Status of lingcod (*Ophiodon elongatus*) along the northern U.S. west coast in 2021

by

Ian G. Taylor[1]

Kelli F. Johnson[1]

Brian J. Langseth[1]

Andi Stephens[2]

Laurel S. Lam[3]

Melissa H. Monk[4]

Alison D. Whitman[5]

Melissa A. Haltuch[1]

[1]Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, Washington 98112

[2]Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 2032 Southeast OSU Drive, Newport, Oregon 97365

[3]Pacific States Marine Fisheries Commission, Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, Washington 98112

[4]Southwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 110 McAllister Way, Santa Cruz, California 95060

[5]Oregon Department of Fish and Wildlife, 2040 Southeast Marine Science Drive, Newport, Oregon 97365

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Stock

This assessment reports the status of lingcod (*Ophiodon elongatus*) north of 40°10'N along the U.S. west coast using data through 2020. Lingcod were modeled as two stocks split at 40°10'N. This choice is informed by a consideration of genetic differences (Longo et al. 2020) as well as differences in growth and management. Models for lingcod do not include catches or dynamics from the Alaskan, Canadian, or Mexican populations.

Catches

The first known records of lingcod landings date back to the late 1800s (Figure i). Catch reconstructions for these early landings were informed by state resources. Recent landings were available from PacFIN and RecFIN (Table i). Commercial discards were modeled using discard rates and length compositions, which facilitated the estimation of retention curves. Discard mortality was assumed to be 50% for commercial trawl and 7% for commercial fixed-gear and recreational fleets. Recreational catches included estimates of dead discards (Table i).

The fleet structure for commercial landings included two fleets, trawl (TW) and fixed gear (FG). Trawl landings included information from bottom trawls, shrimp trawls, net gear, and dredging activities. Landings from all other gear types, mainly hook and line, were assigned to FG. This fleet structure matches the fleet structure used in the previous assessment.

Table i: Recent commercial landings and recreational catches by fleet (mt), total across fleets, and the total dead including internal estimates of commercial discards.

Year	Comm. trawl	Comm. fixed	Rec. WA	Rec. OR	Rec. CA	Total	Total dead
2011	285.45	64.60	128.56	113.53	39.00	631.14	657.19
2012	384.45	70.45	131.10	152.59	45.44	784.03	811.65
2013	374.22	84.97	125.83	223.46	51.70	860.19	881.28
2014	251.16	90.95	131.33	175.40	67.29	716.13	728.86
2015	182.92	152.43	121.15	229.06	110.60	796.16	808.29
2016	288.88	113.63	166.28	152.48	68.17	789.45	806.49
2017	609.02	129.93	158.65	183.69	63.18	1144.47	1172.02
2018	448.13	141.99	144.50	222.39	57.24	1014.26	1035.71
2019	440.81	159.32	164.68	171.85	44.26	980.92	1004.75
2020	316.46	138.67	116.75	172.47	39.30	783.66	803.86

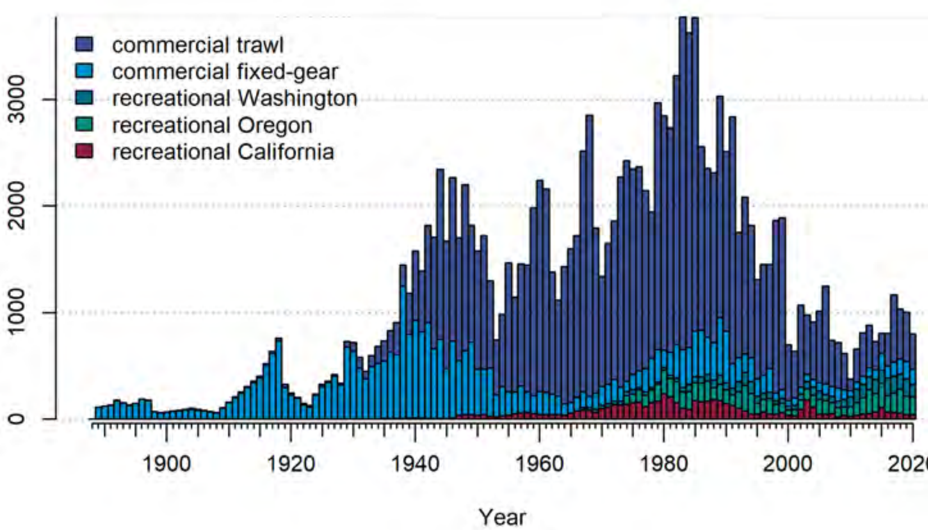

Figure i: Estimated total dead (mt) by fleet (colors) across years since 1889.

Data and assessment

Lingcod has been modeled using various age-structured forward-projection models since the mid 1990s and was most recently assessed in 2017 (Haltuch et al. 2018). This assessment fit all data using a single stock assessment framework, Stock Synthesis 3.30.17.01 (SS3). Data included in the base model provided information on landings for each commercial and recreational fleet; commercial discards, available from the West Coast Groundfish Observer Program; relative abundance as informed by the Triennial Survey, West Coast Groundfish Bottom Trawl Survey, commercial trawl fishery, and each recreational fishery; and length and age compositions, available from the previous sources as well as research by L. Lam.

For this northern stock, information on relative abundance was also available from the Oregon FG fleet.

Age data were explored using conditional-age-at-length rather than marginal ages. Length data were modeled as sex-specific compositions for fish that were sexed and combined-sex compositions for fish that were measured but not sexed. Unsexed fish that were aged and measured for length were not included in the conditional age-at-length data.

Key parameters related to productivity were estimated and parameters related to growth and mortality were sex specific and time invariant. Compensatory stock-recruitment dynamics were assumed, and thus, the Beverton-Holt stock-recruit function was used to model recruitment. Steepness, h, was estimated to account for uncertainty in the shape of the stock-recruit relationship. Main annual recruitment deviations were set to start in 1960, just prior to the availability of reliable length- and age-composition data. Selectivity for each fleet was modeled using a double-normal function of length that allowed for dome or asymptotic shapes that were supported by the data. Time blocks were used for selectivity and retention to account for management changes.

A wide range of sensitivity runs were conducted to explore various model structures related to biology and recruitment, changes to the data that were included in the model, ways in which selectivity was parameterized, etc. Results were particularly sensitive to the addition and subtraction of age data, which typically changed the scale of the population and estimates of key productivity parameters.

Stock biomass and dynamics

The stock biomass is currently trending downwards, though the rate of the decline is highly uncertain (Table ii; Figure ii). Although the biomass is currently estimated to be declining, no estimate is below the minimum stock size threshold and all estimates since the late 1990s are above the management target (Figure iii).

Table ii: Estimated recent trend in spawning biomass and the fraction unfished and the 95 percent intervals.

Year	Spawning biomass (mt)	Lower interval	Upper interval	Fraction unfished	Lower interval	Upper interval
2011	11147	7126	15168	0.650	0.518	0.781
2012	12969	8282	17656	0.756	0.603	0.909
2013	13732	8807	18656	0.800	0.640	0.960
2014	13843	8932	18754	0.807	0.648	0.965
2015	13408	8746	18070	0.781	0.633	0.930
2016	13143	8619	17667	0.766	0.623	0.909
2017	13377	8802	17951	0.780	0.635	0.924
2018	12433	8168	16697	0.725	0.590	0.859
2019	11658	7642	15672	0.679	0.552	0.807
2020	11183	7288	15078	0.652	0.527	0.777
2021	11010	7143	14878	0.642	0.515	0.768

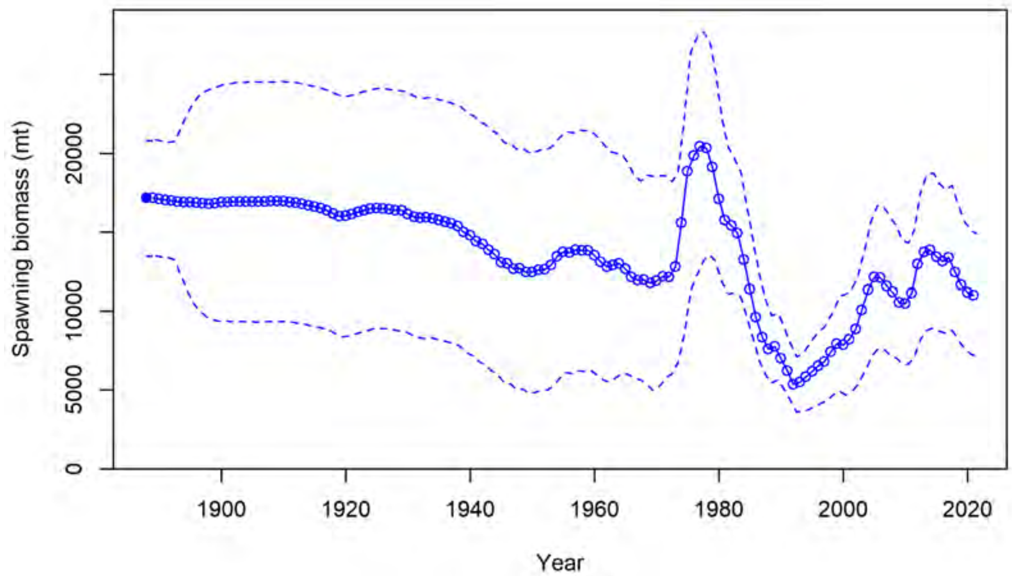

Figure ii: Estimated time series of spawning output (circles and line are maximum likelihood estimates; light broken lines are 95% intervals) for the base model.

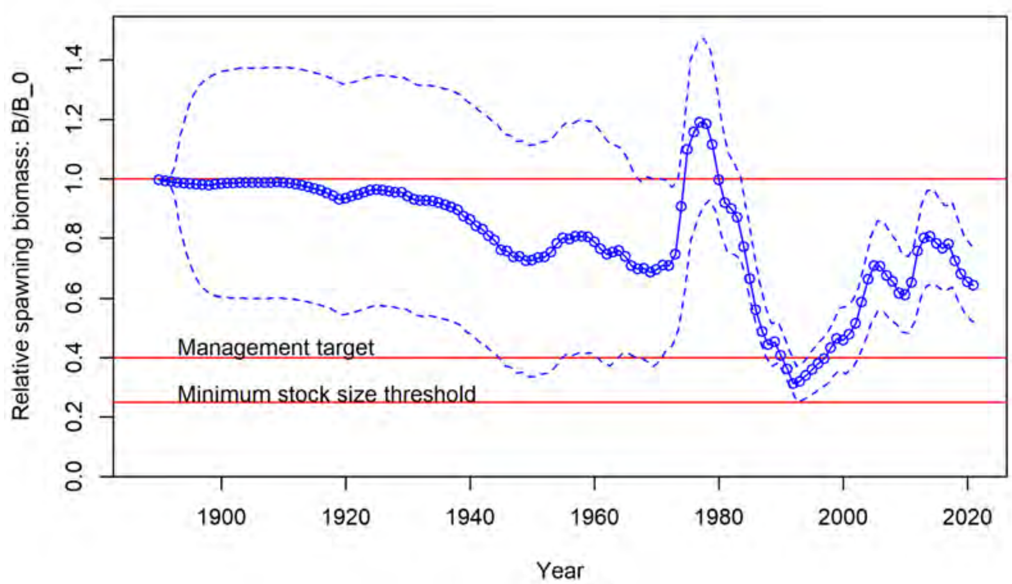

Figure iii: Estimated time series of fraction of unfished spawning output (circles and line are maximum likelihood estimates; light broken lines are 95% intervals) for the base model.

Recruitment

Steepness was estimated ($\hat{h} = 0.80$) rather than fixed at a point value to capture uncertainty in the resilience of lingcod to harvesting. Lingcod appear to have moderate variability in estimates of recruitment with recruitment variability (σ_R) fixed at 0.6 (Figures iv and v).

Large recruitments of age-0 fish were estimated as having occurred in 2013 and 2018. The south area also had a large recruitment event in 2013, but not 2018.

The 2019 and 2020 estimates of recruitment deviations were not included in the main recruitment deviations and are instead termed late recruitment deviations that are not constrained to sum to zero (Table iii). Given the pandemic and the lack of recent survey information, there was little information in the data to estimate recruitment in 2019 and the uncertainty about this estimate is relatively large. Lingcod are not collected as age-0 fish in appreciable quantities, limiting the ability to estimate the terminal year of recruitment.

Table iii: Estimated recent trend in recruitment and recruitment deviations and the 95 percent intervals.

Year	Recruitment (1000s)	Lower interval	Upper interval	Recruitment deviations	Lower interval	Upper interval
2011	10611	6232	18067	-0.250	-0.460	-0.041
2012	10832	6421	18274	-0.243	-0.442	-0.044
2013	21762	13156	36000	0.450	0.300	0.601
2014	7629	4459	13052	-0.599	-0.840	-0.357
2015	10034	5986	16818	-0.322	-0.526	-0.118
2016	13159	7804	22188	-0.050	-0.257	0.158
2017	9854	5661	17153	-0.340	-0.629	-0.051
2018	18745	10567	33253	0.309	-0.026	0.644
2019	7823	3231	18942	-0.637	-1.444	0.170
2020	16198	5131	51141	0.000	-1.176	1.176
2021	16175	5123	51066	0.000	-1.000	1.000

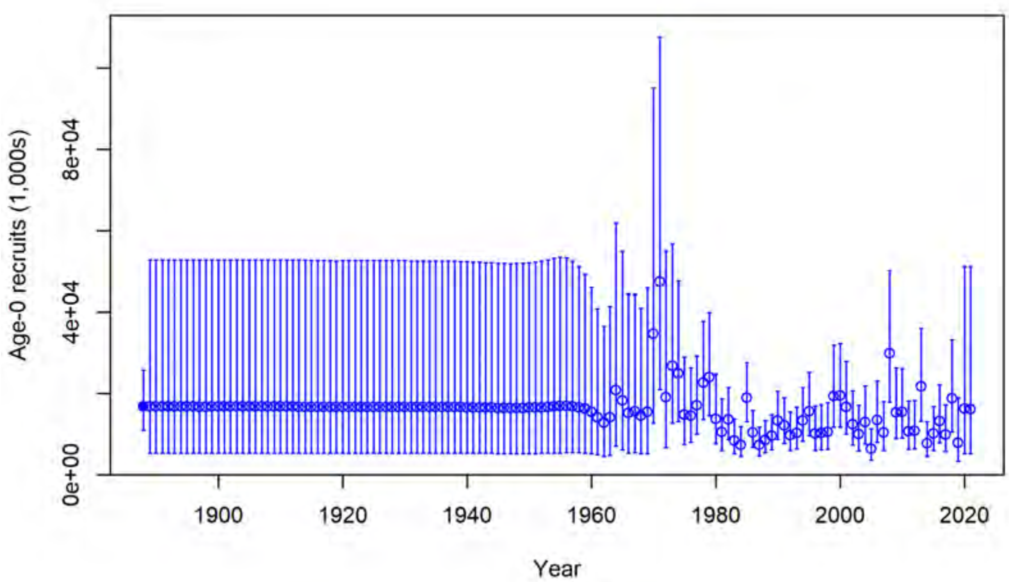

Figure iv: Estimated time series of age-0 recruits (1000s) for the base model with 95% intervals.

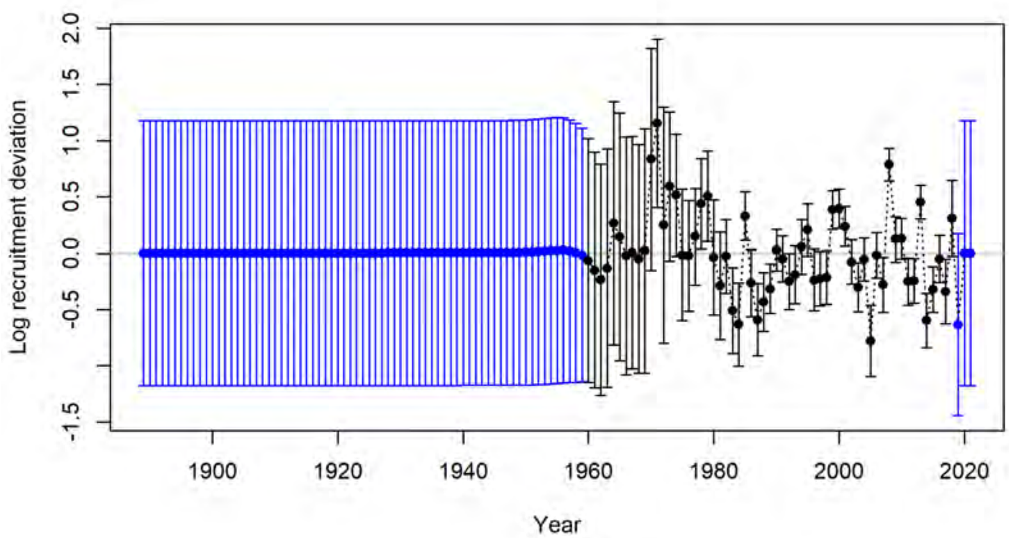

Figure v: Estimated time series of recruitment deviations. Black points are for years that were constrained to sum to zero and are part of the 'main' period, and blue points are for early deviations (left) and late or forecast deviations (right). Bars represent 95% intervals.

Exploitation status

The exploitation rate, annual total dead catch divided by age 3+ biomass, was estimated to have never been above the target proxy exploitation rate (Table iv; Figure vi). Recent estimates of fishing intensity, $1 - SPR$, indicate stability within the fishery and are close to pre-1950 estimates. Relative fishing intensity, $(1 - SPR)/(1 - SPR_{45\%})$, is estimated to have peaked in 1991 at 0.93.

Table iv: Estimated recent trend in relative fishing intensity, $(1 - SPR)/(1 - SPR45\%)$, and exploitation rate with associated 95% intervals. Fishing intensity is $1-SPR$, where the spawning potential ratio (SPR) has a target of 45%, $SPR_{45\%}$. Exploitation rate is annual total dead catch divided by age 3+ biomass.

Year	Relative fishing intensity	Lower interval	Upper interval	Exploitation rate	Lower interval	Upper interval
2011	0.214	0.129	0.300	0.026	0.016	0.036
2012	0.232	0.141	0.323	0.031	0.019	0.042
2013	0.232	0.141	0.323	0.032	0.020	0.044
2014	0.193	0.116	0.269	0.028	0.017	0.038
2015	0.217	0.133	0.301	0.032	0.020	0.043
2016	0.222	0.137	0.307	0.030	0.019	0.041
2017	0.314	0.200	0.428	0.047	0.030	0.063
2018	0.297	0.187	0.407	0.044	0.029	0.060
2019	0.306	0.193	0.419	0.044	0.029	0.060
2020	0.262	0.163	0.361	0.038	0.024	0.051

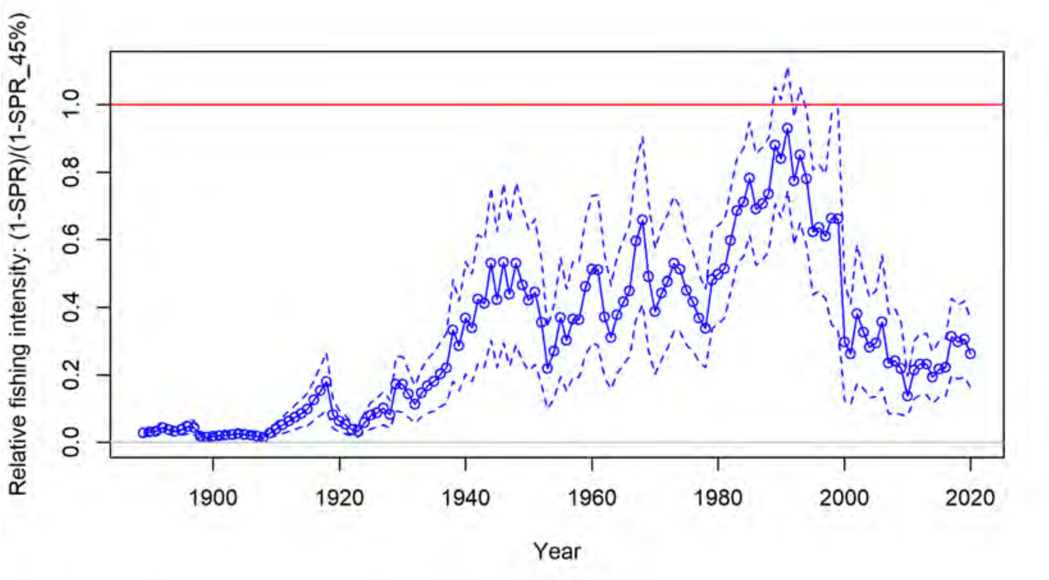

Figure vi: Estimated relative fishing intensity, $(1 - SPR)/(1 - SPR45\%)$, with 95% intervals. Fishing intensity is $1 - SPR$, where the spawning potential ratio (SPR) has a target of 45%, $SPR_{45\%}$. The red horizontal line at 1.0 indicates fishing intensity equal to the target and values above this reflect harvest in excess of the proxy harvest rate.

Ecosystem considerations

Ecosystem considerations were not explicitly included in this analysis. However, habitat variables were included in some of the models used to standardize commercial and recreational catch per unit effort (CPUE) data prior to including that information as an index in the stock assessment model. Future work could expand upon that done by Bassett et al. (2018), which found that ontogenetic habitat shifts could be an age restriction on the lingcod able to benefit from the placement of Rockfish Conservation Areas (RCAs) and Marine Protected Areas (MPAs).

Given the predatory nature of lingcod, they more than likely influence the natural mortality of rockfish species that are highly targeted by recreational fishers (e.g., Beaudreau and Essington 2007). When diet data are collected at a sufficient spatial resolution to inform predatory relationships, the estimated abundance of lingcod could be used to inform estimates of time-varying natural mortality for these longer-lived rockfish species.

Reference points

The estimate of 2021 spawning biomass relative to unfished equilibrium biomass (fraction unfished = 0.6416) was well above the management target of 40% (Table v and Figure vii). Even the lower 95% interval was estimated to be above the target (Table v). Only a few years during the modeled period were estimated to be below the target (blue points to the left of the vertical line at 0.4 in Figure vii).

Equilibrium yield given the estimate of steepness shows disparity between maximum sustainable yield (blue) and the target biomass (red; Figure viii). Whereas, the target biomass is in line with the SPR target (green; Figure viii).

Table v: Summary of reference points and management quantities, including estimates of the 95 percent intervals.

Reference point	Estimate	Lower interval	Upper interval
Unfished Spawning Biomass (mt)	17159.8	13486.7	20832.9
Unfished Age 3+ Biomass (mt)	32693	24945	40441
Unfished Recruitment (R0)	16734.6	9454.1	24015.1
Spawning Biomass (mt) (2021)	11010.2	7142.9	14877.5
Fraction Unfished (2021)	0.6416	0.5154	0.7679
Reference Points Based SB40%	-	-	-
Proxy Spawning Biomass (mt) SB40%	6863.91	5394.67	8333.15
SPR Resulting in SB40%	0.4372	0.3741	0.5002
Exploitation Rate Resulting in SB40%	0.2322	0.1794	0.2849
Yield with SPR Based On SB40% (mt)	3707.56	2395.74	5019.38
Reference Points Based on SPR Proxy for MSY	-	-	-
Proxy Spawning Biomass (mt) (SPR45)	7098.53	5534.9	8662.16
SPR45	0.45	NA	NA
Exploitation Rate Corresponding to SPR45	0.2224	0.2043	0.2404
Yield with SPR45 at SB SPR (mt)	3644.93	2488.92	4800.94
Reference Points Based on Estimated MSY Values	-	-	-
Spawning Biomass (mt) at MSY (SB MSY)	3675.78	1155.11	6196.45
SPR MSY	0.2629	0.0618	0.4639
Exploitation Rate Corresponding to SPR MSY	0.4301	0.0889	0.7713
MSY (mt)	4222.53	2271.07	6173.99

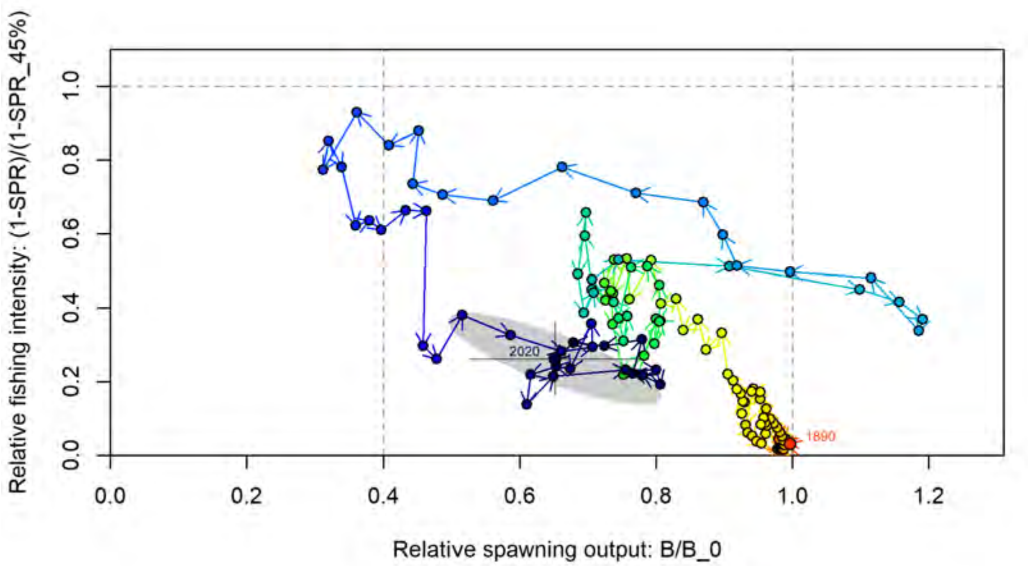

Figure vii: Phase plot of biomass ratio vs. spawning potential ratio (SPR) ratio. Each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show 95% intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95% region which accounts for the estimated correlation between the two quantities.

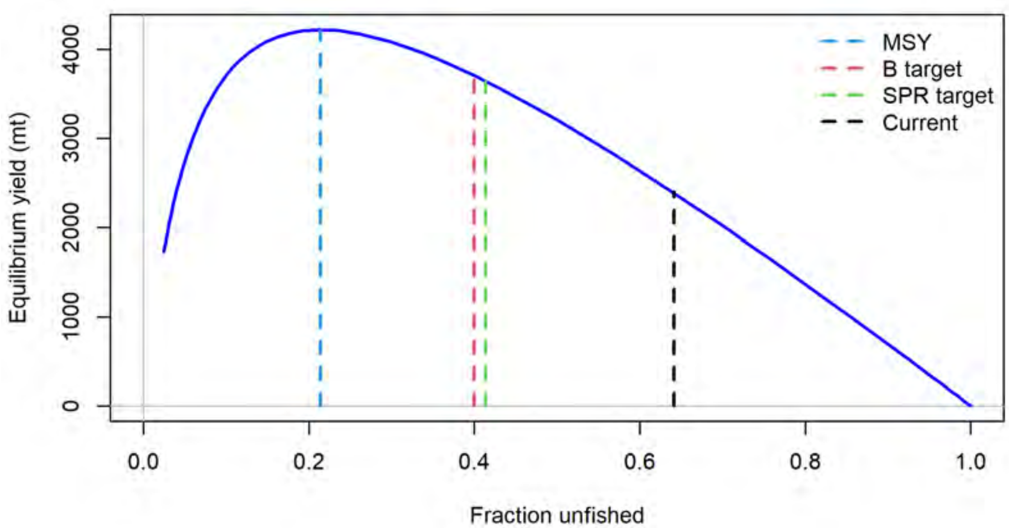

Figure viii: Equilibrium yield curve. Values are based on the 2020 fishery selectivities.

Management performance

In the last ten years, the annual catch limit has been set equal to or below the annual catch limit (Table vi). Landings and total dead catches (including estimated dead discards) have been well below the annual catch limit.

Table vi: Recent trend in the overfishing limits (OFLs), the acceptable biological catches (ABCs), the annual catch limits (ACLs), the total landings, and total mortality (mt).

Year	OFL	ABC	ACL	Landings	Total dead
2011	2438	2330	2330	631.14	657.19
2012	2251	2151	2151	784.03	811.65
2013	3334	3036	3036	860.19	881.28
2014	3162	2878	2878	716.13	728.86
2015	3010	2830	2830	796.16	808.29
2016	2891	2719	2719	789.45	806.49
2017	3549	3333	3333	1144.47	1172.02
2018	3310	3110	3110	1014.26	1035.71
2019	5110	4884	4871	980.92	1004.75
2020	4768	4558	4541	783.66	803.86

Unresolved problems and major uncertainties

The base-model configuration was developed with the goal of balancing parsimony with realism while fitting the data. To achieve parsimony, some simplification of the model structure was assumed relative to known processes, which may impact the interpretation and fit to specific data sets. For example, a clear break between the northern and southern stock at Cape Mendocino is unrealistic but we do not currently have the resources necessary to add spatial dynamics to the stock assessment or estimate the level of overlap between the stocks.

Patterns of sex-specific selectivity were apparent in the data, particularly for the fishing fleets. Unfortunately, we were unable to configure the model in such a way that the model fit all data sources equally as well as the base-model configuration when attempting to account for these patterns. Numerous attempts at sex-specific selectivity were explored shortly before and during the stock assessment review. However, overparameterization proved an insurmountable problem. There are more than 50 selectivity parameters in the base model (with selectivity equal for females and males), so adding sex-specific offsets or separate parameters caused estimation problems and implausible selectivity patterns. Options explored included sex-specific offsets for the height of the peak selectivity as well as offsets for the position of the peak and the descending slopes. Therefore, new research to develop an theoretical basis for sex-specific differences in selectivity or availability using differences in spatial distribution or behavior may be a more fruitful path for future selectivity setups than relying simply on fits to data and other model diagnostics.

Uncertainty in parameter estimates are quite large relative to recent assessments because of the choice to estimate both natural mortality and steepness. Recent work has shown the utility of estimating both parameters with respect to management reference points, and although estimates provided in this document are imprecise, we predict that the estimated reference points are less biased than if the model would have been configured with one or more of these parameters as fixed inputs rather than estimated. Estimating both parameters led to counter-intuitive differences in estimates of natural mortality between the southern and northern areas. Hopefully, future work on parameterizing selectivity will lead to more precise estimates of male and female natural mortality given the life history of this species, specifically the nest-guarding behavior of males.

The internal estimates of total catch including dead discards for some recent years are higher than those provided by the Groundfish Expanded Multiyear Mortality (GEMM) reports. This may be the result of the status-quo data weighting approach which applies the same sample size multiplier to the discard and retained length composition data within any given fleet, in spite of the sample sizes often being unbalanced among these sources relative to the magnitude of the catch. Alternative models were explored during the assessment review, whereby the input sample sizes for the discard data were adjusted as an ad-hoc refinement to the data weighting or the uncertainty associated with the discard rate was reduced to force the model to fit these rates more precisely. Neither sensitivity had much impact on estimates of population trajectories or stock status so this issue was shelved for future research.

Decision table

The forecast of stock abundance and yield was developed using the base model (Table vii). The total catches for the first two years of the forecast period were based on values provided by the Groundfish Management Team. These assumed removals are likely higher than what the true removals will be for this year and next year but their influence on the assessment of stock status and future removals are limited.

The states of nature in the decision table (Table viii) do not fall on a single axis of uncertainty. Instead, two alternative model structures were chosen from the set of sensitivity analyses to represent alternative states of nature. This represents the consensus among the participants in the STAR panel as a better representation of uncertainty than any axis could. The low state of nature included sex-specific selectivity while the high state excluded the fishery-dependent age data.

Three alternative catch streams were created for the decision table (Table viii). The first option uses recent average catch as provided by the Groundfish Management Team, the second option uses a P^* of 0.40, and the third option uses a P^* of 0.45. These P^* values are combined with the category 2 default $\sigma = 1.0$ in calculating the buffer between overfishing limit (OFL) and Acceptable Biological Catch (ABC).

Table vii: Projections of potential overfishing limits (OFLs; mt), allowable biological catches (ABCs; mt), annual catch limits (ACLs; mt), estimated summary biomass (mt), spawning biomass (mt), and fraction unfished. Values are based on removals for the first two years. ABCs include a buffer for scientific uncertainty based on a P^* of 0.45 and the category 2 default sigma = 1.0. ACLs additionally include the 40:10 adjustment for projections which fall below the B_{40} reference point.

Year	Assumed Removal (mt)	Predicted OFL (mt)	ABC Catch (mt)	ACL Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Fraction Unfished
2021	1,200.00	-	-	-	22,609.40	11,010.20	0.64
2022	1,200.00	-	-	-	21,210.50	11,090.40	0.65
2023	-	5,009.58	4,378.38	4,378.38	21,713.70	10,721.60	0.62
2024	-	4,455.19	3,853.74	3,853.74	19,834.90	9,344.89	0.54
2025	-	4,236.98	3,631.09	3,631.09	19,014.60	8,725.91	0.51
2026	-	4,163.11	3,534.48	3,534.48	18,678.90	8,448.57	0.49
2027	-	4,139.97	3,481.71	3,481.71	18,503.70	8,320.40	0.48
2028	-	4,128.36	3,438.92	3,438.92	18,389.40	8,244.60	0.48
2029	-	4,119.63	3,402.82	3,402.82	18,312.30	8,195.34	0.48
2030	-	4,113.85	3,365.13	3,365.13	18,266.10	8,165.81	0.48
2031	-	4,113.46	3,331.91	3,331.91	18,251.90	8,156.13	0.48
2032	-	4,118.34	3,307.03	3,307.03	18,263.50	8,162.47	0.48

Table viii: Decision table with 10-year projections based on two years of recent average catch, alternative states of nature (columns), and management assumptions (rows) annual catch limits (ACLs) defined using an estimate of uncertainty (i.e., P^*) of 0.40 and 0.45. Colors of catch and fraction unfished are relative with lighter colors representing lower values. Italics indicate years were the full catch could not be removed from the low state of nature because of insufficient biomass.

			Low (sex-selectivity)		Base		High (no fishery ages)	
Assumption	Year	Catch	SSB (mt)	Frac. unfished	SSB (mt)	Frac. unfished	SSB (mt)	Frac. unfished
Recent avg. catch	2021	1200	22435	0.614	11010	0.642	17623	0.719
	2022	1200	22194	0.608	11090	0.646	18276	0.746
	2023	1200	21710	0.595	10722	0.625	17921	0.731
	2024	1200	21378	0.586	10967	0.639	18031	0.736
	2025	1200	21145	0.579	11415	0.665	18325	0.748
	2026	1200	20980	0.575	11879	0.692	18656	0.761
	2027	1200	20871	0.572	12299	0.717	18975	0.774
	2028	1200	20809	0.570	12657	0.738	19264	0.786
	2029	1200	20786	0.569	12955	0.755	19515	0.797
	2030	1200	20789	0.569	13199	0.769	19729	0.805
	2031	1200	20817	0.570	13396	0.781	19908	0.813
	2032	1200	20858	0.571	13554	0.790	20057	0.819
ACL P^*=0.40	2021	1200	22435	0.614	11010	0.642	17623	0.719
	2022	1200	22194	0.608	11090	0.646	18276	0.746
	2023	3817	21710	0.595	10722	0.625	17921	0.731
	2024	3418	19403	0.531	9628	0.561	16608	0.678
	2025	3246	17270	0.473	9175	0.535	15882	0.648
	2026	3165	15256	0.418	9005	0.525	15454	0.631
	2027	3117	13339	0.365	8957	0.522	15194	0.620
	2028	3073	11512	0.315	8950	0.522	15024	0.613
	2029	3028	9780	0.268	8963	0.522	14913	0.609
	2030	2984	8141	0.223	8993	0.524	14846	0.606
	2031	2942	6597	0.181	9038	0.527	14813	0.605
	2032	2905	5143	0.141	9096	0.530	14809	0.604
ACL P^*=0.45	2021	1200	22435	0.614	11010	0.642	17623	0.719
	2022	1200	22194	0.608	11090	0.646	18276	0.746
	2023	4378	21710	0.595	10722	0.625	17921	0.731
	2024	3854	18967	0.519	9345	0.545	16305	0.665
	2025	3631	16435	0.450	8726	0.509	15386	0.628
	2026	3534	14047	0.385	8449	0.492	14825	0.605
	2027	3482	11768	0.322	8320	0.485	14464	0.590
	2028	3439	9587	0.263	8245	0.480	14209	0.580
	2029	3403	7509	0.206	8195	0.478	14024	0.572
	2030	3365	*5541*	*0.152*	8166	0.476	13887	0.567
	2031	3332	*3805*	*0.104*	8156	0.475	13790	0.563
	2032	3307	*2392*	*0.066*	8162	0.476	13723	0.560

Scientific uncertainty

The model estimated uncertainty around the 2021 spawning biomass was $\sigma = 0.18$ and the uncertainty around the OFL was $\sigma = 0.23$.

This is likely an underestimate of overall uncertainty because there is no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature).

The category 2 default $\sigma = 1.0$ is used to apply scientific uncertainty in the projections.

Regional management considerations

Commercial quotas for lingcod are set separately for the areas north and south of 40°10'N. This management boundary, which is based on the boundary between International North Pacific Fishery Commission (INPFC) areas, happens to align with the stock boundary used for this assessment.

Recreational quotas for lingcod are set separately for each state, which aligns with the fleet structure used in this model. The catch associated with the California recreational fleet was split at 40°10'N based on location of landing, and thus, at least some California recreational catches are assigned to each stock. Projections for this fleet should be a combination of those given in this report as well as those reported in the output for the south model.

The average proportions of the total dead catch, including estimated dead discards, associated with each fleet over the period 2011-2020 are:

- commercial trawl: 0.432,
- commercial fixed-gear: 0.135,
- recreational Washington: 0.159,
- recreational Oregon: 0.206, and
- recreational California: 0.067.

Research and data needs

Investigating and or addressing the following items could improve future assessments of lingcod:

- Sex-specific selectivity is likely given the life history of lingcod. However, knowledge of the fine-scale spatial distribution of ages and sexes relative to the distribution of fishing effort and survey sampling locations is lacking to inform these patterns. Some relationships may be dome-shaped while others may be asymptotic and these relationships could depend on whether the process is governed by length or age. Care should be taken during explorations of selectivity to ensure that the model does not become overparameterized given that selectivity and mortality are correlated.

- Some data sources that were provided by state representatives were not fully explored, e.g., information from video landers and remote operated vehicles (ROVs). Currently, there is not a method to include multiple indices for a given fishery, and thus, the best-case scenario would be to provide comparisons of model results given fits to these alternative data sources rather than those that were used to fit the model. Additional work would be needed to formulate a method to combine them or allow for the inclusion of multiple CPUE indices for a given fleet.
- It is likely that natural mortality is not constant across age as it was parameterized. Exploration of the Lorenzen natural mortality function produced results that were similar to the base model for the north and implausibly low in the south. Additional approaches are available to model age-specific natural mortality that could also be explored.
- Data-weighting approaches that separate tuning of sample sizes for discarded and retained fish from the same fleet should be explored such that data on discard rates and mean body weight can be weighted appropriately. These changes will hopefully bring the estimates of total mortality for years with high discard rates closer to the values reported in the Groundfish Expanded Mortality Multi-Year (GEMM) data product based on data collected by West Coast Groundfish Observer Program (WCGOP).
- Conflicts were present in the information provided by the age and length data.

1 Introduction

1.1 Basic information

This assessment reports the status of lingcod (*Ophiodon elongatus*) north of 40°10'N along the U.S. west coast using data through 2020. Lingcod were modeled as two stocks split at 40°10'N. This choice is informed by a consideration of genetic differences (Longo et al. 2020) as well as differences in growth and management. Models for lingcod do not include catches or dynamics from the Alaskan, Canadian, or Mexican populations.

1.2 Life history

1.2.1 Geography

Lingcod are large opportunistic predators endemic to the North Pacific (Figure 1), ranging from the Gulf of Alaska to central Baja California, Mexico (Wilby 1937; Hart 1973). Typically, the center of abundance can be found off the coasts of British Columbia and Washington State (Hart 1973). Lingcod are demersal on the continental shelf, display a patchy distribution, and are most abundant in areas of hard bottom with rocky relief (Rickey 1991). They typically occur at depths less than 200 m but are caught in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) up to depths of 450 m.

1.2.2 Growth and maturity

Lingcod are sexually dimorphic, with females typically growing faster and attaining larger asymptotic sizes than males (Richards et al. 1990). Females also reach maturity at larger sizes (Miller and Geibel 1973; Cass et al. 1990) than males. Both males and females exhibit a latitudinal trend in growth, longevity, and size at maturity. Consequently, individuals from northern waters generally grow faster, live longer, and mature at larger sizes than individuals from southern regions (Richards et al. 1990; Silberberg et al. 2001; Lam 2019).

Lingcod are iteroparous spawners. Male lingcod aggregate in late fall and move to rocky habitat in intertidal waters to depths of up to 126 m (Giorgi 1981; O'Connell 1993) where they guard areas suitable for spawning. This movement has been correlated with a decline in the proportion of males in offshore trawl landings in late fall off California (Miller and Geibel 1973), British Columbia (Cass et al. 1990), and Washington (Jagielo 1994). Mature females are rarely seen on the spawning grounds and appear to move from deep-water habitats into spawning areas only for a brief period to deposit eggs (Giorgi 1981). Larger and older females appear to spawn first (Cass et al. 1990), depositing up to 500,000 eggs in high current areas (Hart 1973; Low and Beamish 1978). After fertilization, males guard clutches until the eggs hatch in six to eight weeks (Withler et al. 2004; King and Withler 2005), between January and June (Jewell 1968; Low and Beamish 1978). Recent maturity studies suggest that lingcod are batch spawners with the ability to spawn year round (pers. comm., M. Head, Northwest Fisheries Science Center (NWFSC)). Peak spawning takes place during October through December.

At hatching, lingcod larvae are about 12 mm in total length and are epipelagic for approximately 90 days, until reaching about 70 mm and settling to soft bottom habitats (Hart 1973; Phillips and Barraclough 1977; Cass et al. 1990). Epipelagic larvae feed on small copepods and copepod eggs, shifting to larger copepods and fish larvae as they grow (Phillips and Barraclough 1977). Young of the year (YOY) typically recruit to sandy, low-relief habitat near eelgrass or kelp beds, staying on soft bottom until they grow to at least 350 mm in length. After reaching 350 mm, they move into rocky, high-relief substrate, which is the preferred adult habitat (Petrie and Ryer 2006; Bassett et al. 2018).

Newly settled juveniles are typically found at depths ranging from 9-55 m (Miller and Geibel 1973; Phillips and Barraclough 1977; Coley et al. 1986). They often start in nearshore areas of sandy substrate (Buckley et al. 1984), move to a wider range of flat bottom areas by September (Cass et al. 1990), and then move into habitats of similar relief and substrate inhabited by adults while ages one to two but remain at shallower depths. Off the coast of California, they tend to initiate this latter move starting at around 35 cm in length (Miller and Geibel 1973). Whereas, off the coast of Washington, juveniles have been found in hard bottom shell-cobble habitat near rocks in 9-15 m of water off the coast of Grays Harbor as soon as October (Coley et al. 1986).

Juvenile density in trawlable habitats tends to be higher in the south than in the north (Tolimieri et al. 2020). Particularly, in central California shelf waters (50-240 m) between 34° N and 39° N and, just north of Cape Mendocino and Cape Blanco between 41° N and 43° N, albeit at smaller densities. These results are based on the WCGBTS, which has an inshore limit of 55 m, and thus, the results do not account for potential differences in juvenile habitat in the north versus the south. Off of Washington, juveniles have been collected from the mouth of the Pysht River in the Strait of Juan de Fuca, Grays Harbor and Willapa Bay, and from coastal waters nearshore to these embayments (Buckley et al. 1984; Jagielo 1994).

Juvenile lingcod feed on small fishes (Cass et al. 1990) including Pacific Herring (*Clupea pallasii*), Pacific Sand Lance (*Ammodytes hexapterus*), flatfishes (*Pleuronectidae*), Shiner

Perch (*Cymatogaster aggregate*), Walleye Pollock (*Theragra chalcograma*), and an assortment of invertebrates including shrimps (Neomysis) and prawns (Pandalus). As juvenile lingcod begin to move into rocky habitats and exceed 30 cm, other rocky reef bottomfishes become a more prominent component of their diet, making up 48.8% of total prey biomass by weight (Beaudreau and Essington 2007).

Phillips and Barraclough (1977) estimated that YOY growth was approximately 1.3 mm day^{-1}. Buckley et al. (1984) reported YOY growth from June to September in the Strait of Juan de Fuca also averaged 1.3 mm day^{-1}. Samples from the mouth of the Pysht River averaged 96 mm in June, 135 mm in July, 173 mm in August, and 200 mm in September (Jagielo 1994).

1.2.3 Habitat use

Outside of the spawning season, male and female lingcod are segregated by depth. Females tend to inhabit deeper offshore waters, and males inhabit nearshore rocky reefs. Consequently, the sexes are vulnerable to different types of fishing gear. The majority of nearshore males (66.3%) are caught using hook-and-line or spearfishing gear, and the majority of deep water females (62.4%) are caught using trawl gear (Miller and Geibel 1973). Fishery and survey data indicate that male lingcod tend to be more abundant than females in shallow waters and the size of both sexes increase with depth (Jagielo 1994).

The movement and migration of lingcod has been extensively studied through tag-recapture methods and acoustic arrays. As adults, lingcod have a high (e.g., 95%, Cass et al. 1990; and 81%, Jagielo 1990) degree of site fidelity and tend to stay within an 8 km home range. Movement is apparent between coastal areas off Washington and southwest Vancouver Island but there is little interchange between these areas and the inland marine waters of Puget Sound and the Strait of Georgia (Cass et al. 1990; Jagielo 1990). However, some exceptional movements have been reported. For example fish tagged off of Cape Flattery, Washington were recaptured as far north as Queen Charlotte sound (195 km) and as far south as Cape Falcon (120 km) (Jagielo 1990). One fish tagged as a juvenile was recovered 510 km to the south in Oregon.

High site fidelity was also found using acoustic tags in Alaskan waters (Starr et al. 2005) and off of Central California (Greenley 2009). While lingcod exhibit high site fidelity with an established location of residence, they frequently leave for 1-5 days traveling around 2 km to feed, only to return home for a longer duration. Large females generally had shorter residency times, spending more time outside of their tagged site. Additional acoustic studies in Prince William Sound reported that 50 cm individuals thought to be 2-4 years old disperse from nearshore reefs during spawning season, most likely due to displacement by older and larger spawning individuals (Bishop et al. 2010; Stahl et al. 2014). Overall, residency times varied by sex, size, season, and habitat of residence.

1.2.4 Diet and trophic ecology

Lingcod are top-order predators of the family Hexagrammidae. Among the Hexagrammidae, the genus *Ophiodon* is ecologically intermediate between the more littoral genera *Hexagrammos* and *Oxylebius* and the more pelagic *Pleurogrammus* (Rutenberg 1962).

Being opportunistic predators, lingcod feed on a variety of fishes (pelagic and demersal), cephalopods, and crustaceans (Wilby 1937). Their feeding strategies are known to vary with depth of occurrence, latitude, sex, and size (pers. comm., B. Brown, Moss Landing Marine Laboratories (MLML)). Geographic variation in trophic level is associated with oceanographic factors such as sea-surface temperature or chlorophyll-a density that likely corresponds to shifts in prey availability, suggesting a similar shift in the predatory role of lingcod in coastal environments.

Male lingcod caught in shallow depths have more diverse diets and consume more prey items that are of a lower trophic level (e.g,. cephalopods) than females caught in deep depths that have less diverse diets and consume more prey items that are of a higher trophic level (e.g., groundfishes). Preliminary observations from lingcod stomach contents sampled from Washington to California in both nearshore and offshore habitats indicate a higher occurrence of bony fishes in the diet of northern fish than those collected off of California (pers. comm., B. Brown, MLML). Fish collected off of California and southern Oregon had a higher occurrence of cephalopods in their diet than fish collected from more northern waters. This latitudinal shift in prey composition suggests differences in feeding behavior and the predatory role of lingcod in coastal environments. Being opportunistic feeders, it is not a surprise that rockfish biomass in the lingcod diet increases by three-fold for lingcod found inside marine reserves compared to those found outside of reserves (Beaudreau and Essington 2007).

1.2.5 Stock delineation

Longo et al. (2020) used restriction-site associated deoxyribonucleic acid sequencing techniques and discovered evidence for distinct north and south genetic clusters with the presence of admixed individuals (i.e., mixes of previously diverged or isolated genetic lineages) in the region of overlap. Pure northern-cluster individuals represented over 80% of the samples at 42.2° N and all sampled sites that were further to the north. Pure southern-cluster individuals represented over 80% of the samples at all sampled sites south of 35.2° N. Only two sites were sampled within the range where most admixed individuals were found, 38.6° N and 39.5° N. Thus, it was difficult to define a clean break between the clusters. The general results of the occurrence of two distinct genetic clusters were contrary to previous genetic work using mitochondrial deoxyribonucleic acid that found no genetic differentiation in the lingcod population (Marko et al. 2007).

The recent genetic results concurred with results from recent work demonstrating that lingcod growth, longevity, and timing at maturity exhibit a latitudinal gradient. Lingcod from higher latitudes are larger at age (Figure 2), live longer, and reach biological maturity at larger sizes (Figure 64) compared to conspecifics from lower latitudes (Lam et al. (2021); pers. comm., M. Head, NWFSC).

This known variability in life-history parameters and genetic structure led to the reexamination of the previous stock boundary used for lingcod, located at the California - Oregon border (Hamel et al. 2009; Haltuch et al. 2018). A break point at Cape Mendocino, California ($40^{\circ}10'$ N) was chosen for this assessment because it (1) falls within the mixing zone of the two genetic clusters, (2) falls in the vicinity of where the greatest difference in lingcod size-at-age was detected (Figure 2), and (3) aligns with the federal management boundary for commercial quotas and a boundary between two California Department of Fish and Wildlife (CDFW) management regions, which facilitates the application of assessment results for future management and separation of historical catch.

1.3 Ecosystem considerations

Ecosystem considerations were not explicitly included in this analysis. However, habitat variables were included in some of the models used to standardize commercial and recreational CPUE data prior to including that information as an index in the stock assessment model. Future work could expand upon that done by Bassett et al. (2018), which found that ontogenetic habitat shifts could be an age restriction on the lingcod able to benefit from the placement of RCAs and MPAs.

Given the predatory nature of lingcod, they more than likely influence the natural mortality of rockfish species that are highly targeted by recreational fishers (e.g., Beaudreau and Essington 2007). When diet data are collected at a sufficient spatial resolution to inform predatory relationships, the estimated abundance of lingcod could be used to inform estimates of time-varying natural mortality for these longer-lived rockfish species.

1.4 Historical and current fishery information

Lingcod fisheries have a long history (Table 1 and Figures 15-16). The earliest evidence of fishing for lingcod comes from the remains of 51 archaeological sites representing the period between 6200 BC and 1830 AD on the central California coast from San Mateo to San Luis Obispo (Gobalet and Jones 1995). The commercial fishery off California dates back more than a century to at least the 1890s and the fisheries off of Washington and Oregon date back nearly as far (i.e., 1940s). These commercial fishers are largely harvesting using trawl and longline gear. For longline and other fixed gear in waters off of California, the majority of the landings from these gear types have consistently been landed off of the southern rather than the northern portion of the coast (upper panel of Figure 5). Comparatively, the trawl fishery off of the California coast has progressively shifted north with time (lower panel of Figure 5). Recreational fisheries are dominated by hook-and-line and spear methods.

The commercial fishery steadily grew with the rise of the groundfish trawl industry. Commercial landings peaked in the early 1980s and were followed by decreasing landings because of management measures implemented due to population declines. Management largely relied on seasonal closures and size limits to limit landings. Coastwide, the lingcod fishery was declared overfished in 1999. With the combination of a federal rebuilding plan implemented during 2003 and years of good recruitment, the population was deemed recovered in 2005, four years ahead of the projected recovery time.

In California, the recreational lingcod fishery has had substantial landings that have surpassed that of the commercial fleet operating in California waters since 1998 (Table 1). At the peak of the lingcod fishery, in 1980, the landings were nearly equally divided between the commercial and recreational fleets. From 1980 to 2008, 95% to 97% of lingcod caught were taken by boat-based anglers via commercial passenger fishing vessels (CPFVs) and private/rental boats. Private boat landings were higher than those from CPFVs. A small fraction of landings are from spear fishers using SCUBA or free diving gear (Lynn 2008).

Catches of lingcod in Oregon and Washington have shifted from the commercial trawl fleet, which accounted for 90% of landings during its mid-1980s peak, to a fishery evenly split between commercial and recreational landings in recent years. Between 1980 and 1996, the majority of lingcod were caught by the bottom trawl fishery (>75%), followed by troll and hook-and-line (between 10-20%), with a small fraction of additional landings from pots and traps, nets, and shrimp trawls (Jagielo et al. 1997). Since 1999, however, the recreational fishery has contributed about half of all lingcod Oregon and Washington landings, on average, and has continued to grow.

1.5 Summary of management history and performance

1.5.1 Commercial fishery

Prior to 1977, lingcod stocks in the northeast Pacific were managed by the Canadian Government within its waters and by the individual states in waters out to three miles off their respective coastlines. With the implementation of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) in 1976, primary responsibility for the management of groundfish stocks off Washington, Oregon, and California shifted from the states to the Pacific Fishery Management Council (PFMC). The U.S. west coast ABC for lingcod was set at 7,000 mt, but catch was consistently below this level. In 1994, a harvest guideline (HG) of 4,000 mt was set. In 1995, both the ABC and HG were dropped to 2,400 mt based on results of Jagielo (1994). Further reductions were made in 1998 to 1,532 mt with a HG of 838 mt based on an assessment of the northern area (Jagielo et al. 1997).

In 1995 a minimum size limit for the limited entry fishery was imposed for the first time that restricted landed lingcod to be at least 22 inches. This size restriction matched the restriction within the recreational fishery and trawl-caught lingcod, with a 100 lb exception for the latter. The minimum size was increased to 24 inches in 1998. Minimum size across areas diverged in 2000 (Jagielo et al. 2000), when the minimum size of lingcod landed south of 40°10'N latitude in the limited entry fixed gear fishery increased to 26 inches. Currently, the minimum size limits for the limited entry fixed gear and open access commercial fisheries are 22 inches north of of 42° N. latitude and 24 inches south of 42° N. latitude. This corresponds to fish 18 and 19.5 inches after the head has been removed.

Trip limits on commercial lingcod catch were first instituted in 1995, when a 20,000 lbs/month limit was imposed. In 1998, a two-month cumulative limit of 1,000 lbs was imposed. Since then, management of the fishery has occurred through individual-year ABC and optimum yield (OY) levels (Table 2).

The PFMC implemented an initial Rebuilding Plan in 2000 with size and seasonal limitations in the recreational fishery and a change to limited entry and open access sectors in the commercial fishery. Additionally, the coastwide ABC was reduced from 960 mt to 700 mt based on a new assessment of the southern area (Adams et al. 1999) and the rebuilding plan (Jagielo 1999). In the commercial fishery sector, HGs in 2000 were reduced by over 80% from 1998 limits. To achieve these restricted harvests, all commercial fishing for lingcod was closed for six months during the year, from January to April and November to December. During the open period between April and November, all commercial vessels were limited to 400 lbs per month and non-trawl vessels had a minimum size limit of 26 inches south of Cape Mendocino (40°10'N) and 24 inches to the north of Cape Mendocino.

Between 2000 and 2005, while the fishery was rebuilding, cumulative trip limits were very low, at 800 lbs bimonthly, with frequent closures. After 2006, ABCs and trip limits were increased, with a bimonthly limit of 1,200 lbs. Concurrently, MPAs in California, RCAs, and the Cowcod Conservation Area (CCA) were established. In these areas, take of all groundfish is prohibited within specified depths, habitats, and locations.

Monitoring of the commercial catch of lingcod began earlier compared to some other U.S. West Coast groundfish species, and lingcod have almost always been their own market category for recording and sampling purposes.

At-sea monitoring of the commercial catch of lingcod began when the West Coast Groundfish Observer Program (WCGOP) was started in 2002. Initially about 20% of trawl trips and a smaller faction of fixed-gear trips were randomly chosen for observer coverage. In 2011, the limited entry trawl sector became a catch share program and has had 100% observer coverage since that time. In recent years electronic monitoring (EM) has replaced human observers on a subset of the vessels in the limited entry trawl sector. The number of bottom trawl trips with EM monitoring has increased from 24 in 2015 to 193 in 2019, however that still represents a small minority of the vessels and trips.

1.5.2 Recreational fishery

Recreational regulations for lingcod were established in 1976 in Oregon that included a five fish sub-bag limit for marine species. Bag limits in Oregon were reduced to three fish in 1978 and remained at three until 1999. Regulations in Washington were established in 1994 and included a bag limit of three fish. In California, a bag limit of five fish was implemented in 1994 and a minimum size limit of 22 inches was adopted in Washington and California. The 22 inch minimum size limit was not adopted in Oregon in until 1995 and increased to 24 inches in all three states in 1998. In 1998, the bag limit in Washington and California dropped to two fish per day. Oregon followed suite in 1999, and the two-fish bag limit largely remained coastwide until 2008. The minimum size limit for California increased in 2000 to 26 inches.

Between 2000 and 2004, the California recreational bag limit dropped to 1 fish per day and the size limit increased from 26 to 30 inches. Oregon's bag limit fluctuated between one and two fish per day. Regulations have become less restrictive since the rebuilding period. In 2015, the bag limit increased to 3 fish per day in California, while the two-fish bag limit was retained in Oregon and Washington. A size limit of 22 inches was adopted in all three states. More recently, the bag limit in California has decreased to 2 fish per day. In Oregon, there have been multiple recreational groundfish in-season closures to reduce impacts to overfished rockfish.

1.6 Foreign fisheries

Alaskan fisheries for lingcod may not be foreign, but given that they are managed external to the PFMC, we summarize them here along with information regarding Canadian and Mexican fisheries for lingcod.

Lingcod fisheries in the Gulf of Alaska are managed in state waters by the State of Alaska Board of Fisheries and in federal waters by the North Pacific Fishery Management Council (NPFMC), though no formal stock assessment exists for lingcod in Alaskan waters. Commercial fisheries are restricted by catch and bycatch quotas. The sport fishery is restricted by daily bag and possession limits. Lingcod are a non-target species in the subsistence fishery.

Lingcod in western Canada are managed under the British Columbia Integrated Groundfish Program (Integrated Program) by Fisheries and Oceans Canada (DFO) for take by First Nations, the commercial sector, and the recreational sector. Beginning in 1997, the Integrated Program implemented an individual vessel quota program that now incorporates all commercially-caught trawl and hook-and-line groundfish. Stocks in distinct management areas are regularly assessed, with the most recent assessment of lingcod in outer British Columbia waters occurring in 2011 (King et al. 2011) and in the Strait of Georgia in 2014 (Holt et al. 2016).

The 2011 outer British Columbia assessment (King et al. 2011) implemented a Bayesian surplus production model to assess the status of lingcod in four assessment areas. Overall the stock appears to have remained stable between 1927-1970, declined until 1980, increased until 1990, and has continued to decline since then. However, at no time has the stock been estimated to have been below target reference points.

The assessment of the resource as of 2014 (Holt et al. 2016) implemented a two-sex Bayesian statistical catch-at-age model. The stock was estimated to have declined between 1927 and the late 1980s. This was followed by a slow increase between 1990 and 2014. Spawning biomass in 2014 was estimated to be greater than the spawning biomass at the start of the current management regime during 2006 but likely still in a precautionary management zone.

Lingcod are known to inhabit waters off the coast of Baja California, including Ensenada and Bahia de Todo Santos, as far south as Punta San Carlos, Baja California (https://mexican-fish.com/lingcod/). There are some specimens held at Scripps Institute of Oceanography that document its distribution along Baja California (Rosales-Casián and Gonzalez-Camacho 2003) to Bahia San Quintin (Arista Palacios 2018) and the Cedros archipelago (Ramírez-Valdez et al. 205AD). But, the National Fisheries Registry that lists fisheries within Mexican waters does not list lingcod. Multiple researchers reported that lingcod is fished off Baja California using harpoons (pers. comm., H.N. Morzaria Luna, NWFSC) but not being recorded at the species level and instead perhaps under a general finfish permit. Though, it is listed as bycatch of the rockfish (rocotes; scorpinidae) fishery in the National Fisheries Charter, which contains the management framework for species that are commercially fished. There are no known stock assessments for lingcod off the coast of Mexico.

Southern California recreational fishers have reported fishing in Mexican waters and landing fish in U.S. ports. The Declaration For Entry Into California of Game, Fish, Birds Or Animals represents a potential future source of information for documenting catches that occur off the coast of Mexico but are landed in California. Anglers are required to fill out the report prior to entering U.S. waters but it is not clear if this information is currently included in RecFIN.

2 Data

Data comprise the foundational components of stock assessment models. The decision to include or exclude particular data sources in an assessment model depends on many factors. These factors often include, but are not limited to, the way in which data were collected (e.g., measurement method and consistency); the spatial and temporal coverage of the data; the quantity of data available per desired sampling unit; the representativeness of the data to inform the modeled processes of importance; timing of when the data were provided; limitations imposed by the Terms of Reference; and the presence of an avenue for the inclusion of the data in the assessment model. Attributes associated with a data source can change through time, as can the applicability of the data source when different modeling approaches are explored (e.g., stock structure or time-varying processes). Therefore, the specific data sources included or excluded from this assessment should not necessarily constrain the selection of data sources applicable to future stock assessments for lingcod. Even if a data source is not directly used in the stock assessment they can provide valuable insights into biology, fishery behavior, or localized dynamics.

Data from a wide range of programs were available for possible inclusion in the current assessment model. Descriptions of each data source included in the model (Figure 4) and sources that were explored but not included in the base model are provided below. Data that were excluded from the base model were explicitly explored during the development of this stock assessment or have not changed since their past exploration in a previous lingcod stock assessment. In some cases, the inclusion of excluded data sources were explored through sensitivity analyses (see Section 3.2.6.2).

2.1 Fishery-Dependent data

2.1.1 Commercial landings

2.1.1.1 Commercial fleet structure

The fleet structure for commercial landings included two fleets, trawl (TW) and fixed gear (FG). Trawl landings included information from bottom trawls, shrimp trawls, net gear, and dredging activities. Landings from all other gear types, mainly hook and line, were assigned to FG. This fleet structure matches the fleet structure used in the previous assessment. Note that the model estimated total dead catch may not be the same as the WCGOP estimates of total mortality (Somers et al. 2021), which are the 'official' records for determining whether the annual catch limit (ACL) has been exceeded.

2.1.1.2 Reconstruction of commercial landings

2.1.1.2.1 Washington commercial reconstruction

The reconstruction of commercial landings for coastal waters off of Washington was provided by Washington Department of Fish and Wildlife (WDFW). This reconstruction included landings starting in 1889. Data from the reconstruction was used instead of data in Pacific Fisheries Information Network (PacFIN) when there was overlap because WDFW separates landings from each fish ticket by area. This is important for fish tickets that include landings from Alaskan, Canadian, Puget Sound, and oceanic waters. In PacFIN, it is more than likely that landings from different areas included on a single fish ticket would be assigned to just one area and partitioning out these landings to area would require accessing logbook information as well as fish ticket information, which is difficult and not part of the current PacFIN protocols. The reconstruction should largely match what is in PacFIN because PacFIN does not currently have landings for years prior to 1980 and Canadian waters have been closed to U.S. fishers targeting groundfish since 1978.

The reconstruction includes data from many sources, but consistently recorded data were largely available starting in 1943 from U.S. Fish Commission reports. Landings from prior to 1941 were converted to round fish weight using a conversion factor of 1.431 because it is assumed that reports were of filleted fish. Linear interpretation between adjacent years was used to fill in years without landings information. In the 2017 assessment, (Haltuch et al. 2018) missing years were filled forward rather than linearly interpolated (Figure 8). These differences were minor, and there were no major changes in the time series compared to what was used in the previous assessment.

2.1.1.2.2 Oregon commercial reconstruction

In Oregon, historical commercial landings from 1892 to 1986 were provided by Oregon Department of Fish and Wildlife (ODFW) (Karnowski and Gertseva 2014). Historical landings began with exclusively longline landings, which was the primary gear type until the development of the trawl fishery in the 1940s. Historical landings exhibited an increasing trend until peaking at 1738 mt in 1983 and averaged 318.2 mt annually.

2.1.1.2.3 California commercial reconstruction

Sette and Fiedler (1928) provided information from interviews and state records on fishing patterns from 1888 to 1926 for eight regions within U.S. waters. States along the Pacific Coast comprised one region, though state-specific landings were provided for Washington, Oregon, and California by species or species groups. For lingcod, the first positive record was from 1892 and positive landings were documented for 14 years. We used linear interpolation to fill in years with missing data, ramping up from zero in 1888 to create a time series of 39 years (Figure 6).

Catches by gear type were only available from 1926, and thus, the calculated proportion of of the landings caught by FG and TW in 1926 was applied to all years because it was assumed that ratios were similar across the time series. Proportionally, FG represented 0.28 and 0.32 of the total catch for the north and south areas, respectively. The Northern California district was assumed to represent north of 40 degrees ten minutes and all other districts combined were used to represent the southern area.

Landings from California fish market data, available within the ERDDAP database, were used to estimate the proportion of early landings that occurred in the northern area versus the southern area because fish market data were recorded by region on a yearly basis (Mason 2004) within this data set. Whereas, Sette and Fiedler (1928) only contained information on area for a single year. California fish market data represent a multi-organizational effort, but most landings are from fish ticket information collected by CDFW. First, we calculated the yearly proportion of landings that occurred within the Eureka region north of Point Arena compared to all other regions (0.24) from port-specific landings from 1928 to 1933. Second, the proportion of landings within Eureka region that occurred north versus south of Cape Mendocino (0.88) was calculated from 100-200 block data (Miller et al. 2014) starting in 1925 to 1931. The product of the means of these two proportions was used to partition data from Sette and Fiedler (1928) to area.

California fish market data, were available from the ERDDAP database over many years, but only those years that were missing between Sette and Fiedler (1928) and the California Catch Reconstruction Project (Ralston et al. 2010) were used. This resulted in keeping data from 1928 to 1930.

Information on region of landing was available and provided a means to assign the landings to the northern and southern areas. Though as previously mentioned, the Eureka region needed to be partitioned to area. We used the mean proportion of fish landed in the northern Eureka region (0.88) from block data (Miller et al. 2014) to partition the sum of yearly landings within the Eureka region between areas.

Ralston et al. (2010) represents the effort led by the Southwest Fisheries Science Center (SWFSC) to reconstruct groundfish landings for the PFMC, which are seen as the best available data for historical commercial landings from California ports. The data includes information on region of landing based on block assignments. Landings within region nine were assumed to be caught off of Mexico and were removed. Landings with a region code of two were partitioned to the northern and southern areas using the same method used above for California fish market landings. To check the validity of this assumption, we compared the proportion of landings assigned to the north versus the south to proportions calculated from confidential fish ticket data available in CalCOM database for the California Cooperative Survey (CalCOM) that have information on port of landing for available years between 1951 - 1968 (pers. comm., M. Monk, SWFSC). The proportions showed similar trends, though the former were consistently higher than the latter for all years (Figure 7).

The Ralston et al. (2010) data also had to be partitioned to fleet given it does not contain information about gear. Fish ticket information in CalCOM was used to calculate the proportion of landings landed by each fleet for the northern and southern areas separately; thus, partitioning landings by year into four groups, northern TW, northern FG, southern TW, and southern FG. Proportions were only available for the following years: 1951, 1955, 1957, 1960, 1963, 1964, 1965, 1966, 1967, 1968, 1951, 1955, 1957, 1960, 1963, 1964, 1965, 1966, 1967, and 1968. Years with no information were back filled using adjacent years.

Starting in 1969, commercial landings were available for California by port-group complex and gear group from CalCOM. The following gear groups HKL, FPT, OTH, and UNK were combined to encompass FG and TWL and NET gear groups were combined to encompass TW.

Unfortunately, the port-group complexes did not exactly align with the north-south split. But, it was assumed that the amount of landings within the Eureka port-group complex that occurred in the south was minor, and thus, all landings within the Crescent City and Eureka port-group complexes were assigned to the northern area and all other ports were assigned to the southern area.

For combinations of year, area, and fleet that were missing in the reconstruction of California commercial landings, landings were interpolated based on a linear approximation between adjacent years with data (Figure 6). Thus, the reconstruction ramped up from zero starting in 1888 to 16.14 mt in 1892 and all subsequent missing years of data were filled in based on linear interpolation between missing years for a given area and fleet combination.

2.1.1.3 Pacific Fisheries Information Network (PacFIN)

Commercial data were downloaded from the PacFIN database and provided landings for Washington, Oregon, and California (Figure 9). These landings were treated as the best available information for California since 1981 and for Washington and Oregon since the beginning of 1995 and 1987, respectively.

Though lingcod are encountered in a wide variety of gear types in Oregon, most landings are from bottom trawl gear types (70.1 percent from 1987 - 2020). Landings from all other gear types are minimal relative to TW and FG and relatively sporadic. Commercial landings from Oregon waters between 1986 - 2020 peaked in 1991 at 1425.72 before declining and fluctuating between 38.03 and 440.14 mt since 2000.

Before splitting the commercial landings to area, all landings that were known to have been caught outside of the U.S. Exclusive Economic Zone (0.08 mt) were removed. These were landings that occurred in an unknown INPFC area noted as XX or PacFIN area 02 or 4A.

The split at 40°10'N required finding a method for splitting data within the Eureka (ERA) port-group complex. Data with the port of landing of Shelter Cove, a port within ERA, were assigned to the southern model and data from all other ports within ERA, i.e., Eureka (1763.49 mt), Fields Landing (645.31 mt), Trinidad (34.95 mt), Humboldt (1.67 mt), Arcata (1.17 mt), Crannell, King Salmon, Loleta, Moonstone Beach, Eureka Area, and Ruth, were assigned to the northern model. If landings were not assigned to a port-group complex, then the physical location of the port of landing was used to assign an area. Lastly, if both port-group complex and port of landing were unknown, then the landings were assigned to an area based on a vessel's historical behavior while landing lingcod. This ad hoc method that was used to assign area of landing to a trivial amount of landings without spatial information ((0.48 mt)) has almost zero influence on the resulting catch streams and was done largely as an exercise to document how to do this should the stock boundary change again and the numbers would need to be recalculated. For example, if more than half of a vessel's landings of lingcod were in ERA or CCA, then all of their landings without an assigned area were assigned to the northern area.

2.1.2 Recreational landings

2.1.2.1 Recreational fleet structure

Recreational data were first compiled to the state level as a single fleet with all gear types. Then, data from northern California was added to the northern model as its own fleet rather than being combined with Oregon recreational data because each fishery is subject to unique regulations that affect selectivity (Figure 12). The remaining data from California was used to model recreational fisheries in the southern area as a single fleet.

2.1.2.2 Washington recreational landings

The time series of recreational catches (numbers of fish) were provided by WDFW and included information on fishing within Washington's coastal areas sampled by the Ocean Sampling Program in Marine Areas 1-4. Catches that were landed within the Strait of Juan de Fuca, i.e., Bonilla-Tatoosh line to the mouth of the Sekiu River, and sampled by the Puget Sound Sampling Program were included in the landings because they were potentially caught in ocean waters even though they were landed in coastal waters. All other landings from the Puget Sound Sampling Program were excluded because they are from the Puget Sound rather than the Pacific Ocean.

First, we calculated the mean length (696.25 mm) of fish landed within Washington recreational fishery (Figure 13) across all years (2001 to 2020) and sexes. Next, we used this mean length and the weight-length relationship as calculated from the most recent survey data to determine the mean weight. Finally, weight (mt) was determined from mean weight and numbers. Final landings include retained and 7% of discarded fish to account for those that died. The previous assessment modeled Washington landings in terms of numbers of fish rather than weight (Figure 11). A comparison among the two assessments showed similar patterns in the catch when compared in the same units by using the internally estimated values calculated within the final models which are based on the estimated values for growth, selectivity, and age composition in each year showed similar patterns (Figure 14).

2.1.2.3 Oregon recreational landings

The recreational fishery in Oregon likely began in the early 1950s or 1960s but data on catches prior to 1974 are not available. ODFW provided the time series of catches that includes information on shoreside activities, estuary boats, private ocean boats, and charter ocean boats.

Recently, ODFW undertook an effort to comprehensively reconstruct all marine fish recreational ocean boat landings prior to 2001 (pers. comm., A. Whitman, ODFW). Reconstructed catch estimates from Ocean Recreational Boat Survey, ODFW (ORBS) improve upon estimates from the federal Marine Recreational Fisheries Statics Survey (MRFSS), which have known biases related to effort estimation and sampling (van Voorhees et al. 2000) that resulted in catch estimates considered implausible by ODFW. However, the ORBS sample estimates are known to lack the comprehensive spatial and temporal coverage of MRFSS. Addressing this coverage issue is a major part of this reconstruction. In general, the base data and methodology for these reconstructed estimates are consistent with recent assessments for other nearshore species (Dick et al. 2016, 2018; Haltuch et al. 2018; Cope et al. 2019).

Prior to 2001, ORBS monitored marine species in both multi-species categories, such as rockfish, flatfish, and other miscellaneous fishes, and as individual species, such as lingcod or halibut. For this comprehensive reconstruction, four species categories were selected to reconstruct, including rockfish, lingcod, flatfish, and miscellaneous, which constitute the bulk of the managed marine fish species. Lingcod have been a single species category throughout this time period.

Category-level estimates were expanded to account for gaps in sampling coverage in two separate pathways. First, estimates from five major ports were expanded to include unsampled winter months in years lacking complete coverage. Expansions were based on available year-round sampling data and excluded years where regulations may have impacted the temporal distribution of catch. Second, all other minor port estimates were expanded to include seasonal estimates in years lacking any sampling based on the amount of minor port catch as compared to all major port estimates. A subset of landings were sampled by ORBS for species compositions within these categories. Once category-level landings were comprehensive in space and time, species compositions were applied for the three multi-species categories, including rockfish, flatfish, and miscellaneous fish. Borrowing rules for species compositions were specific to the category and determined based on a series of regression tree analyses that detailed the importance of each domain (year, month, port, and fishing mode) to variability in compositions.

Ocean boat estimates from 1979 – 2000 in numbers of fish of lingcod from the above described methods were converted to biomass using biological samples from MRFSS (pers. comm., A. Whitman, ODFW). MRFSS biological data are available from 1980 – 1989 and 1993 – 2000. An annual average weight was applied to the total annual number of fish to obtain an annual landings estimate. Several years missing biological data (1979, 1990 – 1992) were filled in using neighboring years or interpolation. Landings from 1974 – 1978 were estimated using similar methods to the above reconstruction, but are not currently part of this reconstructed time period, and were not updated from the 2017 assessment (Haltuch et al. 2018). Updated landings include only those from 1979 – 2000. These landings in biomass were provided by ODFW and do not include an estimate of discards. Landings during this time period fluctuate, with a peak of 237.2 mt in 1993, and fluctuate between approximately 50 and 200 mt following that peak (1979 – 2000).

Recreational landings for ocean boat modes from 2001 – 2020 are available from Recreational Fishery Information Network (RecFIN) (extracted on 03/19/2021). Both retained and released estimates of mortality are included, though retained mortality contributes the vast majority to total mortality. Release mortality is estimated from angler-reported release rates and the application of discard mortality rates from the PFMC. From 2001 – 2020, landings averaged 139.4 mt, ranging from 60.1 mt in 2001 to 229.1 mt in 2015. In 2020, Oregon ocean boat landings were 172.5 mt.

ODFW provided reconstructed estimates of shore and estuary landings for lingcod from 1980 – 2020, using methodology similar to recent assessments (Berger et al. 2015; Dick et al. 2018; Cope et al. 2019). Data sources include MRFSS and Shore and Estuary Boat Survey, ODFW (SEBS). Numbers of fish were provided by MRFSS from 1980 – 1989 and 1993 – June 2003, and by SEBS from July 2003 – June 2005. An annual mode-specific average weight was applied to numbers of lingcod from 1980 – 1989 and 1993 – 2005. Separate weights were calculated for shore and estuary boat modes and excluded extreme outliers and imputed values. This reconstruction also applied two scaling factors to remove bias towards freshwater sampling and underestimation of estuary boats (Dick et al. 2018). To estimate lingcod landings from July – December 2005, an expansion was developed using the three year average of the ratio between the first six months of the year and the total annual landings from MRFSS and SEBS landings from 2002 - 2004. Separate expansions were developed for shore mode and estuary boat modes.

The ODFW does not currently sample shore and estuary boat fishing trips, so a 10 year average landing (1996 – 2005; 6.7 mt/year) was used to estimate shore and estuary boat landings during 2006 – 2020. Shore and estuary boat landings combined fluctuate but gradually increase until peaking in 1993 at 16.7 mt. Shore and estuary boat landings average

6.5 mt annually from 1980 – 2003. Shore and estuary landings were combined with the ocean boat landings for the total Oregon recreational landings (1974 – 2020).

2.1.2.4 California recreational landings

California recreational lingcod catches since 1980 are available within the MRFSS database (Figure 10) and stored in the RecFIN database. Data were provided in terms of weight, and thus, converting from numbers to weight using mean length ((Figure 13)) was not needed. The first year of data are typically not used because of the lack of standardization within the sampling protocols which led to vastly different estimates of catches compared to later years. Thus, 1981 is used as the first year of MRFSS data. Data were provided by John Field for years prior to 1981 and these data have been unchanged since the 2009 assessment of lingcod (Hamel et al. 2009).

For this assessment, we had to split the historical data provided by John Field and MRFSS to area. This was accomplished using data from Albin et al. (1993) that includes county-specific estimates of landings. Area-specific landings were informative about the proportion of landings in Del Norte and Humboldt county relative to the rest of the California coast. A catch-weighted mean proportion for the years 1981, 1982, 1983, 1984, 1985, and 1986 was used to split coast-wide recreational landings to area.

Between 1990 and 1992, the MRFSS sampling program ceased because of budgetary limitations. Additionally, there was a transition year between MRFSS and California Recreational Fisheries Survey (CRFS) without data. Thus, linear interpolation was used to provide proxy estimates for 1990, 1991, 1992, and 2004 (Figure 10).

Sampling under CRFS started in January of 2001 and data are still currently being collected. Information includes data on port group that was used to partition landings to area. Redwood was assigned to the northern area for all years since 2005, even though Redwood in 2005 through 2007 also contained landings from Shelter Cove. This time series also includes landings from Mexico and Canada that were excluded from this analysis.

2.1.3 Comparison of current catch stream to previous model

The current time series of catches were aggregated using the previous model structure, i.e., the northern area included Washington and Oregon and the southern area included California, for comparison purposes (Figure 8). This comparison revealed differences in the current catch stream for the commercial FG and TW fleets compared to what was previously used for the southern model. It was determined that the 2017 catch stream for the California TW fleet included catches from both TW and FG fleets. This has since been corrected, and the current catch stream represents what is known to be the best available data.

Differences in the reconstructions for commercial catches are the result of linearly interpolating historical data rather than assuming it was equal to the previous year (Figure 8). Differences in the early reconstruction for California commercial catches are the result of using landings from Sette and Fiedler (1928) instead of ramping up catches from zero (Figure 8).

There were small differences in the recreational catches from California and Oregon but the main differences were in Washington recreational catches. As mentioned previously, Washington recreational catches were converted from numbers to weight prior to fitting them as data, whereas the previous assessment fit them as numbers (Figure 11). Differences in Oregon recreational catches were the result of ODFW's efforts to create comprehensive sport fishing reconstructions. These reconstructions are noted to be more robust than information from MRFSS and explain the differences in the trajectories prior to 2000.

2.1.4 Catch per unit effort

2.1.4.1 PacFIN trawl logbook index

A commercial trawl CPUE index was retained from the previous assessment (Haltuch et al. 2018). The index spans the years 1981-1997, ending before the 1998 changes in management (Figure 70). As in the last assessment, the coastwide estimates were post-stratified to produce a time series for each area. The stratification was updated to reflect the new boundary at 40°10'N (pers. comm., J. Wallace, NWFSC). The choice to not re-estimate the fits to the data and just update the stratification was driven by the intense computational needs to refit the model and the similarity of the results of the fishery-independent CPUE regardless of how they were modeled.

2.1.4.2 Oregon nearshore commercial fishery logbook index

Oregon Department of Fish and Wildlife has required nearshore, permitted vessels and open access vessels within the commercial fishery to submit fishing logbooks since 2004. Compliance is generally high, averaging around 80%. Early compliance was lower, e.g., 65% in 2007; while recent compliance has reached greater than 90%. Furthermore, although fishers are required to provide all requested information in the logbook per fishing gear set, there has been substantial variation in the quantity and quality of information reported. In theory, the database contains information per gear set on catch by species (retained and released fish), effort (hook hours, number of hooks used multiplied by the number of hours fished), sample location (port), date, vessel, fishing depth, fishing gear, fishing permit, number of fishers, and harvest trip limits. For this analysis, multi-set trips were aggregated to the trip level, and the full data set included data from 38,350 trips from 2004–2020. Weight of released fish (numbers) was converted converted to weight by multiplying numbers by median catch weight prior to calculating CPUE.

Data were filtered to increase their consistency (Table 3). Filtering helps to attain the best possible consistent and representative data set for the time period available such that trends in relative abundance reflect stock biomass. In general, encounter rates for lingcod were relatively high, and thus, filtering was minimal compared to that done for some other species. Records were eliminated if they contained missing or unrealistic values. Trips were reduced to only those from permitted vessels using hook-and-line jig gear from Port Orford, Gold Beach, and Brookings ports and vessels that fished in at least three years since the implementation of logbooks. Filtering did not account for vessel operator and was tied only to the vessel name. Gear types other than hook-and-line were excluded because hook-and-line gear accounted for approximately 78.5% of all documented trips for lingcod. Data were also filtered for trips that were not abnormally deep. Some of these filters are new relative to the previous assessment (Haltuch et al. 2018) and were developed for the recent cabezon assessment (Cope et al. 2019).

Catch per unit effort was modeled using a Bayesian delta-Generalized Linear Model (GLM) model (Goodrich et al. 2020). Probability of occurrence, the binomial component, was modeled using a logit link. Log of positive catch, the rate component, was modeled using a Gaussian distribution with an identity link function. Covariates were selected using Akaike information criterion (AIC) and Bayesian information criterion (BIC), retaining only those that improved model fit. The full model included covariates for year, month, vessel, port, depth, and people. Depth, a continuous variable, was included to account for general differences in bathymetry and restrictions where fishing can take place. People was included to control for the potential oversaturation of hooks at a given fishing location and increased fishing efficiency with more fishers onboard. Accounting for vessel also accounts for variability in fishing capacity. Period, two-month interval was also considered but was excluded due to multicollinearity with month.

A quantile-quantile plot of the simulated (Hartig 2021) residuals suggested the binomial model provided a reasonable approximation of the data (Figure 17). However, the fits were not as good for the rate model (Figure 18). Despite filtering, there were a wide range of positive CPUE values, resulting in a heavy left skew. The binomial model closely matched the distribution from replicate datasets and the positive model matched less closely. Multiple alternative distributions and more parsimonious positive models were explored, as well as aggressive filtering for outliers. But, none of the efforts led to improved diagnostics. There was insufficient time to fully resolve these diagnostic issues and alternative approaches may be need for future assessments. The final time series indicated an increase in 2010 that was in line with other data sets (Figure 70).

2.1.4.3 Washington recreational index

The Washington dockside sampling program (Ocean Sampling Program and Puget Sound Baseline Sampling Program) is supported by WDFW and collects biological as well as catch data. The coastal portion of this program is largely sampled at three major ports, Westport, La Push, and Neah Bay. Lingcod are highly targeted by recreational fishers, and thus, they have been recorded to the species level since the beginning of the program.

Information on retained lingcod from dockside interviews were available from WDFW between 1981 and 2020. Recent data also included information on discarded fish, but this information was not used for this analysis because it was not available for the entire time series and the composition data that are associated with this index only include retained fish. Information from dockside interviews were previously thought to be more reliable than information contained in the MRFSS database, and thus, MRFSS data were not explored with respect to Washington recreational CPUE. Though, WDFW noted during the review of this assessment that future work could use data from MRFSS.

The dockside data were filtered prior to being fit to models to identify the best subset of the available data that are likely to be consistent over the time series and provide a reliable index of abundance once standardized (Table 4). Depth was not recorded consistently during the time period of available data, and thus was not included as a filter or a subsequent covariate. The filtering procedure led to a final positive rate of 57.73%.

Stephens-MacCall (2004) filtering approach was explored to predict the probability of catching lingcod based on the species composition of the sampler-observed catch in a given trip. Prior to applying the Stephens-MacCall filter, we identified potentially informative predictor species, i.e., species with sufficient sample sizes and temporal coverage (at least 1.5 % of all trips) to inform the binomial GLM used in the Stephens-MacCall approach. Thus, the remaining species all co-occurred with lingcod in at least one trip and were retained for the Stephens-MacCall logistic regression. Estimated coefficients from the Stephens-MacCall analysis are positive for species that are likely to co-occur with the target species and negative for species that are likely to not co-occur with the target species. The top five species with high probability of co-occurrence with lingcod included halibut, yelloweye, vermilion, canary, and yellowtail (Figure 19), all of which are associated with rocky reef and kelp habitats. The species with the lowest probability of co-occurrence with lingcod was blue. Given the high positivity rate of lingcod prior to the Stephens-MacCall filtering, we choose to not use this additional filtering process.

The filtered data were used to fit Bayesian delta-GLMs using the same modelling framework, rstanarm (Goodrich et al. 2020), as the other CPUE indices developed for lingcod. Covariates considered included year, boat type, area, and month. A management covariate was investigated previously, but the framework cannot estimate both fixed effects for year and groups of years. A full model with all covariates was fit and goodness of fit was tested using Chi-square goodness of fit test, that indicated a model with all variables fit the data the best. This process was repeated for several distributional assumptions for the positive component and posterior predictive checks of the Bayesian model fit for all models regardless of the distributional assumptions used to fit the data were similar (results not shown).

The Gamma distribution was chosen going forward given a better match of the theoretical quantiles to the data quantiles than the lognormal (Figures 20 and 21).

The terminal year of the index was poorly estimated and indicated a sharp increase in the abundance of the stock. This sharp increase in the terminal year is not new and was present in the last standardization of this data set.

2.1.4.4 Oregon recreational index

Trip-level CPUE data from ORBS dockside sampling program was analyzed by ODFW and included in the assessment as a relative index of abundance for the Oregon recreational fleet. The dataset represents the longest time series available for this fleet and contains information on catch by species (number of retained fish), effort (angler hours), sample location (port where data were collected), date, bag limits, boat type (charter or private), and trip type (e.g., bottom-associated fish). CPUE, expressed in terms of fish per angler-hour. Angler-hour is the number of anglers multiplied by the number of hours fished minus by travel time. Travel time is twice the distance between the port of origin and the fished reef multiplied by 13 mph for charter boat trips and 18 mph for private boat trips.

The unfiltered data set contained 411,528 trips. Multiple filters were applied to the trip-level data to increase the number of positive trips for lingcod (Table 5). These filters removed trips from several ports with extremely small sample sizes; trips that met criteria for implausible effort values or extreme catch rates; trips with incorrect interview times, which impact calculation of effort; unreasonably long or short trips; catches exceeding bag limits, which would impact catch rates; private vessel trips; and trips that did not target bottom fish. Filters were also utilized to account for temporal or spatial closures impacting fishing. Stephens-MacCall filtering was also investigated to identify trips that were likely to catch lingcod given the occurrence of other species in the catch (Stephens and MacCall 2004). Stephens-MacCall filtering did not change the diagnostics of the resulting model, and thus, it was not utilized to filter the data.

A Bayesian delta-GLM was used to model CPUE (Goodrich et al. 2020). Investigated covariates included month, mega-region (north and south coasts divided at the port of Florence on the central Oregon coast), port, season (summer and winter), lingcod bag limit, and depths available to the recreational fleet for fishing (Figure 24). Season and mega-region were collinear with month and port, respectively, and not investigated further.

The binomial model component for positive catches was modeled using a logit link function. Based on AIC and BIC, the best binomial model included year, port, month, and depths available to fishing. Models with interactions between year and port or month did not converge due to missing trips in some strata. A quantile-quantile plot of the simulated residuals (Hartig 2021) suggests that the binomial component of the delta-model is a reasonable approximation of the data (Figure 22). Diagnostics were substantially improved by excluding interactions between year and open depths and the removal of private boat trips.

The rate component for log of positive CPUE was modeled with a Gaussian distribution and an identity link function. The positive model included year, port, month and open depths available to fishing. There were issues in the DHARMa simulated residuals, including curvature and significant outliers (Figure 23). However, these diagnostics were improved by exclusion of any interaction terms and the removal of the private vessel trips. There was insufficient time to fully resolve these diagnostic issues and alternative approaches may need to be explored for future assessments. For example, an area-weighted model was not utilized for lingcod, as has been used for other nearshore species in recent assessments, such as cabezon (Cope et al. 2019) or blue rockfish (Dick et al. 2018).

The final index (Figure 70) matched major trends in other CPUE fits with an increase in 2010 and a current decrease in abundance.

2.1.4.5 California recreational index

The California recreational index includes catch and effort data from CRFS dockside sampling of private boats, which started in 2004. The data include catch in numbers by species, number of anglers, angler-reported distance from shore, county, port, interview site, year, month, and CRFS district.

Records were limited to 'PR1' sites and hook-and-line gear (Table 6. Percent of groundfish within the catch from a trip was used as a proxy for retaining trips for index standardization because fishing location was unknown. Since 2005, the recreational fishery for shelf rockfish north of Pt. Conception has been closed from January through part of April and May. Angler reported distance from shore had no samples in the outside 3 nm category from 2004-2011. The category was retained due to the relaxation of depth restrictions beginning in 2017.

A gamma distribution was used to model positive catch per angler hour in a Bayesian delta-GLM. A lognormal distribution also fit the data equally well (Figure 25). Year-area interactions were not investigated. The final model included year, wave, and area. Posterior predictive checks of the model fits were reasonable. The binomial model generated data sets with the proportion zeros similar to the 46% zeroes in the observed data. The predicted marginal effects from both the binomial and Gamma models can be found in (Figures 26 and 27). Future work should investigate the use of other indices for the California recreational fleet in northern California or how to partition the fleet into multiple fleets such that more than one index can be used.

2.1.5 Commercial length- and age-composition data

Length and age compositions from commercial landings for the TW and FG fleets were developed from the PacFIN database using PacFIN.Utilities. Many more length and age samples were available for the northern stock than the southern stock. Both the differences in sampling programs by WDFW and ODFW compared to CDFW and larger commercial catches in the north compared to the south contributed to the differences in sample sizes.

Length and age samples from west coast groundfish commercial fisheries are typically expanded to account for variability in the number of fish sampled per trip relative to the total catch. This allows greater weight to be given to samples from a very large trip compared to one with a small catch. However, the commercial data for lingcod, as represented in the PacFIN database, have a large fraction of trips without trip weights. This leads to large variability in the expanded sample sizes among trips and implausible amounts of variability in the resulting composition data among length bins within a given fleet and year. Unexpanded data did not show this variability, and thus, models were fit to unexpanded composition data for the commercial fisheries.

Commercial TW length-composition data started in 1965 (Table 9; Figure 72). Commercial FG length-composition data started in 1986, with additional samples in 1971, 1980, and 1982 (Tables 9 and 11; Figures 72-73).

Commercial age samples covered 43 years for TW and 35 years for FG years, starting in 1978 for TW and 1986 for FG (Tables 10 and 12). The commercial age data were processed as both marginal and conditional age-at-length compositions to allow explorations of either format in the models. Unsexed fish were represented as separate compositions in addition to the compositions of fish with known sex.

Length compositions and mean body weight observations were also available from commercial discards for the years 2004 to 2019. These observations were all unsexed and represented in the model as independent vectors to facilitate estimation of retention functions for the TW and FG fleets. The mean body weight observations were calculated from counted baskets of discarded fish and represented a larger number of individuals than the subsamples from which lengths were available but in general they provide similar information (Figures 98-103).

2.1.6 Recreational length- and age-composition data

Recreational fishery length (Figures 28-33) and age compositions (Figures 34-37) were obtained directly from WDFW and ODFW and from RecFIN for California. California data included data from the following sampling programs, MRFSS (1980-2003), CRFS (2004-2020), and CPFV (2003-2020). Lengths from CPFV were of fish that were measured prior to their release, i.e., Type 3d data in RecFIN. Even though WDFW and ODFW data are present in RecFIN, state representatives provided data thought to be more reliable than that in RecFIN. Lengths from WDFW with the designation of total length (n = 591) were converted to fork length using the conversions of Laidig et al. (1997). Length and age compositions were created for male, female, and unsexed fish, though the number of samples of unsexed, aged fish was small. Many of these composition data lack information on the number of fish sampled out of those landed in a given trip, and therefore, composition data were used without expansion to the sample level. Sample sizes used in the model were based on the number of fish sampled for each year and data set (Tables 9 and Table 10). Conditional-length-at-age distributions were also created for Washington and Oregon recreational fleets and explored as a sensitivity.

Measurements from fish designated as released were excluded from the length and age compositions. This led the to the exclusion of 2,920 samples, which was approximately 2 percent of the total samples.

It has been reported that recreational fishers in Oregon sometimes release large fish that are assumed to be female so they can spawn. However, other anglers tend to target and retain these large fish. It remains unclear how this tendency to keep or discard trophy females interacts with minimum size limits. In Oregon, the minimum size limits for lingcod have changed between 22 inches during 1995 to 1997 and 2006 to present and 24 inches during 1998 to 2006.

Lengths for the Oregon recreational fishery were available from three sources, MRFSS, ORBS, and ODFW special project sampling. The majority of these samples are from the central Oregon coast (n = 4,440), including Newport (18.7%), Garibaldi (18.6%) and Depoe Bay (15.0%), followed by Brookings on the south coast (n = 2,321; 27.3%). MRFSS collected Oregon samples from ocean areas only (n = 8,769) and measured total length from 1980–1989 and fork length 1993–2000. These data have the additional complication of lengths for some fish being estimated from weights instead of direct measurements. These estimated lengths were flagged by ODFW to allow for selection of directly measured values. However, most imputed weights were conversions from total length to fork length, which do not introduce a great deal of uncertainty. Therefore, all lengths sampled in Oregon from MRFSS were used to fit the model. Length samples from 2001–2020 from the ORBS sampling program were in terms of fork length (n =105,197), sampled from ocean trips, and available on RecFIN. Special projects samples collected by ODFW staff were provided from 2001 (n = 72). These samples were not used to fit the model.

2.1.7 Discard data

2.1.7.1 Discard rates

Discard rates were modeled for the commercial fisheries only (TW and FG) using data from the West Coast Groundfish Observer Program (WCGOP). This program is part of the NWFSC and has been recording discard observations starting in 2002. Since 2011, when the IFQ program was implemented, observer coverage rates increased to nearly 100 percent for all the limited entry trawl vessels in the program and discard rates for the trawl fishery declined compared to pre-2011 rates. Discard rates were obtained for both the IFQ catch-share (observed and electronic monitored vessels) and the non-catch share sector for lingcod. A single aggregated annual discard rate for each fleet was calculated by weighting discard rates from three sectors within each gear group: catch-shares, non-catch-shares, and electronic monitoring, where the weights were based on the commercial landings by each sector.

The variances of the total discard estimates were calculated for the non-catch shares sector and pre-catch share years by bootstrapping vessels within ports because the observer program randomly chooses vessels within ports to be observed. Post trawl rationalization, all catch-share vessels (including electronic monitoring) have 100 percent observer coverage and discarding from the catch-share subset of the fleet is assumed to be known.

The variance of the aggregated annual discard amount was calculated as the sum of the variances of the total annual discard for each sector under the assumption that the variances are independent. This variance of the total discard amount was then converted to a standard error of the aggregated discard rate.

The resulting aggregated discard rates for the commercial trawl fishery show high values (77%) during the first five years of data: 2002-2006, then declining to an average of 7% during the catch-shares period (2011-onward). The rates from the catch-shares period are more precise due to the 100% observer coverage during this period.

The commercial fixed-gear discard rates were never as high as the trawl rates and did not fall as low during the catch-shares period (the catch-shares management only applied to a subset of the fixed-gear catches). After a lower initial value of 21% in 2002, the rates were stable over the period 2003-2010, with a mean of 48% and then dropped to a mean of 30% for the period 2011-onward.

The precise trawl discard rates from 2011 onward were found in initial model runs to be overly influential so a value of 0.05 was added to the standard error of all discard rates to account for unmodeled variability in the retention process rather than add additional parameters representing that annual variability.

2.1.8 Unused fishery-dependent data

2.1.8.1 Recreational catch per unit effort

Recreational CPUE time series were abundant for lingcod; but, only one index could be added to the stock assessment for each fleet representing state-specific recreational fishing. Some additional time series were provided but not included in the base model. Most often, the longest time series available was included instead.

2.1.8.1.1 Oregon at-sea commercial passenger fishing vessel

ODFW initiated an onboard CPFV observer program in 2001, which became a yearly sampling program in 2003. The data, 15,632 drifts, were filtered to remove drifts without catches, longer than the 99th percentile, deeper than the 99th percentile (60 fms), and focused on midwater species. Filters were intended to provide a final drift-level dataset free of drifts that were unlikely to encounter lingcod. Low sample sizes also necessitated the removal of 2020 and drifts from February. The final dataset included 8472 drifts, 46% of which encountered lingcod.

Bayesian delta-GLM were fit using rstanarm. Catch (number of retained and discarded fish) with an offset for effort (angler hours) was best fit using a negative binomial model. Investigated covariates included year and two-month wave, port, and depth. Depth was defined as the starting depth for the drift and binned to five fm bins from 0 - 30 fms with a plus 30 fm bin for all drifts with a starting depth $>$ 30 fms. Year and port interactions were not considered. Based on AIC, no covariates were excluded from the analysis.

Posterior predictive checks of the Bayesian model fit for the negative binomial model were reasonable. The negative binomial model generated data sets with the proportion zeros similar to the 54% zeroes in the observed data. The estimated time series had a trend similar to the arithmetic mean of the annual CPUE and the Oregon recreational CPUE derived from the ORBS data set (Figure 39).

2.1.8.1.2 California Recreational Fisheries Survey

CRFS samples private boats in the California recreational fishery dockside. Number of lingcod per number of anglers is available as well as distance fished from shore, county, port, interview site, year, month, and district. Data on private boats using hook-and-line gear provide a proxy for recreational CPUE. Currently there is no way to include multiple indices for the California recreational fleet and time did not allow for inclusion of this index as a sensitivity.

2.1.8.2 Fin rays from California Department of Fish and Wildlife

The CDFW collected lingcod fin rays from the commercial and recreational fisheries in recent years and cleaned them in preparation for ageing. Sampling occurred from February through June 2019 between Crescent City and Santa Barbara, California. Samples were aquired for priority species, not just lingcod. In total, 113 lingcod fin rays were collected. The majority of samples were landed utilizing hook-and-line gear, though some trawl-caught samples were also obtained. Meta data for these samples includes port of landing, gear type, length, weight, sex, and maturity.

Unfortunately, restricted access to ageing laboratories because of the COVID-19 pandemic made it nearly impossible to finish ageing even routinely-aged collections. Sectioning and mounting the fin rays typically requires a hood and ventilation, which limited the options for alternative laboratory space. The fin rays collected by CDFW are adequately preserved and can still be aged at a later date allowing for future exploration of this data source.

In 2017, CDFW began opportunistically collecting filleted groundfish carcasses from the recreational fishery to increase recreational biological data. Samples were collected in a partnership with CPFV operators and at public fillet stations, launch ramps, and piers. Current efforts have been primarily focused in the Crescent City and Monterey Bay port complexes as well as samples from south of Point Conception in collaboration with the Sportfishing Association of California, yielding a total of 324 lingcod fin rays. In addition to age structures, meta data includes port of landing, carcass length, and sex when it can be determined from the filleted carcass. A graduate student at California Polytechnic University, San Luis Obispo is working on a study of total length to carcass length for recreational species, including rockfish and lingcod, results of which will help inform the best treatment of length information attained from carcasses. These samples could be included in future assessments potentially as conditional age-at-length compositions or as marginal compositions. Both types of data are helpful for estimating growth and selectivity patterns.

2.2 Fishery-Independent data

2.2.1 Survey indices

2.2.1.1 NWFSC West Coast Groundfish Bottom Trawl Survey

The WCGBTS, which began in 2003, is the longest time series of fishery-independent data included in this assessment and the most recent. This survey samples the shelf and slope off the U.S. West Coast covering depths from 30 - 700 fathoms (55 - 1,280 meters; Figure 41) on an annual basis (excluding 2020 due to the COVID-19 pandemic). The survey is based on a random-grid design (Bradburn et al. 2011) that generally uses four industry-chartered vessels per year assigned to a roughly equal number of randomly selected grid cells and divided into two ‘passes’ of the coast. Two vessels fish from north to south during each pass between late May to early October. This design therefore incorporates vessel-to-vessel differences in catchability and variance associated with selecting a relatively small number (approximately 700) of possible cells from a very large set of possible cells spread from the Mexican to the Canadian borders.

The following three data inputs used to fit the base model were generated from WCGBTS data, an index of relative abundance, length-composition distributions, and age-composition distributions. Length-weight parameters were also estimated from data collected from the WCGBTS (see Section 2.3 for details).

An index of abundance was estimated by fitting density data from the WCGBTS to a spatio-temporal delta-model (Thorson et al. 2015) using VAST (Thorson and Barnett 2017), which is publicly available at github.com/James-Thorson/VAST. Spatial and spatio-temporal variation is specifically included in both encounter probability and positive catch rates. A logit-link was used for encounter probability and a log-link for positive catch rates. Vessel-year effects were included for each unique combination of vessel and year in the data to account for the random selection of commercial vessels used during sampling (Helser et al. 2004; Thorson and Ward 2014). Spatial variation was approximated using 500 knots (Figure 42), and the model used the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016).

The spatiotemporal model was specific to the area included in this assessment (Figures 41 and 42) because separate models were fit for each area rather than using the stratification functionality to partition the results from a single model to area. This was done to ensure that the correlation structure from one area did not influence the estimates for another area. The estimated index of abundance (Figure 70) was assumed to follow a gamma distribution (Figure 43) but both the lognormal and the gamma fit equally well. The quantile-quantile plot did not a significant departure from the theoretical quantiles (Figure 43) and the gradient was sufficiently low to suggest the model had converged. Furthermore, there was no clear pattern in the residuals (Figure 44).

2.2.1.2 AFSC/NWFSC West Coast Triennial Shelf Survey

The AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) was first conducted by the Alaska Fisheries Science Center (AFSC) in 1977, and the survey continued until 2004 (Weinberg et al. 2002). Its basic design was a series of equally-spaced east-to-west transects across the continental shelf from which searches for tows in a specific depth range were initiated. The survey design changed slightly over time. In general, all of the surveys were conducted in the mid summer through early fall. The 1977 survey was conducted from early July through late September. The surveys from 1980 through 1989 were conducted from mid-July to late September. The 1992 survey was conducted from mid July through early October. The 1995 survey was conducted from early June through late August. The

1998 survey was conducted from early June through early August. Finally, the 2001 and 2004 surveys were conducted from May to July.

Haul depths ranged from 91-457 m during the 1977 survey with no hauls shallower than 91 m. Due to haul performance issues and truncated sampling with respect to depth, the data from 1977 were omitted from this analysis. The surveys in 1980, 1983, and 1986 covered the US West Coast south to 36.8°N latitude and a depth range of 55-366 m (Figures 45 and 46). The surveys in 1989 and 1992 covered the same depth range but extended the southern range to 34.5°N (near Point Conception). From 1995 through 2004, the surveys covered the depth range 55-500 m and surveyed south to 34.5°N. In 2004, the final year of the Triennial Survey series, the NWFSC Fishery Resource and Monitoring division (FRAM) conducted the survey following similar protocols to earlier years.

The triennial data have historically been split into early (1980-1992) and late (1995-2004) survey time series and treated independently. However for this assessment, we combined across time series into a single fleet.

Vector autoregressive spatio-temporal was used in the same manner as was done for (Section 2.2.1.1). The gamma distribution with random strata-year and vessel effects fit the data well (Figure 47) and had a low gradient.

The resulting index was generally cup shaped but with a large increase in 2004, the terminal year (Figure 70). The 2004 data point increased at a rate beyond what may be anticipated given the life history of lingcod. A similar spike in abundance in 2004 has been observed for other species (e.g., petrale sole, dover) sampled observed in the Triennial Survey which may be indicative of a change in the application of the survey rather than an increase in biomass. However, there was no clear spatial pattern in the residuals (Figure 48).

2.2.2 Survey length- and age-composition data

2.2.2.1 NWFSC West Coast Groundfish Bottom Trawl Survey lengths

The length compositions of survey catches in each year was summarized using length bins in 2 cm increments from 10 to 130 cm (Figure 50). The first bin includes all observations less than 10 cm, and the last bin includes all fish larger than 130 cm. The observed length compositions were expanded to account for subsampling of tows, and the expansion was stratified by depth. Depth strata of 55 - 183 m and 183 - 400 m were selected, based on the sampling design of the survey (Keller et al. (2017)). Depth strata were capped at 400 m because catches of lingcod in the WCGBTS occur infrequently beyond 400 m (Figure 40). Samples were often sexed, so only male and female length frequencies were used. The few unsexed individuals were assigned as male or female according to the sex ratio of the respective length bin. An assumed sex ratio of 0.5 was applied for unsexed fish in length bin less than 40 cm, as sex of smaller sized lingcod is harder to differentiate. A bin of 40 cm was chosen as this is the length bin at which the length-weight relationship starts to diverge for males and females, and therefore, equal assignment is not influenced by sex-specific size differences.

The input sample sizes (Table 9) for length and marginal age-composition data for all fishery-independent surveys were calculated according to Stewart and Hamel (2014), which determined that the approximate realized sample size for species in the "others" category (which included lingcod) was $2.38 * N_{\mathrm{tow}}$.

2.2.2.2 AFSC/NWFSC West Coast Triennial Shelf Survey lengths

Post-processing of length data for the Triennial Survey (Table 9; Figure 54) followed the same methods as those used for the WCGBTS but depth strata were bracketed using depths of 55–183 m and 183–350 m. Strata were split at 183 m because sampling became less intense in depths deeper than 183 m and raw CPUE was more variable deeper than 183 m than it was in shallower waters (Figure 49). A maximum depth of 350 m was used because lingcod were infrequently caught at depths greater than 350 m (Figure 49).

2.2.2.3 Lam research lengths

In collaboration, the NWFSC and Moss Landing Marine Labs sampled lingcod in nearshore and offshore rocky reef habitats between January 2016 and January 2017 via hook and line on chartered CPFVs (Lam (2019)). Sixteen latitudinal distinct sampling sites, or ports, were chosen for sampling from northern Washington to southern California. At each port, 85–120 individuals were caught using methods identical to those used by the onboard recreational lingcod fishery, except that individuals smaller than the legal-size limit of 22 inches were retained and areas closed to recreational harvest were occasionally utilized (CDFW Permit #SC-6477, ODFW Permit #20237, WDFW Permit ID Samhouri 16-138). Deviating from the onboard-sampling methods was necessary to ensure an even distribution of size and age classes from each port, such that estimates of von Bertalanffy growth curves could be region specific and easily comparable. Of the total fish samples (n = 1,784, 922 Males, 862 Females; Table 9), 32 were removed because they were sampled on California Collaborative Fisheries Research Program (CCFRP) and would have led to double counting. Four additional samples were also excluded because they had no year associated with them. Length compositions from this survey were used as numbers of fish and were not expanded (Figure 56). Length measurements were taken using total length, which were converted to fork length following conversions from Laidig et al. (1997). Total and fork lengths for lingcod are generally similar for lingcod given their tail shape.

2.2.2.4 NWFSC West Coast Groundfish Bottom Trawl Survey ages

Age-composition data from the WCGBTS (Figure 51) were included in the model as sex-specific conditional age-at-length (CAAL) distributions by year (Figures 52-53). These data were not expanded, which is standard for CAAL data, and thus, numbers of fish were used for the input sample size without any adjustment. Each age bin included just one year and summarized ages ranging from 0–20 with a plus group for all fished aged older than 20 years.

Individual length and age observations can be thought of as entries in an age-length key (matrix). Age-length keys are typically structured with age across the columns and length down the rows. The CAAL approach consists of tabulating the sums within rows as the standard length-composition distribution and, instead of also tabulating the sums to the age margin, the distribution of ages in each row of the age-length key is treated as a separate observation, conditioned on the row (length) from which it came. Using CAAL instead of marginal ages has several benefits. First, age structures are generally collected as a subset of the fish that have been measured. If the ages are to be used to create an external age-length key to transform the lengths to ages, then the uncertainty due to sampling and missing data in the key are not included in the resulting age-compositions used in the stock assessment. If the marginal age compositions are used with the length compositions in the assessment, the information content on sex-ratio and year class strength is largely double-counted as the same fish are contributing to likelihood components that are assumed to be independent. Using CAAL distributions for each length bin allows only the additional information provided by the limited age data (relative to the generally far more numerous length observations) to be captured, without creating a 'double-counting' of the data in the total likelihood. Second, in addition to being able to estimate the basic growth parameters inside the assessment model, the distribution of lengths at a given age, governed by two parameters for the standard deviation of length at a young age and the standard deviation at an older age, is also quite reliably estimated. This information could only be derived from marginal age-composition observations where very strong and well-separated cohorts existed and where they were quite accurately aged and measured; rare conditions at best. By fully estimating the growth specifications within the stock assessment model, this major source of uncertainty is included in the assessment results, and bias in the observation of length-at-age is avoided.

CAAL compositions were only implemented for male and female lingcod and no sex ratio was applied to unsexed fish (Table 10). This resulted in 60 unsexed fish being excluded from the CAAL distributions, or approximately one percent of the aged fish. Sensitivities to using CAAL data instead of marginal age data were explored by replacing CAAL compositions with marginal-age compositions.

2.2.2.5 AFSC/NWFSC West Coast Triennial Shelf Survey ages

The preparation of age data from Triennial Survey (Table 10; Figure 55) followed the same methods as the WCGBTS.

2.2.2.6 Lam research ages

A random stratified subsample by size and sex was selected per region for ageing and genetic analysis. The age-composition data were post-processed as CAAL data similar to the other surveys (Table 10; Figure 57)

2.2.3 Unused fishery-independent data

2.2.3.1 AFSC Slope Survey

The AFSC Slope Survey (Slope Survey) operated during the months of October to November aboard the R/V *Miller Freeman*. Partial survey coverage of the U.S. west coast occurred during the years 1988-1996 and complete coverage (north of 34°30'S latitude) during the years 1997 and 1999-2001. Typically, only these four years that are seen as complete surveys are included in assessments.

Sample sizes of lingcod were low during these four complete years, with 119 samples across 55 tows coastwide. Given that lingcod are primarily a shelf species, data from this survey was not included in the model.

2.2.3.2 NWFSC Slope Survey

The NWFSC also operated Slope Survey during the years 1998-2002. Coastwide, 184 lingcod were sampled across 64 tows. Data from this survey were not included in the model because lingcod is primarily a shelf species and sample sizes were low.

2.2.3.3 International Pacific Halibut Commission longline survey

Data from International Pacific Halibut Commission (IPHC) longline survey were examined in the past for their utility in measuring CPUE from fixed gear. However, depth and hook size are not appropriate for lingcod.

2.2.3.4 Oregon video lander survey

ODFW provided density estimates and a range of estimated population abundances from underwater video lander data for lingcod. The lander data was collected over nine years by ODFW (Rasmuson et al. 2020). The data includes information from ten independent studies carried out in both nearshore rocky reefs coastwide, as well as select reef structures offshore of the central coast of Oregon. Underwater video landers are stationary platforms consisting of one to three video cameras. Landers used in deeper water employ advanced lighting systems for optimal viewing of fish and benthic habitat. Ambient light is used in shallow surveys. The variability in detection range by depth is an important factor to consider when deriving fish density from lander data.

Variability in range, and therefore area viewed, directly influences estimates of fish abundance. Thus, density estimates were calculated using five estimates of range, average range, +/- one standard deviation from the mean, and maximum and minimum ranges. The area viewed is calculated using both the range and the horizontal field of view. This viewed area was then combined with fish-count data to generate fish densities. Count data were provided from Rasmuson et al. (2020). As expected, the viewed range has a large effect on the calculated density, with larger ranges resulting in a lower density of fish. There is no way to know which range most accurately reflects the true density of fish, and thus, multiple range estimates were combined into a single density estimate using a weighted arithmetic mean. Area viewed increases exponentially suggesting the use of a geometric mean may be more appropriate than an arithmetic mean. The geometric mean density was calculated three ways to address the presence of zeros in the data. Abundance estimates (numbers of fish) were calculated by multiplying the density estimate by an estimate of the habitat area. Coastwide habitat area was limited to primary or secondary habitat containing hard substrate. The western boundary was defined as the 200 m contour based on the depth of the continental shelf-break. The eastern boundary was based on the shallowest lander observation for each species. Lingcod were observed on lander video in water as shallow as 4 m; therefore, the 0 m contour was used. It should be noted that, while the depth range of the lander surveys conducted by ODFW extends to 212 m, the majority of lander surveys have been conducted in either nearshore rocky reefs or at Stonewall Bank RCA on the central Oregon coast.

For lingcod, density estimates ranged from 0.020 $\pm$ 0.052 (number fish / m^2 $\pm$ standard deviation) to 0.793 $\pm$ 1.850 for the maximum range method and the third geometric mean method, respectively. The estimated habitat area was 1,940 thousands km^2. Abundance estimates ranged from 38.8 $\pm$ 100.8 (millions of fish $\pm$ standard deviation) to 1,537 $\pm$ 3,585. Estimates of abundance from the five range models produced similar results to the weighted arithmetic mean, ranging from 38.8 $\pm$ 100.8 for the maximum range to 170.5 $\pm$ 472.8 for the minimum range. These were generally considered more plausible than the results based on the geometric means.

2.2.3.5 Oregon Marine Reserve Program

ODFW Marine Reserve Program in has routinely monitored state marine reserves and associated comparison areas since 2011. Surveys in 2011 and 2012 only visited Redfish Rocks marine reserve. Surveys from 2013 – 2019 include reserves and comparison areas from four marine reserves, Redfish Rocks, Cape Falcon, Cape Perpetua, and Cascade Head (Table 8).

Each of these marine reserves has one to three associated comparison areas. Comparison areas are specifically selected for each marine reserve to be similar in location, habitat, and depth to the reserve but are subject to fishing pressure. Not all sites are sampled in each year because of the gradual implementation of the reserve network and availability of staff to execute surveys.

A 500 meter square grid overlaid on the area defines the sampling units or cells. Cells are randomly selected within a marine reserve or comparison area for each sampling event. Three replicate drifts are executed in each cell. The specific location of the drifts within the cell is selected by the captain. Over time, cells without appropriate habitat for the focus species, mainly groundfish, have been removed from the selection procedures, and information from all inactive cells is removed from the data prior to any analyses being conducted. The number of cells visited in a day ranges from three to five cells. Data are aggregated to the cell-day.

Of the 940 total cell-days at 14 areas, 626 (66.6%) of those had positive lingcod catches (Table 7). The number of lingcod caught ranged from 0 to 34 fish in a cell-day (Figure 58). Areas differ in both geographic location and the level of fishing pressure experienced or allowed. Staff from the Marine Reserves Program suggested that the treatment (reserve vs. comparison area) may not be a delineating factor for the catch of lingcod due to the recent implementation of the reserves. It was suggested that data could be aggregated to the site level, functioning at the level of a reef complex, to examine patterns at different locations along the coast. However, this may not be possible with the sample size available at some sites. CPUE was calculated using the number of fish per angler hour, where the number of anglers and hooks are standardized for each survey. Angler hours have been adjusted for non-fishing time (i.e., travel time, etc.).

Additional filtering may not be necessary, as the filtering for active cells has already likely removed any unsuitable sampling units, based on habitat, depth, and local knowledge. Based on the annual proportion of positive cell-days and the relatively high encounter rate of lingcod in this survey, there could be enough data to move forward with a time series at a coastwide level. Additionally, Redfish Rocks has been sampled yearly since 2011, except for 2018, making it the best single reserve complex to monitor inter-annual trends. CPUE at this site shows a relatively stable trend since 2011 for lingcod (Figure 59). Coastwide, lingcod CPUE appears to be oscillating around the long-term mean, with the last two years being below average (Figure 60).

2.2.3.5.1 Oregon remote operated vehicle surveys

ODFW has collected data from ROVs on lingcod. Some of these observations are from MPAs. Unfortunately, these data have not been post processed and were unavailable for this assessment.

2.2.3.6 Washington Department of Fish and Wildlife research compositions

WDFW conducted mark-recapture experiments in the nearshore area at Cape Flattery from 1986 - 1994. Though study results were published in several journal articles (Jagielo 1990). Additional surveys were conducted in 1997, 2001, 2002, 2003, and 2016 using bottom fish troll gear. Biological data collected from these surveys were investigated in the previous assessment but were ultimately removed from the base model because they were not informative (Haltuch et al. 2018).

2.2.3.7 Washington Department of Fish and Wildlife hook and line survey

The WDFW hook and line survey started as a pilot study and now includes more than five years of data. Unfortunately, the methods have changed over time and the data were not ready for their inclusion in this assessment.

2.2.3.8 California Collaborative Fisheries Research Program

The CCFRP is a fishery-independent hook-and-line survey designed to monitor nearshore fish populations at a series of sampling locations both inside and adjacent to MPAs along the central California coast (Wendt and Starr 2009; Starr et al. 2015). The CCFRP surveys began in 2007 and were originally designed as a statewide program in collaboration with scientists from National Marine Fisheries Service (NMFS) and fishermen. Between 2007-2016 the CCFRP surveys were focused on the central California coast, consistently monitoring four MPAs. In 2017, the program was expanded to the coast of California.

The survey design for CCFRP consists of a number 500 x 500 m cells both within and outside each MPA. On any given survey day, cells are randomly selected within a stratum (inside or outside an MPA). CPFVs are chartered for the survey and the fishing captain is allowed to search within the cell for a fishing location. During a sampling event, each cell is fished for a total of 30-45 minutes by volunteer anglers. Each fish encountered is recorded, measured, is linked back to a particular angler, and released (or descended to depth). Fishing is restricted to shallow depths to avoid barotrauma-induced mortality. Starting in 2017, a subset of fish have been retained to collect otoliths and fin clips that provide needed biological information for nearshore species.

The index of abundance developed for lingcod focused drift-level information from the four consistently-sampled MPAs, Año Nuevo and Point Lobos, sampled by Moss Landing Marine Labs, and Point Buchon and Piedras Blancas, sampled by California Polytechnic State University (Cal Poly) (Table 13). Therefore, the index, as constructed, pertains to just the southern stock because the data was collected off of central California but future work could investigate the utility of generating two indices given the expansion of the sampling program in 2017.

2.2.3.9 Rockfish Recruitment and Ecosystem Assessment Survey

Data on the relative abundance of YOY lingcod are available from pelagic midwater trawl surveys that target YOY rockfish, other YOY groundfish, and forage species along the U.S. west coast. The Rockfish Recruitment and Ecosystem Assessment Survey has been conducted off central California annually between 1983 and 2003 and off most California waters from 2004-2019 (Adams et al. 1993; Sakuma et al. 2016), while the NWFSC pre-recruit survey has been conducted off the coasts of Oregon and Washington in most years since 2011 (Brodeur et al. 2019). Data from these two surveys are typically combined to provide coastwide indices of recruitment for several rockfish stock assessments, and as lingcod are encountered with some frequency, data from these surveys could be explored for the development of pre-recruit index for lingcod. Some additional research and analysis would be necessary to develop this index, primarily related to standardizing YOY abundance levels to a common age, as is done for juvenile rockfish, and evaluating how well past abundance patterns relate to assessment year class strength estimates.

2.3 Biological data

2.3.1 Natural mortality

Natural mortality was modeled as a single value for each sex applied across all ages within that sex with a Hamel-Then prior applied as in the previous assessments. However, whereas the 2017 assessment used a maximum age of 21 for in calculating the prior for both females and males, here the maximum age has been updated to match the 99.9 percentile of the approximately 9,000 ages for males and 30,000 ages for females in the PacFIN database to develop separate priors for males and females. Those percentiles are 18 years for females and 13 years for males. The number of ages available in the south model were too few to explore a separate maximum age calculation for that area.

The mean of the lognormal Hamel-Then prior is 5.4 divided by the maximum age, so the resulting prior means were 0.3 for females and 0.415 for males. The oldest aged lingcod in the commercial fishery was 35 for females and 16 for males. No fish older than age 17 were seen in any of the surveys and the oldest fish landed by the recreational fleet was 23.

This represents a significant increase from the 0.257 mean used in the previous assessments for both sexes.

The log-scale standard error of the Hamel-Then prior is 0.438, so the the central 95% of the resulting prior for female M covered the range 0.127 to 0.708. The central 95% of the resulting prior for male M covered the range 0.176 to 0.98.

These values were at the upper end of the range of values estimated in previous studies. Jagielo (1994) estimated M for male and female lingcod using three empirical models based on life-history parameters (Alverson and Carney 1975; Pauly 1980; Hoenig 1983). Estimates of M for male lingcod ranged from 0.23 to 0.39, while estimates for female lingcod ranged from 0.16 to 0.19. The averages of the estimates were 0.18 for females and 0.32 for males. Starr et al. (2005) estimated natural mortality rates from a short term tag-recapture study and came up with ranges of 0.24 to 0.34 for females and 0.13 to 0.23 for males. However, these estimates do not take into account variation in M across the year (or between years), especially for males during nest-guarding.

2.3.2 Maturation and fecundity

A new estimate of functional maturity-at-age (Figure 63) based on histological analysis of ovaries was developed for these models (pers. comm., M. Head, NWFSC; Figure 64). The previous assessment (Haltuch et al. 2018) used length-based maturity but noted that differences in maturity at length between north and south areas appeared attributable to regional differences in growth. The estimated age at 50% maturity was 3.23 for the north based on 327 samples for which both ovaries and age estimates were available and 2.74 years for the south based on 322 samples.

2.3.3 Sex ratio

The observed sex ratio by length confirmed that males grow to a smaller size than females and suggested that there are slightly more females in the population or that females are better sampled than males (Figure 61). The impact of nest guarding may be limiting the availability of males, but there is limited data to investigate this. A cursory look at length by latitude and sex using data from the WCGBTS suggested that males and females are equally dispersed coastwide (Figure 62), and thus, a sex ratio of 50:50 was assumed for this assessment.

2.3.4 Length-Weight relationship

The weight-length relationship for lingcod was estimated outside of the assessment model by fitting biological data to the standard power function, $W = aL^b$. W is weight in kilograms and L is fork length in centimeters.

Spatial differences were investigated by comparing the residuals across latitude, region, and depth for a model that included the standard power relationship fit to all coastwide samples. Comparisons were made using Tukey's honestly significant difference test for pairwise multiple comparisons (Tukey 1949). Residuals of the fit between length and weight showed significant differences among latitude (p-value < 0.001, as a continuous variable) and among regions north and south of 40°10'N (p-value < 0.001, as factors). The relationship between length and weight changed with depth (p-value $= 0.02$, as a continuous variable) but not when applying similar depth categories (55 - 183, 183 - 400, and >400 m) as was used to expand composition data (p-value $= 0.16$) or more refined depth categories (55 - 85, 85 - 110, 110 - 140, 140 - 183, and >183 m; p-value $= 0.20$).

The parameters of the weight-length relationship were re-estimated using data from the WCGBTS. Data included lengths and weights collected between 2003 and 2019 for 7,869 fish. Of these samples, 4,978 were female and 2,805 were male. These data resulted in the following estimates of the weight-length relationship, $W = 0.000002802 * L^{3.2766}$ for females and $W = 0.000001493 * L^{3.4449}$ for males (Figure 65). These relationships are very similar to those used for the previous assessment (Haltuch et al. 2018). Additionally, Hart (1967) reported the relationship between W and L as $log(W) = 3.6558 * log(L) - 9.4845$. Jagielo (1994) reported $W = 0.000001760 * L^{3.3978}$ for females and $W = 0.000003953 * L^{3.2149}$ for males when fitting to mean weight-at-length as measured from data collected by the West Coast survey.

2.3.5 Growth (length-at-age)

A model based change-point analysis (Kapur et al. 2020) was used to identify a biologically relevant stock boundary using size-at-age data from the WCGBTS and Lam research samples (Lam et al. 2021). A generalized additive model was fit to observed lingcod lengths of a single age as the response variable. Predictor variables included a smoother for latitude. Each age-sex combination was analyzed separately. The first derivative was taken from the fitted spline to detect the latitude at which differences in size-at-age were most pronounced (i.e., the maximum absolute value) and statistically significant (i.e., where the confidence interval does not include 0). The resulting latitude was rounded to the nearest integer as there were no detectable differences when half-degrees were used. 77.8% of significant age-sex combinations detected a break between latitudes 38°00′ and 40°00′ N (Figure 3). This range is in agreement with the genetic break point identified for lingcod by Longo et al. (2020).

Lingcod display sexually dimorphic growth. Females grow faster and reach larger sizes than males. Jagielo (1994) estimated growth using a fixed length at age 1 of 30 cm that resulted in estimates of L_∞ for males of 93.21 cm and females of 131.05 cm and k of 0.1694 for males and 0.1137 for females. He also found that the average length for age-0 fish, i.e., YOY, lingcod was 11.99 cm and for age-2 fish was 48.1 cm for Washington samples. Additionally, growth trajectories diverge considerably by sex after the age of three because female lingcod tend to grow faster and live longer than male lingcod. Male lingcod mature at age three.

Estimates of growth parameters were investigated and starting values for model inputs were updated using the WCGBTS data. Spatial differences were investigated by fitting an overall von Bertalanffy relationship between age and length across all coastwide samples and then comparing the residuals across latitude and depth using Tukey's honestly significant difference test for pairwise multiple comparisons. Residuals of the fit between age and length showed significant differences among latitude (p-value < 0.001, as a continuous variable) and among regions north and south of 40°10'N (p-value < 0.001, as factors). Lingcod grow faster and attained a larger size north of 40°10'N. The relationship between age and length changed with depth (p-value $= 0.02$, as a continuous variable), and unlike with the length-weight relationship, age and length fits varied by depth bins (p-value < 0.001). When applying similar depth categories (55 - 183, 183 - 400, and >400 m), as was used to expand composition data, patterns were not statistically distinguishable between shallow (55 - 183 m) and deep (>400 m) depths (p-value $= 0.62$) and mid (183-400 m) and deep depths (p-value $= 0.24$). When using more refined depth categories (55 - 85, 85 - 110, 110 - 140, 140 - 183, and >183 m), patterns were nearly not statistically distinguishable between shallow (<85 m) and mid-shallow (85-110 m) depths (p-value $= 0.043$) and were not statistically distinguishable between mid-deep (140-183 m) and deep (>183 m) depths (p-value $= 0.84$).

Externally estimated von Bertalanffy growth parameters for lingcod using WCGBTS data were as follows: $k = 0.193$ and $L_\infty = 103.645$ for females and $k = 0.282$ and $L_\infty = 79.115$ for males. These estimates were used as initial values within the base model for estimating growth. Samples used to generate these estimates include 5,145 age and length samples, of which 3,290 are female and 1,795 are male.

2.3.6 Ageing precision and bias

Lingcod are aged using dorsal fin rays, which has been found to have the highest accuracy, readability, and minimal between-reader bias when compared to other ageing structures (e.g., Chilton and Beamish 1982; Cass and Beamish 1983; Claiborne et al. 2016). However, recent studies suggest that surface reads from otoliths may be comparable in terms of accuracy and readability. For this assessment, lingcod samples from fishery-dependent and -independent sources were aged using the fin-ray method.

During the process of reading ages, the first and second annuli can be re-absorbed as the fish ages, obscuring early annulus rings and leading under-ageing. However, error can be minimized using known mean annular radii measurements for the first, second, and third annuli, as established by Beamish and Chilton (1977) and later validated by McFarlane and King (2001).

For this assessment, between-reader ageing error was determined using the nwfscAgeingError package (Johnson et al. 2021b), which is publicly available at https://github.com/nwfsc-assess/nwfscAgeingError. This package implements the Punt et al. (2008) model. It calculates the likelihood of model parameters given an observed data set that includes age reads provided by multiple readers for a set of ageing structures. For each reader, two sets of parameters are estimated that define the standard deviation and bias of the reads provided by that reader. The set of parameters that best describes the standard deviation and bias between age readers is determined with a step-wise model-selection function and compared using AIC.

Initial explorations for seven different combinations of age readers showed little bias among readers. Therefore, all 2,441 double reads were pooled into a single analysis to estimate variability in age estimation (Figure 66). The best fit model, as chosen by both AIC and BIC, used "Curvilinear CV" (a 3-parameter Hollings-form relationship of CV with true age). The standard deviation in estimated age was 0.24 years at age one, 0.56 years at age five, 1.1 years at age ten, and 1.65 years at age fifteen (Figure 67).

3 Model

3.1 Previous assessments and reviews

3.1.1 History of modeling approaches

Since 1986, there have been nine assessments of lingcod covering at least part of the U.S. west coast. The first assessment was performed by Adams (1986) and consisted of a yield per recruit analysis. Each of the subsequent assessments utilized an age-structured model, though the structure and form has changed with time.

The second assessment, conducted by Jagielo (1994), was conducted using an earlier version of Stock Synthesis (Methot and Wetzel 2013) and focused on the northern area. Data were limited to the region between Cape Falcon in Northern Oregon and 49°00'N latitude (off of southwest Vancouver Island in British Columbia). This included Pacific States Marine Fisheries Commission (PSMFC) areas 3A, 3B, and 3C, inclusive of Canada. Two fleets were modeled, trawl and recreational, from 1979-1993, two CPUE time series were included, Triennial Survey and trawl, and length- and age-composition data were used to estimate selectivity. The final spawning output was estimated to be approximately 20% of pristine levels, and catch recommendations ranged between 2500 and 3000 mt based on fishing mortality levels of 20% and 40%.

The third assessment was conducted in 1997 (Jagielo et al. 1997) and expanded the area included south to Cape Blanco (42°50'N latitude). The estimated fraction unfished was below 0.10, which led to the Council implementing substantial coastwide reductions in harvest and recommending that the southern portion of the stock also be assessed. Two years later, Adams et al. (1999) conducted a length-based, age-structured population model implemented in AD Model Builder (ADMB) (Fournier 1996) for the southern area, including Eureka, Monterey, and Conception INPFC areas. Since then, lingcod assessments have covered the entire U.S. west coast but been broken into two assessments using various spatial delineations.

In 2000, Jagielo et al. (2000) fit data to ADMB models using the same spatial delineation but removing data from Canadian waters. Both stocks showed increasing trends in their abundance and new ageing methods suggested the stocks were younger and more productive. The populations were assessed again in 2003, this time using Coleraine (Jagielo et al. 2003). In 2005, Jagielo et al. (2005) switched back to Stock Synthesis, which was then at version 2 of the code base. Estimates suggested that the northern stock had recovered substantially from a low point in the 1990s and was at 0.87 fraction unfished, while the southern area was not estimated to have recovered and was at 0.24 fraction unfished, with a 0.64 coastwide fraction unfished.

The 2009 stock assessment, which used Stock Synthesis 2, divided the northern (Washington and Oregon) and southern (California) stocks at the Oregon-California state line (Hamel et al. 2009). The northern and southern models were made as equivalent as possible by keeping fixed and estimated parameters largely the same for the two assessments. Natural mortality was fixed at 0.18 for females and 0.32 for males in both assessments, while steepness was fixed at 0.8. Age data were removed because of issues with outliers and possible aging bias. The estimate of fraction unfished at the start of 2009 was 0.619 for the northern area and 0.737 for the southern area, indicating the stocks had recovered. For the northern stock, the axis of uncertainty for the decision table provided to managers was M. The low, base, and high values of M_{female} were 0.16, 0.18, and 0.20. The low, base, and high values of M_{male} were 0.285, 0.320, and 0.355. For the southern stock, the lower axis of uncertainty was for the he exclusion of the dockside recreational CPUE index and the higher axis of uncertainty was the inclusion of age data.

The 2017 assessment (Haltuch et al. 2018) was conducted using Stock Synthesis and matched the spatial structure used for 2009 (Hamel et al. 2009). The assessment updated the existing data sources, as per normal protocol, and also included the following changes:

- expansion of the time period of the assessments back to 1889,
- separation of commercial fleets into TW and FG,

- separation of recreational fleets in the northern stock to state-specific fleets,
- addition of numerous fishery-dependent CPUE indices and the NWFSC Hook and Line Survey (Hook and Line Survey) index
- updated prior on natural mortality
- updated biological parameters for maturity and length-weight relationship
- updated ageing uncertainty
- included some age data as marginal ages instead of ages conditioned on length

The estimated scale of the population was sensitive to the inclusion of age data for both stocks. These estimates of status remained the same regardless of whether or not the model was fit to age data. The northern stock was estimated to be above the target reference point of 0.40 fraction unfished. The southern stock was estimated to be below the target reference point of 0.40 fraction unfished at 0.321.

In 2019, a catch-only projection was conducted. This update assessment included observed catches for 2017 and 2018 in the forecast calculations. Expected catches for 2019 and 2020 were also included in the forecast calculations. The results provided updated catch limits for management.

3.1.2 Most recent STAR panel and SSC recommendations

The 2017 STAR report noted four unresolved problems and three major sources of uncertainty as well as provided three specific recommendations for future research with respect to lingcod (Haltuch et al. 2018). In addition, the Panel made four recommendations for stock assessments in general.

All four **unresolved problems** were addressed during this assessment.

1. **The models did not use the available age data sampled from the fishing fleets due to concerns that unsexed fish had been assigned equally to the sexes without regard to length and because of evidence there had been non-random subsampling of fish for age-reading.**

Age data included in the northern model were conditioned on length for sexed lingcod. Unsexed age samples were not included in either model. Length distributions of unsexed fish were represented as independent vectors in addition to the vectors of female and male compositions.

2. **The available age-readings had been done by at least two laboratories. It was unclear that age-reading protocols had been employed consistently.**

Analyses on ageing error did not show differences between readers, labs, or cohorts (see Section 2.3.6). The ages available for the north model were fit reasonably well while those available in the south from sources other than WCGBTS showed a lack of fit that was unlikely attributable to ageing uncertainty alone.

3. **In the northern model the STAT fixed the parameter for female length at age 14 years because when this parameter was freely estimated the model estimated asymptotic selection for the trawl fishery and greatly altered the estimates of spawning biomass. It was unclear what data sources were responsible for this result.**

The addition of more years of age data from the WCGBTS along with the inclusion of ages from the fisheries resulted in a total of 72,121 age samples represented in the north model which was more than adequate to provide reasonable estimates of growth.

4. **Sensitivity analyses for draft versions of both models indicated they were sensitive to underlying structural assumptions such as the starting year for recruitment deviations and which indices were included. Although the revisions to the models developed during the STAR may have lessened the sensitivity of the models by removing sources of tension and keeping the more reliable data, there was not sufficient time during the review to explore the sensitivity of the final base models.**

A number of sensitivities were explored that excluded data sources and attempted to reconcile data conflicts. Additional explorations made during the STAR panel review led to changing the timing of the main recruitment period in the southern model given removal of the early length data that had small sample sizes and were only representative of a small portion of the coast. Sensitivity to underlying structural assumptions is a general issue of stock assessment modeling and not unique to lingcod.

All three **major uncertainties** were explored during this assessment.

1. **Stock structure: Aspects of the length- and age-compositions evident in the NWFSC survey data strongly indicate spatial patterns that probably cannot be well mimicked with separate, independent models for the north and the south.**

Research on lingcod stock structure that was completed since the last stock assessment provided evidence of a stock break in central California (Longo et al. 2020). Details were described in the Stock delineation section. Although this may not resolve evidence of wide scale spatial patters, major Uncertainty 1 can now be rexamined under additional information on stock structure. The data from the WCGBTS was, in general, well fit by both models.

2. **Key productivity parameters: Neither the northern model nor the southern model were able to estimate the steepness or the female natural mortality parameters given the available data. Values for these key parameters had to be fixed but there is very little knowledge to inform the choice of those values. As such this is a source of considerable uncertainty. During review of this report the STAT suggested that including the age-composition data in the northern base model (data had been removed during the STAR) would allow estimation of M and h.**

Stock-recruit steepness and natural mortality (for both females and males) were estimated in both north and south models and provided plausible estimates. The representation of the uncertainty in these estimates provides a better treatment of the uncertainty in quantities of interest, such as the management reference points.

3. **Habitat area, north versus south: The northern and southern base models estimate appreciable differences in the unfished spawning biomass of lingcod (37,974 mt in the north versus 20,462 mt in the south). It is unknown whether such a difference is consistent with the habitat areas suitable to support lingcod in the north versus the south.**

Using simple assumptions on available habitat, by assuming the relative difference in the amount of area in depths between 55 m and 300 m, roughly approximates the relative difference in habitat area between modeled regions.

Next, we provide responses to each of the three **specific recommendations** from the 2017 STAR panel.

1. **There should be a study to cross-validate age-readings of lingcod among the different laboratories contributing age data to the assessment. It may be necessary to develop laboratory-specific (and possibly year-specific) ageing-error vectors.**

Additional ageing comparisons were conducted and the ageing uncertainty was re-estimated as described in the Ageing Error section of this report. However, the new estimates showed similar uncertainty in ageing to the previous assessment. The differences among age distributions within the same length bins among sources available for the southern model are large enough that they are unlikely due to uncertainty in ageing alone. Removing all ages in the southern model other than those from the WCGBTS resolved this issue.

2. **Available information on lingcod catches, abundance trends, and age-compositions should be acquired from Canadian and Mexican authorities to take an initial step towards a more spatially-comprehensive view of lingcod population trends and dynamics.**

Additional information on lingcod in Mexico, Canada, and Alaska is provided in the Foreign Fisheries section of this report.

3. **The next iteration of this assessment could be an update assessment. If a full assessment is done it should explore developing a spatial model that encompasses the northern and southern areas rather than again treating them as independent stocks, as in the current and previous assessments.**

New information on genetic differences between the modeled areas supports the treatment of these areas as independent models (see Section 1.2.5). A spatially-explicit model encompassing data from both stocks was not investigated for this assessment because the widespread use of such approaches are not yet standard and remain operational for only a few select data-rich stocks, largely in a simulation context. Limitations still exist because of the model complexity associated with increasing spatiotemporal dimensions, including underlying data limitations, confronting the expanding number of decisions or assumptions that need to be made, and the amount of analyst time required to develop, test, and vet spatial procedures given production stock assessment timelines (Punt 2019; Berger et al. 2021). Scientifically, there is growing appreciation and application of spatial stock assessment methods using simulations and the results of this research underlines the importance of acknowledging spatial processes (e.g., connectivity dynamics between unique segments of a stock; biological characteristics that change across environmental gradients; and regulations that impose local changes in fishing patterns) across the management domain (Cadrin et al. 2020; Berger et al. 2021). But, a production-level spatially-explicit stock assessment framework was not available for this assessment.

The four general recommendations on stock assessments were as follows:

1. Modify the software used to develop length- and age-compositions from PacFIN data so that unsexed fish are flagged rather than including them in compositions after the automatic application of an assumed sex-ratio (e.g., 50:50). If the analysts preparing the composition data need to develop sex-ratio coefficients to accommodate unsexed fish (e.g., by length-bin), the assessment documents should clearly state the methods and data used for this purpose and the resulting sex-ratio coefficients.

2. If assessments use marginal age-compositions the STATs should evaluate whether the raw data are consistent with random sub-sampling from the available lengths. If the ages appear to have been subsampled non-randomly (e.g., no more than 5 fish from any length-bin), the age data should be suitably expanded to reflect the variable sampling fraction.
3. A standard approach for combining conditional age-at-length sample data into annual CAAL compositions should be developed and reviewed. If age data are not selected in proportion to the available lengths, simple aggregation of the ages by length-bin may provide biased views of the overall age-composition and year-class strength.
4. Comprehensively evaluate whether the Triennial survey should be split into early and late segments and the basis for making the decision. The lingcod assessment split the Triennial survey into separate early and late surveys, whereas there was a single Triennial survey in the draft assessment for Pacific ocean perch brought to this STAR.

Ongoing work by the NWFSC staff has addressed recommendations 1, 2, 3, and explorations by the lingcod STAT can inform recommendation 4, though not comprehensively. The lingcod STAT chose to represent ages as conditioned on length rather than apply an expansion to reverse the effect of non-random sampling.

3.1.3 Response to Groundfish Subcommittee recommendations

3.2 Model structure, assumptions, and results

3.2.1 Model changes from the last assessment

The following is a brief list of changes that were made to the model configuration compared to the previous assessment (Haltuch et al. 2018).

Data

- Change the boundary between north and south from 42°00'N to 40°10'N
- Add new data from 2017-2020
- Add new ages from earlier years in the WCGBTS

- Re-analyze all data inputs from the raw data with the exception of the trawl logbook index which was re-stratified to account for the change in boundary

Fleet structure

- Early and late periods of the Triennial Survey were combined into a continuous time-series
- A California recreational fishery for the catches and length compositions between 40°10'N and 42°00'N was added

Biology

- Use new area-specific age-based maturity estimates
- Update weight-length relationship to include additional samples
- Separate M priors for males and females based on a lower maximum age (18 for females, 13 for males, compared to 21 for both sexes)
- Estimate female M instead of fixing it at the mean of the prior
- Estimate all 5 growth parameters within each model rather than fixing the parameter controlling the length at age 14

Recruitment

- Fix $\sigma_R = 0.6$ for both models (in the 2017 assessment, σ_R had been iteratively tuned to 0.55 for the north model and 0.75 for the south)
- Estimate the stock-recruit steepness parameter with a prior instead of fixing it at 0.7
- Extend the end of the "main" period of recruitment deviations and the recruitment bias adjustment settings by three years to account for the additional survey data from 2017-2019 (no surveys were conducted in 2020 do the pandemic)

Selectivity and retention

- Estimate three double-normal selectivity parameters within each time block for each fleet (whereas the previous model had fewer or more parameters estimated depending on the fleet or time block)
- Fix the retention parameters for the early period of the commercial TW and FG fisheries to retain all selected fish prior to 1998

- Revise the blocking on numerous selectivity parameters
- Turn off male selectivity offsets to simplify the model

Software and workflow

- Use a newer version of Stock Synthesis, version 3.30.17.01
- Use previously unavailable or updated versions of numerous R packages related to processing input and output files for the assessment, including *nwfscDiag*, *sa4ss*, *r4ss*, and *PacFIN.Utilities*.
- Created a *lingcod* R package in a publicly accessible repository on github to provide a transparent and reproducible system for processing the data, modifying the model files, and writing these reports.

3.2.2 General model specifications

With the exceptions noted above, the general model specifications were retained from the previous assessment. The assessment is sex-specific, including the estimation of separate growth curves and natural mortality for males and females. The sex ratio at birth is assumed to be 50:50. Female spawning biomass is used in calculating stock status.

The model starts at equilibrium, assuming an unfished initial age structure in 1889. The internal population dynamics include ages 0-25, where age 25 is the plus-group. As there is little growth occurring at age 25 and very few observations, the data use a plus group of age 20.

The following likelihood components are included in this model: catch, indices, discards, length compositions, age compositions, recruitments, parameter priors, and parameter soft bounds (Table 16). See the Stock Synthesis technical documentation for details (Methot and Wetzel 2013). Estimated likelihood components from the base models can be found in the model output files archived with this report.

3.2.2.1 Selectivity and retention

Selectivity was modeled using the double-normal function of length (option 24 in Stock Synthesis; Table 14) with three of the six possible parameters estimated for each fleet.

The estimated parameters controlled the length at peak selectivity, the slope of the ascending limb and the slope of the descending limb (parameters 1, 3, and 4 in SS). The parameter controlling the width of the top was fixed at a small value (-15) to make a smooth transition from ascending to descending with no flat top.

Parameters 5 and 6 which control additional scaling of initial and final values were not used (via the -999 code in SS).

Retention was modeled for the commercial trawl and commercial fixed-gear fleets using a logistic function of length with 2 of the possible 4 parameters estimated. The two estimated parameters controlled the length at 50% retention and the slope of the ascending curve. Asymptotic retention was fixed at 100% and no sex-specific differences in retention were estimated.

Changes in selectivity and retention over time were modeled to account for management changes and gear changes. For changes in selectivity, all three estimated double-normal parameters were allowed to vary among time blocks as any change in the peak parameter will impact the shape associated with the other two. For changes in retention, the length at 50% retention was allowed to vary over time, but the slope parameter was assumed to apply to all years after the management measures were imposed in 1998.

Prior to 1998, all selected fish are assumed to be retained in the commercial fisheries in keeping with comments from those familiar with the history of the commercial fishery at the pre-assessment workshop and the Pikitch study in which more than 99% of the observed lingcod were retained (pers. comm., J. Wallace, NWFSC).

For commercial fisheries the assumed discard mortality rates are retained from the previous assessment: 50% for trawl and 7% for fixed gear.

Selectivity for the recreational fisheries was modeled as representing retained fish only and the retention process is represented within the assessment model only through time-varying selectivity that accounts for changes in minimum size limits. A 7% mortality rate has been assumed for lingcod discarded in recreational fisheries and these dead discards are accounted for in the total catch, but an exploratory analysis (Figure 38) indicated the the difference between the expected length distributions with or without the dead discards included was small. Therefore, the length compositions from recreational fisheries exclude all discards. Alternative approaches to these assumptions were considered, but the available data do not support them as it would "require 'unscrambling the egg' since B1 is a mixture of retained and discarded fish in the MRFSS data" (pers. comm., E.J. Dick, SWFSC).

The specific years with time blocks used for each fleet are noted below.

For commercial trawl, the time period of blocking on selectivity parameters were reduced from the the 2017 assessment, removing some blocks from the early years. The remaining points of change in selectivity were:

- 1993 (change in mesh size)

- 1998 (trip limits and size limits)
- 2011 (implementation of the catch shares program)

Additionally, there were retention changes modeled in the following years, retained from the 2017 assessment.

- 1998 (implementation of groundfish regulations)
- 2007 (groundfish regulations)
- 2010 (pre-catch share behavior change and clear reduction in discard rate)
- 2011 (implementation of the catch shares program)

All blocks were applied to the length at 50% retention, but only the changes in 1998 and 2011 were applied to the parameter controlling the slope of the retention function.

For commercial fixed-gear, selectivity was assumed to be constant and retention was assumed to change in the following years:

- 1998 (implementation of groundfish regulations)
- 2011 (implementation of the catch shares program)

The 2017 south model had a additional blocks starting in 2002 and 2003 for the south model to account for closed areas. However, the composition data don't show evidence of a change around that time.

Changes in selectivity of the recreational WA fleet began in

- 1987 (management changes)
- 1995 (management changes)
- 1998 (first year of a series of management changes also made in 1999, 2000, 2001)
- 2007 (management changes)
- 2011 (management changes)
- 2017 (22" minimum size requirement was lifted from July 2017 to current for all catch areas but the change happened in the middle of the year)

Changes in selectivity of the recreational OR fleet began in

- 1995 (the first year with a minimum size limit–22 inches)
- 1998 (min size limit was increased to 24 inches)
- 2007 (min size limit was reduced from 24 to 22 inches)

Not accounted for is a max size limit in place in Oregon for one year only (2000) of 34 inches, which is visible in the data, but the absence of larger fish observed in a single year was assumed to have a negligible impact on the model results.

Changes in selectivity of the recreational CA fleet began in

- 1999 (min size limit 24 inches)
- 2011 (min size limit decreased to 22)

This represents a smaller number of blocks than used in the south model which also included blocks starting in 1983 and 2017 as the data from northern California used in the north model are sparser and correspond to a small fraction of the catch compared to the south model.

A block on selectivity associated for the Triennial survey was explored beginning 1995, the year associated with expanded spatial coverage and shift in timing, but not included in the base model.

3.2.3 Model parameters

3.2.3.1 Priors

The prior distributions for female and male natural mortality (Figure 130) were based on the Hamel (2015) meta-analytic approach with an assumed maximum age of 18 and 13 years old for females and males, respectively (see Section 2.3 for details).

The prior distribution for steepness (Figure 130) was based on the prior distribution used in the assessment of Pacific Hake, *Merluccius productus* (Johnson et al. 2021a), which is based on the 20th, 50th, and 80th percentiles (0.67, 0.79, and 0.87, respectively) from Myers et al. (Myers et al. 1999). The prior has a beta distribution given the following parameters: 9.76 and 2.80, which translates to a mean of 0.777 and a log-standard deviation of 0.113. This prior has been used for Pacific Hake since 2007. The terms of reference for groundfish managed by the PFMC suggest that priors on steepness for rockfish should have a mean of 0.72 and a standard deviation of 0.16 but do not specify anything related to lingcod. An analysis from FishLife suggested a prior with a mean of 0.67 and a standard deviation of 0.22.

3.2.3.2 Estimated parameters

The base model has a total of 212 estimated parameters (Table 15) that can be grouped into the following categories and are described in more detail in the following sections:

- 2 natural mortality parameters (female and male M)
- 10 growth parameters, where females and males each had
  - 3 von Bertalanffy parameters (length at age 0.5, length at age 14, and k)
  - 2 parameters controlling variability in growth, the CV in length at age 0.5 and the CV in length at age 14 with a linear ramp in length-at-age
- 134 recruitment parameters
  - $log(R_0)$ controlling equilibrium recruitment
  - h controlling the steepness of the stock-recruit relationship
  - 144 recruitment deviations parameters covering the range 1889-2020, with 1960-2018 representing the "main" period modeled as a zero-centered deviation vector
- 4 extra standard deviation parameters for indices
- 53 selectivity parameters, of which 34 represented changes over time
- 9 retention parameters, all of which represented changes over time because the retention prior to 1998 was assumed to be high for all selected fish.

3.2.3.3 Fixed parameters

Commercial fishery retention parameters for the period prior to 1998 were fixed at values that led to almost 100% retention as discussed in Section 3.2.2.1.

The extra standard deviation parameters for two Oregon CPUE indices were fixed at 0 as discussed in Section 3.2.4. The parameter controlling the descending slope of the dome-shaped selectivity function hit a bound for many combinations of fleet and time-block in the north model. Model diagnostics indicated that these parameters were causing problems with convergence so they were all fixed equal to the bound.

Selectivity was estimated as asymptotic in many cases (Figure @ref(fig:selectivity_comm)-69), including the commercial trawl prior to 1993, the fixed-gear fleet (not time-varying), any many of the time-blocks for the recreational fleets. In all these cases, the parameter controlling the descending slope of the dome-shaped selectivity was fixed at the upper bound. One descending slope parameter hit the lower bound, for commercial trawl in the period 1993-1997. This parameter was also fixed at that bound

(1.0). The length at 50% retention for the commercial trawl fleet hit the upper bound of 100 cm for the period 1998-2006 and was likewise fixed at that bound.

The following additional parameters were fixed based on standard practices for west coast assessments.

The standard deviation of recruitment deviations was fixed at 0.60. A tuning algorithm (Methot et al. 2011) indicated little change was needed from this starting value and sensitivity analyses showed the results to be relatively insensitive to alternative values.

The maturity parameters were fixed at values based on the analysis described in Section 2.3.2.

The weight-length parameters were fixed at values estimated externally using data with paired observations of length and weight from the WCGBTS, as described in Section 2.3.4.

3.2.4 Base model selection

The initial structural changes from the previous assessment described above were made in parallel to both models to provide a common set of assumptions as a starting place for both models based on current best practices and common approaches. Assumptions for the north and south diverged once the fits to the data and model performance were examined.

Following the previous assessment, all fishery-dependent indices initially an estimated extra standard deviation parameter estimated and fishery-independent indices did not.

However, the 2004 observation in the Triennial Survey had a poor fit (while the other points were reasonable, including those around the transition between early and late periods). Furthermore, likelihood profiles over $log(R_0)$ indicated a strong influence of this index on the scale of the north model far above the model expectation (as has been the case for this survey year in many other species), so an extra SD parameter was added to the north model for that index. Conversely, the extra standard deviation parameter for the Oregon nearshore logbook index and the Oregon Recreational Boat Survey index hit the lower bound of 0 indicating that the input uncertainty was appropriate for the degree of fit within the model. That parameter was fixed at 0 both both indices.

Initial selectivity assumptions had fewer blocks in some cases, but examination of patterns in the data and the model fits, as well as consideration of the management history led to refinements in the time blocks for selectivity and retention.

The north model also had a number of parameters on bounds that needed to be fixed in order to enable good convergence (see Section 3.2.4 for details). One of these that was most problematic was the length at 50% retention for the commercial trawl fleet during the period 1998-2006, which hit the upper bound of 100 cm. Alternative time-blocks were explored, but did not solve the problem. Increasing the bound provided a better fit to the discard and retained length compositions for this fleet, but a much worse fit to the discard ratios for 2002-2006. There is no established data-weighting method to tune the uncertainty in discard ratios so the bound on the retention parameter was retained to keep the fit to the discards within a reasonable range.

Recruitment assumptions were adjusted to account for the additional years of data but otherwise unchanged from the initial setup.

The biggest difference between the north and south models was in the treatment of age data. In the north model, ages were available from a large number of years from almost every fleet and these were included as conditional-age-at-length (CAAL) data to reduce potential biases associated with non-representative sampling of age structures within the sampled population (as discussed under the STAR panel recommendations from 2017 in Section 3.1.2). The fit to the CAAL data was generally good across fleets and time periods in the north model and the model results were plausible.

In contrast, the south model had sparse sampling of ages in all but the WCGBTS and the fits to all data sets other than the WCGBTS were poor when represented either as CAAL or marginal age compositions. Likelihood profiles and other sensitivity analyses showed that the ages were strongly influencing the model results and pushing the scale of the estimated population to high levels. The problems of the age data in the south model could be due to a number of factors including sparse sampling and variability in sampling location, variability in growth over time or space, or misspecification of some population dynamics process. However, a comparison of the fit to the Triennial Survey CAAL composition data from 1995 with the ages observed within the same length bins in the commercial TW and FG fleets from that same time period showed strong differences, suggesting that it would not be possible to simultaneously fit both data sources within the existing model structure, or even a more complex model with time-varying growth. Therefore, only the CAAL composition data from the WCGBTS was included in the south model (which already represented a majority of the ages) and all other age data were removed. This removed the conflict within the model, allowing reasonable estimates of population scale while retaining sufficient information about age at length to provide reasonable estimates of growth.

3.2.5 Base model results

3.2.5.1 Parameter estimates

Estimates of key parameters include female $M = 0.418$, male $M = 0.414$, and stock-recruit steepness $h = 0.801$ (Table 15). Females were estimated as growing larger than males with female length at age 14 (the second reference age) equal to 105.1 cm compared to 76.2 cm for males. The L_∞ associated with the estimated growth parameters was 118.7 cm for females and 77.5 cm for males.

Selectivity was estimated as asymptotic for the commercial fixed-gear fleet and the earliest period of the commercial trawl fleet, while from 1993 onward the commercial trawl fishery was estimated as asymptotic (Figure 68).

Commercial trawl retention was estimated as shifting to the right during the period with strict trip limits from 1998 to 2009, then shifting back to the left as catch shares were implemented, with the length at 50% retention from 2011 onward estimated at 55.7 cm.

The recreational fishery selectivity in Washington was estimated as asymptotic in the early and late periods but dome-shaped during the two blocks covering the years 1998-2010. Oregon and California recreational selectivity was estimated as asymptotic for most time blocks, but dome-shaped in the most recent block in each case (Figure 69).

Selectivity for the two surveys and the Lam research sampling were all estimated as dome-shaped although the Triennial Survey is almost asymptotic. Peak selectivity is estimated at 104 cm for the Triennial Survey and 83.2 cm for the WCGBTS. The survey selectivity is notably different from the south model, where those two surveys have peak selectivity below 30 cm (Figure 69). Strong differences in the presence of small fish in the survey samples from the north and south areas indicate that the differences in estimated selectivity curves are necessary to fit the data in each case.

3.2.5.2 Fits to the data

The fit to the seven indices of abundance are all reasonably good, with the timing and magnitude of changes in expected abundance following the observed patterns (Figure 70). The five contemporary indices all increased over the 2010s with a peak around 2005, which the model expectation fits well driven by a large 2008 cohort. The areas with the biggest lack of fit are the first two years of the trawl logbook CPUE index, which are much higher than the rest of the time series, and are also poorly fit in the south model, the 2004 observations of the Triennial Survey, and the 2020 observation of the Washington recreational CPUE index. All of these observations are inconsistent with the adjacent observations in the same index suggesting that they may be outlier rather than a signal about the true dynamics of the underlying population.

The fit to the length data, when aggregated over time (Figure 71), shows some imbalances in the sex ratios but the modes are generally falling in the right places. The commercial trawl discards show modes associated with the length at ages 1 and 2 the first of which is better fit than the second. This could be due to the fishery taking places over a protracted season while the model expectation is based on a mid-year snapshot. Looking at the fits for individual years (Figures 72 and 73) shows high variability for the commercial trawl length comps and a large blotches in the Pearson residuals. In general, the recreational and survey length compositions are reasonably well fit.

Ages in the north model are all conditioned on length, but also included as marginal "ghost age comps" which are excluded from the likelihood for purposes of visualizing the implied fit. These data do not show strong cohorts very clearly, although some modes progress through the population, such as the 2008 cohort as observed by the WCGBTS in the years 2008-2011 (the observed mode in 2012 is off by 1 year).

The conditional age-at-length data (CAAL) in the north model are numerous (Figures 74 - 97). They represent over 72,000 individual fish from a total of 161 fleet/year combinations. In general, most years and most fleets show no strong patterns in the Pearson residuals, but there are a few exceptions (Figures 74 - 97). For instance, the commercial trawl fit in 1980 has many fish older than expected within all of the smaller length bins, while in 1981 the ages observations all fall in the middle of the expected range. Both the mean age in each length bin and the variability in age at length have a good match for most years and most fleets.

The expected commercial trawl discard fractions (Figures 98 and 99) are higher than observed for the period 2002-2009, where the large uncertainty in estimated discards allows the model to misfit these to better fit the length comps, with the parameter for length at 50% retention pushed to the upper bound as discussed in Section 3.2.4. However, discards prior to 1998 are assumed to be low and the fits from 2010 onward are good, so the impact of the lack of fit on the estimated mortality is limited to a 12-year period. The commercial fixed-gear discards show less variability over time, are more uncertain, and the fits are well within the uncertainty intervals for all but 2002.

The fit to the mean body weight of discards are good for most years although the observed discards in the first two years (2002 and 2003) were lighter than the expectation (Figures 101 and 103). There are no discard length compositions from those years so it's difficult to judge the reasons for the lack of fit.

3.2.5.3 Population trajectory

The spawning stock biomass is estimated as having declined from an unfished equilibrium of 17,160 mt to a 2021 value of 11,010 mt or 0.64 fraction unfished of. The lowest fraction unfished was 0.3121 in 1992 (Table 18; Figures 104 and 105). The 2021 total biomass (all ages from both sexes) was 24,989 mt (Figure 106). Total biomass (Figure 106) largely followed the same trajectory as spawning stock biomass (Figure 104).

The last large recruitment event for this stock occurred in 2013 and a smaller event may have also occurred within the last half-decade, though its magnitude is more uncertain (Table

18; Figures 107–108). Most large recruitment events appear to preceded or be followed by a smaller number of similarly large recruitment events compared to the number of poor recruitment events that occur before another recruitment event that is estimated to be above average. There is little information regarding recruitment prior to 1959, and thus, these early recruitment events fall on the stock-recruitment curve (Figure 109). Estimates of steepness are highly uncertain (Table 15) even though the stock has been observed at a range of biomass levels. This uncertainty in steepness, as well as other parameters, likely contributes to the large uncertainty in recruitment and spawning stock biomass.

3.2.6 Model diagnostics

3.2.6.1 Convergence

Model convergence was in part based on starting the minimization process from dispersed values of the maximum likelihood estimates to determine if the estimation routine results in a smaller likelihood. Starting parameters were jittered using the built-in functionality of Stock Synthesis, where you specify a jitter fraction. Here we used a jitter fraction of 0.05 and the jittering was repeated one hundred times. A better, i.e., lower negative log-likelihood, fit was not found. Several models resulted in similar log-likelihood values with little difference in the overall model estimates, indicating a relatively flat likelihood surface around the maximum likelihood estimate. Through the jittering analysis performed here and the estimation of likelihood profiles, we are confident that the base model as presented represents the best fit to the data given the assumptions made.

3.2.6.2 Sensitivity analyses

The sensitivity analyses were divided into three groups: biology and recruitment, composition, indices, and selectivity (Tables 20 - 23; Figures 113 - 116).

The biology and recruitment sensitivities included

- fix female M at 0.3 and h at 0.7 (values used in the 2017 assessment)
- fix female M at 0.3
- fix h at 0.7
- estimate a single M for both sexes with a prior which is a mixture distribution of the two priors sex-specific priors in the base model (a lognormal with mean = 0.358, sd = 0.467)

- decrease σ_R from 0.6 to 0.4
- increase σ_R from 0.6 to 0.8

The composition sensitivities included

- add all additional ages as CAAL to the south model
- add all additional ages as marginal
- use the "combM+F" option in stock synthesis to ignore sex ratios among small fish
- remove all composition data vectors for unsexed fish (which were already represented separately from the sexed fish in the base model)
- apply the Dirichlet-multinomial likelihood to automatically tune the composition sample sizes (instead of the Francis method applied in the base model)

Additional composition-related sensitivities were conducted in earlier versions of the model but were not repeated for the final base model.

The index sensitivities involved removing each index from the model as well as removing all the fishery-dependent indices together.

Also included in the index sensitivities was changing the index associated with the Oregon recreational fishery from one based on the ORBS sampling program to an alternative index developed from onboard CPFV observations.

The selectivity sensitivities included

- allow sex-specific selectivity by adding for each fleet representing the difference between females and males in the height of the peak selectivity
- allow sex-specific selectivity as above while also fixing female $M = 0.3$
- make retention in the early period equal to the recent period
- make the scale and descending slope of the selectivity function sex-specific for all fisheries selectivity but retain shared selectivity for females and males in the surveys

Numerous additional sensitivities related to sex-specific selectivity were conducted for the north model during the STAR review, none of which provided model results which were more plausible than the chosen base model. See the STAR report for more detail on these additional sensitivities.

Among the biology and recruitment sensitivities, (Table 20, Figure 113), the north model was most sensitive to the two where female M was fixed at 0.3 with or without also fixing $h = 0.7$ (compared to the base model with M estimated at 0.42). The lower M pushed the unfished equilibrium spawning biomass down slightly, but the lower productivity associated with these parameters meant that the catch history drove the stock below the 25% minimum stock size threshold in the 1990s whereas the base model estimates that stock never fell below that limit. The fraction unfished at the start of 2021 was 32% when $M = 0.3$ and $h = 0.7$ and 34% when h was estimated, compared to 64% in the base model. The negative log-likelihood for both sensitivities with $M = 0.3$ were about 17 units worse than the base model, with worse fits to all data sources with the exception of the age comps which have an improvement in fit of about 12 units.

Among the composition sensitivities (Table 21, Figure 114), the north model was sensitive to removing the fishery-dependent ages, which reduced the estimate of female M from 0.42 to 0.33 and pushed the scale upwards. Applying the Dirichlet-multinomial likelihood for the composition data, which led to higher weights for these data relative to the Francis method (Table 19, Figure 117), had the opposite effect, bringing the scale downwards. The two sensitivities related to combining male and female samples for small fish and excluding unsexed fish from the likelihood had relatively little impact on the model results.

The sensitivities related to an alternative recreational Oregon index or removing indices from the north model (Table 22, Figure 115) also had relatively little impact with the exception of the one in which all fishery CPUE indices were removed, which increased the scale from 64% of B_0% in 2021 to 82%. The individual index which had the most influence, as measured by the impact of it's removal, was the Washington recreational CPUE. This time series is the longest among all indices and also spanned the period of greatest change in estimated abundance.

The sensitivities related to selectivity (Table 23, Figure 116) showed large differences in estimated M and trends in abundance. However, the estimated selectivity curves from these models showed implausibly large differences in selectivity at sizes which did not have any clear biological basis. Furthermore, the choice of which selectivity parameters and/or time blocks on which to apply the sex-specific differences made selecting among these models difficult and risked overparameterization of the model. One of these models was chosen for an alternative state of nature, and further exploration of differences in selectivity or availability between females and males is a research priority for future assessments.

A final note on the sensitivities is that convergence issues associated with selectivity parameters hitting bounds, which were resolved for the base model, have the potential to impact some of the sensitivity analyses which could not be examined as carefully as the base or alternative candidate base models which were considered during the model selection process.

3.2.6.3 Likelihood profiles

Likelihood profiles were conducted by fixing a given parameter that was estimated in the base model at a range of values in turn while estimating the remaining parameters. These profiles were conducted for female M, h, and R_0. We choose to not profile over male M because male and female M are highly correlated, and therefore, it is instructive to see the estimates of male M given a fixed value for females.

Female M was most informed by length-composition data and secondarily by the Washington recreational index and the Triennial Survey (Figure 120). This information conflicted with age-compositions from the Washington recreational fleet (left panels of Figure 120). Data from the commercial FG fleet suggested a much smaller M, closer to that of the previous assessment.

From the stock trajectories, it is apparent that the upper range of investigated female M values are implausible given that they lead to a highly unlikely increase in stock size relative to all other values (Figure 121). Male M changed non-linearly with fixed values of female M, where the most similar estimates of M between the sexes occurred near values of 0.3 (Table 24). The current status of the stock was highly dependent upon the assumed value of female M (Figure 122).

There was less information in the data available to estimate h than female M, which can be seen with the smaller differences in likelihoods across fixed values compared to female M (Figure 123). This was not surprising, as estimating h is notoriously difficult.

Almost all values of h that were explored are equally likely, but the age-composition data appear to have pushed the estimate higher than the prior (lower left panel of Figure 123).

The largest changes in the time series of spawning stock biomass with different values of h are in the historical period before the main recruitment deviations are estimated or before there are reliable composition data (Figure 124) The current status of the stock was highly dependent upon the assumed value of h (Figure 125).

The length data were highly informative with respect to R_0, in particular the commercial TW lengths and recreational lengths from Oregon and Washington (Figure 126). All investigated values of R_0 led to the different estimates of the time series of spawning stock biomass with the population increasing in scale incrementally with R_0, which is not surprising (Figures 127 and 128). Though, the current fraction unfished never reached 1.0 for any value investigated and remained above the minimum stock size threshold of 0.25 for all values except 8.0.

3.2.6.4 Retrospective analysis

A five-year retrospective analysis was conducted by successively removing years of data starting with the most recent year. For the removal of the most recent year of data there were no changes to the model trajectory or estimates of fraction unfished (Table 25; Figures 118 and 119).

Peeling off more than one year of data led to a retrospective pattern with respect to the estimated scale of the population but not current status.

Given time constraints, each of these models were not tuned, i.e., data weighting was not performed in an iterative fashion and bias adjustment was not conducted, which could impact the model results.

3.2.7 Evaluation of uncertainty

The model estimated uncertainty around the 2021 spawning biomass was $\sigma = 0.18$ and the uncertainty around the OFL was $\sigma = 0.23$.

This is likely an underestimate of overall uncertainty because there is no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature).

The category 2 default $\sigma = 1.0$ is used to apply scientific uncertainty in the projections.

3.2.8 Reference points

The estimate of 2021 spawning biomass relative to unfished equilibrium biomass (fraction unfished = 0.6416) was well above the management target of 40% (Table 17 and Figure 111). Even the lower 95% interval was estimated to be above the target (Table 17). Only a few years since the start of the modeled period were estimated to be below the target (blue points to the left of the vertical line at 0.4 in Figure 111).

Equilibrium yield given the estimate of steepness shows disparity between maximum sustainable yield (blue) and the target biomass (red; Figure 112). Whereas, the target biomass is in line with the SPR target (green; Figure 112). The time series of fishing intensity was estimated to have been below the management harvest rate limit for all years included in the model (Figure 110).

3.2.9 Decision table

The forecast of stock abundance and yield was developed using the base model (Table 27). The total catches for the first two years of the forecast period were based on values provided by the Groundfish Management Team. These assumed removals are likely higher than what the true removals will be for this year and next year but their influence on the assessment of stock status and future removals are limited.

The states of nature in the decision table (Table 28) do not fall on a single axis of uncertainty. Instead, two alternative model structures were chosen from the set of sensitivity analyses to represent alternative states of nature. This represents the consensus among the participants in the STAR panel as a better representation of uncertainty than any axis could. The low state of nature included sex-specific selectivity while the high state excluded the fishery-dependent age data.

Three alternative catch streams were created for the decision table (Table 28). The first option uses recent average catch as provided by the Groundfish Management Team, the second option uses a P^* of 0.40, and the third option uses a P^* of 0.45. These P^* values are combined with the category 2 default $\sigma = 1.0$ in calculating the buffer between OFL and ABC.

3.2.10 Unresolved problems and major uncertainties

The base-model configuration was developed with the goal of balancing parsimony with realism while fitting the data. To achieve parsimony, some simplification of the model structure was assumed relative to known processes, which may impact the interpretation and fit to specific data sets. For example, a clear break between the northern and southern stock at Cape Mendocino is unrealistic but we do not currently have the resources necessary to add spatial dynamics to the stock assessment or estimate the level of overlap between the stocks.

Patterns of sex-specific selectivity were apparent in the data, particularly for the fishing fleets. Unfortunately, we were unable to configure the model in such a way that the model fit all data sources equally as well as the base-model configuration when attempting to account for these patterns. Numerous attempts at sex-specific selectivity were explored shortly before and during the stock assessment review. However, overparameterization proved an insurmountable problem. There are more than 50 selectivity parameters in the base model (with selectivity equal for females and males), so adding sex-specific offsets or separate parameters caused estimation problems and implausible selectivity patterns. Options explored included sex-specific offsets for the height of the peak selectivity as well as offsets for the position of the peak and the descending slopes. Therefore, new research to develop an theoretical basis for sex-specific differences in selectivity or availability using differences in spatial distribution or behavior may be a more fruitful path for future selectivity setups than relying simply on fits to data and other model diagnostics.

Uncertainty in parameter estimates are quite large relative to recent assessments because of the choice to estimate both natural mortality and steepness. Recent work has shown the utility of estimating both parameters with respect to management reference points, and although estimates provided in this document are imprecise, we predict that the estimated reference points are less biased than if the model would have been configured with one or more of these parameters as fixed inputs rather than estimated. Estimating both parameters led to counter-intuitive differences in estimates of natural mortality between the southern and northern areas. Hopefully, future work on parameterizing selectivity will lead to more precise estimates of male and female natural mortality given the life history of this species, specifically the nest-guarding behavior of males.

The internal estimates of total catch including dead discards for some recent years are higher than those provided by the Groundfish Expanded Multiyear Mortality (GEMM) reports. This may be the result of the status-quo data weighting approach which applies the same sample size multiplier to the discard and retained length composition data within any given fleet, in spite of the sample sizes often being unbalanced among these sources relative to the magnitude of the catch. Alternative models were explored during the assessment review, whereby the input sample sizes for the discard data were adjusted as an ad-hoc refinement to the data weighting or the uncertainty associated with the discard rate was reduced to force the model to fit these rates more precisely. Neither sensitivity had much impact on estimates of population trajectories or stock status so this issue was shelved for future research.

3.2.11 Research and data needs

Investigating and or addressing the following items could improve future assessments of lingcod:

- Sex-specific selectivity is likely given the life history of lingcod. However, knowledge of the fine-scale spatial distribution of ages and sexes relative to the distribution of fishing effort and survey sampling locations is lacking to inform these patterns. Some relationships may be dome-shaped while others may be asymptotic and these relationships could depend on whether the process is governed by length or age. Care should be taken during explorations of selectivity to ensure that the model does not become overparameterized given that selectivity and mortality are correlated.
- Some data sources that were provided by state representatives were not fully explored, e.g., information from video landers and ROVs. Currently, there is not a method to include multiple indices for a given fishery, and thus, the best-case scenario would be to provide comparisons of model results given fits to these alternative data sources rather than those that were used to fit the model. Additional work would be needed to formulate a method to combine them or allow for the inclusion of multiple CPUE indices for a given fleet.
- It is likely that natural mortality is not constant across age as it was parameterized. Exploration of the Lorenzen natural mortality function produced results that were

similar to the base model for the north and implausibly low in the south. Additional approaches are available to model age-specific natural mortality that could also be explored.

- Data-weighting approaches that separate tuning of sample sizes for discarded and retained fish from the same fleet should be explored such that data on discard rates and mean body weight can be weighted appropriately. These changes will hopefully bring the estimates of total mortality for years with high discard rates closer to the values reported in the GEMM data product based on data collected by WCGOP.
- Conflicts were present in the information provided by the age and length data.

3.2.12 Comparison of north and south models

The north and south models represent genetically distinct sub-populations of lingcod and may differ in numerous ways. However, there are enough similarities in management, fisheries, and biology that some similarity across these stocks and the models used to represent them is to be expected. A fundamental challenge in fisheries stock assessment is understanding spatial variability among stocks and finding appropriate ways to share information across stocks (Punt et al. 2011). The following section is intended to provide information regarding the evaluation of the plausibility of the estimates for the two areas.

Estimates of growth in the two areas match prior expectations for males with faster growth in the north relative to the south (Figure 129), but females are estimated to growth to a slightly larger size in the south. The estimated variability in growth is smaller in the north compared to the south, which may reflect differences in biology or a greater spatial heterogeneity in growth in the south. Estimated growth in both areas use a reference age of 14 for mean length at age, but the corresponding L_∞ values are 118.7 and 77.5 for females and males respectively in the north and 122.6 and 65.2 in the south. The estimated length at age 14 in the north is more precise than in the south (Figure 130), reflecting the larger volume of conditional age-at-length data include in the north model. Thus, the estimate of larger L_∞ in the south is unlikely to be statistically significant.

Estimates of key productivity parameters (i.e., M and h) differ significantly among the two areas, indicating that the southern stock is less productive than the northern stock (Figure 130). Additionally, the north model estimates almost equal M for females and males (0.418 and 0.414 respectively), whereas the south model has a lower estimate of female M than male M (0.17 and 0.222). The M estimates are uncertain in both models, although more so in the south than the north.

Estimates of unfished spawning biomass in the two areas are higher in the south than the north (17,160 mt and 26,444 mt for north and south), but this comparison is misleading due to the differences in M between areas resulting in a smaller fraction of recruits reaching spawning ages in the north than the south. The estimates of unfished age-3+ biomass are similar: 32,693 mt and 32,617 mt for the north and south (Figure 131). The differences in estimated maximum sustainable yields (MSYs) are larger than those for biomass because the lower estimates of M and h in the south equate to lower productivity relative to stock size.

There are no precise estimates for the amount of lingcod habitat in either area, but a rough approximation can be found by calculating the spatial extent of the WCGBTS survey area between the 55 m inner limit and 300 m, a depth which represents a decline in frequency of lingcod in that survey. By this measure, the ratio of north to south areas is about 2.3:1. Thus, the biomass estimates (Figure 132) are more closer to each other than would be expected had the densities been equal in the two areas. However, one must account for catchability and because the WCGBTS does not provide an absolute estimate of abundance with a non-trivial amount of habitat and biomass inside the 55 m isobath. The estimated catchability of the WCGBTS is similar among areas, 0.81 in the north and 0.95 in the south.

The differences in scale (Table 26) among the two areas are less plausible when matching values are used for the productivity parameters (fixing female $M = 0.3$ and $h = 0.7$). In those sensititivity analyses, the estimated spawning biomass in the south model is greater than that of the north for almost all years from the 1940s onward and never falls below $B_{40\%}$. The catchability of the WCGBTS in those scenarios is likewise implausibly different: 2.05 in the north and 0.32 in the south Thus, the different parameter estimates (Table 26) for the north and south play an important role in providing values for quantities of interest that are balanced among the two model, and likely provide better advice for managing the lingcod lingcod stocks throughout the U.S. west coast.

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6 Tables

Table 1: Commercial (by fleet and state) and recreational (by state) landings (mt) with yearly totals. Commercial landings were modeled as gear-specific landings and separated here by state for information purposes only.

	Fixed gear			Trawl			Recreational			
Year	CA	OR	WA	CA	OR	WA	CA	OR	WA	Total
1889	4.04	0.00	109.00	1.55	0.00	0.00	0.00	0.00	0.00	114.58
1890	8.07	0.00	112.67	3.09	0.00	0.00	0.00	0.00	0.00	123.83
1891	12.11	0.00	115.53	4.64	0.00	0.00	0.00	0.00	0.00	132.27
1892	16.14	11.79	146.56	6.18	0.00	0.00	0.00	0.00	0.00	180.68
1893	14.00	6.58	128.09	5.36	0.00	0.00	0.00	0.00	0.00	154.03
1894	11.85	6.58	109.62	4.54	0.00	0.00	0.00	0.00	0.00	132.59
1895	9.71	45.63	91.15	3.72	0.00	0.00	0.00	0.00	0.00	150.21
1896	9.87	100.36	77.65	3.78	0.00	0.00	0.00	0.00	0.00	191.66
1897	10.03	100.81	64.15	3.84	0.00	0.00	0.00	0.00	0.00	178.83
1898	10.18	6.80	50.65	3.90	0.00	0.00	0.00	0.00	0.00	71.54
1899	10.34	8.08	37.15	3.96	0.00	0.00	0.00	0.00	0.00	59.53
1900	12.37	9.36	41.48	4.74	0.00	0.00	0.00	0.00	0.00	67.94
1901	14.39	10.64	45.81	5.51	0.00	0.00	0.00	0.00	0.00	76.35
1902	16.42	11.91	50.13	6.29	0.00	0.00	0.00	0.00	0.00	84.76
1903	18.45	13.19	54.46	7.07	0.00	0.00	0.00	0.00	0.00	93.16
1904	20.47	14.47	58.79	7.84	0.00	0.00	0.00	0.00	0.00	101.57
1905	18.27	15.75	50.42	7.00	0.00	0.00	0.00	0.00	0.00	91.44
1906	16.07	17.02	42.05	6.16	0.00	0.00	0.00	0.00	0.00	81.30
1907	13.87	18.30	33.68	5.31	0.00	0.00	0.00	0.00	0.00	71.16
1908	11.67	19.58	25.31	4.47	0.00	0.00	0.00	0.00	0.00	61.03
1909	15.77	20.85	67.44	6.04	0.00	0.00	0.00	0.00	0.00	110.11
1910	19.87	22.13	109.57	7.61	0.00	0.00	0.00	0.00	0.00	159.19
1911	23.98	23.41	151.70	9.18	0.00	0.00	0.00	0.00	0.00	208.27
1912	28.08	24.69	193.82	10.76	0.00	0.00	0.00	0.00	0.00	257.35
1913	32.18	25.96	235.95	12.33	0.00	0.00	0.00	0.00	0.00	306.43
1914	36.28	27.24	278.08	13.90	0.00	0.00	0.00	0.00	0.00	355.50
1915	40.39	28.52	320.21	15.47	0.00	0.00	0.00	0.00	0.00	404.58
1916	48.26	29.80	425.83	18.49	0.00	0.00	0.00	0.00	0.00	522.37
1917	56.13	31.07	531.45	21.50	0.00	0.00	0.00	0.00	0.00	640.16
1918	64.00	32.35	637.07	24.52	0.00	0.00	0.00	0.00	0.00	757.94
1919	74.27	33.63	190.15	28.45	0.00	0.00	0.00	0.00	0.00	326.50
1920	48.07	34.90	142.59	18.42	0.00	0.00	0.00	0.00	0.00	243.98

Table 1: Commercial (by fleet and state) and recreational (by state) landings (mt) with yearly totals. Commercial landings were modeled as gear-specific landings and separated here by state for information purposes only. *(continued)*

Year	CA	OR	WA	CA	OR	WA	CA	OR	WA	Total
1921	29.77	36.18	129.73	11.40	0.00	0.00	0.00	0.00	0.00	207.08
1922	39.69	37.46	55.75	15.20	0.00	0.00	0.00	0.00	0.00	148.10
1923	32.63	38.74	43.68	12.50	0.00	0.00	0.00	0.00	0.00	127.55
1924	27.95	40.01	155.82	10.71	0.00	0.00	0.00	0.00	0.00	234.49
1925	47.72	41.29	219.20	18.28	0.00	0.00	0.00	0.00	0.00	326.50
1926	45.07	42.57	252.22	17.26	0.00	0.00	0.00	0.00	0.00	357.12
1927	38.90	43.85	318.52	14.90	0.00	0.00	0.00	0.00	0.00	416.17
1928	32.73	40.35	250.29	12.54	0.00	0.00	0.00	0.00	0.00	335.91
1929	111.34	171.36	394.91	42.65	0.00	8.01	0.52	0.00	0.00	728.80
1930	146.96	121.63	361.67	56.30	0.00	31.75	1.04	0.00	0.00	719.35
1931	220.91	77.83	178.57	97.01	0.00	7.16	1.56	0.00	0.00	583.04
1932	122.74	64.02	187.44	61.36	4.52	5.69	2.08	0.00	0.00	447.85
1933	125.75	121.97	246.87	71.18	16.52	11.31	2.60	0.00	0.00	596.20
1934	105.52	82.57	334.97	67.36	1.56	89.99	3.13	0.00	0.00	685.09
1935	114.43	67.00	359.87	82.11	3.31	103.40	3.65	0.00	0.00	733.77
1936	64.32	96.84	465.29	51.77	12.58	137.22	4.17	0.00	0.00	832.20
1937	94.85	78.87	425.69	85.51	19.53	193.01	6.46	0.00	0.00	903.92
1938	75.60	175.33	990.79	76.30	0.00	121.41	7.82	0.00	0.00	1447.24
1939	57.96	99.05	626.40	65.48	38.66	282.26	10.79	0.00	0.00	1180.60
1940	64.81	161.19	689.79	82.01	108.77	457.23	11.34	0.00	0.00	1575.13
1941	29.91	181.39	600.46	42.47	383.19	142.48	10.48	0.00	0.00	1390.38
1942	31.13	174.63	694.84	49.71	538.04	318.58	5.57	0.00	0.00	1812.49
1943	68.70	174.86	414.47	123.79	429.27	478.27	5.32	0.00	0.00	1694.70
1944	71.86	149.14	525.21	146.73	636.67	797.78	4.37	0.00	0.00	2331.77
1945	59.50	113.53	294.80	138.44	546.49	502.72	5.83	0.00	0.00	1661.31
1946	94.62	129.73	501.44	252.70	618.05	648.68	10.03	0.00	0.00	2255.25
1947	153.00	99.70	260.58	473.39	270.47	399.11	36.39	0.00	0.00	1692.65
1948	136.82	123.65	343.82	521.62	359.36	661.86	39.67	0.00	0.00	2186.79
1949	75.48	191.82	413.71	369.88	238.78	476.87	43.25	0.00	0.00	1809.80
1950	54.21	90.54	285.15	320.51	311.31	471.93	38.85	0.00	0.00	1572.50
1951	47.88	74.48	305.31	322.81	463.91	456.56	40.16	0.00	0.00	1711.12
1952	30.40	77.29	345.03	217.81	235.87	358.57	28.58	0.00	0.00	1293.56
1953	27.68	49.03	134.93	219.50	164.15	124.10	21.08	0.00	0.00	740.48
1954	21.65	58.69	192.55	192.96	153.47	329.66	33.95	0.00	0.00	982.93
1955	18.41	47.67	151.49	166.79	206.09	835.05	36.35	0.00	0.00	1461.86
1956	16.76	33.66	153.65	131.39	124.72	633.21	49.56	0.00	0.00	1142.94
1957	50.88	29.03	174.80	339.15	303.23	498.37	57.30	0.00	0.00	1452.76

Table 1: Commercial (by fleet and state) and recreational (by state) landings (mt) with yearly totals. Commercial landings were modeled as gear-specific landings and separated here by state for information purposes only. *(continued)*

Year	CA	OR	WA	CA	OR	WA	CA	OR	WA	Total
1958	31.86	19.78	141.88	262.35	194.53	725.61	63.02	0.00	0.00	1439.03
1959	28.16	25.40	118.78	252.59	184.91	1308.80	49.69	0.00	0.00	1968.34
1960	24.44	39.83	157.45	265.06	307.31	1392.59	41.53	0.00	0.00	2228.20
1961	42.30	41.78	127.68	263.69	303.72	1325.24	41.02	0.00	0.00	2145.42
1962	48.55	20.50	128.54	204.15	372.76	562.55	40.00	0.00	0.00	1377.05
1963	61.45	18.55	92.81	198.90	246.76	451.14	39.95	0.00	0.00	1109.56
1964	23.40	1.27	79.42	156.06	364.90	760.71	38.77	0.00	0.00	1424.53
1965	15.91	23.00	60.89	170.78	399.41	866.18	56.63	0.00	0.00	1592.80
1966	24.36	21.32	80.58	127.70	460.63	916.30	79.17	0.00	0.00	1710.07
1967	16.70	33.25	93.62	215.86	537.67	1492.48	83.63	0.00	26.50	2499.70
1968	10.65	43.00	53.58	299.56	704.87	1611.05	80.70	0.00	27.98	2831.38
1969	16.32	65.82	69.43	270.49	524.71	742.35	62.78	0.00	29.47	1781.36
1970	21.97	78.84	79.99	185.00	447.59	395.37	96.08	0.00	30.96	1335.79
1971	43.84	72.73	65.59	329.53	626.24	355.24	111.81	0.00	32.45	1637.43
1972	73.92	82.60	46.11	510.42	676.80	286.73	136.64	0.00	33.93	1847.16
1973	11.72	67.99	52.62	513.64	993.33	441.38	136.03	0.00	35.42	2252.14
1974	20.88	34.63	46.82	414.37	952.72	682.03	138.84	80.38	36.91	2407.57
1975	19.21	22.86	99.89	316.23	736.63	858.67	151.95	84.80	38.40	2328.64
1976	54.28	38.93	63.97	341.06	472.71	1086.44	159.21	116.75	21.45	2354.81
1977	32.80	47.18	138.08	193.75	417.67	1046.96	116.82	110.20	28.94	2132.40
1978	53.52	55.88	162.97	200.60	481.08	682.28	155.74	118.88	24.20	1935.15
1979	29.76	68.36	207.59	352.13	752.78	1195.77	169.08	159.60	20.71	2955.79
1980	17.68	46.18	97.84	208.82	709.88	1263.96	241.24	219.95	27.01	2832.57
1981	18.42	50.49	149.85	259.20	997.60	834.31	207.64	174.30	29.86	2721.67
1982	24.66	64.74	227.20	341.40	1394.16	768.83	155.43	195.88	33.05	3205.35
1983	17.11	79.47	258.28	186.11	1658.47	1255.61	103.75	153.09	40.85	3752.74
1984	15.60	50.61	279.79	177.46	1013.15	1739.33	90.57	170.31	68.52	3605.34
1985	42.07	88.20	300.58	139.51	964.74	1816.29	174.18	169.50	53.75	3748.83
1986	65.04	243.63	130.50	79.54	1066.74	564.68	165.96	173.65	56.79	2546.53
1987	71.42	131.88	147.47	127.88	587.22	855.65	169.24	186.79	65.42	2342.96
1988	88.40	116.83	146.98	113.65	893.03	574.44	184.87	113.84	68.79	2300.82
1989	177.99	140.60	216.85	126.85	1034.95	902.03	171.93	158.07	86.41	3015.68
1990	123.08	133.50	227.32	176.94	740.85	752.98	148.94	127.24	66.05	2496.91
1991	40.61	60.87	123.98	114.00	1425.72	760.89	125.95	103.28	63.80	2819.10
1992	37.20	82.70	102.31	70.96	625.64	466.35	102.96	155.52	95.32	1738.96
1993	25.09	84.95	63.43	92.09	748.31	614.81	79.97	237.24	121.73	2067.62

Table 1: Commercial (by fleet and state) and recreational (by state) landings (mt) with yearly totals. Commercial landings were modeled as gear-specific landings and separated here by state for information purposes only. *(continued)*

Year	CA	OR	WA	CA	OR	WA	CA	OR	WA	Total
1994	24.32	138.15	63.75	84.38	721.07	419.79	44.30	195.58	112.78	1804.13
1995	62.44	73.01	30.45	97.17	576.86	247.75	48.59	98.44	67.58	1302.29
1996	37.74	93.60	41.02	86.86	623.91	318.98	65.55	118.38	59.76	1445.80
1997	42.82	134.75	47.76	96.30	634.05	242.00	47.94	145.61	56.29	1447.52
1998	12.35	42.85	10.80	41.21	118.41	27.43	45.79	92.70	36.88	428.42
1999	14.23	47.87	17.32	43.80	125.96	24.33	61.96	87.99	42.69	466.15
2000	8.87	26.82	14.45	17.96	37.50	11.19	35.05	54.74	31.24	237.83
2001	11.12	38.56	15.14	17.29	29.52	10.31	29.33	60.61	38.04	249.92
2002	15.36	35.92	13.14	21.14	46.38	28.66	91.41	87.63	55.72	395.34
2003	10.66	36.04	13.99	4.43	32.99	29.72	180.51	107.25	66.25	481.84
2004	9.66	40.46	13.61	5.44	33.16	27.36	113.96	111.07	79.02	433.74
2005	12.45	38.43	21.43	8.27	44.93	34.63	47.41	135.09	82.36	424.98
2006	12.09	43.56	36.46	15.95	76.13	39.95	44.57	128.92	58.48	456.09
2007	15.54	49.41	24.04	13.09	67.65	46.79	50.77	102.41	61.23	430.93
2008	17.48	57.33	37.44	10.32	66.45	53.09	21.30	87.10	62.92	413.44
2009	8.29	44.61	38.18	7.48	60.68	33.01	34.80	78.54	68.89	374.48
2010	6.97	34.76	13.91	1.92	42.50	35.31	26.89	92.01	90.49	344.77
2011	5.74	49.43	9.43	0.65	145.39	139.42	39.00	113.53	128.56	631.14
2012	4.72	54.10	11.63	4.98	215.73	163.74	45.44	152.59	131.10	784.03
2013	4.08	64.94	15.95	12.79	214.65	146.79	51.70	223.46	125.83	860.19
2014	6.75	58.43	25.76	23.33	168.77	59.06	67.29	175.40	131.33	716.13
2015	18.72	114.34	19.37	16.22	135.49	31.20	110.60	229.06	121.15	796.16
2016	14.08	83.07	16.48	21.11	169.37	98.41	68.17	152.48	166.28	789.45
2017	15.28	103.18	11.47	93.79	336.96	178.28	63.18	183.69	158.65	1144.47
2018	18.34	107.22	16.43	143.11	203.22	101.80	57.24	222.39	144.50	1014.26
2019	15.60	118.79	24.93	136.34	279.47	25.01	44.26	171.85	164.68	980.92
2020	17.08	105.86	15.73	144.45	164.63	7.38	39.30	172.47	116.75	783.66

Table 2: Recent trends in observed landings and expected dead biomass (mt) relative to management guidelines (overfishing limit, OFL; Acceptable Biological Catch, ABC; annual catch limit, ACL). Expected dead biomass represents the total landings plus the model-estimated dead discard biomass. Note that the model estimated total dead catch may not be the same as the WCGOP estimates of total mortality [@somers2021], which are the 'official' records for determining whether the ACL has been exceeded. Additionally, management in 2011 and 2012 was based on a break at 42°00'N versus all other years used 40°10'N.

	Management			Landings	
Year	OFL	ABC	ACL	Observed	Expected
2011	2438.00	2330.00	2330.00	631.14	657.19
2012	2251.00	2151.00	2151.00	784.03	811.65
2013	3334.00	3036.00	3036.00	860.19	881.28
2014	3162.00	2878.00	2878.00	716.13	728.86
2015	3010.00	2830.00	2830.00	796.16	808.29
2016	2891.00	2719.00	2719.00	789.45	806.49
2017	3549.00	3333.00	3333.00	1144.47	1172.02
2018	3310.00	3110.00	3110.00	1014.26	1035.71
2019	5109.72	4884.49	4871.00	980.92	1004.75
2020	4767.97	4558.18	4541.00	783.66	803.86
2021	5816.00	5385.62	5369.00	NA	NA
2022	5395.00	4974.19	4958.00	NA	NA

Table 3: Filtering criteria used for the Oregon nearshore commercial fishery catch per unit effort generated from logbook data. Columns include information on the resulting number of records (N) and percent positive (pos) records after filtering.

Filter	Criteria	N pos	% pos
All Data	Full data set aggregated to trip	31464	81.7
Depth min	Ensure depth = 1 fathom	28890	81.8
Fishermen	Ensure fishermen > 0	28294	81.9
Gear ID	Gear ID is present	27995	81.9
Secondary Gear ID	Secondary Gear ID is present	26968	81.7
CPUE calculation	CPUE data are present	26179	81.3
Gear	Hook and line gear only	20216	78.5
Port	Port Orford south only	15410	81.7
CPUE outliers	Remove outlier values above 99 percentile	14619	81.1
Vessel	Vessel fished at least 3 years	13530	81.3
Depth	Remove abnormally deep trips	13443	81.6

Table 4: Data filtering steps to increase the percent positive (pos) or number (N) of trips that landed lingcod in the Washington recreational index derived from dockside-sampling data.

Filter	Description	N pos	% pos
complete info	Remove records with missing information	124905	16.18506
summer	Keep April-August	115685	18.40327
groundfish trip	Remove all trips not targeting groundfish	68396	56.53730
open water	Remove shore-based fishing	68326	57.49992
coastal areas	Remove coastal estuaries and rivers	67720	57.72591

Table 5: Data filtering steps to increase the percent positive (pos) or number (N) of trips that landed lingcod in the Oregon recreational catch per unit effort derived from Ocean Recreational Boat Survey, ODFW data.

Filter	Description	N pos	% pos
All Data	Full data set aggregated to trip	85494	20.8
Bottomfish trips	Retain bottomfish trips only	70672	52.8
Trip time length	Remove exceedingly long or short trips ($<$ 1 hr or $>$ 12 hrs)	70442	53.5
Interview time	Remove trips with interviews within one minute	62633	53.5
Closed Season	Remove trips during closed season	62633	54.2
Outside 40fm	Remove trips outside of 40 fm (closed depths)	61900	53.6
Catches above boat limits	Remove trips above the catch limit	51049	51.7
Ports with rare catch encounters	Removed trips from Ports 30, 32 and 38	50888	48.9
Negative effort	Remove trips with negative effort when accounting for travel time	50779	49.0
Anomalously high catch rates	Removes catch rates above the 97.5 percentile	48194	47.7
Charter vessels only	Removes private vessel trips	17977	74.8

Table 6: Data filtering of the California Recreational Fisheries Survey private rental dockside index for the California recreational fishery.

Filter	Description	Trip	Positive Trips	% drifts retained
All data	Pre-filtered for drifts with marked for exclusion	20924	10056	48%
MOnths samples	Remove waves less than 3 due to small sample sizes and fishery closures.	20916	10053	48%
Groundfish	Removed trips with no observed groundfish	18615	10053	54%
HMS	Remove trips with more than half the catch composed of HMS species	18613	10052	54%
Final trips	Retained trips with at least 0.95 groundfish.	17371	9357	54%

Table 7: Number (N) and percent positive (pos.) cell-days and number caught across all cell-days for the Oregon hook and line survey inside marine reserves. Data were aggregated across sets within a cell for a given day (cell-day).

Year	N pos.	% pos.	N caught
2011	24	54.5	61
2012	25	48.1	39
2013	66	68.0	190
2014	115	81.6	572
2015	118	70.7	534
2016	80	71.4	477
2017	71	68.9	252
2018	69	59.5	244
2019	58	53.7	131
Total	626	66.6	2500

Table 8: Summary of marine reserves sampled within the Oregon hook and line survey by the Marine Reserve Program.

Site	Area	Years Sampled	Total Years Sampled

Redfish Rocks	Humbug CA	2011 - 2019	8
Redfish Rocks	Redfish Rocks MR	2011 - 2019	8
Redfish Rocks	Orford Reef CA	2014, 2015, 2017, 2019	4
Cape Falcon	CA Adjacent to Cape Falcon MR	2014, 2015, 2017, 2019	4
Cape Falcon	Cape Falcon MR	2014, 2015, 2017, 2019	4
Cape Falcon	Cape Meares CA	2014, 2015, 2017, 2019	4
Cape Falcon	Three Arch Rocks CA	2014, 2015, 2017, 2019	4
Cape Perpetua	CA Outside Cape Perpetua MR	2016, 2018	2
Cape Perpetua	Cape Perpetua MR	2013, 2014, 2017, 2018	4
Cape Perpetua	Postage Stamp CA	2013, 2014, 2017, 2018	4
Cascade Head	Cape Foulweather CA	2015, 2016, 2018	3
Cascade Head	Cascade Head MR	2013 - 2016, 2018	5
Cascade Head	Cavalier CA	2013, 2015, 2016, 2018	4
Cascade Head	Schooner Creek CA	2013 - 2016, 2018	5

Table 9: Sample sizes of length data.

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
1965	comm. trawl	Sexed	Ntrips		4	223
1966	comm. trawl	Sexed	Ntrips		2	597
1968	comm. trawl	Sexed	Ntrips		16	1062
1975	comm. trawl	Sexed	Ntrips		12	1476
1976	comm. trawl	Sexed	Ntrips		1	210
1977	comm. trawl	Sexed	Ntrips		1	262
1978	comm. trawl	Sexed	Ntrips		3	223
1979	comm. trawl	Sexed	Ntrips		8	724
1980	comm. trawl	Sexed	Ntrips		28	2068
1981	comm. trawl	Sexed	Ntrips		16	1426
1982	comm. trawl	Sexed	Ntrips		43	1300
1983	comm. trawl	Sexed	Ntrips		28	894
1984	comm. trawl	Sexed	Ntrips		13	650
1985	comm. trawl	Sexed	Ntrips		15	764
1986	comm. trawl	Sexed	Ntrips		22	926
1987	comm. trawl	Sexed	Ntrips		32	823
1988	comm. trawl	Sexed	Ntrips		37	930
1989	comm. trawl	Sexed	Ntrips		36	898
1990	comm. trawl	Sexed	Ntrips		37	926
1991	comm. trawl	Sexed	Ntrips		41	1010
1992	comm. trawl	Sexed	Ntrips		85	2427
1993	comm. trawl	Sexed	Ntrips		79	2541
1994	comm. trawl	Sexed	Ntrips		65	2707
1995	comm. trawl	Sexed	Ntrips		61	1599
1996	comm. trawl	Sexed	Ntrips		58	1450

Table 9: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
1997	comm. trawl	Sexed	Ntrips		84	2010
1998	comm. trawl	Sexed	Ntrips		63	1377
1999	comm. trawl	Sexed	Ntrips		73	1579
2000	comm. trawl	Sexed	Ntrips		40	734
2001	comm. trawl	Sexed	Ntrips		49	868
2002	comm. trawl	Sexed	Ntrips		61	938
2003	comm. trawl	Sexed	Ntrips		54	904
2004	comm. trawl	Sexed	Ntrips		41	651
2005	comm. trawl	Sexed	Ntrips		38	739
2006	comm. trawl	Sexed	Ntrips		66	987
2007	comm. trawl	Sexed	Ntrips		97	1486
2008	comm. trawl	Sexed	Ntrips		98	1449
2009	comm. trawl	Sexed	Ntrips		78	1174
2010	comm. trawl	Sexed	Ntrips		76	933
2011	comm. trawl	Sexed	Ntrips		60	939
2012	comm. trawl	Sexed	Ntrips		67	1107
2013	comm. trawl	Sexed	Ntrips		102	1701
2014	comm. trawl	Sexed	Ntrips		86	1168
2015	comm. trawl	Sexed	Ntrips		66	1029
2016	comm. trawl	Sexed	Ntrips		101	1460
2017	comm. trawl	Sexed	Ntrips		134	2103
2018	comm. trawl	Sexed	Ntrips		128	1714
2019	comm. trawl	Sexed	Ntrips		156	1628
2020	comm. trawl	Sexed	Ntrips		70	772
2021	comm. trawl	Sexed	Ntrips		2	9
1965	comm. trawl	Unsexed	Ntrips		4	349
1967	comm. trawl	Unsexed	Ntrips		1	247
1968	comm. trawl	Unsexed	Ntrips		13	3771
1969	comm. trawl	Unsexed	Ntrips		6	1449
1970	comm. trawl	Unsexed	Ntrips		6	1616
1971	comm. trawl	Unsexed	Ntrips		9	2656
1972	comm. trawl	Unsexed	Ntrips		1	194
1973	comm. trawl	Unsexed	Ntrips		1	59
1974	comm. trawl	Unsexed	Ntrips		1	142
1975	comm. trawl	Unsexed	Ntrips		6	1587
1989	comm. trawl	Unsexed	Ntrips		1	1
1994	comm. trawl	Unsexed	Ntrips		1	1
1997	comm. trawl	Unsexed	Ntrips		2	20
2004	comm. trawl	Unsexed	Ntrips		1	14
2009	comm. trawl	Unsexed	Ntrips		1	30
2010	comm. trawl	Unsexed	Ntrips		5	11
2011	comm. trawl	Unsexed	Ntrips		2	3
2013	comm. trawl	Unsexed	Ntrips		3	103
2014	comm. trawl	Unsexed	Ntrips		1	1
2018	comm. trawl	Unsexed	Ntrips		3	4

Table 9: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2004	comm. trawl discards	Unsexed	Nhauls		427	1869
2005	comm. trawl discards	Unsexed	Nhauls		505	2943
2006	comm. trawl discards	Unsexed	Nhauls		219	809
2007	comm. trawl discards	Unsexed	Nhauls		101	333
2008	comm. trawl discards	Unsexed	Nhauls		75	230
2009	comm. trawl discards	Unsexed	Nhauls		203	625
2010	comm. trawl discards	Unsexed	Nhauls		72	203
2011	comm. trawl discards	Unsexed	Nhauls		361	1442
2012	comm. trawl discards	Unsexed	Nhauls		371	1764
2013	comm. trawl discards	Unsexed	Nhauls		318	1315
2014	comm. trawl discards	Unsexed	Nhauls		370	1595
2015	comm. trawl discards	Unsexed	Nhauls		288	970
2016	comm. trawl discards	Unsexed	Nhauls		299	769
2017	comm. trawl discards	Unsexed	Nhauls		291	957
2018	comm. trawl discards	Unsexed	Nhauls		319	1093
2019	comm. trawl discards	Unsexed	Nhauls		479	1853
1980	comm. fixed	Sexed	Ntrips		2	4
1982	comm. fixed	Sexed	Ntrips		1	34
1986	comm. fixed	Sexed	Ntrips		2	35
1987	comm. fixed	Sexed	Ntrips		12	231
1988	comm. fixed	Sexed	Ntrips		7	158
1989	comm. fixed	Sexed	Ntrips		7	136
1990	comm. fixed	Sexed	Ntrips		8	208
1991	comm. fixed	Sexed	Ntrips		3	51
1992	comm. fixed	Sexed	Ntrips		3	2
1993	comm. fixed	Sexed	Ntrips		20	320
1994	comm. fixed	Sexed	Ntrips		18	584
1995	comm. fixed	Sexed	Ntrips		16	382
1996	comm. fixed	Sexed	Ntrips		16	301
1997	comm. fixed	Sexed	Ntrips		23	221

Table 9: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
1998	comm. fixed	Sexed	Ntrips		15	208
1999	comm. fixed	Sexed	Ntrips		46	79
2000	comm. fixed	Sexed	Ntrips		57	288
2001	comm. fixed	Sexed	Ntrips		110	402
2002	comm. fixed	Sexed	Ntrips		96	303
2003	comm. fixed	Sexed	Ntrips		72	265
2004	comm. fixed	Sexed	Ntrips		127	569
2005	comm. fixed	Sexed	Ntrips		40	189
2006	comm. fixed	Sexed	Ntrips		66	313
2007	comm. fixed	Sexed	Ntrips		123	718
2008	comm. fixed	Sexed	Ntrips		75	460
2009	comm. fixed	Sexed	Ntrips		71	309
2010	comm. fixed	Sexed	Ntrips		133	512
2011	comm. fixed	Sexed	Ntrips		136	720
2012	comm. fixed	Sexed	Ntrips		163	916
2013	comm. fixed	Sexed	Ntrips		162	1004
2014	comm. fixed	Sexed	Ntrips		214	1243
2015	comm. fixed	Sexed	Ntrips		303	2468
2016	comm. fixed	Sexed	Ntrips		259	1750
2017	comm. fixed	Sexed	Ntrips		288	2184
2018	comm. fixed	Sexed	Ntrips		269	1634
2019	comm. fixed	Sexed	Ntrips		339	2138
2020	comm. fixed	Sexed	Ntrips		193	1039
2021	comm. fixed	Sexed	Ntrips		3	9
1971	comm. fixed	Unsexed	Ntrips		1	61
1987	comm. fixed	Unsexed	Ntrips		1	25
1989	comm. fixed	Unsexed	Ntrips		1	1
1992	comm. fixed	Unsexed	Ntrips		3	20
1993	comm. fixed	Unsexed	Ntrips		6	74
1994	comm. fixed	Unsexed	Ntrips		2	10
1996	comm. fixed	Unsexed	Ntrips		4	27
1997	comm. fixed	Unsexed	Ntrips		10	131
1998	comm. fixed	Unsexed	Ntrips		3	20
1999	comm. fixed	Unsexed	Ntrips		41	207
2000	comm. fixed	Unsexed	Ntrips		6	21
2001	comm. fixed	Unsexed	Ntrips		37	139
2002	comm. fixed	Unsexed	Ntrips		11	35
2003	comm. fixed	Unsexed	Ntrips		1	1
2006	comm. fixed	Unsexed	Ntrips		2	9
2007	comm. fixed	Unsexed	Ntrips		5	16
2008	comm. fixed	Unsexed	Ntrips		2	15
2009	comm. fixed	Unsexed	Ntrips		4	6
2010	comm. fixed	Unsexed	Ntrips		1	2
2011	comm. fixed	Unsexed	Ntrips		7	34
2012	comm. fixed	Unsexed	Ntrips		9	60
2013	comm. fixed	Unsexed	Ntrips		1	5

Table 9: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2014	comm. fixed	Unsexed	Ntrips		5	8
2015	comm. fixed	Unsexed	Ntrips		2	2
2016	comm. fixed	Unsexed	Ntrips		5	23
2017	comm. fixed	Unsexed	Ntrips		9	16
2018	comm. fixed	Unsexed	Ntrips		6	34
2019	comm. fixed	Unsexed	Ntrips		9	27
2020	comm. fixed	Unsexed	Ntrips		4	34
2004	comm. fixed discards	Unsexed	Nhauls		174	823
2005	comm. fixed discards	Unsexed	Nhauls		132	686
2006	comm. fixed discards	Unsexed	Nhauls		217	885
2007	comm. fixed discards	Unsexed	Nhauls		176	606
2008	comm. fixed discards	Unsexed	Nhauls		165	613
2009	comm. fixed discards	Unsexed	Nhauls		172	531
2010	comm. fixed discards	Unsexed	Nhauls		189	645
2011	comm. fixed discards	Unsexed	Nhauls		256	1085
2012	comm. fixed discards	Unsexed	Nhauls		260	1090
2013	comm. fixed discards	Unsexed	Nhauls		219	1068
2014	comm. fixed discards	Unsexed	Nhauls		202	884
2015	comm. fixed discards	Unsexed	Nhauls		237	843
2016	comm. fixed discards	Unsexed	Nhauls		335	1186
2017	comm. fixed discards	Unsexed	Nhauls		210	824
2018	comm. fixed discards	Unsexed	Nhauls		237	1160
2019	comm. fixed discards	Unsexed	Nhauls		258	915
1979	rec. WA	Sexed	Nfish			13
1980	rec. WA	Sexed	Nfish			235
1981	rec. WA	Sexed	Nfish			98
1982	rec. WA	Sexed	Nfish			72
1983	rec. WA	Sexed	Nfish			43
1985	rec. WA	Sexed	Nfish			3
1986	rec. WA	Sexed	Nfish			359
1987	rec. WA	Sexed	Nfish			336
1988	rec. WA	Sexed	Nfish			279
1989	rec. WA	Sexed	Nfish			296
1990	rec. WA	Sexed	Nfish			239
1991	rec. WA	Sexed	Nfish			310
1992	rec. WA	Sexed	Nfish			522
1993	rec. WA	Sexed	Nfish			542
1994	rec. WA	Sexed	Nfish			674
1995	rec. WA	Sexed	Nfish			1030
1996	rec. WA	Sexed	Nfish			812
1997	rec. WA	Sexed	Nfish			446
1998	rec. WA	Sexed	Nfish			517
1999	rec. WA	Sexed	Nfish			431
2000	rec. WA	Sexed	Nfish			479
2001	rec. WA	Sexed	Nfish			619
2002	rec. WA	Sexed	Nfish			951

Table 9: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2003	rec. WA	Sexed	Nfish			1085
2004	rec. WA	Sexed	Nfish			1081
2005	rec. WA	Sexed	Nfish			1277
2006	rec. WA	Sexed	Nfish			897
2007	rec. WA	Sexed	Nfish			936
2008	rec. WA	Sexed	Nfish			452
2009	rec. WA	Sexed	Nfish			670
2010	rec. WA	Sexed	Nfish			516
2011	rec. WA	Sexed	Nfish			409
2012	rec. WA	Sexed	Nfish			415
2013	rec. WA	Sexed	Nfish			354
2014	rec. WA	Sexed	Nfish			697
2015	rec. WA	Sexed	Nfish			501
2016	rec. WA	Sexed	Nfish			864
2017	rec. WA	Sexed	Nfish			1562
2018	rec. WA	Sexed	Nfish			910
2019	rec. WA	Sexed	Nfish			1674
2020	rec. WA	Sexed	Nfish			1302
1979	rec. WA	Unsexed	Nfish			35
1980	rec. WA	Unsexed	Nfish			12
1981	rec. WA	Unsexed	Nfish			62
1982	rec. WA	Unsexed	Nfish			11
1983	rec. WA	Unsexed	Nfish			3
1984	rec. WA	Unsexed	Nfish			1
1986	rec. WA	Unsexed	Nfish			5
1987	rec. WA	Unsexed	Nfish			5
1992	rec. WA	Unsexed	Nfish			4
1993	rec. WA	Unsexed	Nfish			6
1994	rec. WA	Unsexed	Nfish			3
1995	rec. WA	Unsexed	Nfish			25
1996	rec. WA	Unsexed	Nfish			51
1997	rec. WA	Unsexed	Nfish			70
1998	rec. WA	Unsexed	Nfish			34
1999	rec. WA	Unsexed	Nfish			40
2000	rec. WA	Unsexed	Nfish			1
2001	rec. WA	Unsexed	Nfish			1
2002	rec. WA	Unsexed	Nfish			168
2003	rec. WA	Unsexed	Nfish			410
2004	rec. WA	Unsexed	Nfish			228
2005	rec. WA	Unsexed	Nfish			347
2006	rec. WA	Unsexed	Nfish			271
2007	rec. WA	Unsexed	Nfish			170
2008	rec. WA	Unsexed	Nfish			138
2009	rec. WA	Unsexed	Nfish			207
2010	rec. WA	Unsexed	Nfish			306
2011	rec. WA	Unsexed	Nfish			661

Table 9: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2012	rec. WA	Unsexed	Nfish			637
2013	rec. WA	Unsexed	Nfish			299
2014	rec. WA	Unsexed	Nfish			346
2015	rec. WA	Unsexed	Nfish			261
2016	rec. WA	Unsexed	Nfish			220
2017	rec. WA	Unsexed	Nfish			770
2018	rec. WA	Unsexed	Nfish			811
2019	rec. WA	Unsexed	Nfish			1226
2020	rec. WA	Unsexed	Nfish			293
1999	rec. OR	Sexed	Nfish			1649
2000	rec. OR	Sexed	Nfish			2246
2001	rec. OR	Sexed	Nfish			1948
2002	rec. OR	Sexed	Nfish			860
2003	rec. OR	Sexed	Nfish			817
2004	rec. OR	Sexed	Nfish			692
2005	rec. OR	Sexed	Nfish			564
2006	rec. OR	Sexed	Nfish			1186
2007	rec. OR	Sexed	Nfish			1047
2008	rec. OR	Sexed	Nfish			1036
2009	rec. OR	Sexed	Nfish			1029
2010	rec. OR	Sexed	Nfish			1011
2011	rec. OR	Sexed	Nfish			1048
2012	rec. OR	Sexed	Nfish			1037
2013	rec. OR	Sexed	Nfish			1031
2014	rec. OR	Sexed	Nfish			1012
2015	rec. OR	Sexed	Nfish			1025
2016	rec. OR	Sexed	Nfish			988
2017	rec. OR	Sexed	Nfish			949
2018	rec. OR	Sexed	Nfish			1068
2019	rec. OR	Sexed	Nfish			995
2020	rec. OR	Sexed	Nfish			851
1980	rec. OR	Unsexed	Nfish			196
1981	rec. OR	Unsexed	Nfish			88
1982	rec. OR	Unsexed	Nfish			279
1983	rec. OR	Unsexed	Nfish			129
1984	rec. OR	Unsexed	Nfish			274
1985	rec. OR	Unsexed	Nfish			397
1986	rec. OR	Unsexed	Nfish			178
1987	rec. OR	Unsexed	Nfish			289
1988	rec. OR	Unsexed	Nfish			325
1989	rec. OR	Unsexed	Nfish			300
1993	rec. OR	Unsexed	Nfish			1082
1994	rec. OR	Unsexed	Nfish			1040
1995	rec. OR	Unsexed	Nfish			474
1996	rec. OR	Unsexed	Nfish			601
1997	rec. OR	Unsexed	Nfish			664

Table 9: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
1998	rec. OR	Unsexed	Nfish			467
1999	rec. OR	Unsexed	Nfish			73
2000	rec. OR	Unsexed	Nfish			15
2001	rec. OR	Unsexed	Nfish			1465
2002	rec. OR	Unsexed	Nfish			2933
2003	rec. OR	Unsexed	Nfish			3453
2004	rec. OR	Unsexed	Nfish			2228
2005	rec. OR	Unsexed	Nfish			3268
2006	rec. OR	Unsexed	Nfish			4800
2007	rec. OR	Unsexed	Nfish			5469
2008	rec. OR	Unsexed	Nfish			5631
2009	rec. OR	Unsexed	Nfish			4964
2010	rec. OR	Unsexed	Nfish			5867
2011	rec. OR	Unsexed	Nfish			6592
2012	rec. OR	Unsexed	Nfish			8114
2013	rec. OR	Unsexed	Nfish			8130
2014	rec. OR	Unsexed	Nfish			6446
2015	rec. OR	Unsexed	Nfish			7060
2016	rec. OR	Unsexed	Nfish			5428
2017	rec. OR	Unsexed	Nfish			5630
2018	rec. OR	Unsexed	Nfish			7528
2019	rec. OR	Unsexed	Nfish			6642
2020	rec. OR	Unsexed	Nfish			1447
2004	rec. CA	Sexed	Nfish			3
2005	rec. CA	Sexed	Nfish			2
2006	rec. CA	Sexed	Nfish			2
2007	rec. CA	Sexed	Nfish			1
2008	rec. CA	Sexed	Nfish			29
2009	rec. CA	Sexed	Nfish			11
2010	rec. CA	Sexed	Nfish			30
2012	rec. CA	Sexed	Nfish			9
2013	rec. CA	Sexed	Nfish			667
2014	rec. CA	Sexed	Nfish			1349
2015	rec. CA	Sexed	Nfish			2607
2016	rec. CA	Sexed	Nfish			2045
2017	rec. CA	Sexed	Nfish			2276
2018	rec. CA	Sexed	Nfish			1794
2019	rec. CA	Sexed	Nfish			1157
2020	rec. CA	Sexed	Nfish			3
1983	rec. CA	Unsexed	Nfish			44
1984	rec. CA	Unsexed	Nfish			84
1985	rec. CA	Unsexed	Nfish			185
1986	rec. CA	Unsexed	Nfish			88
1987	rec. CA	Unsexed	Nfish			37
1988	rec. CA	Unsexed	Nfish			37
1989	rec. CA	Unsexed	Nfish			32

Table 9: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
1993	rec. CA	Unsexed	Nfish			111
1994	rec. CA	Unsexed	Nfish			80
1995	rec. CA	Unsexed	Nfish			58
1996	rec. CA	Unsexed	Nfish			155
1997	rec. CA	Unsexed	Nfish			24
1998	rec. CA	Unsexed	Nfish			126
1999	rec. CA	Unsexed	Nfish			121
2000	rec. CA	Unsexed	Nfish			49
2001	rec. CA	Unsexed	Nfish			36
2002	rec. CA	Unsexed	Nfish			33
2003	rec. CA	Unsexed	Nfish			126
2004	rec. CA	Unsexed	Nfish			206
2005	rec. CA	Unsexed	Nfish			1399
2006	rec. CA	Unsexed	Nfish			996
2007	rec. CA	Unsexed	Nfish			1120
2008	rec. CA	Unsexed	Nfish			700
2009	rec. CA	Unsexed	Nfish			804
2010	rec. CA	Unsexed	Nfish			410
2011	rec. CA	Unsexed	Nfish			809
2012	rec. CA	Unsexed	Nfish			1300
2013	rec. CA	Unsexed	Nfish			1042
2014	rec. CA	Unsexed	Nfish			284
2015	rec. CA	Unsexed	Nfish			74
2016	rec. CA	Unsexed	Nfish			163
2017	rec. CA	Unsexed	Nfish			88
2018	rec. CA	Unsexed	Nfish			52
2019	rec. CA	Unsexed	Nfish			72
1983	Triennial	Sexed	Nsamp	2	1	70
1986	Triennial	Sexed	Nsamp	76	32	203
1989	Triennial	Sexed	Nsamp	228	96	318
1992	Triennial	Sexed	Nsamp	149	63	460
1995	Triennial	Sexed	Nsamp	218	92	267
1998	Triennial	Sexed	Nsamp	273	115	419
2001	Triennial	Sexed	Nsamp	411	173	1109
2004	Triennial	Sexed	Nsamp	268	113	693
2003	WCGBTS	Sexed	Nsamp	264	111	882
2004	WCGBTS	Sexed	Nsamp	235	99	627
2005	WCGBTS	Sexed	Nsamp	287	121	770
2006	WCGBTS	Sexed	Nsamp	299	126	782
2007	WCGBTS	Sexed	Nsamp	309	130	557
2008	WCGBTS	Sexed	Nsamp	280	118	550
2009	WCGBTS	Sexed	Nsamp	297	125	575
2010	WCGBTS	Sexed	Nsamp	347	146	1131
2011	WCGBTS	Sexed	Nsamp	383	161	1225
2012	WCGBTS	Sexed	Nsamp	340	143	1053
2013	WCGBTS	Sexed	Nsamp	278	117	683

Table 9: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2014	WCGBTS	Sexed	Nsamp	357	150	1439
2015	WCGBTS	Sexed	Nsamp	328	138	945
2016	WCGBTS	Sexed	Nsamp	337	142	1003
2017	WCGBTS	Sexed	Nsamp	373	157	986
2018	WCGBTS	Sexed	Nsamp	295	124	796
2019	WCGBTS	Sexed	Nsamp	188	79	356
2016	Research	Sexed	Nfish		24	835

Table 10: Sample sizes of age data. Compositions used as conditional age-at-length are included as sums across lengths within a year.

Year	Fleet	Gender	Units	Nsamp	Ntows/trips	Nfish
1978	comm. trawl	Sexed	Ntrips		3	35
1979	comm. trawl	Sexed	Ntrips		8	694
1980	comm. trawl	Sexed	Ntrips		28	1854
1981	comm. trawl	Sexed	Ntrips		16	1423
1982	comm. trawl	Sexed	Ntrips		43	537
1983	comm. trawl	Sexed	Ntrips		28	443
1984	comm. trawl	Sexed	Ntrips		13	339
1985	comm. trawl	Sexed	Ntrips		15	312
1986	comm. trawl	Sexed	Ntrips		22	663
1987	comm. trawl	Sexed	Ntrips		32	741
1988	comm. trawl	Sexed	Ntrips		37	821
1989	comm. trawl	Sexed	Ntrips		36	761
1990	comm. trawl	Sexed	Ntrips		37	887
1991	comm. trawl	Sexed	Ntrips		41	999
1992	comm. trawl	Sexed	Ntrips		85	2399
1993	comm. trawl	Sexed	Ntrips		79	2503
1994	comm. trawl	Sexed	Ntrips		65	1704
1995	comm. trawl	Sexed	Ntrips		61	1488
1996	comm. trawl	Sexed	Ntrips		58	1341
1997	comm. trawl	Sexed	Ntrips		84	1260
1998	comm. trawl	Sexed	Ntrips		63	903
1999	comm. trawl	Sexed	Ntrips		73	750
2000	comm. trawl	Sexed	Ntrips		40	390
2001	comm. trawl	Sexed	Ntrips		49	749
2002	comm. trawl	Sexed	Ntrips		61	794
2003	comm. trawl	Sexed	Ntrips		54	834
2004	comm. trawl	Sexed	Ntrips		41	529
2005	comm. trawl	Sexed	Ntrips		38	532
2006	comm. trawl	Sexed	Ntrips		66	629

Table 10: Sample sizes of available age data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/trips	Nfish
2007	comm. trawl	Sexed	Ntrips		97	825
2008	comm. trawl	Sexed	Ntrips		98	761
2009	comm. trawl	Sexed	Ntrips		78	562
2010	comm. trawl	Sexed	Ntrips		76	261
2011	comm. trawl	Sexed	Ntrips		60	391
2012	comm. trawl	Sexed	Ntrips		67	448
2013	comm. trawl	Sexed	Ntrips		102	448
2014	comm. trawl	Sexed	Ntrips		87	232
2015	comm. trawl	Sexed	Ntrips		66	91
2016	comm. trawl	Sexed	Ntrips		101	170
2017	comm. trawl	Sexed	Ntrips		134	434
2018	comm. trawl	Sexed	Ntrips		128	494
2019	comm. trawl	Sexed	Ntrips		156	351
2020	comm. trawl	Sexed	Ntrips		70	32
1988	comm. trawl	Unsexed	Ntrips		1	1
1989	comm. trawl	Unsexed	Ntrips		1	1
1992	comm. trawl	Unsexed	Ntrips		1	1
1993	comm. trawl	Unsexed	Ntrips		1	1
1994	comm. trawl	Unsexed	Ntrips		2	3
1995	comm. trawl	Unsexed	Ntrips		1	1
1997	comm. trawl	Unsexed	Ntrips		2	1
2018	comm. trawl	Unsexed	Ntrips		3	1
1980	comm. fixed	Sexed	Ntrips		2	1
1982	comm. fixed	Sexed	Ntrips		1	34
1986	comm. fixed	Sexed	Ntrips		2	34
1987	comm. fixed	Sexed	Ntrips		14	229
1988	comm. fixed	Sexed	Ntrips		7	145
1989	comm. fixed	Sexed	Ntrips		7	128
1990	comm. fixed	Sexed	Ntrips		8	204
1991	comm. fixed	Sexed	Ntrips		7	176
1992	comm. fixed	Sexed	Ntrips		6	6
1993	comm. fixed	Sexed	Ntrips		20	275
1994	comm. fixed	Sexed	Ntrips		18	295
1995	comm. fixed	Sexed	Ntrips		16	271
1996	comm. fixed	Sexed	Ntrips		16	265
1997	comm. fixed	Sexed	Ntrips		23	221
1998	comm. fixed	Sexed	Ntrips		15	150
1999	comm. fixed	Sexed	Ntrips		47	75
2000	comm. fixed	Sexed	Ntrips		57	119
2001	comm. fixed	Sexed	Ntrips		110	92
2002	comm. fixed	Sexed	Ntrips		96	41
2003	comm. fixed	Sexed	Ntrips		72	69
2004	comm. fixed	Sexed	Ntrips		127	99
2005	comm. fixed	Sexed	Ntrips		40	61
2006	comm. fixed	Sexed	Ntrips		66	93
2007	comm. fixed	Sexed	Ntrips		123	72

Table 10: Sample sizes of available age data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/trips	Nfish
2008	comm. fixed	Sexed	Ntrips		75	40
2009	comm. fixed	Sexed	Ntrips		71	26
2010	comm. fixed	Sexed	Ntrips		133	25
2011	comm. fixed	Sexed	Ntrips		136	50
2012	comm. fixed	Sexed	Ntrips		164	55
2013	comm. fixed	Sexed	Ntrips		162	91
2014	comm. fixed	Sexed	Ntrips		214	194
2015	comm. fixed	Sexed	Ntrips		306	33
2016	comm. fixed	Sexed	Ntrips		264	24
2017	comm. fixed	Sexed	Ntrips		288	192
2018	comm. fixed	Sexed	Ntrips		271	213
2019	comm. fixed	Sexed	Ntrips		340	268
2020	comm. fixed	Sexed	Ntrips		193	98
1987	comm. fixed	Unsexed	Ntrips		3	39
1989	comm. fixed	Unsexed	Ntrips		1	1
1991	comm. fixed	Unsexed	Ntrips		4	18
1992	comm. fixed	Unsexed	Ntrips		6	18
1993	comm. fixed	Unsexed	Ntrips		6	3
1994	comm. fixed	Unsexed	Ntrips		2	7
1997	comm. fixed	Unsexed	Ntrips		10	63
1999	comm. fixed	Unsexed	Ntrips		42	25
2007	comm. fixed	Unsexed	Ntrips		5	1
2014	comm. fixed	Unsexed	Ntrips		5	2
2016	comm. fixed	Unsexed	Ntrips		7	4
2017	comm. fixed	Unsexed	Ntrips		10	3
2018	comm. fixed	Unsexed	Ntrips		8	1
2019	comm. fixed	Unsexed	Ntrips		10	10
1979	rec. WA	Sexed	Nfish			13
1980	rec. WA	Sexed	Nfish			226
1981	rec. WA	Sexed	Nfish			14
1982	rec. WA	Sexed	Nfish			19
1983	rec. WA	Sexed	Nfish			39
1985	rec. WA	Sexed	Nfish			3
1986	rec. WA	Sexed	Nfish			342
1987	rec. WA	Sexed	Nfish			276
1988	rec. WA	Sexed	Nfish			250
1989	rec. WA	Sexed	Nfish			227
1990	rec. WA	Sexed	Nfish			207
1991	rec. WA	Sexed	Nfish			247
1992	rec. WA	Sexed	Nfish			499
1993	rec. WA	Sexed	Nfish			530
1994	rec. WA	Sexed	Nfish			449
1995	rec. WA	Sexed	Nfish			648
1996	rec. WA	Sexed	Nfish			461
1997	rec. WA	Sexed	Nfish			446
1998	rec. WA	Sexed	Nfish			416

Table 10: Sample sizes of available age data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/trips	Nfish
1999	rec. WA	Sexed	Nfish			432
2000	rec. WA	Sexed	Nfish			394
2001	rec. WA	Sexed	Nfish			560
2002	rec. WA	Sexed	Nfish			650
2003	rec. WA	Sexed	Nfish			619
2004	rec. WA	Sexed	Nfish			570
2005	rec. WA	Sexed	Nfish			566
2006	rec. WA	Sexed	Nfish			398
2007	rec. WA	Sexed	Nfish			483
2008	rec. WA	Sexed	Nfish			429
2009	rec. WA	Sexed	Nfish			334
2010	rec. WA	Sexed	Nfish			384
2011	rec. WA	Sexed	Nfish			296
2012	rec. WA	Sexed	Nfish			254
2013	rec. WA	Sexed	Nfish			344
2014	rec. WA	Sexed	Nfish			688
2015	rec. WA	Sexed	Nfish			487
2016	rec. WA	Sexed	Nfish			800
2017	rec. WA	Sexed	Nfish			1476
2018	rec. WA	Sexed	Nfish			826
2019	rec. WA	Sexed	Nfish			1593
2020	rec. WA	Sexed	Nfish			1220
1979	rec. WA	Unsexed	Nfish			19
1980	rec. WA	Unsexed	Nfish			2
1983	rec. WA	Unsexed	Nfish			1
1986	rec. WA	Unsexed	Nfish			3
1987	rec. WA	Unsexed	Nfish			2
1992	rec. WA	Unsexed	Nfish			5
1993	rec. WA	Unsexed	Nfish			7
1994	rec. WA	Unsexed	Nfish			3
1995	rec. WA	Unsexed	Nfish			12
1996	rec. WA	Unsexed	Nfish			76
1999	rec. WA	Unsexed	Nfish			1
2000	rec. WA	Unsexed	Nfish			1
2001	rec. WA	Unsexed	Nfish			1
2002	rec. WA	Unsexed	Nfish			4
2003	rec. WA	Unsexed	Nfish			5
2004	rec. WA	Unsexed	Nfish			4
2005	rec. WA	Unsexed	Nfish			5
2006	rec. WA	Unsexed	Nfish			9
2007	rec. WA	Unsexed	Nfish			15
2008	rec. WA	Unsexed	Nfish			11
2009	rec. WA	Unsexed	Nfish			12
2010	rec. WA	Unsexed	Nfish			17
2011	rec. WA	Unsexed	Nfish			6
2012	rec. WA	Unsexed	Nfish			15

Table 10: Sample sizes of available age data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/trips	Nfish
2013	rec. WA	Unsexed	Nfish			8
2014	rec. WA	Unsexed	Nfish			13
2015	rec. WA	Unsexed	Nfish			14
2016	rec. WA	Unsexed	Nfish			5
2017	rec. WA	Unsexed	Nfish			150
2018	rec. WA	Unsexed	Nfish			176
2019	rec. WA	Unsexed	Nfish			27
2020	rec. WA	Unsexed	Nfish			34
1999	rec. OR	Sexed	Nfish			178
2000	rec. OR	Sexed	Nfish			264
2001	rec. OR	Sexed	Nfish			791
2002	rec. OR	Sexed	Nfish			857
2003	rec. OR	Sexed	Nfish			805
2004	rec. OR	Sexed	Nfish			647
2005	rec. OR	Sexed	Nfish			540
2006	rec. OR	Sexed	Nfish			799
2007	rec. OR	Sexed	Nfish			788
2008	rec. OR	Sexed	Nfish			740
2012	rec. OR	Sexed	Nfish			260
2013	rec. OR	Sexed	Nfish			258
2014	rec. OR	Sexed	Nfish			259
2015	rec. OR	Sexed	Nfish			259
2016	rec. OR	Sexed	Nfish			260
2017	rec. OR	Sexed	Nfish			260
2018	rec. OR	Sexed	Nfish			258
2019	rec. OR	Sexed	Nfish			258
2002	rec. OR	Unsexed	Nfish			1
2003	rec. OR	Unsexed	Nfish			2
2004	rec. OR	Unsexed	Nfish			6
2005	rec. OR	Unsexed	Nfish			1
1992	Triennial	Sexed	Nsamp	14	6	55
1995	Triennial	Sexed	Nsamp	190	80	211
1998	Triennial	Sexed	Nsamp	249	105	324
2001	Triennial	Sexed	Nsamp	235	99	594
2004	Triennial	Sexed	Nsamp	252	106	548
2003	WCGBTS	Sexed	Nsamp	242	102	568
2004	WCGBTS	Sexed	Nsamp	223	94	459
2005	WCGBTS	Sexed	Nsamp	278	117	579
2006	WCGBTS	Sexed	Nsamp	299	126	521
2007	WCGBTS	Sexed	Nsamp	249	105	398
2008	WCGBTS	Sexed	Nsamp	273	115	443
2009	WCGBTS	Sexed	Nsamp	218	92	235
2010	WCGBTS	Sexed	Nsamp	273	115	293
2011	WCGBTS	Sexed	Nsamp	308	133	308
2012	WCGBTS	Sexed	Nsamp	225	112	225
2013	WCGBTS	Sexed	Nsamp	251	106	251

Table 10: Sample sizes of available age data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/trips	Nfish
2014	WCGBTS	Sexed	Nsamp	221	113	221
2015	WCGBTS	Sexed	Nsamp	242	122	242
2016	WCGBTS	Sexed	Nsamp	204	108	204
2018	WCGBTS	Sexed	Nsamp	105	75	105
2019	WCGBTS	Sexed	Nsamp	93	49	93
2016	Research	Sexed	Nfish		23	606

Table 11: Sample sizes of commercial retained and discard length data by fleet and state combined across sexes.

Year	Fleet	WA Trips	WA Fish	OR Trips	OR Fish	CA Trips	CA Fish
1965	comm. trawl	4	572	0	0	0	0
1966	comm. trawl	2	597	0	0	0	0
1967	comm. trawl	1	247	0	0	0	0
1968	comm. trawl	16	4833	0	0	0	0
1969	comm. trawl	6	1449	0	0	0	0
1970	comm. trawl	6	1616	0	0	0	0
1971	comm. trawl	9	2656	0	0	0	0
1972	comm. trawl	1	194	0	0	0	0
1973	comm. trawl	1	59	0	0	0	0
1974	comm. trawl	1	142	0	0	0	0
1975	comm. trawl	12	3063	0	0	0	0
1976	comm. trawl	1	210	0	0	0	0
1977	comm. trawl	1	262	0	0	0	0
1978	comm. trawl	3	223	0	0	0	0
1979	comm. trawl	8	724	0	0	0	0
1980	comm. trawl	27	2062	0	0	1	6
1981	comm. trawl	16	1426	0	0	0	0
1982	comm. trawl	24	1141	0	0	19	159
1983	comm. trawl	15	800	0	0	13	94
1984	comm. trawl	13	650	0	0	0	0
1985	comm. trawl	15	764	0	0	0	0
1986	comm. trawl	22	926	0	0	0	0
1987	comm. trawl	32	823	0	0	0	0
1988	comm. trawl	37	930	0	0	0	0
1989	comm. trawl	36	899	0	0	0	0
1990	comm. trawl	37	926	0	0	0	0
1991	comm. trawl	41	1010	0	0	0	0
1992	comm. trawl	46	1149	39	1278	0	0
1993	comm. trawl	42	1048	32	1316	5	177
1994	comm. trawl	42	1050	18	1468	5	190

Table 11: Sample sizes of commercial retained and discard length data *(continued)*

Year	Fleet	WA Trips	WA Fish	OR Trips	OR Fish	CA Trips	CA Fish
1995	comm. trawl	44	1100	12	405	5	94
1996	comm. trawl	36	900	10	288	12	262
1997	comm. trawl	27	675	28	741	29	614
1998	comm. trawl	30	708	19	443	14	226
1999	comm. trawl	30	750	29	675	14	154
2000	comm. trawl	13	294	21	352	6	88
2001	comm. trawl	15	309	22	418	12	141
2002	comm. trawl	29	404	23	436	9	98
2003	comm. trawl	31	499	19	357	4	48
2004	comm. trawl	13	266	23	345	5	54
2005	comm. trawl	14	316	16	316	8	107
2006	comm. trawl	16	330	22	411	28	246
2007	comm. trawl	24	497	36	711	37	278
2008	comm. trawl	19	471	48	700	31	278
2009	comm. trawl	21	386	45	740	12	78
2010	comm. trawl	8	201	55	671	13	72
2011	comm. trawl	14	464	33	418	13	60
2012	comm. trawl	14	479	35	566	18	62
2013	comm. trawl	19	779	62	805	21	220
2014	comm. trawl	8	217	61	713	18	239
2015	comm. trawl	4	202	46	617	16	210
2016	comm. trawl	16	318	57	801	28	341
2017	comm. trawl	24	479	79	1136	31	488
2018	comm. trawl	22	365	87	972	19	381
2019	comm. trawl	23	226	113	983	20	419
2020	comm. trawl	8	32	56	649	6	91
2021	comm. trawl	2	9	0	0	0	0
2004	comm. trawl discards	147	729	262	976	18	164
2005	comm. trawl discards	207	1398	272	1379	26	166
2006	comm. trawl discards	67	292	130	420	22	97
2007	comm. trawl discards	6	21	81	250	14	62
2008	comm. trawl discards	18	61	52	151	5	18
2009	comm. trawl discards	19	62	182	557	2	6
2010	comm. trawl discards	7	7	62	188	3	8
2011	comm. trawl discards	33	120	319	1298	9	24
2012	comm. trawl discards	34	141	319	1527	18	96

Table 11: Sample sizes of commercial retained and discard length data *(continued)*

Year	Fleet	WA Trips	WA Fish	OR Trips	OR Fish	CA Trips	CA Fish
2013	comm. trawl discards	19	61	250	1028	49	226
2014	comm. trawl discards	13	24	287	1182	70	389
2015	comm. trawl discards	1	1	223	694	64	275
2016	comm. trawl discards	4	5	244	583	51	181
2017	comm. trawl discards	1	2	232	704	58	251
2018	comm. trawl discards	5	14	209	686	105	393
2019	comm. trawl discards	13	20	337	1300	129	533
1971	comm. fixed	1	61	0	0	0	0
1980	comm. fixed	2	4	0	0	0	0
1982	comm. fixed	1	34	0	0	0	0
1986	comm. fixed	2	35	0	0	0	0
1987	comm. fixed	14	256	0	0	0	0
1988	comm. fixed	7	158	0	0	0	0
1989	comm. fixed	7	137	0	0	0	0
1990	comm. fixed	8	208	0	0	0	0
1991	comm. fixed	7	51	0	0	0	0
1992	comm. fixed	6	22	0	0	0	0
1993	comm. fixed	14	281	2	93	4	20
1994	comm. fixed	11	308	6	283	1	3
1995	comm. fixed	12	281	4	101	0	0
1996	comm. fixed	10	250	2	51	4	27
1997	comm. fixed	16	285	2	33	5	34
1998	comm. fixed	6	150	8	73	1	5
1999	comm. fixed	4	75	3	8	40	203
2000	comm. fixed	4	100	49	190	4	19
2001	comm. fixed	3	63	70	339	37	139
2002	comm. fixed	2	27	86	285	8	26
2003	comm. fixed	2	15	70	251	0	0
2004	comm. fixed	0	0	127	569	0	0
2005	comm. fixed	1	17	39	172	0	0
2006	comm. fixed	2	50	64	272	0	0
2007	comm. fixed	0	0	119	706	4	28
2008	comm. fixed	1	25	68	414	6	36
2009	comm. fixed	0	0	64	308	7	7
2010	comm. fixed	0	0	127	492	6	22
2011	comm. fixed	1	1	122	696	13	57
2012	comm. fixed	0	0	153	928	11	48
2013	comm. fixed	5	52	145	904	12	53
2014	comm. fixed	8	65	188	1145	18	41

Table 11: Sample sizes of commercial retained and discard length data *(continued)*

Year	Fleet	WA Trips	WA Fish	OR Trips	OR Fish	CA Trips	CA Fish
2015	comm. fixed	18	55	261	2205	27	210
2016	comm. fixed	25	82	220	1563	19	128
2017	comm. fixed	26	156	246	1965	16	79
2018	comm. fixed	31	133	220	1421	20	114
2019	comm. fixed	72	296	265	1836	3	33
2020	comm. fixed	26	187	150	758	17	128
2021	comm. fixed	3	9	0	0	0	0
2004	comm. fixed discards	1	1	104	526	69	296
2005	comm. fixed discards	22	73	72	496	38	117
2006	comm. fixed discards	10	25	189	798	18	62
2007	comm. fixed discards	8	9	135	481	33	116
2008	comm. fixed discards	43	141	105	421	17	51
2009	comm. fixed discards	19	38	123	414	30	79
2010	comm. fixed discards	4	10	177	621	8	14
2011	comm. fixed discards	4	6	209	952	43	127
2012	comm. fixed discards	3	5	224	980	33	105
2013	comm. fixed discards	5	6	185	956	29	106
2014	comm. fixed discards	25	51	165	804	12	29
2015	comm. fixed discards	1	1	209	777	27	65
2016	comm. fixed discards	9	18	303	1069	23	99
2017	comm. fixed discards	15	33	173	743	22	48
2018	comm. fixed discards	12	21	197	1085	28	54
2019	comm. fixed discards	19	29	212	833	27	53

Table 12: Sample sizes of commercial age data by fleet and state combined across sexes.

Year	Fleet	CA Trips	CA Fish	OR Trips	OR Fish	WA Trips	WA Fish
1978	comm. trawl	3	35	0	0	0	0
1979	comm. trawl	8	694	0	0	0	0
1980	comm. trawl	27	1854	0	0	0	0
1981	comm. trawl	16	1423	0	0	0	0
1982	comm. trawl	24	537	0	0	0	0
1983	comm. trawl	15	443	0	0	0	0
1984	comm. trawl	13	339	0	0	0	0
1985	comm. trawl	15	312	0	0	0	0
1986	comm. trawl	22	663	0	0	0	0
1987	comm. trawl	32	741	0	0	0	0
1988	comm. trawl	37	822	0	0	0	0
1989	comm. trawl	36	762	0	0	0	0
1990	comm. trawl	37	887	0	0	0	0
1991	comm. trawl	41	999	0	0	0	0

Table 12: Sample sizes of commercial age data by fleet and state combined across sexes. *(continued)*

Year	Fleet	CA Trips	CA Fish	OR Trips	OR Fish	WA Trips	WA Fish
1992	comm. trawl	46	1141	39	1259	0	0
1993	comm. trawl	42	1024	32	1306	5	174
1994	comm. trawl	42	1037	18	494	5	176
1995	comm. trawl	44	1094	12	330	5	65
1996	comm. trawl	36	820	10	288	12	233
1997	comm. trawl	27	674	0	0	29	587
1998	comm. trawl	30	706	0	0	14	197
1999	comm. trawl	30	750	0	0	0	0
2000	comm. trawl	13	294	21	96	0	0
2001	comm. trawl	15	269	22	357	12	123
2002	comm. trawl	29	375	23	321	9	98
2003	comm. trawl	31	499	19	287	4	48
2004	comm. trawl	13	266	23	228	5	35
2005	comm. trawl	14	316	16	216	0	0
2006	comm. trawl	16	329	22	300	0	0
2007	comm. trawl	24	497	36	328	0	0
2008	comm. trawl	19	469	48	292	0	0
2009	comm. trawl	21	381	45	181	0	0
2010	comm. trawl	8	107	55	154	0	0
2011	comm. trawl	14	224	33	167	0	0
2012	comm. trawl	14	295	35	153	0	0
2013	comm. trawl	19	274	62	174	0	0
2014	comm. trawl	8	99	61	133	0	0
2015	comm. trawl	4	25	46	66	0	0
2016	comm. trawl	16	118	57	52	0	0
2017	comm. trawl	24	234	79	200	0	0
2018	comm. trawl	22	264	87	231	0	0
2019	comm. trawl	23	136	113	215	0	0
2020	comm. trawl	8	32	0	0	0	0
1980	comm. fixed	2	1	0	0	0	0
1982	comm. fixed	1	34	0	0	0	0
1986	comm. fixed	2	34	0	0	0	0
1987	comm. fixed	14	268	0	0	0	0
1988	comm. fixed	7	145	0	0	0	0
1989	comm. fixed	7	129	0	0	0	0
1990	comm. fixed	8	204	0	0	0	0
1991	comm. fixed	7	194	0	0	0	0
1992	comm. fixed	6	24	0	0	0	0
1993	comm. fixed	14	278	0	0	0	0
1994	comm. fixed	11	302	0	0	0	0
1995	comm. fixed	12	271	0	0	0	0
1996	comm. fixed	10	247	2	18	0	0
1997	comm. fixed	16	284	0	0	0	0
1998	comm. fixed	6	150	0	0	0	0
1999	comm. fixed	4	100	0	0	0	0

Table 12: Sample sizes of commercial age data by fleet and state combined across sexes. *(continued)*

Year	Fleet	CA Trips	CA Fish	OR Trips	OR Fish	WA Trips	WA Fish
2000	comm. fixed	4	100	49	19	0	0
2001	comm. fixed	3	62	70	30	0	0
2002	comm. fixed	2	27	86	14	0	0
2003	comm. fixed	2	15	70	54	0	0
2004	comm. fixed	0	0	127	99	0	0
2005	comm. fixed	1	17	39	44	0	0
2006	comm. fixed	2	50	64	43	0	0
2007	comm. fixed	0	0	119	73	0	0
2008	comm. fixed	1	24	68	16	0	0
2009	comm. fixed	0	0	64	26	0	0
2010	comm. fixed	0	0	127	25	0	0
2011	comm. fixed	1	1	122	49	0	0
2012	comm. fixed	0	0	153	55	0	0
2013	comm. fixed	0	0	145	91	0	0
2014	comm. fixed	8	47	188	149	0	0
2015	comm. fixed	0	0	261	33	0	0
2016	comm. fixed	25	27	220	1	0	0
2017	comm. fixed	26	100	246	95	0	0
2018	comm. fixed	31	75	220	139	0	0
2019	comm. fixed	72	190	265	88	0	0
2020	comm. fixed	26	98	0	0	0	0

Table 13: California Collaborative Fisheries Research Program (CCFRP) samples of lingcod by subregion used to generate an index of abundance.

Year	Samples	Positive Samples	% Positive
South Cape Mendocino	131	289	45%
Ten Mile	139	297	47%
Stewarts Point	127	293	43%
Bodega Head	139	275	51%
Ano Nuevo	701	1879	37%
Point Lobos	553	1369	40%
Piedras Blancas	384	953	40%
Point Buchon	535	1324	40%
Anacapa Island	3	52	6%
Carrington Point	93	182	51%
South La Jolla	9	50	18%

Table 14: Specifications and structure of the base output.

Section	Parameterization
Population characteristics	
Maximum age	25
Sexes	Females & males
Population bins	10-140 cm by 2 cm bins
Summary biomass (mt) age	3+
Number of areas	1
Number of seasons	1
Number of growth patterns	1
Data characteristics	
Start year	1889
Catch units	mt
Data length bins	10-130 cm by 2 cm bins
Data age bins	0-20 cm by 1 year
First age with positive maturity	1
First year of main recruitment deviations	1960
Fishing characteristics	
Fishing mortality (F) method	Hybrid F
commercial trawl selectivity	double normal
commercial fixed-gear selectivity	double normal
recreational Washington selectivity	double normal
recreational Oregon selectivity	double normal
recreational California selectivity	double normal
Triennial Survey selectivity	double normal
WCGBT Survey selectivity	double normal
Lam research samples selectivity	double normal

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model.

Label	Value	Phase	Bounds	Status	SD	Prior
NatM_uniform_Fem_GP_1	0.418	7	(0.050, 0.800)	OK	0.02	lognormal(0.300, 0.438)
L_at_Amin_Fem_GP_1	12.668	1	(4.000, 60.000)	OK	0.54	-
L_at_Amax_Fem_GP_1	105.084	7	(40.000, 130.000)	OK	0.50	-
VonBert_K_Fem_GP_1	0.152	3	(0.010, 0.500)	OK	0.00	-
CV_young_Fem_GP_1	0.191	4	(0.010, 0.500)	OK	0.01	-
CV_old_Fem_GP_1	0.040	4	(0.010, 0.500)	OK	0.00	-
Wtlen_1_Fem_GP_1	0.000	-3	(-3.000, 3.000)	-	-	-
Wtlen_2_Fem_GP_1	3.277	-3	(-3.000, 5.000)	-	-	-
Mat50%_Fem_GP_1	3.230	-3	(-3.000, 100.000)	-	-	-
Mat_slope_Fem_GP_1	-2.942	-3	(-5.000, 5.000)	-	-	-
Eggs/kg_inter_Fem_GP_1	1.000	-3	(-3.000, 3.000)	-	-	-
Eggs/kg_slope_wt_Fem_GP_1	0.000	-3	(-3.000, 3.000)	-	-	-
NatM_uniform_Mal_GP_1	0.414	7	(0.150, 0.800)	OK	0.02	lognormal(0.415, 0.438)
L_at_Amin_Mal_GP_1	18.008	2	(10.000, 60.000)	OK	0.52	-
L_at_Amax_Mal_GP_1	76.188	2	(40.000, 110.000)	OK	0.47	-
VonBert_K_Mal_GP_1	0.282	3	(0.010, 1.000)	OK	0.01	-
CV_young_Mal_GP_1	0.108	4	(0.010, 0.500)	OK	0.01	-
CV_old_Mal_GP_1	0.075	4	(0.010, 0.500)	OK	0.00	-
Wtlen_1_Mal_GP_1	0.000	-3	(-3.000, 3.000)	-	-	-
Wtlen_2_Mal_GP_1	3.445	-3	(-5.000, 5.000)	-	-	-
CohortGrowDev	1.000	-1	(0.100, 10.000)	-	-	-
FracFemale_GP_1	0.500	-3	(0.000, 1.000)	-	-	-
SR_LN(R0)	9.725	1	(5.000, 15.000)	OK	0.22	-
SR_BH_steep	0.801	4	(0.200, 0.990)	OK	0.14	beta(0.777, 0.113)
SR_sigmaR	0.600	-3	(0.000, 2.000)	-	-	-

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued.*

Label	Value	Phase	Bounds	Status	SD	Prior
SR_regime	0.000	-5	(-5.000, 5.000)	-	-	-
SR_autocorr	0.000	-50	(0.000, 2.000)	-	-	-
Early_RecrDev_1889	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1890	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1891	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1892	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1893	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1894	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1895	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1896	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1897	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1898	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1899	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1900	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1901	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1902	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1903	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1904	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1905	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1906	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1907	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1908	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1909	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1910	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1911	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued.*

Label	Value	Phase	Bounds	Status	SD	Prior
Early_RecrDev_1912	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1913	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1914	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1915	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1916	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1917	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1918	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1919	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1920	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1921	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1922	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1923	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1924	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1925	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1926	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1927	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1928	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1929	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1930	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1931	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1932	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1933	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1934	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1935	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1936	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued.*

Label	Value	Phase	Bounds	Status	SD	Prior
Early_RecrDev_1937	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1938	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1939	0.000	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1940	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1941	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1942	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1943	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1944	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1945	0.002	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1946	0.002	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1947	0.003	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1948	0.004	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1949	0.005	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1950	0.006	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1951	0.008	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1952	0.011	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1953	0.016	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1954	0.020	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1955	0.024	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1956	0.025	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1957	0.018	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1958	0.003	6	(-4.000, 4.000)	-	0.59	normal(0.00, 0.60)
Early_RecrDev_1959	-0.018	6	(-4.000, 4.000)	-	0.58	normal(0.00, 0.60)
Main_RecrDev_1960	-0.064	1	(-4.000, 4.000)	-	0.55	normal(0.00, 0.60)
Main_RecrDev_1961	-0.151	1	(-4.000, 4.000)	-	0.53	normal(0.00, 0.60)

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued*.

Label	Value	Phase	Bounds	Status	SD	Prior
Main_RecrDev_1962	-0.237	1	(-4.000, 4.000)	-	0.52	normal(0.00, 0.60)
Main_RecrDev_1963	-0.131	1	(-4.000, 4.000)	-	0.54	normal(0.00, 0.60)
Main_RecrDev_1964	0.266	1	(-4.000, 4.000)	-	0.55	normal(0.00, 0.60)
Main_RecrDev_1965	0.145	1	(-4.000, 4.000)	-	0.56	normal(0.00, 0.60)
Main_RecrDev_1966	-0.023	1	(-4.000, 4.000)	-	0.54	normal(0.00, 0.60)
Main_RecrDev_1967	0.005	1	(-4.000, 4.000)	-	0.53	normal(0.00, 0.60)
Main_RecrDev_1968	-0.052	1	(-4.000, 4.000)	-	0.52	normal(0.00, 0.60)
Main_RecrDev_1969	0.019	1	(-4.000, 4.000)	-	0.56	normal(0.00, 0.60)
Main_RecrDev_1970	0.833	1	(-4.000, 4.000)	-	0.50	normal(0.00, 0.60)
Main_RecrDev_1971	1.153	1	(-4.000, 4.000)	-	0.38	normal(0.00, 0.60)
Main_RecrDev_1972	0.249	1	(-4.000, 4.000)	-	0.54	normal(0.00, 0.60)
Main_RecrDev_1973	0.594	1	(-4.000, 4.000)	-	0.34	normal(0.00, 0.60)
Main_RecrDev_1974	0.514	1	(-4.000, 4.000)	-	0.28	normal(0.00, 0.60)
Main_RecrDev_1975	-0.015	1	(-4.000, 4.000)	-	0.30	normal(0.00, 0.60)
Main_RecrDev_1976	-0.023	1	(-4.000, 4.000)	-	0.25	normal(0.00, 0.60)
Main_RecrDev_1977	0.146	1	(-4.000, 4.000)	-	0.22	normal(0.00, 0.60)
Main_RecrDev_1978	0.436	1	(-4.000, 4.000)	-	0.20	normal(0.00, 0.60)
Main_RecrDev_1979	0.508	1	(-4.000, 4.000)	-	0.20	normal(0.00, 0.60)
Main_RecrDev_1980	-0.038	1	(-4.000, 4.000)	-	0.26	normal(0.00, 0.60)
Main_RecrDev_1981	-0.290	1	(-4.000, 4.000)	-	0.24	normal(0.00, 0.60)
Main_RecrDev_1982	-0.029	1	(-4.000, 4.000)	-	0.17	normal(0.00, 0.60)
Main_RecrDev_1983	-0.510	1	(-4.000, 4.000)	-	0.20	normal(0.00, 0.60)
Main_RecrDev_1984	-0.633	1	(-4.000, 4.000)	-	0.19	normal(0.00, 0.60)
Main_RecrDev_1985	0.327	1	(-4.000, 4.000)	-	0.11	normal(0.00, 0.60)
Main_RecrDev_1986	-0.264	1	(-4.000, 4.000)	-	0.15	normal(0.00, 0.60)

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued*.

Label	Value	Phase	Bounds	Status	SD	Prior
Main__RecrDev__1987	-0.591	1	(-4.000, 4.000)	-	0.16	normal(0.00, 0.60)
Main__RecrDev__1988	-0.432	1	(-4.000, 4.000)	-	0.13	normal(0.00, 0.60)
Main__RecrDev__1989	-0.316	1	(-4.000, 4.000)	-	0.11	normal(0.00, 0.60)
Main__RecrDev__1990	0.027	1	(-4.000, 4.000)	-	0.09	normal(0.00, 0.60)
Main__RecrDev__1991	-0.051	1	(-4.000, 4.000)	-	0.10	normal(0.00, 0.60)
Main__RecrDev__1992	-0.251	1	(-4.000, 4.000)	-	0.13	normal(0.00, 0.60)
Main__RecrDev__1993	-0.191	1	(-4.000, 4.000)	-	0.13	normal(0.00, 0.60)
Main__RecrDev__1994	0.057	1	(-4.000, 4.000)	-	0.12	normal(0.00, 0.60)
Main__RecrDev__1995	0.205	1	(-4.000, 4.000)	-	0.12	normal(0.00, 0.60)
Main__RecrDev__1996	-0.237	1	(-4.000, 4.000)	-	0.14	normal(0.00, 0.60)
Main__RecrDev__1997	-0.224	1	(-4.000, 4.000)	-	0.12	normal(0.00, 0.60)
Main__RecrDev__1998	-0.216	1	(-4.000, 4.000)	-	0.12	normal(0.00, 0.60)
Main__RecrDev__1999	0.382	1	(-4.000, 4.000)	-	0.09	normal(0.00, 0.60)
Main__RecrDev__2000	0.394	1	(-4.000, 4.000)	-	0.09	normal(0.00, 0.60)
Main__RecrDev__2001	0.236	1	(-4.000, 4.000)	-	0.09	normal(0.00, 0.60)
Main__RecrDev__2002	-0.078	1	(-4.000, 4.000)	-	0.10	normal(0.00, 0.60)
Main__RecrDev__2003	-0.304	1	(-4.000, 4.000)	-	0.11	normal(0.00, 0.60)
Main__RecrDev__2004	-0.057	1	(-4.000, 4.000)	-	0.10	normal(0.00, 0.60)
Main__RecrDev__2005	-0.779	1	(-4.000, 4.000)	-	0.16	normal(0.00, 0.60)
Main__RecrDev__2006	-0.019	1	(-4.000, 4.000)	-	0.10	normal(0.00, 0.60)
Main__RecrDev__2007	-0.280	1	(-4.000, 4.000)	-	0.13	normal(0.00, 0.60)
Main__RecrDev__2008	0.785	1	(-4.000, 4.000)	-	0.07	normal(0.00, 0.60)
Main__RecrDev__2009	0.122	1	(-4.000, 4.000)	-	0.10	normal(0.00, 0.60)
Main__RecrDev__2010	0.128	1	(-4.000, 4.000)	-	0.09	normal(0.00, 0.60)
Main__RecrDev__2011	-0.251	1	(-4.000, 4.000)	-	0.11	normal(0.00, 0.60)

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued*.

Label	Value	Phase	Bounds	Status	SD	Prior
Main_RecrDev_2012	-0.243	1	(-4.000, 4.000)	-	0.10	normal(0.00, 0.60)
Main_RecrDev_2013	0.450	1	(-4.000, 4.000)	-	0.08	normal(0.00, 0.60)
Main_RecrDev_2014	-0.599	1	(-4.000, 4.000)	-	0.12	normal(0.00, 0.60)
Main_RecrDev_2015	-0.322	1	(-4.000, 4.000)	-	0.10	normal(0.00, 0.60)
Main_RecrDev_2016	-0.049	1	(-4.000, 4.000)	-	0.11	normal(0.00, 0.60)
Main_RecrDev_2017	-0.340	1	(-4.000, 4.000)	-	0.15	normal(0.00, 0.60)
Main_RecrDev_2018	0.309	1	(-4.000, 4.000)	-	0.17	normal(0.00, 0.60)
Late_RecrDev_2019	-0.637	8	(-4.000, 4.000)	-	0.41	normal(0.00, 0.60)
Late_RecrDev_2020	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2021	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2022	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2023	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2024	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2025	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2026	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2027	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2028	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2029	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2030	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2031	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
ForeRecr_2032	0.000	8	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
LnQ_base_1_Comm_Trawl(1)	-1.909	-1	(-15.000, 15.000)	-	-	-
Q_extraSD_1_Comm_Trawl(1)	0.089	2	(0.000, 2.000)	OK	0.04	-
LnQ_base_2_Comm_Fix(2)	-8.074	-1	(-15.000, 15.000)	-	-	-
Q_extraSD_2_Comm_Fix(2)	0.000	-2	(0.000, 2.000)	-	-	-

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued.*

Label	Value	Phase	Bounds	Status	SD	Prior
LnQ_base_3_Rec_WA(3)	-8.483	-1	(-15.000, 15.000)	-	-	-
Q_extraSD_3_Rec_WA(3)	0.138	2	(0.000, 2.000)	OK	0.02	-
LnQ_base_4_Rec_OR(4)	-8.848	-1	(-15.000, 15.000)	-	-	-
Q_extraSD_4_Rec_OR(4)	0.000	-2	(0.000, 2.000)	-	-	-
LnQ_base_5_Rec_CA(5)	-8.937	-1	(-15.000, 15.000)	-	-	-
Q_extraSD_5_Rec_CA(5)	0.188	2	(0.000, 2.000)	OK	0.04	-
LnQ_base_6_Surv_TRI(6)	-0.853	-1	(-15.000, 15.000)	-	-	-
Q_extraSD_6_Surv_TRI(6)	0.233	2	(0.000, 2.000)	OK	0.09	-
LnQ_base_7_Surv_WCGBTS(7)	-0.209	-1	(-15.000, 15.000)	-	-	-
Size_DblN_peak_1_Comm_Trawl(1)	93.919	2	(20.000, 120.000)	OK	5.11	-
Size_DblN_top_logit_1_Comm_Trawl(1)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_1_Comm_Trawl(1)	6.515	3	(-1.000, 9.000)	OK	0.22	-
Size_DblN_descend_se_1_Comm_Trawl(1)	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_start_logit_1_Comm_Trawl(1)	-999.000	-2	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_1_Comm_Trawl(1)	-999.000	-3	(-5.000, 9.000)	-	-	-
Retain_L_infl_1_Comm_Trawl(1)	10.000	-4	(10.000, 100.000)	-	-	-
Retain_L_width_1_Comm_Trawl(1)	15.000	-4	(1.000, 15.000)	-	-	-
Retain_L_asymptote_logit_1_Comm_Trawl(1)	10.000	-5	(-10.000, 10.000)	-	-	-
Retain_L_maleoffset_1_Comm_Trawl(1)	0.000	-5	(-2.000, 2.000)	-	-	-
DiscMort_L_infl_1_Comm_Trawl(1)	0.000	-4	(-1.000, 1.000)	-	-	-
DiscMort_L_width_1_Comm_Trawl(1)	0.000	-5	(-1.000, 1.000)	-	-	-
DiscMort_L_level_old_1_Comm_Trawl(1)	0.500	-6	(0.010, 1.000)	-	-	-
DiscMort_L_male_offset_1_Comm_Trawl(1)	0.000	-4	(-2.000, 2.000)	-	-	-
Size_DblN_peak_2_Comm_Fix(2)	69.430	2	(20.000, 120.000)	OK	1.82	-
Size_DblN_top_logit_2_Comm_Fix(2)	-15.000	-3	(-20.000, 4.000)	-	-	-

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued.*

Label	Value	Phase	Bounds	Status	SD	Prior
Size_DblN_ascend_se_2_Comm_Fix(2)	5.698	3	(-1.000, 9.000)	OK	0.11	-
Size_DblN_descend_se_2_Comm_Fix(2)	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_start_logit_2_Comm_Fix(2)	-999.000	-2	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_2_Comm_Fix(2)	-999.000	-3	(-5.000, 9.000)	-	-	-
Retain_L_infl_2_Comm_Fix(2)	10.000	-4	(10.000, 100.000)	-	-	-
Retain_L_width_2_Comm_Fix(2)	15.000	-4	(1.000, 15.000)	-	-	-
Retain_L_asymptote_logit_2_Comm_Fix(2)	10.000	-5	(-10.000, 10.000)	-	-	-
Retain_L_maleoffset_2_Comm_Fix(2)	0.000	-5	(-2.000, 2.000)	-	-	-
DiscMort_L_infl_2_Comm_Fix(2)	0.000	-4	(-1.000, 1.000)	-	-	-
DiscMort_L_width_2_Comm_Fix(2)	0.000	-5	(-1.000, 1.000)	-	-	-
DiscMort_L_level_old_2_Comm_Fix(2)	0.070	-6	(0.010, 1.000)	-	-	-
DiscMort_L_male_offset_2_Comm_Fix(2)	0.000	-4	(-2.000, 2.000)	-	-	-
Size_DblN_peak_3_Rec_WA(3)	82.696	2	(20.000, 120.000)	OK	4.51	-
Size_DblN_top_logit_3_Rec_WA(3)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_3_Rec_WA(3)	6.330	3	(-1.000, 9.000)	OK	0.27	-
Size_DblN_descend_se_3_Rec_WA(3)	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_start_logit_3_Rec_WA(3)	-999.000	-2	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_3_Rec_WA(3)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_peak_4_Rec_OR(4)	63.376	2	(20.000, 120.000)	OK	3.03	-
Size_DblN_top_logit_4_Rec_OR(4)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_4_Rec_OR(4)	5.492	3	(-1.000, 9.000)	OK	0.27	-
Size_DblN_descend_se_4_Rec_OR(4)	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_start_logit_4_Rec_OR(4)	-999.000	-2	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_4_Rec_OR(4)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_peak_5_Rec_CA(5)	77.708	2	(20.000, 120.000)	OK	4.80	-

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued.*

Label	Value	Phase	Bounds	Status	SD	Prior
Size_DblN_top_logit_5_Rec_CA(5)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_5_Rec_CA(5)	5.502	3	(-1.000, 9.000)	OK	0.38	-
Size_DblN_descend_se_5_Rec_CA(5)	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_start_logit_5_Rec_CA(5)	-999.000	-2	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_5_Rec_CA(5)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_peak_6_Surv_TRI(6)	104.003	2	(20.000, 120.000)	OK	20.54	-
Size_DblN_top_logit_6_Surv_TRI(6)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_6_Surv_TRI(6)	7.505	3	(-1.000, 9.000)	OK	0.41	-
Size_DblN_descend_se_6_Surv_TRI(6)	10.123	3	(-1.000, 15.000)	OK	78.33	-
Size_DblN_start_logit_6_Surv_TRI(6)	-999.000	-2	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_6_Surv_TRI(6)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_peak_7_Surv_WCGBTS(7)	83.189	2	(20.000, 120.000)	OK	5.25	-
Size_DblN_top_logit_7_Surv_WCGBTS(7)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_7_Surv_WCGBTS(7)	7.116	3	(-1.000, 9.000)	OK	0.17	-
Size_DblN_descend_se_7_Surv_WCGBTS(7)	5.381	3	(-1.000, 15.000)	OK	1.42	-
Size_DblN_start_logit_7_Surv_WCGBTS(7)	-999.000	-2	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_7_Surv_WCGBTS(7)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_peak_9_Research_Lam(9)	88.388	2	(20.000, 120.000)	OK	4.46	-
Size_DblN_top_logit_9_Research_Lam(9)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_9_Research_Lam(9)	6.414	3	(-1.000, 9.000)	OK	0.23	-
Size_DblN_descend_se_9_Research_Lam(9)	4.751	3	(-1.000, 15.000)	OK	1.62	-
Size_DblN_start_logit_9_Research_Lam(9)	-999.000	-2	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_9_Research_Lam(9)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_peak_1_Comm_Trawl(1)_BLK1repl_1993	103.345	2	(20.000, 120.000)	OK	4.17	-
Size_DblN_peak_1_Comm_Trawl(1)_BLK1repl_1998	77.666	2	(20.000, 120.000)	OK	3.13	-

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued.*

Label	Value	Phase	Bounds	Status	SD	Prior
Size_DblN_peak_1_Comm_Trawl(1)_BLK1repl_2011	91.906	2	(20.000, 120.000)	OK	3.55	-
Size_DblN_ascend_se_1_Comm_Trawl(1)_BLK1repl_1993	6.955	3	(-1.000, 9.000)	OK	0.14	-
Size_DblN_ascend_se_1_Comm_Trawl(1)_BLK1repl_1998	6.693	3	(-1.000, 9.000)	OK	0.13	-
Size_DblN_ascend_se_1_Comm_Trawl(1)_BLK1repl_2011	6.967	3	(-1.000, 9.000)	OK	0.08	-
Size_DblN_descend_se_1_Comm_Trawl(1)_BLK1repl_1993	1.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_descend_se_1_Comm_Trawl(1)_BLK1repl_1998	5.439	3	(-1.000, 15.000)	OK	0.42	-
Size_DblN_descend_se_1_Comm_Trawl(1)_BLK1repl_2011	4.806	3	(-1.000, 15.000)	OK	1.34	-
Retain_L_infl_1_Comm_Trawl(1)_BLK2repl_1998	100.000	-99	(40.000, 100.000)	-	-	-
Retain_L_infl_1_Comm_Trawl(1)_BLK2repl_2007	90.420	4	(40.000, 100.000)	OK	5.48	-
Retain_L_infl_1_Comm_Trawl(1)_BLK2repl_2010	64.404	4	(40.000, 100.000)	OK	5.60	-
Retain_L_infl_1_Comm_Trawl(1)_BLK2repl_2011	55.740	4	(40.000, 100.000)	OK	0.49	-
Retain_L_width_1_Comm_Trawl(1)_BLK3repl_1998	10.075	4	(1.000, 15.000)	OK	0.98	-
Retain_L_width_1_Comm_Trawl(1)_BLK3repl_2011	2.328	4	(1.000, 15.000)	OK	0.21	-
Retain_L_infl_2_Comm_Fix(2)_BLK4repl_1998	72.851	4	(40.000, 100.000)	OK	2.14	-
Retain_L_infl_2_Comm_Fix(2)_BLK4repl_2011	59.916	4	(40.000, 100.000)	OK	1.42	-
Retain_L_width_2_Comm_Fix(2)_BLK5repl_1998	13.646	4	(1.000, 15.000)	OK	1.59	-
Retain_L_width_2_Comm_Fix(2)_BLK5repl_2011	8.857	4	(1.000, 15.000)	OK	0.79	-
Size_DblN_peak_3_Rec_WA(3)_BLK6repl_1987	60.590	2	(20.000, 120.000)	OK	1.97	-
Size_DblN_peak_3_Rec_WA(3)_BLK6repl_1995	60.211	2	(20.000, 120.000)	OK	1.29	-
Size_DblN_peak_3_Rec_WA(3)_BLK6repl_1998	63.994	2	(20.000, 120.000)	OK	0.60	-
Size_DblN_peak_3_Rec_WA(3)_BLK6repl_2007	63.007	2	(20.000, 120.000)	OK	1.04	-
Size_DblN_peak_3_Rec_WA(3)_BLK6repl_2011	63.243	2	(20.000, 120.000)	OK	1.18	-
Size_DblN_peak_3_Rec_WA(3)_BLK6repl_2017	67.289	2	(20.000, 120.000)	OK	2.35	-
Size_DblN_ascend_se_3_Rec_WA(3)_BLK6repl_1987	4.617	3	(-1.000, 9.000)	OK	0.29	-
Size_DblN_ascend_se_3_Rec_WA(3)_BLK6repl_1995	3.339	3	(-1.000, 9.000)	OK	0.42	-

Table 15: Parameter estimates, estimation phase, parameter bounds, estimation status, ... *continued*.

Label	Value	Phase	Bounds	Status	SD	Prior
Size_DblN_ascend_se_3_Rec_WA(3)_BLK6repl_1998	2.907	3	(-1.000, 9.000)	OK	0.23	-
Size_DblN_ascend_se_3_Rec_WA(3)_BLK6repl_2007	3.556	3	(-1.000, 9.000)	OK	0.29	-
Size_DblN_ascend_se_3_Rec_WA(3)_BLK6repl_2011	3.669	3	(-1.000, 9.000)	OK	0.29	-
Size_DblN_ascend_se_3_Rec_WA(3)_BLK6repl_2017	5.206	3	(-1.000, 9.000)	OK	0.23	-
Size_DblN_descend_se_3_Rec_WA(3)_BLK6repl_1987	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_descend_se_3_Rec_WA(3)_BLK6repl_1995	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_descend_se_3_Rec_WA(3)_BLK6repl_1998	8.359	3	(-1.000, 15.000)	OK	0.78	-
Size_DblN_descend_se_3_Rec_WA(3)_BLK6repl_2007	7.246	3	(-1.000, 15.000)	OK	0.40	-
Size_DblN_descend_se_3_Rec_WA(3)_BLK6repl_2011	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_descend_se_3_Rec_WA(3)_BLK6repl_2017	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_peak_4_Rec_OR(4)_BLK7repl_1995	59.625	2	(20.000, 120.000)	OK	1.44	-
Size_DblN_peak_4_Rec_OR(4)_BLK7repl_1998	62.426	2	(20.000, 120.000)	OK	0.21	-
Size_DblN_peak_4_Rec_OR(4)_BLK7repl_2007	58.198	2	(20.000, 120.000)	OK	0.14	-
Size_DblN_ascend_se_4_Rec_OR(4)_BLK7repl_1995	3.328	3	(-1.000, 9.000)	OK	0.46	-
Size_DblN_ascend_se_4_Rec_OR(4)_BLK7repl_1998	1.663	3	(-1.000, 9.000)	OK	0.15	-
Size_DblN_ascend_se_4_Rec_OR(4)_BLK7repl_2007	1.867	3	(-1.000, 9.000)	OK	0.09	-
Size_DblN_descend_se_4_Rec_OR(4)_BLK7repl_1995	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_descend_se_4_Rec_OR(4)_BLK7repl_1998	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_descend_se_4_Rec_OR(4)_BLK7repl_2007	7.496	3	(-1.000, 15.000)	OK	0.12	-
Size_DblN_peak_5_Rec_CA(5)_BLK8repl_1999	66.734	2	(20.000, 120.000)	OK	0.97	-
Size_DblN_peak_5_Rec_CA(5)_BLK8repl_2011	62.338	2	(20.000, 120.000)	OK	0.53	-
Size_DblN_ascend_se_5_Rec_CA(5)_BLK8repl_1999	3.505	3	(-1.000, 9.000)	OK	0.26	-
Size_DblN_ascend_se_5_Rec_CA(5)_BLK8repl_2011	3.431	3	(-1.000, 9.000)	OK	0.15	-
Size_DblN_descend_se_5_Rec_CA(5)_BLK8repl_1999	15.000	-99	(-1.000, 15.000)	-	-	-
Size_DblN_descend_se_5_Rec_CA(5)_BLK8repl_2011	7.563	3	(-1.000, 15.000)	OK	0.25	-

Table 16: Likelihoods components by source.

Label	Total
Total	5088.02
Catch	0.00
Equil catch	0.00
Survey	-162.88
Discard	-65.21
Mean body weight	-23.42
Length composition	2108.36
Age composition	3242.70
Recruitment	-12.33
Initial equil regime	0.00
Forecast recruitment	0.56
Parameter priors	0.23
Parameter softbounds	0.01
Parameter deviations	0.00
Crash penalty	0.00

Table 17: Estimates of reference points and management quantities and their associated upper and lower 95% intervals.

Label	Estimate	Lower	Upper
SSB_Virgin	17159.80	13485.56	20834.04
SSB_2021	11010.20	7142.85	14877.55
Recr_Virgin	16734.60	9453.93	24015.27
Recr_2021	16174.80	-4141.58	36491.18
SPRratio_2021	0.46	0.30	0.62
F_2021	0.07	0.04	0.10
Bratio_2021	0.64	0.52	0.77
SSB_SPR	7098.53	5534.88	8662.18
annF_SPR	0.22	0.20	0.24
Dead_Catch_SPR	3644.93	2488.90	4800.96
SSB_MSY	3675.78	1155.06	6196.50
SPR_MSY	0.26	0.06	0.46
annF_MSY	0.43	0.09	0.77
Dead_Catch_MSY	4222.53	2271.04	6174.02
Ret_Catch_MSY	3937.89	2271.40	5604.38
B_MSY/SSB_unfished	0.21	0.09	0.34

ForeCatch_2021	1576.72	1576.72	1576.72
OFLCatch_2021	5084.77	2773.05	7396.49
ForeCatchret_2021	1534.59	1524.67	1544.51

Table 18: Time series of population estimates for the base model.

	Biomass (mt)				Numbers	Rate		
Year	Total	Spawning	Age-3+	Mortality	Age-0	Fraction unfished	1-SPR	F
1890	36183	17099	32259	124.015	16731	1.00	0.030	0.004
1891	36153	17044	32229	132.475	16728	0.99	0.032	0.004
1892	35984	16995	32060	180.953	16725	0.99	0.044	0.006
1893	36075	16931	32150	154.264	16721	0.99	0.038	0.005
1894	36148	16894	32224	132.797	16718	0.98	0.032	0.004
1895	36086	16877	32162	150.438	16717	0.98	0.037	0.005
1896	35941	16857	32017	191.940	16716	0.98	0.047	0.006
1897	35985	16819	32060	179.093	16714	0.98	0.044	0.006
1898	36362	16795	32438	71.656	16712	0.98	0.018	0.002
1899	36405	16833	32481	59.635	16714	0.98	0.015	0.002
1900	36376	16872	32452	68.058	16717	0.98	0.017	0.002
1901	36347	16900	32423	76.481	16719	0.98	0.019	0.002
1902	36318	16918	32394	84.904	16720	0.99	0.021	0.003
1903	36289	16926	32364	93.327	16720	0.99	0.023	0.003
1904	36259	16928	32335	101.750	16720	0.99	0.025	0.003
1905	36295	16924	32370	91.595	16720	0.99	0.022	0.003
1906	36330	16926	32406	81.440	16720	0.99	0.020	0.003
1907	36366	16933	32441	71.285	16721	0.99	0.018	0.002
1908	36402	16944	32477	61.131	16721	0.99	0.015	0.002
1909	36229	16959	32305	110.285	16722	0.99	0.027	0.003
1910	36058	16945	32134	159.440	16721	0.99	0.039	0.005
1911	35887	16906	31963	208.595	16719	0.99	0.051	0.006
1912	35717	16848	31793	257.750	16715	0.98	0.062	0.008
1913	35546	16775	31622	306.906	16711	0.98	0.074	0.010
1914	35375	16691	31451	356.062	16706	0.97	0.086	0.011
1915	35203	16597	31279	405.219	16700	0.97	0.098	0.013
1916	34802	16497	30878	523.184	16693	0.96	0.125	0.017
1917	34401	16356	30478	641.150	16684	0.95	0.153	0.020
1918	34000	16180	30076	759.119	16672	0.94	0.180	0.024
1919	35435	15978	31511	327.102	16658	0.93	0.082	0.011

Table 18: Time series of population estimates for the base ... *continued.*

Year	Total	Spawning	Age-3+	Mortality	Age-0	Fraction unfished	1-SPR	F
1920	35729	16042	31805	244.415	16663	0.93	0.062	0.008
1921	35864	16149	31940	207.426	16670	0.94	0.052	0.007
1922	36081	16260	32157	148.382	16678	0.95	0.038	0.005
1923	36157	16379	32233	127.786	16685	0.95	0.032	0.004
1924	35781	16486	31857	234.867	16693	0.96	0.058	0.007
1925	35466	16514	31541	327.037	16694	0.96	0.080	0.010
1926	35358	16483	31434	357.700	16692	0.96	0.087	0.011
1927	35153	16439	31229	416.818	16690	0.96	0.101	0.013
1928	35422	16371	31498	336.441	16685	0.95	0.083	0.011
1929	34127	16358	30203	730.062	16685	0.95	0.172	0.023
1930	34144	16140	30220	720.789	16670	0.94	0.172	0.023
1931	34579	15962	30655	584.379	16658	0.93	0.143	0.019
1932	35022	15892	31098	448.835	16654	0.93	0.112	0.015
1933	34529	15917	30605	597.533	16656	0.93	0.147	0.019
1934	34249	15863	30325	686.852	16653	0.92	0.168	0.022
1935	34088	15768	30164	735.755	16647	0.92	0.180	0.024
1936	33758	15664	29835	834.394	16640	0.91	0.202	0.027
1937	33543	15530	29619	906.711	16632	0.91	0.220	0.030
1938	31819	15379	27896	1450.310	16622	0.90	0.332	0.048
1939	32601	14989	28678	1184.290	16594	0.87	0.286	0.040
1940	31469	14788	27546	1580.800	16580	0.86	0.369	0.054
1941	31893	14418	27970	1395.420	16552	0.84	0.339	0.049
1942	30730	14229	26807	1820.040	16540	0.83	0.424	0.064
1943	30998	13848	27076	1702.860	16510	0.81	0.411	0.061
1944	29374	13600	25452	2344.110	16492	0.79	0.528	0.086
1945	30903	13056	26981	1670.590	16445	0.76	0.423	0.063
1946	29321	12997	25399	2267.460	16446	0.76	0.532	0.085
1947	30661	12648	26739	1701.870	16419	0.74	0.439	0.065
1948	29394	12676	25471	2199.180	16435	0.74	0.530	0.084
1949	30215	12432	26293	1818.970	16425	0.72	0.467	0.071
1950	30945	12457	27022	1581.400	16452	0.73	0.421	0.061
1951	30616	12594	26693	1721.030	16504	0.73	0.445	0.066
1952	31805	12634	27881	1300.270	16560	0.74	0.356	0.050
1953	33713	12907	29789	744.508	16656	0.75	0.219	0.028
1954	33016	13431	29092	988.208	16787	0.78	0.271	0.036
1955	31734	13728	27810	1470.800	16876	0.80	0.370	0.053
1956	32625	13686	28702	1149.570	16889	0.80	0.303	0.041
1957	31787	13845	27864	1461.240	16791	0.81	0.365	0.052

Table 18: Time series of population estimates for the base ... *continued.*

Year	Total	Spawning	Age-3+	Mortality	Age-0	Fraction unfished	1-SPR	F
1958	31838	13816	27915	1447.750	16544	0.81	0.363	0.052
1959	30516	13811	26593	1981.120	16199	0.80	0.461	0.071
1960	29793	13505	25870	2242.810	15437	0.79	0.512	0.081
1961	29833	13104	25910	2159.650	14067	0.76	0.509	0.080
1962	31706	12793	27783	1385.710	12773	0.75	0.372	0.052
1963	32538	12907	28614	1116.280	14094	0.75	0.311	0.042
1964	31681	13003	27758	1433.690	20799	0.76	0.377	0.055
1965	31150	12657	27227	1602.920	18244	0.74	0.416	0.064
1966	30686	12124	26763	1720.920	15235	0.71	0.449	0.070
1967	28643	11934	24721	2516.740	15517	0.70	0.595	0.099
1968	27753	11964	23831	2852.220	14547	0.70	0.657	0.111
1969	30091	11760	26168	1793.870	15474	0.69	0.491	0.072
1970	31493	11912	27570	1344.030	34654	0.69	0.387	0.054
1971	30754	12165	26831	1647.630	47443	0.71	0.442	0.066
1972	30263	12124	26340	1859.190	19053	0.71	0.477	0.074
1973	29566	12784	25644	2269.760	26795	0.75	0.530	0.076
1974	29808	15569	25886	2427.170	24893	0.91	0.512	0.063
1975	30656	18855	26733	2346.190	14719	1.10	0.450	0.059
1976	31101	19850	27178	2370.790	14523	1.16	0.416	0.057
1977	31737	20435	27813	2145.230	17088	1.19	0.368	0.051
1978	32118	20338	28195	1944.950	22640	1.19	0.337	0.049
1979	30161	19135	26239	2971.160	24042	1.12	0.480	0.081
1980	29923	17099	26001	2846.960	13723	1.00	0.497	0.085
1981	29693	15767	25771	2736.270	10530	0.92	0.514	0.084
1982	28483	15417	24562	3223.900	13590	0.90	0.597	0.099
1983	27213	14913	23292	3775.930	8380	0.87	0.686	0.125
1984	26827	13226	22906	3626.870	7347	0.77	0.710	0.138
1985	25725	11370	21805	3770.030	18943	0.66	0.781	0.161
1986	27017	9630	23096	2559.130	10316	0.56	0.690	0.130
1987	26746	8363	22826	2354.820	7322	0.49	0.706	0.139
1988	26364	7602	22443	2313.720	8481	0.44	0.735	0.132
1989	24091	7761	20172	3033.550	9558	0.45	0.879	0.180
1990	24706	7001	20787	2511.450	13279	0.41	0.840	0.171
1991	23412	6205	19493	2838.480	12073	0.36	0.930	0.213
1992	25716	5355	21796	1749.460	9644	0.31	0.774	0.145
1993	24431	5487	20517	2082.730	10284	0.32	0.851	0.160
1994	25523	5824	21607	1817.140	13305	0.34	0.781	0.134
1995	28031	6178	24112	1311.750	15582	0.36	0.622	0.096

Table 18: Time series of population estimates for the base ... *continued*.

Year	Total	Spawning	Age-3+	Mortality	Age-0	Fraction unfished	1-SPR	F
1996	27834	6511	23916	1456.090	10090	0.38	0.635	0.103
1997	28173	6810	24254	1457.330	10291	0.40	0.610	0.096
1998	26447	7433	22553	1864.760	10500	0.43	0.663	0.111
1999	26479	7947	22585	1888.940	19266	0.46	0.661	0.113
2000	32149	7867	28235	699.523	19457	0.46	0.297	0.043
2001	32720	8210	28803	637.235	16709	0.48	0.262	0.038
2002	30917	8855	27005	1070.550	12309	0.52	0.381	0.055
2003	31814	10067	27897	979.046	9960	0.59	0.327	0.045
2004	32467	11351	28550	915.730	12902	0.66	0.281	0.038
2005	32240	12128	28324	1014.310	6301	0.71	0.294	0.042
2006	31232	12105	27320	1253.660	13478	0.71	0.358	0.054
2007	33122	11575	29204	743.007	10334	0.67	0.234	0.033
2008	33029	11218	29110	721.340	29896	0.65	0.241	0.035
2009	33358	10570	29439	620.877	15329	0.62	0.219	0.030
2010	34596	10471	30673	378.711	15405	0.61	0.137	0.019
2011	33576	11147	29653	657.191	10611	0.65	0.214	0.026
2012	33332	12969	29409	811.652	10832	0.76	0.232	0.031
2013	33305	13732	29382	881.276	21763	0.80	0.232	0.032
2014	33863	13843	29939	728.855	7629	0.81	0.193	0.027
2015	33490	13408	29566	808.287	10034	0.78	0.217	0.032
2016	33453	13143	29530	806.486	13159	0.77	0.222	0.030
2017	32148	13377	28226	1172.020	9854	0.78	0.314	0.047
2018	32364	12433	28441	1035.710	18745	0.72	0.297	0.044
2019	32250	11658	28328	1004.750	7823	0.68	0.306	0.044
2020	32875	11183	28952	803.856	16198	0.65	0.262	0.038

Table 19: Data weightings applied to length and age compositions according to the 'Francis' method.

Type	Fleet	Francis
Length	commercial trawl	0.34
Length	commercial fixed-gear	0.28
Length	recreational Washington	0.13
Length	recreational Oregon	0.11
Length	recreational California	0.15
Length	Triennial Survey	0.10
Length	WCGBT Survey	0.08
Length	Lam research samples	0.17
Age	commercial trawl	0.08
Age	commercial fixed-gear	0.27
Age	recreational Washington	0.15
Age	recreational Oregon	0.10
Age	Triennial Survey	0.18
Age	WCGBT Survey	0.17
Age	Lam research samples	0.14

Table 20: Differences in likelihood, estimates of key parameters, and estimates of derived quantities between the base model and several alternative models related to biology and recruitment (columns). See main text for details on each sensitivity analysis. Red values indicate negative log likelihoods that were lower than that for the base model.

Label	Base	$M = 0.3$, $h = 0.7$	$M = 0.3$	$h = 0.7$	share M	$\sigma_R = 0.4$	$\sigma_R = 0.8$
Diff. in likelihood from base model							
Total	0	17.08	16.97	0.24	0.35	-4.65	7.57
Indices	0	8.07	7.97	0.04	0.8	-0.54	0.33
Length comp	0	17.46	17.7	-0.09	3.94	3.35	-1.39
Age comp	0	-11.84	-12.05	0.08	-4.26	0.62	0.04
Discard	0	2.62	2.71	-0.04	0.13	0.19	-0.1
Parm priors	0	0.38	0.08	0.41	-0.24	0.09	-0.02
Estimates of key parameters							
Recr Virgin millions	16.73	5.71	5.4	17.28	14.68	15.67	18.76
SR BH steep	0.8	0.7	0.76	0.7	0.8	0.77	0.82
M Female	0.42	0.3	0.3	0.42	0.41	0.42	0.42
M Male	0.41	0.3	0.3	0.41	0.41	0.41	0.41
Estimates of derived quantities							
SSB Virgin 1000 mt	17.16	15.33	14.49	17.72	16.41	16.13	19.14
SSB 2021 1000 mt	11.01	4.87	4.95	10.97	10.05	11.53	10.79
Fraction unfished 2021	0.64	0.32	0.34	0.62	0.61	0.71	0.56
Fishing intensity 2020	0.26	0.69	0.68	0.26	0.29	0.25	0.27
Retained Catch MSY mt	3937.89	1938.34	2001.74	3518.76	3569.9	3531.58	4497.53
Dead Catch MSY mt	4222.53	2012.76	2087.64	3720.17	3815.91	3765.71	4838.59
Virgin age 3+ bio 1000 mt	32.69	26.2	24.78	33.76	30.69	30.72	36.48
OFL mt 2021	5084.77	1488.13	1512.32	5065.4	4411.8	5320.54	4992.95

Table 21: Differences in likelihood, estimates of key parameters, and estimates of derived quantities between the base model and several alternative models related to composition data (columns). See main text for details on each sensitivity analysis. Red values indicate negative log likelihoods that were lower than that for the base model.

Label	Base	no fisheryages	combMF	no unsexed	DM
Diff. in likelihood from base model					
Total	0	-2828.04	7.93	-995.43	-344201.02
Indices	0	-1.44	0.01	-0.3	8.49
Length comp	0	-213.09	-2.54	-924.92	-385274.36
Age comp	0	-2614.89	10.25	-73.35	40963.2
Discard	0	-1.6	0.04	5.86	13.51
Parm priors	0	0.14	0.01	0.2	77.09
Estimates of key parameters					
Recr Virgin millions	16.73	11.84	17.27	24.82	9.14
SR BH steep	0.8	0.77	0.8	0.84	0.86
M Female	0.42	0.33	0.42	0.47	0.37
M Male	0.41	0.29	0.42	0.44	0.36
Estimates of derived quantities					
SSB Virgin 1000 mt	17.16	24.5	17.39	17.77	13.36
SSB 2021 1000 mt	11.01	17.62	11.32	10.63	6.78
Fraction unfished 2021	0.64	0.72	0.65	0.6	0.51
Fishing intensity 2020	0.26	0.22	0.25	0.22	0.44
Retained Catch MSY mt	3937.89	4323.34	4044.7	5503.93	2775.54
Dead Catch MSY mt	4222.53	4536.78	4340.94	5862.19	3009.08
Virgin age 3+ bio 1000 mt	32.69	46	33.28	37.02	24.96
OFL mt 2021	5084.77	6421.62	5297.6	6227.24	2699.85

Table 22: Differences in likelihood, estimates of key parameters, and estimates of derived quantities between the base model and several alternative models related to indices (columns). See main text for details on each sensitivity analysis. Red values indicate negative log likelihoods that were lower than that for the base model. The first sensitivity is an alternative recreational index. Other column names refer to index data that were taken out of the model.

Label	Base	ORCPFV	no fishery	no Comm-Trawl	no Comm-Fix	no RecWA	no RecOR	no RecCA	no SurvTRI	no SurvWCG-BTS
Diff. in likelihood from base model										
Total	0	40.81	126.39	13.89	14.73	46.07	36.81	15.79	4.45	22.05
Indices	0	41.43	135.87	14.05	14.98	52.1	37.44	15.85	3.98	22.3
Length comp	0	0.26	-5.22	-2.4	-0.05	-1.76	0.34	-0.99	0.82	-0.33
Age comp	0	-0.95	-4.59	2.69	-0.57	-3.66	-1.04	1.08	-0.66	0.24
Discard	0	0.01	-0.9	-0.34	0.46	-1.25	0	-0.08	0.18	-0.2
Parm priors	0	0.01	0.11	0.05	-0.01	0.04	0.01	0	0	0.01
Estimates of key parameters										
Recr Virgin millions	16.73	17.04	26.16	20.27	16.27	20.33	17.01	16.86	16.2	17.02
SR BH steep	0.8	0.8	0.79	0.81	0.8	0.79	0.8	0.8	0.8	0.8
M Female	0.42	0.42	0.44	0.43	0.42	0.42	0.42	0.42	0.42	0.42
M Male	0.41	0.42	0.43	0.43	0.41	0.42	0.42	0.41	0.41	0.42
Estimates of derived quantities										
SSB Virgin 1000 mt	17.16	17.26	23.09	18.83	16.98	19.89	17.25	17.26	16.91	17.29
SSB 2021 1000 mt	11.01	10.98	18.99	12.88	10.84	15.43	10.98	11.12	10.61	11.14
Fraction unfished 2021	0.64	0.64	0.82	0.68	0.64	0.78	0.64	0.64	0.63	0.64
Fishing intensity 2020	0.26	0.26	0.15	0.22	0.27	0.19	0.26	0.26	0.27	0.26
Retained Catch MSY mt	3937.89	3984.83	5585.83	4578.79	3858.17	4596.03	3979.02	3966.07	3834.3	3984.39
Dead Catch MSY mt	4222.53	4275.73	6013.98	4930.5	4133.77	4931.18	4269.09	4253.89	4106.87	4274.11
Virgin age 3+ bio 1000 mt	32.69	32.92	44.73	36.36	32.28	38.03	32.89	32.88	32.15	32.97
OFL mt 2021	5084.77	5081.31	9182.97	6252.38	4958.36	7140.19	5081.7	5141.97	4865.3	5167.25

Table 23: Differences in likelihood, estimates of key parameters, and estimates of derived quantities between the base model and several alternative models related to selectivity (columns). See main text for details on each sensitivity analysis. Red values indicate negative log likelihoods that were lower than that for the base model.

Label	Base	fem. sel. offset	fem. sel. offset, $M = 0.3$	sex sel. scale and descend fisheries
Diff. in likelihood from base model				
Total	0	-492.24	-492.18	-427.52
Indices	0	5.63	5.04	10.77
Length comp	0	-347.24	-346.57	-374.52
Age comp	0	-150.24	-150.1	-165.51
Discard	0	-1.14	-1.14	-2.8
Parm priors	0	-0.23	-0.23	103.91
Estimates of key parameters				
Recr Virgin millions	16.73	6.78	7.18	2.46
SR BH steep	0.8	0.79	0.8	0.92
M Female	0.42	0.29	0.3	0.15
M Male	0.41	0.47	0.48	0.27
Estimates of derived quantities				
SSB Virgin 1000 mt	17.16	19.08	19.22	36.51
SSB 2021 1000 mt	11.01	9.29	9.71	22.43
Fraction unfished 2021	0.64	0.49	0.51	0.61
Fishing intensity 2020	0.26	0.48	0.46	0.56
Retained Catch MSY mt	3937.89	2166.72	2244	1832.65
Dead Catch MSY mt	4222.53	2294.38	2380.99	1935.1
Virgin age 3+ bio 1000 mt	32.69	24.1	24.31	44.14
OFL mt 2021	5084.77	2265.5	2417.01	1716.08

Table 24: Parameter estimates of natural mortality, M, from the likelihood profile over M_{female} showing the correlation between the two parameters.

M_{female}	M_{male}
0.100	0.150
0.150	0.157
0.200	0.205
0.250	0.254
0.300	0.302
0.350	0.350
0.400	0.398
0.418	0.414
0.450	0.443
0.500	0.486

Table 25: The average relative bias of retrospective estimates (Mohn's rho; Mohn, 1999) given the removal of five years of data for fishing intensity (F), fraction unfished (Figure 119), recruitment, and spawning stock biomass (*SSB*; Figure 118). Columns are derivations of Mohn's rho used by the Alaska Fisheries Science Center (AFSC), suggested by Hurtado-Ferro et al. (2015), and used by the Northeast Fisheries Science Center (NEFSC).

Quantity	AFSC	Hurtado-Ferro	NEFSC
F	-0.2794828	-1.575257	-1.459318
Fraction unfished	0.05215519	0.3079804	0.2855171
Recruitment	1.609991	8.208597	9.167618
SSB	0.4338891	2.23666	2.200132

Table 26: Comparison of estimates of key parameters and derived quantities between the base model for north and south and the 2017 assessments for north and south. Note that the boundary between north and south differs between the current and 2017 assessments.

Label	North.base	South.base	North = .2017	South = .2017
Estimates of key parameters				
Recr Virgin millions	16.73	2.25	8.66	4.85
log(R0)	9.73	7.72	9.07	8.49
M Female	0.42	0.17	0.26	0.26
M Male	0.41	0.22	0.3	0.32
Estimates of derived quantities				
SSB Virgin 1000 mt	17.16	26.44	37.97	20.26
SSB 2021 1000 mt	11.01	10.41	25.19	6.85
SSB 2017 1000 mt	13.38	9.16	21.98	6.51
Fraction unfished 2017	0.78	0.35	0.58	0.32
Fraction unfished 2021	0.64	0.39	0.66	0.34
Fishing intensity 2016	0.22	0.63	0.25	0.61
Fishing intensity 2020	0.26	0.35	0.32	0.78
Retained Catch MSY mt	3937.89	834.05	3268.9	1828.24
Dead Catch MSY mt	4222.53	839.06	3408.94	1855.69
Virgin age 3+ bio 1000 mt	32.69	32.62	56	31.24
OFL mt 2021	5084.77	277.8	5476.51	1594.48

Table 27: Projections of potential overfishing limits (OFLs; mt), allowable biological catches (ABCs; mt), annual catch limits (ACLs; mt), estimated summary biomass (mt), spawning biomass (mt), and fraction unfished. Values are based on removals for the first two years. ABCs include a buffer for scientific uncertainty based on a P^* of 0.45 and the category 2 default sigma = 1.0. ACLs additionally include the 40:10 adjustment for projections which fall below the B_{40} reference point.

Year	Assumed Removal (mt)	Predicted OFL (mt)	ABC Catch (mt)	ACL Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Fraction Unfished
2021	1,200.00	-	-	-	22,609.40	11,010.20	0.64
2022	1,200.00	-	-	-	21,210.50	11,090.40	0.65
2023	-	5,009.58	4,378.38	4,378.38	21,713.70	10,721.60	0.62
2024	-	4,455.19	3,853.74	3,853.74	19,834.90	9,344.89	0.54
2025	-	4,236.98	3,631.09	3,631.09	19,014.60	8,725.91	0.51
2026	-	4,163.11	3,534.48	3,534.48	18,678.90	8,448.57	0.49
2027	-	4,139.97	3,481.71	3,481.71	18,503.70	8,320.40	0.48
2028	-	4,128.36	3,438.92	3,438.92	18,389.40	8,244.60	0.48
2029	-	4,119.63	3,402.82	3,402.82	18,312.30	8,195.34	0.48
2030	-	4,113.85	3,365.13	3,365.13	18,266.10	8,165.81	0.48
2031	-	4,113.46	3,331.91	3,331.91	18,251.90	8,156.13	0.48
2032	-	4,118.34	3,307.03	3,307.03	18,263.50	8,162.47	0.48

Table 28: Decision table with 10-year projections based on two years of recent average catch, alternative states of nature (columns), and management assumptions (rows) annual catch limits (ACLs) defined using an estimate of uncertainty (i.e., P^*) of 0.40 and 0.45. Colors of catch and fraction unfished are relative with lighter colors representing lower values. Italics indicate years were the full catch could not be removed from the low state of nature because of insufficient biomass.

			Low (sex-selectivity)		Base		High (no fishery ages)	
Assumption	Year	Catch	SSB (mt)	Frac. unfished	SSB (mt)	Frac. unfished	SSB (mt)	Frac. unfished
Recent avg. catch	2021	1200	22435	0.614	11010	0.642	17623	0.719
	2022	1200	22194	0.608	11090	0.646	18276	0.746
	2023	1200	21710	0.595	10722	0.625	17921	0.731
	2024	1200	21378	0.586	10967	0.639	18031	0.736
	2025	1200	21145	0.579	11415	0.665	18325	0.748
	2026	1200	20980	0.575	11879	0.692	18656	0.761
	2027	1200	20871	0.572	12299	0.717	18975	0.774
	2028	1200	20809	0.570	12657	0.738	19264	0.786
	2029	1200	20786	0.569	12955	0.755	19515	0.797
	2030	1200	20789	0.569	13199	0.769	19729	0.805
	2031	1200	20817	0.570	13396	0.781	19908	0.813
	2032	1200	20858	0.571	13554	0.790	20057	0.819
ACL P^*=0.40	2021	1200	22435	0.614	11010	0.642	17623	0.719
	2022	1200	22194	0.608	11090	0.646	18276	0.746
	2023	3817	21710	0.595	10722	0.625	17921	0.731
	2024	3418	19403	0.531	9628	0.561	16608	0.678
	2025	3246	17270	0.473	9175	0.535	15882	0.648
	2026	3165	15256	0.418	9005	0.525	15454	0.631
	2027	3117	13339	0.365	8957	0.522	15194	0.620
	2028	3073	11512	0.315	8950	0.522	15024	0.613
	2029	3028	9780	0.268	8963	0.522	14913	0.609
	2030	2984	8141	0.223	8993	0.524	14846	0.606
	2031	2942	6597	0.181	9038	0.527	14813	0.605
	2032	2905	5143	0.141	9096	0.530	14809	0.604
ACL P^*=0.45	2021	1200	22435	0.614	11010	0.642	17623	0.719
	2022	1200	22194	0.608	11090	0.646	18276	0.746
	2023	4378	21710	0.595	10722	0.625	17921	0.731
	2024	3854	18967	0.519	9345	0.545	16305	0.665
	2025	3631	16435	0.450	8726	0.509	15386	0.628
	2026	3534	14047	0.385	8449	0.492	14825	0.605
	2027	3482	11768	0.322	8320	0.485	14464	0.590
	2028	3439	9587	0.263	8245	0.480	14209	0.580
	2029	3403	7509	0.206	8195	0.478	14024	0.572
	2030	3365	*5541*	*0.152*	8166	0.476	13887	0.567
	2031	3332	*3805*	*0.104*	8156	0.475	13790	0.563
	2032	3307	*2392*	*0.066*	8162	0.476	13723	0.560

7 Figures

Many more figures are available for the base model than what are included in this document. For easy viewing in your web browser please feel free to view them on the web at iantaylor-noaa.gthub.io/Lingcod_2021.

7.1 Data figures

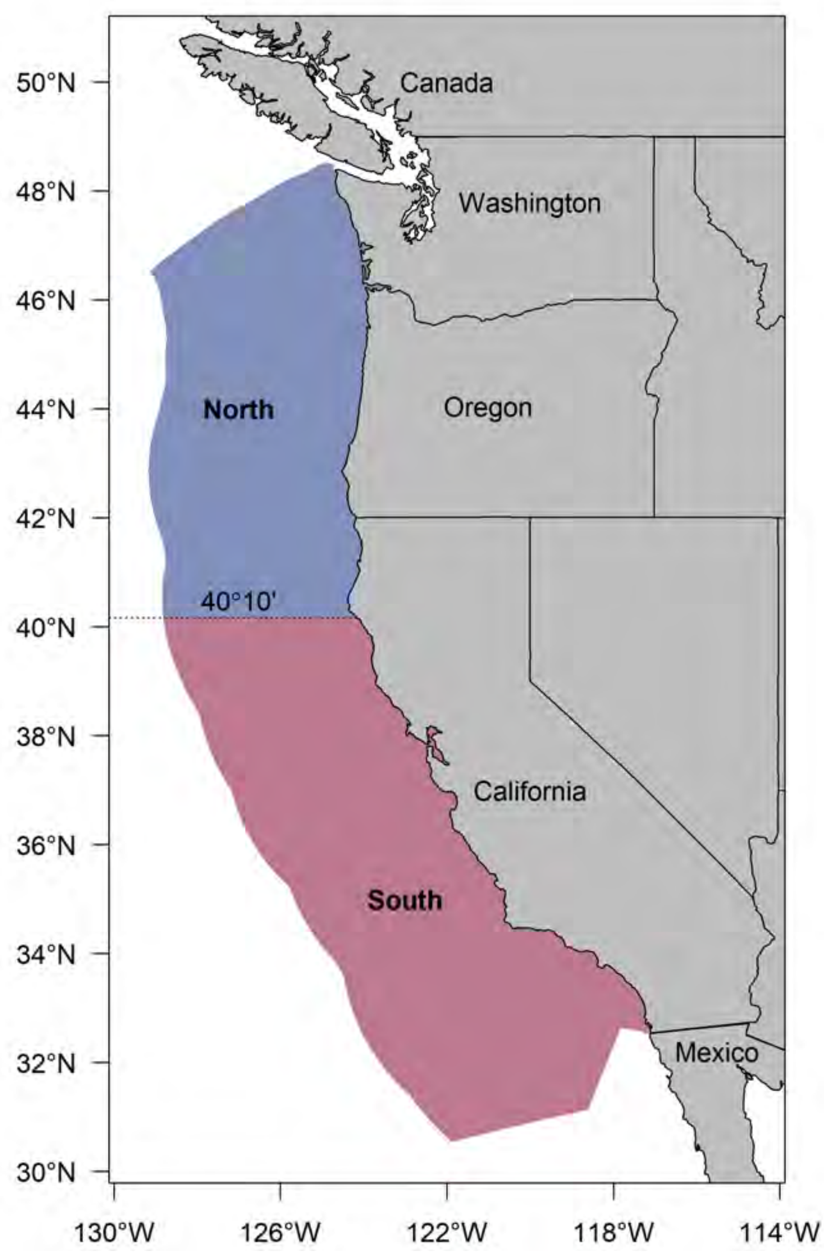


Figure 1: Map of the U.S. west coast and the area included in this assessment (blue). The dashed line at 40°10'N and colors delineate the northern (blue) from the southern (red) assessed area.

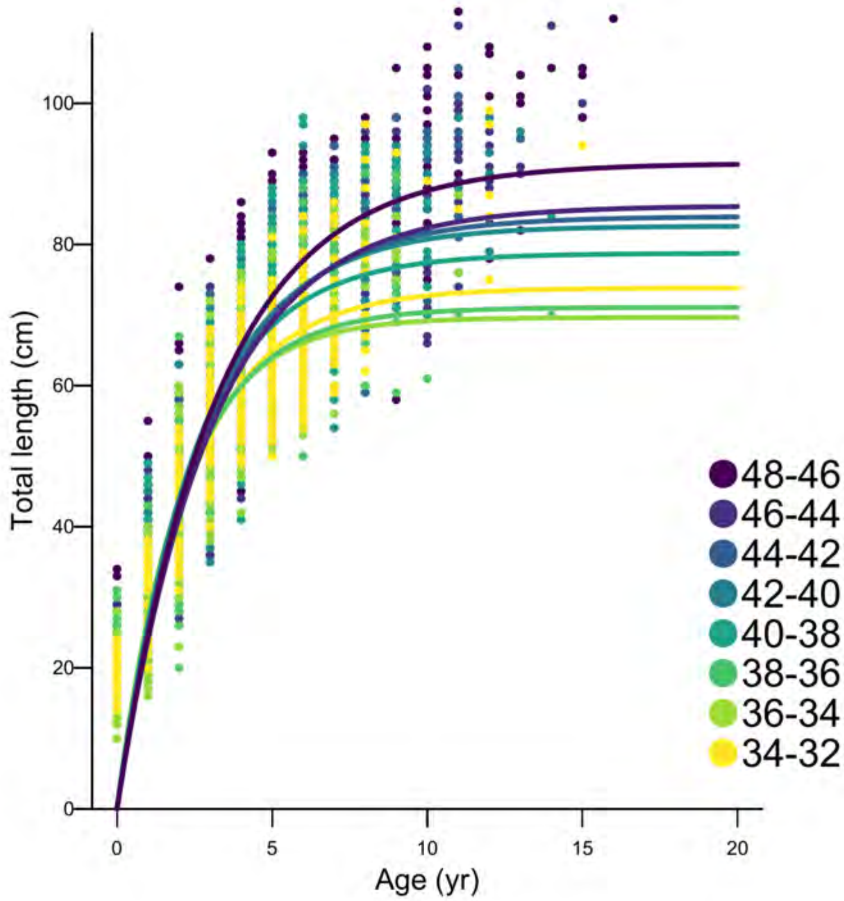


Figure 2: Length (cm) versus age (yr) and associated von Bertalanffy growth curves (lines) by latitude (colors). Models were fit to data from Lam research samples and NWFSC West Coast Groundfish Bottom Trawl Survey data.

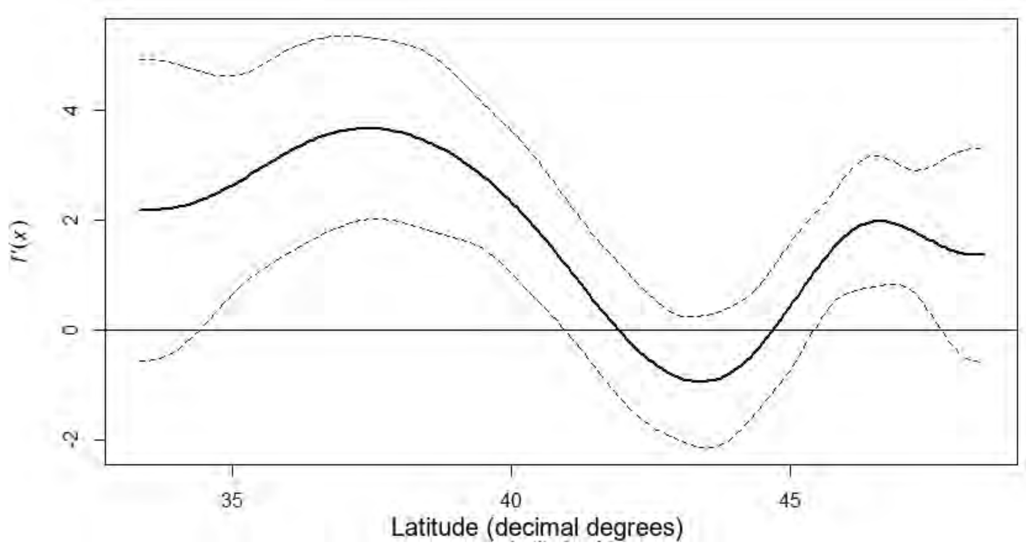


Figure 3: Estimated smoother of latitude (decimal degrees) for age-7 female fish when fitting length-at-age data.

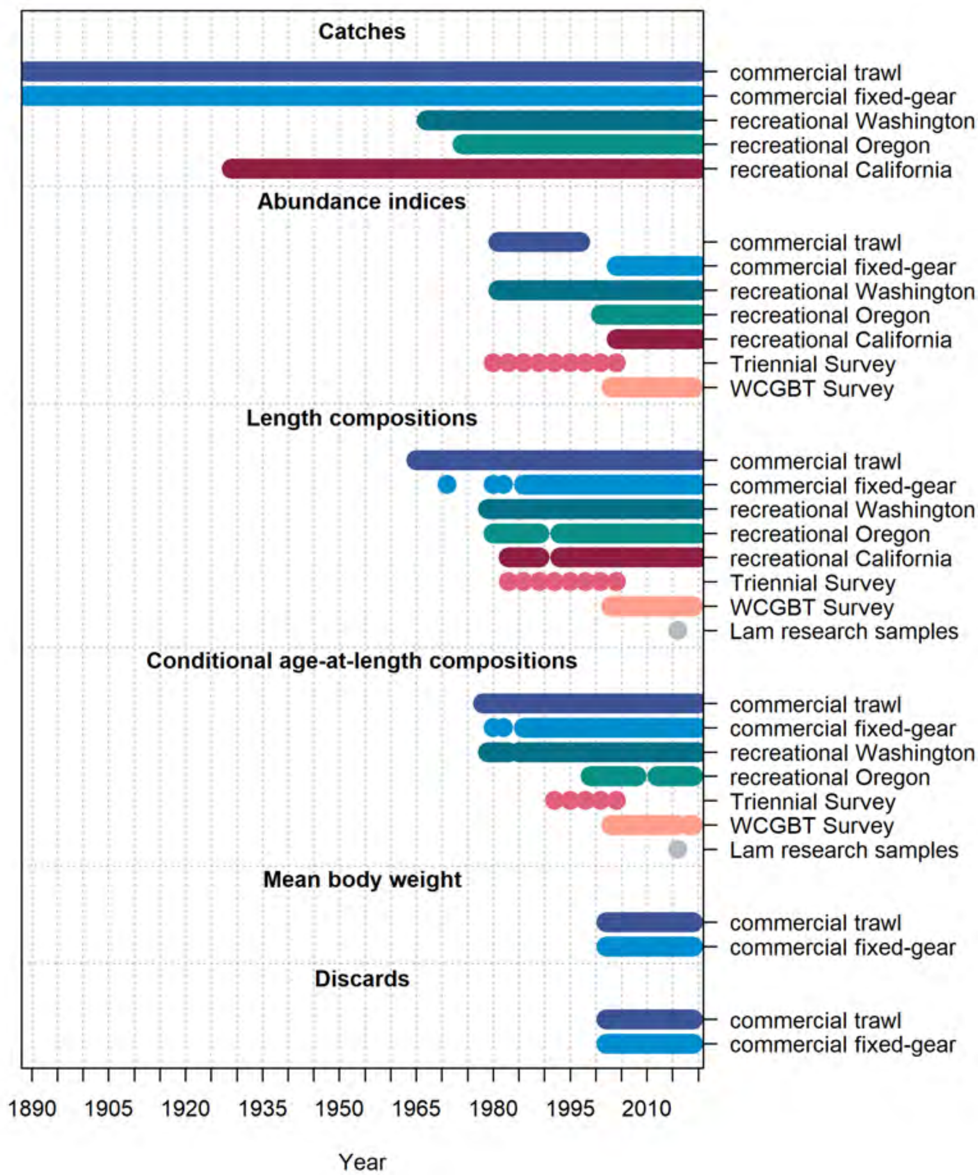


Figure 4: Data presence by year for each fleet and data type.

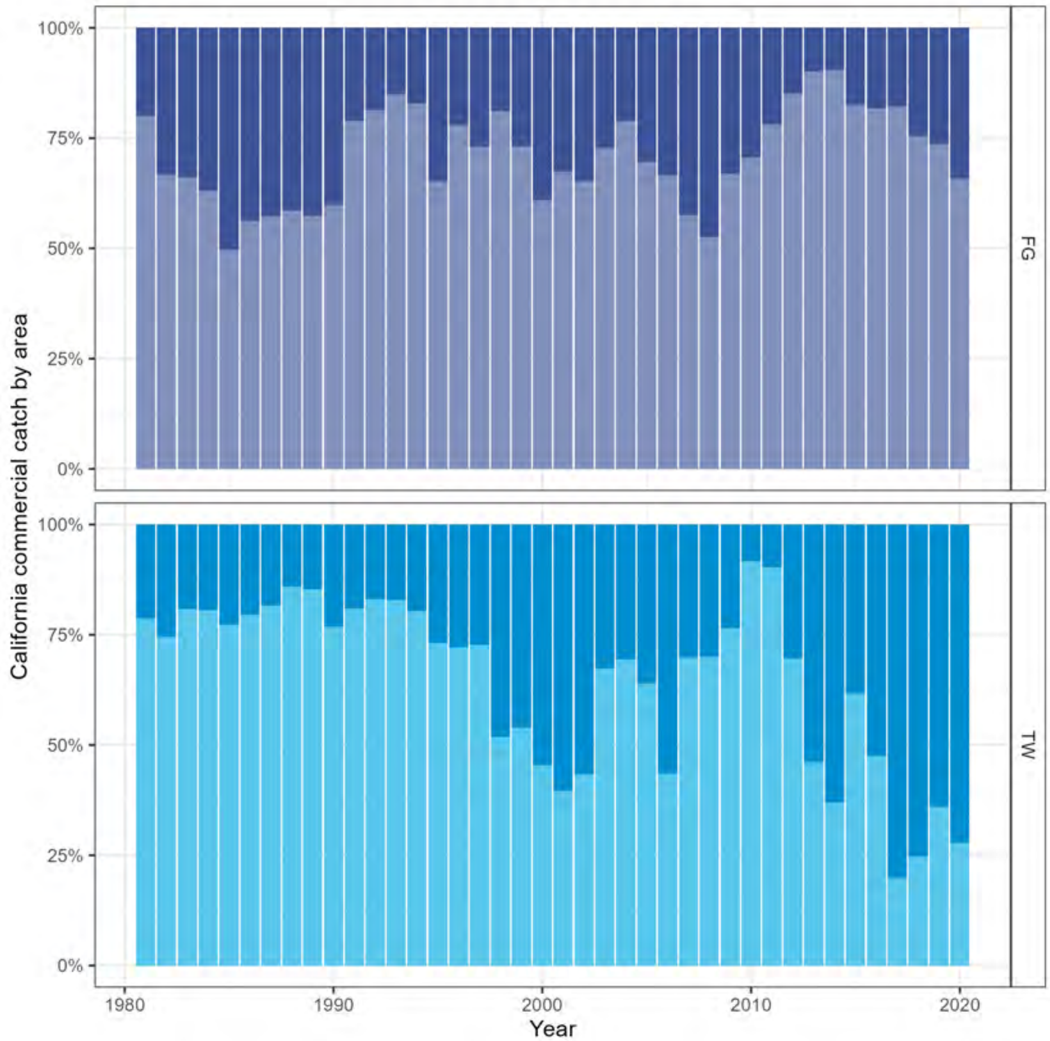


Figure 5: Percentage of California commercial catch by area within each fleet (fixed gear, FG, upper panel; trawl, TW, lower panel) since 1981. Darker shades represent the northern area and lighter shades represent the southern area.

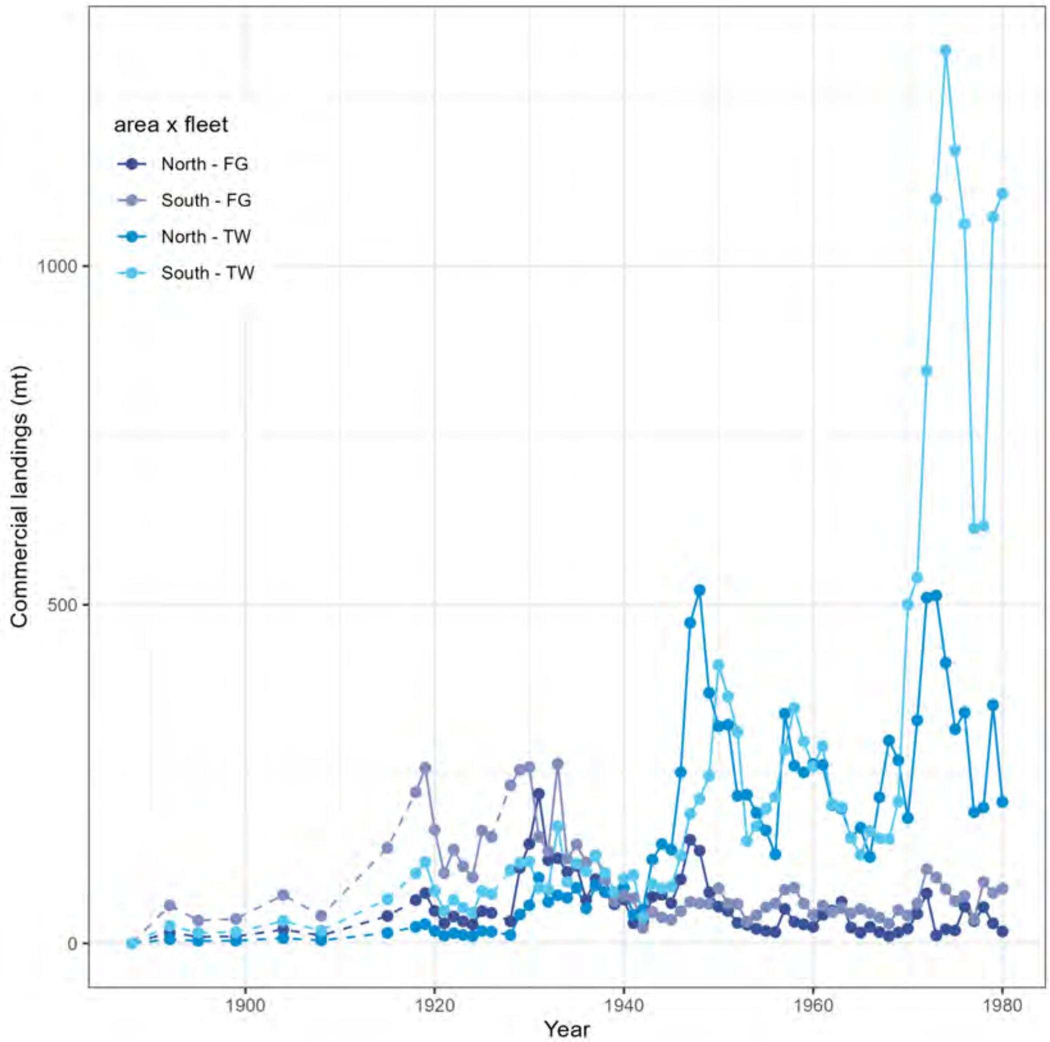


Figure 6: Reconstructed commercial landings for the state of California by fleet (fixed gear, FG, circles; trawl gear, TW, triangles) and area (northern region, blue; southern region, red). Dashed line indicates data were interpolated across years.

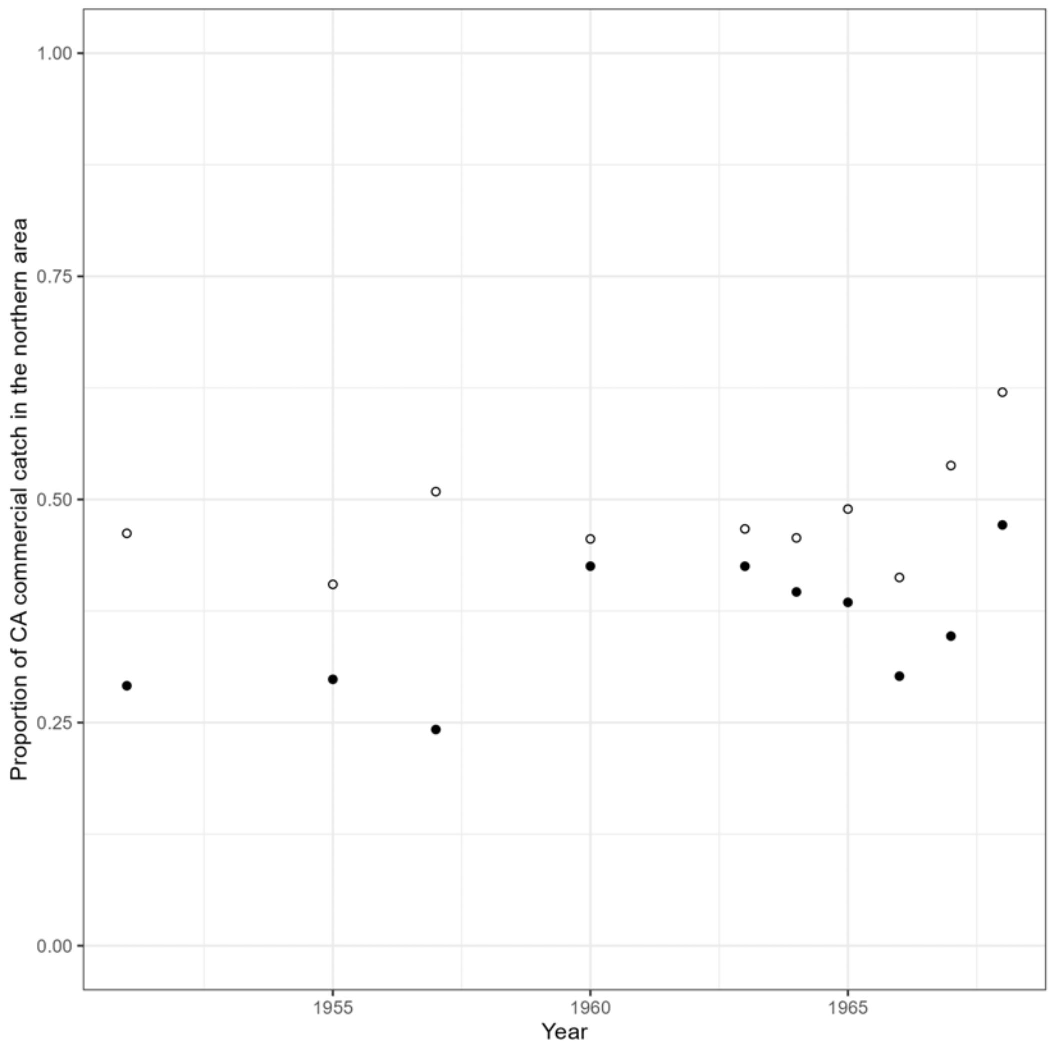


Figure 7: Yearly proportion of California (CA) commercial catch landed in the the northern region (i.e., north of forty degrees ten minutes latitude) of all CA commercial catches from two data sources, the Raltson et al. (2010) catch reconstruction effort (open circles) and fish ticket data in CALCOM, the database used by the California Cooperative Groundfish Survey to store and manage commercial market sample data, (filled circles).

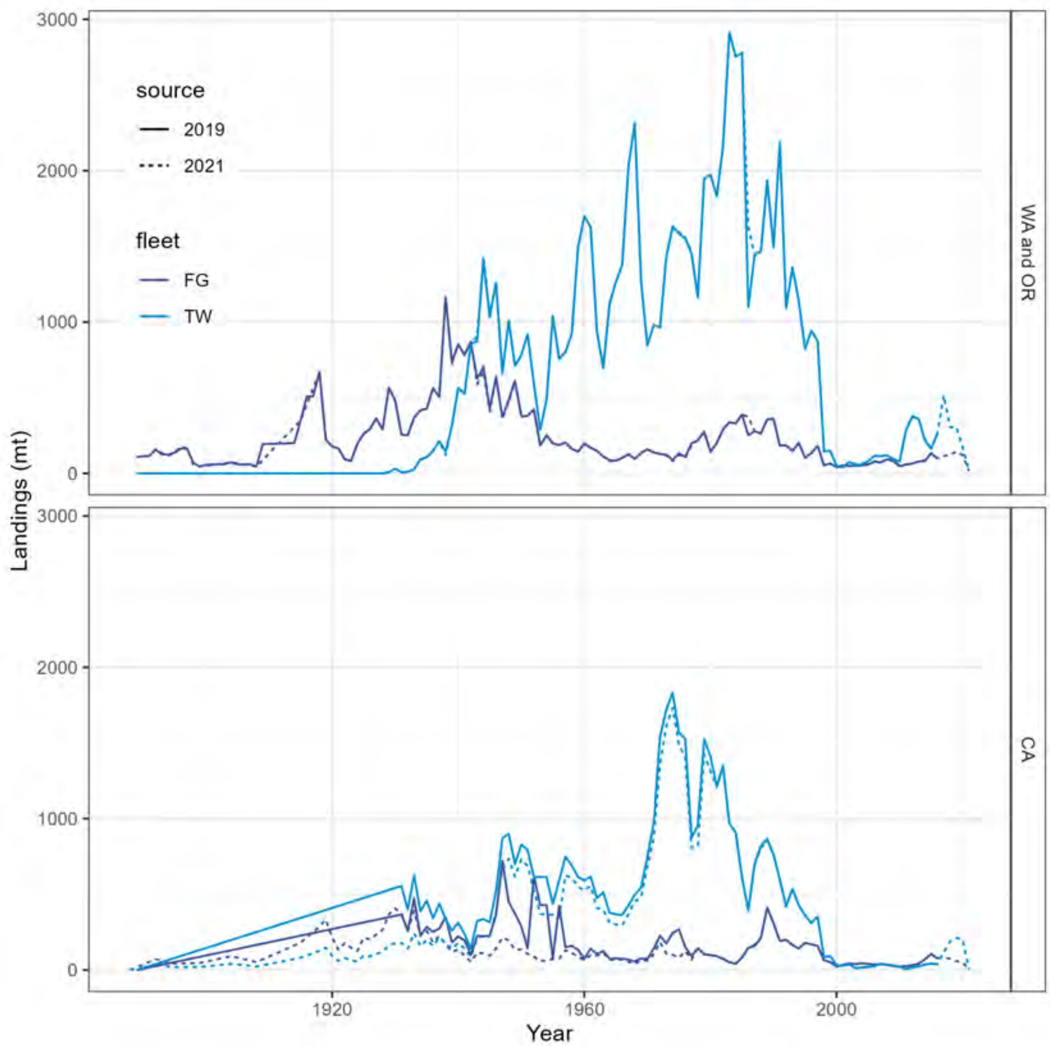


Figure 8: Comparison of current landings (dashed line) and those used in the previous assessment model (solid line) by state (panel). Fixed gear (FG; dark blue) and trawl (TW; light blue) landings are shown for Washington and Oregon (top panel) and California (bottom panel) because the previous assessment model used the Oregon-California border to define the stocks.

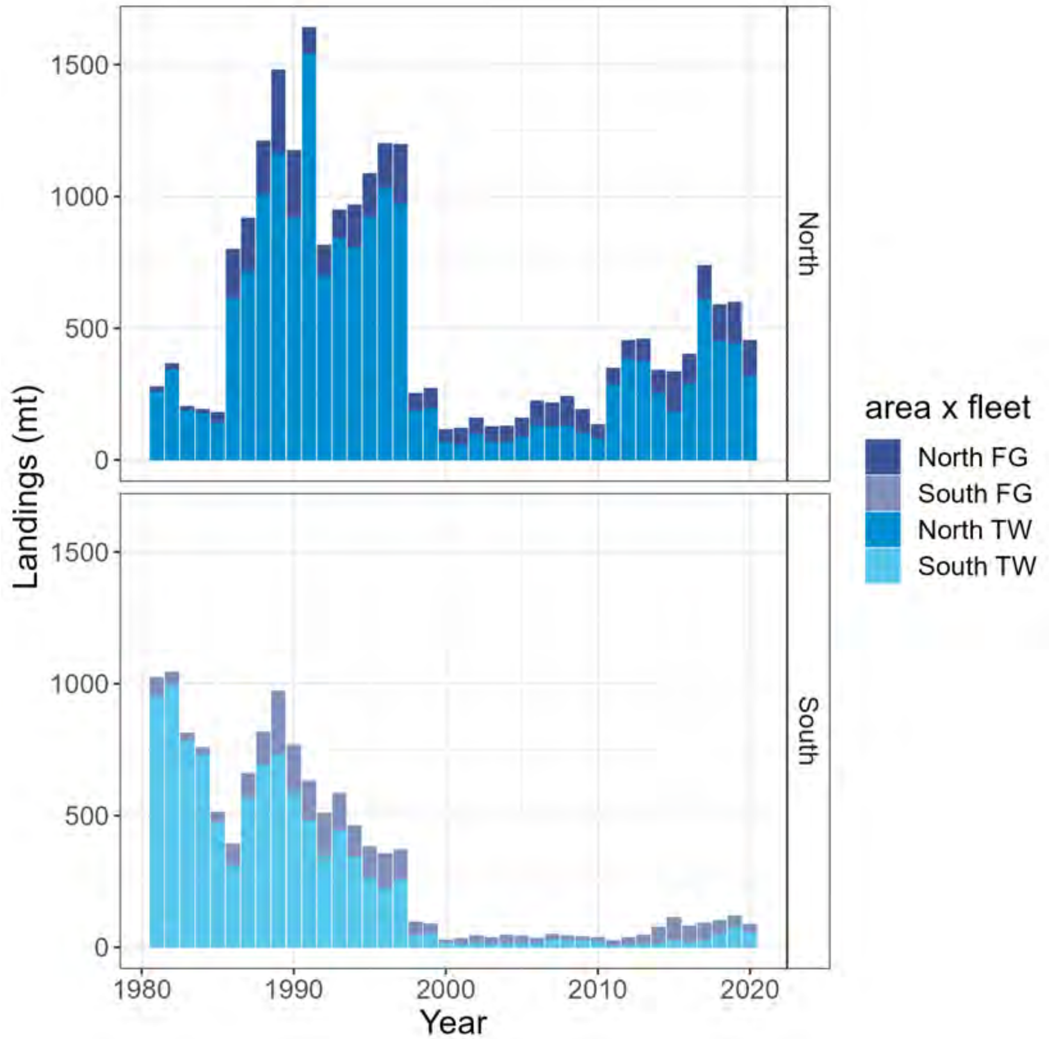


Figure 9: Yearly commercial landings (mt) from the PacFIN database since 1981 by area (panel and color) and fleet (shading). Trawl gear (TW) includes all trawl, nets, and dredging. Fixed gear (FG) includes all other gear types.

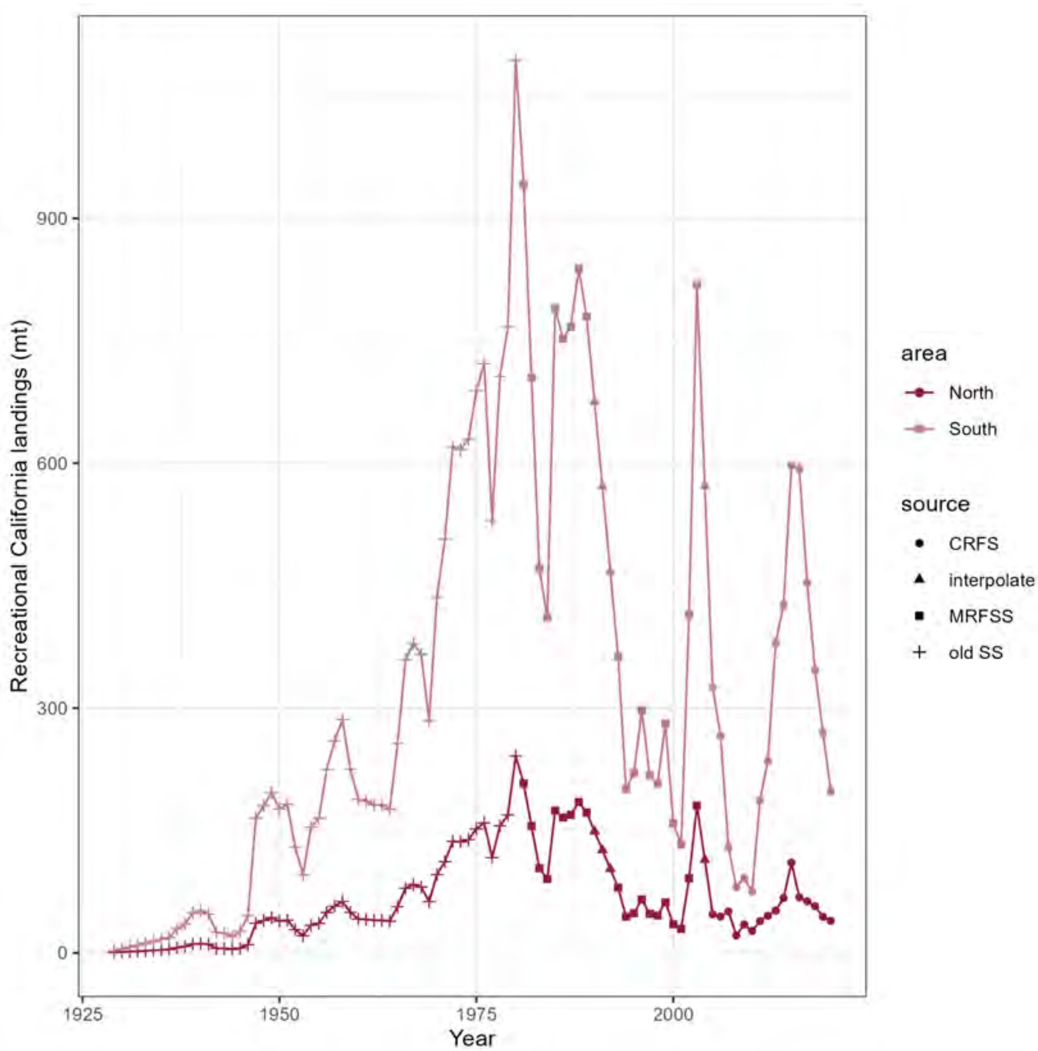


Figure 10: Time series of California recreational landings (mt) for the northern (darker color) and southern (lighter color) areas. The shape of the points indicates the information source (California Recreational Fisheries Survey, CRFS; linear interpolation, interpolate; Marine Recreational Fisheries Statistics Survey, MRFSS; old Stock Synthesis, SS, model).

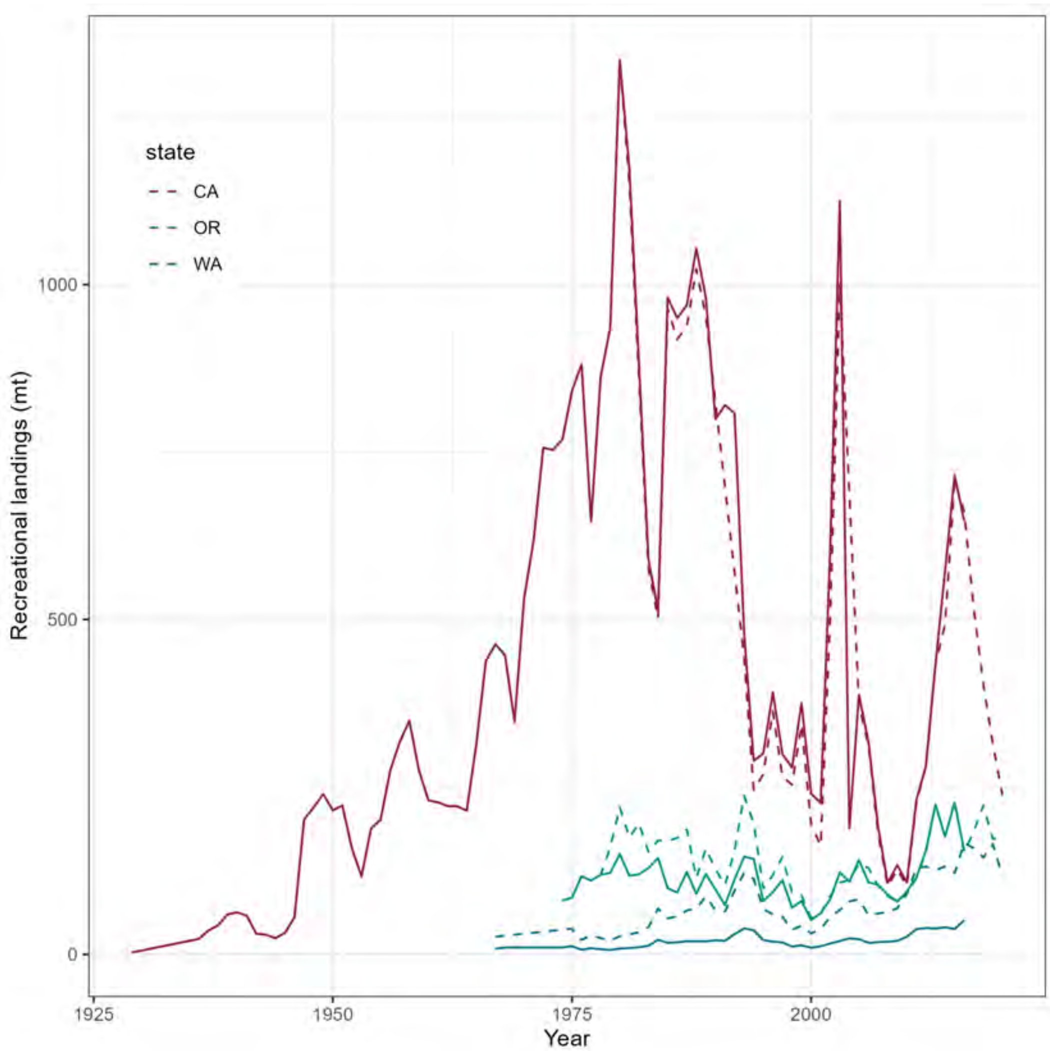


Figure 11: Comparison of recreational landings from this assessment (dashed line) versus the previous assessment (solid line) for each state (colors). The previous assessment used numbers for WA recreational landings, whereas this assessment used weight.

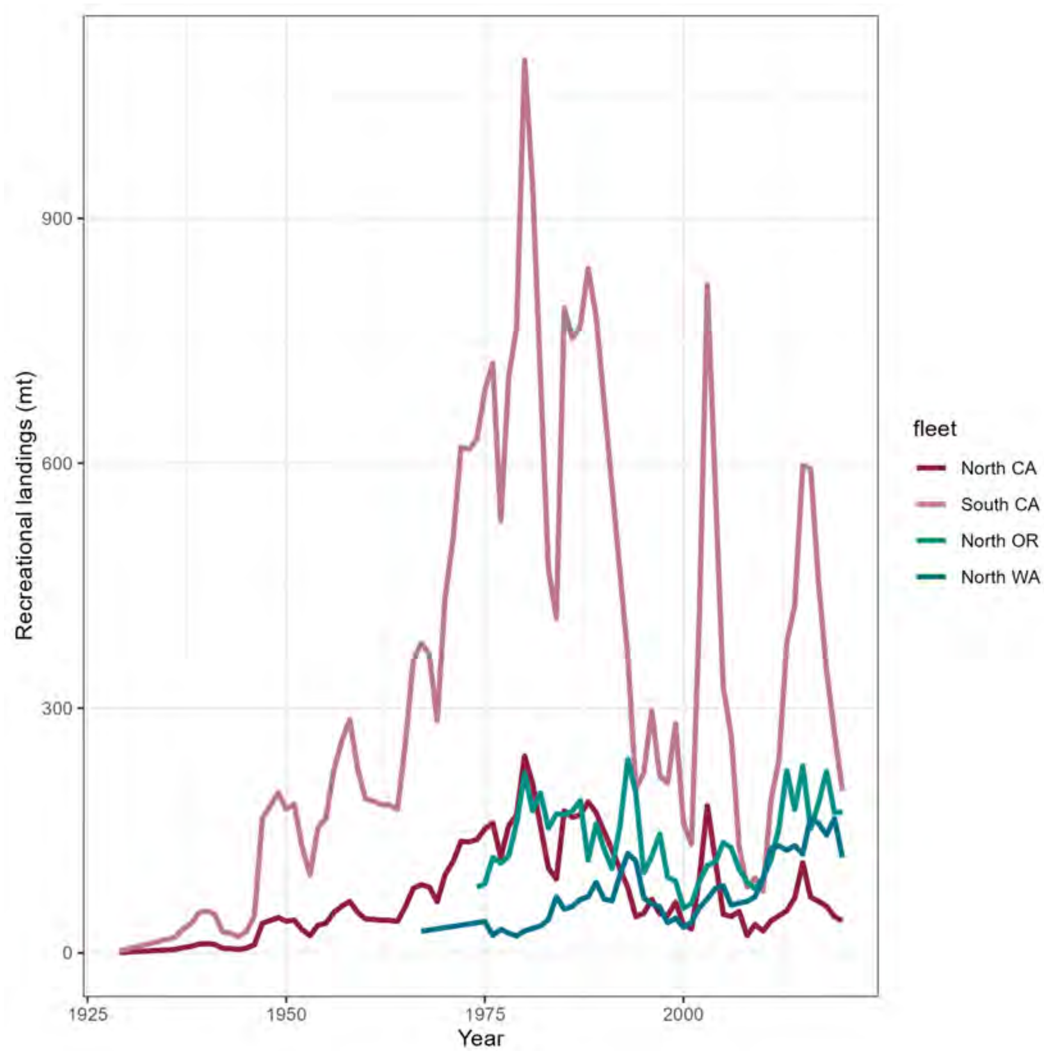


Figure 12: Time series of recreational landings by state and area.

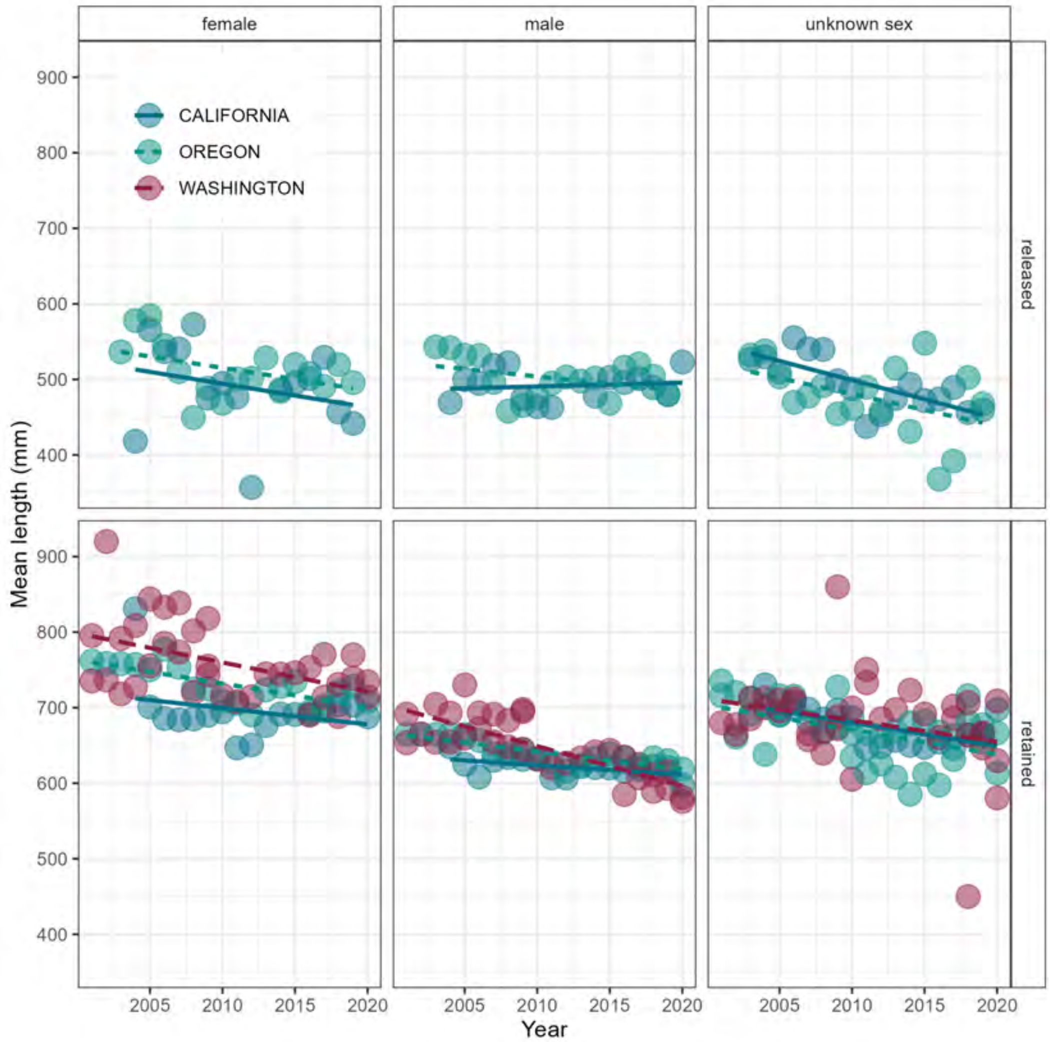


Figure 13: Mean length (mm) of released (top panel) and retained (bottom panel) fish from the recreational fishery for Washington (long dashes), Oregon (short dashes), and California (solid line) by sex (columns). The average length of retained fish across all years was used to translate numbers to weight for Washington.

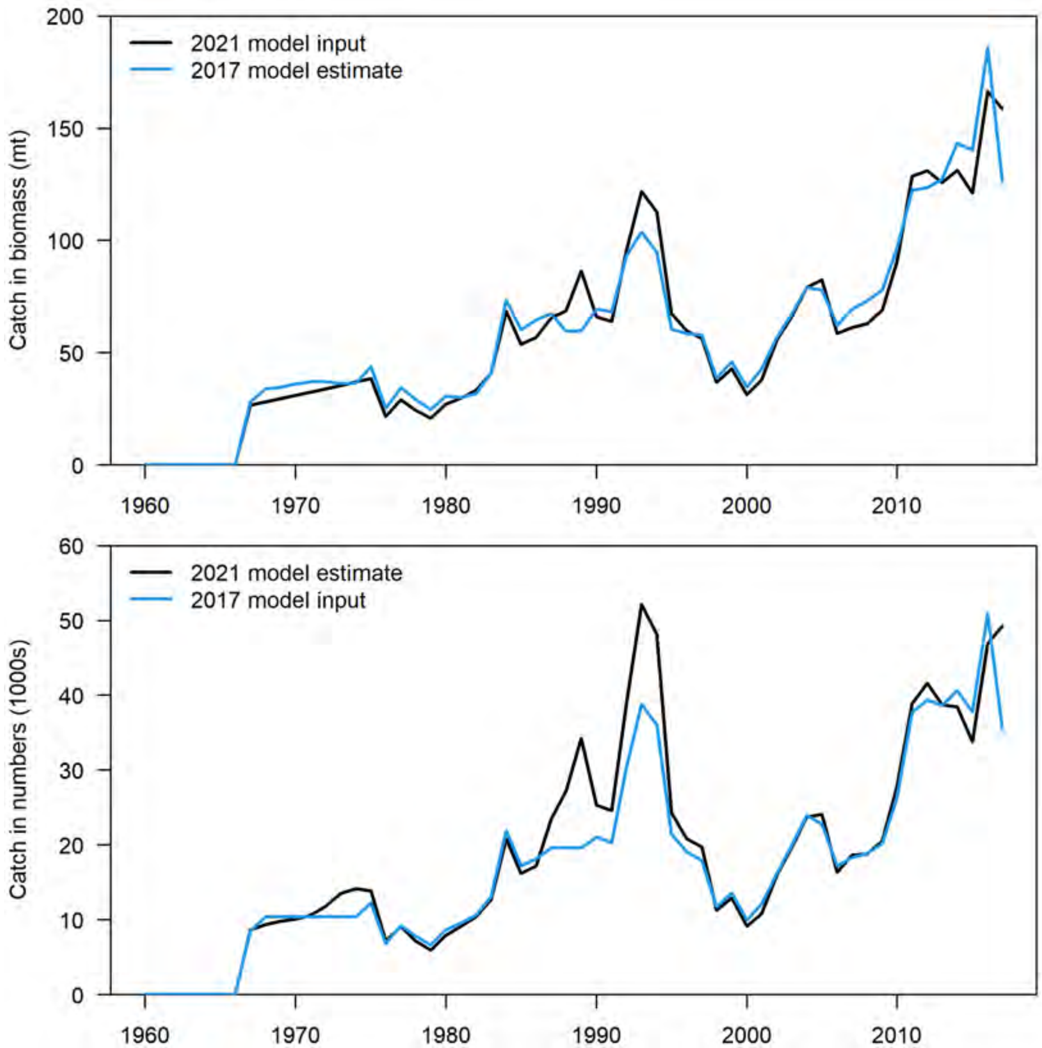


Figure 14: Comparison of catch in biomass (top) and numbers (bottom) for the Washington recreational fishery between the 2017 assessment, where catch was input in numbers, and the current assessment, where catch was converted from numbers to biomass outside the model. The 'estimate' lines in each panel respresent the results of internal calculation on the final base model based on the input values and the internally estimated values for growth, selectivity, and age composition in each year.

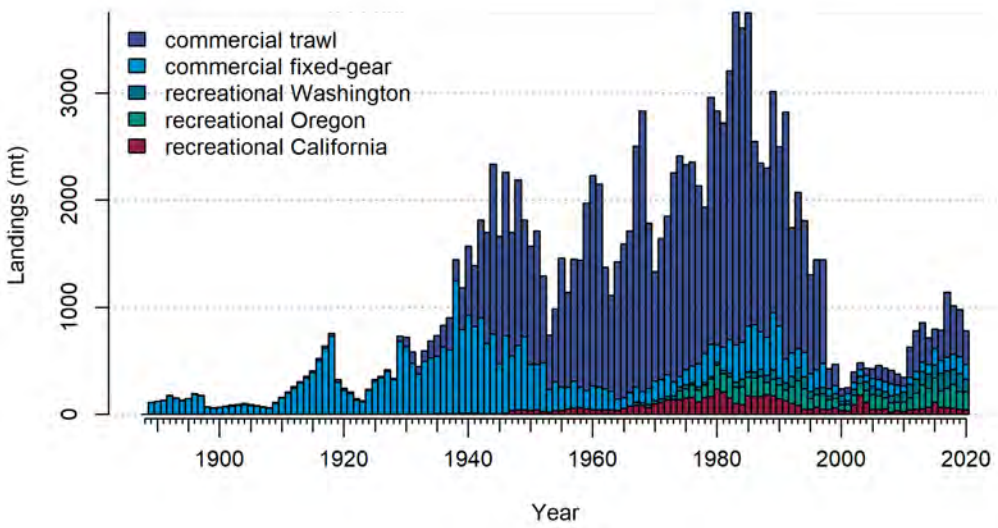


Figure 15: Landings (mt) by fleet used in the base model.

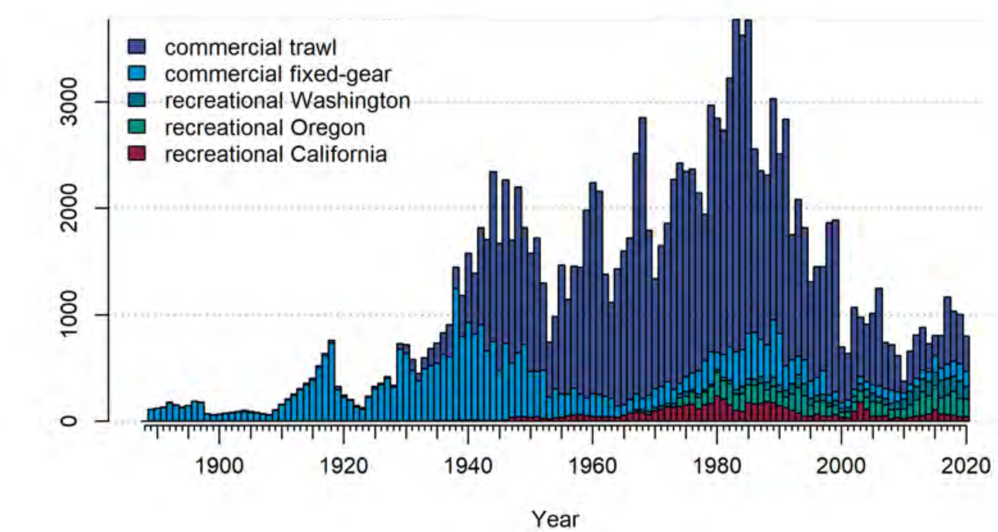


Figure 16: Landings plus dead discards (mt) by fleet as estimated in the base model.

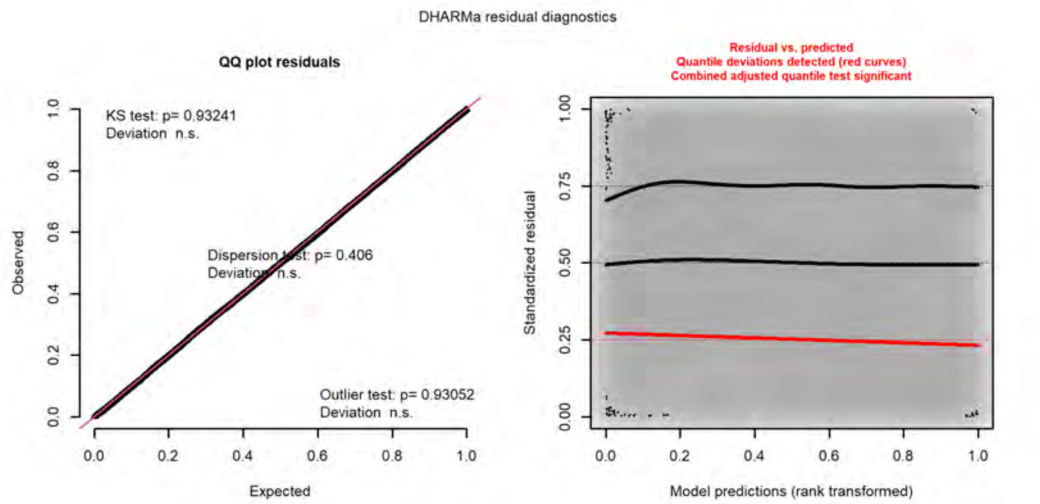


Figure 17: Scaled quantile-quantile plot (left) and rank-transformed versus standardized residuals (right) for the binomial model of the commercial fixed-gear index.

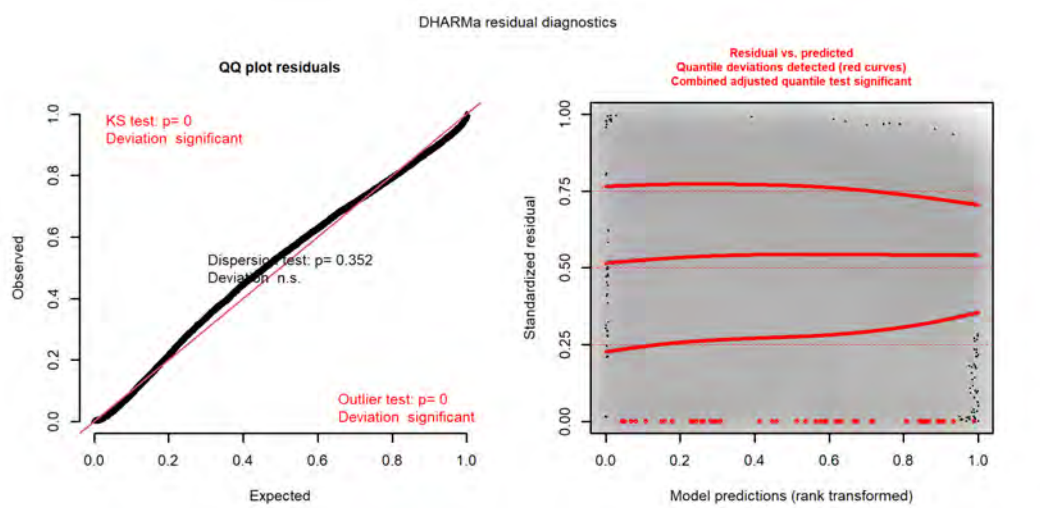


Figure 18: Scaled quantile-quantile plot (left) and rank-transformed versus standardized residuals (right) for the positive model of the commercial fixed-gear index.

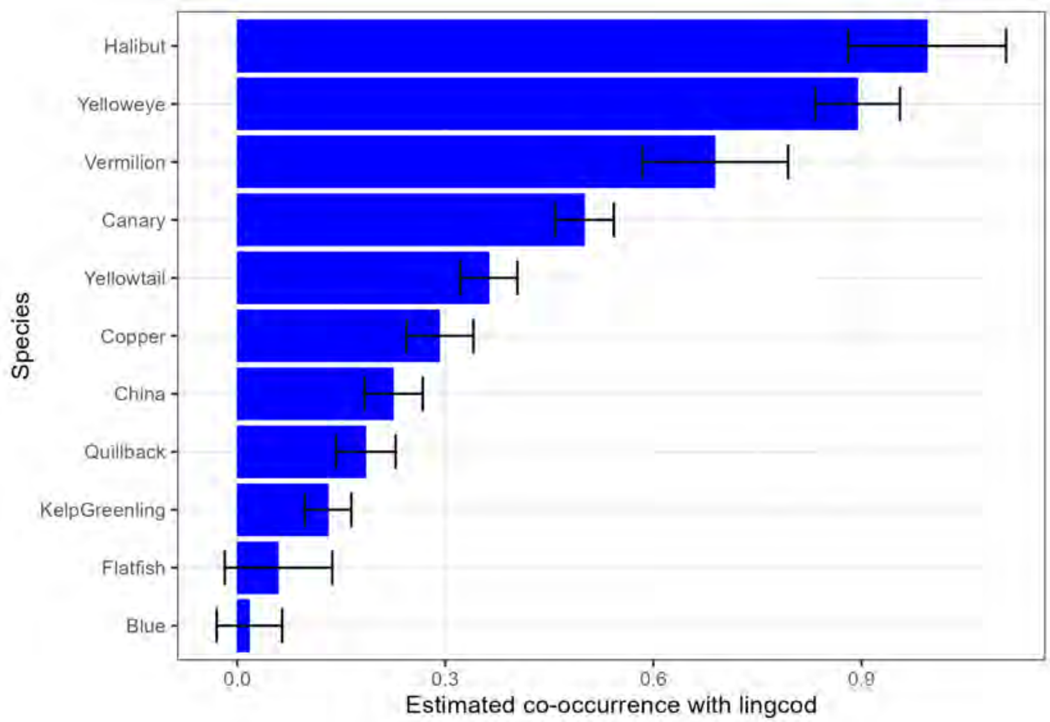


Figure 19: Estimates of species coefficients (blue bars) from the binomial generalized linear model (GLM) for presence/absence of lingcod in the Washington recreational dockside interview data. Horizontal black bars represent the 95% confidence intervals.

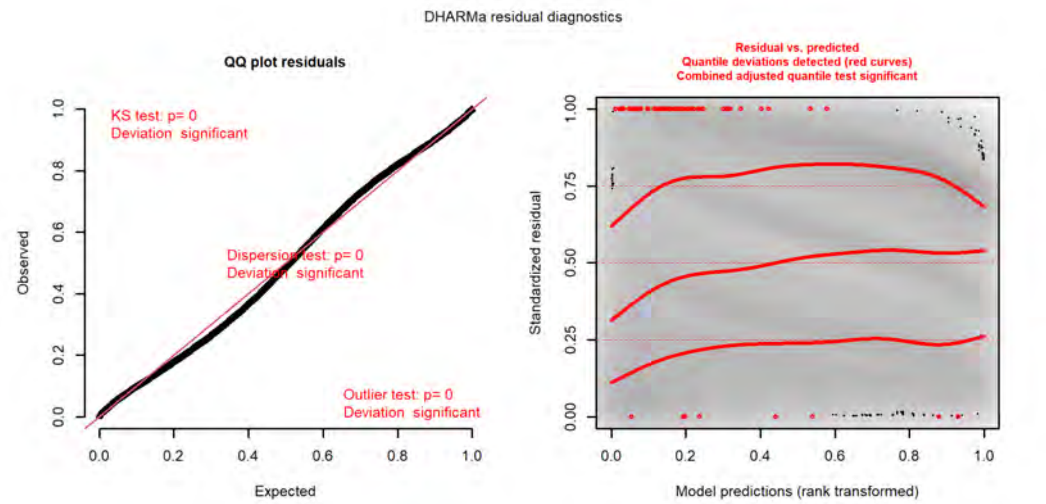


Figure 20: Scaled quantile-quantile (QQ) plot (left panel) and rank-transformed versus standardized residuals (right panel) for the binomial model of the Washington recreational index.

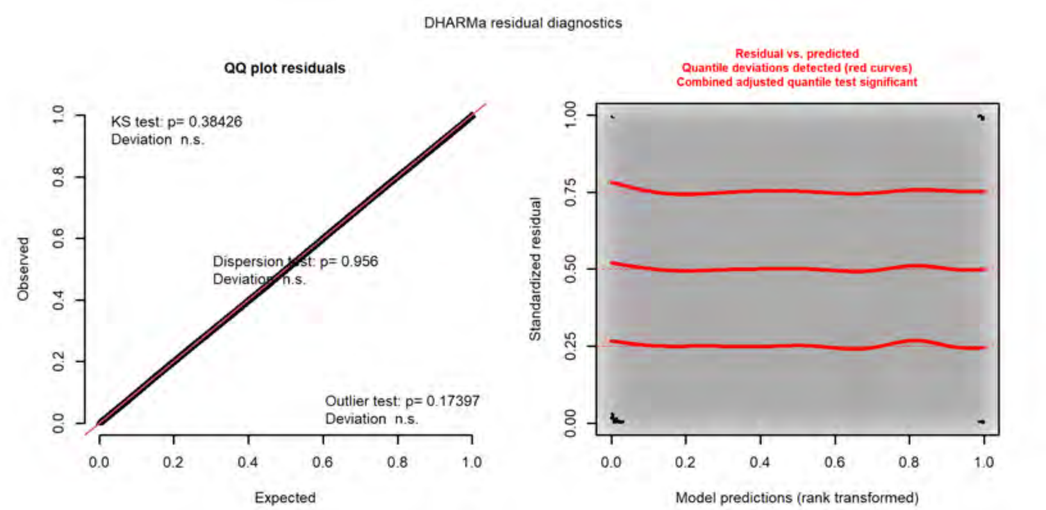


Figure 21: Scaled quantile-quantile (QQ) plot (left panel) and rank-transformed versus standardized residuals (right panel) for the positive model of the Washington recreational index.

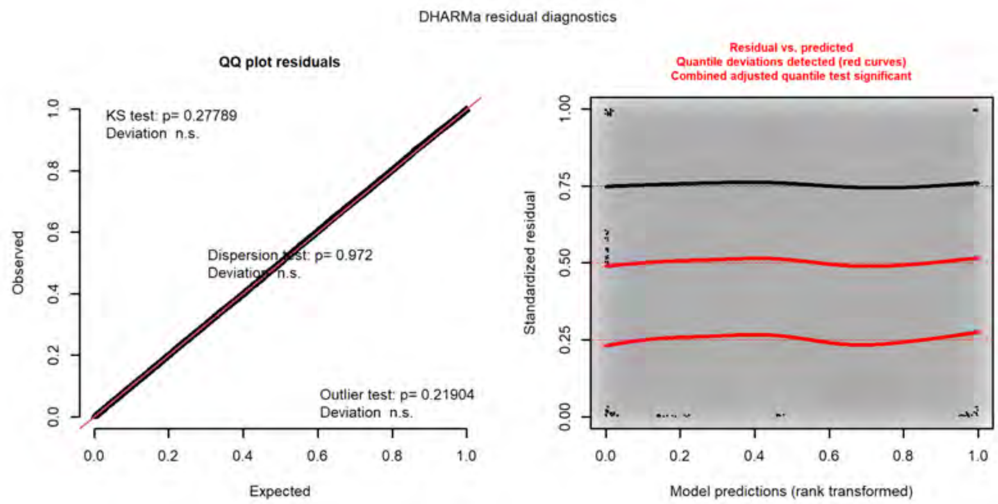


Figure 22: Scaled quantile-quantile plot (left) and rank-transformed versus standardized residuals (right) for the binomial model of the recreational Oregon index.

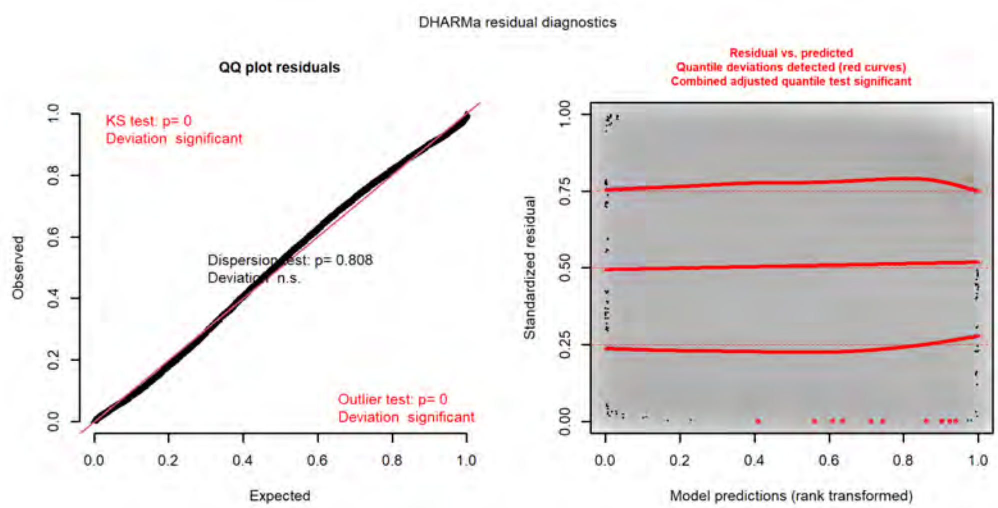


Figure 23: Scaled quantile-quantile plot (left) and rank-transformed versus standardized residuals (right) for the positive model of the recreational Oregon index.

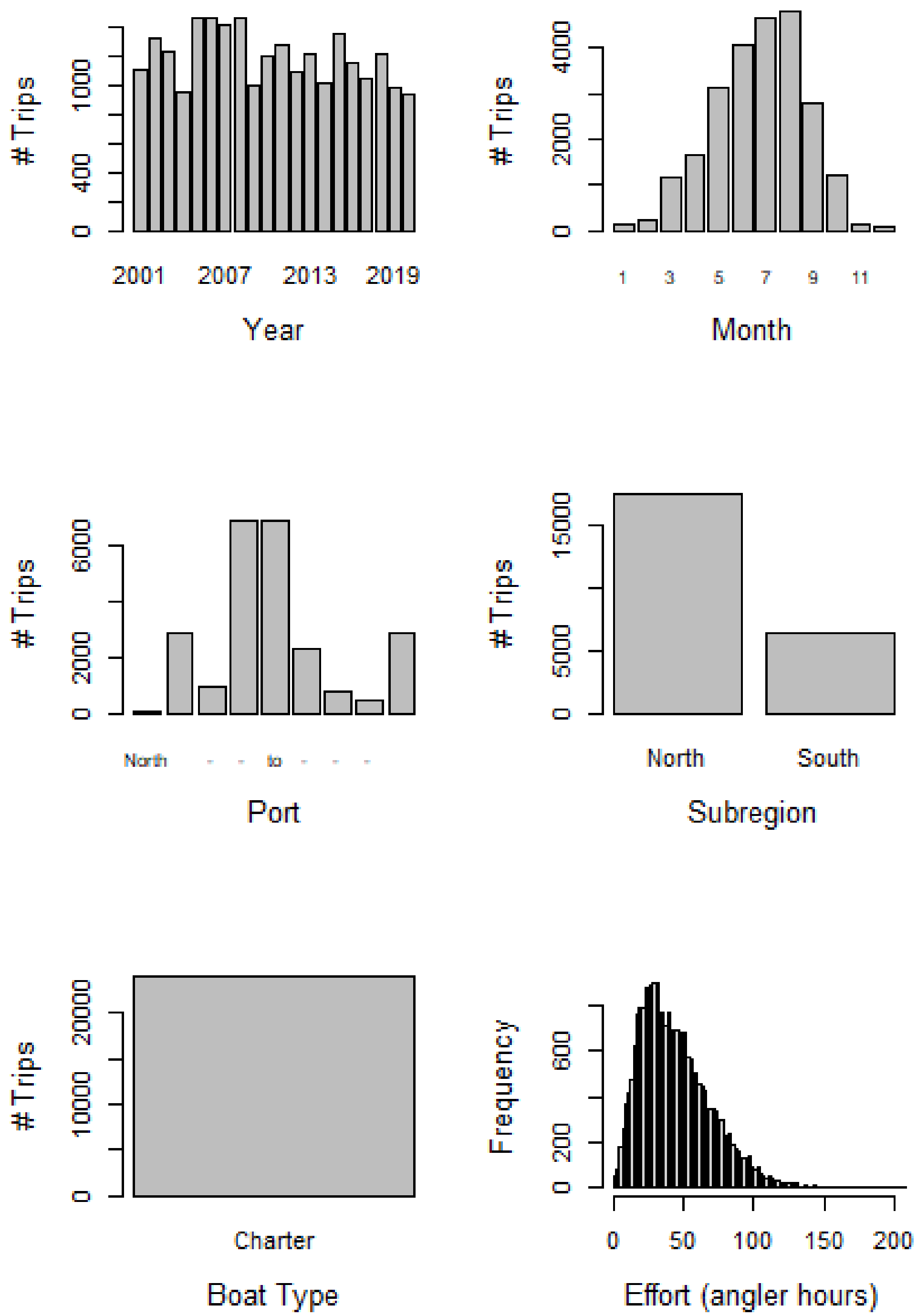


Figure 24: Number of trips versus year, month, port, subregion, boat type, and effort (angler hours) from Ocean Recreational Boat Survey, ODFW data that was used to estimate catch per unit effort for the Oregon recreational fleet.

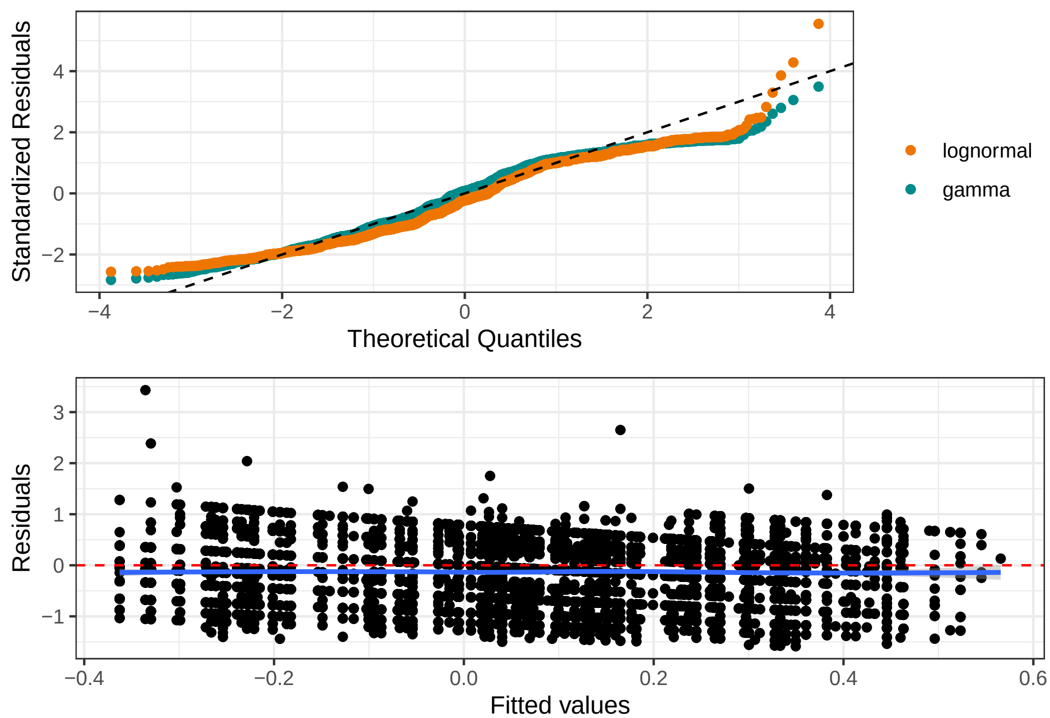


Figure 25: Quantile-quantile plot (top panel) of the positive observations for both lognormal and gamma distributions and fitted values vs residuals for the Gamma model (bottom panel) for the California Recreational Fisheries Survey private rental dockside index representing the California recreational fleet.

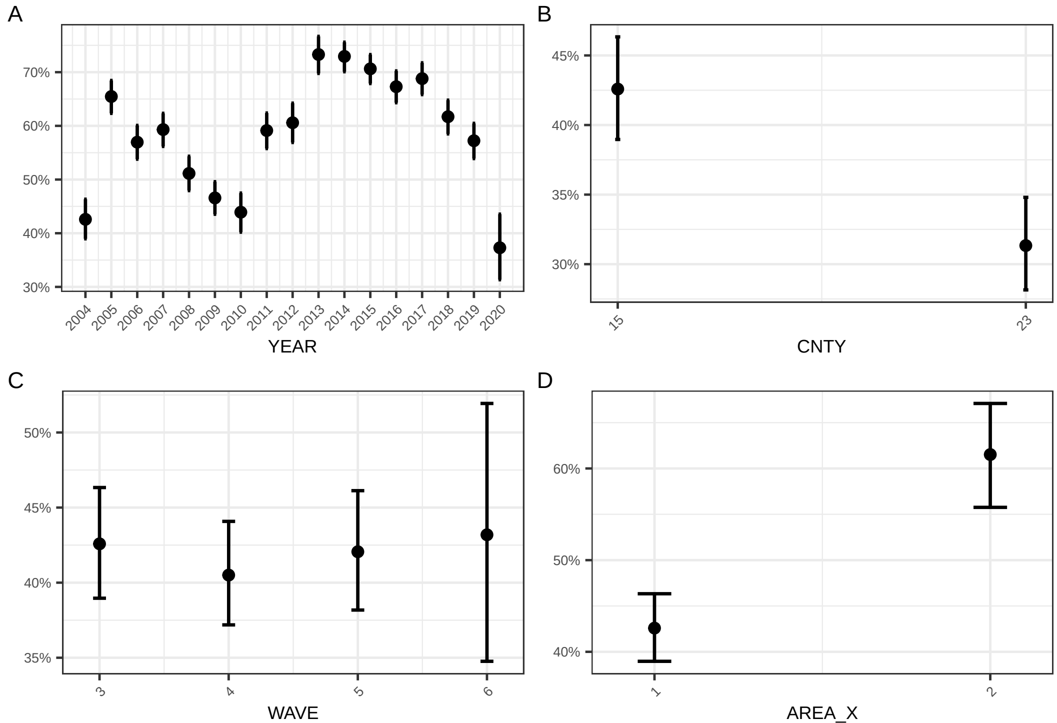


Figure 26: Binomial marginal effects from the final model of California Recreational Fisheries Survey private rental dockside data representing the California recreational fleet.

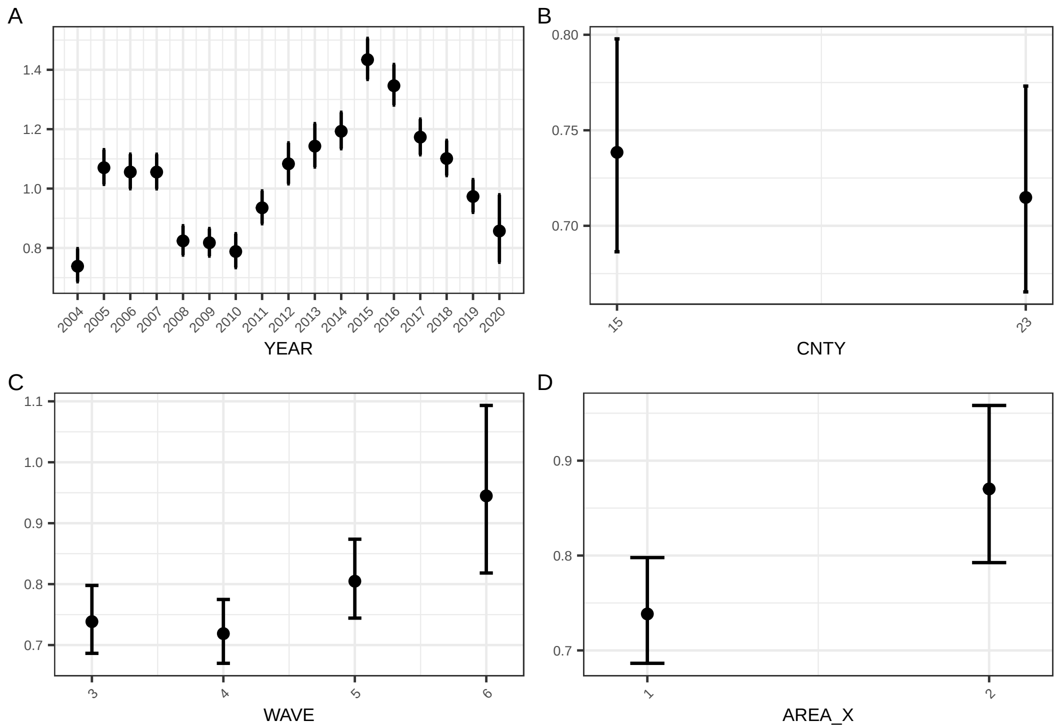


Figure 27: Positive model marginal effects from the final model of California Recreational Fisheries Survey private rental dockside data representing the California recreational fleet.

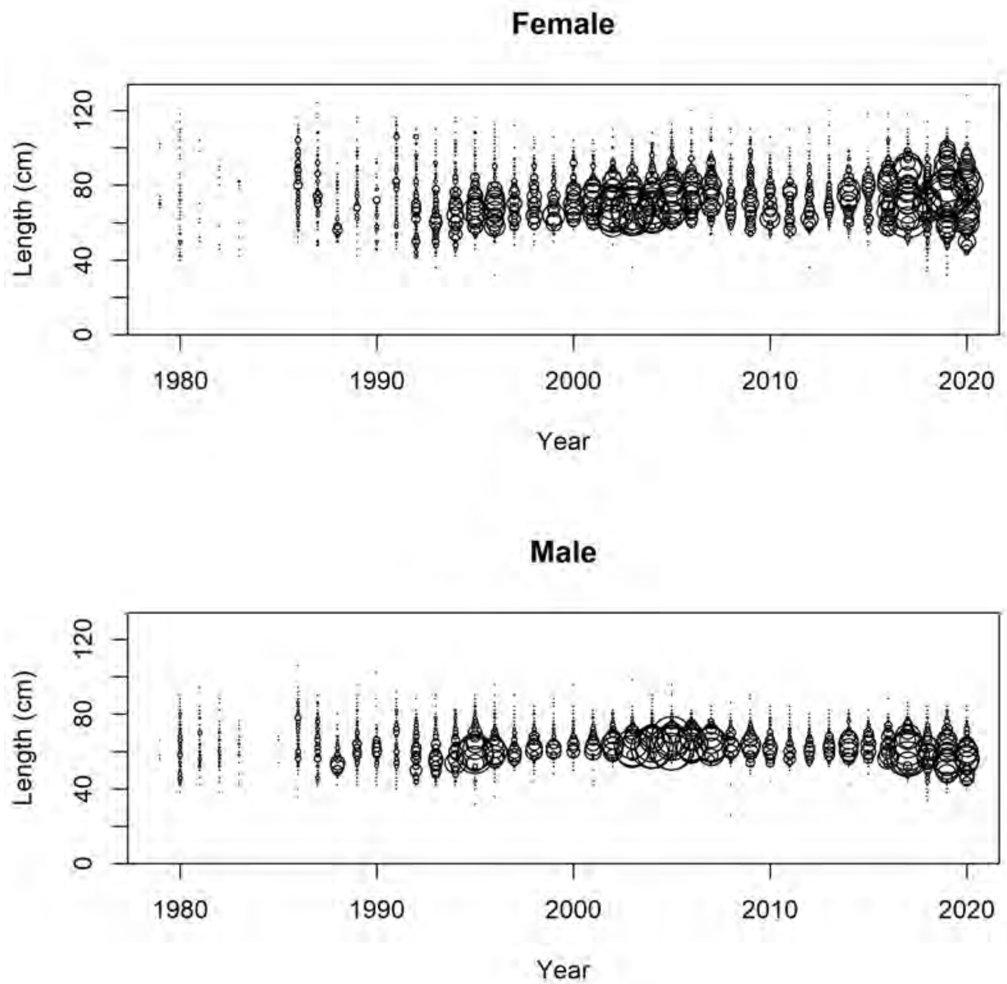


Figure 28: Length-composition data for the WA recreational fleet for sexed fish.

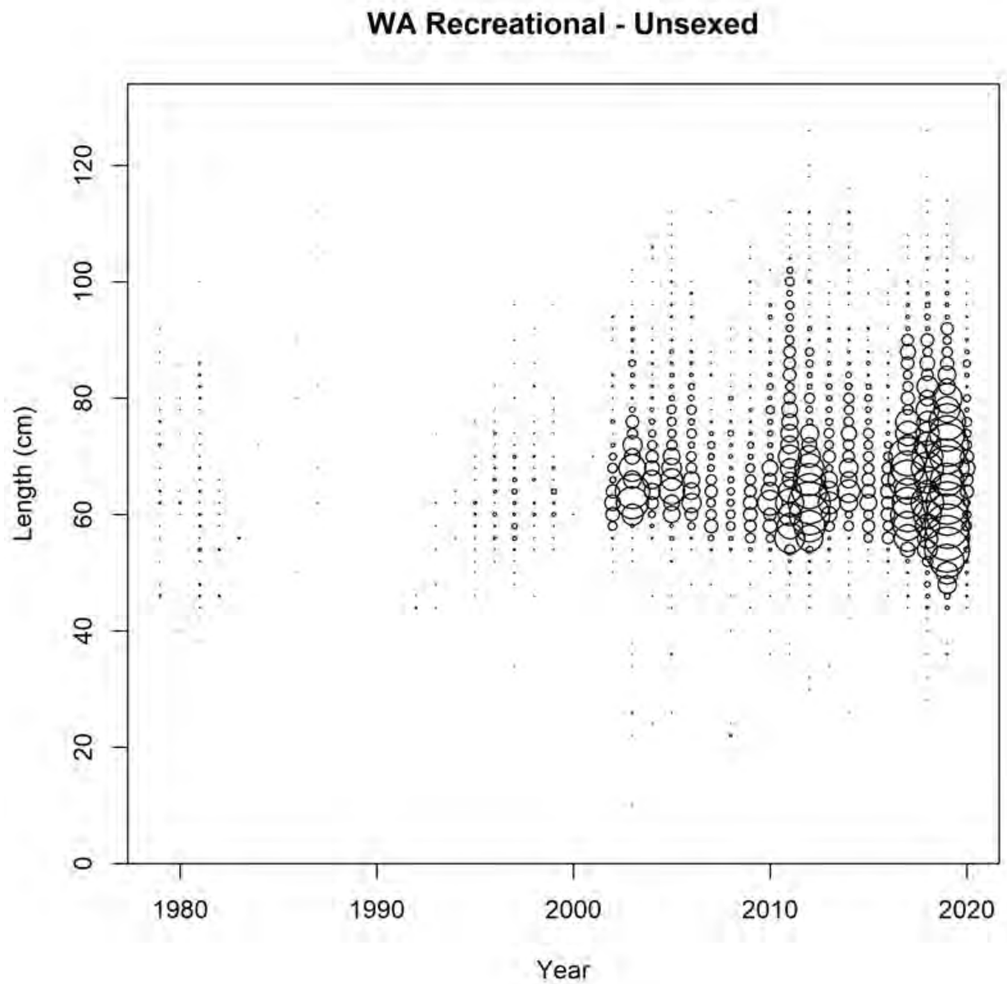


Figure 29: Length-composition data for the WA recreational fleet for unsexed fish.

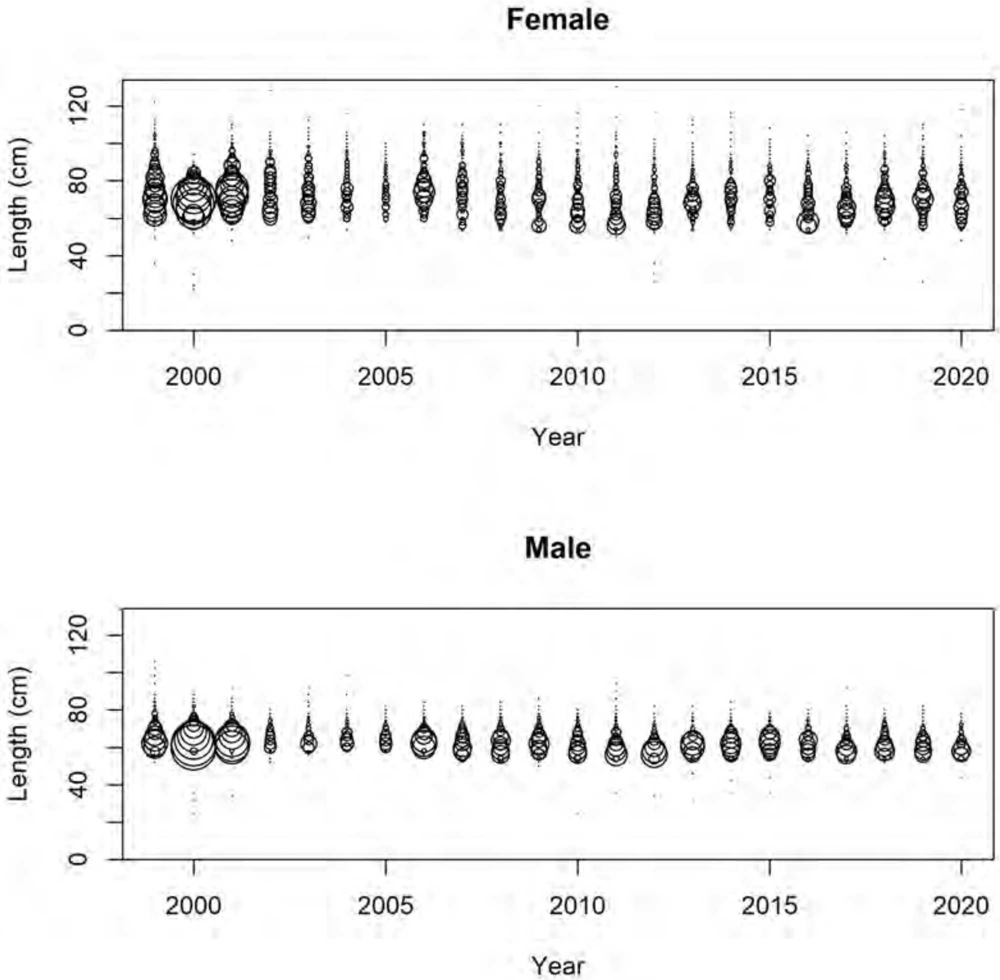


Figure 30: Length-composition data for the OR recreational fleet for sexed fish.

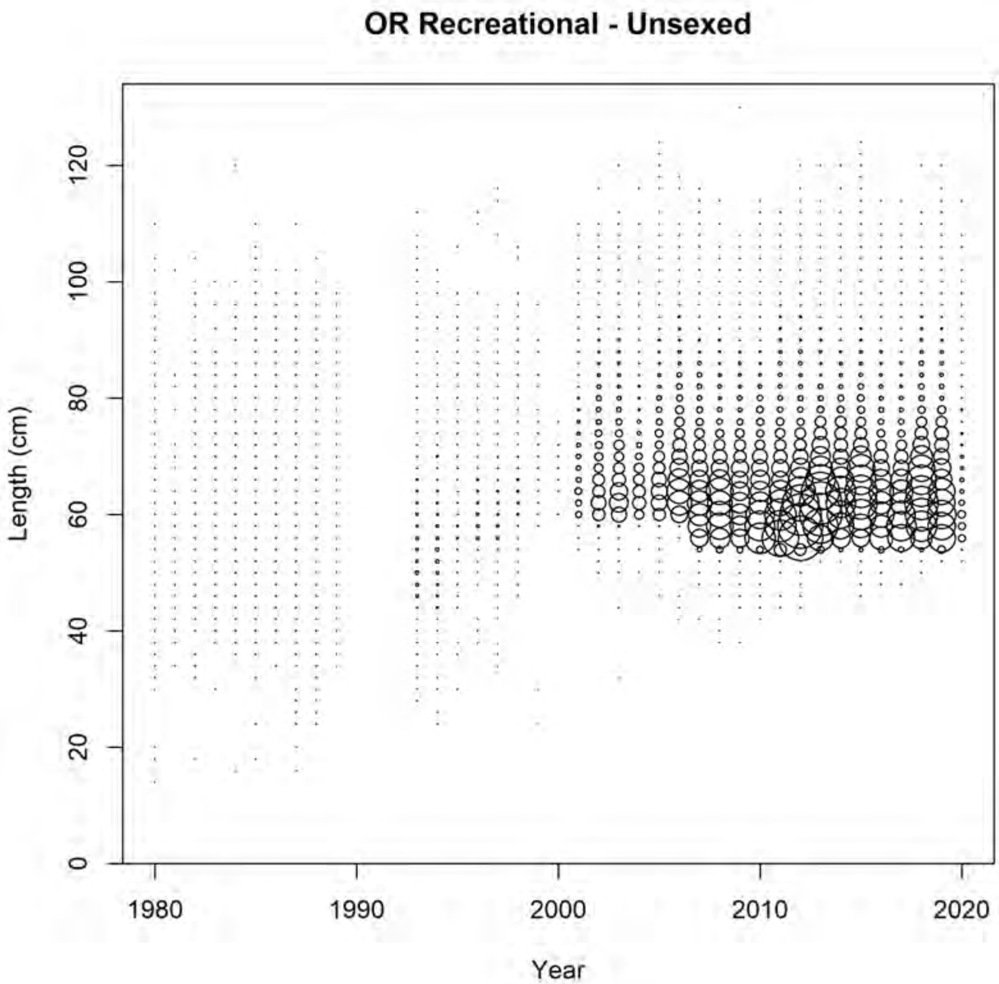


Figure 31: Length-composition data for the OR recreational fleet for unsexed fish.

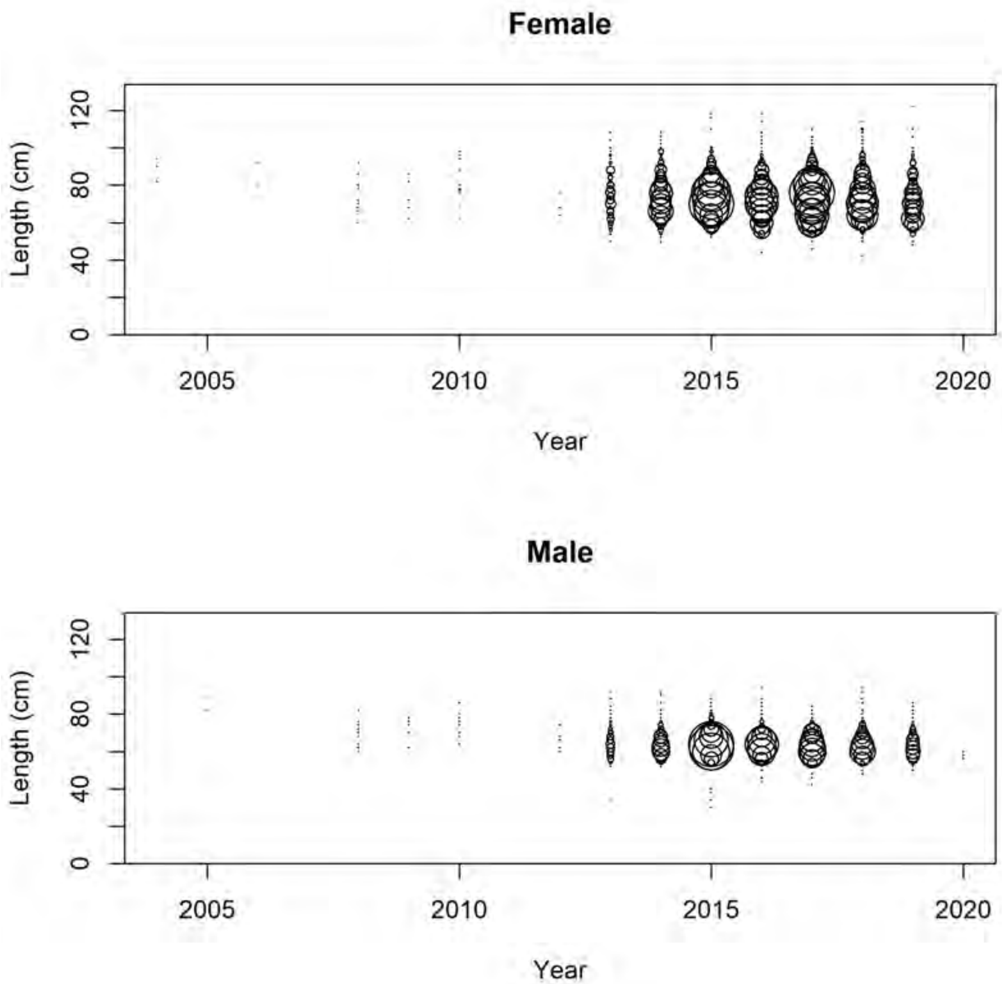


Figure 32: Length-composition data for the CA recreational fleet for sexed fish.

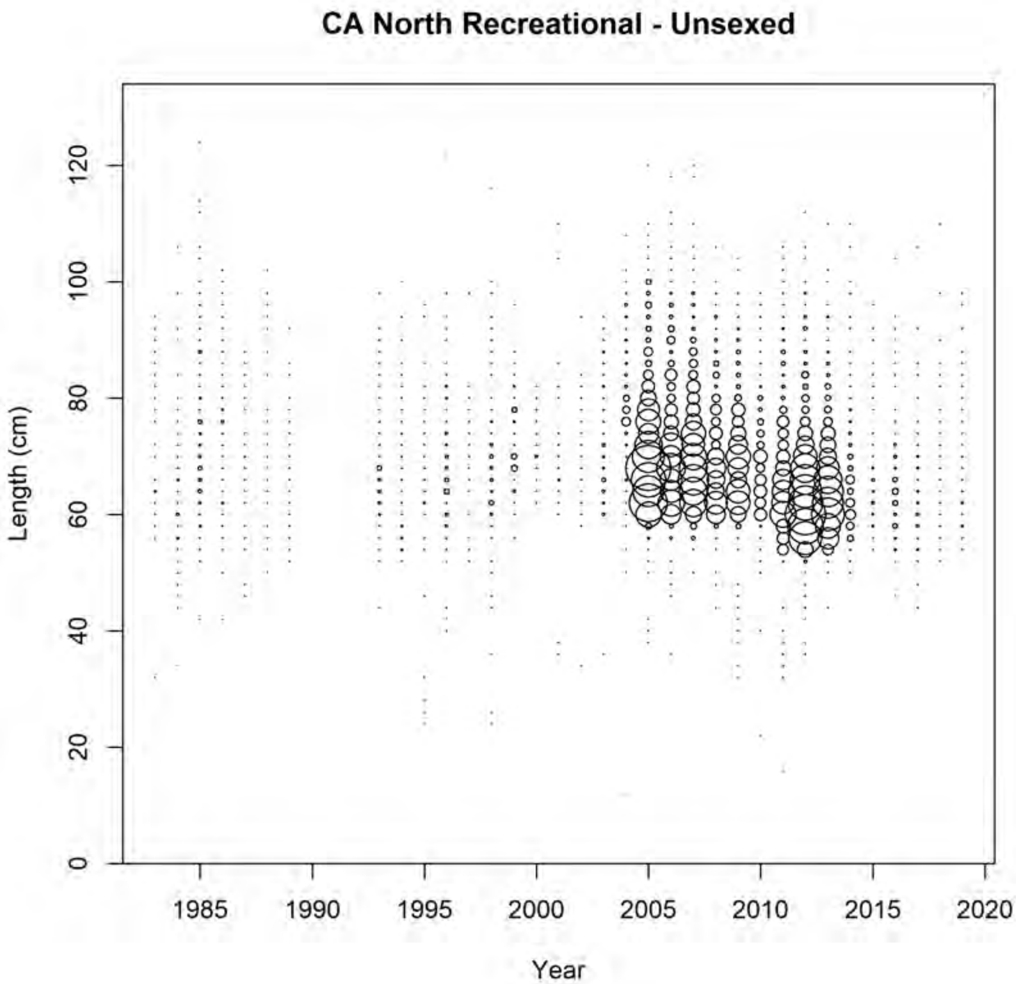


Figure 33: Length-composition data for the CA recreational fleet for unsexed fish.

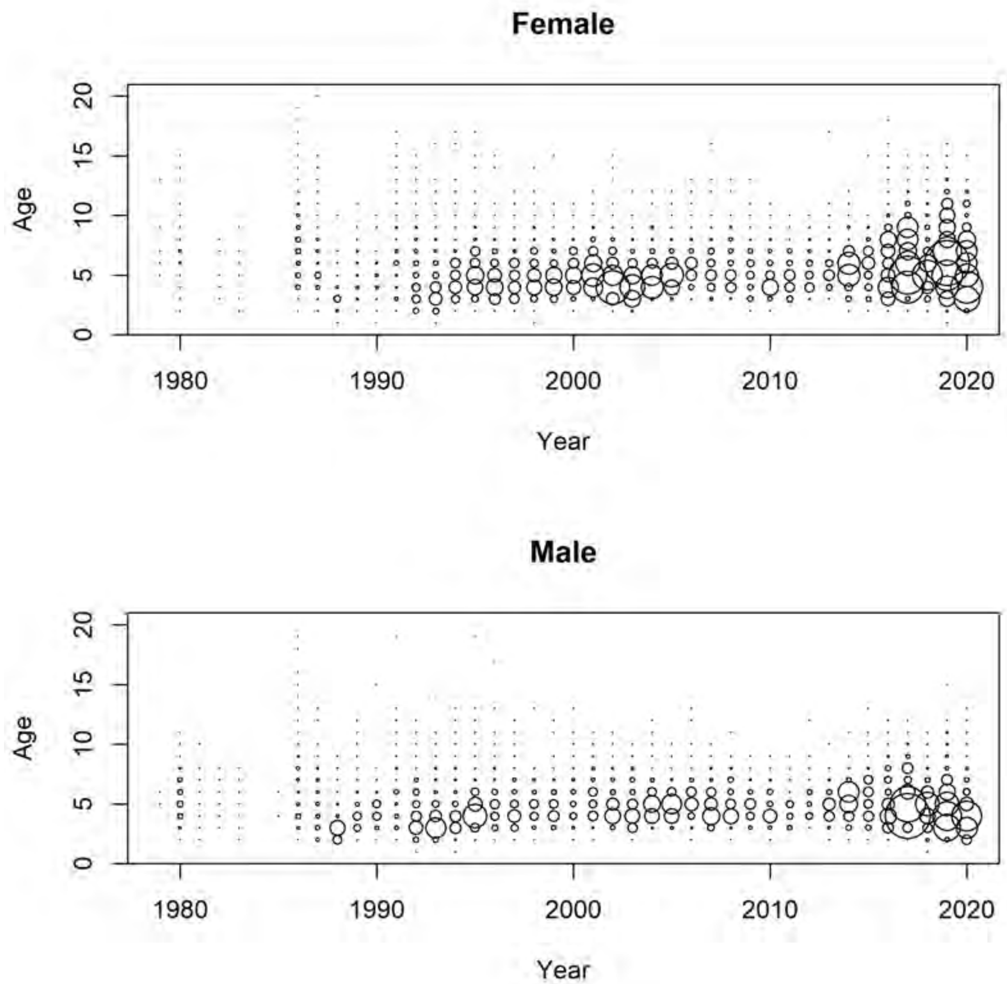


Figure 34: Age-composition data for the WA recreational fleet for sexed fish.

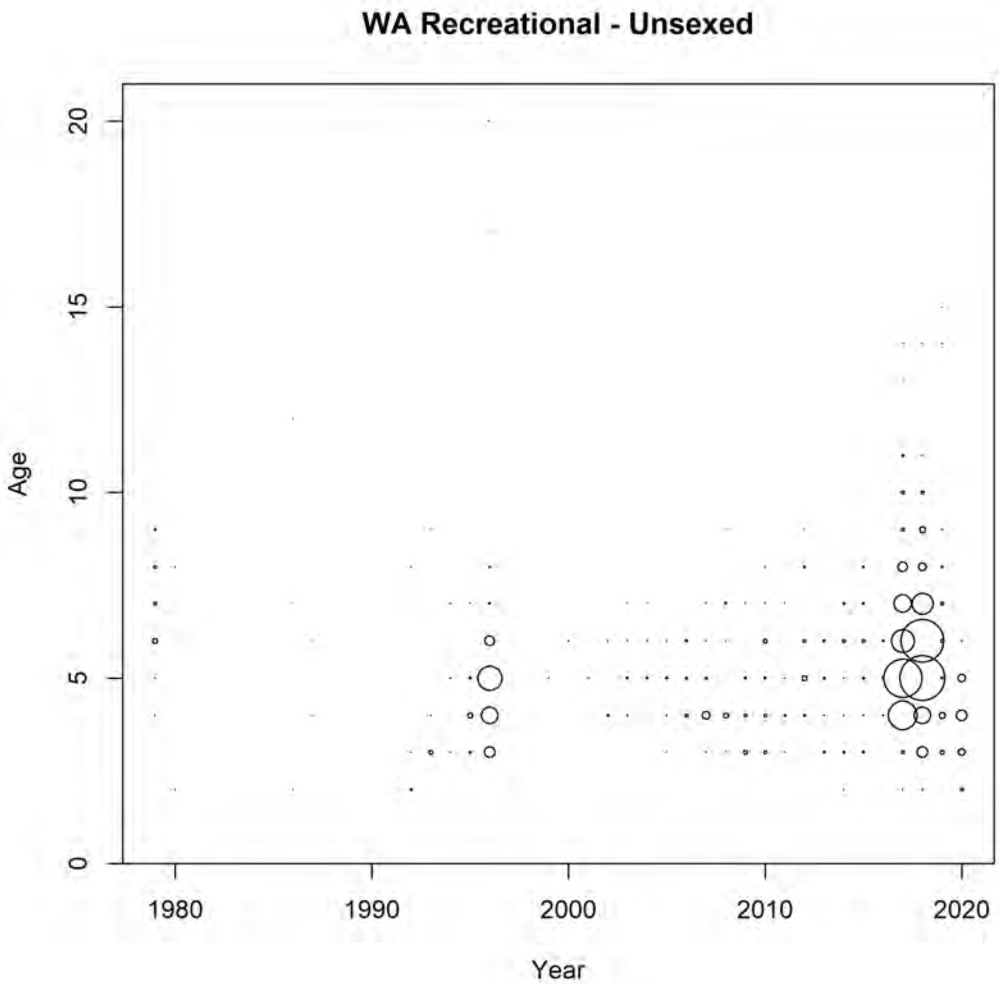


Figure 35: Age-composition data for the WA recreational fleet for unsexed fish.

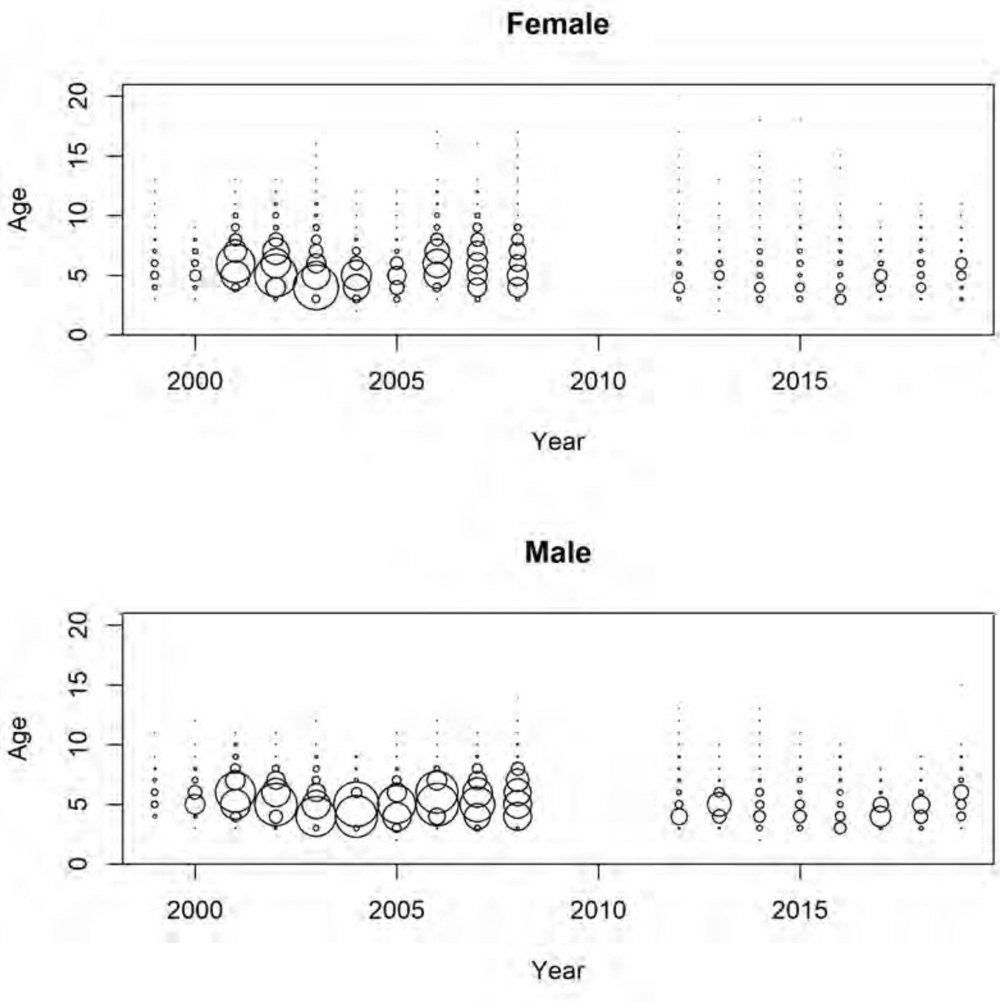


Figure 36: Age-composition data for the OR recreational fleet for sexed fish.

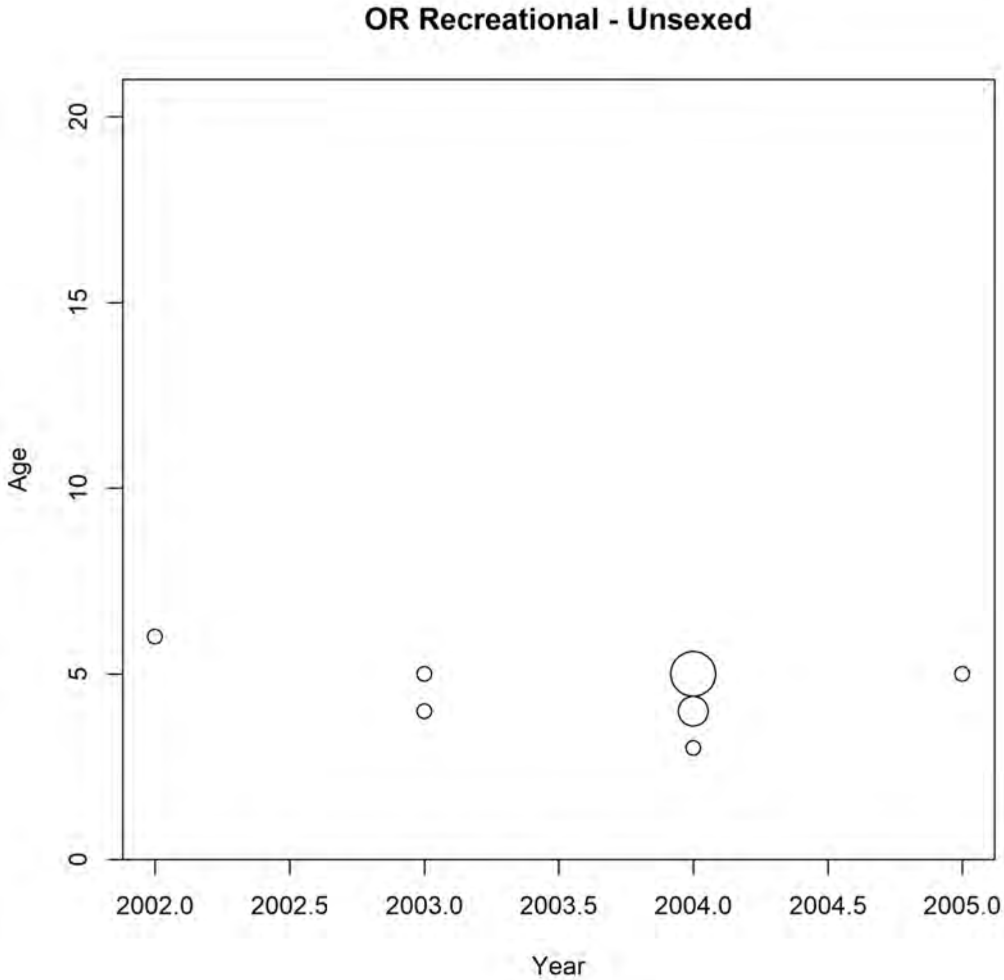


Figure 37: Age-composition data for the OR recreational fleet for unsexed fish.

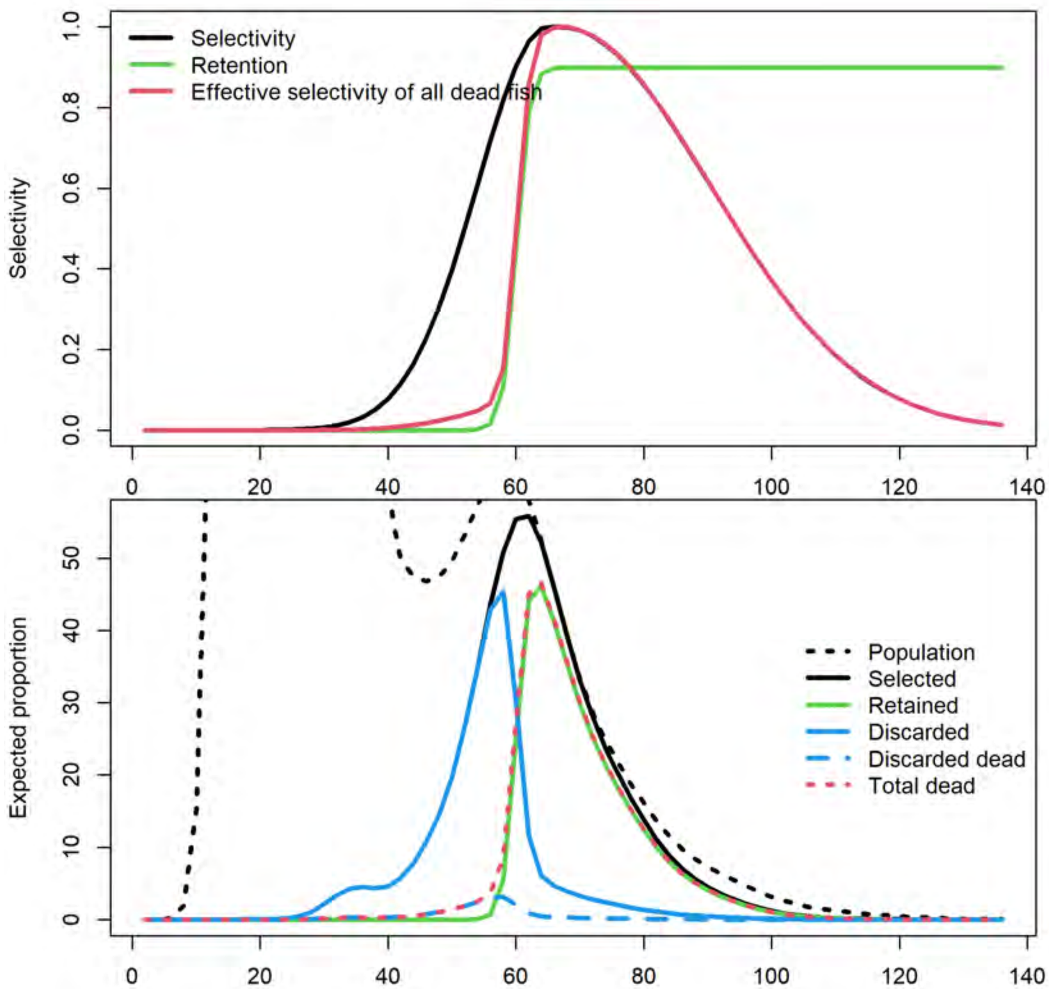


Figure 38: Illustration of the effective selectivity associated with retained recreational catch (upper panel) and the difference in expected proportion at length between retained-only (as used in the model), and retained plus dead discards (unavailable due to the nature of the sampling process). Selectivity, retention, and numbers-at-length are based on the California recreational fishery in the 2017 south model for the year 2000.

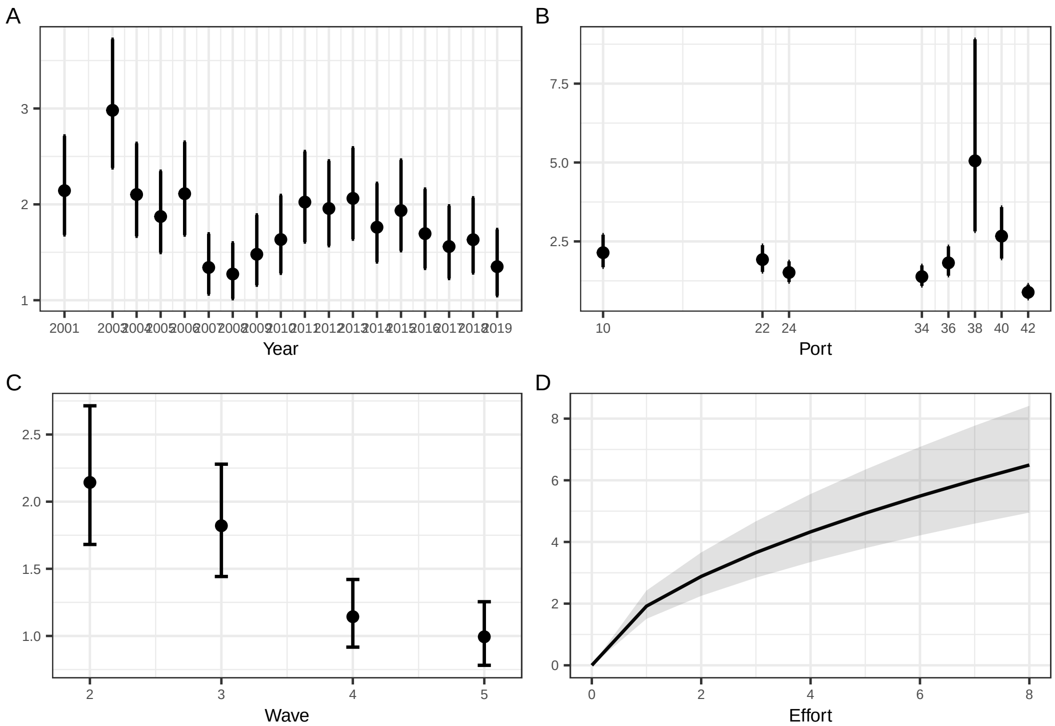


Figure 39: Marginal effects from the final model.

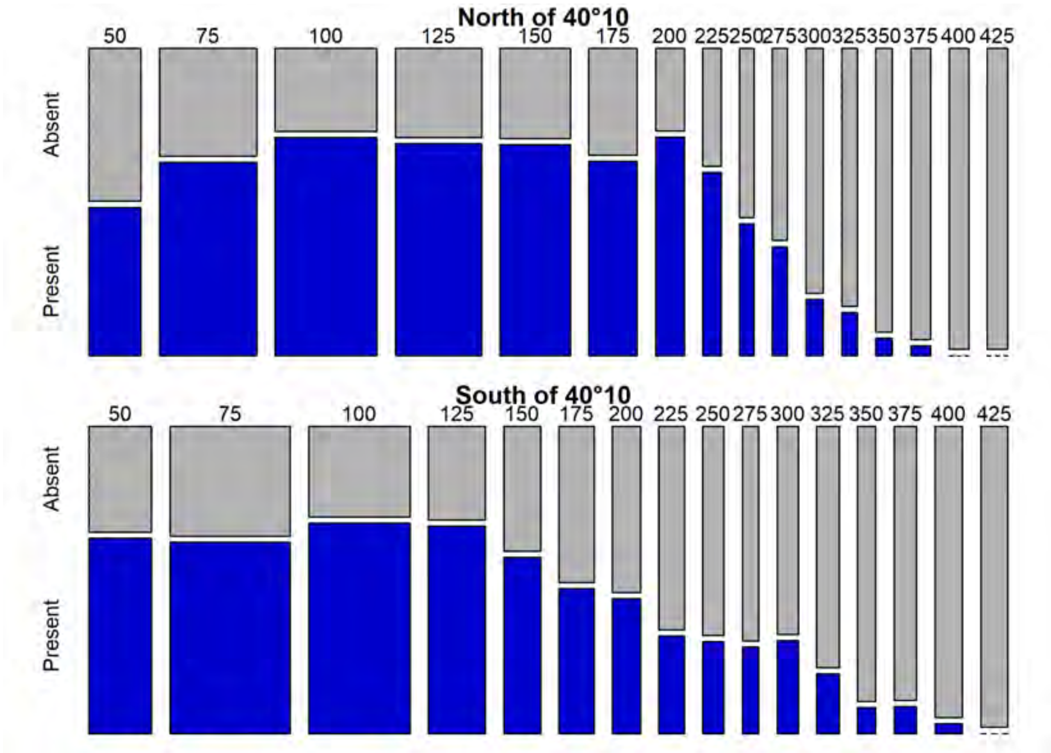


Figure 40: Presence/absence of lingcod in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) by 25 m depth increments.

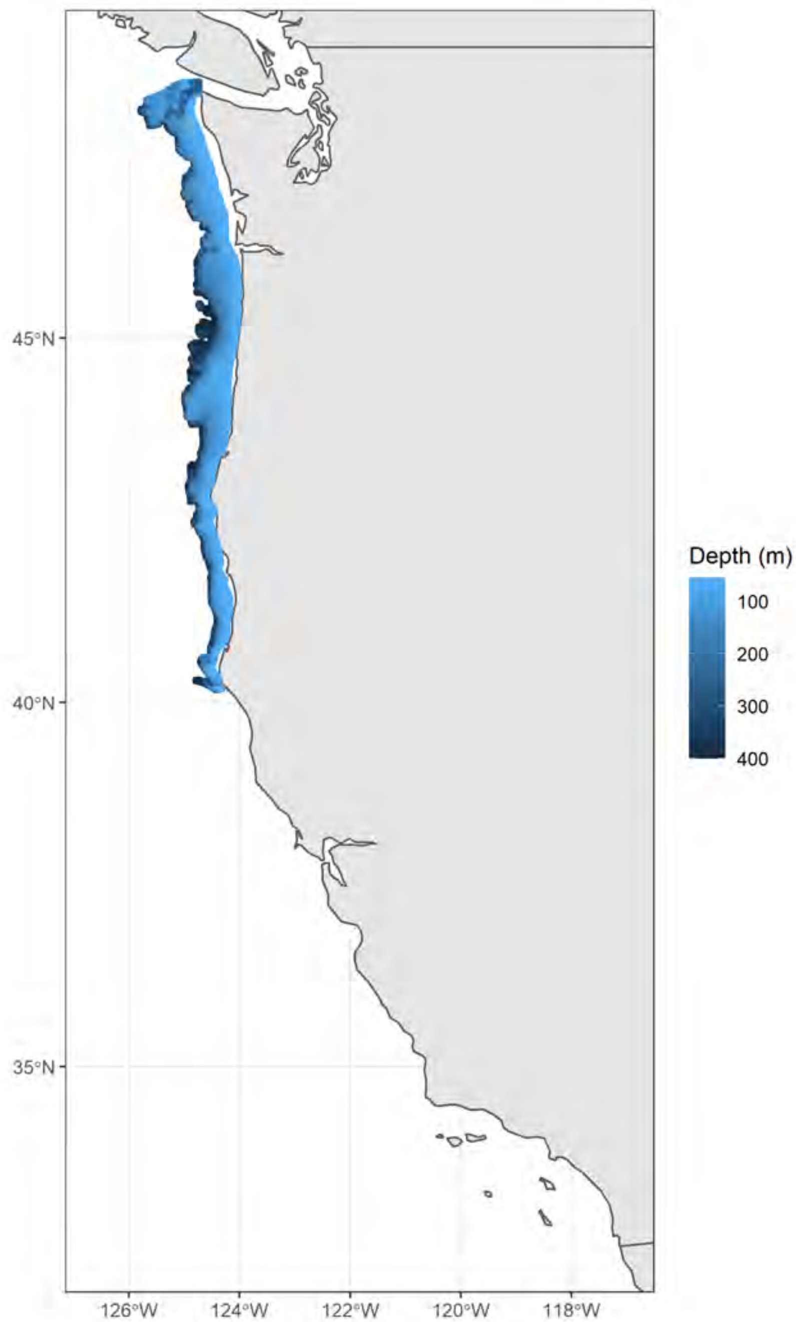


Figure 41: Map of the area modeled by the index-standardization process for the index-standardization process for the WCGBT Survey.

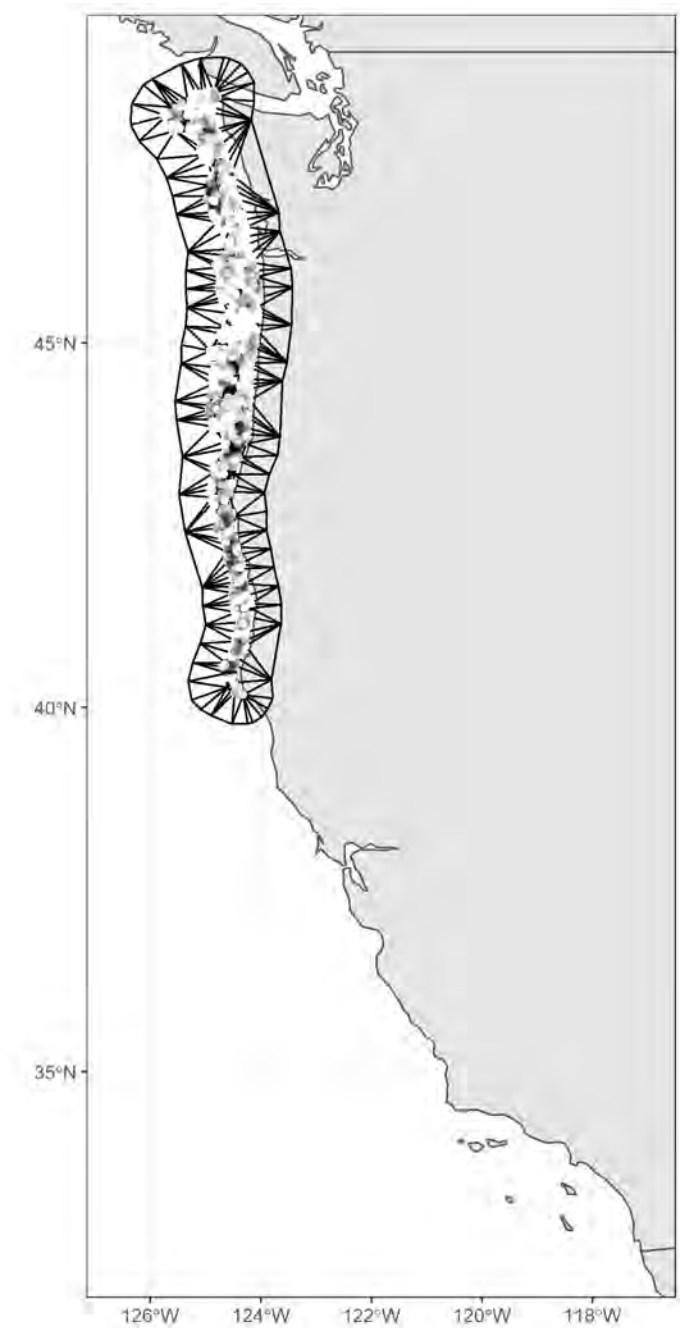


Figure 42: Map of knot locations used to approximate the spatial field for the index-standardization process for the WCGBT Survey.

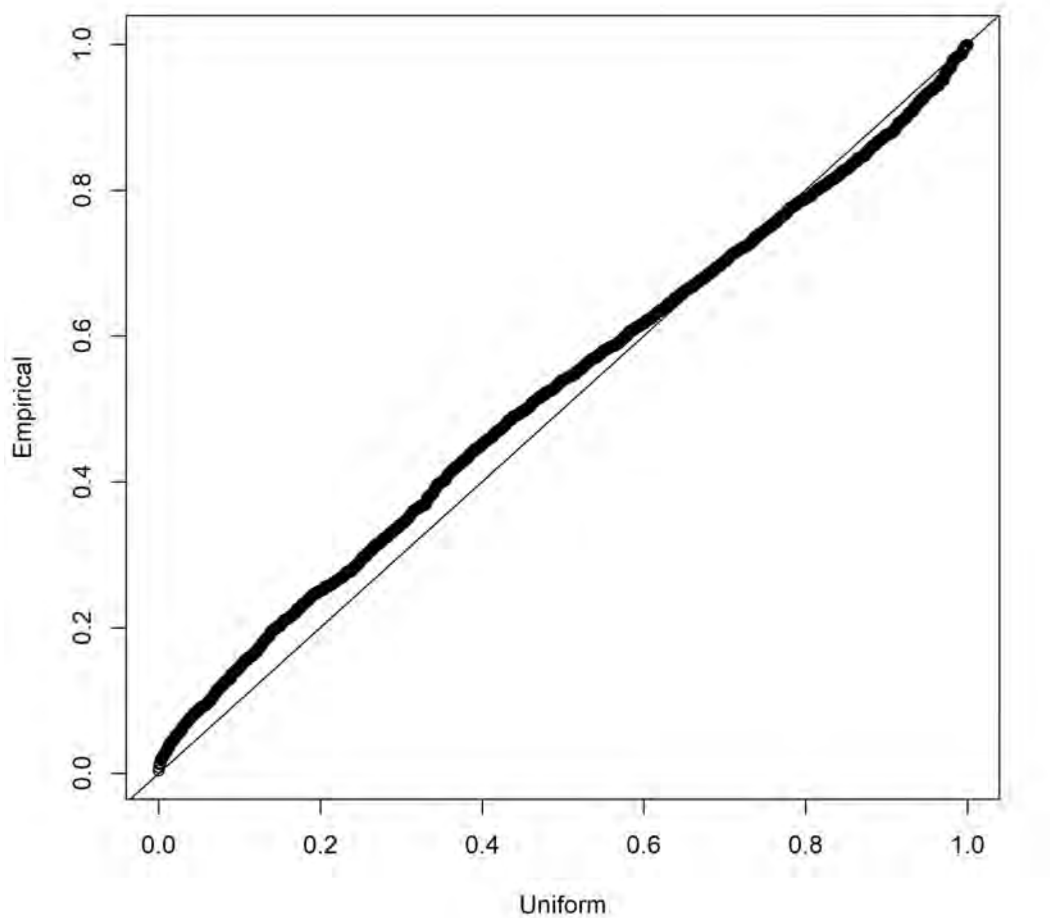


Figure 43: Quantile-Quantile (QQ) plot of the theoretical quantiles versus the standardized quantiles given fits to the data for the index-standardization process for the WCGBT Survey.

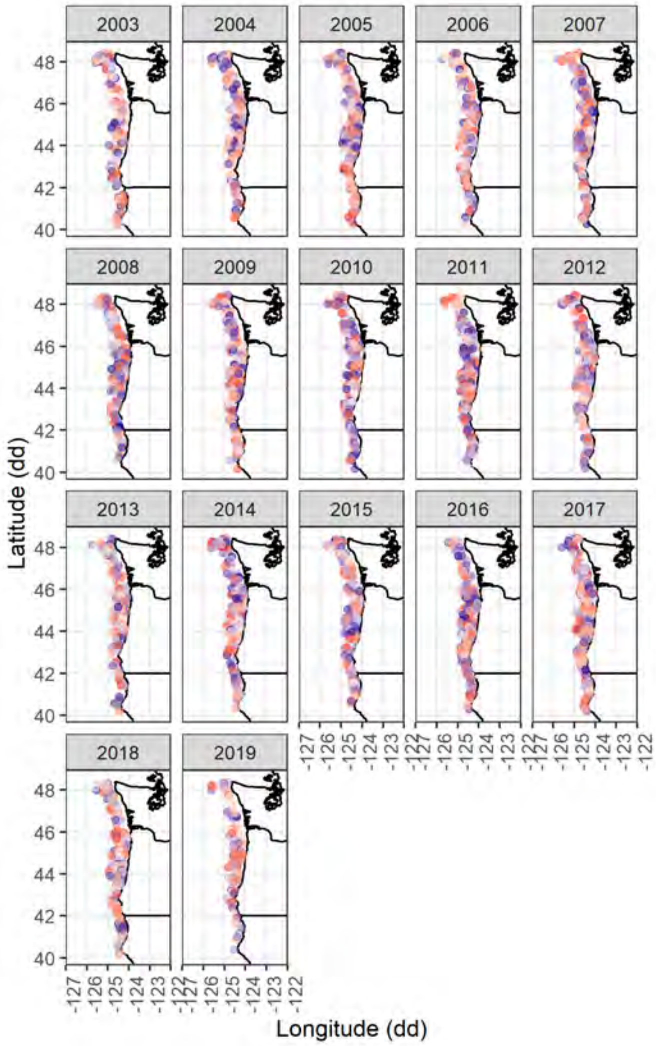


Figure 44: Map of standardized residuals by year (panels) from the index-standardization process for the WCGBT Survey. Dark blue are the lowest value, white are closest to the mean, and red are the highest values.

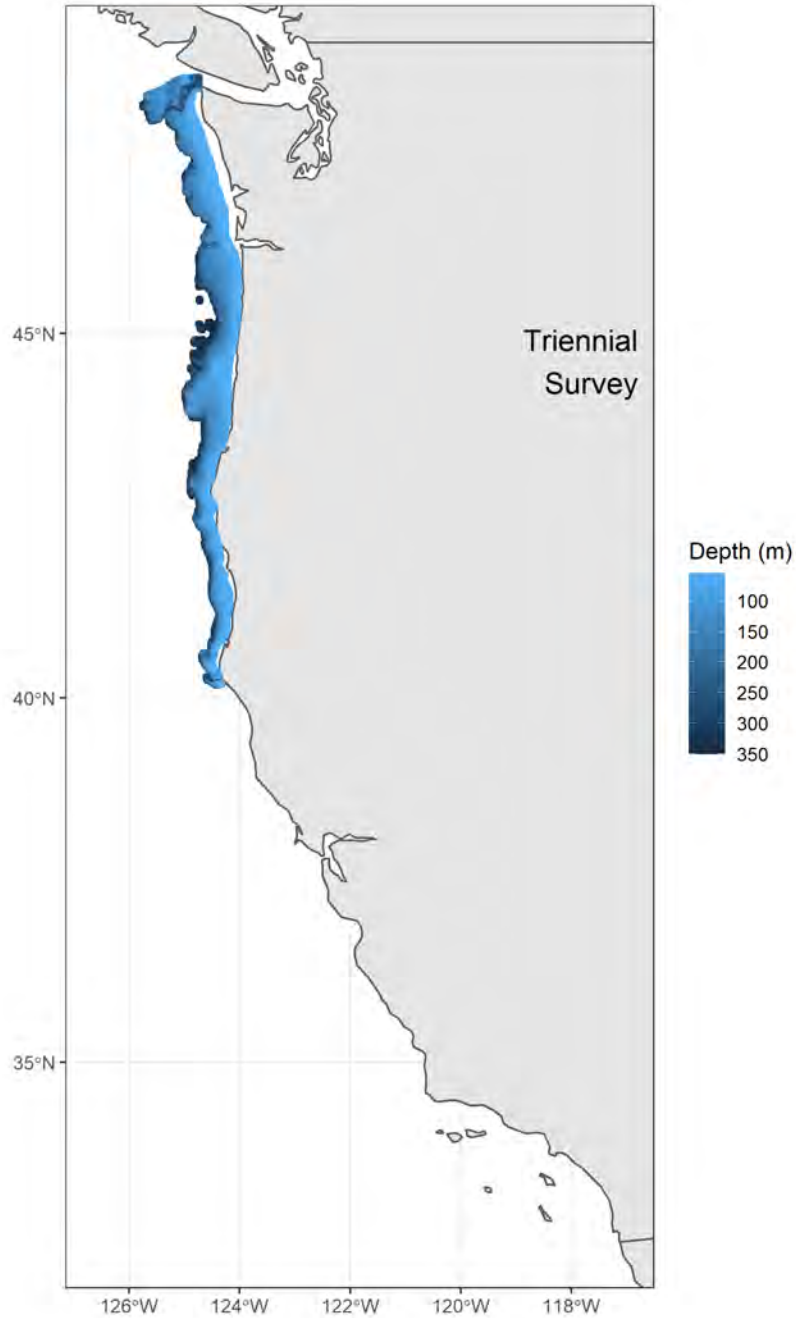


Figure 45: Map of the area modeled by the index-standardization process for the index-standardization process for the Triennial Survey.

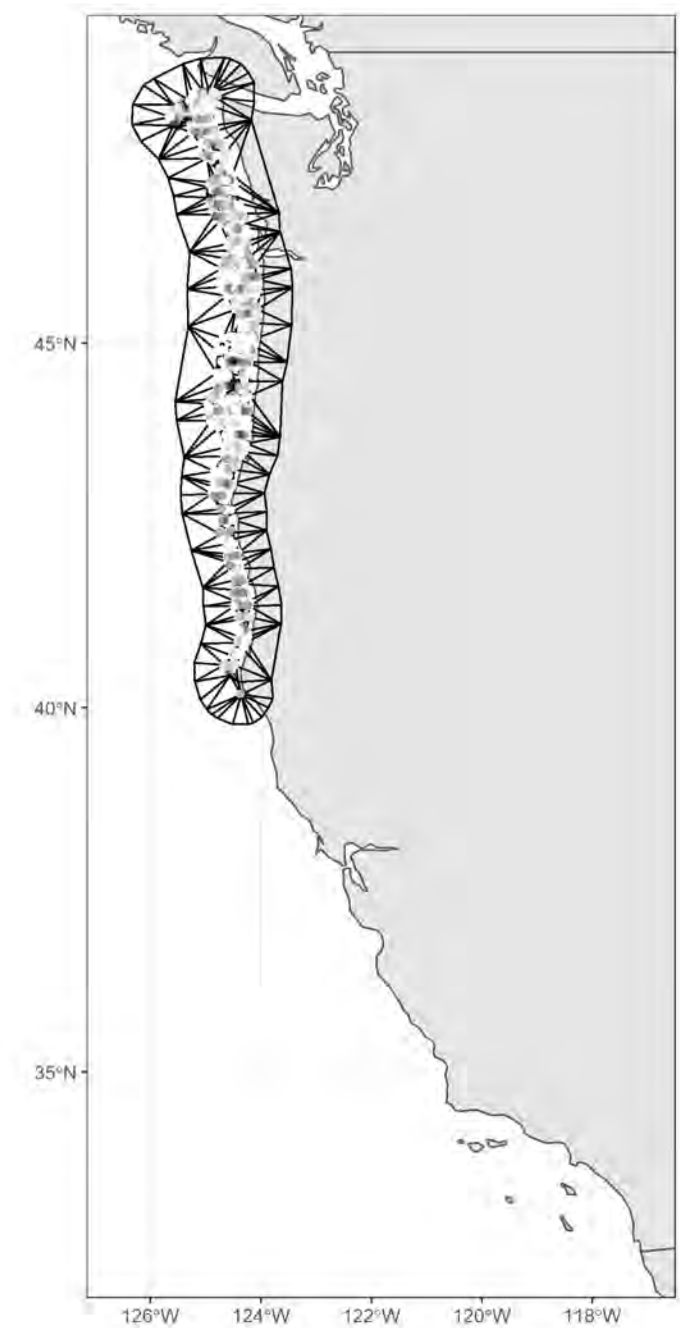


Figure 46: Map of knot locations used to approximate the spatial field for the index-standardization process for the Triennial Survey.

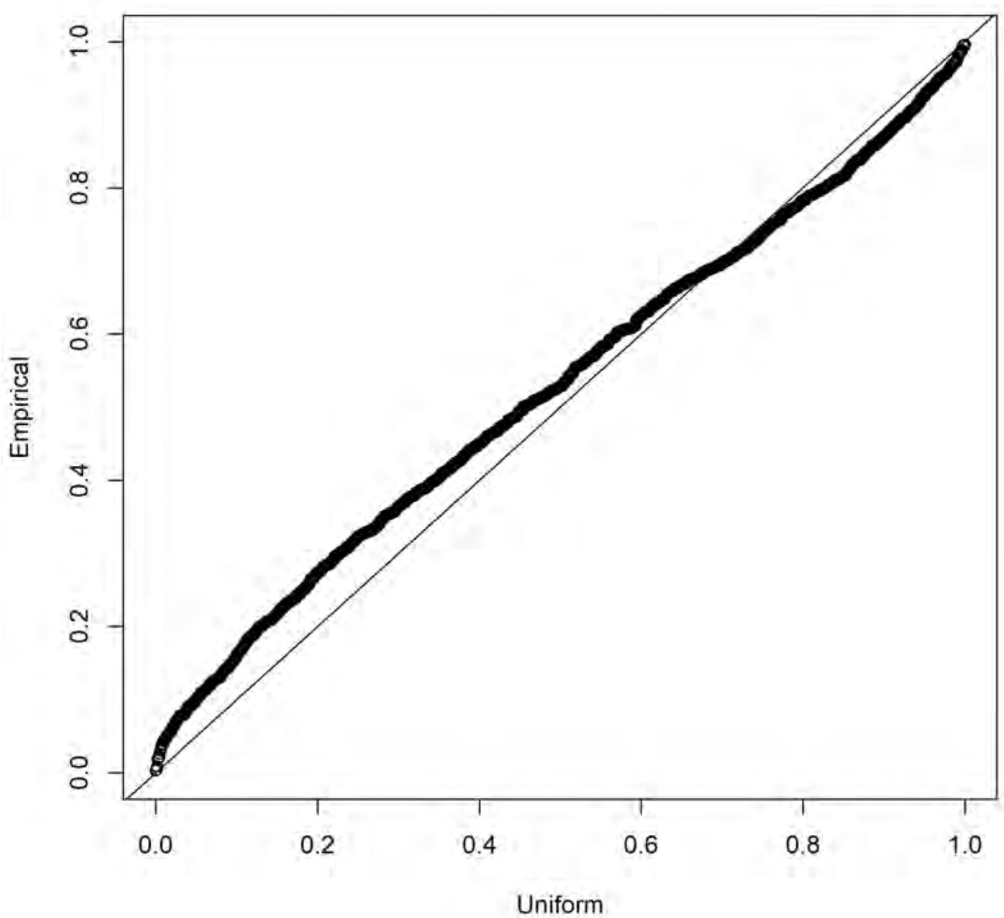


Figure 47: Quantile-Quantile (QQ) plot of the theoretical quantiles versus the standardized quantiles given fits to the data for the index-standardization process for the Triennial Survey.

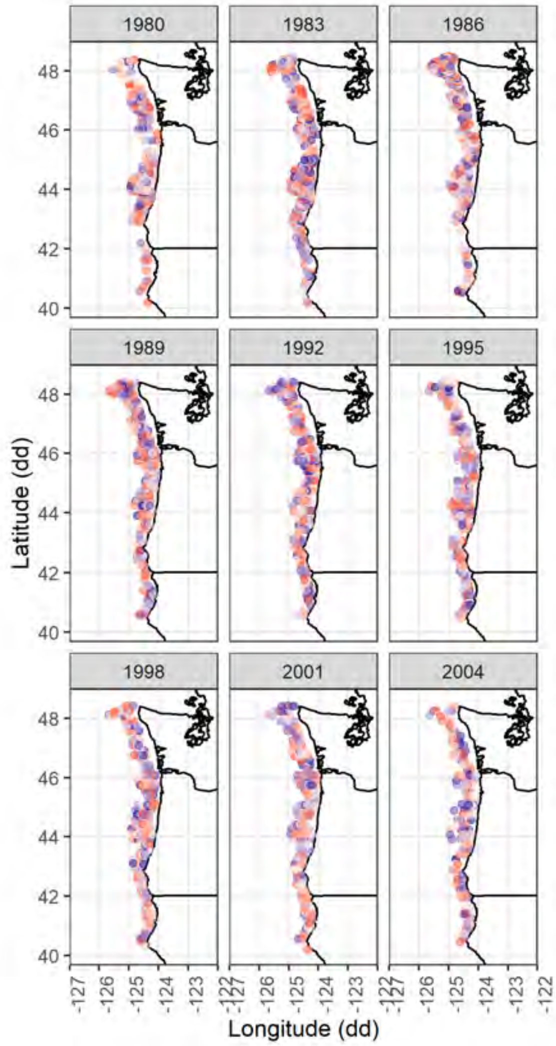


Figure 48: Map of standardized residuals by year (panels) from the index-standardization process for the Triennial Survey. Dark blue are the lowest value, white are closest to the mean, and red are the highest values.

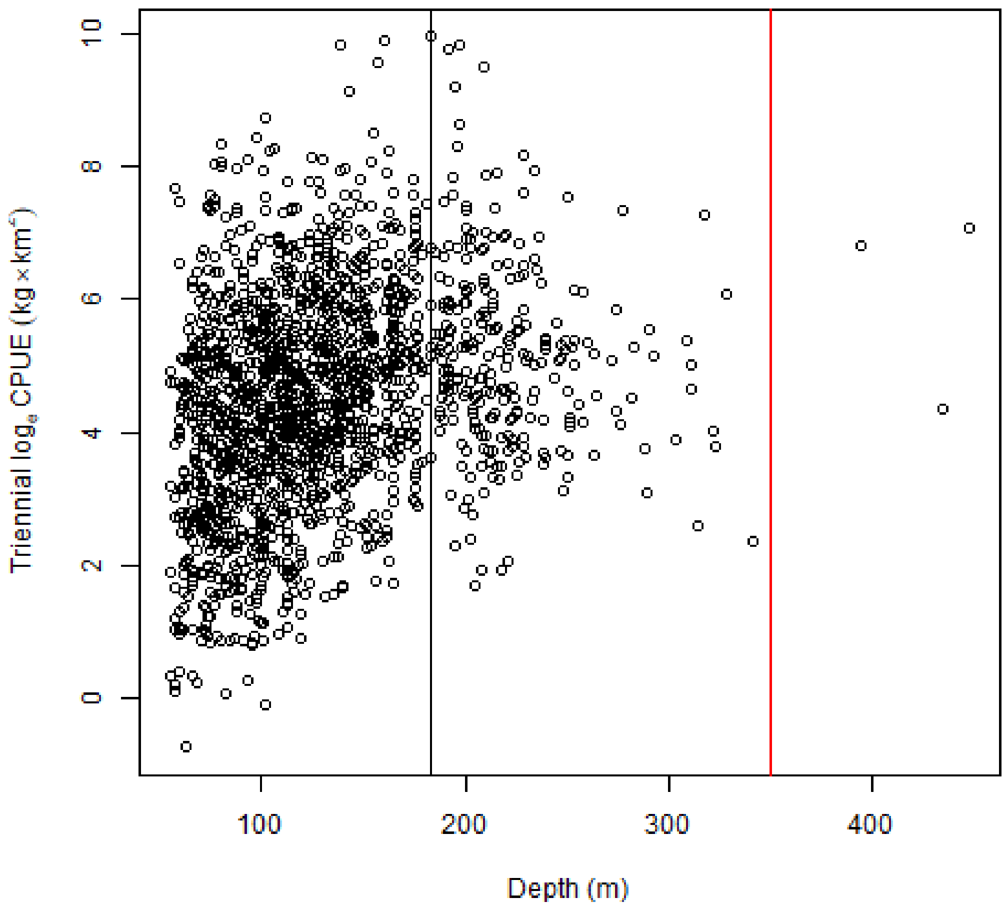


Figure 49: Raw catch per unit effort in by depth in the triennial survey. The black vertical line indicate split in depth strata at 183 m, and red vertical line shows end of depth strata at 350 m.

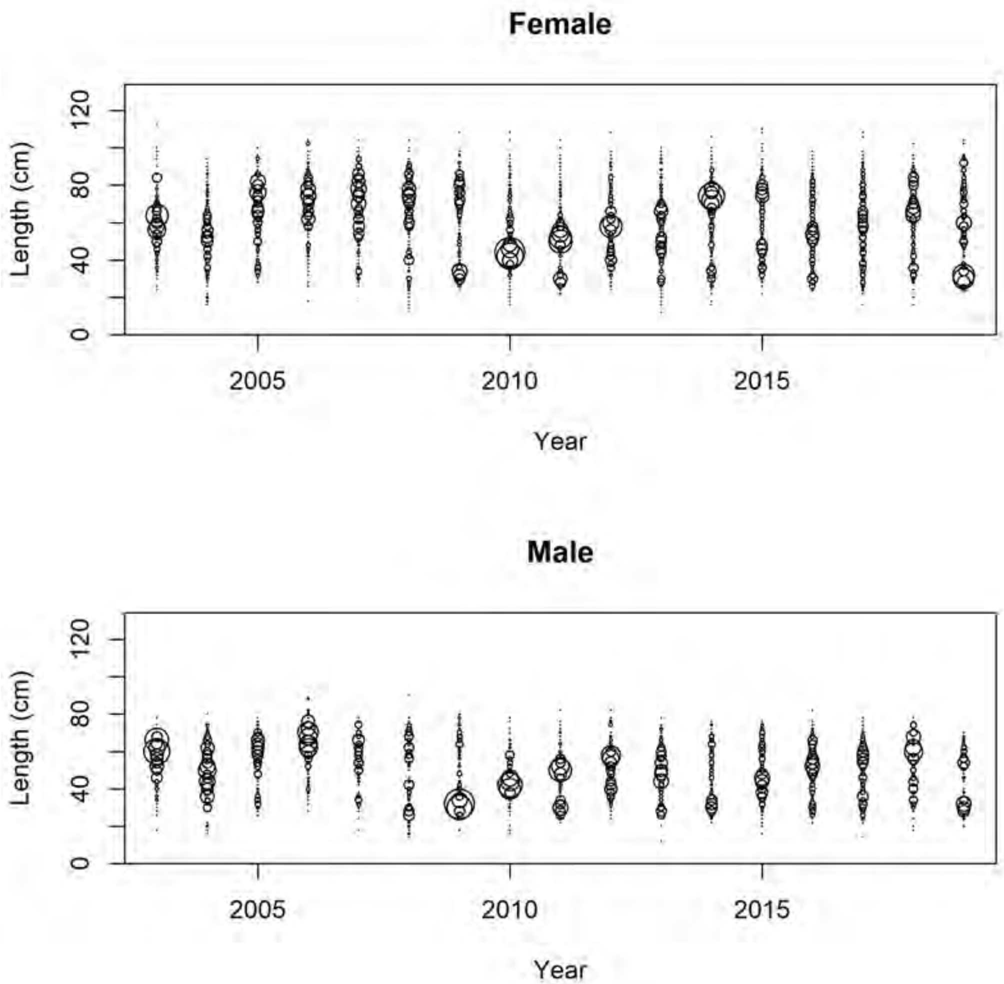


Figure 50: Length-composition data for males and females in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS).

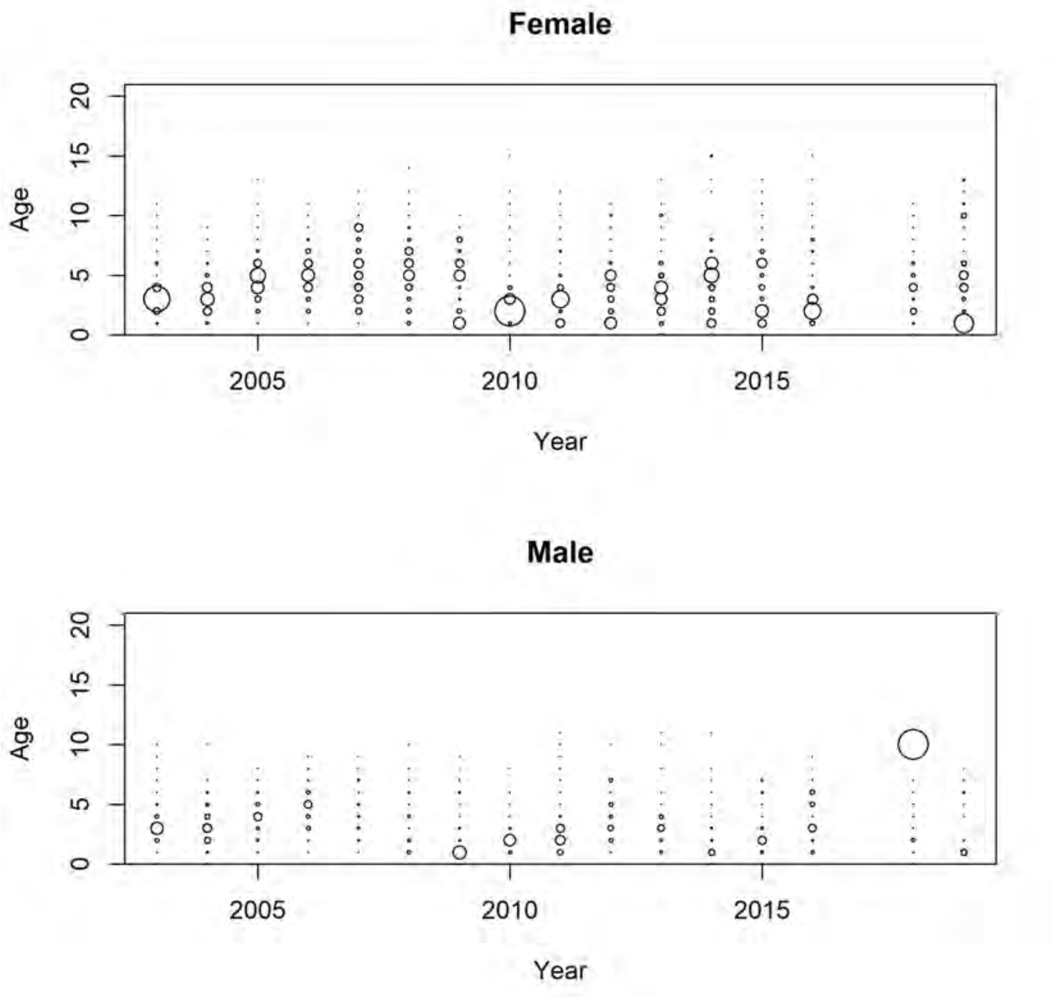


Figure 51: Age-composition data for males and females in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS).

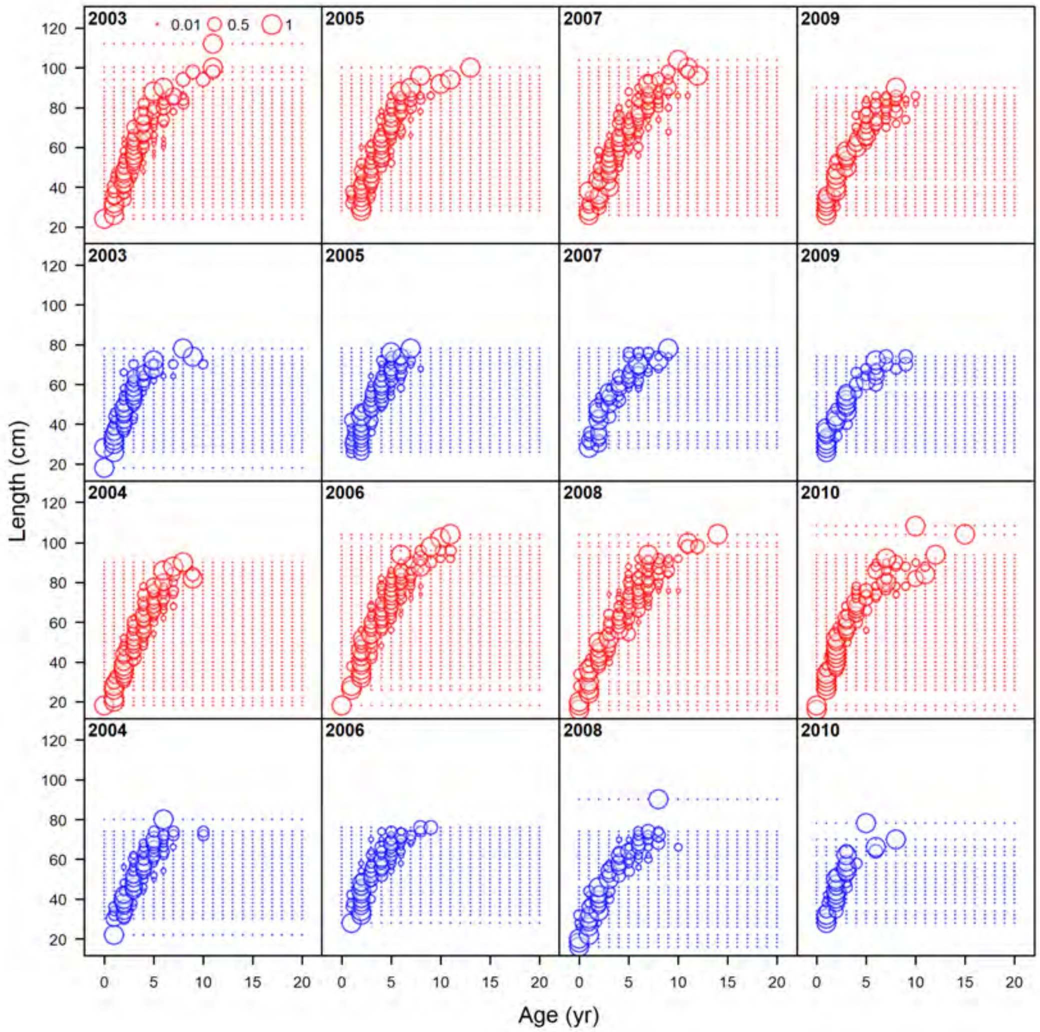


Figure 52: Conditional age-at-length data, whole catch, WCGBT Survey (max=0.98) (plot 1 of 2).

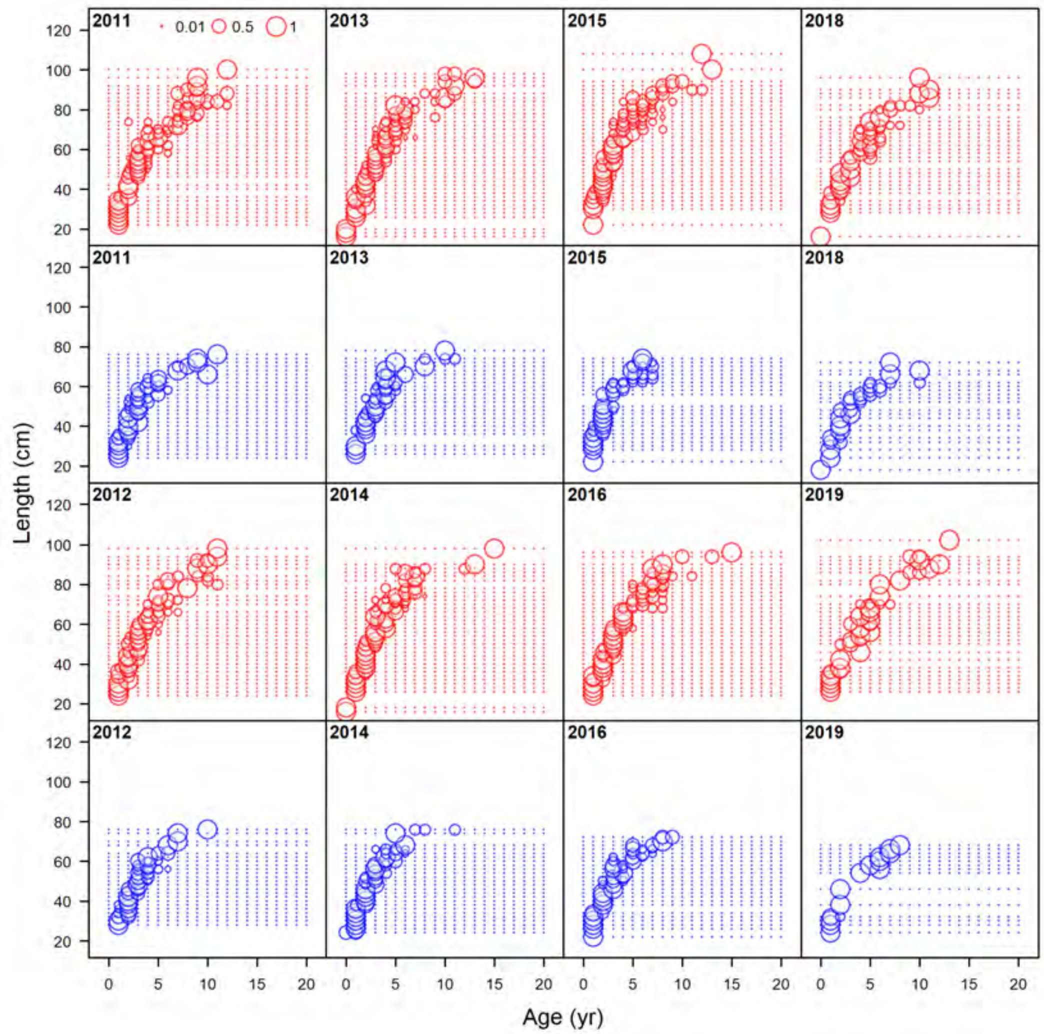


Figure 53: Conditional age-at-length data, whole catch, WCGBT Survey (max=0.98) (plot 2 of 2).

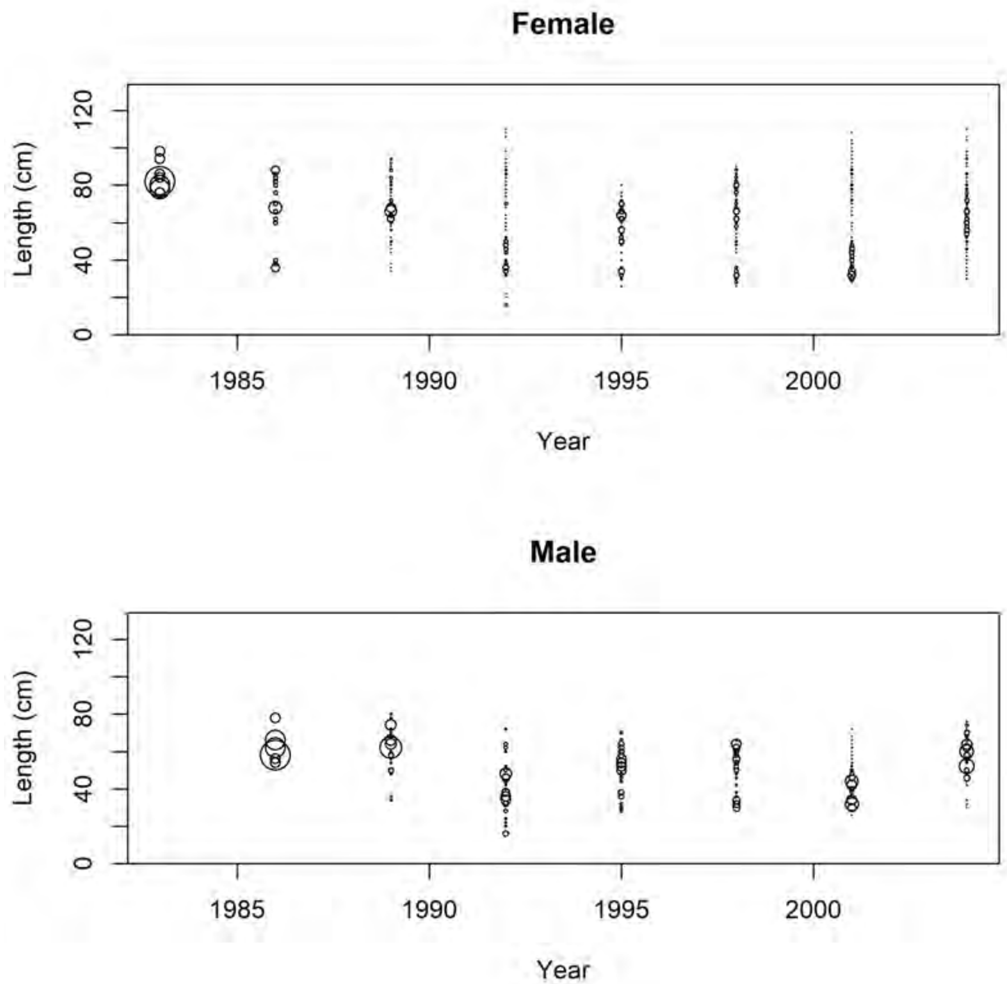


Figure 54: Length-composition data for males and females in the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey).

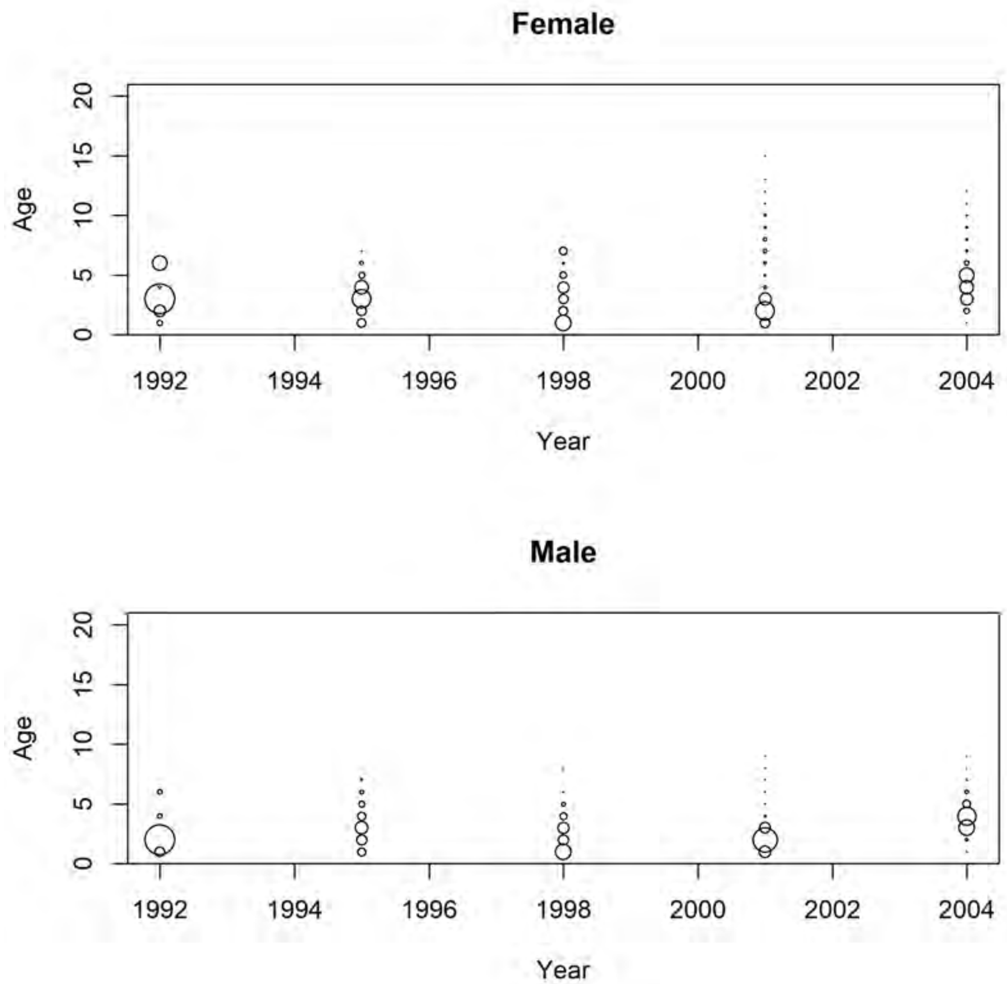
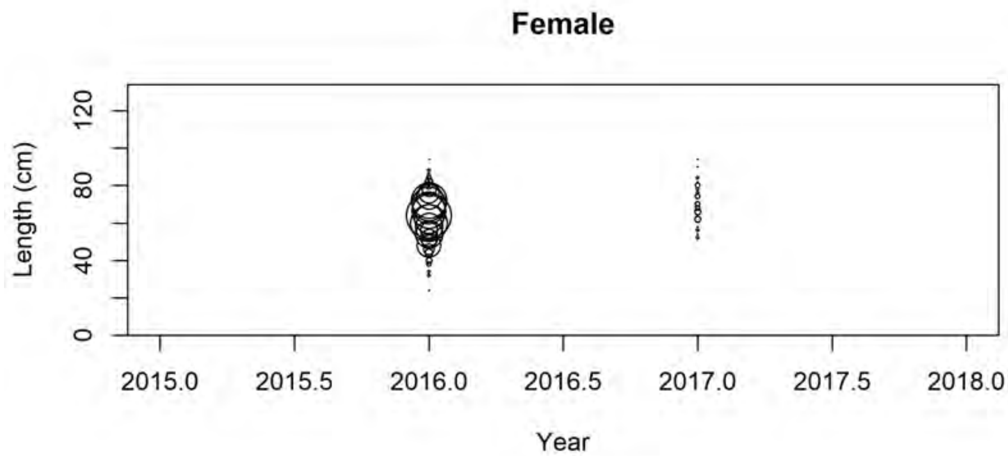


Figure 55: Age-composition data for males and females in the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey).



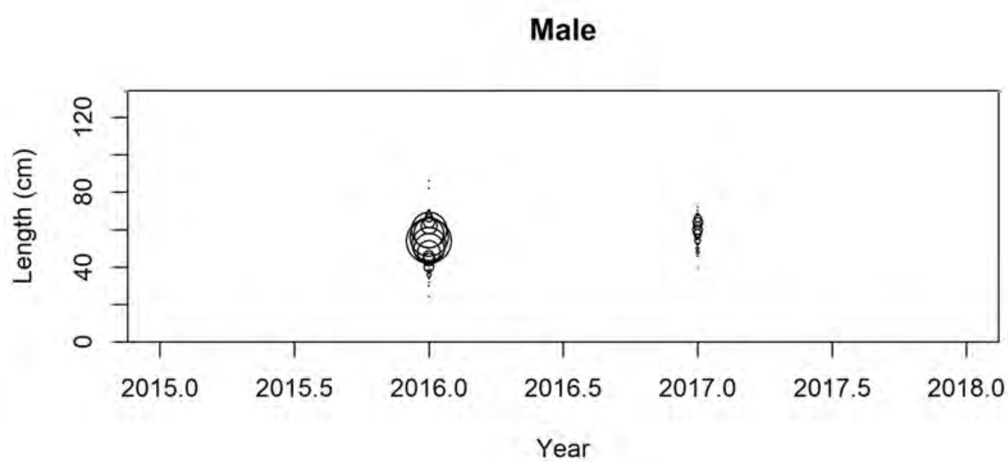


Figure 56: Length-composition data for male and females from Lam Research data.

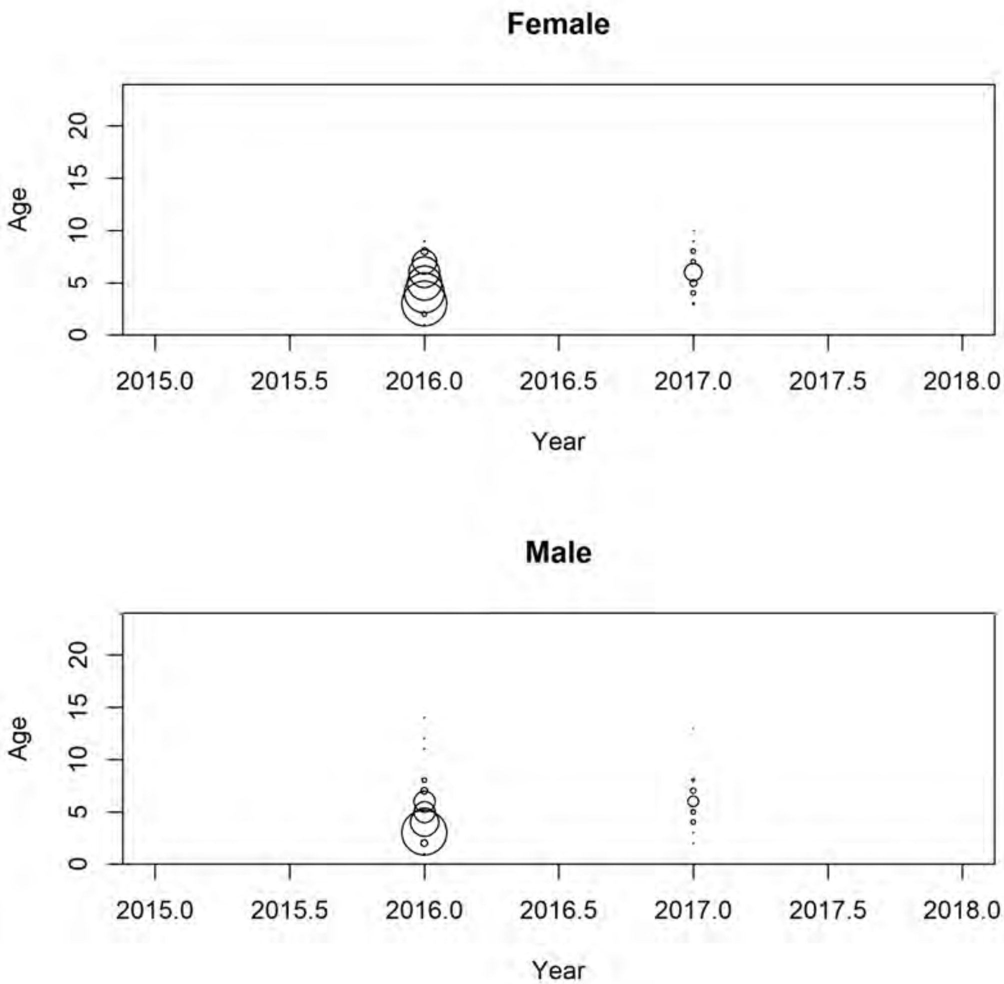


Figure 57: Age-composition data for male and females from Lam Research data.

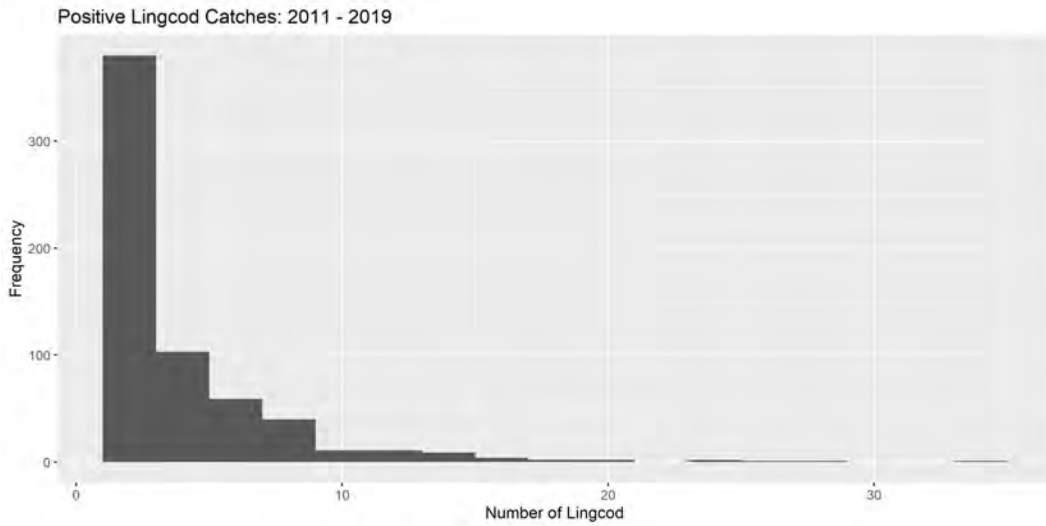


Figure 58: Catch per unit effort (CPUE) of positive, lingcod records within the Oregon hook and line survey within marine reserves.

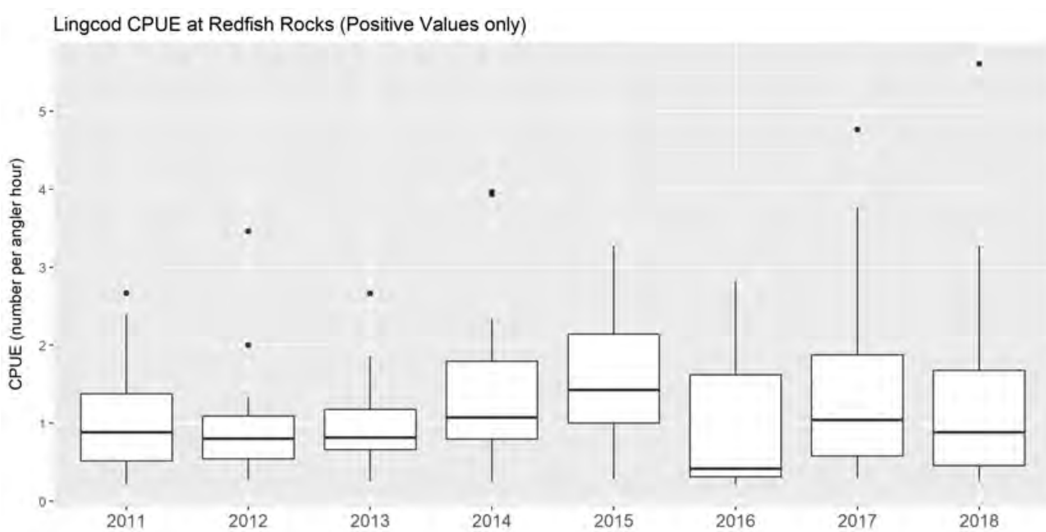


Figure 59: Frequency of positive catches of, lingcod across all years for the Oregon hook and line survey within marine reserves.

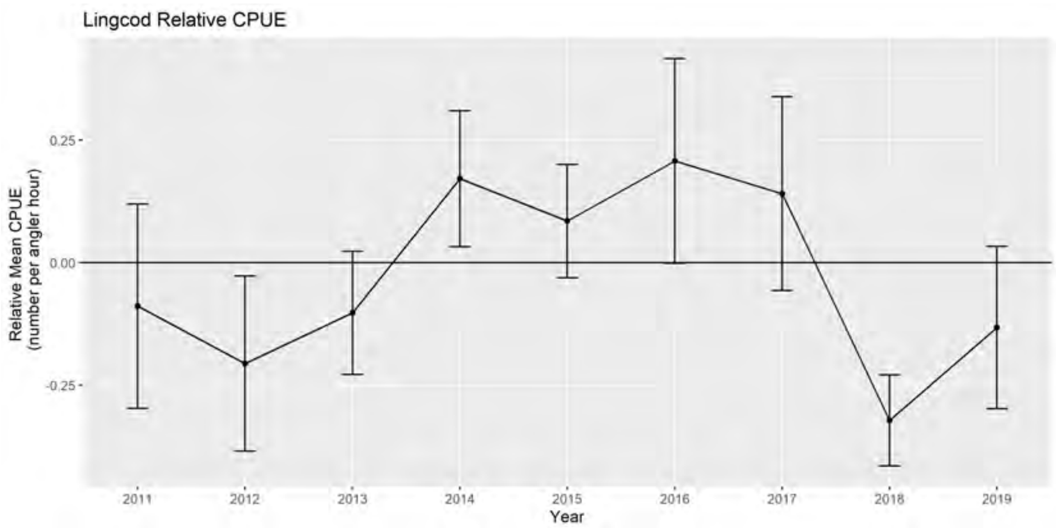


Figure 60: Relative mean Catch per unit effort (CPUE), i.e., number of positive records per angler hour, for lingcod in the Oregon hook and line survey within marine reserves.

7.2 Biology figures

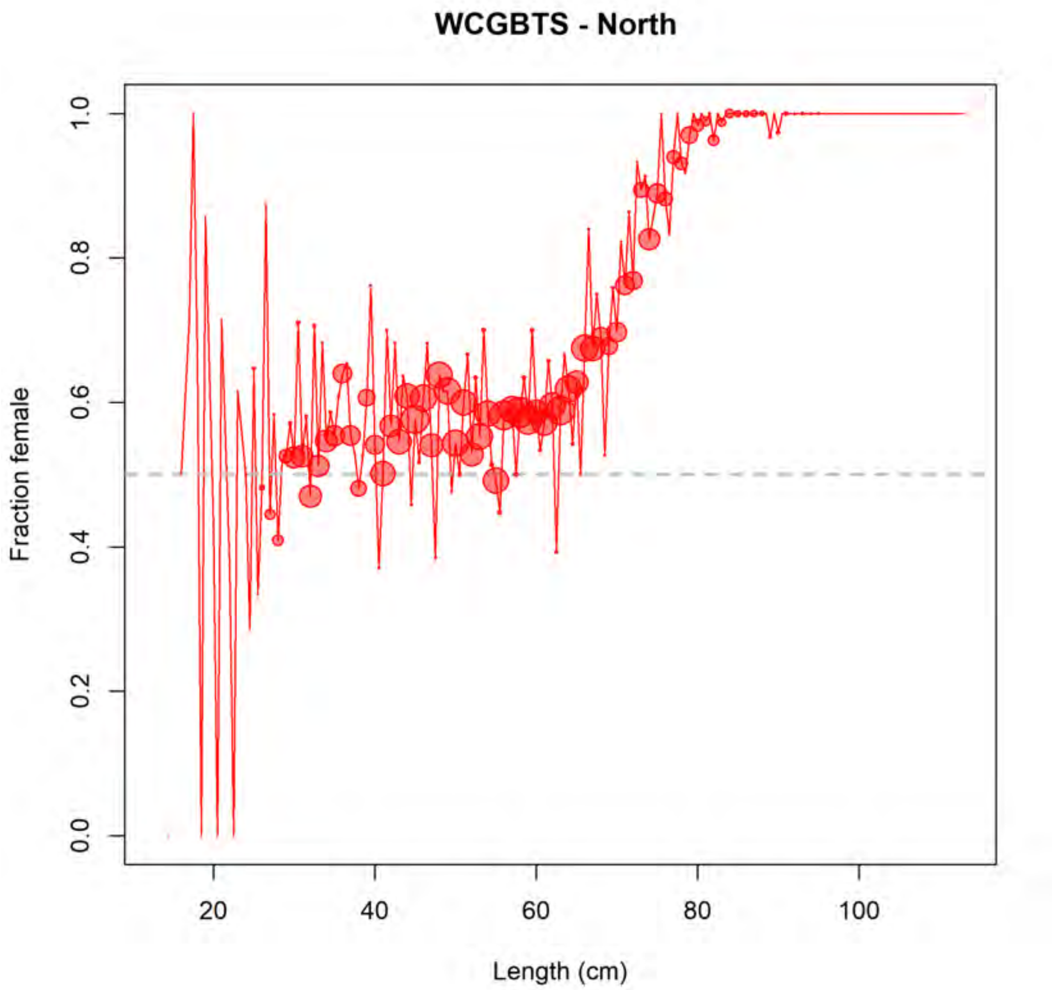


Figure 61: Fraction of the biological data from the WCGBTS subset to just the area included in this assessment that are female by length (cm).

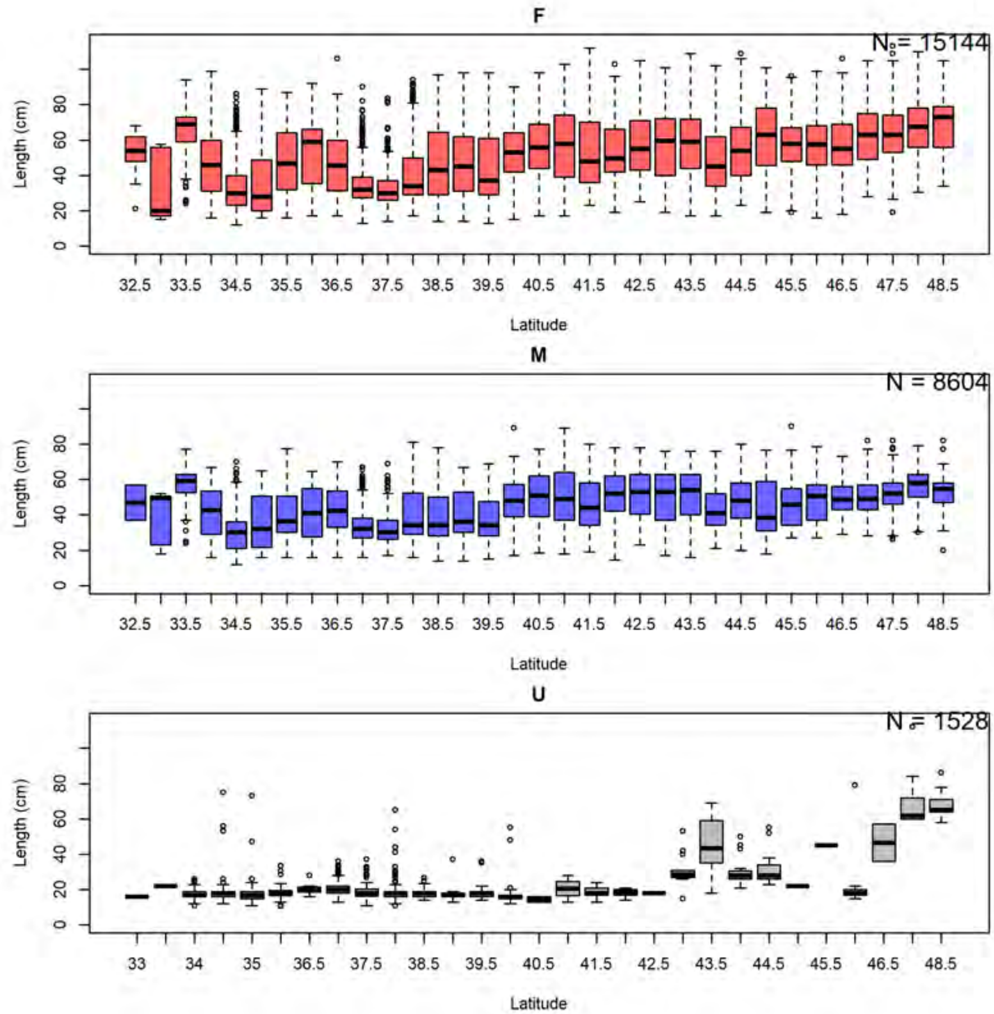


Figure 62: Histograms of lengths for female (top panel), male (middle panel) and unsexed (bottom panel) fish by latitude, in half degree increments. Samples sizes (N) for each sex are displayed in the upper left of each panel. Histograms show the median (solid bar), quartiles (colored boxes), 1.5 times interquartile range from the closest quartile or the most extreme data point (whiskers), and data beyond 1.5 times the interquartile range from the closest quartile (points).

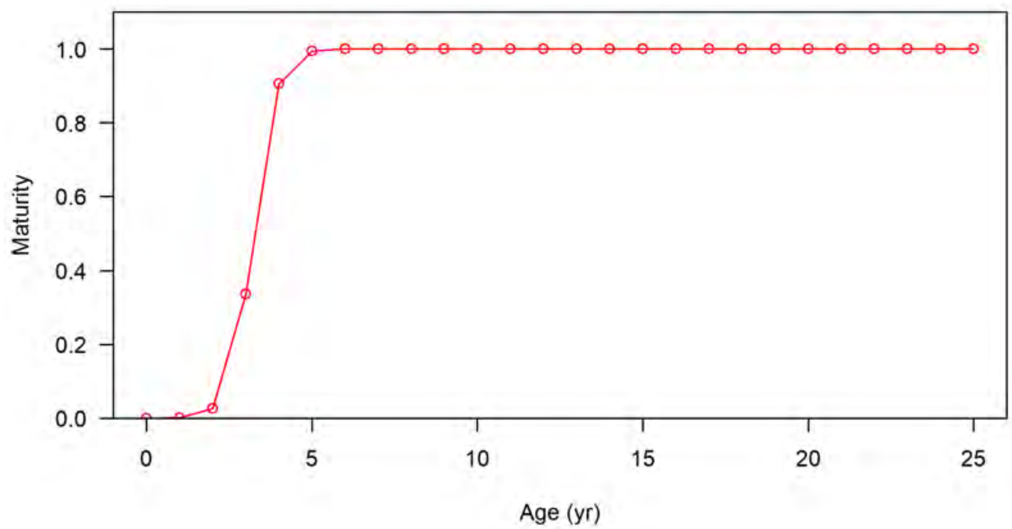


Figure 63: Maturity at age.

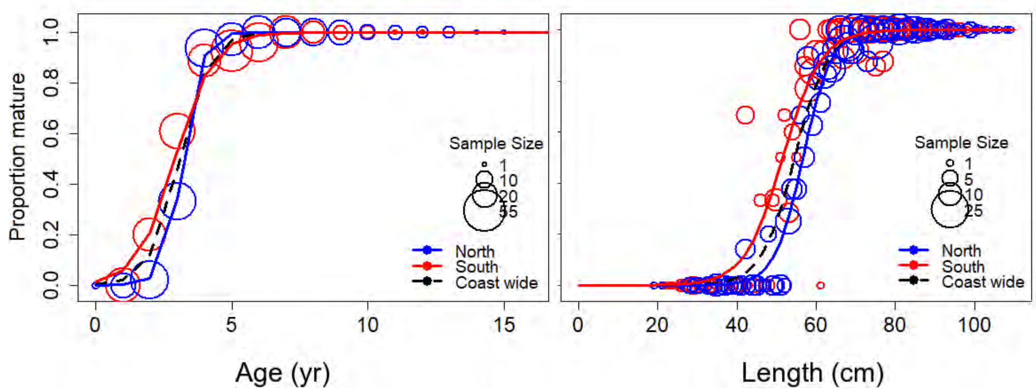


Figure 64: Proportion mature versus age (left panel; years) and length (right panel; cm) from fishery-independent and -dependent data sources. See Section 2.3.2 for details on the analysis.

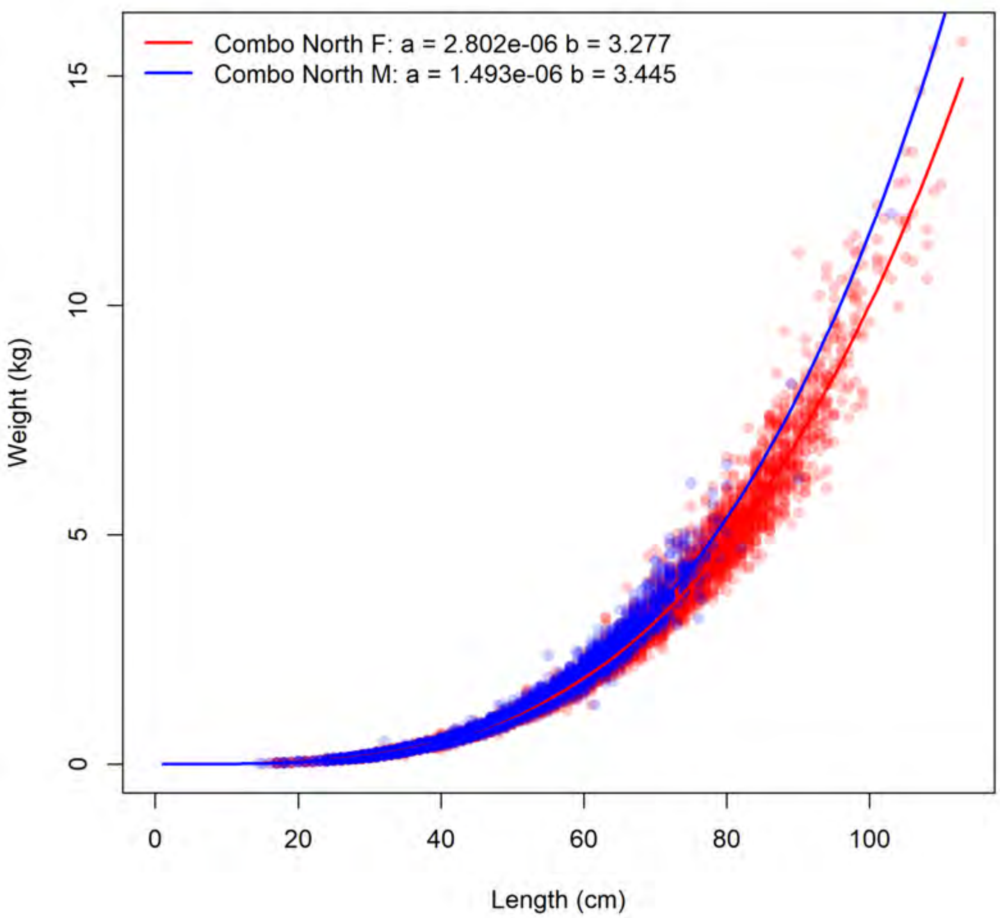


Figure 65: Weight-length relationship for males and females from the WCGBTS.

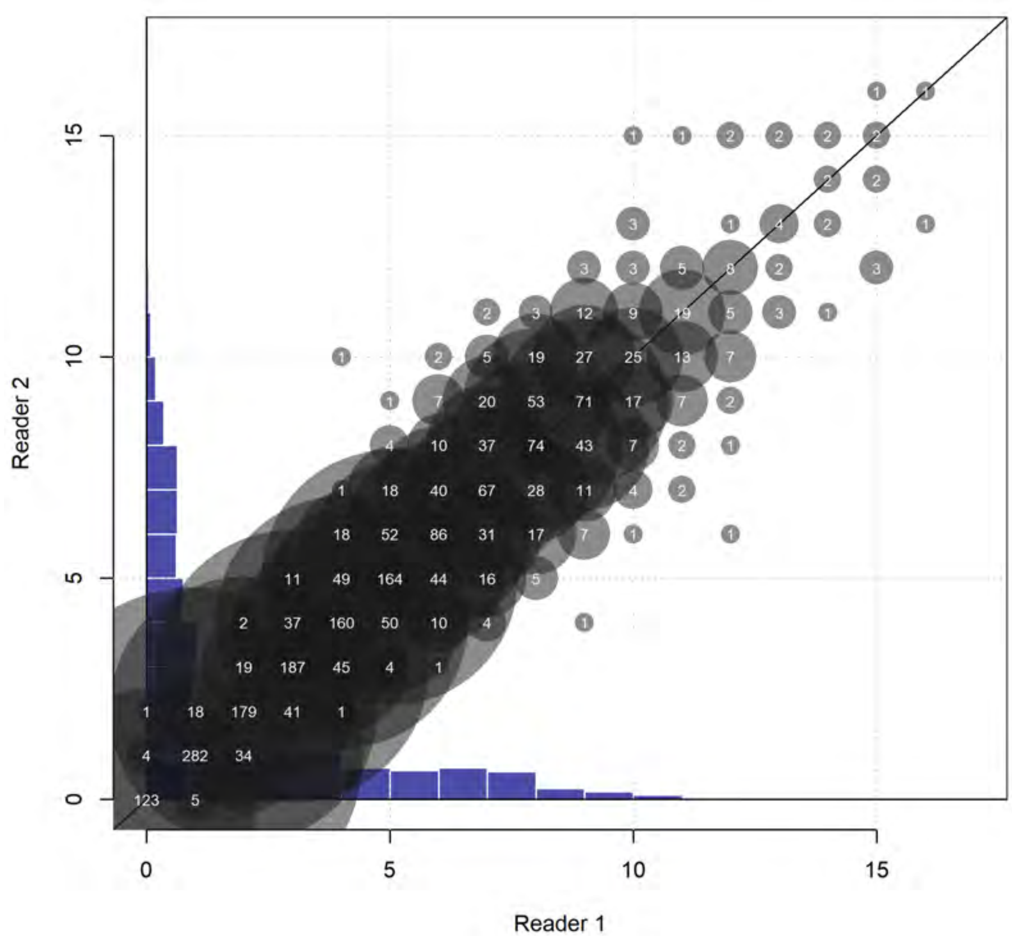


Figure 66: Comparison of age estimates from the double reads. Sample sizes associated with each combination of ages are shown by the size circles and the values within the circles. The blue histograms show the distribution of ages. This represents all double reads pooled together so 'Reader 1' and 'Reader 2' are generic and descriptions do not represent specific individuals.

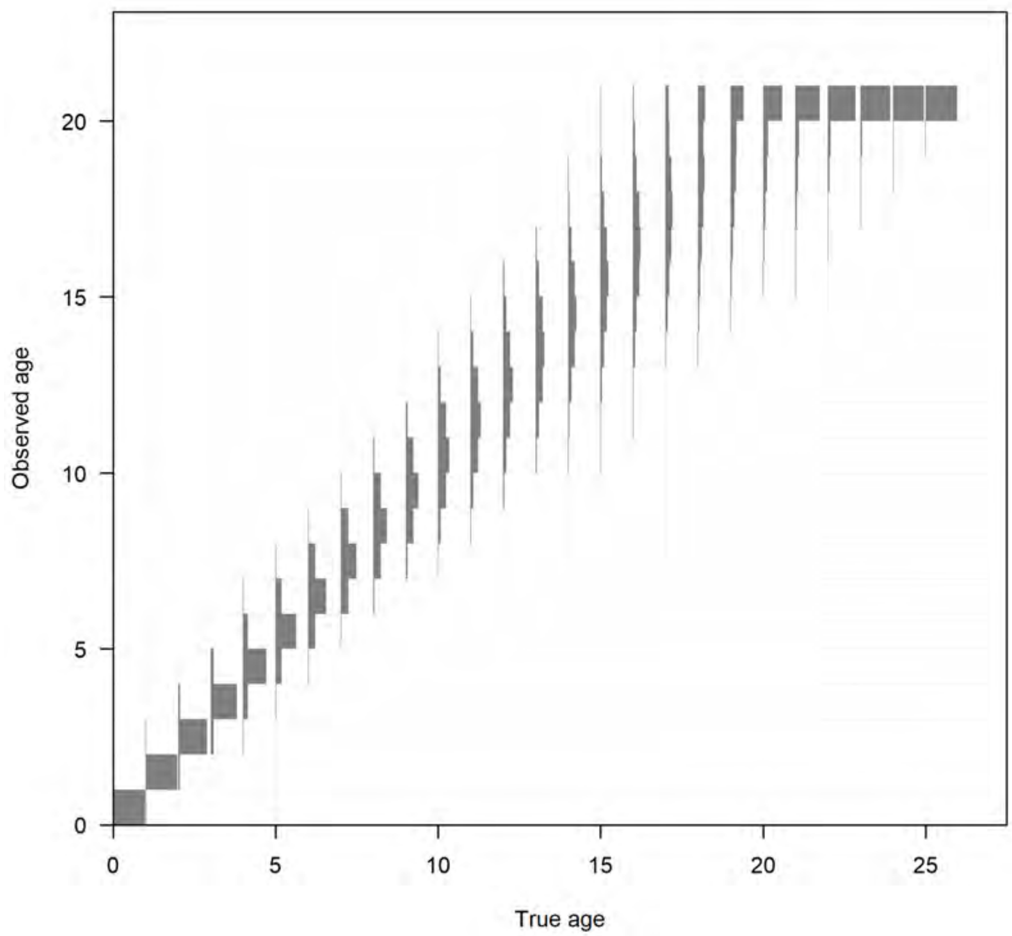


Figure 67: Distribution of observed age at true age for ageing error type 1.

7.3 Model results figures

7.3.1 Selectivity

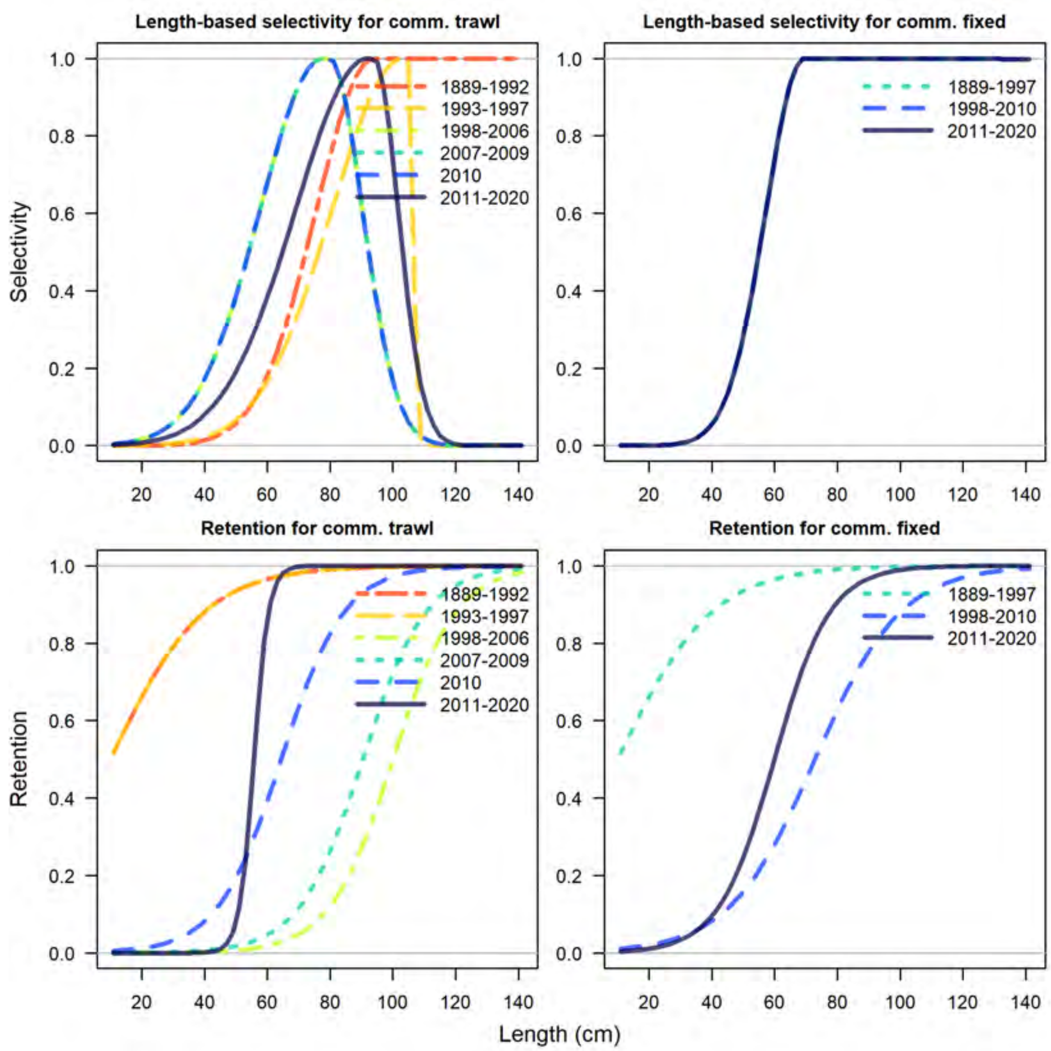


Figure 68: Time-varying selectivity (top) and retention (bottom) for the commercial trawl and fixed-gear fleets.

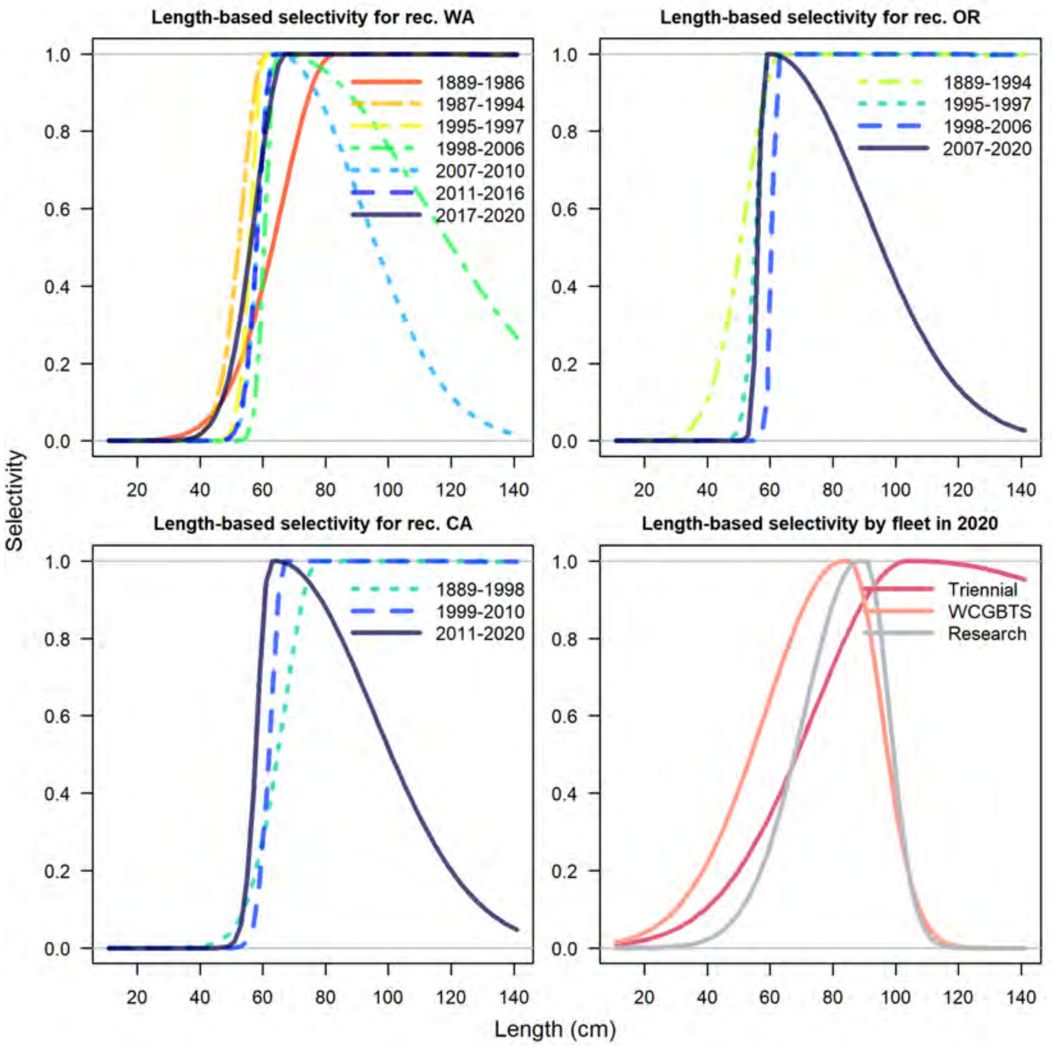


Figure 69: Time-varying selectivity for the three recreational fleets and comparison of selectivity among the different surveys.

7.3.2 Fits to data

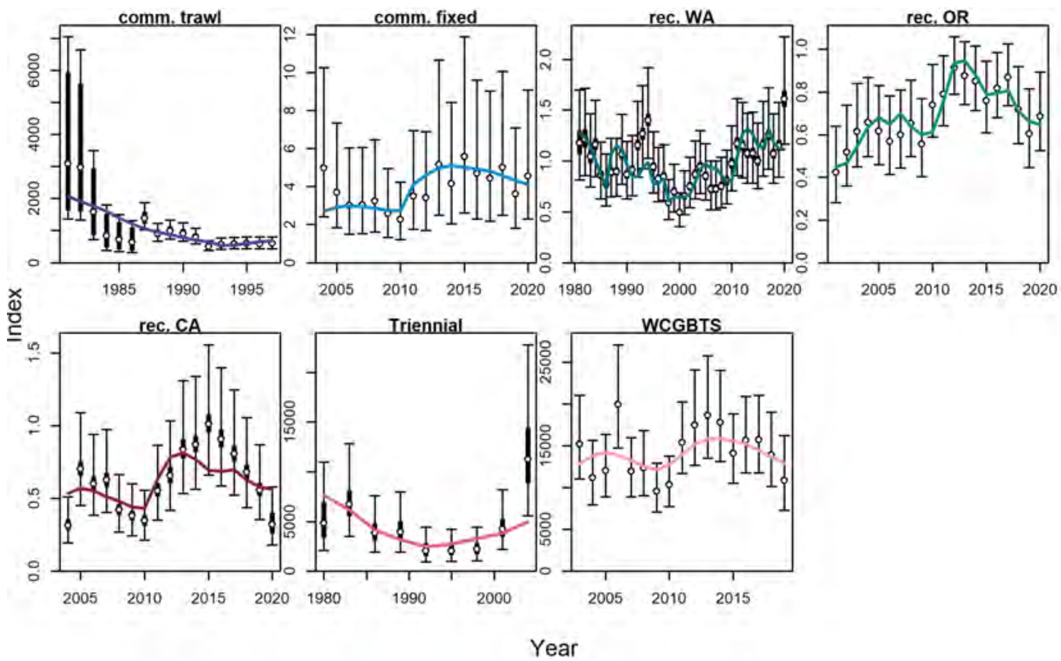


Figure 70: Index fits for all fleets. Lines indicate 95% uncertainty interval around estimated values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of an estimated additional uncertainty parameter which is added to the standard error of all years within an index.

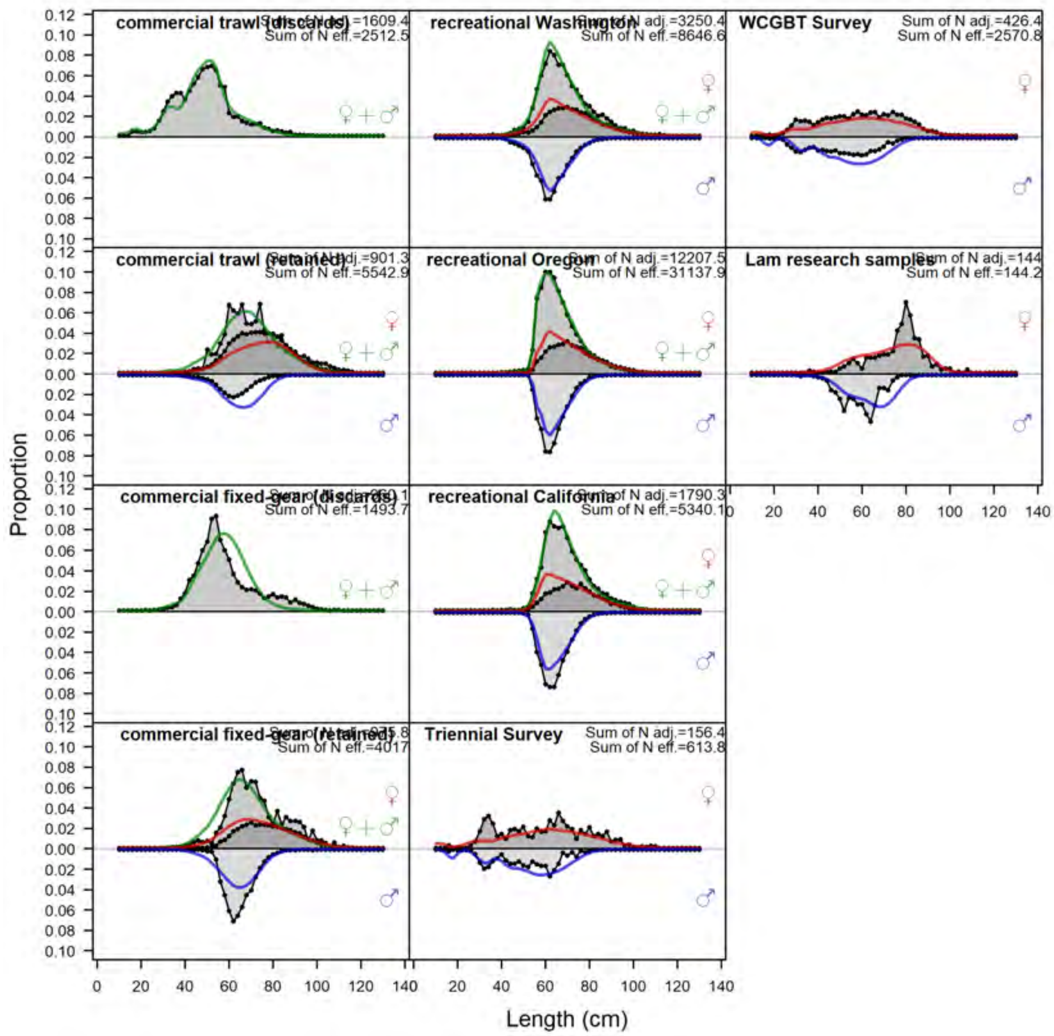


Figure 71: Length comps, aggregated across time by fleet. Labels 'retained' and 'discard' indicate discarded or retained sampled for each fleet. Panels without this designation represent the whole catch.

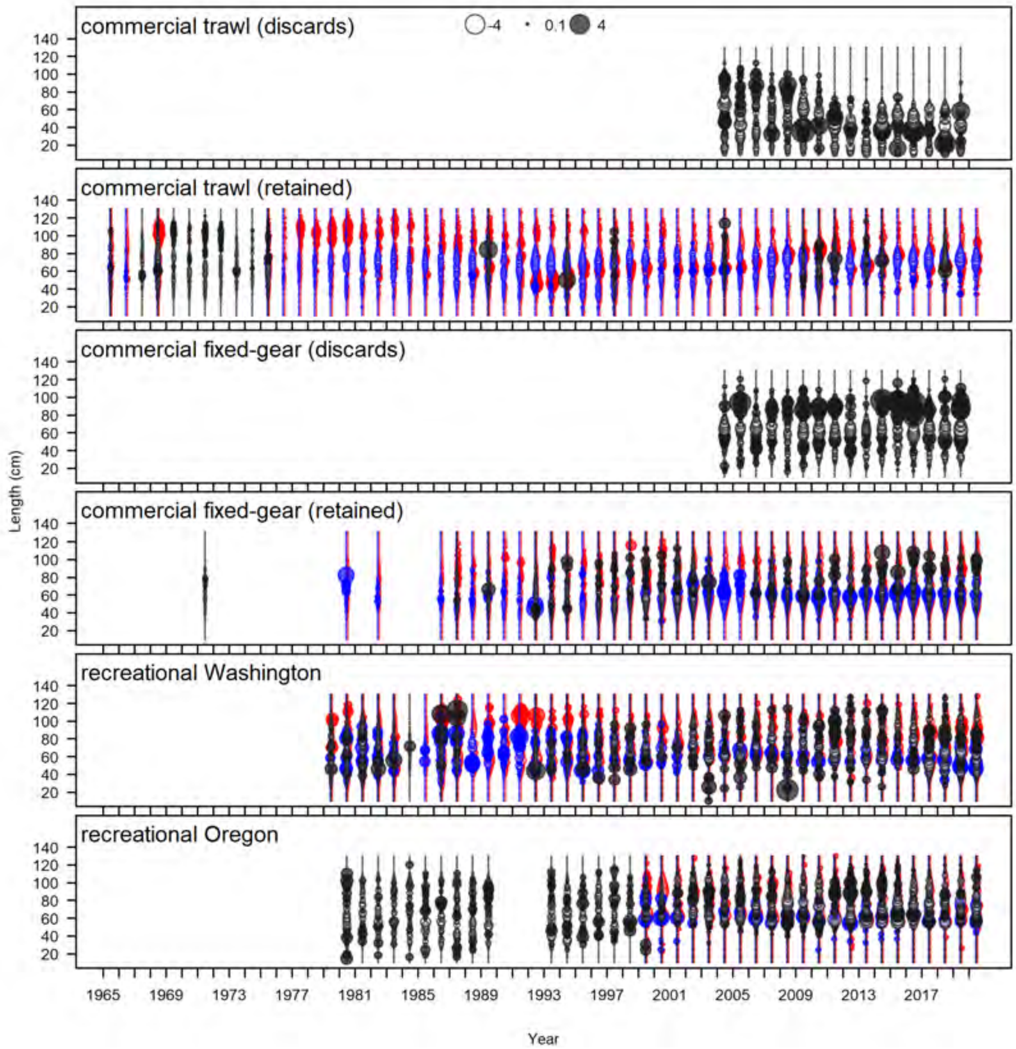


Figure 72: Pearson residuals, comparing across fleets (plot 1 of 2) Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

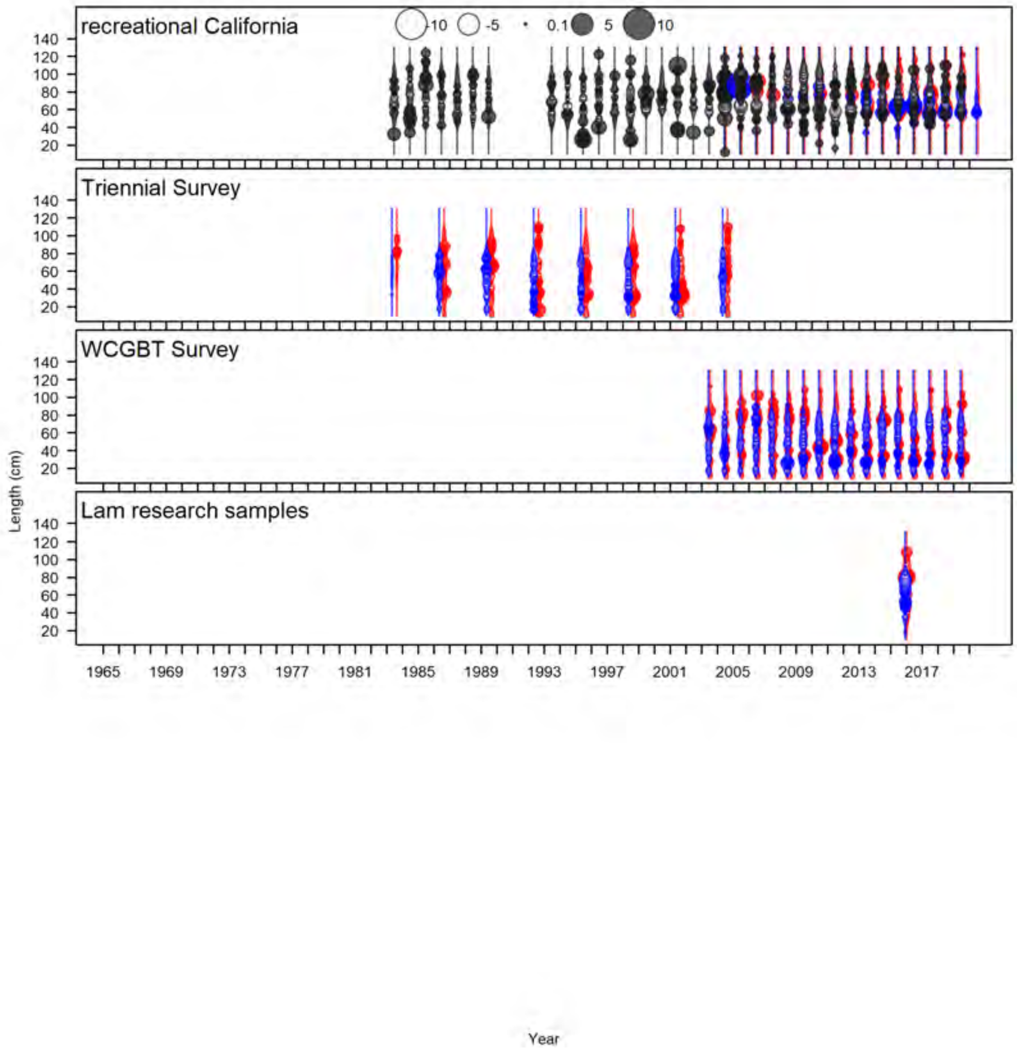


Figure 73: Pearson residuals, comparing across fleets (plot 2 of 2).

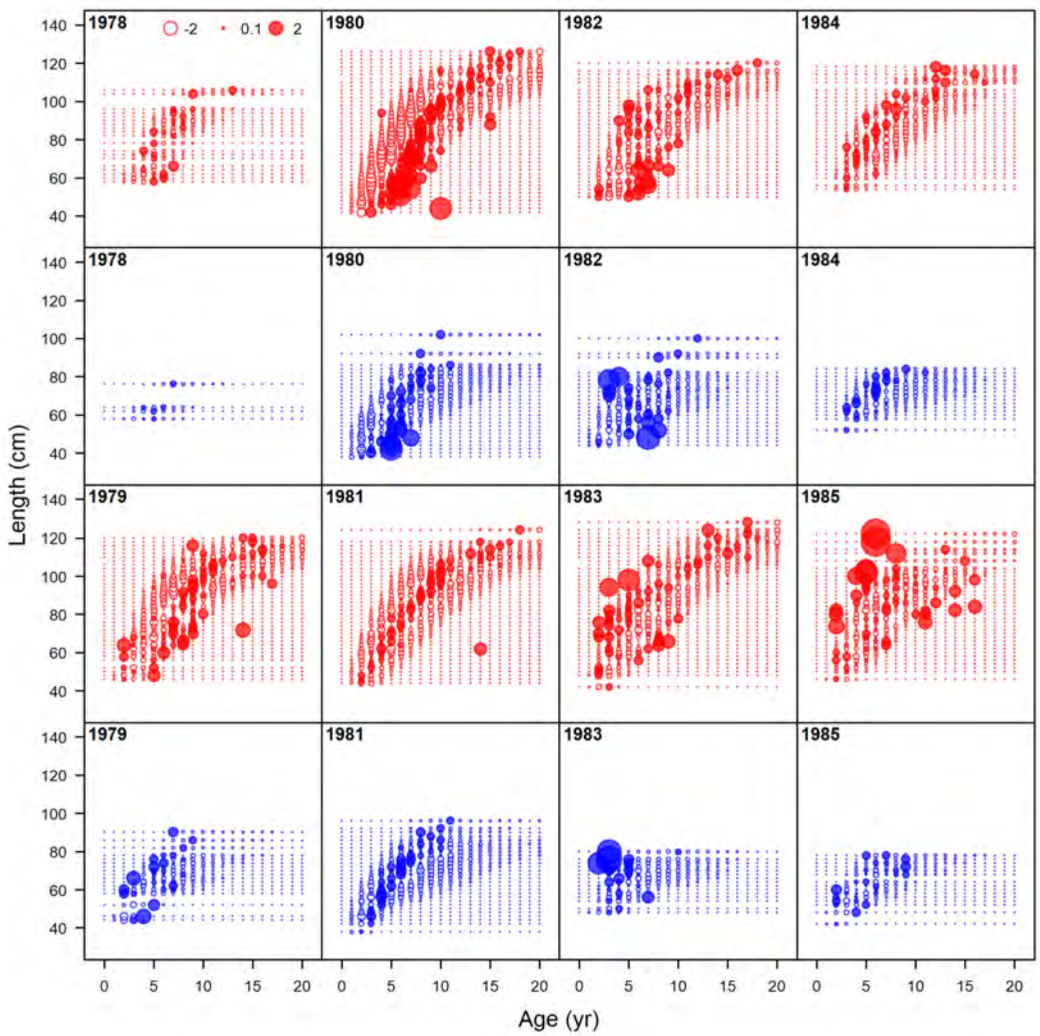


Figure 74: Pearson residuals, retained, commercial trawl (max=8.71) (plot 1 of 6).

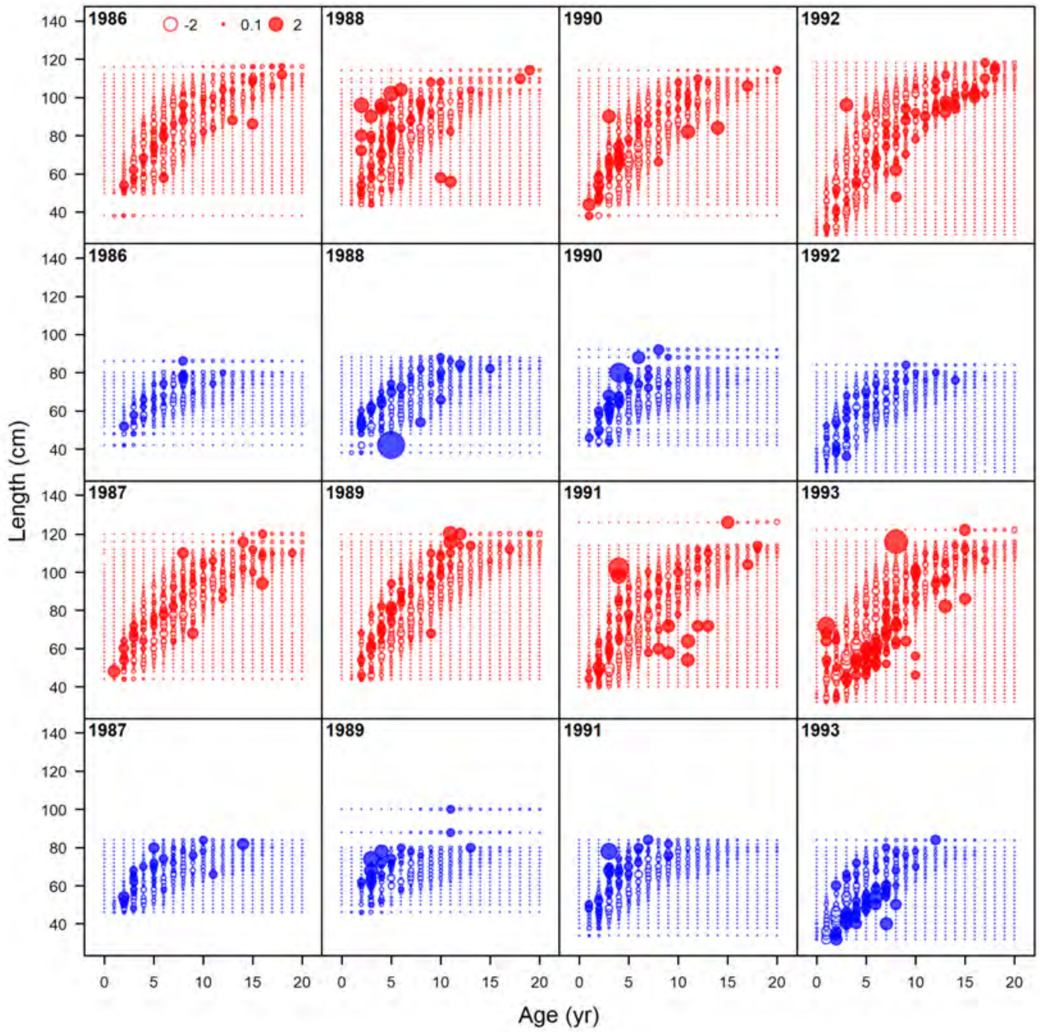


Figure 75: Pearson residuals, retained, commercial trawl (max=8.71) (plot 2 of 6).

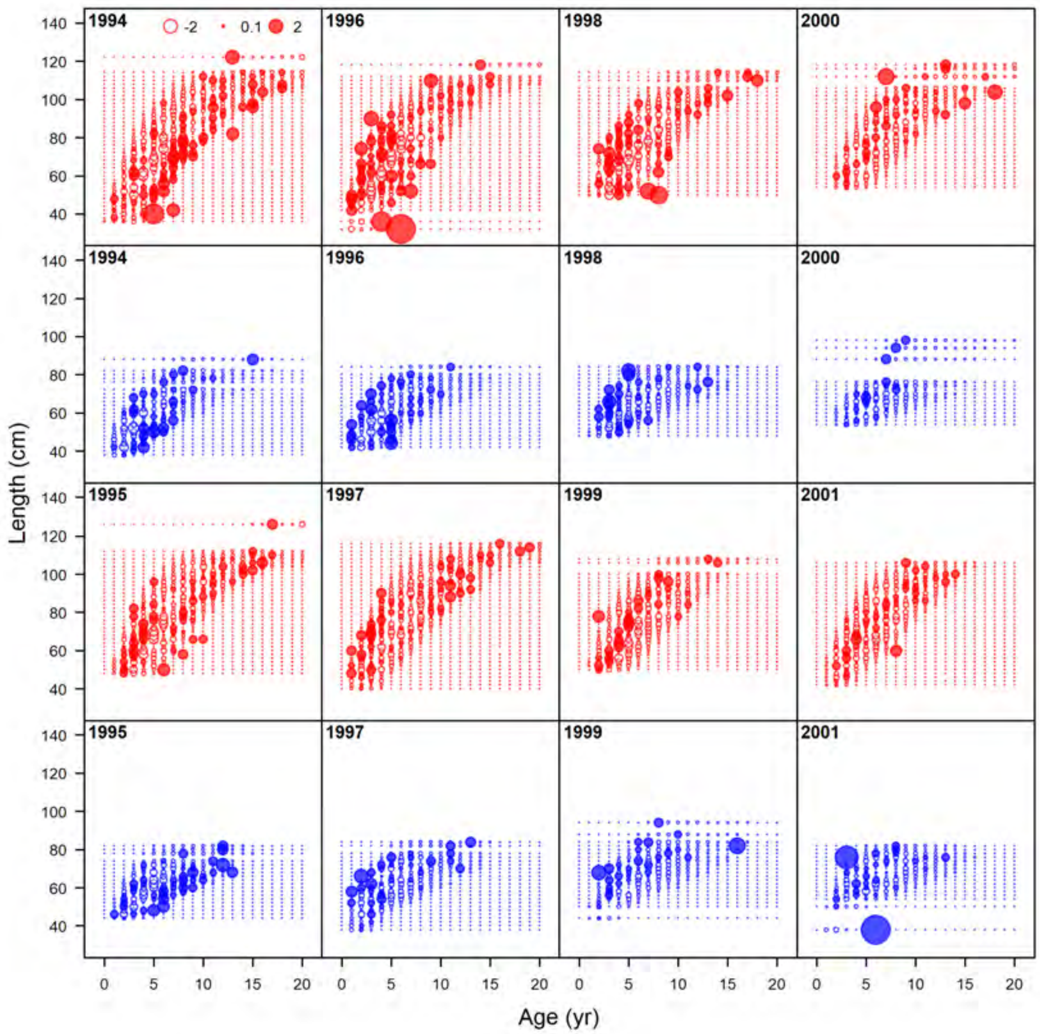


Figure 76: Pearson residuals, retained, commercial trawl (max=8.71) (plot 3 of 6).

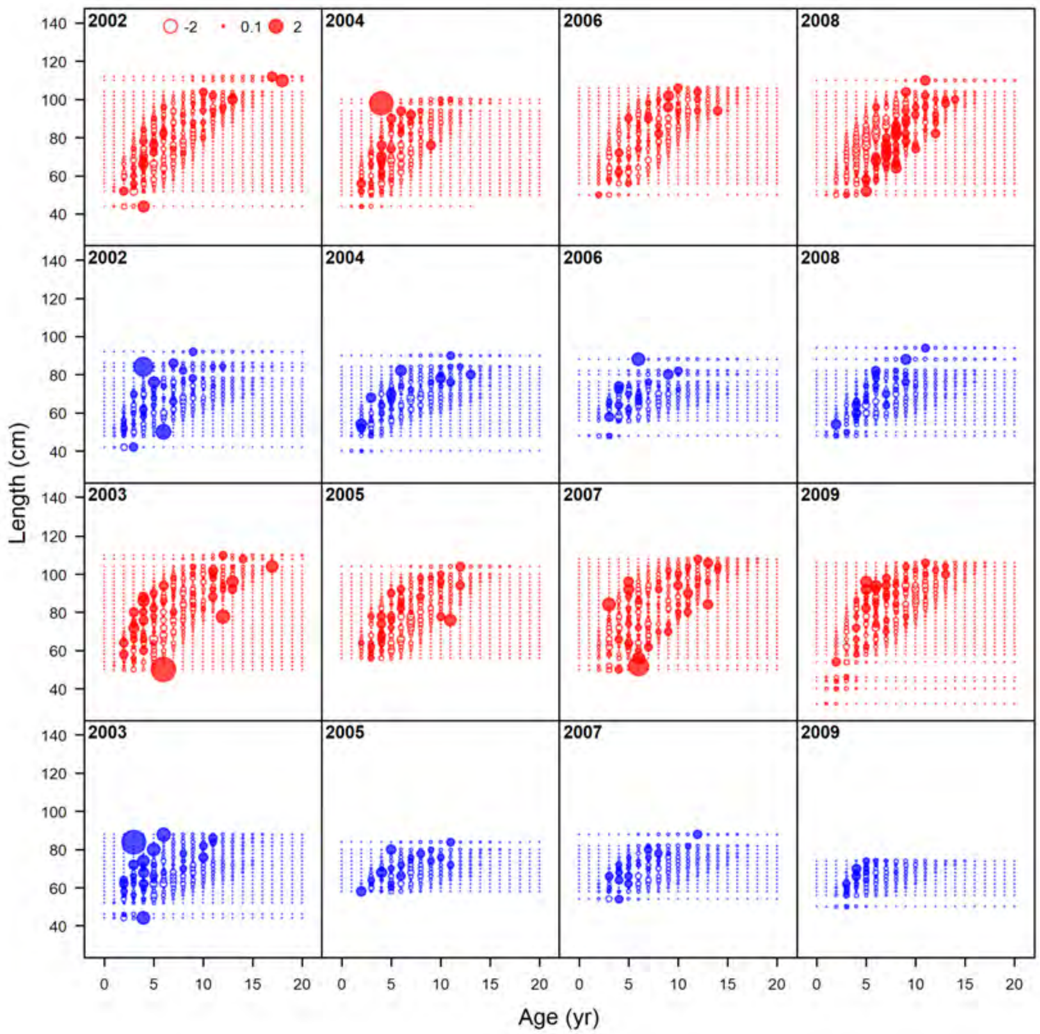


Figure 77: Pearson residuals, retained, commercial trawl (max=8.71) (plot 4 of 6).

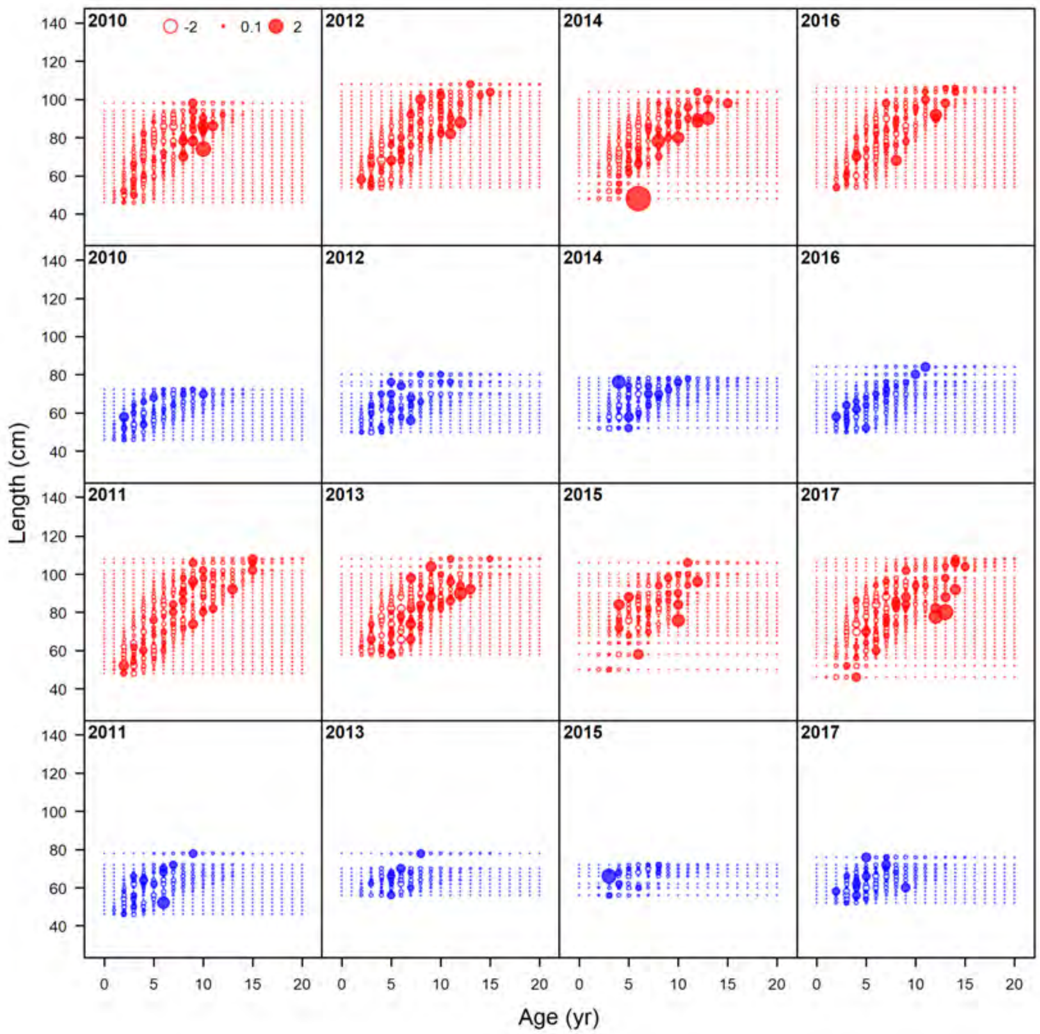


Figure 78: Pearson residuals, retained, commercial trawl (max=8.71) (plot 5 of 6).

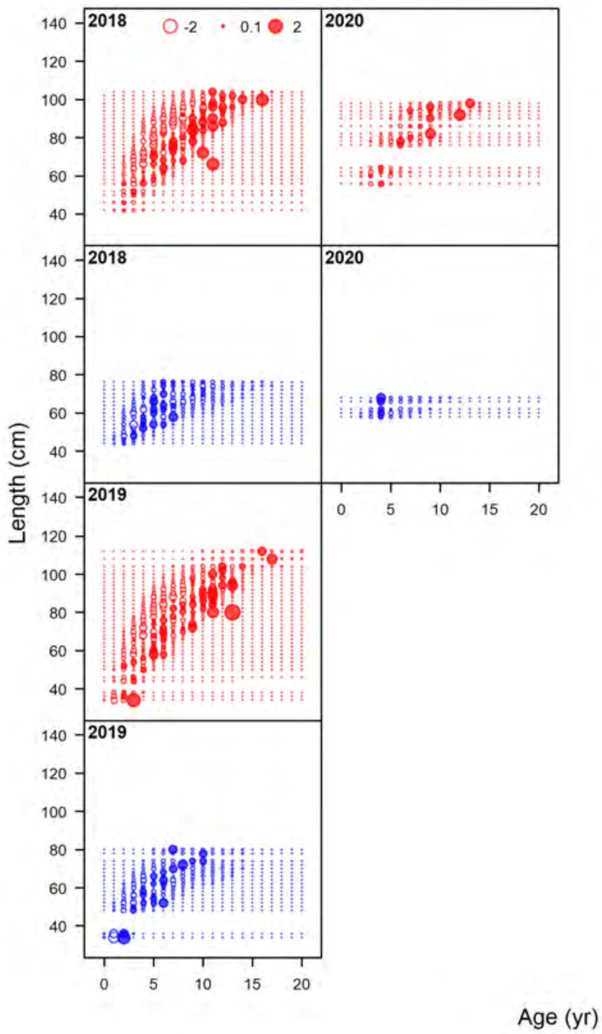


Figure 79: Pearson residuals, retained, commercial trawl (max=8.71) (plot 6 of 6).

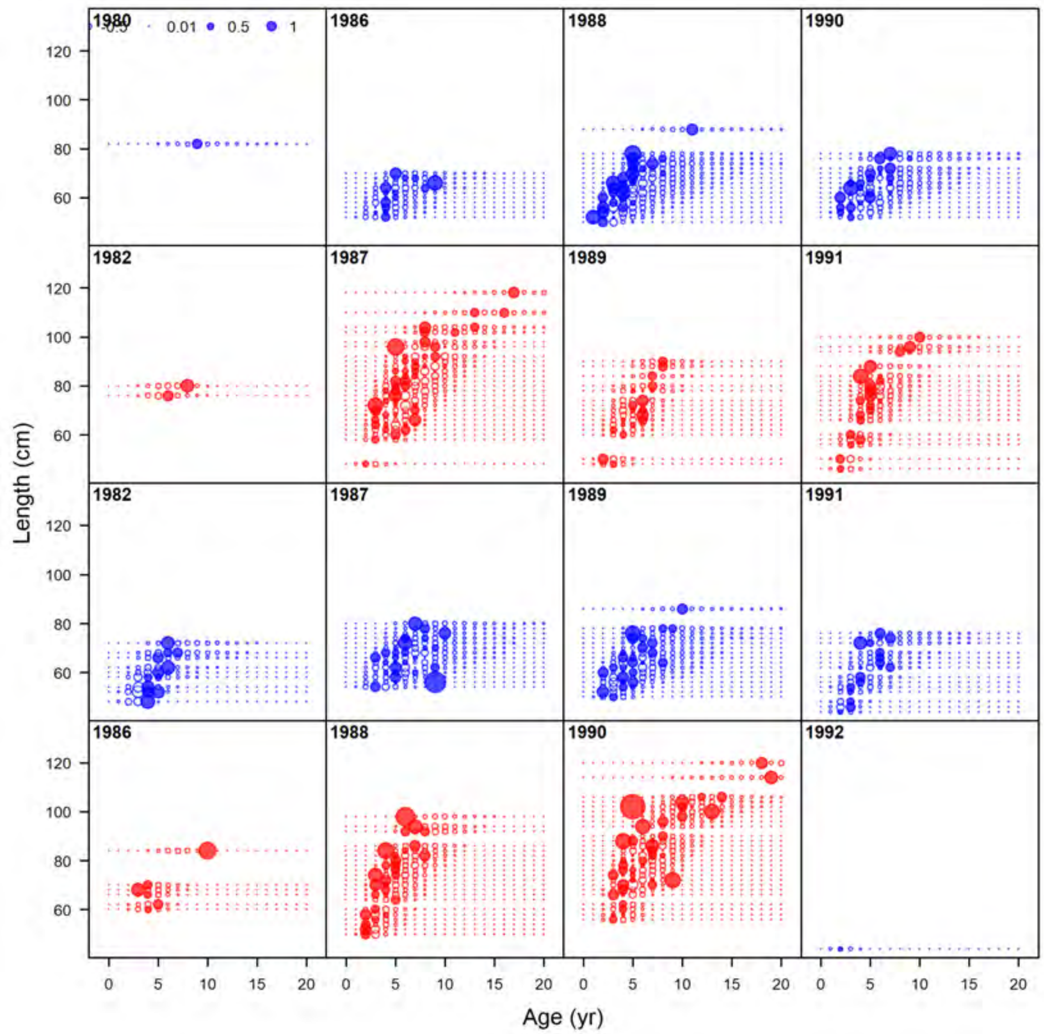


Figure 80: Pearson residuals, retained, commercial fixed-gear (max=16.25) (plot 1 of 5).

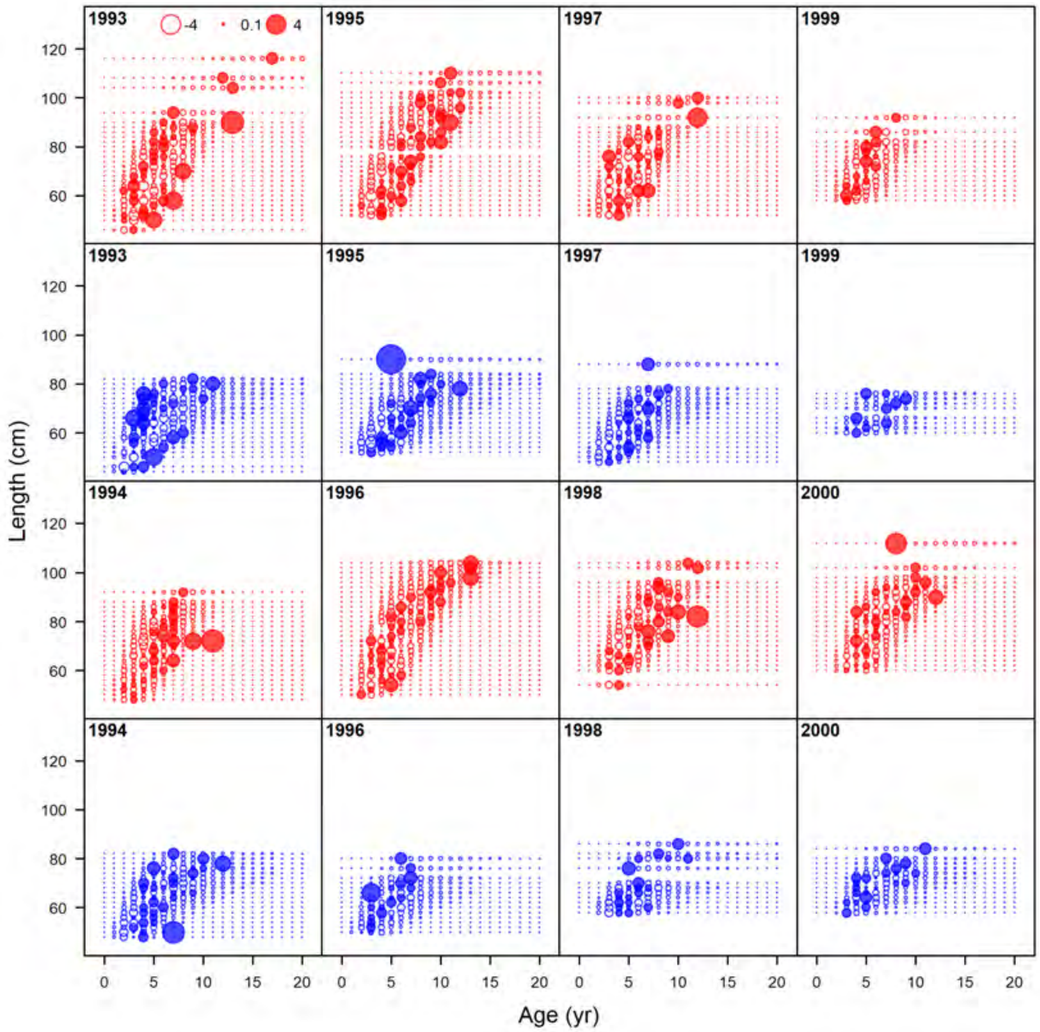


Figure 81: Pearson residuals, retained, commercial fixed-gear (max=16.25) (plot 2 of 5).

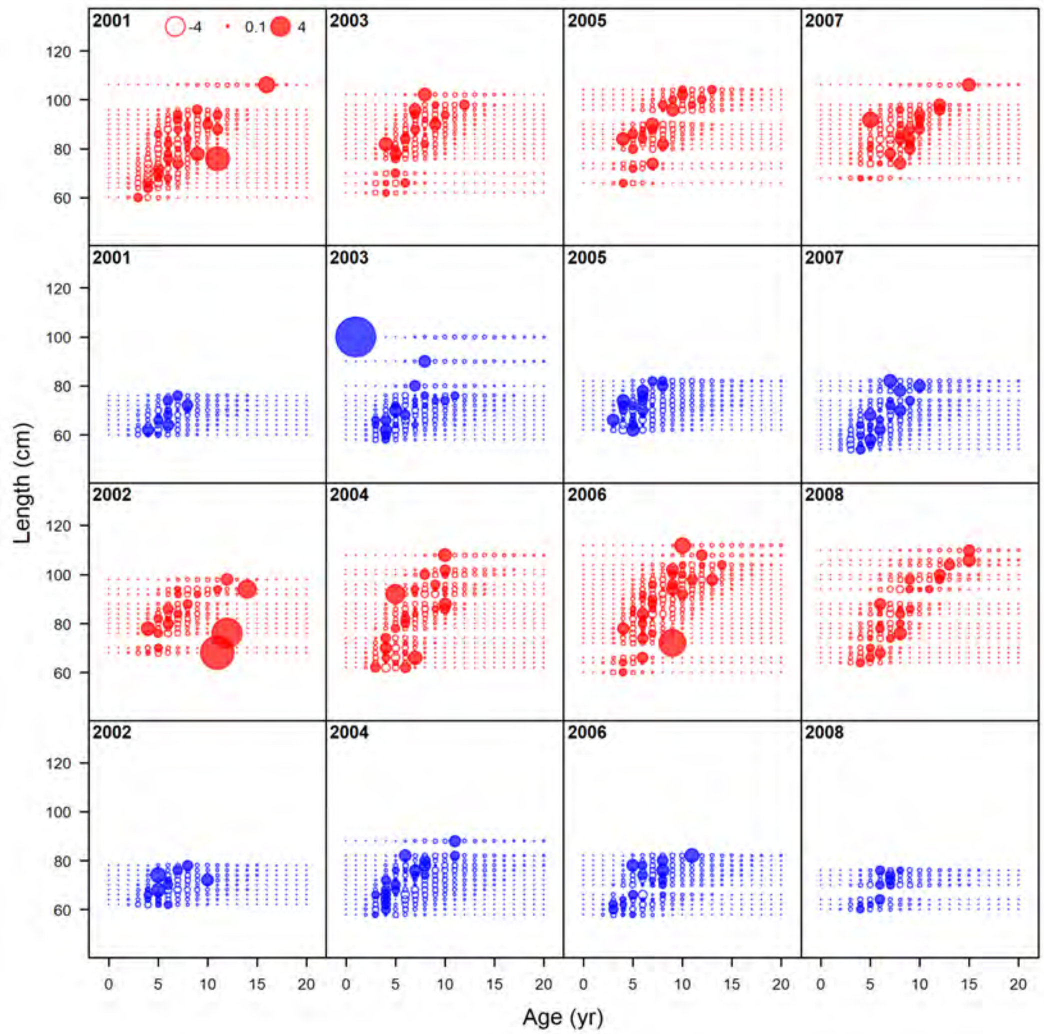


Figure 82: Pearson residuals, retained, commercial fixed-gear (max=16.25) (plot 3 of 5).

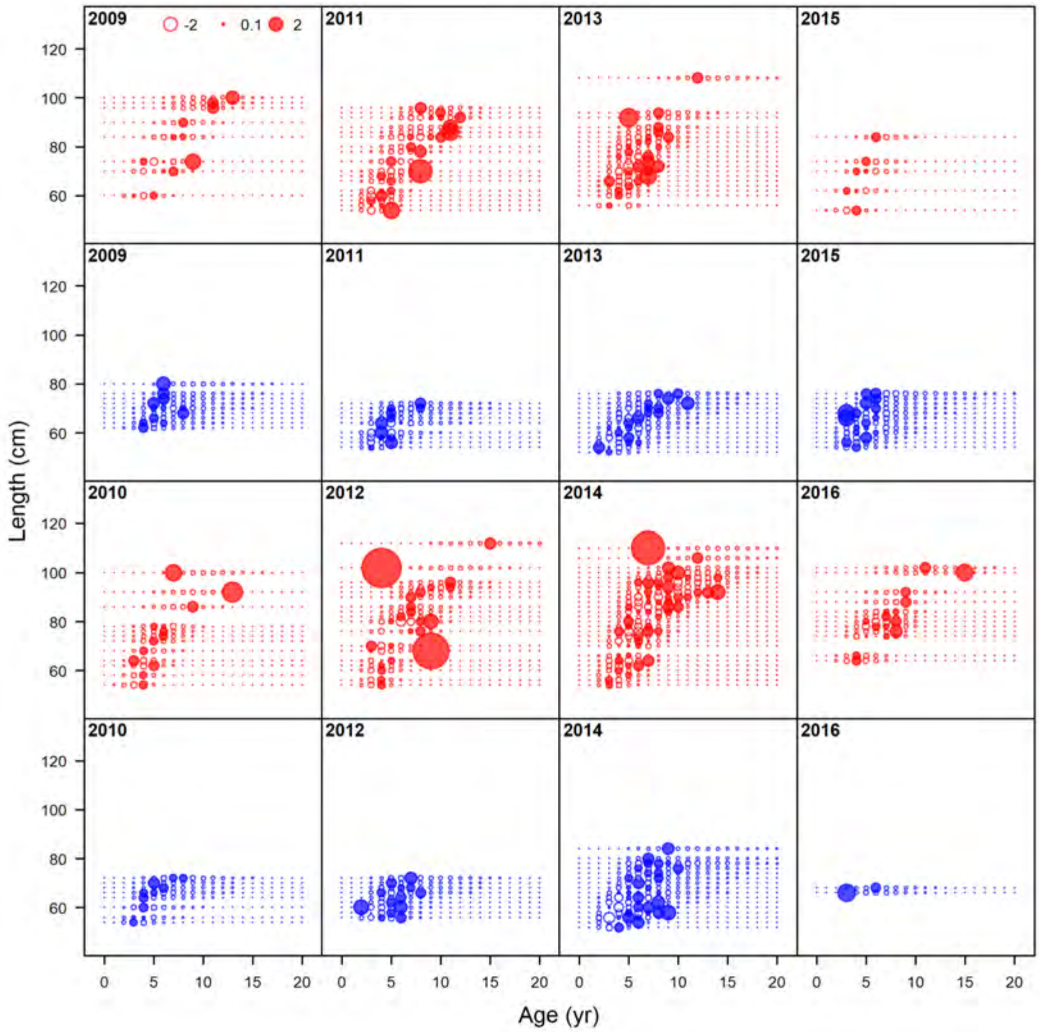


Figure 83: Pearson residuals, retained, commercial fixed-gear (max=16.25) (plot 4 of 5).

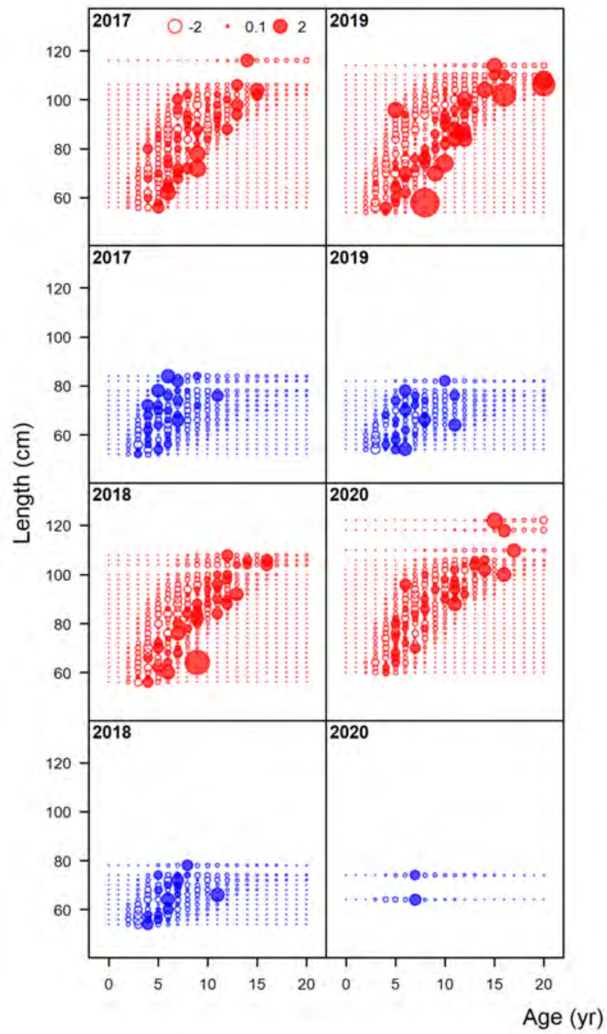


Figure 84: Pearson residuals, retained, commercial fixed-gear (max=16.25) (plot 5 of 5).

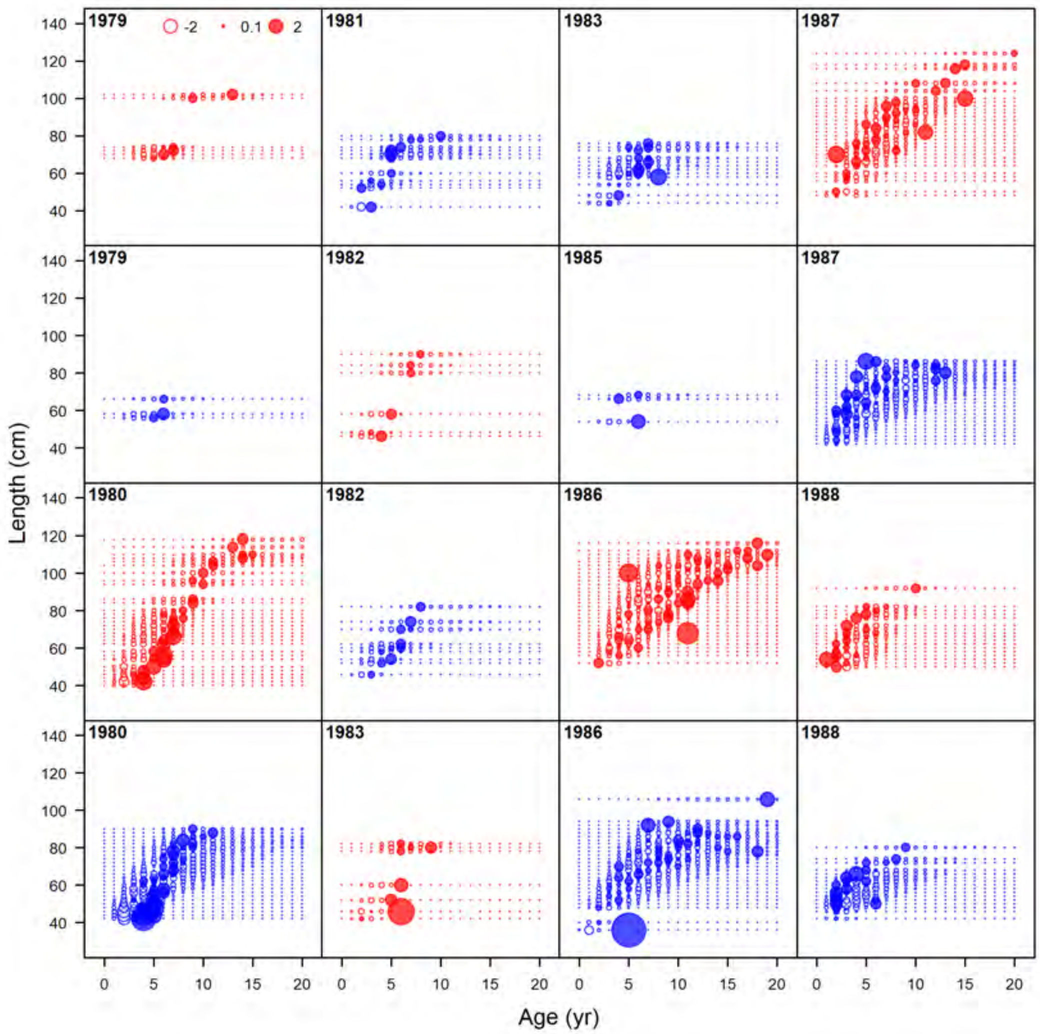


Figure 85: Pearson residuals, whole catch, recreational Washington (max=11.97) (plot 1 of 6).

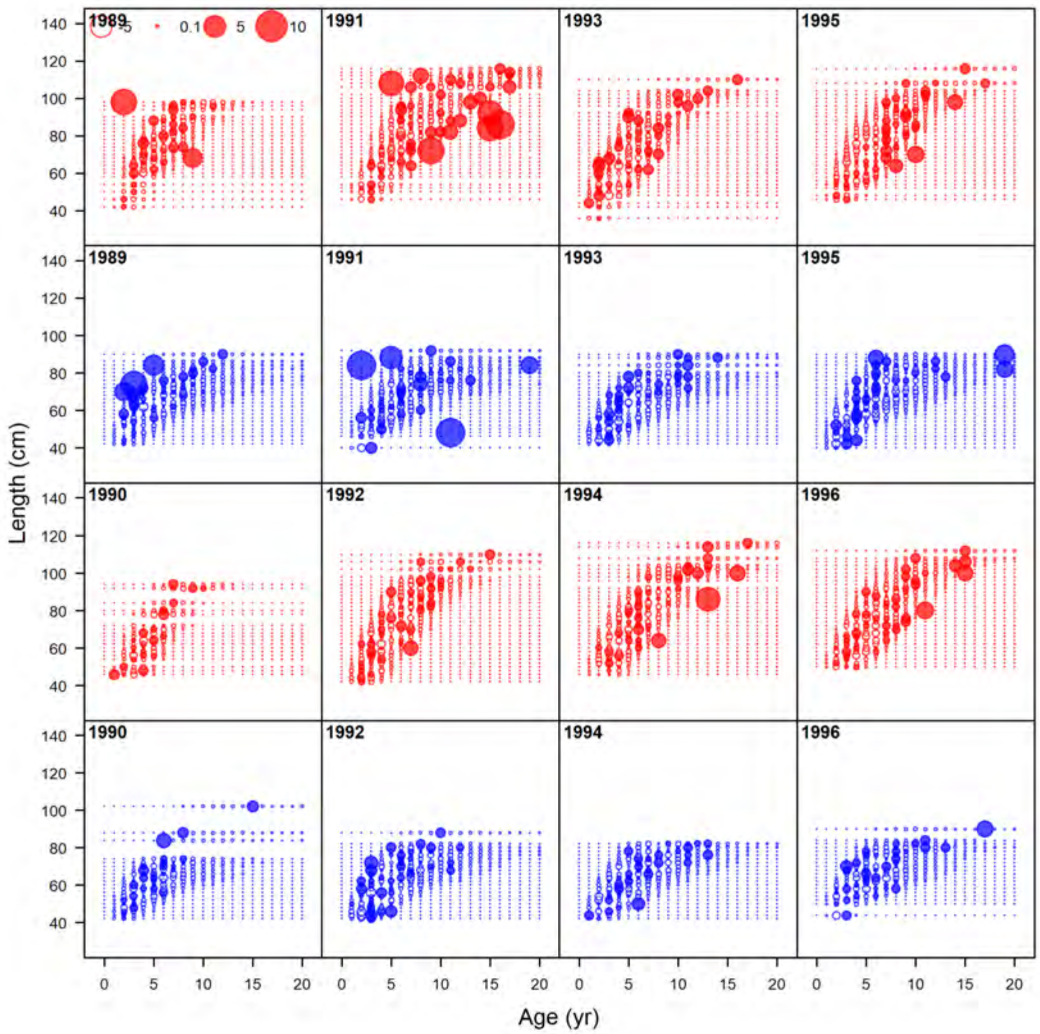


Figure 86: Pearson residuals, whole catch, recreational Washington (max=11.97) (plot 2 of 6).

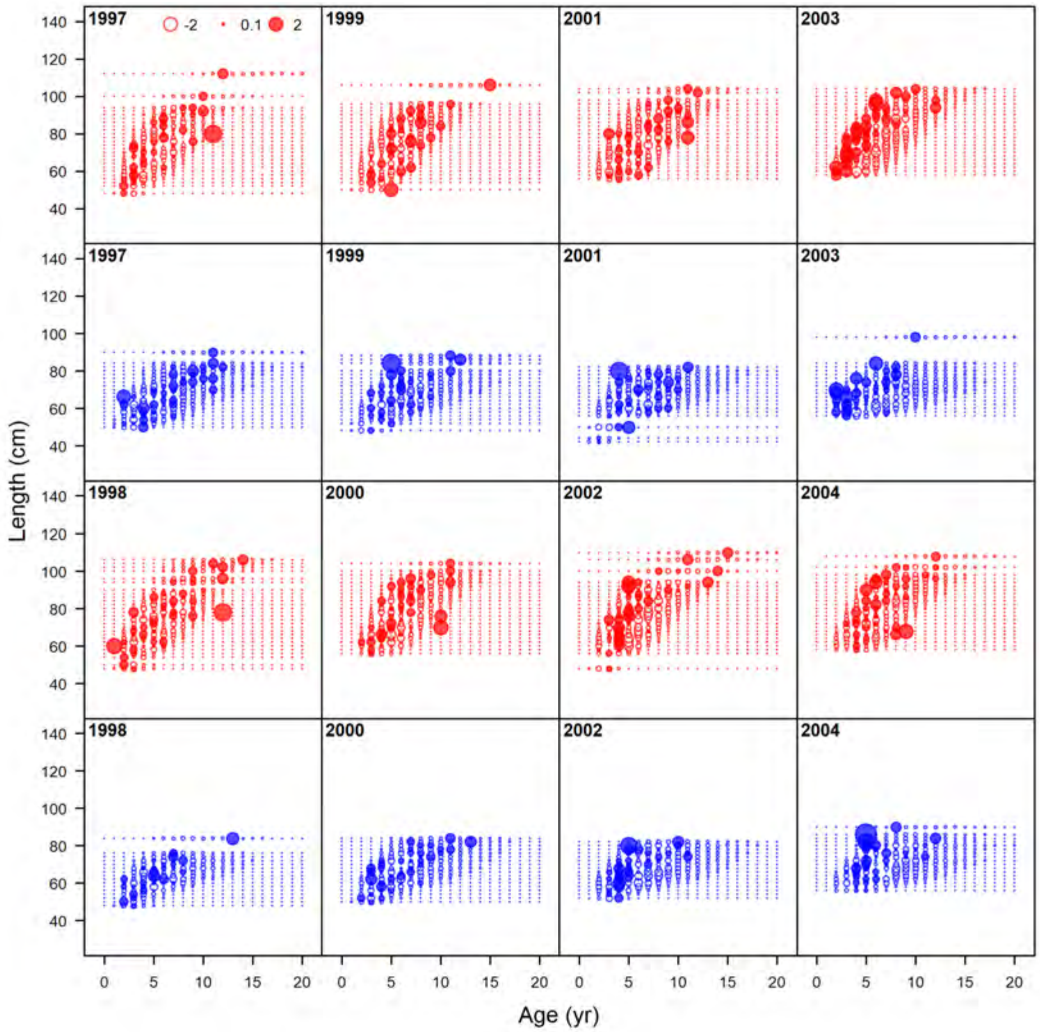


Figure 87: Pearson residuals, whole catch, recreational Washington (max=11.97) (plot 3 of 6).

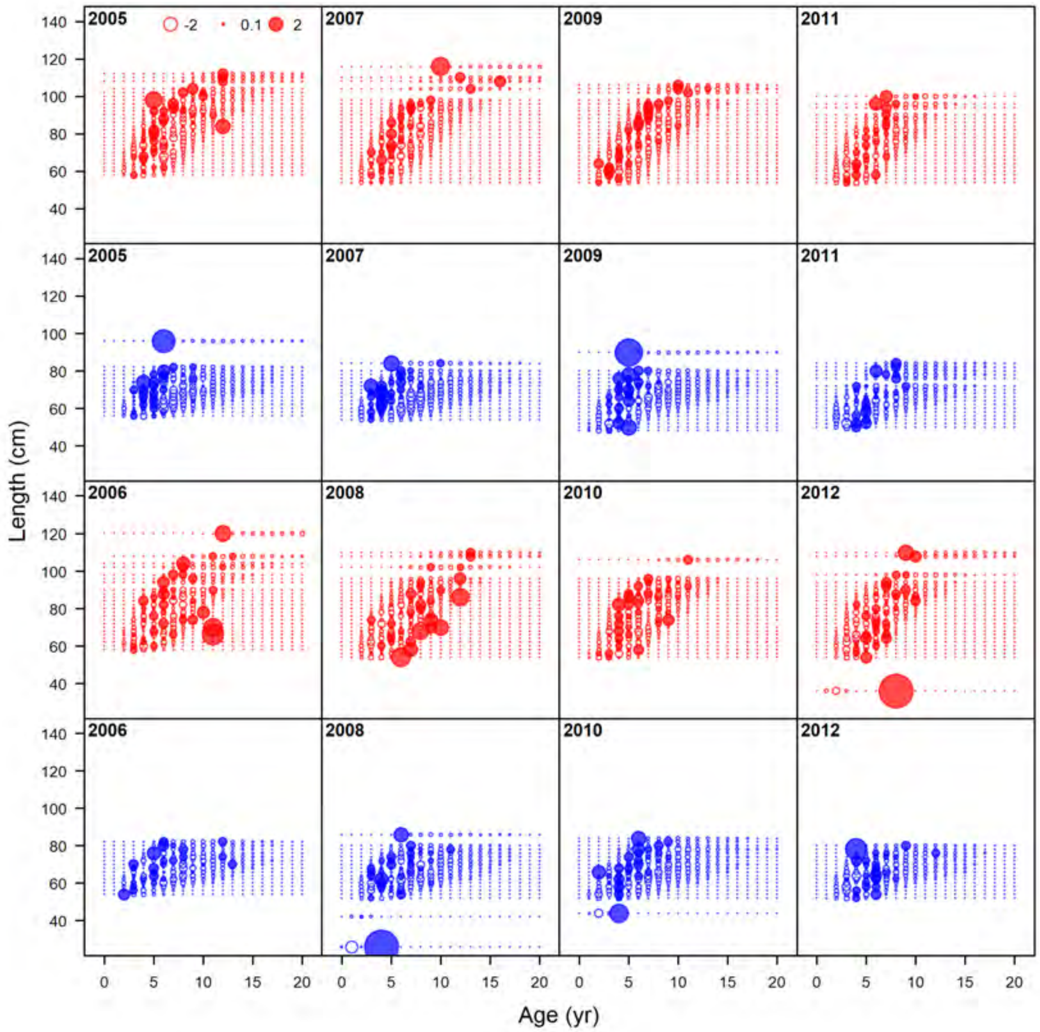


Figure 88: Pearson residuals, whole catch, recreational Washington (max=11.97) (plot 4 of 6).

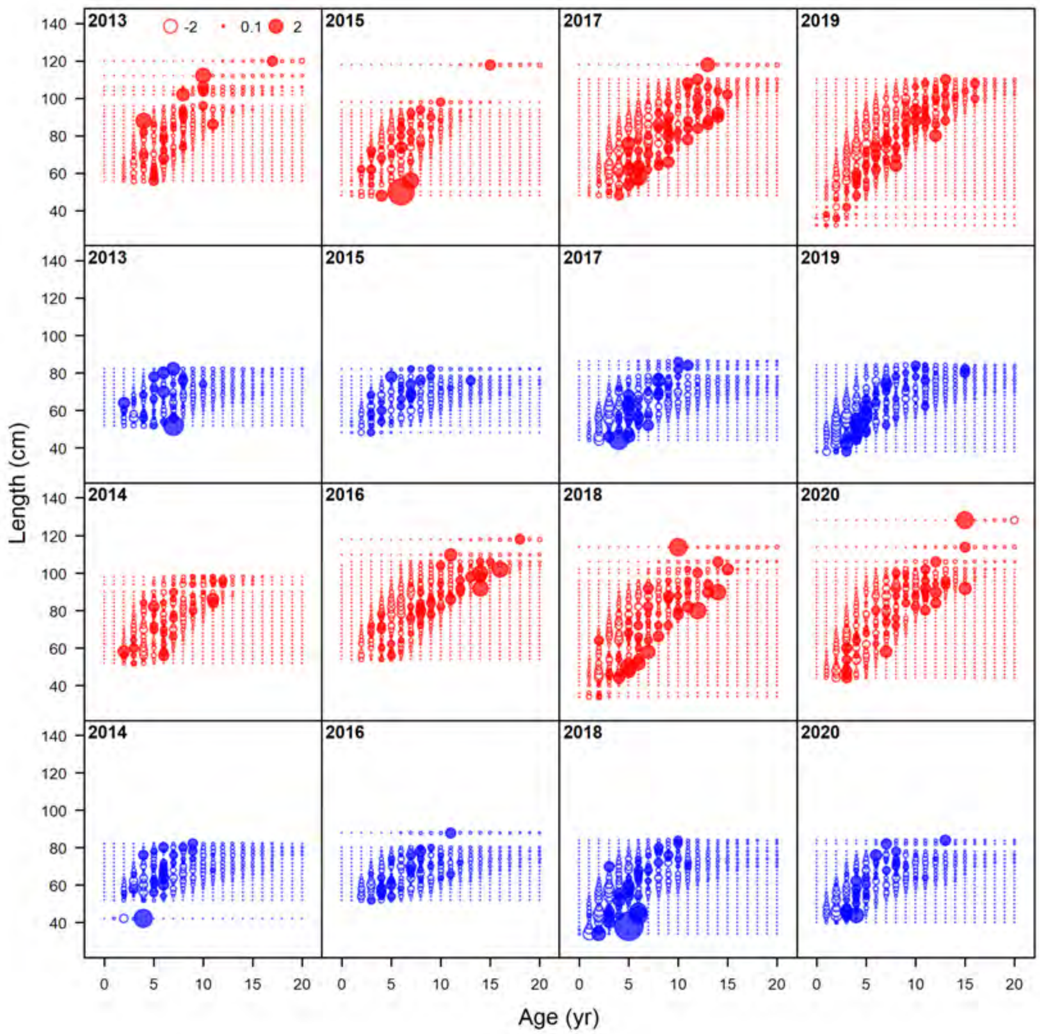


Figure 89: Pearson residuals, whole catch, recreational Washington (max=11.97) (plot 5 of 6).

Figure 90: Pearson residuals, whole catch, recreational Washington (max=11.97) (plot 6 of 6).

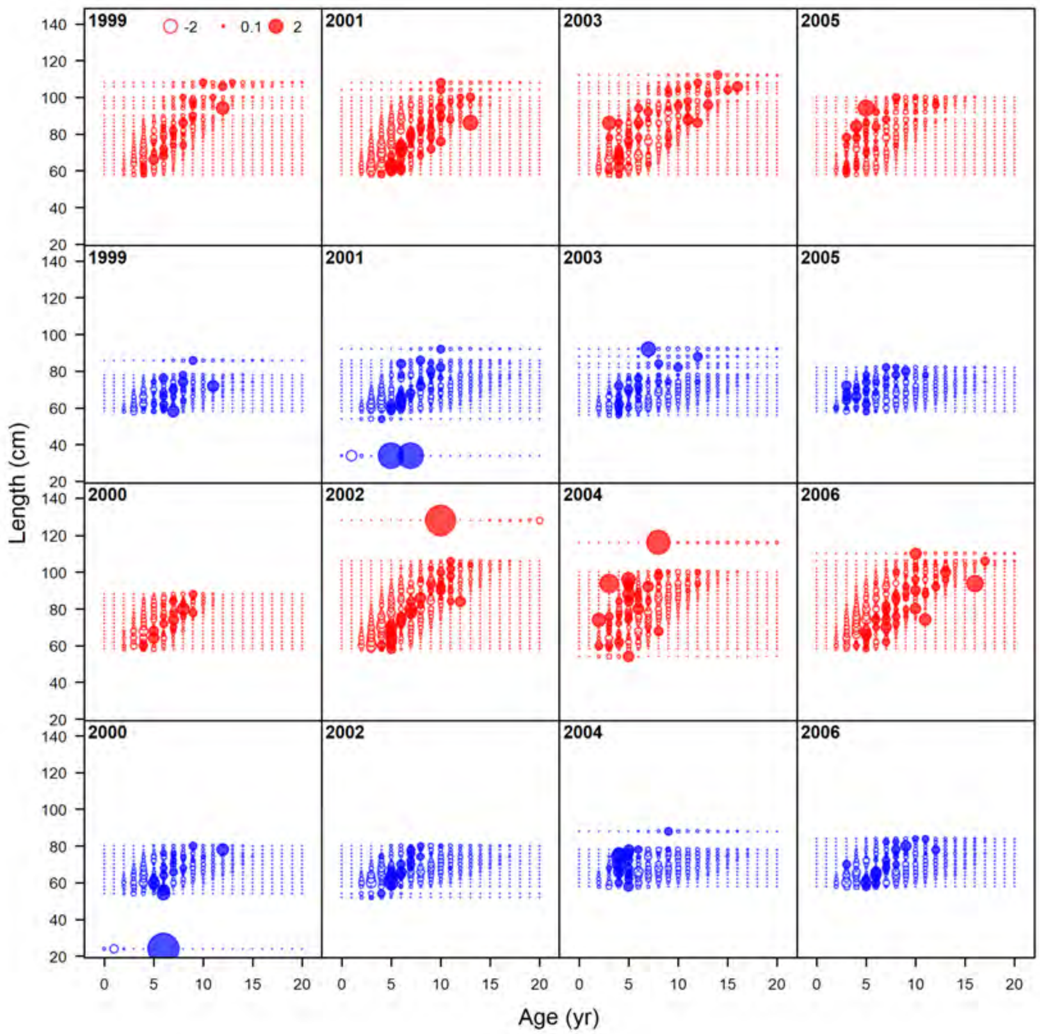


Figure 91: Pearson residuals, whole catch, recreational Oregon (max=9.96) (plot 1 of 3).

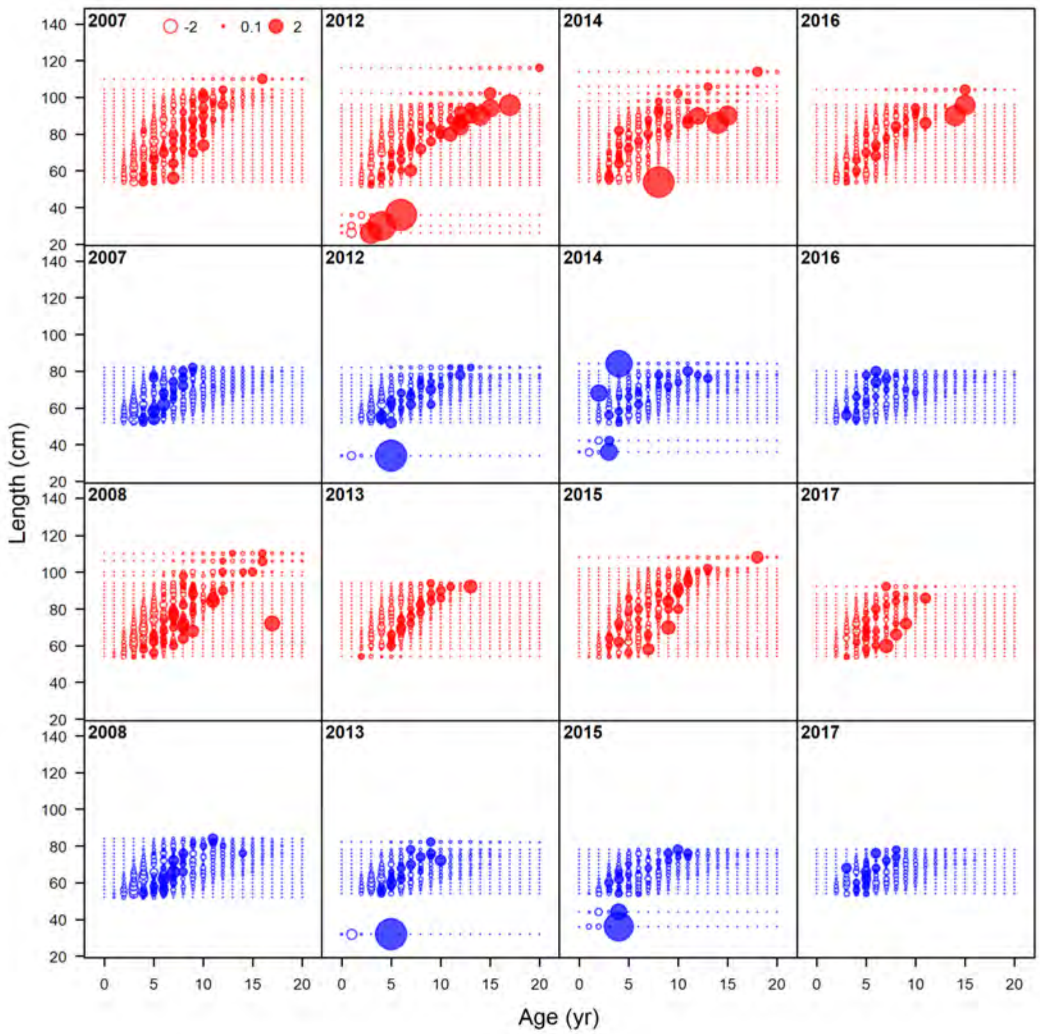


Figure 92: Pearson residuals, whole catch, recreational Oregon (max=9.96) (plot 2 of 3).

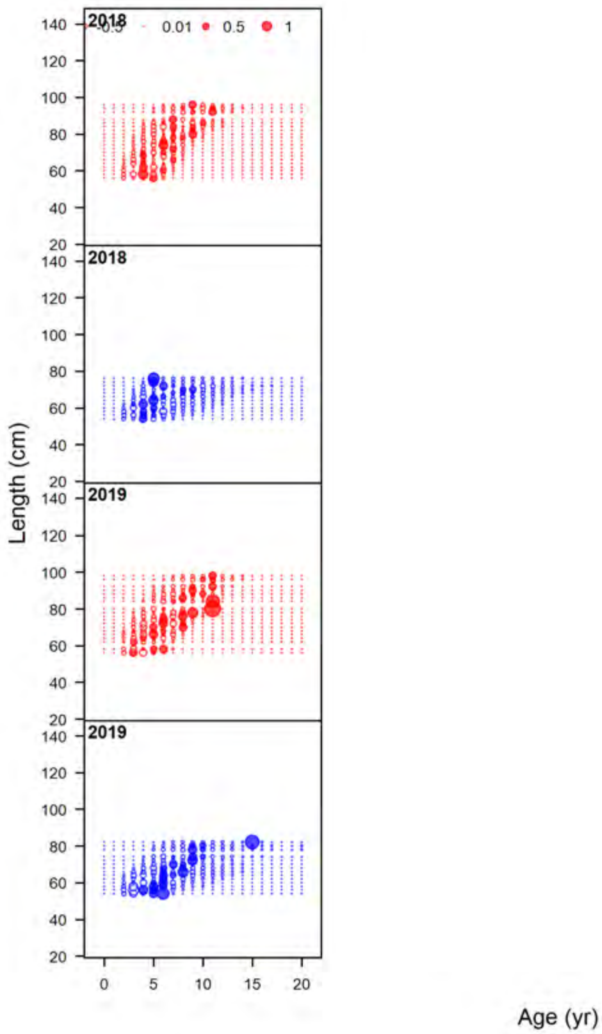


Figure 93: Pearson residuals, whole catch, recreational Oregon (max=9.96) (plot 3 of 3).

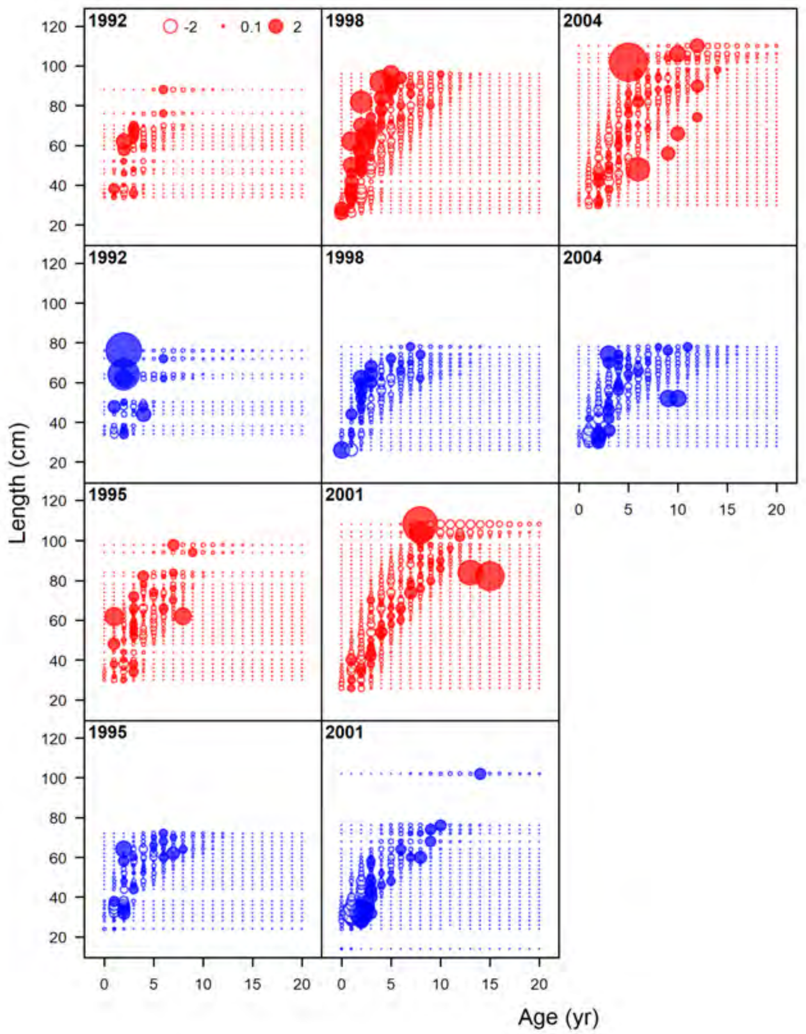


Figure 94: Pearson residuals, whole catch, Triennial Survey (max=14.99).

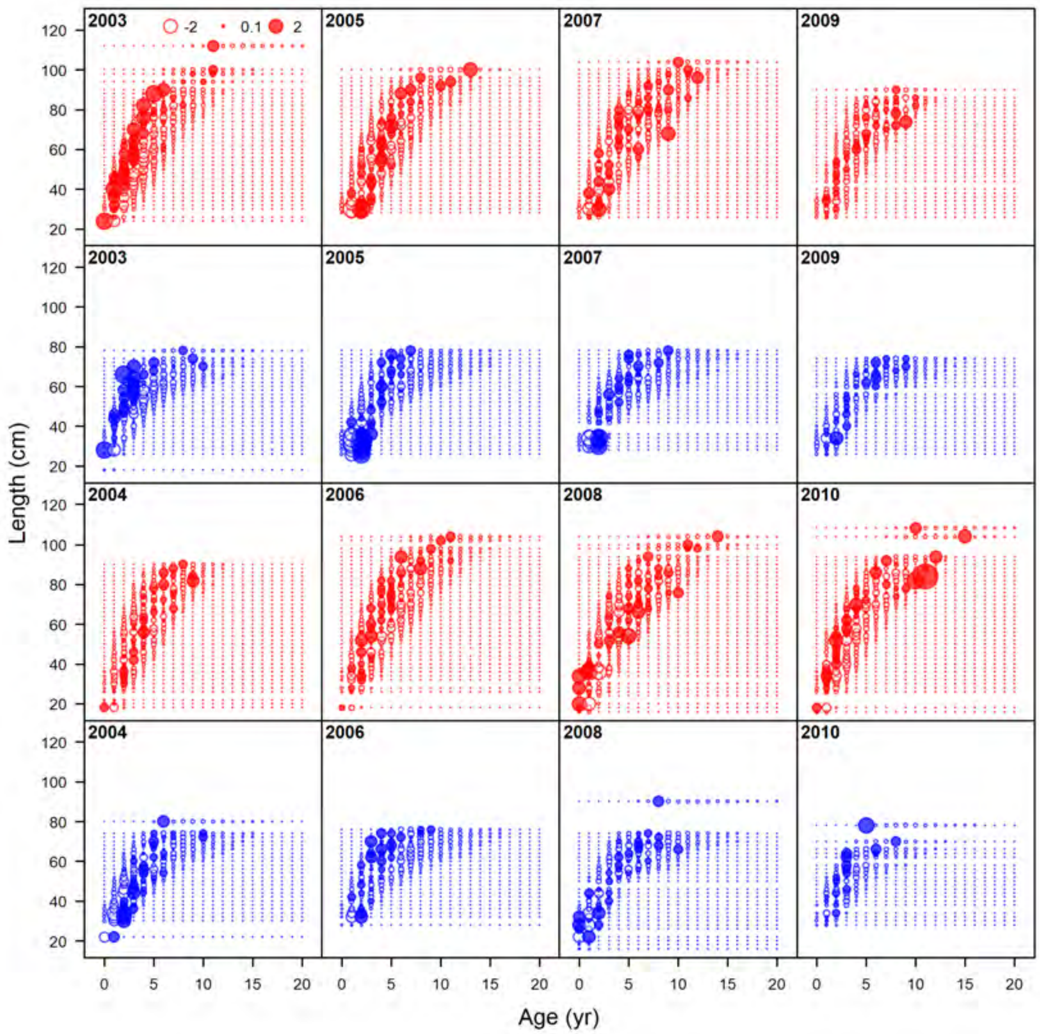


Figure 95: Pearson residuals, whole catch, WCGBT Survey (max=6.49) (plot 1 of 2).

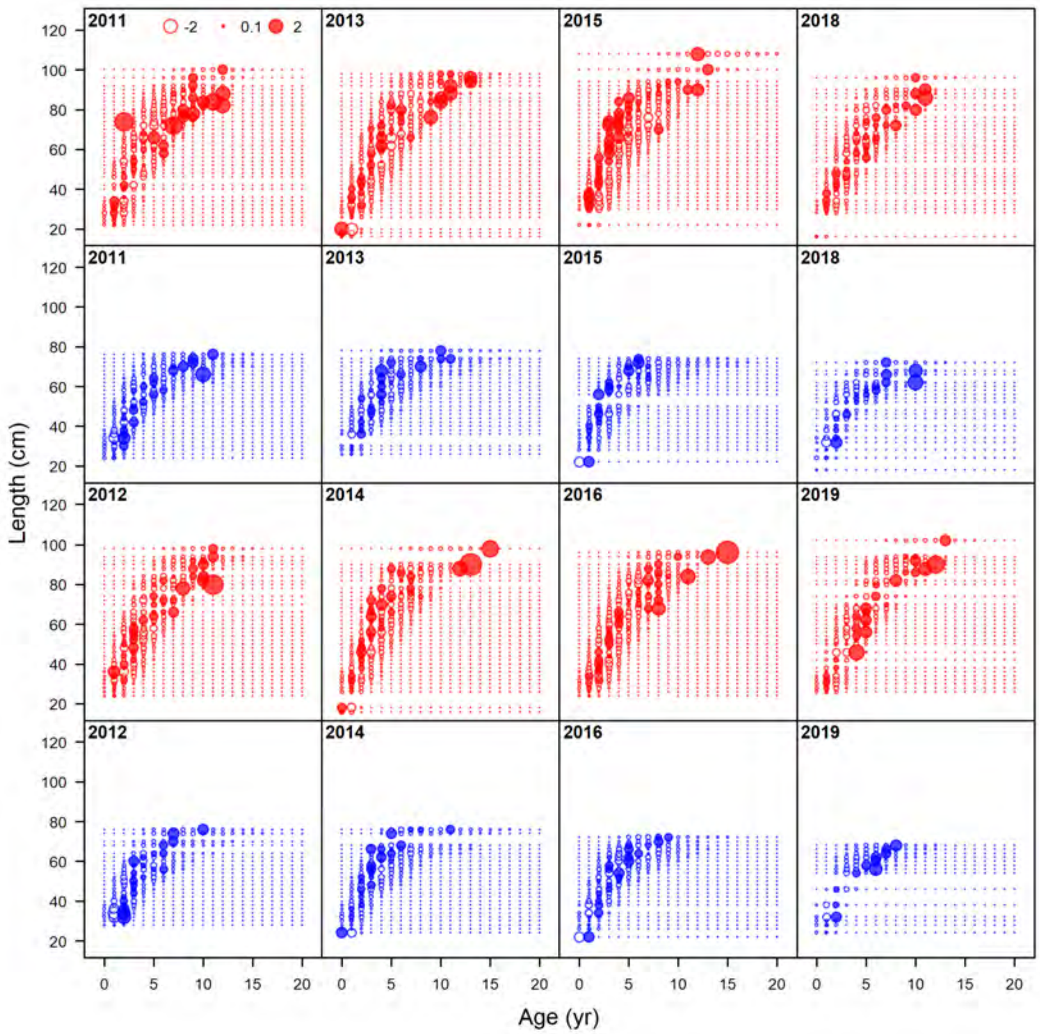


Figure 96: Pearson residuals, whole catch, WCGBT Survey (max=6.49) (plot 2 of 2).

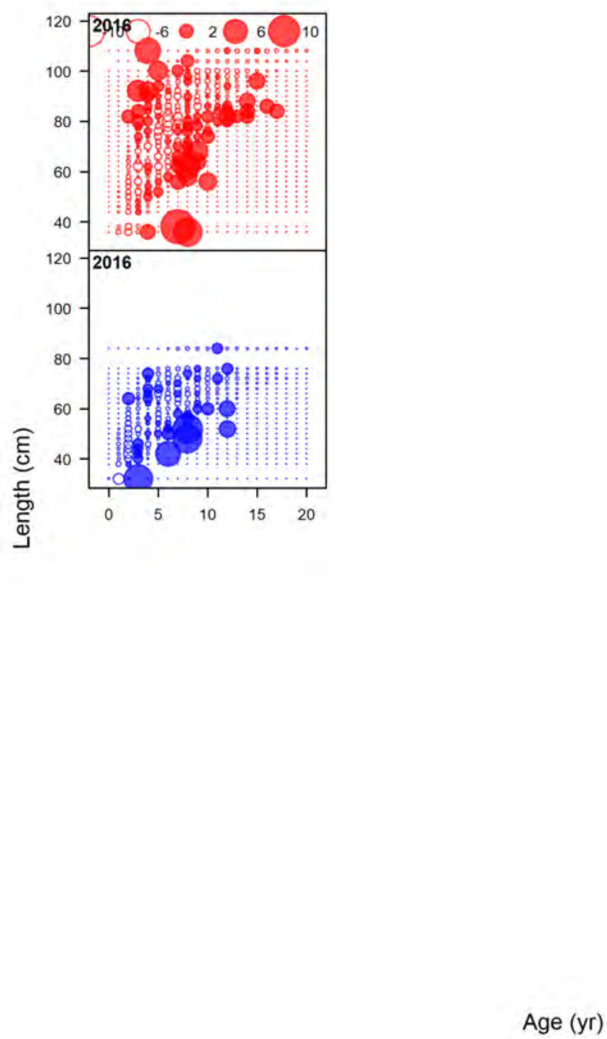


Figure 97: Pearson residuals, whole catch, Lam research samples (max=11.9).

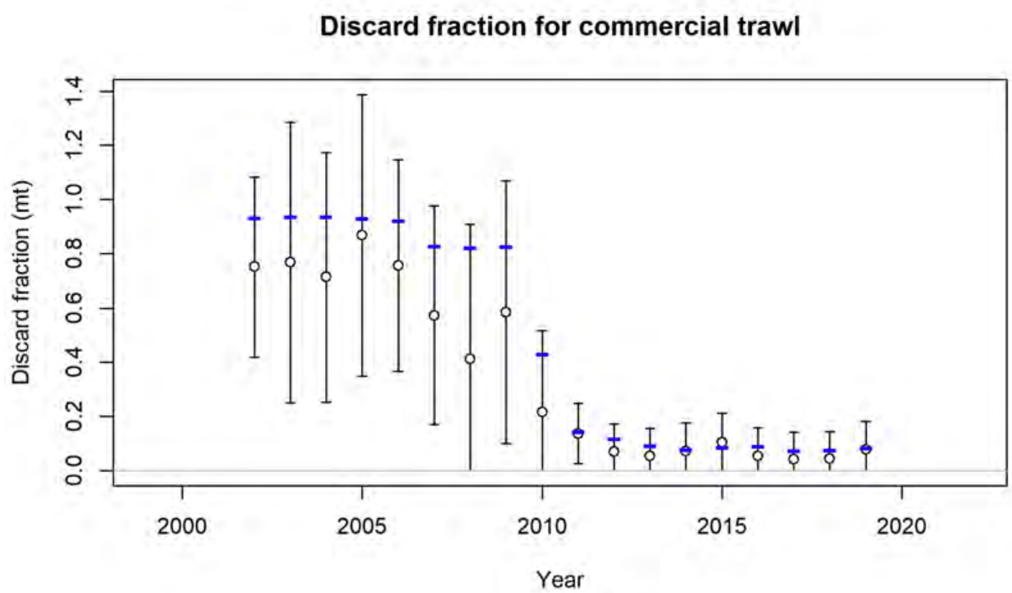


Figure 98: Discard fraction for commercial trawl.

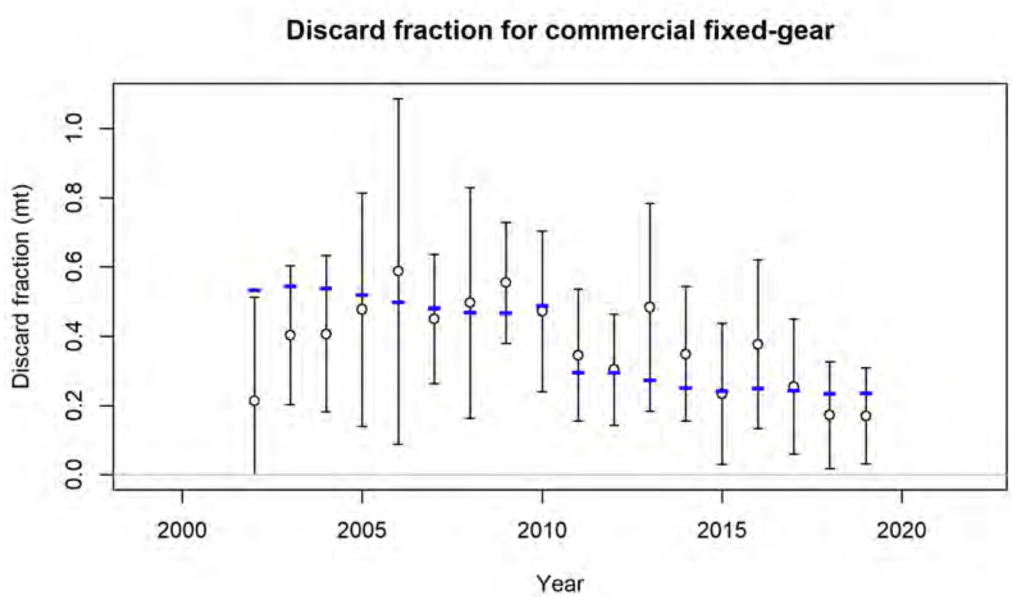


Figure 99: Discard fraction for commercial fixed-gear.

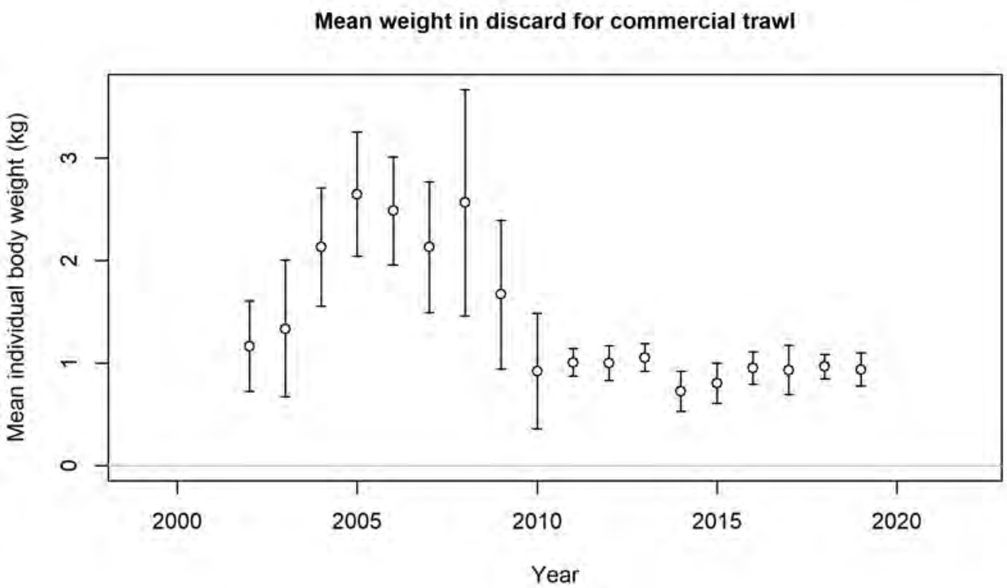


Figure 100: Mean weight in discard for commercial trawl.

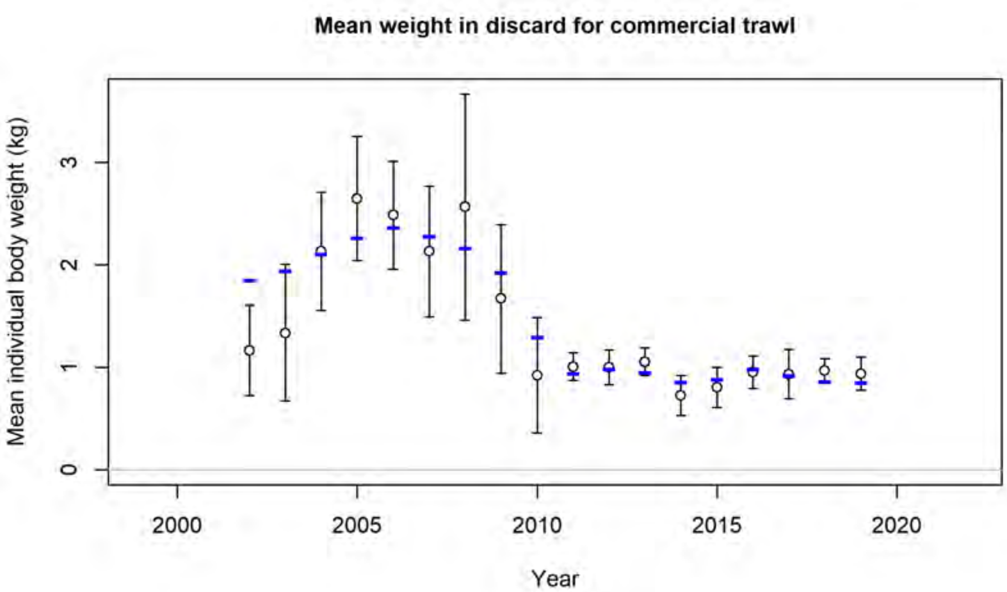


Figure 101: Mean weight in discard for commercial trawl.

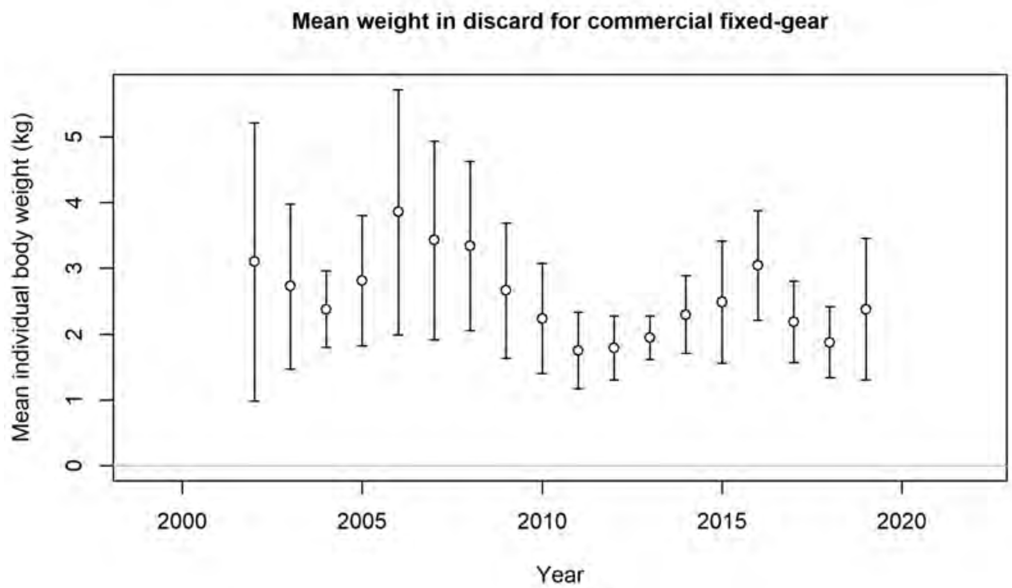


Figure 102: Mean weight in discard for commercial fixed-gear.

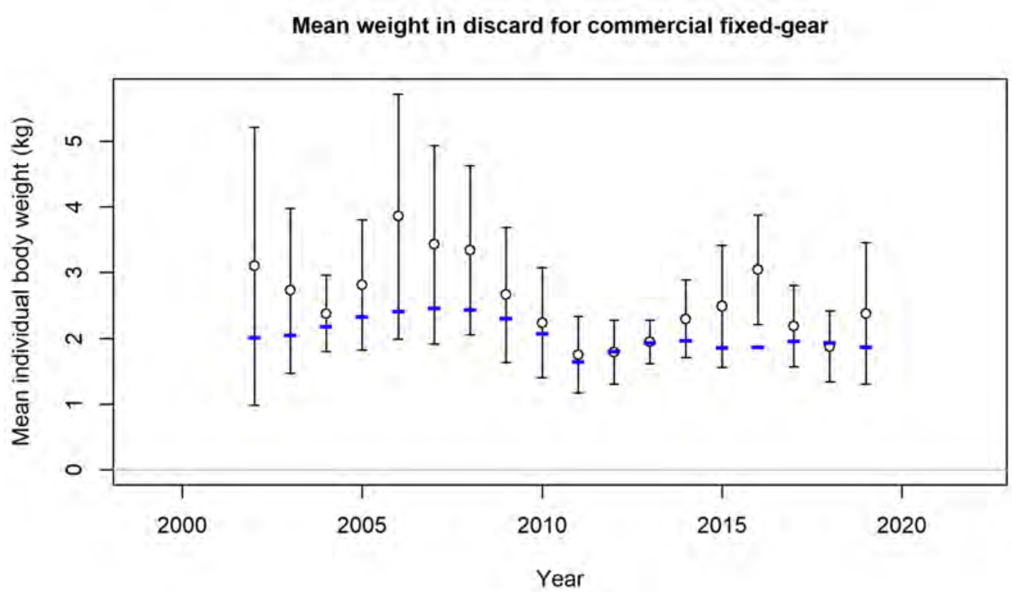


Figure 103: Mean weight in discard for commercial fixed-gear.

7.3.3 Time series figures

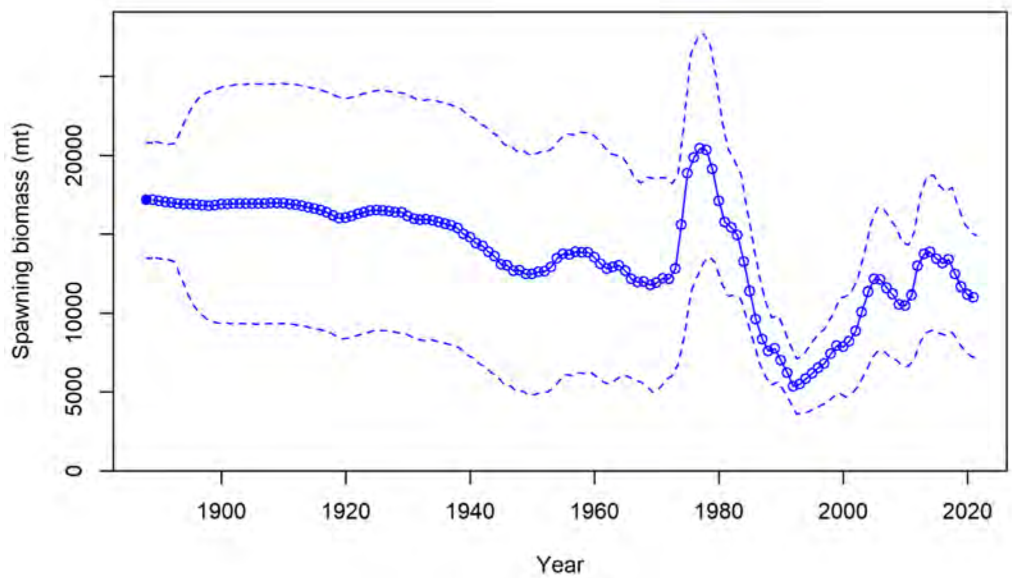


Figure 104: Spawning biomass (mt) with ~95% asymptotic intervals.

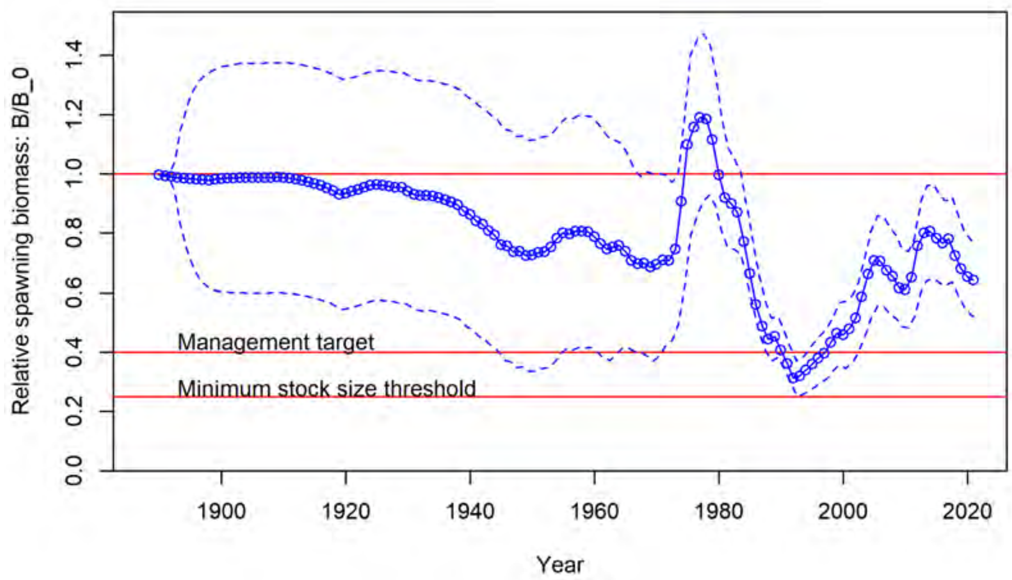


Figure 105: Relative spawning biomass: B/B_0 with ~95% asymptotic intervals.

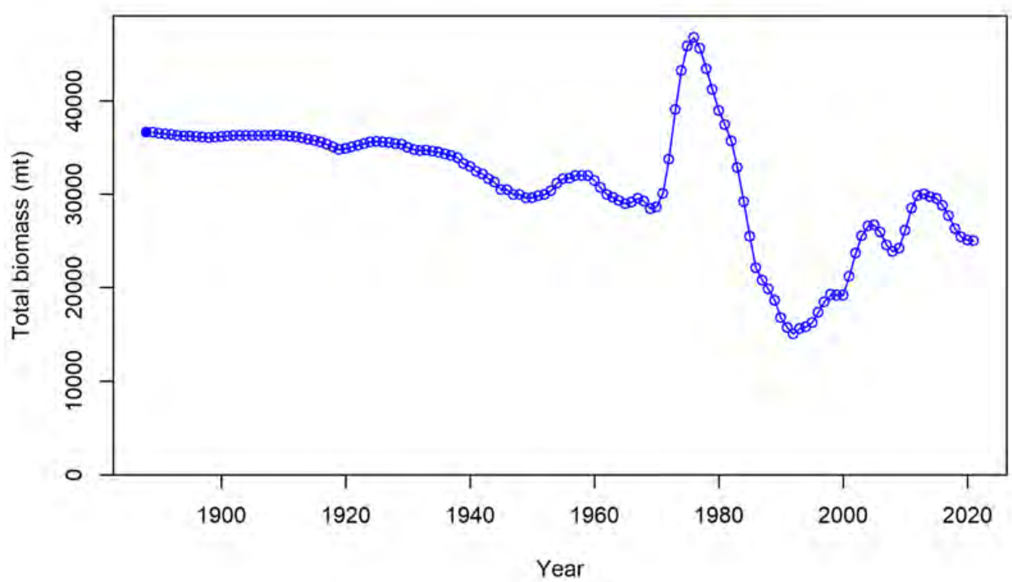


Figure 106: Total biomass (mt).

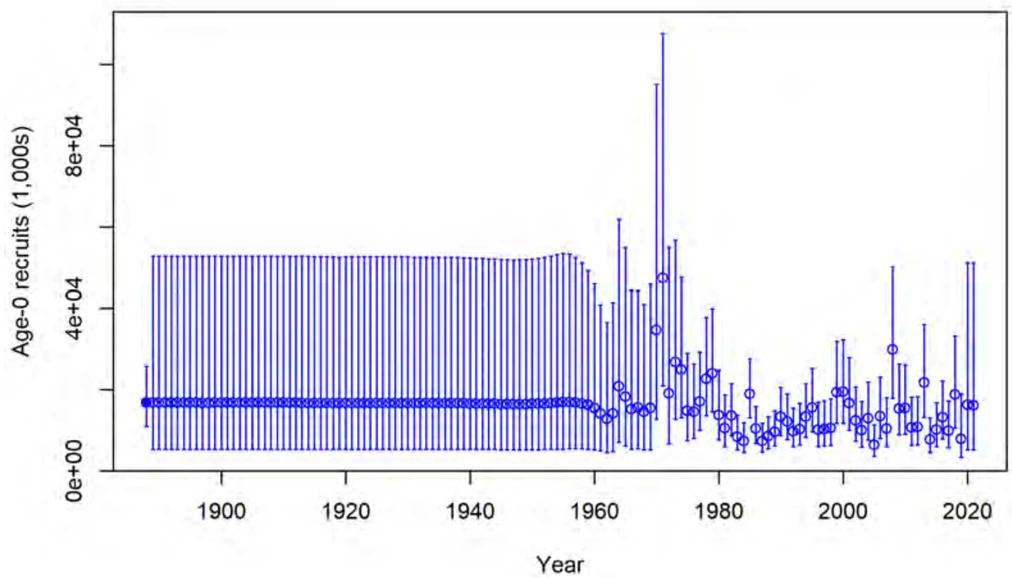


Figure 107: Age-0 recruits (1,000s) with ~95% asymptotic intervals.

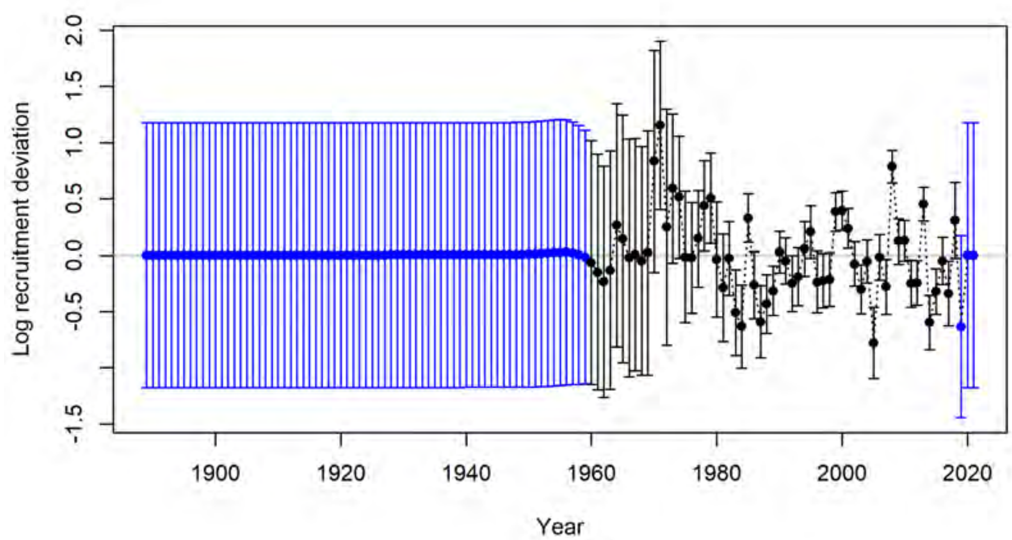


Figure 108: Recruitment deviations with 95% intervals.

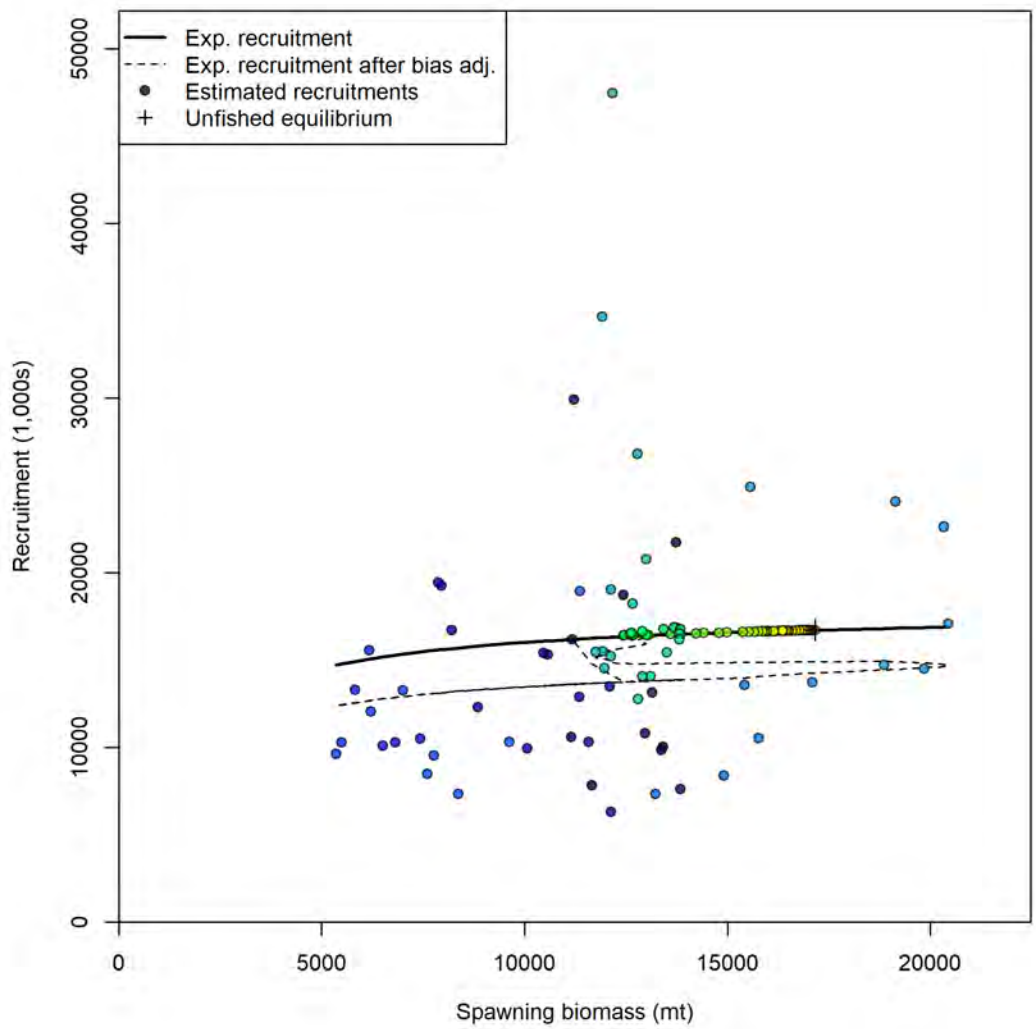


Figure 109: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

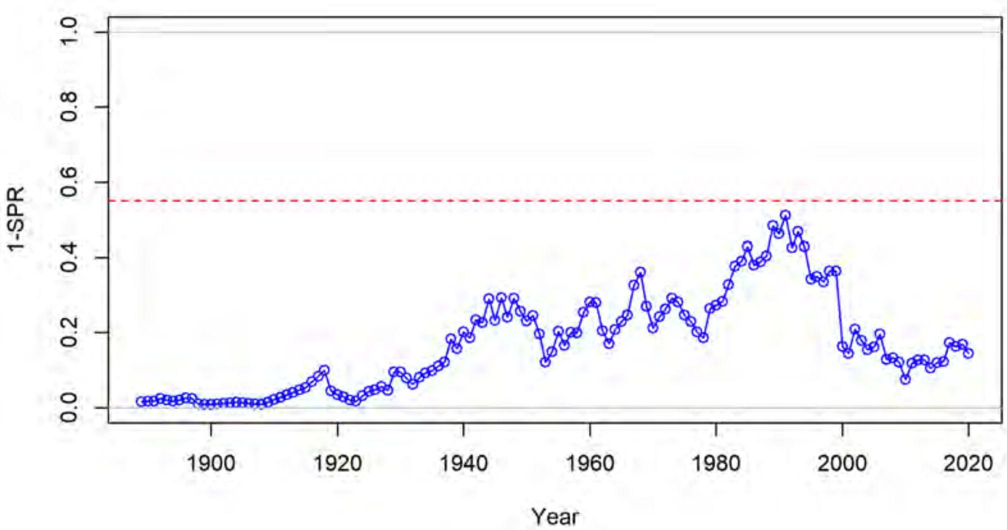


Figure 110: Timeseries of 1-SPR.

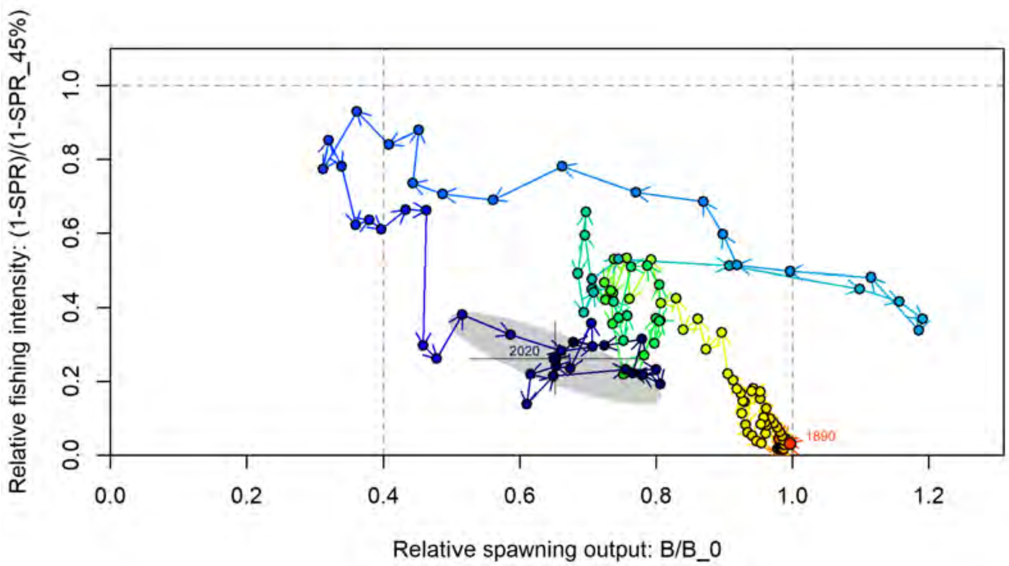


Figure 111: Phase plot of biomass ratio vs. SPR ratio. Each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show 95% intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95% region which accounts for the estimated correlation between the two quantities: -0.818. The vertical line at 0.4 indicates the reference point as defined in the forecast.ss which can be removed from the plot via SS_plots(..., btarg = -1).

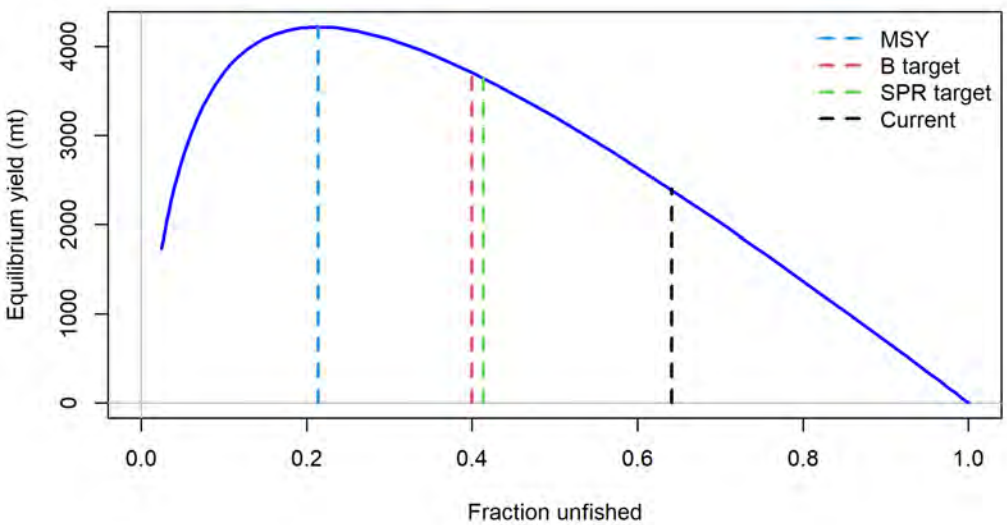


Figure 112: Yield curve with reference points.

7.3.4 Sensitivity analyses and retrospectives

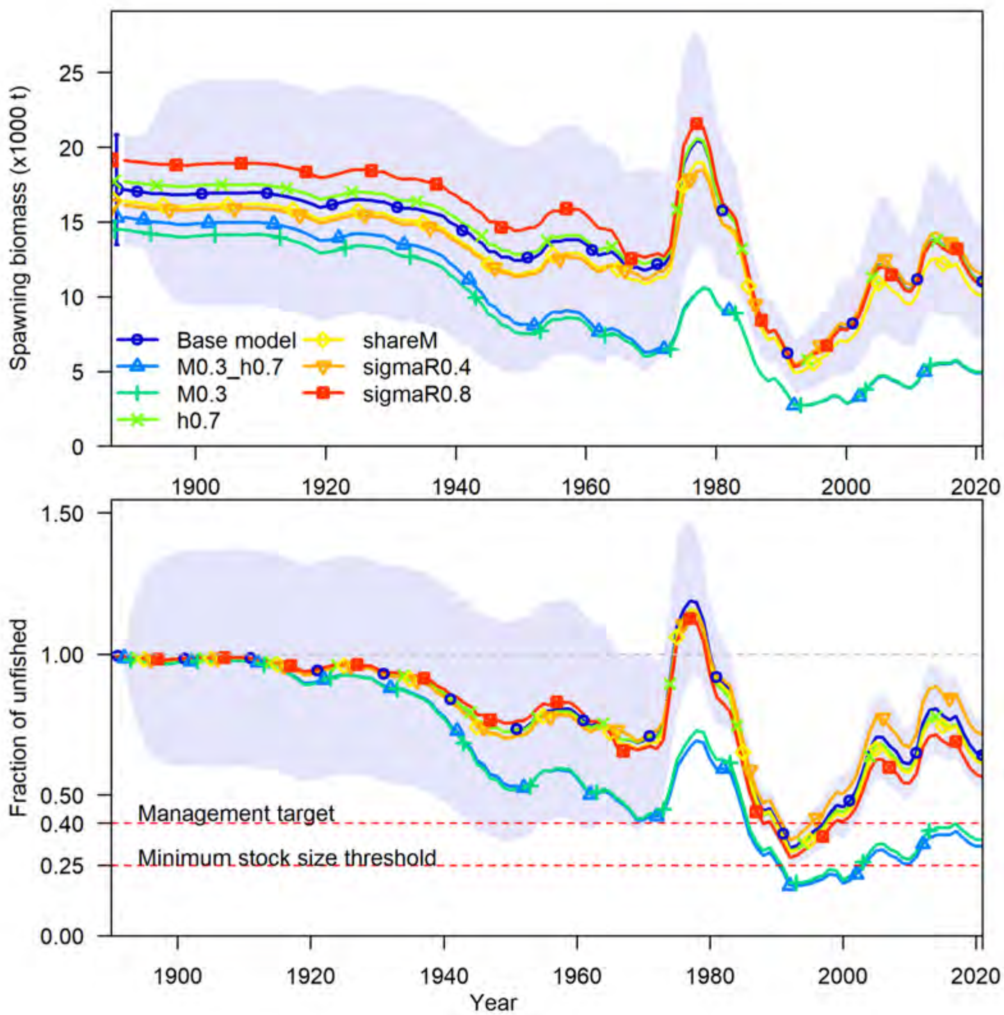


Figure 113: Time series of spawning biomass (top) and fraction of unfished (bottom) for the sensitivity analyses related to biology and recruitment.

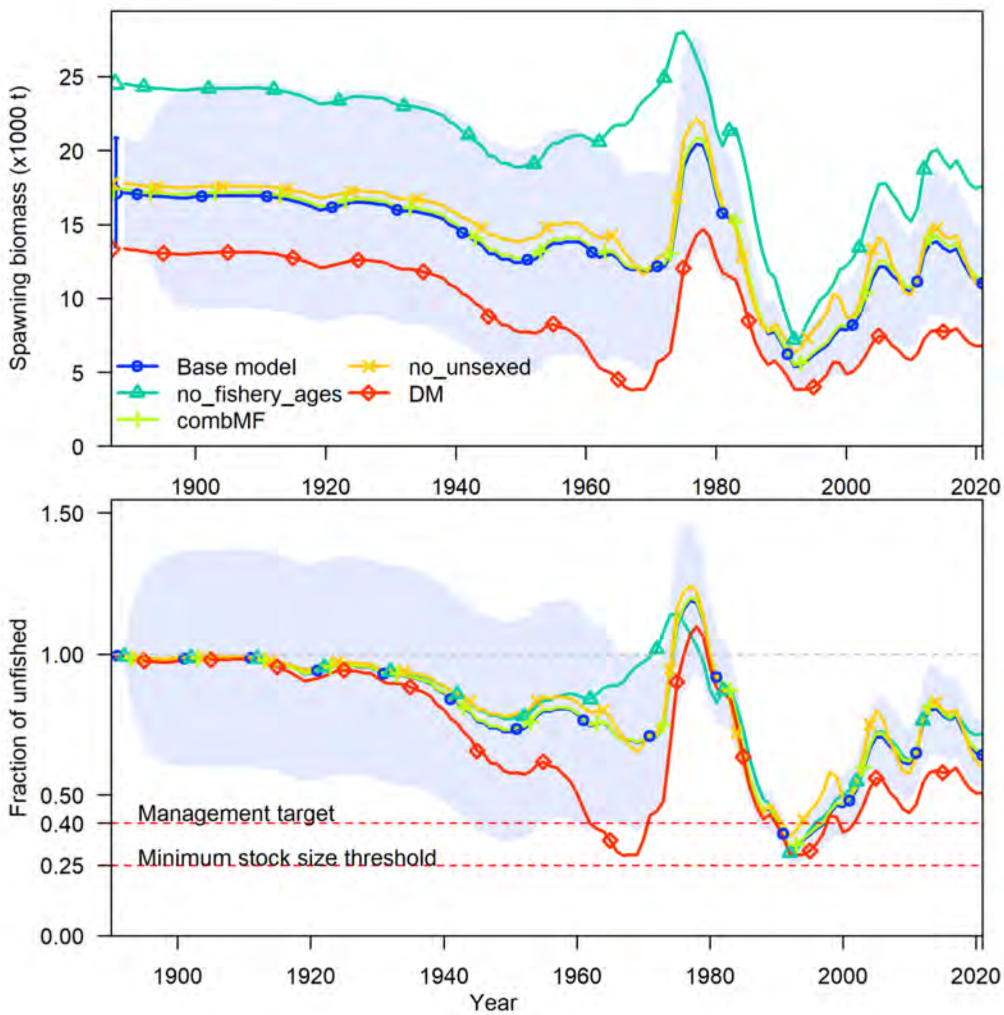


Figure 114: Time series of spawning biomass (top) and fraction of unfished (bottom) for the sensitivity analyses related to composition data.

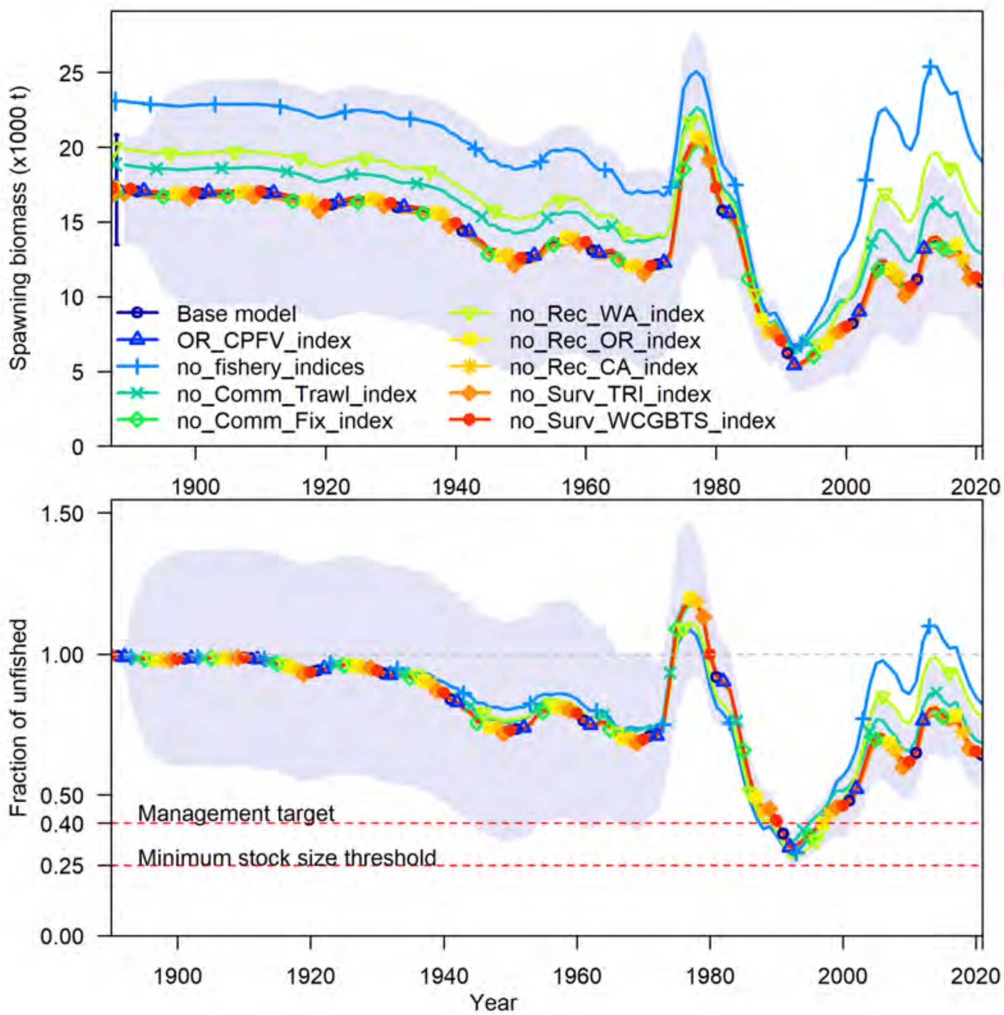


Figure 115: Time series of spawning biomass (top) and fraction of unfished (bottom) for the sensitivity analyses related to indices of abundance.

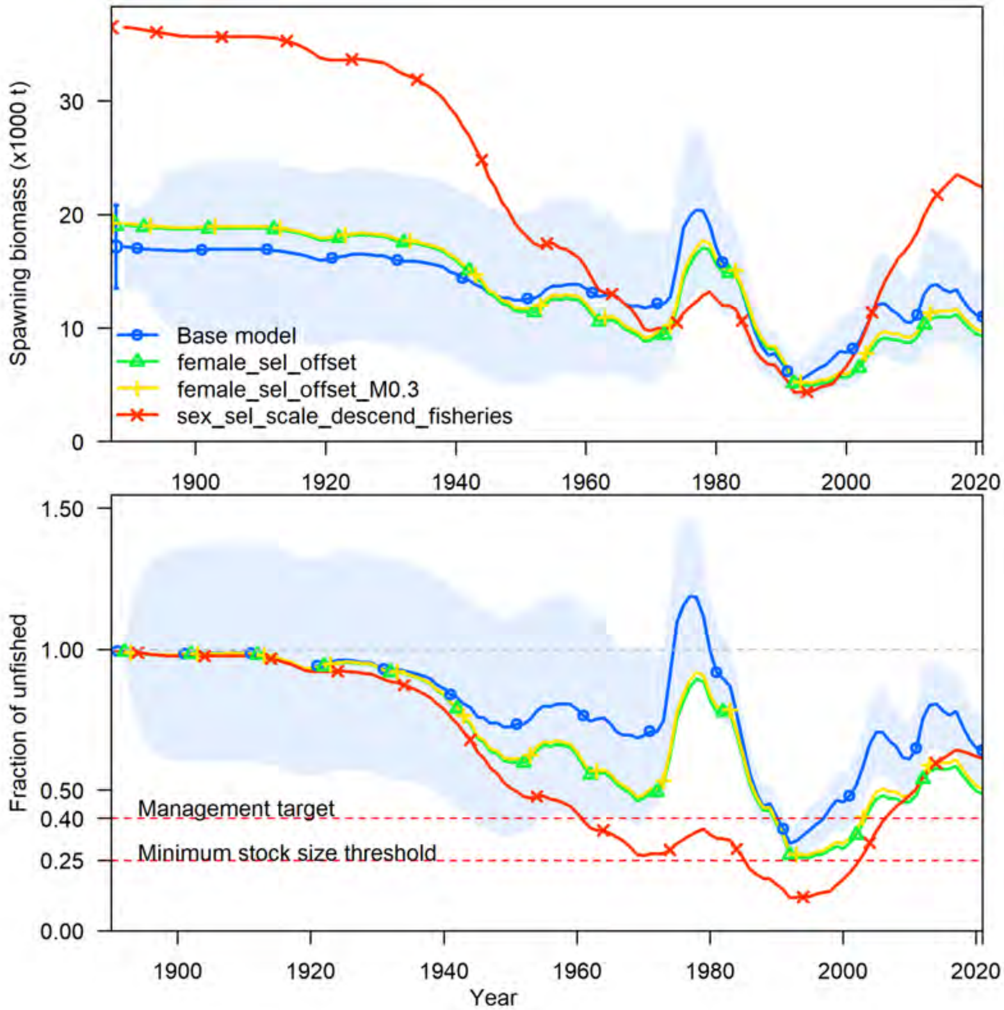


Figure 116: Time series of spawning biomass (top) and fraction of unfished (bottom) for the sensitivity analyses related to .

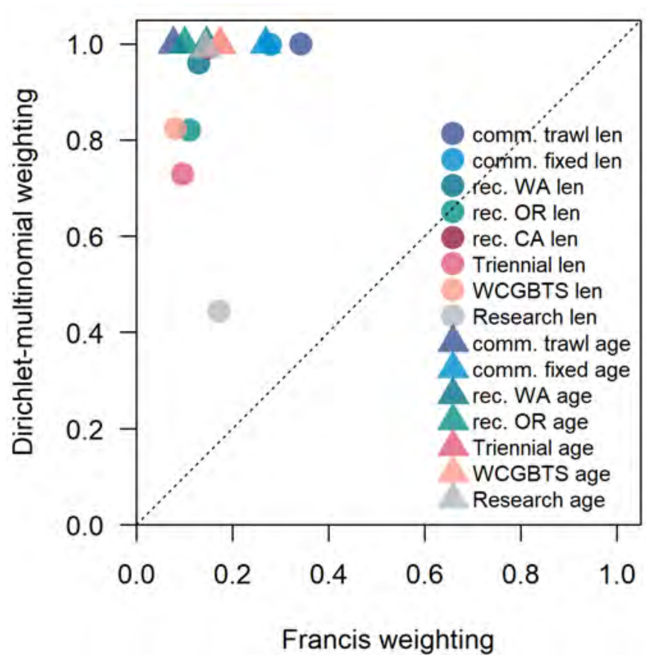


Figure 117: Weights applied to the length- and age-composition data by the Francis weighting used in the base model vs the Dirichlet-multinomial weighting used in a sensitivity analyses.

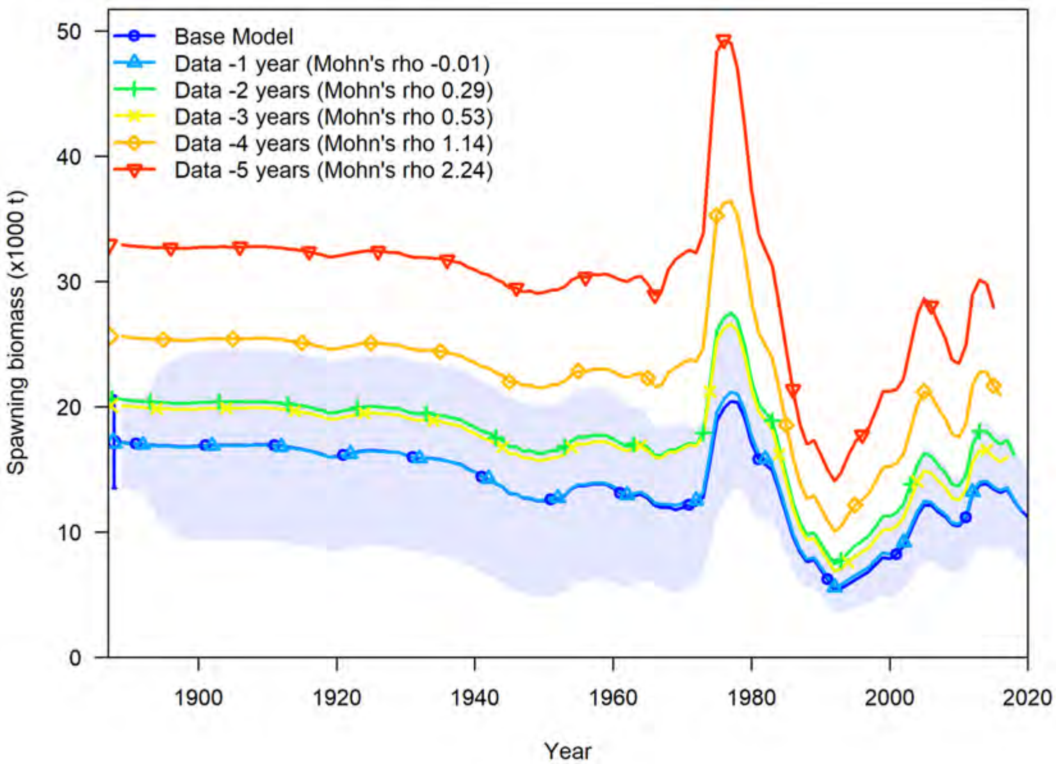


Figure 118: Change in the spawning biomass when the most recent 5 years of data are removed sequentially.

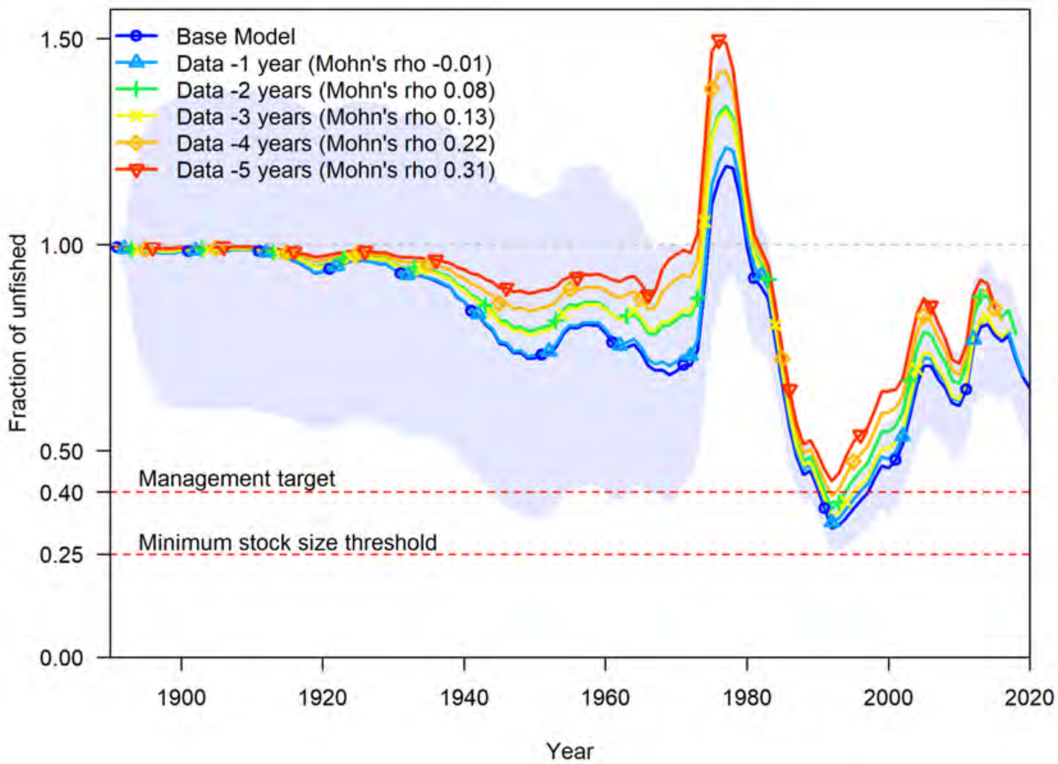


Figure 119: Change in the fraction unfished when the most recent 5 years of data are removed sequentially.

7.3.5 Likelihood profiles

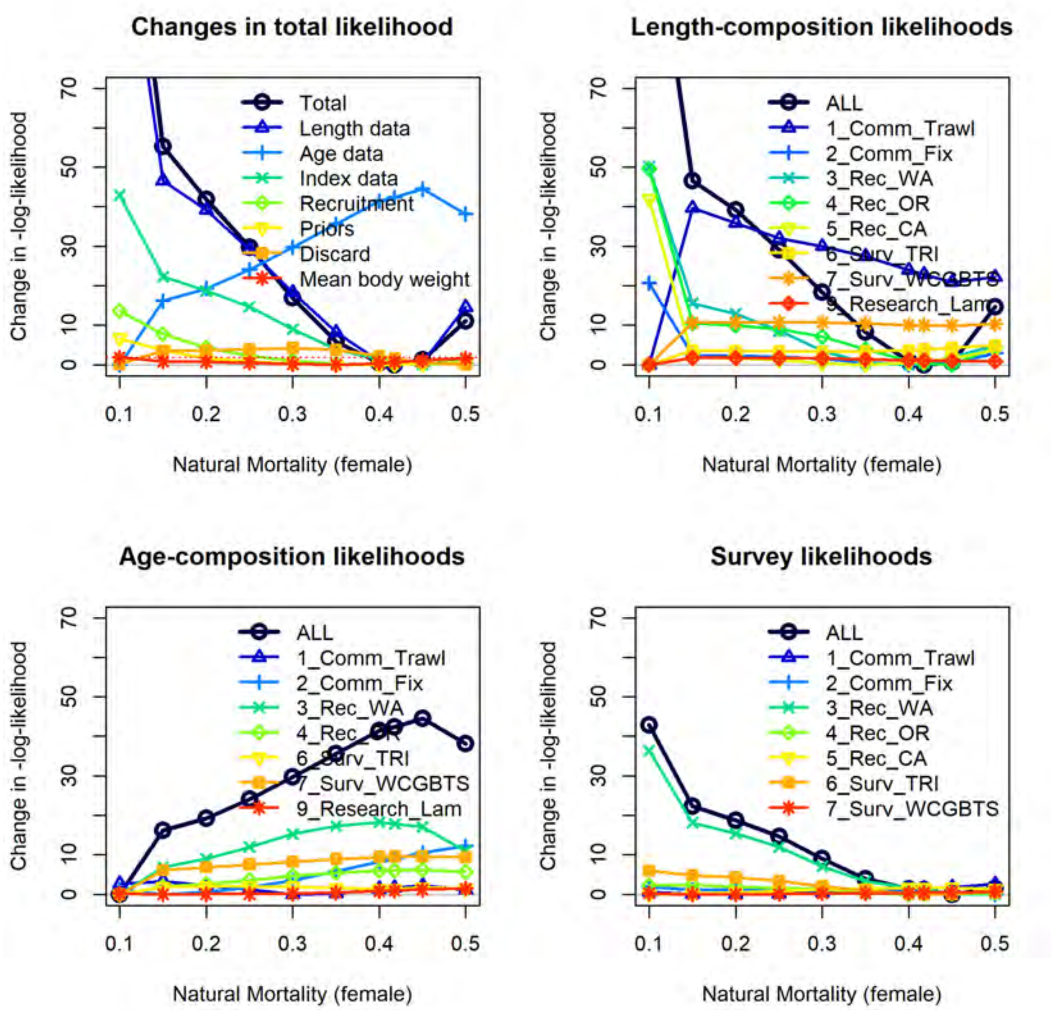


Figure 120: Change in the negative log-likelihood across a range of female M values.

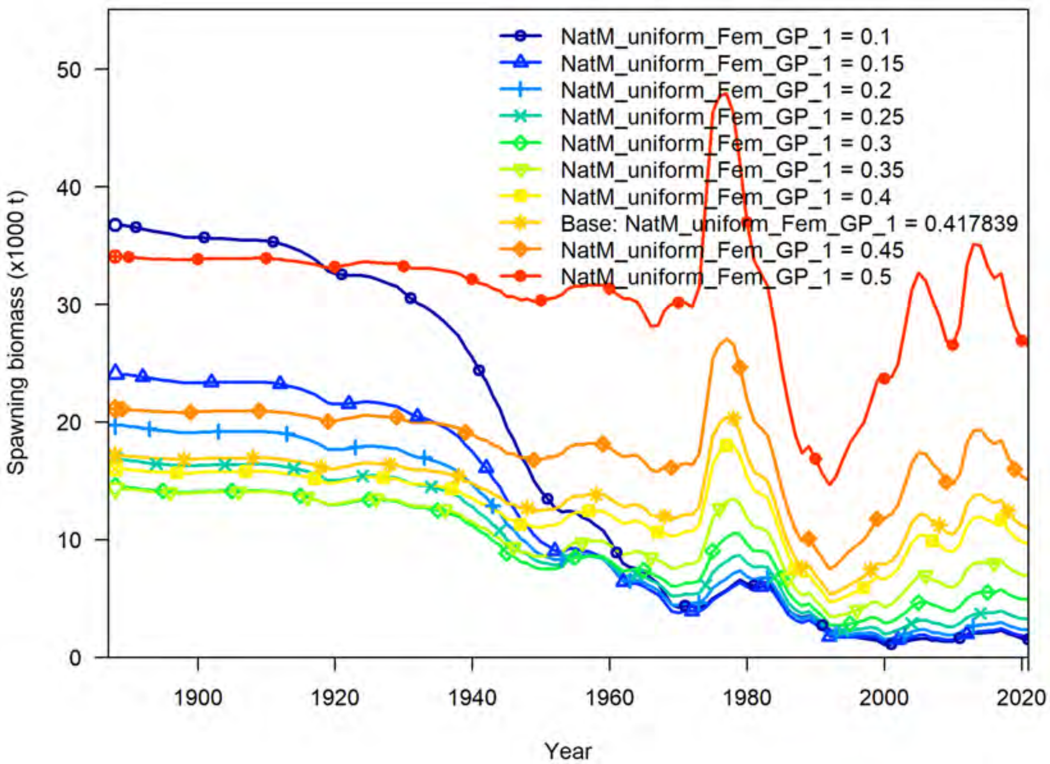


Figure 121: Change in the spawning biomass across a range of female M values.

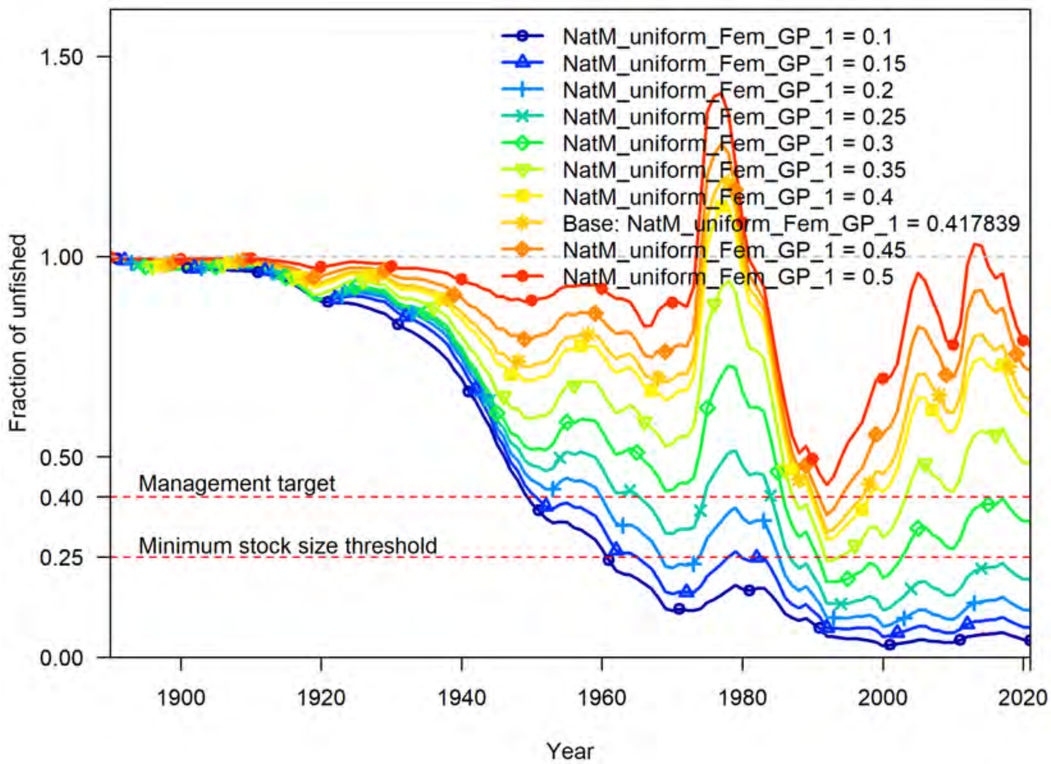


Figure 122: Change in the fraction of unfished across a range of female M values.

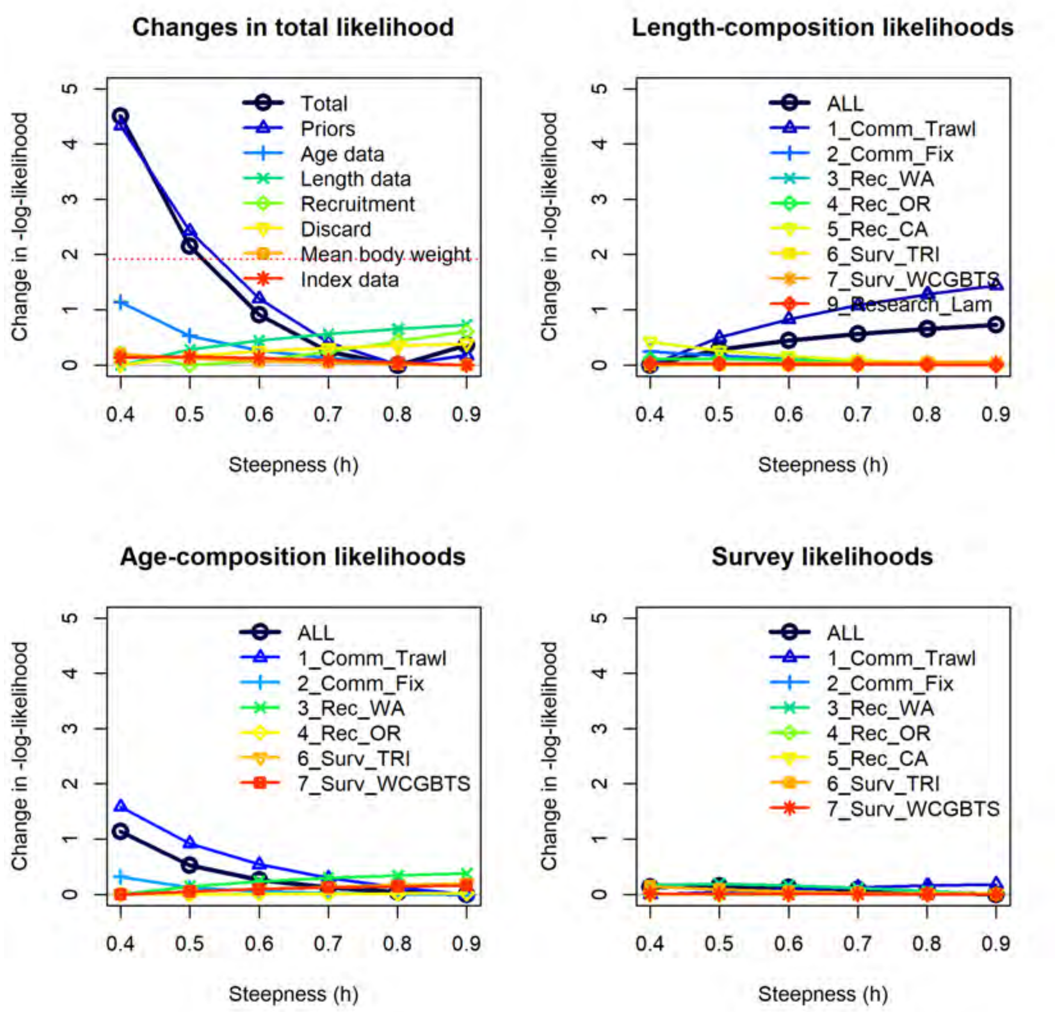


Figure 123: Change in the negative log-likelihood across a range of steepness values.

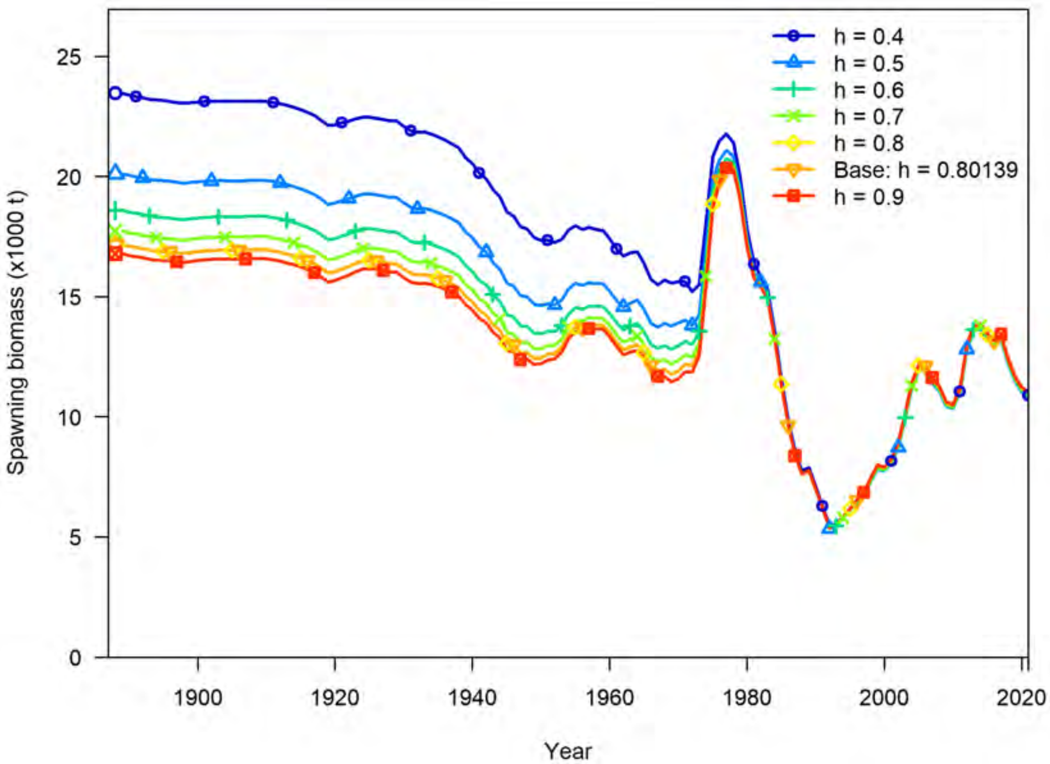


Figure 124: Change in the spawning biomass across a range of steepness values.

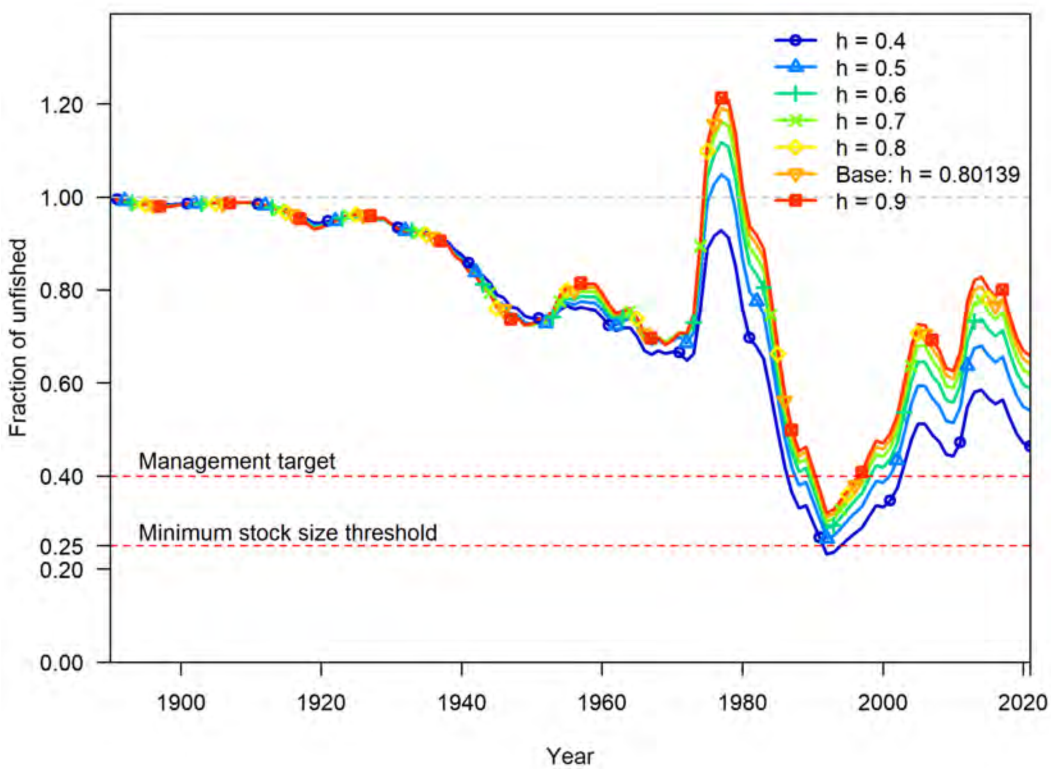


Figure 125: Change in the fraction of unfished across a range of steepness values.

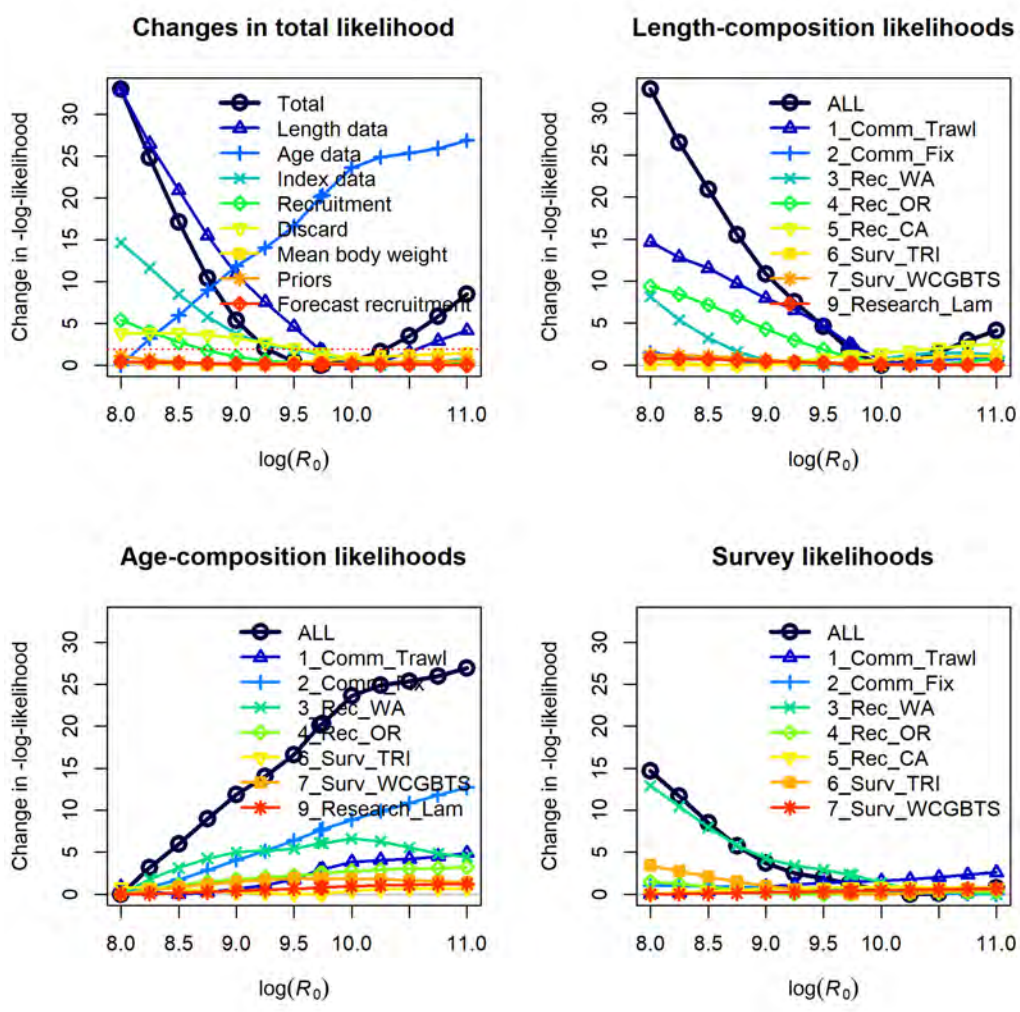


Figure 126: Change in the negative log-likelihood across a range of $log(R0)$ values.

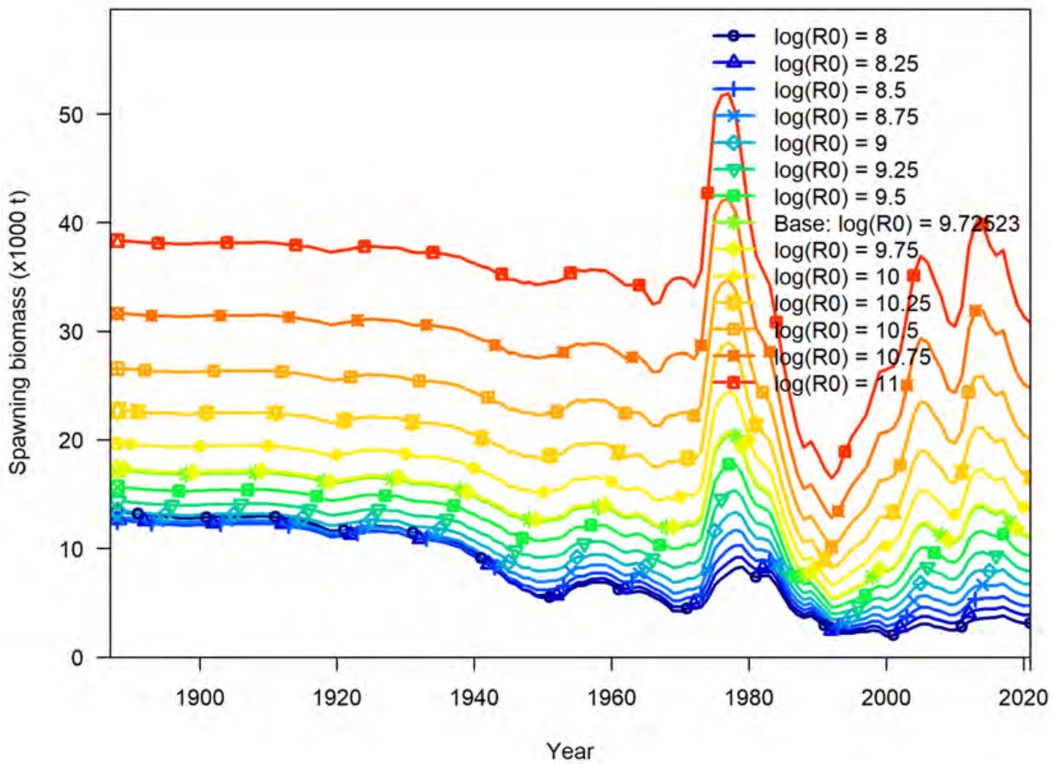


Figure 127: Change in the spawning biomass across a range of $log(R0)$ values.

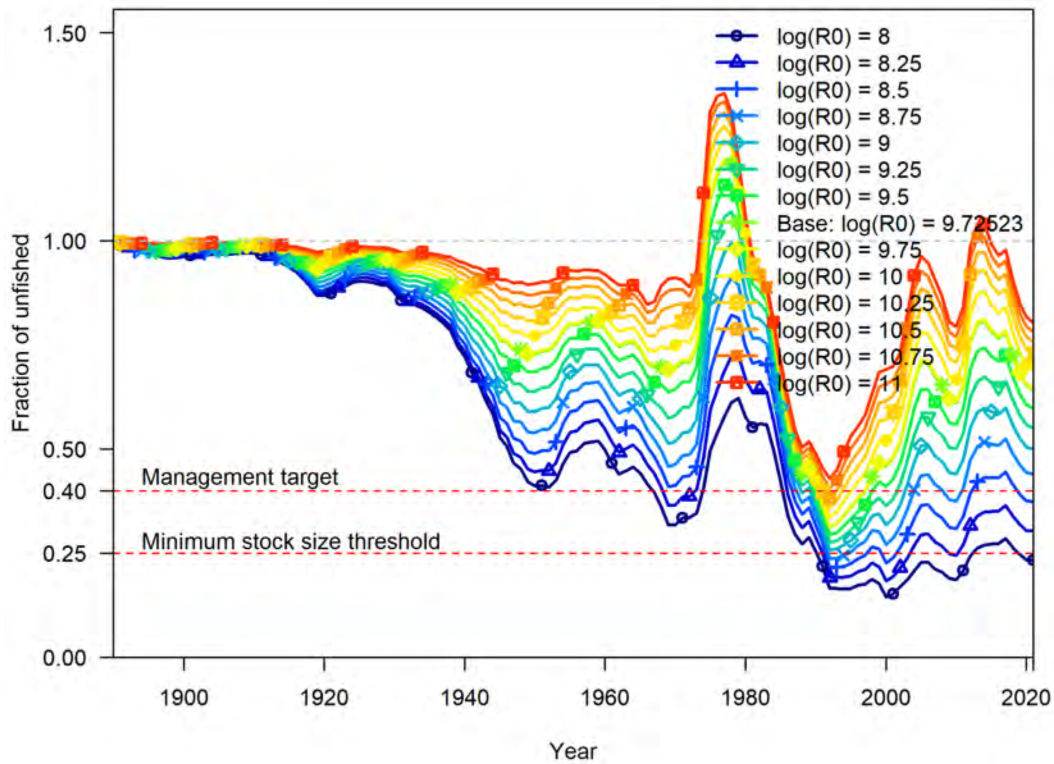


Figure 128: Change in the fraction of unfished across a range of $log(R0)$ values.

7.3.6 Reference points and forecasts

7.3.7 Comparisons of north and south models

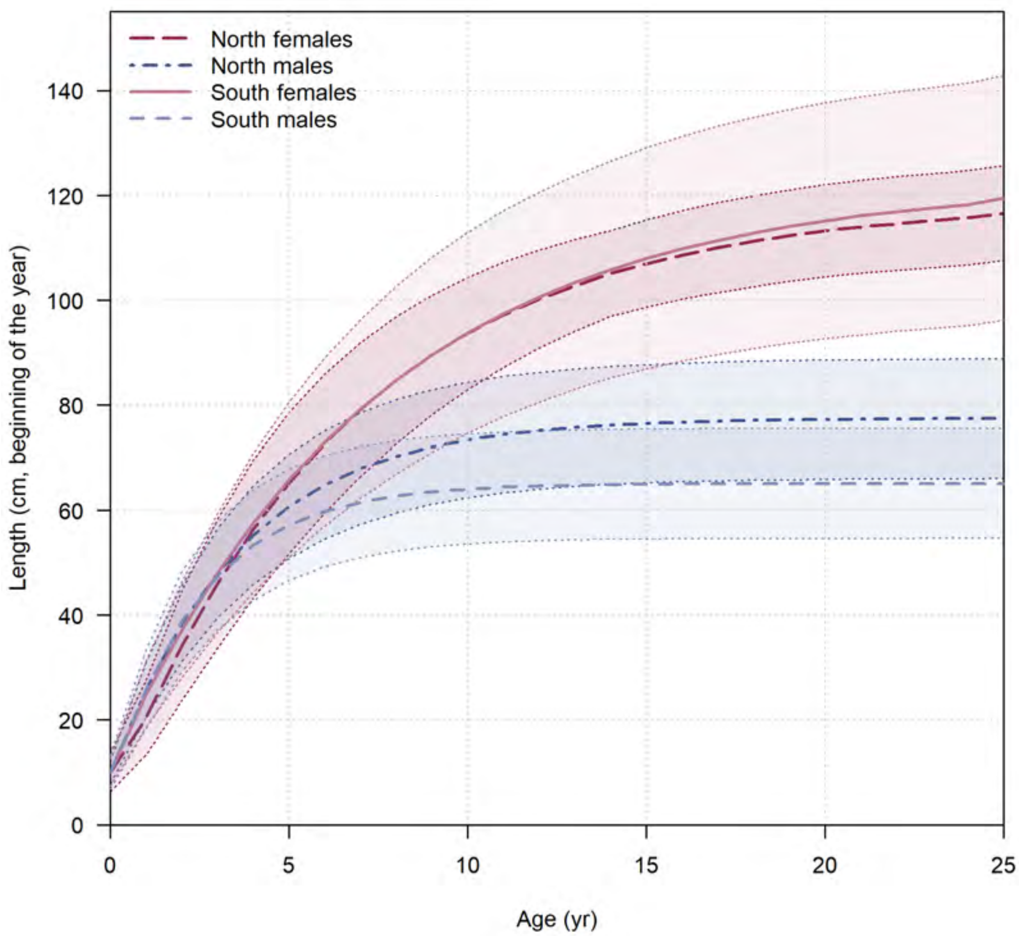


Figure 129: Comparison of estimated growth curves and variability in growth for the north and south base models.

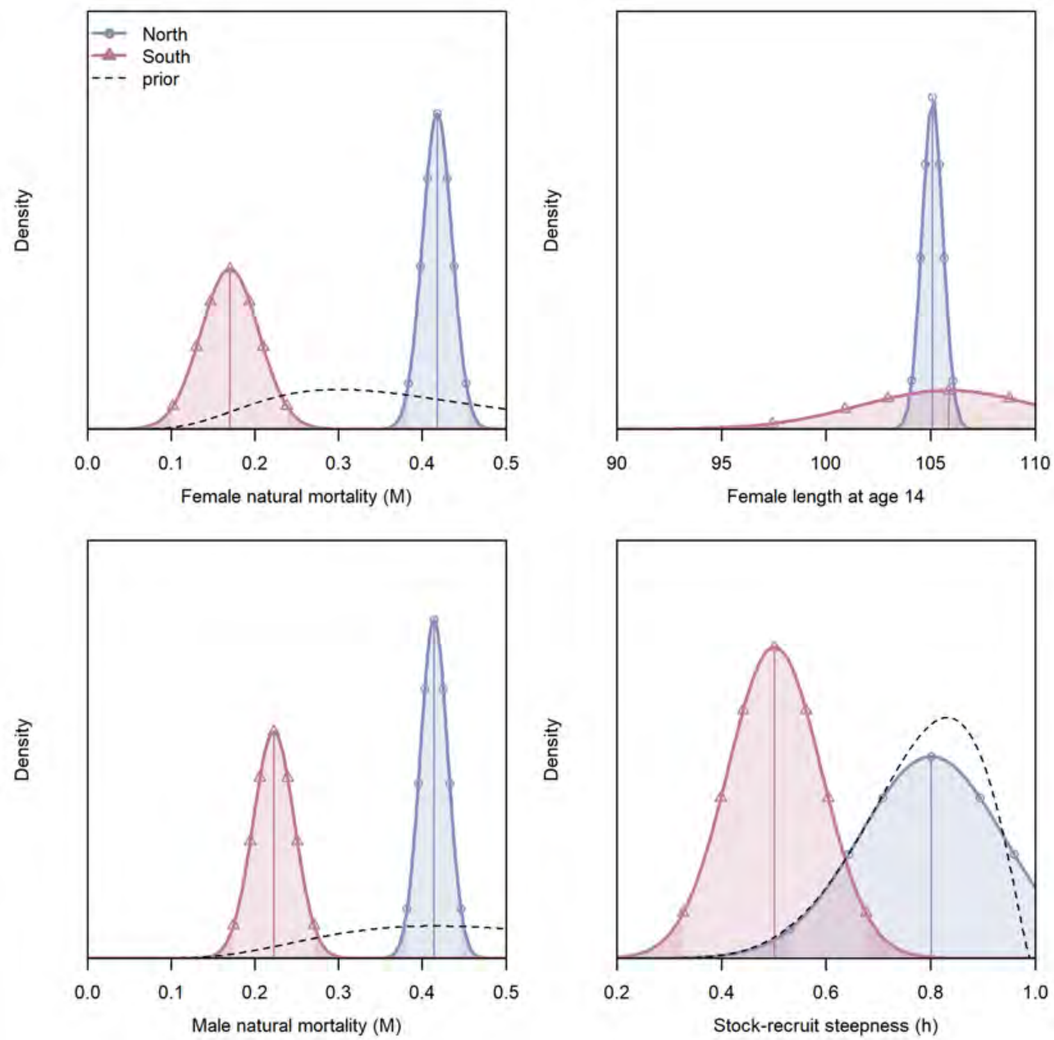


Figure 130: Comparison estimates for parameters of interest from each model with normal approximation to posterior based on asymptotic standard error with priors shown in black.

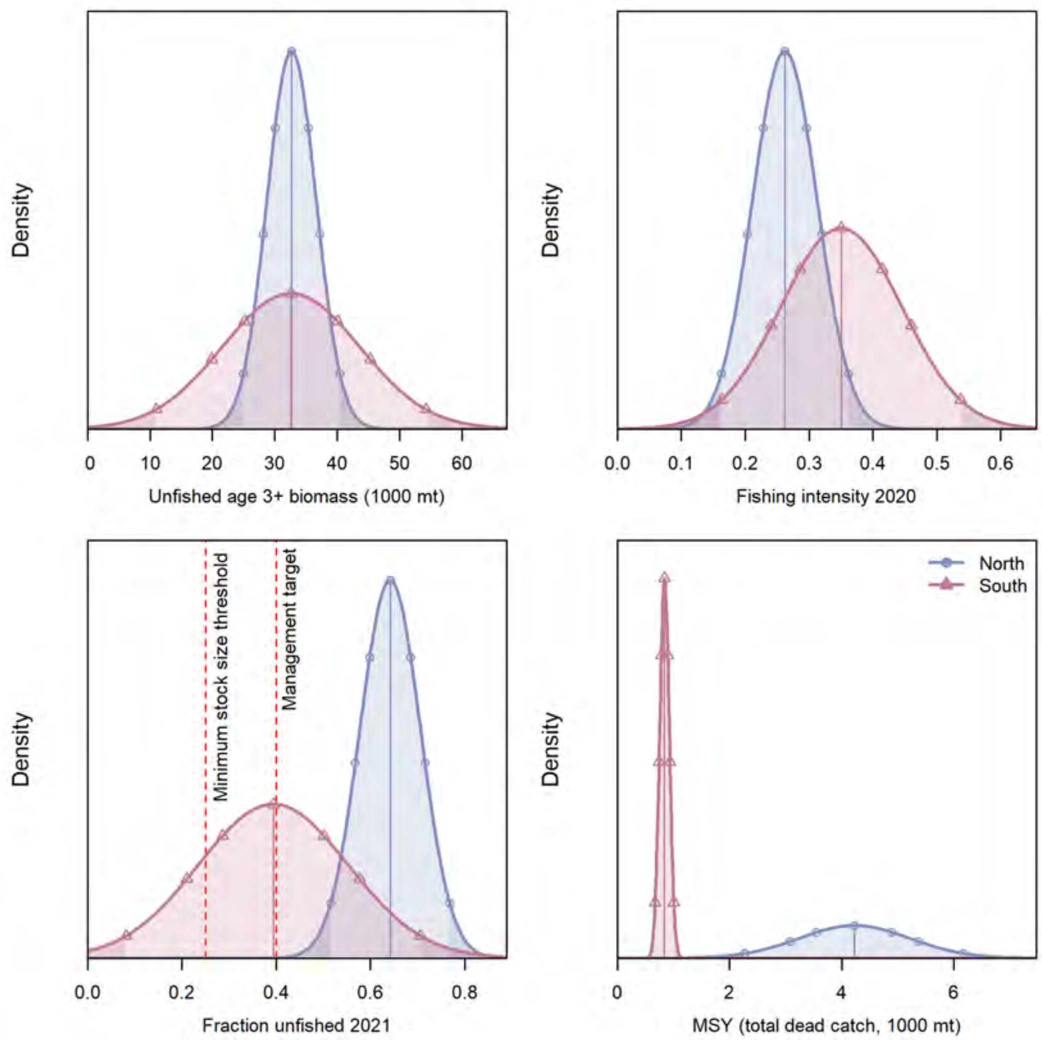


Figure 131: Comparison estimates for quantities of interest from each model with normal approximation to posterior based on asymptotic standard error.

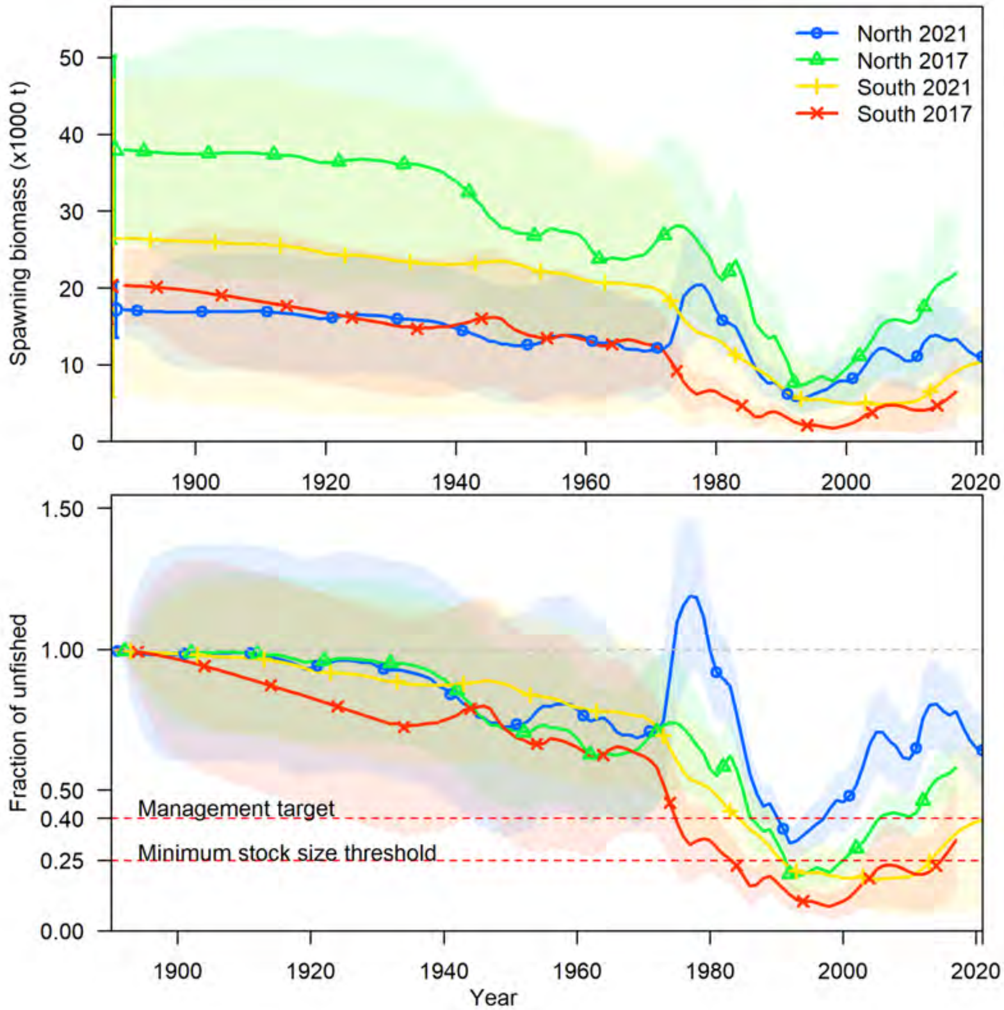


Figure 132: Time series of spawning biomass (top) and fraction of unfished (bottom) from the 2021 and 2017 base models for north and south. Note that the 2017 models had a break at 42°00'N instead of 40°10'N used in the 2021 models.