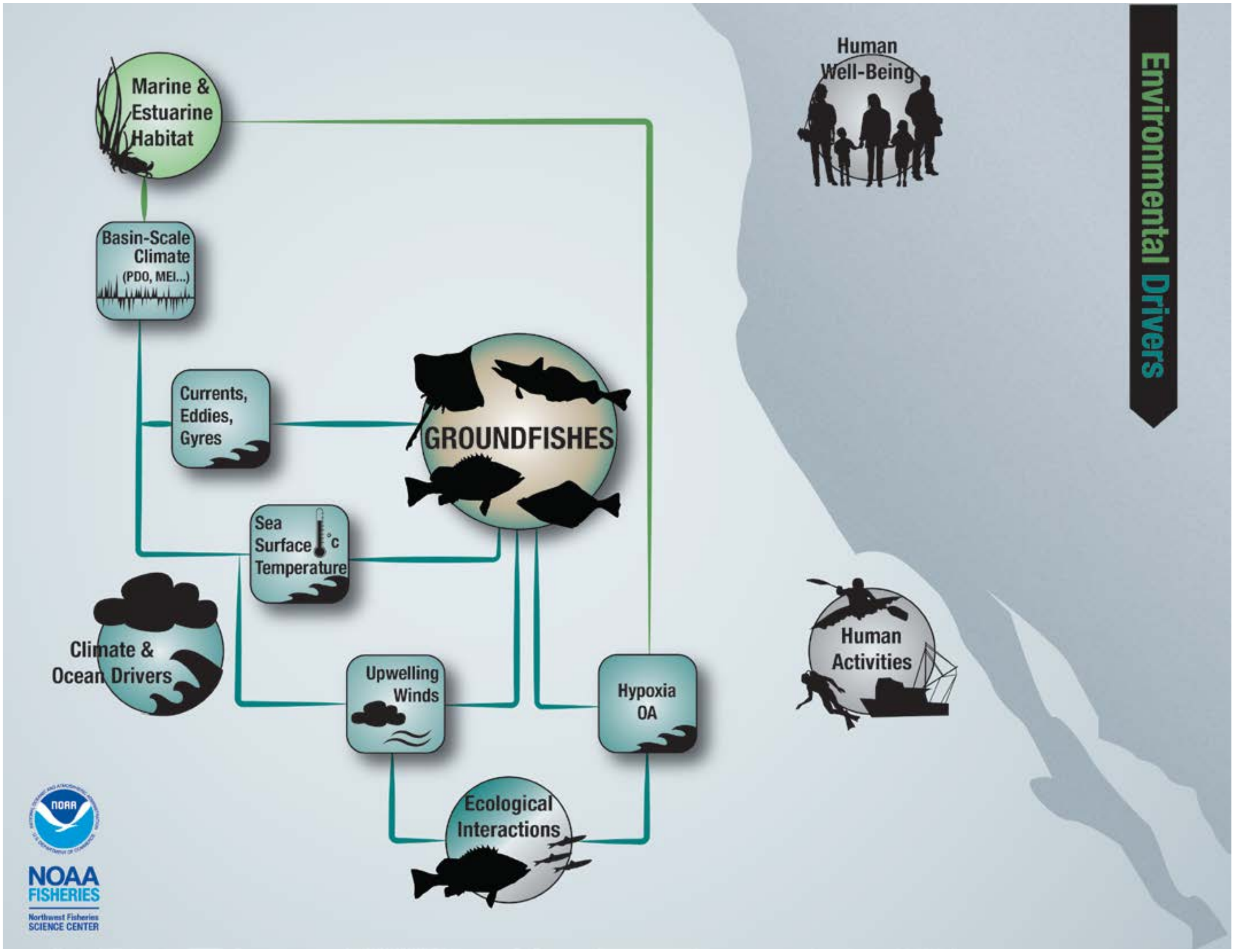

Figure 5: Conceptual diagram of environmental drivers that impact groundfish species in California Current large marine ecosystem.

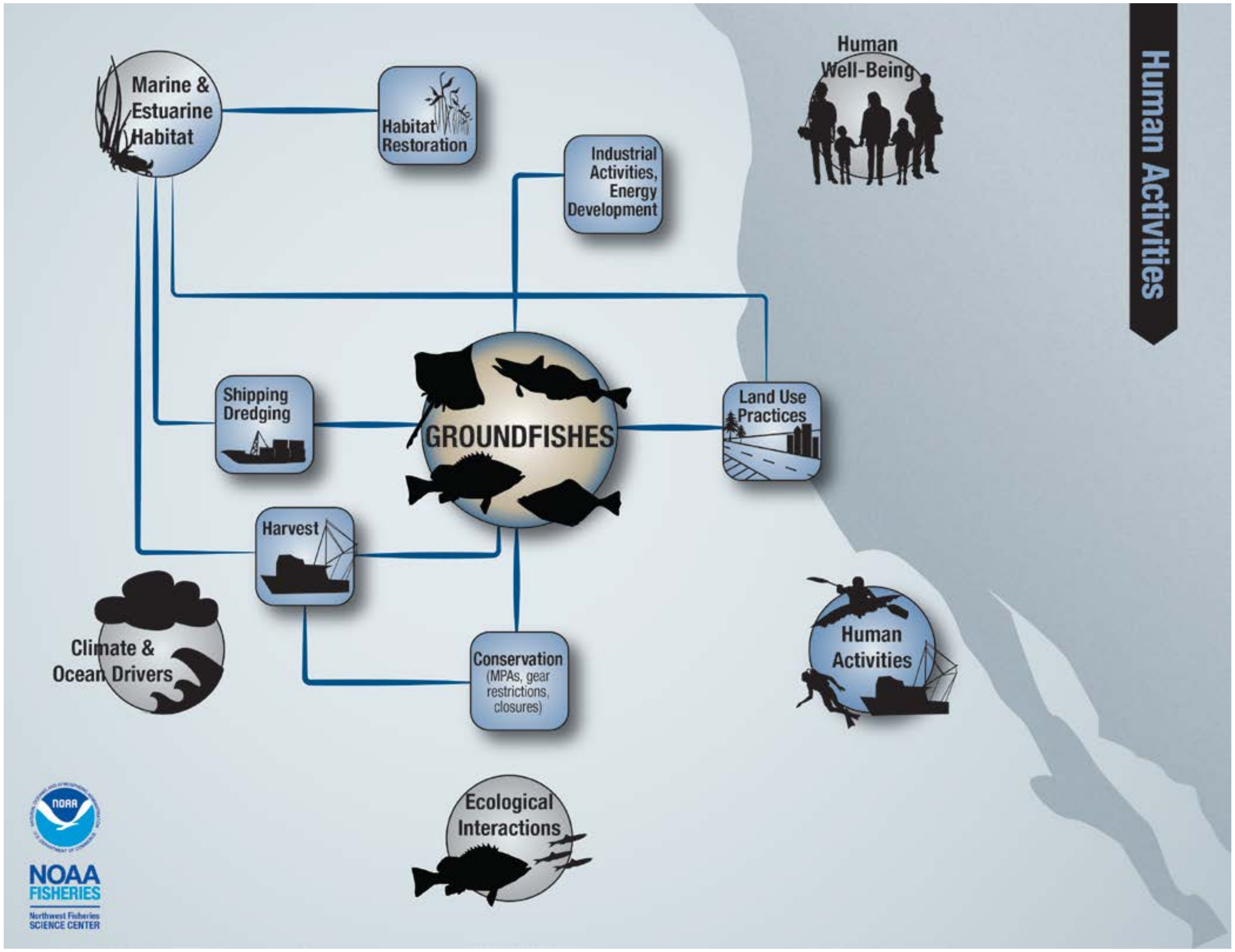

Figure 6: Conceptual diagram of human activities that affect groundfish species in California Current large marine ecosystem.

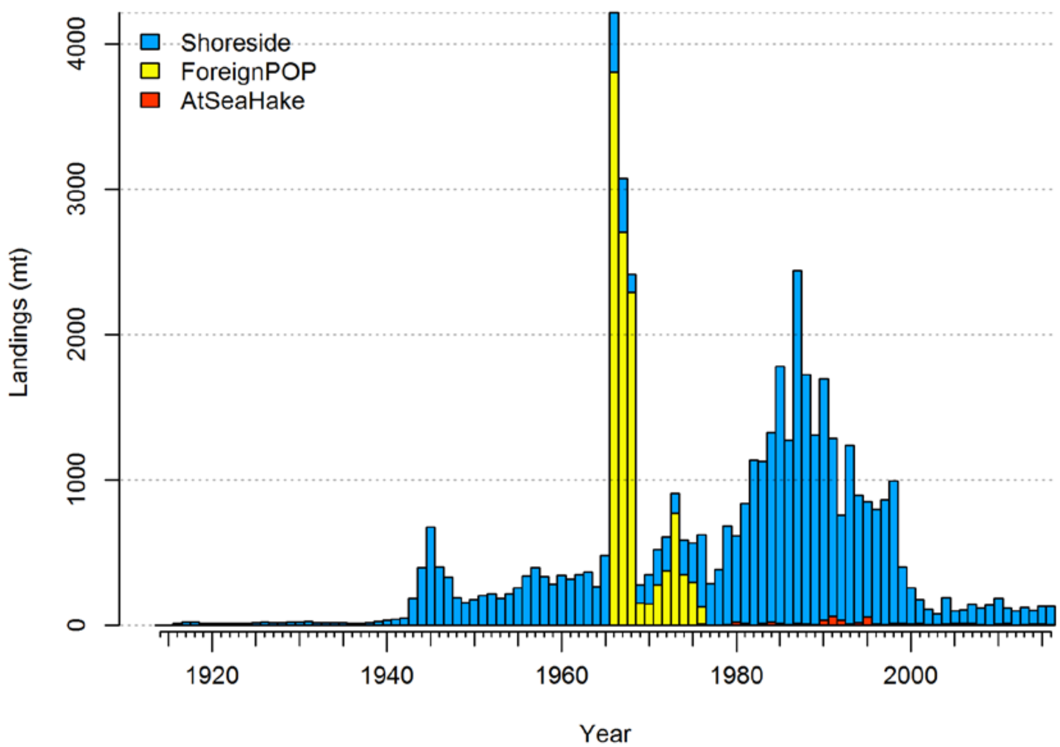

Figure 7: Darkblotched rockfish landings history, 1915-2014, by fleet.

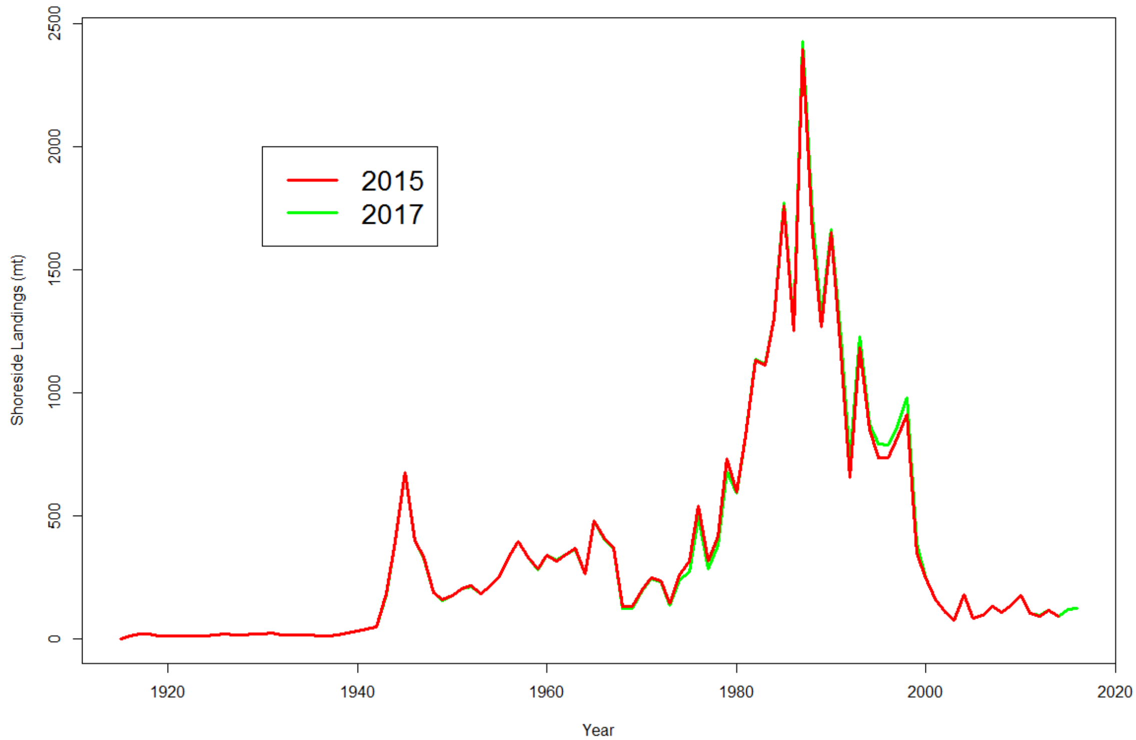

Figure 8: Comparison of darkblotched rockfish landings within the shoreside fleet used in the 2015 assessment and in this 2017 assessment.

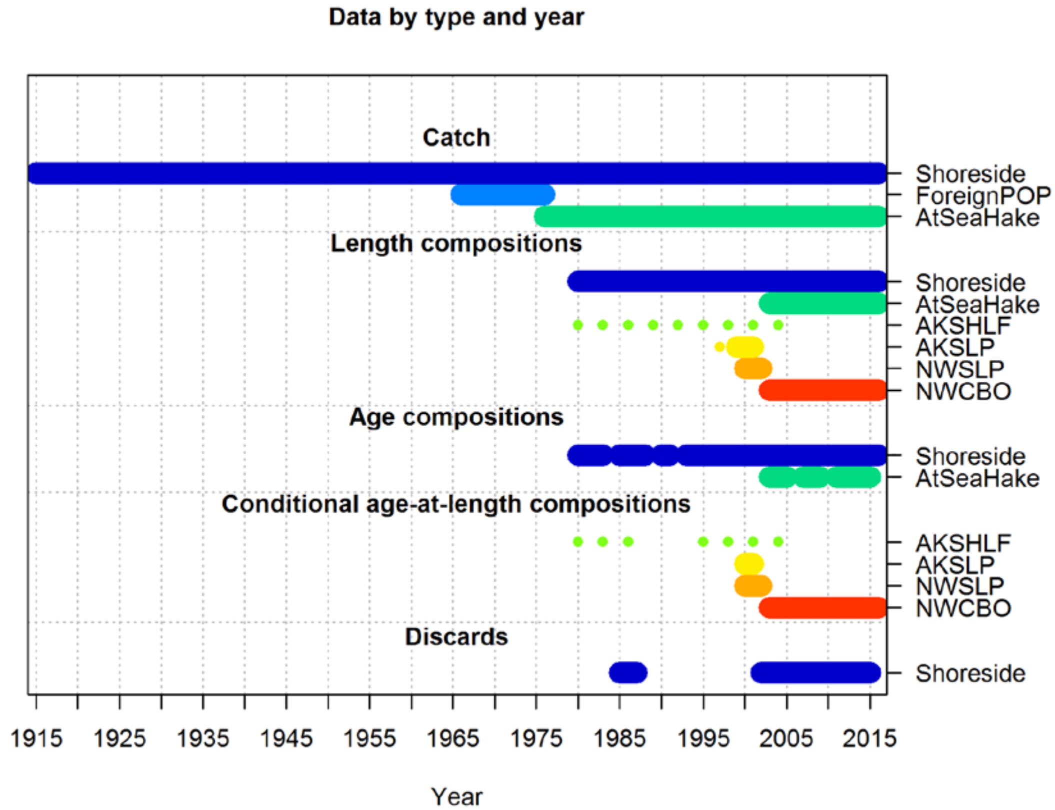

Figure 9: Summary of sources and data used in the assessment.

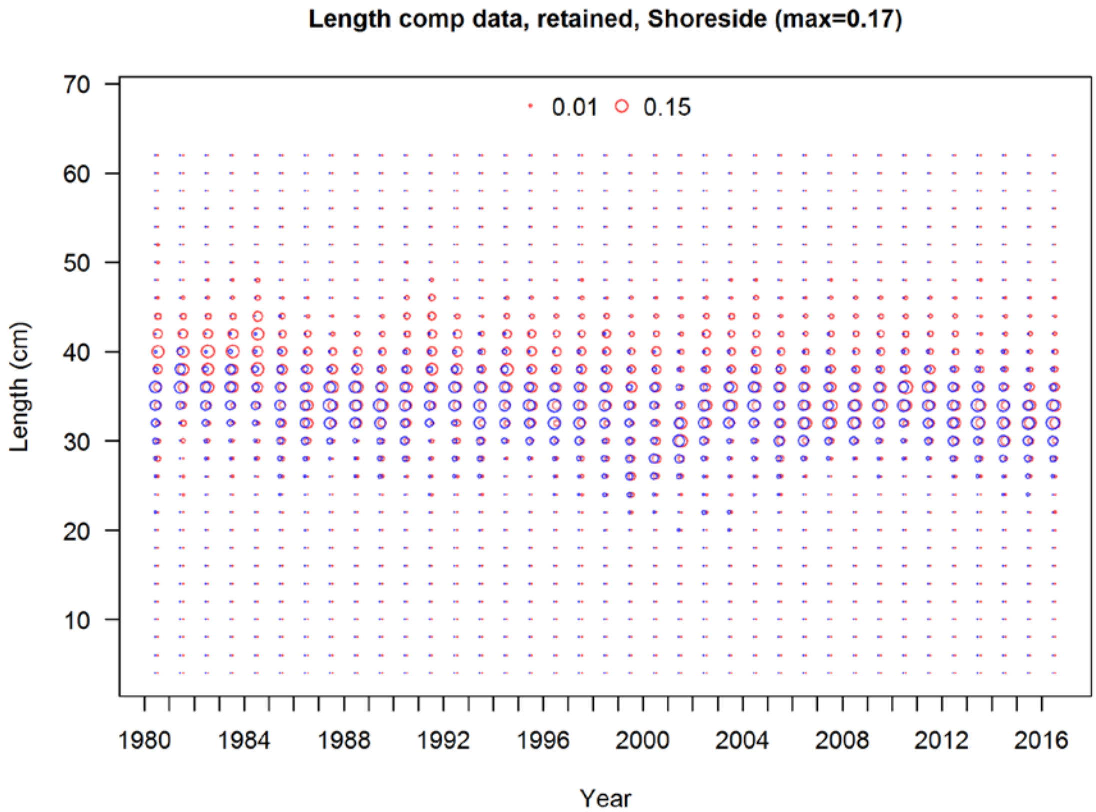

Figure 10: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the shoreside landings by year.

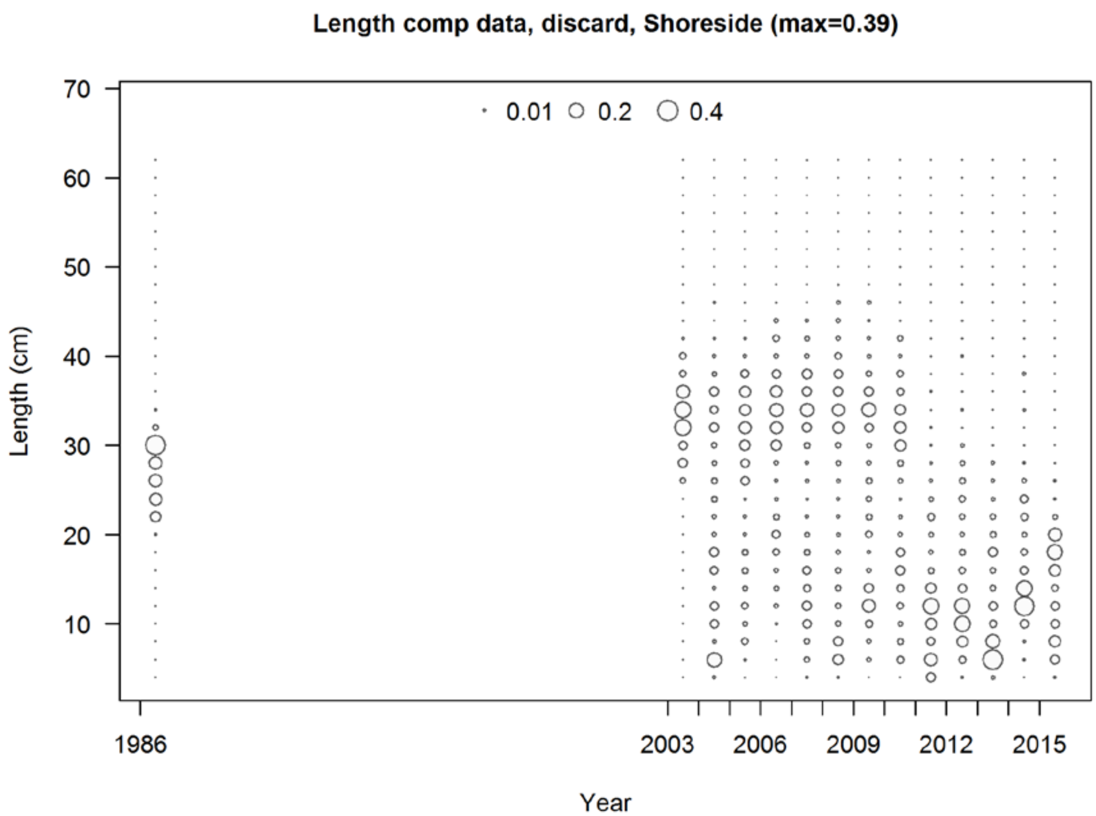

Figure 11: Annual length-frequency distributions for discarded darkblotched rockfish (sexes combined) from the shoreside fleet.

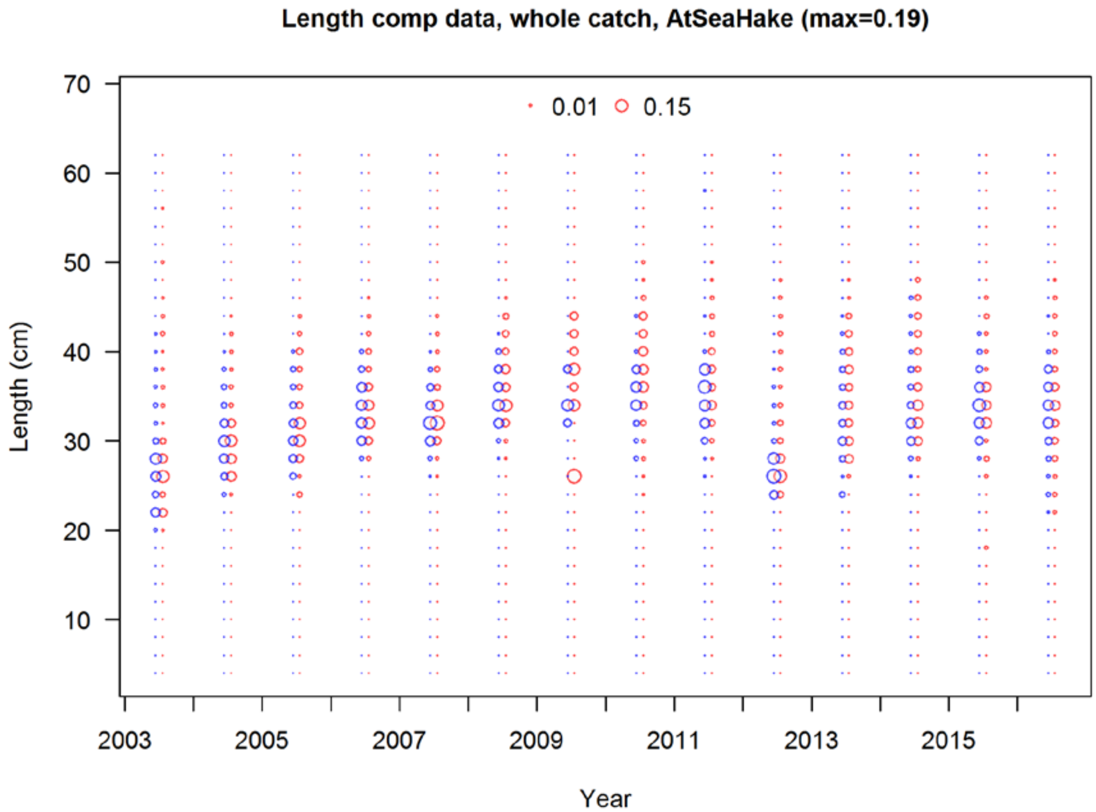

Figure 12: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the at-sea hake fishery removals by year.

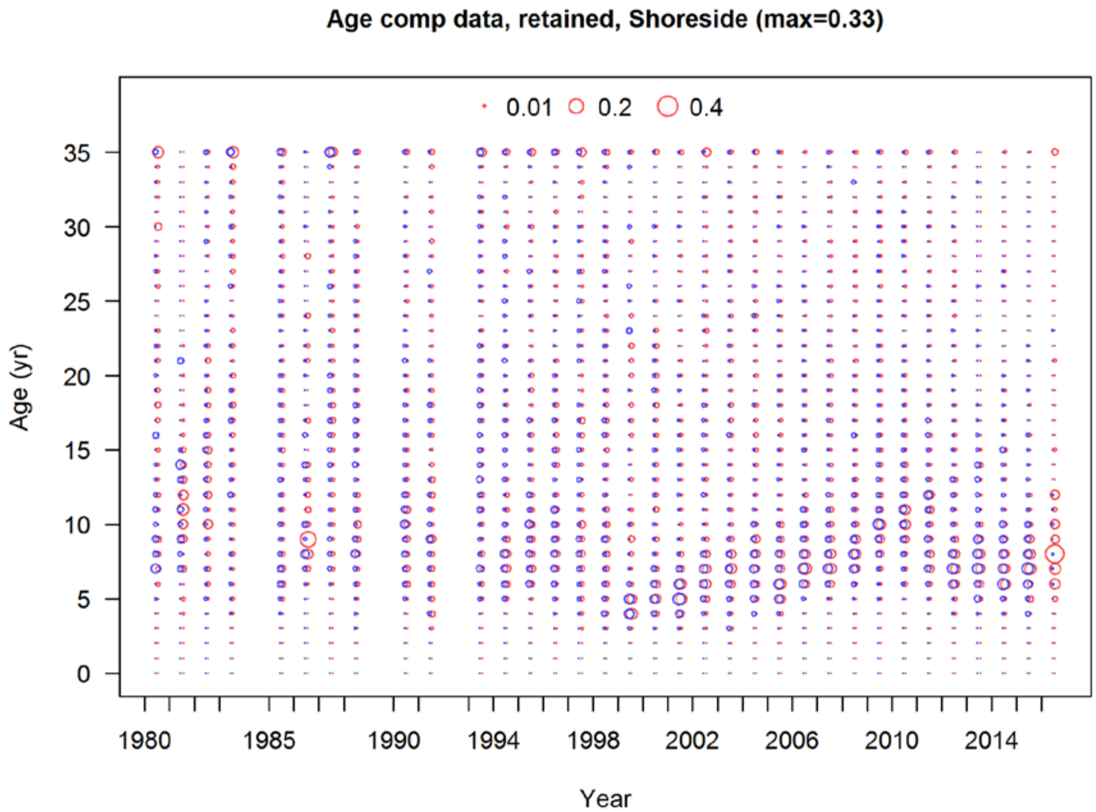

Figure 13: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the shoreside landings by year.

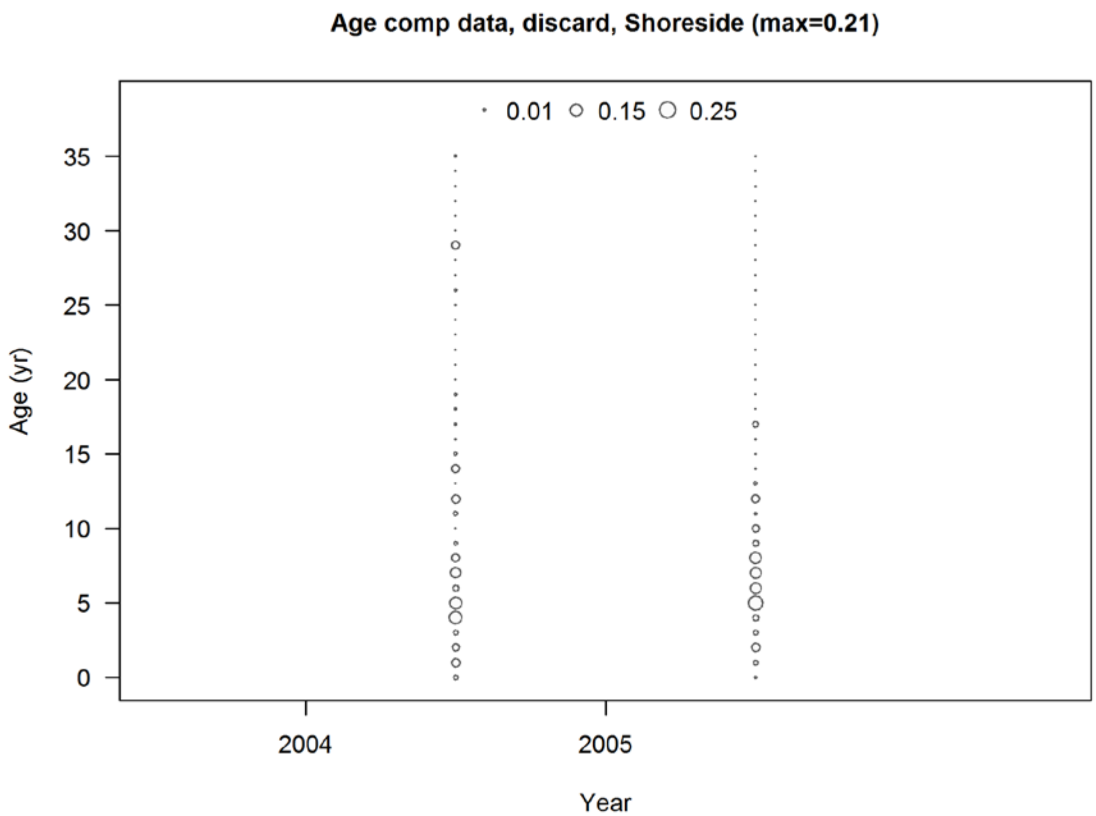

Figure 14: Age-frequency distributions for discarded darkblotched rockfish (sexes combined) from the shoreside fleet.

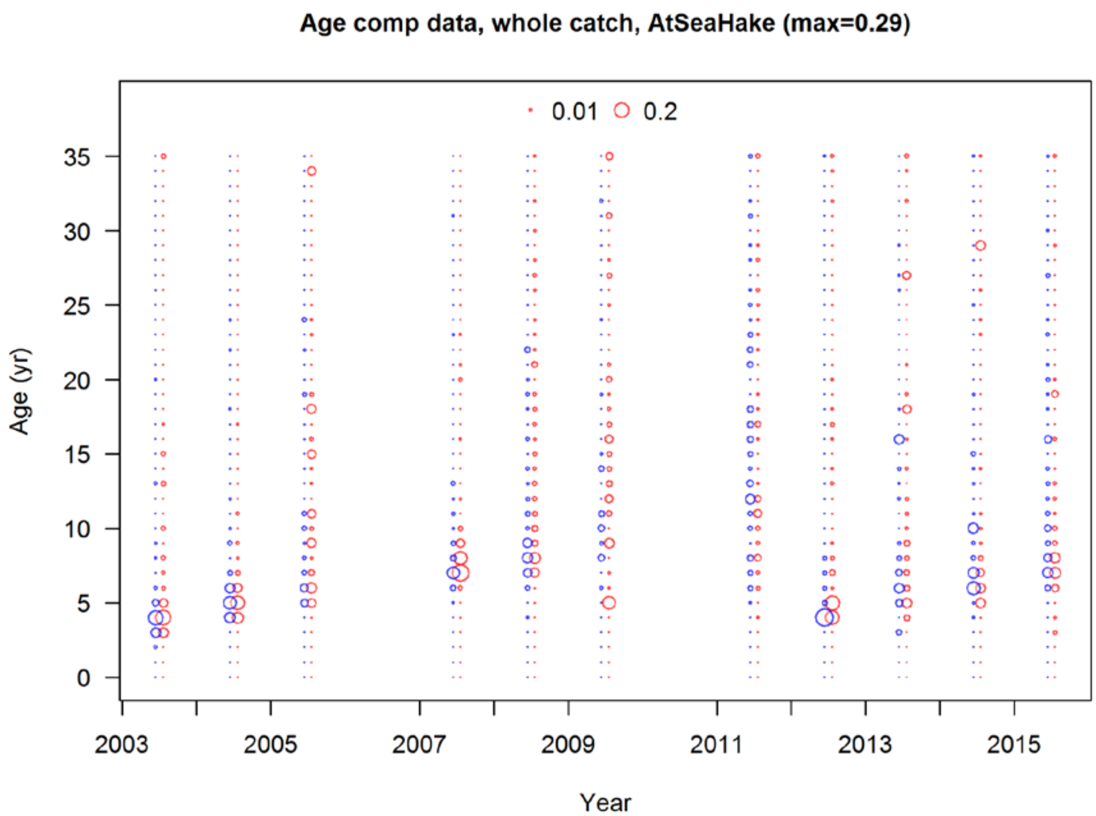

Figure 15: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the at-sea hake fishery removals by year.

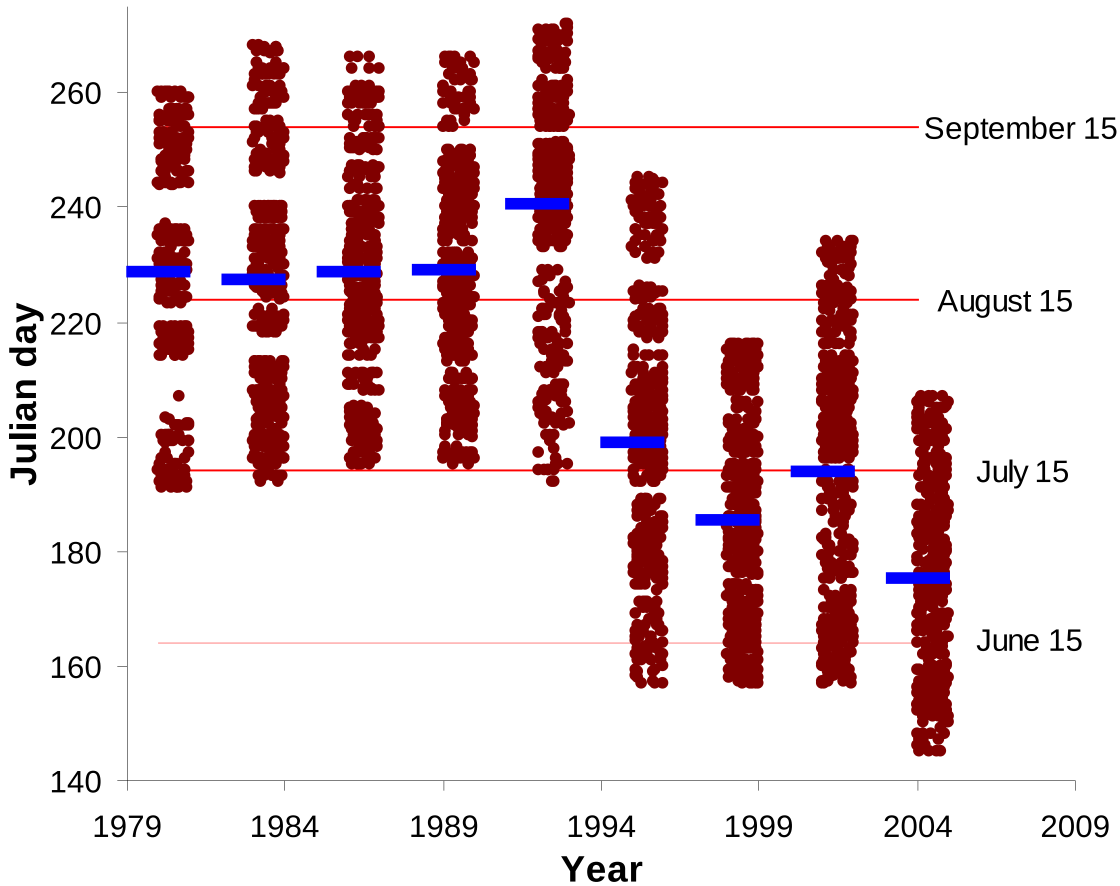

Figure 16: Distribution of dates of operation for the AFSC shelf (Triennial) bottom trawl survey (1980-2004). Solid bars show the mean date for each survey year, points represent individual hauls dates, but are jittered to allow better delineation of the distribution of individual points.

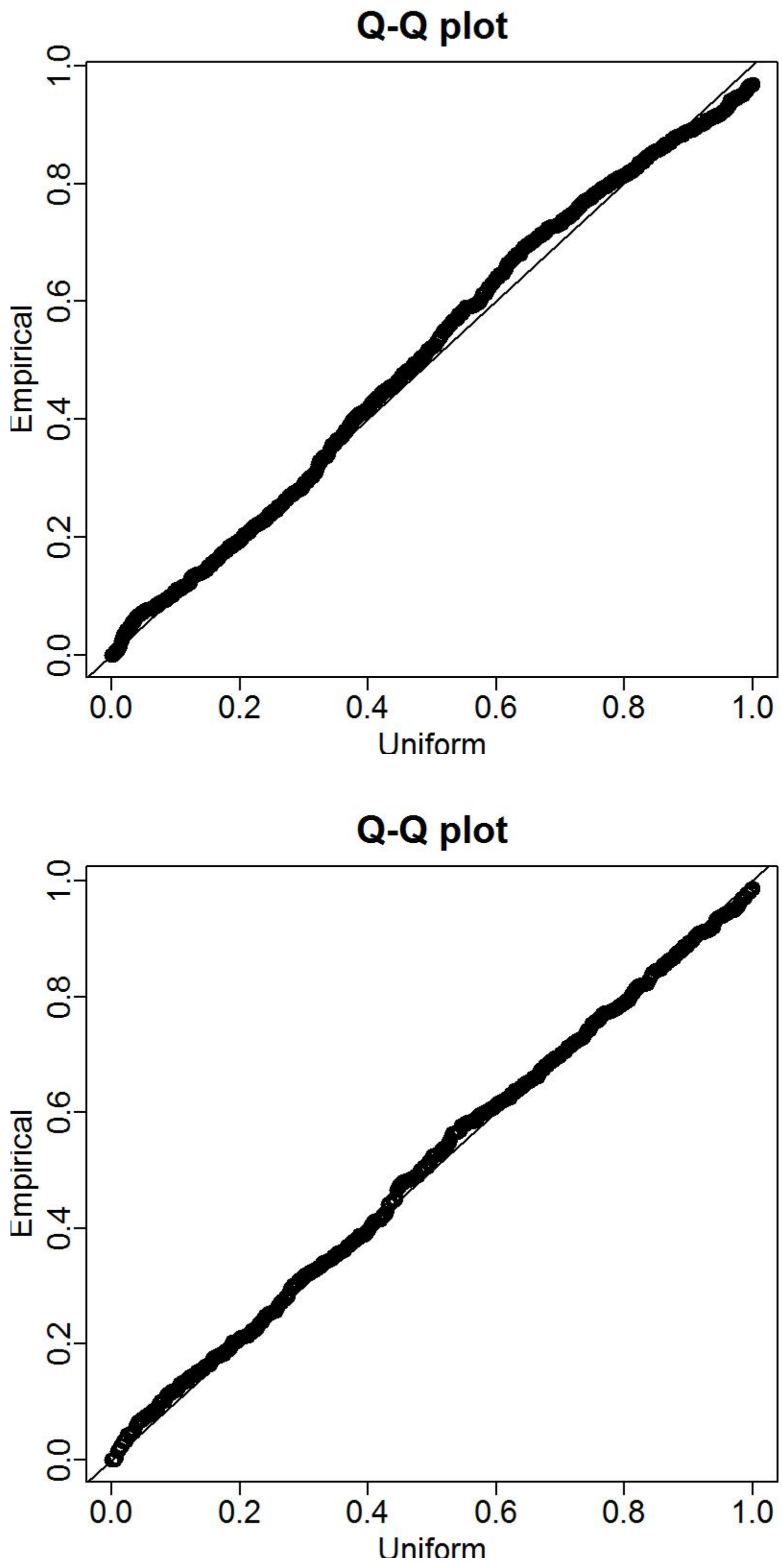

Figure 17: Bayesian Q-Q plot for AFSC shelf survey for 1980-1992 (upper panel) and 1995-2004 (lower panel).

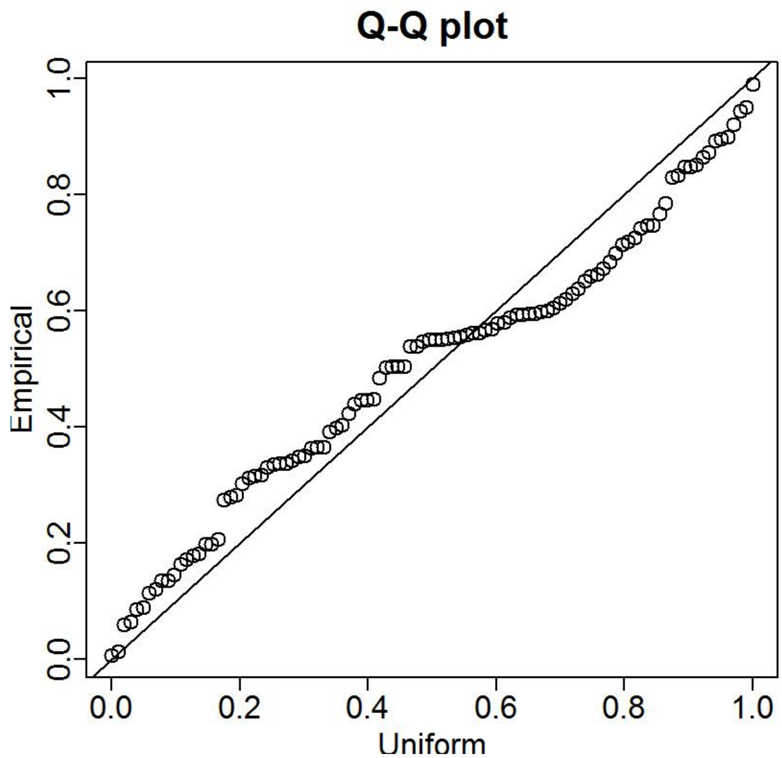

Figure 18: Bayesian Q-Q plot for AFSC slope survey.

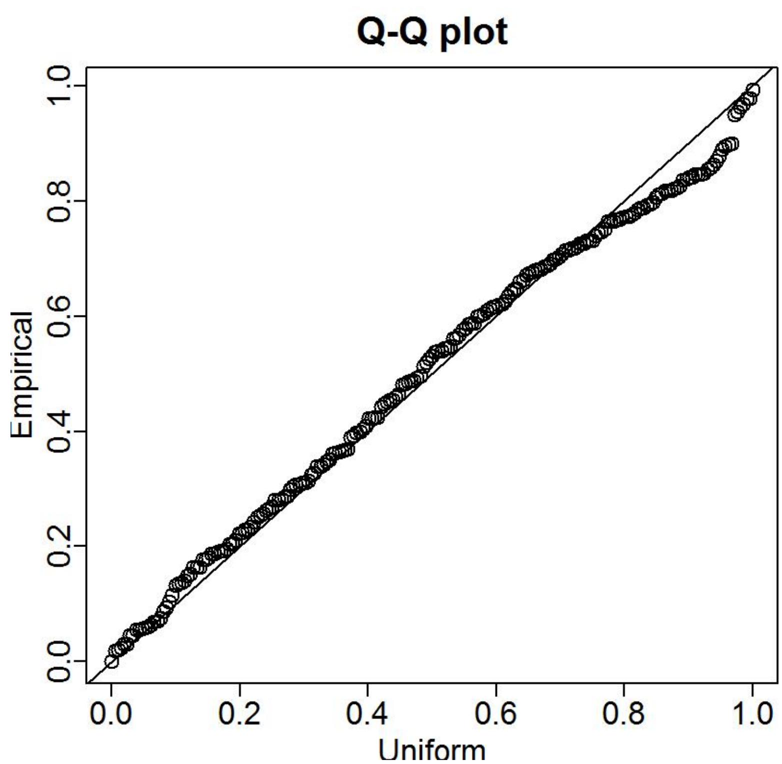

Figure 19: Bayesian Q-Q plot for NWFSC slope survey.

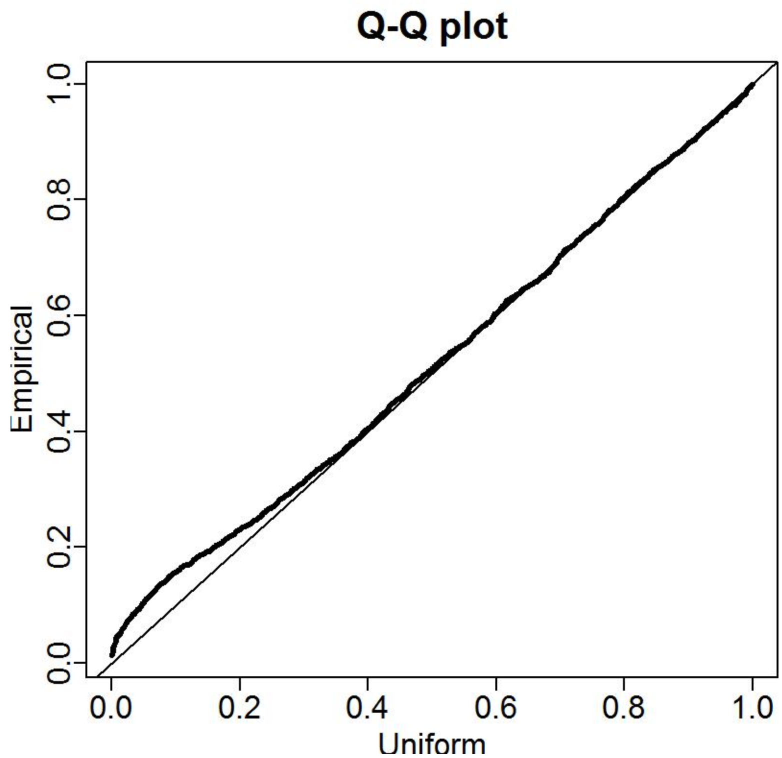

Figure 20: Q-Q plot for gamma model used in VAST for the NWFSC shelf-slope survey.

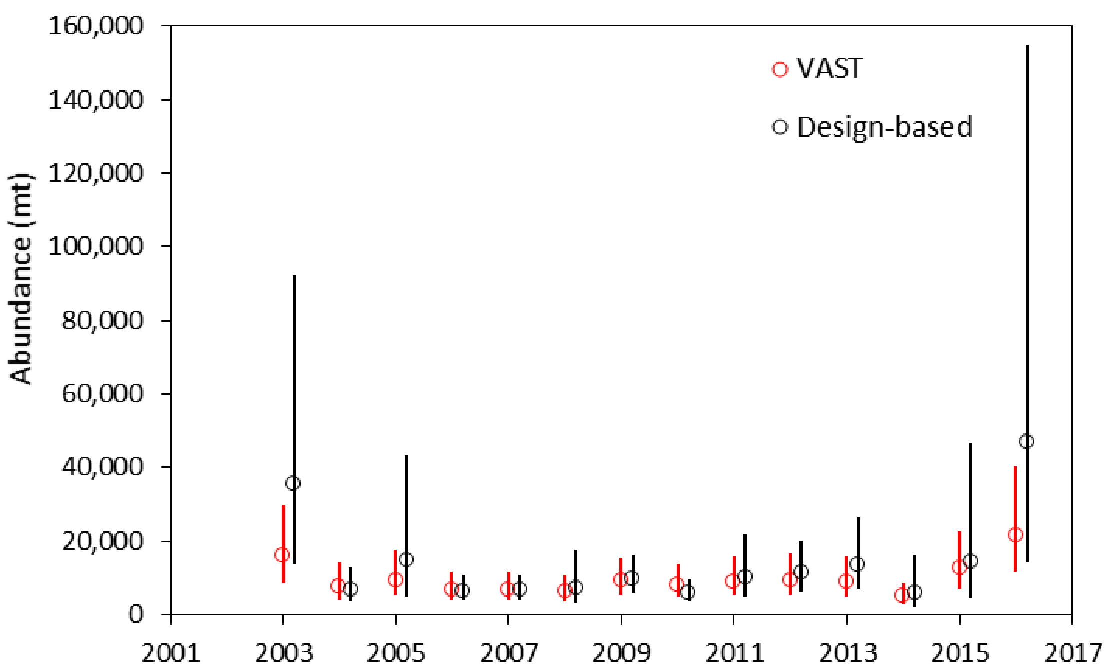

Figure 21: Comparison of NWFSC shelf-slope survey index estimated using VAST with design-based swept area biomass estimates.

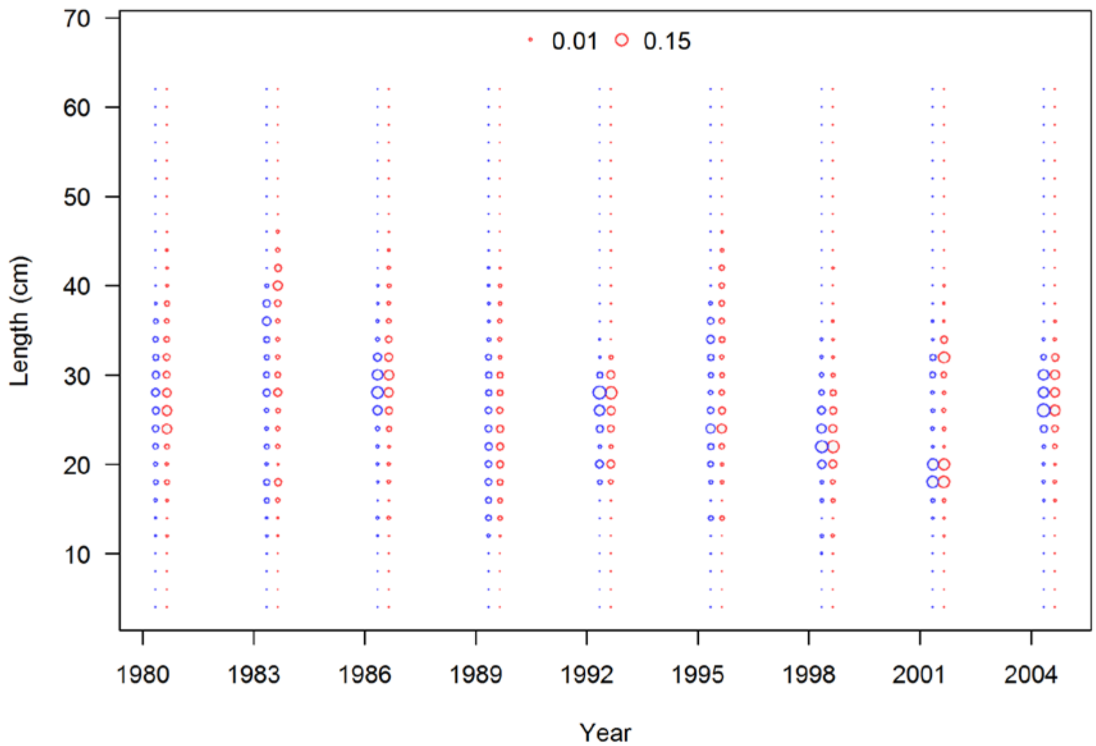

Figure 22: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey.

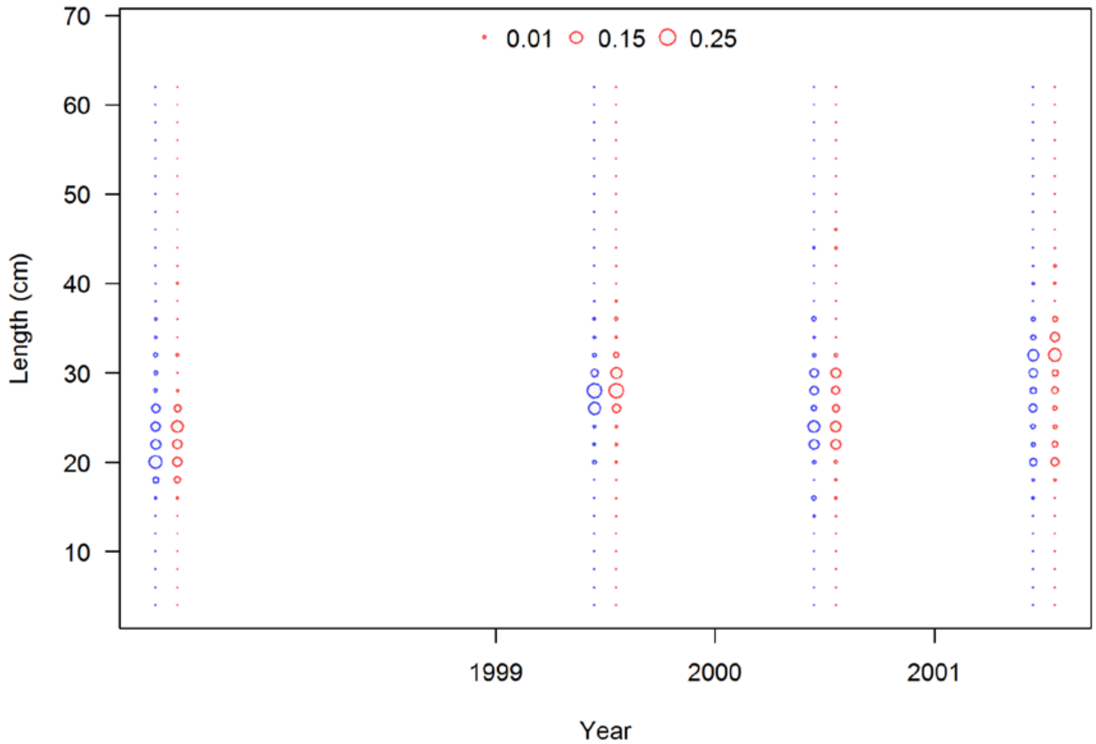

Figure 23: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the AFSC slope survey.

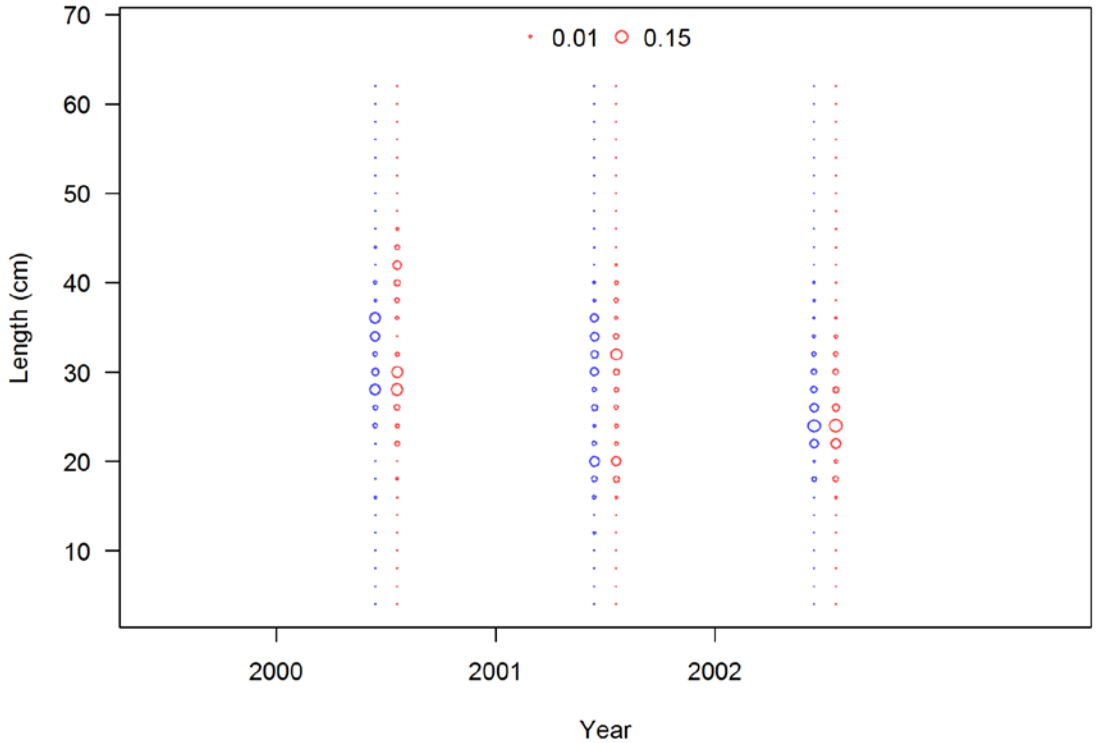

Figure 24: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the NWFSC slope survey.

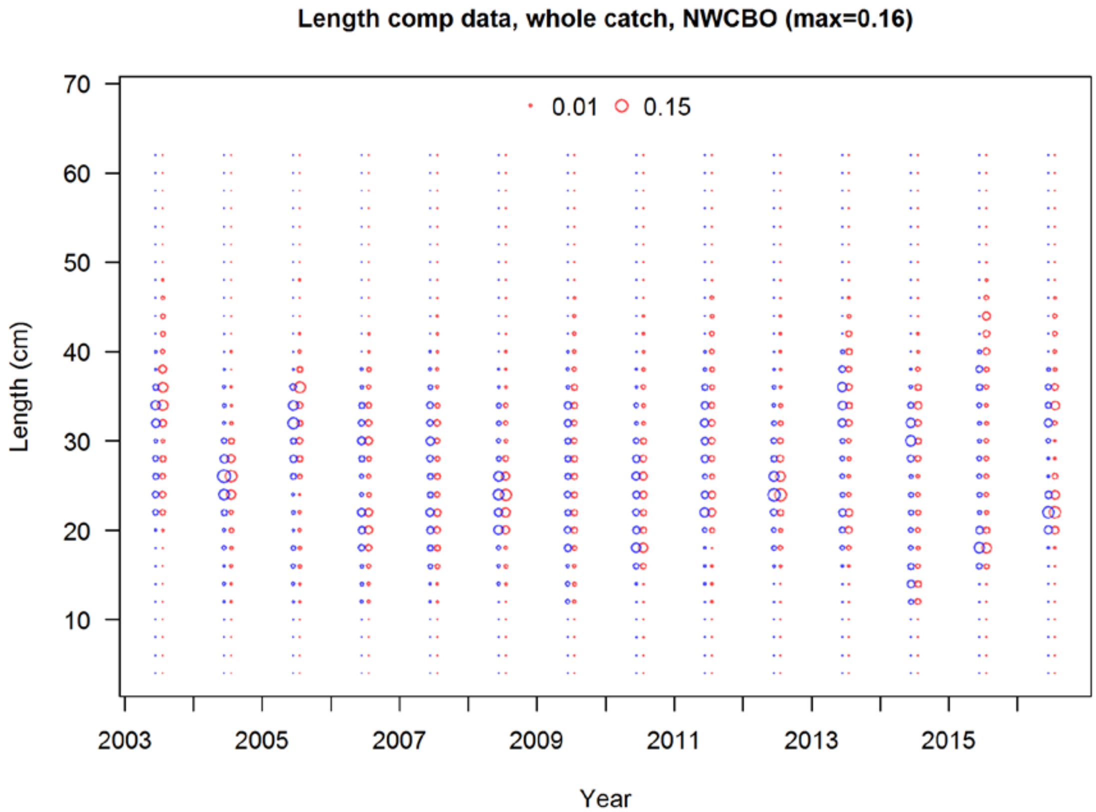

Figure 25: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

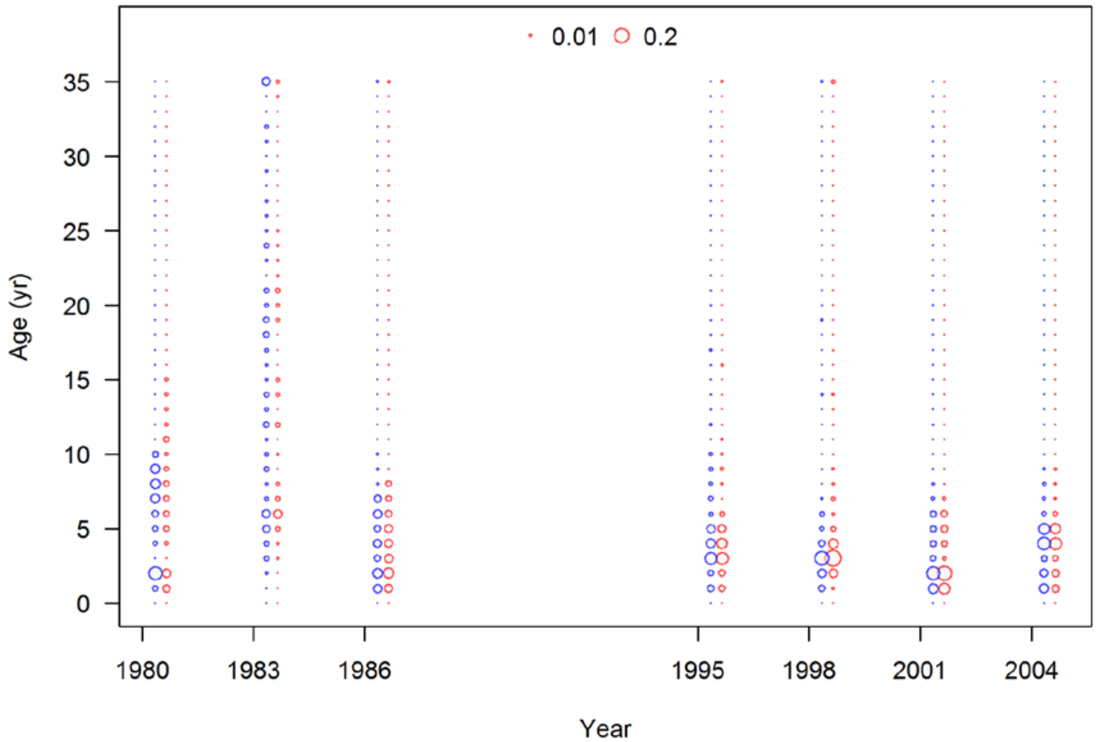

Figure 26: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey.

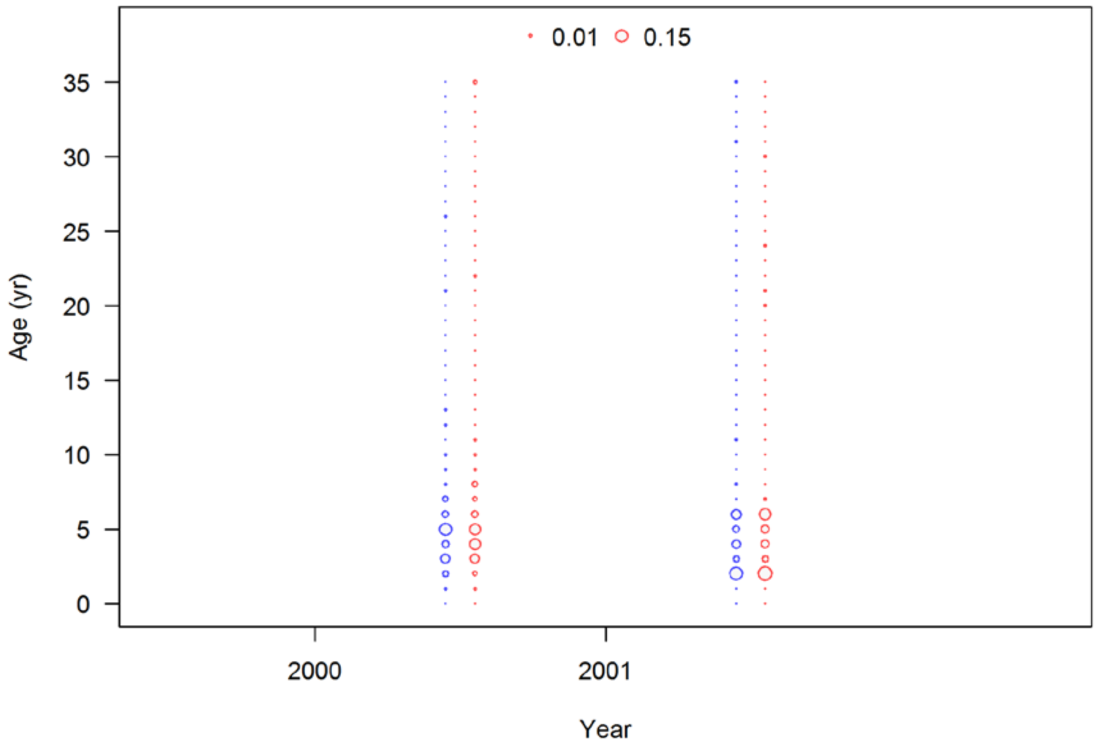

Figure 27: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the AFSC slope survey.

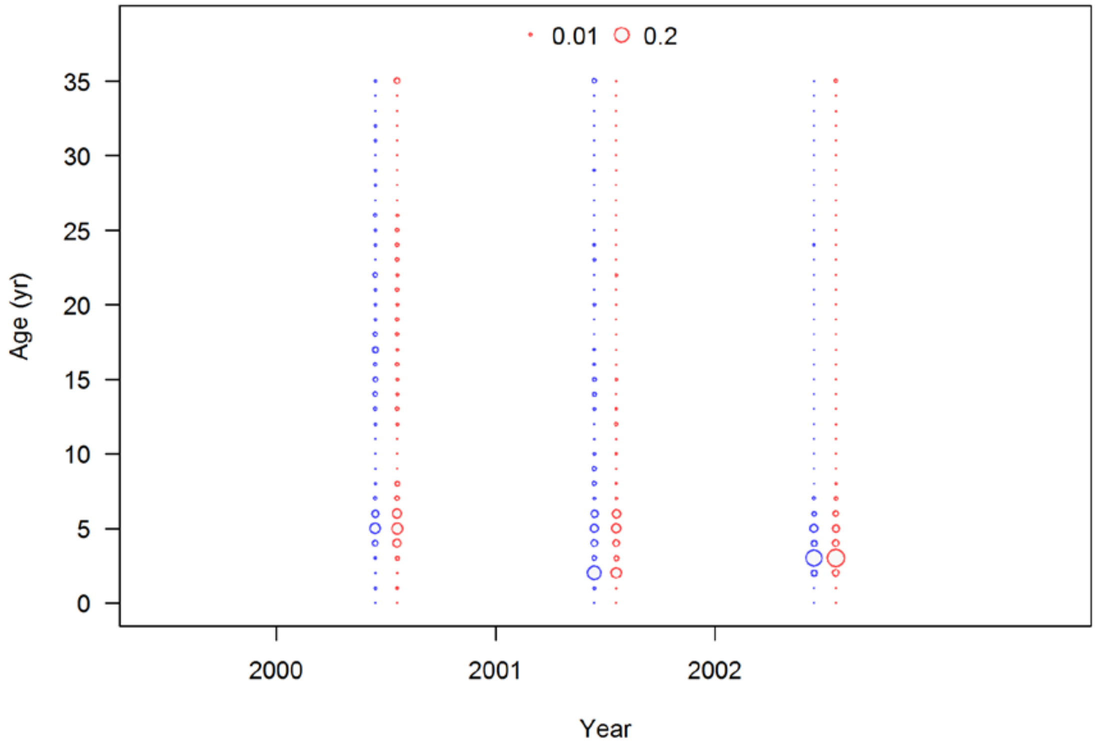

Figure 28: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the NWFSC slope survey.

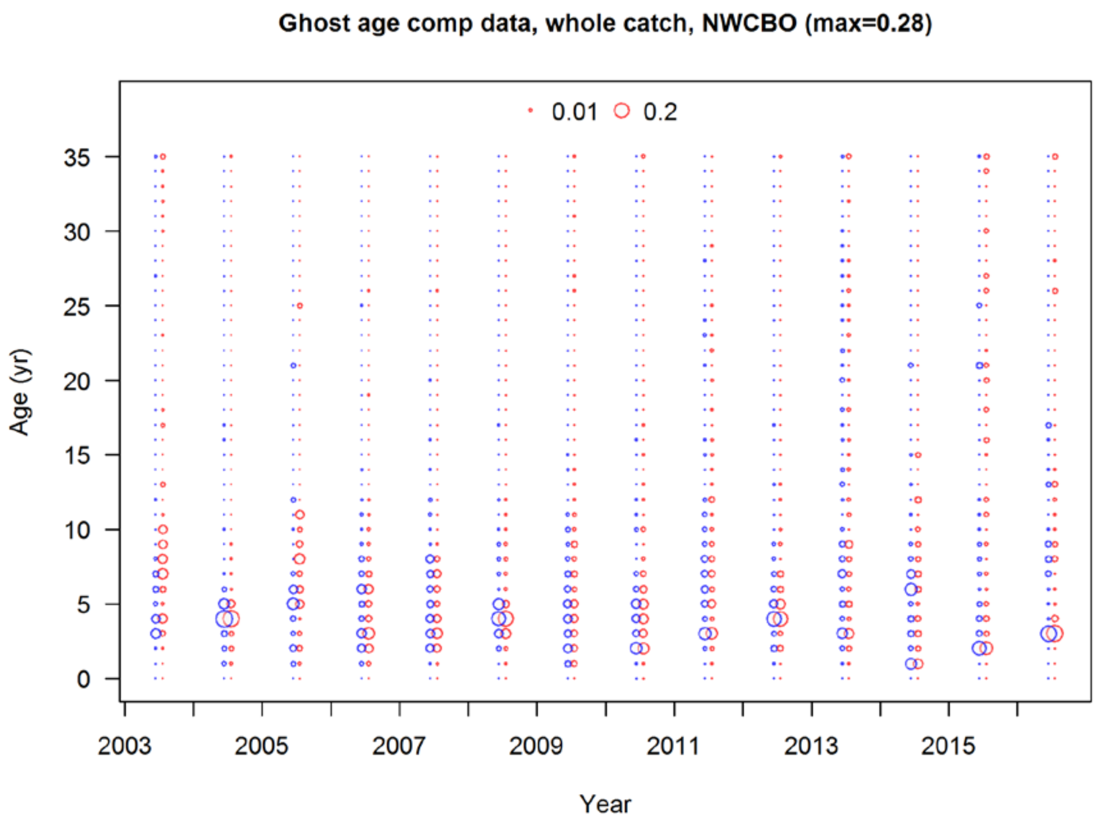

Figure 29: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) rockfish from the NWFSC shelf-slope survey.

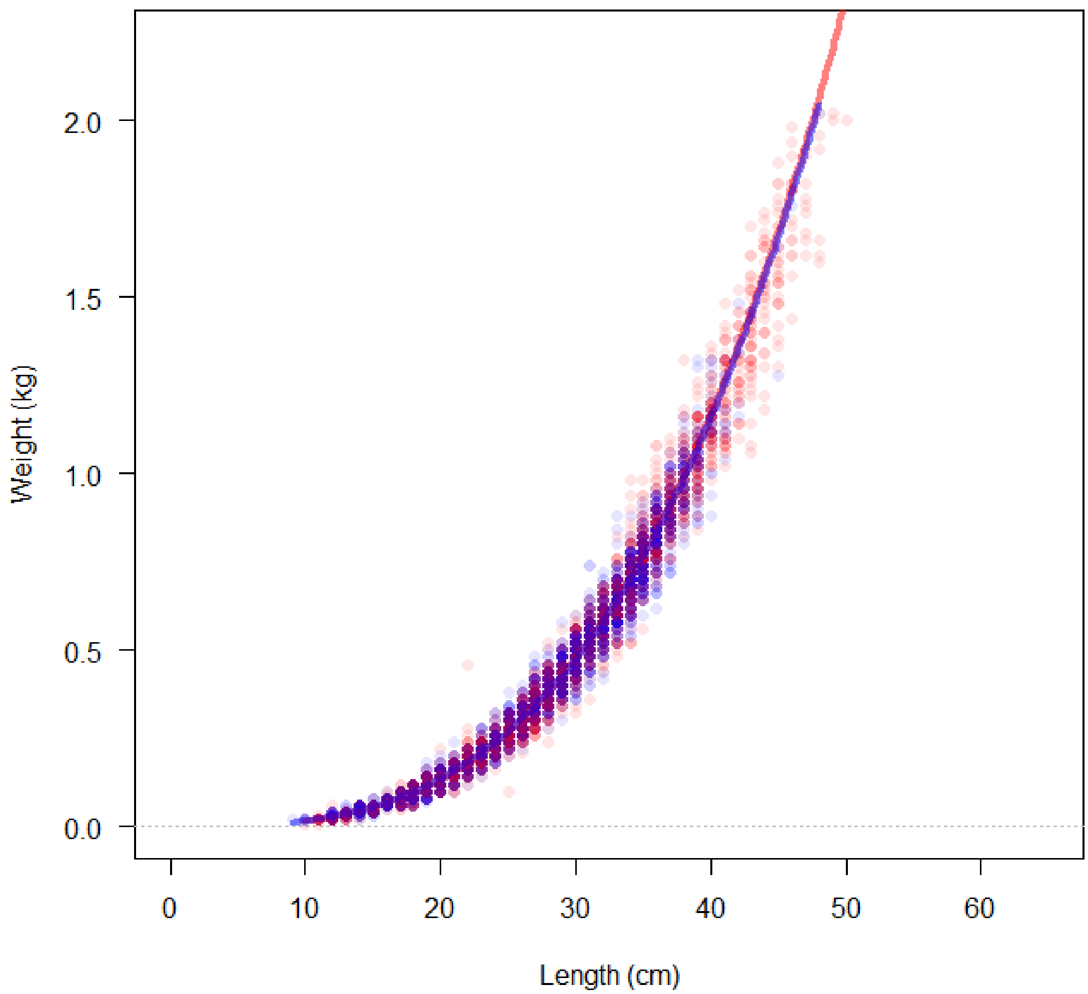

Figure 30: Weight-length relationship for female (red) and male (blue) darkblotched rockfish used in the assessment, shown with fit to the data from the NWFSC shelf-slope survey samples (shaded points).

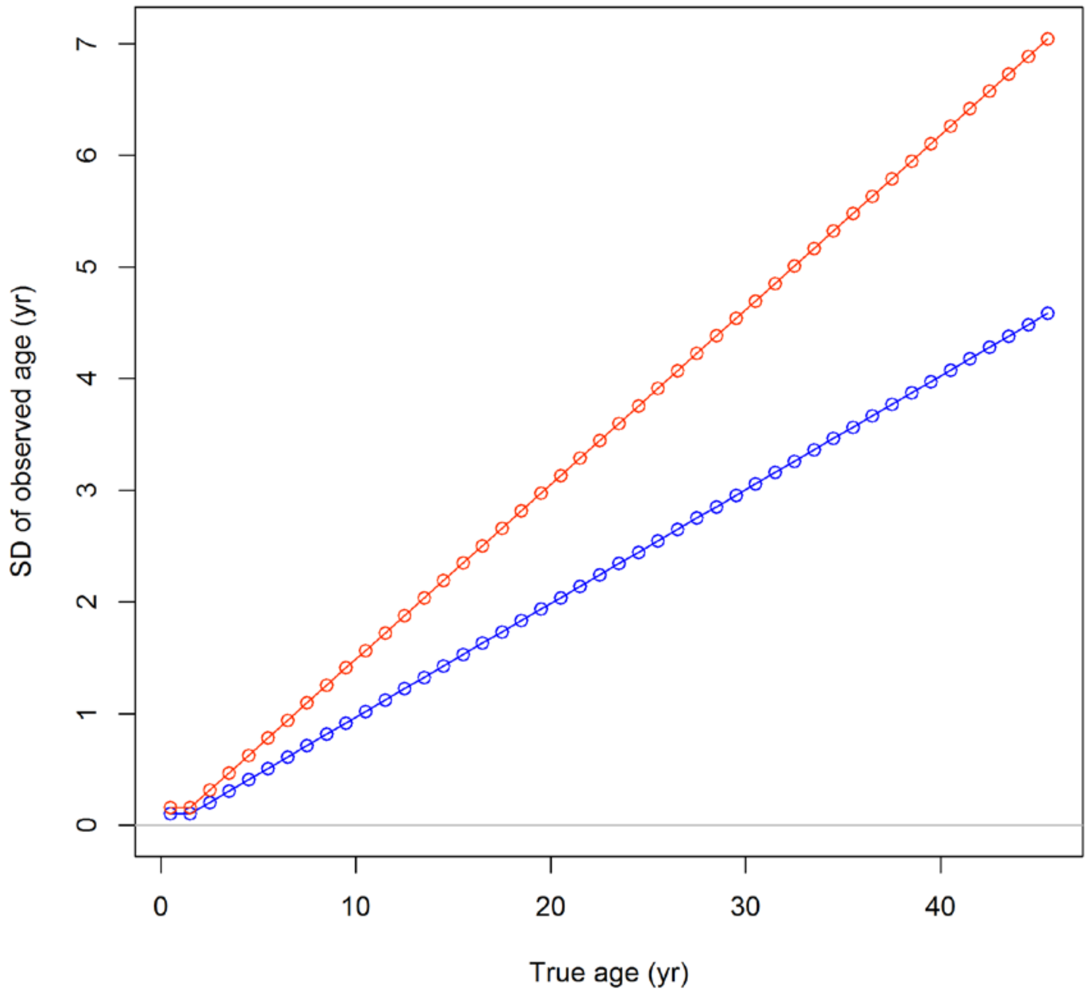

Figure 31: SD of observed age versus true age for “early” (red) and “late” (blue) age data used in the assessment.

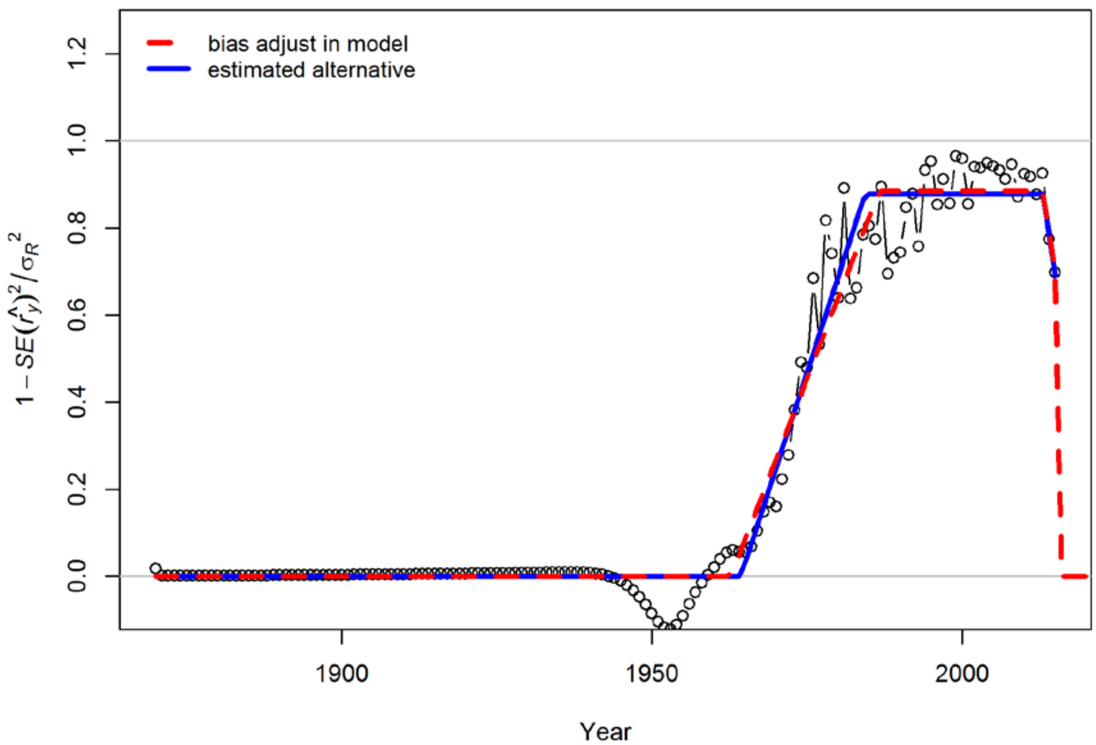

Figure 32: Bias correction ramp estimated by R4SS using particle swarm optimization to avoid local minima.

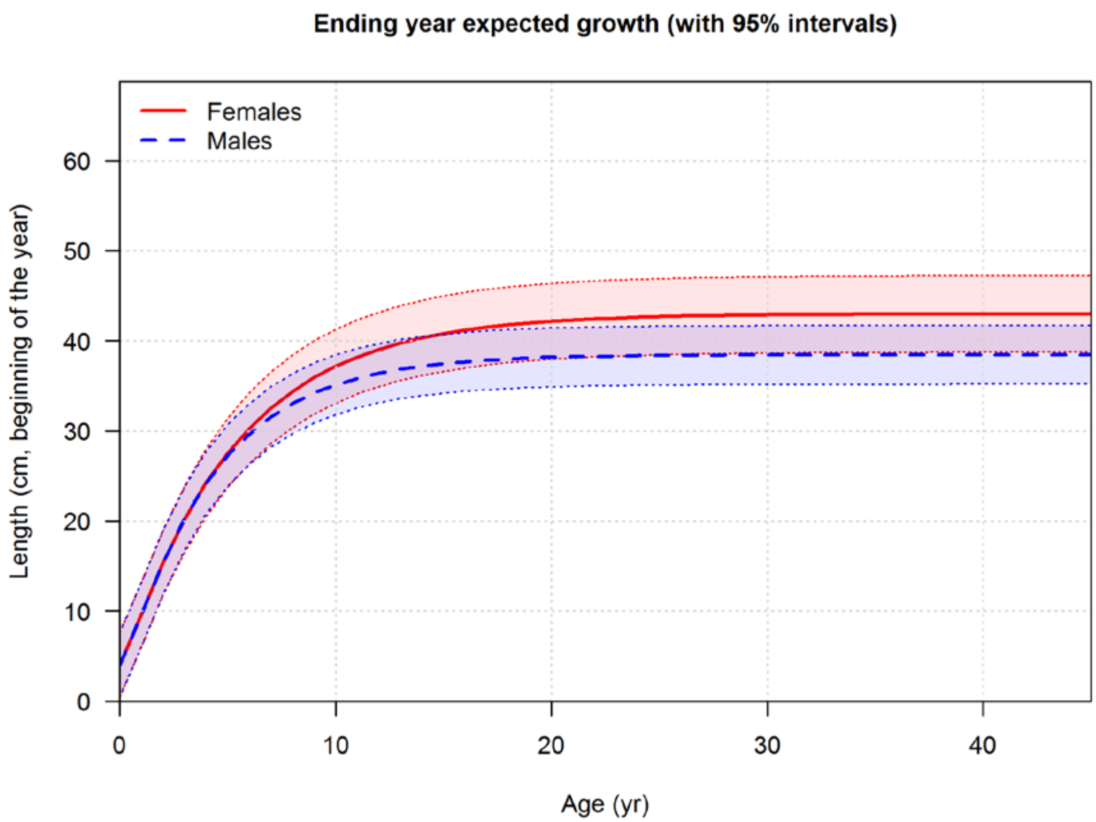

Figure 33: Growth curves for females and males of darkblotched rockfish used in the assessment model.

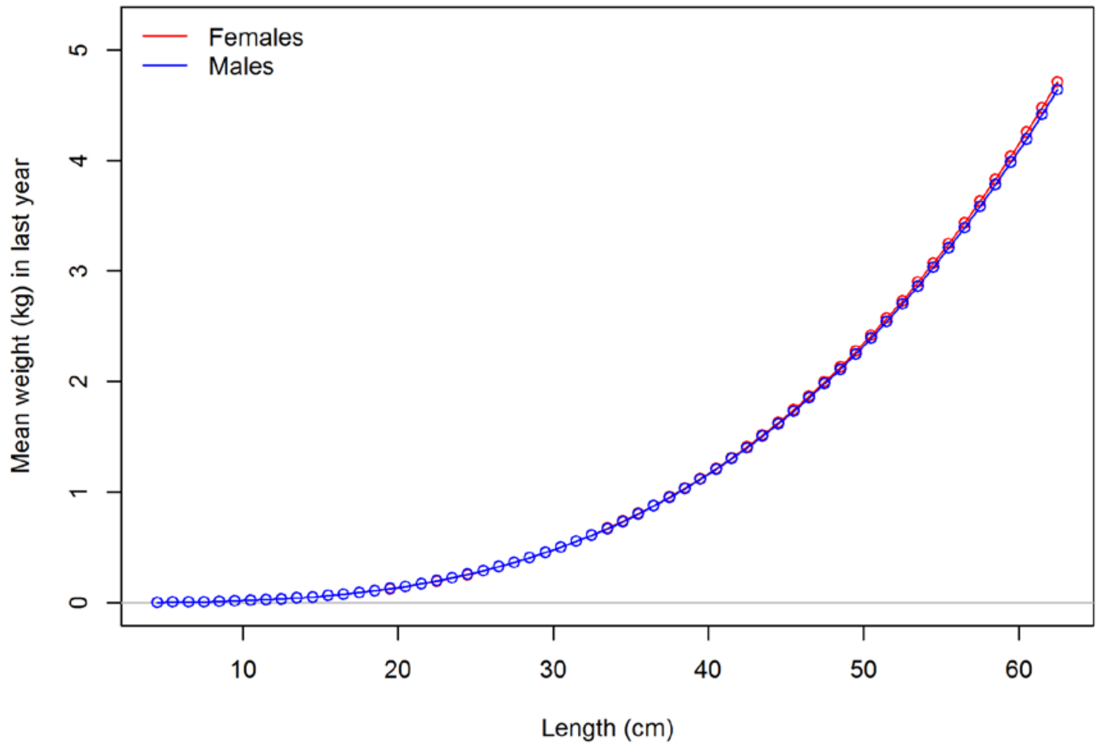

Figure 34: Weight-at-length relationship for females and males of darkblotched rockfish used in the assessment model.

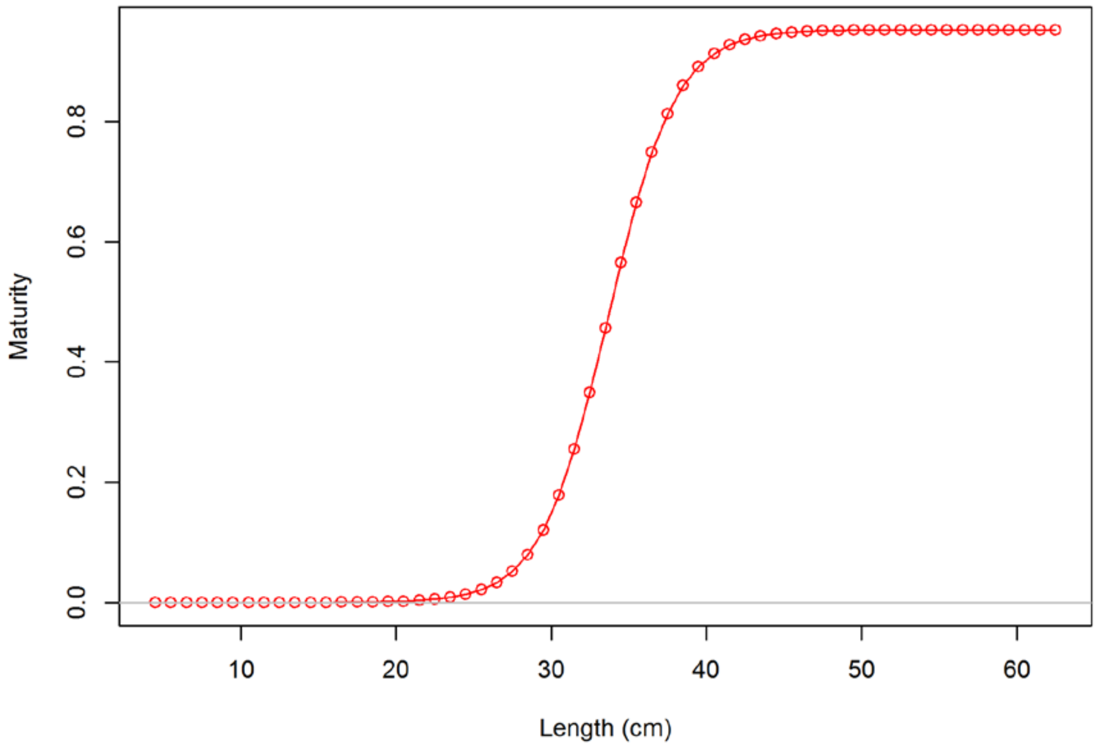

Figure 35: Female maturity at length relationship used in the assessment model. The parameters were estimated from the data collected within the NWFSC shelf-slope survey between 2011 and 2012.

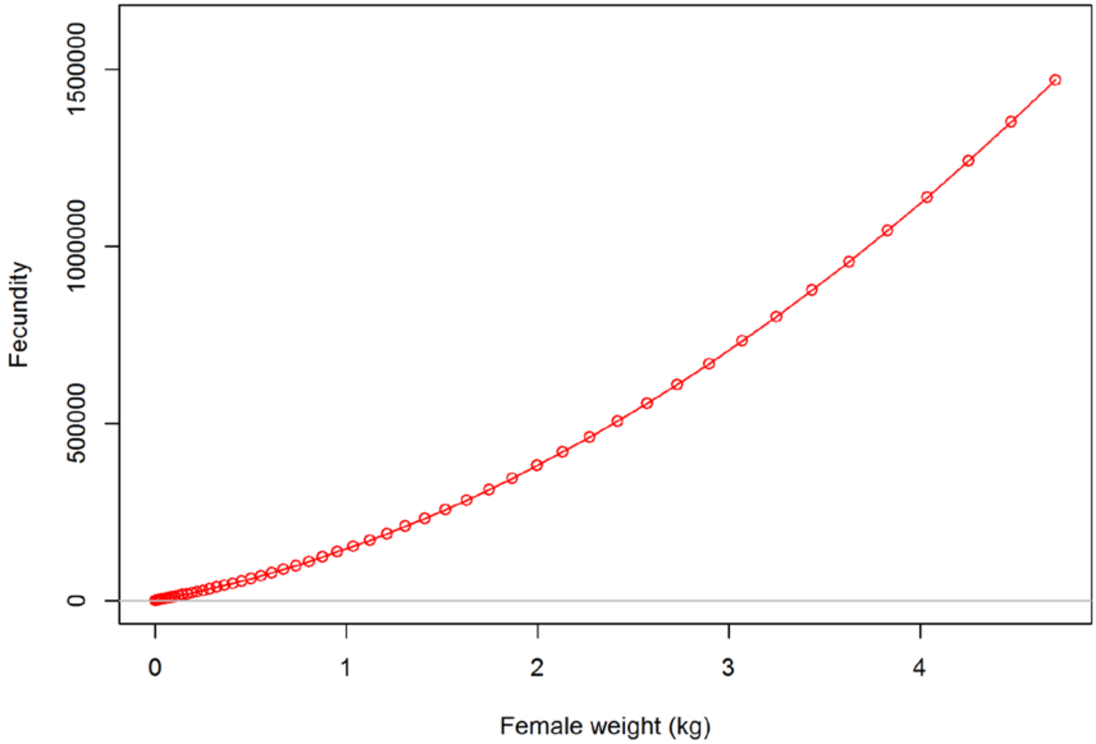

Figure 36: Female darkblotched rockfish fecundity at weight relationship used in the assessment, based on the parameters estimated by Dick (2009).

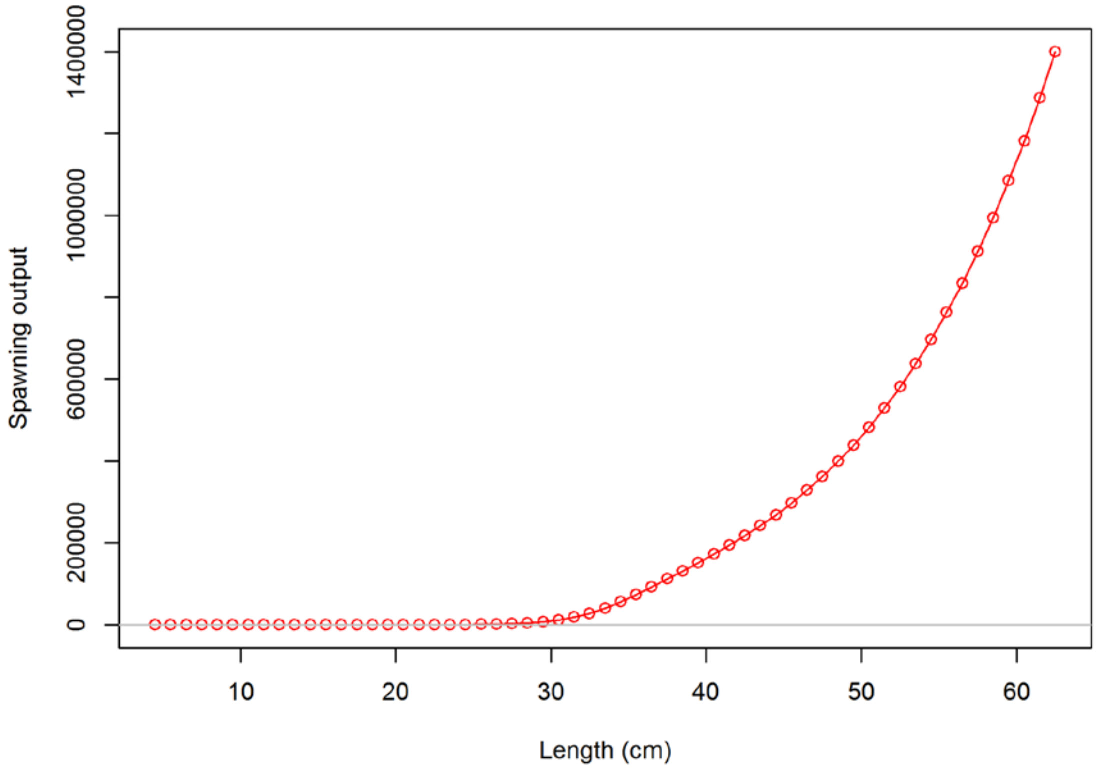

Figure 37: Female darkblotched rockfish spawning output-at-length relationship used in the assessment model.

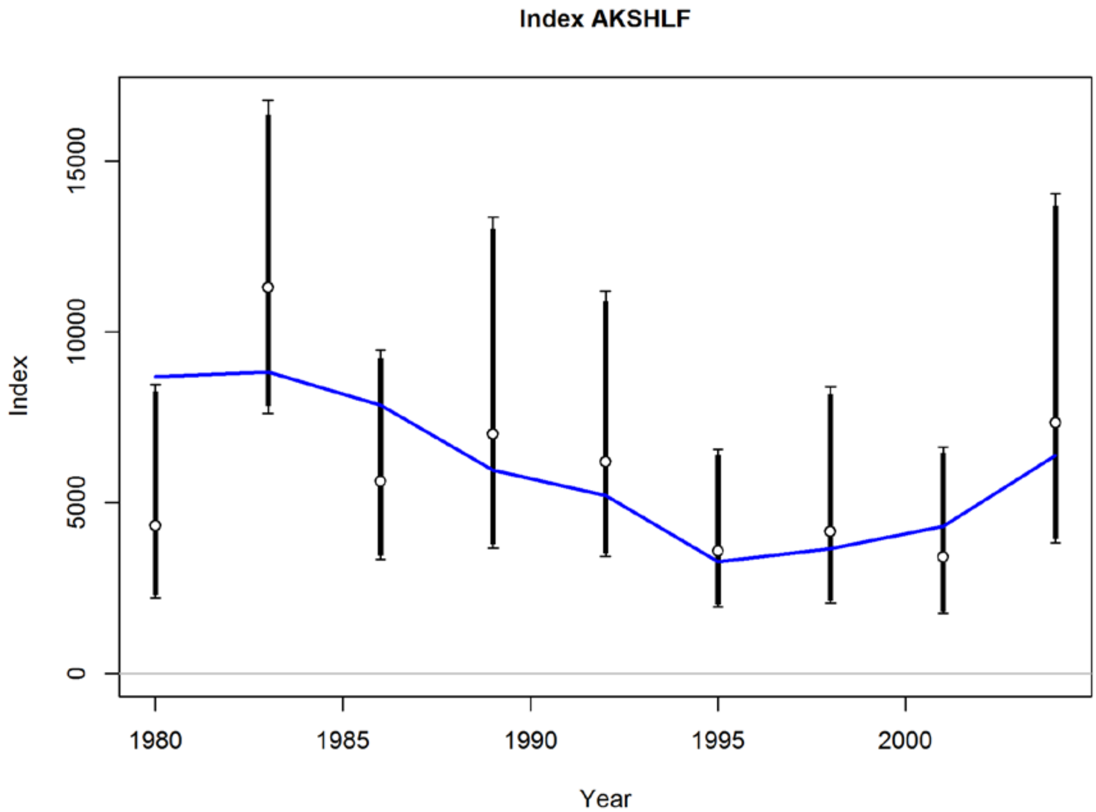

Figure 38: Observed and expected values of darkblotched rockfish biomass index (mt) for the AFSC shelf survey.

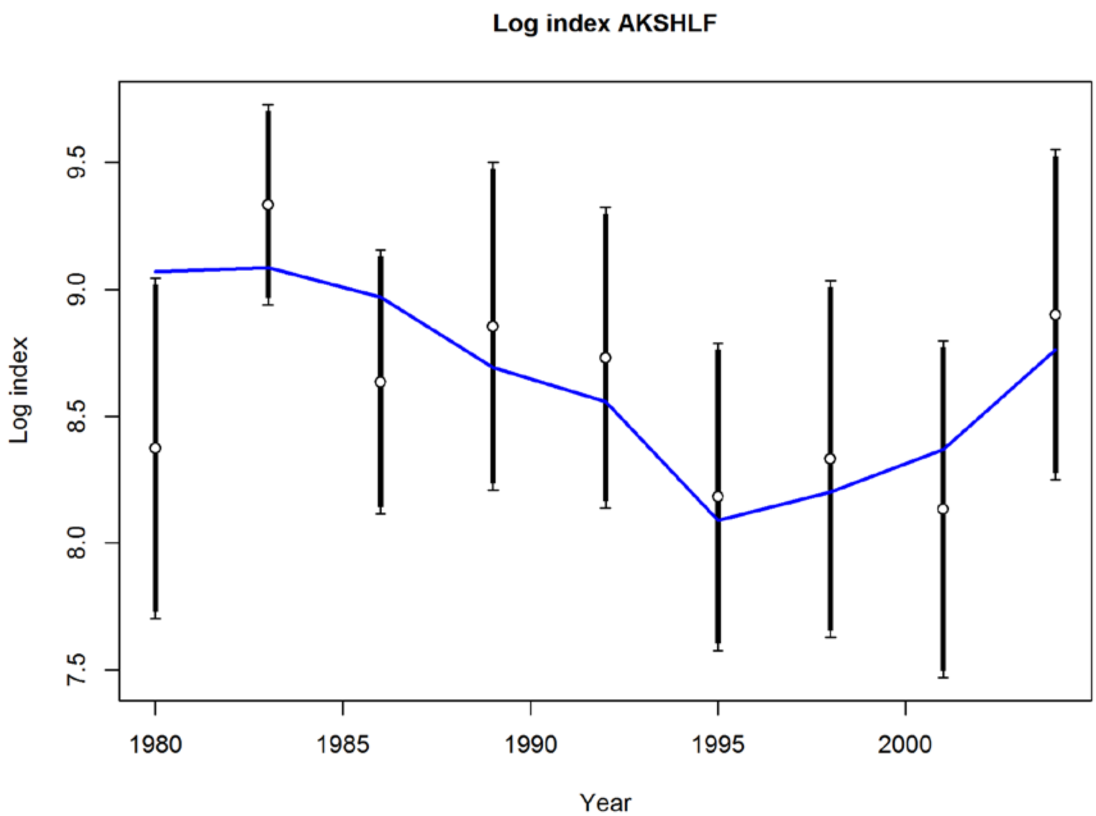

Figure 39: Observed and expected values of darkblotched rockfish biomass index (mt) for the AFSC shelf survey, on log scale.

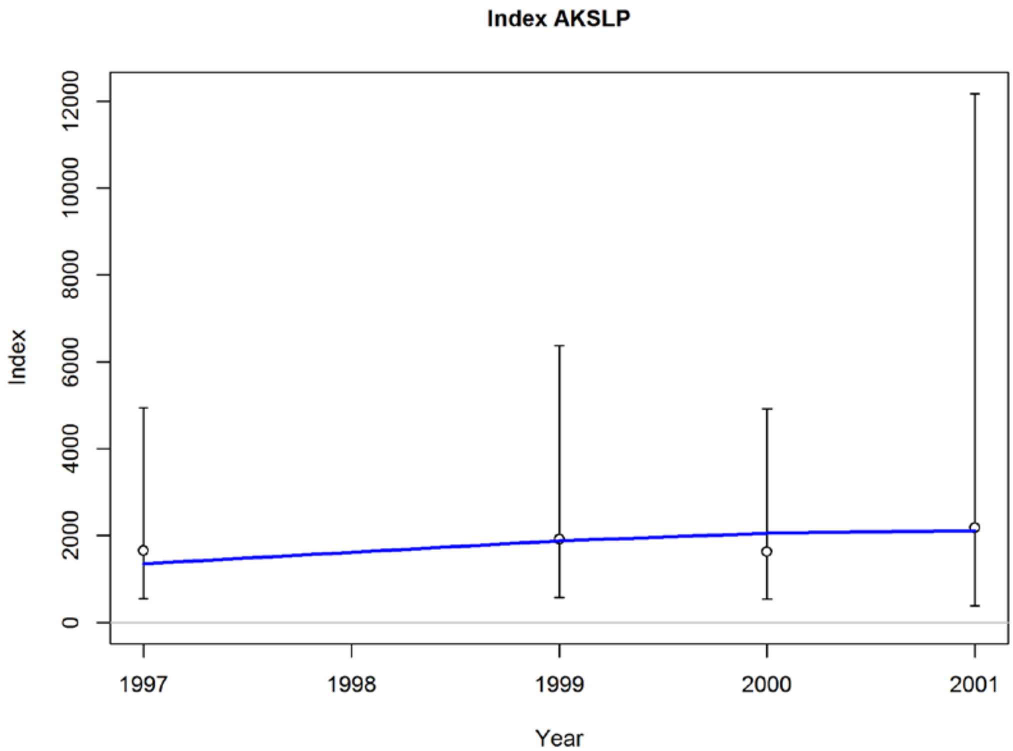

Figure 40: Observed and expected values of darkblotched rockfish biomass index (mt) for the AFSC slope survey.

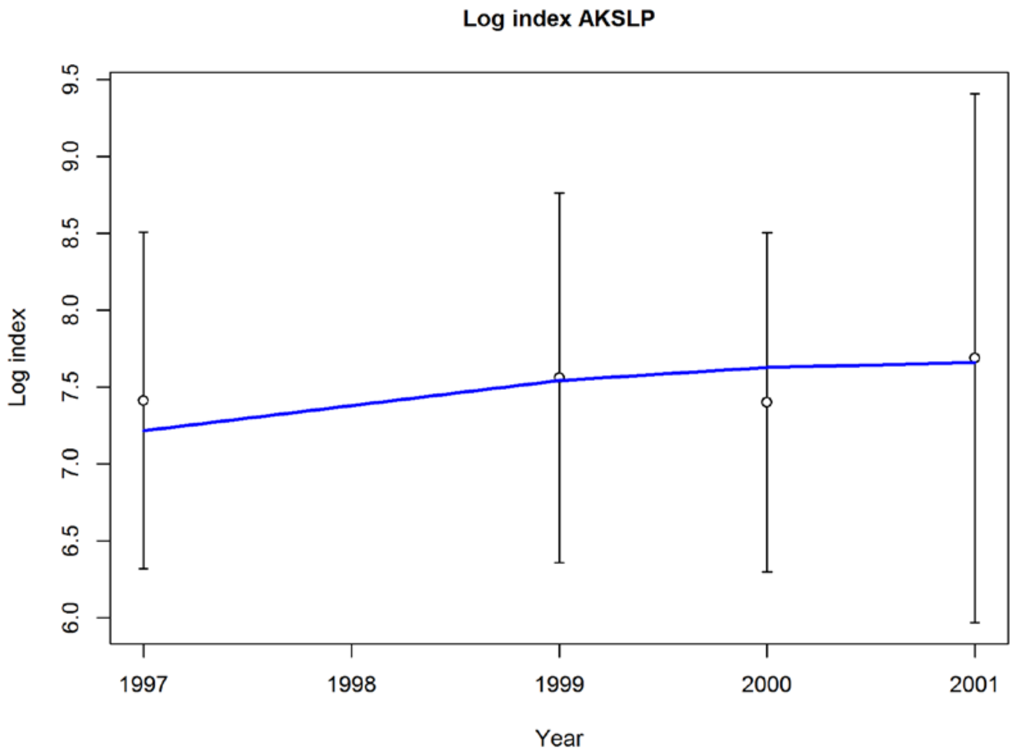

Figure 41: Observed and expected values of darkblotched rockfish biomass index (mt) for the AFSC slope survey, on log scale.

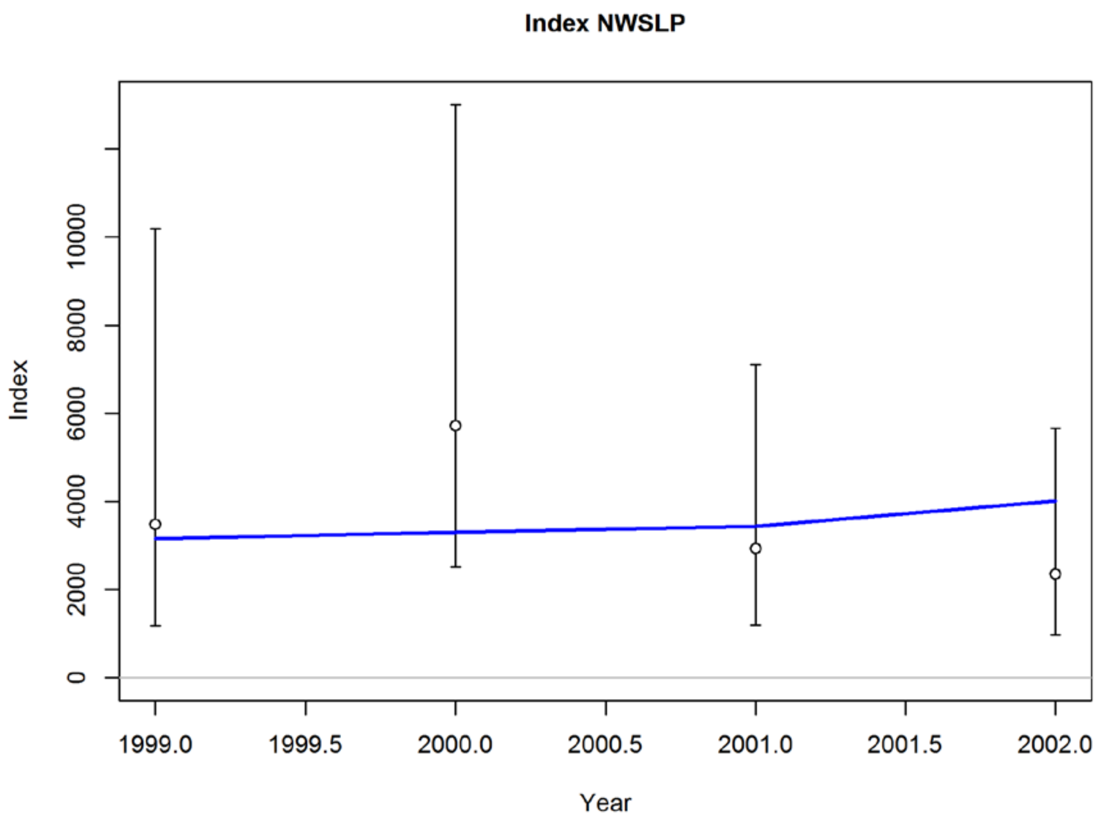

Figure 42: Observed and expected values of darkblotched rockfish biomass index (mt) for the NWFSC slope survey.

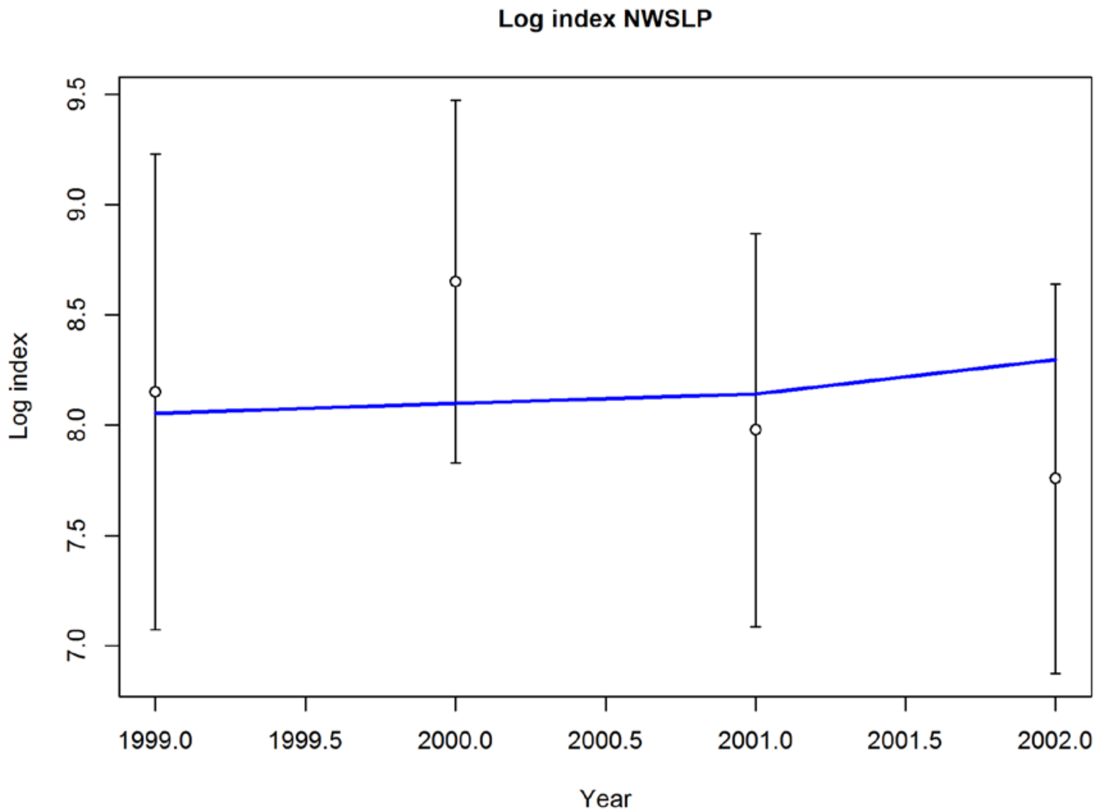

Figure 43: Observed and expected values of darkblotched rockfish biomass index (mt) for the NWFSC slope survey, on log scale.

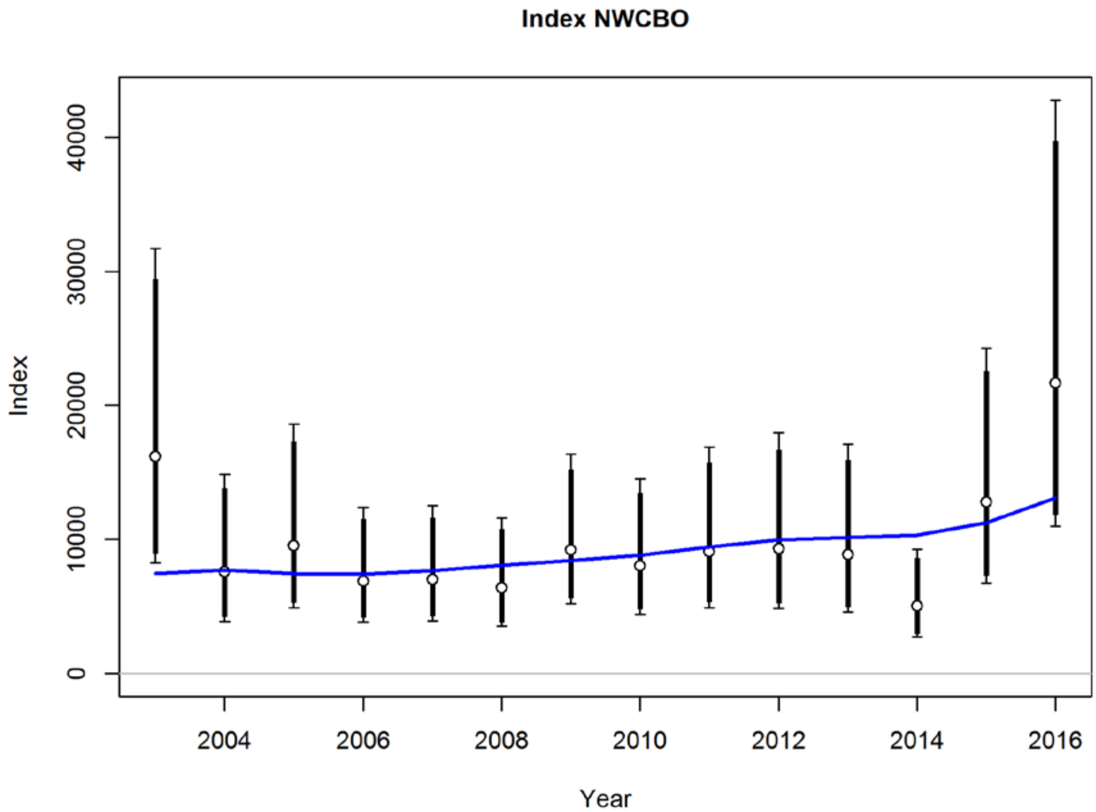

Figure 44: Observed and expected values of darkblotched rockfish biomass index (mt) for the NWFSC shelf-slope survey.

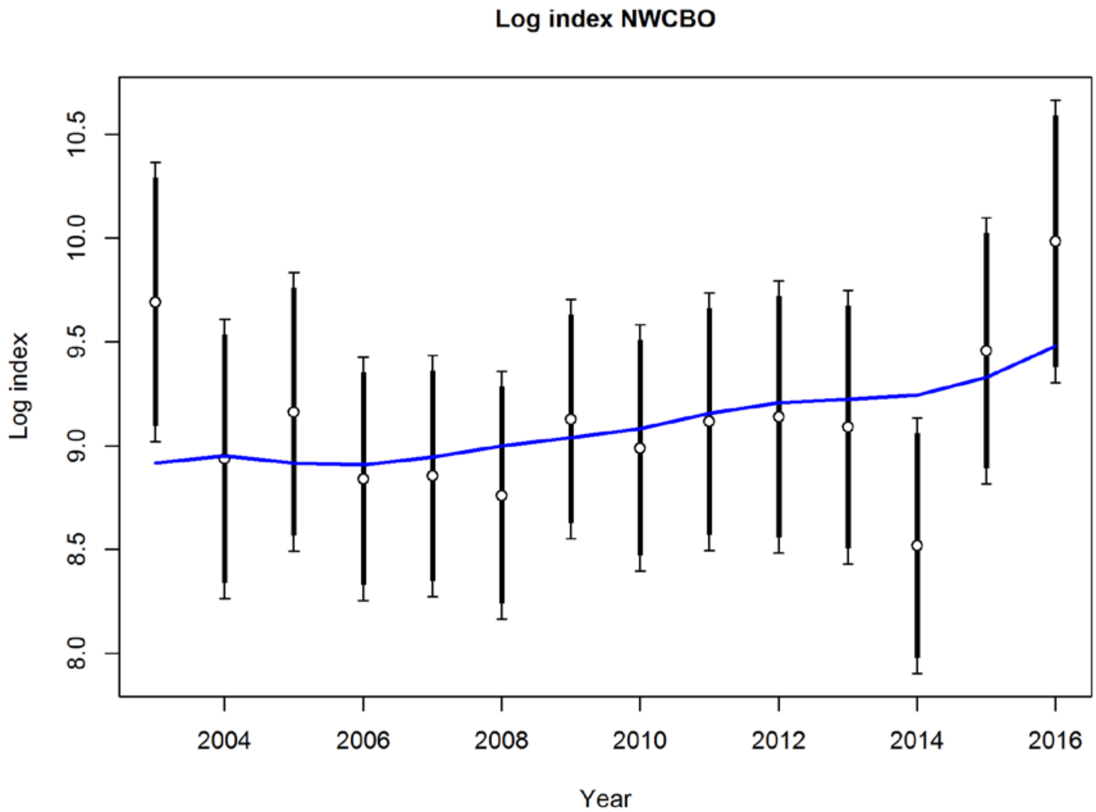

Figure 45: Observed and expected values of darkblotched rockfish biomass index (mt) for the NWFSC shelf-slope survey, on log scale.

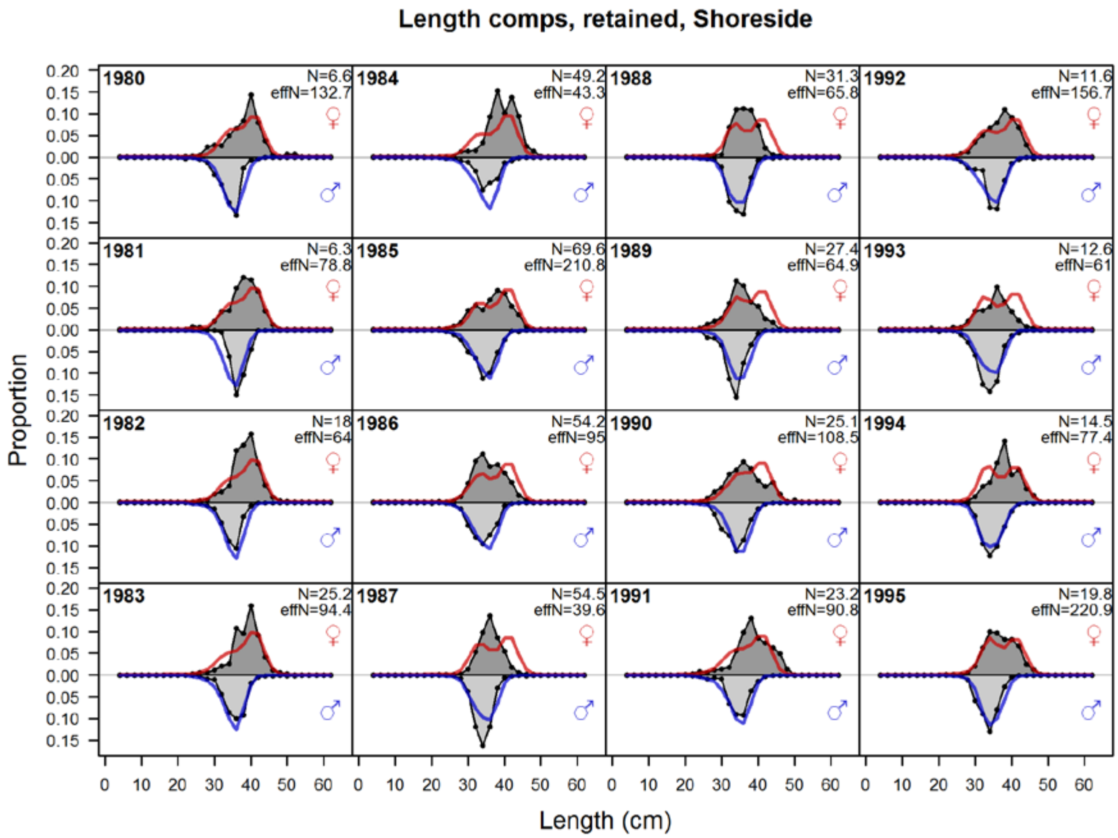

Figure 46: Fit to length-frequency distributions of darkblotched rockfish for the shoreside landings, by year.

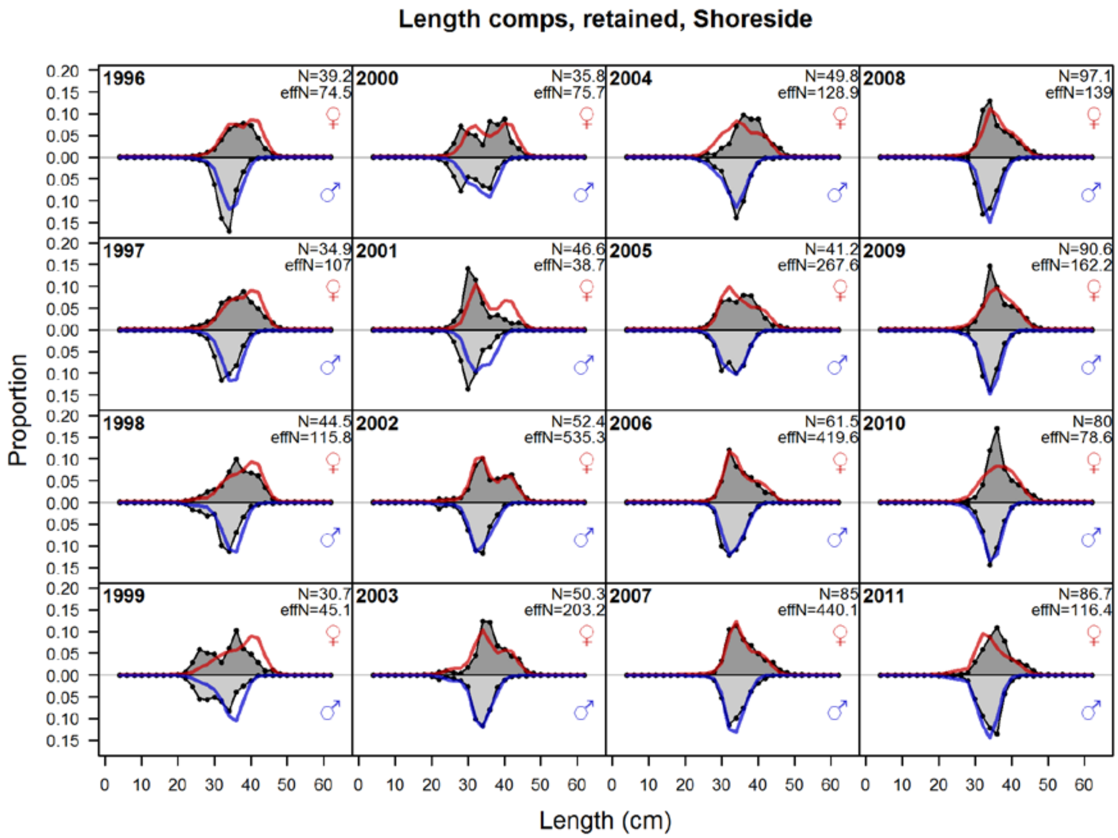

Figure 46 (continued): Fit to length-frequency distributions of darkblotched rockfish for the shoreside landings, by year.

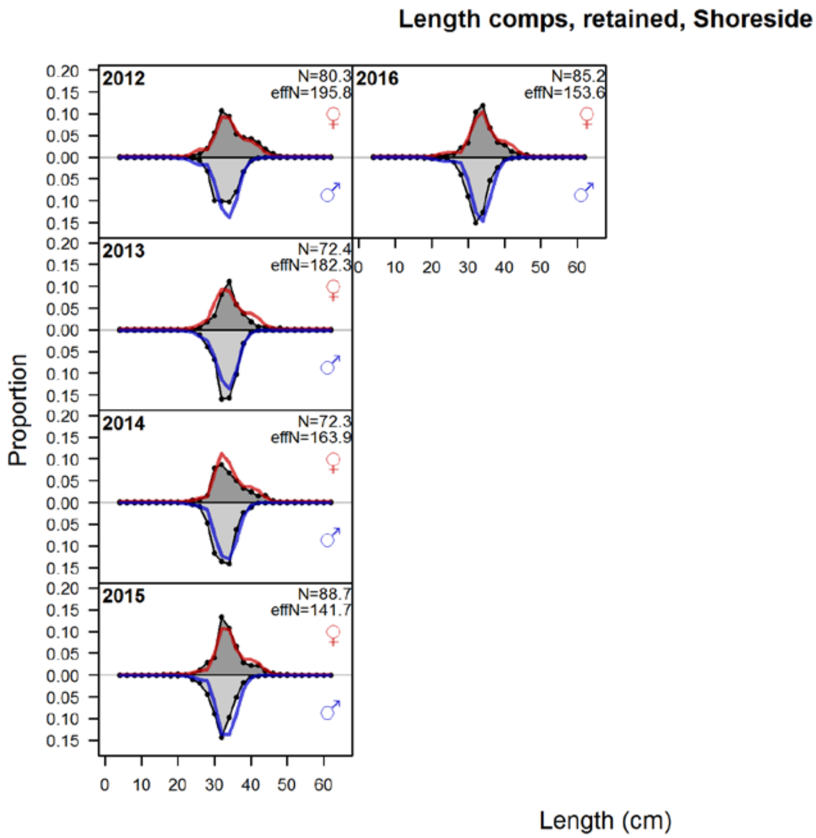

Figure 46 (continued): Fit to length-frequency distributions of darkblotched rockfish for the shoreside landings, by year.

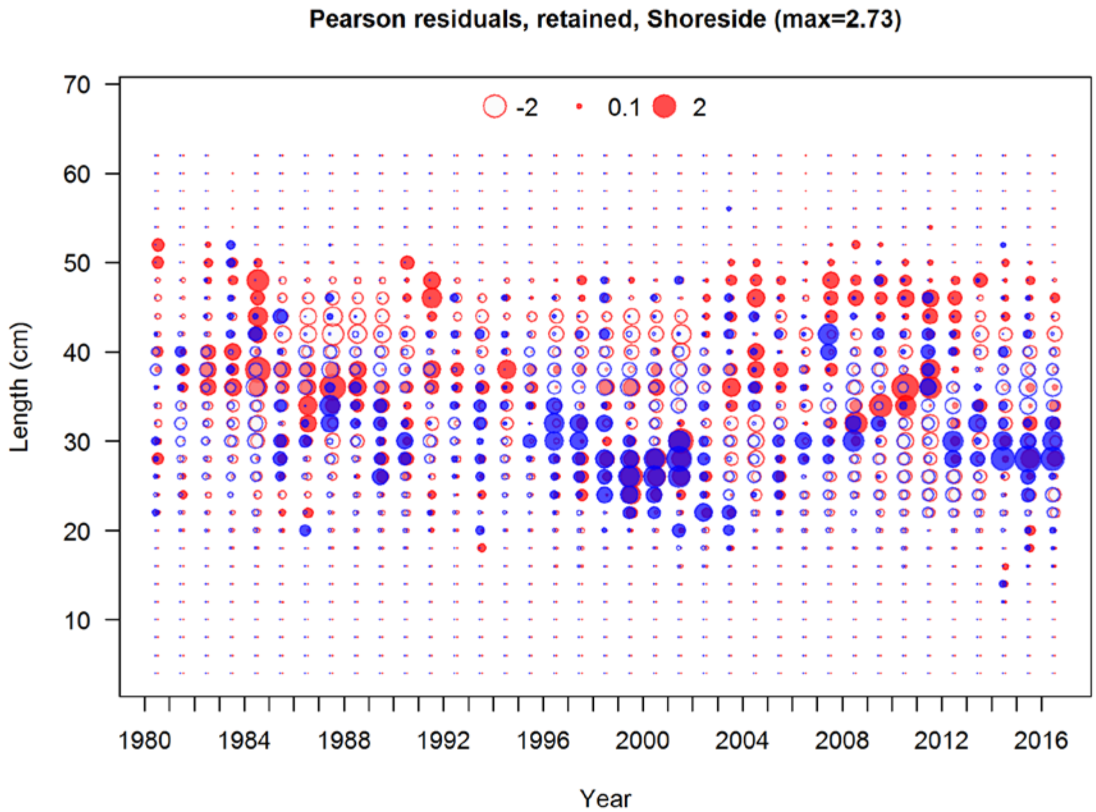

Figure 47: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) for the shoreside landings, by year.

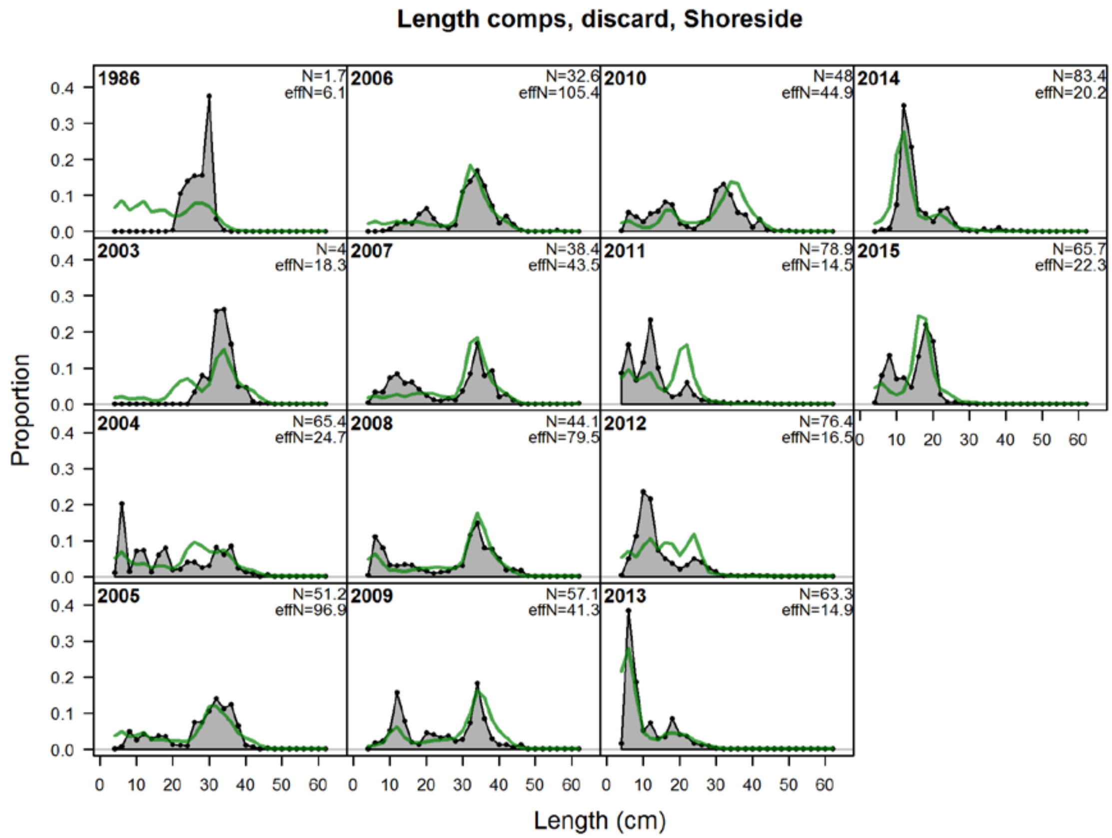

Figure 48: Fit to length-frequency distributions of darkblotched rockfish (sexes combined) for the shoreside fleet discard, by year.

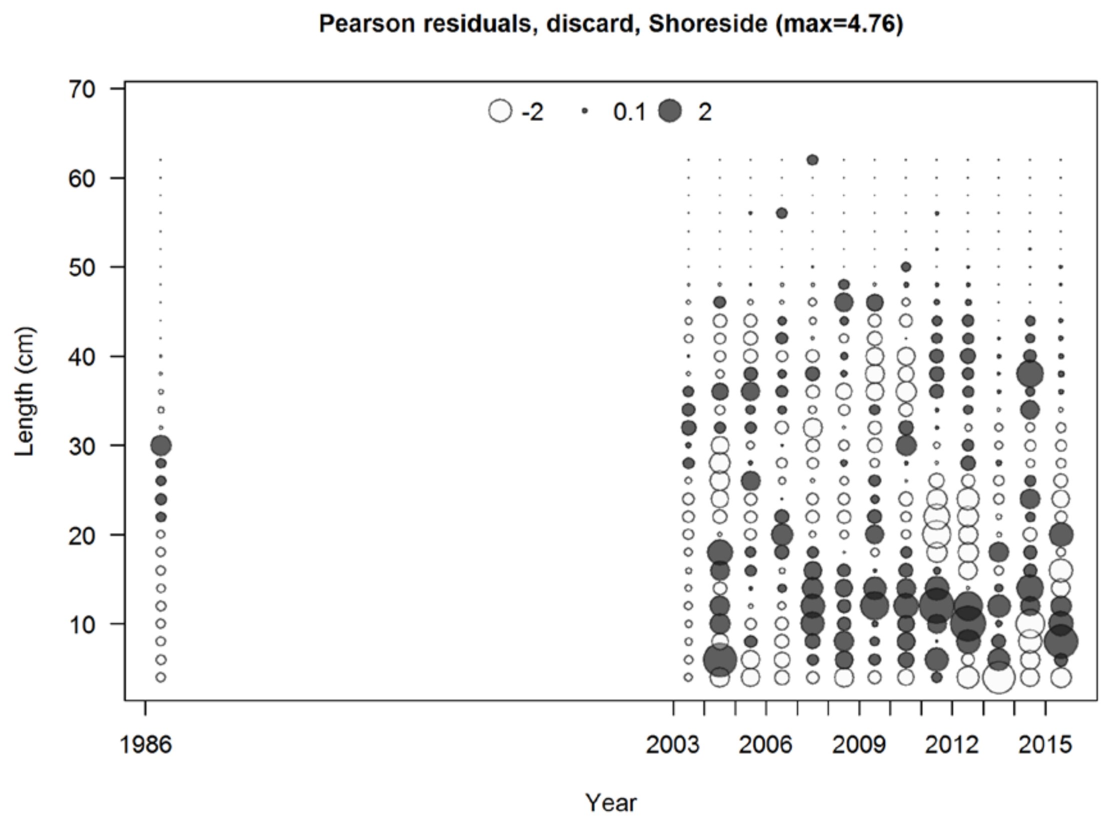

Figure 49: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (sexes combined) for the shoreside fleet discard, by year.

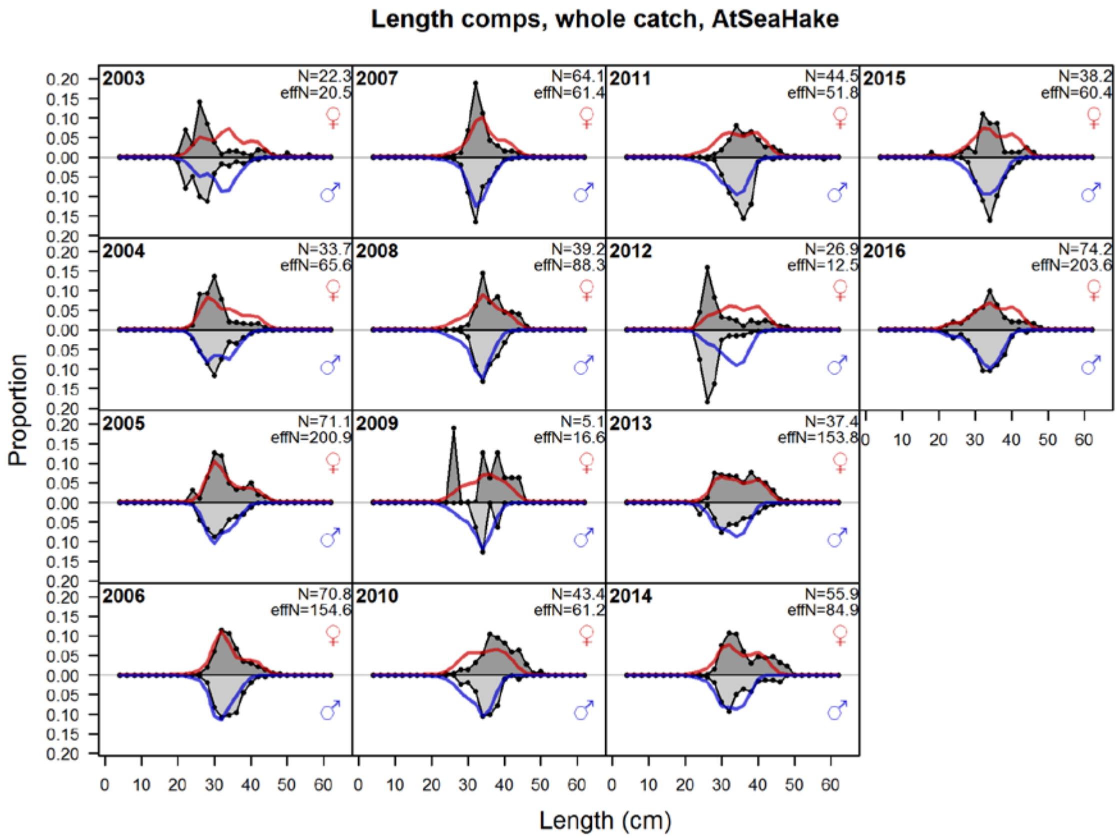

Figure 50: Fit to length-frequency distributions of darkblotched rockfish for at sea hake fishery bycatch, by year.

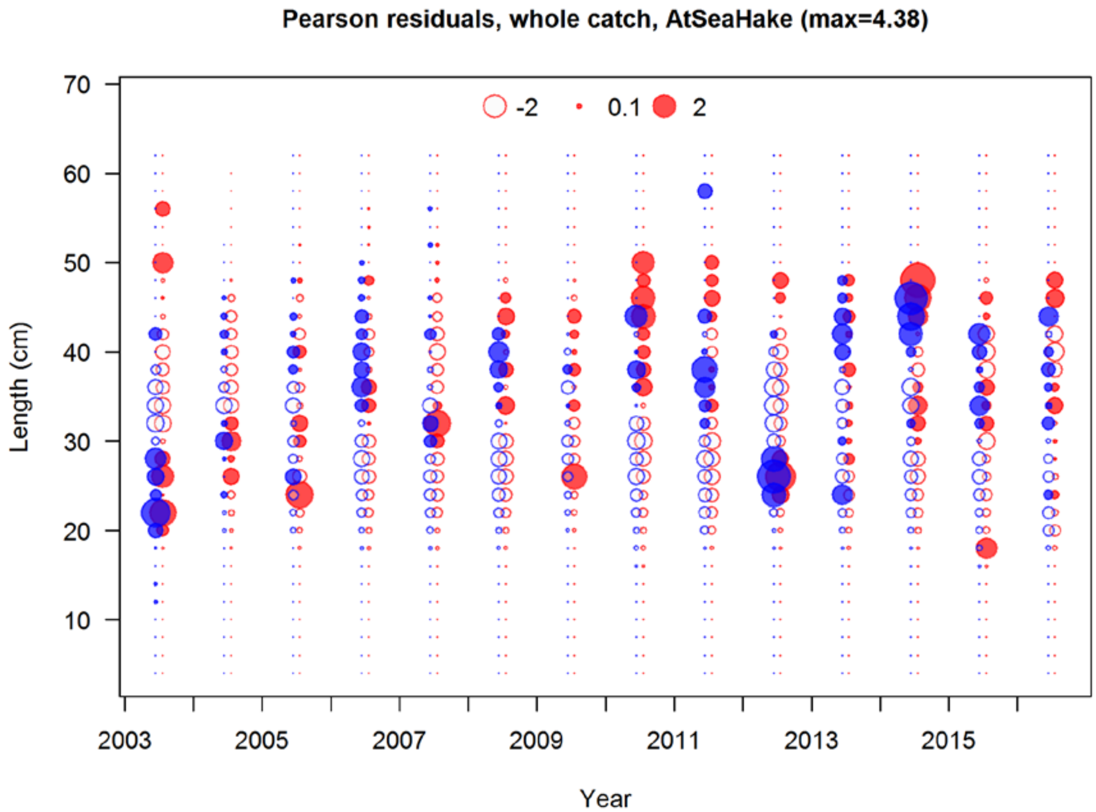

Figure 51: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) for the shoreside landings, by year.

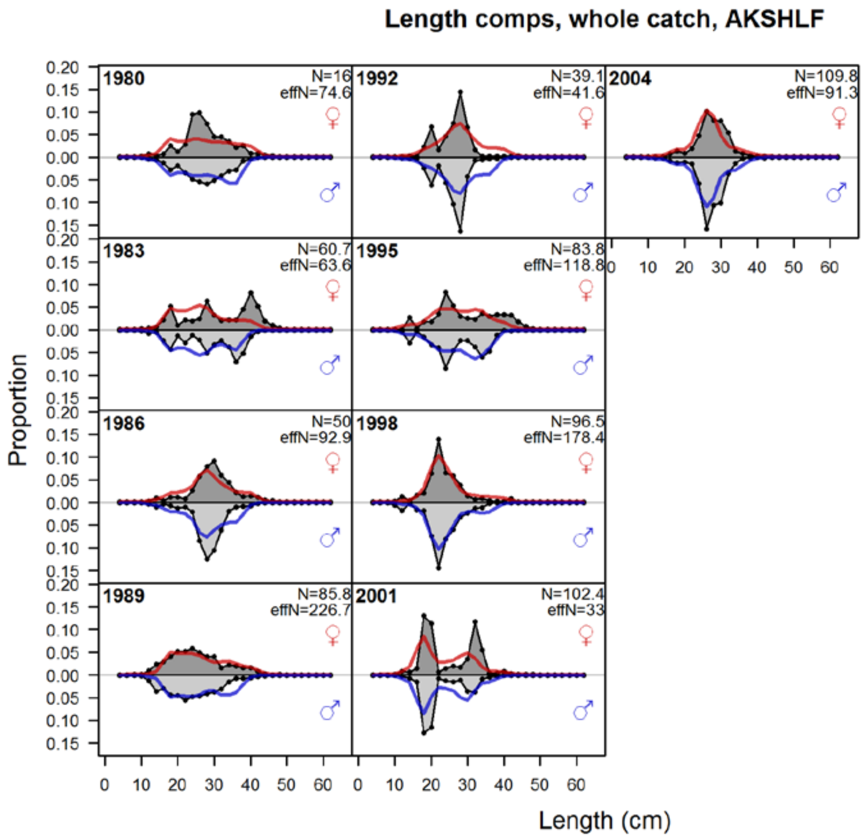

Figure 52: Fit to length-frequency distributions of darkblotched rockfish from the AFSC shelf survey, by year.

Figure 53: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey, by year.

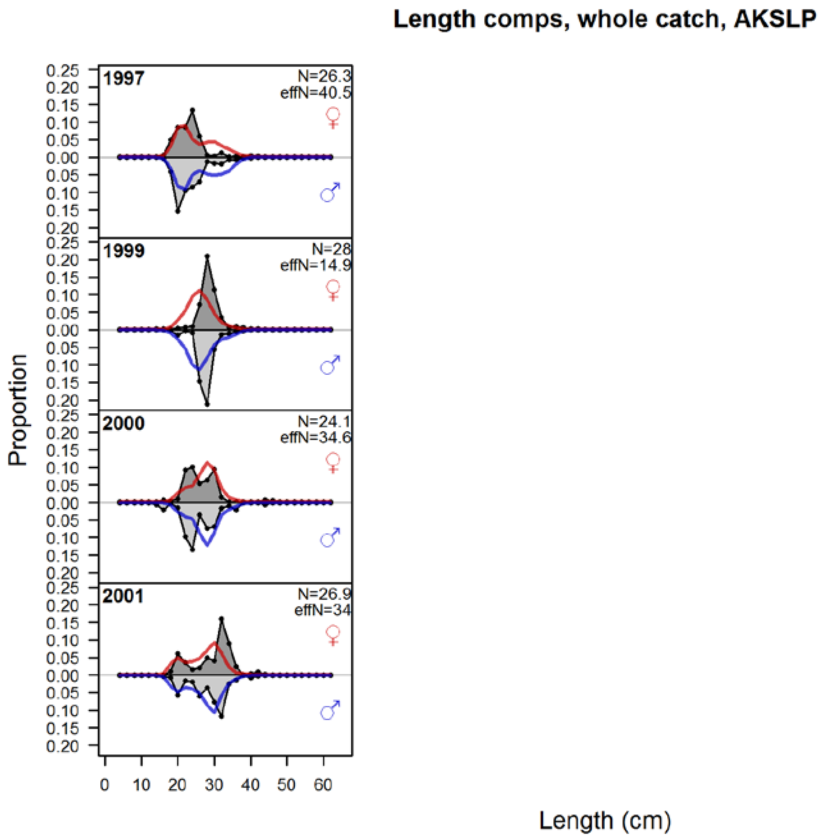

Figure 54: Fit to length-frequency distributions of darkblotched rockfish from the AFSC slope survey, by year.

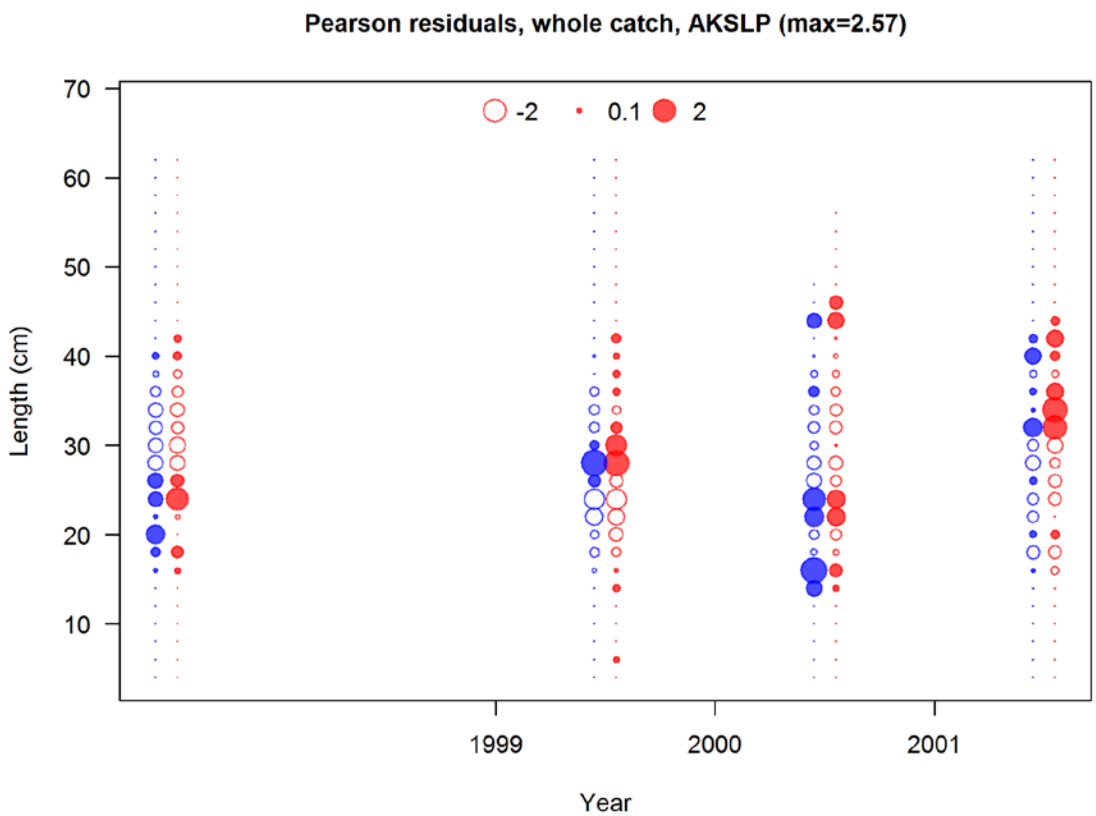

Figure 55: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the AFSC slope survey, by year.

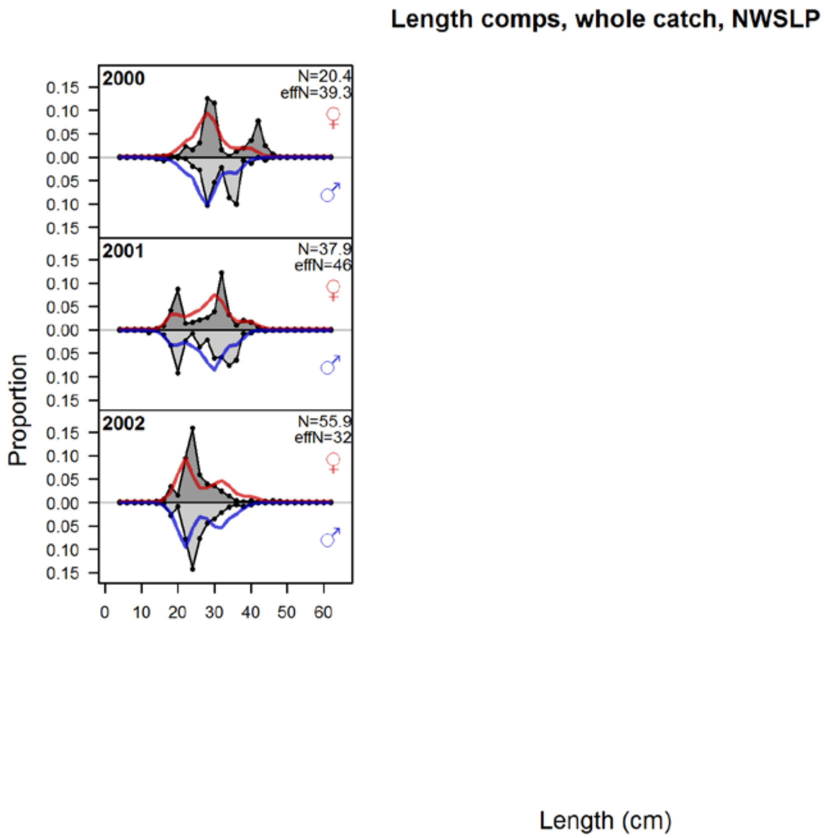

Figure 56: Fit to length-frequency distributions of darkblotched rockfish from the NWFSC slope survey, by year.

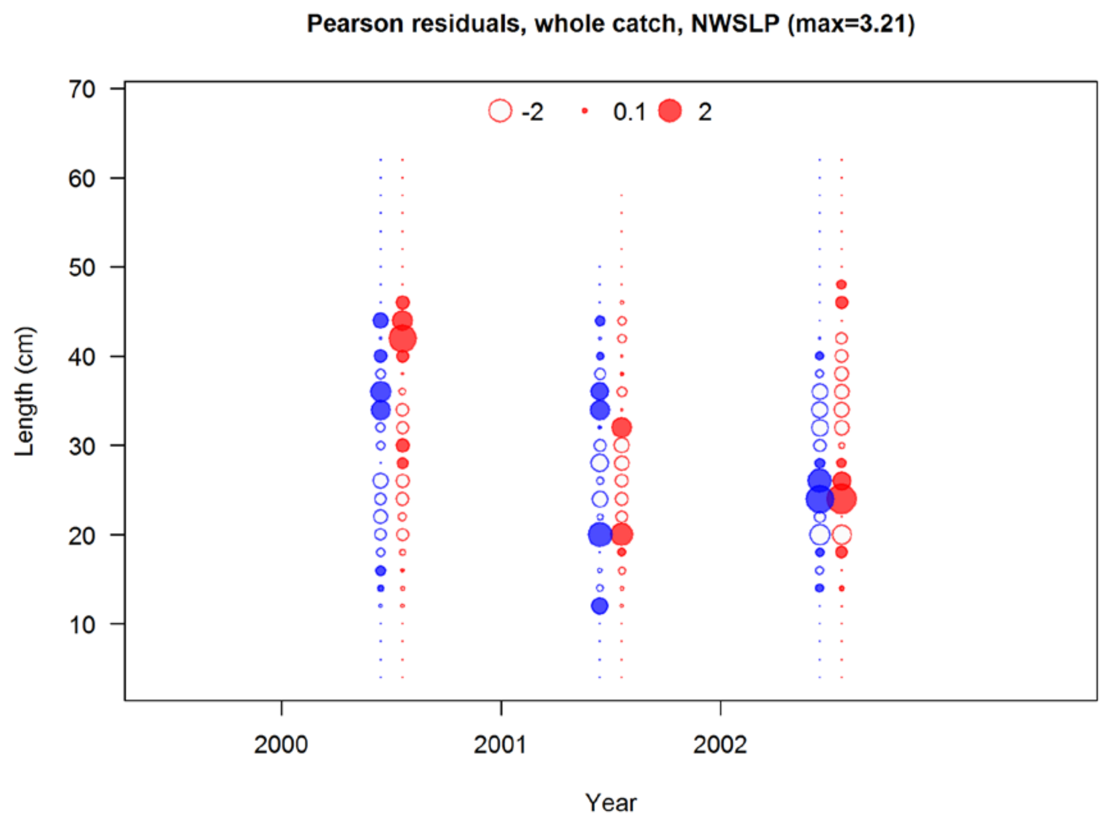

Figure 57: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC slope survey, by year.

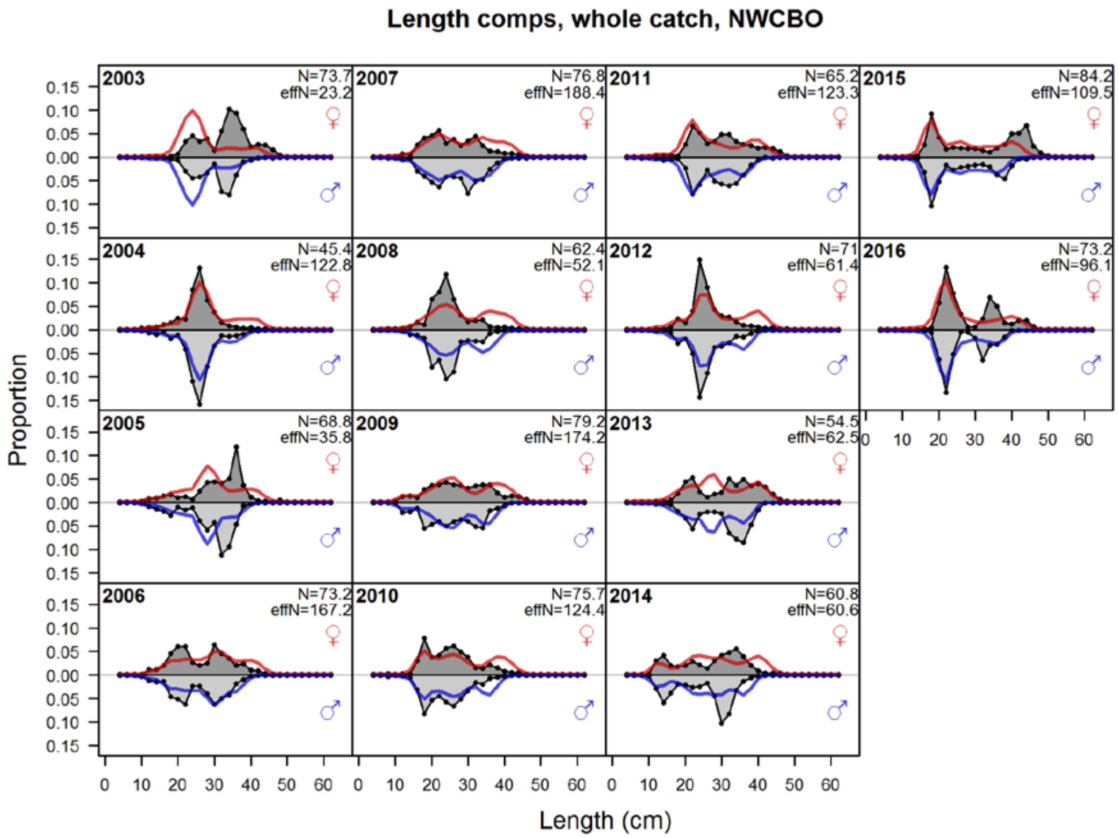

Figure 58: Fit to length-frequency distributions of darkblotched rockfish from the NWFSC shelf-slope survey by year.

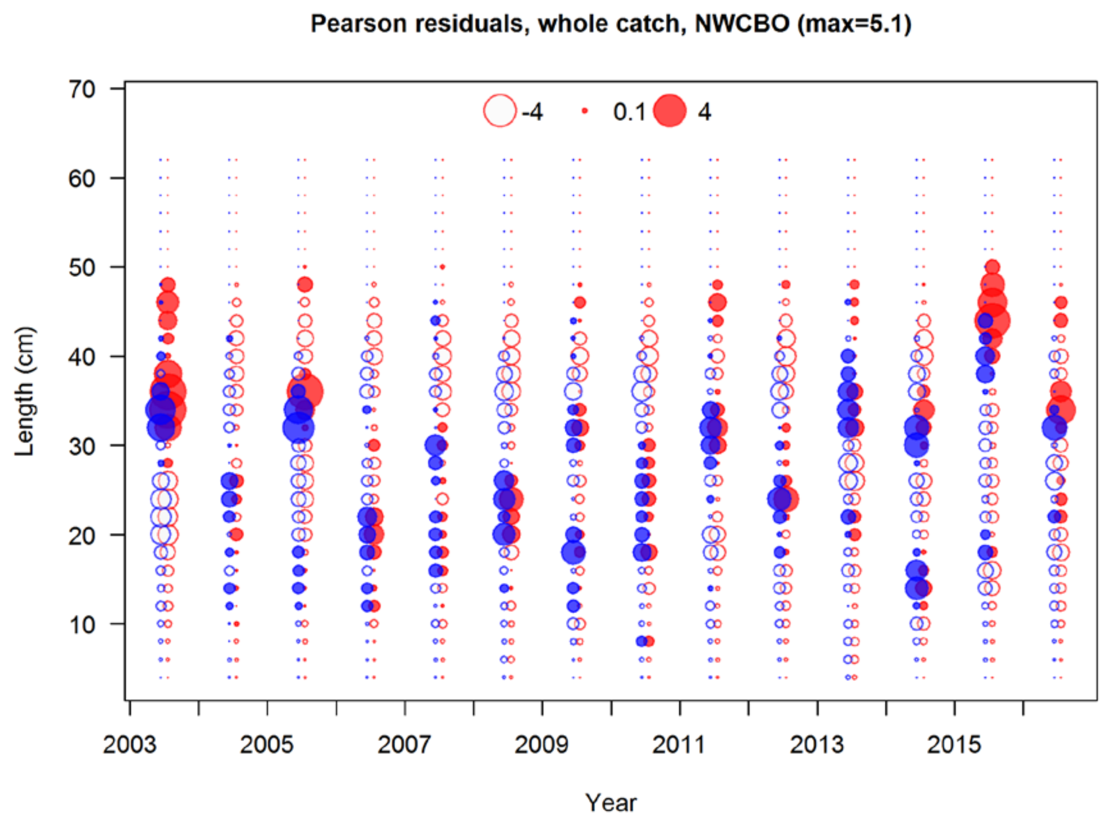

Figure 59: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey by year.

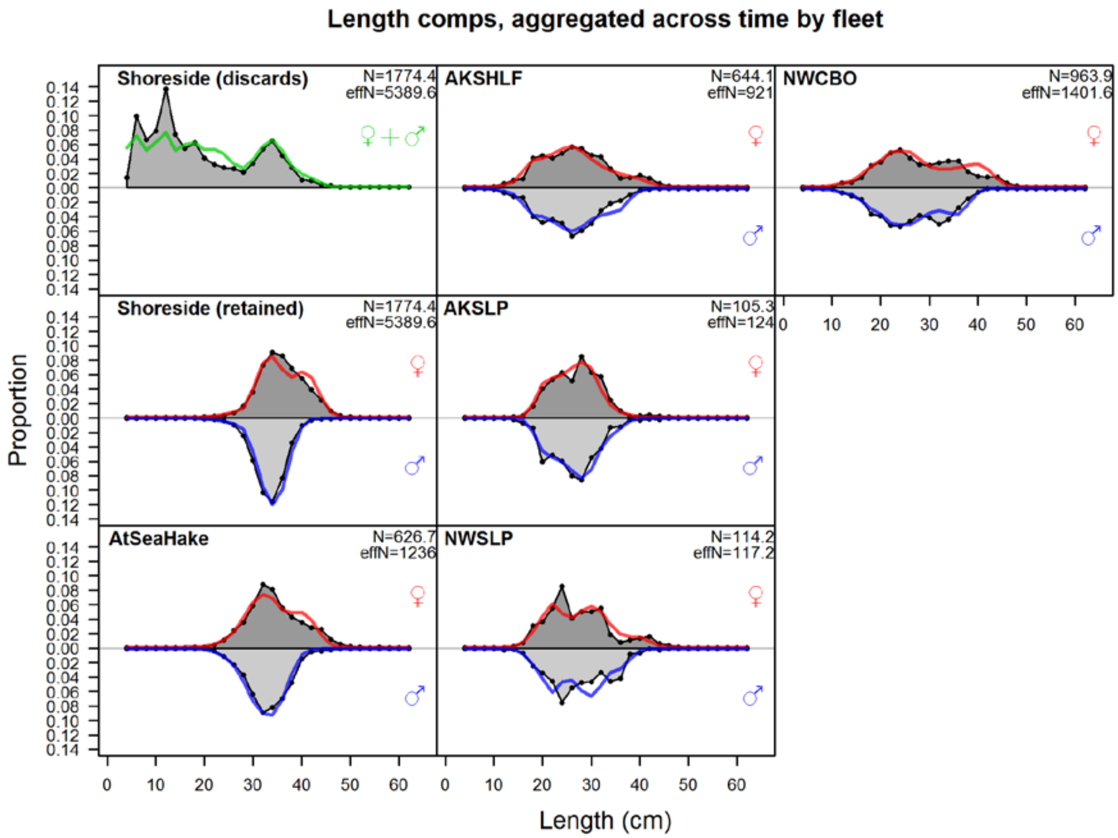

Figure 60: Fit to length-frequency distributions of darkblotched rockfish for all fleets, aggregated across all years.

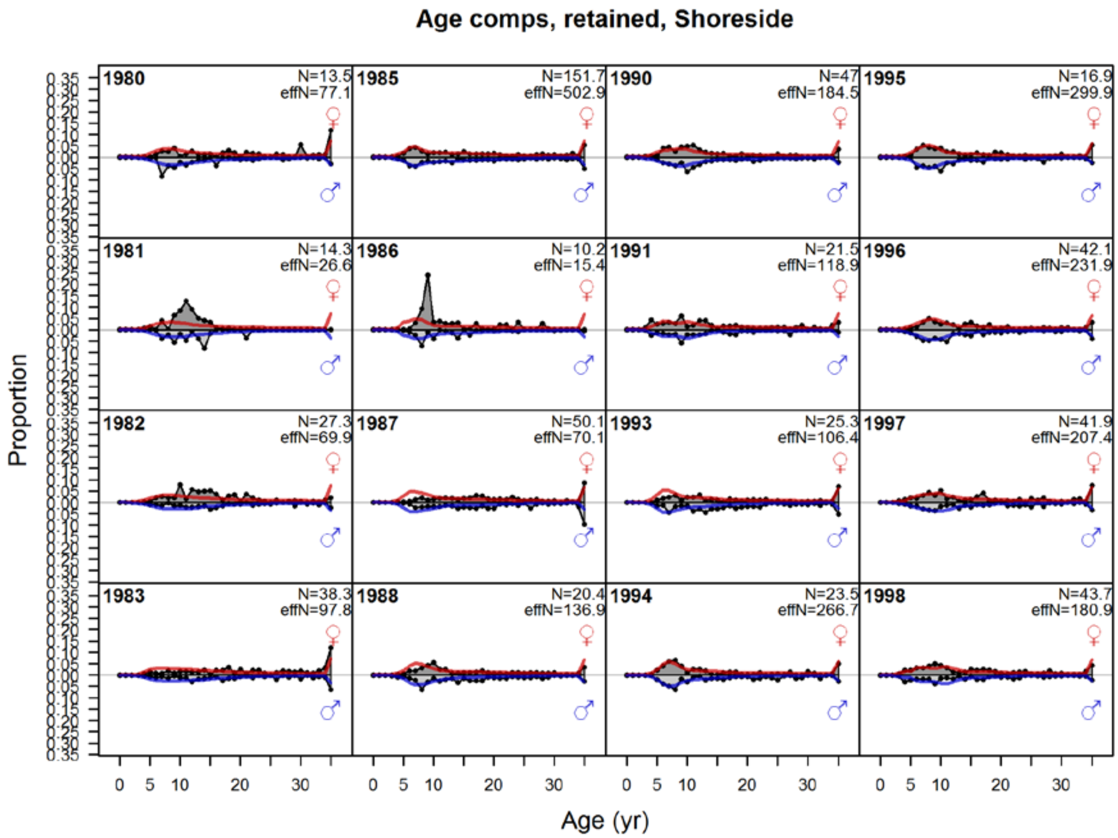

Figure 61: Fit to age-frequency distributions of darkblotched rockfish from the shoreside landings by year.

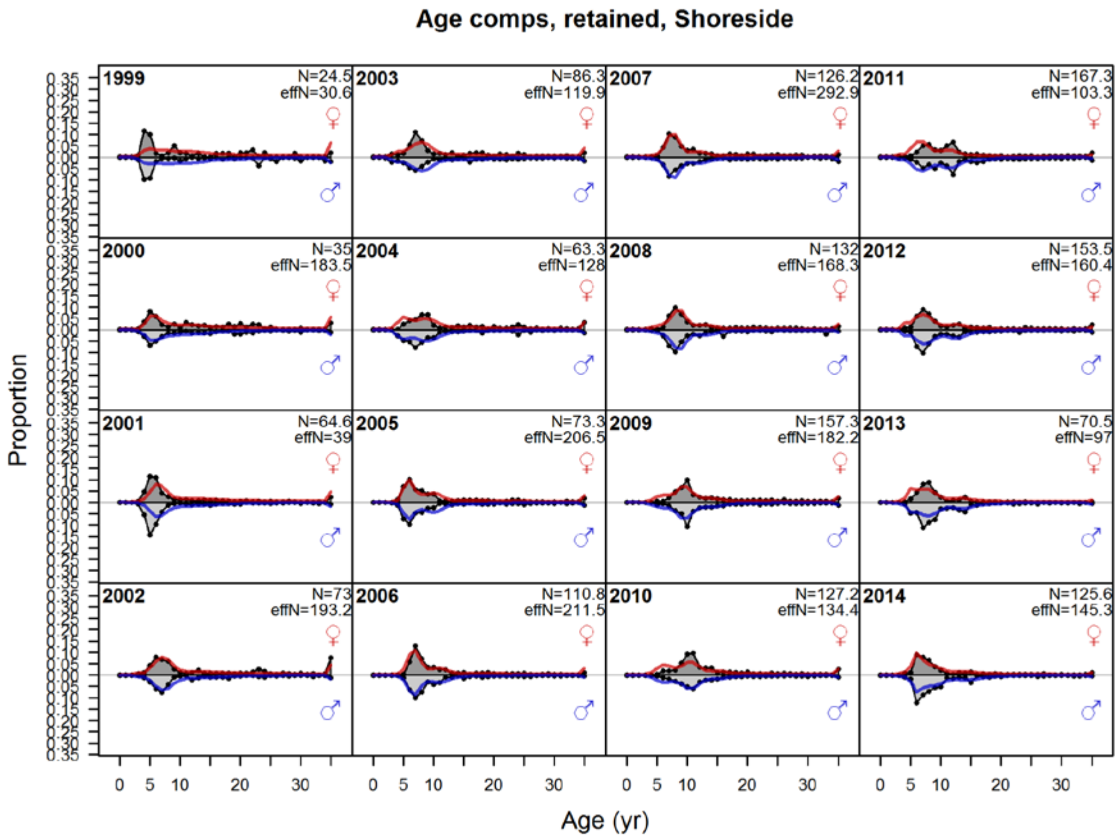

Figure 61 (continued): Fit to age-frequency distributions of darkblotched rockfish from the shoreside landings by year.

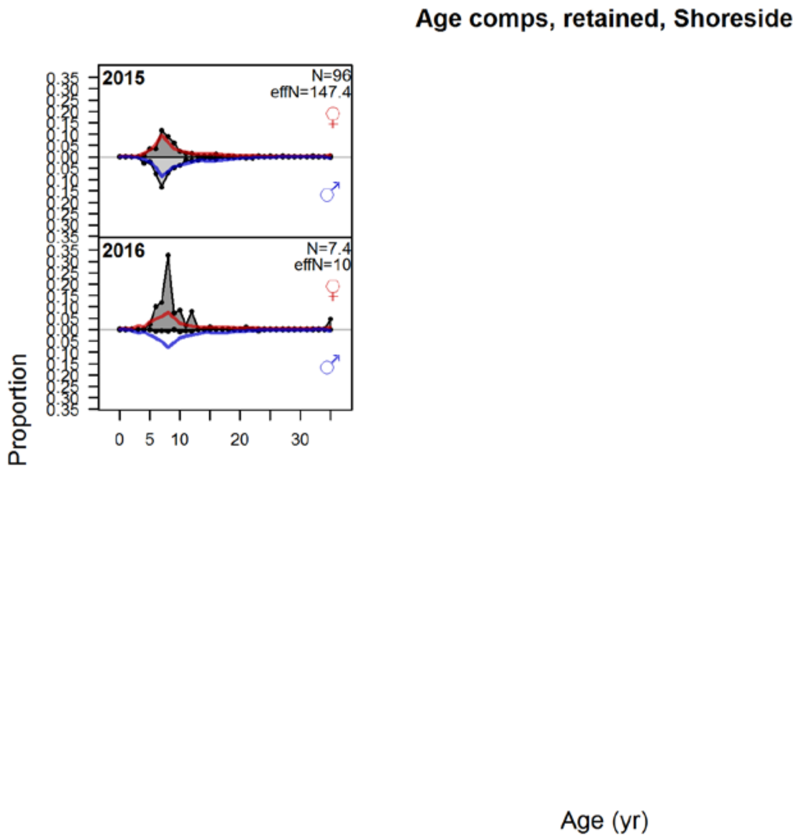

Figure 61 (continued): Fit to age-frequency distributions of darkblotched rockfish from the shoreside landings by year.

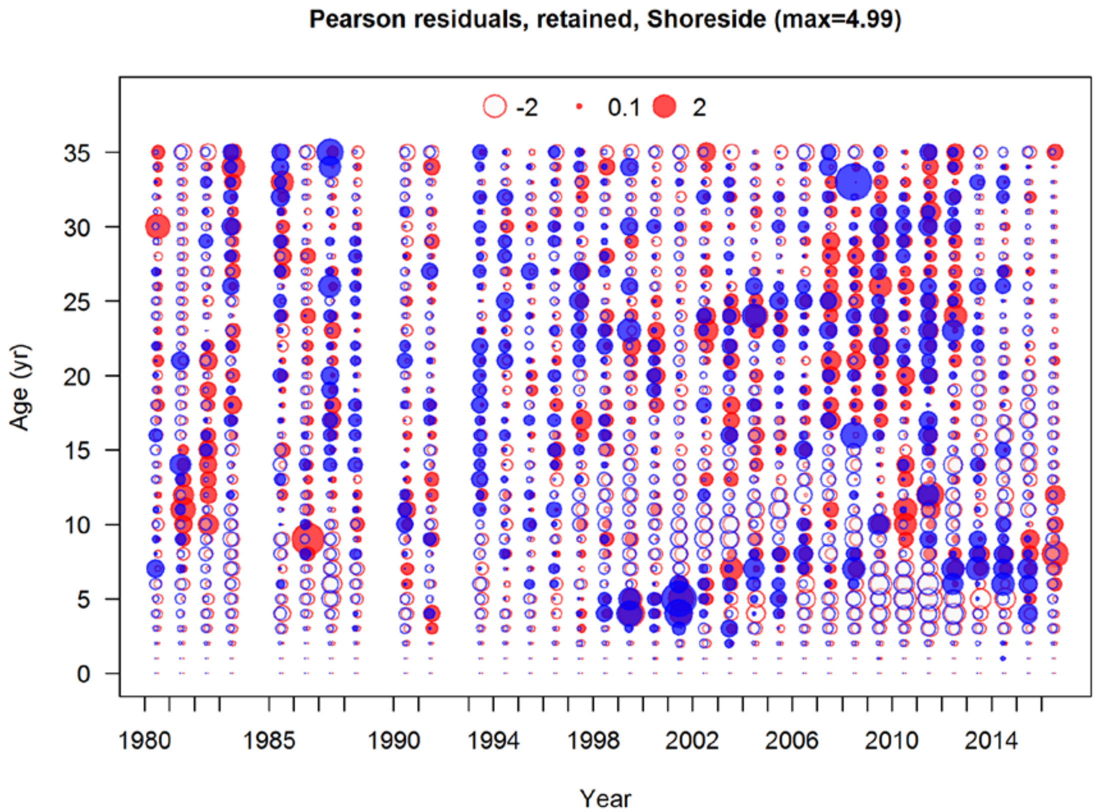

Figure 62: Pearson residuals for the fit to age-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the shoreside landings.

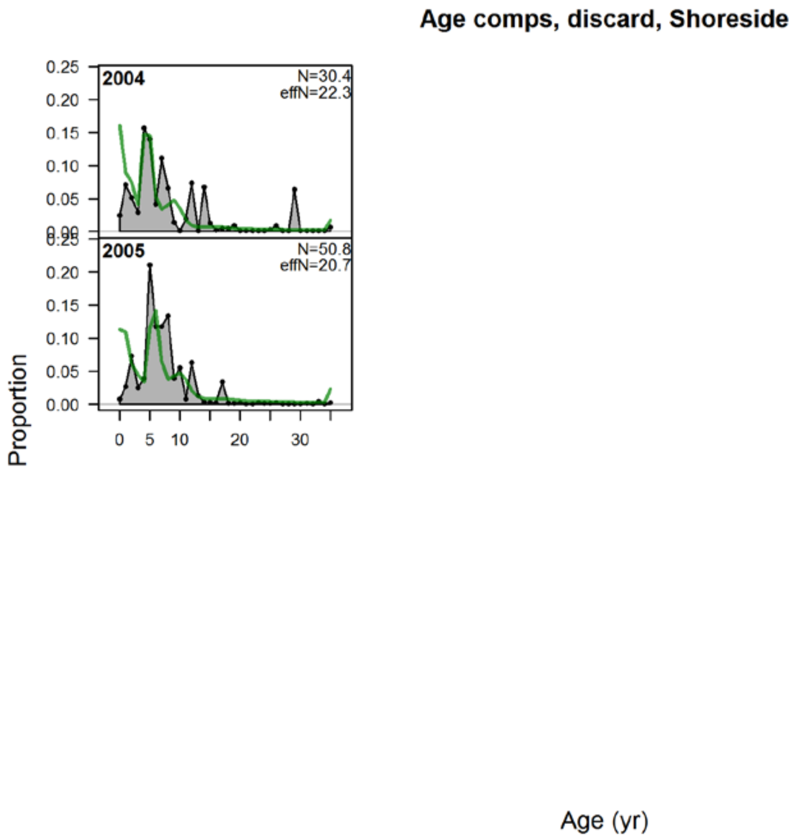

Figure 63: Fit to age-frequency distributions of darkblotched rockfish (sexes combined) from the shoreside fishery discard by year.

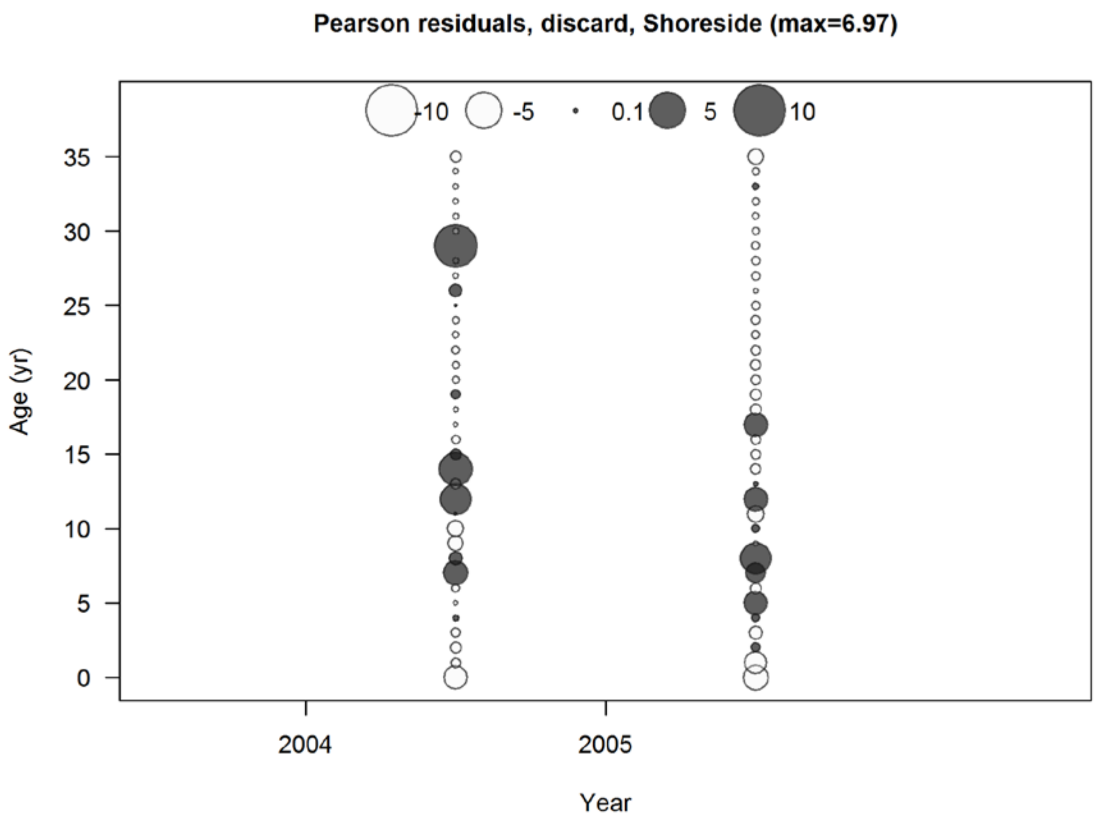

Figure 64: Pearson residuals for the fit to age-frequency distributions of darkblotched rockfish (sexes combined) from the shoreside fishery discard**.**

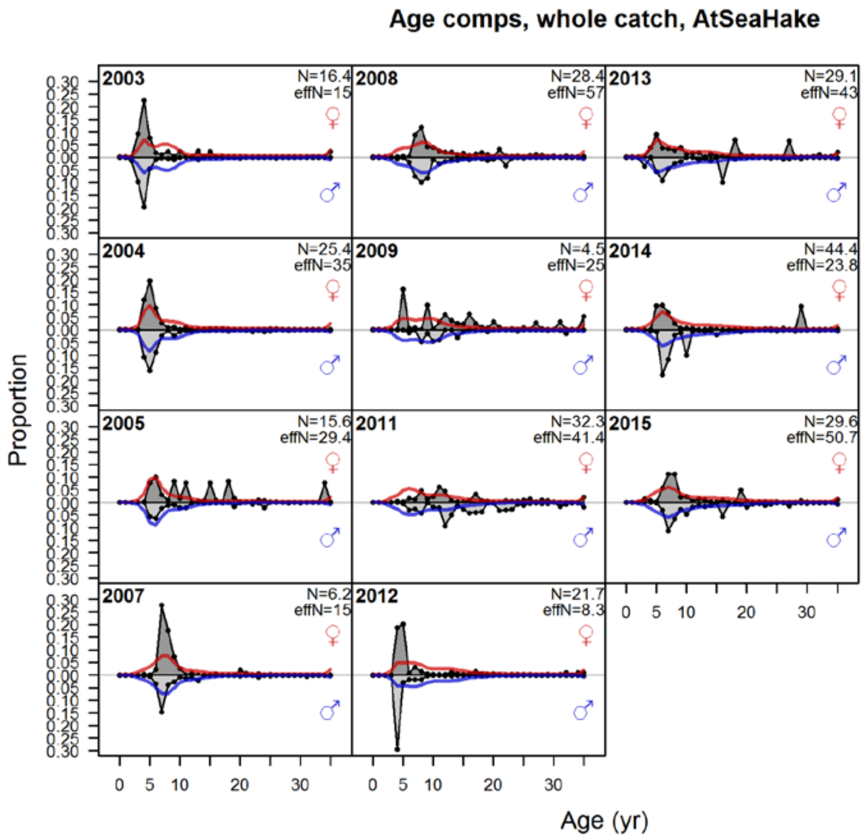

Figure 65: Fit to age-frequency distributions of darkblotched rockfish from the at-sea hake fishery bycatch by year.

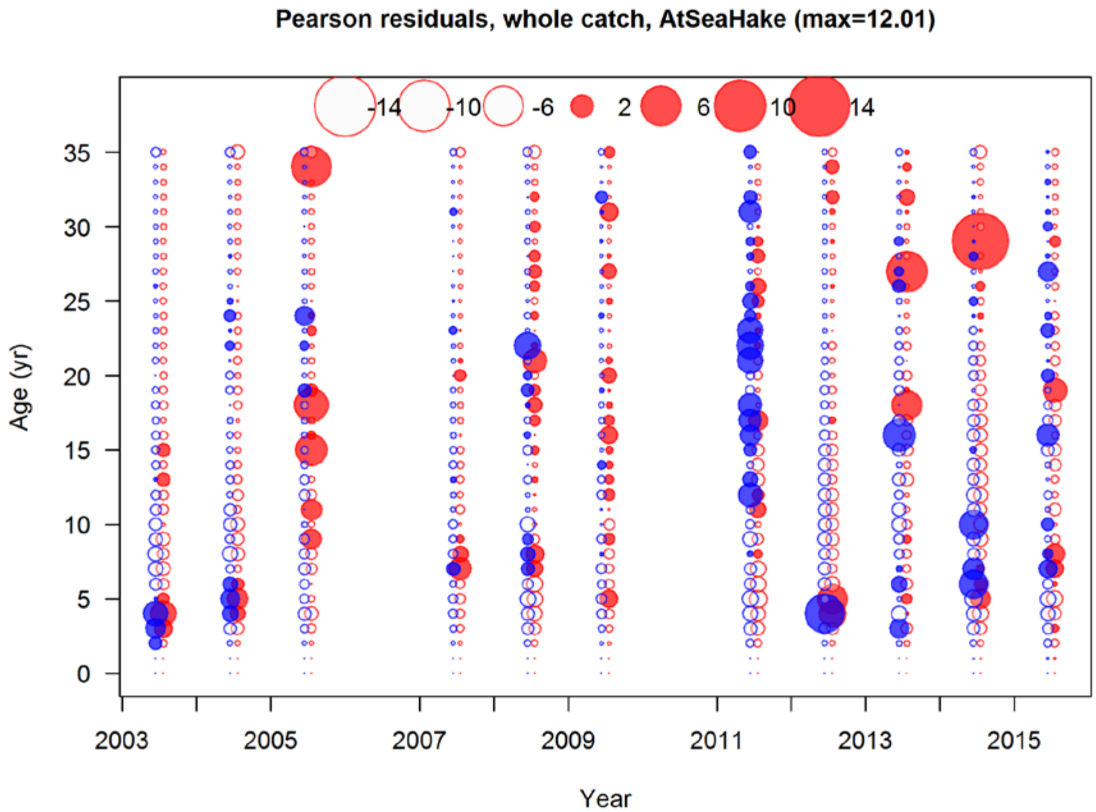

Figure 66: Pearson residuals for the fit to age-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the shoreside landings.

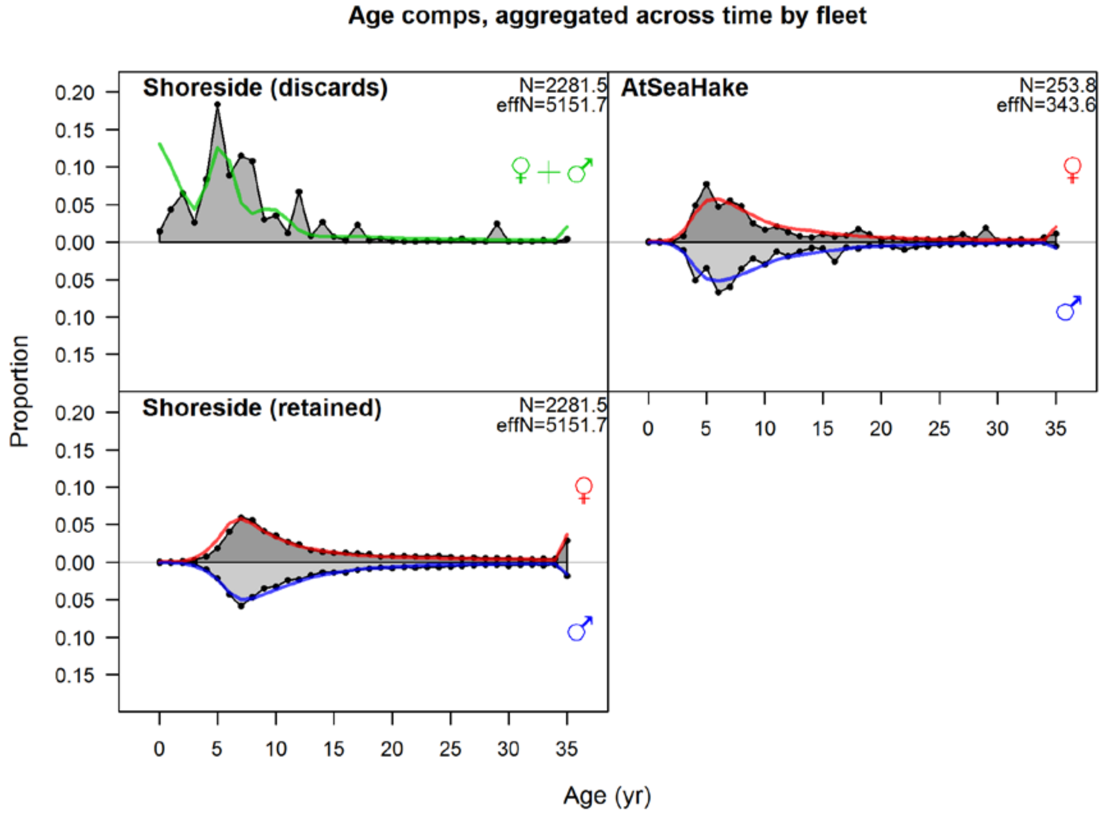

Figure 67: Fit to age-frequency distributions of darkblotched rockfish from shoreside retained, shoreside discards, and at-sea fishery bycatch, aggregated across all years.

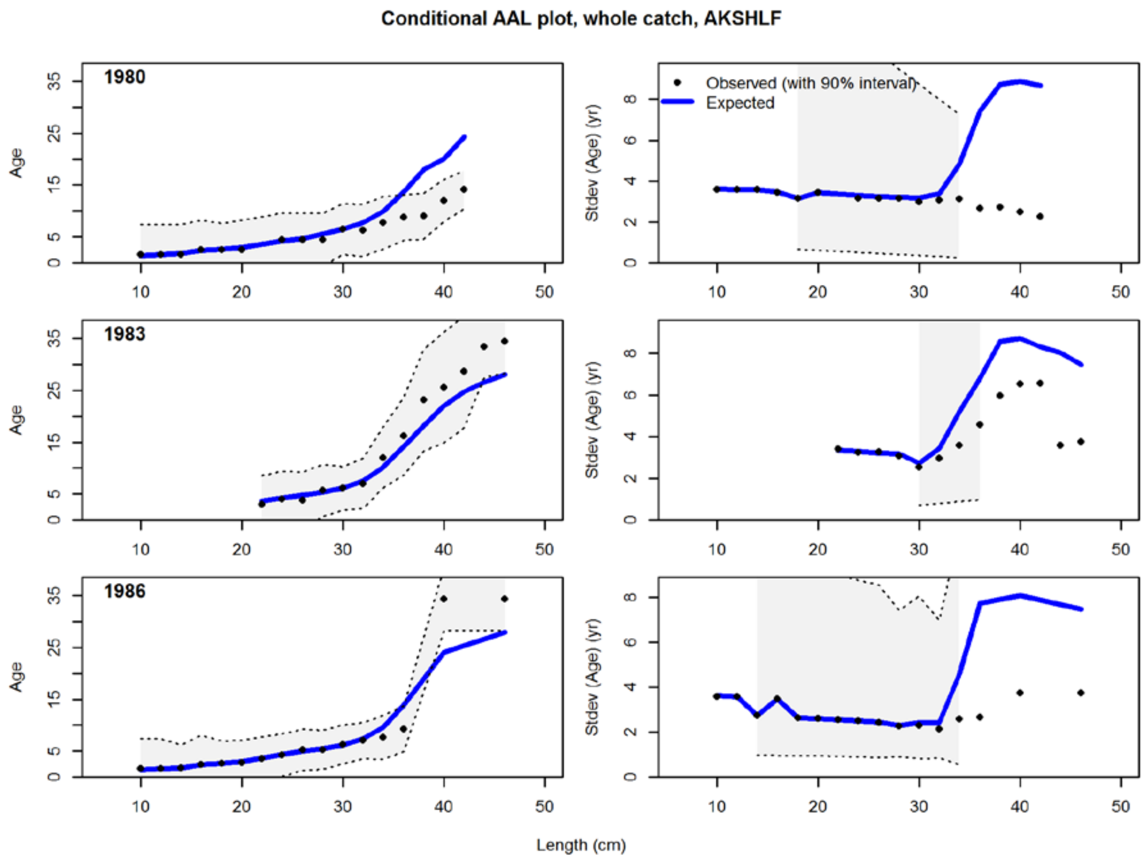

Figure 68: Fit to conditional ages-at-length compositions of female darkblotched rockfish from the AFSC shelf survey.

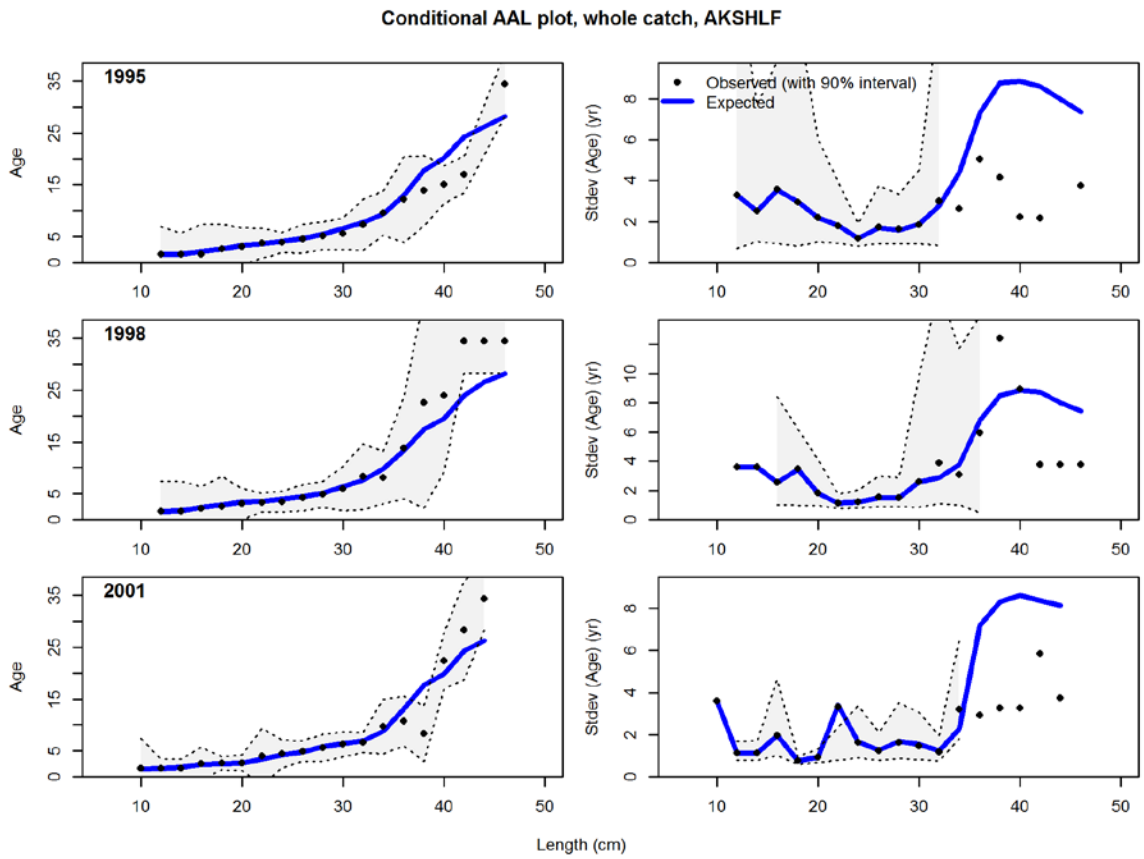

Figure 68 (continued): Fit to conditional ages-at-length compositions of female darkblotched rockfish from the AFSC shelf survey.

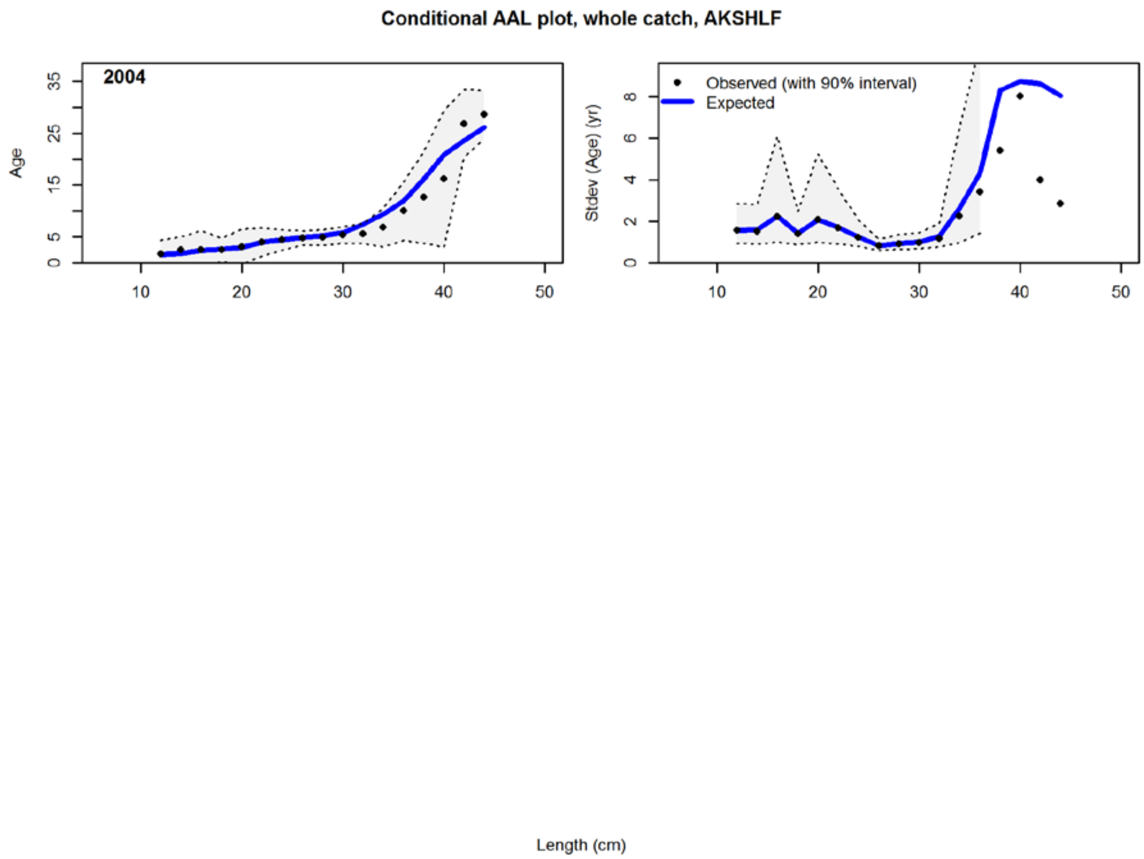

Figure 68 (continued): Fit to conditional ages-at-length compositions of female darkblotched rockfish from the AFSC shelf survey.

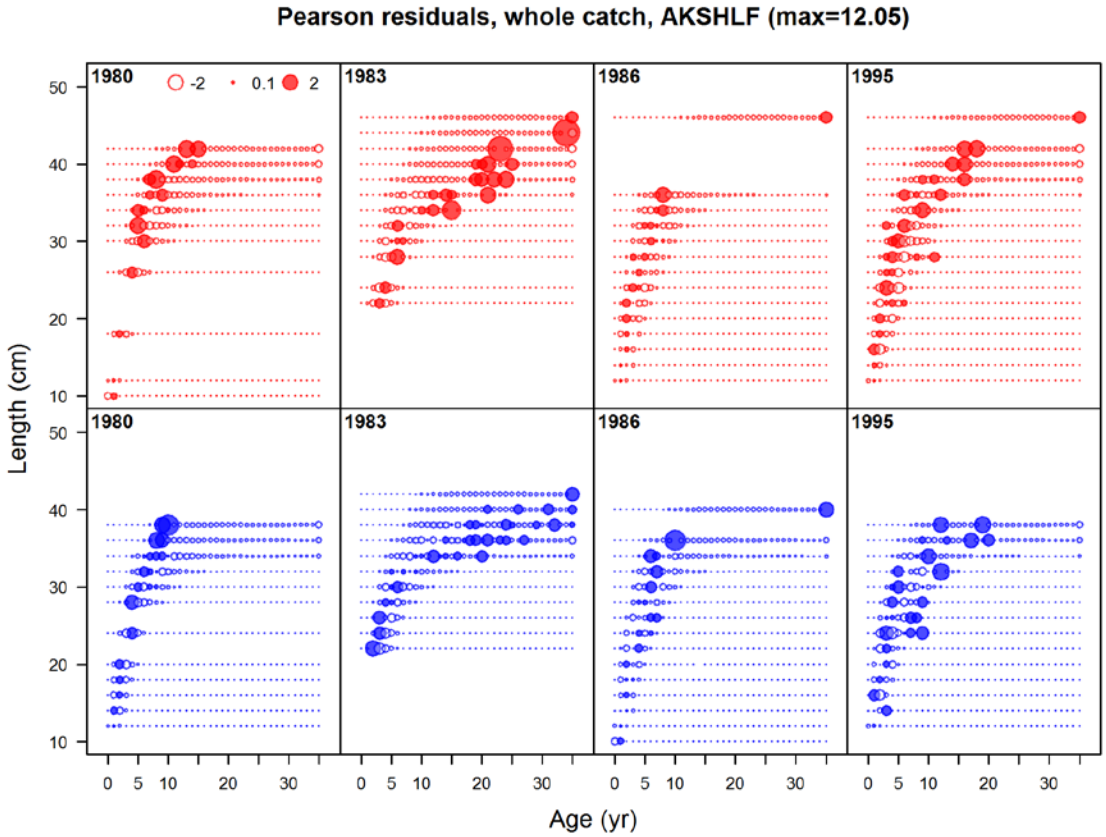

Figure 69: Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey.

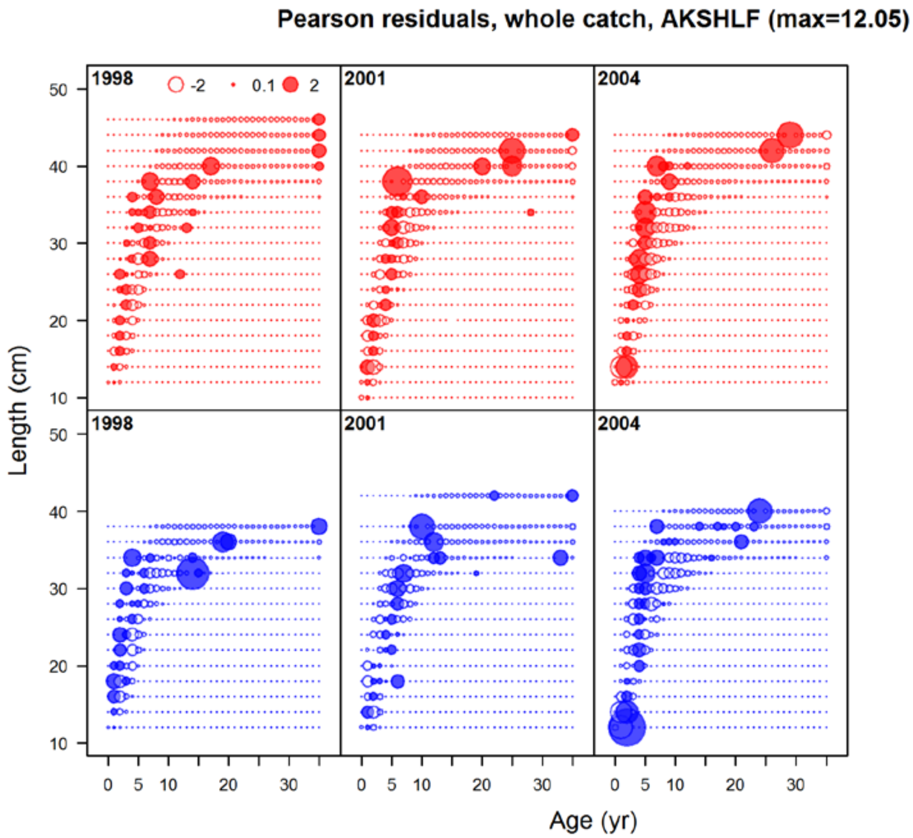

Figure 69 (continued): Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey.

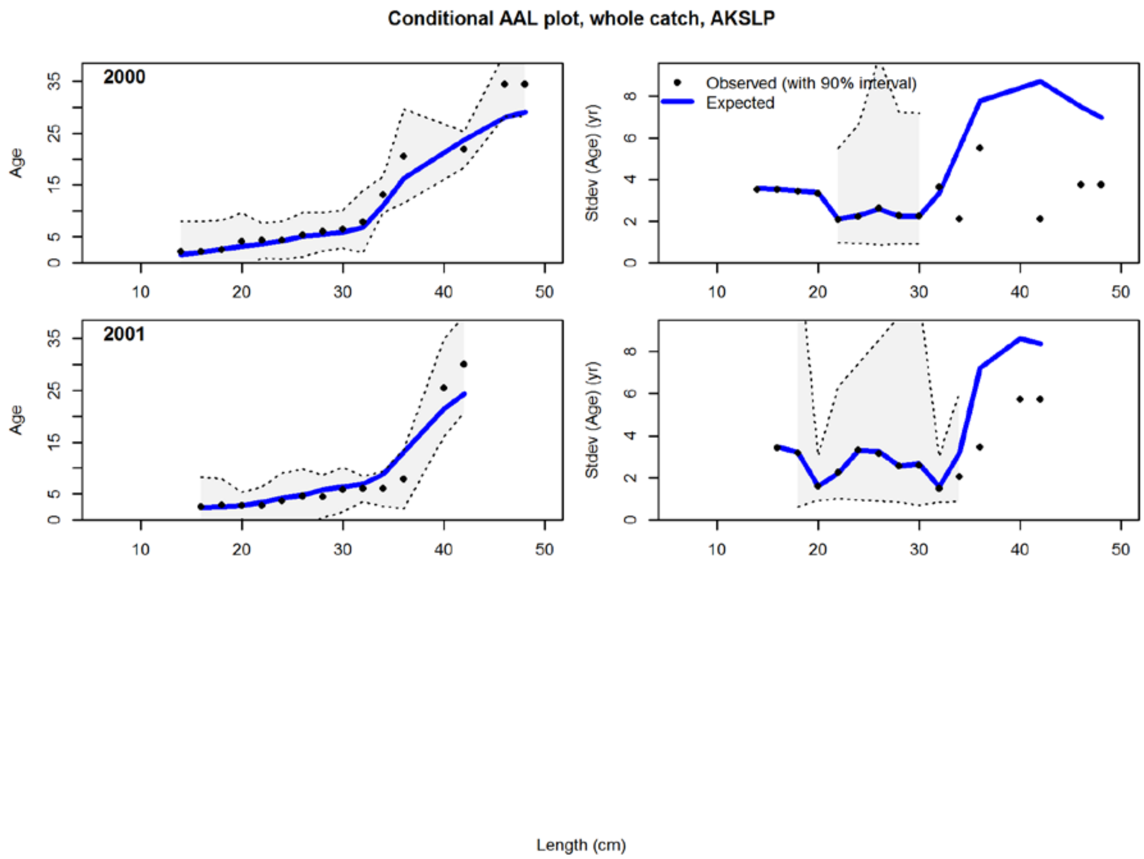

Figure 70: Fit to conditional ages-at-length compositions of darkblotched rockfish from the AFSC slope survey.

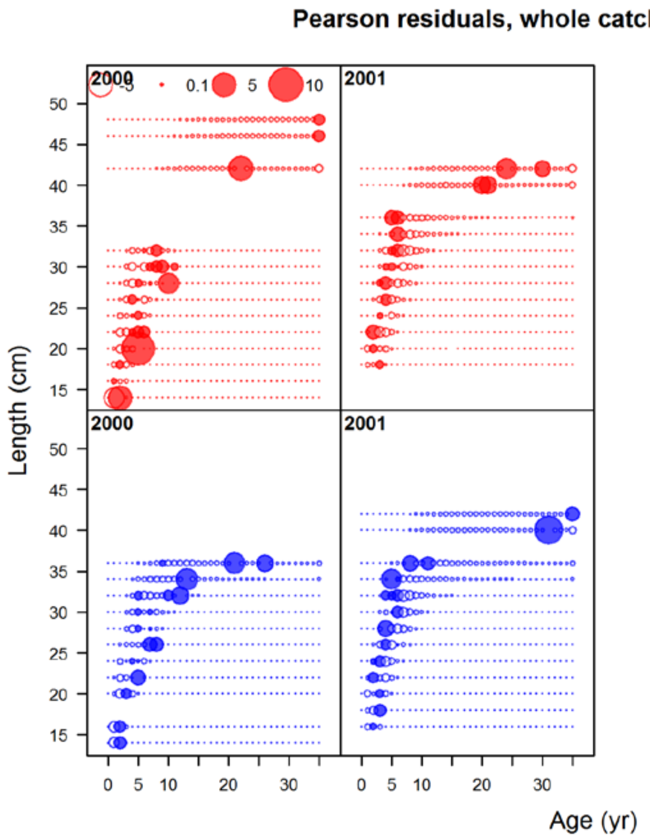

Figure 71: Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown red, males in blue) from the AFSC slope survey.

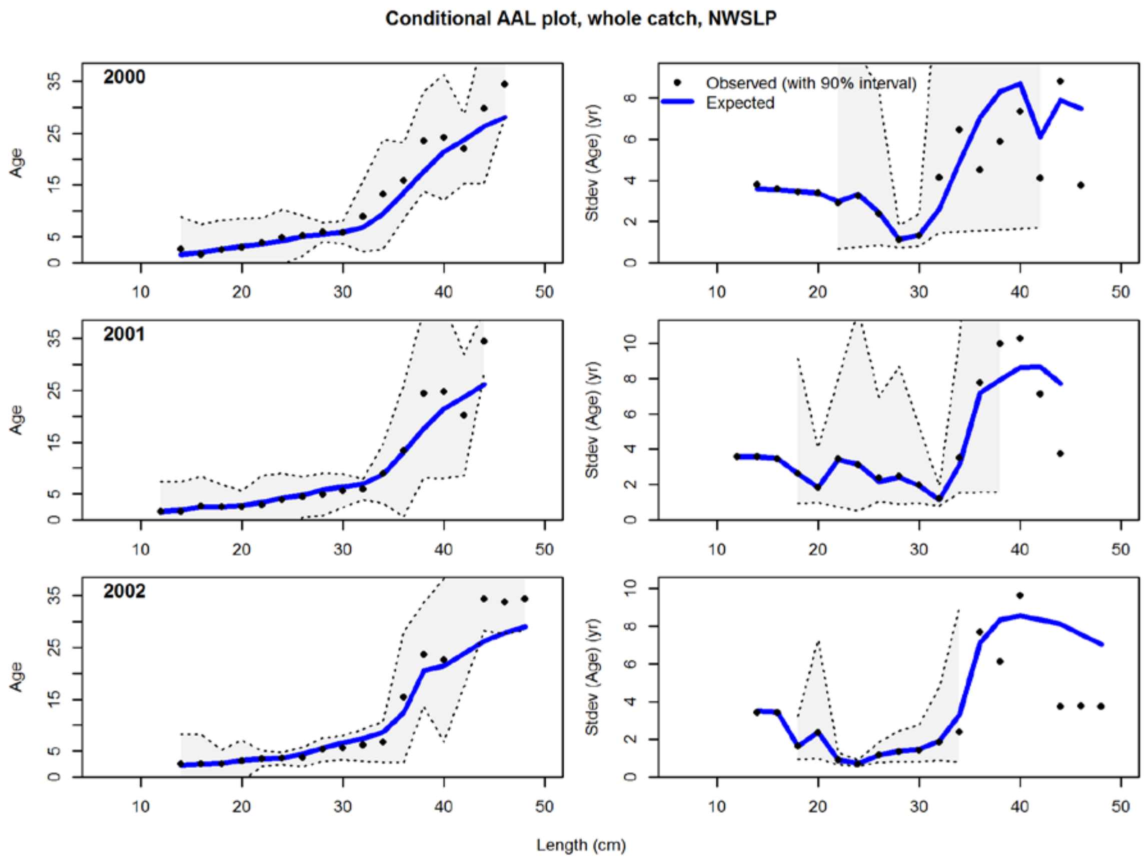

Figure 72: Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC slope survey.

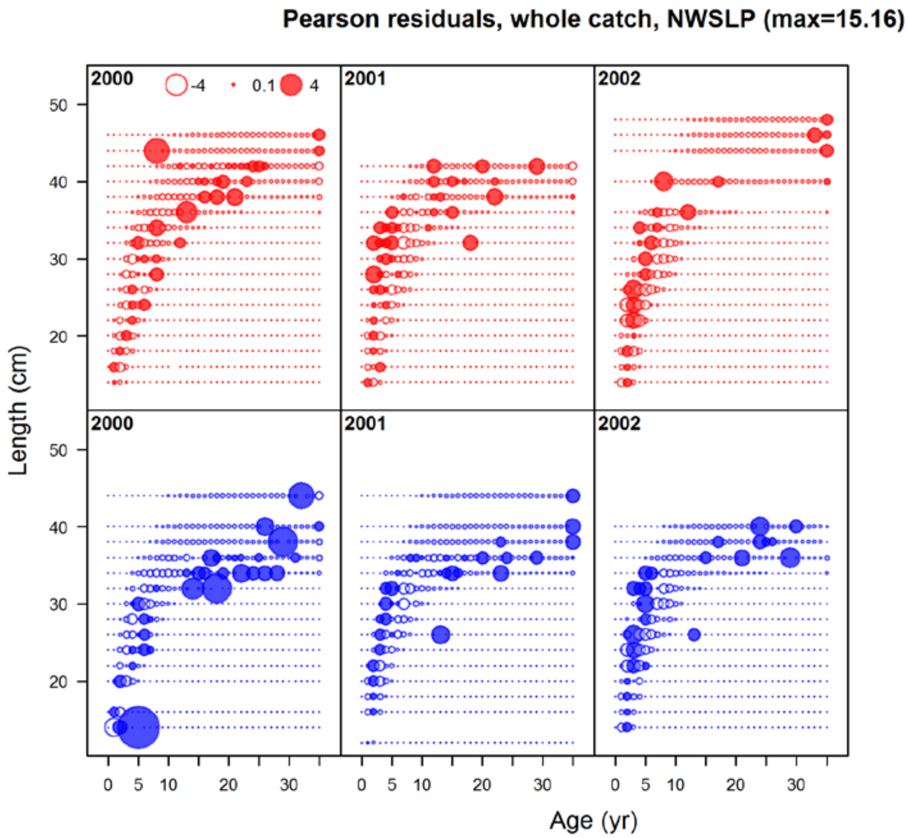

Figure 73: Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC slope survey.

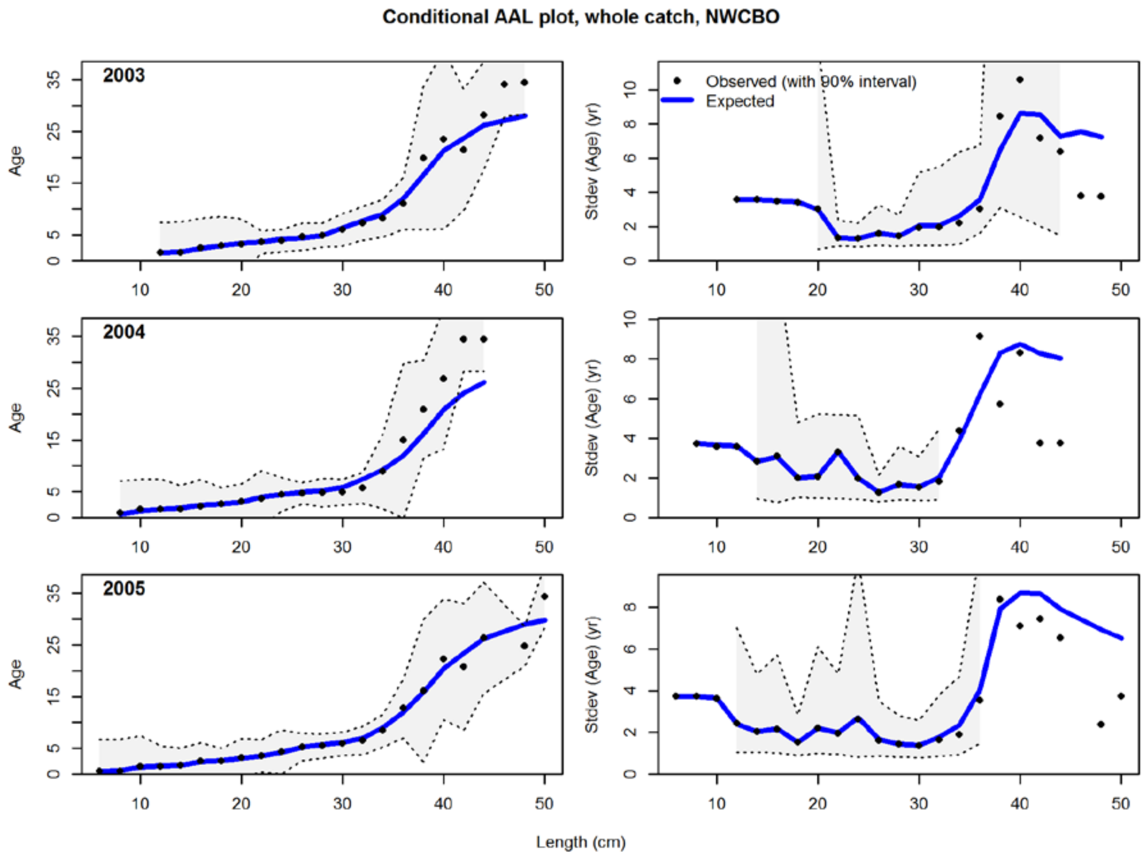

Figure 74: Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

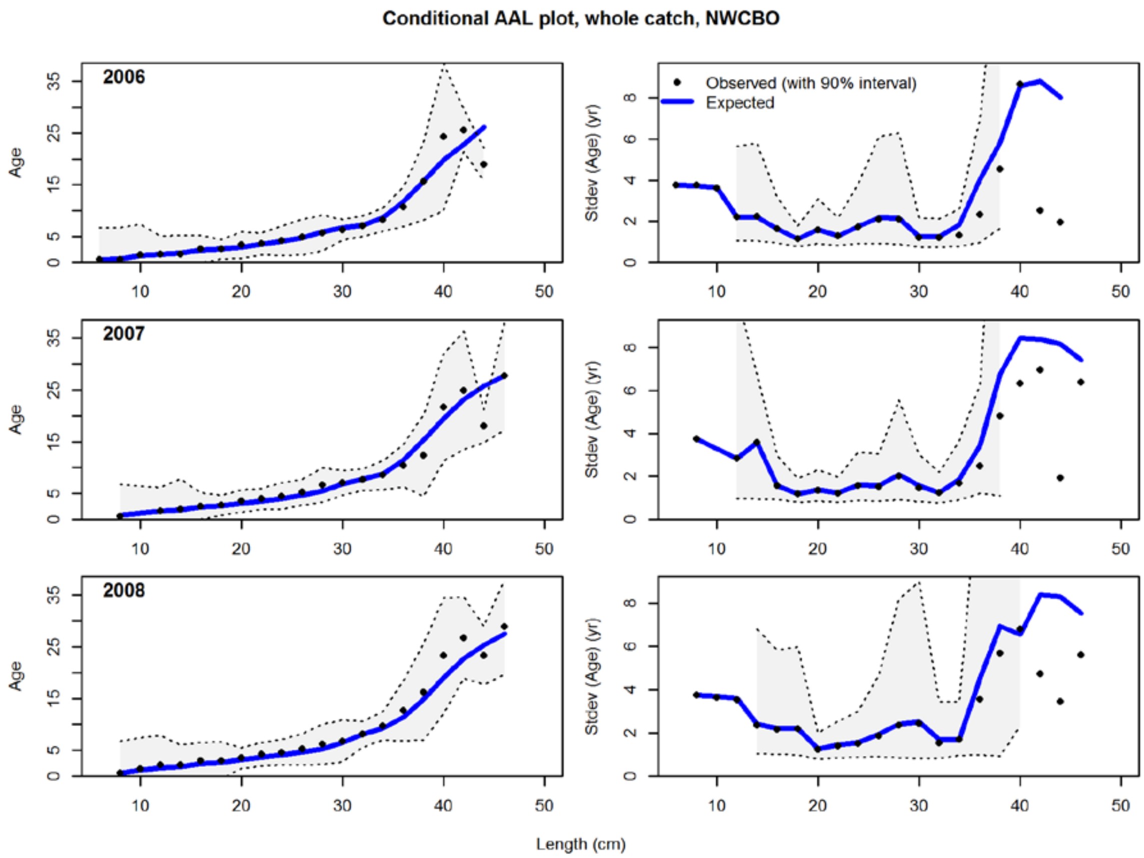

Figure 74 (continued): Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

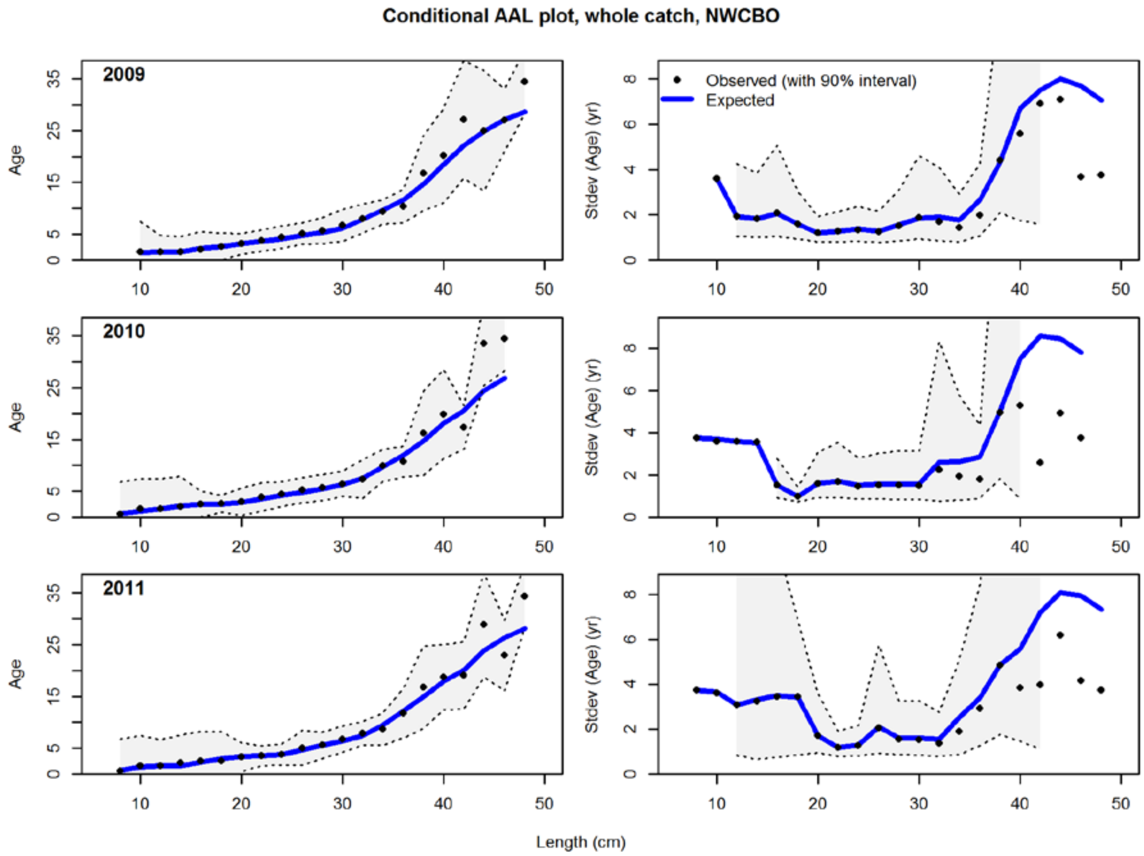

Figure 74 (continued): Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

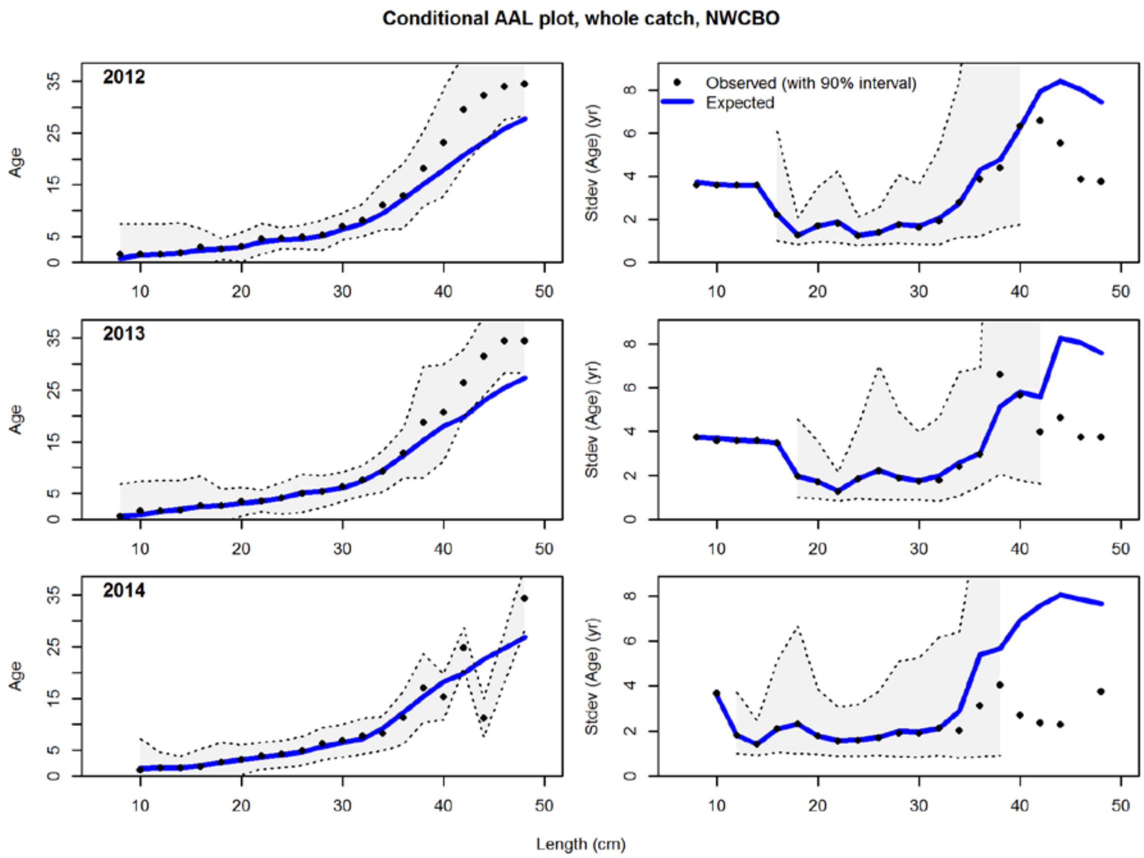

Figure 74 (continued): Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

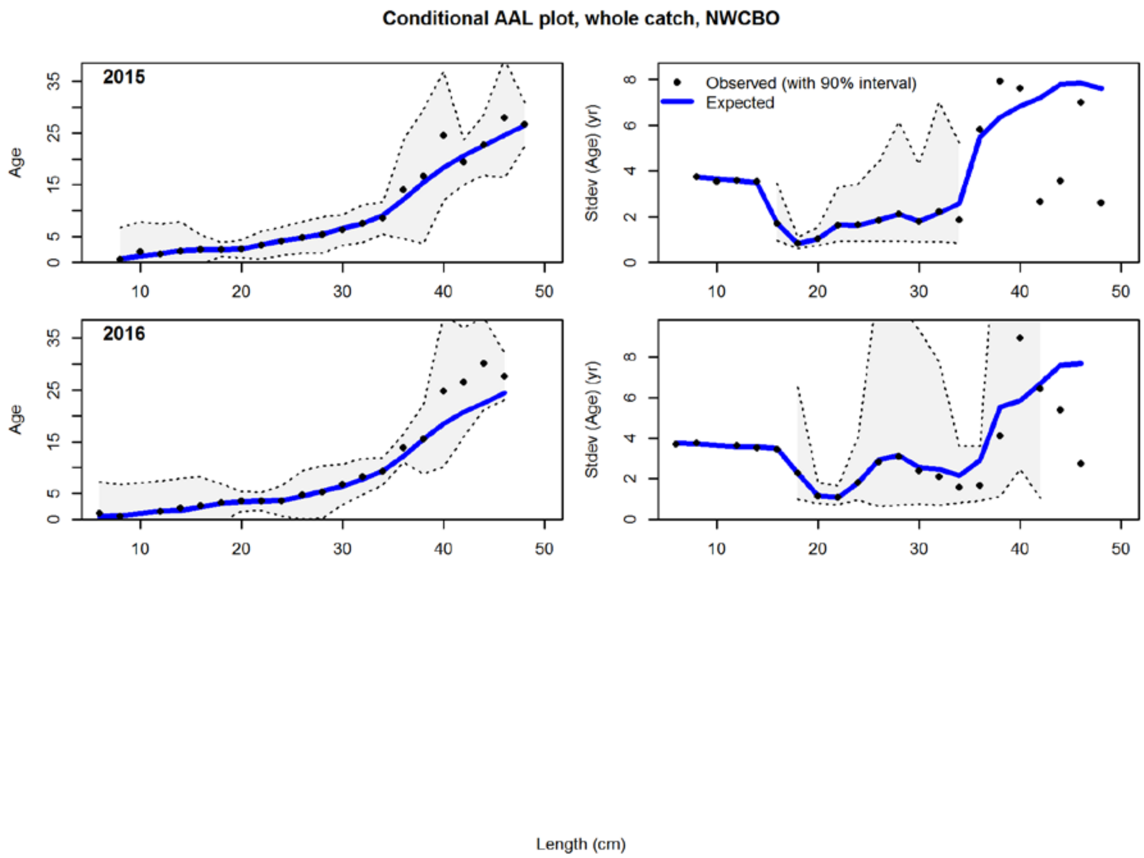

Figure 74 (continued): Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

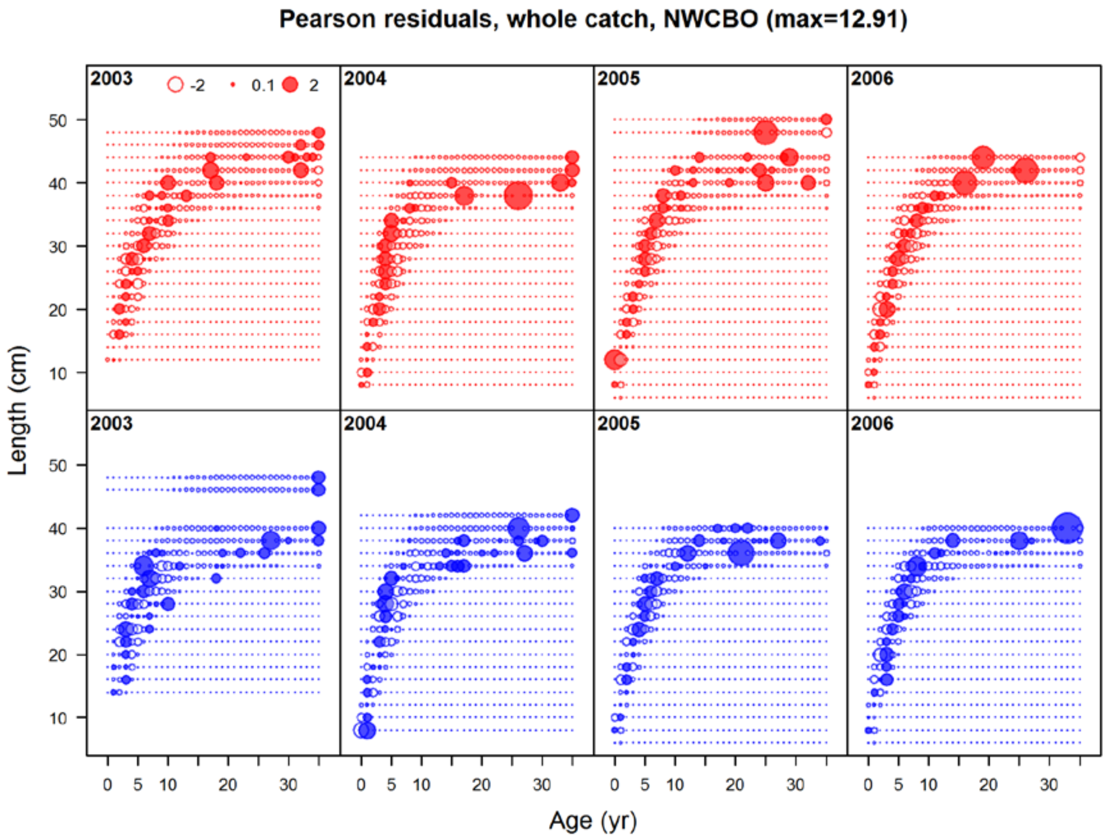

Figure 75: Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

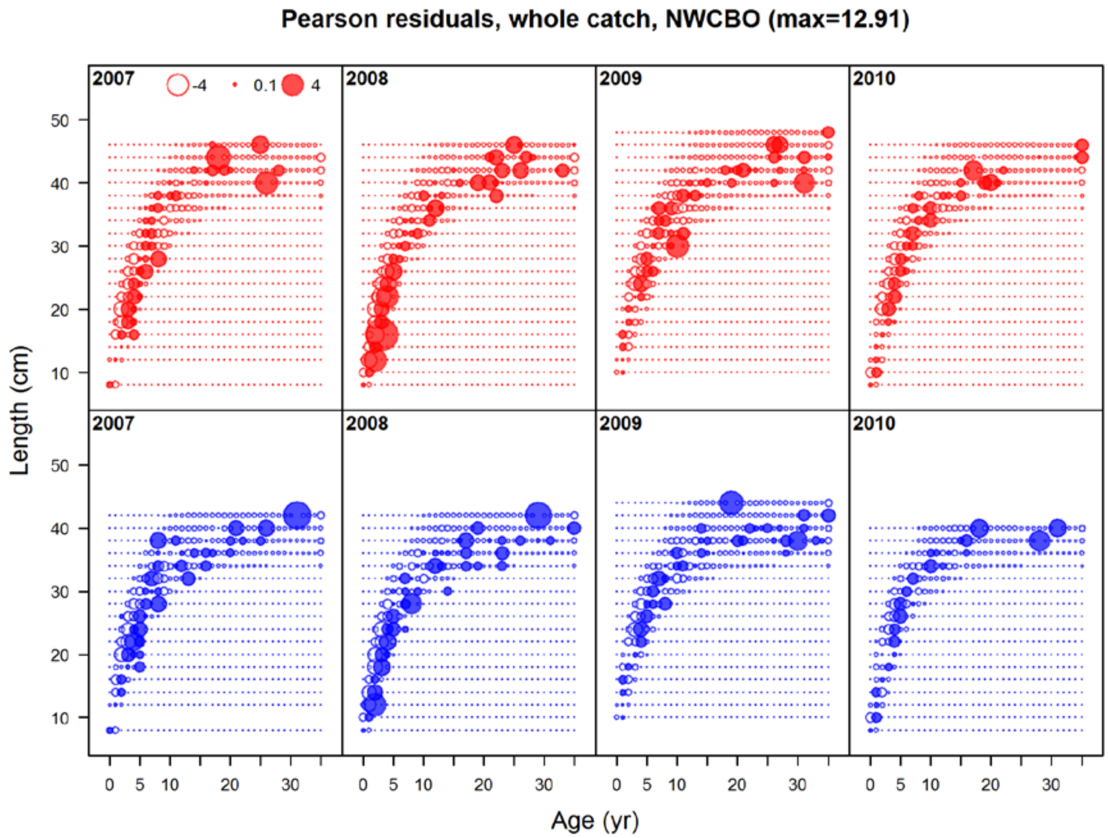

Figure 75 (continued): Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

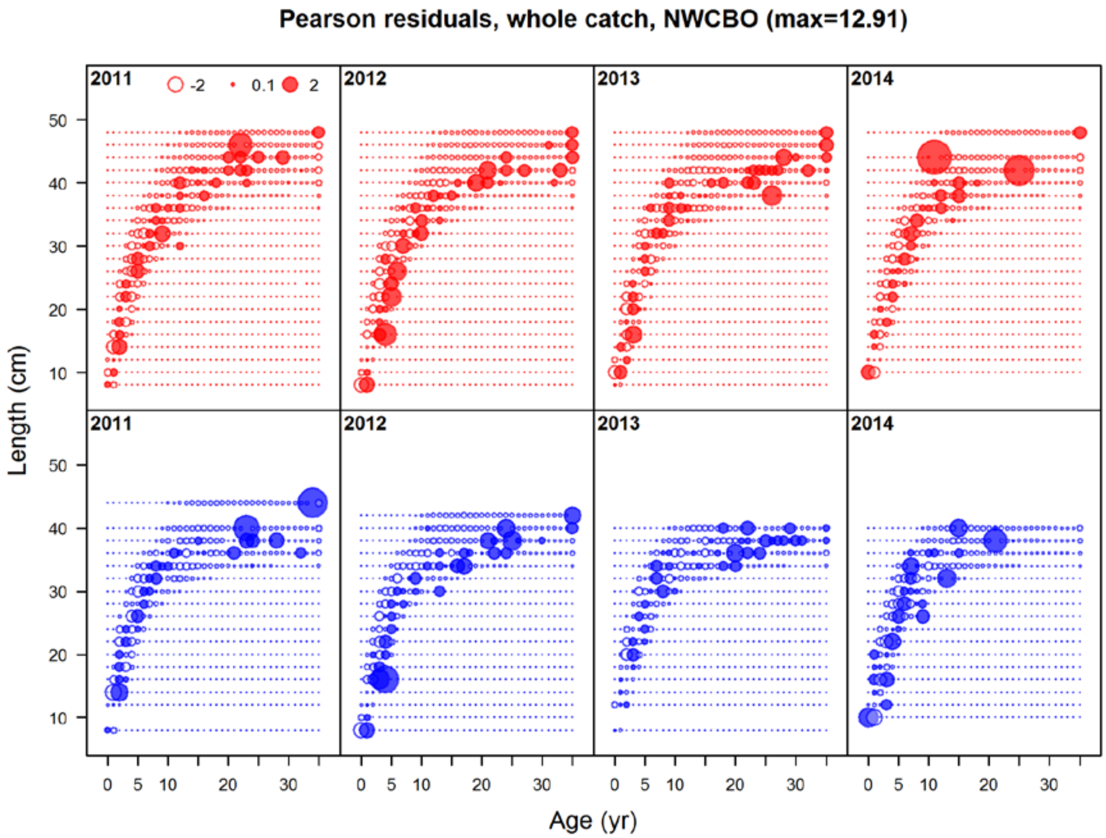

Figure 75 (continued): Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

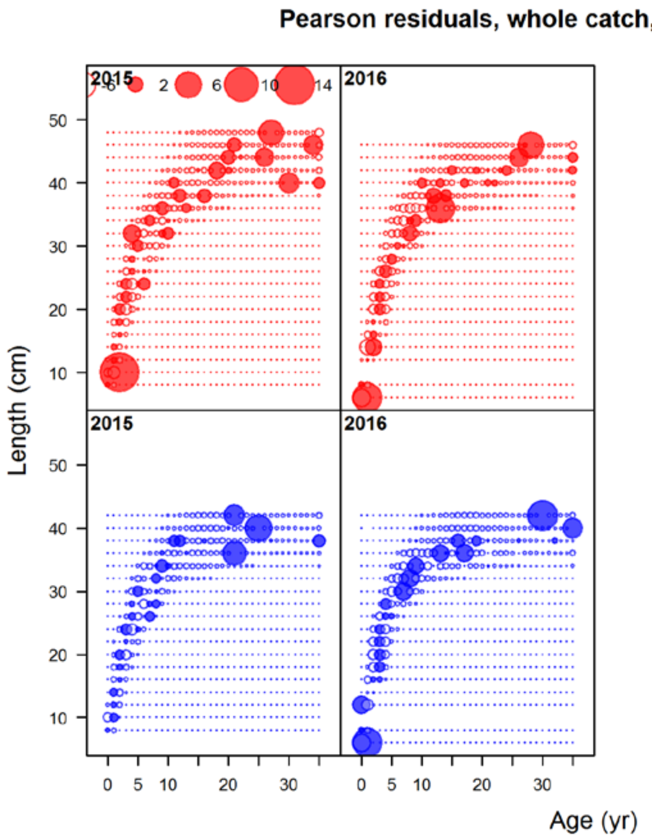

Figure 75 (continued): Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

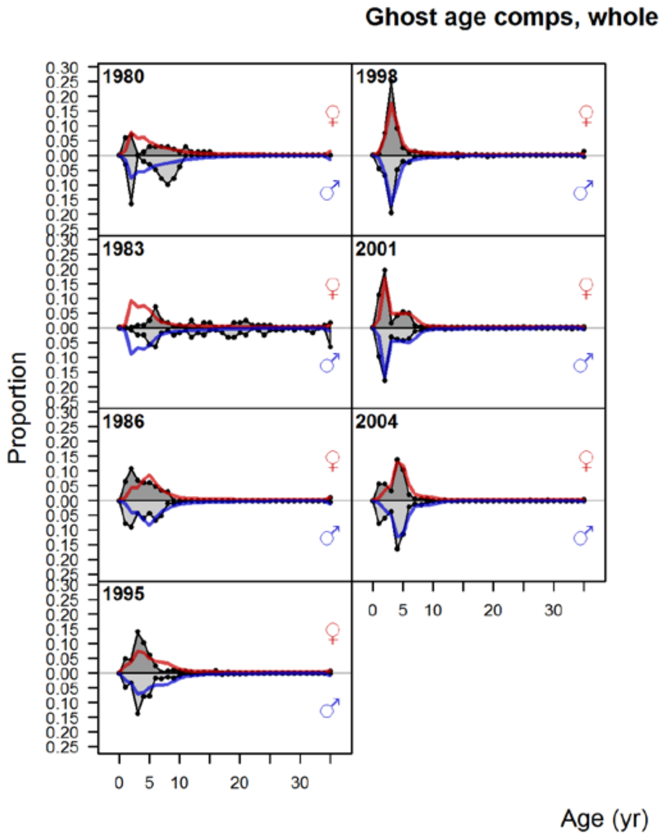

Figure 76: Implied fit to conditional ages-at-length compositions of darkblotched rockfish from the AFSC shelf survey marginal age frequencies. Fits are provided for evaluation only, but are not included in the model likelihood.

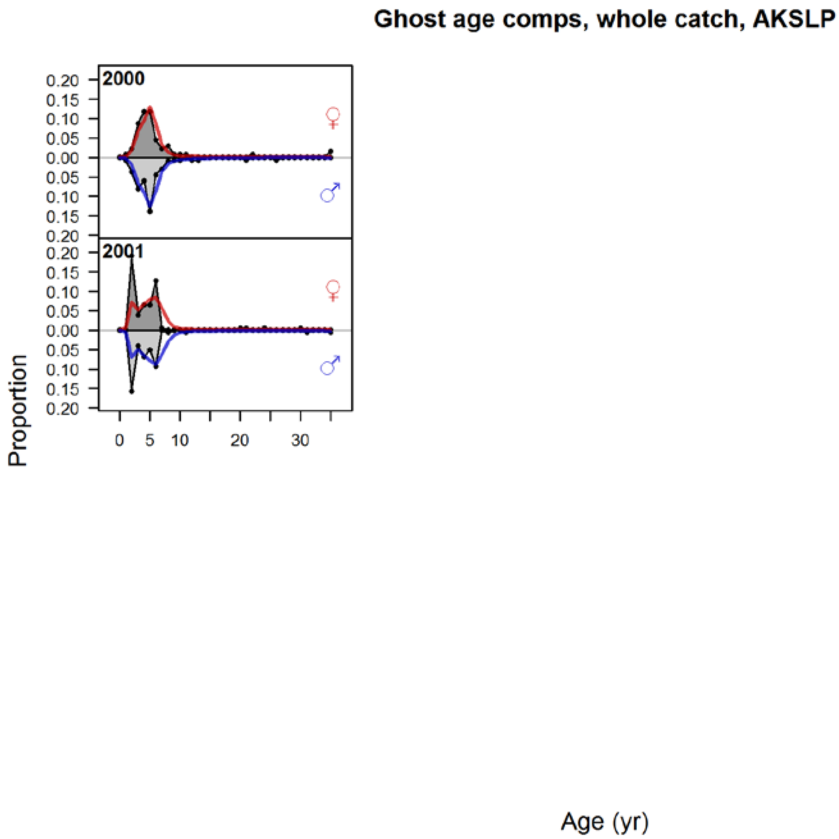

Figure 77: Implied fit to conditional ages-at-length compositions of darkblotched rockfish from the AFSC slope survey marginal age frequencies. Fits are provided for evaluation only, but not included in the model likelihood.

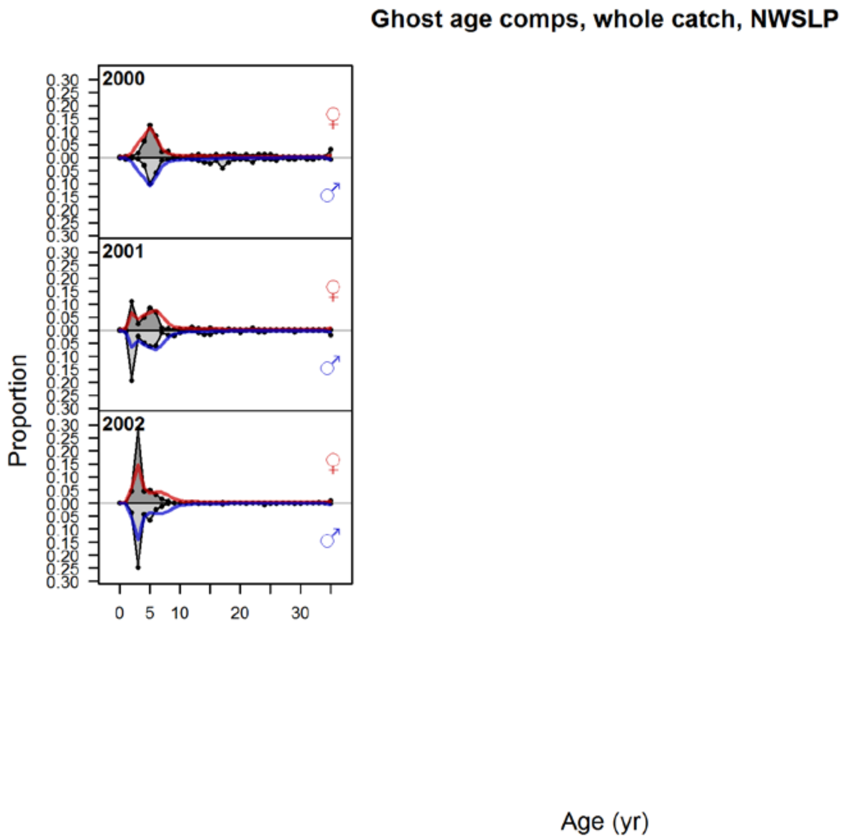

Figure 78: Implied fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC slope survey marginal age frequencies. Fits are provided for evaluation only, but not included in the model likelihood.

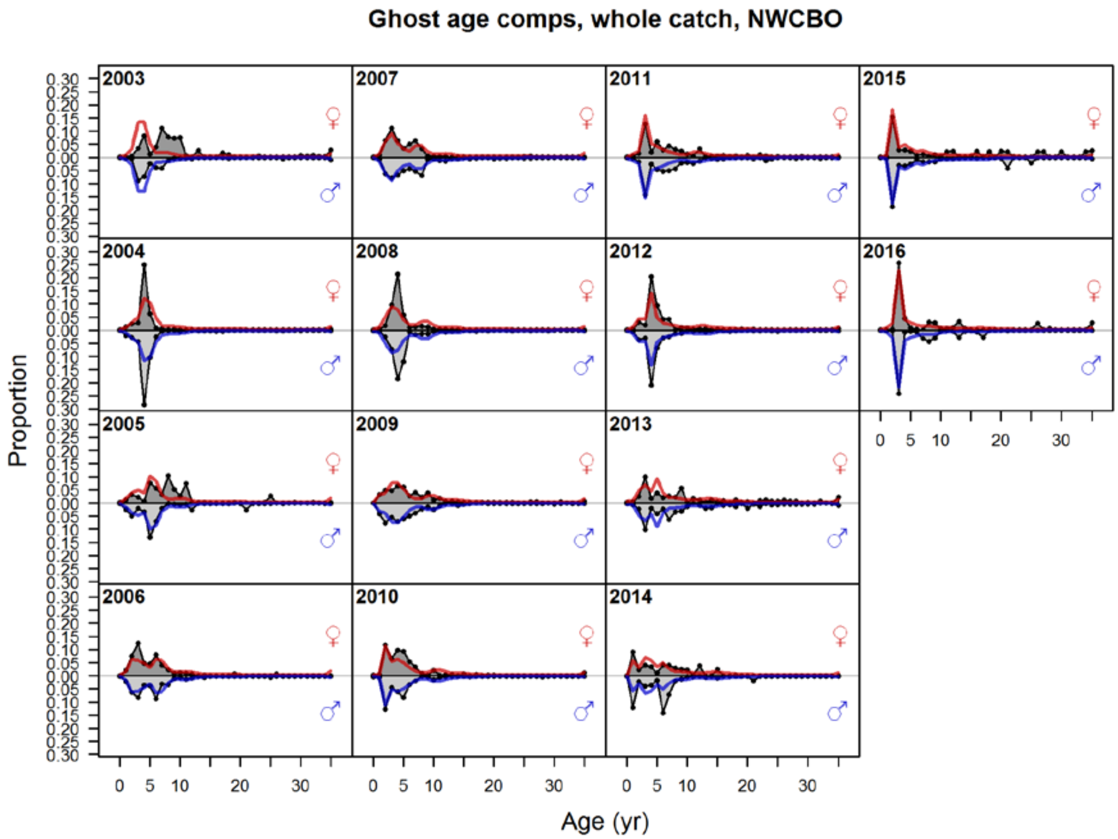

Figure 79: Implied fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey marginal age frequencies. Fits are provided for evaluation only, but not included in the model likelihood.

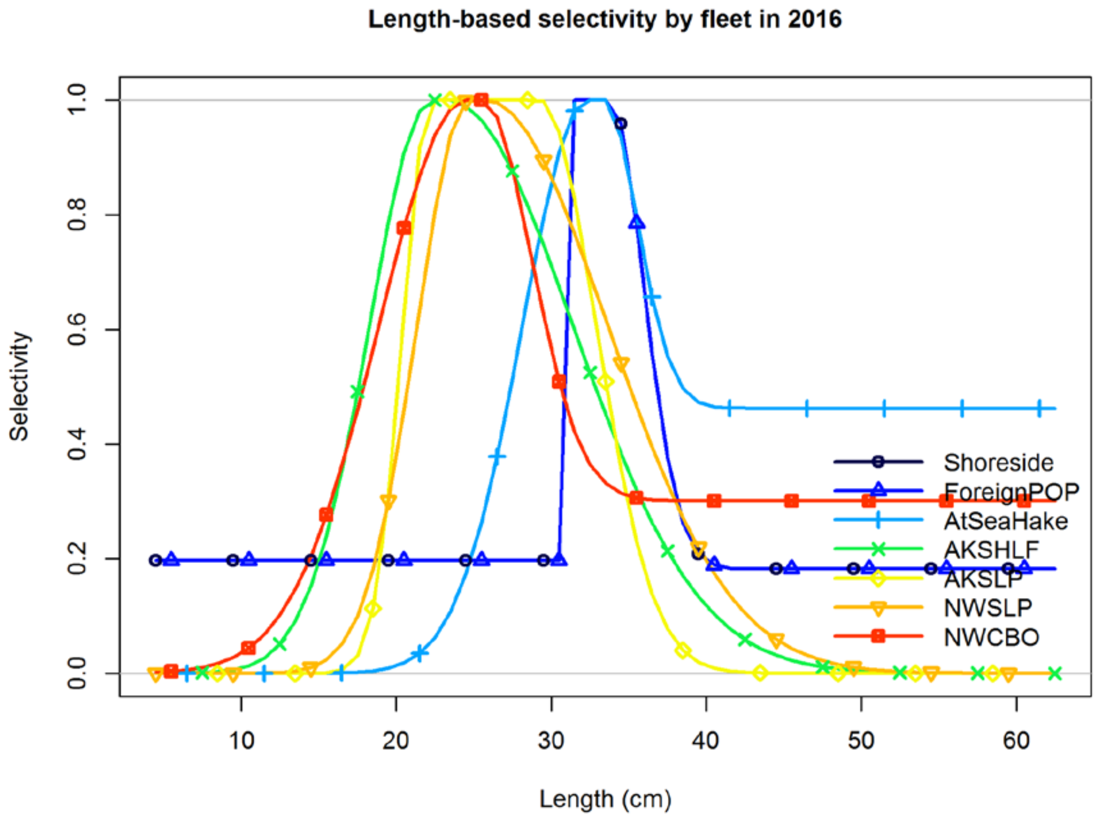

Figure 80: Final year selectivity curves for the all fleets used in the assessment.

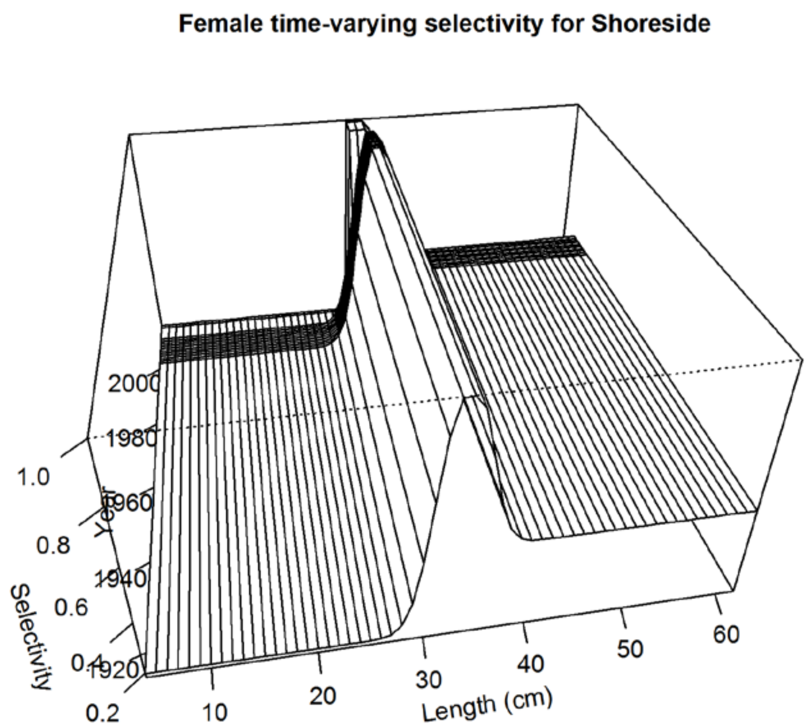

Figure 81: Estimated female time-varying selectivity for the shoreside fishery.

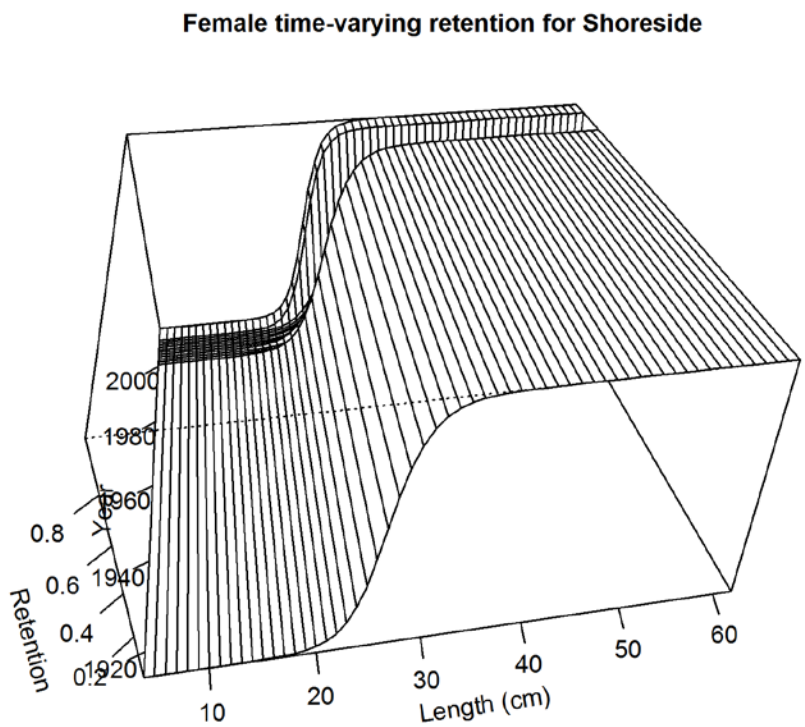

Figure 82: Estimated female time-varying length-based retention of shoreside fishery.

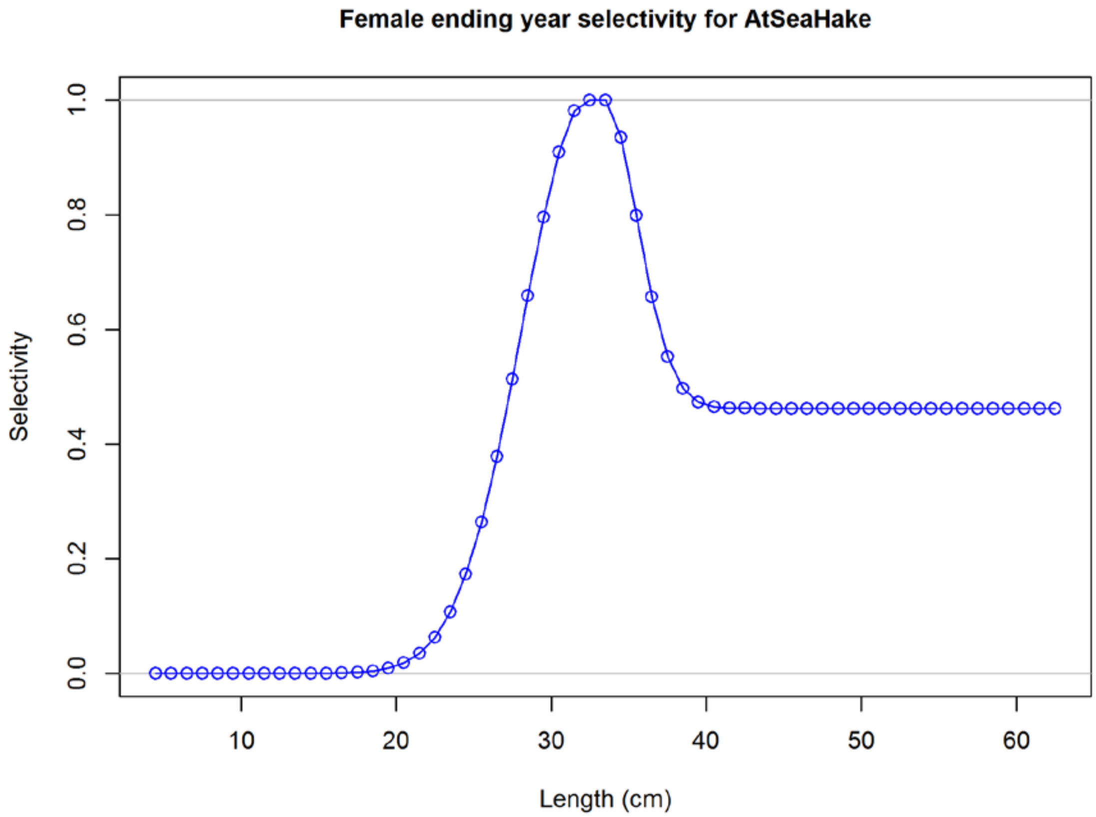

Figure 83: Length-based female ending year selectivity curve for historical at-sea hake bycatch fleet.

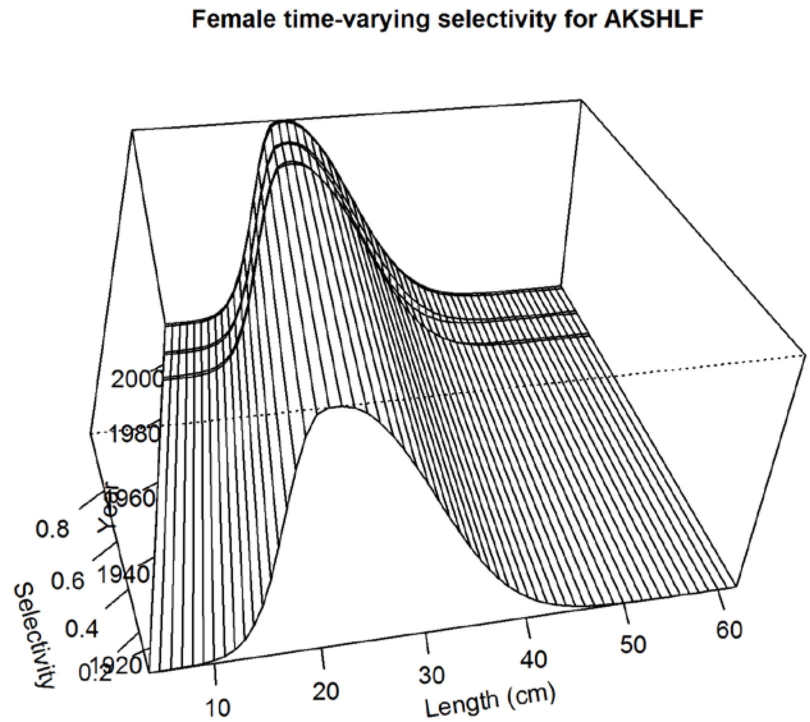

Figure 84: Estimated female time-varying length-based selectivity curve for the AFSC shelf survey.

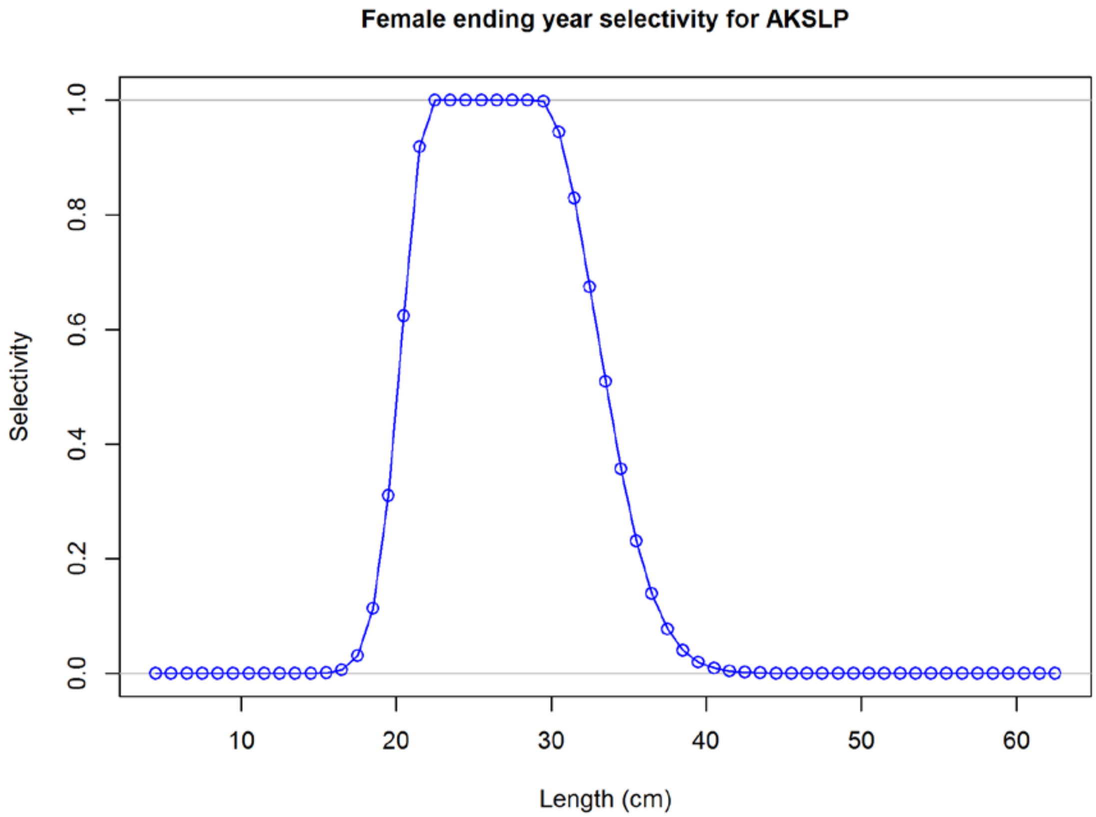

Figure 85: Estimated female ending year length-based selectivity curve for the AFSC slope survey.

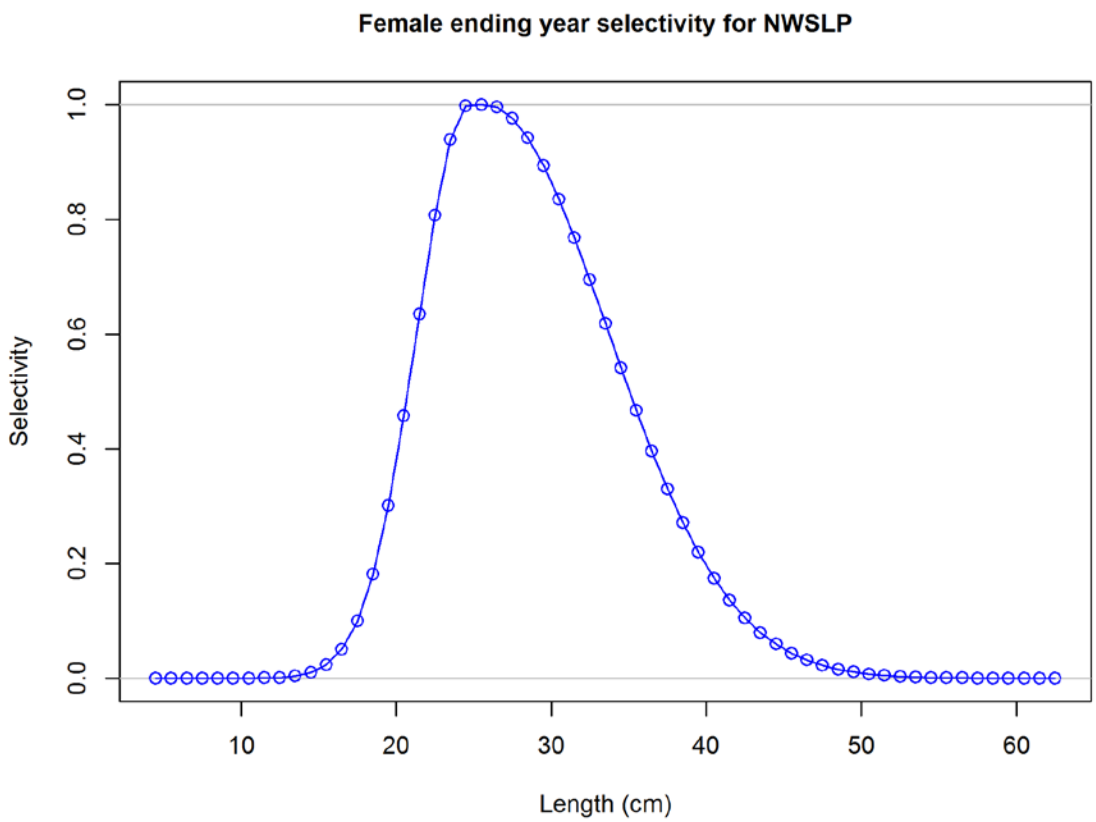

Figure 86: Estimated female ending year length-based selectivity curve for the NWFSC slope survey.

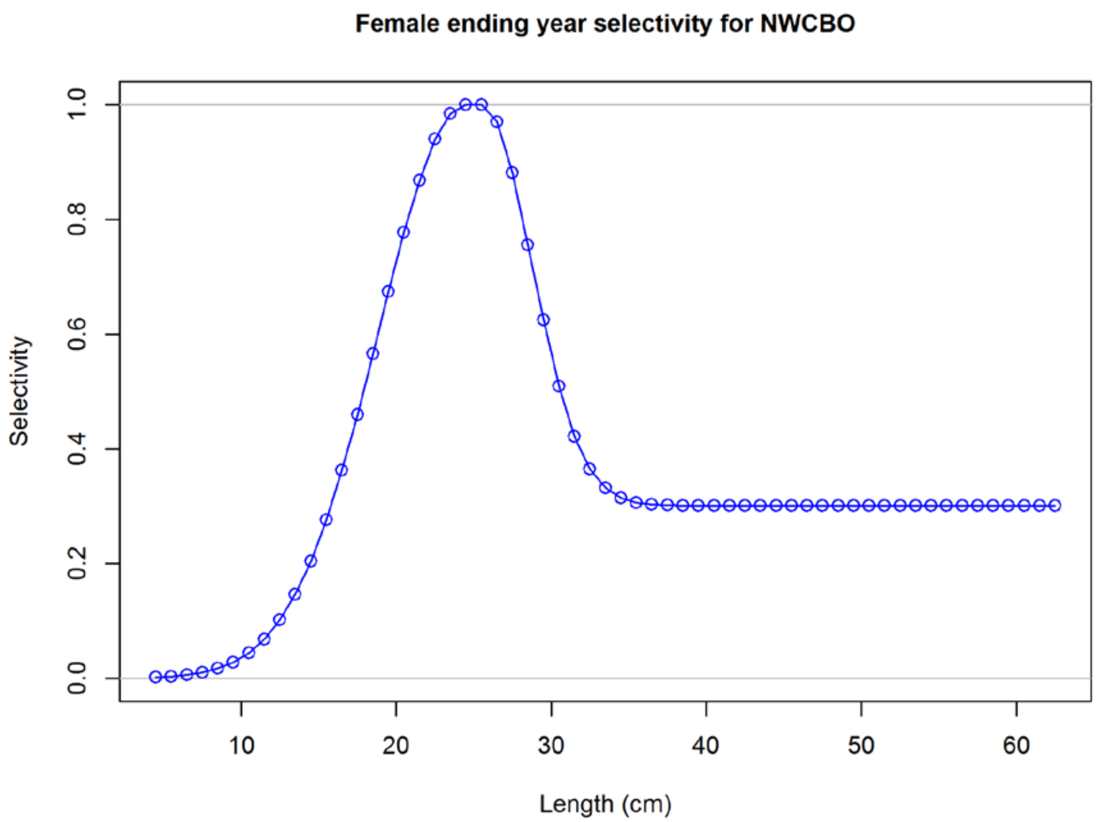

Figure 87: Estimated female ending year length-based selectivity curve for the NWFSC shelf-slope survey.

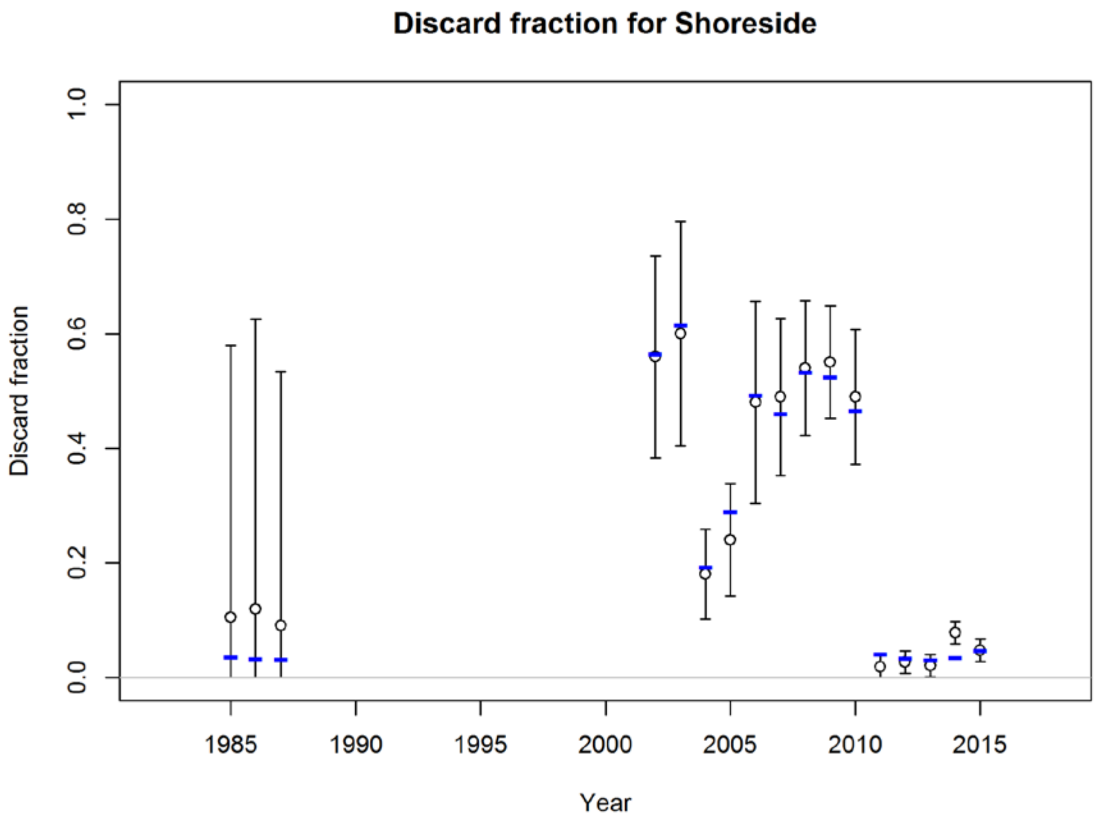

Figure 88: Fit to the discard ratio data of the shoreside fishery.

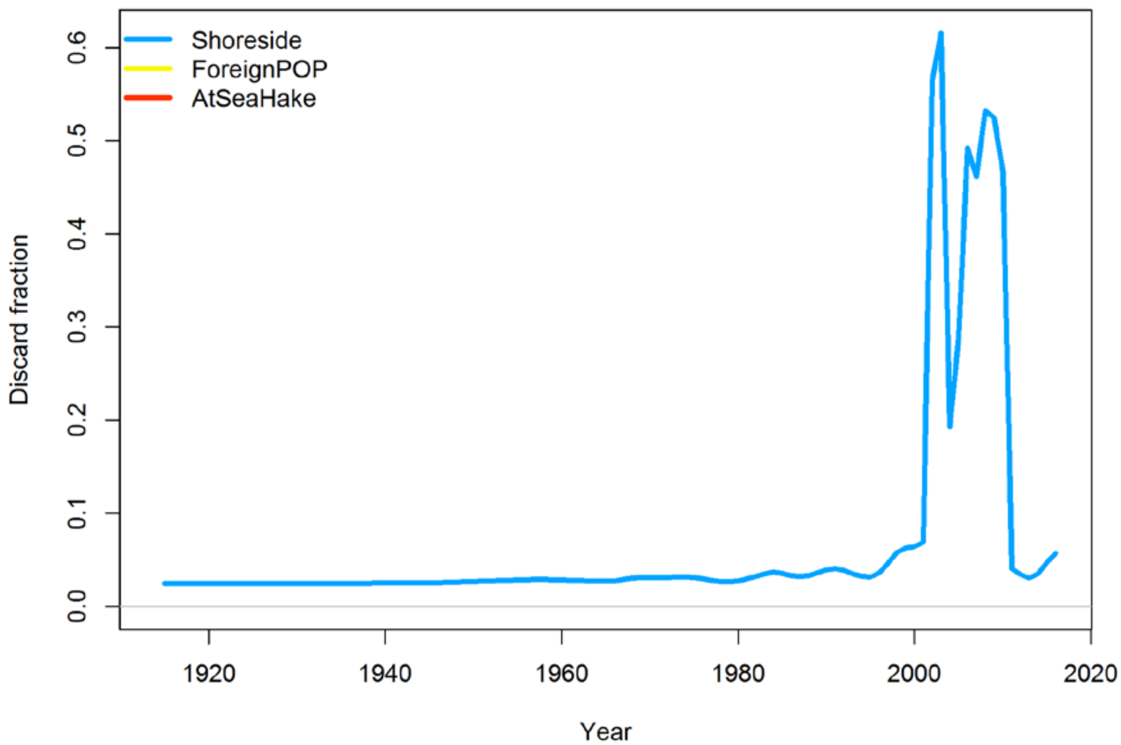

Figure 89: Discard fraction for the shoreside fishery estimated in the assessment.

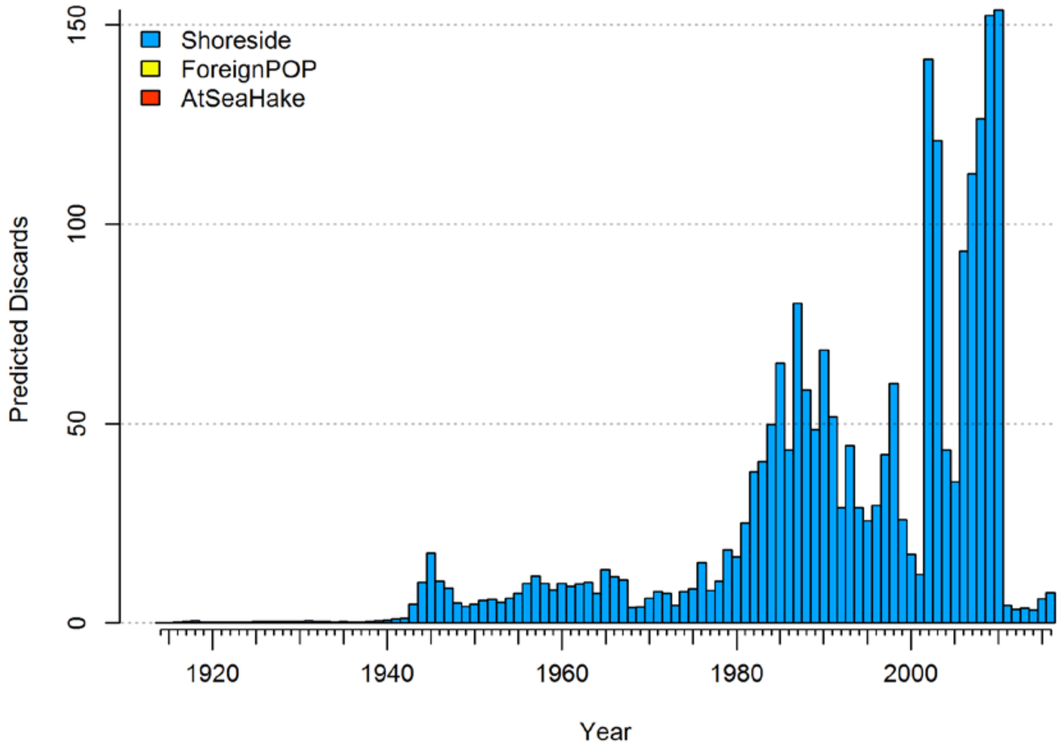

Figure 90: Predicted discard (mt) for the shoreside fishery.

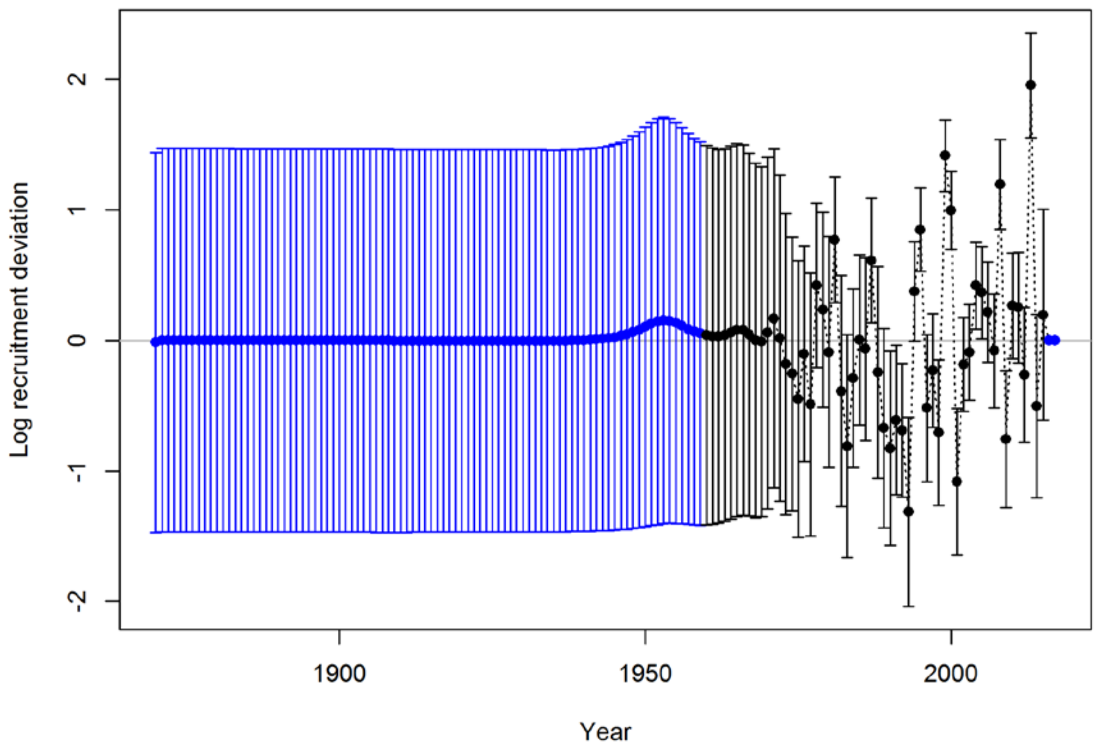

Figure 91: Recruitment deviation time-series estimated in the assessment model with 95% confidence intervals.

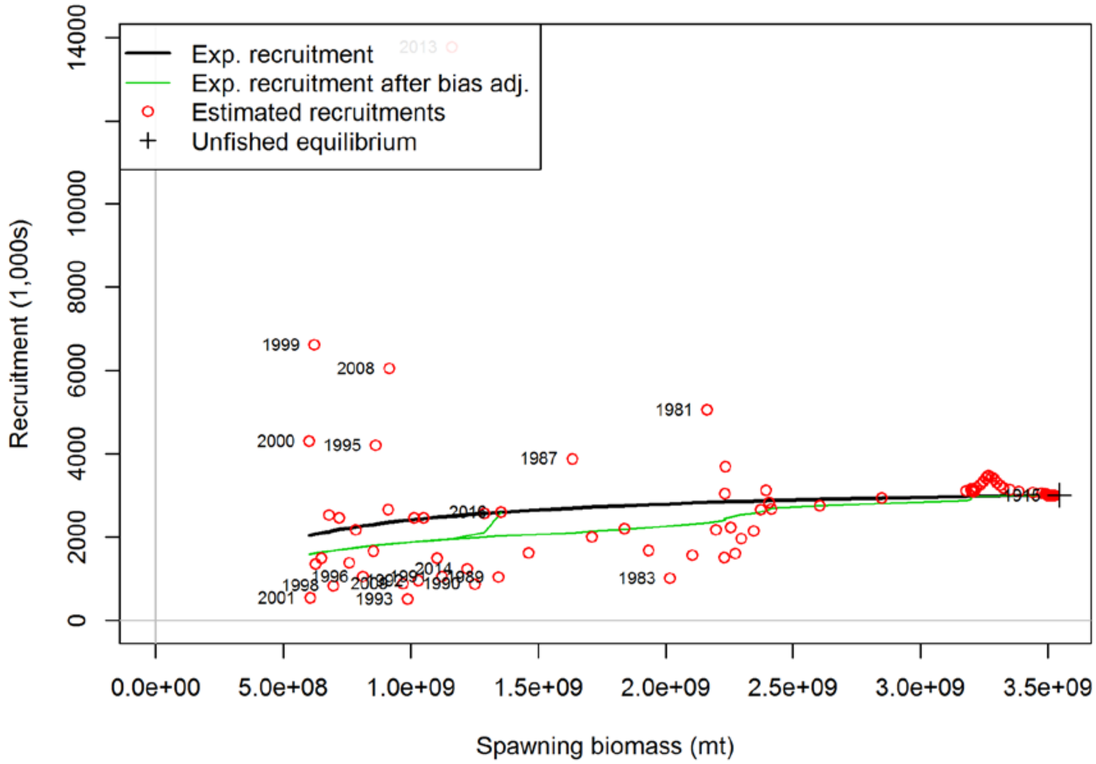

Figure 92: Estimated stock-recruit function for the assessment model.

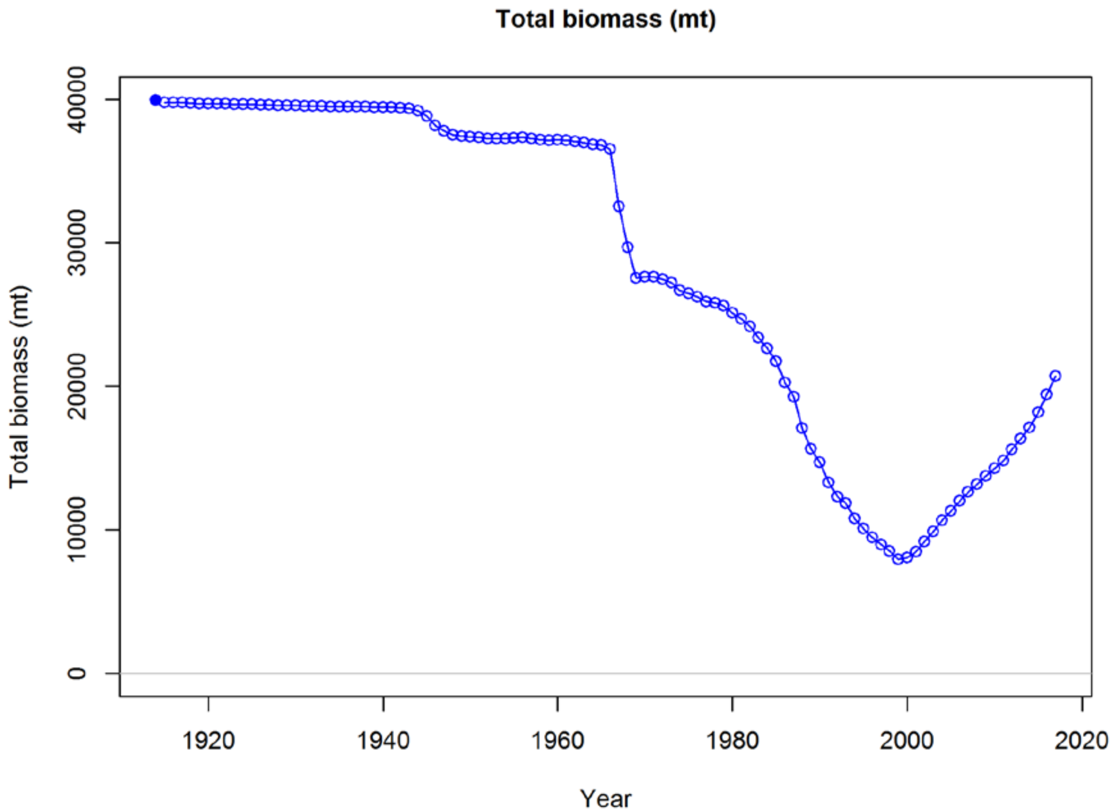

Figure 93: Time series of total biomass (mt) estimated in the assessment model.

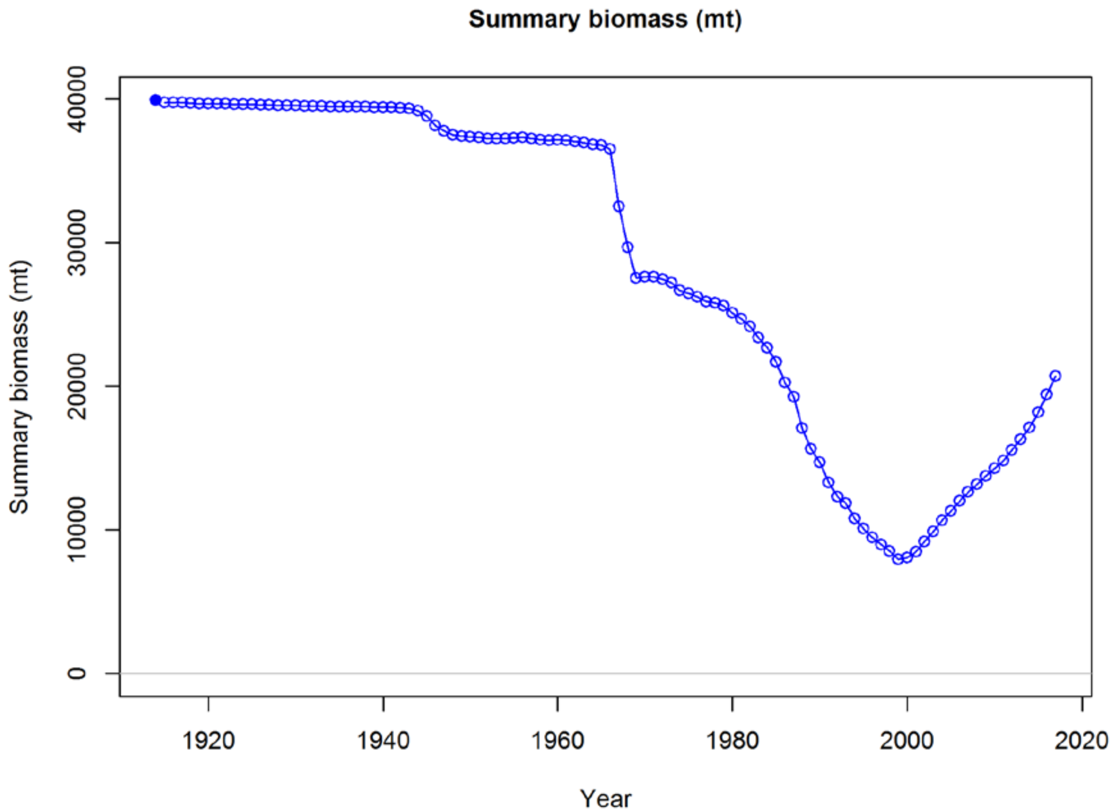

Figure 94: Time series of summary biomass (mt) estimated in the assessment model.

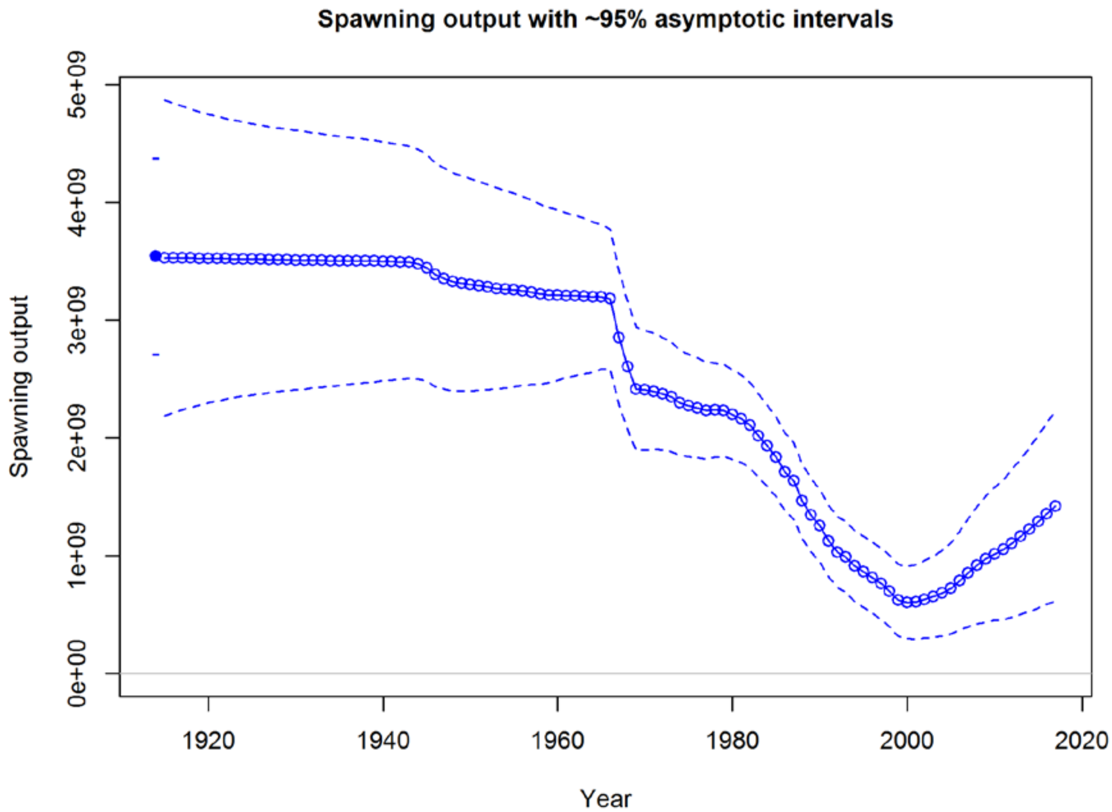

Figure 95: Time series of spawning output estimated in the assessment model (solid line) with ~ 95% interval (dashed lines). Spawning output is expressed in number of eggs.

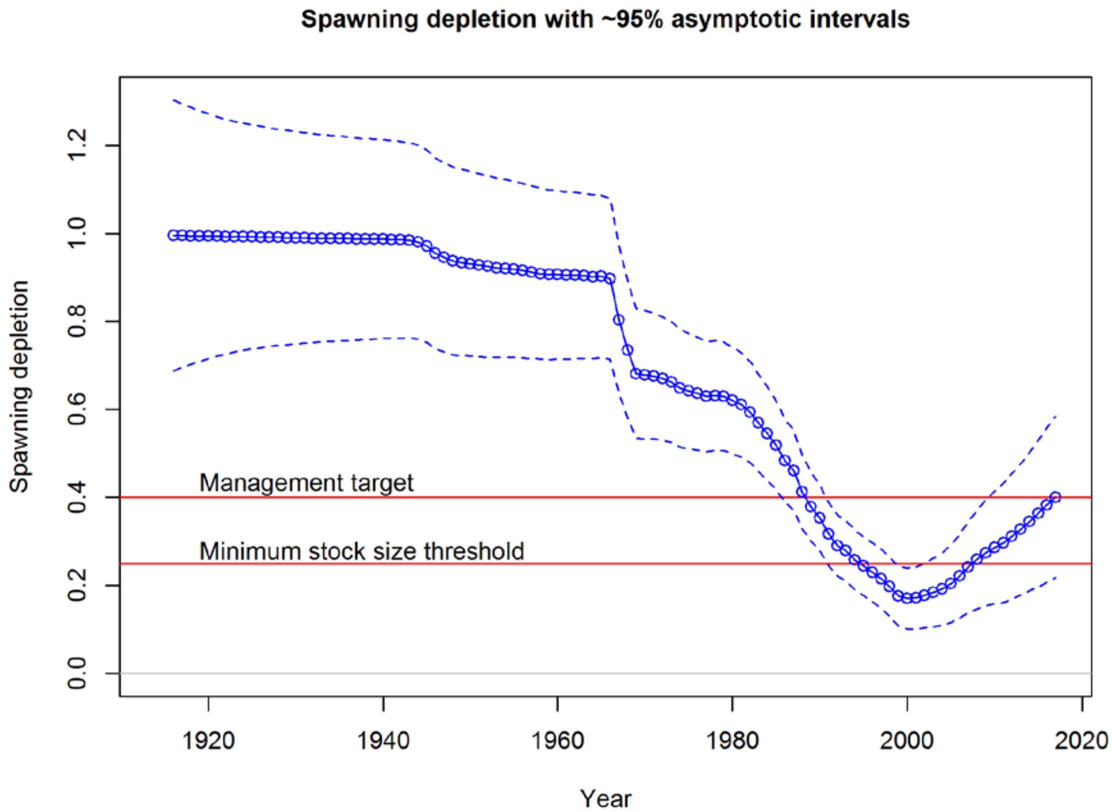

Figure 96: Time series of spawning depletion estimated in the assessment model (solid line) with ~ 95% interval (dashed lines).

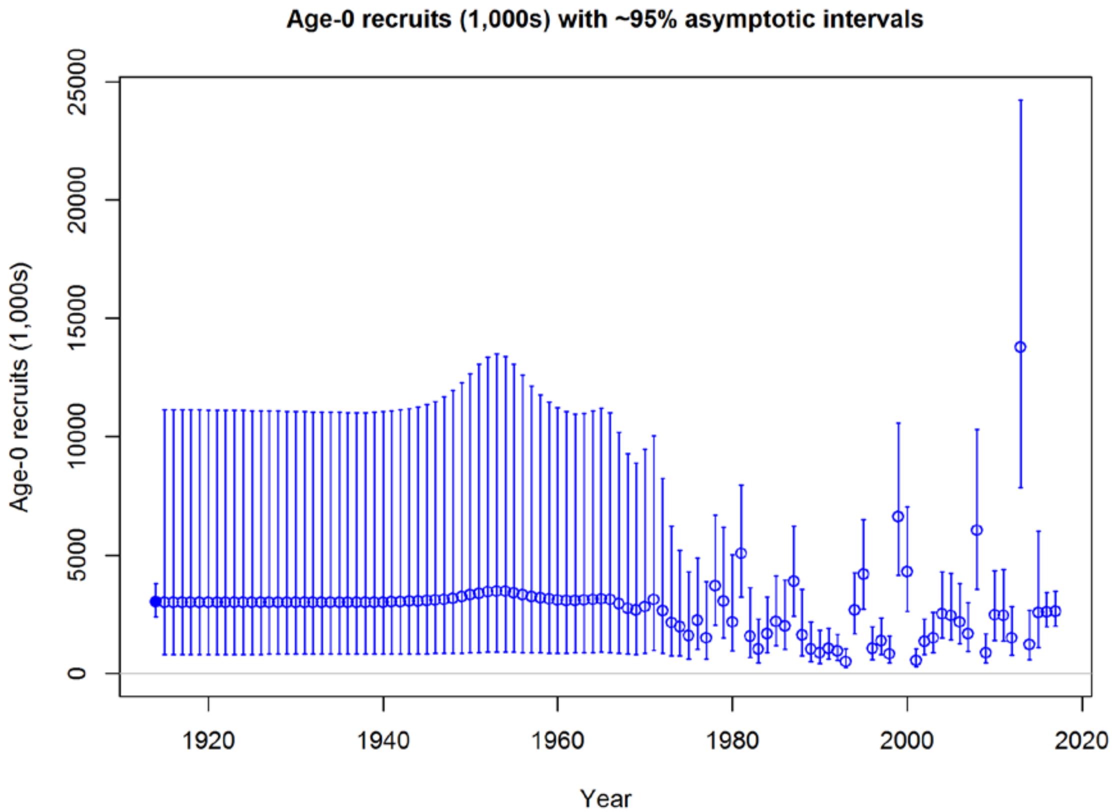

Figure 97: Time series of recruitment estimated in the assessment model with ~ 95% interval.

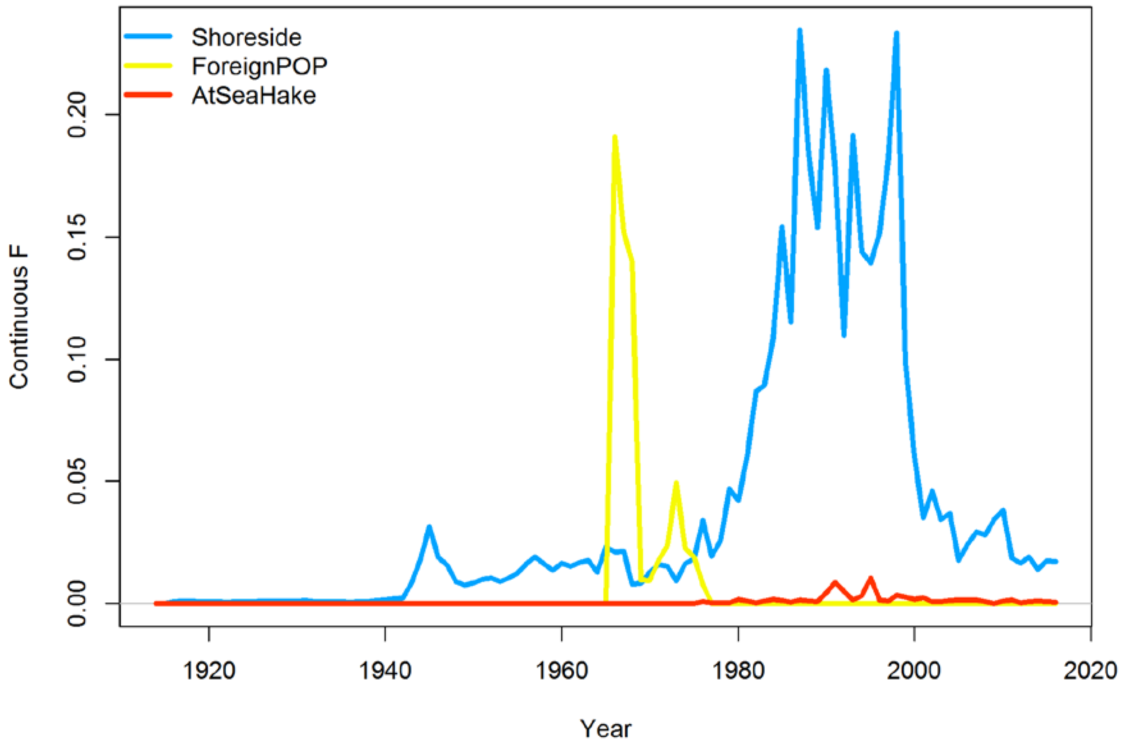

Figure 98: Time series of fishing mortality of darkblotched rockfish estimated by the assessment model.

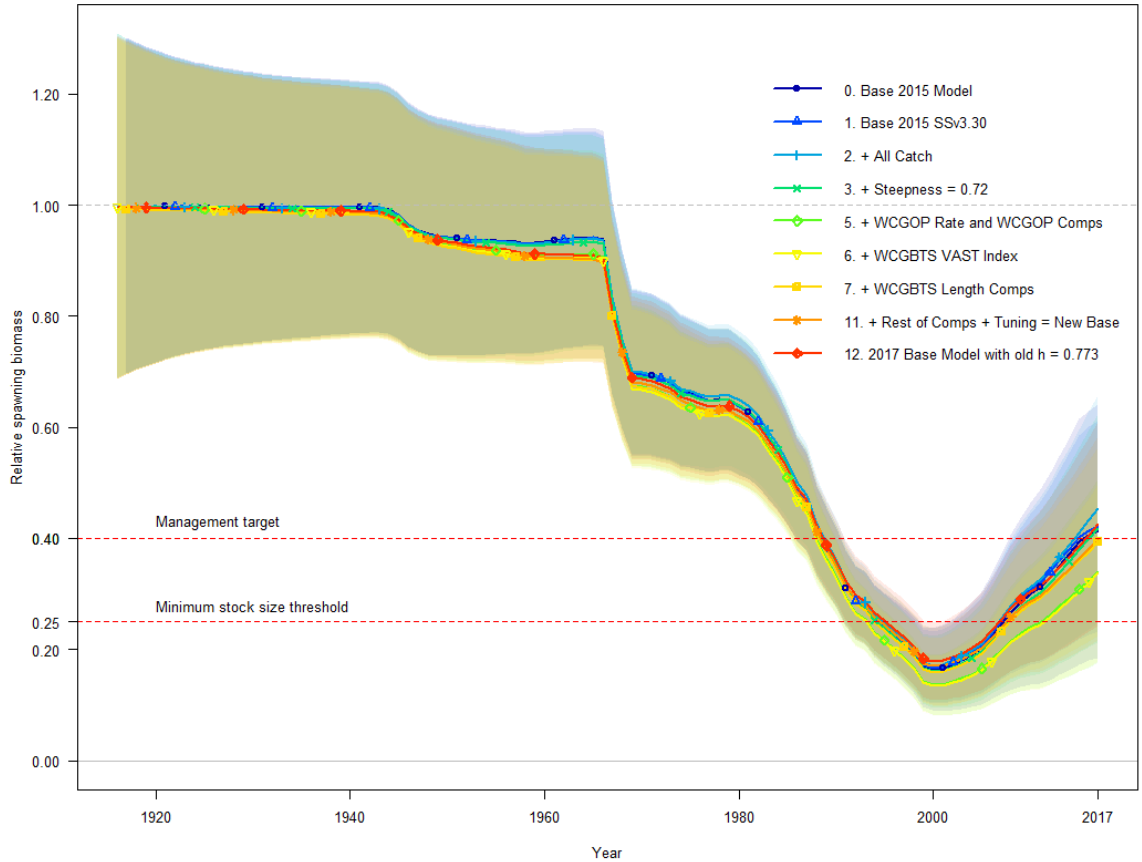

Figure 99. Model changes from 2015 base to 2017 base, including the new base with the old steepness of 0.773.

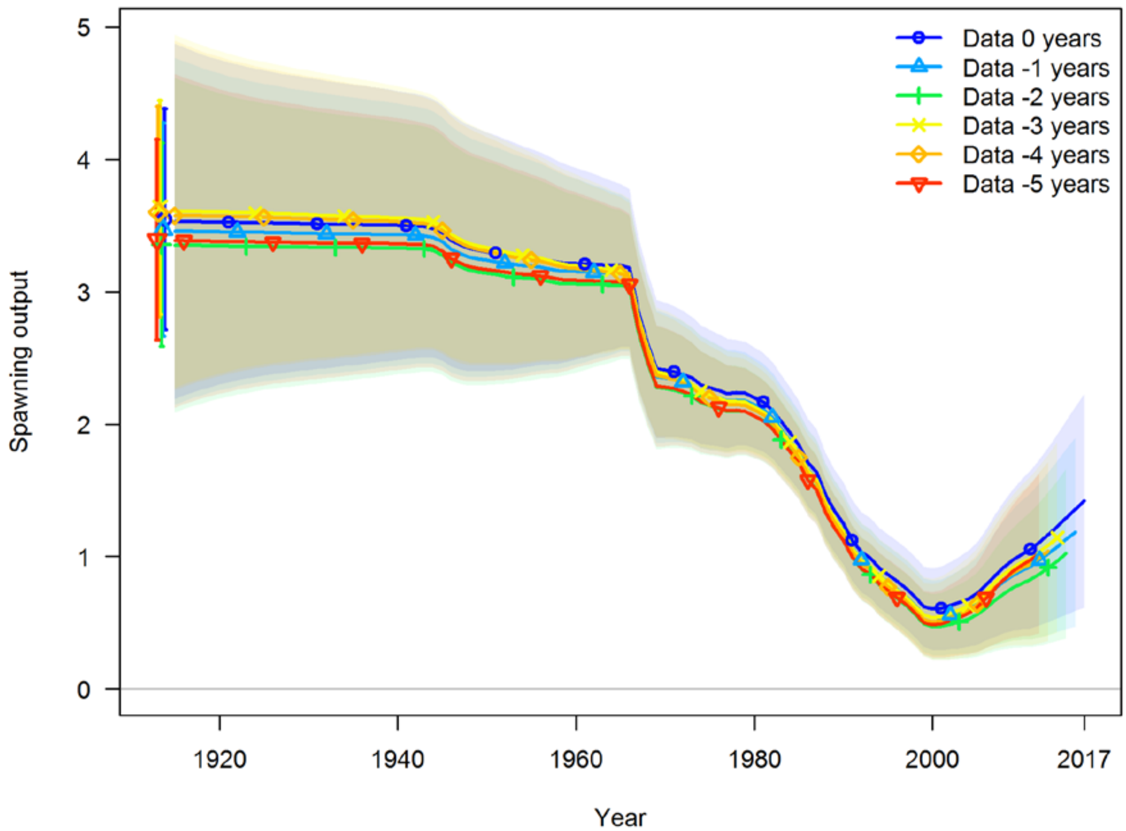

Figure 100: Results of retrospective analysis. Spawning output time series of this assessment base model are provided with ~ 95% interval.

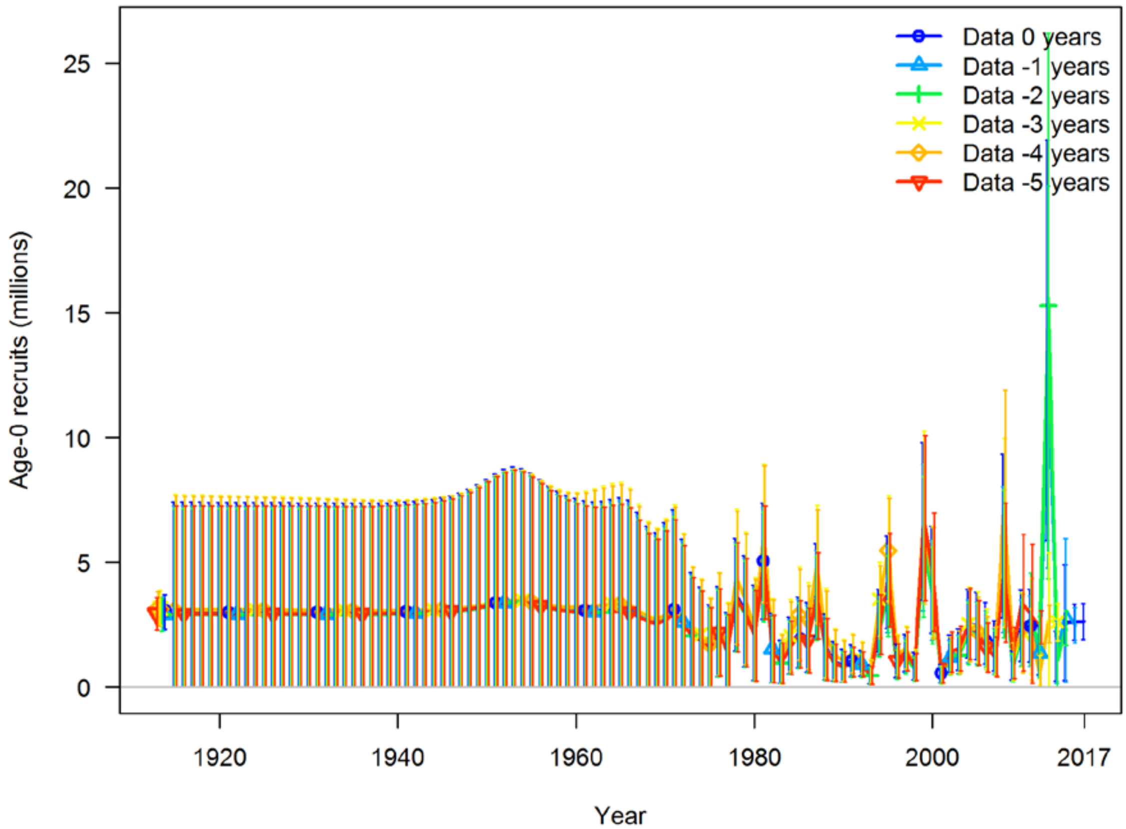

Figure 101: Results of retrospective analysis. Recruitment time series of this assessment base model are provided with ~ 95% interval.

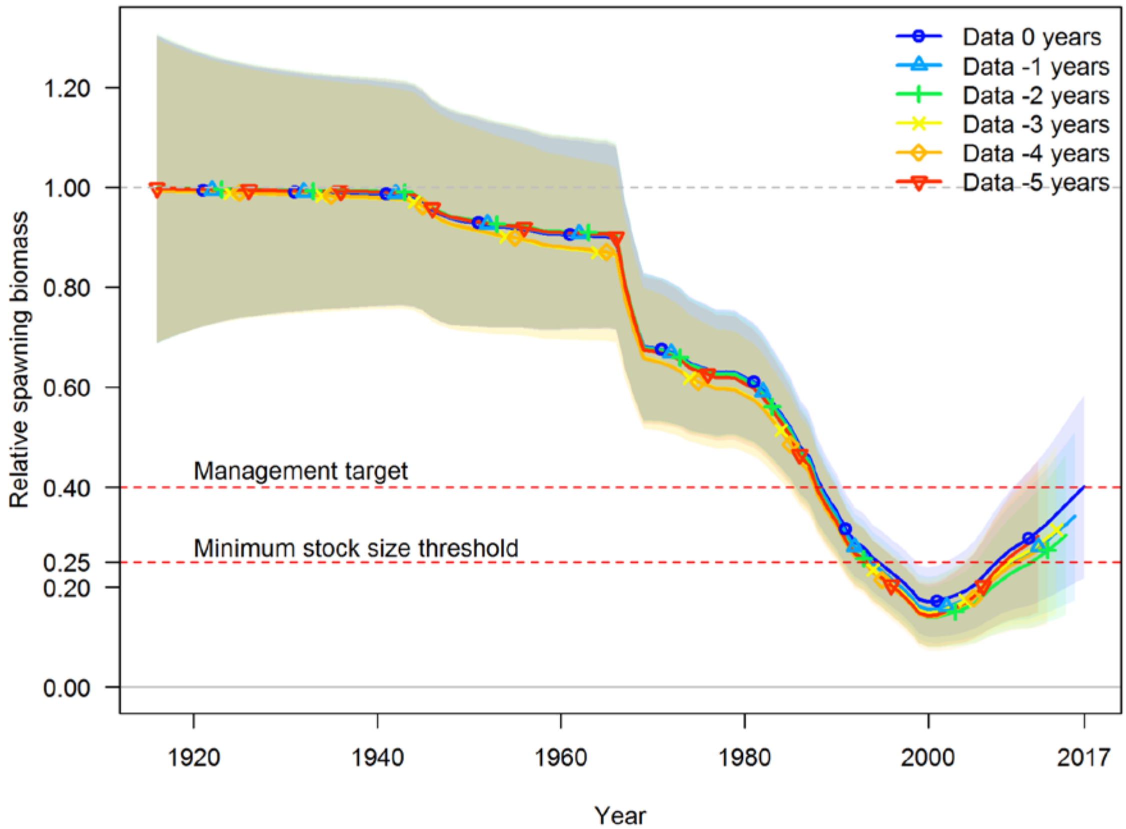

Figure 102: Results of retrospective analysis. Spawning depletion time series of this assessment base model are provided with ~ 95% interval.

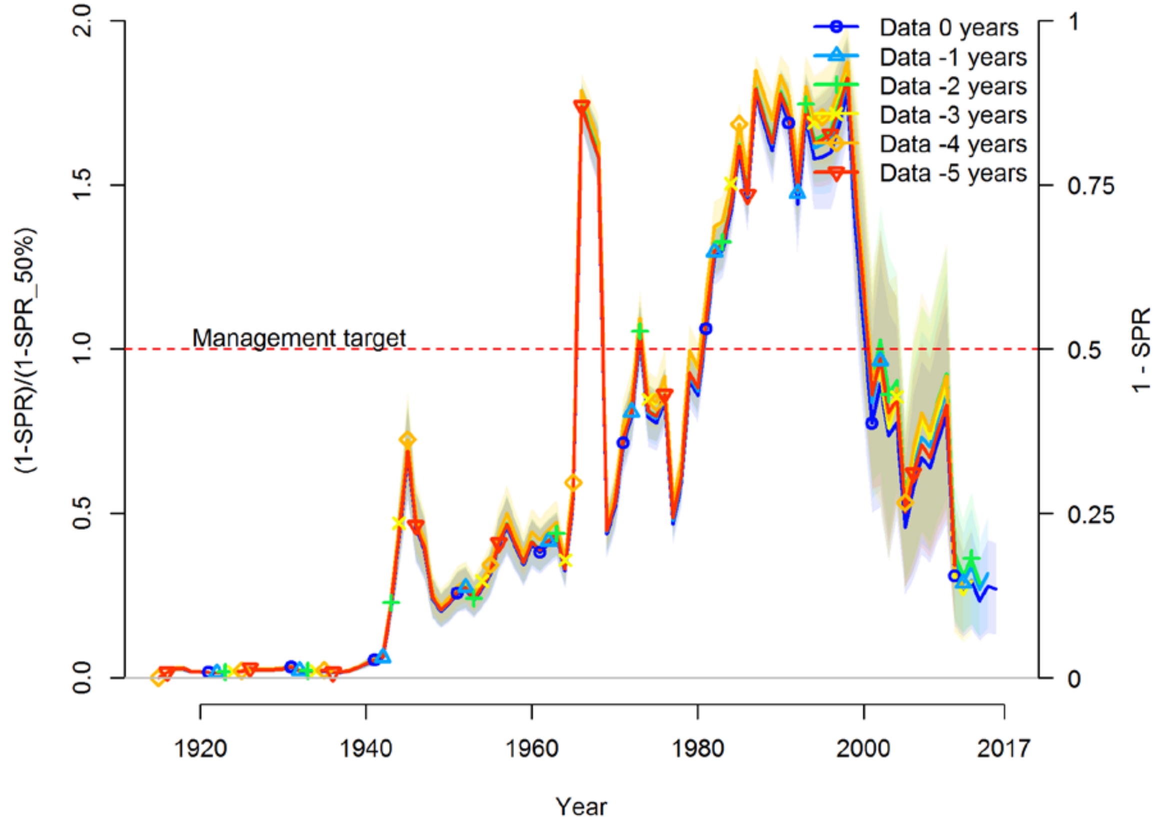

Figure 103: Results of retrospective analysis. Relative SPR ratio (1-SPR/1-SPR$_{Target=0.50}$) time series of this assessment base model are provided with ~ 95% interval.

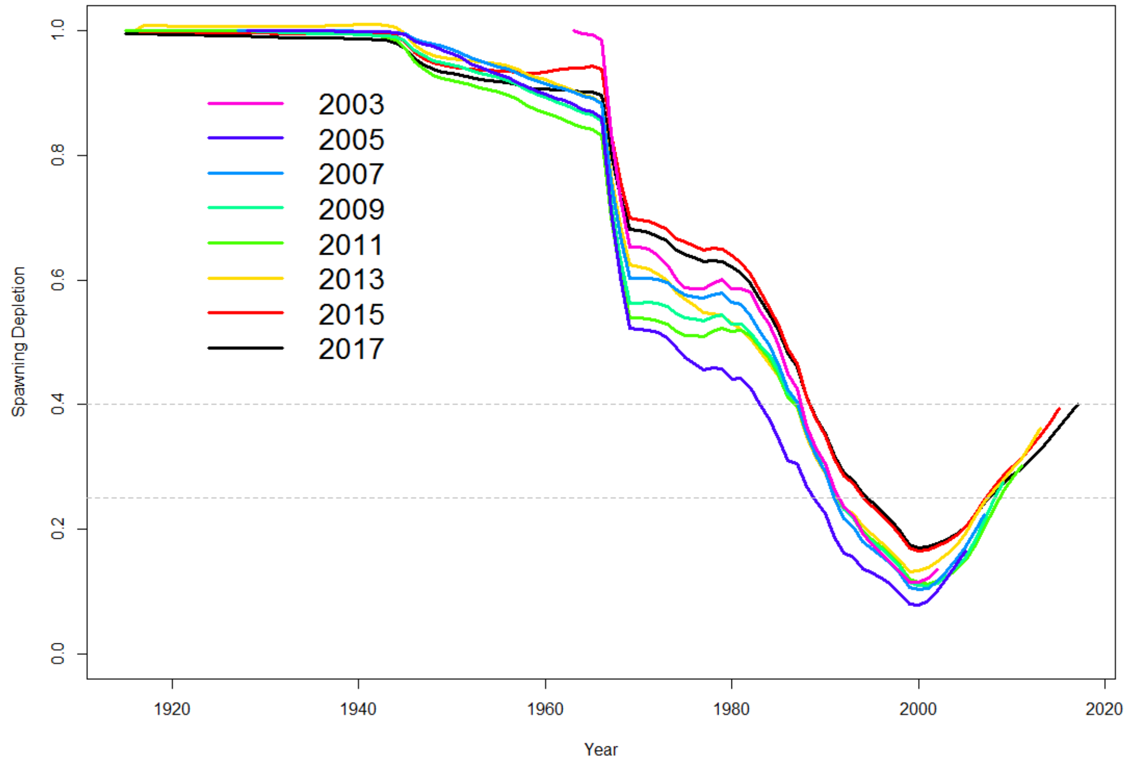

Figure 104: Comparison of spawning depletion time series among darkblotched rockfish assessments.

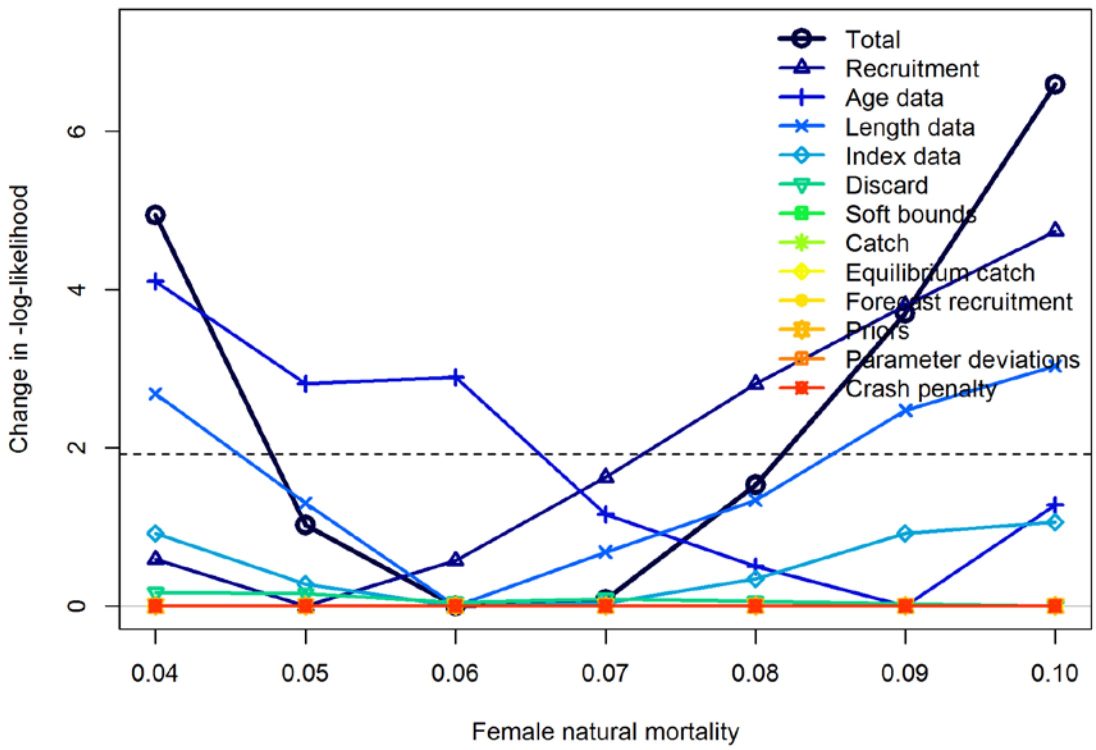

Figure 105: Negative log-likelihood profile for each data component and in total given different values of **female natural mortality** ranging from 0.04 to 0.10 by increments of 0.01.

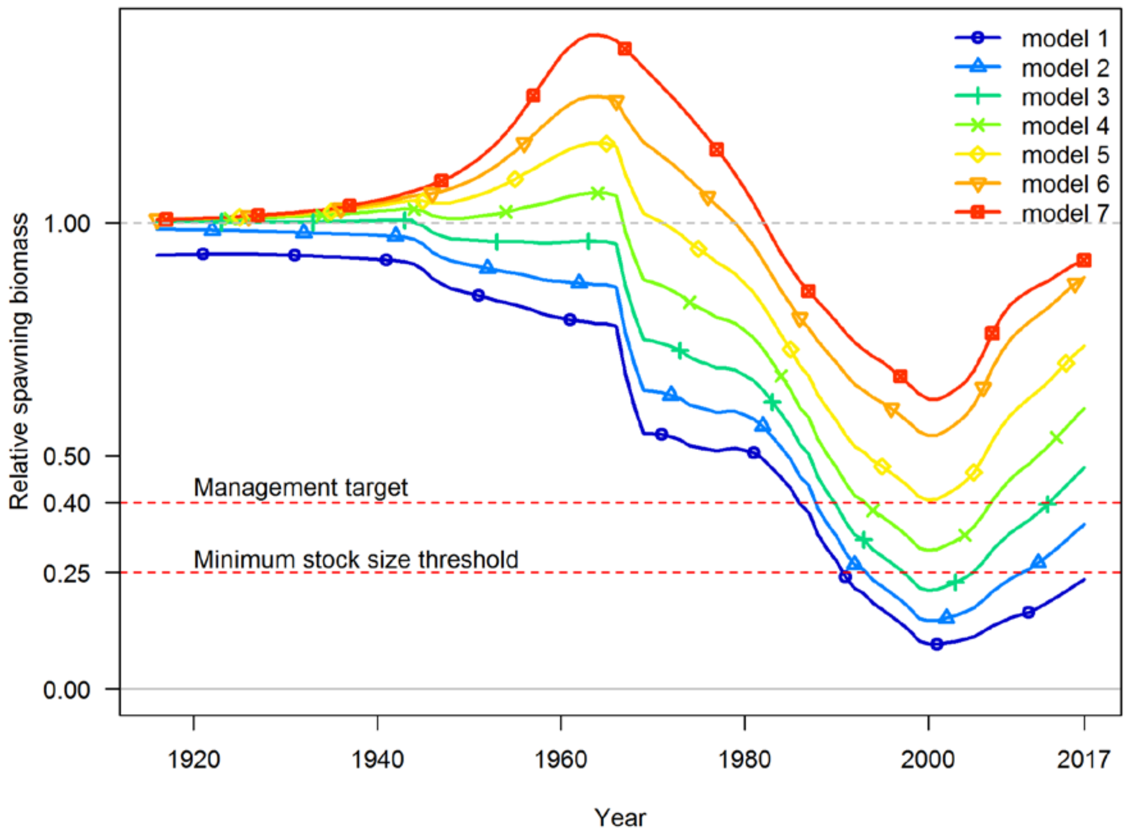

Figure 106: Time series of spawning depletion associated with different values of **female natural mortality** ranging from 0.04 (Model 1) to 0.1 (Model 7) by increments of 0.01.

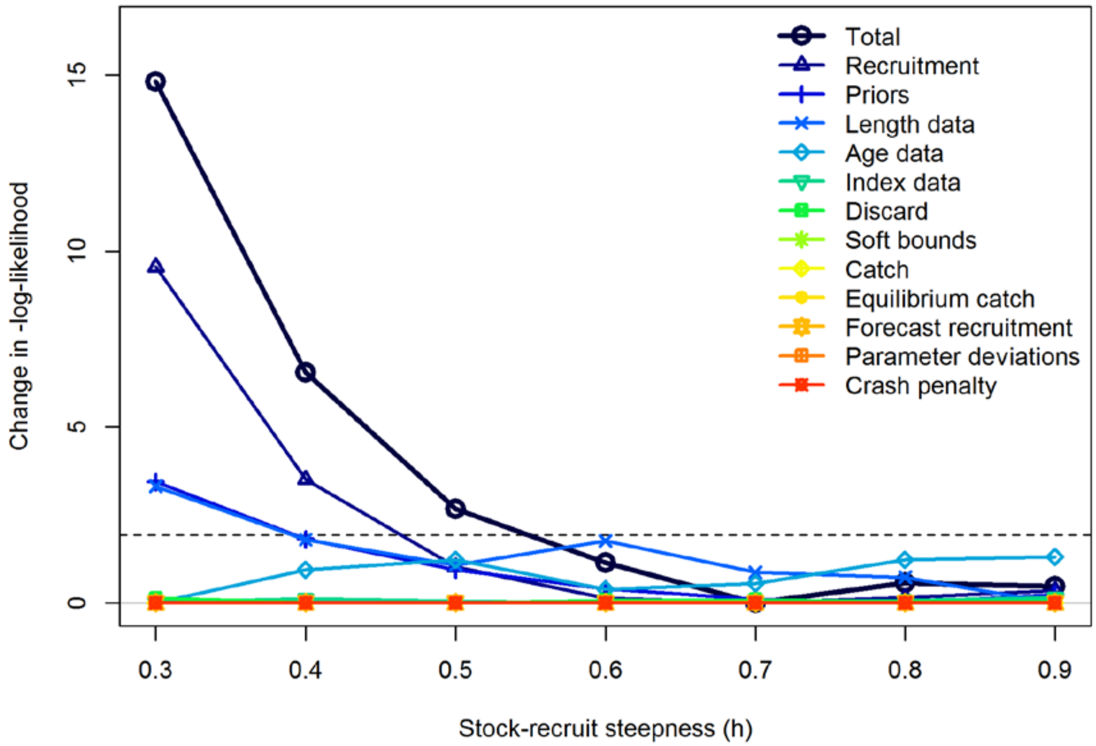

Figure 107: Negative log-likelihood profile for each data component and in total given different values of stock-recruit **steepness** ranging from 0.3 to 0.9 by increments of 0.1.

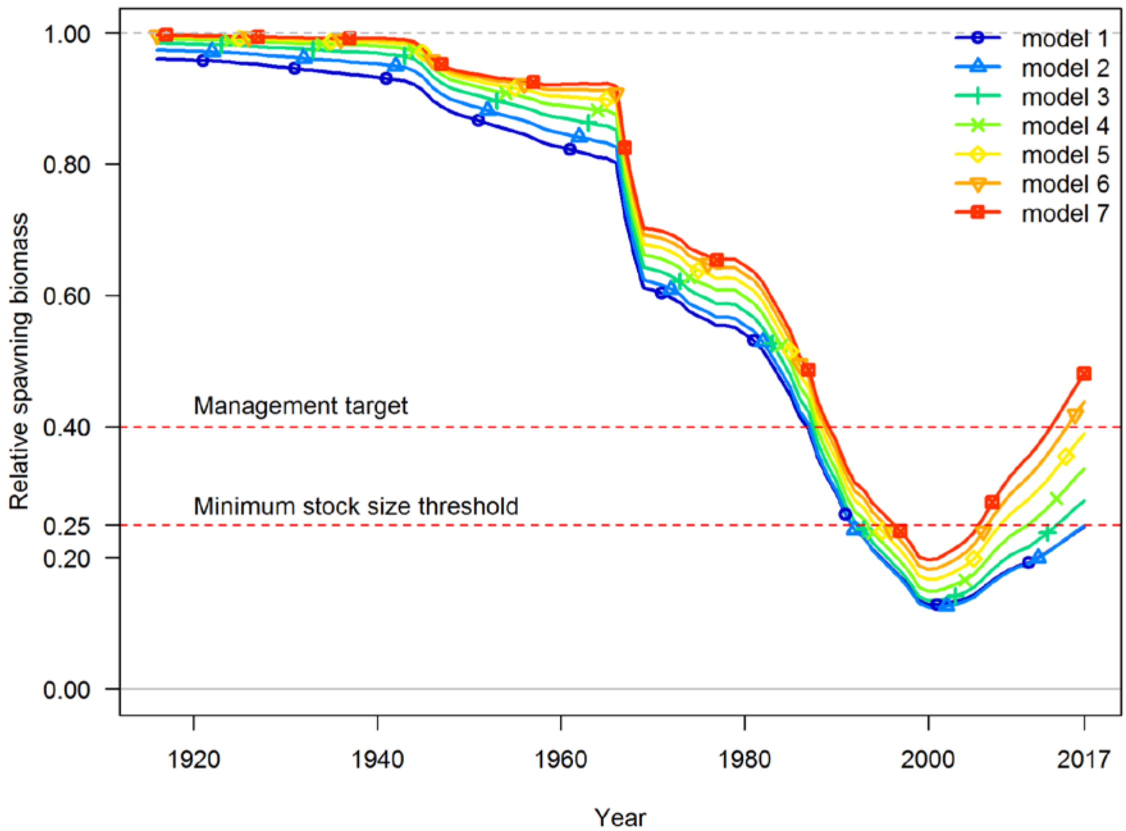

Figure 108: Time series of spawning depletion associated with different values of **steepness** ranging from 0.3 (Model 1) to 0.9 (Model 7) by increments of 0.1.

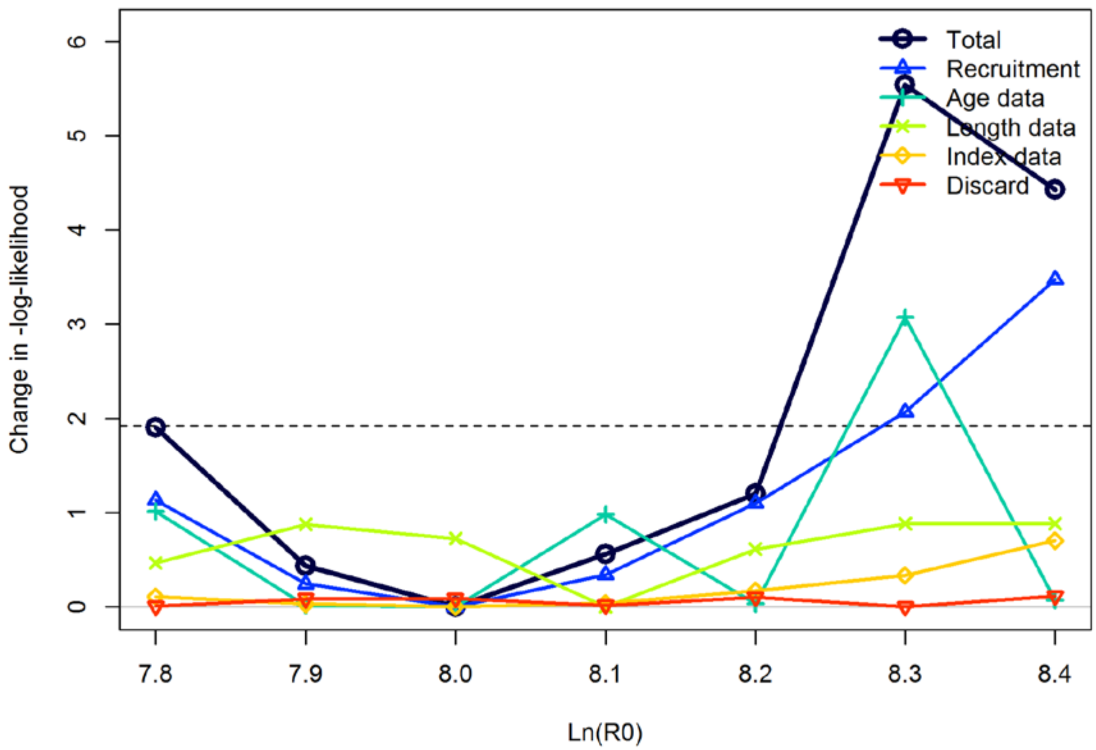

Figure 109: Negative log-likelihood profile for the base model, for each data component and in total given different values of **ln(*R*₀)** ranging from 7.8 to 8.4 by increments of 0.1.

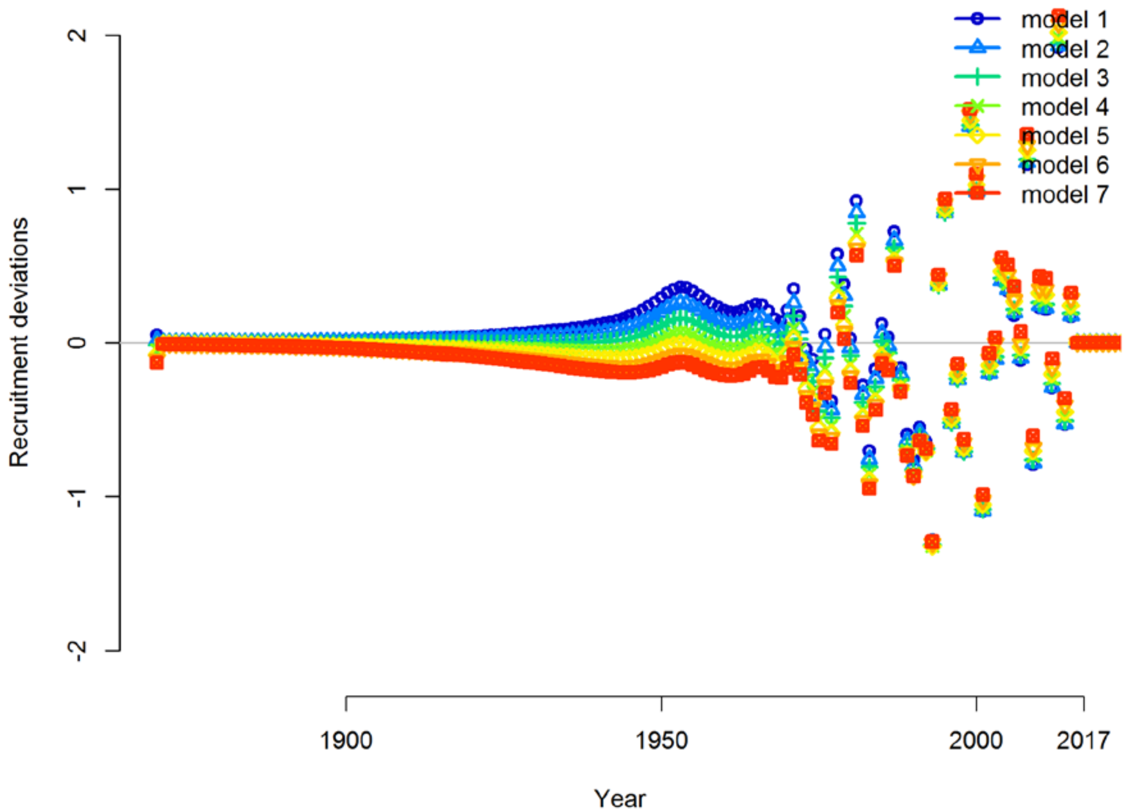

Figure 110: Values of recruitment deviations given different values of $\mathbf{ln(}\boldsymbol{R_0}\mathbf{)}$ ranging from 7.8 to 8.4 by increments of 0.1.

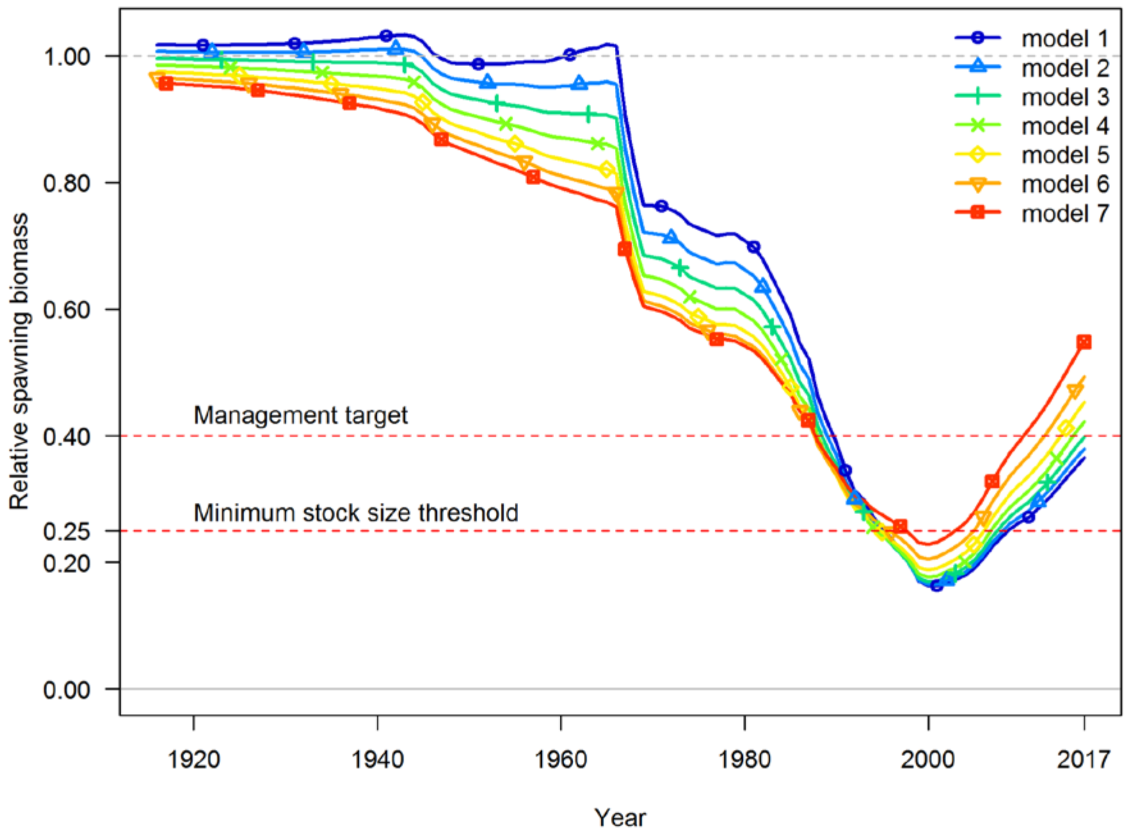

Figure 111: Time series of spawning depletion associated with different values of **ln(*R_0*)** ranging from 7.8 to 8.4 by increments of 0.1.

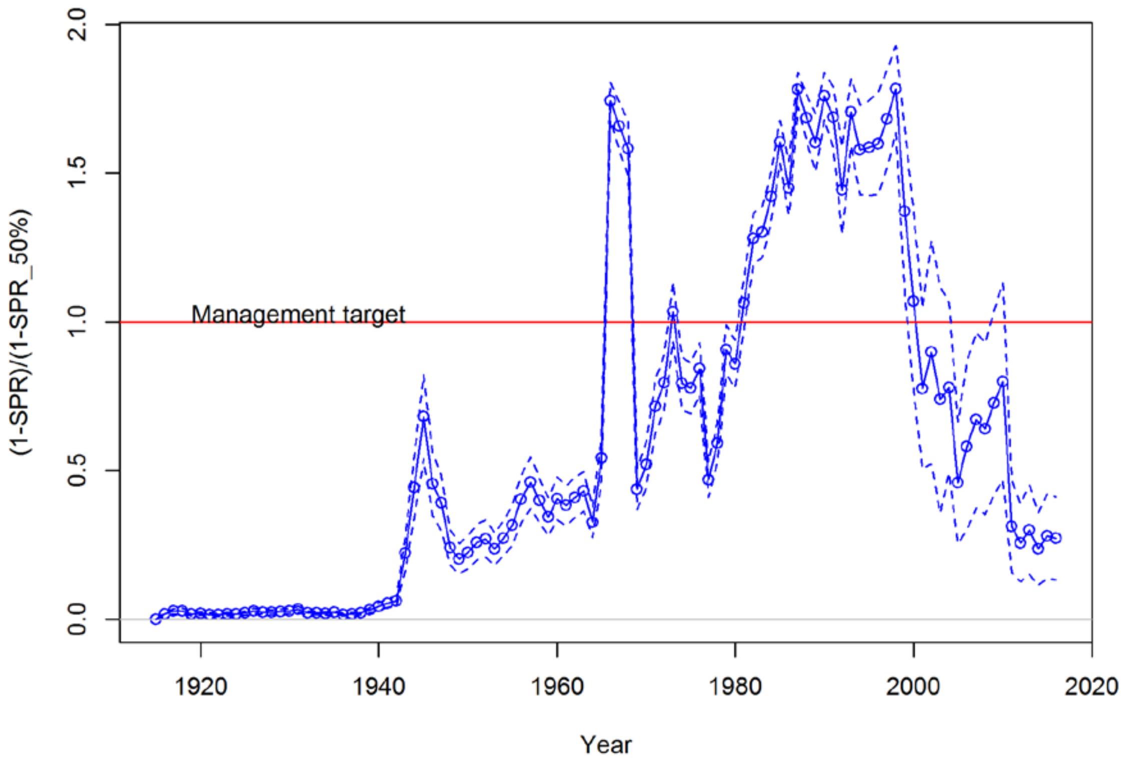

Figure 112: Time series of estimated relative spawning potential ratio (1-SPR/1-SPR$_{Target=0.5}$) for the base model (round points) with ~95% intervals (dashed lines). Values of relative SPR above 1.0 reflect harvests in excess of the current overfishing.

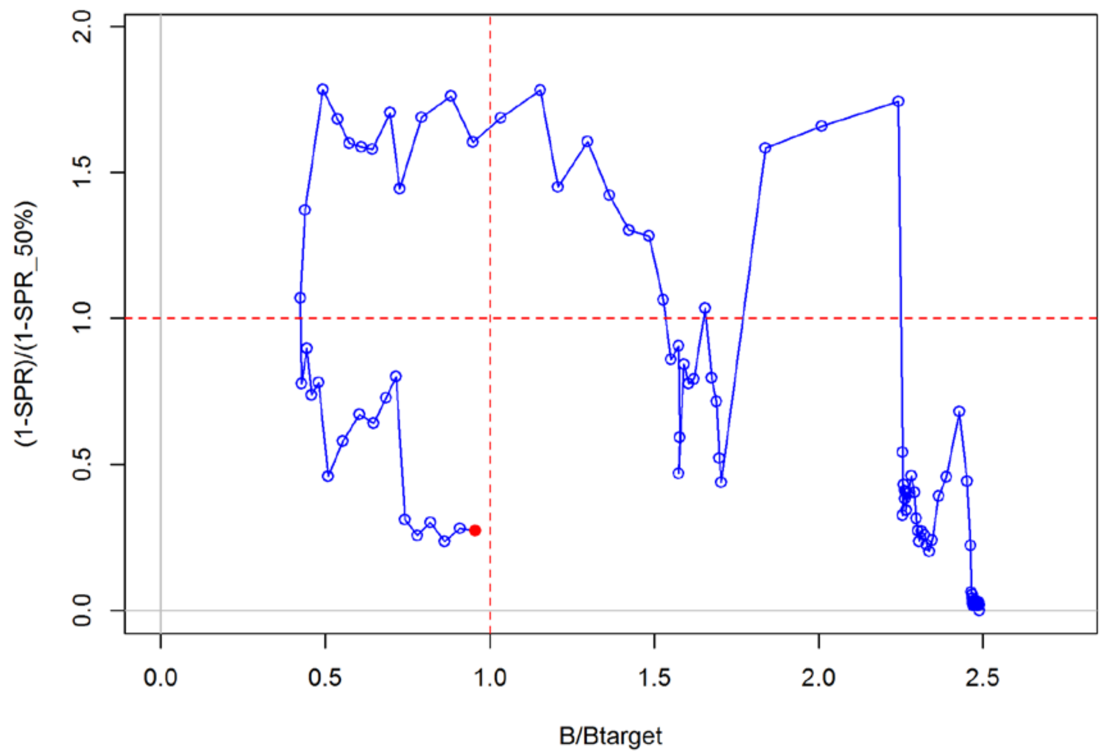

Figure 113: Phase plot of estimated relative (1-SPR) vs. relative spawning biomass for the base model. The relative (1-SPR) is (1-SPR) divided by 0.649 (the SPR target). Relative depletion is the annual spawning biomass divided by the spawning biomass corresponding to 40% of the unfished spawning biomass. The red point indicates the year 2016.

Appendix A. Management shifts related to West Coast groundfish species

Effective October 18, 1982

- First trip limits established (widow rockfish and sablefish).

Effective January 1, 1983

- Established first coast wide trip limits on Sebastes complex

Effective January 1, 1992

- First **cumulative trip limits** for various species and species groups (widow RF; Sebastes complex; Pacific ocean perch; deepwater complex; non-trawl sablefish).

Effective May 9, 1992

- Increased the **minimum legal codend mesh size** for roller trawl gear north of Point Arena, California (40^o 30' N latitude) from 3.0 inches to 4.5 inches; prohibited double-walled codends; removed provisions regarding rollers and tickler chains for roller gear with codend mesh smaller than 4.5 inches.

Effective January 1, 1994

- Divided the commercial groundfish fishery into two components: the **limited entry** fishery and the open access fishery.
    - o A federal limited entry permit is required to participate in the limited entry segment of the fishery. Permits are issued based on the fishing history of qualifying fishing vessels.

Effective September 8, 1995

- The **trawl minimum mesh size** now applies throughout the net; removed the legal distinction between bottom and roller trawls and the requirement for continuous riblines; clarified the distinction between bottom and pelagic (midwater) trawls; modified chafing gear requirements;

Effective January 1, 1997

- Established first Dover sole, thornyheads, and trawl-caught sablefish (DTS) complex cumulative limits

Effective January 1, 1999:

- Dividing line between north and south management areas moved to 40^o 10'.

Effective January 1, 2000

- **chafing gear** may be used only on the last 50 meshes of a small footrope trawl, running the length of the net from the terminal (closed) end of the codend.

New rockfish categories in 2000.

- Rockfish (except thornyheads) are divided into new categories north and south of 40° 10' N. lat., depending on the depth where they most often are caught:

nearshore, shelf, or slope. New trip limits have been established for "minor rockfish" species according to these categories.

- Nearshore: numerous minor rockfish species including black and blue rockfishes.
- Shelf: shortbelly, widow, yellowtail, bocaccio, chilipepper, cowcod rockfishes, and others.
- Slope: Pacific ocean perch, splitnose rockfish, and others

New Limited Entry Trawl Gear Restrictions in 2000.

- Limited entry trip limits may vary depending on the type of trawl gear that is onboard a vessel during a fishing trip: large footrope, small footrope, or midwater trawl gear.
  - **Large footrope trawl gear** is bottom trawl gear, with a footrope diameter larger than 8 in. (20 cm) (including rollers, bobbins or other material encircling or tied along the length of the footrope).
  - **Small footrope trawl gear** is bottom trawl gear, with a footrope diameter 8 in. (20 cm) or smaller (including rollers, bobbins or other material encircling or tied along the length of the footrope), except chafing gear may be used only on the last 50 meshes of a small footrope trawl, running the length of the net from the terminal (closed) end of the codend.
  - **Midwater trawl gear** is pelagic trawl gear, The footrope of midwater trawl gear may not be enlarged by encircling it with chains or by any other means.

Effective during 2001:

- First conservation area was established (Cowcod Conservation Area)
- The West Coast Observer Program was initiated
- It is unlawful to take and retain, possess or land petrale sole from a fishing trip if large footrope gear is onboard and the trip is conducted at least in part between May 1 and October 31

Effective during 2002:

- Darkblotched rockfish Conservation Area was established.

Effective during 2003:

- Vessel buyback program was initiated (December 4, 2003)
- Yelloweye Rockfish Conservation Area was established
- Rockfish Conservation areas for several rockfish species were established.

Effective during 2004:

- Vessel Monitoring System (VMS) was initiated.

Effective during 2005:

- Selective flatfish trawl required shoreward of the RCA North of 40º 10’.