Agenda Item F.4
Attachment 4
June 2017

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

(Update of 2015 assessment model)

by

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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 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 coastwide 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 coastwide 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 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.

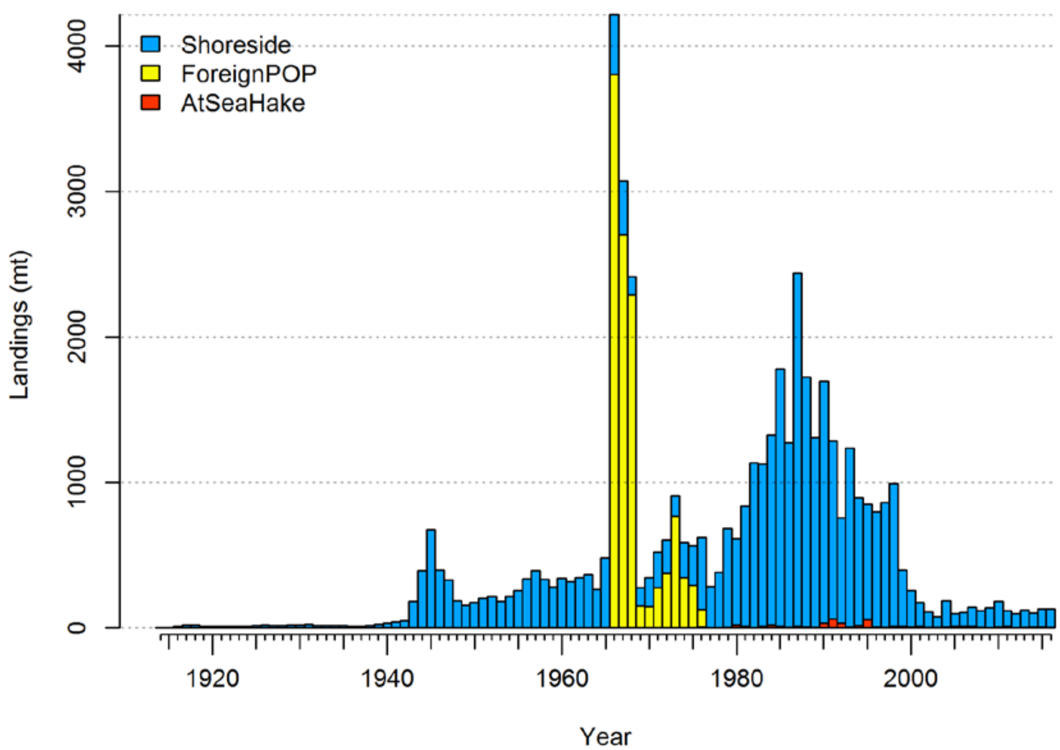

Figure ES-1: Darkblotched rockfish landings history between 1915 and 2016 by fleet.

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).

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. The assessment here uses the Stock Synthesis modeling framework developed by Dr. Richard Methot at the NWFSC. The most recent version (SSv3.30.01.12) available at the time this assessment was undertaken was used, since it included improvements in the output statistics for producing assessment results and several corrections to older versions. 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.

The data used in the assessment include landings, length and age compositions of the retained commercial catch from Pacific Fisheries Information Network (PacFIN) and, for the first time since 2005, includes historical age data from 1980 forward. 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 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. Natural mortality is fixed at the value of 0.054 yr^{-1} for females and estimated for males.

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 3,548 million eggs (95% confidence interval: 2,714-4,382 million eggs). At the beginning of 2017, the spawning stock output is estimated to be 1,423 million eggs (95% confidence interval: 615-2,230 million eggs), which represents 40.11% of the unfished spawning output level.

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	920	421–1,418	25.9%	14.7–37.1%
2009	973	440–1,507	27.4%	15.4–39.5%
2010	1,017	452–1,582	28.7%	15.9–41.4%
2011	1,055	458–1,651	29.7%	16.2–43.2%
2012	1,109	481–1,736	31.2%	17.0–45.5%
2013	1,165	506–1,825	32.8%	17.9–47.8%
2014	1,226	532–1,921	34.6%	18.8–50.3%
2015	1,294	561–2,026	36.5%	19.8–53.1%
2016	1,359	589–2,130	38.3%	20.8–55.8%
2017	1,423	616–2,231	40.1%	21.8–58.4%

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	6,064	3,561–10,327	1.195	0.853–1.537
2009	875	457–1,675	-0.757	-1.283–-0.231
2010	2,463	1,394–4,350	0.265	-0.139–0.669
2011	2,457	1,373–4,397	0.253	-0.170–0.676
2012	1,494	786–2,839	-0.258	-0.774–0.259
2013	13,912	7,911–24,465	1.961	1.560–2.362
2014	1,239	573–2,680	-0.496	-1.197–0.205
2015	2,588	1,105–6,065	0.202	-0.607–1.011
2016	2,602	1,974–3,431	0.000	0.000–0.000
2017	2,628	1,997–3,458	0.000	0.000–0.000

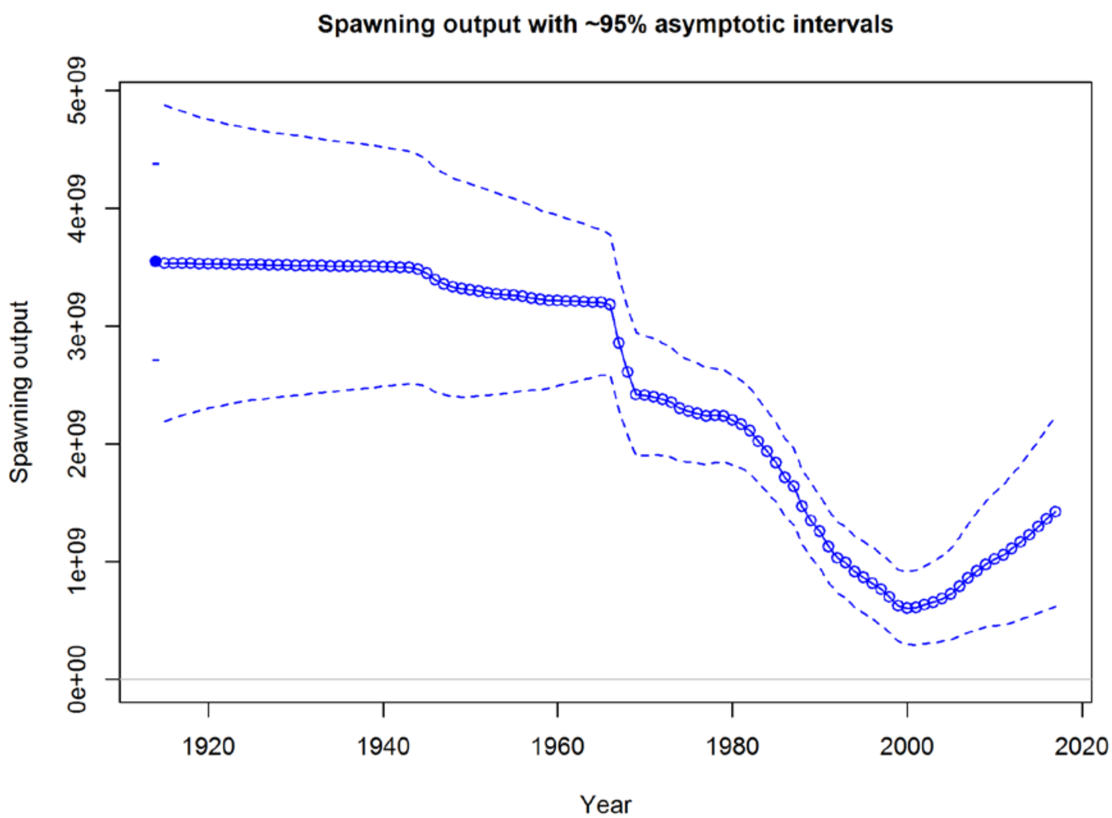

Figure ES-2: Estimated spawning biomass time-series (1915-2017) for the base-case model (circles) with ~ 95% interval (dashed lines). Spawning output is expressed in the number of eggs.

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 steepness parameter (*h*) is fixed in the assessment at the value of 0.72 (down from 0.773 in 2015), which is the mean of steepness prior probability distribution, derived from this year's meta-analysis of Tier 1 rockfish assessments.

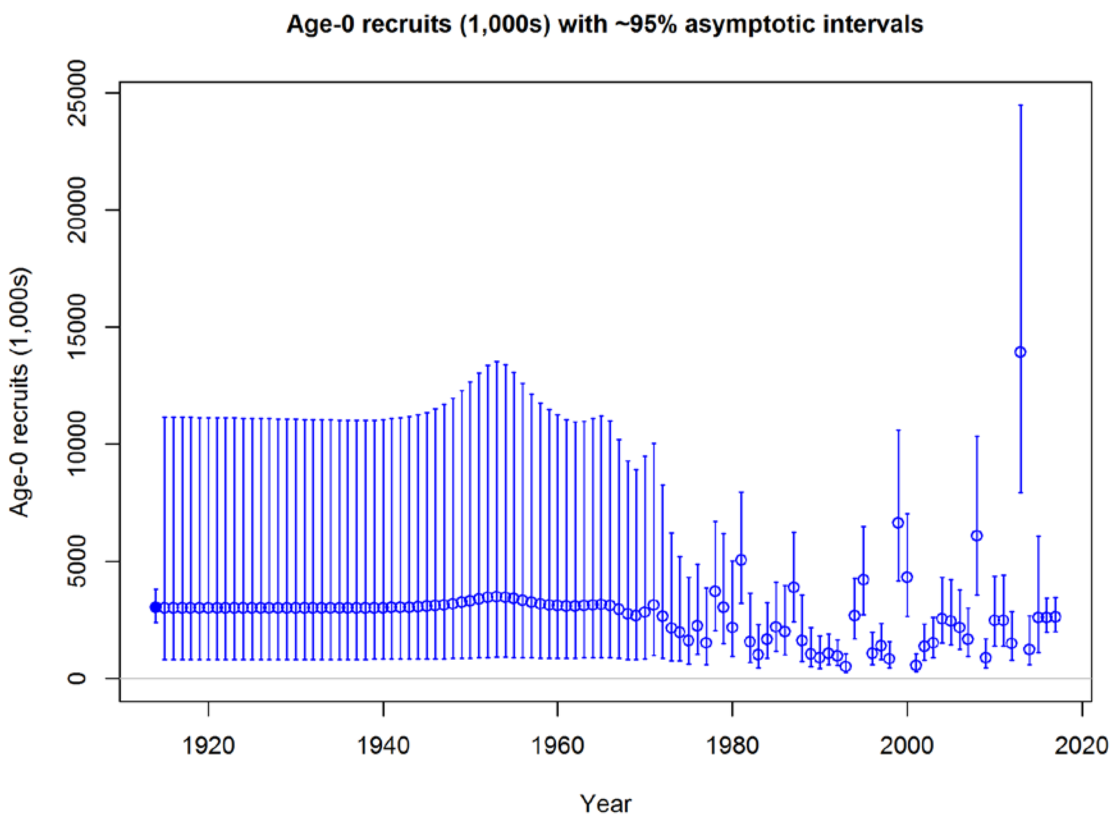

Figure ES-3: Time series of estimated darkblotched rockfish recruitments for the base-case model (solid line) with ~95% intervals (vertical lines).

Reference points

Unfished spawning stock output for darkblotched rockfish was estimated to be 3,548 million eggs (95% confidence interval: 2,714-4,382 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 1,419 million eggs (95% confidence interval: 1,086-1,753), which corresponds to an exploitation rate of 0.037.

This harvest rate provides an equilibrium yield of 641 mt at $SB_{40\%}$ (95% confidence interval: 496-785 mt). The model estimate of maximum sustainable yield (MSY) is 641 mt (95% confidence interval: 496-785 mt). The estimated spawning stock output at MSY is 1,019 million eggs (95% confidence interval: 779-1,259 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)	3,548	2,714–4,382
Unfished Age 1+ Biomass (mt)	39,969	30,999–48,938
Spawning output (million eggs, 2017)	1,423	615–2,230
Unfished Recruitment (R0)	3,010	2,306–3,713
Depletion (2017)	40.11	21.78–58.45
Reference Points Based SB40%		
Proxy spawning output ($B_{40\%,}$ million eggs)	1,419	1,086–1,753
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)	641	496–785
Reference Points based on SPR proxy for MSY		
Proxy spawning biomass (SPR_{50}, million eggs)	1,583	1,211–1,955
SPR_{50}	50%	NA
Exploitation rate corresponding to SPR_{50}	0.032	0.031–0.033
Yield with SPR_{50} at SB_{SPR} (mt)	614	476–753
Reference points based on estimated MSY values		
Spawning biomass at MSY (SB_{MSY})	1,019	779–1,259
SPR_{MSY}	35.6%	0.351–0.362
Exploitation rate corresponding to SPR_{MSY}	0.052	0.050–0.054
MSY (mt)	671	520–823

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 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.

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.

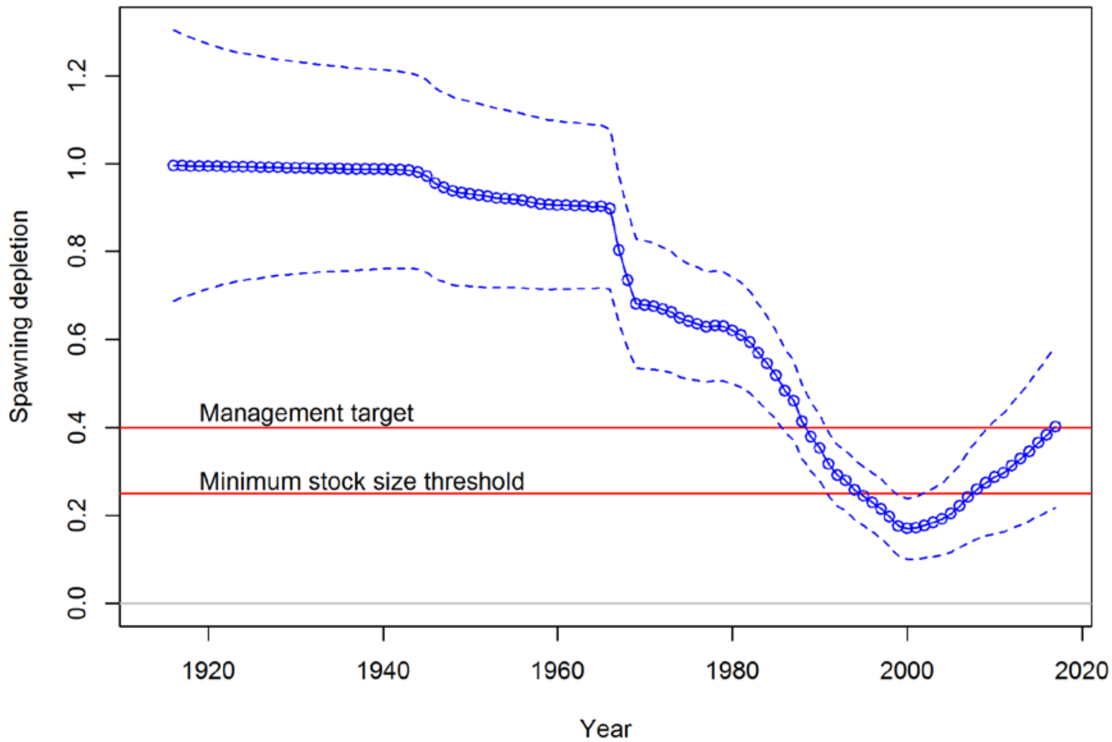

Figure ES-4. Estimated relative depletion with approximate 95% asymptotic confidence intervals (dashed lines) for the base case assessment model.

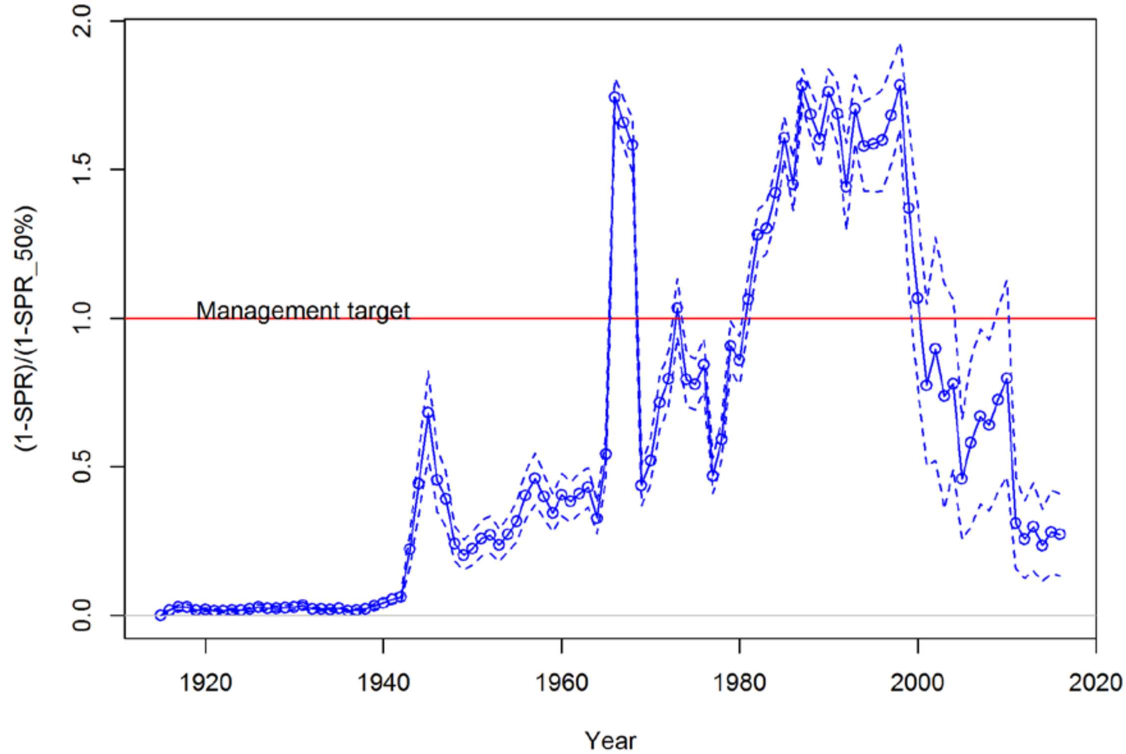

Figure ES-5. Time series of estimated relative spawning potential ratio (1-SPR/1-$SPR_{Target=0.5}$) for the base-case model (round points) with ~95% intervals (dashed lines). Values of relative SPR above 1.0 reflect harvests in excess of the current overfishing proxy.

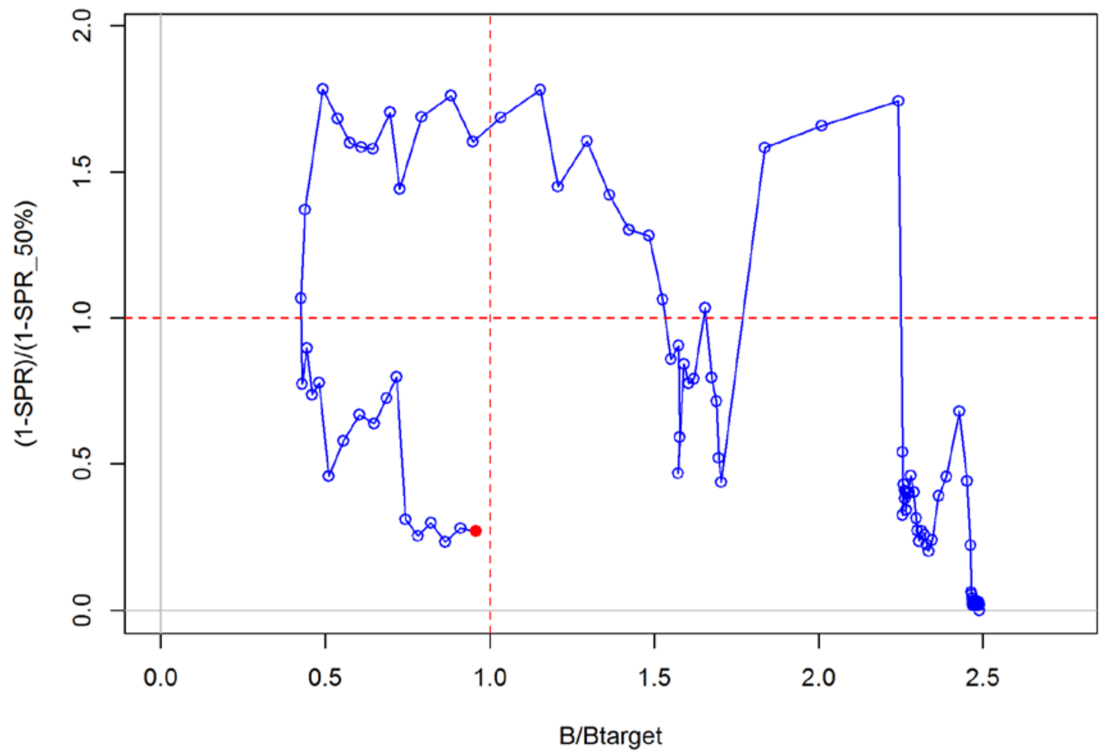

Figure ES-6. Phase plot of estimated relative (1-SPR) vs. relative spawning biomass for the base case model. The relative (1-SPR) is (1-SPR) divided by 0.5 (the SPR target). Relative depletion is the annual spawning biomass divided by the spawning biomass corresponding to 40% of the unfished spawning 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	66.92%	37.57–96.28%	0.020	0.009–0.032
2008	63.89%	35.16–92.63%	0.018	0.008–0.029
2009	72.55%	41.80–103.31%	0.021	0.009–0.033
2010	79.72%	46.70–112.73%	0.024	0.010–0.037
2011	31.02%	15.62–46.41%	0.008	0.004–0.013
2012	25.51%	12.56–38.45%	0.007	0.003–0.010
2013	29.78%	14.87–44.69%	0.008	0.004–0.012
2014	23.48%	11.43–35.54%	0.006	0.003–0.010
2015	27.95%	13.79–42.11%	0.007	0.003–0.012
2016	27.11%	13.28–40.93%	0.007	0.003–0.011

Ecosystem considerations

Darkblotched rockfish is most abundant from off British Columbia to Central California. This is a slope species that 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. Young darkblotched are eaten by king salmon and albacore.

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. However, we used the recently developed geostatistical VAST approach to estimate an abundance index from NWFSC shelf-slope survey data. This method uses information on the location of samples (i.e., whether located in high- or low-density habitats) to explain a portion of the variability in catch rates, and thus indirectly incorporates information on habitat quality that, in many respects, shapes spatial distribution of organisms and determines their density of occurrence.

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 dead catch (as estimated in this assessment) exceeded the AnnualCatch Limit (ACL) in two years: 2009 and 2010. The total dead catch has not exceeded the Overfishing Limit (OFL) during the last decade.

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.

Year	OFL (mt)	ACL (mt)	Landings (mt)	Estimated Total Catch (mt)
2007	456	260	143.6	256.1
2008	456	260	117.4	243.8
2009	437	282	138.4	290.7
2010	437	282	184.3	337.8
2011	508	298	116.9	121.2
2012	508	298	99.0	102.4
2013	541	317	124.1	127.8
2014	541	317	103.2	106.5
2015	574	549	130.7	136.7
2016	580	554	129.1	136.5

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. 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 California and Oregon landings, 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 40.11%. The primary axis of uncertainty about this estimate used in the decision table was based on female natural mortality. To identify female natural mortality values that correspond to low and high states of nature, a multi-step algorithm was followed in 2015 (Gertseva, et al., 2016). Those same natural mortality levels are used in this update.

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 of 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 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 along the coast; such information is currently lacking.

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 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. The Councill and Harford method is an example of one approach; it models natural mortality as a decaying function of size, with assumptions that mortality rates should be constrained by lifetime mortality rate.

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.

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. Decision

			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	868	25%	1,423	40%	1,687	46%
	2018	122	919	26%	1,493	42%	1,762	48%
	2019	122	985	28%	1,584	45%	1,861	51%
	2020	122	1,066	31%	1,699	48%	1,987	54%
	2021	122	1,153	33%	1,821	51%	2,120	58%
	2022	122	1,236	36%	1,933	54%	2,240	61%
	2023	122	1,310	38%	2,030	57%	2,343	64%
	2024	122	1,376	40%	2,113	60%	2,430	66%
	2025	122	1,435	41%	2,184	62%	2,502	68%
	2026	122	1,488	43%	2,245	63%	2,563	70%
	2027	122	1,537	44%	2,299	65%	2,616	72%
	2028	122	1,583	45%	2,346	66%	2,662	73%
2018 ACL catch assumed for years between 2018 and 2028 with SPR = 0.50	2017	641	868	25%	1,423	40%	1,687	46%
	2018	653	889	26%	1,463	41%	1,732	47%
	2019	653	920	26%	1,522	43%	1,798	49%
	2020	653	964	28%	1,600	45%	1,888	52%
	2021	653	1,008	29%	1,679	47%	1,979	54%
	2022	653	1,041	30%	1,745	49%	2,054	56%
	2023	653	1,063	31%	1,793	51%	2,110	58%
	2024	653	1,076	31%	1,828	52%	2,150	59%
	2025	653	1,082	31%	1,851	52%	2,176	59%
	2026	653	1,083	31%	1,866	53%	2,193	60%
	2027	653	1,081	31%	1,875	53%	2,203	60%
	2028	653	1,075	31%	1,878	53%	2,206	60%
Projections based on current rebuilding SPR of 64.9% applied to the base model For 2017 and 2018, adopted ACLs are used.	2017	641	868	25%	1,423	40%	1,687	46%
	2018	653	889	26%	1,463	41%	1,732	47%
	2019	496	920	26%	1,522	43%	1,798	49%
	2020	532	973	28%	1,609	45%	1,897	52%
	2021	528	1,025	29%	1,696	48%	1,996	55%
	2022	507	1,068	31%	1,772	50%	2,081	57%
	2023	488	1,103	32%	1,832	52%	2,149	59%
	2024	474	1,131	32%	1,880	53%	2,201	60%
	2025	465	1,153	33%	1,918	54%	2,242	61%
	2026	460	1,171	34%	1,949	55%	2,274	62%
	2027	457	1,185	34%	1,973	56%	2,299	63%
	2028	456	1,198	34%	1,993	56%	2,318	63%

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	868	25%	1,423	40%	1,687	46%
	2018	122	919	26%	1,493	42%	1,762	48%
	2019	122	985	28%	1,584	45%	1,861	51%
	2020	122	1,066	31%	1,699	48%	1,987	54%
	2021	653	1,153	33%	1,821	51%	2,120	58%
	2022	653	1,204	35%	1,901	54%	2,209	60%
	2023	653	1,240	36%	1,962	55%	2,275	62%
	2024	653	1,265	36%	2,005	57%	2,323	63%
	2025	653	1,281	37%	2,035	57%	2,355	64%
	2026	653	1,290	37%	2,054	58%	2,374	65%
	2027	653	1,292	37%	2,064	58%	2,385	65%
	2028	653	1,290	37%	2,068	58%	2,389	65%

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	94	124	103	131	129	NA
Estimated Total catch (mt)	261	250	289	351	118	95	125	104	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	0.23	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)	12,688	13,220	13,780	14,331	14,874	15,625	16,363	17,191	18,252	19,498	20,799
Spawning output (million eggs)	857	920	973	1,017	1,055	1,109	1,165	1,226	1,294	1,359	1,423
~95% Confidence Interval	397–1,318	421–1,418	440–1,507	452–1,582	458–1,651	481–1,736	506–1,825	532–1,921	561–2,026	589–2,130	616–2,231
Recruitment	1,654	6,064	875	2,463	2,457	1,494	13,912	1,239	2,588	2,602	2,628
~95% Confidence Interval	916–2,985	3,561–10,327	457–1,675	1,394–4,350	1,373–4,397	786–2,839	7,911–24,465	573–2,680	1,105–6,065	1,974–3,431	1,997–3,458
Depletion (%)	24.2	25.9	27.4	28.7	29.7	31.2	32.8	34.6	36.5	38.3	40.1
~95% Confidence Interval	13.8–34.5	14.7–37.1	15.4–39.5	15.9–41.4	16.2–43.2	17.0–45.5	17.9–47.8	18.8–50.3	19.8–53.1	20.8–55.8	21.8–58.4

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 current rebuilding SPR of 64.9%. Projections assume total catch of 641 and 653 mt (the Council's adopted ACLs) for 2017 and 2018, respectively.

Year	Predicted OFL (mt)	Potential ACL (mt)	Summary biomass (mt)	Spawning output (million eggs)	Depletion (%)
2019	810	496	22,117	1,522	43%
2020	869	532	22,730	1,609	45%
2021	861	528	23,162	1,696	48%
2022	828	507	23,474	1,772	50%
2023	797	488	23,710	1,832	52%
2024	774	474	23,894	1,880	53%
2025	760	465	24,040	1,918	54%
2026	751	460	24,156	1,949	55%
2027	747	457	24,250	1,973	56%
2028	744	456	24,327	1,993	56%

Table ES-10. 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 catch of 641 and 653 mt (the Council's adopted ACLs) for 2017 and 2018, respectively.

Year	Predicted OFL (mt)	Potential ACL (mt)	Summary biomass (mt)	Spawning output (million eggs)	Depletion (%)
2019	810	775	22,117	1,522	43%
2020	855	819	22,442	1,593	45%
2021	834	798	22,565	1,662	47%
2022	791	757	22,577	1,715	48%
2023	752	720	22,536	1,754	49%
2024	723	692	22,465	1,781	50%
2025	704	673	22,378	1,800	51%
2026	691	661	22,279	1,811	51%
2027	682	652	22,174	1,817	51%
2028	675	646	22,065	1,819	51%

Table ES-11. 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 (%)
2019	810	653	22,117	1,522	43%
2020	861	653	22,568	1,600	45%
2021	848	653	22,868	1,679	47%
2022	810	653	23,039	1,745	49%
2023	774	653	23,114	1,793	51%
2024	746	653	23,118	1,828	52%
2025	726	653	23,071	1,851	52%
2026	712	653	22,989	1,866	53%
2027	702	653	22,884	1,875	53%
2028	695	653	22,762	1,878	53%

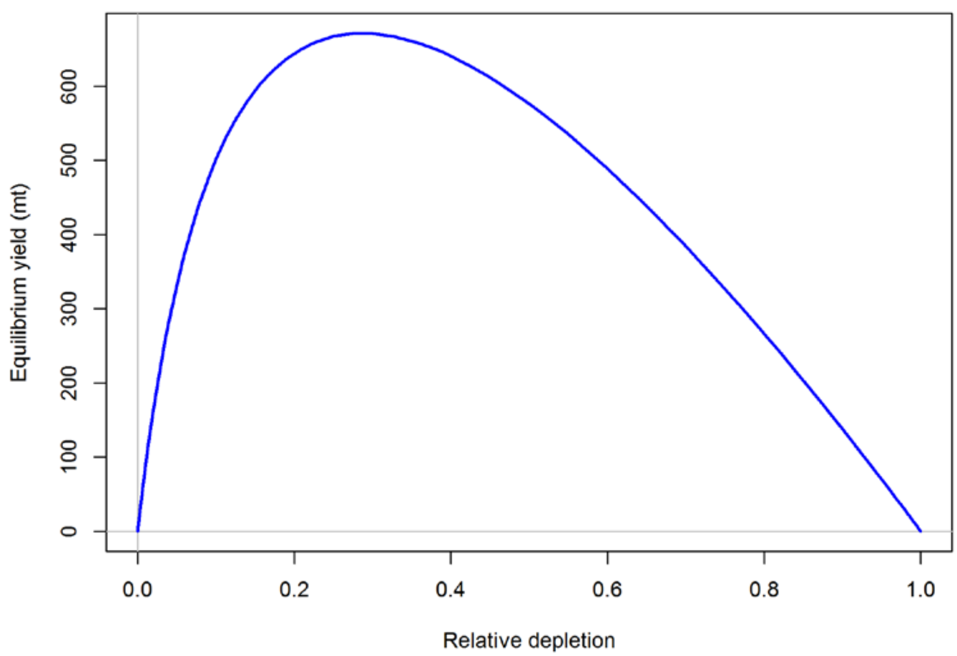

Figure ES-7. Equilibrium yield curve (derived from reference point values reported in Table ES-5) for the base case model. Values are based on 2014 fishery selectivity and distribution with steepness fixed at 0.773. The depletion is relative to unfished spawning biomass.

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).

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 fishery landings and catch distributions (Figure 1). 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 attain maximum length earlier 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 juvenile 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 may 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.

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 area of assessment. 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. Therefore, it is reasonable to assume that mixing of individuals within assessment area happens not only at the stage of pelagic juveniles, but also at the adult life stages. Given that, the spatial scope of the assessment is treated as a single coastwide area.

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 juveniles darkblotched 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 deepwater 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 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. They are preyed upon by large fishes and marine mammals. 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. Also, 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. However, we used the recently developed Vector Autoregressive Spatio-Temporal (VAST) model to estimate an abundance index from NWFSC shelf-slope survey data. This method is designed to estimate total abundance for a species taking into account spatial variation in density using spatially referenced data, and thus indirectly incorporates information on habitat quality that, in many respects, shapes spatial distribution of organisms and determines their density of occurrence.

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 coastwide 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).

The rockfish fishery off the U.S. Pacific coast first developed off California in the late 19th century. At that time, most rockfish were taken by hook and line, with a minor amount taken by gillnets (Love et al., 2002). Until the 1940s, catches of rockfish were very small because almost all fishing efforts were directed toward the various salmon species and Pacific halibut.

The rockfish fishery was established in the early 1940s, when the United States became involved in World War II and wartime shortage of red meat created an increased demand for other sources of protein (Alverson et al., 1964; Harry and Morgan, 1961). Also, in 1943, the new balloon trawls were introduced. These balloon trawls were lighter than the old paranzellas and otter trawl nets. They were built to fish over low-lying rocky reefs and proved to be successful in taking rockfish (Love et al., 2002). With this new technology and increased demands during the World War II, the catch of rockfish increased in the mid-1940s. The increased demand caused the fishery to shift toward previously unexploited areas, including those preferred by darkblotched rockfish. The California fishery moved north, to the Eureka INPFC area; and both the California and Oregon fisheries had moved deeper into the slope area; those areas greater than 100 fm (183 m) (Harry and Morgan, 1961; Scofield, 1948). This is when darkblotched rockfish catch first became significant.

Domestic demand for rockfish declined after World War II and rockfish catches dropped (Cleaver, 1951), but in the early 1950s, the Pacific ocean perch fishery developed in Oregon and Washington (Love et al., 2002), and landings of darkblotched rockfish, which co-occur with Pacific ocean perch, also increased. Prior to 1965, Pacific ocean perch and species incidentally caught in the Pacific ocean perch fishery off of the U. S. West Coast were harvested almost entirely by U. S. and Canadian vessels. Most of these vessels were of multi-purpose design and used in other fisheries, such as salmon and herring, when not engaged in the groundfish fishery. Generally under 200 gross tons and less than 33 m in length, these vessels had very little at-sea processing capabilities. These characteristics, for the most part, restricted the distance these vessels could fish from home ports, and limited the size of their landings.

In the mid-1960s, 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 over high-relief rocky outcrops (Love et al., 2002). Using very large vessels (often called factory trawlers), foreign fleets, particularly the Soviet, had the capacity to operate independently, by processing and freezing their own catch. Support vessels, such as refrigerated transports, oil tankers, and supply ships permitted these large stern trawlers to operate at sea for extended periods of time. Foreign fleets were known not to discard fish (Rogers, 2003).

Foreign catch was particularly significant between 1966 and 1968. Within a short period of time, catches of Pacific ocean perch and rockfish co-occurring with Pacific ocean perch (including darkblotched rockfish) skyrocketed. However, regulations increasingly reduced catch of slope rockfish by foreign fleets. Catches declined rapidly, and the fishery proceeded with more moderate landings. By the late-1960s, the Soviet fleet had more or less abandoned the fishery, although the Japanese fleet continued fishing for some time. In 1976, on-bottom trawling by foreign fleets was prohibited, and the depleted Pacific ocean perch fishery became largely domestic (Love et al., 2002).

A small amount of darkblotched rockfish has also been taken as bycatch in the at-sea Pacific hake fishery. The at-sea Pacific hake fishery dates back to the 1960s when foreign

vessels participated. In the 1980s, the fishery evolved into a joint venture with U.S. catcher vessels delivering to foreign processing vessels. By 1991, foreign vessels were no longer allowed to fish in U.S. waters, and the Pacific hake fishery became completely domesticated, allowing only U.S. vessels to catch and process fish.
Prior to 1977, darkblotched rockfish in the waters off the United States were managed by the individual states (within three miles of shore). With implementation of the Magnuson-Stevens Fishery Conservation and Management Act (MFCMA) in 1976, primary responsibility for management of the groundfish stocks off Washington, Oregon and California shifted from the states to a partnership between the National Marine Fisheries Service (NMFS) and the Pacific Fishery Management Council (PFMC). A summary of the major management shifts on the West Coast of the United States related to groundfish species through 2005 (prepared by PFMC' Groundfish Management team (GMT)) is provided in Appendix 1.

Limits on shoreside rockfish catch were first instituted in 1983, with darkblotched rockfish managed as part of a group of around 50 species, designated as the *Sebastes* complex (Hamel, 2008). Commercial vessels were not required to separate most rockfish catches into individual species, and port biologists in each state routinely sampled mixed-species market categories, such as the *Sebastes* complex, to determine the actual species composition of these mixed-species categories. In 1994, the *Sebastes* complex was divided into northern and southern components, for annual harvest specifications and setting bimonthly cumulative landings limits (a.k.a. "trip limits"). In 1996, an assessment of the major species in the *Sebastes* complex was conducted (Rogers et al., 1996). This assessment led to a species-specific Overfishing Limit (OFL) (then called Acceptable Biological Catch (ABC)) for darkblotched rockfish in 1997.

The stock assessment conducted by Rogers et al. (2000) found the darkblotched rockfish stock to be depleted, and an overfished determination was made In 2001, darkblotched rockfish was managed with stock-specific harvest specifications with an ABC and an Optimum Yield (OY) specified. However, landed catch of darkblotched rockfish continued to be managed by trip limits established for the northern and southern minor slope rockfish complexes. Since 2000, when the stock was declared overfished, landings of darkblotched rockfish decreased substantially, primarily due to management regulations instituted for the species.

In 2002, Rockfish Conservation Areas (RCAs), which are large marine areas closed to commercial fishing, were implemented by NMFS as a measure to reduce bycatch of overfished rockfish species. Specific boundaries for the RCAs have varied considerably among bimonthly periods, years and areas; the extent and complexity of their structure has also waxed and waned since first instituted. The description of exact boundaries of the RCAs and how they change over time are available upon request. Trawl gear that is used shoreward of the RCAs is required to have small footropes (<8" diameter), which increases the risk of gear loss in rocky areas. Reductions in trip limits for shelf rockfish species have also reduced incentives to fish in rocky areas shoreward of the RCA. Since 2005, vessels using trawl gear shoreward of the RCA north of $40^{o}10'$ N latitude have also been required to use nets that are designed to be more selective for flatfish.

Since 2011, the shorebased trawl allocation (including non-hake groundfish trawl, and shorebased hake trips) has been managed under a catch share fishery, using Individual Fishing Quotas (IFQ), where each permit holder fishes an annual quota. Under this system, discard of darkblotched rockfish and many other species has decreased dramatically. This is evident in observer data. The primary driver for this decrease is that both landed and discarded fish count towards each fisher's annual quota. Under the previous system of bimonthly landing accumulation limits (a.k.a. trip limits), discard rates could fluctuate wildly, and were negatively correlated with trip limits. Pre-IFQ discard rates for darkblotched averaged 44.2 % (2002-2010), whereas under IFQ, the annual discard rate has averaged just 2.4 % (2011-2013).

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

The background provided in the 2015 assessment on Canadian and Alaskan fisheries for darkblotched rockfish has not been updated for this assessment.

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.

The shoreside fishery has historically reported landed catch only, even though a portion of the darkblotched catch was discarded at sea. The foreign POP fishery, on the other hand, was known not to discard fish based on fish size or species, while the at-sea hake fishery reports total catch, which includes both retained and discarded fish. To account for differences in discarding practices and catch reporting, and most importantly to avoid inflating darkblotched removals in the POP and at-sea hake fisheries, the shoreside fleet and bycatch fisheries were separated. The historical discarded portion of the shoreside fleet was estimated within the model based on data collected by the West Coast Groundfish Observer Program (WCGOP) and historical discard data provided in the Pikitch study (Pikitch et al., 1988) (both described in detail below). Contemporary estimates of discard are provided by WCGOP annually (2002-present).

Catches in the shoreside fishery have been traditionally dominated by bottom trawl removals, with catches of all other gear types (including non-trawl gears and mid-water trawl) contributing 2% of overall darkblotched landings. For the assessment, we combined catches from all gear types within the shoreside fishery into one fishing fleet.

Historically, landed catch of rockfish have been reported as mixed-species groups that have similar market value, rather than as individual species (Barss and Niska, 1978; Douglas, 1998; Lynde, 1986; Niska, 1976; Tagart and Kimura, 1982). These groups are called "market categories". The species compositions of these mixed-species market categories have changed over time. In the 1960s, the state agencies in California, Oregon and Washington initiated sampling programs of commercial trawl rockfish landings, in which port biologists sampled species compositions of mixed-species category landings to determine contributions of different species to each market category and derive per species landings time series. Sampling efforts focused on rockfish landings in the trawl fishery, since commercial landings of rockfish species with other gear types have been low. Prior to the 1960s, many of the market categories were not sampled for composition by species, so that the annual contributions of different species to these categories are largely unknown (Barss and Niska, 1978; Douglas, 1998; Lynde, 1986; Niska, 1976).

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 update assessment, as new Washington catch reconstruction became available. Also, ODFW provided estimates of darkblotched rockfish landings within unspecified categories (i.e., URCK and POP1) for the period between 1987 and 1999; these new estimates were included in this assessment.

Comparison of shoreside landings from 2015 assessment and landings used in this update assessment is presented in Figure 8. The souses of information for landed catch used in this assessment are briefly described below.

2.1.1.1.1 Washington

For this assessment, landings of darkblotched rockfish in Washington 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.

2.1.1.1.2 Oregon

As in 2015 assessment, time series of Oregon historical landings of darkblotched rockfish through 1986 were obtained from Karnowski et al. (2014). Estimates of recent shoreside landings of darkblotched rockfish (between 1986 and 2016) were obtained from the Pacific Fisheries Information Network (PacFIN). The data were extracted on March 17, 2017. The PacFIN landings 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. 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. The total landings of darkblotched rockfish in Oregon used in this assessment are presented in Table 2.

2.1.1.1.3 California

Estimates of recent shoreside landings of darkblotched rockfish in California (between 1981 and 2016) were obtained from PacFIN (extracted on March 17, 2017). Historical landings (between 1916 and 1980) were obtained from CalCOM (Field, J. and Pearson, J. pers. com.). These landings were identical to ones used in 2015 assessment. The California landings used in this assessment are presented in Table 2.

2.1.1.2 Discard

There are three main sources of rockfish discard information on the West Coast of the United States. Since 2002, the WCGOP has collected bycatch and discard information on board fishing vessels in the trawl and fixed gear fleets along the entire coast, and produced discard ratio and total fishing mortality estimates for all species observed. The WCGOP was implemented in 2001 and began with gathering data for the limited entry trawl and fixed gear fleets. Observer coverage has expanded to include the California halibut trawl, the nearshore fixed gear and pink shrimp trawl fisheries. Since 2011, darkblotched rockfish has been harvested with a catch share fishery, using Individual Fishing Quotas (IFQ), where each permit holder has an annual quota. The WCGOP provides 100% at-sea observer monitoring of catch for this new, catch share based IFQ fishery.

Prior to 2002, there were two studies of bycatch and discard in the trawl fishery, including the Enhanced Data Collection Project (EDCP) and the Pikitch study (Pikitch et al., 1988). The EDCP, which was administered by the ODFW, collected data on bycatch and discard of groundfish species off the Oregon coast from late 1995 to early 1999 (Sampson, pers.com.). The project had limited spatial coverage (Oregon waters only) and due to time constraints, the observers only recorded discarded catch for darkblotched rockfish. Retained catch of darkblotched rockfish was recorded in the logbooks and fish tickets, but only as part of a mixed-species group of rockfish, which prevented calculation of the species-specific discard ratios for darkblotched rockfish. For this reason, the EDCP data were not included in the assessment.

The Pikitch study was conducted between 1985 and 1987. The northern and southern boundaries of the study were 48°42’ and 42°60’ North latitude respectively, which is primarily within the Columbia INPFC area (Pikitch et al., 1988; Rogers and Pikitch, 1992). Participation in the study was voluntary and included vessels using bottom, midwater, and shrimp trawl gears. Observers of normal fishing operations on commercial fishing vessels collected the data, estimated the total weight of the catch by tow and recorded the weight of each species retained or discarded in the sample.

Discard ratios for 1985 and 1987 were estimated from observations of retained and discarded catch collected in the Pikitch study (Pikitch et al., 1988), as described in Wallace (in review). Rodgers and Pikitch (1992) produced post-hoc assemblages based on co-occurrence of species observed in the Pikitch study tows. Wallace (in review) developed a link between Rodgers and Pikitch (1992) post-hoc strategies and fisheries landings data reported in PacFIN and expanded discard ratios and length composition from the Pikitch et al. (1988) to a fleet-wide level.

The WCGOP provided estimates of the discard ratios of darkblotched rockfish for the period between 2002 and 2015. The WCGOP data are collected by gear type, fishery (e.g., open access, limited entry) and species/management units. The discard ratios were computed as the total estimated discarded weight (in pounds) on observed trips divided by the estimated total catch (discarded and retained). To aggregate these ratios into the fleet modeled in this assessment, each state, fishery and gear combination was weighted by the total estimated catch (discarded and retained weight). Thus, the discard rates used for each fleet represent the weighted estimates from each contributing segment within that fleet. Uncertainty in these values were quantified via bootstrapping the individual observations and then aggregating to the total estimate, providing a distribution of the discard rate. From this distribution, a standard error associated with year specific discard ratio estimate was provided.

2.1.1.3 Catch in the foreign POP fishery

As described in the Introduction, between the mid-1960s and mid-1970s, foreign trawl fleets from the former Soviet Union, Japan, Poland, Bulgaria and East Germany targeted aggregations of Pacific ocean perch in the Northeast Pacific Ocean, in the waters off the U.S. West Coast (Love et al., 2002). Rogers (2003) estimated removals of POP and other species caught within this foreign POP fishery, including removals of darkblotched rockfish. In the assessment, we used estimates of darkblotched bycatch in the foreign POP fishery between 1966 and 1976 as estimated by Rogers (2003).

2.1.1.4 Bycatch in the at-sea Pacific hake fishery

As also described in the Introduction, small amounts of darkblotched rockfish are incidentally caught in in the Pacific hake fishery. The At-Sea Hake Observer Program (A-SHOP) monitors the at-sea hake processing vessels and collects total catch and bycatch data. Since the 1970s observers were deployed onto foreign fishing vessels that were catching Pacific hake. After 1991, observers continued to be deployed aboard U.S. flagged catcher processor and mothership vessels.

The annual amounts of darkblotched rockfish bycatch in the at-sea hake fishery, collected by A-SHOP, were obtained from the North Pacific Database Program (NORPAC). Since 1991, virtually 100% of hauls in the at-sea hake fishery have been sampled for catch and species composition, and the total catch (retained and discarded) has been estimated for both targeted and bycatch species for each haul. To derive the total amount of darkblotched rockfish bycatch by year, we simply summed the estimated catch in every haul within a year. Prior to 1991 (when the foreign and joint venture fishery was operating), not every haul was sampled. For these years, NORPAC provided an expansion factor (one for each year), which is a ratio of total hauls to sampled hauls. These year-specific expansion factors were used to estimate the total amount of darkblotched rockfish caught by multiplying the amount of total catch in sampled hauls by the expansion factor. The removals of darkblotched in the at-sea hake fishery between 1976 and 2016 are presented in Table 2 and Figure 7.

2.1.1.5 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 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 removals in the foreign POP fishery.

2.1.1.5.1 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. 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 coastwide 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 coastwide sex-specific length frequency distributions by year.

We only used randomly collected samples. 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 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 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 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 Miller (pers. com.):

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

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

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.

2.1.1.5.2 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 state (
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 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 depth range 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 34^{o}50' 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 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 34^{o}30' 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 34^{o}50' and 48^{o}07' 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 32º34' and 48º22' 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

Indices of abundance for three out of four bottom trawl surveys (that include AFSC shelf, AFSC slope and NWFSC slope surveys) were retained from the last 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).

For each survey abundance index, spatial strata were first identified based on depth and latitude, via examination of trends in size across latitude and depth and evaluation of the presence (or absence) of darkblotched in certain depth- or latitudinal areas. Survey data are based on a randomly-stratified survey design with pre-specified strata. We attempted to retain strata already recognized by the survey, while balancing the need to inform strata designation by species-specific characteristics of the stock. Also, the number of positive tows in each strata x year combination were computed to ensure that each stratum x year combination has a sufficient number of positive tows for the estimation model to perform adequately.

Darkblotched exhibit ontogenetic movement, when fish move into deeper water as they mature, a common phenomenon observed in the genus *Sebastes* (Love et al., 2002). Survey data we evaluated also exhibited a rapid increase in fish size over the shallowest depths to roughly 300 m. Therefore, 300 m was used as the depth break for AFSC slope, NWFSC slope surveys and the late period (1995-2004) of the AFSC Triennial shelf survey. In the early period (prior to 1995) the AFSC Triennial survey went only to 400 meters and to satisfy requirement for a positive tow number, a single depth stratum was used for early AFSC survey. No darkblotched was found beyond 550 m, and in order to avoid extrapolating biomass into those deeper areas, for the analysis surveys that went past 550 m, were cut at 549 m.

INPFC area boundaries were used as latitudinal breaks; however, due to few occurrences of darkblotched in the water off California, Conception and Monterey INPFC areas were combined into a single stratum. Also, Columbia and U.S. Vancouver INPFC areas were combined in the later period of the AFSC Triennial shelf survey and AFSC slope survey, again due to very few positive tows in those areas. Resultant strata for all the surveys are shown in Table 6. These strata were used in constructing the survey abundance indices used in the assessment.

The delta-GLMM approach used to construct all the survey abundance indices except the NWFSC shelf-slope survey. Every tow is explicitly modeled for both the probability that it encounters the target species (using a logistic regression), and the expected catch for an encounter (using a generalized linear model). The product of these two components yields an estimate of overall abundance. Year is always included in both model components (because it is the design variable), and strata are generally included as a fixed effect. The delta-mixed-model implementation is necessary to treat vessels as a random effect for the NWFSC slope survey, because these vessels are selected in an open-bid for the sampling contract from the population of all possible commercial vessels (Helser et al., 2004). Lognormal and gamma errors structures were considered for the model component representing positive catches, while a Bernoulli error structure was assumed for the presence/absence model component.

Abundance index for the NWFSC shelf-slope survey was derived using a new Vector Autoregressive Spatio-Temporal model (VAST), developed by J. Thorson of NWFSC.

We analyzed data from the Combo survey 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 (Figure 21).

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.

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 coastwide 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 within the tow by the total weight of darkblotched 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 within a stratum by the total weight of darkblotched 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 Miller (NWFSC, pers.com.):

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

$N_{input} = 4.89 N_{tows}$ 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 on. 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 were fixed while male natural mortality rate was estimated in this update (as in 2015 assessment).

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.

2.3 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.

2.3.2 Modeling software

This assessment use 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. The population within this area is treated as a single coastwide stock, given the lack of data suggesting the presence of multiple stocks. 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 difference 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. 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 coastwide 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 to be 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 thirty six 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.

Iterative re-weighting 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.

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 either derived from data or obtained from the literature, as described in Section 2.1.3.

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).

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 0.72, from the most recent likelihood profile approximation to a maximum marginal likelihood mixed-effect model for steepness from ten Tier-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 are 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 size. Separate size-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.

The selectivity curve for the shoreside fleet was fully estimated. 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 2011-2014. 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 fixed, 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 selectivity curve intermediate between asymptotic and dome-shaped. For the 2015 base model, the last 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 for 2015.

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 growth. 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). Fit to index data on log scale are presented in Figure 39, Figure 41, Figure 43 and Figure 45. With the offset estimate for the AFSC Triennial survey beginning in 1995, 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 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 intermediate between asymptotic and dome-shaped, which is reasonable given that we do observe large fish in the fishery landings. Intermediate-shaped 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. 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 38% 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). 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 assessment (full and update assessment) conducted since 2000. In aggregate, these assessments have largely drawn the same conclusions regarding historical trends: that the darkblotched 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 estimate stock to be at 40.11% of its unfished state.

2.6.2 Likelihood profile analyses

The base model included several key parameters, including natural mortality and stock-recruit steepness, which were fixed at the values determined based on life-history traits of the species in meta-analyses, using species with similar life-history characteristics. Likelihood profiles were conducted 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 natural mortality shows that the negative log-likelihood for the base model is minimized at a value of around 0.6 (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. 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 0.72. 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).

The primary source of information about $\ln(R_0)$ is in the recruitment penalties. 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 (Figure 109). 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 3,548 million eggs (95% confidence interval: 2,714-4,382 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 1,419 million eggs (95% confidence interval: 1,086-1,753), which corresponds to an exploitation rate of 0.037. This harvest rate provides an equilibrium yield of 641 mt at $SB_{40\%}$ (95% confidence interval: 496-785 mt). The model estimate of maximum sustainable yield (MSY) is 641 mt (95% confidence interval: 496-785 mt). The estimated spawning stock output at MSY is 1,019 million eggs (95% confidence interval: 779-1,259 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 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, is 64.9%. Historically, the darkblotched rockfish was fished beyond the relative SPR ratio (calculated as $1\text{-}SPR/1\text{-}SPR_{Target=0.5}$) 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). 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 13. A summary of recent trends in estimated darkblotched rockfish exploitation and stock level from the assessment model are given in Table 14.

4 Harvest Projections and Decision Table

The base model estimate for 2017 spawning depletion is 40.11%. The primary axis of uncertainty about this estimate used in the decision table was based on female natural mortality. As in 2015 assessment, female natural mortality of 0.0412 and 0.059 were used to define low and high states of nature respectively and construct the decision table (Table 15).

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 of 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.

5 Regional Management Considerations

In the waters of the western United States, off California, Oregon and Washington, this species is managed coastwide, with coastwide ACLs determined for management purposes. The population within the assessed area is treated as a single coastwide 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 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 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 along the coast; such information is currently lacking.

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 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. The Councill and Harford method is an example of one approach; it models natural mortality as a decaying function of size, with assumptions that mortality rates should be constrained by lifetime mortality rate.

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.

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9 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.

Year	OFL (mt)	ACL (mt)	Commercial Landings (mt)	Estimated Total Catch (mt)*
2007	456	260	143.6	256.1
2008	456	260	117.4	243.8
2009	437	282	138.4	290.7
2010	437	282	184.3	337.8
2011	508	298	116.9	121.2
2012	508	298	99.0	102.4
2013	541	317	124.1	127.8
2014	541	317	103.2	106.5
2015	574	549	130.7	136.7
2016	580	554	129.1	136.5

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

Table 6: Spatial strata used in constructing survey abundance indices via stratified delta-GLMM method or VAST.

Survey	Latitude (N. lat.)	Depth (m)
AFSC shelf (1980-1992)	$36^0$5" – $40^0$5"	55-400
	$40^0$5" – 43^0	55-400
	43^0 – $47^0$5"	55-400
	$47^0$5" – 49^0	55-400
AFSC shelf (1995-2004)	$34^0$5" – $40^0$5"	55-300 300-500
	$40^0$5" – 43^0	55-300 300-500
	43^0 – 49^0	55-300 300-500
AFSC slope	$34^0$5" – 43^0	183-300 300-549
	43^0 – 49^0	183-300 300-549
NWFSC shelf-slope	32^0 – 49^0	55-1,280

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	Estimated value	Bounds (low, high)	Fixed value
Natural mortality (M, female)	-	NA	0.054
Natural mortality (M, male)	0.069	(0.01,0.15)	-
	Individual growth		
Females:			
Length at A_1	15.326	(1,20)	-
Length at A_2	42.88	(20,60)	-
von Bertalanffy K	0.19	(0.05,0.3)	-
SD of length at A_1	1.81	(0.5,15)	-
SD of length at A_2	2.16	(0.5,15)	-
Males:			
Length at A_1 (set equal to females)	-	NA	0.0
Length at A_2	38.43	(50,60)	-
von Bertalanffy K	0.24	(0.05,0.3)	-
SD of length at A_1 (set equal to females)	-	NA	0.0
SD of length at A_2	1.67	(0.5,15)	-
	Weight at length		
Females:			
Coefficient	-	NA	1.15E-05
Exponent	-	NA	3.12536
Males:			
Coefficient	-	NA	1.22E-05
Exponent	-	NA	3.10647
	Fecundity at length		
Inflection	-	NA	101100
Slope	-	NA	44800
	Stock and recruitment		
Ln(R_0)	8.00	(5,12)	-
Steepness (h)	-	NA	0.72
Recruitment SD (σ_r)	-	NA	0.75
	Survey catchability and variability		
Ln(Q) – AFSC shelf (1980-1992)	0.518	(-10,2)	
Ln(Q) – AFSC shelf offset (1995-2004) to early	0.0089	(-4,4)	
Ln(Q) – AFSC slope	-0.175	(-10,2)	
Ln(Q) – NWFSC slope	0.023	(-10,2)	
Ln(Q) – NWFSC shelf-slope	0.475	(-10,2)	
Extra additive SD for AFSC shelf	0.013	(0,1)	
Extra additive SD for NWFSC shelf-slope	0.038	(0,1)	
	Selectivity and retention		
Shoreside fishery (double-normal)			
Peak	33.68	(20, 45)	-
Peak block (2011-2016)	32.35	(20, 45)	-
Top: width of plateau	-5.95	(-6, 4)	-
Top: width of plateau block (2011-2016)	-3.71	(-6, 4)	-
Ascending slope	2.25	(-1,9)	-
Ascending slope block (2011-2016)	1.20	(-1,9)	-

Parameter	Estimated value	Bounds (low, high)	Fixed value
Descending slope	1.80	(-1,9)	-
Descending slope block (2011-2016)	2.15	(-1,9)	-
Selectivity at first bin	-1.41	(-1,9)	-
Selectivity at last bin	0.01	(-1,9)	-
Selectivity at last bin block (2011-2016)	-1.46	(-1,9)	-
Shoreside retention (logistic function)			
Inflection base	27.29	(15,70)	-
Inflection block (2011-2016)	25.46	(15,70)	-
Slope base	1.95	(0.1,10)	-
Slope block (2011-2016)	1.40	(0.1,10)	-
Asymptotic retention base	-	NA	1
Asymptotic retention block (2002)	-0.11	(0,1)	-
Asymptotic retention block (2003)	-0.34	(0,1)	-
Asymptotic retention block (2004)	1.87	(0,1)	-
Asymptotic retention block (2005)	1.12	(0,1)	-
Asymptotic retention block (2006)	0.14	(0,1)	-
Asymptotic retention block (2007)	0.26	(0,1)	-
Asymptotic retention block (2008)	-0.04	(0,1)	-
Asymptotic retention block (2009)	-0.01	(0,1)	-
Asymptotic retention block (2010)	0.25	(0,1)	-
Male offset to inflection	-	NA	0
At-sea hake fishery (double-normal)			
Peak	32.31	(10, 45)	-
Top: width of plateau	-5.82	(-6,4)	-
Ascending slope	3.55	(-1,9)	-
Descending slope base	2.25	(-1,9)	-
Selectivity at first bin	-	NA	-999
Selectivity at last bin	-0.15	(-1,9)	-
AFSC shelf survey (double-normal)			
Peak	22.27	(10, 45)	-
Top: width of plateau	-5.97	(-6,4)	-
Ascending slope	3.47	(-1,9)	-
Descending slope base	4.86	(-1,9)	-
Descending slope block (1995-2004)	4.73	(-1,9)	-
Selectivity at first bin	-	NA	-999
Selectivity at last bin	-	NA	-999
AFSC slope survey (double-normal)			
Peak	22.24	(10, 45)	-
Top: width of plateau	-1.69	(-6,4)	-
Ascending slope	1.86	(-1,9)	-
Descending slope	3.28	(-1,9)	-
Selectivity at first bin	-	NA	-999
Selectivity at last bin	-	NA	-999
NWFSC slope survey (double-normal)			
Peak	24.69	(10, 45)	-
Top: width of plateau	-5.97	(-6,4)	-6
Ascending slope	3.11	(-1,9)	-

Parameter	Estimated value	Bounds (low, high)	Fixed value
Descending slope	4.81	(-1,9)	-
Selectivity at first bin	-	NA	-999
Selectivity at last bin	-	NA	-999
NWFSC shelf-slope survey (double-normal)			
Peak	-	NA	24.4731
Top: width of plateau	-	NA	-6
Ascending slope	-	NA	4.13751
Descending slope	-	NA	3
Selectivity at first bin	-	NA	-999
Selectivity at last bin	-	NA	-0.841911

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 fish)	Depletion (%)	Age-0 Recruits (1000s)	Exploitation rate (catch/ age 1+ biomass)
1915	39,799	39,793	3,531	100.00%	2,994	
1916	39,800	39,794	3,531	99.53%	2,994	0.00033
1917	39,787	39,781	3,530	99.50%	2,994	0.00052
1918	39,766	39,760	3,529	99.45%	2,993	0.00054
1919	39,744	39,738	3,527	99.41%	2,993	0.00035
1920	39,730	39,724	3,526	99.37%	2,993	0.00037
1921	39,716	39,710	3,525	99.34%	2,992	0.00031
1922	39,704	39,699	3,524	99.31%	2,992	0.00029
1923	39,694	39,688	3,523	99.29%	2,992	0.00034
1924	39,681	39,675	3,522	99.26%	2,992	0.00035
1925	39,669	39,663	3,521	99.23%	2,991	0.00040
1926	39,655	39,649	3,519	99.19%	2,991	0.00054
1927	39,635	39,629	3,518	99.14%	2,991	0.00047
1928	39,619	39,613	3,516	99.10%	2,991	0.00046
1929	39,603	39,598	3,515	99.06%	2,991	0.00049
1930	39,588	39,582	3,513	99.02%	2,991	0.00054
1931	39,570	39,564	3,512	98.97%	2,991	0.00066
1932	39,549	39,543	3,510	98.92%	2,991	0.00042
1933	39,538	39,532	3,508	98.88%	2,991	0.00041
1934	39,528	39,522	3,507	98.86%	2,991	0.00039
1935	39,519	39,513	3,507	98.83%	2,991	0.00044
1936	39,509	39,503	3,505	98.80%	2,992	0.00030
1937	39,505	39,499	3,505	98.78%	2,993	0.00034
1938	39,500	39,494	3,504	98.77%	2,994	0.00042
1939	39,492	39,486	3,503	98.74%	2,999	0.00060
1940	39,477	39,471	3,502	98.70%	3,004	0.00083
1941	39,455	39,449	3,500	98.64%	3,012	0.00106
1942	39,424	39,418	3,497	98.56%	3,022	0.00121
1943	39,390	39,384	3,494	98.46%	3,034	0.00465
1944	39,219	39,213	3,479	98.04%	3,049	0.01011
1945	38,835	38,829	3,445	97.11%	3,068	0.01739
1946	38,175	38,169	3,388	95.49%	3,093	0.01046
1947	37,817	37,811	3,355	94.55%	3,129	0.00874
1948	37,548	37,542	3,328	93.79%	3,177	0.00503
1949	37,445	37,439	3,314	93.40%	3,237	0.00420
1950	37,395	37,389	3,304	93.11%	3,307	0.00470

Year	Total biomass (mt)	Summary biomass (mt)	Spawning output (million fish)	Depletion (%)	Age-0 Recruits (1000s)	Exploitation rate (catch/ age 1+ biomass)
1951	37,350	37,343	3,293	92.82%	3,379	0.00548
1952	37,301	37,294	3,282	92.50%	3,439	0.00575
1953	37,270	37,263	3,271	92.20%	3,471	0.00494
1954	37,302	37,295	3,265	92.02%	3,457	0.00580
1955	37,332	37,325	3,258	91.82%	3,404	0.00685
1956	37,348	37,341	3,250	91.59%	3,327	0.00907
1957	37,299	37,292	3,237	91.23%	3,249	0.01062
1958	37,203	37,196	3,222	90.81%	3,182	0.00899
1959	37,174	37,168	3,215	90.61%	3,132	0.00759
1960	37,195	37,189	3,214	90.59%	3,096	0.00921
1961	37,140	37,134	3,210	90.48%	3,074	0.00861
1962	37,093	37,087	3,209	90.45%	3,072	0.00934
1963	36,999	36,993	3,206	90.35%	3,089	0.00989
1964	36,869	36,863	3,199	90.17%	3,114	0.00716
1965	36,830	36,824	3,200	90.20%	3,144	0.01307
1966	36,557	36,551	3,181	89.67%	3,108	0.11535
1967	32,531	32,525	2,851	80.34%	2,938	0.09452
1968	29,695	29,690	2,607	73.49%	2,745	0.08134
1969	27,570	27,565	2,418	68.14%	2,662	0.01008
1970	27,626	27,620	2,408	67.87%	2,819	0.01248
1971	27,628	27,622	2,397	67.57%	3,115	0.01892
1972	27,465	27,459	2,375	66.94%	2,647	0.02211
1973	27,234	27,230	2,349	66.20%	2,143	0.03330
1974	26,712	26,708	2,299	64.81%	1,963	0.02197
1975	26,494	26,490	2,276	64.16%	1,602	0.02132
1976	26,255	26,251	2,256	63.59%	2,232	0.02380
1977	25,892	25,889	2,232	62.92%	1,499	0.01107
1978	25,822	25,815	2,238	63.06%	3,694	0.01486
1979	25,616	25,610	2,234	62.95%	3,034	0.02677
1980	25,108	25,104	2,200	62.00%	2,168	0.02450
1981	24,723	24,713	2,166	61.04%	5,051	0.03386
1982	24,173	24,169	2,107	59.38%	1,560	0.04703
1983	23,395	23,393	2,019	56.91%	1,009	0.04815
1984	22,677	22,673	1,935	54.52%	1,667	0.05844
1985	21,730	21,726	1,840	51.85%	2,193	0.08208
1986	20,257	20,253	1,713	48.28%	1,999	0.06290
1987	19,281	19,274	1,636	46.11%	3,880	0.12660
1988	17,091	17,088	1,465	41.29%	1,610	0.10097
1989	15,667	15,665	1,346	37.93%	1,032	0.08367

Year	Total biomass (mt)	Summary biomass (mt)	Spawning output (million fish)	Depletion (%)	Age-0 Recruits (1000s)	Exploitation rate (catch/ age 1+ biomass)
1990	14,701	14,699	1,253	35.32%	870	0.11541
1991	13,318	13,316	1,123	31.67%	1,052	0.09644
1992	12,332	12,330	1,031	29.06%	951	0.06147
1993	11,848	11,847	990	27.90%	505	0.10447
1994	10,815	10,810	914	25.77%	2,666	0.08265
1995	10,105	10,097	865	24.39%	4,205	0.08406
1996	9,476	9,474	815	22.96%	1,053	0.08400
1997	8,999	8,996	762	21.47%	1,372	0.09592
1998	8,530	8,528	699	19.70%	830	0.11655
1999	7,957	7,943	623	17.56%	6,636	0.05046
2000	8,078	8,069	604	17.01%	4,305	0.03208
2001	8,505	8,504	608	17.14%	541	0.02061
2002	9,203	9,200	630	17.75%	1,348	0.01220
2003	9,917	9,914	652	18.38%	1,502	0.00806
2004	10,671	10,666	682	19.23%	2,548	0.01774
2005	11,342	11,337	723	20.37%	2,452	0.00862
2006	12,067	12,062	787	22.19%	2,157	0.00888
2007	12,691	12,688	857	24.16%	1,654	0.01132
2008	13,232	13,220	920	25.92%	6,064	0.00888
2009	13,782	13,780	973	27.43%	875	0.01004
2010	14,336	14,331	1,017	28.66%	2,463	0.01286
2011	14,879	14,874	1,055	29.73%	2,457	0.00786
2012	15,628	15,625	1,109	31.24%	1,494	0.00634
2013	16,391	16,363	1,165	32.85%	13,912	0.00758
2014	17,194	17,191	1,226	34.57%	1,239	0.00600
2015	18,257	18,252	1,294	36.46%	2,588	0.00716
2016	19,504	19,498	1,359	38.32%	2,602	0.00662
2017	20,804	20,799	1,423	40.11%	2,628	NA

Table 13: Summary of reference points for the base model.

Quantity	Estimate	~95% Confidence Interval
Unfished Spawning output (million eggs)	3,548	2,714–4,382
Unfished Age 1+ Biomass (mt)	39,969	30,999–48,938
Spawning output (million eggs, 2017)	1,423	615–2,230
Unfished Recruitment (R0)	3,010	2,306–3,713
Depletion (2017)	40.11	21.78–58.45
Reference Points Based SB40%		
Proxy spawning output (B40%, million eggs)	1,419	1,086–1,753
SPR resulting in SB40%	0.458	0.458–0.458
Exploitation Rate Resulting in SB40%	0.037	0.036–0.038
Yield with SPR Based On SB40% (mt)	641	496–785
Reference Points based on SPR proxy for MSY		
Proxy spawning biomass (SPR50, million eggs)	1,583	1,211–1,955
SPR50	50%	NA
Exploitation rate corresponding to SPR50	0.032	0.031–0.033
Yield with SPR50 at SBSPR (mt)	614	476–753
Reference points based on estimated MSY values		
Spawning biomass at MSY (SBMSY)	1,019	779–1,259
SPRMSY	35.6%	0.351–0.362
Exploitation rate corresponding to SPRMSY	0.052	0.050–0.054
MSY (mt)	671	520–823

Table 14: 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	94	124	103	131	129	NA
Estimated Total catch (mt)	261	250	289	351	118	95	125	104	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	0.23	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)	12,688	13,220	13,780	14,331	14,874	15,625	16,363	17,191	18,252	19,498	20,799
Spawning output (million eggs)	857	920	973	1,017	1,055	1,109	1,165	1,226	1,294	1,359	1,423
~95% Confidence Interval	397–1,318	421–1,418	440–1,507	452–1,582	458–1,651	481–1,736	506–1,825	532–1,921	561–2,026	589–2,130	616–2,231
Recruitment	1,654	6,064	875	2,463	2,457	1,494	13,912	1,239	2,588	2,602	2,628
~95% Confidence Interval	916–2,985	3,561–10,327	457–1,675	1,394–4,350	1,373–4,397	786–2,839	7,911–24,465	573–2,680	1,105–6,065	1,974–3,431	1,997–3,458
Depletion (%)	24.2	25.9	27.4	28.7	29.7	31.2	32.8	34.6	36.5	38.3	40.1
~95% Confidence Interval	13.8–34.5	14.7–37.1	15.4–39.5	15.9–41.4	16.2–43.2	17.0–45.5	17.9–47.8	18.8–50.3	19.8–53.1	20.8–55.8	21.8–58.4

Table 15: 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	868	25%	1,423	40%	1,687	46%
	2018	122	919	26%	1,493	42%	1,762	48%
	2019	122	985	28%	1,584	45%	1,861	51%
	2020	122	1,066	31%	1,699	48%	1,987	54%
	2021	122	1,153	33%	1,821	51%	2,120	58%
	2022	122	1,236	36%	1,933	54%	2,240	61%
	2023	122	1,310	38%	2,030	57%	2,343	64%
	2024	122	1,376	40%	2,113	60%	2,430	66%
	2025	122	1,435	41%	2,184	62%	2,502	68%
	2026	122	1,488	43%	2,245	63%	2,563	70%
	2027	122	1,537	44%	2,299	65%	2,616	72%
	2028	122	1,583	45%	2,346	66%	2,662	73%
2018 ACL catch assumed for years between 2018 and 2028 with SPR = 0.50	2017	641	868	25%	1,423	40%	1,687	46%
	2018	653	889	26%	1,463	41%	1,732	47%
	2019	653	920	26%	1,522	43%	1,798	49%
	2020	653	964	28%	1,600	45%	1,888	52%
	2021	653	1,008	29%	1,679	47%	1,979	54%
	2022	653	1,041	30%	1,745	49%	2,054	56%
	2023	653	1,063	31%	1,793	51%	2,110	58%
	2024	653	1,076	31%	1,828	52%	2,150	59%
	2025	653	1,082	31%	1,851	52%	2,176	59%
	2026	653	1,083	31%	1,866	53%	2,193	60%
	2027	653	1,081	31%	1,875	53%	2,203	60%
	2028	653	1,075	31%	1,878	53%	2,206	60%
Projections based on current rebuilding SPR of 64.9% applied to the base model For 2017 and 2018, adopted ACLs are used.	2017	641	868	25%	1,423	40%	1,687	46%
	2018	653	889	26%	1,463	41%	1,732	47%
	2019	496	920	26%	1,522	43%	1,798	49%
	2020	532	973	28%	1,609	45%	1,897	52%
	2021	528	1,025	29%	1,696	48%	1,996	55%
	2022	507	1,068	31%	1,772	50%	2,081	57%
	2023	488	1,103	32%	1,832	52%	2,149	59%
	2024	474	1,131	32%	1,880	53%	2,201	60%
	2025	465	1,153	33%	1,918	54%	2,242	61%
	2026	460	1,171	34%	1,949	55%	2,274	62%
	2027	457	1,185	34%	1,973	56%	2,299	63%
	2028	456	1,198	34%	1,993	56%	2,318	63%

Table 15 (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 2011-2014 catch assumed for 2017-2020 and 2018 ACL catch for 2021-2028 with SPR = 0.50	2017	122	868	25%	1,423	40%	1,687	46%
	2018	122	919	26%	1,493	42%	1,762	48%
	2019	122	985	28%	1,584	45%	1,861	51%
	2020	122	1,066	31%	1,699	48%	1,987	54%
	2021	653	1,153	33%	1,821	51%	2,120	58%
	2022	653	1,204	35%	1,901	54%	2,209	60%
	2023	653	1,240	36%	1,962	55%	2,275	62%
	2024	653	1,265	36%	2,005	57%	2,323	63%
	2025	653	1,281	37%	2,035	57%	2,355	64%
	2026	653	1,290	37%	2,054	58%	2,374	65%
	2027	653	1,292	37%	2,064	58%	2,385	65%
	2028	653	1,290	37%	2,068	58%	2,389	65%

10 Figures

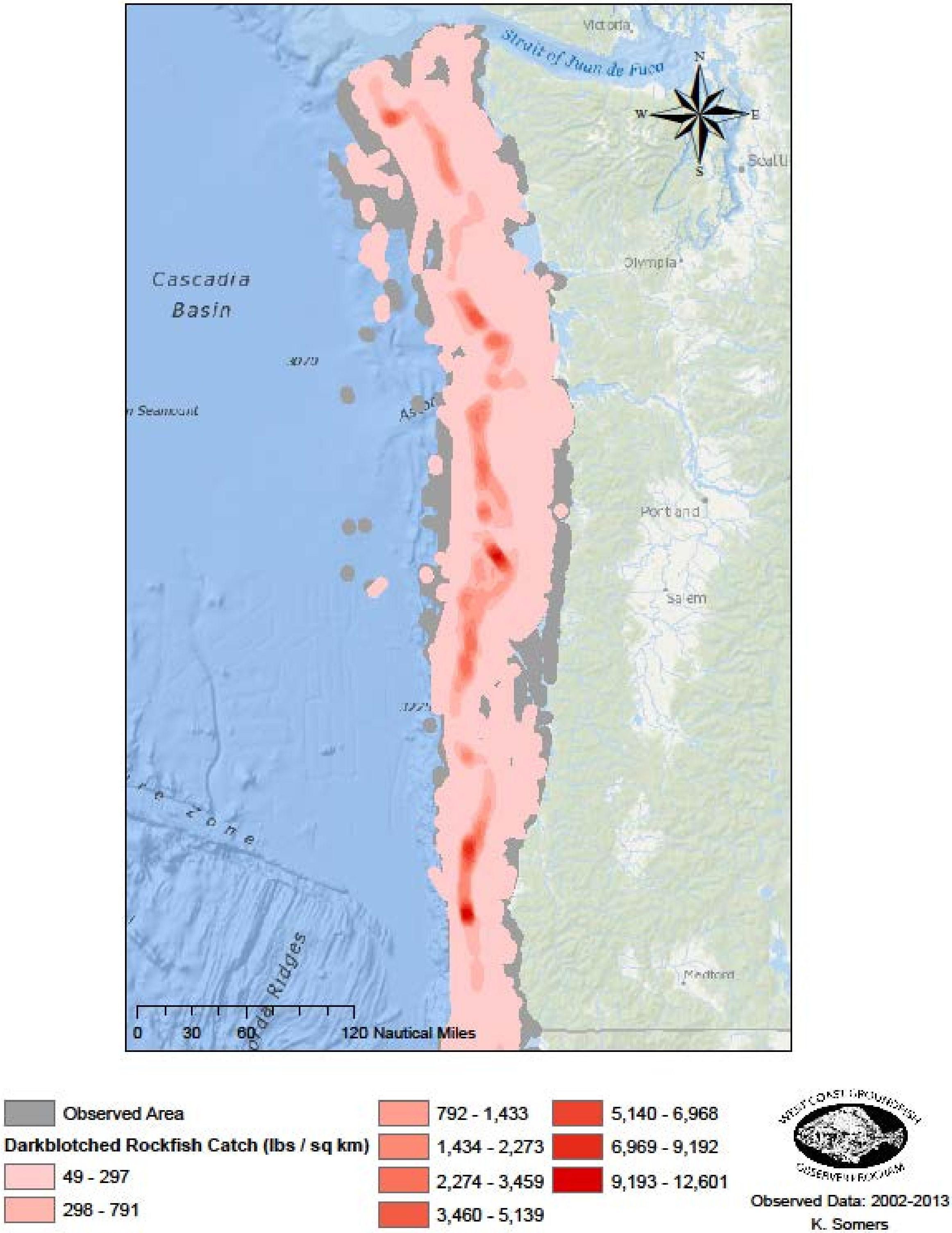

Figure 1: Spatial distribution of darkblotched rockfish catch observed by the West Coast Groundfish Observer Program and the summary area of all observed fishing events.

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.

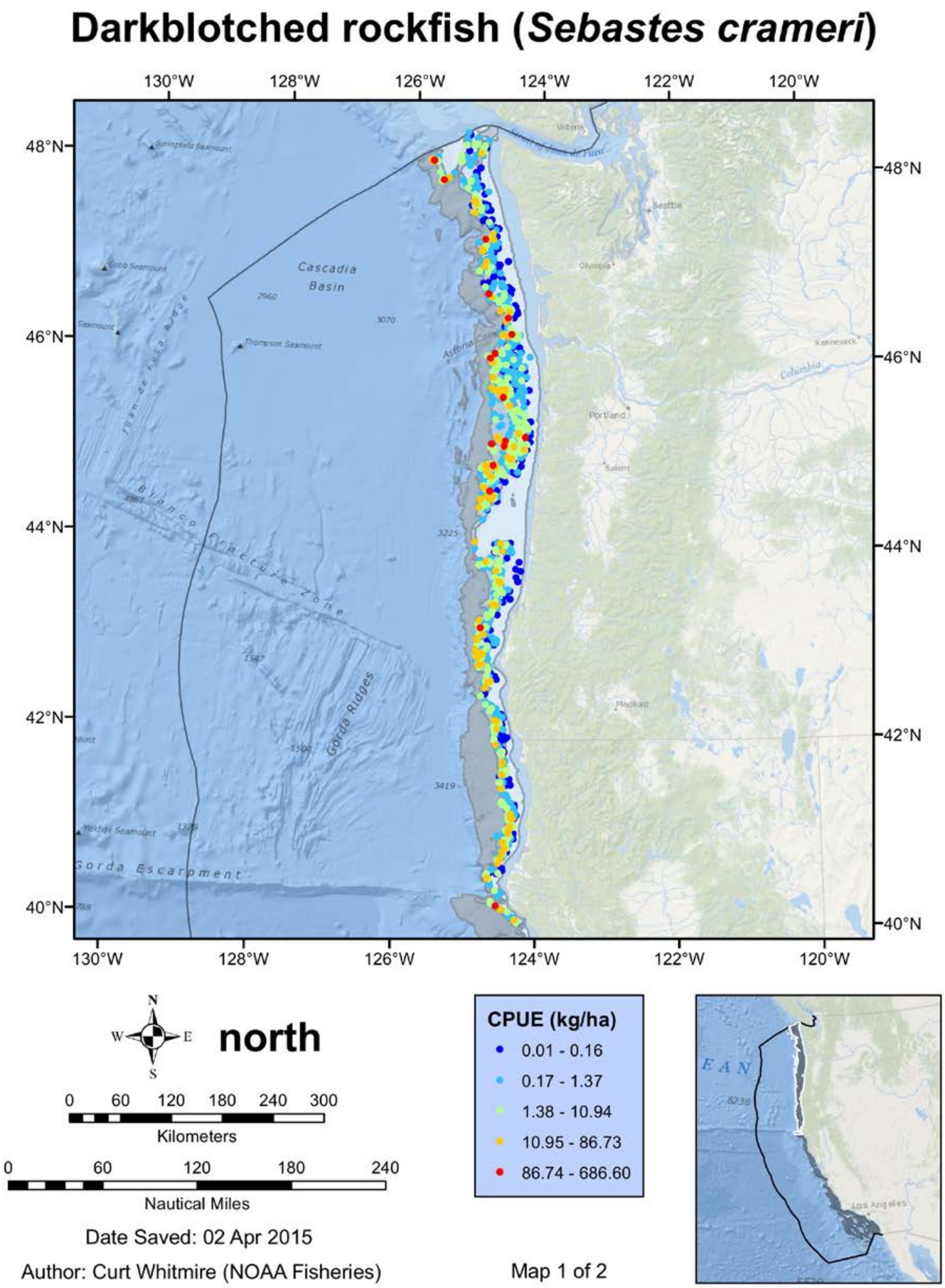

Figure 2: Spatial distribution of darkblotched rockfish (*Sebastes crameri*) catch in the NWFSC groundfish survey (2003-2012) by INPFC area.

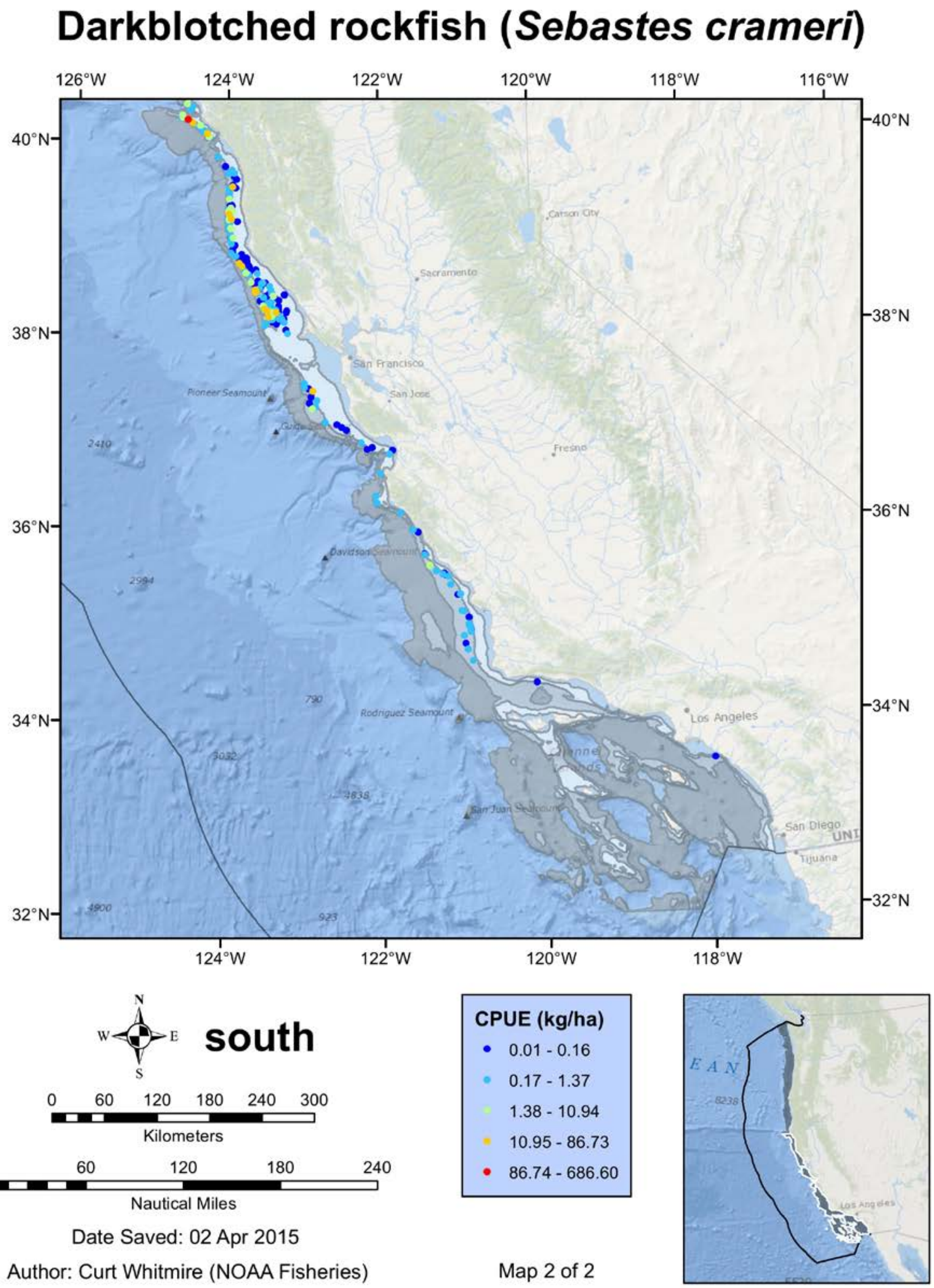

Figure 2 (continued): Spatial distribution of darkblotched rockfish (*Sebastes crameri*) catch in the NWFSC groundfish survey (2003-2012) by INPFC area.

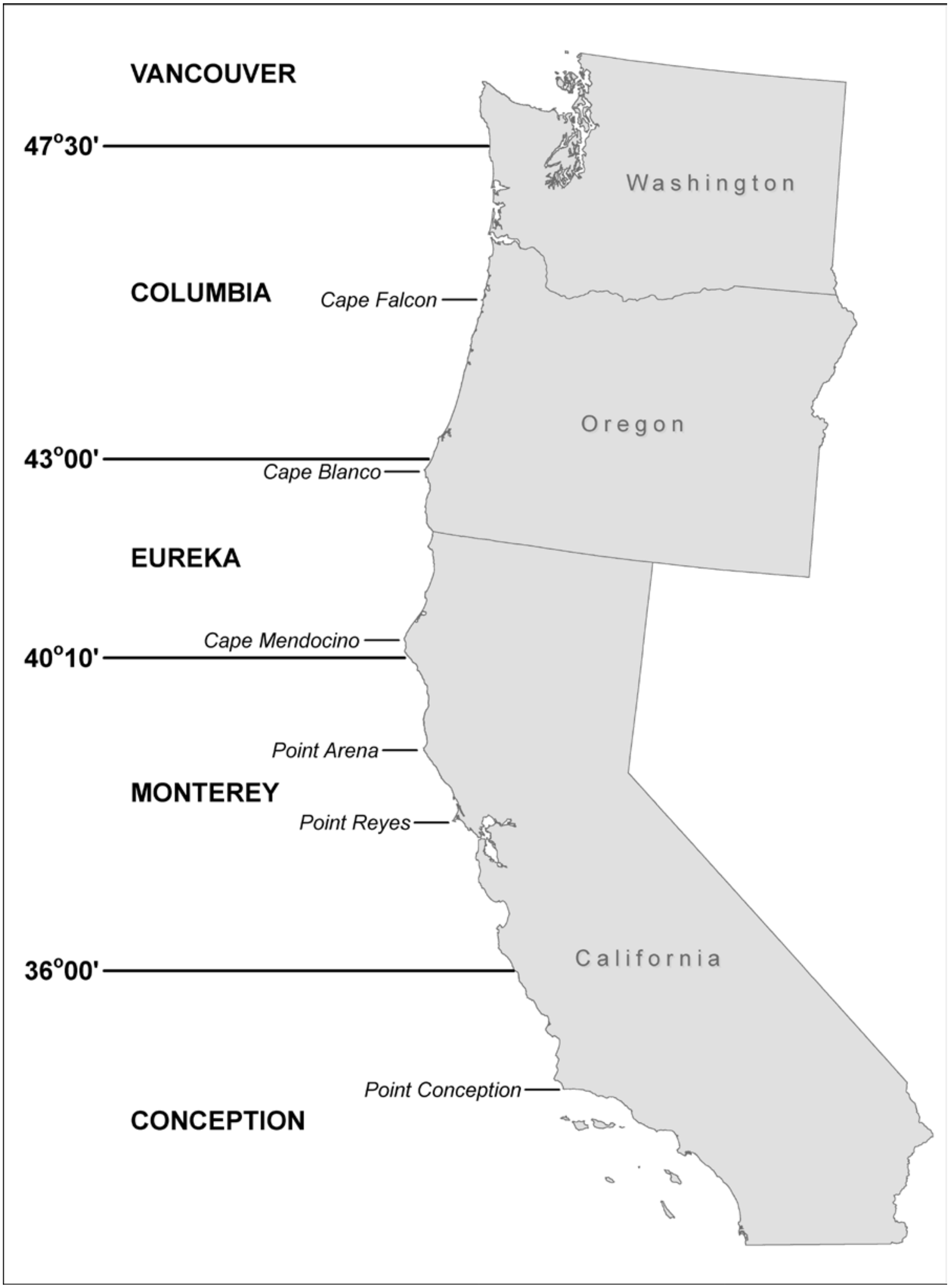

Figure 3: A map of the assessment area that includes coastal waters off three U.S. west coast states and five International North Pacific Fisheries Commission (INPFC) areas.

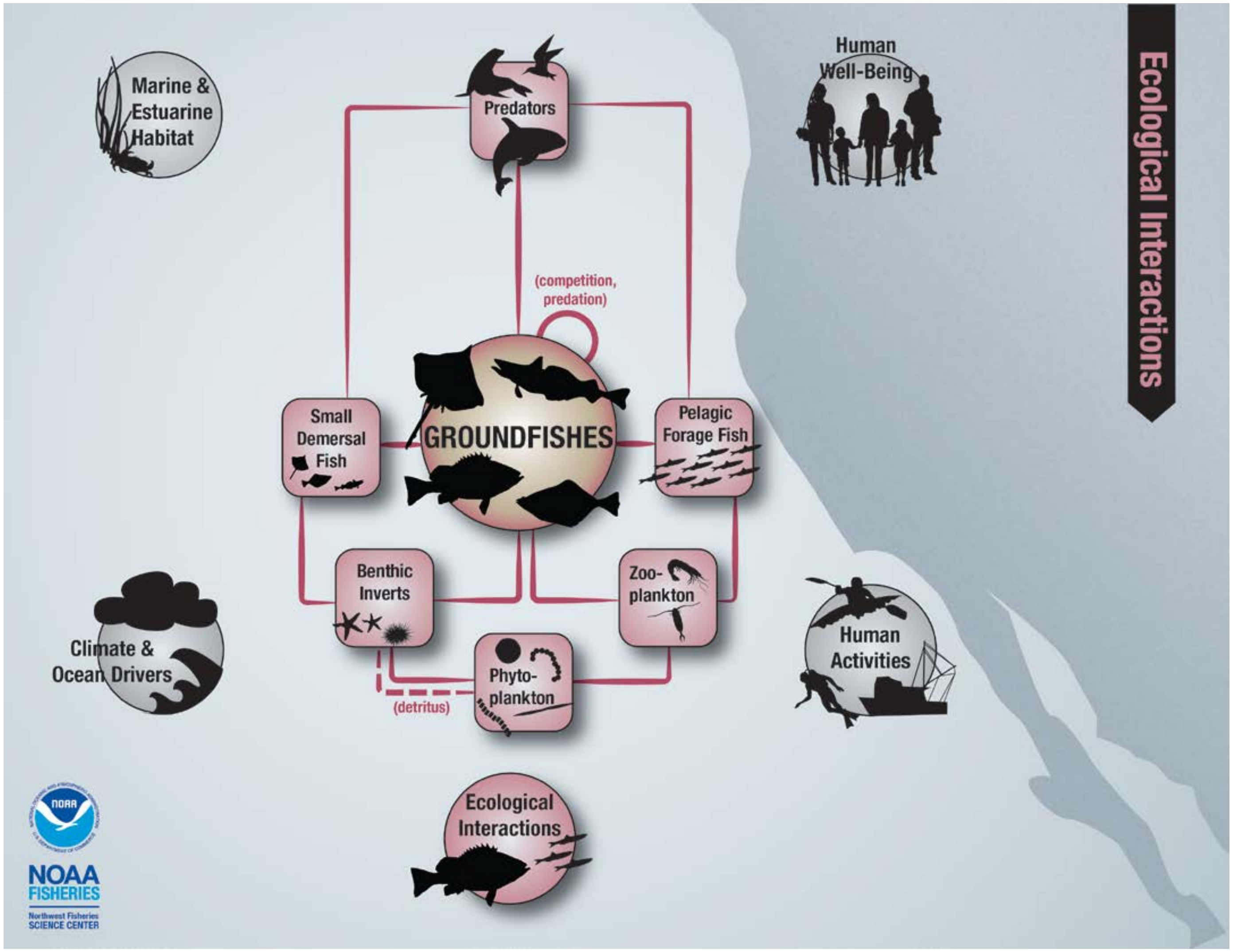

Figure 4: Conceptual diagram of ecological interactions of groundfish species in California Current large marine ecosystem.

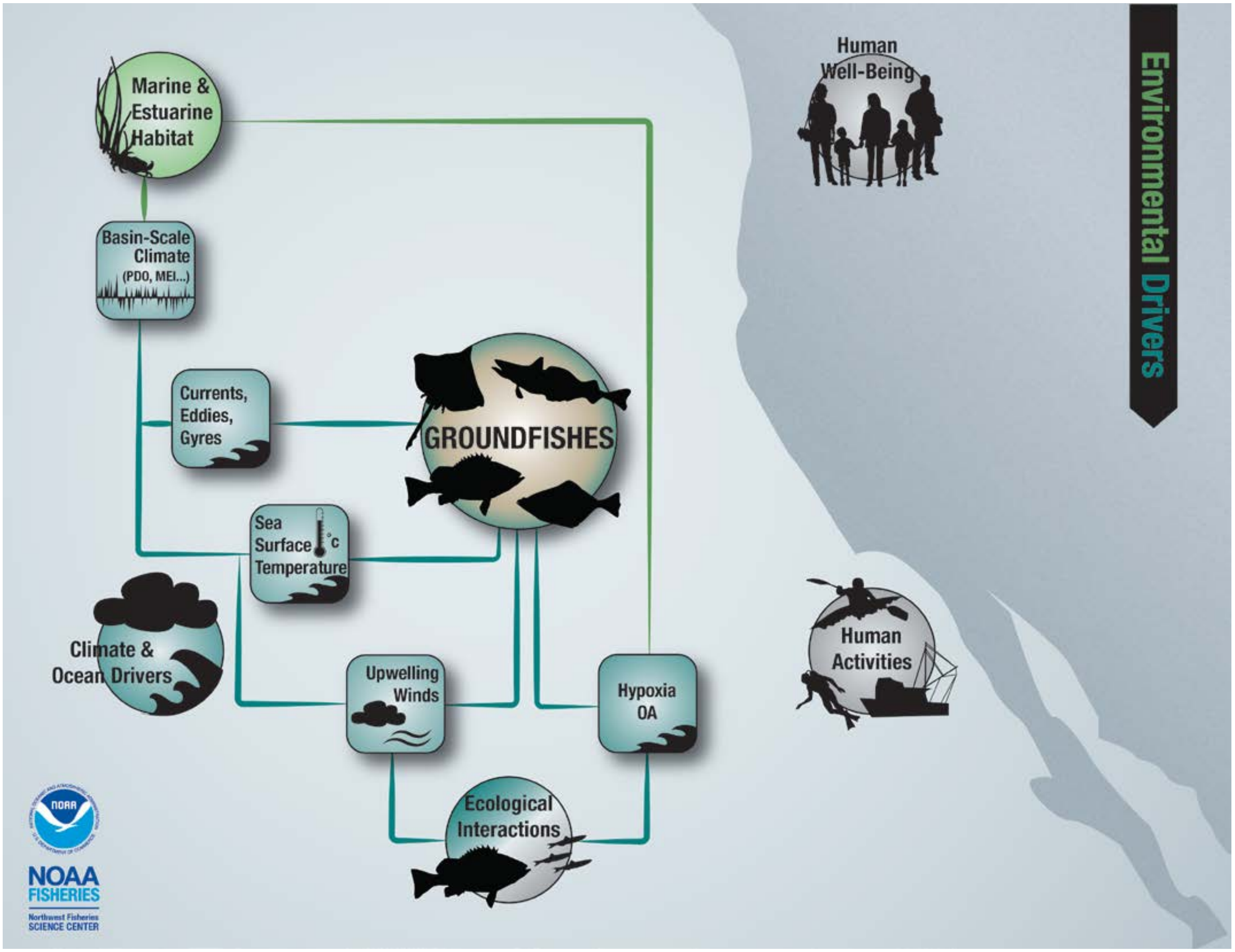

Figure 5: Conceptual diagram of environmental drivers that impact groundfish species in California Current large marine ecosystem.

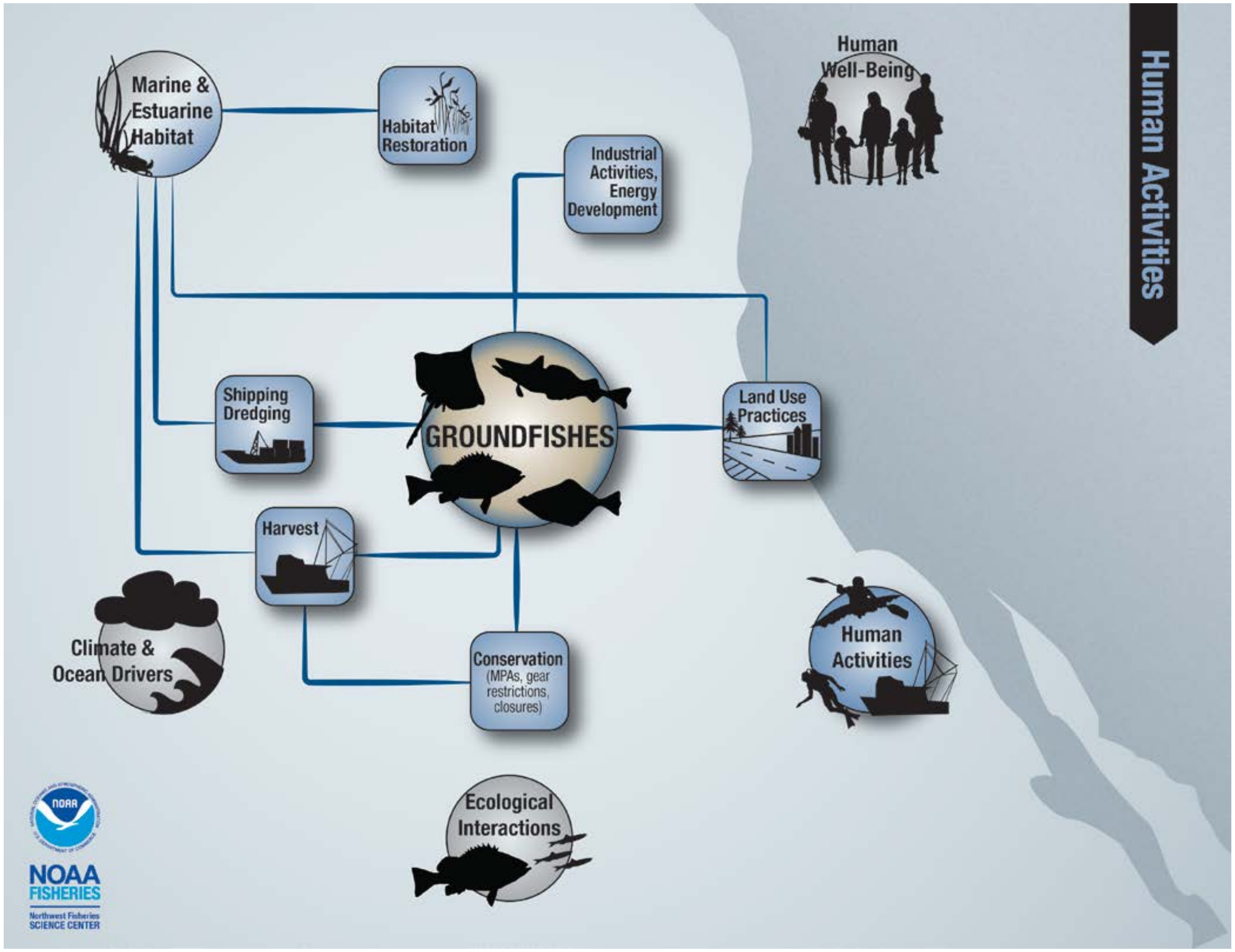

Figure 6: Conceptual diagram of human activities that affect groundfish species in California Current large marine ecosystem.

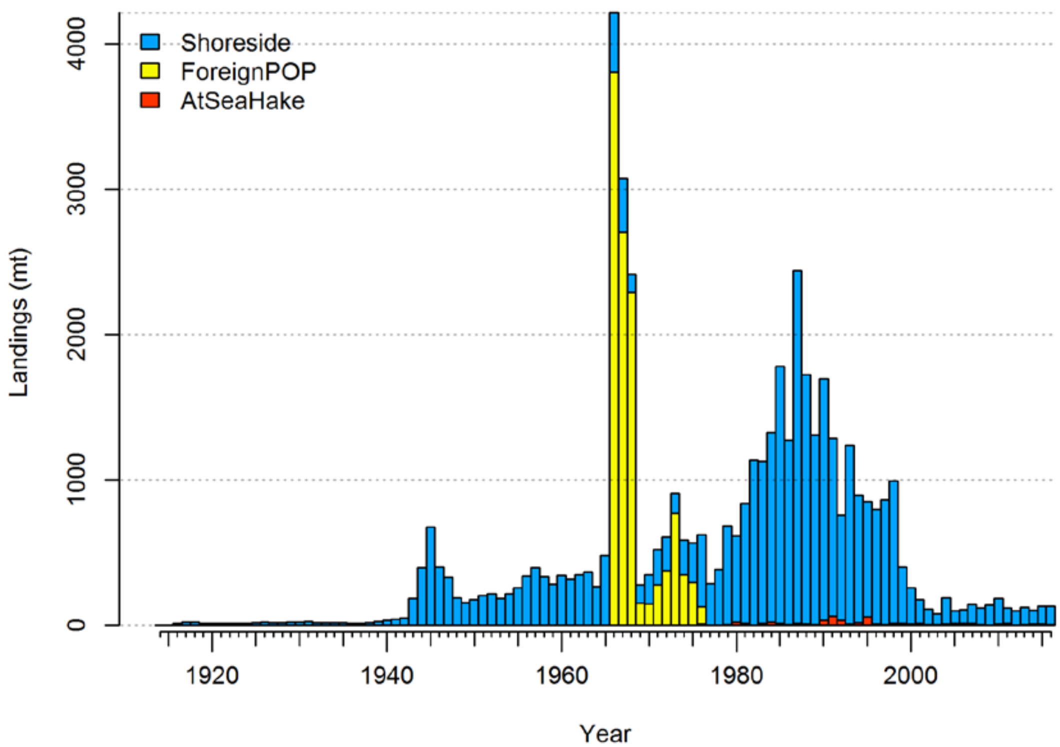

Figure 7: Darkblotched rockfish landings history, 1915-2014, by fleet.

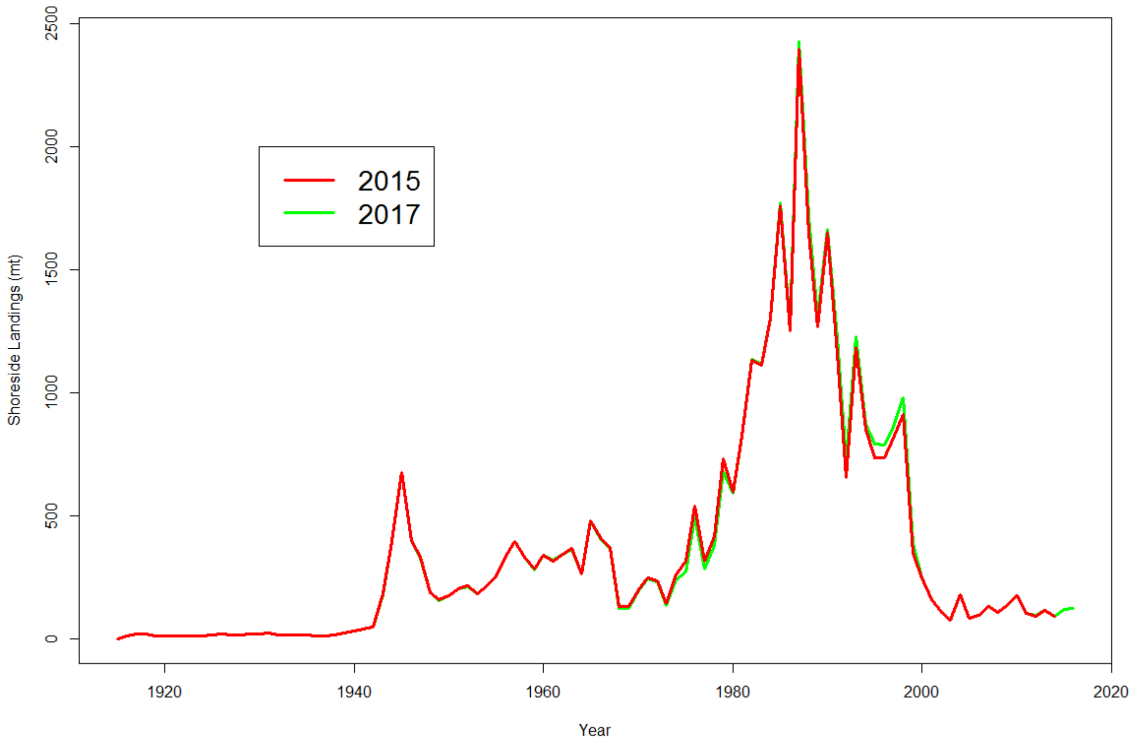

Figure 8: Comparison of darkblotched rockfish landings within the shoreside fleet used in the 2015 assessment and in this 2017 assessment.

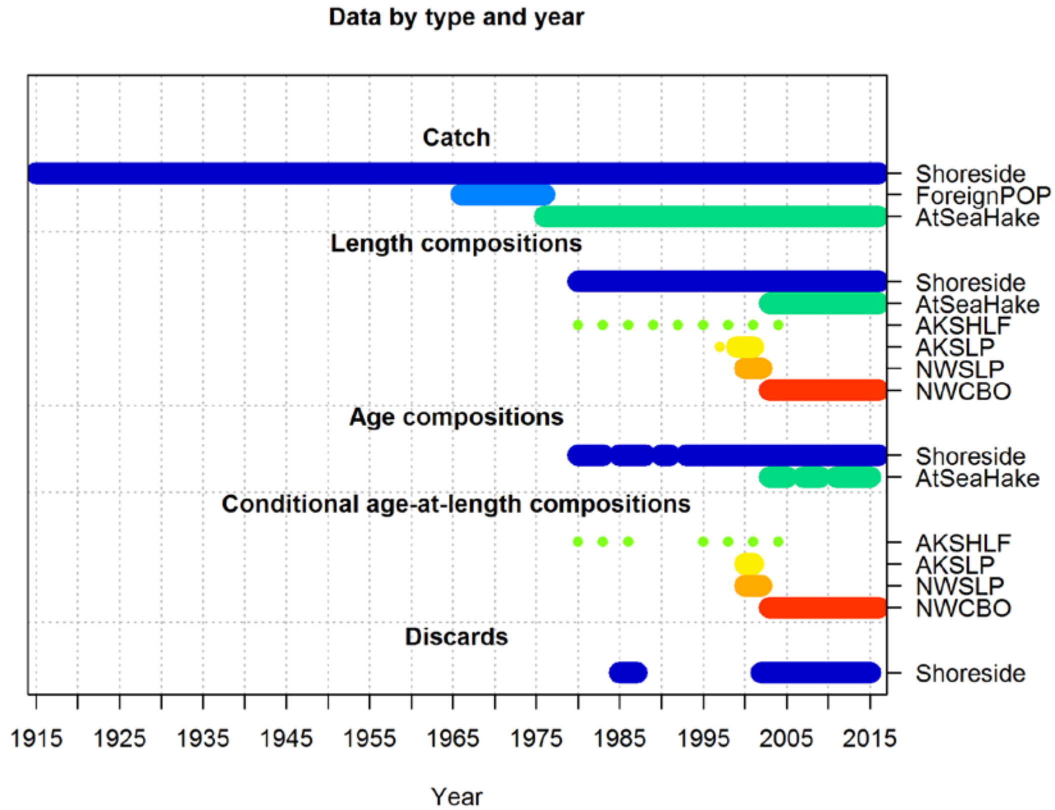

Figure 9: Summary of sources and data used in the assessment.

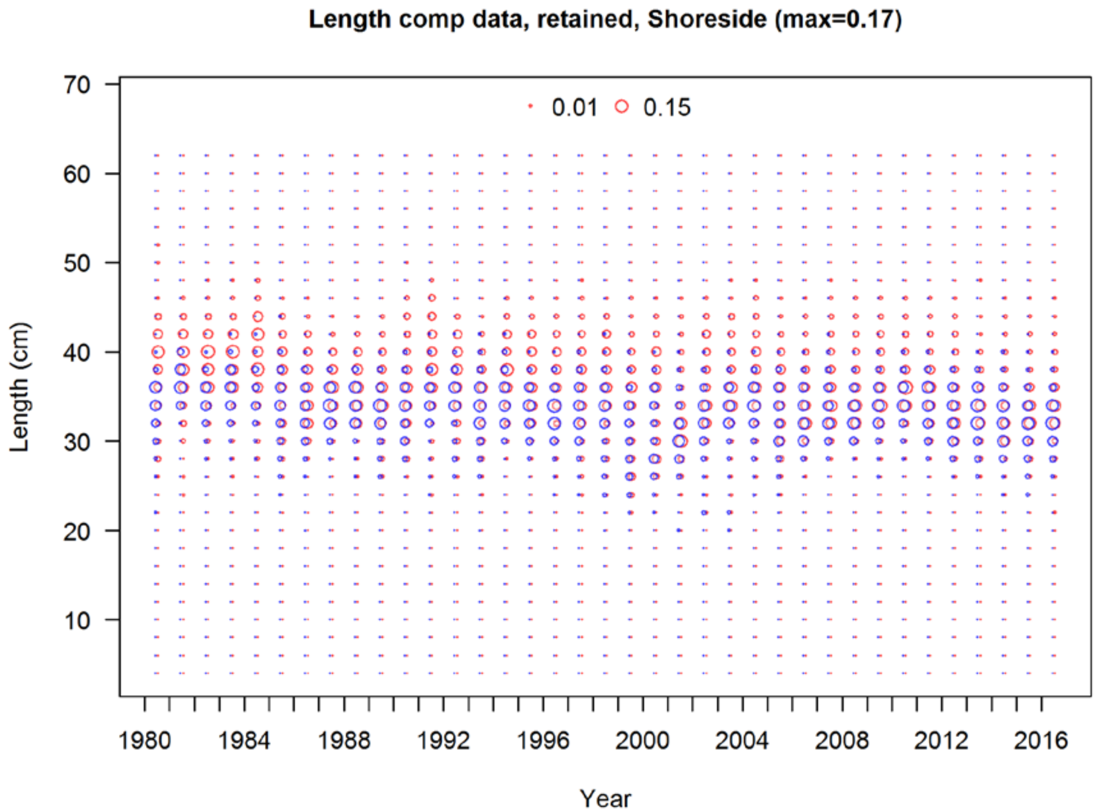

Figure 10: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the shoreside landings by year.

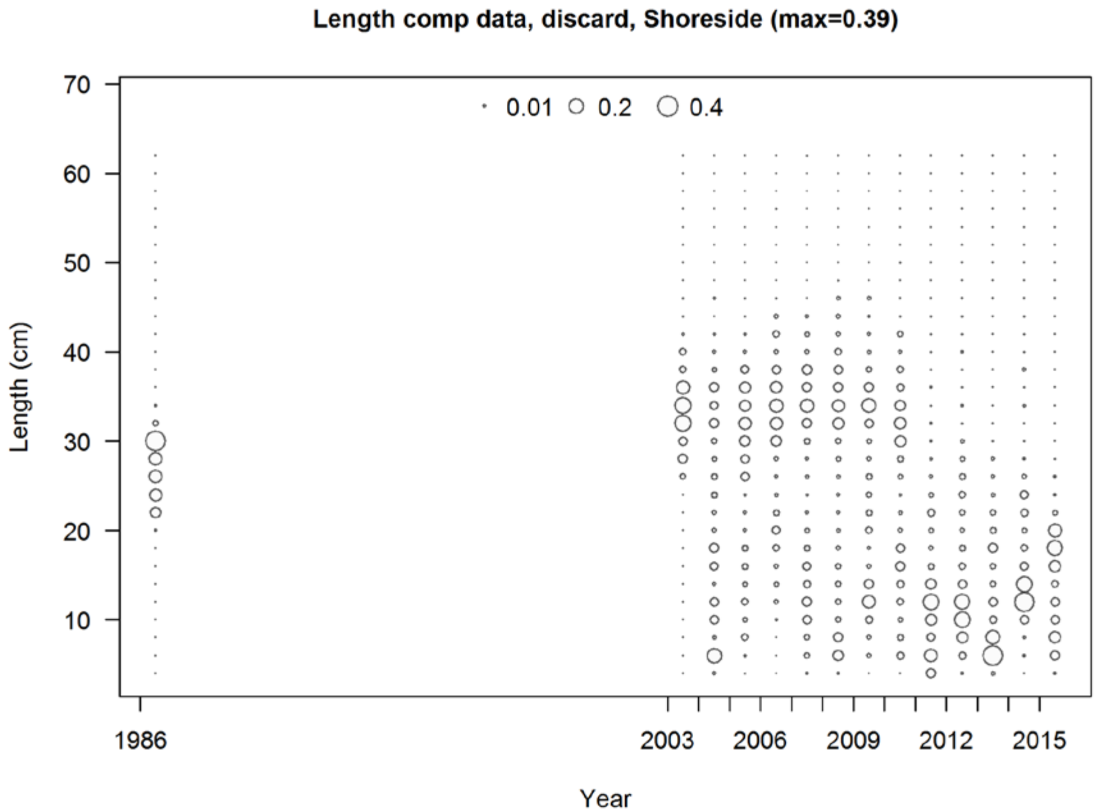

Figure 11: Length-frequency distributions for darkblotched rockfish (sexes combined) from the shoreside fleet discards by year.

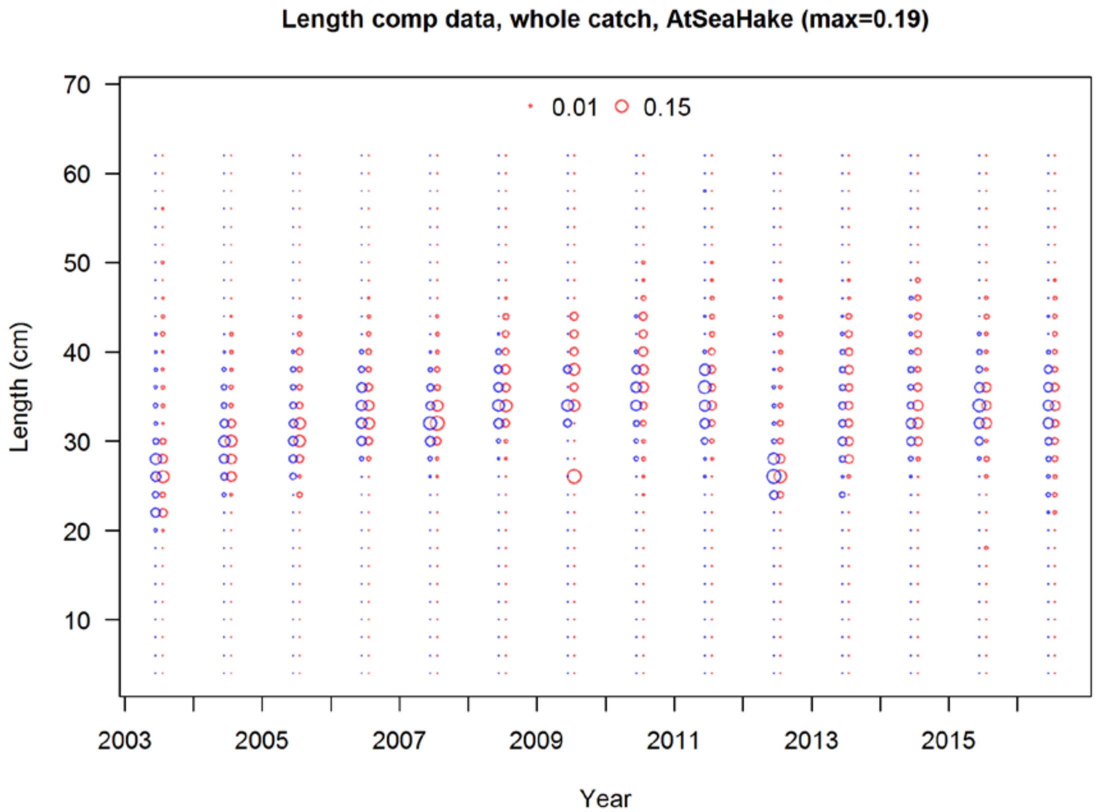

Figure 12: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the at-sea hake fishery removals by year.

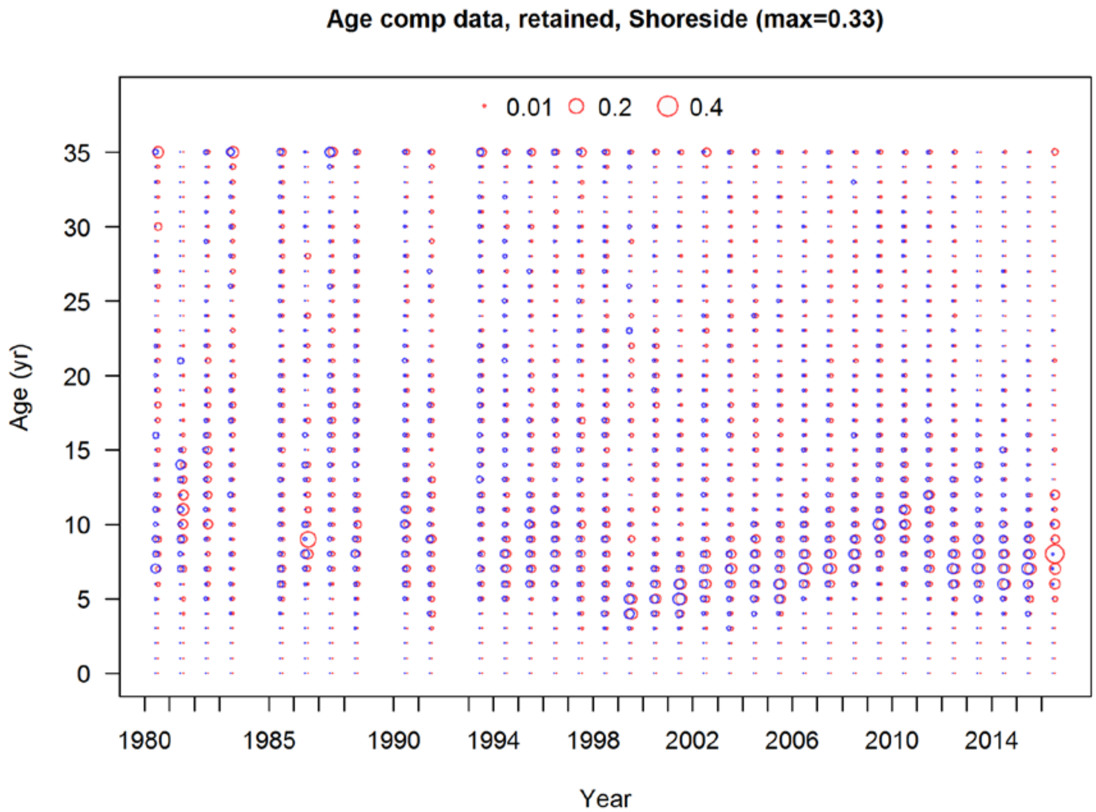

Figure 13: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the shoreside landings by year.

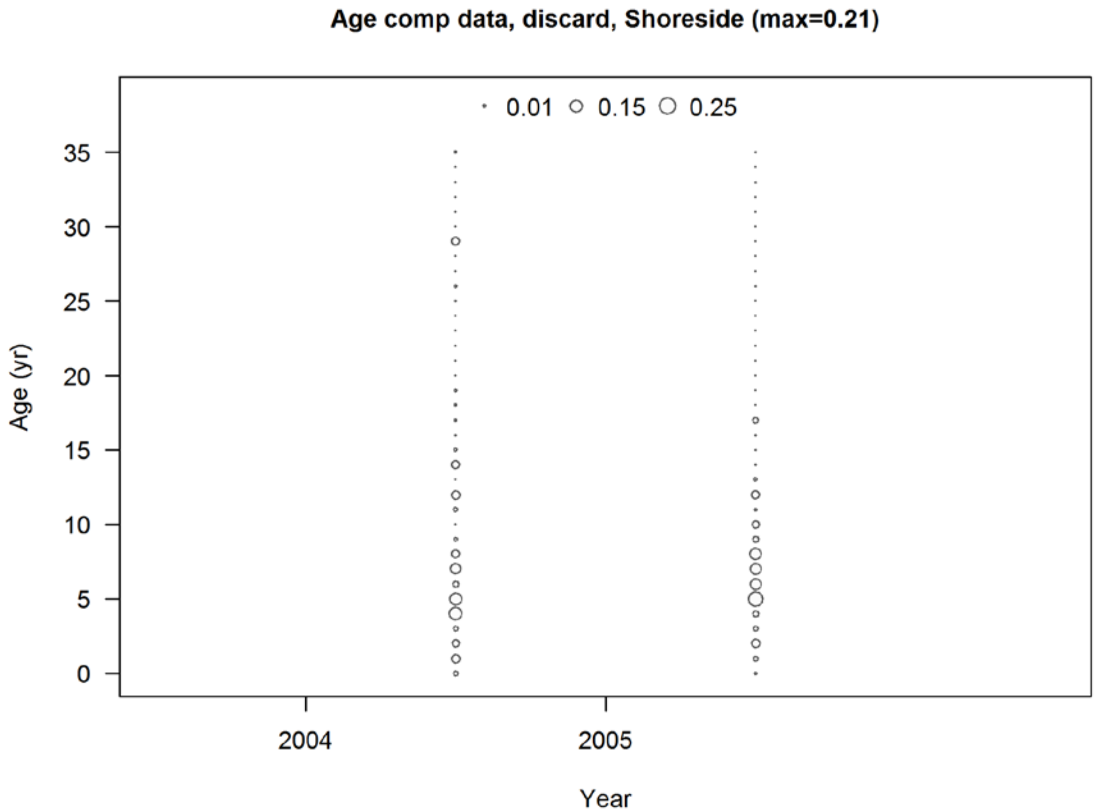

Figure 14: Age-frequency distributions for darkblotched rockfish (sexes combined) from the shoreside fleet discards by year.

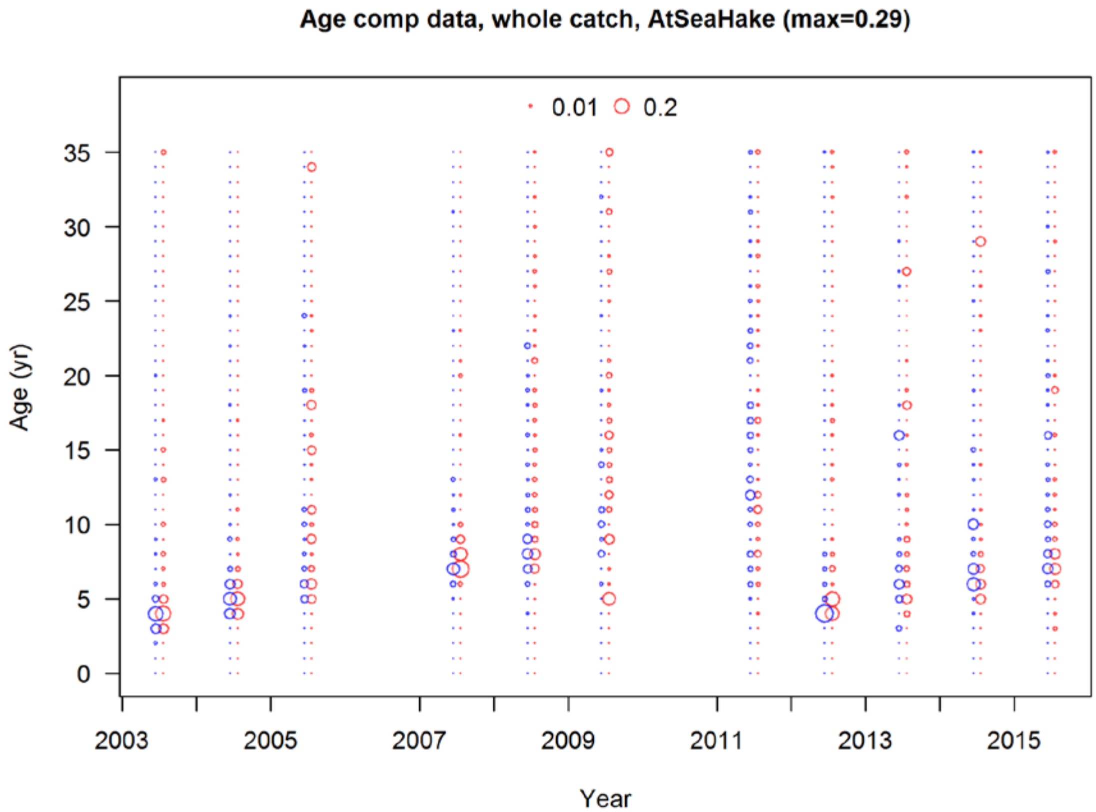

Figure 15: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the at-sea hake fishery removals by year.

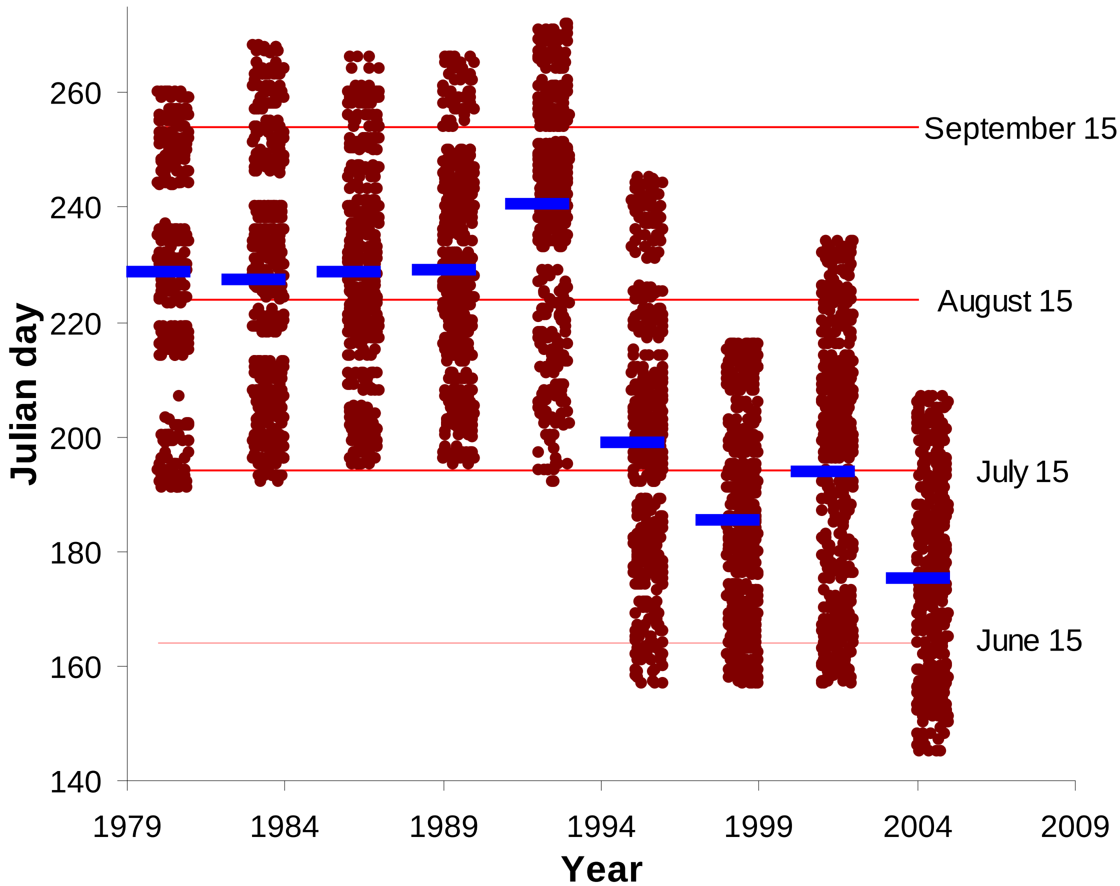

Figure 16: Distribution of dates of operation for the AFSC shelf (Triennial) bottom trawl survey (1980-2004). Solid bars show the mean date for each survey year, points represent individual hauls dates, but are jittered to allow better delineation of the distribution of individual points.

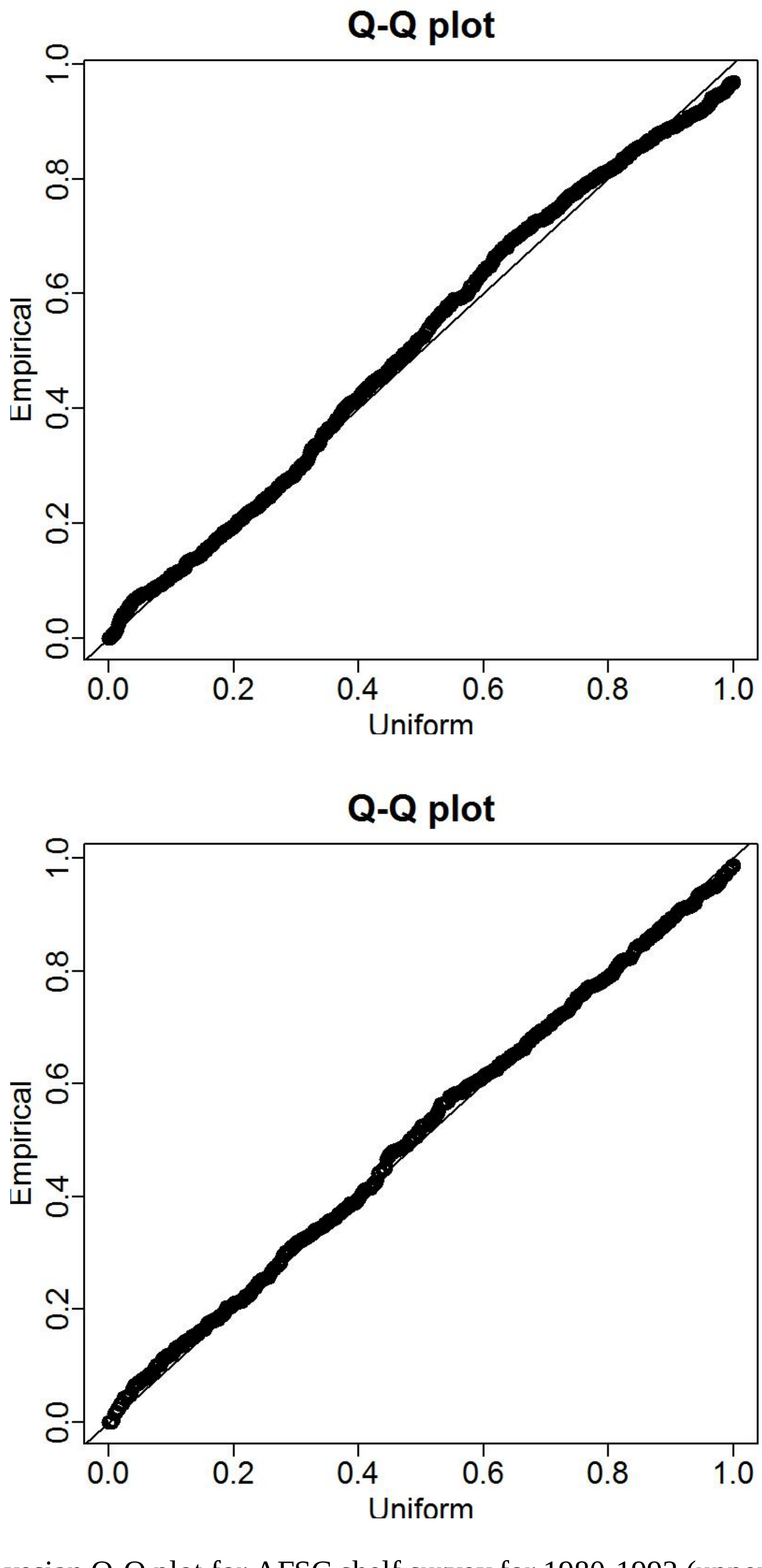

Figure 17: Bayesian Q-Q plot for AFSC shelf survey for 1980-1992 (upper panel) and 1995-2004 (lower panel).

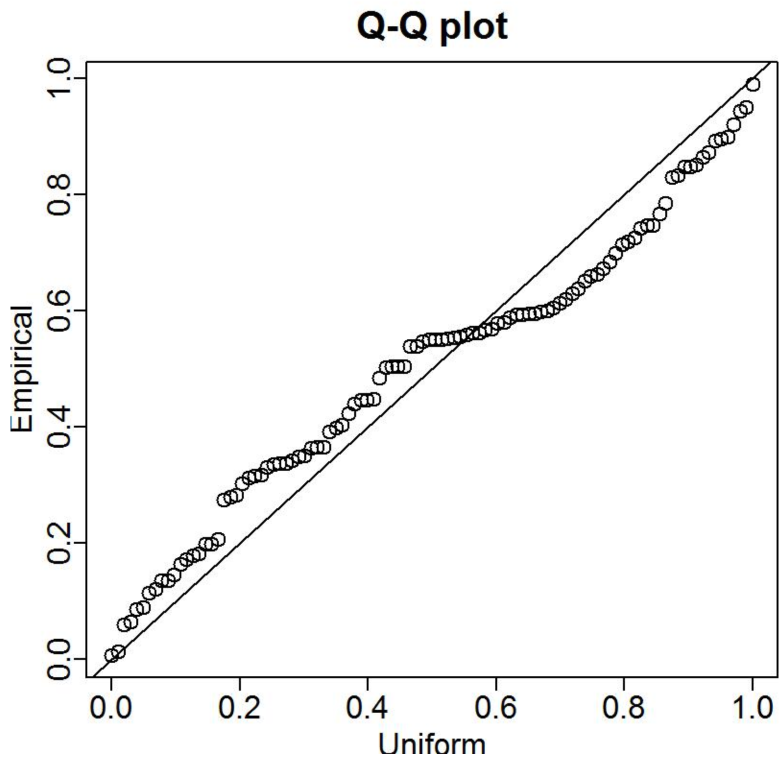

Figure 18: Bayesian Q-Q plot for AFSC slope survey.

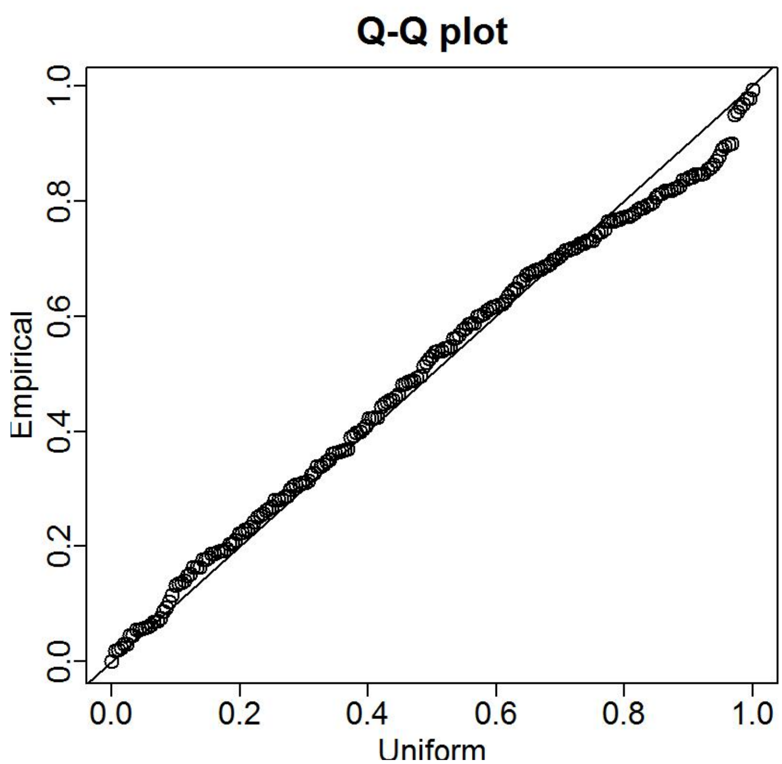

Figure 19: Bayesian Q-Q plot for NWFSC slope survey.

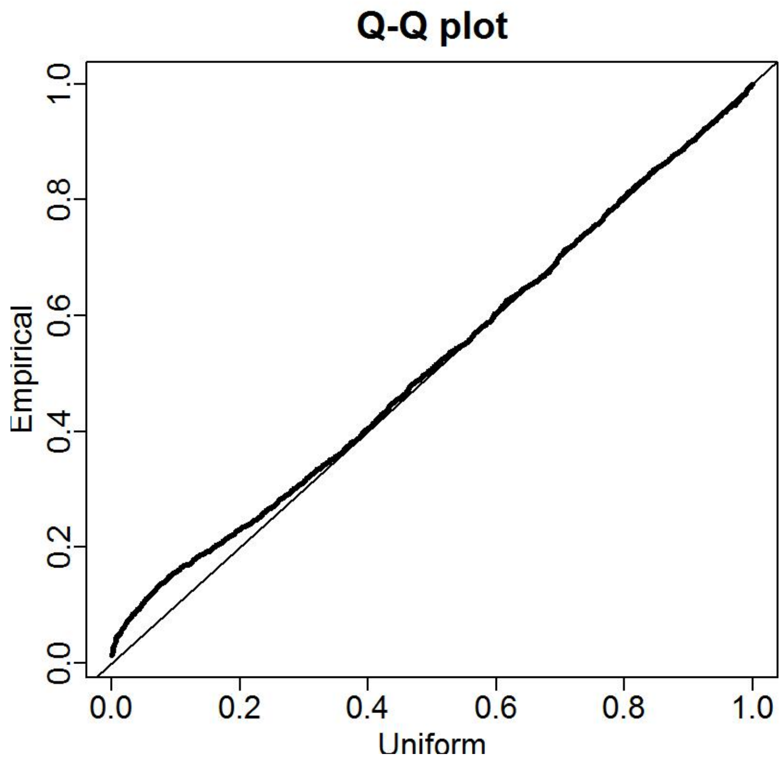

Figure 20: Q-Q plot for gamma model used in VAST for the NWFSC shelf-slope survey.

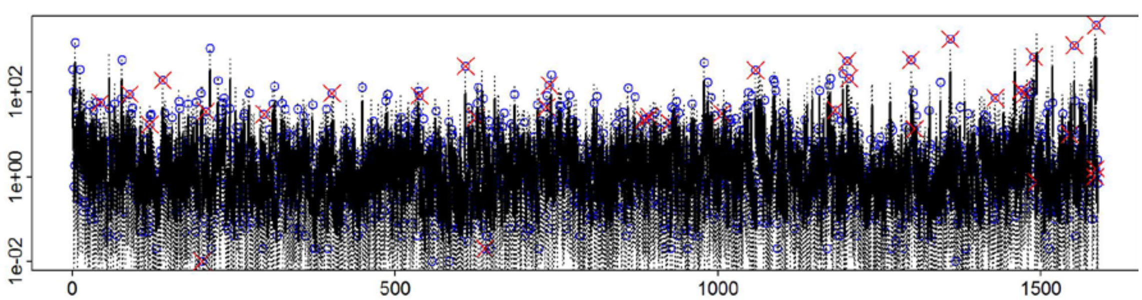

Figure 21: Posterior predictive plot for gamma model used in VAST for the NWFSC shelf-slope survey.

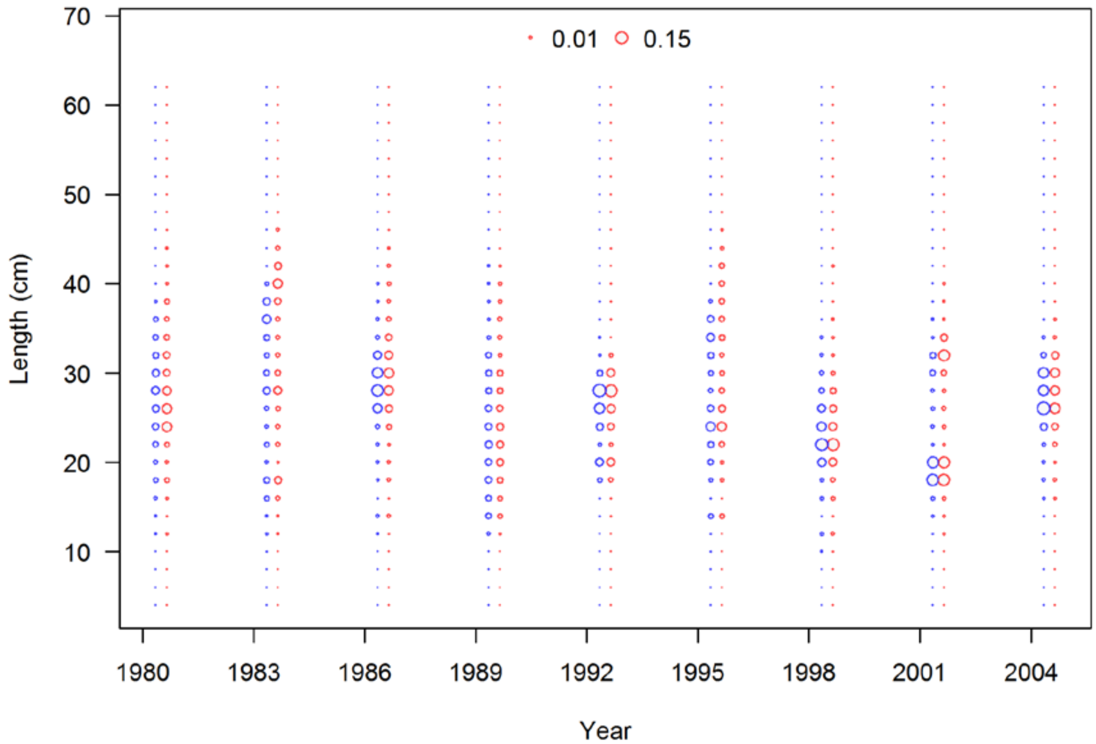

Figure 22: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey.

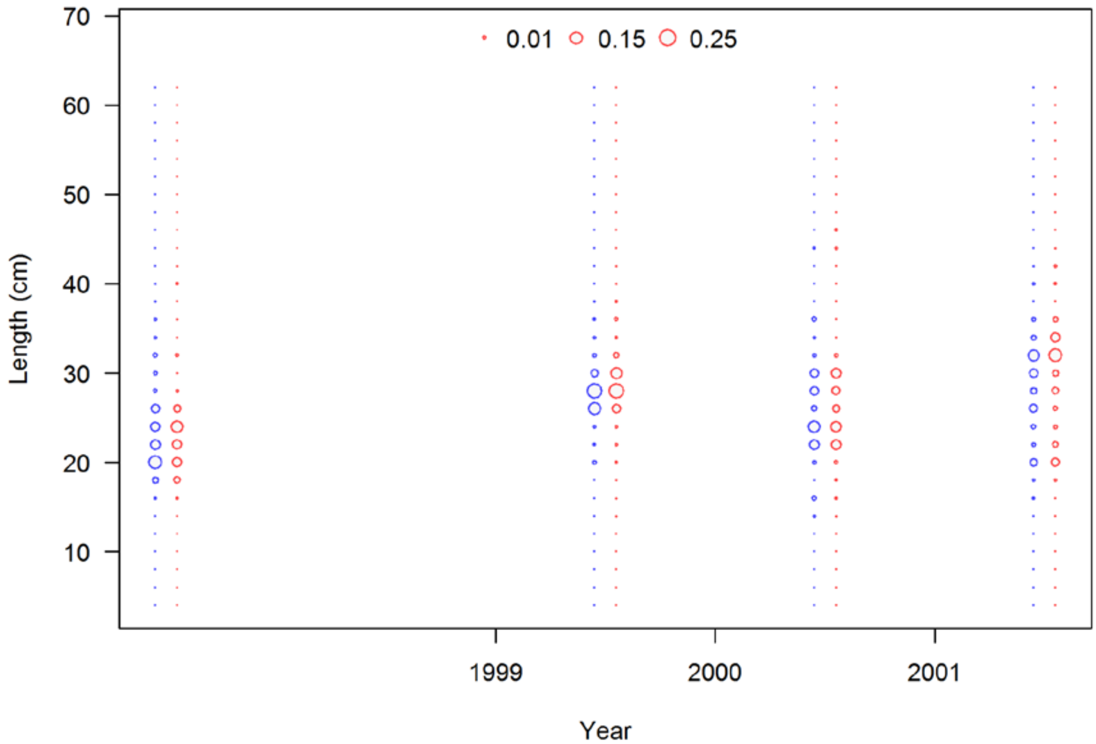

Figure 23: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the AFSC slope survey.

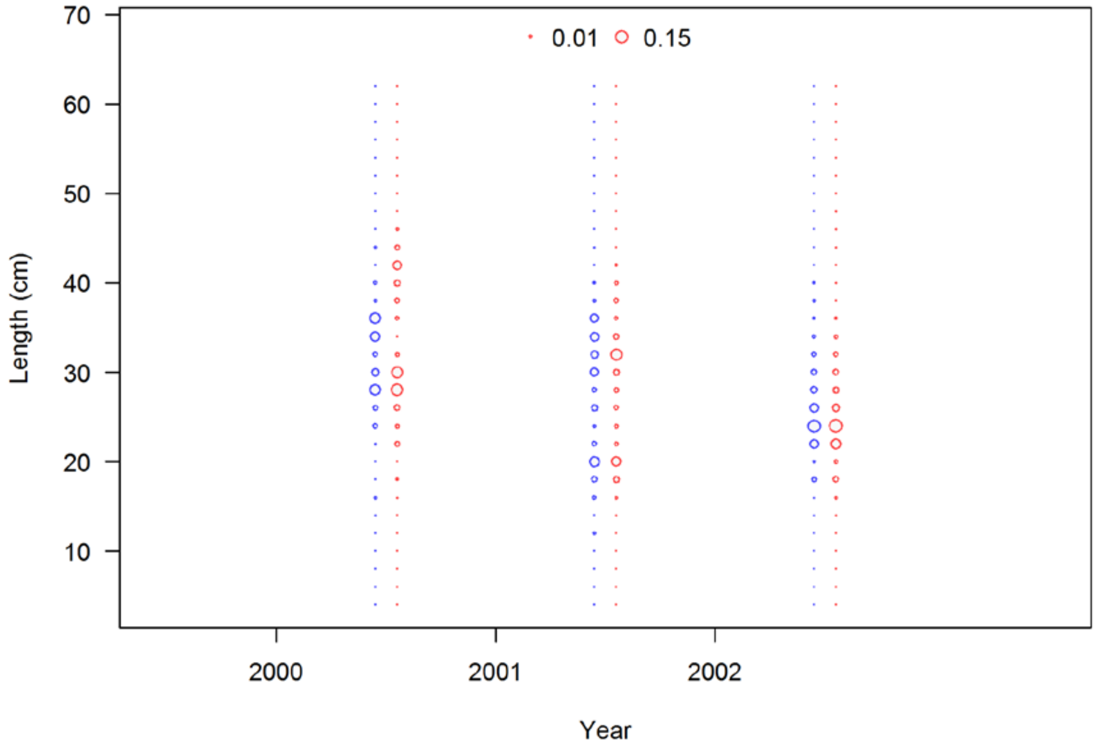

Figure 24: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the NWFSC slope survey.

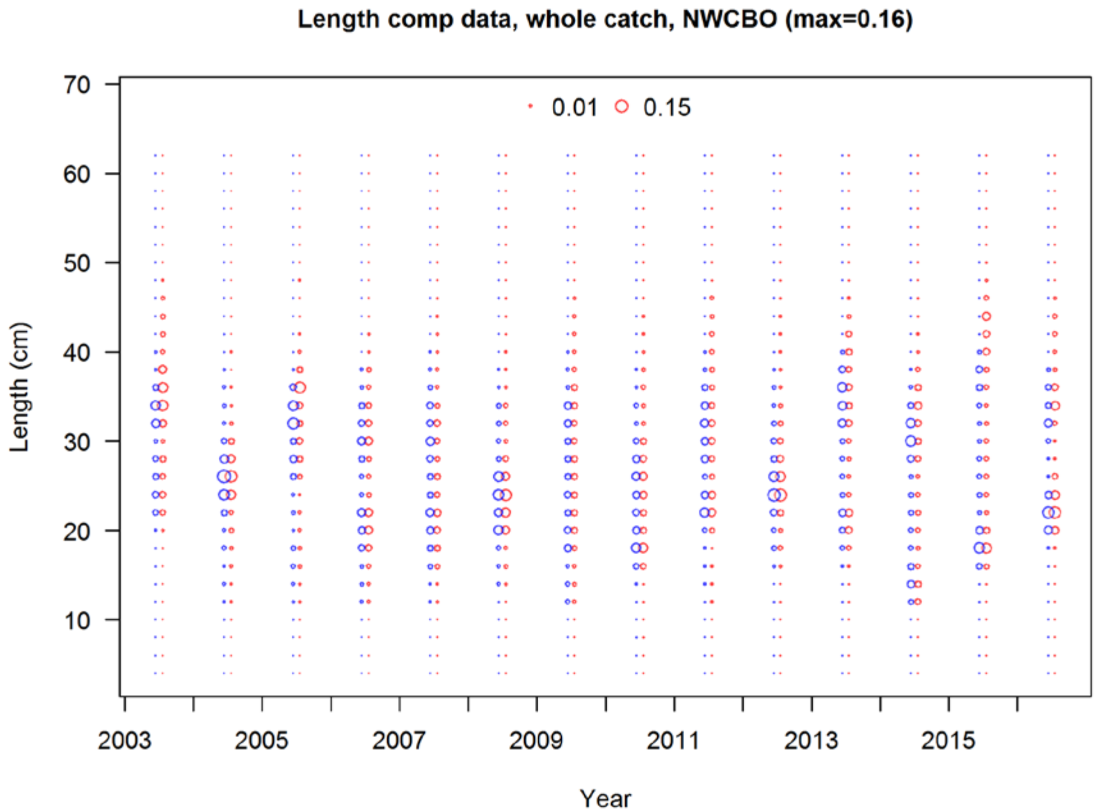

Figure 25: Length-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

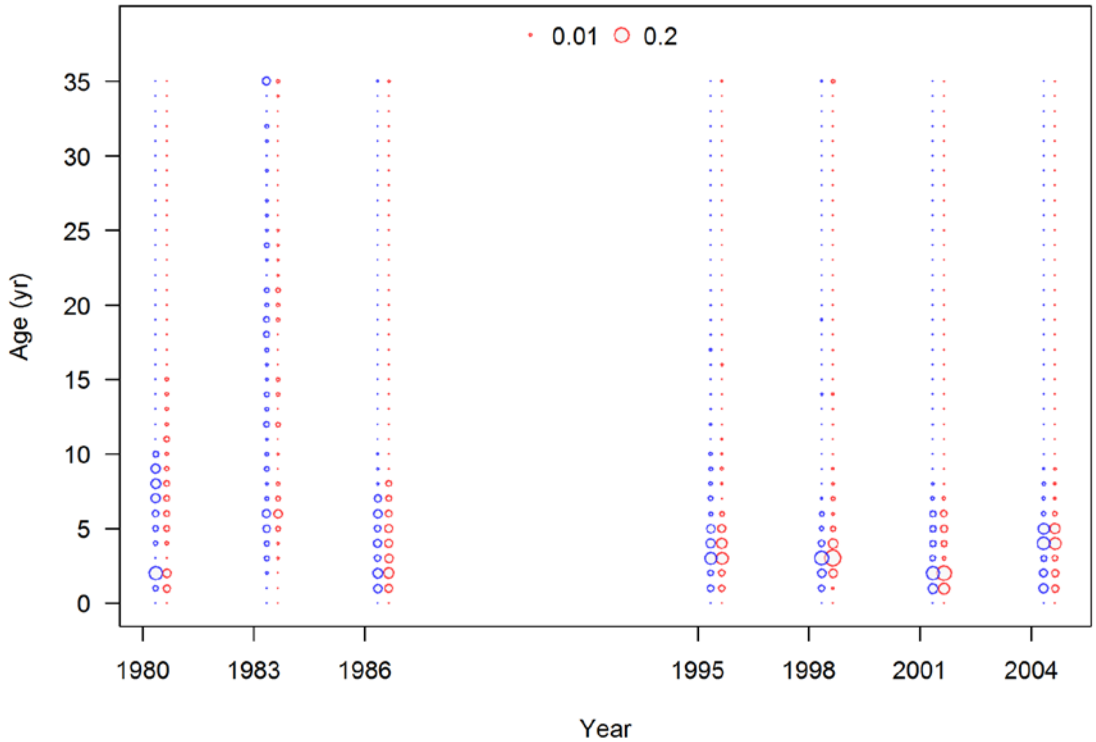

Figure 26: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey.

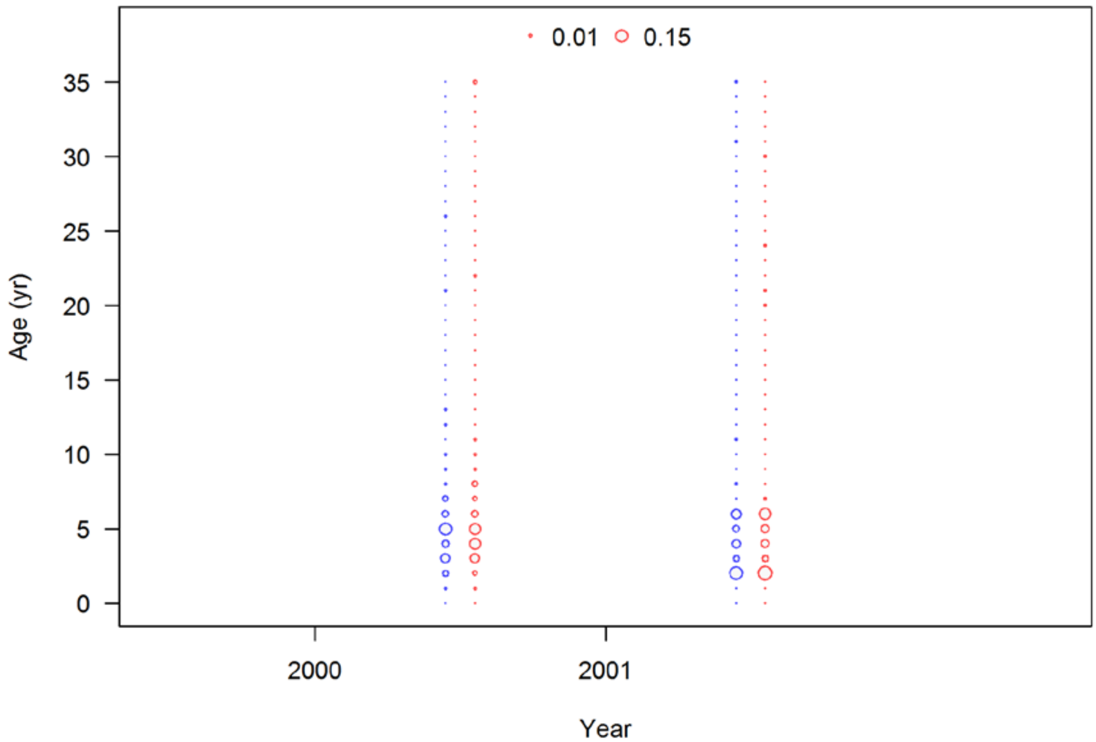

Figure 27: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the AFSC slope survey.

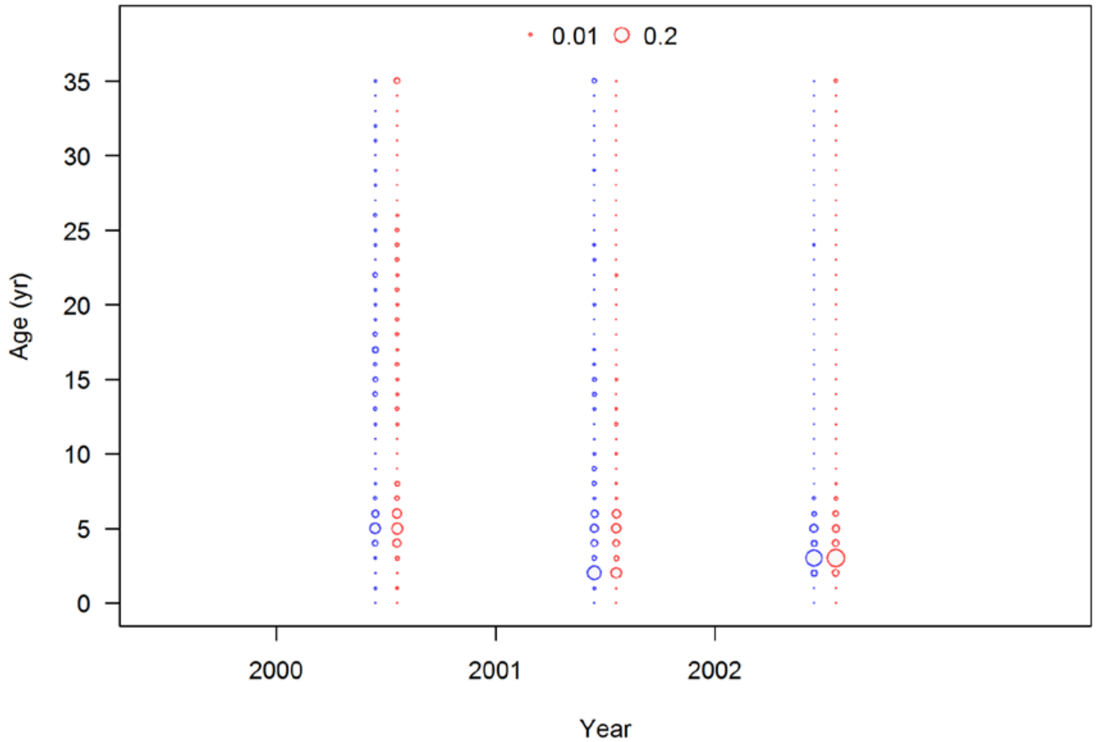

Figure 28: Age-frequency distributions for darkblotched rockfish (females are shown in red, males in blue) from the NWFSC slope survey.

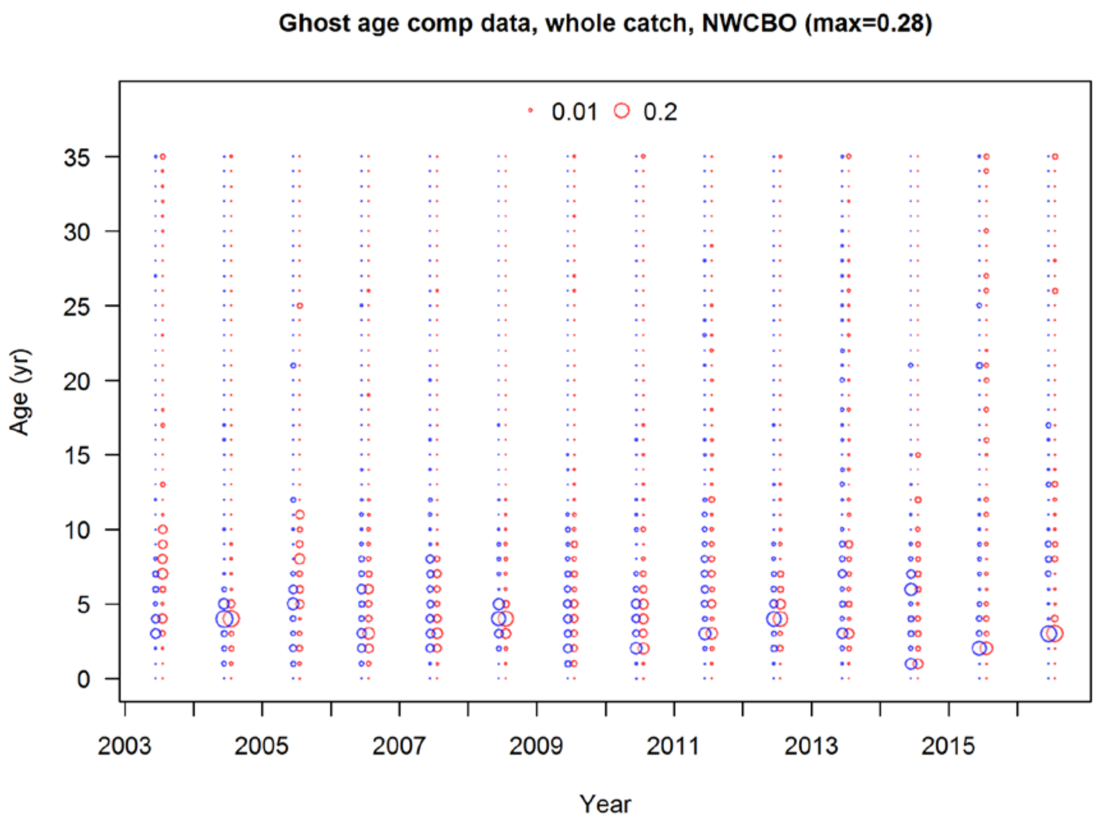

Figure 29: Age-frequency distributions for darkblotched (females are shown in red, males in blue) rockfish from the NWFSC shelf-slope survey.

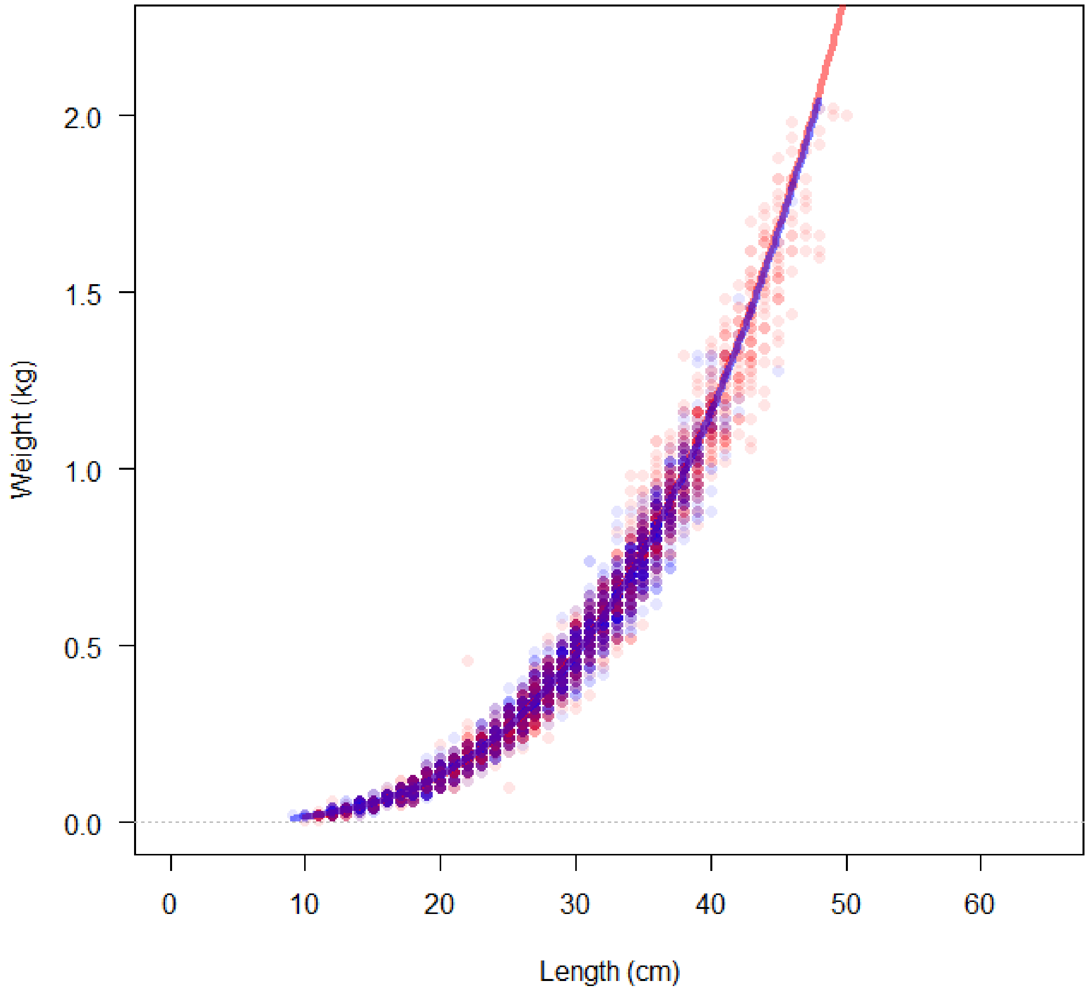

Figure 30: Weight-length relationship for female (red) and male (blue) darkblotched rockfish used in the assessment, shown with fit to the data from the NWFSC shelf-slope survey samples (shaded points).

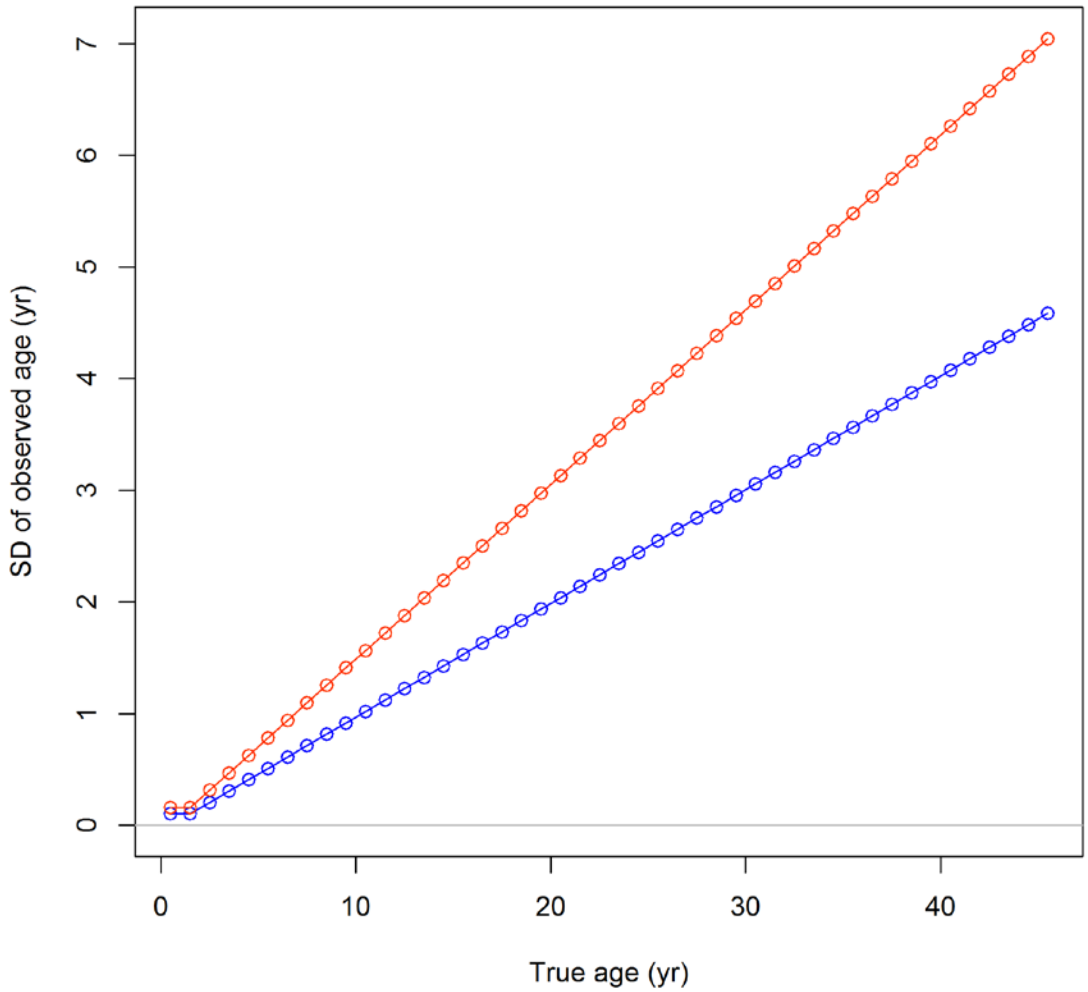

Figure 31: SD of observed age versus true age for "early" (red) and "late" (blue) age data used in the assessment.

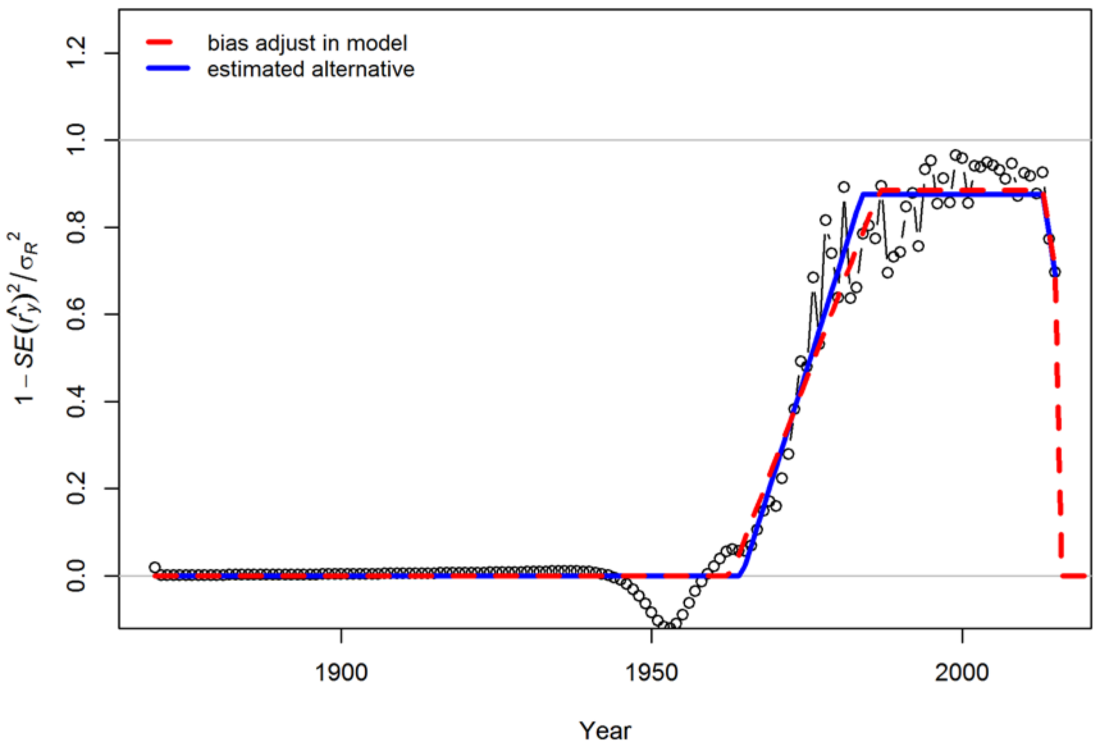

Figure 32: Bias correction ramp estimated by R4SS using particle swarm optimization to avoid local minima.

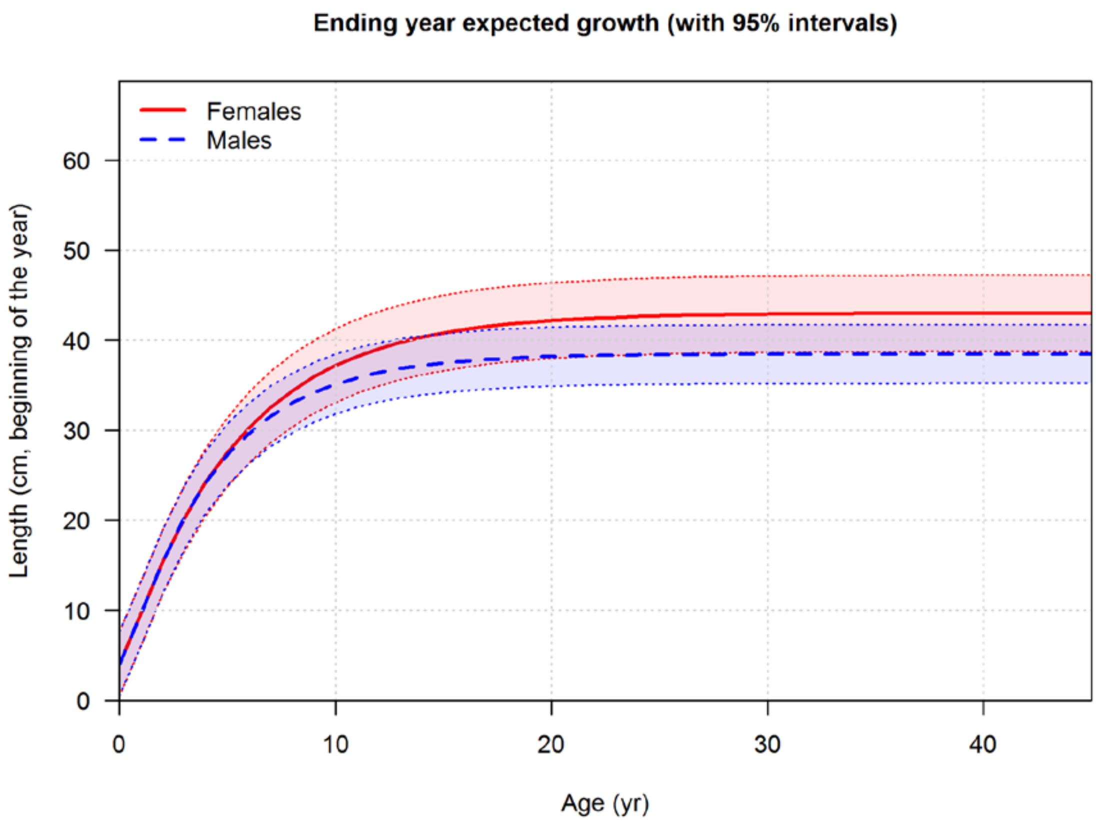

Figure 33: Growth curves for females and males of darkblotched rockfish used in the assessment model.

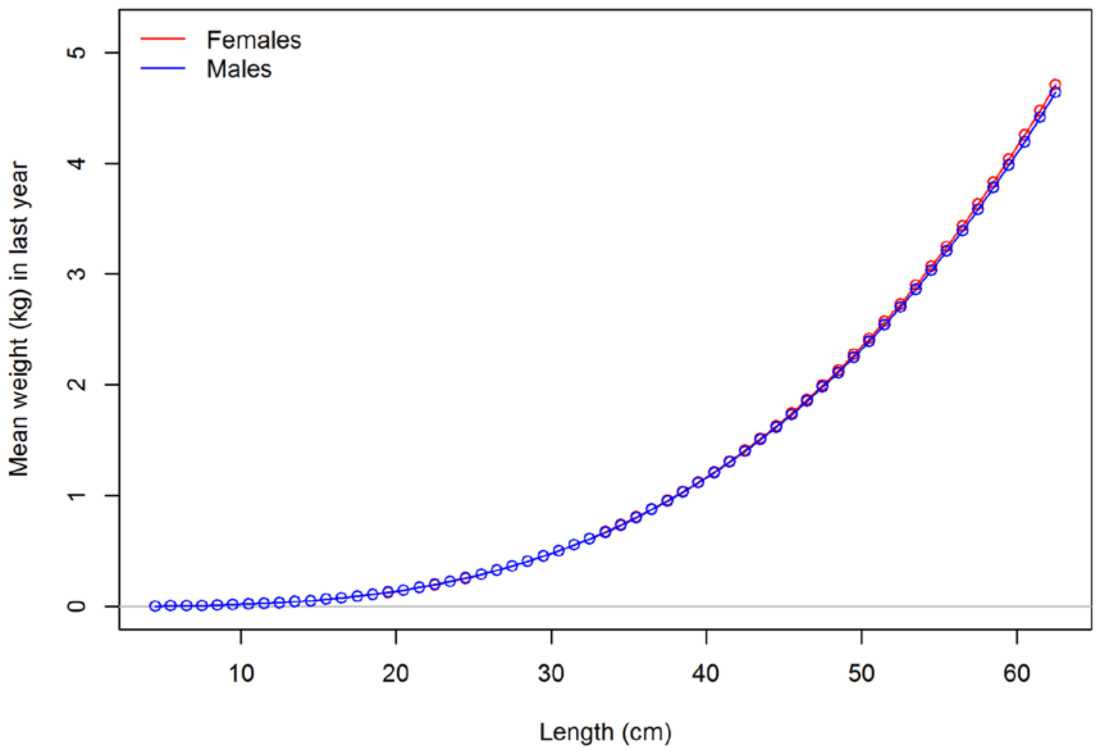

Figure 34: Weight-at-length relationship for females and males of darkblotched rockfish used in the assessment model.

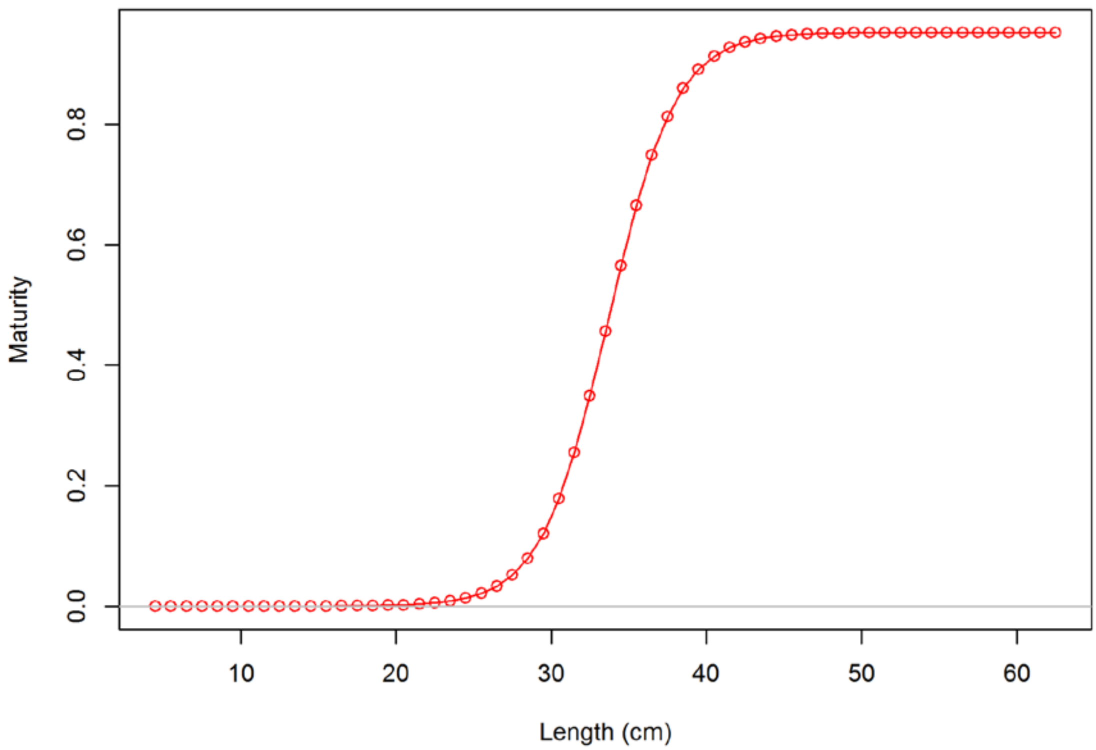

Figure 35: Female maturity at length relationship used in the assessment model. The parameters were estimated from the data collected within the NWFSC shelf-slope survey between 2011 and 2012.

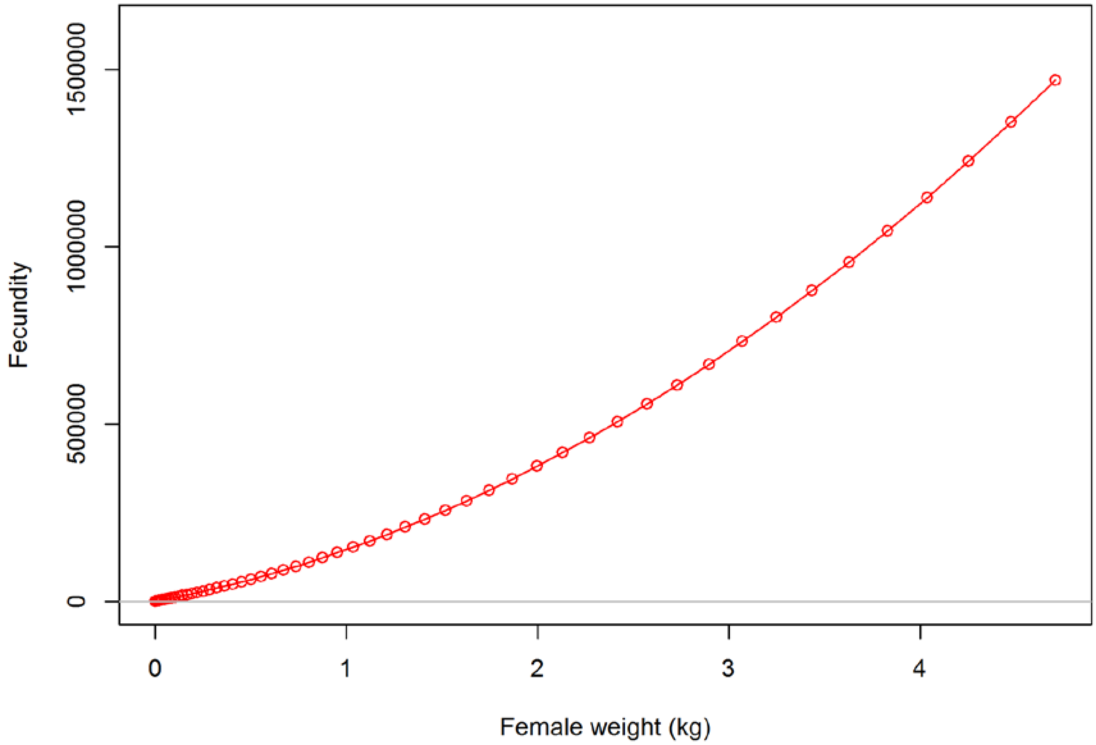

Figure 36: Female darkblotched rockfish fecundity at weight relationship used in the assessment, based on the parameters estimated by Dick (2009).

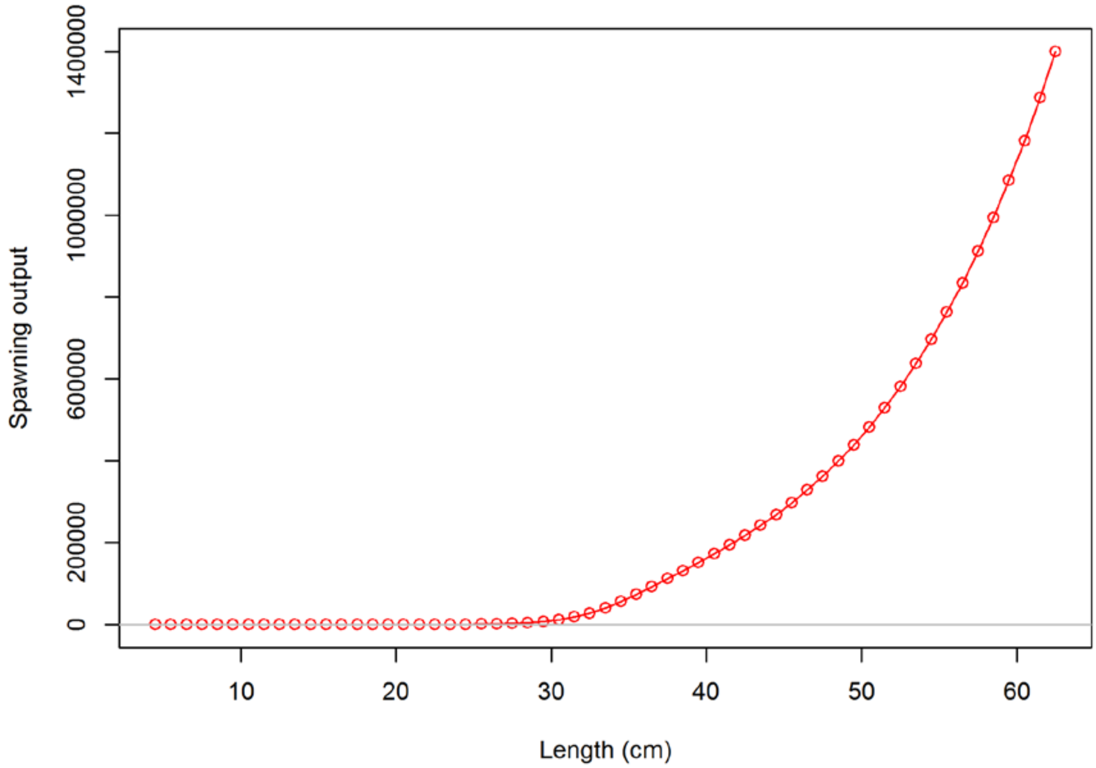

Figure 37: Female darkblotched rockfish spawning output-at-length relationship used in the assessment model.

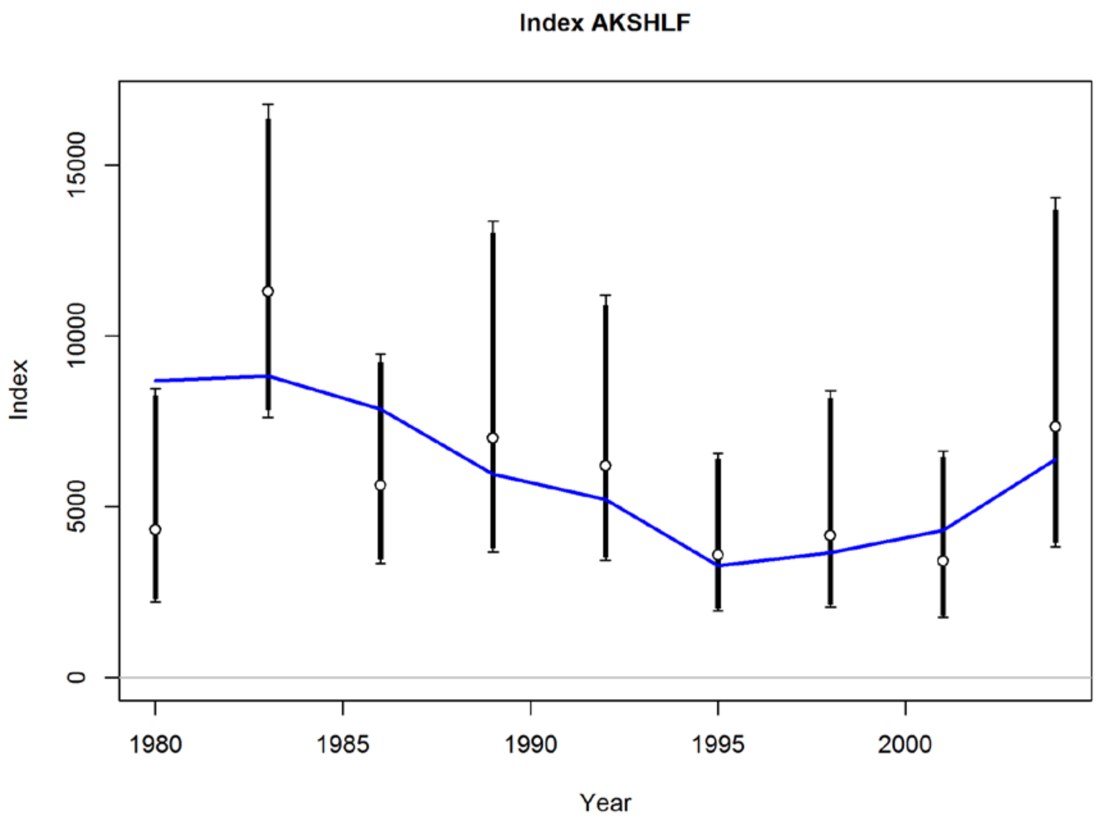

Figure 38: Observed and expected values of darkblotched rockfish biomass index (mt) for the AFSC shelf survey.

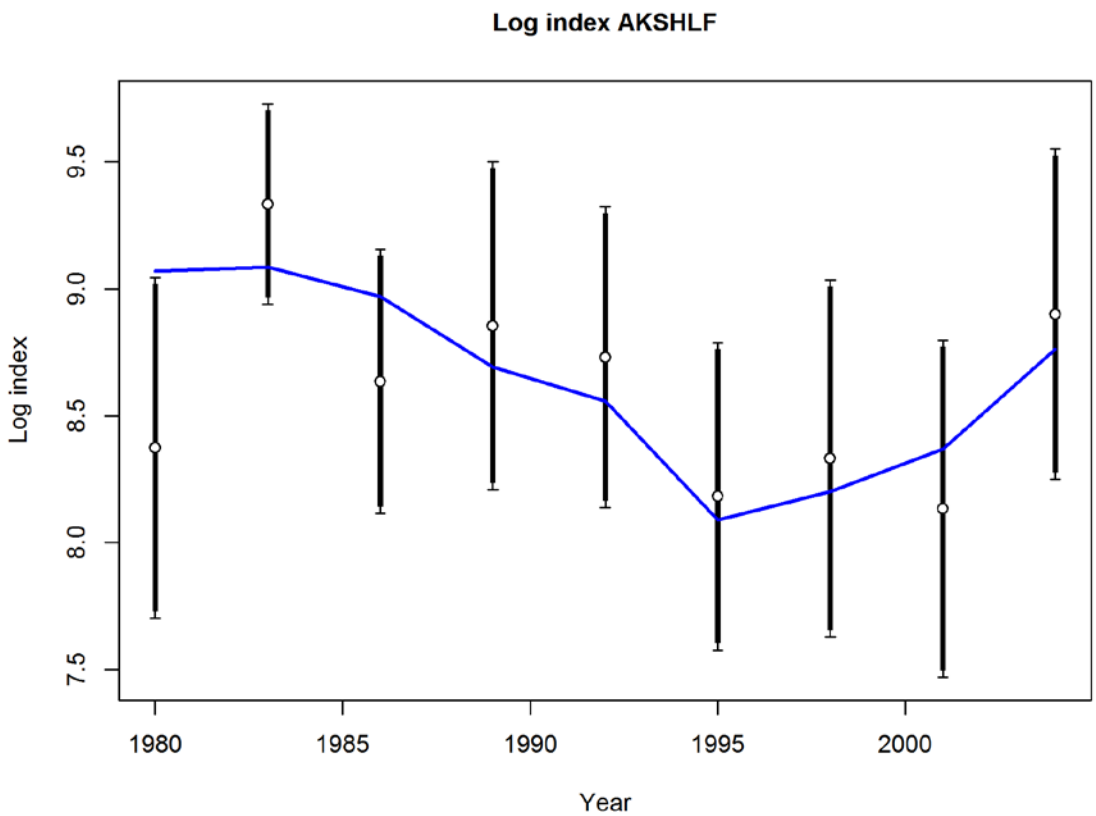

Figure 39: Observed and expected values of darkblotched rockfish biomass index (mt) for the AFSC shelf survey, on log scale.

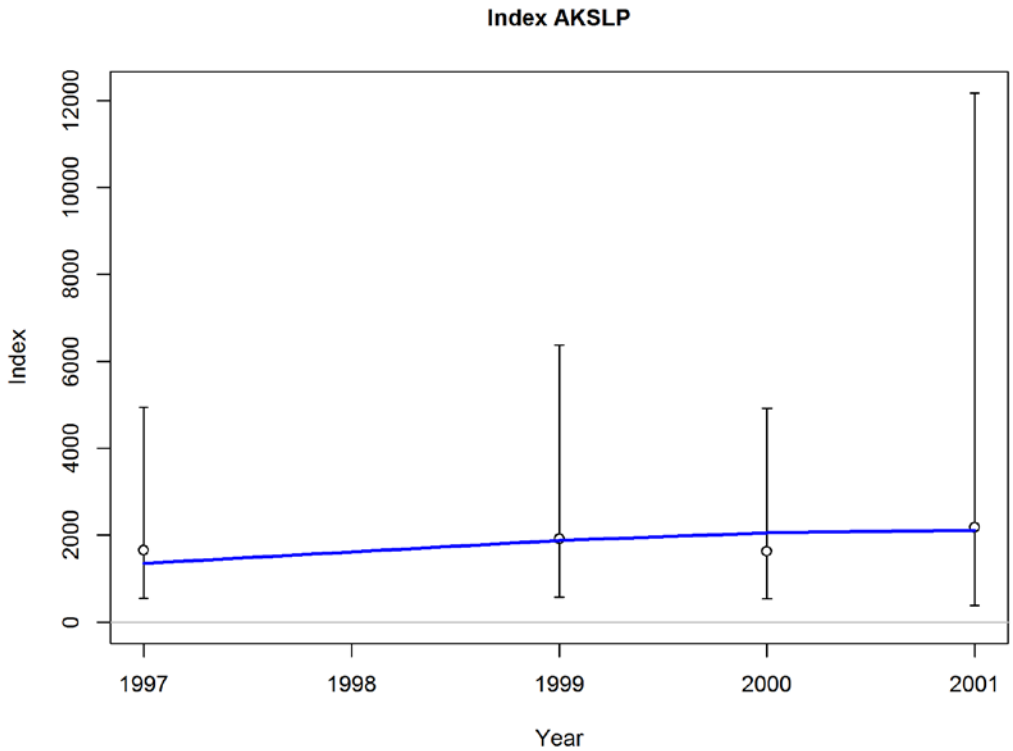

Figure 40: Observed and expected values of darkblotched rockfish biomass index (mt) for the AFSC slope survey.

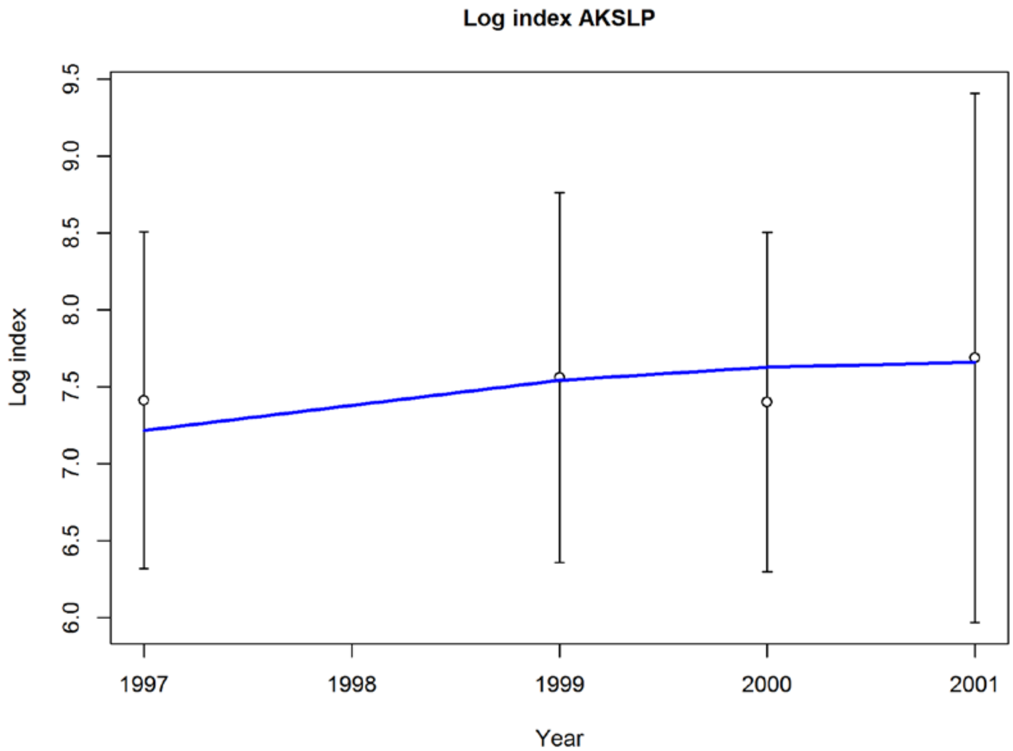

Figure 41: Observed and expected values of darkblotched rockfish biomass index (mt) for the AFSC slope survey, on log scale.

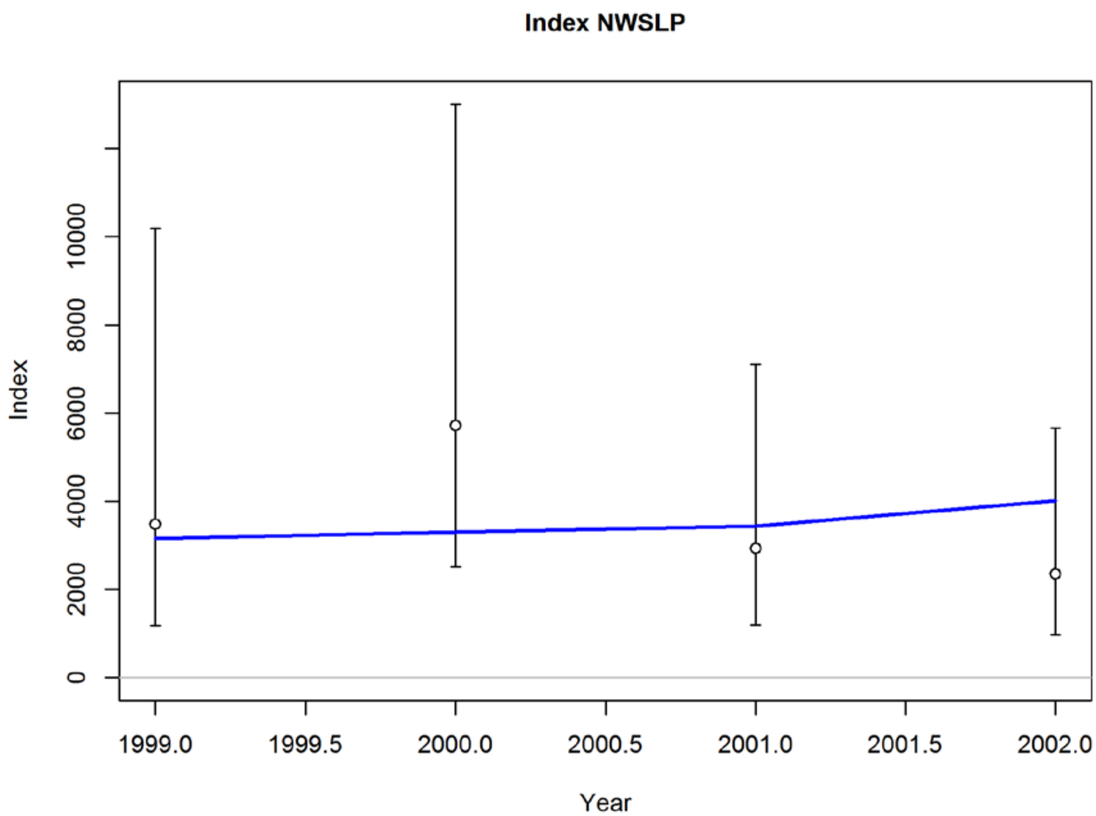

Figure 42: Observed and expected values of darkblotched rockfish biomass index (mt) for the NWFSC slope survey.

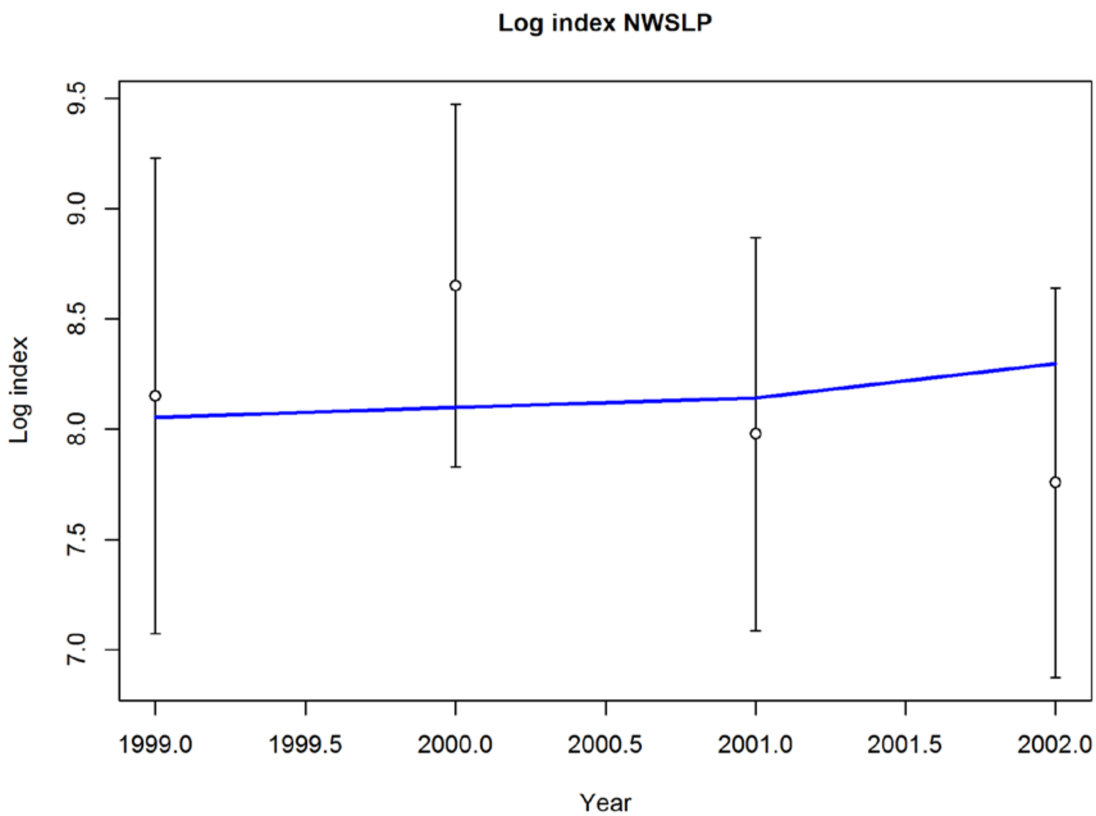

Figure 43: Observed and expected values of darkblotched rockfish biomass index (mt) for the NWFSC slope survey, on log scale.

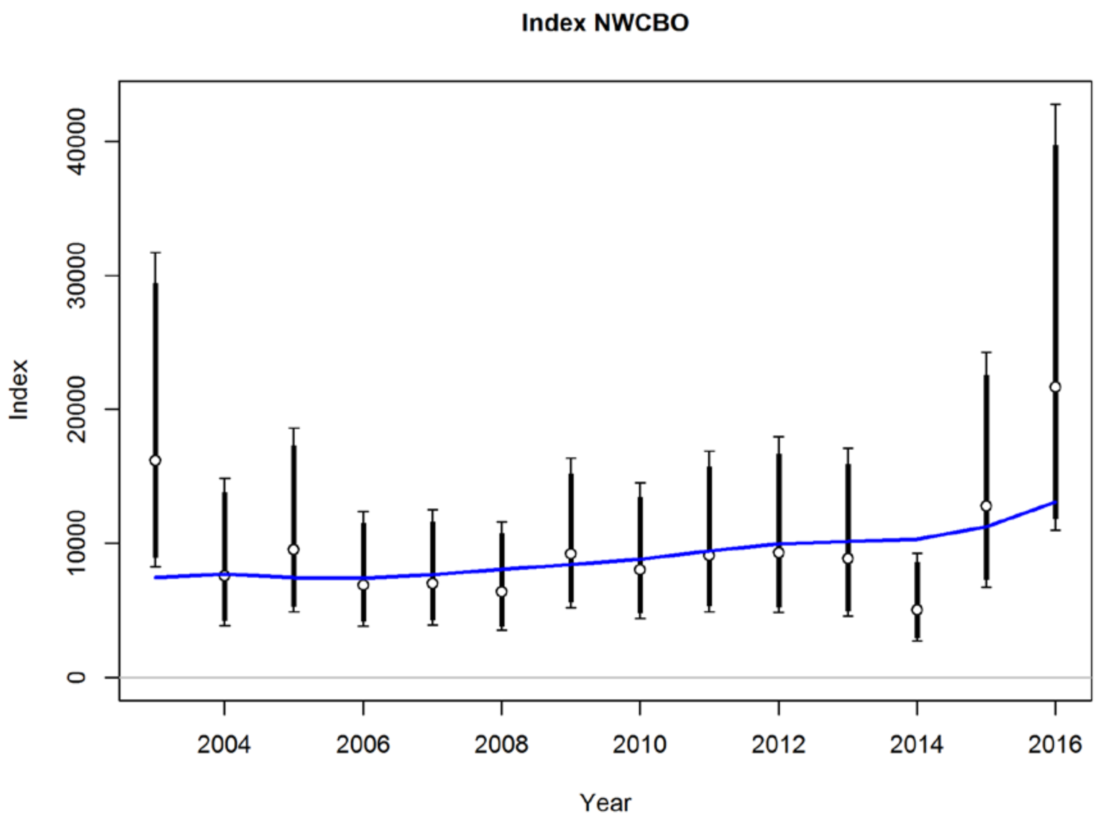

Figure 44: Observed and expected values of darkblotched rockfish biomass index (mt) for the NWFSC shelf-slope survey.

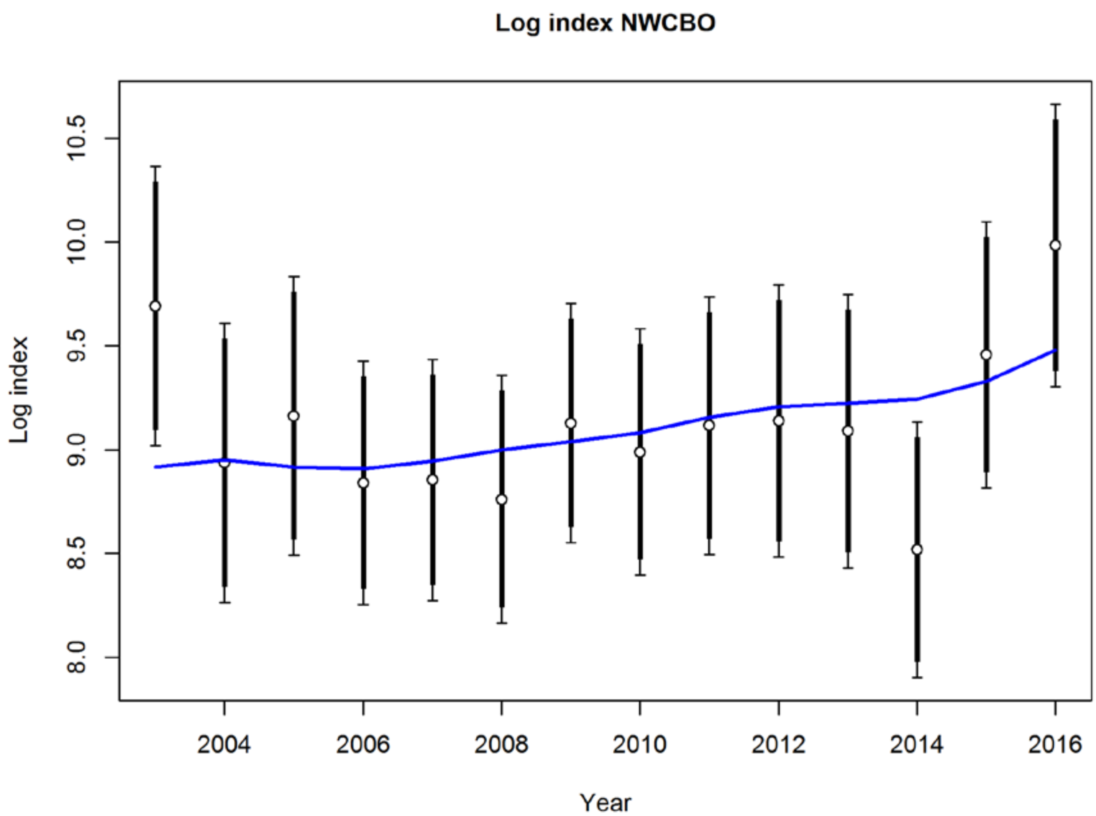

Figure 45: Observed and expected values of darkblotched rockfish biomass index (mt) for the NWFSC shelf-slope survey, on log scale.

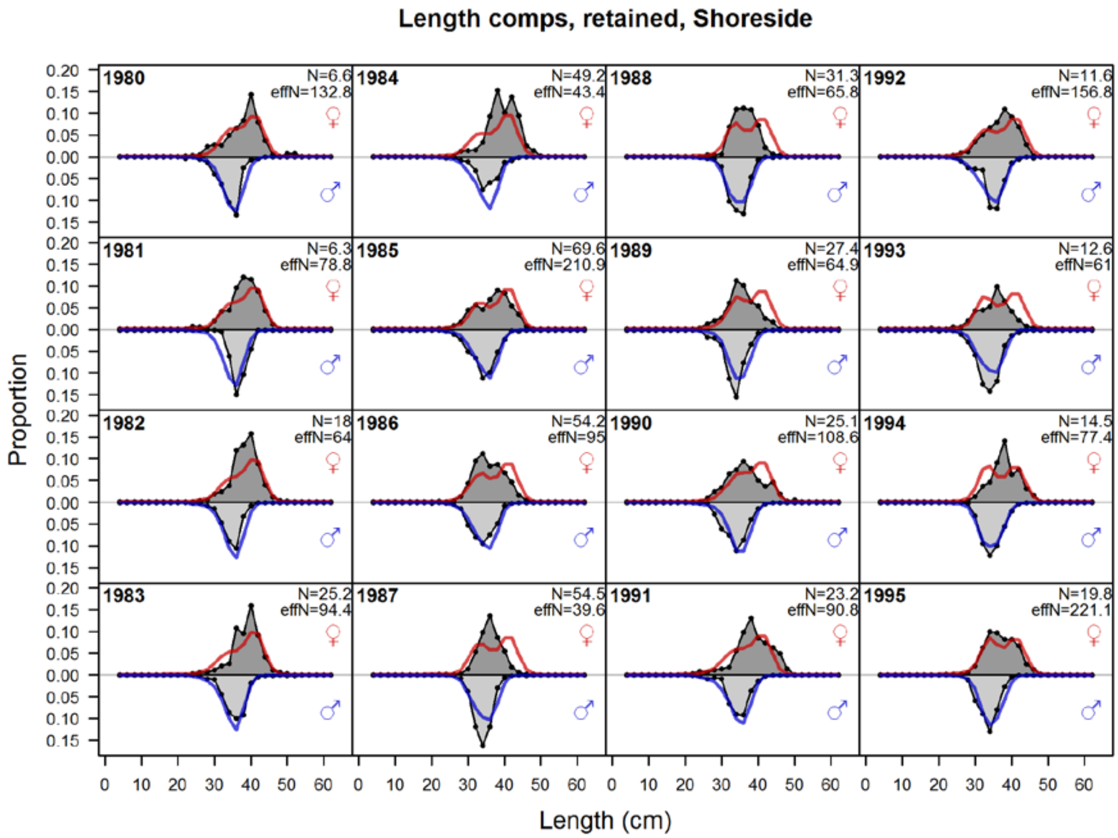

Figure 46: Fit to length-frequency distributions of darkblotched rockfish for the shoreside landings, by year.

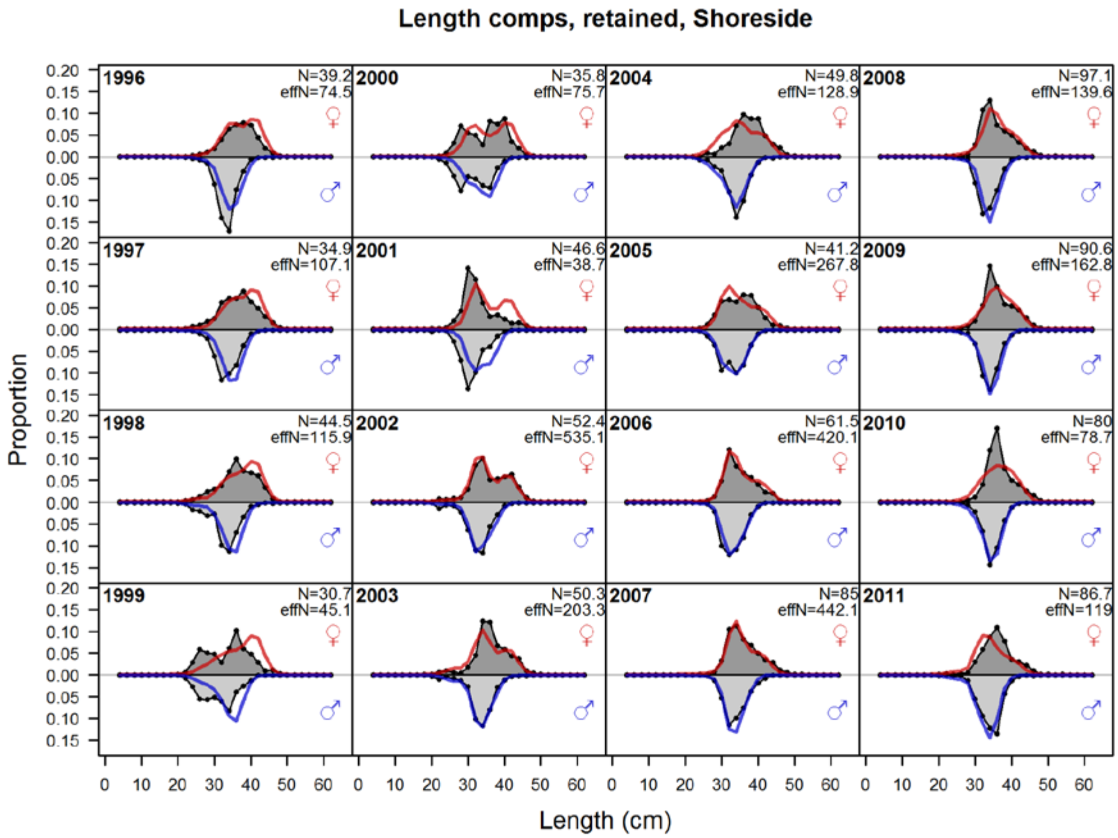

Figure 46 (continued): Fit to length-frequency distributions of darkblotched rockfish for the shoreside landings, by year.

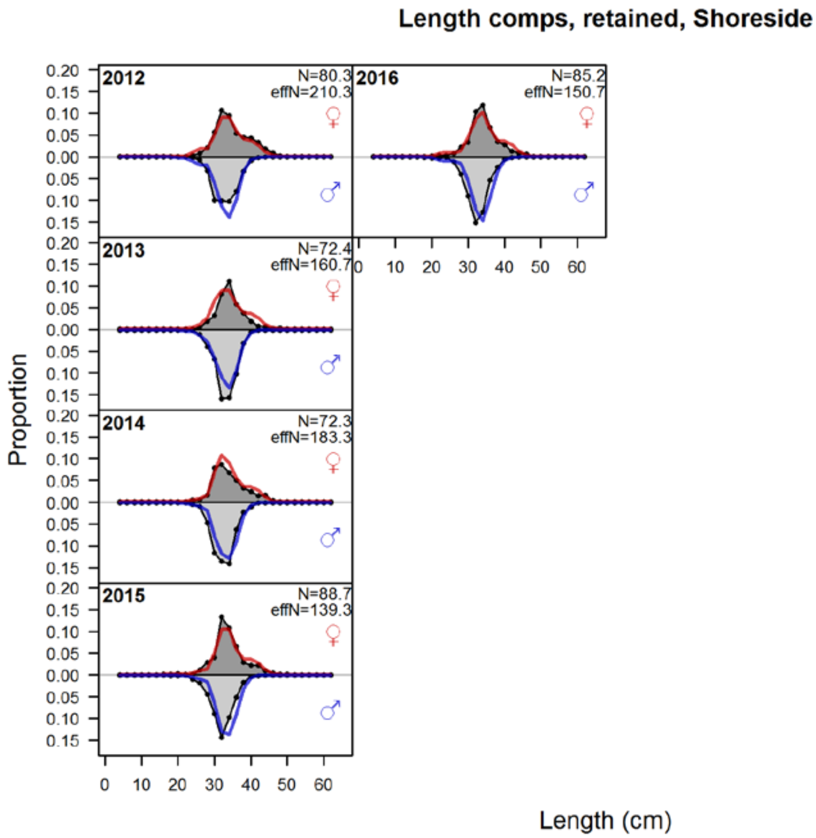

Figure 46 (continued): Fit to length-frequency distributions of darkblotched rockfish for the shoreside landings, by year.

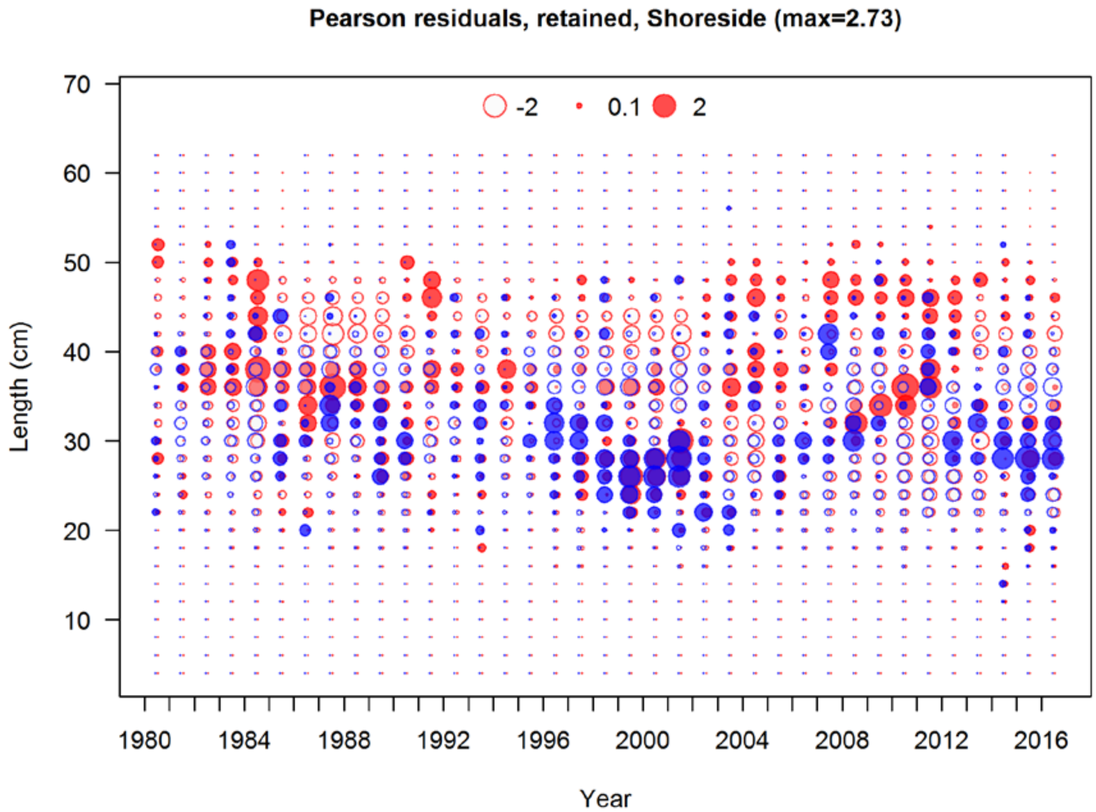

Figure 47: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) for the shoreside landings, by year.

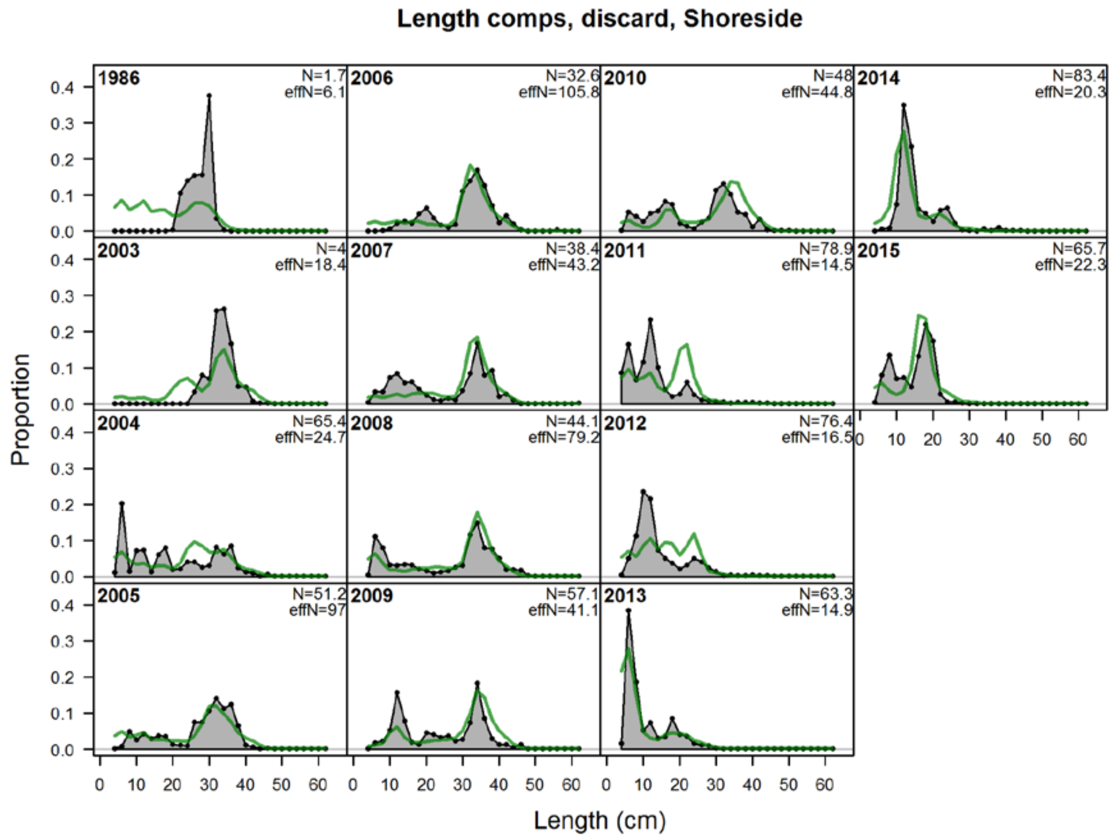

Figure 48: Fit to length-frequency distributions of darkblotched rockfish (sexes combined) for the shoreside fleet discard, by year.

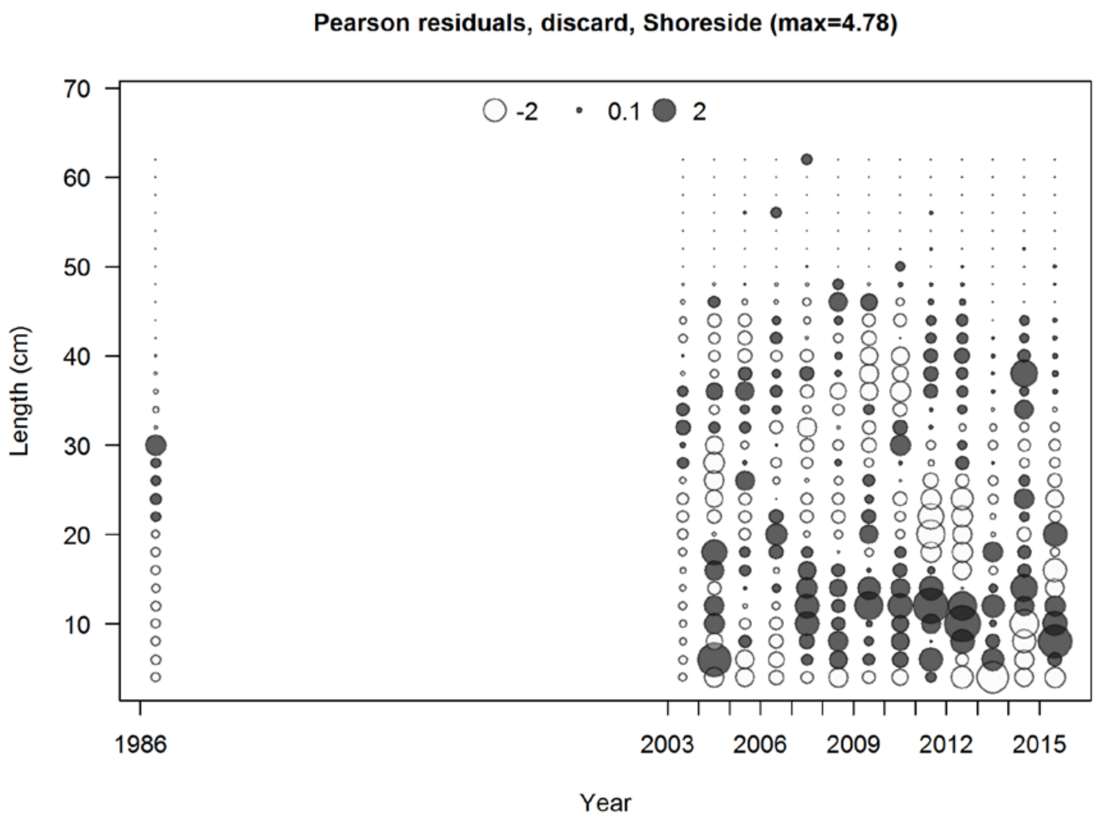

Figure 49: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (sexes combined) for the shoreside fleet discard, by year.

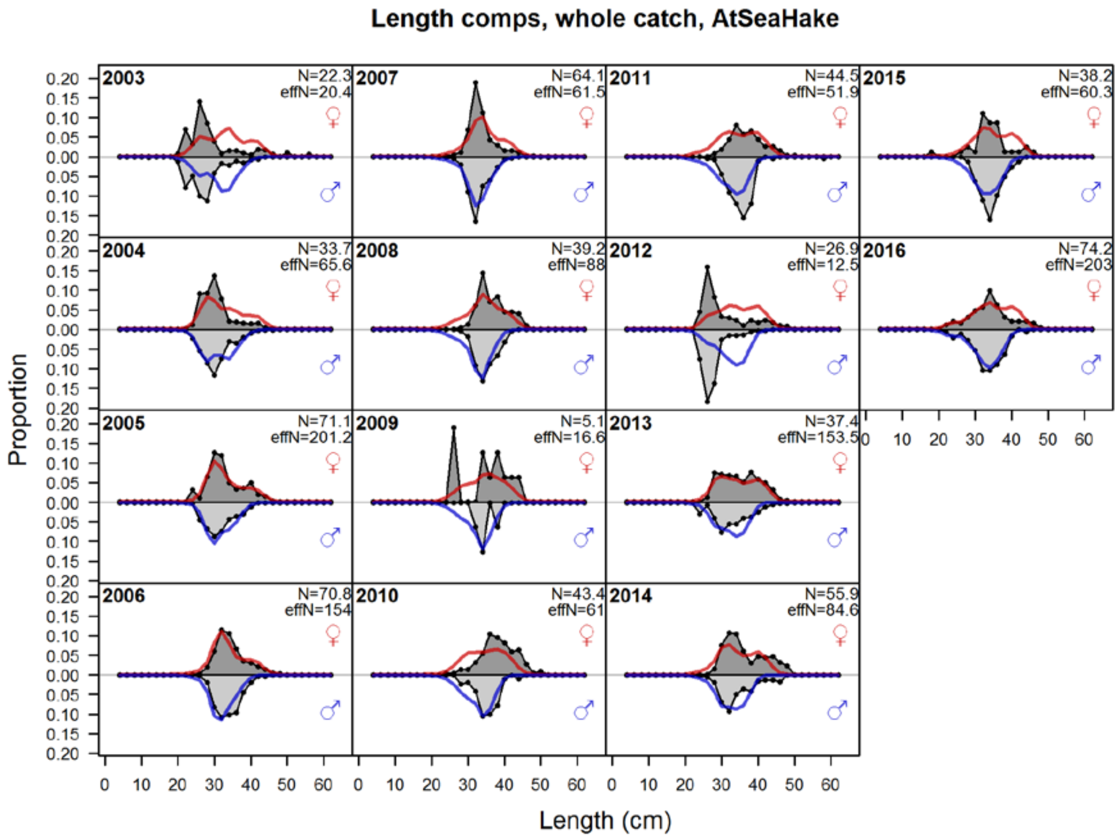

Figure 50: Fit to length-frequency distributions of darkblotched rockfish for at sea hake fishery bycatch, by year.

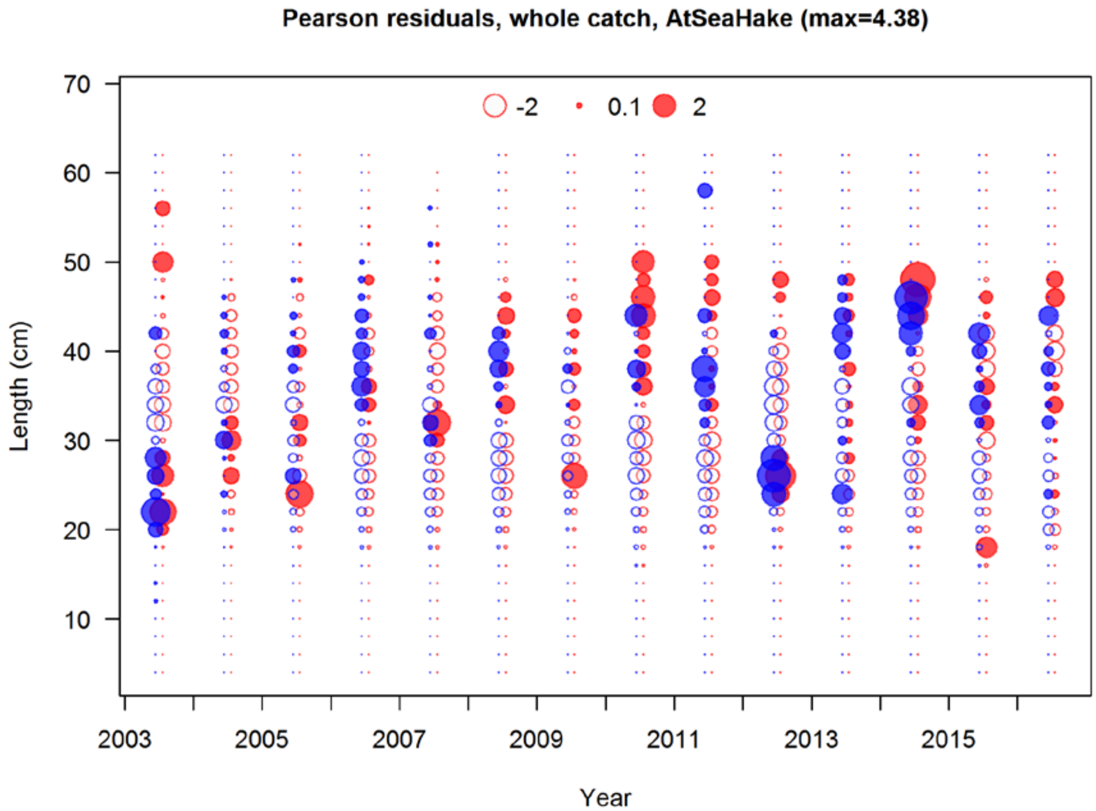

Figure 51: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) for the shoreside landings, by year.

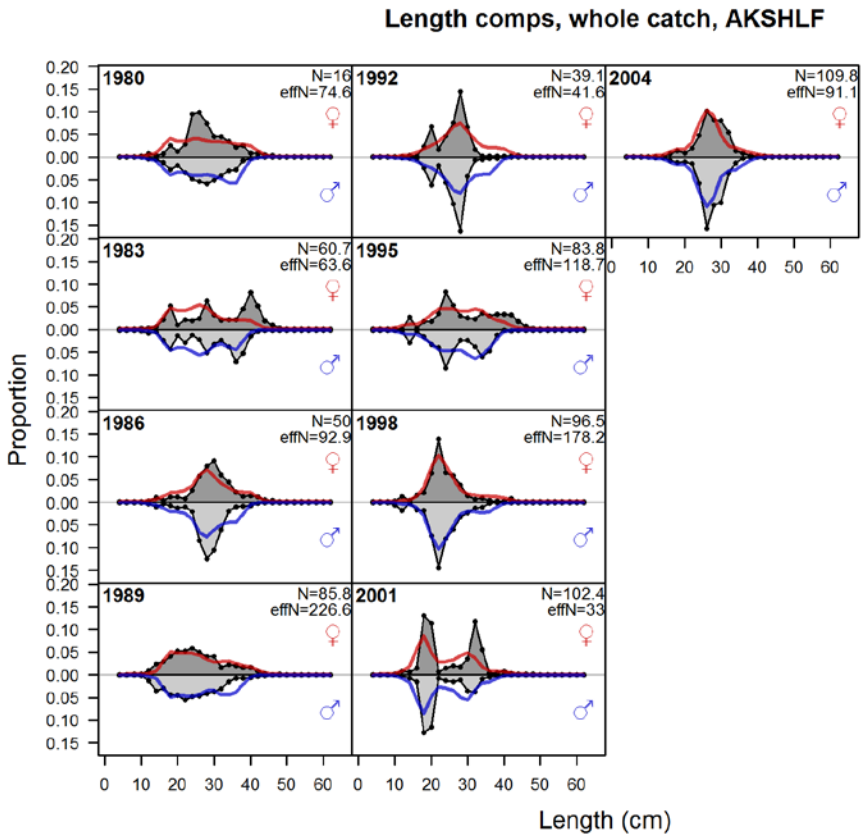

Figure 52: Fit to length-frequency distributions of darkblotched rockfish from the AFSC shelf survey, by year.

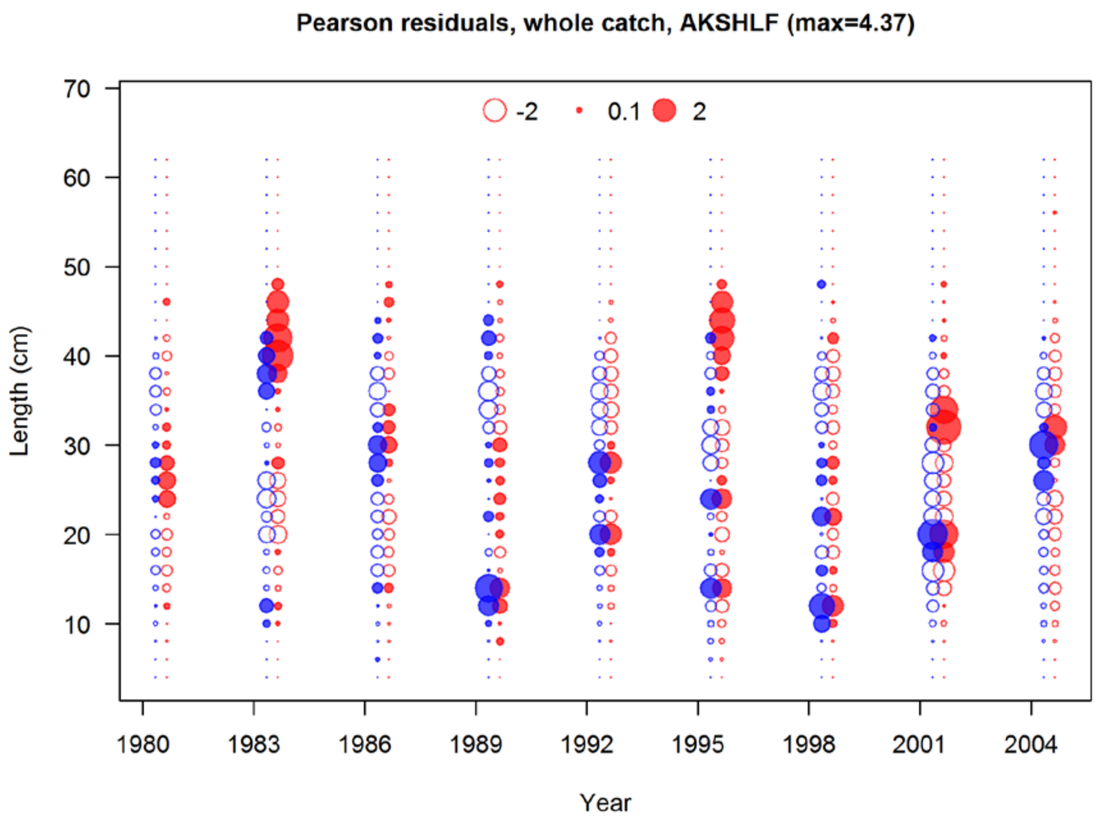

Figure 53: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey, by year.

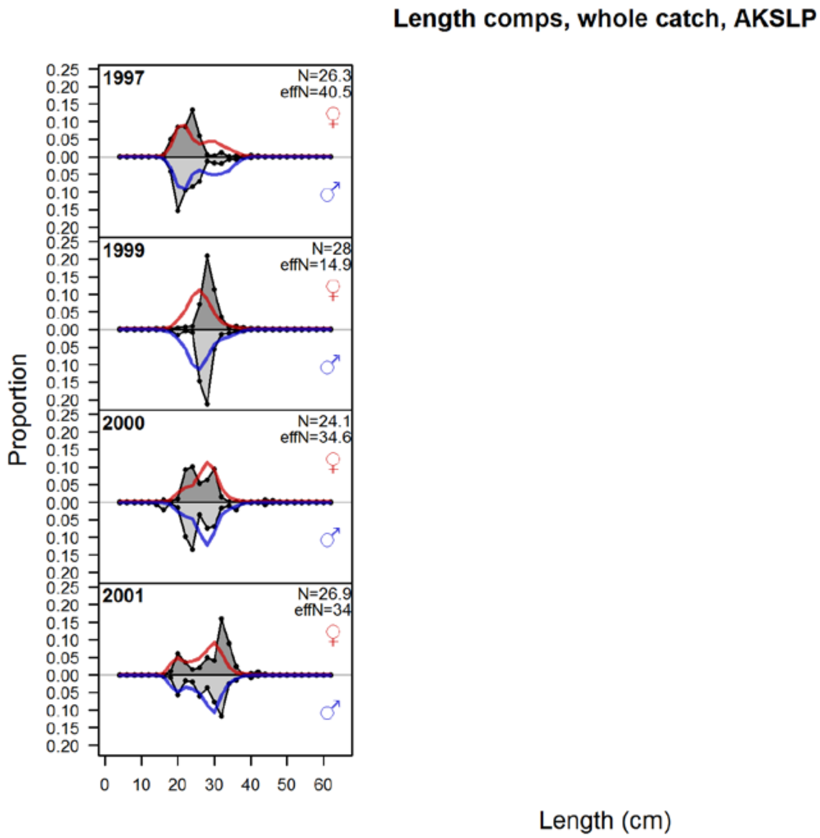

Figure 54: Fit to length-frequency distributions of darkblotched rockfish from the AFSC slope survey, by year.

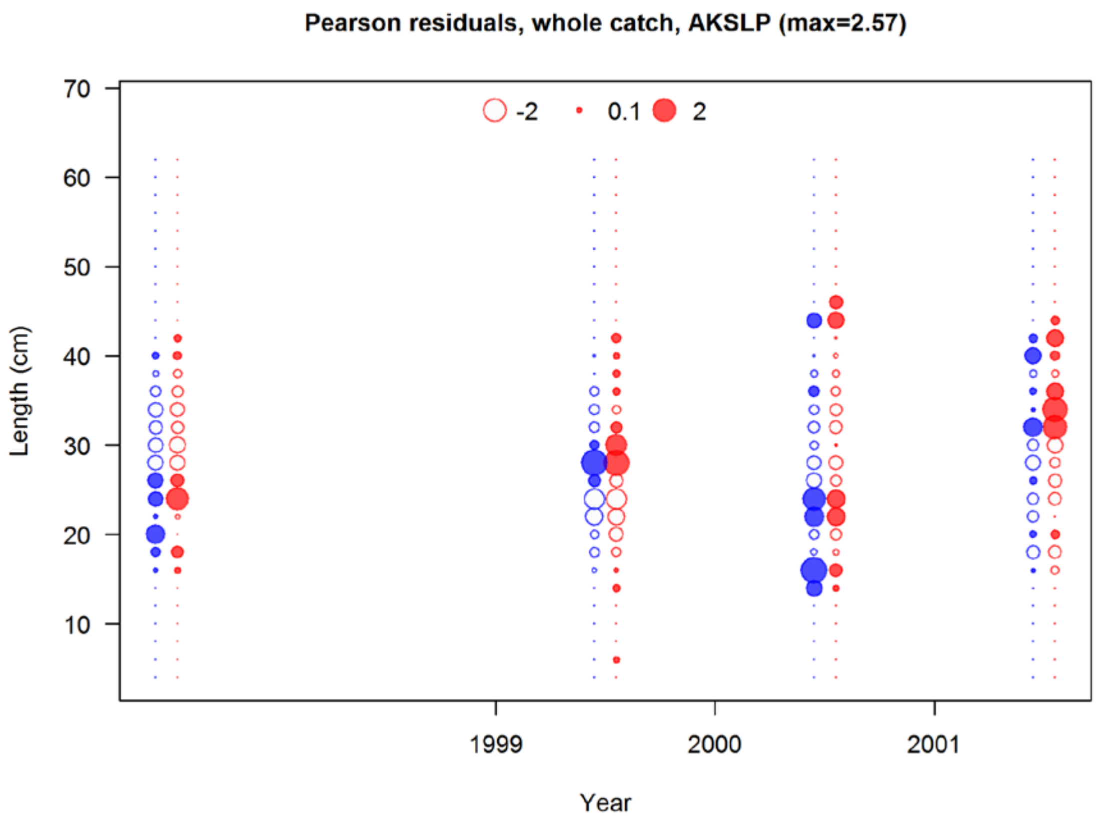

Figure 55: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the AFSC slope survey, by year.

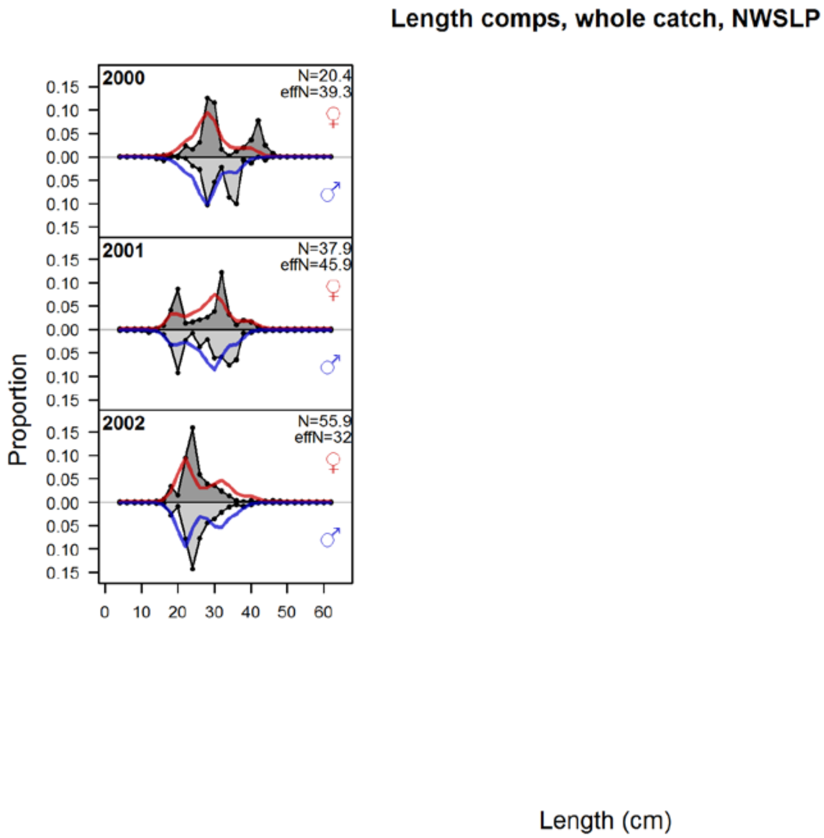

Figure 56: Fit to length-frequency distributions of darkblotched rockfish from the NWFSC slope survey, by year.

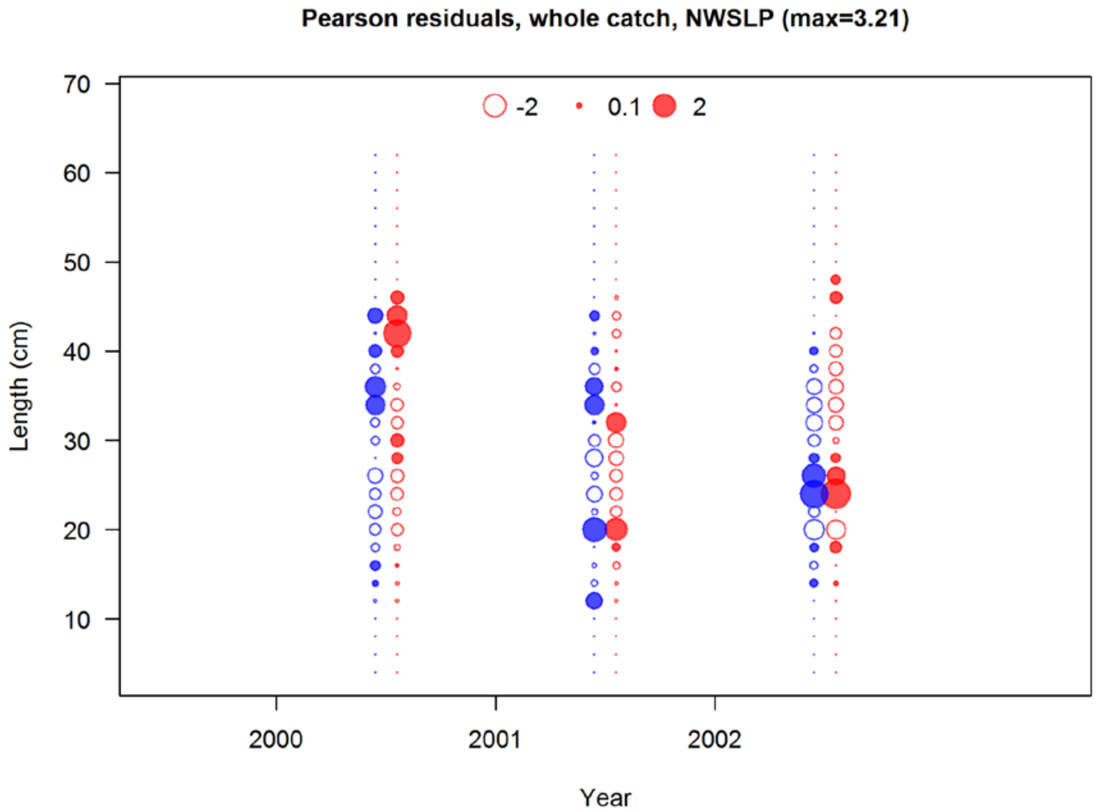

Figure 57: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC slope survey, by year.

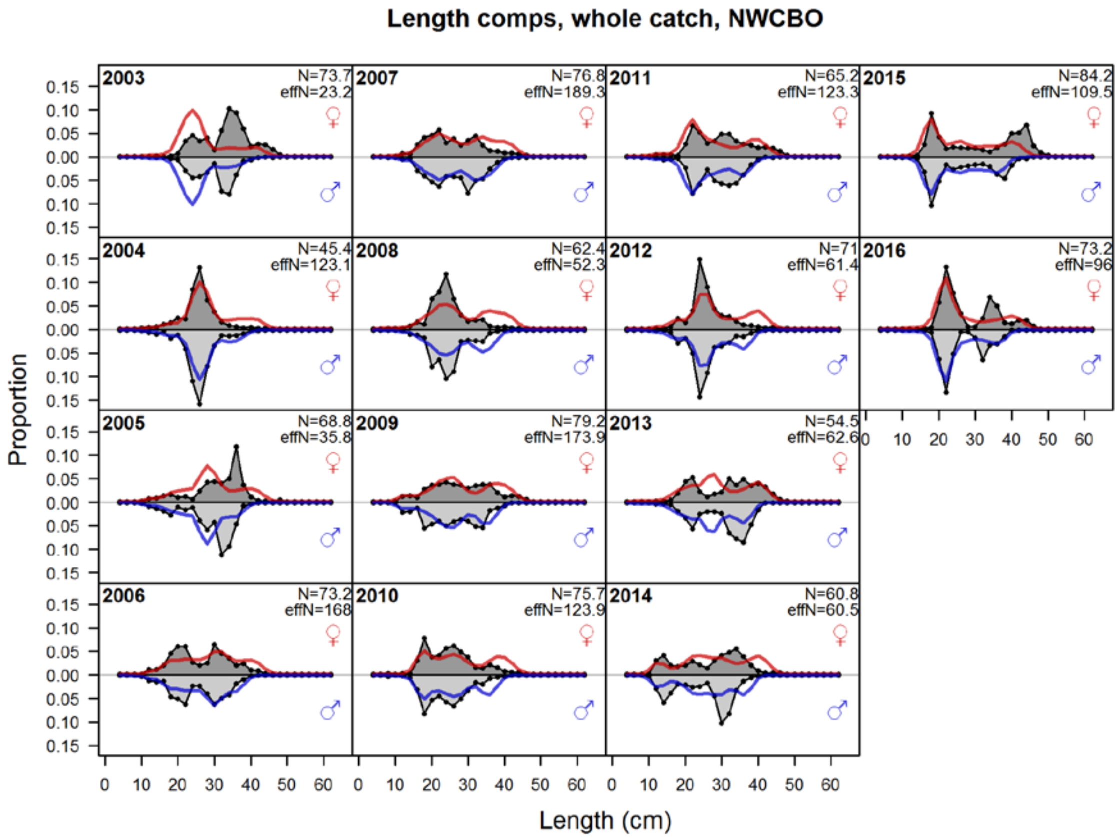

Figure 58: Fit to length-frequency distributions of darkblotched rockfish from the NWFSC shelf-slope survey by year.

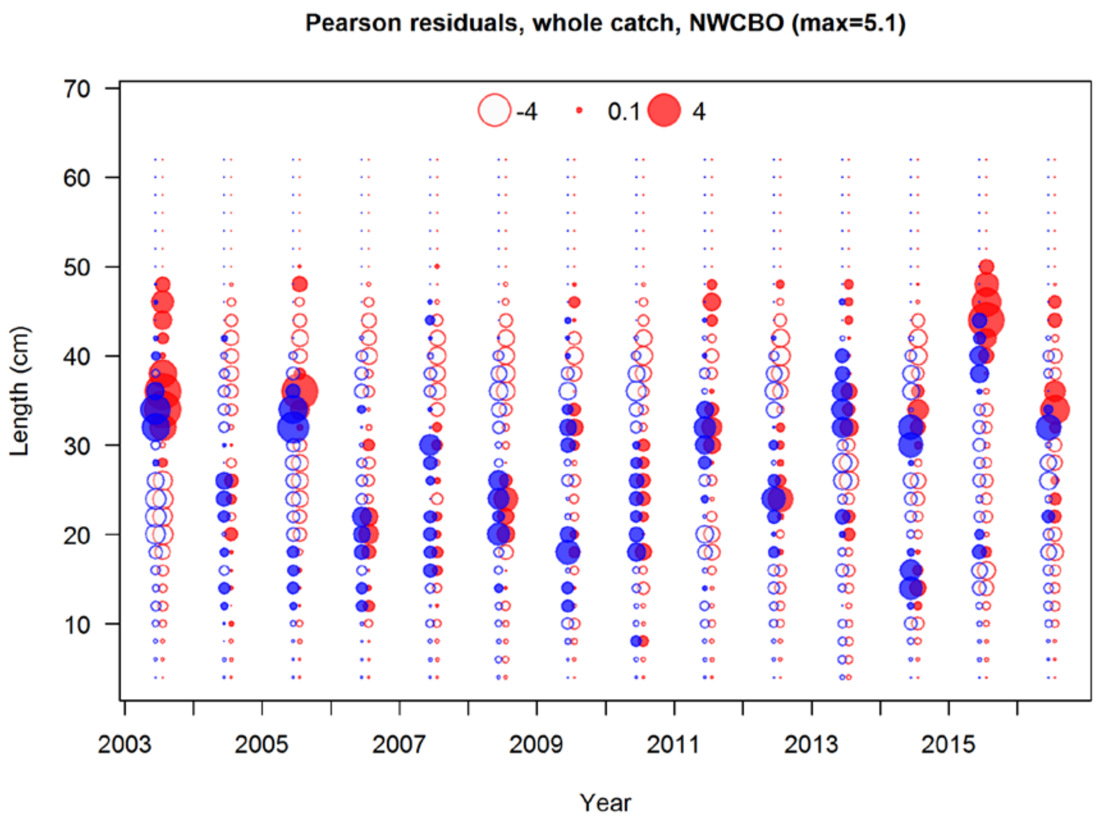

Figure 59: Pearson residuals for the fit to length-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey by year.

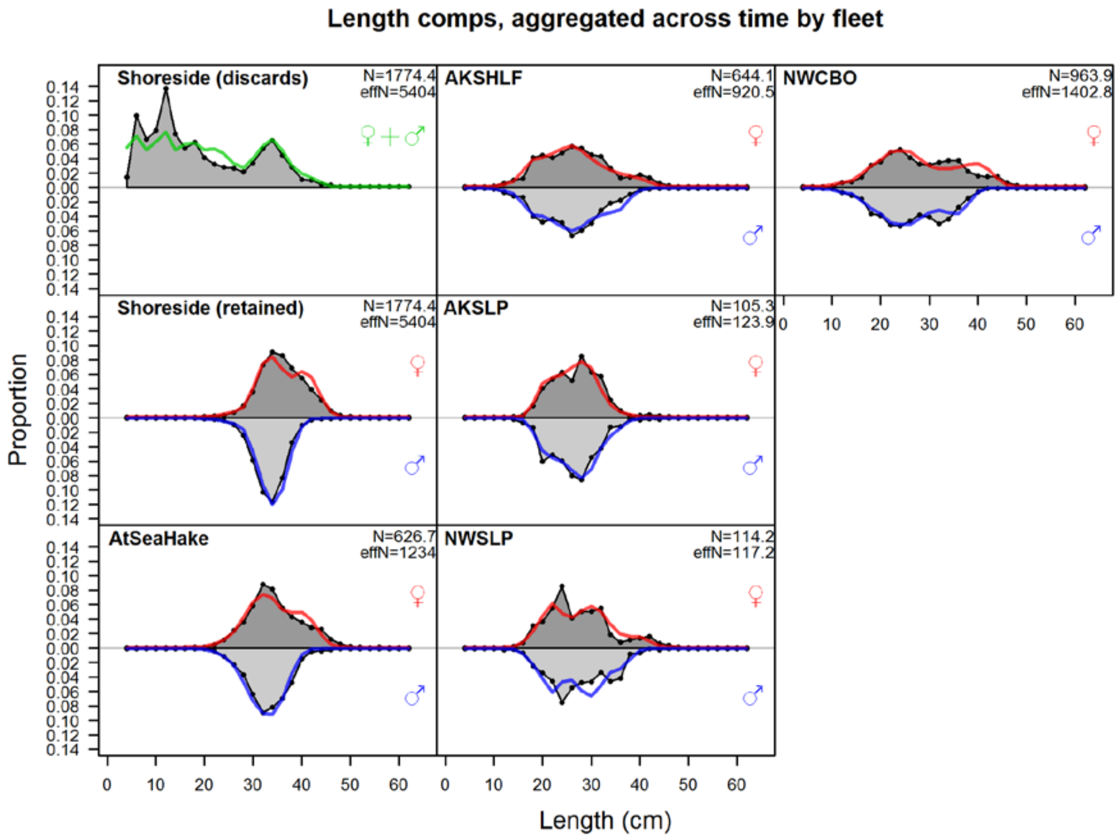

Figure 60: Fit to length-frequency distributions of darkblotched rockfish for all fleets, aggregated across all years.

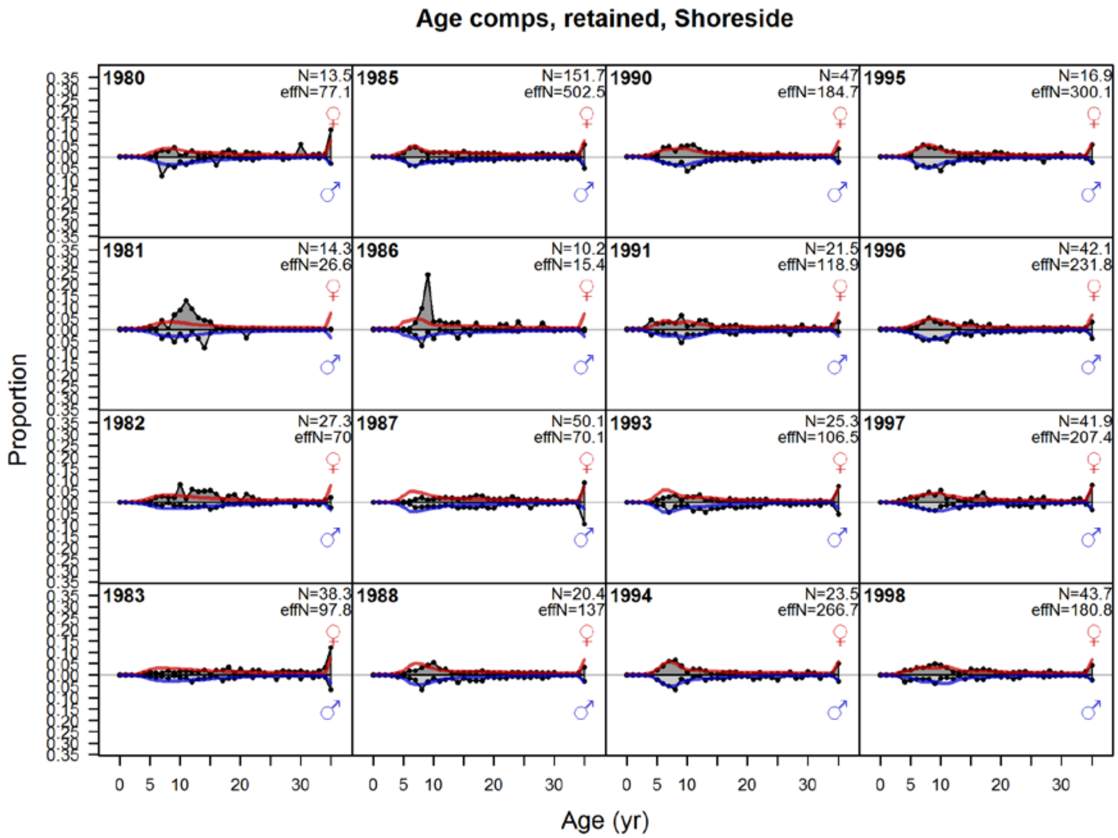

Figure 61: Fit to age-frequency distributions of darkblotched rockfish from the shoreside landings by year.

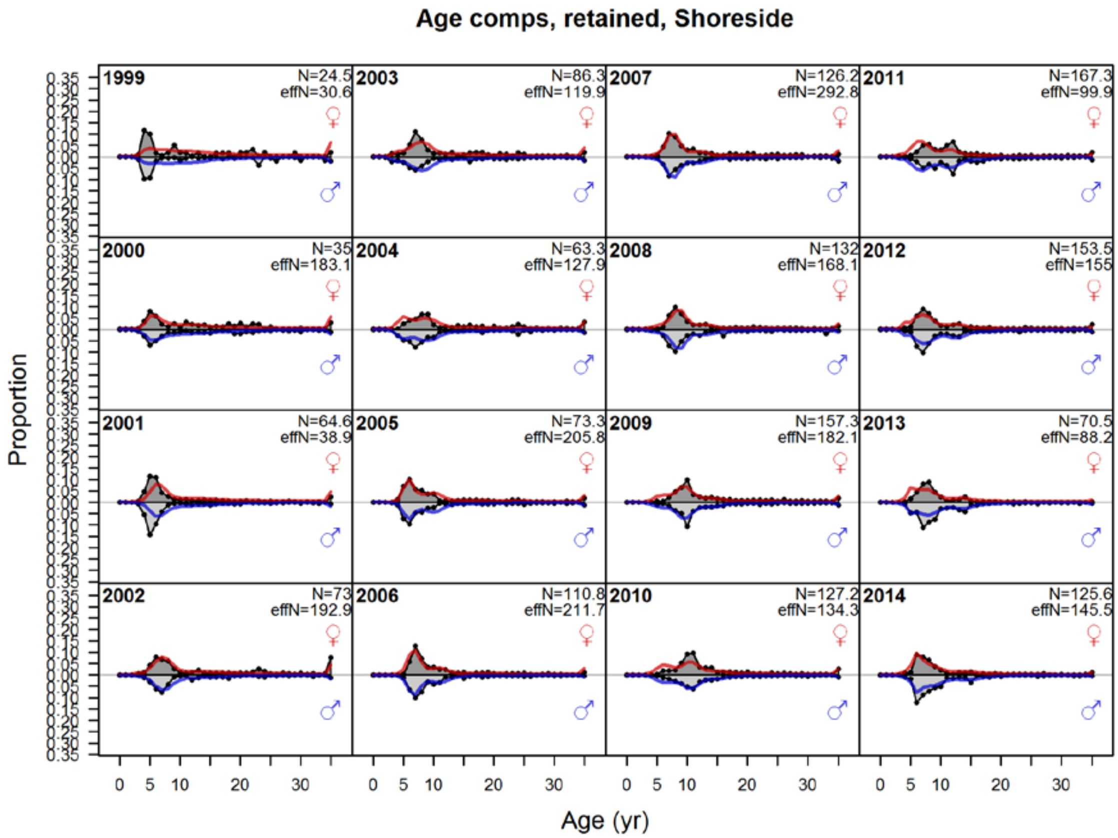

Figure 61 (continued): Fit to age-frequency distributions of darkblotched rockfish from the shoreside landings by year.

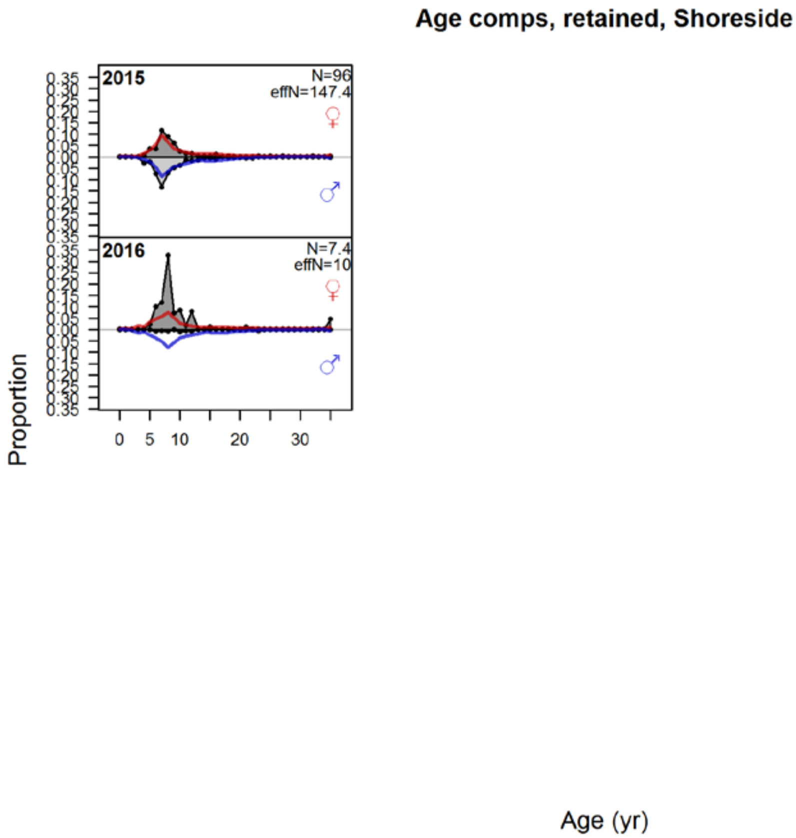

Figure 61 (continued): Fit to age-frequency distributions of darkblotched rockfish from the shoreside landings by year.

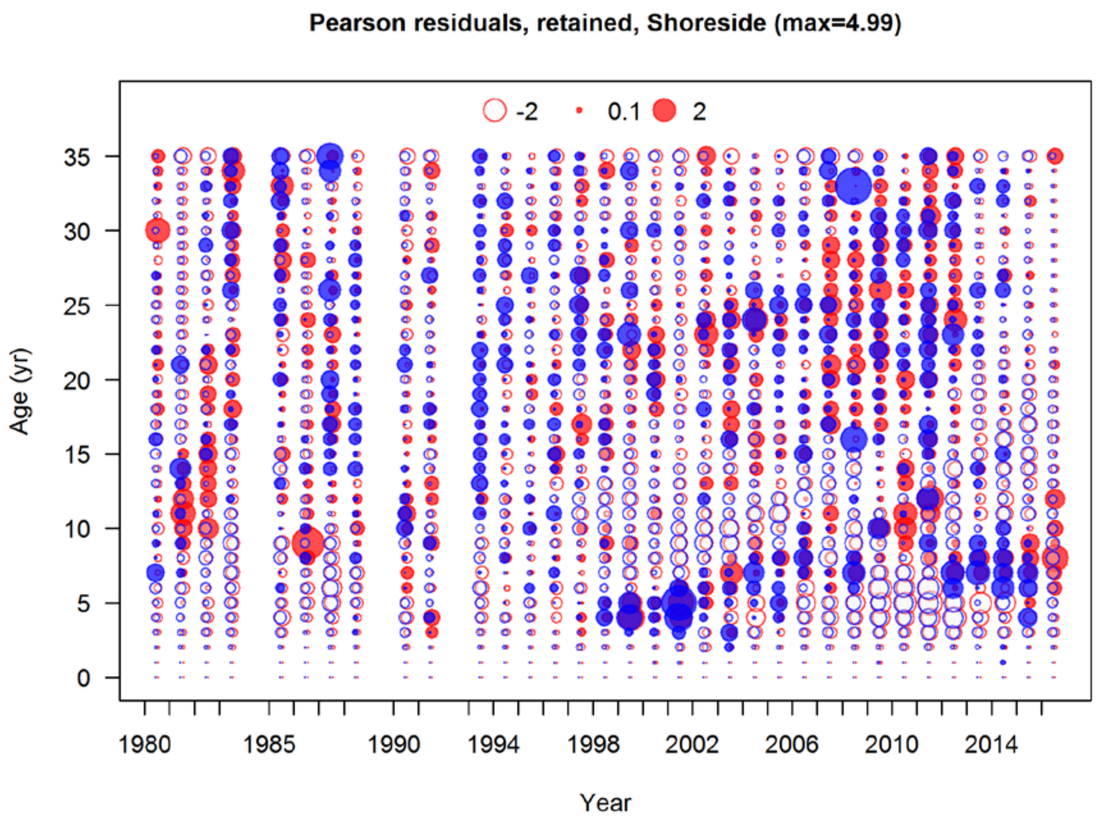

Figure 62: Pearson residuals for the fit to age-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the shoreside landings.

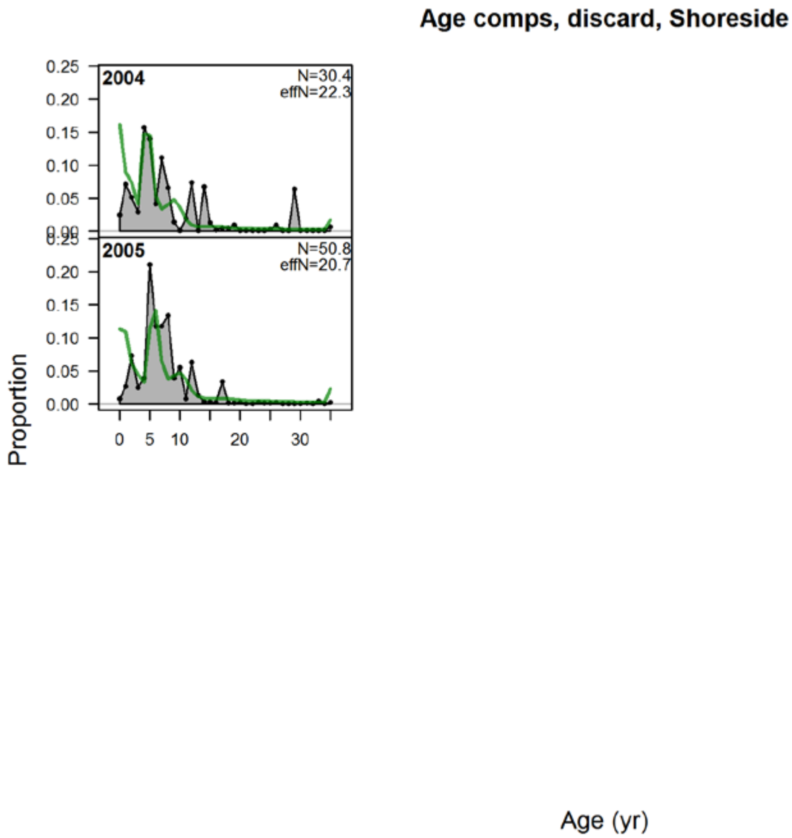

Figure 63: Fit to age-frequency distributions of darkblotched rockfish (sexes combined) from the shoreside fishery discard by year.

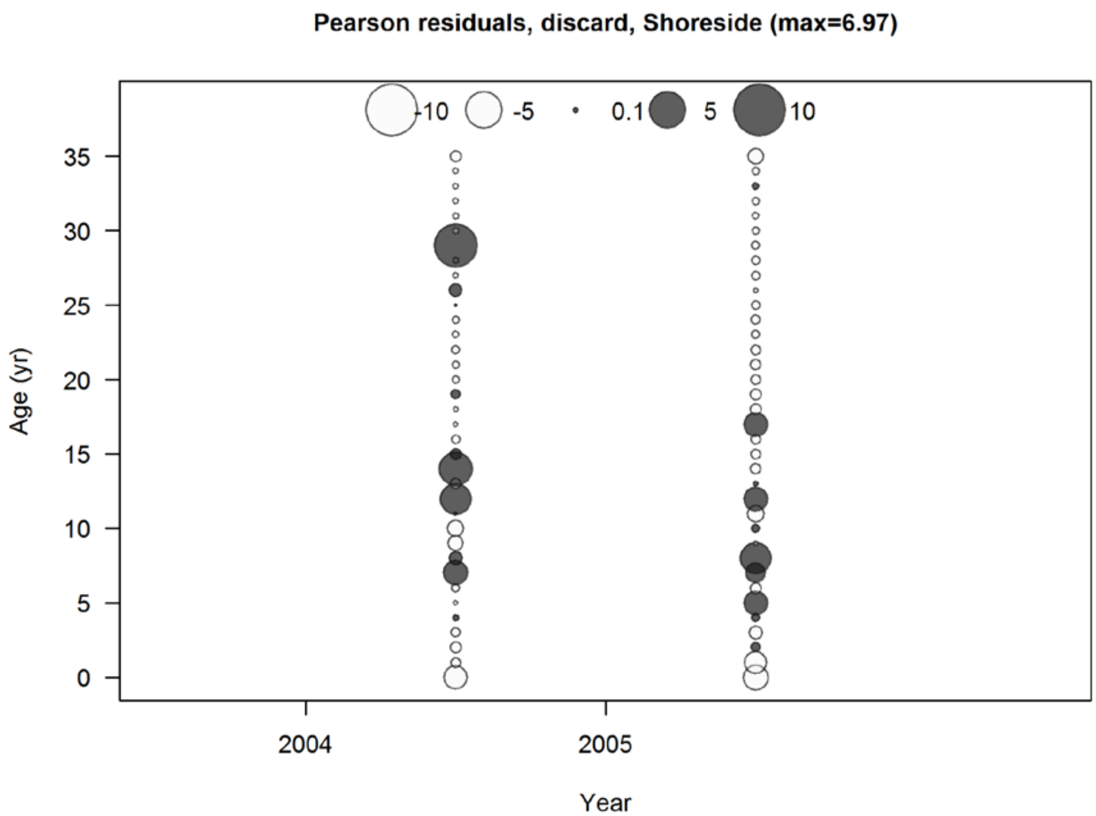

Figure 64: Pearson residuals for the fit to age-frequency distributions of darkblotched rockfish (sexes combined) from the shoreside fishery discard**.**

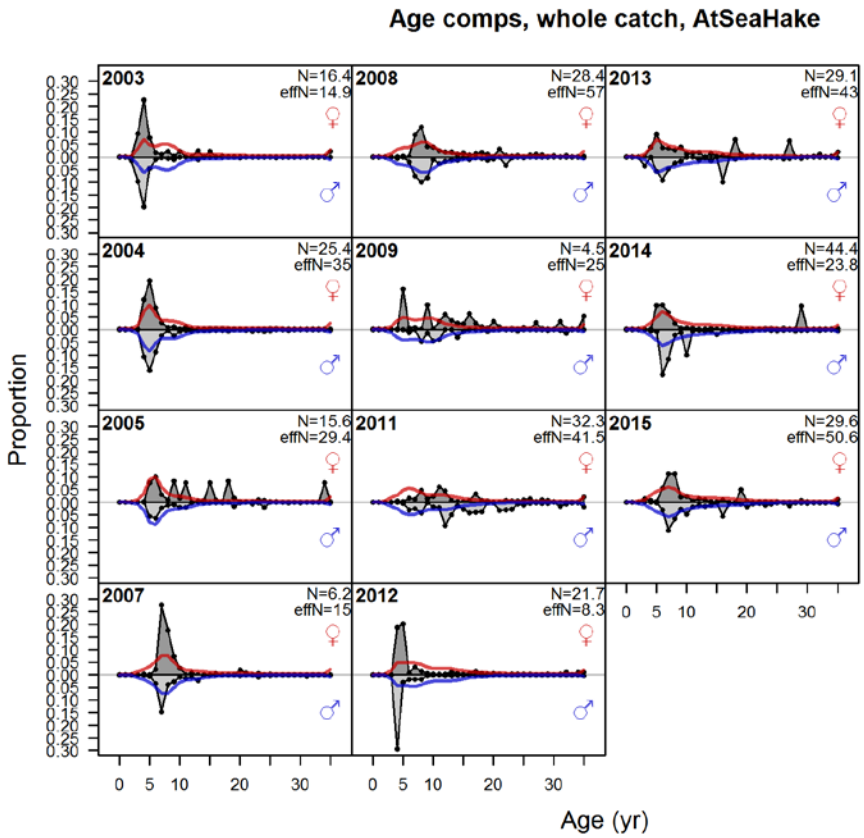

Figure 65: Fit to age-frequency distributions of darkblotched rockfish from the at-sea hake fishery bycatch by year.

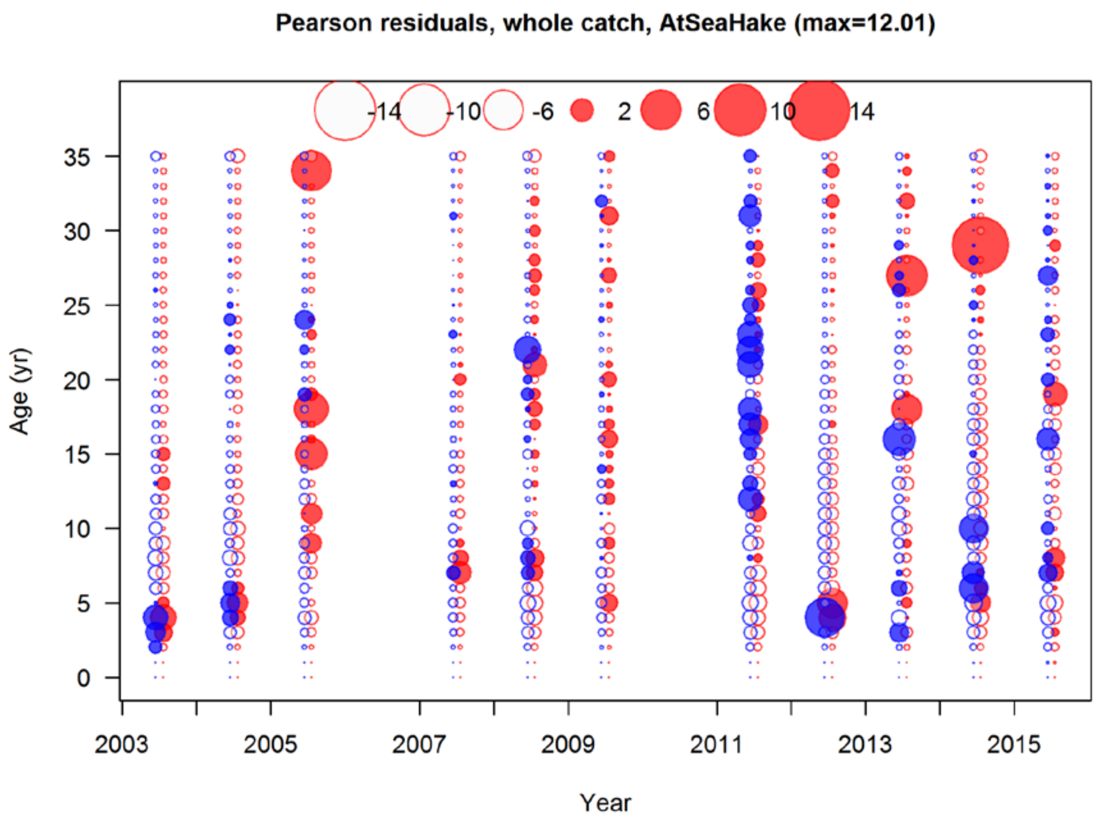

Figure 66: Pearson residuals for the fit to age-frequency distributions of darkblotched rockfish (females are shown in red, males in blue) from the shoreside landings.

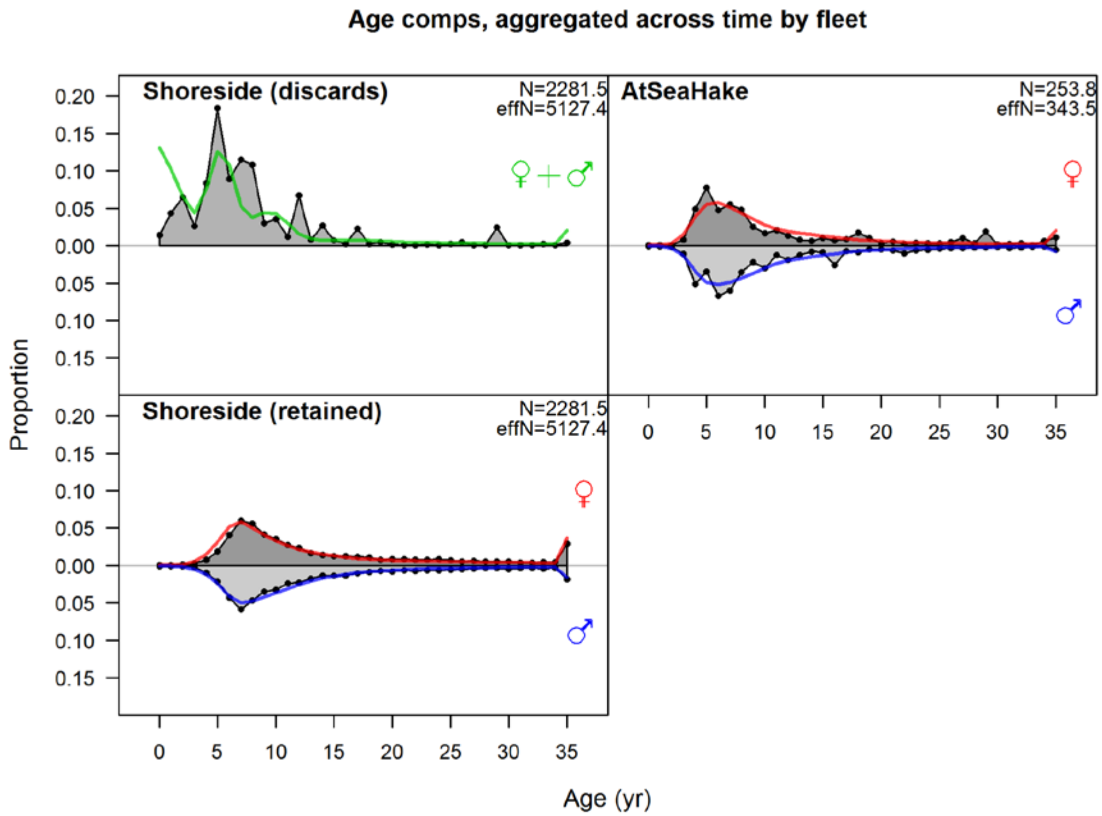

Figure 67: Fit to age-frequency distributions of darkblotched rockfish from shoreside retained, shoreside discards, and at-sea fishery bycatch, aggregated across all years.

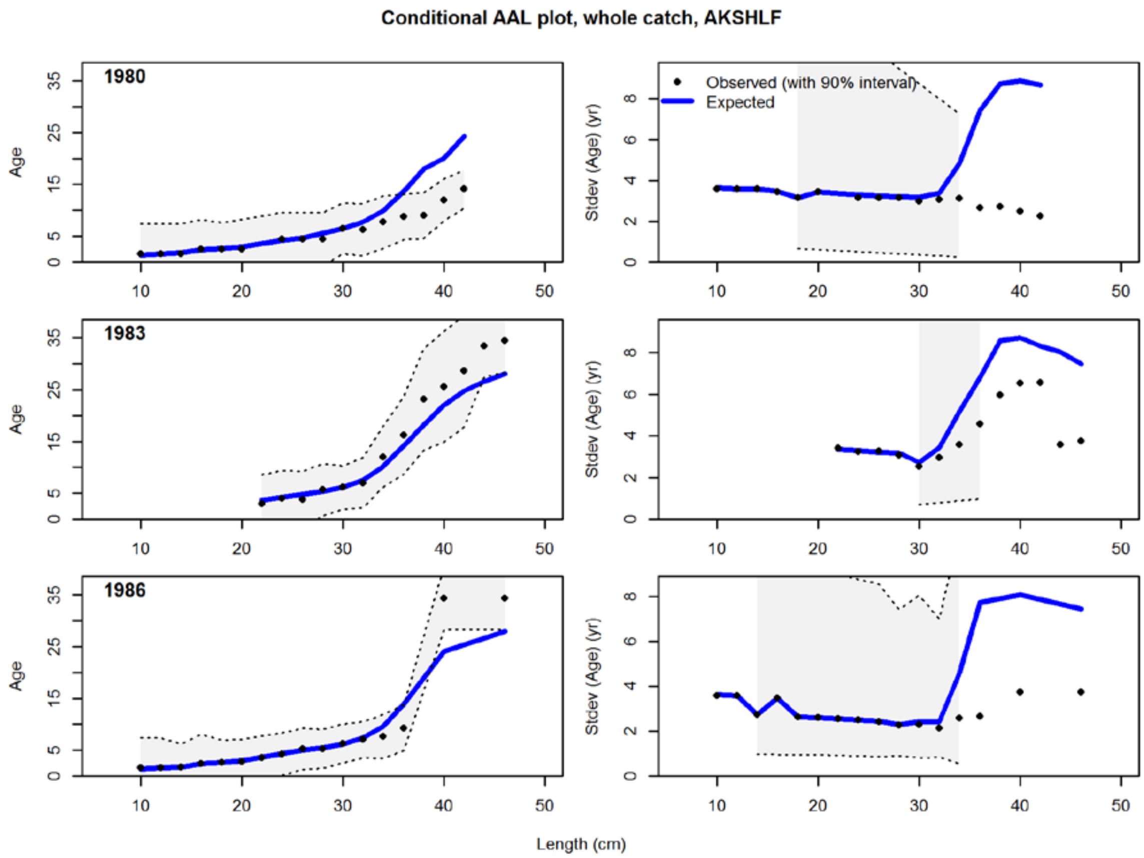

Figure 68: Fit to conditional ages-at-length compositions of female darkblotched rockfish from the AFSC shelf survey.

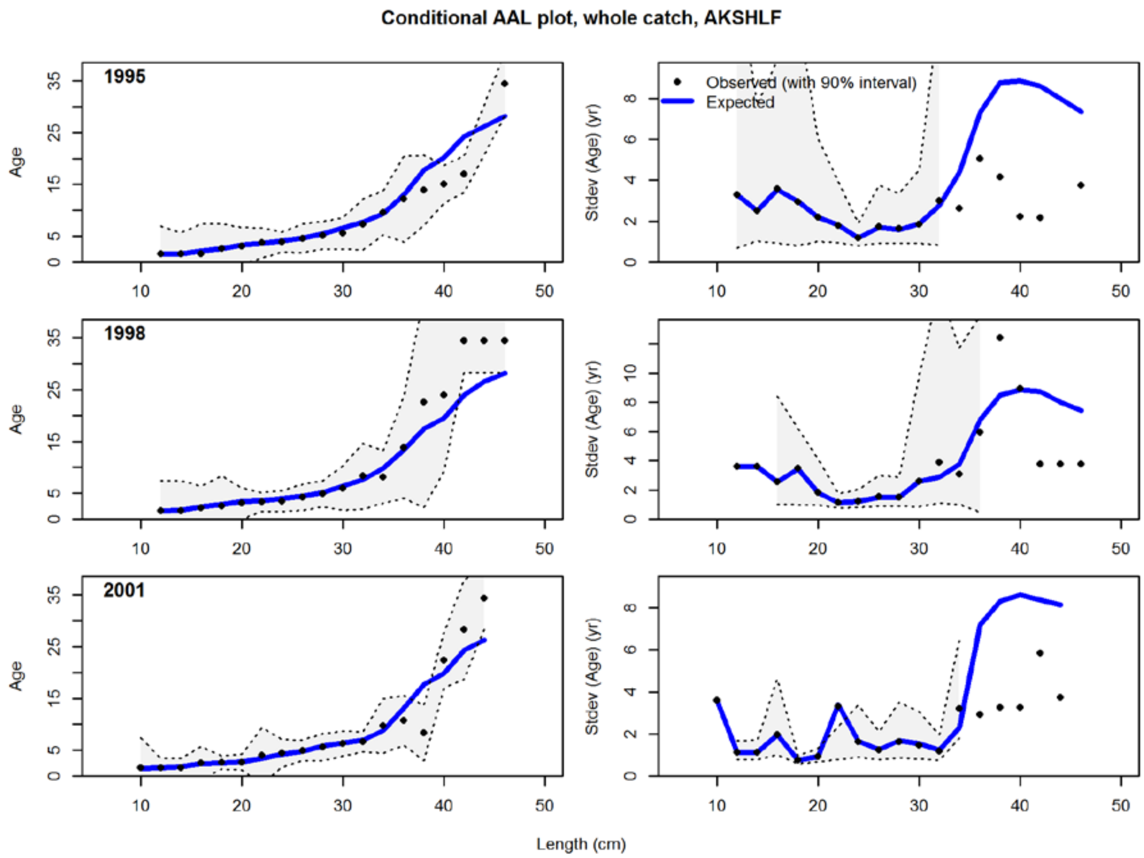

Figure 68 (continued): Fit to conditional ages-at-length compositions of female darkblotched rockfish from the AFSC shelf survey.

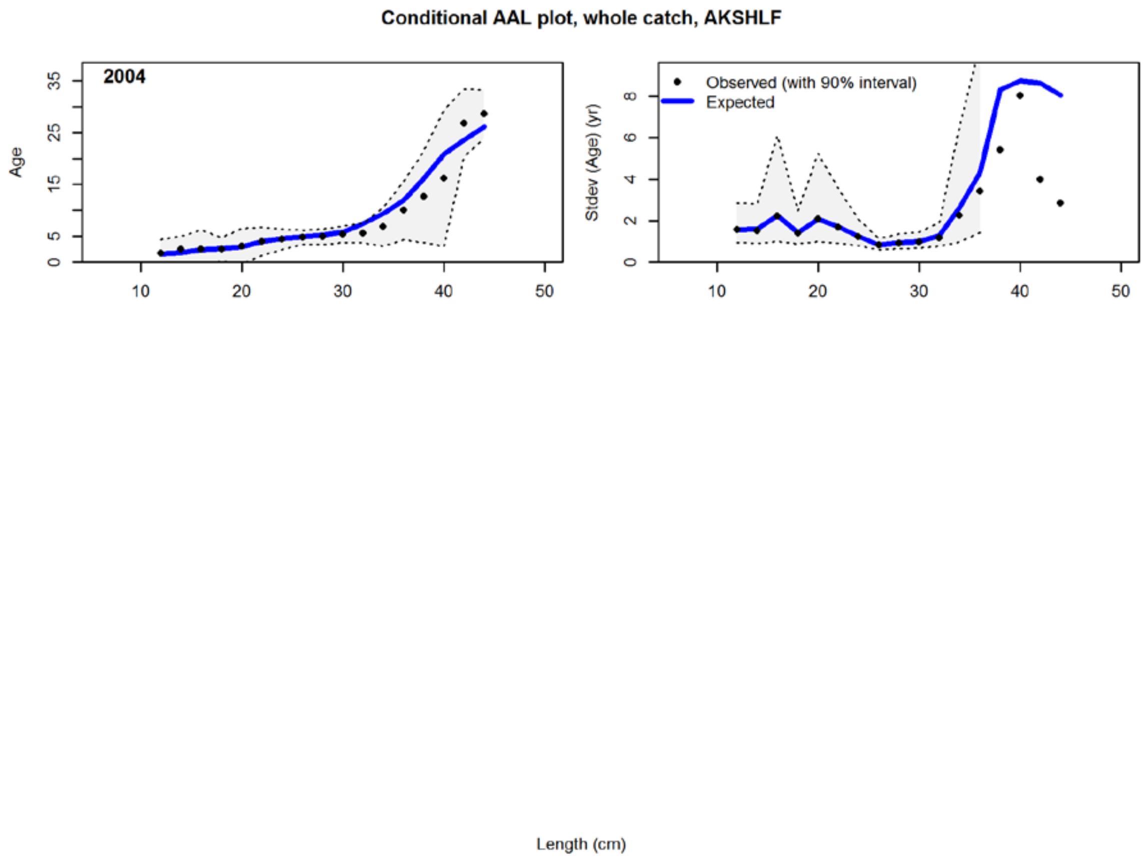

Figure 68 (continued): Fit to conditional ages-at-length compositions of female darkblotched rockfish from the AFSC shelf survey.

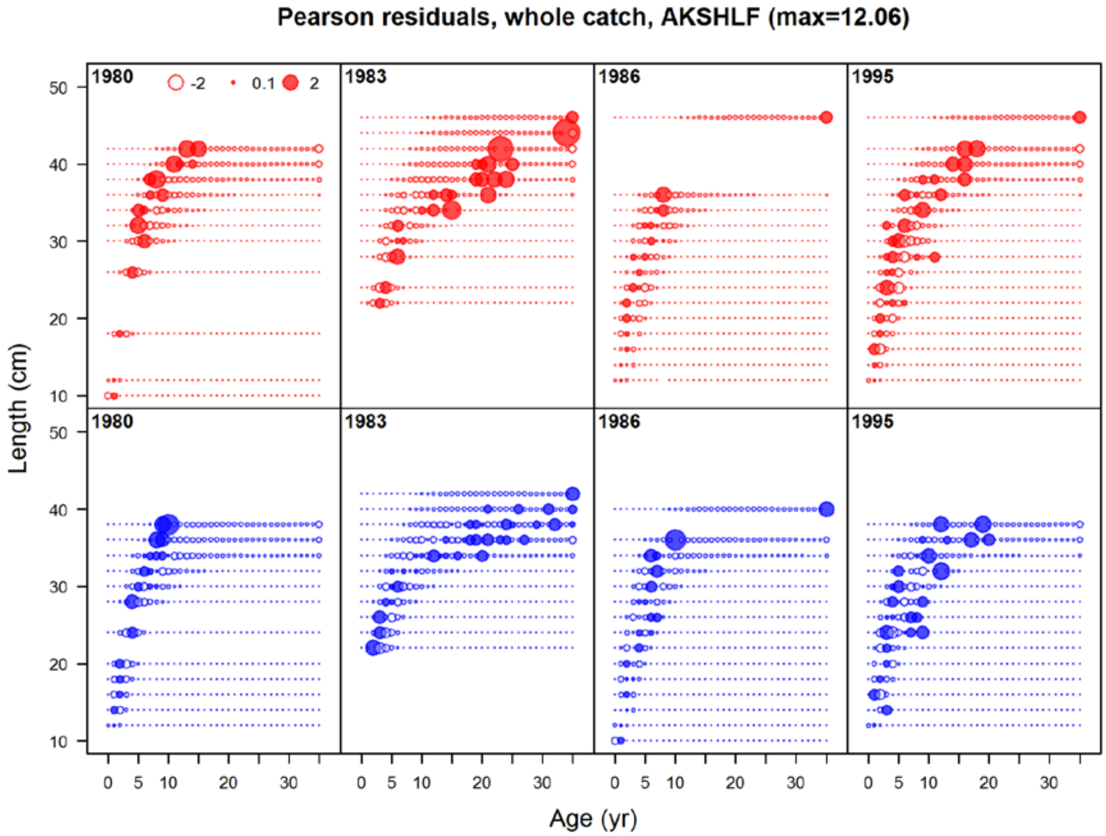

Figure 69: Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey.

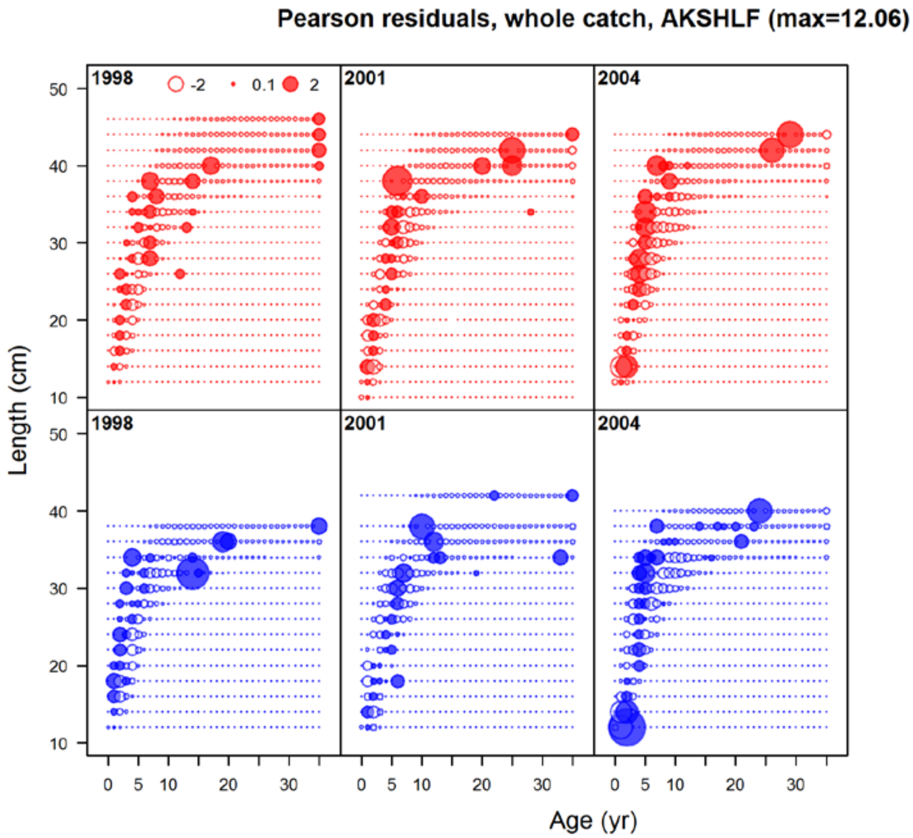

Figure 69 (continued): Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the AFSC shelf survey.

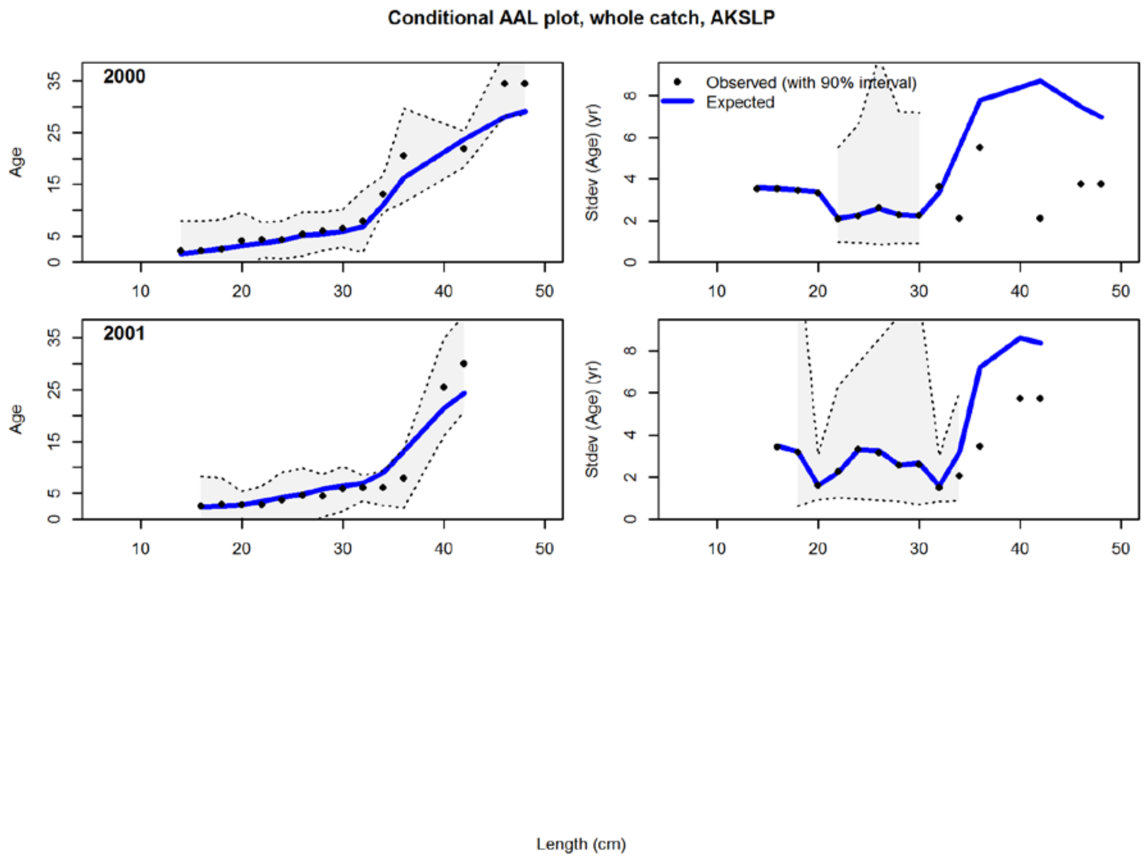

Figure 70: Fit to conditional ages-at-length compositions of darkblotched rockfish from the AFSC slope survey.

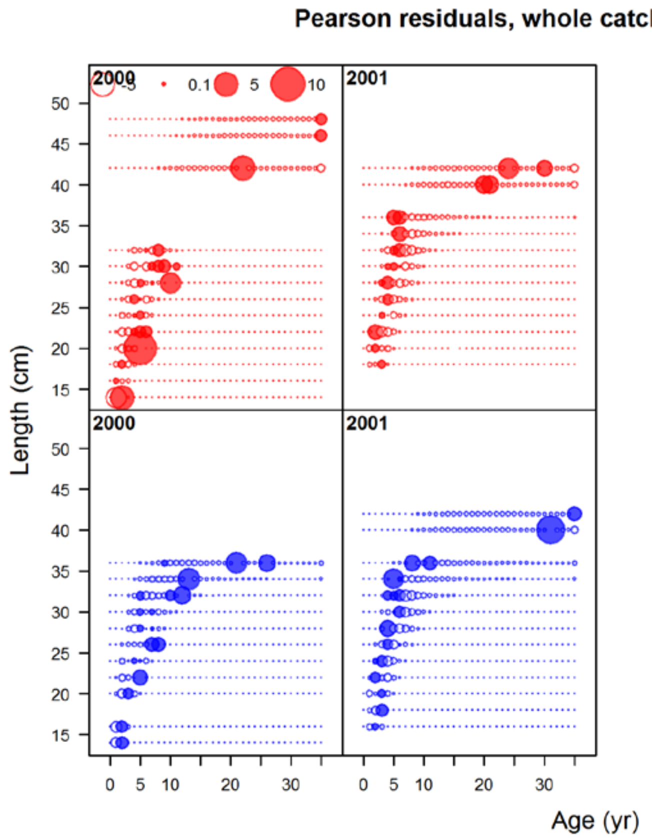

Figure 71: Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown red, males in blue) from the AFSC slope survey.

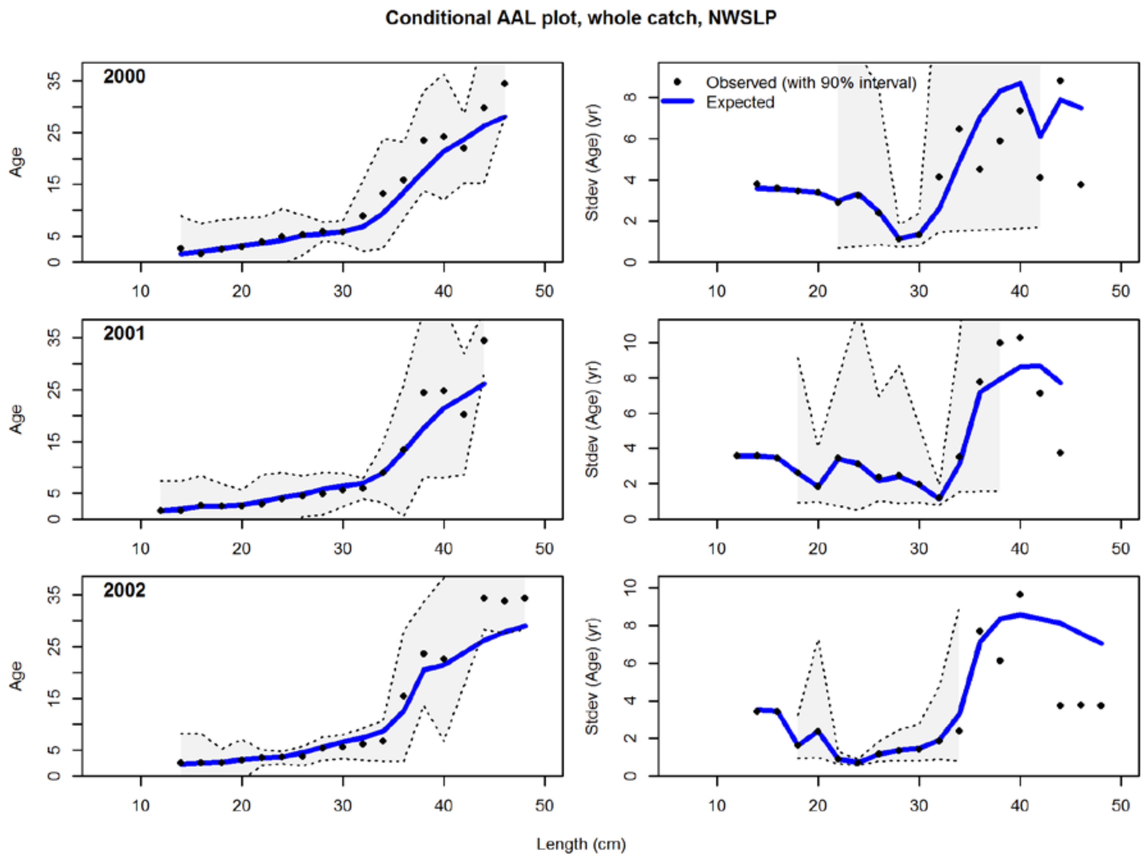

Figure 72: Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC slope survey.

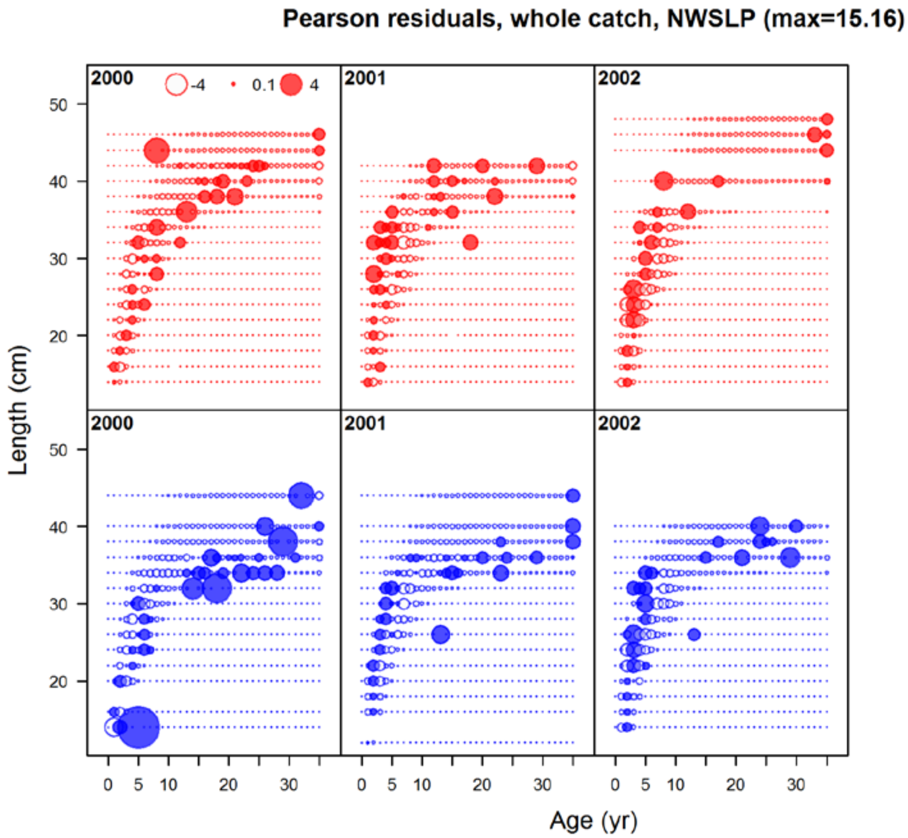

Figure 73: Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC slope survey.

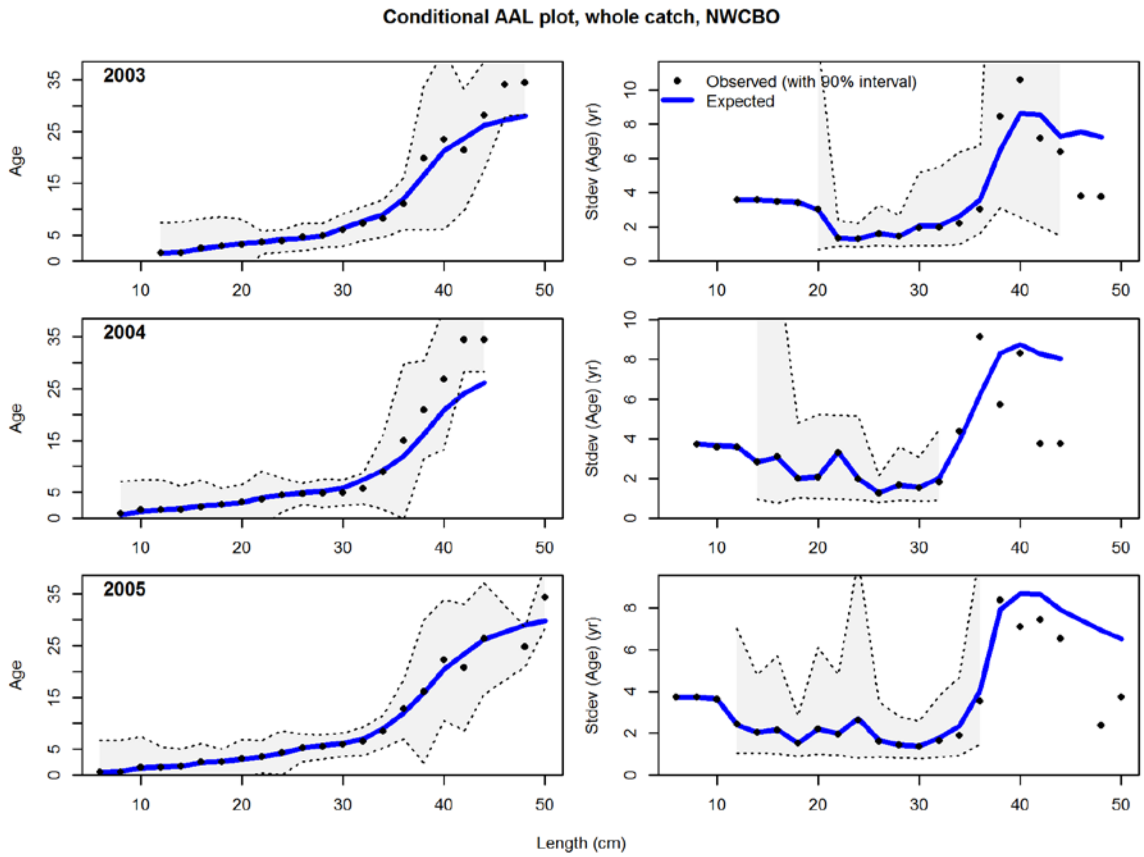

Figure 74: Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

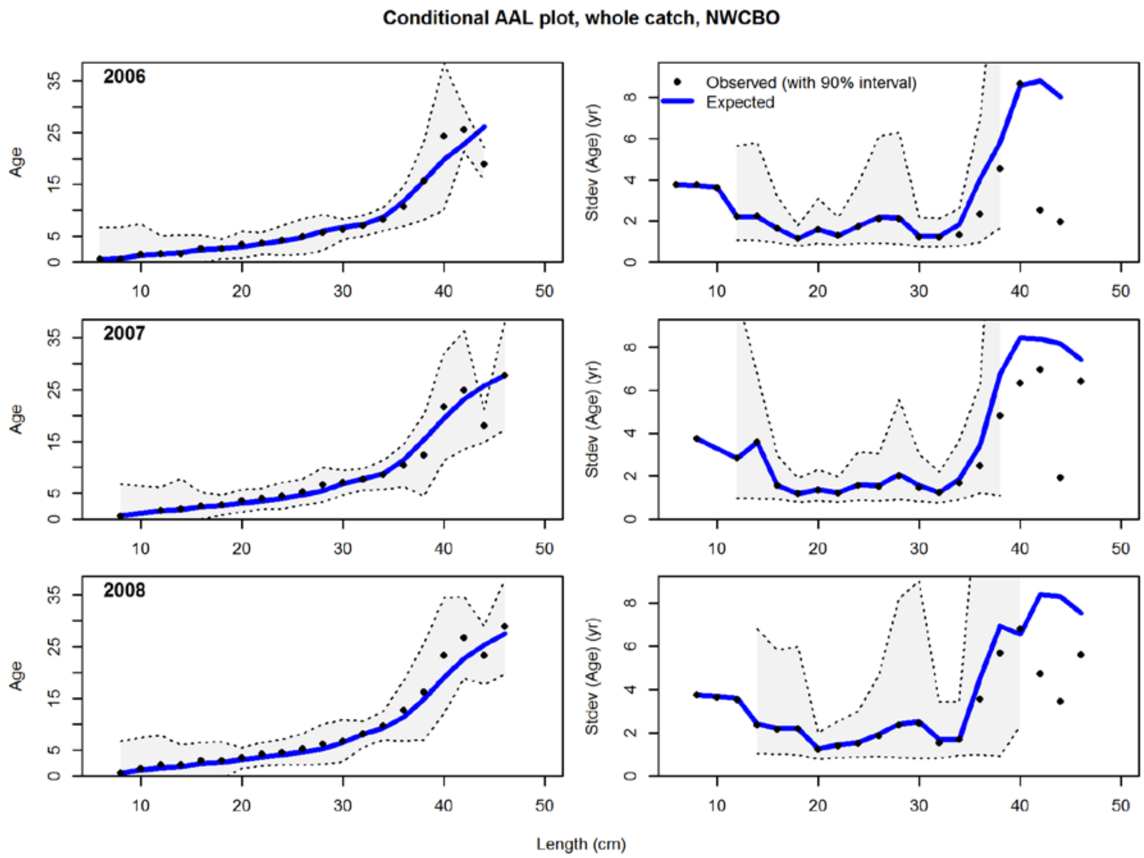

Figure 74 (continued): Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

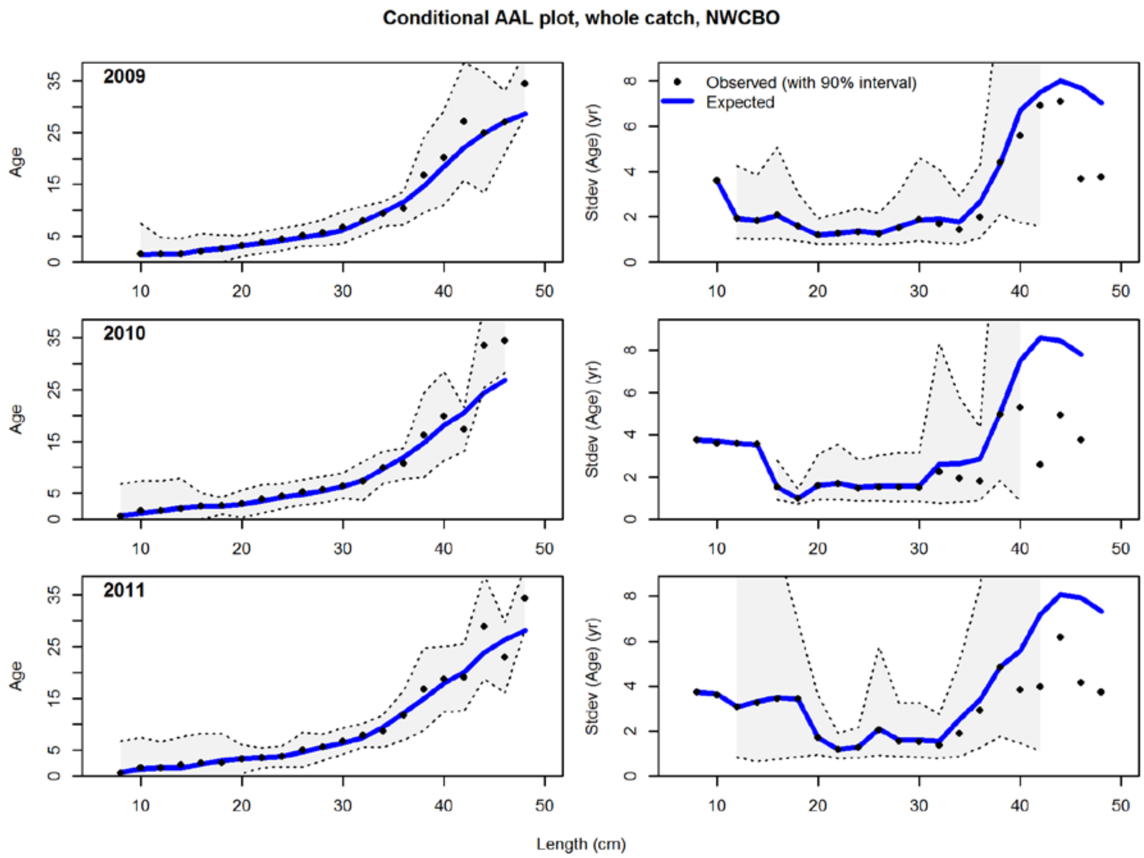

Figure 74 (continued): Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

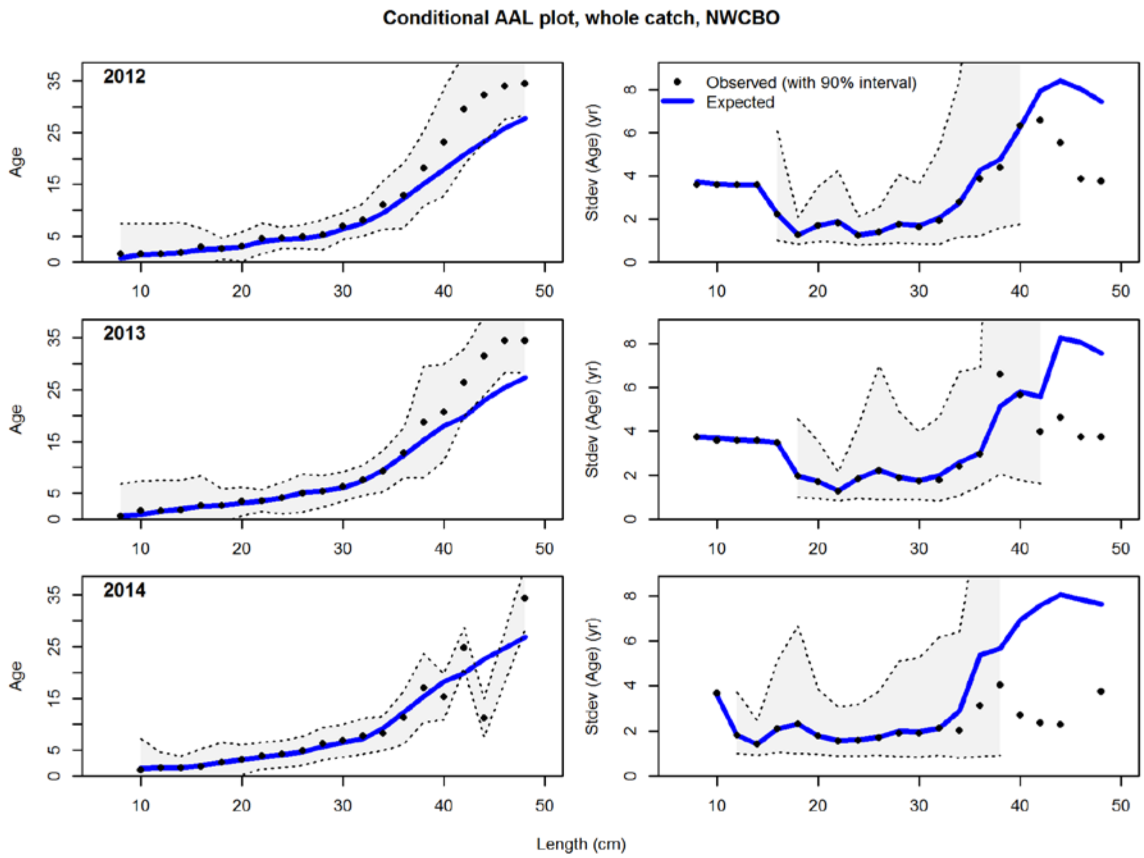

Figure 74 (continued): Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

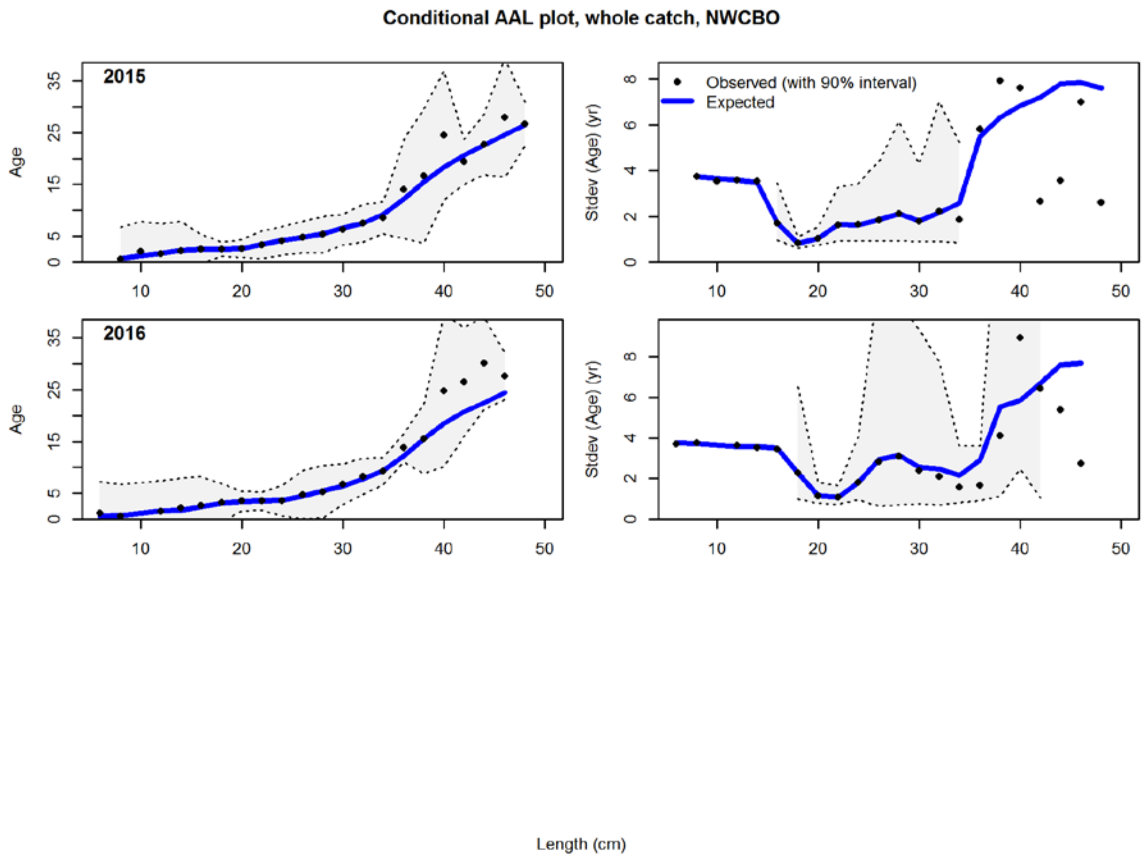

Figure 74 (continued): Fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey.

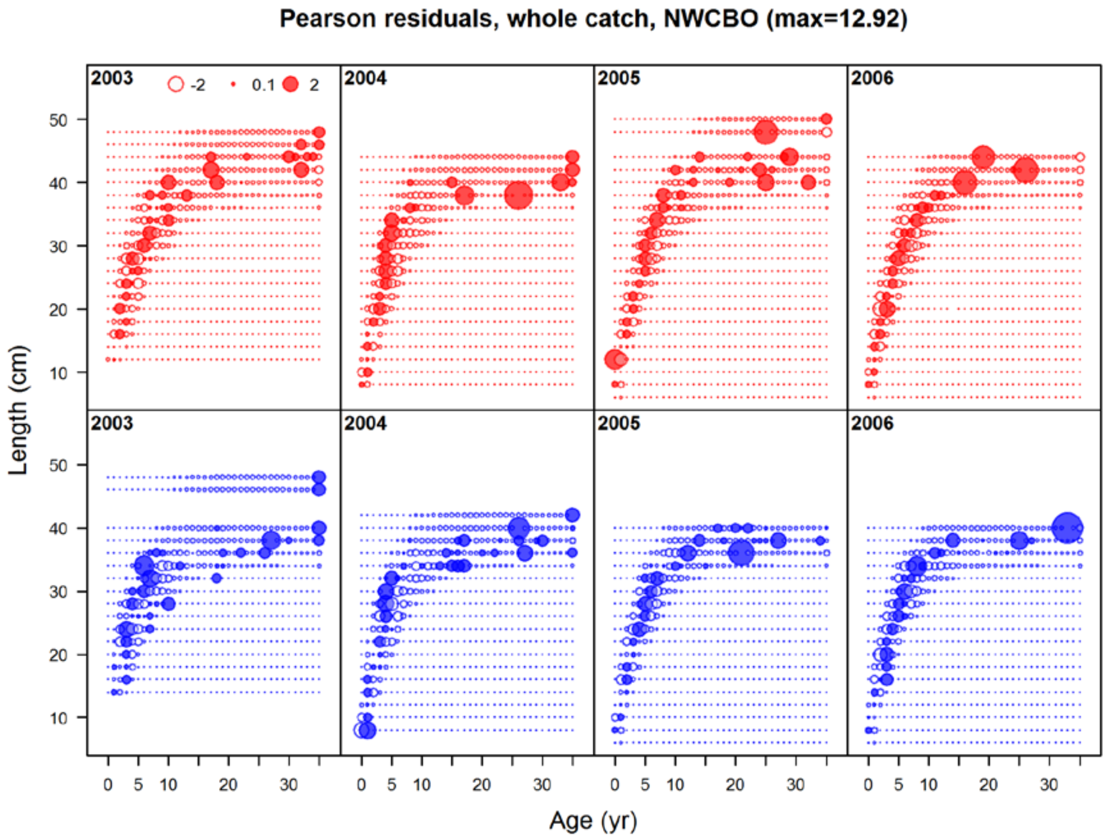

Figure 75: Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

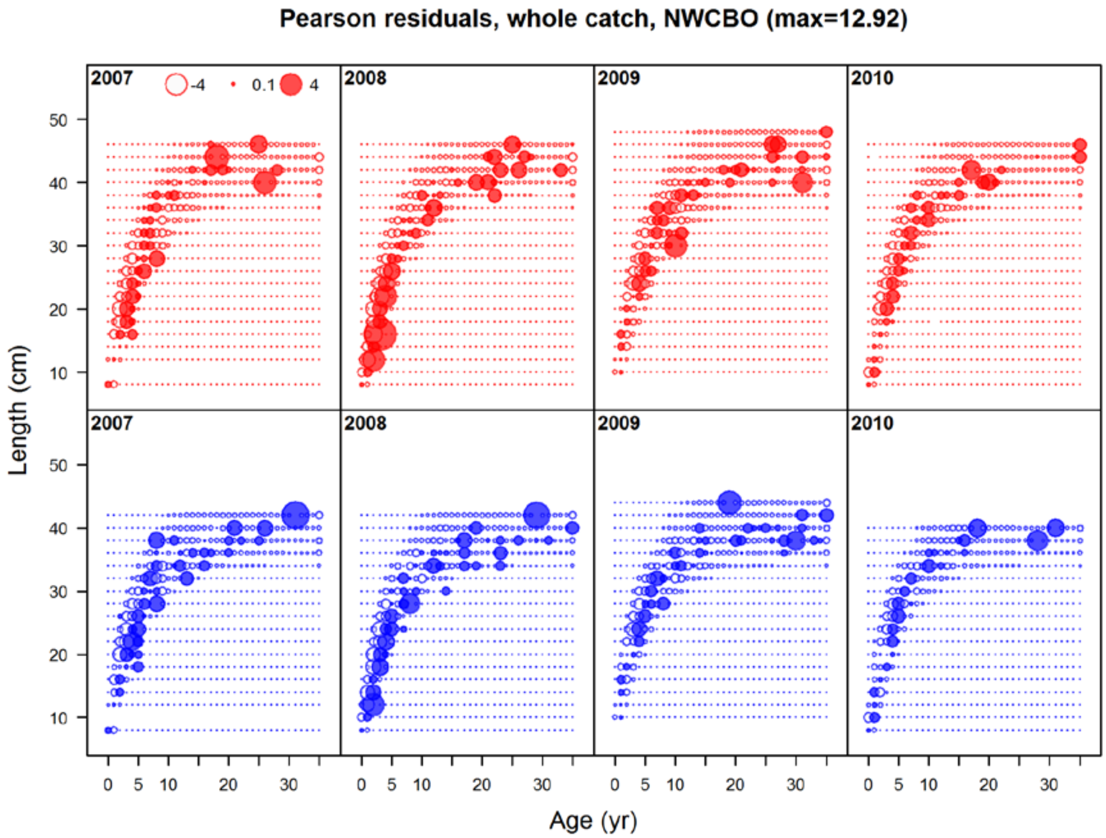

Figure 75 (continued): Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

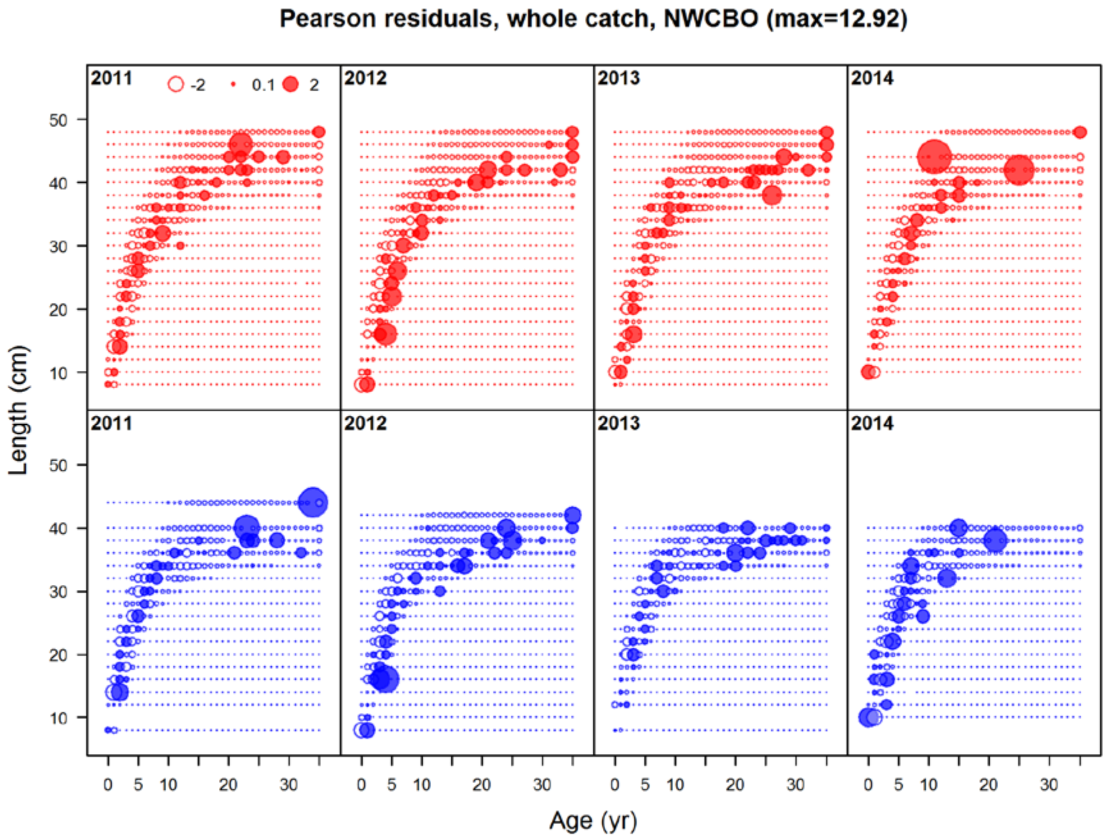

Figure 75 (continued): Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

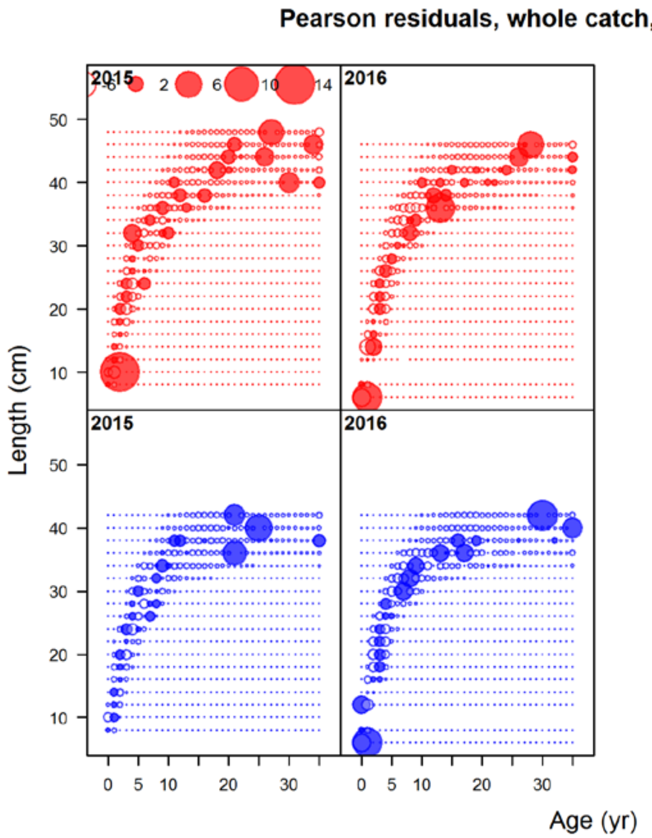

Figure 75 (continued): Pearson residuals for the fit to conditional ages-at-length compositions of darkblotched rockfish (females are shown in red, males in blue) from the NWFSC shelf-slope survey.

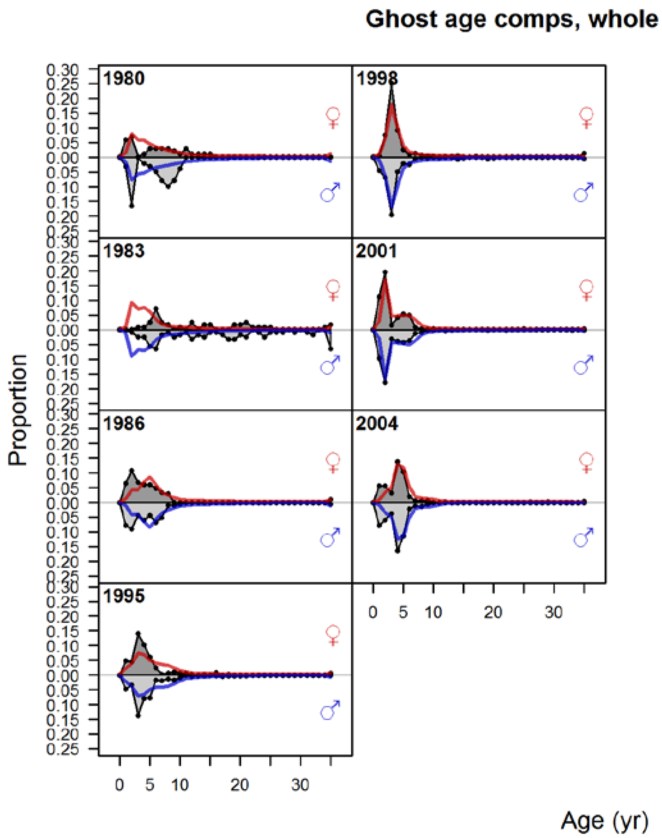

Figure 76: Implied fit to conditional ages-at-length compositions of darkblotched rockfish from the AFSC shelf survey marginal age frequencies. Fits are provided for evaluation only, but are not included in the model likelihood.

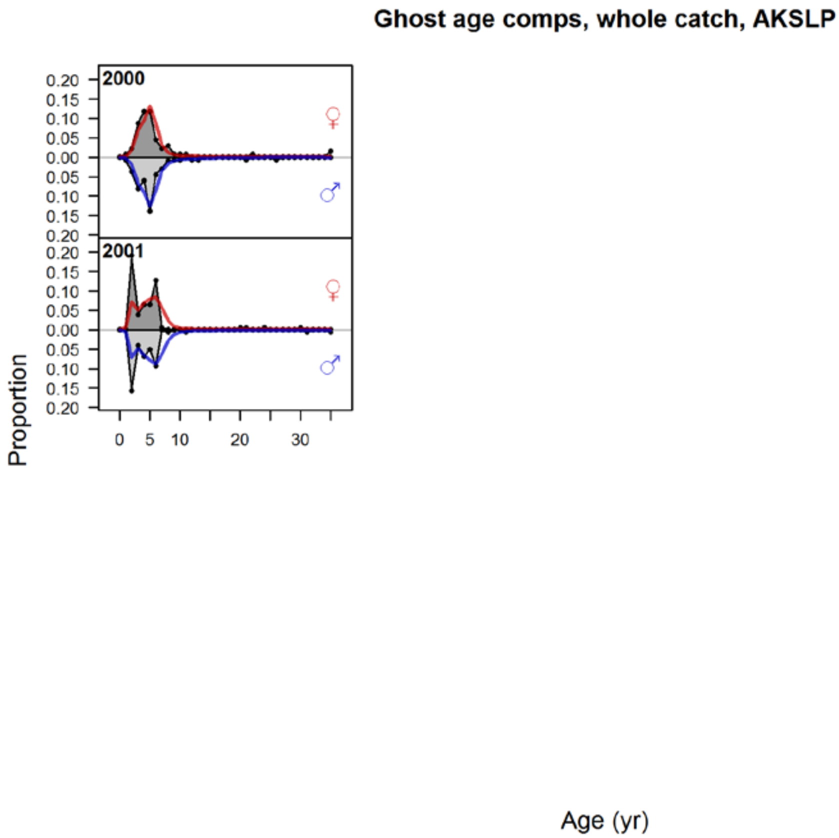

Figure 77: Implied fit to conditional ages-at-length compositions of darkblotched rockfish from the AFSC slope survey marginal age frequencies. Fits are provided for evaluation only, but not included in the model likelihood.

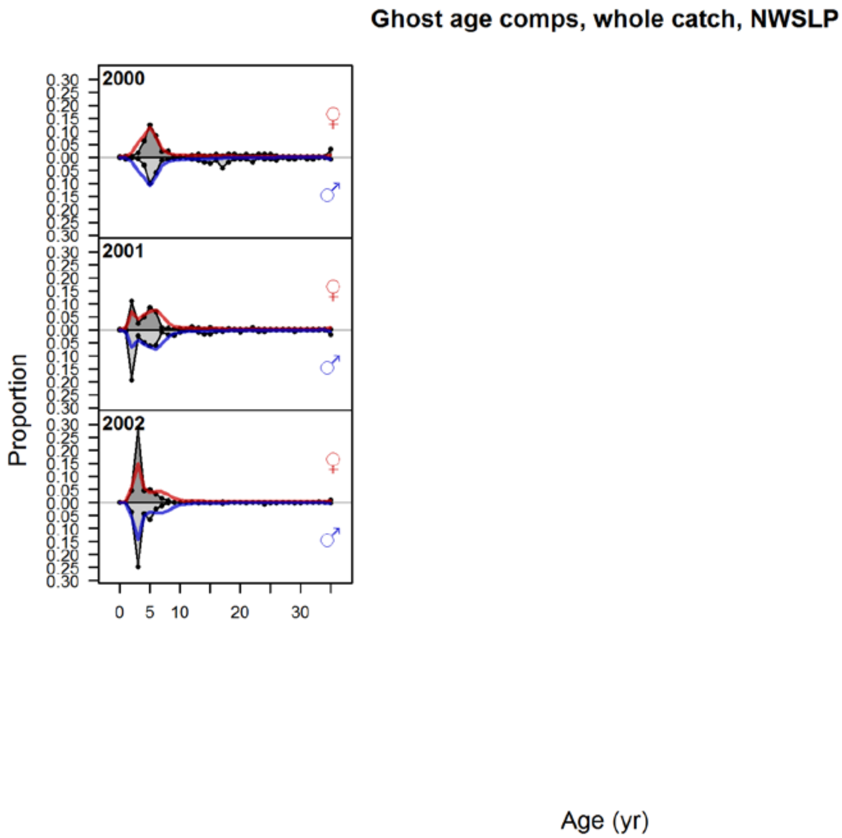

Figure 78: Implied fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC slope survey marginal age frequencies. Fits are provided for evaluation only, but not included in the model likelihood.

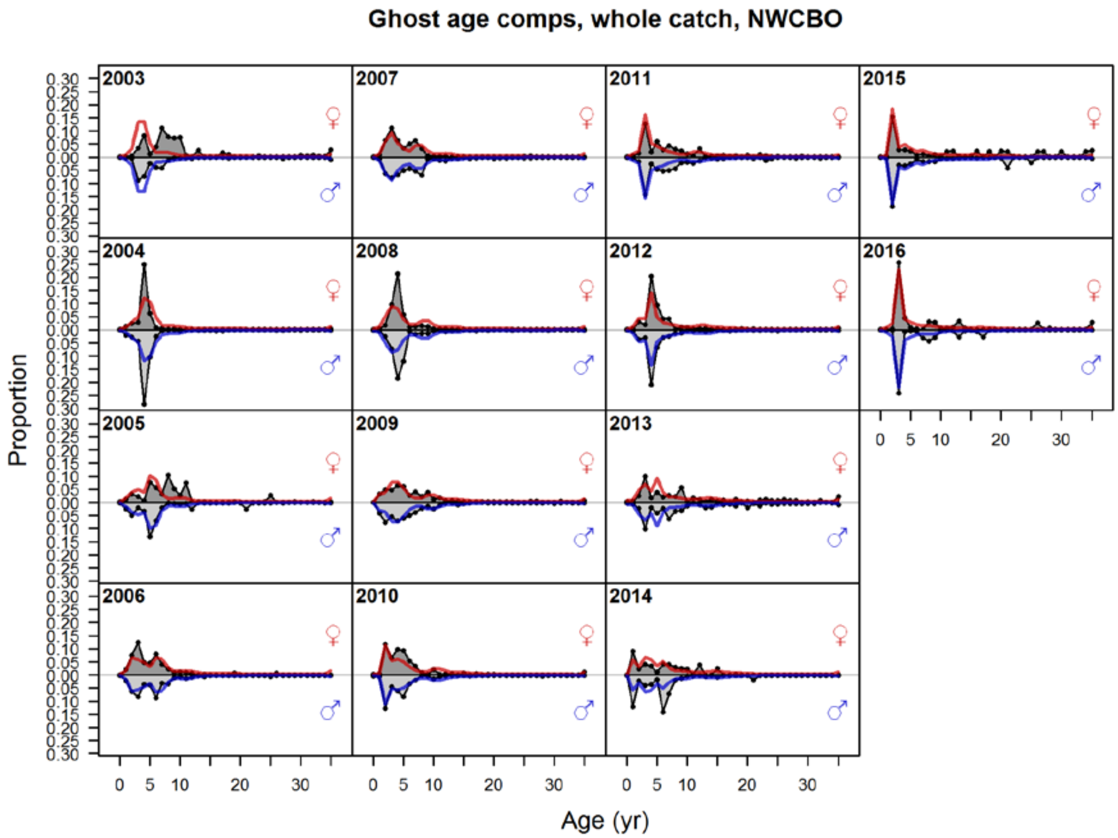

Figure 79: Implied fit to conditional ages-at-length compositions of darkblotched rockfish from the NWFSC shelf-slope survey marginal age frequencies. Fits are provided for evaluation only, but not included in the model likelihood.

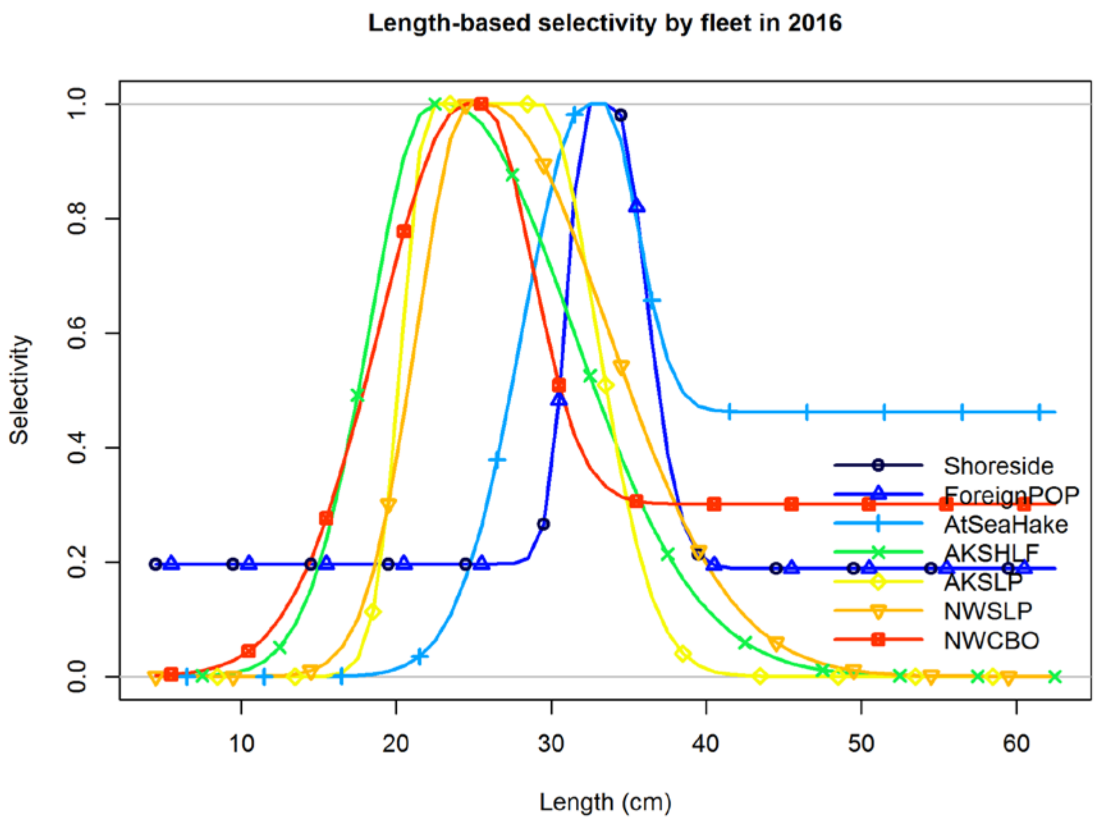

Figure 80: Final year selectivity curves for the all fleets used in the assessment.

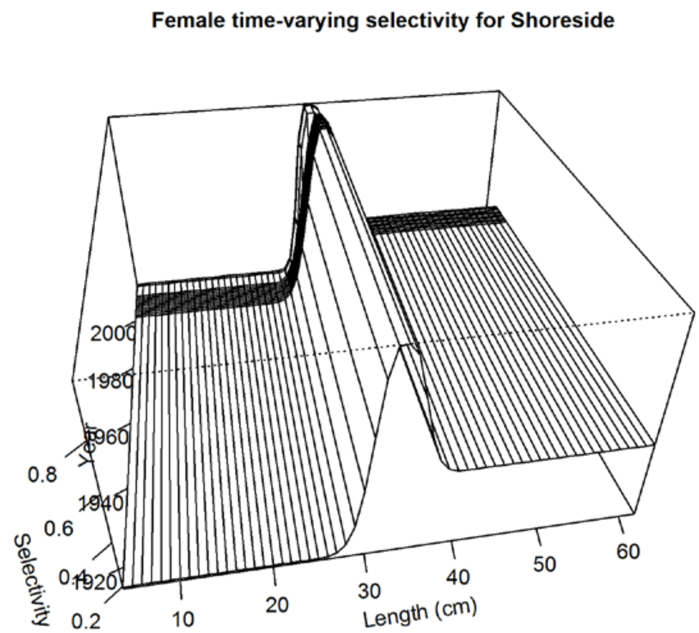

Figure 81: Estimated time-varying selectivity for the shoreside fishery.

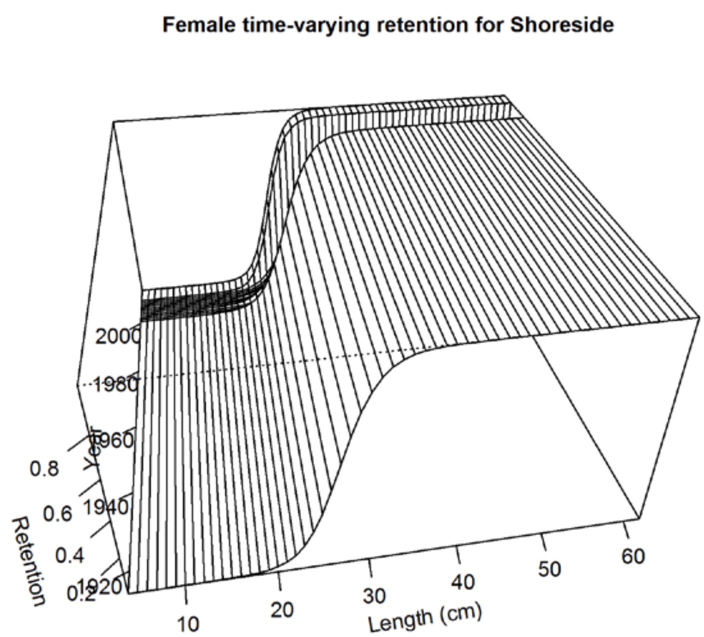

Figure 82: Estimated time-varying length-based retention of shoreside fishery.

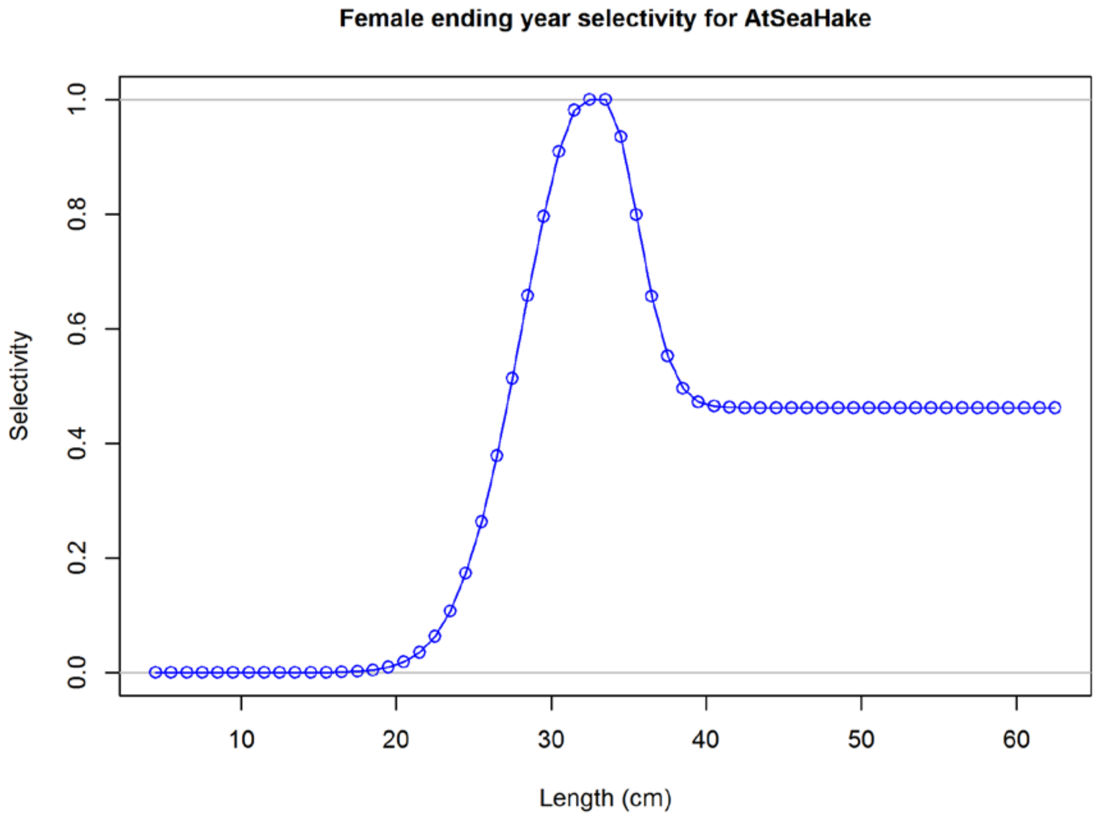

Figure 83: Length-based selectivity curve for historical at-sea hake bycatch fleet.

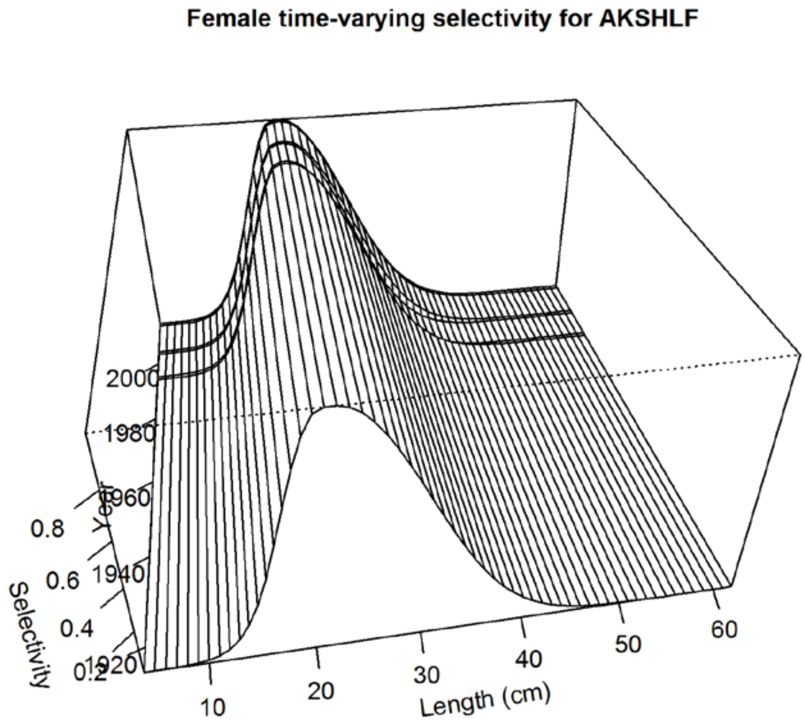

Figure 84: Estimated time-varying length-based selectivity curve for the AFSC shelf survey.

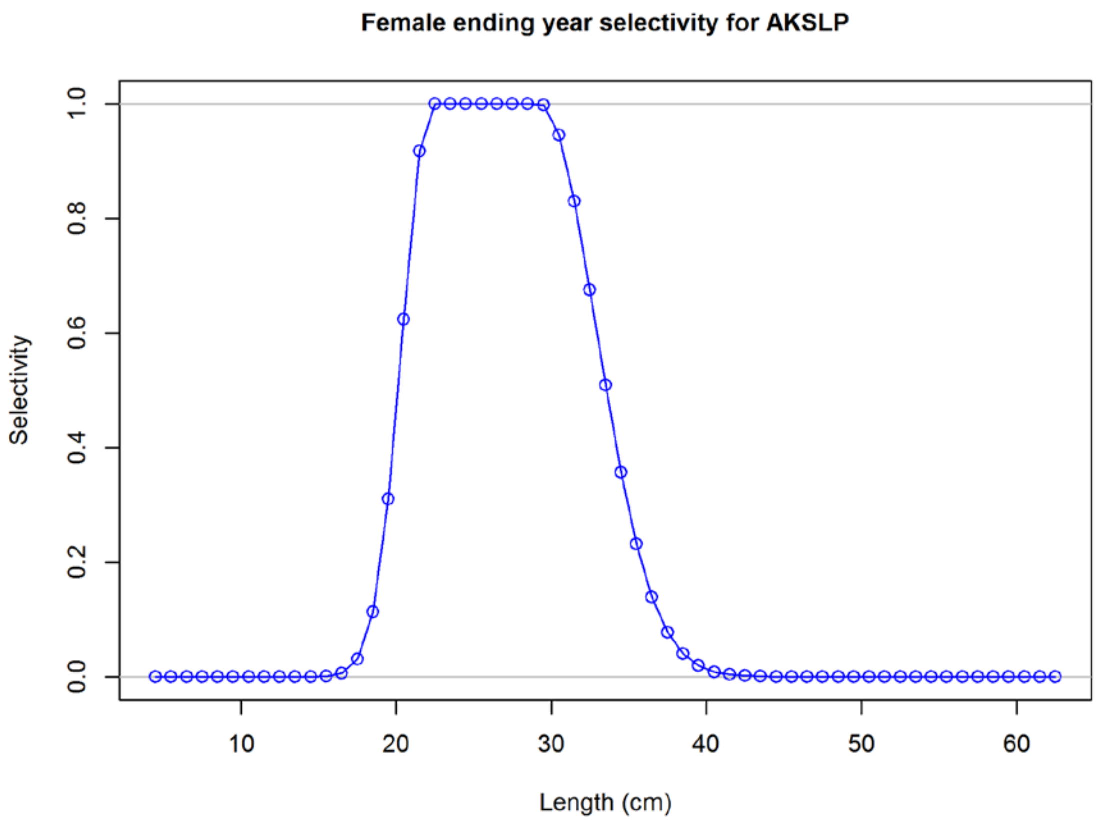

Figure 85: Estimated length-based selectivity curve for the AFSC slope survey.

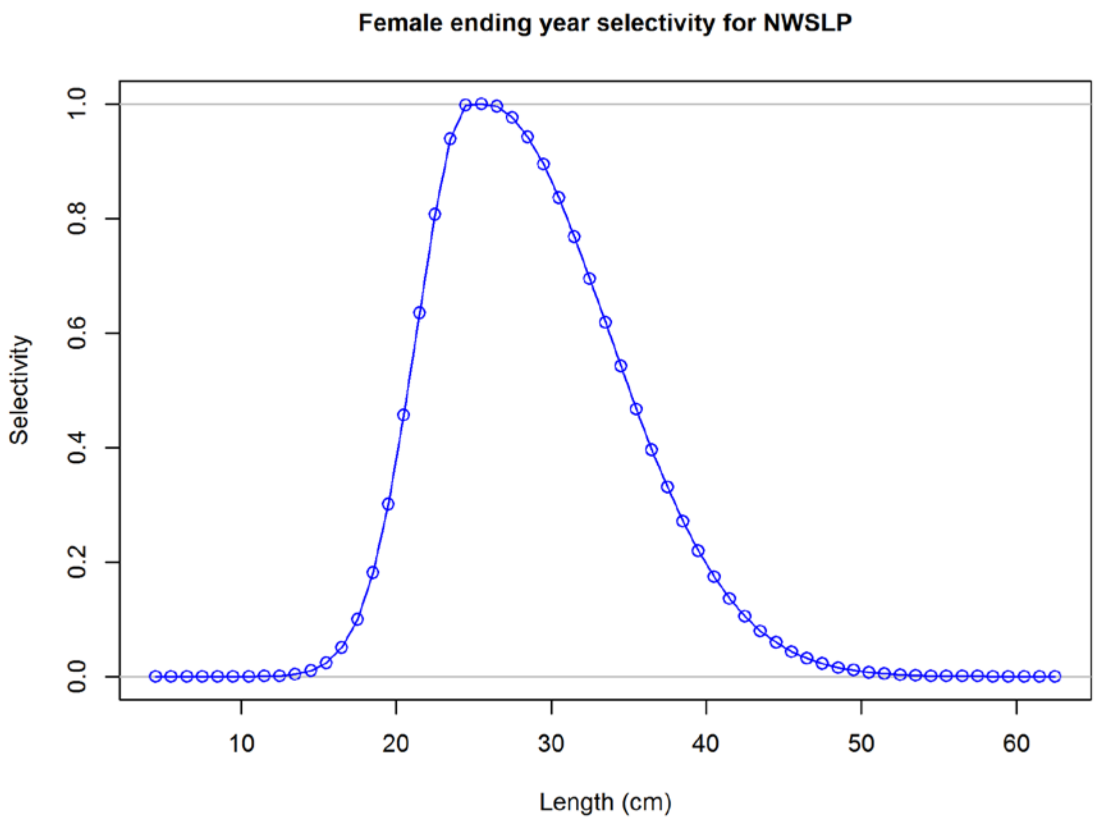

Figure 86: Estimated length-based selectivity curve for the NWFSC slope survey.

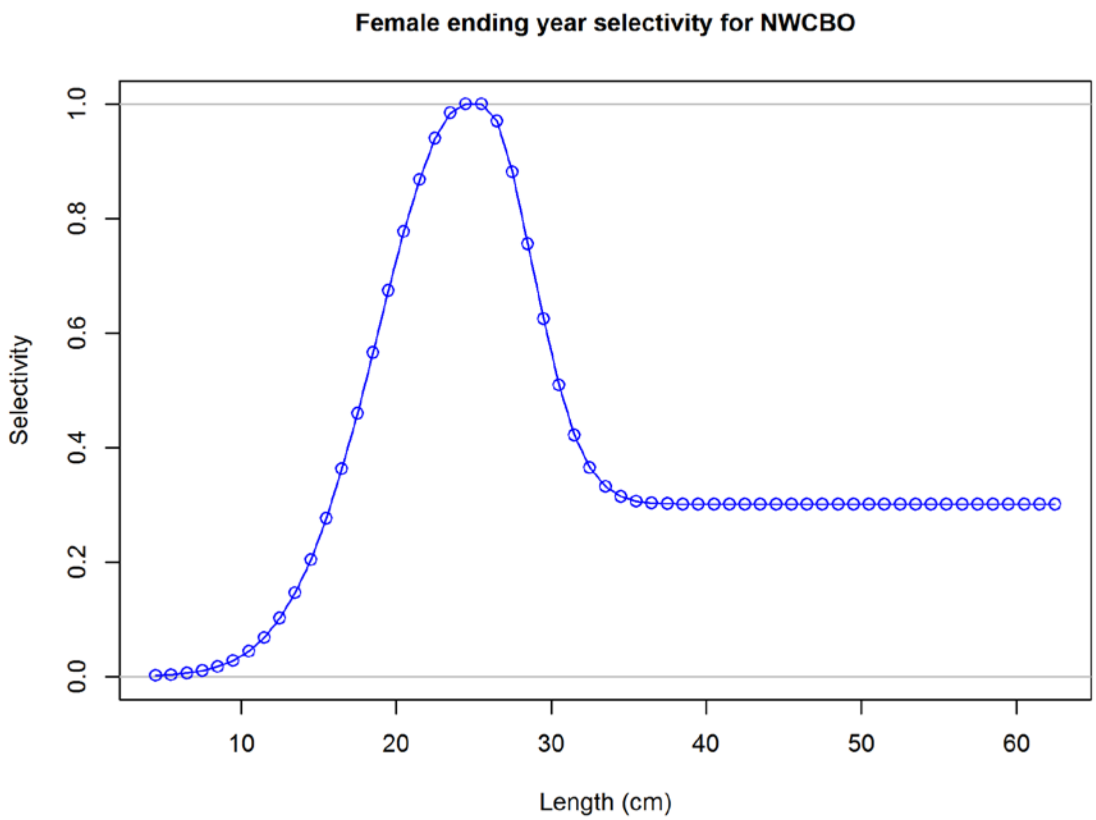

Figure 87: Estimated length-based selectivity curve for the NWFSC shelf-slope survey.

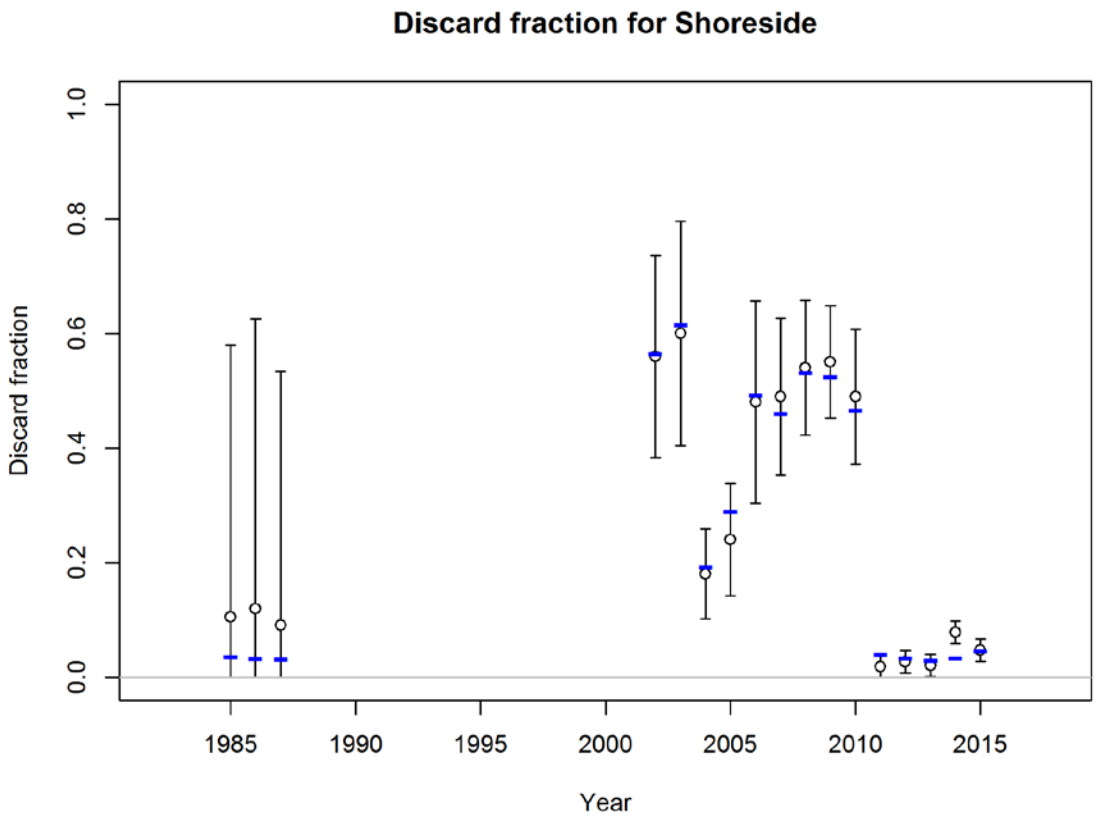

Figure 88: Fit to the discard ratio data of the shoreside fishery.

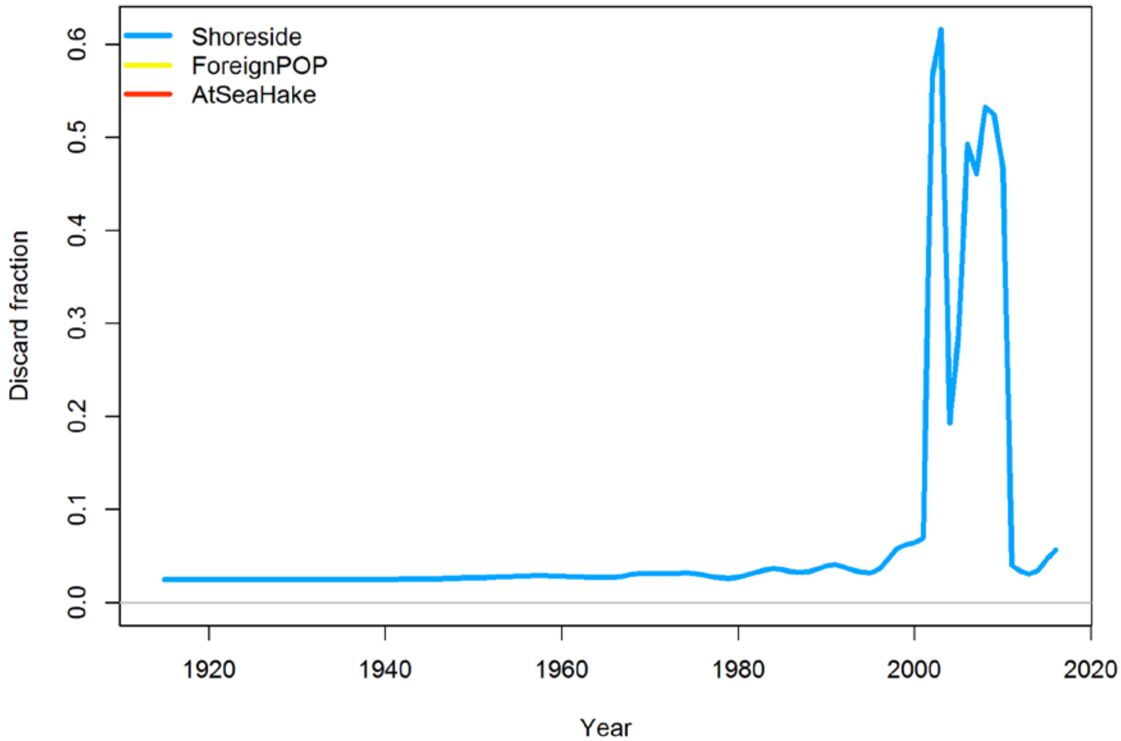

Figure 89: Discard fraction for the shoreside fishery estimated in the assessment.

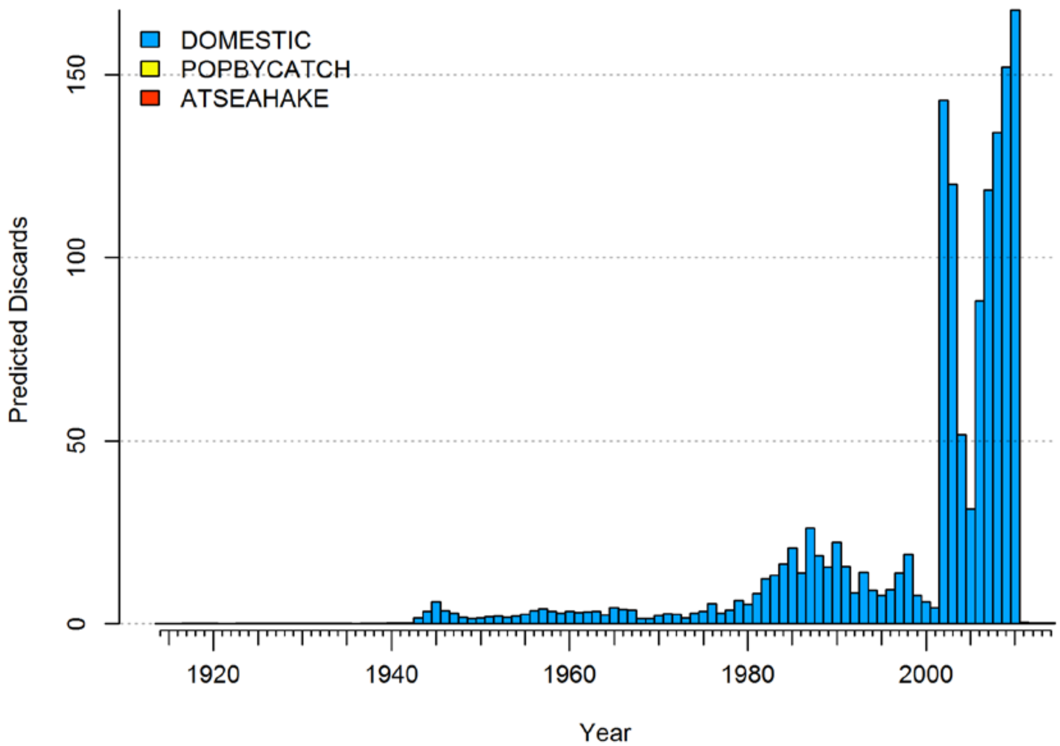

Figure 90: Predicted discard for the shoreside fishery.

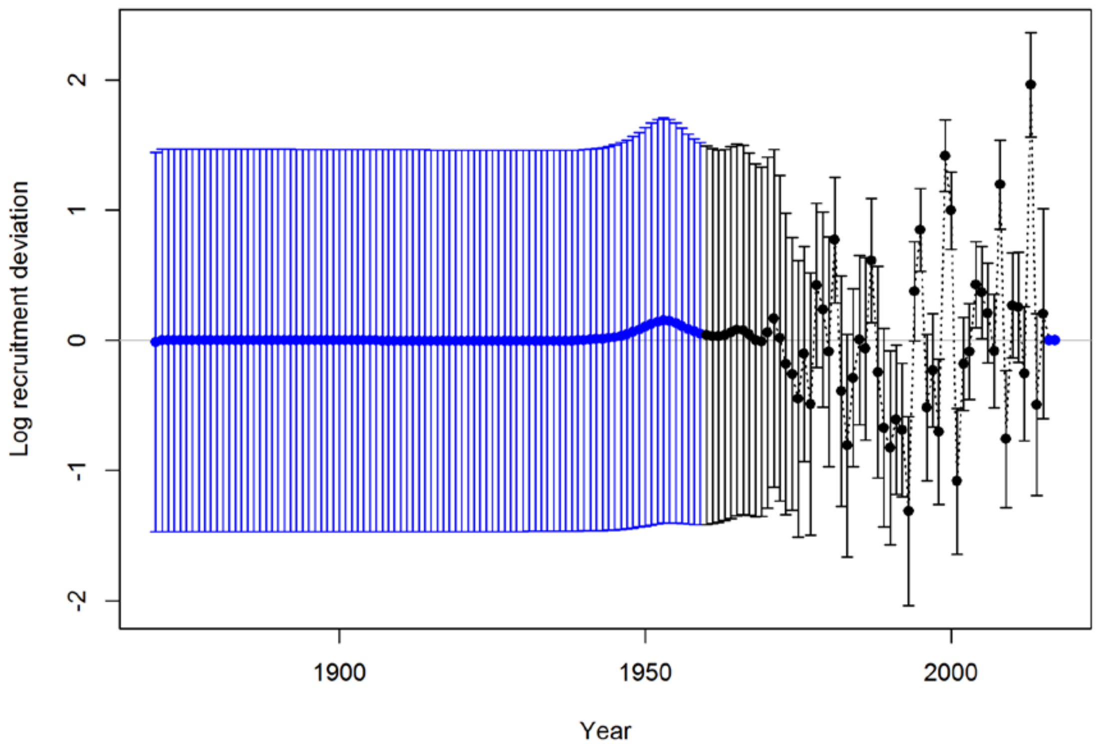

Figure 91: Recruitment deviation time-series estimated in the assessment model with 95% confidence intervals.

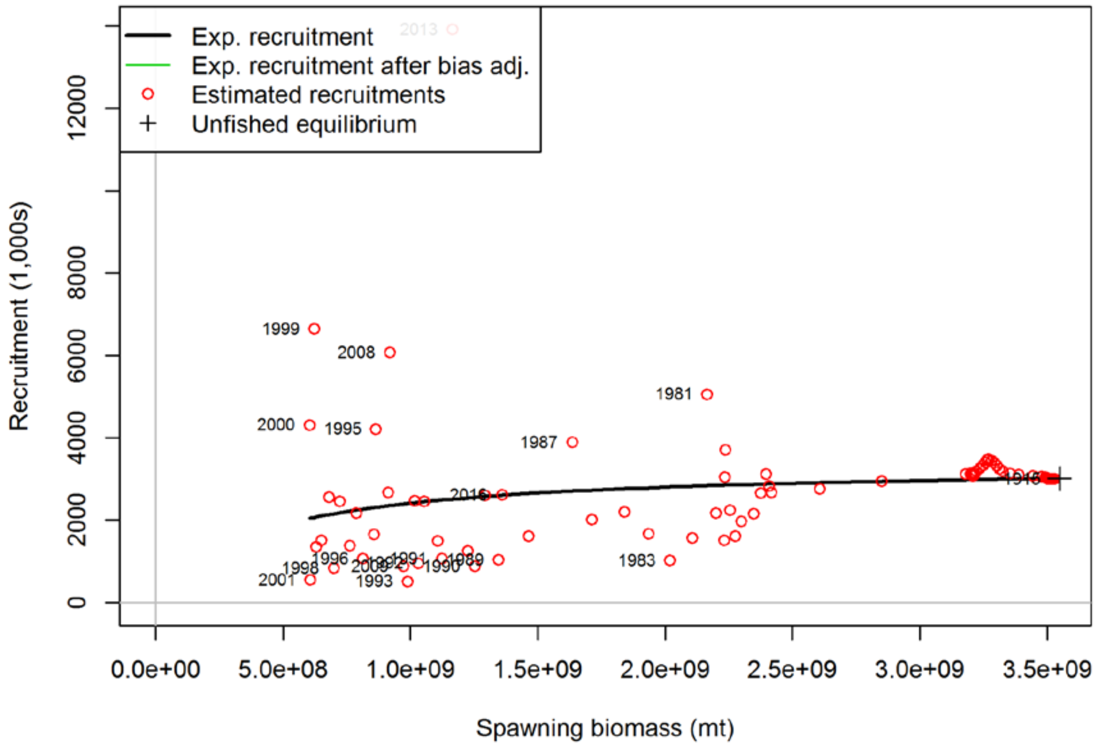

Figure 92: Estimated stock-recruit function for the assessment model.

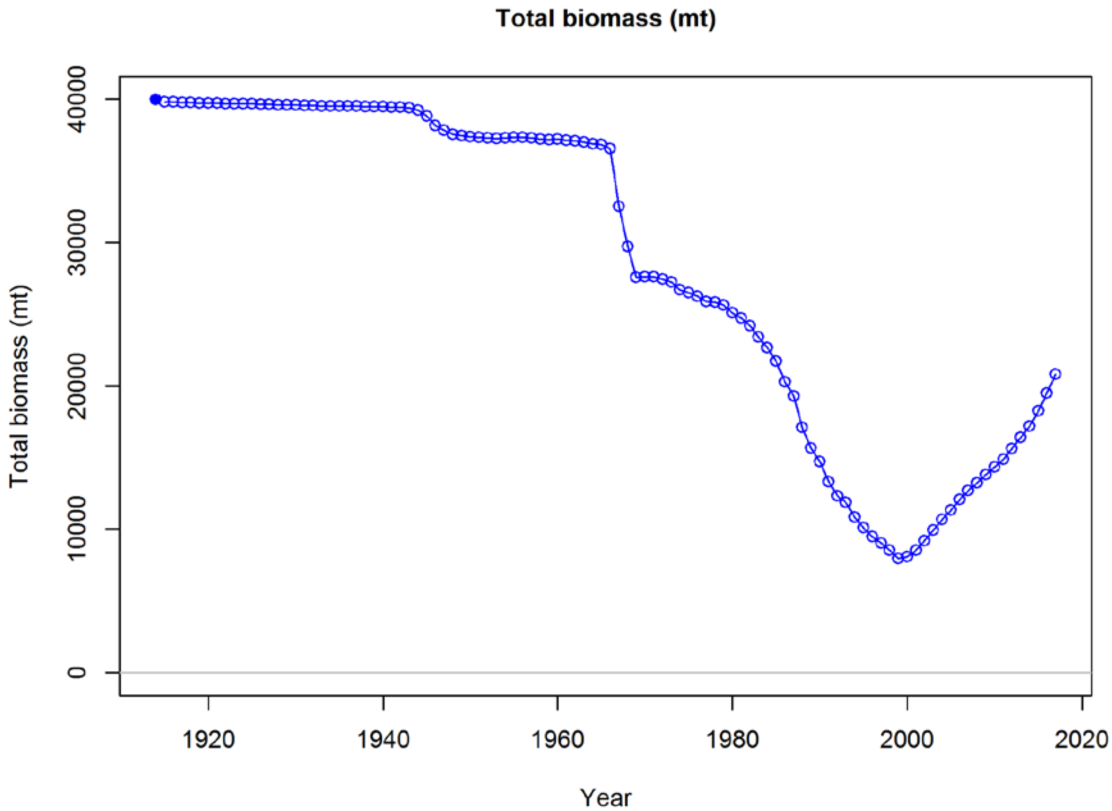

Figure 93: Time series of total biomass (mt) estimated in the assessment model.

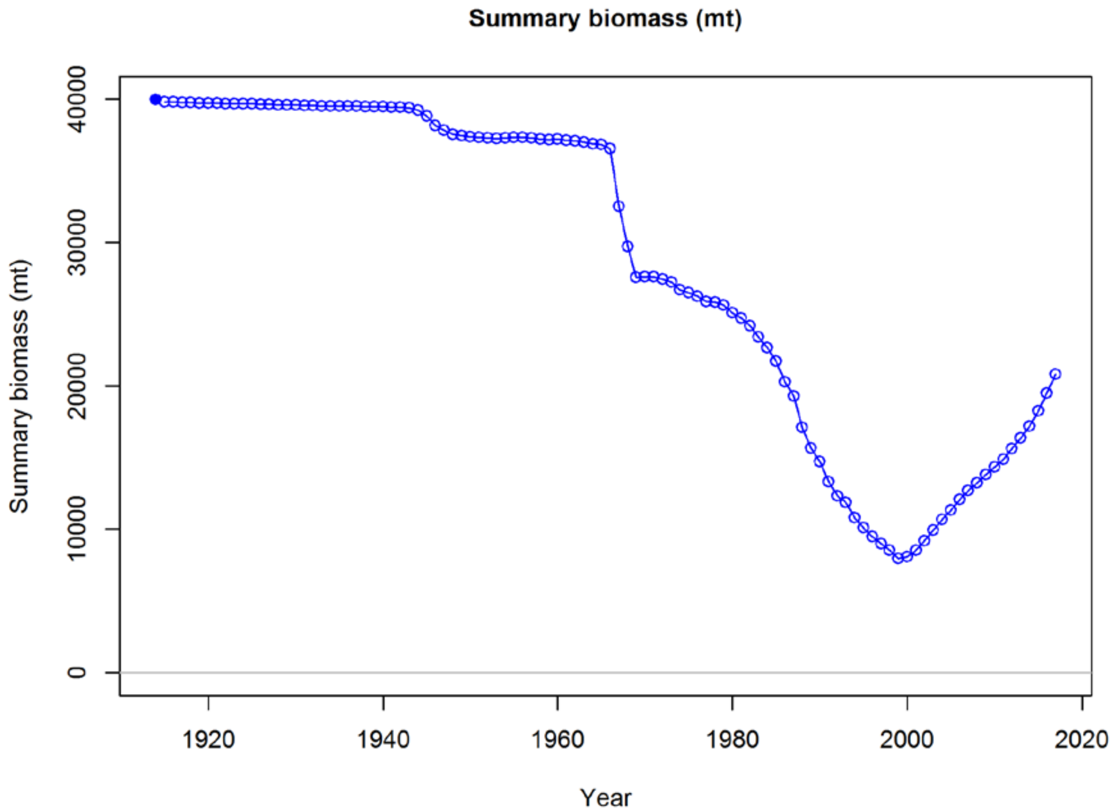

Figure 94: Time series of summary biomass (mt) estimated in the assessment model.

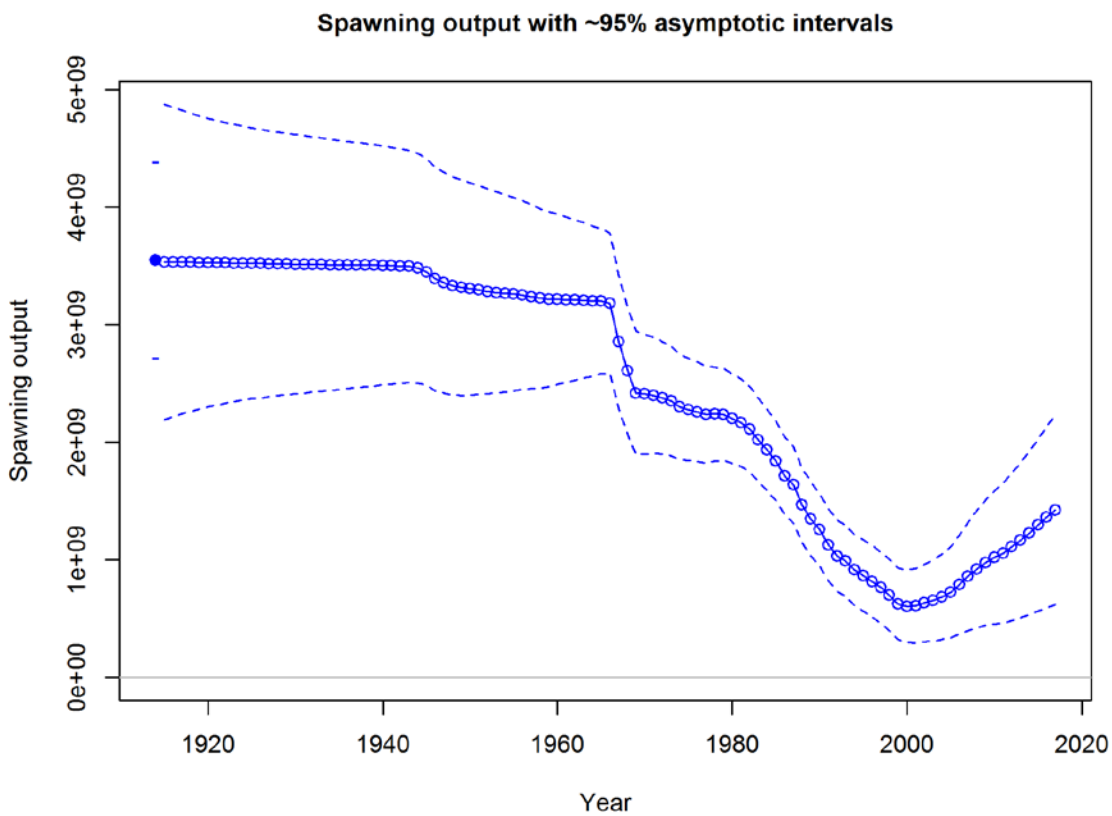

Figure 95: Time series of spawning output estimated in the assessment model (solid line) with ~ 95% interval (dashed lines). Spawning output is expressed in number of eggs.

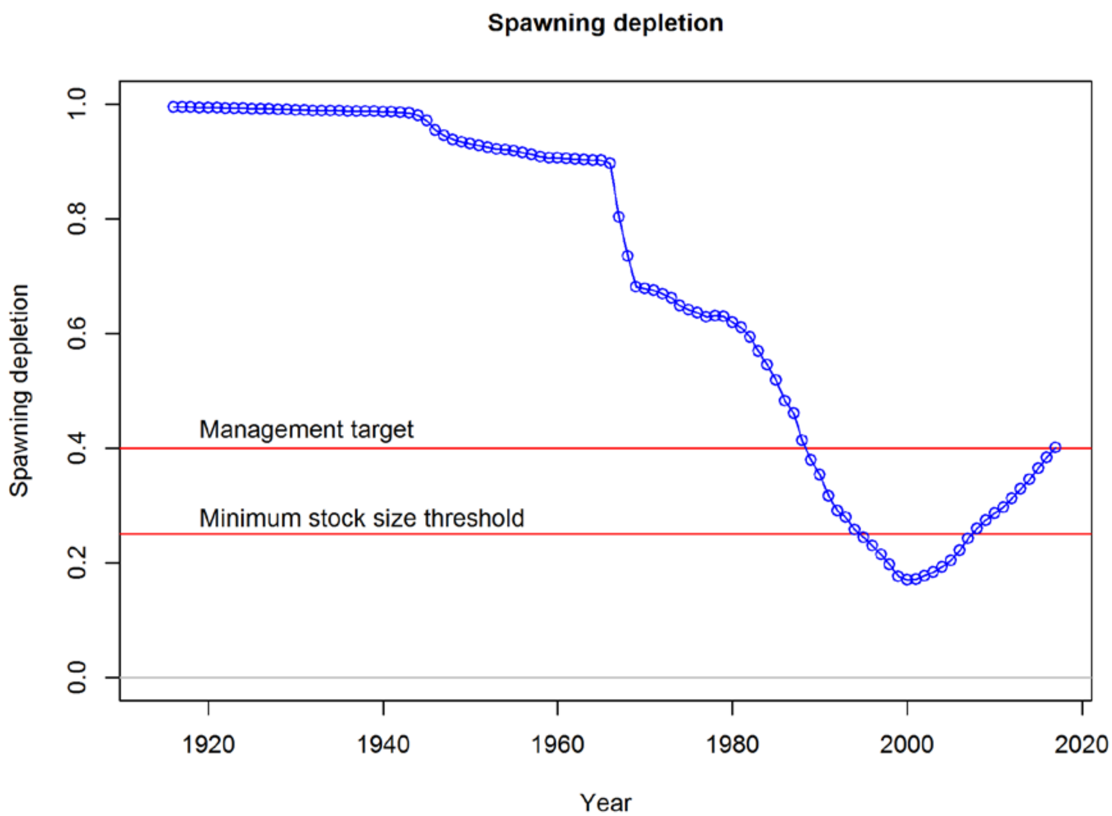

Figure 96: Time series of spawning depletion estimated in the assessment model (solid line) with ~ 95% interval (dashed lines).

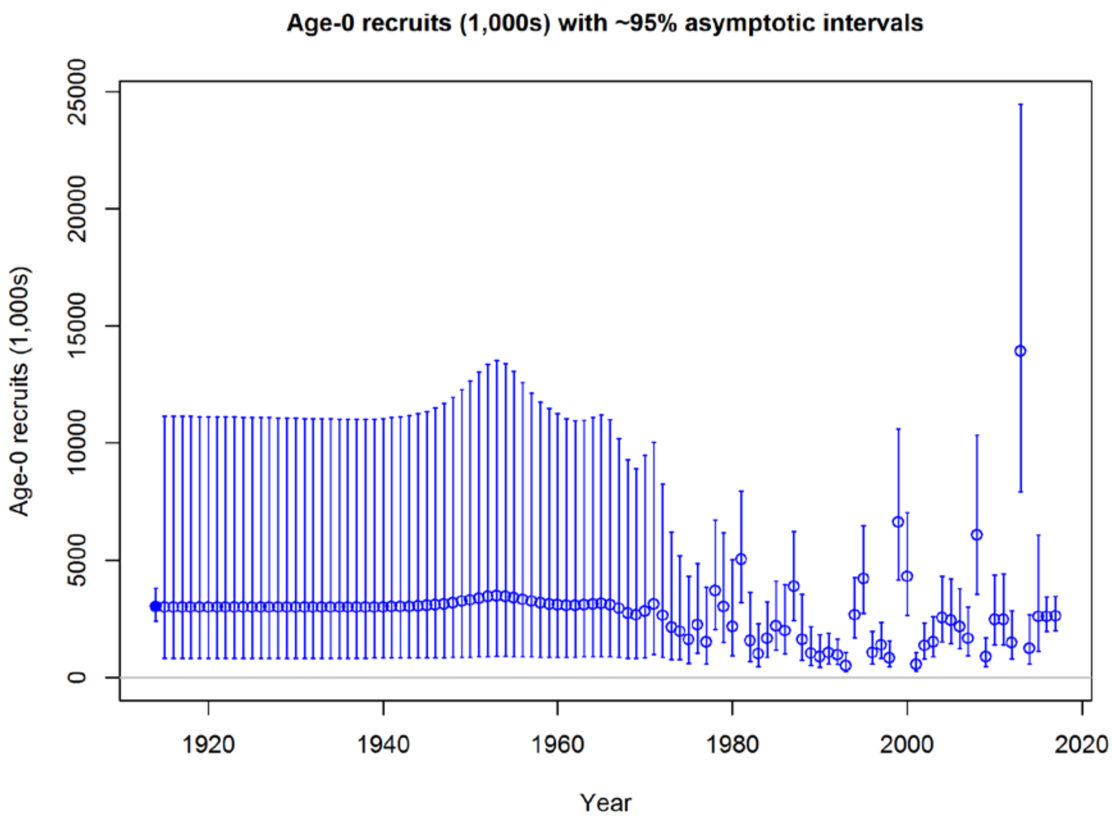

Figure 97: Time series of recruitment estimated in the assessment model with ~ 95% interval.

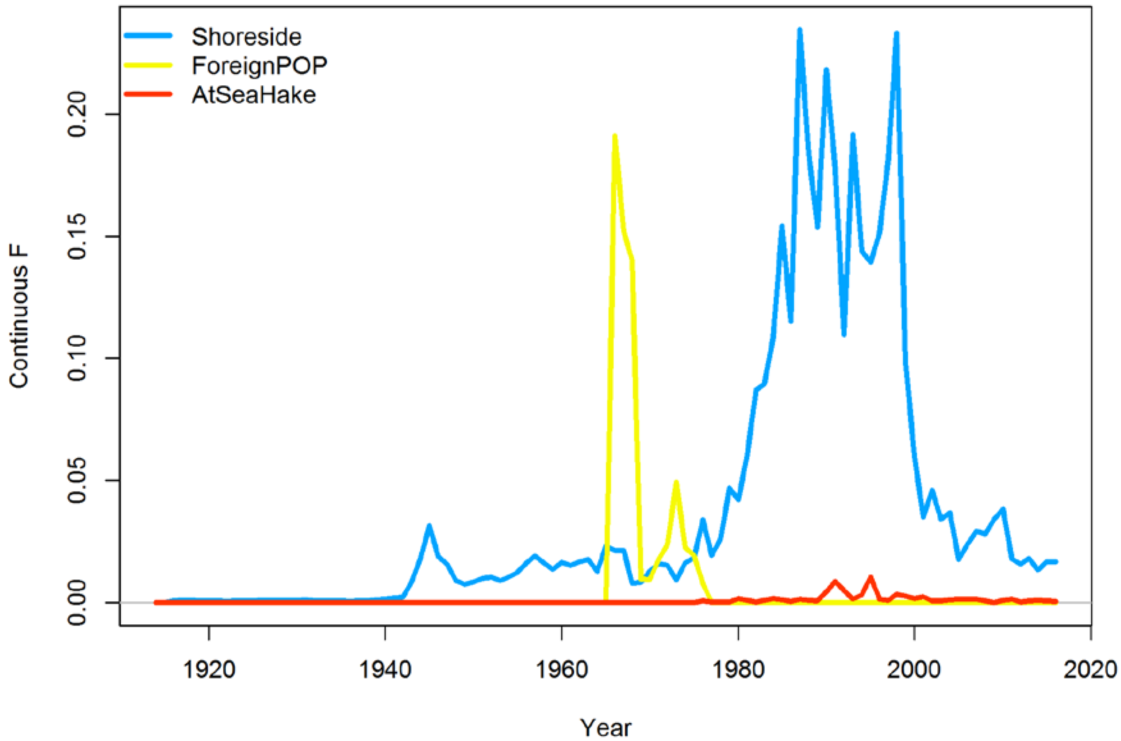

Figure 98: Time series of fishing mortality of darkblotched rockfish estimated by the assessment model.

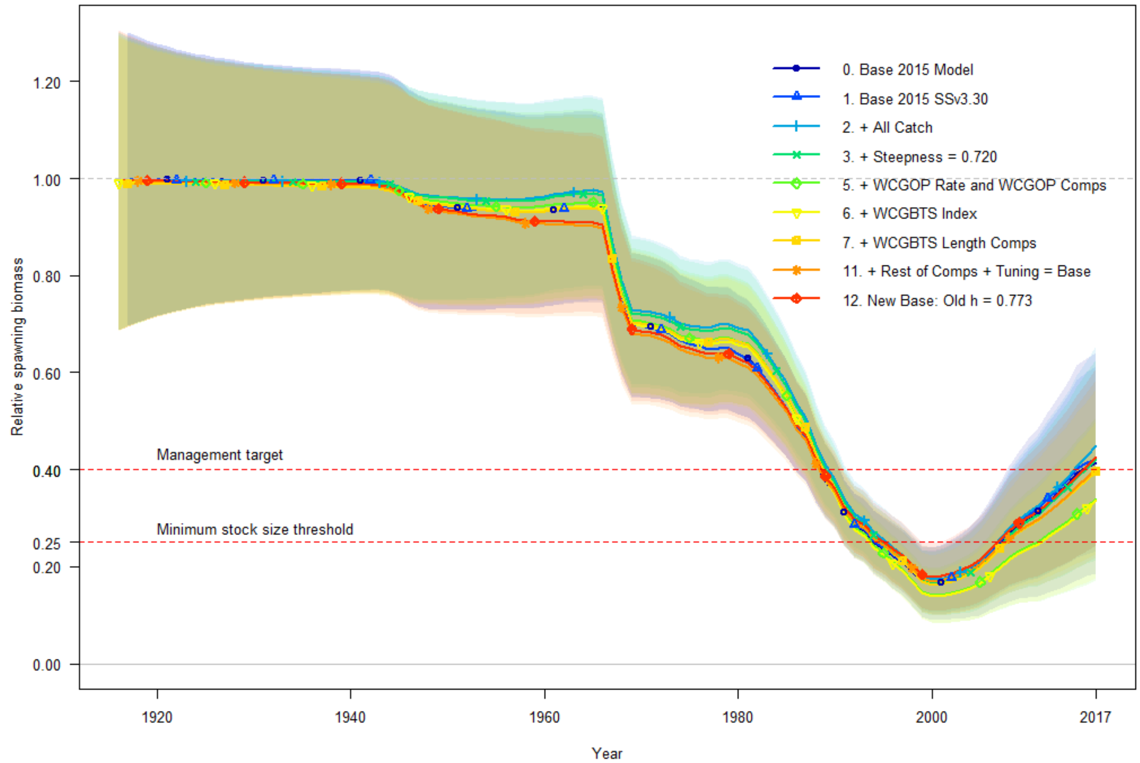

Figure 99. Model changes from 2015 base to 2017 base, including the new base with the old steepness of 0.773.

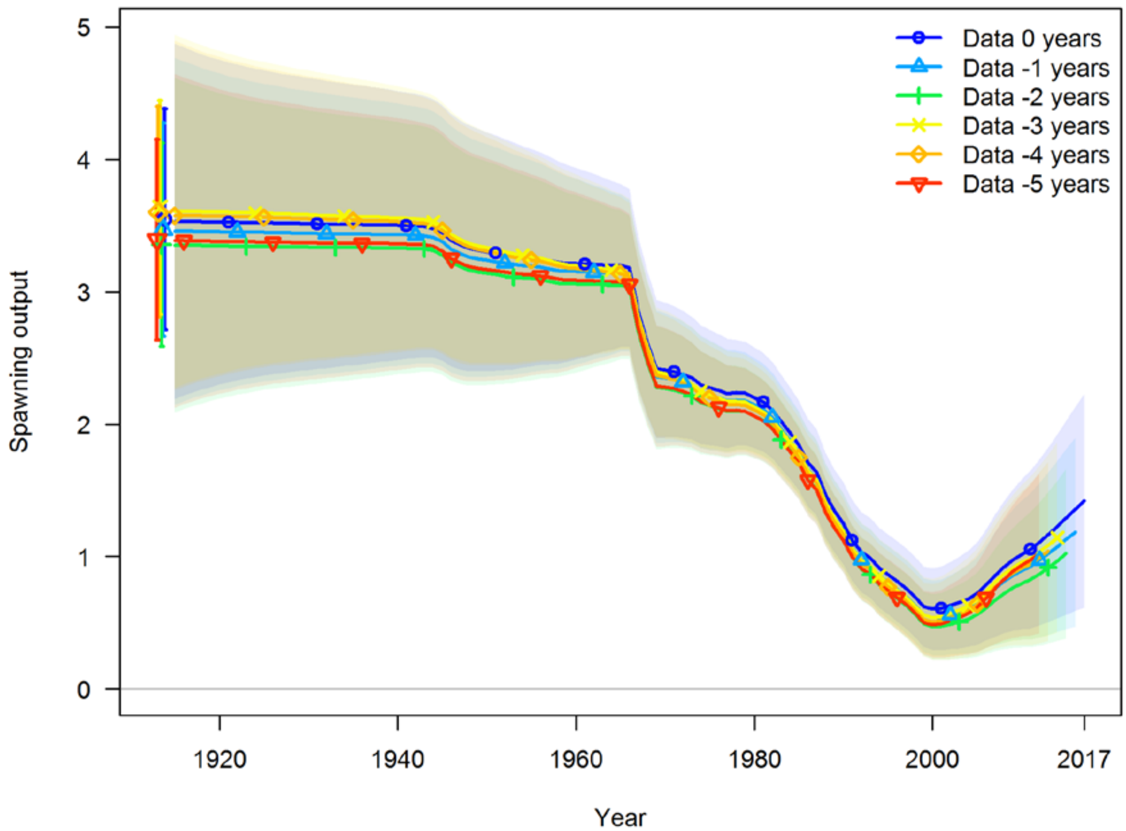

Figure 100: Results of retrospective analysis. Spawning output time series of this assessment base model are provided with ~ 95% interval.

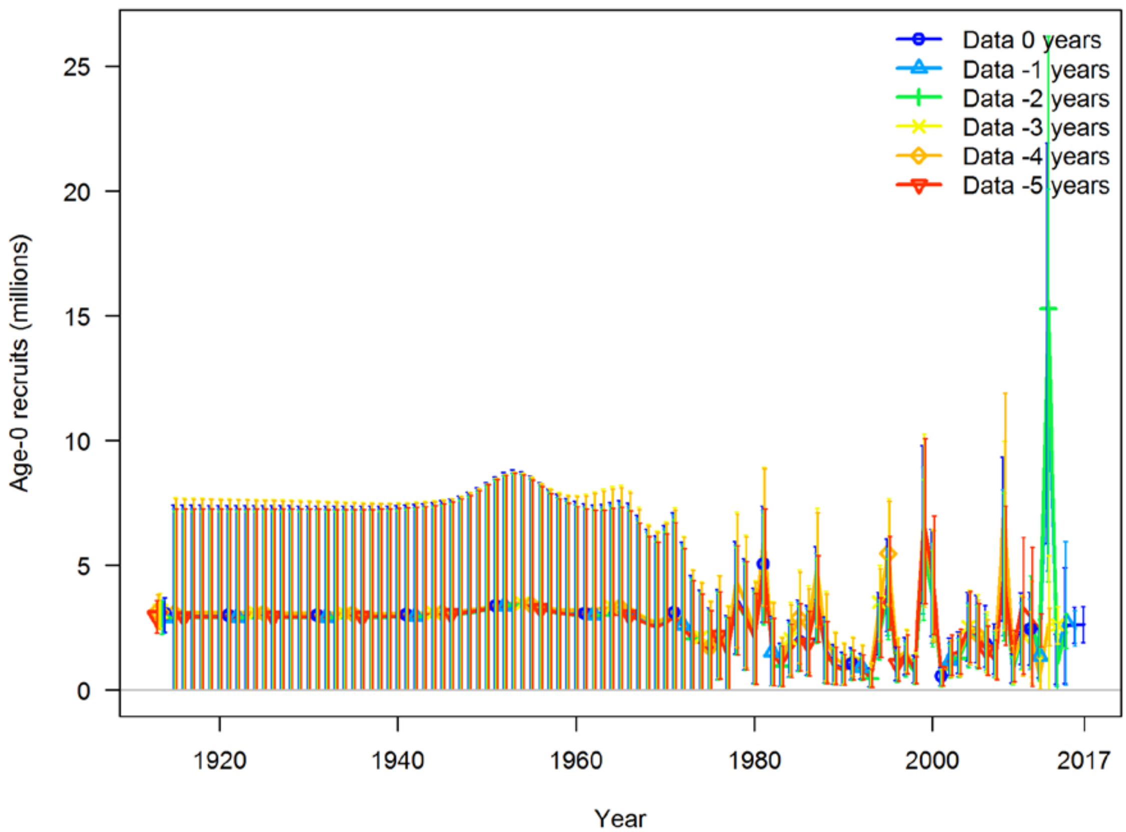

Figure 101: Results of retrospective analysis. Recruitment time series of this assessment base model are provided with ~ 95% interval.

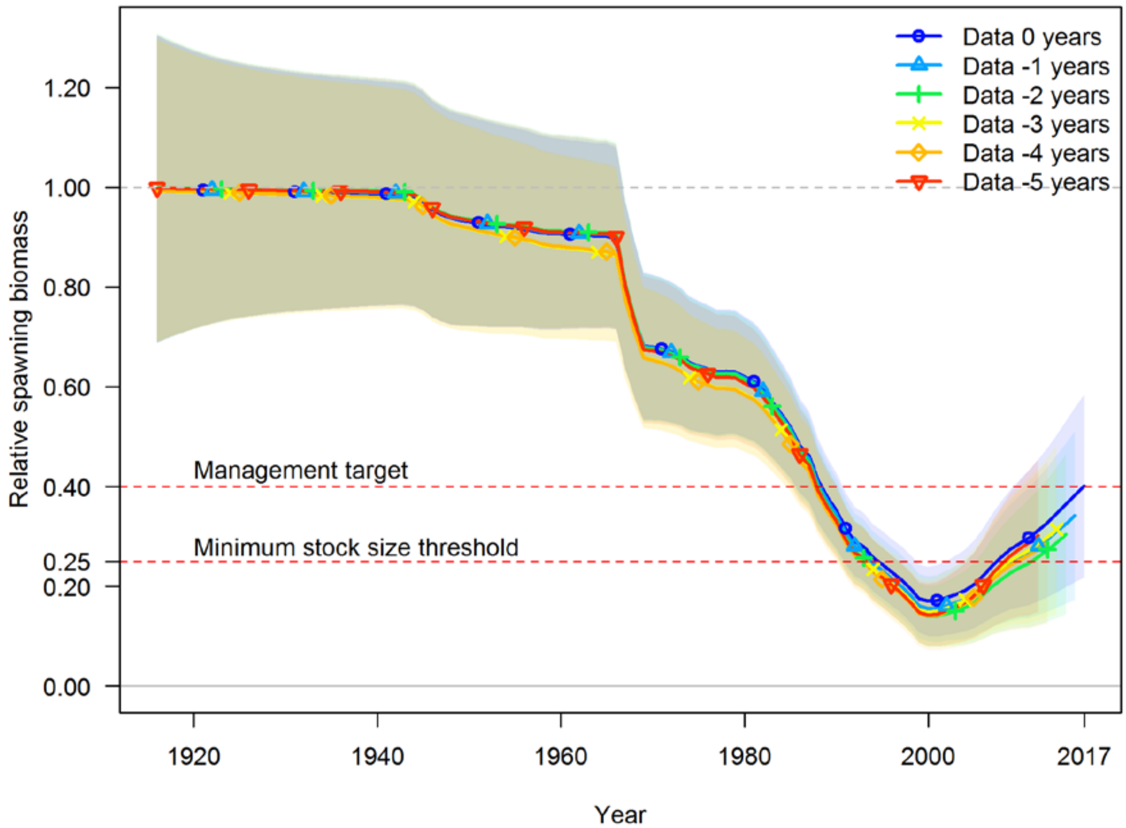

Figure 102: Results of retrospective analysis. Spawning depletion time series of this assessment base model are provided with ~ 95% interval.

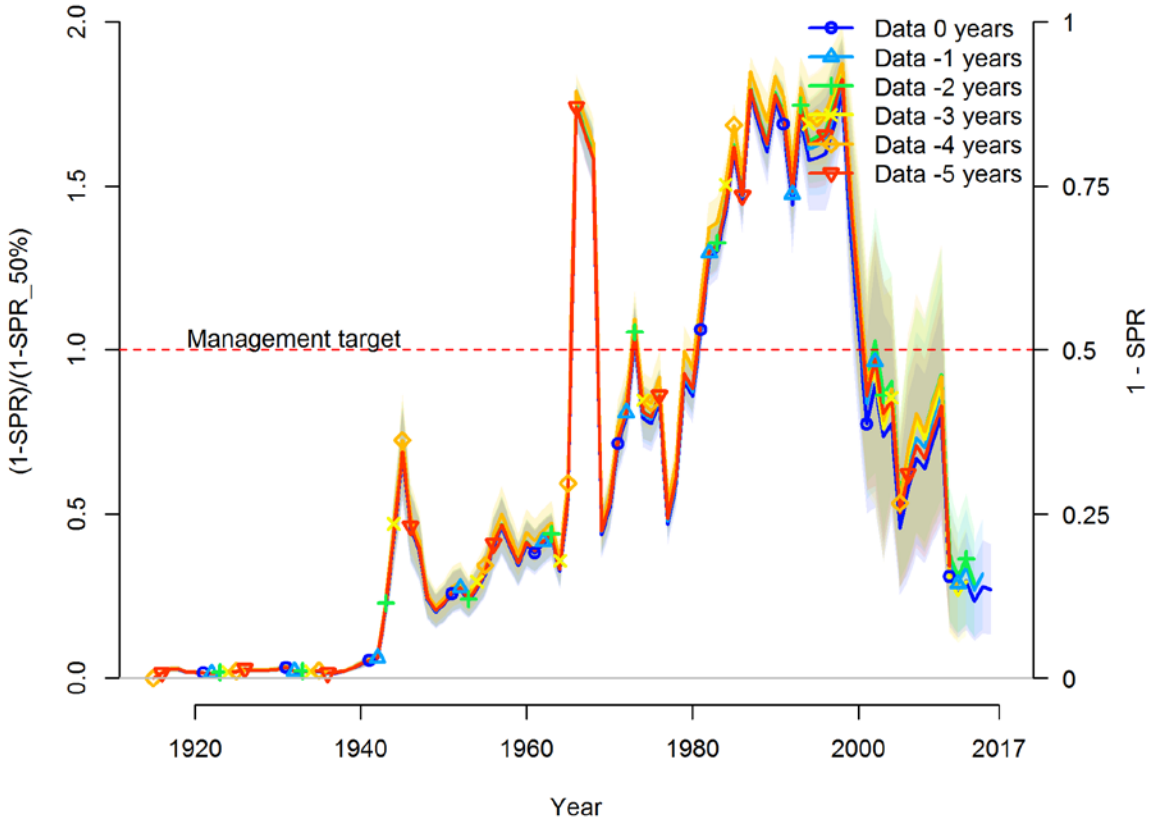

Figure 103: Results of retrospective analysis. Relative SPR ratio (1-SPR/1-$SPR_{Target=0.50}$) time series of this assessment base model are provided with ~ 95% interval.

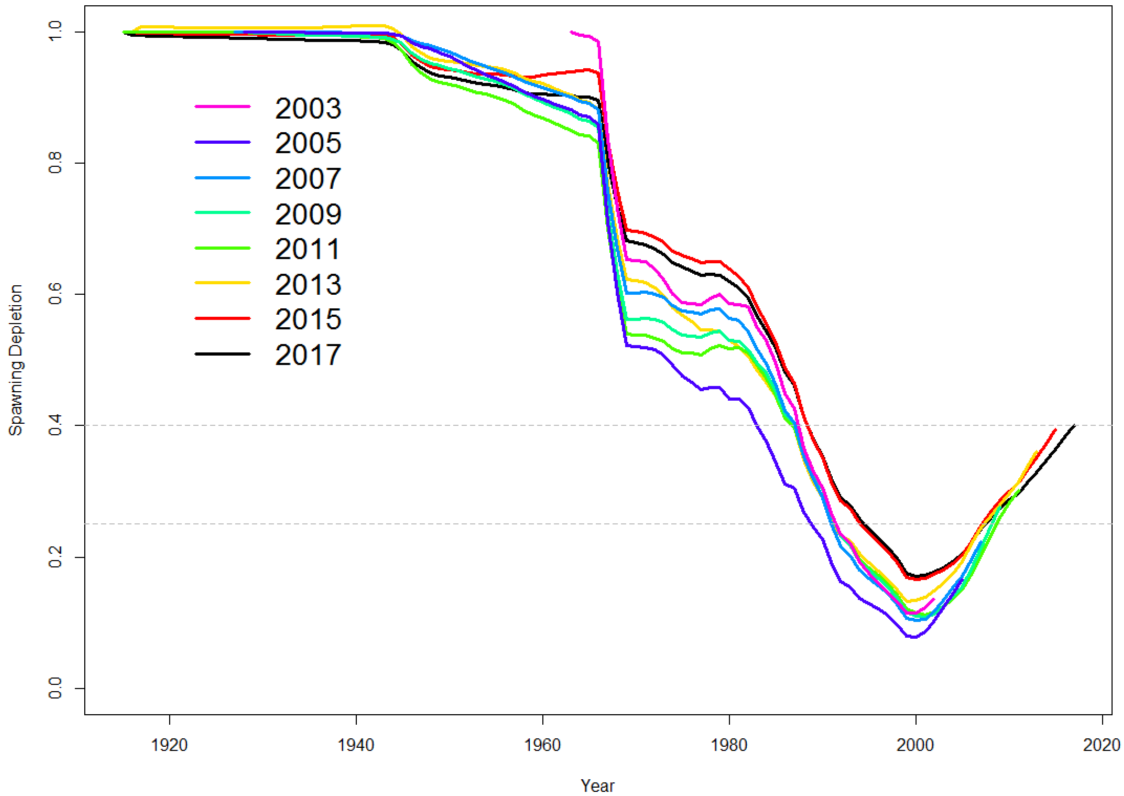

Figure 104: Comparison of spawning depletion time series among darkblotched rockfish assessments.

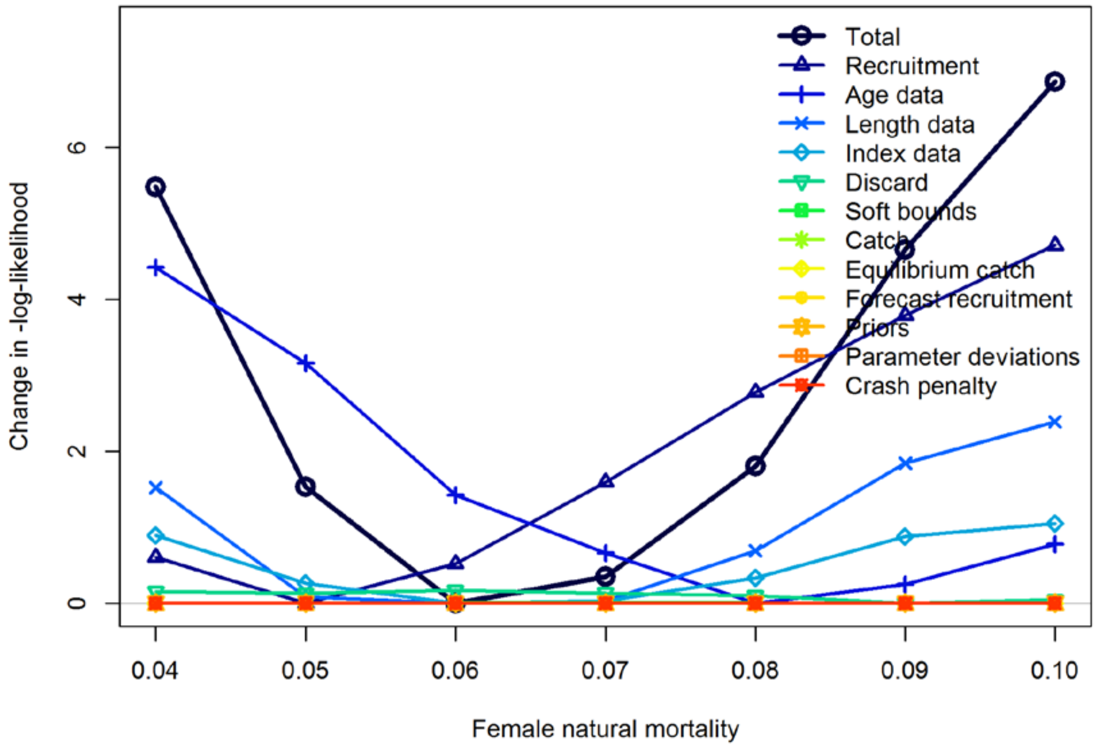

Figure 105: Negative log-likelihood profile for each data component and in total given different values of **female natural mortality** ranging from 0.04 to 0.1 by increments of 0.01.

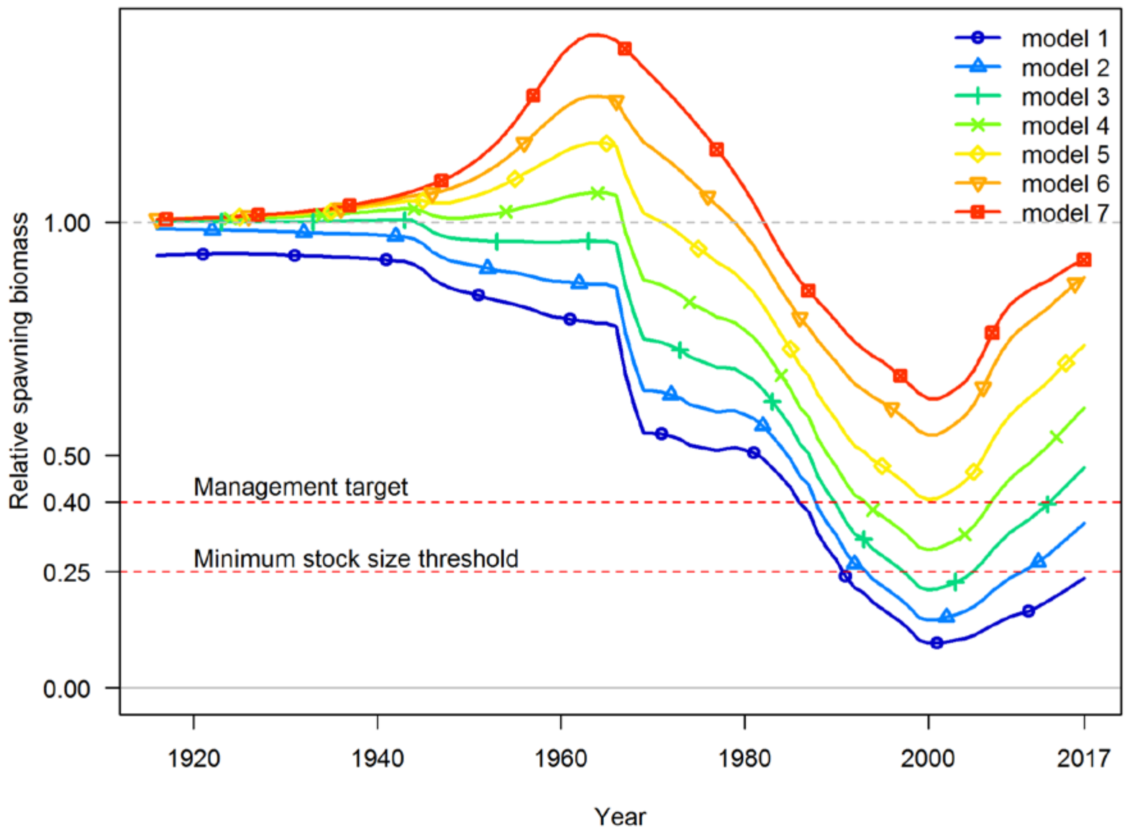

Figure 106: Time series of spawning depletion associated with different values of **female natural mortality** ranging from 0.04 (Model 1) to 0.1 (Model 7) by increments of 0.01.

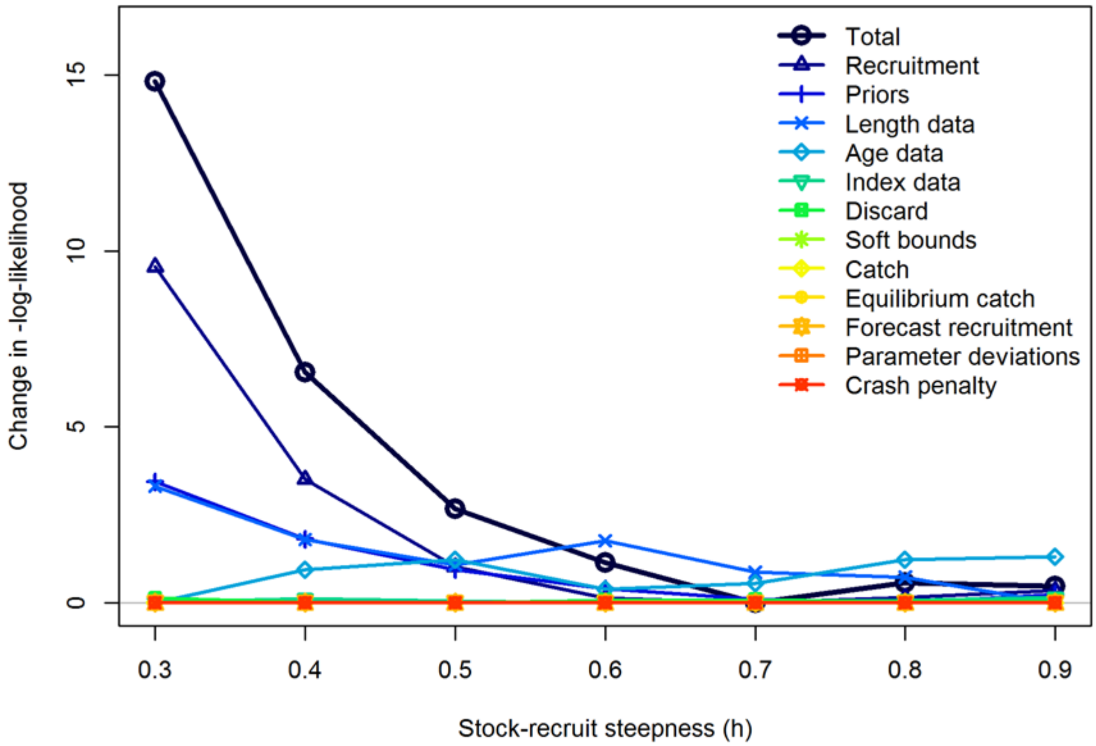

Figure 107: Negative log-likelihood profile for each data component and in total given different values of stock-recruit **steepness** ranging from 0.3 to 0.9 by increments of 0.1.

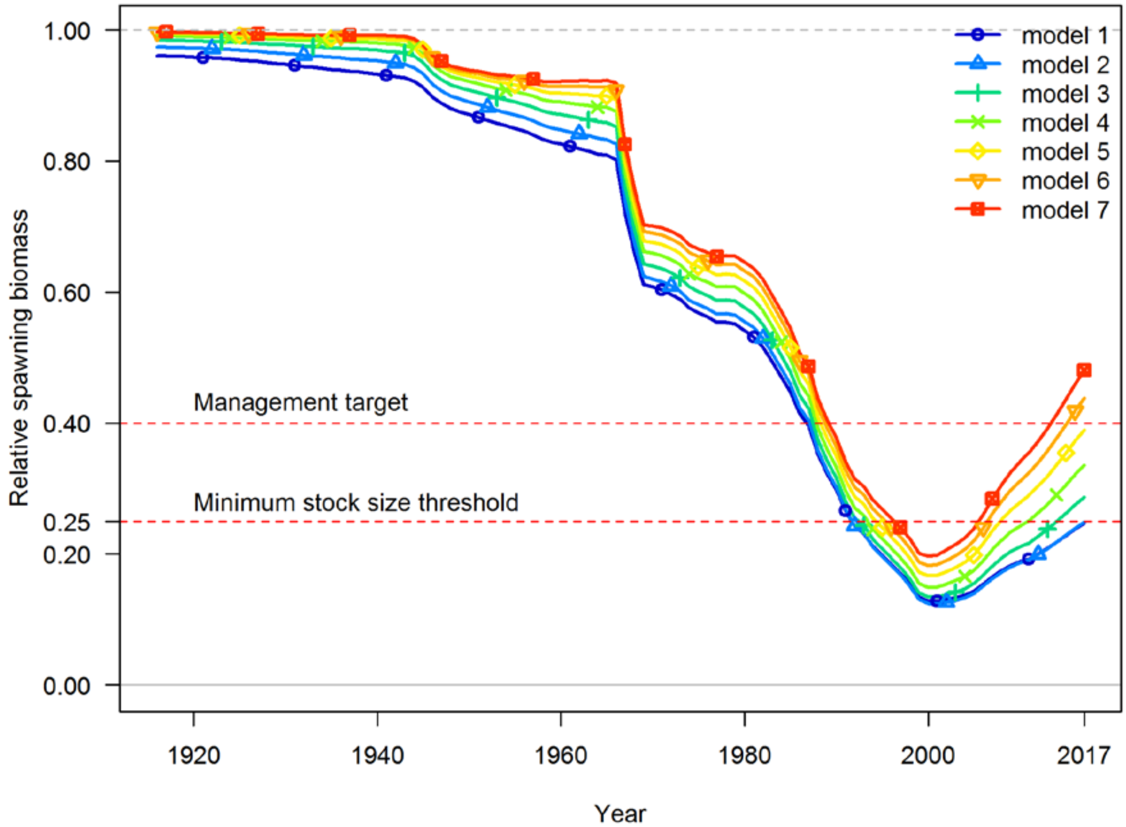

Figure 108: Time series of spawning depletion associated with different values of **steepness** ranging from 0.3 (Model 1) to 0.9 (Model 7) by increments of 0.1.

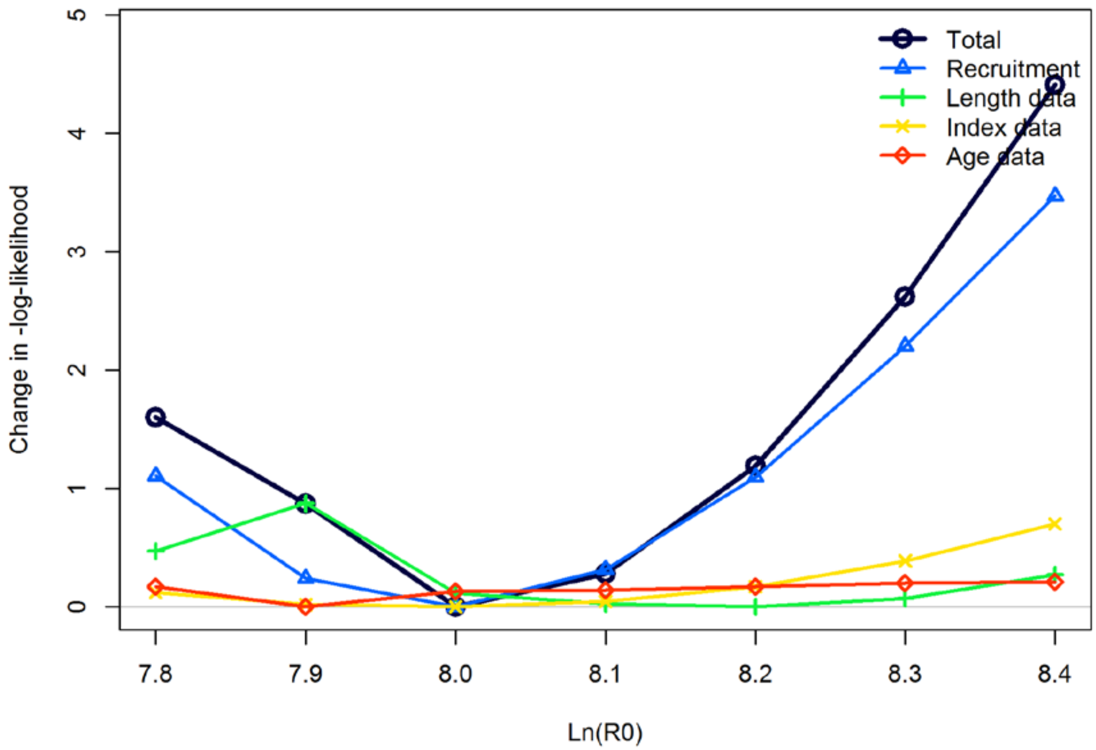

Figure 109: Negative log-likelihood profile for the base model, for each data component and in total given different values of **ln(*R*$_0$)** ranging from 7.8 to 8.4 by increments of 0.1.

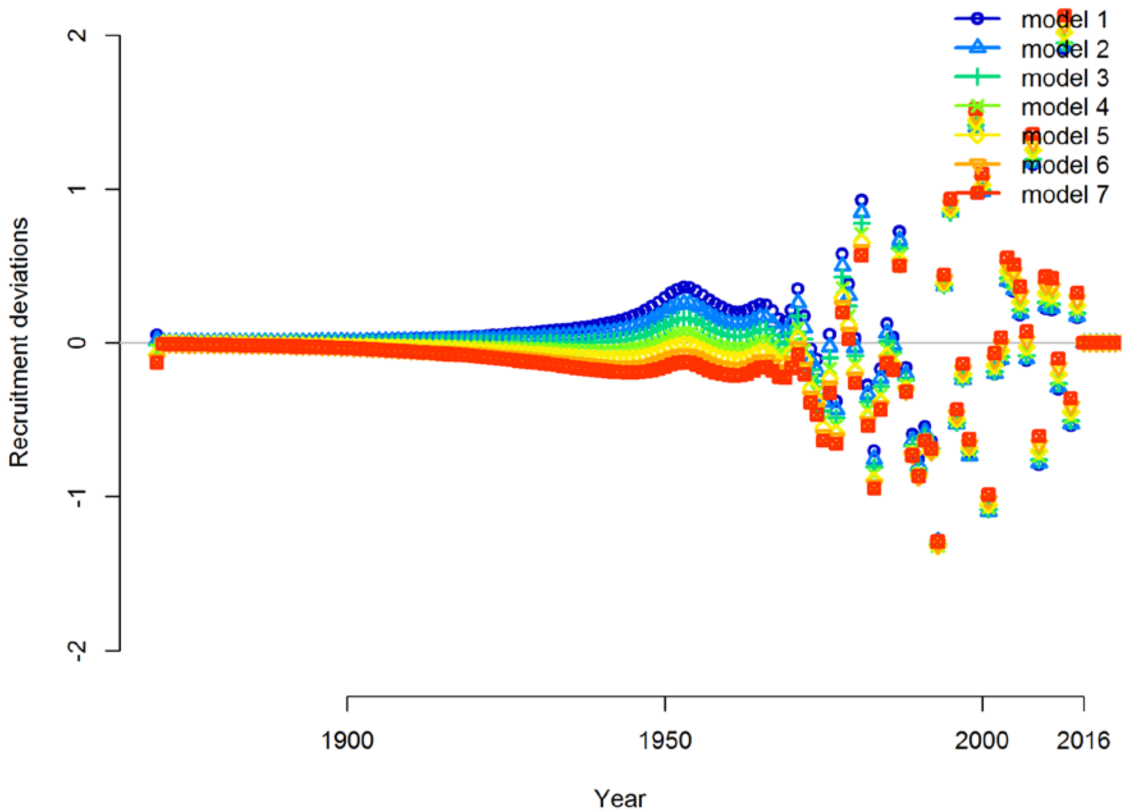

Figure 110: Values of recruitment deviations given different values of **ln(*R*$_0$)** ranging from 7.8 to 8.4 by increments of 0.1.

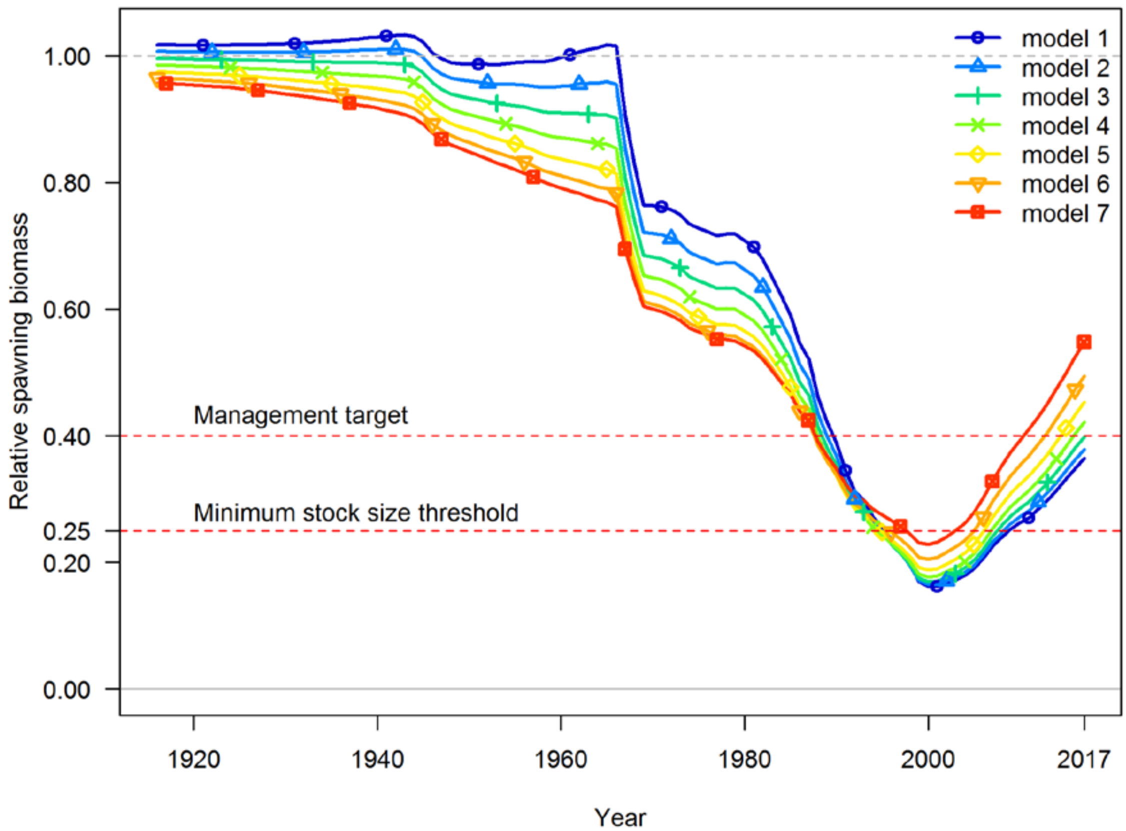

Figure 111: Time series of spawning depletion associated with different values of **ln(*R_0*)** ranging from 7.8 to 8.4 by increments of 0.1.

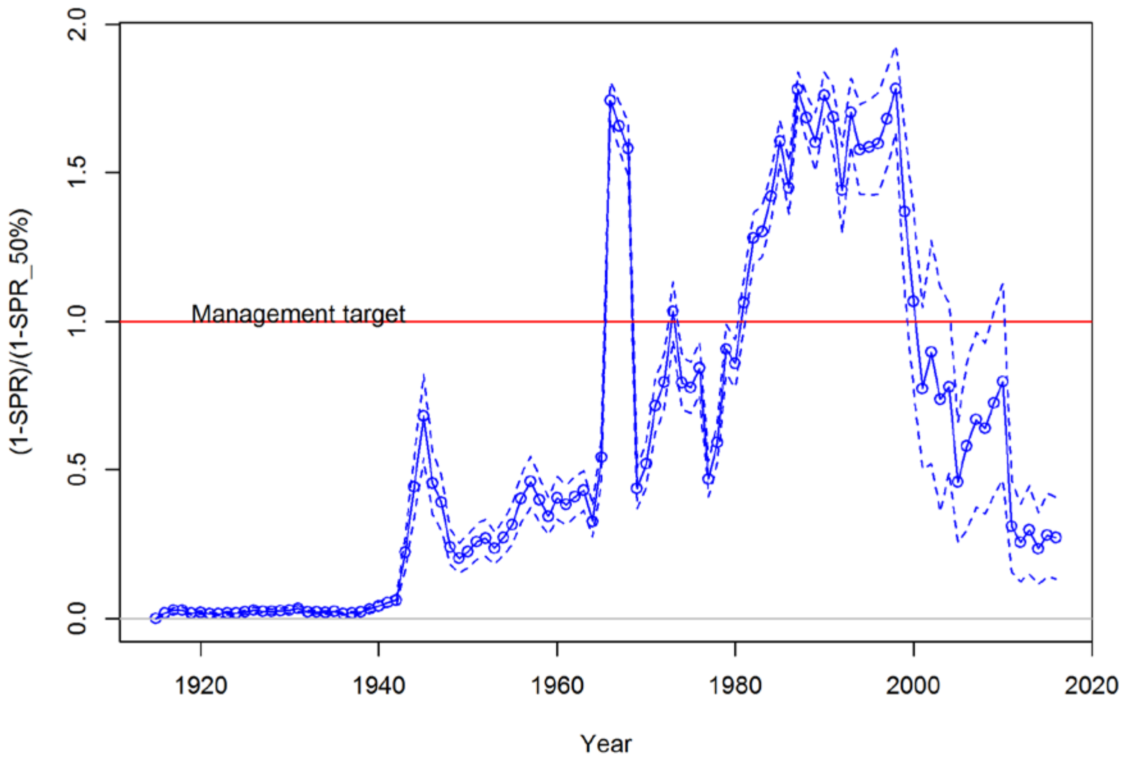

Figure 112: Time series of estimated relative spawning potential ratio (1-SPR/1-$SPR_{Target=0.5}$) for the base model (round points) with ~95% intervals (dashed lines). Values of relative SPR above 1.0 reflect harvests in excess of the current overfishing.

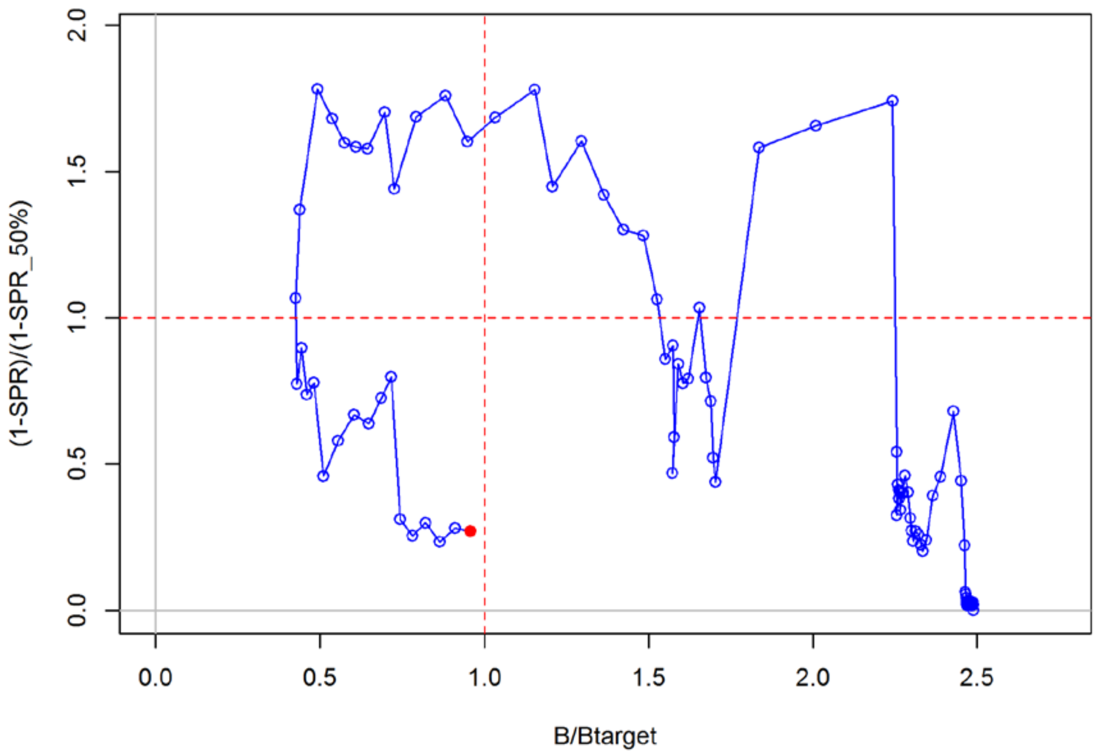

Figure 113: Phase plot of estimated relative (1-SPR) vs. relative spawning biomass for the base model. The relative (1-SPR) is (1-SPR) divided by 0.649 (the SPR target). Relative depletion is the annual spawning biomass divided by the spawning biomass corresponding to 40% of the unfished spawning biomass. 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 coastwide 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.
  - 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 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 40^{o} 10’.