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

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Stock

This assessment reports the status of lingcod (*Ophiodon elongatus*) south 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. CA	Total	Total dead
2011	6.02	20.47	186.70	213.19	215.17
2012	11.36	26.77	235.43	273.56	276.85
2013	10.93	37.07	380.67	428.67	431.79
2014	13.67	63.40	425.99	503.06	506.73
2015	25.94	88.77	596.99	711.70	717.46
2016	19.13	63.19	593.33	675.65	679.53
2017	23.18	69.95	453.05	546.18	549.83
2018	46.76	56.48	346.21	449.46	454.40
2019	76.49	43.42	269.32	389.23	396.61
2020	55.39	32.83	198.28	286.50	291.91

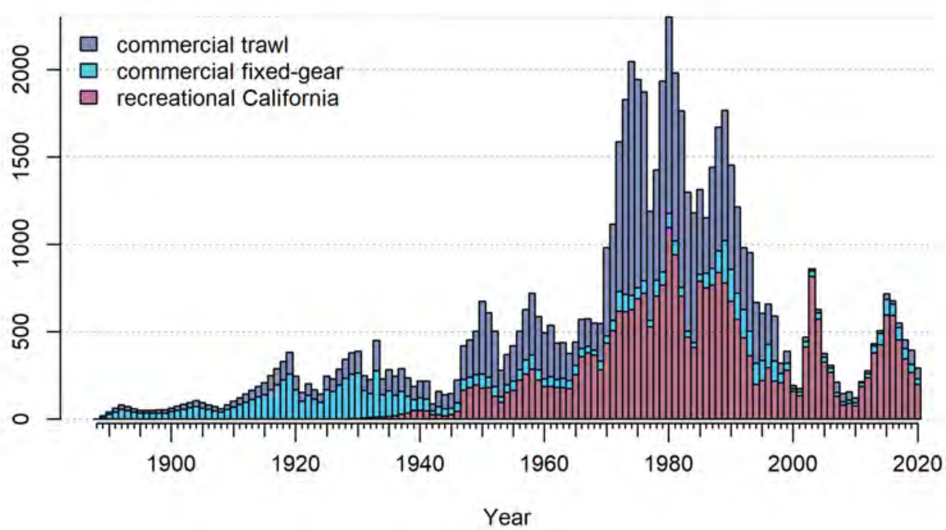

Figure i: Estimated total dead (mt) by fleet (colors) across years since 1889.

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 southern stock, information on relative abundance, length, and age was also available from the NWFSC Hook and Line Survey (Hook and Line Survey). The final model included ages from only the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) because of conflicts between age- and length-composition data.

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 1972, 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

Over the last decade, the spawning biomass has been trending upward due to a period of above-average recruitment which ended in 2013, though the rate of the increase is highly uncertain (Table ii; Figure ii). Uncertainty in the initial stock size is vast and this uncertainty is carried forward until approximately the early 1980s when more informative data are available. The current estimated biomass is below, but close to, the management target with the uncertainty in this estimate spanning well above and below the management target and the minimum stock size threshold (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	5362	1468	9256	0.203	0.053	0.353
2012	5847	1807	9886	0.221	0.055	0.387
2013	6516	2242	10790	0.246	0.057	0.435
2014	7247	2648	11846	0.274	0.060	0.489
2015	7951	2971	12932	0.301	0.062	0.540
2016	8554	3143	13966	0.323	0.062	0.585
2017	9159	3286	15032	0.346	0.063	0.630
2018	9639	3337	15940	0.364	0.067	0.662
2019	9968	3296	16640	0.377	0.071	0.683
2020	10208	3216	17200	0.386	0.076	0.696
2021	10415	3145	17685	0.394	0.082	0.706

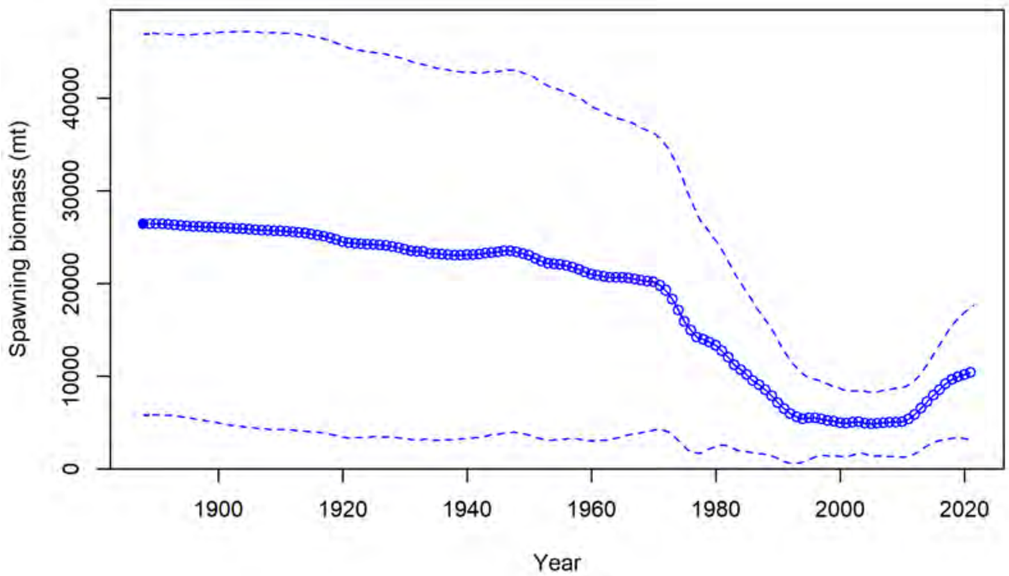

Figure ii: Estimated time series of spawning output (circles and line are maximum likelihood estimates; light broken lines are 95% intervals) for the base model.

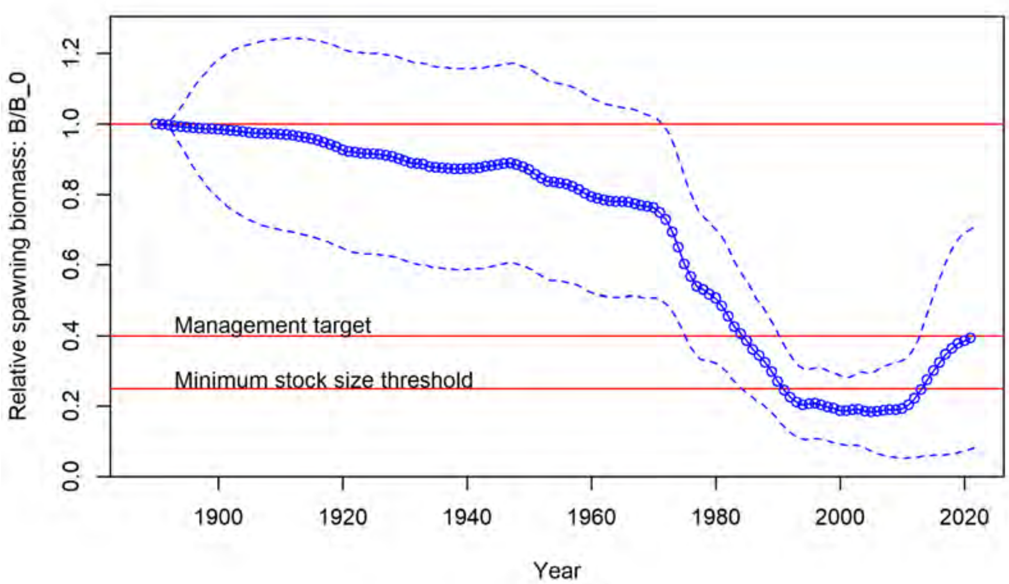

Figure iii: Estimated time series of fraction of unfished spawning output (circles and line are maximum likelihood estimates; light broken lines are 95% intervals) for the base model.

Recruitment

Steepness was estimated ($\hat{h} = 0.50$) 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).

Postive recruitment deviations were estimated for the years 2008–2013. Estimates of recruitment deviations in the subsequent years have been close to zero or negative, leading to lower recruitment.

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	1509	772	2948	0.439	0.157	0.721
2012	1657	850	3231	0.480	0.207	0.753
2013	2622	1341	5126	0.875	0.645	1.105
2014	1134	560	2296	-0.022	-0.313	0.269
2015	943	460	1929	-0.257	-0.573	0.059
2016	1028	498	2120	-0.208	-0.553	0.137
2017	1370	657	2854	0.045	-0.338	0.428
2018	755	334	1707	-0.588	-1.136	-0.039
2019	820	308	2186	-0.590	-1.390	0.211
2020	1603	474	5424	0.000	-1.176	1.176
2021	1630	484	5490	0.000	-1.000	1.000

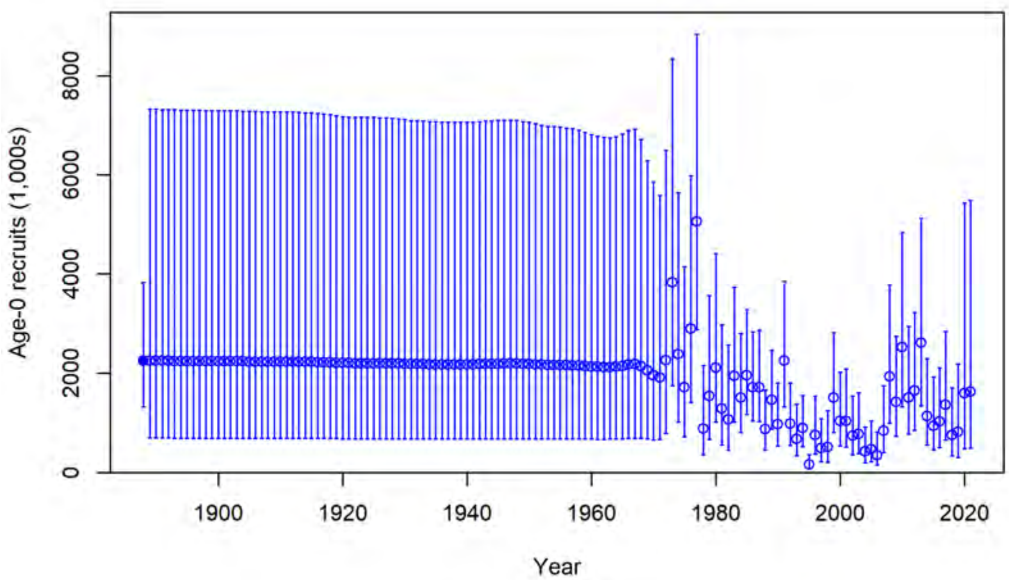

Figure iv: Estimated time series of age-0 recruits (1000s) for the base model with 95% intervals.

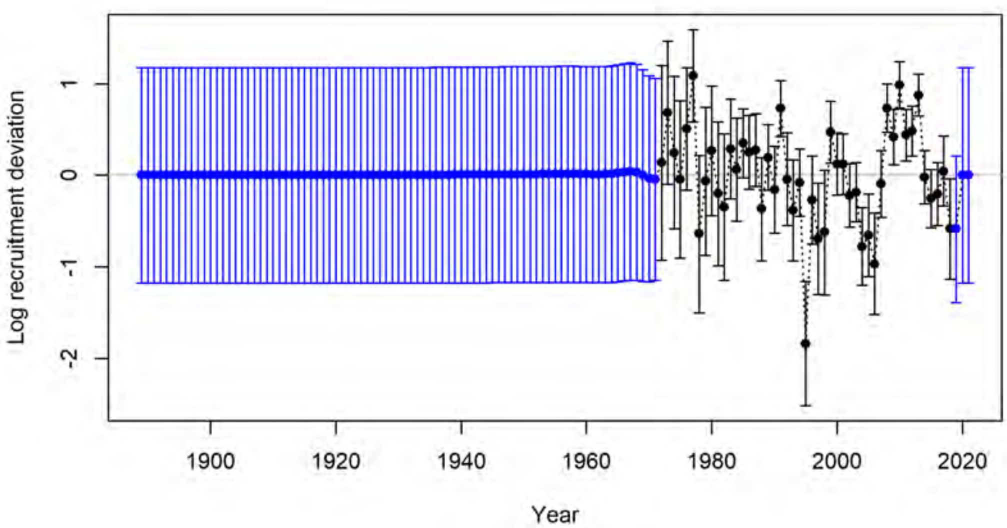

Figure v: Estimated time series of recruitment deviations. Black points are for years that were constrained to sum to zero and are part of the 'main' period, and blue points are for early deviations (left) and late or forecast deviations (right). Bars represent 95% intervals.

Exploitation status

The stock was estimated to have been exploited above the target proxy exploitation rate from the 1970s to approximately the late 1990s and again in the early 2000s (Figure vi). Exploitation rate is defined as the annual total dead catch divided by age 3+ biomass. The relative fishing intensity, $(1 - SPR)/(1 - SPR_{45\%})$, is estimated to have peaked in 1989 at 1.52. Recent estimates of exploitation have all been below the target proxy exploitation rate and the estimate of fishing intensity for the terminal year was the lowest estimated since 2011 (Table iv).

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	0.457	0.225	0.688	0.030	0.012	0.048
2012	0.462	0.235	0.689	0.035	0.014	0.055
2013	0.552	0.296	0.807	0.046	0.021	0.072
2014	0.554	0.298	0.809	0.050	0.022	0.077
2015	0.691	0.389	0.994	0.065	0.029	0.101
2016	0.630	0.339	0.921	0.056	0.025	0.087
2017	0.515	0.262	0.769	0.044	0.019	0.069
2018	0.456	0.224	0.687	0.036	0.015	0.057
2019	0.435	0.210	0.660	0.031	0.012	0.049
2020	0.350	0.163	0.537	0.022	0.009	0.036

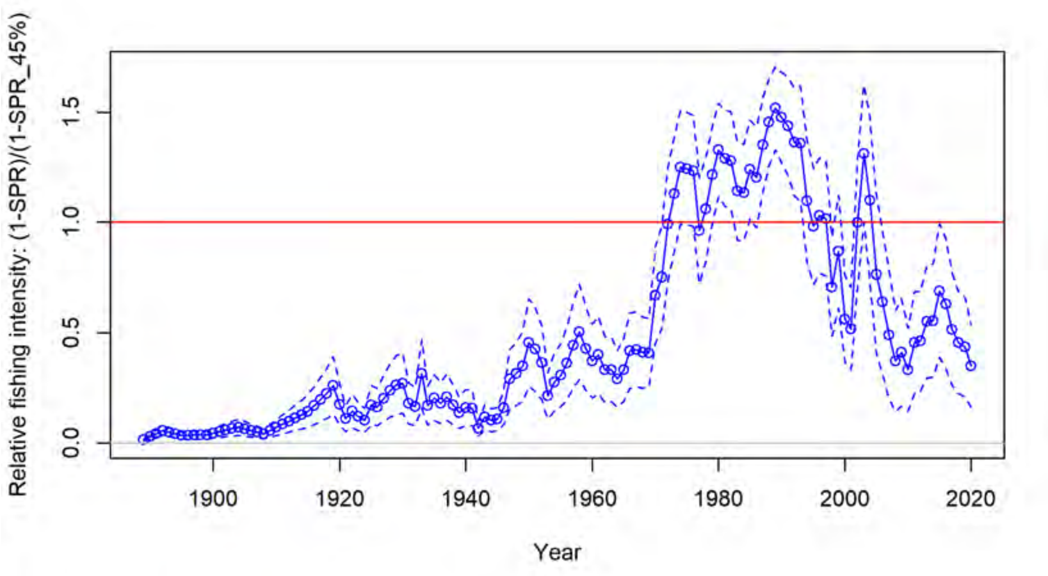

Figure vi: Estimated relative fishing intensity, $(1 - SPR)/(1 - SPR45\%)$, with 95% intervals. Fishing intensity is $1 - SPR$, where the spawning potential ratio (SPR) has a target of 45%, $SPR_{45\%}$. The red horizontal line at 1.0 indicates fishing intensity equal to the target and values above this 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 = 0.3939) was estimated to be close to the management target of 40% (Table v; Figure vii). The uncertainty in this estimate spans above and well below the target, suggesting the current status of the stock is uncertain (Figure vii).

Equilibrium yield given the estimate of steepness shows disparity between maximum sustainable yield (blue) and the SPR target (green Figure viii). Whereas, the target biomass (red) is in line with the maximum sustainable yield and the current biomass (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)	26443.6	9955.9	42931.3
Unfished Age 3+ Biomass (mt)	32617.3	10983.4	54251.2
Unfished Recruitment (R0)	2253.21	1036.6	3469.82
Spawning Biomass (mt) (2021)	10415	3145	17685
Fraction Unfished (2021)	0.3939	0.0818	0.7059
Reference Points Based SB40%	-	-	-
Proxy Spawning Biomass (mt) SB40%	10577.4	3982.3	17172.5
SPR Resulting in SB40%	0.549	0.4448	0.6532
Exploitation Rate Resulting in SB40%	0.0616	0.0209	0.1022
Yield with SPR Based On SB40% (mt)	832.098	675.503	988.693
Reference Points Based on SPR Proxy for MSY	-	-	-
Proxy Spawning Biomass (mt) (SPR45)	7093.73	2578.7	11608.76
SPR45	0.45	NA	NA
Exploitation Rate Corresponding to SPR45	0.0874	0.0401	0.1348
Yield with SPR45 at SB SPR (mt)	810.758	528.925	1092.591
Reference Points Based on Estimated MSY Values	-	-	-
Spawning Biomass (mt) at MSY (SB MSY)	9353.58	2160.9	16546.26
SPR MSY	0.5142	0.3449	0.6836
Exploitation Rate Corresponding to SPR MSY	0.0697	0.0126	0.1269
MSY (mt)	839.056	671.52	1006.592

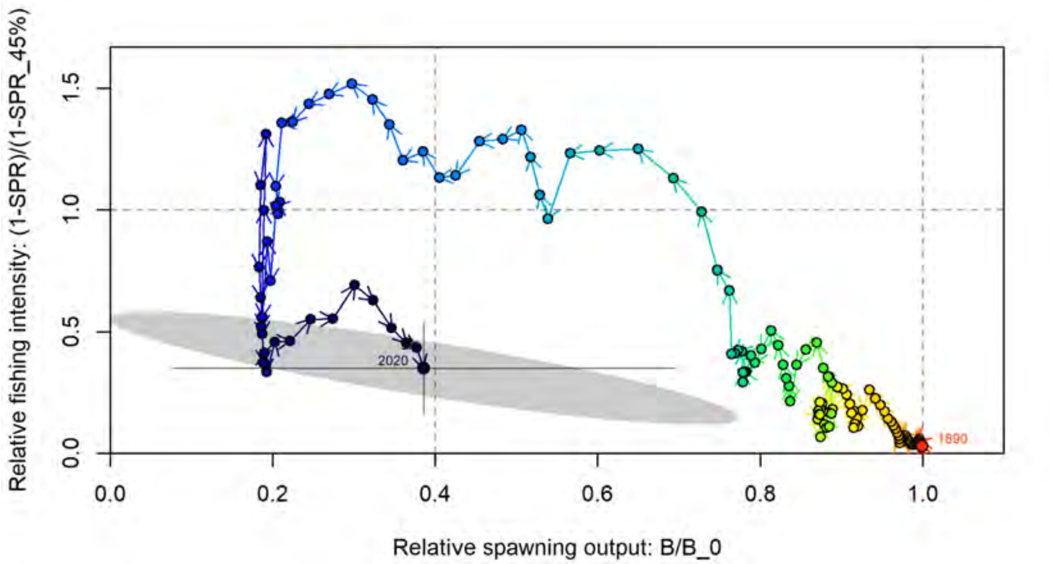

Figure vii: Phase plot of biomass ratio vs. spawning potential ratio (SPR) ratio. Each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show 95% intervals based on the asymptotic uncertainty for each dimension.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

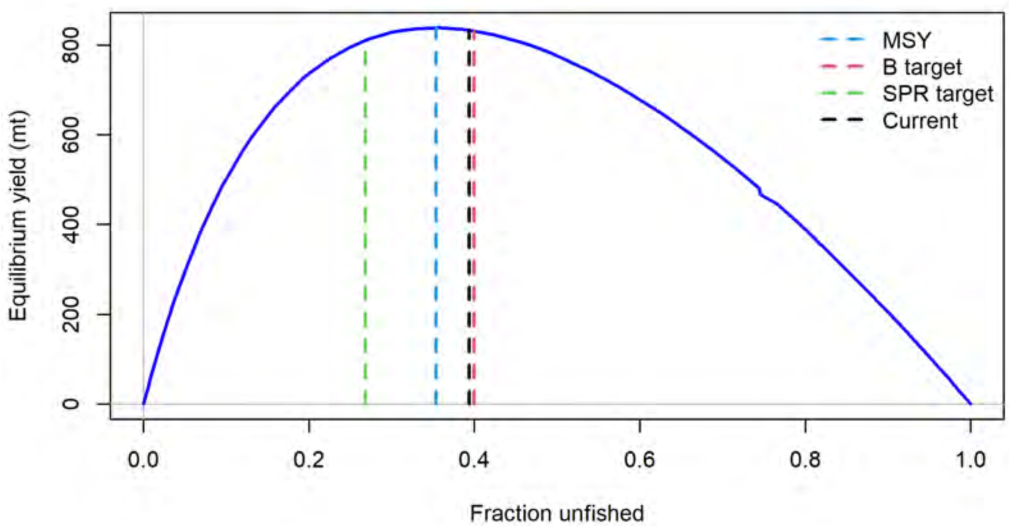

Figure viii: Equilibrium yield curve. Values are based on the 2020 fishery selectivities.

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	2523	2102	2102	213.19	215.17
2012	2597	2164	2164	273.56	276.85
2013	1334	1111	1111	428.67	431.79
2014	1276	1063	1063	503.06	506.73
2015	1205	1004	1004	711.7	717.46
2016	1136	946	946	675.65	679.53
2017	1502	1251	1251	546.18	549.83
2018	1373	1144	1144	449.46	454.4
2019	1143	1093	1039	389.23	396.61
2020	977	934	869	286.5	291.91

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.

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 projections, including the first two years, assume a 40:60 split between the trawl and fixed-gear commercial fleets based on guidance from the Groundfish Management Team.

The axes of uncertainty in the decision table (Table viii) are based on uncertainty in female natural mortality. 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	1,024.97	-	-	-	13,145.00	10,415.00	0.39
2022	907.85	-	-	-	12,602.00	10,224.30	0.39
2023	-	845.56	739.02	725.57	12,407.40	9,994.59	0.38
2024	-	855.31	739.84	722.34	12,315.20	9,831.95	0.37
2025	-	896.54	768.33	748.30	12,312.70	9,760.15	0.37
2026	-	936.59	795.16	773.36	12,330.50	9,720.59	0.37
2027	-	965.62	812.09	788.97	12,344.40	9,690.31	0.37
2028	-	984.37	819.98	795.95	12,354.40	9,666.70	0.37
2029	-	996.22	822.88	798.29	12,363.50	9,650.48	0.36
2030	-	1,003.92	821.21	796.47	12,375.70	9,643.62	0.36
2031	-	1,009.40	817.61	793.07	12,393.40	9,646.52	0.36
2032	-	1,013.68	813.99	789.92	12,418.50	9,659.43	0.37

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 M (M = 0.11)		Base (M ~ 0.17)		High M (M = 0.22)	
Assump-tion	Year	Catch	SSB (mt)	Frac. unfished	SSB (mt)	Frac. unfished	SSB (mt)	Frac. unfished
Recent avg. catch	2021	700	15066	0.296	10415	0.394	6475	0.419
	2022	700	15200	0.299	10224	0.387	6138	0.397
	2023	700	15221	0.299	9995	0.378	5849	0.378
	2024	700	15234	0.299	9858	0.373	5722	0.370
	2025	700	15252	0.300	9810	0.371	5715	0.369
	2026	700	15263	0.300	9813	0.371	5762	0.372
	2027	700	15265	0.300	9846	0.372	5831	0.377
	2028	700	15262	0.300	9901	0.374	5908	0.382
	2029	700	15256	0.300	9972	0.377	5991	0.387
	2030	700	15257	0.300	10057	0.380	6075	0.393
	2031	700	15264	0.300	10152	0.384	6162	0.398
	2032	700	15284	0.300	10254	0.388	6249	0.404
ACL P^***=0.40**	2021	700	15066	0.296	10415	0.394	6475	0.419
	2022	700	15200	0.299	10224	0.387	6138	0.397
	2023	633	15221	0.299	9995	0.378	5849	0.378
	2024	634	15277	0.300	9897	0.374	5758	0.372
	2025	658	15347	0.302	9892	0.374	5787	0.374
	2026	681	15398	0.303	9924	0.375	5856	0.379
	2027	696	15424	0.303	9969	0.377	5929	0.383
	2028	702	15432	0.303	10024	0.379	6001	0.388
	2029	703	15429	0.303	10089	0.382	6074	0.393
	2030	700	15427	0.303	10164	0.384	6149	0.397
	2031	696	15431	0.303	10250	0.388	6228	0.403
	2032	692	15448	0.304	10346	0.391	6310	0.408
ACL P^***=0.45**	2021	700	15066	0.296	10415	0.394	6475	0.419
	2022	700	15200	0.299	10224	0.387	6138	0.397
	2023	726	15221	0.299	9995	0.378	5849	0.378
	2024	722	15205	0.299	9832	0.372	5699	0.368
	2025	748	15194	0.299	9760	0.369	5672	0.367
	2026	773	15154	0.298	9721	0.368	5684	0.367
	2027	789	15076	0.296	9690	0.366	5701	0.369
	2028	796	14972	0.294	9667	0.366	5717	0.370
	2029	798	14848	0.292	9650	0.365	5733	0.371
	2030	796	14718	0.289	9644	0.365	5752	0.372
	2031	793	14586	0.287	9647	0.365	5775	0.373
	2032	790	14462	0.284	9659	0.365	5801	0.375

Scientific uncertainty

The model estimated uncertainty around the 2021 spawning biomass was $\sigma = 0.35$ and the uncertainty around the OFL was $\sigma = 0.03$.

This is likely an underestimate of overall uncertainty because there is no explicit incorporation of structural uncertainty related to the model. 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 north 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: 0.071,
- commercial fixed-gear: 0.114, and
- recreational California: 0.815.

However, for purposes of the projections, the split between commercial trawl and fixed-gear in the south was assumed to be 40:60, based on input from the Groundfish Management Team (GMT), leading to the following proportions among fleets:

- commercial trawl: 0.074,
- commercial fixed-gear: 0.111, and
- recreational California: 0.815.

Estimation of finer-scale differences in lingcod abundance or status within California, such as north and south of Point Conception (34°27'N), was not possible within this assessment. However, the state of California could apply finer-scale spatial management to account for any regional management considerations indicated by other sources of information about the lingcod in those waters.

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*) south 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 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 55) 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 14-15). 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).

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 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.

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 Pacific Fisheries Information Network (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 California recreational landings

California recreational lingcod catches since 1980 are available within the Marine Recreational Fisheries Statics Survey (MRFSS) database (Figure 10) and stored in the Recreational Fishery Information Network (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 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 Oregon Department of Fish and Wildlife (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 61). 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 California recreational index

The California recreational index was a combination of Marine Recreational Fisheries Statics Survey dockside commercial passenger fishing vessel data and Onboard Observer Program data.

From 1980-1989 and 1993-2003 MRFSS program conducted dockside intercept surveys of the recreational CPFV fishing fleet. Data from 1990, 1991, and 1992 are not available because funding for the surveys stopped.

For purposes of this assessment, the MRFSS time series was truncated at 1999 with the start of the Onboard Observer Program, which samples the same catch onboard the vessel as the dockside interviewers do on shore. Trips recorded as having the primary area fished in Mexico or occurring in bays, e.g., San Francisco Bay, were excluded before any filtering on species composition.

MRFSS data were downloaded from the RecFIN Type 3 database, where each entry corresponds to a single fish examined by a sampler at a particular survey site. Additionally, records identify the total number of the species of interest possessed by the group of anglers being interviewed, the number of anglers, and the hours fished. The data, as they exist in RecFIN, do not indicate which records belong to a given trip, though algorithms exist to aggregate the records to the trip level (pers. comm., M. Monk, SWFSC).

Stephens-MacCall (2004) filtering was used to predict the probability of catching lingcod based on the species composition of the sampler observed catch in a given trip. Coefficients from the Stephens-MacCall analysis (a binomial Generalized Linear Model (GLM)) are positive for species that are more likely to co-occur with lingcod and negative for species that are less likely to be caught with lingcod. Potentially informative predictor species, i.e., species with sufficient sample sizes and temporal coverage of at least 5% of all trips, were used to inform the binomial model. These 30 species co-occurred with lingcod in at least one trip and were retained for the Stephens-MacCall logistic regression. The top five species with high probability of co-occurrence with lingcod include Yellowtail, Treefish, Canary, Olive, and Brown rockfishes, all of which are associated with rocky reef and kelp habitats. The five species with the lowest probability of co-occurrence were Barred sandbass, Kelp bass, Pacific bonito, Squarespot rockfish, and California barracuda. The filter is useful in identifying co-occurring or non-occurring species assuming all effort was exerted in pursuit of a single target. However, when more than one species or species comples is targeted, co-occurrence can suggest associations that are nor informative for an index of abundance. Guidance suggests including all trips above a threshold that balances false negatives and false positives (Stephens and MacCall 2004). For this data set, false positives equaled false negatives at a rate of 0.35. However, this does not have any biological relevance and for this data set and therefore the filtering was not used.

Catch in numbers per angler hour (CPUE) was modeled using a Bayesian delta-GLM. Initial exploration of negative binomial models proved to be ill-fitting and was not further explored. A lognormal distribution was selected for the positive observations using Akaike information criterion (AIC) (66.36) over a Gamma distribution (Figure 16).

Investigated covariates included year, 2-month wave height, geographic region based on county, and primary area fished, i.e., inshore <3 nm, offshore >3 nm. The two geographic regions included 1) Del Norte to Santa Cruz ("N"), 2) Monterey to San Luis Obispo ("C") north of Pt. Conception, and 3) for models that span counties north and south of Pt. Conception, Santa Barbara to San Diego counties compose a third region ("S"). Trends in the average CPUE by region were similar in the filtered data set. Indices with a year and area interaction were not considered in model selection. The final model included year, region, wave height, and fishing area for both the positive and rate models. The resulting trend matched that of the Oregon recreational index, with a smaller abundance prior to 2010, followed by and increase, and ending with a downward trend (Figure 61).

The state of California implemented a statewide onboard observer sampling program in 1999 (Monk et al. 2014). During an onboard observer trip the sampler rides along on the CPFV and records location-specific catch and discard information to the species level for a subset of anglers onboard the vessel. The subset of observed anglers is usually a maximum of 15 people and the observed anglers can change during each fishing stop. The catch cannot be linked to an individual but rather to a specific fishing location. The sampler also records the starting and ending time, number of anglers observed, starting and ending depth, and measures discarded fish (Table 3). Additionally, California Polytechnic State University (Cal Poly) has conducted an independent onboard sampling program since 2003 for boats in Port San Luis and Morro Bay following the protocols established in Reilly et al. (1998a). Cal Poly observes fish as they are encountered rather than sampling fishers' bags, and CDFW has since modified their sampling to observe encountered fish as well. Cal Poly still differs in that they measure the length of both retained and discarded fish, whereas CDFW only measures retained. The Cal Poly data are incorporated in the same index as the CDFW data on retained fish since 1999. There are no onboard observer samples from either CDFW or Cal Poly in 2020 because of a lack of sampling given the pandemic. Data sheets from CDFW are not available prior to 2012 and staff constraints have prevented a quality control review of the data. Cal Poly data were checked for quality assurance and quality control upon input.

Each drift was assigned to a reef using the California Seafloor Mapping Project. The California Seafloor Mapping Program (CSMP) provides bathymetry and backscatter data available at a 2 m resolution. Starting in 2017, depth restrictions eased in districts north of Pt. Conception, and the recreational fleet targeted these depths (40-50 fm) that are outside of the mapped habitat available in CSMP (Figure 17).

The final Bayesian delta-GLM model included retained number of fish per angler hour (CPUE) with covariates for year, wave, and depth for the binomial model and an additional covariate of district for the lognormal model (Figure 61).

2.1.4.3 Deb Wilson-Vandenberg Index

The Deb Wilson-Vanedenberg data is onboard observer data conducted by CDFW in central California from 1987-1998 (Reilly et al. 1998a). In 1987, trips were only observed in Monterey, CA and were therefore excluded from the analysis. During an onboard observer trip, the sampler on the CPFV records location-specific catch and discard information to the species level for a maximum of 15 anglers onboard the vessel. The observed anglers can change during each fishing stop. The catch cannot be linked to an individual just fishing location. The sampler also records the starting and ending time, number of anglers observed, starting and ending depth, and measures discarded fish. Of the 2,256 trips observed, 12 launched from port in District 6. This small subset of the data was removed from this analysis.

A large effort was made by the SWFSC to develop a relational database for this survey (Monk et al. 2016). The specific fishing locations at each fishing stop were recorded at a finer scale than the catch data and hours spent fishing and number of fishers were aggregated to match the available catches. Between April 1987 and July 1992, the number of observed anglers was not recorded for each fishing stop. Instead, the number of anglers aboard the vessel was recorded.

Each drift was assigned to a reef using the California Seafloor Mapping Project. The CSMP provides bathymetry and backscatter data available at a 2 m resolution. Reefs were aggregated to four regions, Ft. Bragg to Santa Cruz (V1), Moss Landing to Big Sur (V2), San Luis Obispo to Pt. Conception (V3), and Offshore (deeper) locations including the Farallon Islands and reefs of Half Moon Bay and Monterey Bay (V4). The ports in San Luis Obispo county were sampled more frequently than other regions. The arithmetic mean of CPUE by year was higher in (V3) than other areas.

The resulting index is relatively flat with the lowest point in the mid 1990s (Figure 61).

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. .

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 1977 (Table 7; Figure 63). Commercial FG length-composition data started in 1992, with additional samples in 1988 and 1989 (Table 7; Figure 63).

Commercial age samples covered 10 years for TW and 2 years for FG years, starting in 1993 for TW and 1993 for FG (Table 8). 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 68-73).

2.1.6 Recreational length- and age-composition data

Recreational fishery length compositions (Figures 18 and 19) were obtained directly from MRFSS for years 1980 - 2003 and from CRFS for years 2004 - 2020 from the RecFIN website. RecFIN samples from Mexico were excluded from analysis. Lengths of fish measured by samplers onboard CPFVs prior to being released (Type 3d data) were also obtained from 2003 to 2020 from CDFW. A number of historical datasets that sampled the recreational fishery were also obtained from the CDFW. These include lingcod samples from onboard observers on CPFVs in 1975-1978 (n = 832) and in 1984-1989 (n = 865) from southern California, dockside sampling within the California Cooperative Rockfish survey (CCRS) between 1977-1985 from party/charter vessels (n = 692) in central California, dockside samples from party/charter (n = 4,818) and skiff vessels (n = 4,307) from 1959-1972 in central California that focused on lingcod and Blue rockfish (*Sebastes mystinus*) sampling, and onboard observers on CPFV's in 1987-1998 (n = 8,668) from central California. The CPFV data from 1975-1979 were compiled by Rob Collins and Steve Crooke from the California Department of Fish and Game, and the data from 1984-1989 were compiled by Ray Ally and David Ono from California Department of Fish and Game and published in Ally et al. (1991). The dockside CCRS data are described in (Mason 1995) and (Mason 1998), and the dockside data from 1959 to 1972 are described in (Karpov et al. 1995). The CPFV data from 1987-1998 (Reilly et al. (1998b)) were included as an index (See lingcod_DebWV_onboard_writeup_NCA.pdf) within the assessment. So, length-composition data from this dataset were separated from the other recreational data sources (Figure 64).

Length-composition data collected by California Polytechnic State University (Cal Poly; n = 5,501) between 2003 and 2019 were also considered. These samples were part of CCFPR sampling and were similar in length to other length samples from RecFIN. Given the overlap in sampling years, these data were not used, consistent with the previous assessment.

Annual recreational length compositions were developed following the same bin structure as was used for data from fishery-independent sources. 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 are used without expansion to the sample level. Unexpanded recreational composition data are commonly used in West Coast stock assessments for the above reason. Samples sizes used in the model were therefore set at the number of fish sampled for each year and dataset. Table 7 show the sample sizes for lengths. No ages were available from these recreational data sources.

Only landed fish were included in composition data. Fish designated as released were excluded from length compositions. This occurred for 9,065 samples, which represent approximately 10 percent of the total samples.

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 (73%), during the first four years of data: 2002-2005, a low rate of 14% in 2006, three years of moderate rates, and then a lower period with mean 21% starting in 2010, beginning prior to the implementation of catch shares in 2011. The contrast before and after 2011 is smaller for the south than the north. 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 showed little contrast over time, with a mean of 40% over the full 2002-2019 range of data.

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 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 22) 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 23), 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 22 and 23) 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 61) was assumed to follow a gamma distribution

(Figure 24) but both the lognormal and the gamma fit equally well. The quantile-quantile plot did not a significant departure from the theoretical quantiles (Figure 24) and the gradient was sufficiently low to suggest the model had converged. Furthermore, there was no clear pattern in the residuals (Figure 25).

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 26 and 27). 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 28) and had a low gradient.

The resulting index was generally cup shaped but with a large increase in 2004, the terminal year (Figure 61). 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 29).

2.2.1.3 NWFSC Hook and Line Survey

Since 2004, the NWFSC has conducted an annual Hook and Line Survey targeting shelf rockfish in the genus Sebastes at fixed stations in the Southern California Bight (Table 4). Key species of rockfish targeted by the survey are bocaccio (*S. paucispinis*), cowcod (*S. levis*), greenspotted (*S. chlorostictus*), and vermilion (*S. miniatus* and *S. crocotulus*) rockfishes, although a wide range of groundfish species have been observed by this survey, including lingcod (Table 5), and therefore provide potentially useful data for this assessment (Tables 4 and 6; Figure 31). Starting in 2014 the Hook and Line Survey added sampling sites located within the CCA and currently consists of a total of 201 sites (Table 4).

During each site visit, three deckhands simultaneously deploy 5-hook sampling rigs (this is referred to as a single drop) for a maximum of 5 minutes per line, but individual lines may be retrieved sooner at the angler's discretion (e.g., to avoid losing fish). Five drops are attempted at each site for a maximum possible catch of 75 fish per site per year (3 anglers x 5 hooks x 5 drops). Further details regarding the sample frame, site selection, and survey methodology are described by Harms et al. (2008). Note that depth was used as a continuous variable in the model, and depth bins were created for data exploration only.

A number of distributions were explored to fit an appropriate error distribution to the data. The final model included terms for Year, Site, Drop number within a site, second order depth, and a random effect for each observation.

Models were fit using the "rstanarm" R package (version 2.21.1). Posterior predictive checks of the Bayesian model fit for the binomial model and the positive model were all reasonable (Figures 32 and 33). The model generated data sets with the proportion of zeros similar to the observed data (91%; Figure 34). The depth effect is masked by the site effect in the marginal effects (Figure 35). A model without Site confirms that that depth follows the expected pattern observed in the data. The final index (Figure 61) represents a similar trend to the arithmetic mean of the annual CPUE.

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 36). 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 21). 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 7) 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 $2.38 * N_{\text{tow}}$.

2.2.2.2 AFSC/NWFSC West Coast Triennial Shelf Survey lengths

Post-processing of length data for the Triennial Survey (Table 7; Figure 41) 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 30). A maximum depth of 350 m was used because lingcod were infrequently caught at depths greater than 350 m (Figure 30).

2.2.2.3 NWFSC Hook and Line Survey lengths

The length composition of survey catches in each year was summarized using length bins in 2 cm increments from 10 to 130 cm (Figures 43 and 44). The first bin includes all observations less than 10 cm, and the last bin includes all fish larger than 130 cm. Length compositions from this survey were used as numbers of fish, all fish were measured, and were not expanded (Table 7). As such, composition data are available for male, female, and unsexed lingcod.

2.2.2.4 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 7), 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 46). 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.

2.2.2.5 NWFSC West Coast Groundfish Bottom Trawl Survey ages

Age-composition data from the WCGBTS (Figure 37) were included in the model as sex-specific conditional age-at-length (CAAL) distributions by year (Figures 38-40). 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 8). This resulted in 504 unsexed fish being excluded from the CAAL distributions, or approximately fifteen 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.

2.2.2.6 AFSC/NWFSC West Coast Triennial Shelf Survey ages

The preparation of age data from Triennial Survey (Table 8; Figure 42) followed the same methods as the WCGBTS.

2.2.2.7 NWFSC Hook and Line Survey lengths

The preparation of age data from Hook and Line Survey (Tables 8; Figure 45) followed the same methods as the WCGBTS.

2.2.2.8 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 8; Figure 47)

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 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 Cal Poly (Table 9). 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.

Little filtering of this data set was needed to reduce the number of zeros present in the data set. Cells not consistently sampled over time were excluded as well as cells that never encountered lingcod. This filtering led to 6963 retained drifts, with 2814 drifts encountering lingcod. Number of retained lingcod per angler hour was used as the response variable in a Bayesian delta-GLM (Tables 9 and 10). Models with a year and area interaction were not considered in the model selection process. Trends in the average CPUE by region were similar (Figure 48), as well as arithmetic mean CPUE inside and outside MPAs over time (Figure 49).

Model selection via differences in AIC provided support for year (Table 10), site location (Table 9), and depth bin (Table 11) as linear predictors for both the binomial and positive models even though the predictors were not constrained to be the same between the models (Table 12). The binomial model generated data sets with a proportion of zeros similar to the observed 60% suggesting the model structure was appropriate for the data. A Lognormal distribution was supported over a Gamma distribution for the positive model (Δ AIC of 322.77; Figure 51). The estimated index of abundance (Table 13) exhibited a trend similar to that of the arithmetic mean of the annual CPUE (Figure 50).

2.2.3.5 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 54) based on histological analysis of ovaries was developed for these models (pers. comm., M. Head, NWFSC; Figure 55). 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 52). 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 53), 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 5,547 fish. Of these samples, 3,052 were female and 1,787 were male. These data resulted in the following estimates of the weight-length relationiship, $W = 0.000003450 * L^{3.2364}$ for females and $W = 0.000002425 * L^{3.3367}$ for males (Figure 56). 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: $k = 0.190$ and $L_\infty = 97.906$ for females and $k = 0.227$ and $L_\infty = 80.805$ for males. These estimates were used as initial values within the base model for estimating growth. Samples used to generate these estimates include 3,910 age and length samples, of which 2,178 are female and 1,228 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 57). The best fit model, as chosen by both AIC and Bayesian information criterion (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 58).

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 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
- The recreational CPFV DebWV index and associated length compositions were separated from the California recreational fleet into into a new fleet to allow different assumptions about selectivity

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) with the exception of the Triennial Survey selectivity. In that one case, the estimation of parameter 5 controlling the initial selectivity at for the smallest size bins provided a better fit to the length comps for the smallest individuals and resolved a problem of the ascending slope parameter hitting the lower bound.

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 20) 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 CA fleet began in

- 1983 (notable reduction in the number of small fish observed)
- 1999 (min size limit 24 inches)
- 2000 (min size limit increased to 26)
- 2002 (min size limit decreased to 24)
- 2011 (min size limit decreased to 22)
- 2017 (recreational fishery had access to deeper waters)

Not accounted for is a min size limit of 30 inches in 2004 as sample sizes were low in that year.

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 100) 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 100) 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 213 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
  - 133 recruitment deviations parameters covering the range 1889-2020, with 1972-2018 representing the "main" period modeled as a zero-centered deviation vector
- 3 extra standard deviation parameters for indices
- 2 parameters representing the catchability in the two periods of the index for the recreational California fleet (all other catchability values were derived analytically)
- 52 selectivity parameters, of which 27 represented changes over time
- 10 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 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 Triennial Survey showed high variability among observations indicating that the incomplete spatial coverage of this survey within California waters was leading to high variability not captured in the estimated uncertainty for the index. Therefore an extra SD parameter was added to the south model for that index.

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.

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 $M = 0.17$, male $M = 0.222$, and stock-recruit steepness $h = 0.502$ (Table 15). Females were estimated as growing larger than males with female length at age 14 (the second reference age) equal to 105.9 cm compared to 64.9 cm for males. The L_∞ associated with the estimated growth parameters was 122.6 cm for females and 65.2 cm for males.

Selectivity was estimated as dome-shaped for all fleets. The estimated changes over time for the commercial trawl sector was a shift in selectivity toward larger fish over time. with the peak selectivity from 2011 onward estimated at 78.2 cm. Peak selectivity for the time-invariant commercial fixed-gear fishery was estimated at 69.6 cm (Figure 59).

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 56.1 cm.

The changes in the recreational California selectivity were subtle and presumably driven primarily by changes in minimum size limits. The Triennial Survey and WCGBTS selected more small fish than other fleets, with peak selectivity at 23.1 cm and 21.1 cm, respectively, while selectivity for the Hook and Line Survey peaked at the largest size, 82.2 cm (Figure 60). The survey selectivity is notably different from the north model, where the peak is above 80 cm for all surveys. 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 six indices of abundance available for the south model are reasonably good although many of the indices are noisier than for the north model reflecting the smaller sample sizes associated with the smaller area (Figure 61). The first two years of trawl logbook CPUE are poorly fit but they are much higher than the rest of the time series, and are also poorly fit in the north model. observed patterns (Figure 61). The recreational California CPUE and the WCGBTS both show a the strong increase starting in 2010. The rec CA peaks in 2016 while the WCGBTS is stable across 2014-2016. In the 2017 STAR, the conflict between these indices led to the removal of the CPUE index, but the addition of a low 2019 observation in the WCGBTS makes these indices appear more consistent than before. The lack of 2020 survey due to the COVID-19 pandemic makes it harder to judge whether the 2019 WCGBTS observation is an outlier or representing a steep decline in selected biomass.

The fit to the length data in the south model is generally good, in aggregate (Figure 62). The limited number of ages in the south model means that there is less potential conflict among data sources than in the north. Many sources show clear size modes, including the commercial trawl discards, the Triennial Survey, and the WCGBTS. In general these are well fit. The WCGBTS is estimated as selecting smaller fish in the south than in the north and shows modes indicating strong cohorts for all years 2007-2010, whereas the north model had a single large estimated 2008 cohort. Pearson residuals for the commercial trawl show some noise and lack of fit, but there are few clear trends in the residuals. Some of the biggest residuals come from the recreational California length compositions but this source represents multiple sampling programs with regional variability in sampling location, so some lack of fit is to be expected.

Early explorations of the south model showed bad patterns in the fit to the age data from the commercial trawl fishery, leading to the removal of all ages other than those from WCGBTS in the final model. Nevertheless, these ages are included as marginal "ghost age comps" which are excluded from the likelihood for purposes of visualizing the implied fit. The implied fit to the ages from the commercial trawl and fixed-gear fleets show expected modes at younger ages than observed as discussed in Section 3.2.4. The implied fits to the Triennial Survey is good even though these data are not included in the model likelihood.

The ages included in the south model are all from the WCGBTS survey and are represented as CAAL data (shown for WCGBTS in Figures 65 - 67). These represent about 3,400 fish (compared to over 72,000 in the north model, of which about 5,000 were from the WCGBTS). The fits to these data are all reasonably good, although the expected proportion of males older than 10 years is greater than observed in many years. The observed data would be more consistent with a higher mortality rate for males but the estimated values are similar among the rates, presumably driven by information in the larger volume of length data. The mean age within these data rises from about 2.5 in 2003 to almost 5 in 2007 followed by a steep decline as the addition of new recruits brings down the mean observed age.

The expected commercial trawl discard fractions are lower than observed for the first four years but otherwise are relatively well fit (Figures 68 and 69). The most estimates match the observed decline in discard rate over the most recent 7 years, which is likely driven by the shift toward larger individuals as the above cohorts born in the 2007-2010 period grew older. The commercial fixed-gear discards show little variability over time and the fits are well within the uncertainty intervals.

The fit to the mean body weight ("Mnwt") of discards are within the confidence intervals for most years although there's relatively little signal in those data (Figures 71 and 73).

3.2.5.3 Population trajectory

The spawning stock biomass is estimated as having declined from an unfished equilibrium of 26,444 mt to a 2021 value of 10,415 mt or 0.39 fraction unfished of. The lowest fraction unfished was 0.1829 in 2005 (Table 18; Figures 74 and 75). The 2021 total biomass (all ages from both sexes) was 13,594 mt (Figure 76). Total biomass (Figure 76) largely followed the same trajectory as spawning stock biomass (Figure 74).

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 77–78). 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 1971, and thus, these early recruitment events fall on the stock-recruitment curve (Figure 79). 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 83 - 86).

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

- remove all fishery-dependent age data from the north model
- 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 California recreational fishery in recent years from one based on the onboard CPFV observations to an alternative index developed from the CRFS sampling of private and rental boats.

The selectivity sensitivities included

- make the fixed-gear fishery selectivity asymptotic rather than dome shaped (in the north model it is estimated as asymptotic)
- 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

The south model was sensitivity to many of the sensitivities related to biology and recruitment (Table 20, Figure 83). Those with biggest impact included increasing σ_R from 0.6 to 0.8, which brought the scale of the stock downard, with 2021 biomass below the minimum stock size threshold, while those in which M was fixed at 0.3 or shared among females and males (which led to an estimate of $M = 0.33$) all had 2021 fraction unfished greater than 90% (compared to a base model estimates of female $M = 0.17$ and 2021 fraction unfished at 39%). The negative log-likelihood for the models with alternative assumptions aboutn M were 3 to 5 units units worse than the base model, with worse fits the index and length comp data and better fits to the age compositions.

The south model was also sensitive to changes in composition data (Tables 21 and 19; Figure 84). This is likely due to the smaller volume of composition data available for this model. The addition of ages from all sources resulted in increases in estimated abundance when the ages were conditioned on length, but a decrease in estimated abundance when the ages were represented as marginal distributions. The Dirichlet-multinomial sensitivity, which led to increased weight on the length and age compositions (Figure 87) resulted in a lower estimate of female $M = 0.13$ and pushed 2021 fraction unfished up to 0.83.

Anong the sensitivities related to changing or removing indices (Table 22, Figure 85), removing all fishery-dependent indices had the largest impact, resulting in an estimated fraction unfished that never fell below 50%, suggesting that the fishery-dependent indices provide important information abound historical changes in abundance. The individual indices whose removal had the largest impact were those related to the historical indices: the Triennial Survey and the recreational CPFV Deb Wilson-Vandenberg index. Also, changing the California recreational indices for the recent period from one based on the onboard CPFV observations to an alternative developed from the CRFS sampling of private and rental boats reduced the estimated population significantly.

The sensitivities related to selectivity (Table 23, Figure 86), showed that forcing the fixed-gear fishery to be asymptotic reduced the estimated population size by removing the estimated cryptic biomass of larger individuals unavailable to any fishery. In contrast, a model with sex-specific selectivity had much higher initial abundance but lower productivity, ending below the base model at the end of the time series. Combining sex-specific selectivity with fixing female $M = 0.3$, resulted in the sensitivity which was most similar to the base model.

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 mainly length-composition data and secondarily age-composition data from the WCGBTS because it was the only source for which ages were included in the base model (Figure 90). Information in the surveys provided little information with respect to female M and was slightly conflicting for the Deb WV index, which suggested a lower M. 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 91). 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 92).

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 93). This was not surprising, as estimating h is notoriously difficult.

All data types contributed to the estimate of h, but the information in the ages conflicted with the lengths for all sources except the commercial FG fleet and the California recreational ages in the Deb WV index (Figure 93). This index includes information on discarded fish, and thus may be sampling slightly smaller ages than the other recreational and commercial sources. Information in the surveys provided little information with respect to female M and was slightly conflicting for the Deb WV index, which suggested a lower M. 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 94) The current status of the stock was highly dependent upon the assumed value of h (Figure 95).

Many data sources contributed to the estimate of R_0, including prior information, which happened to have a minimum at the cross roads of where length and age information intersected (Figure 96). Values greater than nine led to large increases in the current estimate of spawning stock biomass and a stock size that was larger than that from the unfished state (Figures 97 and 98).

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 88 and 89).

Removing five years of data led to a different historical time series for the stock, one that indicated much higher productivity. Regardless, the estimate of the current spawning stock biomass remained largely consistent with the estimates from the base model. 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 $\sigma = 0.35$ and the uncertainty around the OFL was $\sigma = 0.03$.

This is likely an underestimate of overall uncertainty because there is no explicit incorporation of structural uncertainty related to the model. 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 = 0.3939) was estimated to be close to the management target of 40% (Table

17; Figure 81). The uncertainty in this estimate spans above and well below the target, suggesting the current status of the stock is uncertain (Figure 81).

Equilibrium yield given the estimate of steepness shows disparity between maximum sustainable yield (blue) and the SPR target (green; Figure 82). Whereas, the target biomass (red) is in line with the maximum sustainable yield and the current biomass (Figure 82). The time series of fishing intensity was estimated to have been below the management harvest rate limit for the early years of the fishery and the most recent years included in the model, i.e., since the early 2000s (Figure 80).

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 projections, including the first two years, assume a 40:60 split between the trawl and fixed-gear commercial fleets based on guidance from the Groundfish Management Team.

The axes of uncertainty in the decision table (Table 28) are based on uncertainty in female natural mortality. 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.

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 99), 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 100), 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 100). 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 101). 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 102) 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	14.09	0.00	0.00	6.53	0.00	0.00	0.00	0.00	0.00	20.61
1890	28.17	0.00	0.00	13.06	0.00	0.00	0.00	0.00	0.00	41.23
1891	42.26	0.00	0.00	19.59	0.00	0.00	0.00	0.00	0.00	61.84
1892	56.34	0.00	0.00	26.12	0.00	0.00	0.00	0.00	0.00	82.46
1893	48.86	0.00	0.00	22.65	0.00	0.00	0.00	0.00	0.00	71.51
1894	41.38	0.00	0.00	19.18	0.00	0.00	0.00	0.00	0.00	60.56
1895	33.90	0.00	0.00	15.71	0.00	0.00	0.00	0.00	0.00	49.62
1896	34.45	0.00	0.00	15.97	0.00	0.00	0.00	0.00	0.00	50.42
1897	35.00	0.00	0.00	16.22	0.00	0.00	0.00	0.00	0.00	51.22
1898	35.55	0.00	0.00	16.48	0.00	0.00	0.00	0.00	0.00	52.03
1899	36.10	0.00	0.00	16.73	0.00	0.00	0.00	0.00	0.00	52.83
1900	43.17	0.00	0.00	20.01	0.00	0.00	0.00	0.00	0.00	63.18
1901	50.24	0.00	0.00	23.29	0.00	0.00	0.00	0.00	0.00	73.53
1902	57.32	0.00	0.00	26.57	0.00	0.00	0.00	0.00	0.00	83.88
1903	64.39	0.00	0.00	29.85	0.00	0.00	0.00	0.00	0.00	94.24
1904	71.46	0.00	0.00	33.13	0.00	0.00	0.00	0.00	0.00	104.59
1905	63.78	0.00	0.00	29.56	0.00	0.00	0.00	0.00	0.00	93.34
1906	56.10	0.00	0.00	26.00	0.00	0.00	0.00	0.00	0.00	82.10
1907	48.41	0.00	0.00	22.44	0.00	0.00	0.00	0.00	0.00	70.86
1908	40.73	0.00	0.00	18.88	0.00	0.00	0.00	0.00	0.00	59.61
1909	55.05	0.00	0.00	25.52	0.00	0.00	0.00	0.00	0.00	80.57
1910	69.37	0.00	0.00	32.16	0.00	0.00	0.00	0.00	0.00	101.53
1911	83.69	0.00	0.00	38.79	0.00	0.00	0.00	0.00	0.00	122.49
1912	98.01	0.00	0.00	45.43	0.00	0.00	0.00	0.00	0.00	143.44
1913	112.33	0.00	0.00	52.07	0.00	0.00	0.00	0.00	0.00	164.40
1914	126.65	0.00	0.00	58.71	0.00	0.00	0.00	0.00	0.00	185.36
1915	140.97	0.00	0.00	65.35	0.00	0.00	0.00	0.00	0.00	206.32
1916	168.45	0.00	0.00	78.08	0.00	0.00	0.00	0.00	0.00	246.54
1917	195.93	0.00	0.00	90.82	0.00	0.00	0.00	0.00	0.00	286.75
1918	223.41	0.00	0.00	103.56	0.00	0.00	0.00	0.00	0.00	326.97
1919	259.26	0.00	0.00	120.18	0.00	0.00	0.00	0.00	0.00	379.44
1920	167.80	0.00	0.00	77.78	0.00	0.00	0.00	0.00	0.00	245.58

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	103.90	0.00	0.00	48.16	0.00	0.00	0.00	0.00	0.00	152.06
1922	138.53	0.00	0.00	64.22	0.00	0.00	0.00	0.00	0.00	202.75
1923	113.90	0.00	0.00	52.80	0.00	0.00	0.00	0.00	0.00	166.70
1924	97.56	0.00	0.00	45.22	0.00	0.00	0.00	0.00	0.00	142.78
1925	166.58	0.00	0.00	77.22	0.00	0.00	0.00	0.00	0.00	243.80
1926	157.31	0.00	0.00	72.92	0.00	0.00	0.00	0.00	0.00	230.24
1927	195.46	0.00	0.00	90.60	0.00	0.00	0.00	0.00	0.00	286.06
1928	233.60	0.00	0.00	108.28	0.00	0.00	0.00	0.00	0.00	341.89
1929	256.50	0.00	0.00	118.90	0.00	0.00	2.36	0.00	0.00	377.76
1930	260.36	0.00	0.00	120.69	0.00	0.00	4.73	0.00	0.00	385.77
1931	157.49	0.00	0.00	82.09	0.00	0.00	7.08	0.00	0.00	246.66
1932	136.39	0.00	0.00	79.60	0.00	0.00	9.45	0.00	0.00	225.44
1933	265.11	0.00	0.00	172.68	0.00	0.00	11.81	0.00	0.00	449.60
1934	125.25	0.00	0.00	90.83	0.00	0.00	14.18	0.00	0.00	230.26
1935	146.33	0.00	0.00	117.91	0.00	0.00	16.54	0.00	0.00	280.78
1936	119.40	0.00	0.00	106.79	0.00	0.00	18.91	0.00	0.00	245.10
1937	129.92	0.00	0.00	128.90	0.00	0.00	29.29	0.00	0.00	288.11
1938	94.49	0.00	0.00	103.99	0.00	0.00	35.45	0.00	0.00	233.93
1939	62.18	0.00	0.00	75.95	0.00	0.00	48.96	0.00	0.00	187.10
1940	70.54	0.00	0.00	95.73	0.00	0.00	51.43	0.00	0.00	217.70
1941	66.89	0.00	0.00	101.03	0.00	0.00	47.53	0.00	0.00	215.45
1942	23.00	0.00	0.00	38.75	0.00	0.00	25.25	0.00	0.00	87.00
1943	46.49	0.00	0.00	87.66	0.00	0.00	24.15	0.00	0.00	158.29
1944	38.40	0.00	0.00	81.36	0.00	0.00	19.82	0.00	0.00	139.59
1945	35.15	0.00	0.00	84.11	0.00	0.00	26.44	0.00	0.00	145.70
1946	47.60	0.00	0.00	129.45	0.00	0.00	45.50	0.00	0.00	222.55
1947	61.52	0.00	0.00	191.70	0.00	0.00	165.06	0.00	0.00	418.28
1948	59.16	0.00	0.00	213.41	0.00	0.00	179.92	0.00	0.00	452.49
1949	58.43	0.00	0.00	247.25	0.00	0.00	196.17	0.00	0.00	501.85
1950	81.38	0.00	0.00	411.09	0.00	0.00	176.22	0.00	0.00	668.68
1951	59.03	0.00	0.00	364.57	0.00	0.00	182.16	0.00	0.00	605.76
1952	58.32	0.00	0.00	312.26	0.00	0.00	129.62	0.00	0.00	500.20
1953	32.15	0.00	0.00	151.14	0.00	0.00	95.62	0.00	0.00	278.90
1954	41.60	0.00	0.00	173.48	0.00	0.00	153.98	0.00	0.00	369.06
1955	53.33	0.00	0.00	198.86	0.00	0.00	164.86	0.00	0.00	417.04
1956	59.04	0.00	0.00	216.27	0.00	0.00	224.76	0.00	0.00	500.07
1957	79.44	0.00	0.00	285.86	0.00	0.00	259.89	0.00	0.00	625.19

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	82.35	0.00	0.00	348.05	0.00	0.00	285.84	0.00	0.00	716.24
1959	59.00	0.00	0.00	298.11	0.00	0.00	225.38	0.00	0.00	582.49
1960	42.21	0.00	0.00	261.20	0.00	0.00	188.36	0.00	0.00	491.77
1961	56.04	0.00	0.00	291.12	0.00	0.00	186.03	0.00	0.00	533.19
1962	46.23	0.00	0.00	205.38	0.00	0.00	181.40	0.00	0.00	433.01
1963	52.20	0.00	0.00	201.15	0.00	0.00	181.20	0.00	0.00	434.56
1964	44.35	0.00	0.00	155.24	0.00	0.00	175.86	0.00	0.00	375.46
1965	50.89	0.00	0.00	131.06	0.00	0.00	256.86	0.00	0.00	438.80
1966	44.64	0.00	0.00	166.12	0.00	0.00	359.09	0.00	0.00	569.84
1967	38.13	0.00	0.00	155.08	0.00	0.00	379.29	0.00	0.00	572.50
1968	29.08	0.00	0.00	154.24	0.00	0.00	366.00	0.00	0.00	549.32
1969	49.34	0.00	0.00	209.33	0.00	0.00	284.72	0.00	0.00	543.38
1970	41.16	0.00	0.00	500.39	0.00	0.00	435.76	0.00	0.00	977.31
1971	59.41	0.00	0.00	540.35	0.00	0.00	507.13	0.00	0.00	1106.88
1972	109.51	0.00	0.00	845.59	0.00	0.00	619.73	0.00	0.00	1574.83
1973	97.53	0.00	0.00	1098.48	0.00	0.00	616.97	0.00	0.00	1812.99
1974	80.11	0.00	0.00	1318.30	0.00	0.00	629.69	0.00	0.00	2028.09
1975	62.38	0.00	0.00	1171.26	0.00	0.00	689.17	0.00	0.00	1922.81
1976	70.08	0.00	0.00	1061.81	0.00	0.00	722.11	0.00	0.00	1854.00
1977	35.68	0.00	0.00	613.07	0.00	0.00	529.84	0.00	0.00	1178.58
1978	90.75	0.00	0.00	616.43	0.00	0.00	706.35	0.00	0.00	1413.53
1979	74.62	0.00	0.00	1072.30	0.00	0.00	766.86	0.00	0.00	1913.77
1980	80.93	0.00	0.00	1106.92	0.00	0.00	1094.15	0.00	0.00	2282.00
1981	73.66	0.00	0.00	950.01	0.00	0.00	941.77	0.00	0.00	1965.43
1982	49.46	0.00	0.00	995.04	0.00	0.00	704.93	0.00	0.00	1749.42
1983	33.39	0.00	0.00	781.04	0.00	0.00	470.57	0.00	0.00	1284.99
1984	26.50	0.00	0.00	732.17	0.00	0.00	410.80	0.00	0.00	1169.47
1985	41.39	0.00	0.00	473.34	0.00	0.00	790.00	0.00	0.00	1304.73
1986	83.48	0.00	0.00	309.66	0.00	0.00	752.72	0.00	0.00	1145.87
1987	95.51	0.00	0.00	566.07	0.00	0.00	767.56	0.00	0.00	1429.14
1988	124.80	0.00	0.00	693.05	0.00	0.00	838.48	0.00	0.00	1656.33
1989	240.13	0.00	0.00	732.36	0.00	0.00	779.78	0.00	0.00	1752.27
1990	183.35	0.00	0.00	584.59	0.00	0.00	675.51	0.00	0.00	1443.45
1991	151.32	0.00	0.00	481.96	0.00	0.00	571.24	0.00	0.00	1204.52
1992	161.58	0.00	0.00	348.35	0.00	0.00	466.97	0.00	0.00	976.90
1993	141.14	0.00	0.00	442.61	0.00	0.00	362.69	0.00	0.00	946.45

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	118.03	0.00	0.00	343.68	0.00	0.00	200.94	0.00	0.00	662.64
1995	116.51	0.00	0.00	264.75	0.00	0.00	220.40	0.00	0.00	601.66
1996	132.58	0.00	0.00	224.66	0.00	0.00	297.31	0.00	0.00	654.54
1997	115.60	0.00	0.00	255.46	0.00	0.00	217.43	0.00	0.00	588.50
1998	52.85	0.00	0.00	44.22	0.00	0.00	207.68	0.00	0.00	304.75
1999	38.61	0.00	0.00	51.32	0.00	0.00	281.03	0.00	0.00	370.96
2000	13.82	0.00	0.00	14.93	0.00	0.00	158.96	0.00	0.00	187.71
2001	22.87	0.00	0.00	11.30	0.00	0.00	133.04	0.00	0.00	167.21
2002	28.69	0.00	0.00	16.12	0.00	0.00	414.58	0.00	0.00	459.39
2003	28.39	0.00	0.00	9.10	0.00	0.00	818.72	0.00	0.00	856.21
2004	35.99	0.00	0.00	12.31	0.00	0.00	572.07	0.00	0.00	620.37
2005	28.32	0.00	0.00	14.59	0.00	0.00	325.41	0.00	0.00	368.32
2006	24.01	0.00	0.00	12.30	0.00	0.00	266.53	0.00	0.00	302.84
2007	21.06	0.00	0.00	30.30	0.00	0.00	129.81	0.00	0.00	181.17
2008	19.28	0.00	0.00	24.02	0.00	0.00	80.65	0.00	0.00	123.95
2009	16.72	0.00	0.00	24.23	0.00	0.00	91.64	0.00	0.00	132.59
2010	16.69	0.00	0.00	21.13	0.00	0.00	75.39	0.00	0.00	113.21
2011	20.47	0.00	0.00	6.02	0.00	0.00	186.70	0.00	0.00	213.19
2012	26.77	0.00	0.00	11.36	0.00	0.00	235.43	0.00	0.00	273.56
2013	37.07	0.00	0.00	10.93	0.00	0.00	380.67	0.00	0.00	428.67
2014	63.40	0.00	0.00	13.67	0.00	0.00	425.99	0.00	0.00	503.06
2015	88.77	0.00	0.00	25.94	0.00	0.00	596.99	0.00	0.00	711.70
2016	63.19	0.00	0.00	19.13	0.00	0.00	593.33	0.00	0.00	675.65
2017	69.95	0.00	0.00	23.18	0.00	0.00	453.05	0.00	0.00	546.18
2018	56.48	0.00	0.00	46.76	0.00	0.00	346.21	0.00	0.00	449.46
2019	43.42	0.00	0.00	76.49	0.00	0.00	269.32	0.00	0.00	389.23
2020	32.83	0.00	0.00	55.39	0.00	0.00	198.27	0.00	0.00	286.50

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	2523.00	2102.00	2102.00	213.19	215.17
2012	2597.00	2164.00	2164.00	273.56	276.85
2013	1334.00	1111.00	1111.00	428.67	431.79
2014	1276.00	1063.00	1063.00	503.06	506.73
2015	1205.00	1004.00	1004.00	711.70	717.46
2016	1136.00	946.00	946.00	675.65	679.53
2017	1502.00	1251.17	1251.00	546.18	549.83
2018	1373.00	1143.71	1144.00	449.46	454.40
2019	1142.95	1092.66	1039.00	389.23	396.61
2020	977.12	934.12	869.00	286.50	291.91
2021	1255.00	1162.13	1102.00	NA	NA
2022	1334.00	1229.95	1172.00	NA	NA

Table 3: Data filtering for the California commercial passenger fishing vessel onboard survey of lingcod in the southern California recreational fishery.

Filter	Description	Trip	Positive Trips	% drifts retained
All	Download from SQL; identifiable errors filtered	41168	1866	5%
Fishery closed	Removed samples when target fish fishery closed	33224	1834	6%
Ocean only	Removed samples from major bays	33029	1834	6%
Catch	Removed samples with zero catch of any species	30469	1834	6%
Depth	Removed samples in less than max depth of species	29858	1817	6%
Time fished	Removed upper two percent of time fished	29252	1802	6%
Percent groundfish in samples	Removed samples with fewer groundfish than when the target observed	14664	1718	12%
Another area gfish filter	Removed samples	9043	1469	16%

Table 4: Positive samples of lingcod in the NWFSC Hook and Line Survey by depth (fm).

Year	Positive Samples	Samples	Percent Positive
(0,50]	4	207	2%
(50,75]	86	724	12%
(75,100]	226	2383	9%
(100,125]	123	1620	8%
(125,150]	101	1121	9%
(150,175]	98	982	10%
(175,200]	20	268	7%
(200,230]	14	97	14%

Table 5: Samples of lingcod in the NWFSC Hook and Line Survey by area and depth bins (ft).

Area name	(125,150]	(175,200]	(200,230]	(0,50]	(50,75]	(75,100]	(100,125]	(150,175]
Fourteen Mile Bank	1%							
107 and 118 Banks		5%	0%					
43 Fathom Bank						3%	10%	
Anacapa Island	18%	0%			0%	4%	4%	9%
Catalina Island	10%	11%			1%	1%		11%
Central Coast						2%	0%	
Cherry Bank	10%	5%				9%	10%	
Cortez Bank	4%			12%	6%	5%	3%	7%
Garrett Bank	6%						0%	
Harrison Reef	0%					2%	1%	
Hidden Reef	25%		7%					9%
Kidney Bank	11%						12%	0%
Nine Mile Bank	1%							0%
Osborn Bank				0%	15%	32%		24%
Point Conception/Arguello	14%	0%				11%	11%	3%
Potato Bank	4%					20%	8%	
San Clemente Island	8%	0%		1%	0%	6%	1%	5%
San Miguel Island	10%				41%	22%	10%	
San Nicolas Island East					17%	25%	33%	5%
San Nicolas Island West	40%	0%			5%	11%	20%	5%
San Pedro Bay					4%	0%		
Santa Barbara				1%	17%	5%		
Santa Barbara Channel	0%	0%				0%	2%	13%
Santa Barbara Island	8%	8%	0%	4%	0%	12%	15%	19%
Santa Cruz Island	33%	15%	20%		6%	9%		17%
Santa Monica Bay	1%					1%	0%	
Santa Rosa Flats	11%	6%	15%				9%	11%
Santa Rosa Island					18%	19%	0%	
Sixty Mile Bank	2%	0%				0%	2%	0%
South Coast				0%	3%	6%		
Tanner Bank		7%	0%			3%		0%

Table 6: Samples of lingcod in the NWFSC Hook and Line Survey by year.

Year	Positive Samples	Samples	Percent Positive
2004	29	270	11%
2005	27	307	9%
2006	17	303	6%
2007	27	335	8%
2008	11	412	3%
2009	16	405	4%
2010	11	414	3%
2011	30	393	8%
2012	53	414	13%
2013	62	409	15%
2014	67	530	13%
2015	75	615	12%
2016	77	623	12%
2017	69	652	11%
2018	64	660	10%
2019	37	660	6%

Table 7: Sample sizes of length data.

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
1977	comm. trawl	Sexed	Ntrips		1	3
1978	comm. trawl	Sexed	Ntrips		25	90
1979	comm. trawl	Sexed	Ntrips		29	207
1980	comm. trawl	Sexed	Ntrips		58	1605
1981	comm. trawl	Sexed	Ntrips		39	1835
1982	comm. trawl	Sexed	Ntrips		18	253
1983	comm. trawl	Sexed	Ntrips		25	275
1984	comm. trawl	Sexed	Ntrips		17	238
1985	comm. trawl	Sexed	Ntrips		11	70
1986	comm. trawl	Sexed	Ntrips		9	84
1987	comm. trawl	Sexed	Ntrips		14	146
1988	comm. trawl	Sexed	Ntrips		29	241
1989	comm. trawl	Sexed	Ntrips		15	106
1992	comm. trawl	Sexed	Ntrips		3	107
1993	comm. trawl	Sexed	Ntrips		35	838
1994	comm. trawl	Sexed	Ntrips		21	458
1995	comm. trawl	Sexed	Ntrips		18	373
1996	comm. trawl	Sexed	Ntrips		11	136

Table 7: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
1997	comm. trawl	Sexed	Ntrips		18	337
1998	comm. trawl	Sexed	Ntrips		4	60
1999	comm. trawl	Sexed	Ntrips		13	141
2000	comm. trawl	Sexed	Ntrips		5	70
2001	comm. trawl	Sexed	Ntrips		4	60
2002	comm. trawl	Sexed	Ntrips		7	163
2003	comm. trawl	Sexed	Ntrips		16	78
2004	comm. trawl	Sexed	Ntrips		21	226
2005	comm. trawl	Sexed	Ntrips		9	47
2006	comm. trawl	Sexed	Ntrips		5	7
2007	comm. trawl	Sexed	Ntrips		21	175
2008	comm. trawl	Sexed	Ntrips		24	149
2009	comm. trawl	Sexed	Ntrips		26	150
2010	comm. trawl	Sexed	Ntrips		26	208
2011	comm. trawl	Sexed	Ntrips		11	6
2012	comm. trawl	Sexed	Ntrips		10	21
2013	comm. trawl	Sexed	Ntrips		12	107
2014	comm. trawl	Sexed	Ntrips		7	53
2015	comm. trawl	Sexed	Ntrips		19	266
2016	comm. trawl	Sexed	Ntrips		26	455
2017	comm. trawl	Sexed	Ntrips		15	159
2018	comm. trawl	Sexed	Ntrips		18	134
2019	comm. trawl	Sexed	Ntrips		14	240
2020	comm. trawl	Sexed	Ntrips		18	168
1978	comm. trawl	Unsexed	Ntrips		9	49
1979	comm. trawl	Unsexed	Ntrips		14	40
1980	comm. trawl	Unsexed	Ntrips		3	5
1983	comm. trawl	Unsexed	Ntrips		1	14
1986	comm. trawl	Unsexed	Ntrips		1	1
1989	comm. trawl	Unsexed	Ntrips		4	9
1990	comm. trawl	Unsexed	Ntrips		2	3
1993	comm. trawl	Unsexed	Ntrips		15	83
1994	comm. trawl	Unsexed	Ntrips		5	5
1995	comm. trawl	Unsexed	Ntrips		3	3
1996	comm. trawl	Unsexed	Ntrips		4	14
1998	comm. trawl	Unsexed	Ntrips		1	15
1999	comm. trawl	Unsexed	Ntrips		3	18
2000	comm. trawl	Unsexed	Ntrips		1	2
2001	comm. trawl	Unsexed	Ntrips		1	1
2003	comm. trawl	Unsexed	Ntrips		2	15
2004	comm. trawl	Unsexed	Ntrips		4	14
2005	comm. trawl	Unsexed	Ntrips		2	7
2006	comm. trawl	Unsexed	Ntrips		3	59
2007	comm. trawl	Unsexed	Ntrips		2	6
2009	comm. trawl	Unsexed	Ntrips		2	5
2010	comm. trawl	Unsexed	Ntrips		3	10

Table 7: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2011	comm. trawl	Unsexed	Ntrips		6	63
2012	comm. trawl	Unsexed	Ntrips		6	46
2013	comm. trawl	Unsexed	Ntrips		3	38
2014	comm. trawl	Unsexed	Ntrips		3	40
2016	comm. trawl	Unsexed	Ntrips		1	1
2017	comm. trawl	Unsexed	Ntrips		1	9
2018	comm. trawl	Unsexed	Ntrips		1	26
2019	comm. trawl	Unsexed	Ntrips		1	4
2004	comm. trawl discards	Unsexed	Nhauls		55	404
2005	comm. trawl discards	Unsexed	Nhauls		152	568
2006	comm. trawl discards	Unsexed	Nhauls		25	43
2007	comm. trawl discards	Unsexed	Nhauls		24	72
2008	comm. trawl discards	Unsexed	Nhauls		42	107
2009	comm. trawl discards	Unsexed	Nhauls		37	118
2010	comm. trawl discards	Unsexed	Nhauls		28	77
2011	comm. trawl discards	Unsexed	Nhauls		123	413
2012	comm. trawl discards	Unsexed	Nhauls		98	287
2013	comm. trawl discards	Unsexed	Nhauls		92	326
2014	comm. trawl discards	Unsexed	Nhauls		152	513
2015	comm. trawl discards	Unsexed	Nhauls		151	532
2016	comm. trawl discards	Unsexed	Nhauls		87	328
2017	comm. trawl discards	Unsexed	Nhauls		103	249
2018	comm. trawl discards	Unsexed	Nhauls		54	182
2019	comm. trawl discards	Unsexed	Nhauls		81	243
1988	comm. fixed	Sexed	Ntrips		1	20
1992	comm. fixed	Sexed	Ntrips		3	10
1993	comm. fixed	Sexed	Ntrips		42	71
1994	comm. fixed	Sexed	Ntrips		9	49
1995	comm. fixed	Sexed	Ntrips		29	17
1997	comm. fixed	Sexed	Ntrips		46	33

Table 7: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2000	comm. fixed	Sexed	Ntrips		33	23
2001	comm. fixed	Sexed	Ntrips		21	13
2002	comm. fixed	Sexed	Ntrips		17	29
2003	comm. fixed	Sexed	Ntrips		6	29
2004	comm. fixed	Sexed	Ntrips		17	40
2005	comm. fixed	Sexed	Ntrips		7	14
2006	comm. fixed	Sexed	Ntrips		17	41
2007	comm. fixed	Sexed	Ntrips		37	74
2008	comm. fixed	Sexed	Ntrips		22	21
2009	comm. fixed	Sexed	Ntrips		23	32
2010	comm. fixed	Sexed	Ntrips		33	45
2011	comm. fixed	Sexed	Ntrips		16	38
2012	comm. fixed	Sexed	Ntrips		19	46
2013	comm. fixed	Sexed	Ntrips		14	41
2014	comm. fixed	Sexed	Ntrips		23	85
2015	comm. fixed	Sexed	Ntrips		48	181
2016	comm. fixed	Sexed	Ntrips		81	347
2017	comm. fixed	Sexed	Ntrips		51	225
2018	comm. fixed	Sexed	Ntrips		41	101
2019	comm. fixed	Sexed	Ntrips		39	68
2020	comm. fixed	Sexed	Ntrips		31	58
1989	comm. fixed	Unsexed	Ntrips		2	3
1992	comm. fixed	Unsexed	Ntrips		2	2
1993	comm. fixed	Unsexed	Ntrips		37	137
1994	comm. fixed	Unsexed	Ntrips		6	54
1995	comm. fixed	Unsexed	Ntrips		28	48
1996	comm. fixed	Unsexed	Ntrips		69	224
1997	comm. fixed	Unsexed	Ntrips		44	146
1998	comm. fixed	Unsexed	Ntrips		23	58
1999	comm. fixed	Unsexed	Ntrips		46	101
2000	comm. fixed	Unsexed	Ntrips		21	72
2001	comm. fixed	Unsexed	Ntrips		17	32
2002	comm. fixed	Unsexed	Ntrips		11	30
2003	comm. fixed	Unsexed	Ntrips		3	8
2004	comm. fixed	Unsexed	Ntrips		2	7
2006	comm. fixed	Unsexed	Ntrips		1	2
2007	comm. fixed	Unsexed	Ntrips		4	7
2008	comm. fixed	Unsexed	Ntrips		4	10
2009	comm. fixed	Unsexed	Ntrips		5	17
2010	comm. fixed	Unsexed	Ntrips		6	18
2011	comm. fixed	Unsexed	Ntrips		1	1
2012	comm. fixed	Unsexed	Ntrips		5	7
2014	comm. fixed	Unsexed	Ntrips		13	52
2015	comm. fixed	Unsexed	Ntrips		12	56
2016	comm. fixed	Unsexed	Ntrips		4	9
2017	comm. fixed	Unsexed	Ntrips		6	36

Table 7: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2018	comm. fixed	Unsexed	Ntrips		3	27
2019	comm. fixed	Unsexed	Ntrips		1	10
2020	comm. fixed	Unsexed	Ntrips		4	7
2004	comm. fixed discards	Unsexed	Nhauls		98	313
2005	comm. fixed discards	Unsexed	Nhauls		66	238
2006	comm. fixed discards	Unsexed	Nhauls		64	163
2007	comm. fixed discards	Unsexed	Nhauls		64	138
2008	comm. fixed discards	Unsexed	Nhauls		19	46
2009	comm. fixed discards	Unsexed	Nhauls		47	219
2010	comm. fixed discards	Unsexed	Nhauls		48	148
2011	comm. fixed discards	Unsexed	Nhauls		90	320
2012	comm. fixed discards	Unsexed	Nhauls		113	394
2013	comm. fixed discards	Unsexed	Nhauls		93	409
2014	comm. fixed discards	Unsexed	Nhauls		86	320
2015	comm. fixed discards	Unsexed	Nhauls		132	490
2016	comm. fixed discards	Unsexed	Nhauls		50	237
2017	comm. fixed discards	Unsexed	Nhauls		76	353
2018	comm. fixed discards	Unsexed	Nhauls		37	144
2019	comm. fixed discards	Unsexed	Nhauls		59	304
1960	rec. CA	Sexed	Nfish			70
1961	rec. CA	Sexed	Nfish			670
1962	rec. CA	Sexed	Nfish			788
1963	rec. CA	Sexed	Nfish			960
1964	rec. CA	Sexed	Nfish			869
1966	rec. CA	Sexed	Nfish			525
1967	rec. CA	Sexed	Nfish			483
1968	rec. CA	Sexed	Nfish			667
1969	rec. CA	Sexed	Nfish			583
1970	rec. CA	Sexed	Nfish			928
1971	rec. CA	Sexed	Nfish			484
1972	rec. CA	Sexed	Nfish			626
1977	rec. CA	Sexed	Nfish			78
1978	rec. CA	Sexed	Nfish			59
1979	rec. CA	Sexed	Nfish			56
1980	rec. CA	Sexed	Nfish			94
1981	rec. CA	Sexed	Nfish			43
1982	rec. CA	Sexed	Nfish			4
1983	rec. CA	Sexed	Nfish			30
1985	rec. CA	Sexed	Nfish			8
2004	rec. CA	Sexed	Nfish			28
2005	rec. CA	Sexed	Nfish			174
2006	rec. CA	Sexed	Nfish			429
2007	rec. CA	Sexed	Nfish			593
2008	rec. CA	Sexed	Nfish			737
2009	rec. CA	Sexed	Nfish			826
2010	rec. CA	Sexed	Nfish			613

Table 7: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2011	rec. CA	Sexed	Nfish			1431
2012	rec. CA	Sexed	Nfish			1663
2013	rec. CA	Sexed	Nfish			4232
2014	rec. CA	Sexed	Nfish			6472
2015	rec. CA	Sexed	Nfish			9175
2016	rec. CA	Sexed	Nfish			7501
2017	rec. CA	Sexed	Nfish			5812
2018	rec. CA	Sexed	Nfish			4178
2019	rec. CA	Sexed	Nfish			2867
2020	rec. CA	Sexed	Nfish			4
1959	rec. CA	Unsexed	Nfish			533
1960	rec. CA	Unsexed	Nfish			835
1961	rec. CA	Unsexed	Nfish			1
1966	rec. CA	Unsexed	Nfish			99
1972	rec. CA	Unsexed	Nfish			4
1975	rec. CA	Unsexed	Nfish			140
1976	rec. CA	Unsexed	Nfish			235
1977	rec. CA	Unsexed	Nfish			237
1978	rec. CA	Unsexed	Nfish			307
1979	rec. CA	Unsexed	Nfish			61
1980	rec. CA	Unsexed	Nfish			142
1981	rec. CA	Unsexed	Nfish			20
1982	rec. CA	Unsexed	Nfish			1
1983	rec. CA	Unsexed	Nfish			169
1984	rec. CA	Unsexed	Nfish			449
1985	rec. CA	Unsexed	Nfish			667
1986	rec. CA	Unsexed	Nfish			690
1987	rec. CA	Unsexed	Nfish			459
1988	rec. CA	Unsexed	Nfish			566
1989	rec. CA	Unsexed	Nfish			542
1993	rec. CA	Unsexed	Nfish			553
1994	rec. CA	Unsexed	Nfish			326
1995	rec. CA	Unsexed	Nfish			339
1996	rec. CA	Unsexed	Nfish			634
1997	rec. CA	Unsexed	Nfish			1309
1998	rec. CA	Unsexed	Nfish			383
1999	rec. CA	Unsexed	Nfish			600
2000	rec. CA	Unsexed	Nfish			194
2001	rec. CA	Unsexed	Nfish			117
2002	rec. CA	Unsexed	Nfish			821
2003	rec. CA	Unsexed	Nfish			1309
2004	rec. CA	Unsexed	Nfish			915
2005	rec. CA	Unsexed	Nfish			2933
2006	rec. CA	Unsexed	Nfish			2933
2007	rec. CA	Unsexed	Nfish			1541
2008	rec. CA	Unsexed	Nfish			1079

Table 7: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2009	rec. CA	Unsexed	Nfish			864
2010	rec. CA	Unsexed	Nfish			543
2011	rec. CA	Unsexed	Nfish			1806
2012	rec. CA	Unsexed	Nfish			2268
2013	rec. CA	Unsexed	Nfish			1483
2014	rec. CA	Unsexed	Nfish			556
2015	rec. CA	Unsexed	Nfish			552
2016	rec. CA	Unsexed	Nfish			254
2017	rec. CA	Unsexed	Nfish			190
2018	rec. CA	Unsexed	Nfish			147
2019	rec. CA	Unsexed	Nfish			134
2020	rec. CA	Unsexed	Nfish			4
1989	Triennial	Sexed	Nsamp	157	66	374
1992	Triennial	Sexed	Nsamp	59	25	171
1995	Triennial	Sexed	Nsamp	111	47	231
1998	Triennial	Sexed	Nsamp	114	48	212
2001	Triennial	Sexed	Nsamp	173	73	346
2004	Triennial	Sexed	Nsamp	161	68	288
2003	WCGBTS	Sexed	Nsamp	176	74	448
2004	WCGBTS	Sexed	Nsamp	168	71	740
2005	WCGBTS	Sexed	Nsamp	178	75	327
2006	WCGBTS	Sexed	Nsamp	107	45	230
2007	WCGBTS	Sexed	Nsamp	88	39	88
2008	WCGBTS	Sexed	Nsamp	171	72	610
2009	WCGBTS	Sexed	Nsamp	228	96	532
2010	WCGBTS	Sexed	Nsamp	211	89	799
2011	WCGBTS	Sexed	Nsamp	249	105	628
2012	WCGBTS	Sexed	Nsamp	254	107	1134
2013	WCGBTS	Sexed	Nsamp	171	72	660
2014	WCGBTS	Sexed	Nsamp	268	113	1485
2015	WCGBTS	Sexed	Nsamp	254	107	893
2016	WCGBTS	Sexed	Nsamp	209	88	750
2017	WCGBTS	Sexed	Nsamp	221	93	639
2018	WCGBTS	Sexed	Nsamp	238	100	758
2019	WCGBTS	Sexed	Nsamp	107	45	196
2004	HKL Survey	Sexed	Nfish		17	30
2005	HKL Survey	Sexed	Nfish		9	27
2006	HKL Survey	Sexed	Nfish		9	11
2007	HKL Survey	Sexed	Nfish		14	23
2008	HKL Survey	Sexed	Nfish		9	12
2009	HKL Survey	Sexed	Nfish		11	19
2010	HKL Survey	Sexed	Nfish		5	14
2011	HKL Survey	Sexed	Nfish		24	28
2012	HKL Survey	Sexed	Nfish		17	27
2013	HKL Survey	Sexed	Nfish		25	71
2014	HKL Survey	Sexed	Nfish		25	50

Table 7: Sample sizes of length data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/hauls/trips	Nfish
2015	HKL Survey	Sexed	Nfish		31	51
2016	HKL Survey	Sexed	Nfish		45	103
2017	HKL Survey	Sexed	Nfish		45	78
2018	HKL Survey	Sexed	Nfish		39	79
2019	HKL Survey	Sexed	Nfish		30	44
2004	HKL Survey	Unsexed	Nfish		1	2
2005	HKL Survey	Unsexed	Nfish		11	12
2006	HKL Survey	Unsexed	Nfish		2	3
2007	HKL Survey	Unsexed	Nfish		2	3
2010	HKL Survey	Unsexed	Nfish		1	1
2011	HKL Survey	Unsexed	Nfish		2	3
2012	HKL Survey	Unsexed	Nfish		19	39
2013	HKL Survey	Unsexed	Nfish		10	23
2014	HKL Survey	Unsexed	Nfish		15	38
2015	HKL Survey	Unsexed	Nfish		19	32
2016	HKL Survey	Unsexed	Nfish		2	2
2016	Research	Sexed	Nfish		13	774
2017	Research	Sexed	Nfish		34	132
1987	rec. DebWV	Unsexed	Nfish			306
1988	rec. DebWV	Unsexed	Nfish			1120
1989	rec. DebWV	Unsexed	Nfish			1075
1990	rec. DebWV	Unsexed	Nfish			225
1991	rec. DebWV	Unsexed	Nfish			359
1992	rec. DebWV	Unsexed	Nfish			718
1993	rec. DebWV	Unsexed	Nfish			543
1994	rec. DebWV	Unsexed	Nfish			565
1995	rec. DebWV	Unsexed	Nfish			952
1996	rec. DebWV	Unsexed	Nfish			1091
1997	rec. DebWV	Unsexed	Nfish			1290
1998	rec. DebWV	Unsexed	Nfish			424

Table 8: Sample sizes of available 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
1993	comm. trawl	Sexed	Ntrips		35	603
1994	comm. trawl	Sexed	Ntrips		21	411
1995	comm. trawl	Sexed	Ntrips		18	205
1996	comm. trawl	Sexed	Ntrips		11	100
1997	comm. trawl	Sexed	Ntrips		18	286
1998	comm. trawl	Sexed	Ntrips		4	60

Table 8: Sample sizes of available age data. *(continued)*

Year	Fleet	Gender	Units	Nsamp	Ntows/trips	Nfish
2001	comm. trawl	Sexed	Ntrips		4	60
2002	comm. trawl	Sexed	Ntrips		7	149
2003	comm. trawl	Sexed	Ntrips		18	50
2004	comm. trawl	Sexed	Ntrips		22	118
1993	comm. trawl	Unsexed	Ntrips		15	1
1994	comm. trawl	Unsexed	Ntrips		5	1
1996	comm. trawl	Unsexed	Ntrips		4	1
1993	comm. fixed	Sexed	Ntrips		42	39
1994	comm. fixed	Sexed	Ntrips		9	19
1995	Triennial	Sexed	Nsamp	102	43	188
1998	Triennial	Sexed	Nsamp	90	38	172
2001	Triennial	Sexed	Nsamp	107	45	208
2004	Triennial	Sexed	Nsamp	147	62	234
2003	WCGBTS	Sexed	Nsamp	166	70	307
2004	WCGBTS	Sexed	Nsamp	159	67	368
2005	WCGBTS	Sexed	Nsamp	164	69	261
2006	WCGBTS	Sexed	Nsamp	107	45	176
2007	WCGBTS	Sexed	Nsamp	85	39	85
2008	WCGBTS	Sexed	Nsamp	166	70	395
2009	WCGBTS	Sexed	Nsamp	168	71	249
2010	WCGBTS	Sexed	Nsamp	188	79	225
2011	WCGBTS	Sexed	Nsamp	192	81	211
2012	WCGBTS	Sexed	Nsamp	185	90	185
2013	WCGBTS	Sexed	Nsamp	114	56	114
2014	WCGBTS	Sexed	Nsamp	230	97	257
2015	WCGBTS	Sexed	Nsamp	195	94	195
2016	WCGBTS	Sexed	Nsamp	162	70	162
2017	WCGBTS	Sexed	Nsamp	195	82	286
2018	WCGBTS	Sexed	Nsamp	221	93	294
2019	WCGBTS	Sexed	Nsamp	97	41	141
2017	HKL Survey	Sexed	Nfish			74
2018	HKL Survey	Sexed	Nfish			79
2019	HKL Survey	Sexed	Nfish			34
2016	Research	Sexed	Nfish		13	290
2017	Research	Sexed	Nfish		22	69

Table 9: 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 10: Samples of lingcod in the California Collaborative Fisheries Research Program (CCFRP) data by year.

Year	Samples	Positive Samples	% Positive
2007	87	552	16%
2008	134	564	24%
2009	94	370	25%
2010	142	420	34%
2011	170	374	45%
2012	237	397	60%
2013	201	428	47%
2014	262	449	58%
2015	135	224	60%
2016	240	429	56%
2017	304	590	52%
2018	332	700	47%
2019	279	740	38%
2020	197	726	27%

Table 11: Positive samples of lingcod in the California Collaborative Fisheries Research Program (CCFRP) data by depth (fm) bin.

Year	Samples	Positive Samples	% Positive
(0,10]	589	1809	33%
(10,15]	1215	2942	41%
(15,20]	834	1827	46%
(20,30]	176	385	46%

Table 12: Model selection for the California Collaborative Fisheries Research Program (CCFRP) index was performed using Akaike information criterion (AIC) to select factors that explained the data in the most parsimonious manner.

Model	Binomial ΔAIC	Lognormal ΔAIC
1	873.41	775.69
YEAR + AREA	237.89	160.63
YEAR + AREA + SITE	55.57	46.76
YEAR + AREA + SITE + DEPTH bin	0.00	0.00
YEAR + SITE + DEPTH bin	83.23	403.90
YEAR + DEPTH bin	241.15	497.94
YEAR + AREA + DEPTH bin	151.37	97.41

Table 13: Standardized index for the California Collaborative Fisheries Research Program (CCFRP) survey index with log-scale standard errors (SE) and 95% highest posterior density (HPD) intervals for lingcod.

Year	Mean	log SE	lower HPD	upper HPD
2007	0.24	0.19	0.16	0.33
2008	0.30	0.16	0.21	0.40
2009	0.35	0.17	0.25	0.49
2010	0.45	0.14	0.33	0.58
2011	0.63	0.13	0.49	0.79
2012	0.85	0.10	0.69	1.03
2013	0.77	0.12	0.60	0.97
2014	1.08	0.10	0.87	1.30
2015	1.19	0.11	0.94	1.46
2016	0.92	0.11	0.74	1.13
2017	0.78	0.10	0.63	0.95
2018	0.56	0.11	0.44	0.68
2019	0.38	0.13	0.29	0.49
2020	0.43	0.15	0.31	0.56

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	1972
Fishing characteristics	
Fishing mortality (F) method	Hybrid F
commercial trawl selectivity	double normal
commercial fixed-gear selectivity	double normal
recreational California selectivity	double normal
Triennial Survey selectivity	double normal
WCGBT Survey selectivity	double normal
Hook & Line Survey selectivity	double normal
Lam research samples selectivity	double normal
recreational CPFV DebWV 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	0.170	7	(0.050, 0.800)	OK	0.03	lognormal(0.300, 0.438)
L_at_Amin_Fem_GP_1	18.047	1	(10.000, 60.000)	OK	0.28	-
L_at_Amax_Fem_GP_1	105.853	7	(40.000, 130.000)	OK	4.30	-
VonBert_K_Fem_GP_1	0.136	3	(0.010, 0.500)	OK	0.02	-
CV_young_Fem_GP_1	0.132	4	(0.010, 0.500)	OK	0.01	-
CV_old_Fem_GP_1	0.100	4	(0.010, 0.500)	OK	0.01	-
Wtlen_1_Fem_GP_1	0.000	-3	(-3.000, 3.000)	-	-	-
Wtlen_2_Fem_GP_1	3.236	-3	(-3.000, 5.000)	-	-	-
Mat50%_Fem_GP_1	2.920	-3	(-3.000, 100.000)	-	-	-
Mat_slope_Fem_GP_1	-1.453	-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	0.222	7	(0.150, 0.800)	OK	0.02	lognormal(0.415, 0.438)
L_at_Amin_Mal_GP_1	17.190	2	(10.000, 60.000)	OK	0.32	-
L_at_Amax_Mal_GP_1	64.941	2	(40.000, 110.000)	OK	0.52	-
VonBert_K_Mal_GP_1	0.401	3	(0.010, 1.000)	OK	0.01	-
CV_young_Mal_GP_1	0.162	4	(0.010, 0.500)	OK	0.01	-
CV_old_Mal_GP_1	0.082	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	3.337	-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)	7.720	1	(5.000, 15.000)	OK	0.28	-
SR_BH_steep	0.502	4	(0.200, 0.990)	OK	0.09	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	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1914	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1915	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1916	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1917	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1918	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1919	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1920	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1921	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1922	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1923	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1924	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1925	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1926	0.001	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1927	0.002	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1928	0.002	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1929	0.002	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1930	0.002	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1931	0.002	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1932	0.002	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1933	0.002	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1934	0.003	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1935	0.003	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1936	0.003	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	0.003	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1938	0.004	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1939	0.004	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1940	0.004	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1941	0.004	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1942	0.005	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1943	0.005	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1944	0.006	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1945	0.006	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1946	0.006	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1947	0.007	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1948	0.007	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1949	0.008	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1950	0.009	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1951	0.009	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1952	0.010	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1953	0.010	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1954	0.010	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1955	0.011	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1956	0.011	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1957	0.011	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1958	0.011	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1959	0.011	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1960	0.010	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1961	0.009	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_1962	0.009	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1963	0.010	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1964	0.014	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1965	0.022	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1966	0.033	6	(-4.000, 4.000)	-	0.61	normal(0.00, 0.60)
Early_RecrDev_1967	0.042	6	(-4.000, 4.000)	-	0.61	normal(0.00, 0.60)
Early_RecrDev_1968	0.033	6	(-4.000, 4.000)	-	0.60	normal(0.00, 0.60)
Early_RecrDev_1969	-0.001	6	(-4.000, 4.000)	-	0.59	normal(0.00, 0.60)
Early_RecrDev_1970	-0.037	6	(-4.000, 4.000)	-	0.57	normal(0.00, 0.60)
Early_RecrDev_1971	-0.044	6	(-4.000, 4.000)	-	0.56	normal(0.00, 0.60)
Main_RecrDev_1972	0.138	2	(-4.000, 4.000)	-	0.54	normal(0.00, 0.60)
Main_RecrDev_1973	0.686	2	(-4.000, 4.000)	-	0.40	normal(0.00, 0.60)
Main_RecrDev_1974	0.245	2	(-4.000, 4.000)	-	0.43	normal(0.00, 0.60)
Main_RecrDev_1975	-0.046	2	(-4.000, 4.000)	-	0.44	normal(0.00, 0.60)
Main_RecrDev_1976	0.506	2	(-4.000, 4.000)	-	0.34	normal(0.00, 0.60)
Main_RecrDev_1977	1.087	2	(-4.000, 4.000)	-	0.26	normal(0.00, 0.60)
Main_RecrDev_1978	-0.642	2	(-4.000, 4.000)	-	0.44	normal(0.00, 0.60)
Main_RecrDev_1979	-0.064	2	(-4.000, 4.000)	-	0.41	normal(0.00, 0.60)
Main_RecrDev_1980	0.266	2	(-4.000, 4.000)	-	0.36	normal(0.00, 0.60)
Main_RecrDev_1981	-0.201	2	(-4.000, 4.000)	-	0.40	normal(0.00, 0.60)
Main_RecrDev_1982	-0.349	2	(-4.000, 4.000)	-	0.41	normal(0.00, 0.60)
Main_RecrDev_1983	0.285	2	(-4.000, 4.000)	-	0.28	normal(0.00, 0.60)
Main_RecrDev_1984	0.058	2	(-4.000, 4.000)	-	0.29	normal(0.00, 0.60)
Main_RecrDev_1985	0.351	2	(-4.000, 4.000)	-	0.19	normal(0.00, 0.60)
Main_RecrDev_1986	0.251	2	(-4.000, 4.000)	-	0.21	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	0.275	2	(-4.000, 4.000)	-	0.20	normal(0.00, 0.60)
Main_RecrDev_1988	-0.371	2	(-4.000, 4.000)	-	0.29	normal(0.00, 0.60)
Main_RecrDev_1989	0.194	2	(-4.000, 4.000)	-	0.18	normal(0.00, 0.60)
Main_RecrDev_1990	-0.161	2	(-4.000, 4.000)	-	0.24	normal(0.00, 0.60)
Main_RecrDev_1991	0.729	2	(-4.000, 4.000)	-	0.16	normal(0.00, 0.60)
Main_RecrDev_1992	-0.045	2	(-4.000, 4.000)	-	0.26	normal(0.00, 0.60)
Main_RecrDev_1993	-0.383	2	(-4.000, 4.000)	-	0.28	normal(0.00, 0.60)
Main_RecrDev_1994	-0.083	2	(-4.000, 4.000)	-	0.19	normal(0.00, 0.60)
Main_RecrDev_1995	-1.840	2	(-4.000, 4.000)	-	0.35	normal(0.00, 0.60)
Main_RecrDev_1996	-0.270	2	(-4.000, 4.000)	-	0.24	normal(0.00, 0.60)
Main_RecrDev_1997	-0.695	2	(-4.000, 4.000)	-	0.31	normal(0.00, 0.60)
Main_RecrDev_1998	-0.626	2	(-4.000, 4.000)	-	0.35	normal(0.00, 0.60)
Main_RecrDev_1999	0.472	2	(-4.000, 4.000)	-	0.17	normal(0.00, 0.60)
Main_RecrDev_2000	0.120	2	(-4.000, 4.000)	-	0.17	normal(0.00, 0.60)
Main_RecrDev_2001	0.119	2	(-4.000, 4.000)	-	0.17	normal(0.00, 0.60)
Main_RecrDev_2002	-0.224	2	(-4.000, 4.000)	-	0.18	normal(0.00, 0.60)
Main_RecrDev_2003	-0.187	2	(-4.000, 4.000)	-	0.17	normal(0.00, 0.60)
Main_RecrDev_2004	-0.778	2	(-4.000, 4.000)	-	0.21	normal(0.00, 0.60)
Main_RecrDev_2005	-0.657	2	(-4.000, 4.000)	-	0.23	normal(0.00, 0.60)
Main_RecrDev_2006	-0.968	2	(-4.000, 4.000)	-	0.28	normal(0.00, 0.60)
Main_RecrDev_2007	-0.096	2	(-4.000, 4.000)	-	0.19	normal(0.00, 0.60)
Main_RecrDev_2008	0.733	2	(-4.000, 4.000)	-	0.14	normal(0.00, 0.60)
Main_RecrDev_2009	0.417	2	(-4.000, 4.000)	-	0.15	normal(0.00, 0.60)
Main_RecrDev_2010	0.988	2	(-4.000, 4.000)	-	0.13	normal(0.00, 0.60)
Main_RecrDev_2011	0.439	2	(-4.000, 4.000)	-	0.14	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	0.480	2	(-4.000, 4.000)	-	0.14	normal(0.00, 0.60)
Main_RecrDev_2013	0.875	2	(-4.000, 4.000)	-	0.12	normal(0.00, 0.60)
Main_RecrDev_2014	-0.022	2	(-4.000, 4.000)	-	0.15	normal(0.00, 0.60)
Main_RecrDev_2015	-0.257	2	(-4.000, 4.000)	-	0.16	normal(0.00, 0.60)
Main_RecrDev_2016	-0.208	2	(-4.000, 4.000)	-	0.18	normal(0.00, 0.60)
Main_RecrDev_2017	0.045	2	(-4.000, 4.000)	-	0.20	normal(0.00, 0.60)
Main_RecrDev_2018	-0.587	2	(-4.000, 4.000)	-	0.28	normal(0.00, 0.60)
Late_RecrDev_2019	-0.590	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)
LnQ_base_1_Comm_Trawl(1)	-2.787	-1	(-15.000, 15.000)	-	-	-
Q_extraSD_1_Comm_Trawl(1)	0.282	2	(0.000, 2.000)	OK	0.06	-
LnQ_base_5_Rec_CA(5)	-9.635	1	(-15.000, 15.000)	OK	0.19	-
Q_extraSD_5_Rec_CA(5)	0.109	2	(0.000, 2.000)	OK	0.05	-
LnQ_base_6_Surv_TRI(6)	-0.498	-1	(-15.000, 15.000)	-	-	-
Q_extraSD_6_Surv_TRI(6)	0.339	2	(0.000, 2.000)	OK	0.14	-
LnQ_base_7_Surv_WCGBTS(7)	-0.046	-1	(-15.000, 15.000)	-	-	-
LnQ_base_8_Surv_HookLine(8)	-15.551	-1	(-15.000, 15.000)	-	-	-
LnQ_base_10_CPFV_DebWV(10)	-9.561	-1	(-15.000, 15.000)	-	-	-
Q_extraSD_10_CPFV_DebWV(10)	0.000	-2	(0.000, 2.000)	-	-	-
LnQ_base_5_Rec_CA(5)_BLK9repl_1999	-7.870	1	(-15.000, 15.000)	OK	0.28	-
Size_DblN_peak_1_Comm_Trawl(1)	43.820	2	(20.000, 100.000)	OK	3.22	-
Size_DblN_top_logit_1_Comm_Trawl(1)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_1_Comm_Trawl(1)	3.564	3	(-1.000, 9.000)	OK	0.92	-
Size_DblN_descend_se_1_Comm_Trawl(1)	7.934	3	(-1.000, 15.000)	OK	0.60	-

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

Label	Value	Phase	Bounds	Status	SD	Prior
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, 80.000)	-	-	-
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)	69.570	2	(20.000, 100.000)	OK	1.82	-
Size_DblN_top_logit_2_Comm_Fix(2)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_2_Comm_Fix(2)	5.842	3	(-1.000, 9.000)	OK	0.12	-
Size_DblN_descend_se_2_Comm_Fix(2)	5.793	3	(-1.000, 15.000)	OK	0.25	-
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, 80.000)	-	-	-
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_5_Rec_CA(5)	64.724	2	(20.000, 100.000)	OK	3.81	-

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)	5.723	3	(-1.000, 9.000)	OK	0.30	-
Size_DblN_descend_se_5_Rec_CA(5)	6.506	3	(-1.000, 15.000)	OK	0.45	-
Size_DblN_start_logit_5_Rec_CA(5)	-999.000	-3	(-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)	23.072	2	(20.000, 100.000)	OK	0.12	-
Size_DblN_top_logit_6_Surv_TRI(6)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_6_Surv_TRI(6)	-7.194	3	(-9.000, 9.000)	OK	18.45	-
Size_DblN_descend_se_6_Surv_TRI(6)	7.058	3	(-1.000, 15.000)	OK	0.23	-
Size_DblN_start_logit_6_Surv_TRI(6)	-2.416	2	(-5.000, 9.000)	OK	0.56	-
Size_DblN_end_logit_6_Surv_TRI(6)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_peak_7_Surv_WCGBTS(7)	21.133	2	(20.000, 100.000)	OK	1.86	-
Size_DblN_top_logit_7_Surv_WCGBTS(7)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_7_Surv_WCGBTS(7)	3.570	3	(-1.000, 9.000)	OK	0.77	-
Size_DblN_descend_se_7_Surv_WCGBTS(7)	8.230	3	(-1.000, 15.000)	OK	0.38	-
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_8_Surv_HookLine(8)	82.222	2	(20.000, 100.000)	OK	4.20	-
Size_DblN_top_logit_8_Surv_HookLine(8)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_8_Surv_HookLine(8)	6.843	3	(-1.000, 9.000)	OK	0.18	-
Size_DblN_descend_se_8_Surv_HookLine(8)	5.071	3	(-1.000, 15.000)	OK	0.71	-
Size_DblN_start_logit_8_Surv_HookLine(8)	-999.000	-2	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_8_Surv_HookLine(8)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_peak_9_Research_Lam(9)	62.199	2	(20.000, 100.000)	OK	3.18	-
Size_DblN_top_logit_9_Research_Lam(9)	-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_9_Research_Lam(9)	5.753	3	(-1.000, 9.000)	OK	0.34	-
Size_DblN_descend_se_9_Research_Lam(9)	5.783	3	(-1.000, 15.000)	OK	0.48	-
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_10_CPFV_DebWV(10)	62.480	2	(20.000, 100.000)	OK	0.48	-
Size_DblN_top_logit_10_CPFV_DebWV(10)	-15.000	-3	(-20.000, 4.000)	-	-	-
Size_DblN_ascend_se_10_CPFV_DebWV(10)	4.132	3	(-1.000, 9.000)	OK	0.08	-
Size_DblN_descend_se_10_CPFV_DebWV(10)	6.212	3	(-1.000, 15.000)	OK	0.14	-
Size_DblN_start_logit_10_CPFV_DebWV(10)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_end_logit_10_CPFV_DebWV(10)	-999.000	-3	(-5.000, 9.000)	-	-	-
Size_DblN_peak_1_Comm_Trawl(1)_BLK1repl_1993	62.676	2	(20.000, 100.000)	OK	6.79	-
Size_DblN_peak_1_Comm_Trawl(1)_BLK1repl_1998	77.185	2	(20.000, 100.000)	OK	3.07	-
Size_DblN_peak_1_Comm_Trawl(1)_BLK1repl_2011	78.171	2	(20.000, 100.000)	OK	4.61	-
Size_DblN_ascend_se_1_Comm_Trawl(1)_BLK1repl_1993	5.751	3	(-1.000, 9.000)	OK	0.64	-
Size_DblN_ascend_se_1_Comm_Trawl(1)_BLK1repl_1998	7.199	3	(-1.000, 9.000)	OK	0.14	-
Size_DblN_ascend_se_1_Comm_Trawl(1)_BLK1repl_2011	7.266	3	(-1.000, 9.000)	OK	0.14	-
Size_DblN_descend_se_1_Comm_Trawl(1)_BLK1repl_1993	6.505	3	(-1.000, 15.000)	OK	0.81	-
Size_DblN_descend_se_1_Comm_Trawl(1)_BLK1repl_1998	4.355	3	(-1.000, 15.000)	OK	0.57	-
Size_DblN_descend_se_1_Comm_Trawl(1)_BLK1repl_2011	4.462	3	(-1.000, 15.000)	OK	1.12	-
Retain_L_infl_1_Comm_Trawl(1)_BLK2repl_1998	64.817	4	(30.000, 80.000)	OK	2.59	-
Retain_L_infl_1_Comm_Trawl(1)_BLK2repl_2007	76.878	4	(30.000, 80.000)	OK	4.60	-
Retain_L_infl_1_Comm_Trawl(1)_BLK2repl_2010	60.342	4	(30.000, 80.000)	OK	5.81	-
Retain_L_infl_1_Comm_Trawl(1)_BLK2repl_2011	56.132	4	(30.000, 80.000)	OK	0.65	-
Retain_L_width_1_Comm_Trawl(1)_BLK3repl_1998	8.638	4	(1.000, 15.000)	OK	1.29	-
Retain_L_width_1_Comm_Trawl(1)_BLK3repl_2011	2.978	4	(1.000, 15.000)	OK	0.36	-

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

Label	Value	Phase	Bounds	Status	SD	Prior
Retain_L_infl_2_Comm_Fix(2)_BLK4repl_1998	65.715	4	(30.000, 80.000)	OK	1.91	-
Retain_L_infl_2_Comm_Fix(2)_BLK4repl_2011	60.704	4	(30.000, 80.000)	OK	0.39	-
Retain_L_width_2_Comm_Fix(2)_BLK5repl_1998	8.589	4	(1.000, 15.000)	OK	1.44	-
Retain_L_width_2_Comm_Fix(2)_BLK5repl_2011	1.931	4	(1.000, 15.000)	OK	0.30	-
Size_DblN_peak_5_Rec_CA(5)_BLK8repl_1983	61.759	2	(20.000, 100.000)	OK	0.90	-
Size_DblN_peak_5_Rec_CA(5)_BLK8repl_1999	63.969	2	(20.000, 100.000)	OK	2.05	-
Size_DblN_peak_5_Rec_CA(5)_BLK8repl_2000	69.919	2	(20.000, 100.000)	OK	3.01	-
Size_DblN_peak_5_Rec_CA(5)_BLK8repl_2002	63.942	2	(20.000, 100.000)	OK	0.45	-
Size_DblN_peak_5_Rec_CA(5)_BLK8repl_2011	58.682	2	(20.000, 100.000)	OK	0.23	-
Size_DblN_peak_5_Rec_CA(5)_BLK8repl_2017	57.437	2	(20.000, 100.000)	OK	0.42	-
Size_DblN_ascend_se_5_Rec_CA(5)_BLK8repl_1983	4.334	3	(-1.000, 9.000)	OK	0.18	-
Size_DblN_ascend_se_5_Rec_CA(5)_BLK8repl_1999	3.611	3	(-1.000, 9.000)	OK	0.58	-
Size_DblN_ascend_se_5_Rec_CA(5)_BLK8repl_2000	4.067	3	(-1.000, 9.000)	OK	0.72	-
Size_DblN_ascend_se_5_Rec_CA(5)_BLK8repl_2002	3.260	3	(-1.000, 9.000)	OK	0.16	-
Size_DblN_ascend_se_5_Rec_CA(5)_BLK8repl_2011	2.509	3	(-1.000, 9.000)	OK	0.11	-
Size_DblN_ascend_se_5_Rec_CA(5)_BLK8repl_2017	2.064	3	(-1.000, 9.000)	OK	0.27	-
Size_DblN_descend_se_5_Rec_CA(5)_BLK8repl_1983	6.345	3	(-1.000, 15.000)	OK	0.20	-
Size_DblN_descend_se_5_Rec_CA(5)_BLK8repl_1999	5.858	3	(-1.000, 15.000)	OK	0.38	-
Size_DblN_descend_se_5_Rec_CA(5)_BLK8repl_2000	5.600	3	(-1.000, 15.000)	OK	0.55	-
Size_DblN_descend_se_5_Rec_CA(5)_BLK8repl_2002	5.827	3	(-1.000, 15.000)	OK	0.12	-
Size_DblN_descend_se_5_Rec_CA(5)_BLK8repl_2011	6.164	3	(-1.000, 15.000)	OK	0.10	-
Size_DblN_descend_se_5_Rec_CA(5)_BLK8repl_2017	6.275	3	(-1.000, 15.000)	OK	0.12	-

Table 16: Likelihoods components by source.

Label	Total
Total	3009.60
Catch	0.00
Equil catch	0.00
Survey	-7.70
Discard	-54.23
Mean body weight	-10.59
Length composition	2185.46
Age composition	892.01
Recruitment	-0.04
Initial equil regime	0.00
Forecast recruitment	0.48
Parameter priors	4.19
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	26443.60	5846.74	47040.46
SSB_2021	10415.00	3145.11	17684.89
Recr_Virgin	2253.21	1036.58	3469.84
Recr_2021	1630.13	-555.19	3815.45
SPRratio_2021	0.35	0.16	0.54
F_2021	0.02	0.01	0.03
Bratio_2021	0.39	0.08	0.71
SSB_SPR	7093.73	2578.62	11608.84
annF_SPR	0.09	0.04	0.13
Dead_Catch_SPR	810.76	528.92	1092.60
SSB_MSY	9353.58	2160.77	16546.39
SPR_MSY	0.51	0.34	0.68
annF_MSY	0.07	0.01	0.13
Dead_Catch_MSY	839.06	671.52	1006.59
Ret_Catch_MSY	834.05	668.02	1000.08
B_MSY/SSB_unfished	0.35	0.28	0.43

ForeCatch_2021	277.80	262.71	292.89
OFLCatch_2021	277.80	262.71	292.89
ForeCatchret_2021	272.73	258.36	287.10

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	33116	26429	32127	41.430	2253	1.00	0.028	0.001
1891	32873	26398	31884	62.145	2252	1.00	0.042	0.002
1892	32630	26351	31641	82.860	2251	1.00	0.056	0.003
1893	32755	26287	31766	71.860	2250	0.99	0.049	0.002
1894	32882	26232	31893	60.860	2249	0.99	0.042	0.002
1895	33010	26185	32022	49.860	2248	0.99	0.034	0.002
1896	33001	26149	32012	50.667	2247	0.99	0.035	0.002
1897	32991	26116	32002	51.474	2247	0.99	0.036	0.002
1898	32981	26086	31992	52.281	2246	0.99	0.036	0.002
1899	32971	26057	31983	53.088	2245	0.99	0.037	0.002
1900	32848	26031	31860	63.491	2245	0.98	0.044	0.002
1901	32725	25999	31736	73.893	2244	0.98	0.051	0.002
1902	32601	25961	31613	84.296	2243	0.98	0.058	0.003
1903	32478	25917	31490	94.698	2242	0.98	0.065	0.003
1904	32354	25867	31366	105.101	2241	0.98	0.072	0.003
1905	32484	25810	31495	93.802	2240	0.98	0.065	0.003
1906	32615	25763	31627	82.503	2239	0.97	0.057	0.003
1907	32748	25726	31760	71.204	2238	0.97	0.050	0.002
1908	32883	25701	31894	59.905	2238	0.97	0.042	0.002
1909	32633	25688	31645	80.966	2238	0.97	0.056	0.003
1910	32385	25663	31397	102.027	2237	0.97	0.071	0.003
1911	32137	25625	31149	123.089	2236	0.97	0.085	0.004
1912	31889	25572	30901	144.151	2235	0.97	0.099	0.005
1913	31640	25504	30652	165.213	2234	0.96	0.114	0.005
1914	31391	25421	30403	186.275	2232	0.96	0.128	0.006
1915	31140	25323	30152	207.338	2230	0.96	0.143	0.007
1916	30671	25211	29683	247.754	2228	0.95	0.170	0.008
1917	30200	25072	29212	288.172	2225	0.95	0.197	0.009
1918	29728	24905	28740	328.591	2221	0.94	0.225	0.011
1919	29119	24711	28131	381.327	2217	0.93	0.261	0.013

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	30589	24482	29601	246.807	2211	0.93	0.175	0.008
1921	31696	24353	30708	152.821	2208	0.92	0.111	0.005
1922	31096	24307	30108	203.762	2207	0.92	0.145	0.007
1923	31528	24240	30540	167.530	2206	0.92	0.120	0.006
1924	31821	24209	30832	143.494	2205	0.92	0.103	0.005
1925	30631	24206	29643	245.016	2206	0.92	0.172	0.008
1926	30780	24136	29792	231.383	2204	0.91	0.164	0.008
1927	30129	24078	29141	287.487	2203	0.91	0.202	0.010
1928	29480	23981	28492	343.592	2201	0.91	0.239	0.012
1929	29051	23843	28063	379.634	2198	0.90	0.264	0.013
1930	28926	23678	27938	387.678	2194	0.90	0.272	0.013
1931	30496	23507	29508	247.933	2190	0.89	0.180	0.009
1932	30751	23442	29763	226.649	2189	0.89	0.165	0.008
1933	28188	23405	27201	452.175	2188	0.89	0.315	0.016
1934	30666	23214	29679	231.594	2184	0.88	0.170	0.008
1935	30066	23181	29078	282.482	2183	0.88	0.205	0.010
1936	30488	23124	29500	246.623	2182	0.87	0.180	0.009
1937	29978	23099	28990	289.932	2182	0.87	0.210	0.010
1938	30622	23051	29634	235.379	2182	0.87	0.173	0.008
1939	31201	23046	30213	188.146	2182	0.87	0.139	0.007
1940	30833	23081	29845	219.008	2184	0.87	0.160	0.008
1941	30862	23100	29874	216.822	2185	0.87	0.159	0.008
1942	32468	23124	31480	87.521	2186	0.87	0.066	0.003
1943	31574	23242	30586	159.463	2190	0.88	0.117	0.006
1944	31811	23315	30823	140.665	2193	0.88	0.104	0.005
1945	31742	23400	30754	146.806	2196	0.88	0.108	0.005
1946	30813	23480	29826	224.234	2199	0.89	0.161	0.008
1947	28596	23502	27609	420.760	2200	0.89	0.290	0.014
1948	28169	23374	27182	455.242	2198	0.88	0.314	0.016
1949	27572	23207	26585	505.028	2195	0.88	0.349	0.018
1950	25731	22995	24745	673.952	2191	0.87	0.456	0.024
1951	26255	22655	25269	610.434	2183	0.86	0.425	0.022
1952	27307	22354	26320	504.234	2176	0.85	0.364	0.018
1953	29896	22134	28908	280.872	2171	0.84	0.214	0.010
1954	28836	22092	27849	371.337	2171	0.84	0.276	0.014
1955	28280	22011	27293	419.655	2169	0.83	0.308	0.015
1956	27341	21909	26354	502.918	2167	0.83	0.363	0.019
1957	25943	21755	24956	628.952	2163	0.82	0.444	0.023

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	24902	21513	23916	720.812	2156	0.81	0.505	0.027
1959	26196	21204	25210	586.403	2146	0.80	0.429	0.022
1960	27166	20991	26180	495.193	2139	0.79	0.372	0.019
1961	26677	20856	25690	537.030	2133	0.79	0.401	0.021
1962	27839	20708	26852	435.734	2127	0.78	0.334	0.017
1963	27833	20643	26846	437.236	2128	0.78	0.334	0.017
1964	28564	20593	27577	377.530	2135	0.78	0.292	0.015
1965	27853	20596	26866	440.571	2151	0.78	0.333	0.017
1966	26365	20566	25379	572.057	2175	0.78	0.420	0.022
1967	26298	20446	25312	574.569	2189	0.77	0.424	0.023
1968	26518	20326	25532	551.376	2147	0.77	0.411	0.022
1969	26542	20232	25556	546.193	2055	0.77	0.409	0.022
1970	22053	20155	21068	983.893	1963	0.76	0.670	0.039
1971	20640	19768	19657	1113.960	1920	0.75	0.753	0.045
1972	16537	19248	15556	1585.840	2265	0.73	0.992	0.067
1973	14149	18332	13171	1827.260	3826	0.69	1.130	0.081
1974	12050	17184	11074	2046.290	2389	0.65	1.250	0.098
1975	12183	15924	11207	1941.420	1724	0.60	1.243	0.101
1976	12361	14977	11384	1870.890	2903	0.57	1.234	0.100
1977	17065	14254	16083	1187.890	5052	0.54	0.961	0.066
1978	15383	13987	14403	1423.690	882	0.53	1.061	0.082
1979	12668	13680	11690	1933.400	1546	0.52	1.216	0.112
1980	10722	13375	9747	2299.540	2112	0.51	1.329	0.129
1981	11394	12788	10418	1979.050	1289	0.48	1.291	0.121
1982	11534	12029	10558	1763.720	1075	0.45	1.281	0.118
1983	13977	11245	12996	1295.810	1950	0.43	1.141	0.092
1984	14098	10714	13118	1179.300	1509	0.41	1.133	0.089
1985	12368	10174	11385	1311.690	1958	0.38	1.241	0.106
1986	13055	9535	12071	1150.760	1715	0.36	1.203	0.097
1987	10456	9094	9475	1438.570	1718	0.34	1.351	0.127
1988	8638	8538	7660	1668.160	873	0.32	1.455	0.155
1989	7512	7873	6535	1765.000	1472	0.30	1.519	0.177
1990	8250	7115	7272	1453.010	978	0.27	1.477	0.160
1991	8970	6469	7991	1212.660	2256	0.24	1.437	0.151
1992	10278	5931	9297	983.045	988	0.22	1.363	0.131
1993	10406	5584	9425	954.140	680	0.21	1.358	0.137
1994	14841	5382	13858	668.565	897	0.20	1.097	0.093
1995	16802	5462	15818	605.841	156	0.21	0.982	0.083

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	15988	5505	15003	657.841	754	0.21	1.031	0.092
1997	16225	5392	15241	591.890	487	0.20	1.016	0.085
1998	21555	5206	20570	321.786	511	0.20	0.709	0.050
1999	18984	5108	17999	390.300	1513	0.19	0.869	0.061
2000	24467	4940	23480	194.072	1042	0.19	0.561	0.032
2001	25154	4912	24167	173.423	1037	0.19	0.519	0.029
2002	16921	5008	15934	469.201	745	0.19	0.998	0.071
2003	11759	5065	10771	862.620	778	0.19	1.312	0.128
2004	15240	4898	14252	628.438	422	0.19	1.101	0.096
2005	20773	4838	19785	376.241	472	0.18	0.765	0.059
2006	22834	4899	21846	308.850	349	0.19	0.640	0.048
2007	25312	4949	24327	212.611	840	0.19	0.490	0.033
2008	27294	4990	26308	147.547	1935	0.19	0.372	0.023
2009	26621	5025	25635	157.294	1417	0.19	0.412	0.025
2010	27945	5086	26958	121.020	2529	0.19	0.333	0.019
2011	25663	5362	24674	215.174	1509	0.20	0.457	0.030
2012	25574	5847	24586	276.854	1657	0.22	0.462	0.035
2013	24047	6516	23058	431.785	2622	0.25	0.552	0.046
2014	24035	7247	23047	506.734	1134	0.27	0.554	0.050
2015	21718	7951	20730	717.455	943	0.30	0.691	0.065
2016	22718	8554	21730	679.525	1028	0.32	0.630	0.056
2017	24661	9159	23673	549.835	1370	0.35	0.515	0.044
2018	25689	9639	24702	454.405	755	0.36	0.456	0.036
2019	26046	9968	25059	396.610	820	0.38	0.435	0.031
2020	27505	10208	26518	291.911	1603	0.39	0.350	0.022

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

Type	Fleet	Francis
Length	commercial trawl	0.68
Length	commercial fixed-gear	0.48
Length	recreational California	0.14
Length	Triennial Survey	0.24
Length	WCGBT Survey	0.07
Length	Hook & Line Survey	0.36
Length	Lam research samples	0.28
Length	recreational CPFV DebWV	0.92
Age	WCGBT Survey	0.66

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	3.36	3.29	0.98	4.99	38.99	1.41
Indices	0	4.21	4.51	2.38	4.39	-5.95	-6.45
Length comp	0	11.58	11.24	0.15	12.66	48.05	12.91
Age comp	0	-9.84	-9.64	-0.21	-9.13	1.52	-12.27
Discard	0	-0.96	-0.98	-0.29	-1.25	0.02	0.03
Parm priors	0	-3.64	-3.98	-2.42	-4.2	0.2	-1.19
Estimates of key parameters							
Recr Virgin millions	2.25	4.81	4.85	2	6.65	2.75	2.59
SR BH steep	0.5	0.7	0.77	0.7	0.78	0.46	0.55
M Female	0.17	0.3	0.3	0.19	0.33	0.19	0.21
M Male	0.22	0.31	0.32	0.24	0.33	0.24	0.22
Estimates of derived quantities							
SSB Virgin 1000 mt	26.44	12.17	12.28	18.35	12.47	27.25	12.95
SSB 2021 1000 mt	10.41	11.01	11.45	12.14	12.2	11.83	1.93
Fraction unfished 2021	0.39	0.91	0.93	0.66	0.98	0.43	0.15
Fishing intensity 2020	0.35	0.16	0.15	0.28	0.12	0.3	0.75
Retained Catch MSY mt	834.05	1568.35	1772.08	997.36	2272.12	826.48	978.43
Dead Catch MSY mt	839.06	1582.92	1790.59	1004.73	2299.31	831.4	983.21
Virgin age 3+ bio 1000 mt	32.62	18.96	19.09	23.28	20.81	33.85	20.17
OFL mt 2021	277.8	269.86	269.41	275.43	269.02	282.82	287.13

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	allCAALages	allmargages	combMF	no unsexed	DM
Diff. in likelihood from base model						
Total	0	883.97	255.95	-3.43	-1362.96	-357513.6
Indices	0	5.55	-8.67	-0.17	-4.77	13.5
Length comp	0	146.66	135.36	3.66	-1315.32	-359011.46
Age comp	0	720.29	112.04	-6.55	-35.48	1436
Discard	0	-1.58	2.21	0.05	-1.39	3.65
Parm priors	0	-4.14	-0.7	-0.75	-3.15	34.76
Estimates of key parameters						
Recr Virgin millions	2.25	12.39	2.65	2.99	7.4	1.78
SR BH steep	0.5	0.83	0.49	0.48	0.63	0.76
M Female	0.17	0.35	0.22	0.23	0.39	0.13
M Male	0.22	0.35	0.24	0.25	0.37	0.2
Estimates of derived quantities						
SSB Virgin 1000 mt	26.44	21.12	16.55	14.98	8.81	42.8
SSB 2021 1000 mt	10.41	23.3	4.42	6.26	9.19	35.36
Fraction unfished 2021	0.39	1.1	0.27	0.42	1.04	0.83
Fishing intensity 2020	0.35	0.07	0.49	0.34	0.13	0.19
Retained Catch MSY mt	834.05	4046.08	804.84	848.03	1590.29	1203.63
Dead Catch MSY mt	839.06	4105.24	809.11	853.13	1603.87	1213.13
Virgin age 3+ bio 1000 mt	32.62	34.73	22.85	21.41	15.86	48.41
OFL mt 2021	277.8	271.99	279.27	277.86	264.07	266.3

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	CACRF-SPR	no fisheryv = 2	no Comm-Trawl	no RecCA	no SurvTRI	no SurvWCG-BTS	no SurvHook-Line	no CPFVDebWV
Diff. in likelihood from base model									
Total	0	117.06	24.35	8.23	12.05	-0.36	-27.15	-5.33	7.78
Indices	0	-2.51	34.68	8.84	12.08	-7.04	-20.87	-5.27	15.46
Length comp	0	117.1	4.14	-0.37	-1.84	13.32	-0.34	0.05	5.18
Age comp	0	-14.25	-7.32	0.31	2.42	-10.58	-3.34	-0.03	-7.48
Discard	0	1.19	-1.3	-0.09	-0.29	0.59	0.47	-0.01	-0.97
Parm priors	0	-0.54	-4.16	-0.31	-0.03	-0.34	-2.11	-0.03	-4.13
Estimates of key parameters									
Recr Virgin millions	2.25	2	21.76	2.24	2.22	2.95	2.7	2.25	7.71
SR BH steep	0.5	0.57	0.85	0.52	0.51	0.48	0.59	0.5	0.83
M Female	0.17	0.18	0.34	0.17	0.17	0.22	0.22	0.17	0.31
M Male	0.22	0.19	0.35	0.22	0.22	0.23	0.26	0.22	0.33
Estimates of derived quantities									
SSB Virgin 1000 mt	26.44	14.12	39	25.5	28.59	13.63	14.42	26.33	18.34
SSB 2021 1000 mt	10.41	1.2	45.31	10.99	12.49	2.26	8.92	10.47	19.66
Fraction unfished 2021	0.39	0.08	1.16	0.43	0.44	0.17	0.62	0.4	1.07
Fishing intensity 2020	0.35	1.05	0.04	0.33	0.32	0.66	0.28	0.35	0.09
Retained Catch MSY mt	834.05	940.51	7864.34	857.14	852.57	887.13	963.24	836.8	2988
Dead Catch MSY mt	839.06	944.52	7985.24	862.41	857.8	891.41	970.06	841.83	3025.3
Virgin age 3+ bio 1000 mt	32.62	21.63	63.26	31.56	34.71	21.21	20.05	32.5	28.36
OFL mt 2021	277.8	286.54	264.44	277.49	277.39	286.61	269.89	277.95	266.79

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	asymptoticFG	fem. sel. offset	fem. sel. offset, $M = 0.3$
Diff. in likelihood from base model				
Total	0	1.92	-203.91	-185.46
Indices	0	-5.71	-14.88	-9.31
Length comp	0	14.73	-137.11	-117.93
Age comp	0	-10.8	-61.91	-64.72
Discard	0	0.59	0.18	-0.2
Parm priors	0	-0.39	4.46	1.89
Estimates of key parameters				
Recr Virgin millions	2.25	2.94	2.35	6.16
SR BH steep	0.5	0.48	0.32	0.34
M Female	0.17	0.22	0.13	0.3
M Male	0.22	0.23	0.32	0.48
Estimates of derived quantities				
SSB Virgin 1000 mt	26.44	13.53	54.65	16.22
SSB 2021 1000 mt	10.41	2.25	12.02	5.32
Fraction unfished 2021	0.39	0.17	0.22	0.33
Fishing intensity 2020	0.35	0.66	0.46	0.32
Retained Catch MSY mt	834.05	894.72	565.68	724.73
Dead Catch MSY mt	839.06	899.03	568.46	728.8
Virgin age 3+ bio 1000 mt	32.62	21.13	58.55	20.04
OFL mt 2021	277.8	287.12	281.15	277.92

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}
0.05	0.150
0.06	0.150
0.07	0.154
0.08	0.161
0.09	0.167
0.10	0.174
0.11	0.181
0.12	0.188
0.13	0.195
0.14	0.202
0.15	0.209
0.16	0.216
0.17	0.222
0.17	0.222
0.18	0.229
0.19	0.236
0.20	0.242
0.21	0.248
0.22	0.250
0.23	0.257
0.24	0.264
0.25	0.271
0.26	0.278
0.27	0.293
0.28	0.301
0.29	0.308
0.30	0.316
0.31	0.323
0.32	0.331
0.33	0.339
0.34	0.346
0.35	0.354
0.36	0.362
0.37	0.370
0.38	0.378
0.39	0.386
0.40	0.393

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 89), recruitment, and spawning stock biomass (SSB; Figure 88). 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	0.09056859	0.5853508	0.4389942
Fraction unfished	-0.1380098	-0.8022862	-0.733893
Recruitment	0.3819505	1.840449	0.330623
SSB	0.01862072	-0.05597815	0.07947266

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	1,024.97	-	-	-	13,145.00	10,415.00	0.39
2022	907.85	-	-	-	12,602.00	10,224.30	0.39
2023	-	845.56	739.02	725.57	12,407.40	9,994.59	0.38
2024	-	855.31	739.84	722.34	12,315.20	9,831.95	0.37
2025	-	896.54	768.33	748.30	12,312.70	9,760.15	0.37
2026	-	936.59	795.16	773.36	12,330.50	9,720.59	0.37
2027	-	965.62	812.09	788.97	12,344.40	9,690.31	0.37
2028	-	984.37	819.98	795.95	12,354.40	9,666.70	0.37
2029	-	996.22	822.88	798.29	12,363.50	9,650.48	0.36
2030	-	1,003.92	821.21	796.47	12,375.70	9,643.62	0.36
2031	-	1,009.40	817.61	793.07	12,393.40	9,646.52	0.36
2032	-	1,013.68	813.99	789.92	12,418.50	9,659.43	0.37

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 M (M = 0.11)		Base (M ~ 0.17)		High M (M = 0.22)	
Assumption	Year	Catch	SSB (mt)	Frac. unfished	SSB (mt)	Frac. unfished	SSB (mt)	Frac. unfished
Recent avg. catch	2021	700	15066	0.296	10415	0.394	6475	0.419
	2022	700	15200	0.299	10224	0.387	6138	0.397
	2023	700	15221	0.299	9995	0.378	5849	0.378
	2024	700	15234	0.299	9858	0.373	5722	0.370
	2025	700	15252	0.300	9810	0.371	5715	0.369
	2026	700	15263	0.300	9813	0.371	5762	0.372
	2027	700	15265	0.300	9846	0.372	5831	0.377
	2028	700	15262	0.300	9901	0.374	5908	0.382
	2029	700	15256	0.300	9972	0.377	5991	0.387
	2030	700	15257	0.300	10057	0.380	6075	0.393
	2031	700	15264	0.300	10152	0.384	6162	0.398
	2032	700	15284	0.300	10254	0.388	6249	0.404
ACL P^*=0.40	2021	700	15066	0.296	10415	0.394	6475	0.419
	2022	700	15200	0.299	10224	0.387	6138	0.397
	2023	633	15221	0.299	9995	0.378	5849	0.378
	2024	634	15277	0.300	9897	0.374	5758	0.372
	2025	658	15347	0.302	9892	0.374	5787	0.374
	2026	681	15398	0.303	9924	0.375	5856	0.379
	2027	696	15424	0.303	9969	0.377	5929	0.383
	2028	702	15432	0.303	10024	0.379	6001	0.388
	2029	703	15429	0.303	10089	0.382	6074	0.393
	2030	700	15427	0.303	10164	0.384	6149	0.397
	2031	696	15431	0.303	10250	0.388	6228	0.403
	2032	692	15448	0.304	10346	0.391	6310	0.408
ACL P^*=0.45	2021	700	15066	0.296	10415	0.394	6475	0.419
	2022	700	15200	0.299	10224	0.387	6138	0.397
	2023	726	15221	0.299	9995	0.378	5849	0.378
	2024	722	15205	0.299	9832	0.372	5699	0.368
	2025	748	15194	0.299	9760	0.369	5672	0.367
	2026	773	15154	0.298	9721	0.368	5684	0.367
	2027	789	15076	0.296	9690	0.366	5701	0.369
	2028	796	14972	0.294	9667	0.366	5717	0.370
	2029	798	14848	0.292	9650	0.365	5733	0.371
	2030	796	14718	0.289	9644	0.365	5752	0.372
	2031	793	14586	0.287	9647	0.365	5775	0.373
	2032	790	14462	0.284	9659	0.365	5801	0.375

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

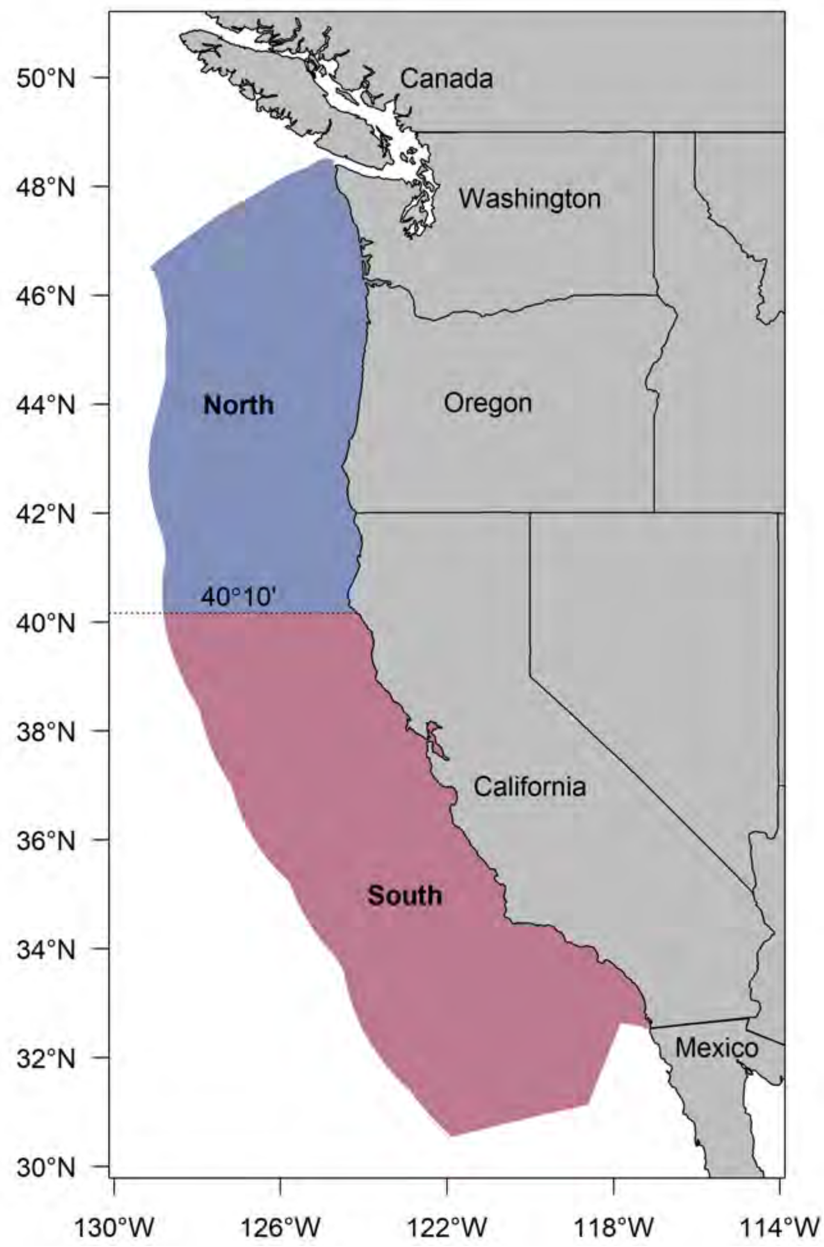

Figure 1: Map of the U.S. west coast and the area included in this assessment (red). The dashed line at 40°10'N and colors delineate the northern (blue) from the southern (red) assessed area.

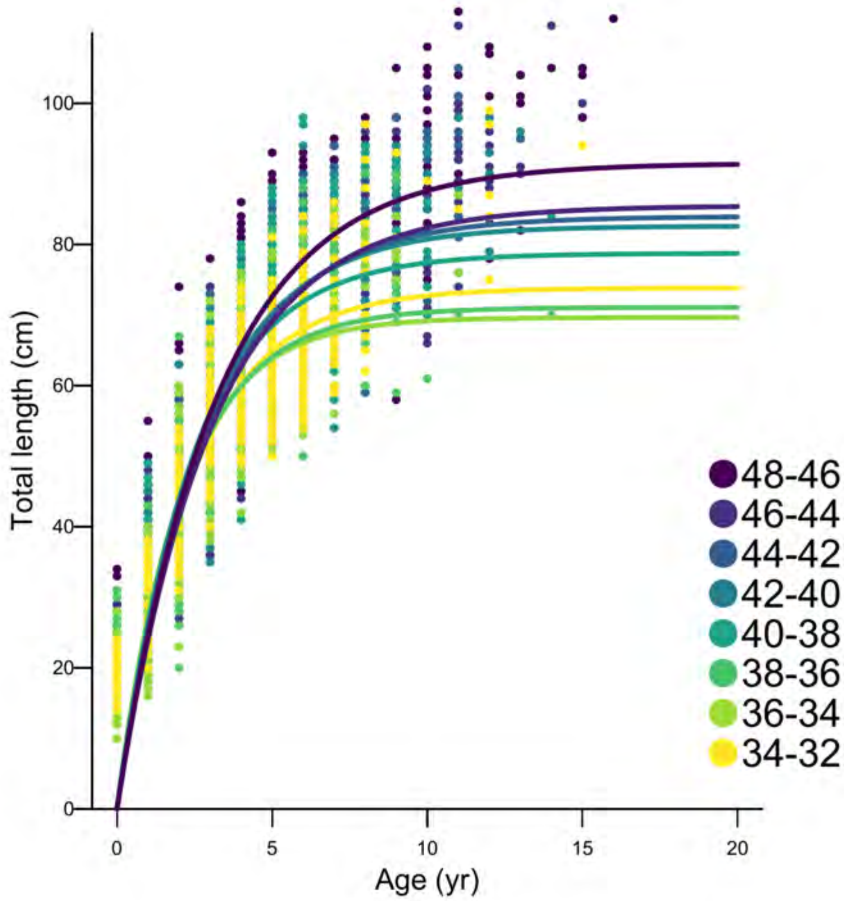

Figure 2: Length (cm) versus age (yr) and associated von Bertalanffy growth curves (lines) by latitude (colors). Models were fit to data from Lam research samples and NWFSC West Coast Groundfish Bottom Trawl Survey data.

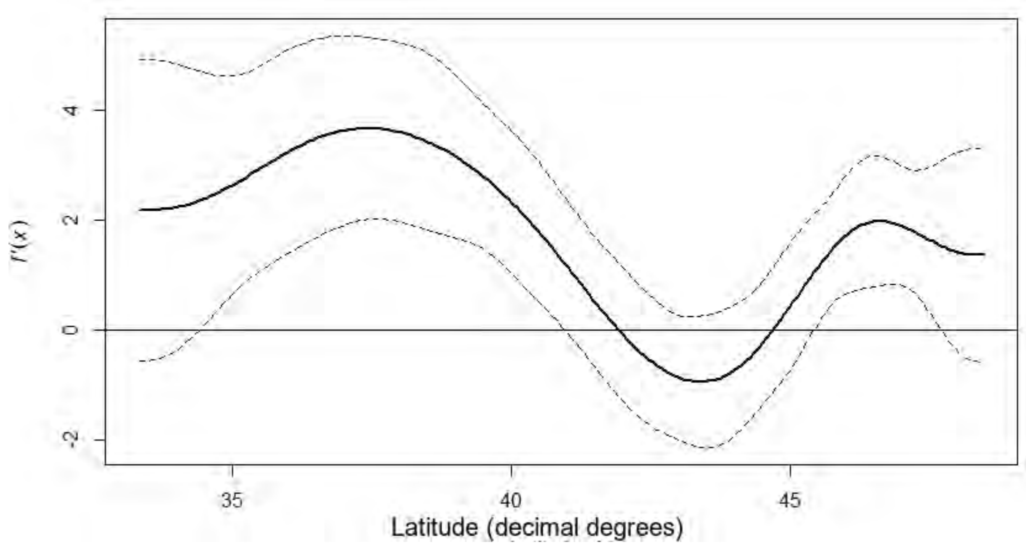

Figure 3: Estimated smoother of latitude (decimal degrees) for age-7 female fish when fitting length-at-age data.

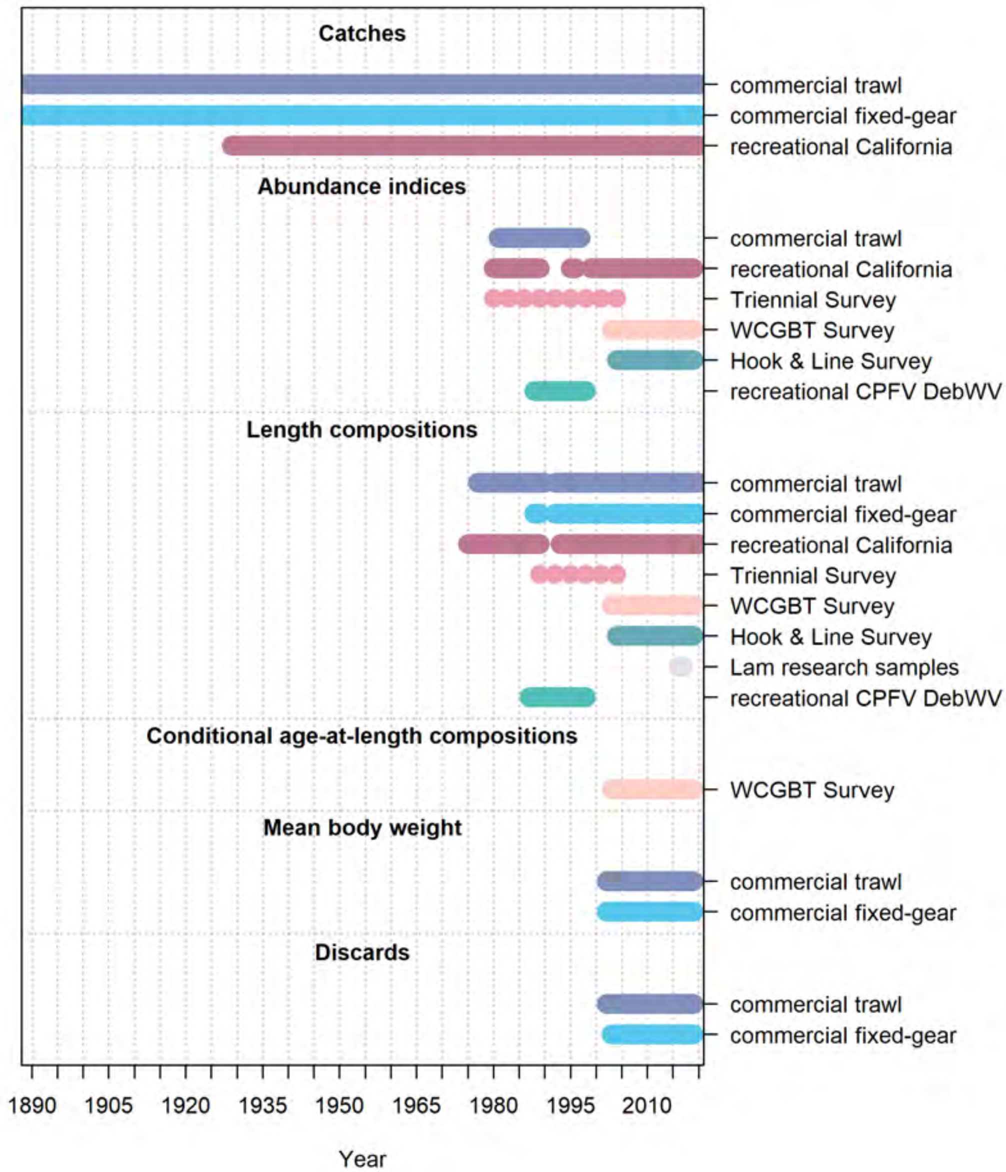

Figure 4: Data presence by year for each fleet and data type.

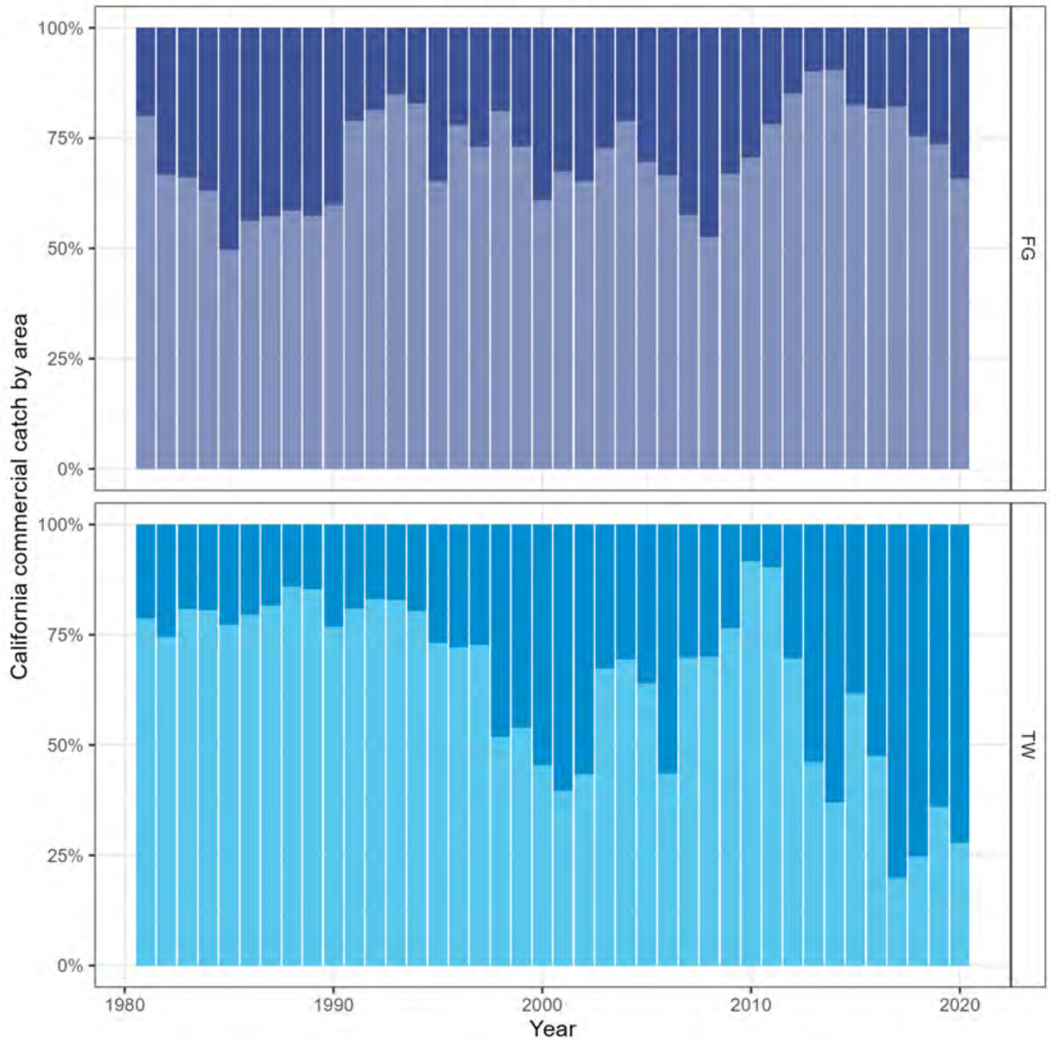

Figure 5: Percentage of California commercial catch by area within each fleet (fixed gear, FG, upper panel; trawl, TW, lower panel) since 1981. Darker shades represent the northern area and lighter shades represent the southern area.

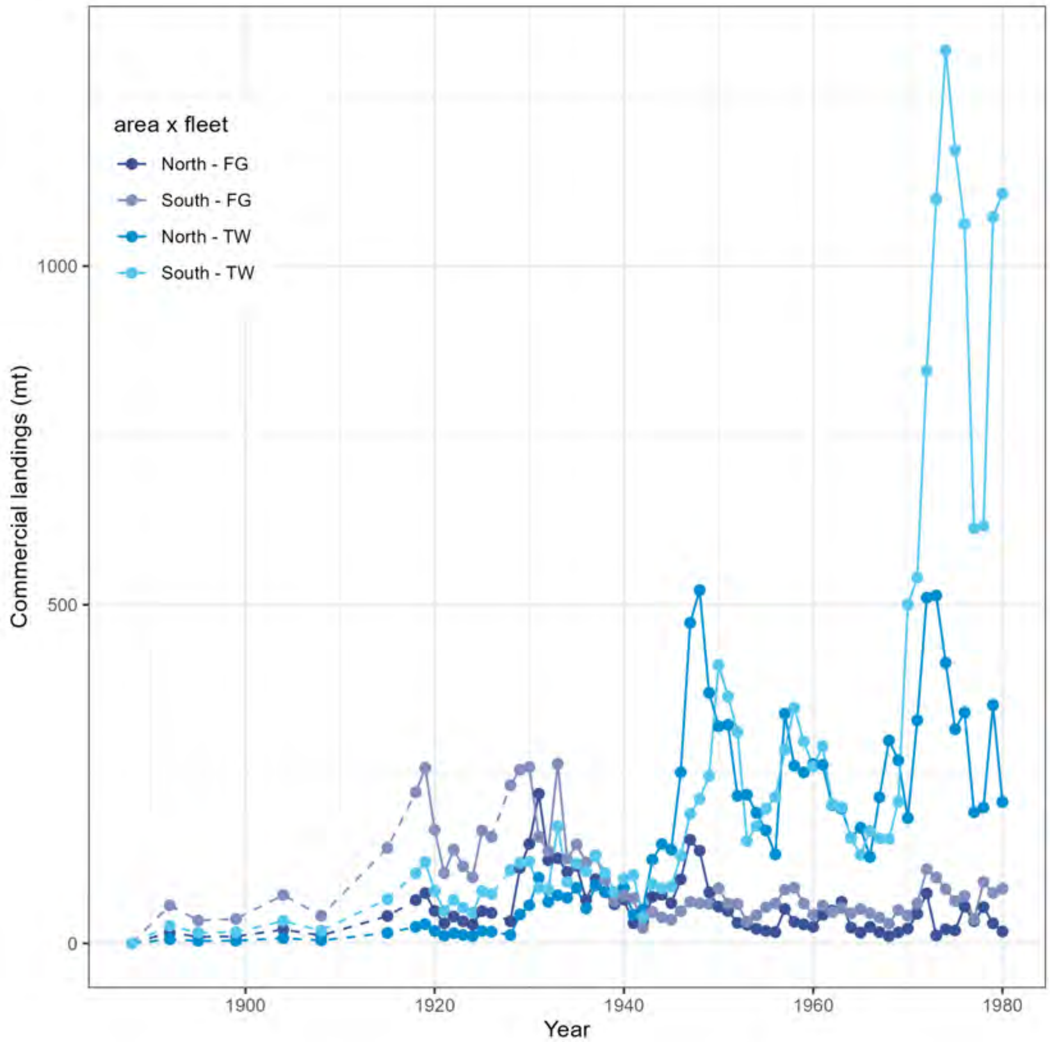

Figure 6: Reconstructed commercial landings for the state of California by fleet (fixed gear, FG, circles; trawl gear, TW, triangles) and area (northern region, blue; southern region, red). Dashed line indicates data were interpolated across years.

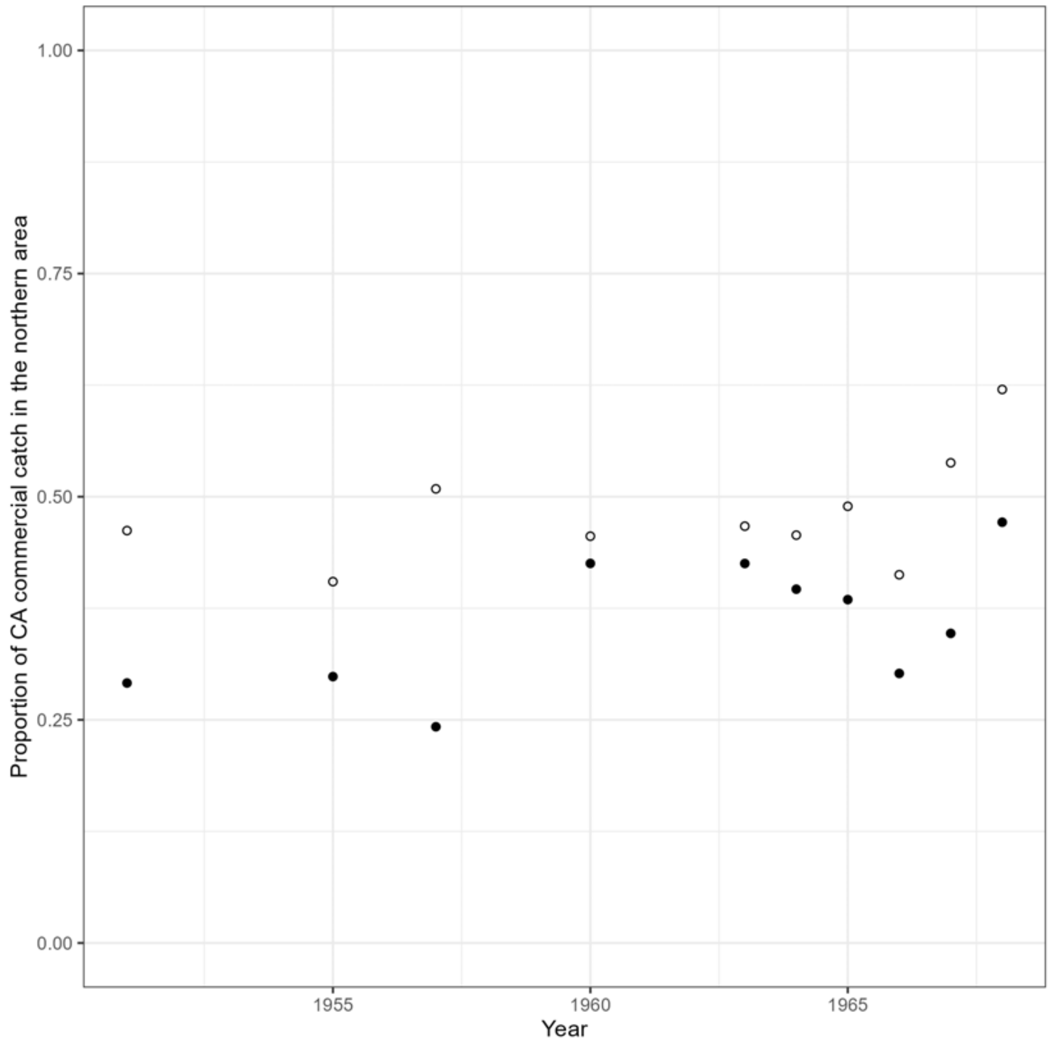

Figure 7: Yearly proportion of California (CA) commercial catch landed in the the northern region (i.e., north of forty degrees ten minutes latitude) of all CA commercial catches from two data sources, the Raltson et al. (2010) catch reconstruction effort (open circles) and fish ticket data in CALCOM,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

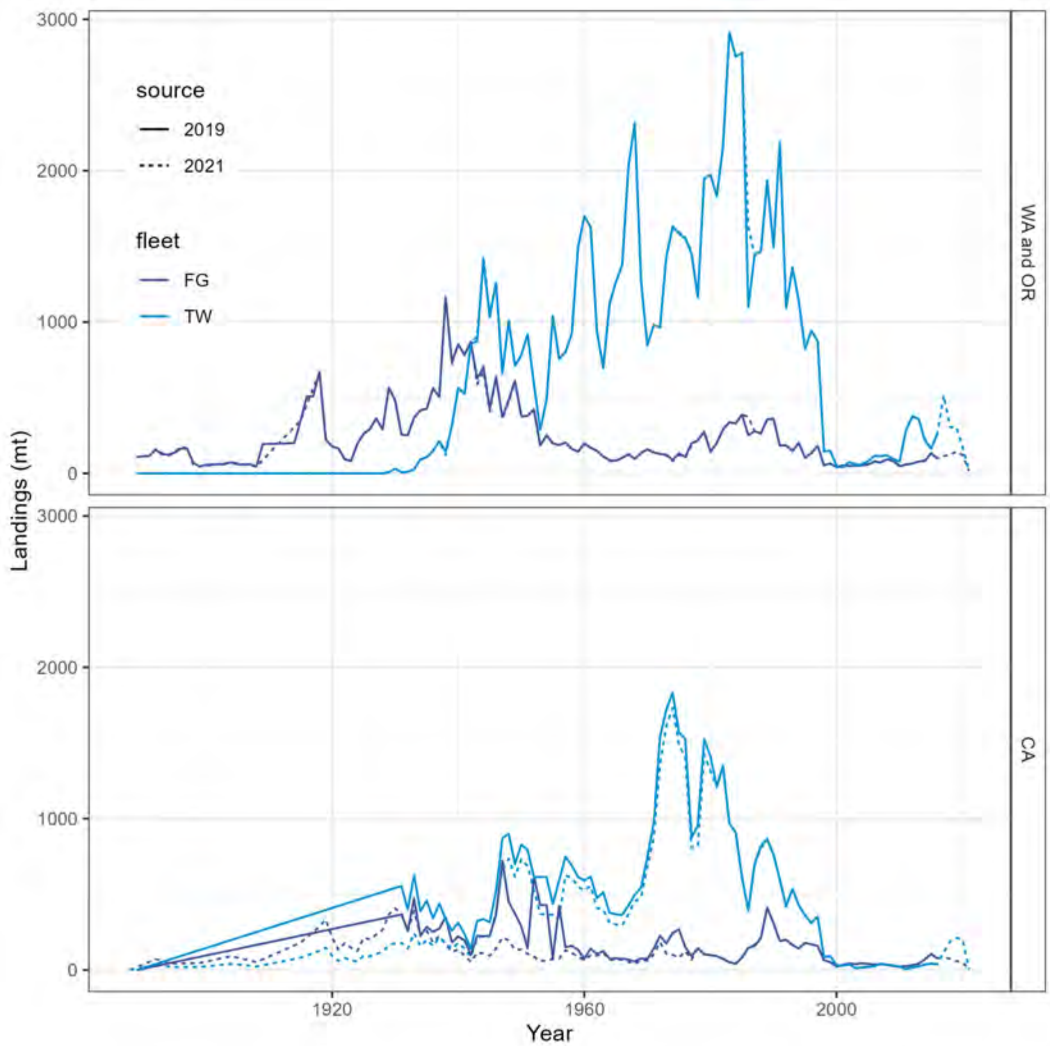

Figure 8: Comparison of current landings (dashed line) and those used in the previous assessment model (solid line) by state (panel). Fixed gear (FG; dark blue) and trawl (TW; light blue) landings are shown for Washington and Oregon (top panel) and California (bottom panel) because the previous assessment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

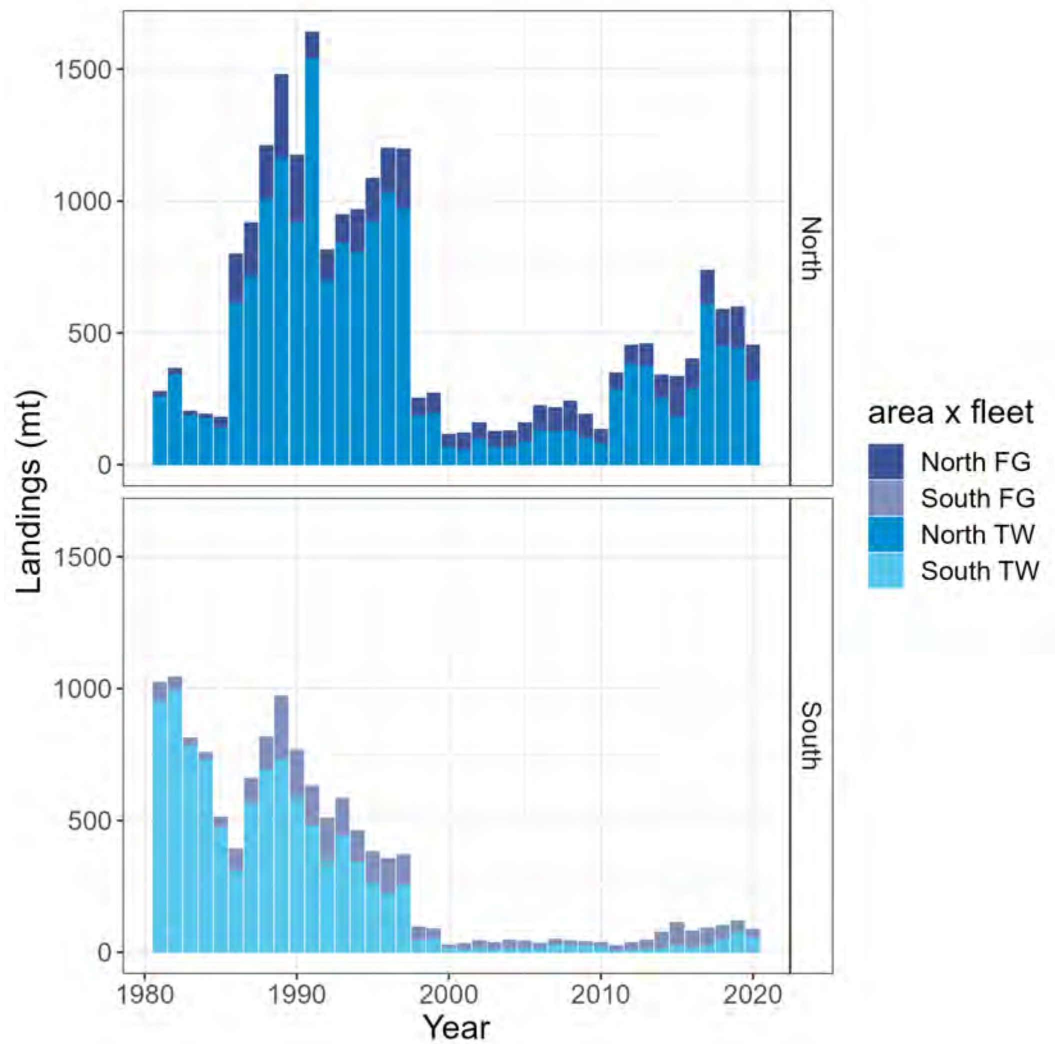

Figure 9: Yearly commercial landings (mt) from the PacFIN database since 1981 by area (panel and color) and fleet (shading). Trawl gear (TW) includes all trawl, nets, and dredging. Fixed gear (FG) includes all other gear types.

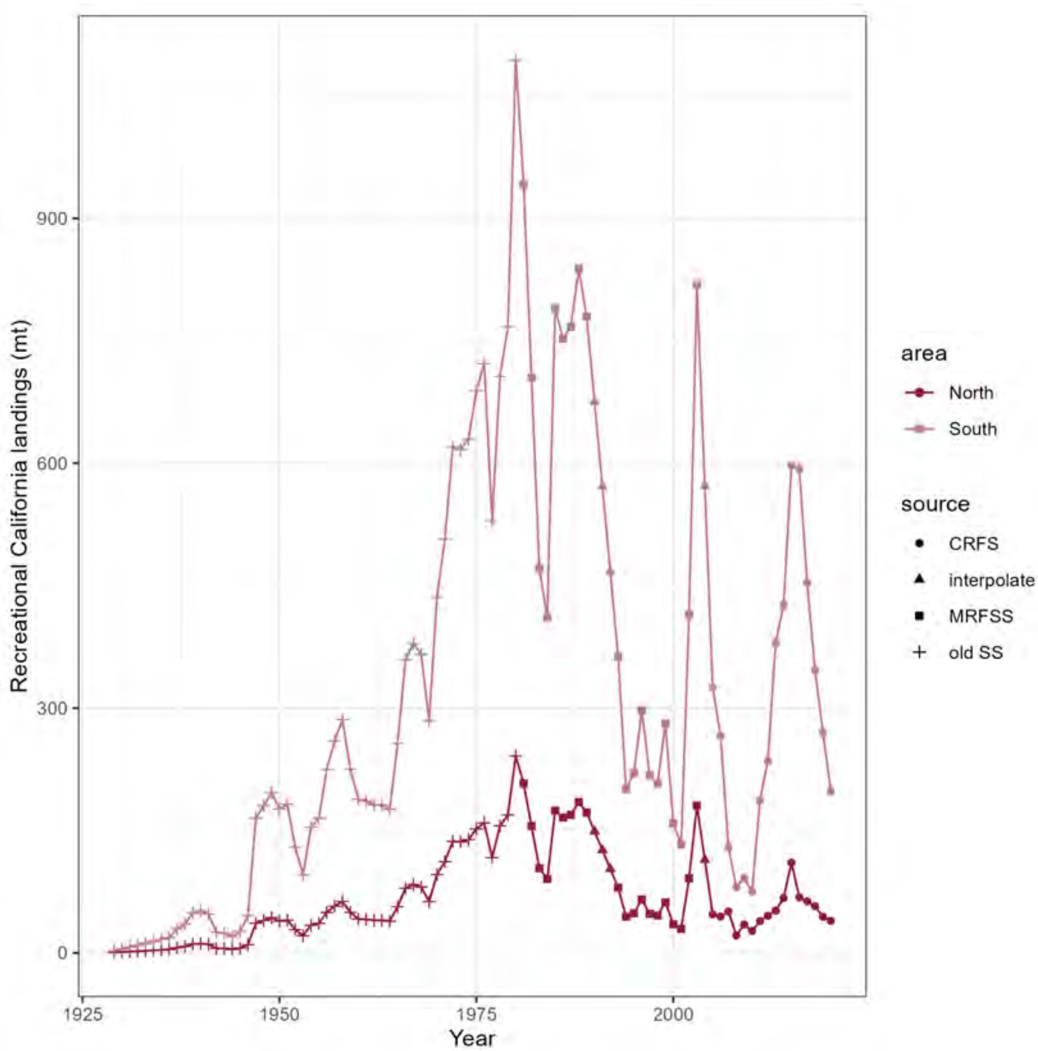

Figure 10: Time series of California recreational landings (mt) for the northern (darker color) and southern (lighter color) areas. The shape of the points indicates the information source (California Recreational Fisheries Survey, CRFS; linear interpolation, interpolate; Marine Recreational Fisheries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

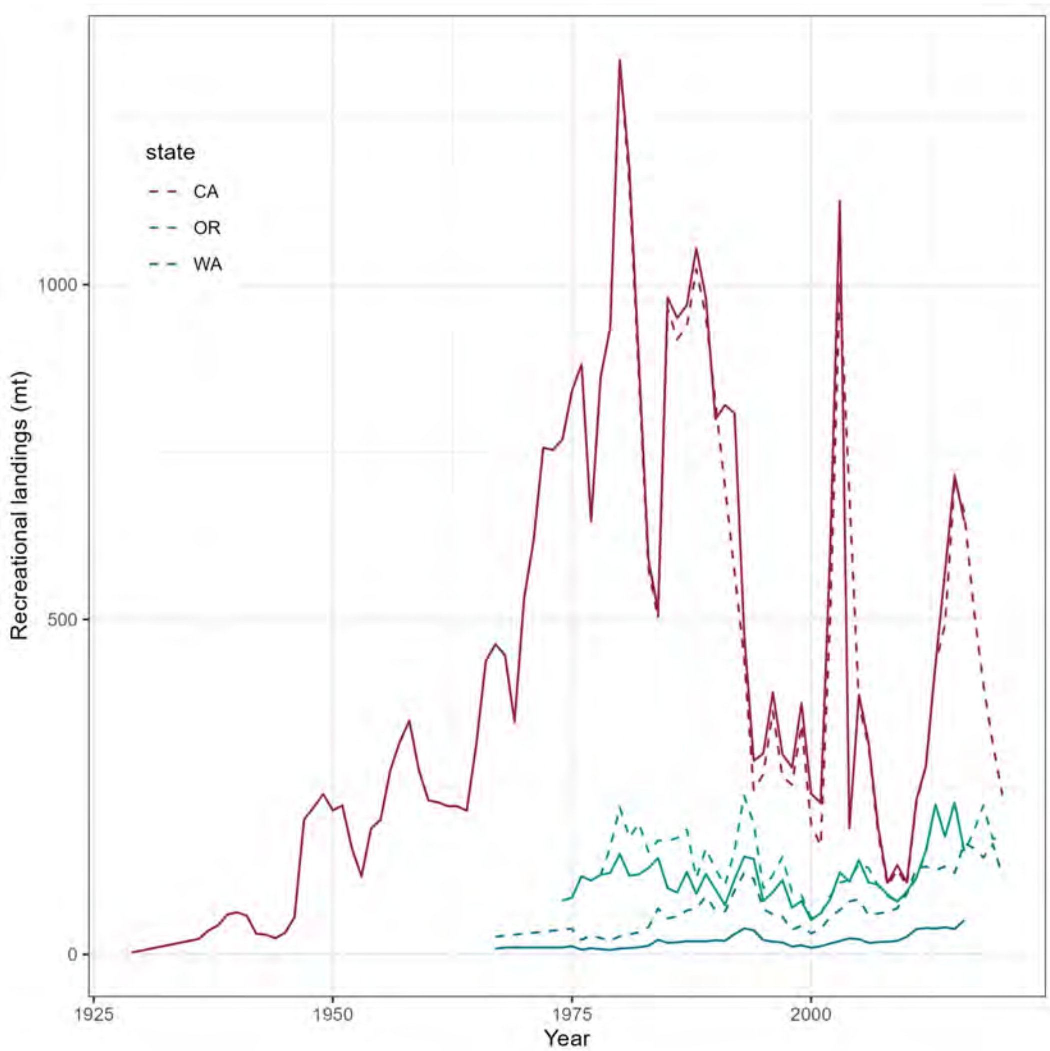

Figure 11: Comparison of recreational landings from this assessment (dashed line) versus the previous assessment (solid line) for each state (colors). The previous assessment used numbers for WA recreational landings, whereas this assessment used weight.

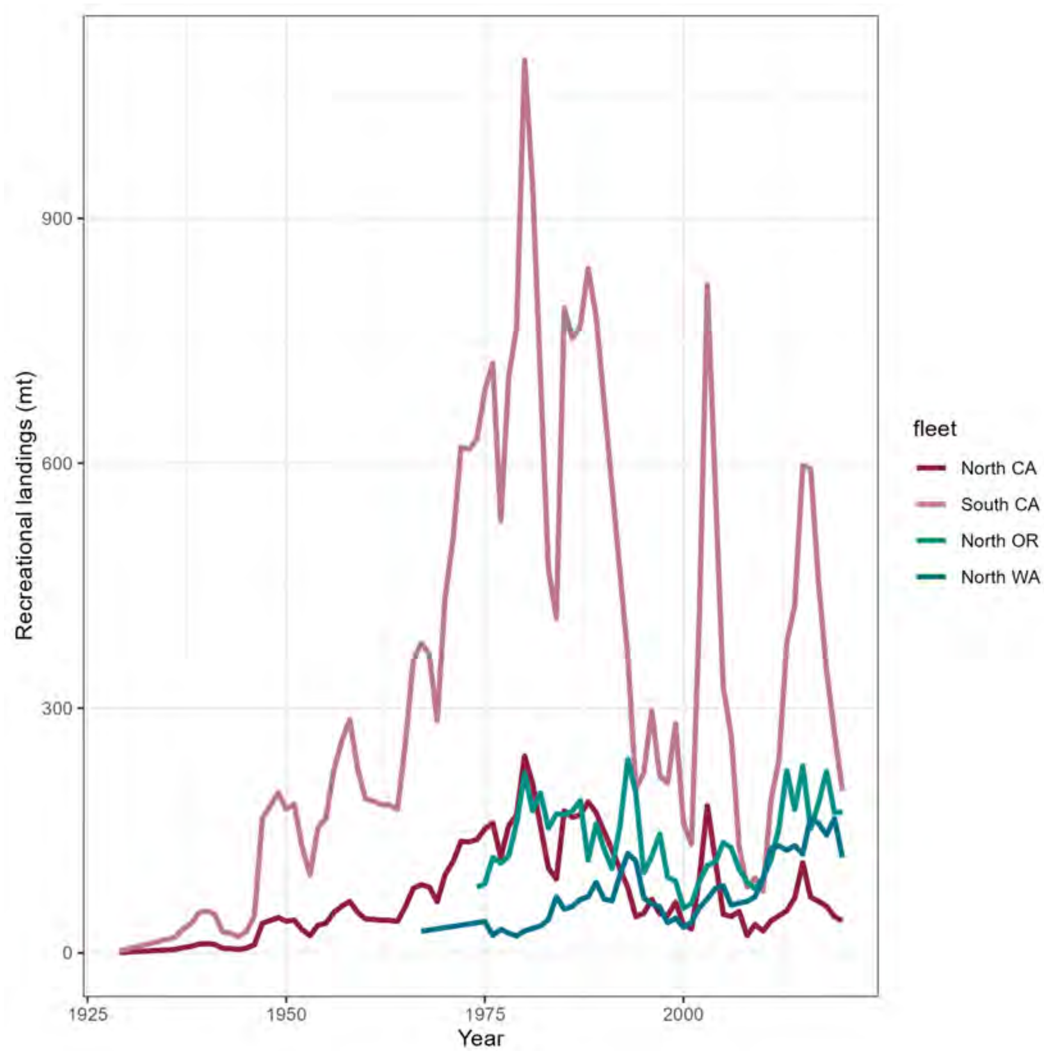

Figure 12: Time series of recreational landings by state and area.

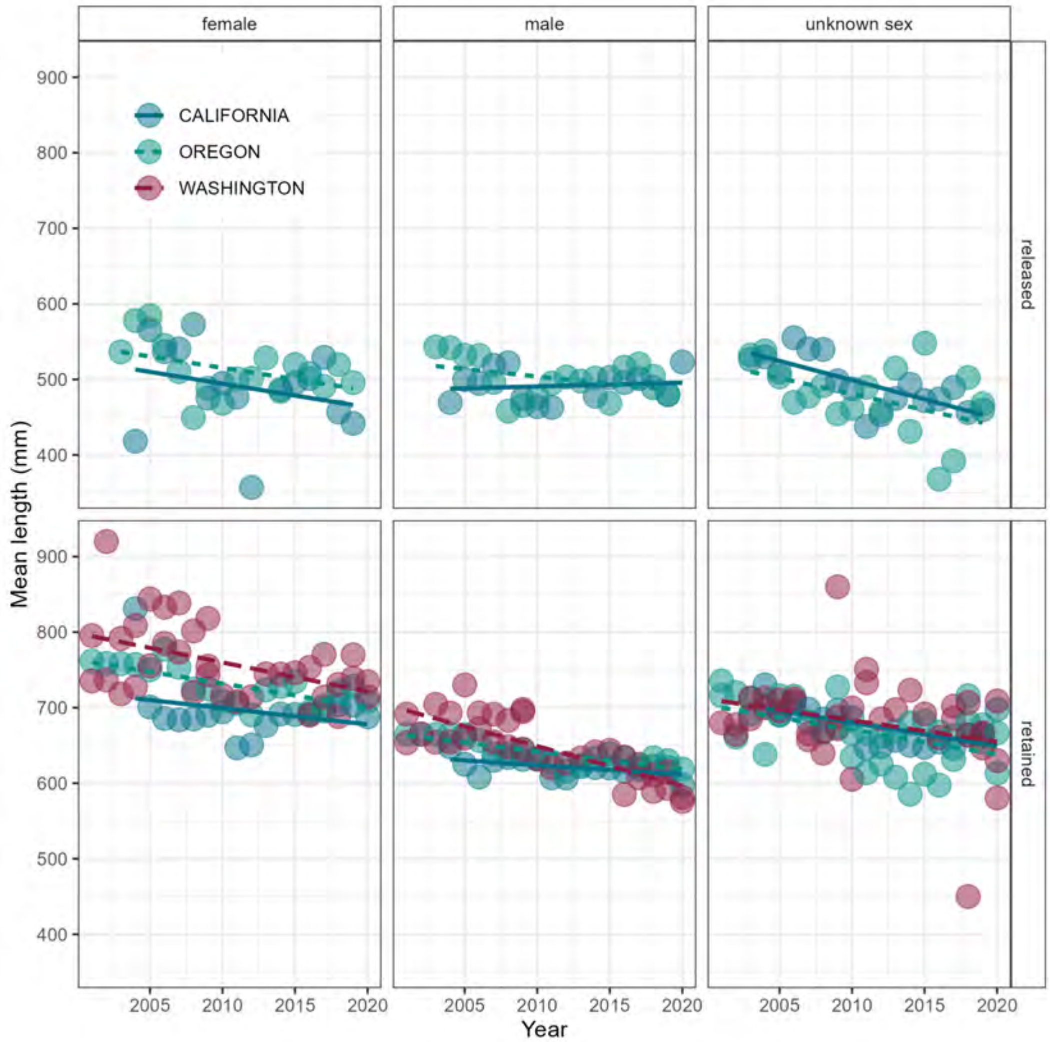

Figure 13: Mean length (mm) of released (top panel) and retained (bottom panel) fish from the recreational fishery for Washington (long dashes), Oregon (short dashes), and California (solid line) by sex (columns). The average length of retained fish across all years was used to translate numbers to weight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

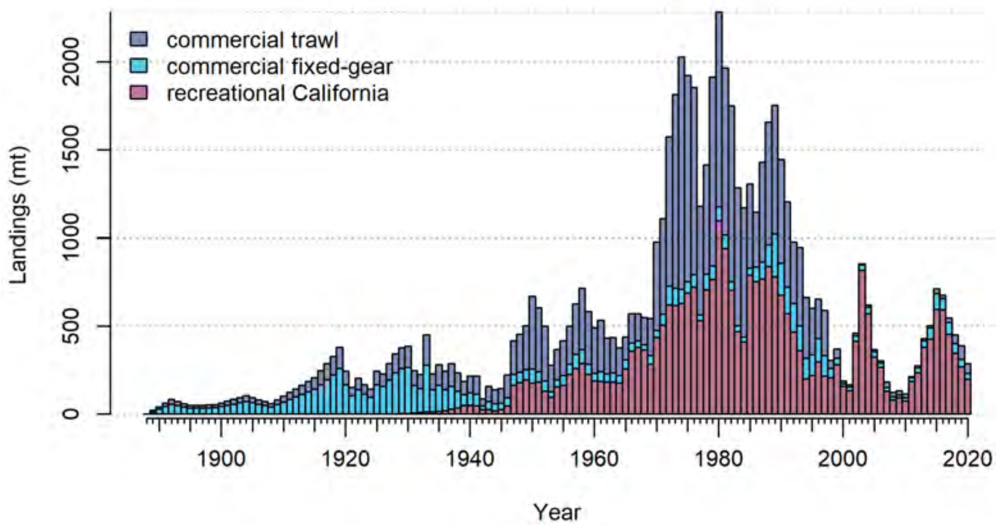

Figure 14: Landings (mt) by fleet used in the base model.

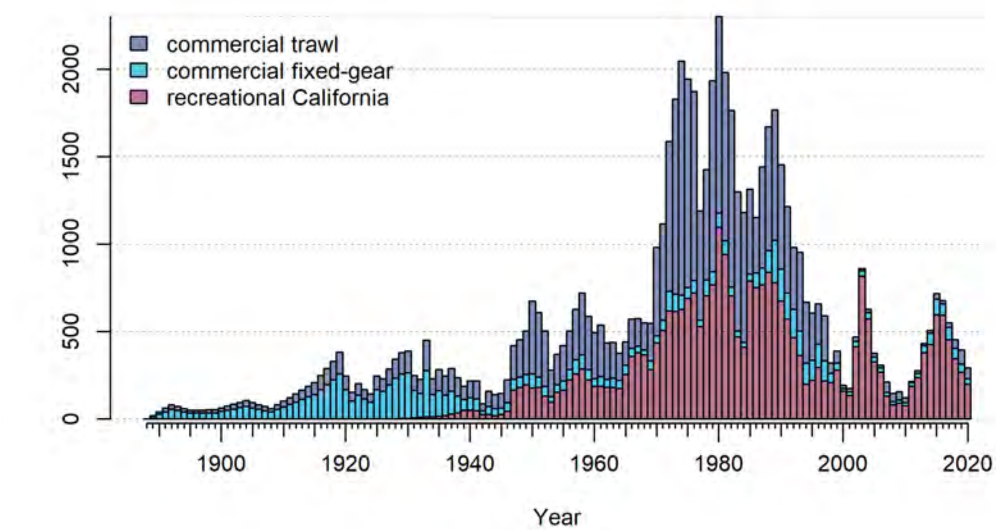

Figure 15: Landings plus dead discards (mt) by fleet as estimated in the base model.

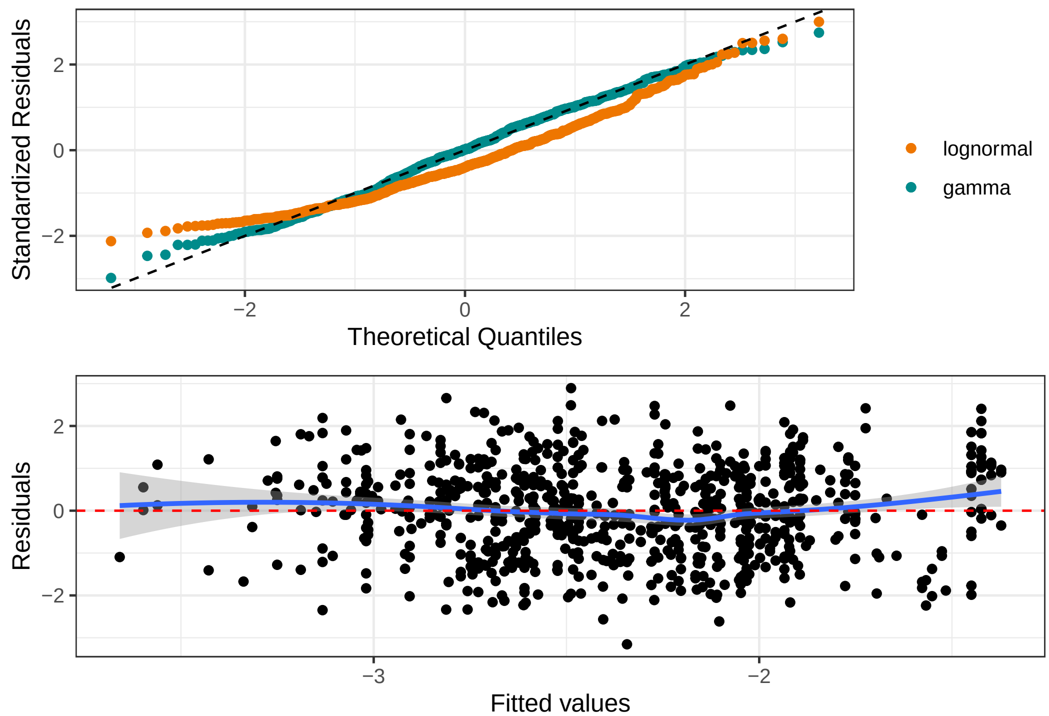

Figure 16: Quantile-quantile fits (upper panel) for the lognormal (orange) and gamma (green) distributions and residuals versus fitted values (bottom panel) for the Marine Recreational Fisheries Statics Survey data used in the California recreational catch per unit effort index.

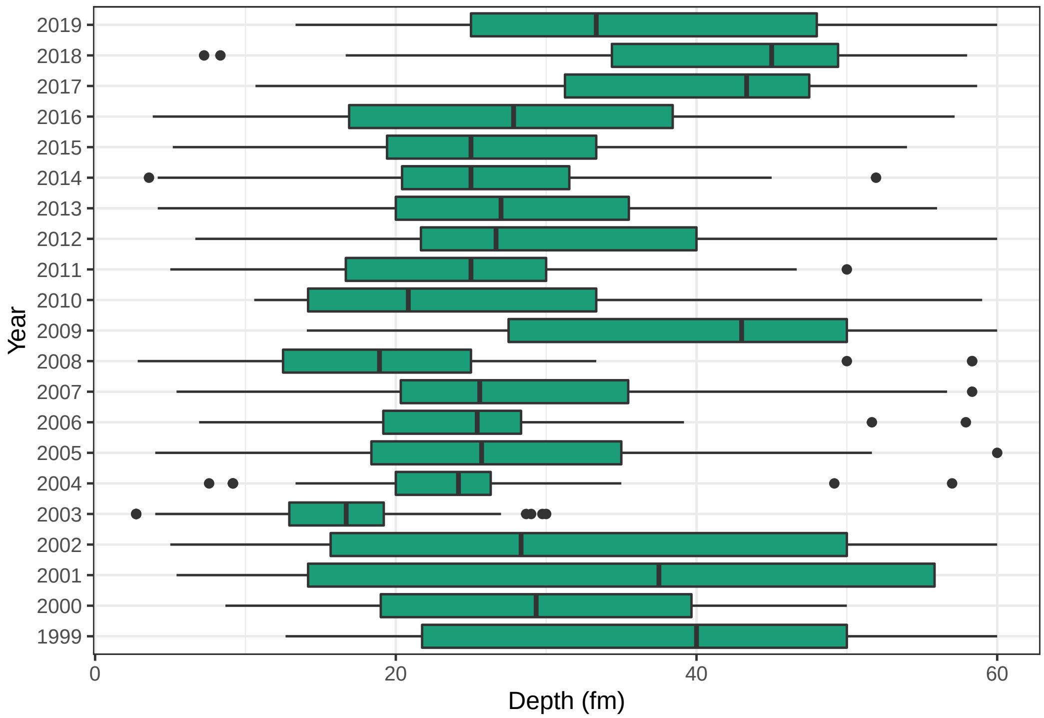

Figure 17: Boxplots of depths fished by year in the filtered data commercial passenger fishing vessel onboard observer data set used for the California recreational fishery catch per unit effort.

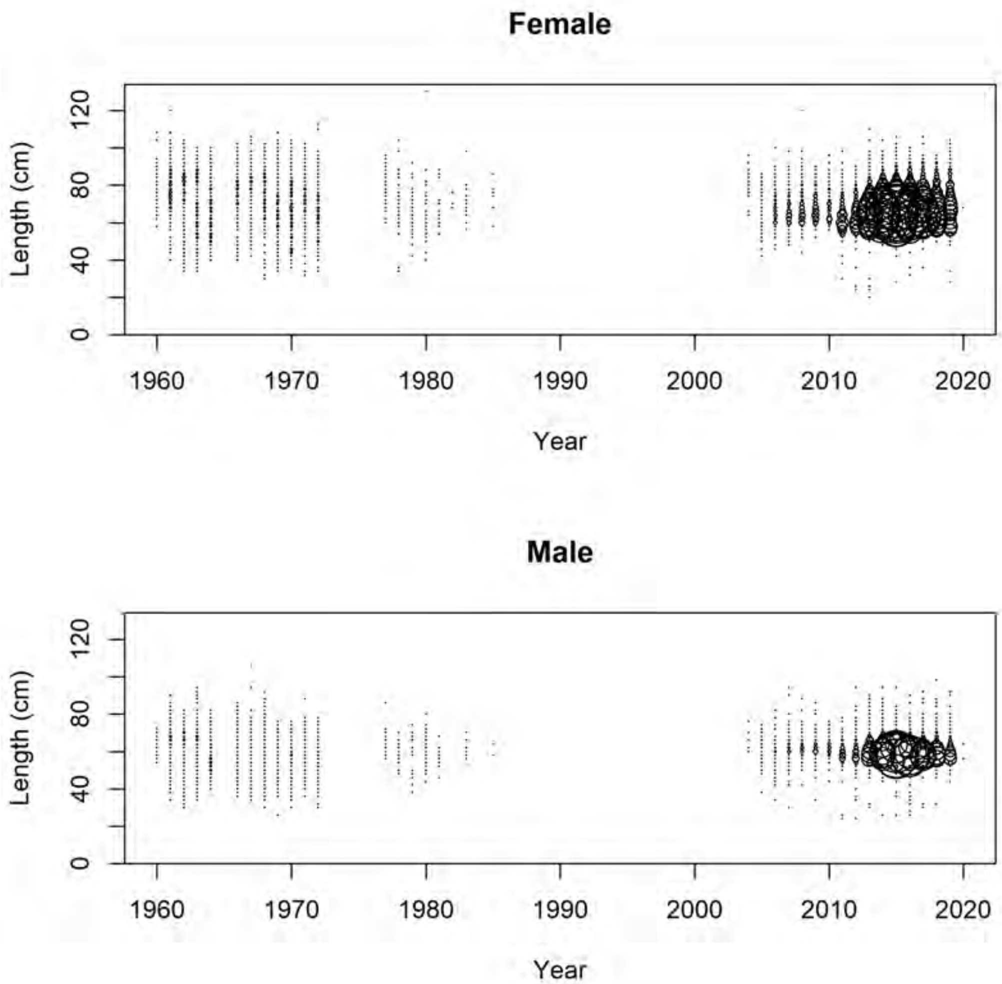

Figure 18: Length-composition data for the CA recreational fleet for sexed fish.

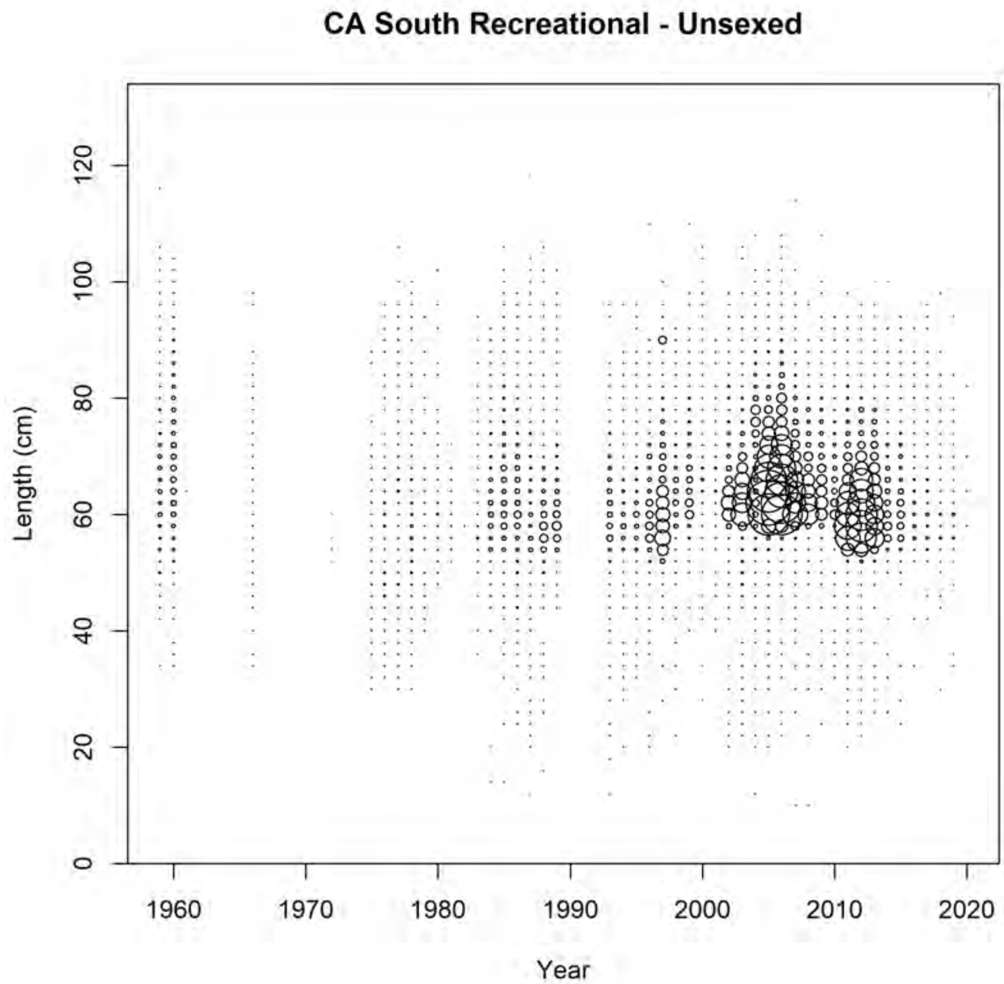

Figure 19: Length-composition data for the CA recreational fleet for unsexed fish.

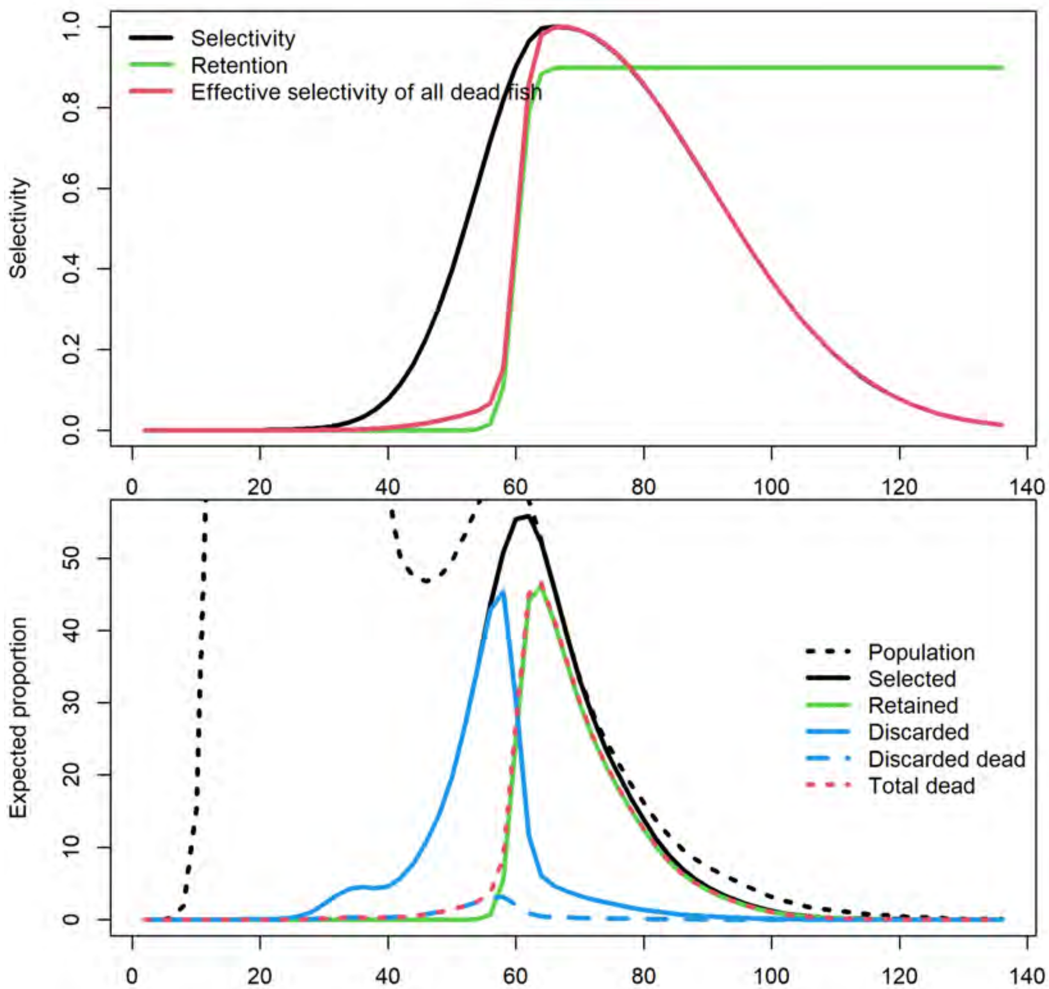

Figure 20: Illustration of the effective selectivity associated with retained recreational catch (upper panel) and the difference in expected proportion at length between retained-only (as used in the model), and retained plus dead discards (unavailable due to the nature of the sampling process). Selectivity, retention, and numbers-at-length are based on the California recreational fishery in the 2017 south model for the year 2000.

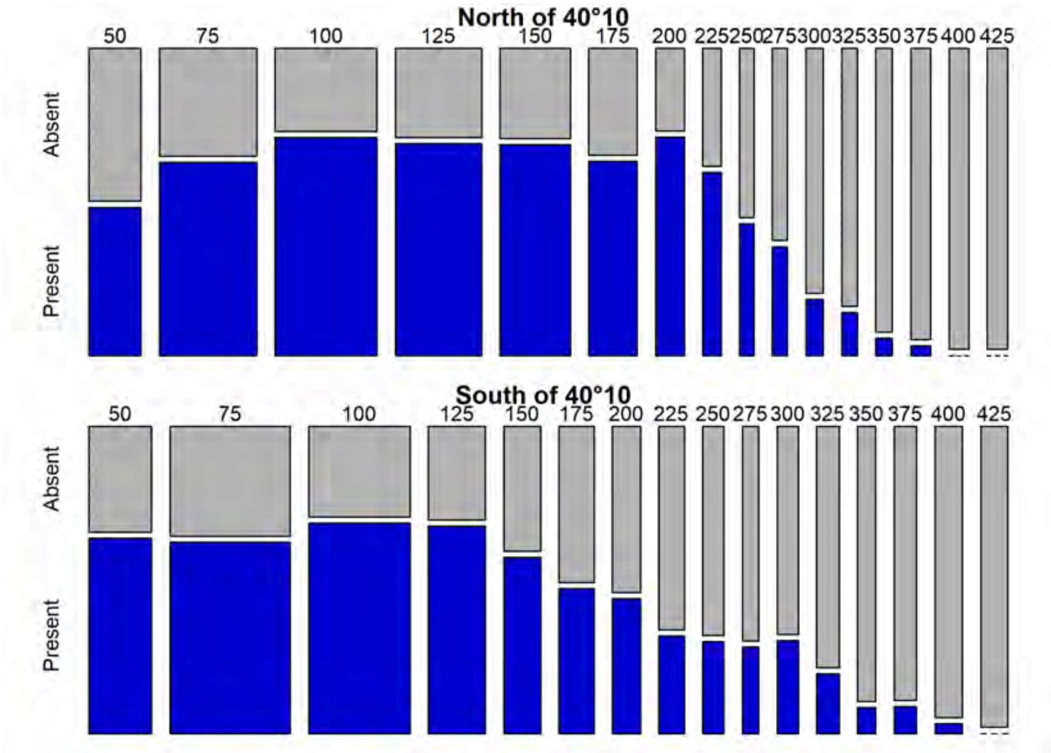

Figure 21: Presence/absence of lingcod in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) by 25 m depth increments.

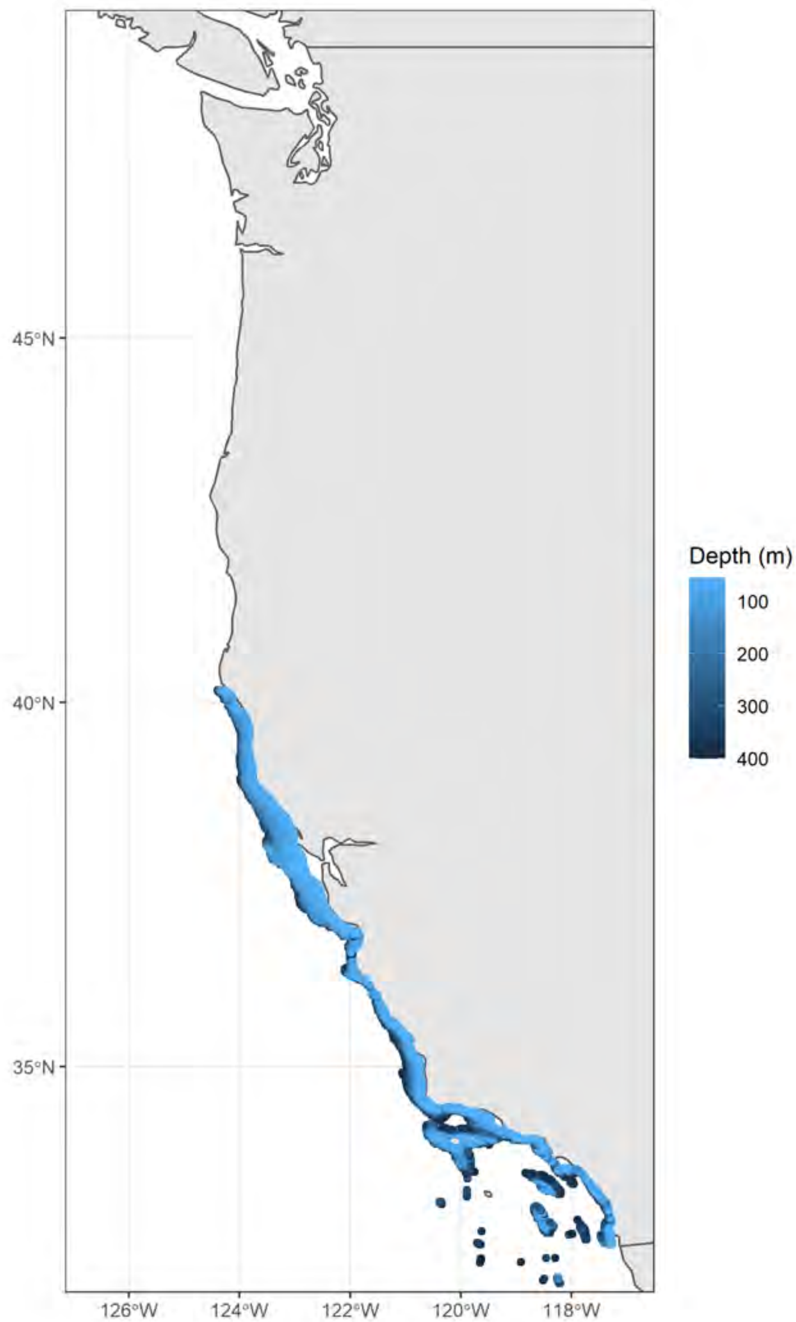

Figure 22: Map of the area modeled by the index-standardization process for the index-standardization process for the WCGBT Survey.

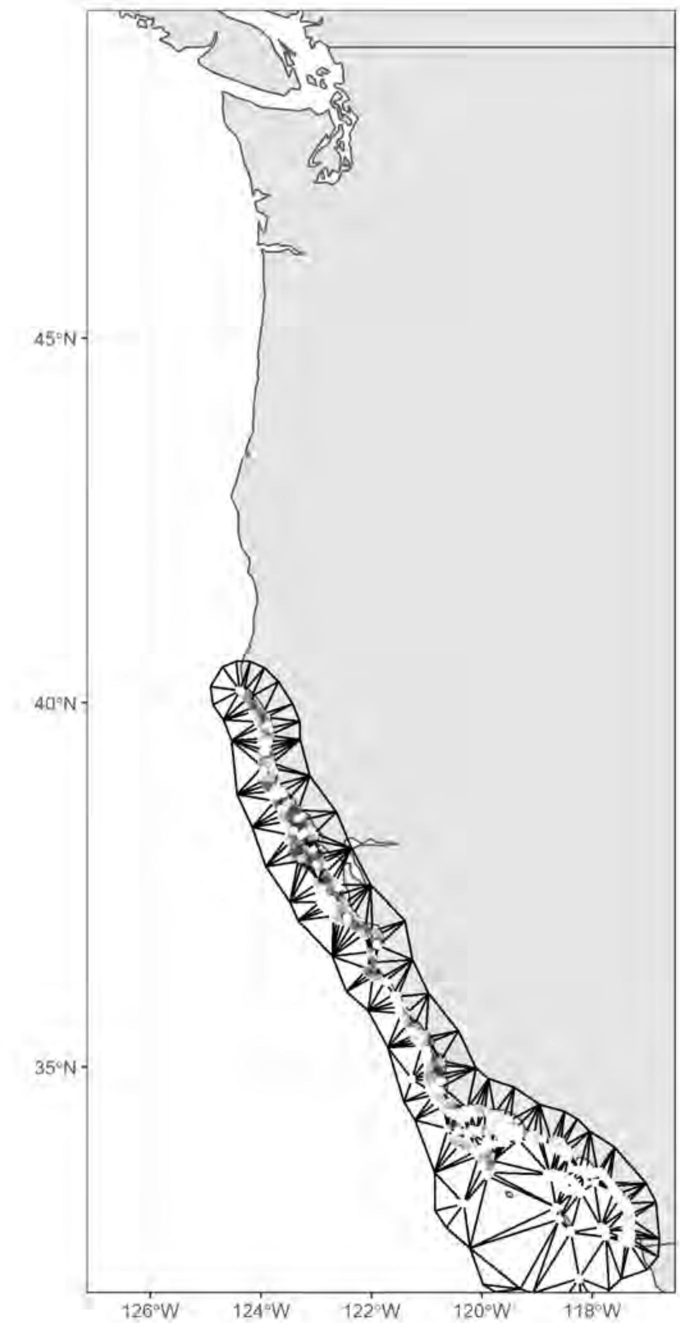

Figure 23: Map of knot locations used to approximate the spatial field for the index-standardization process for the WCGBT Survey.

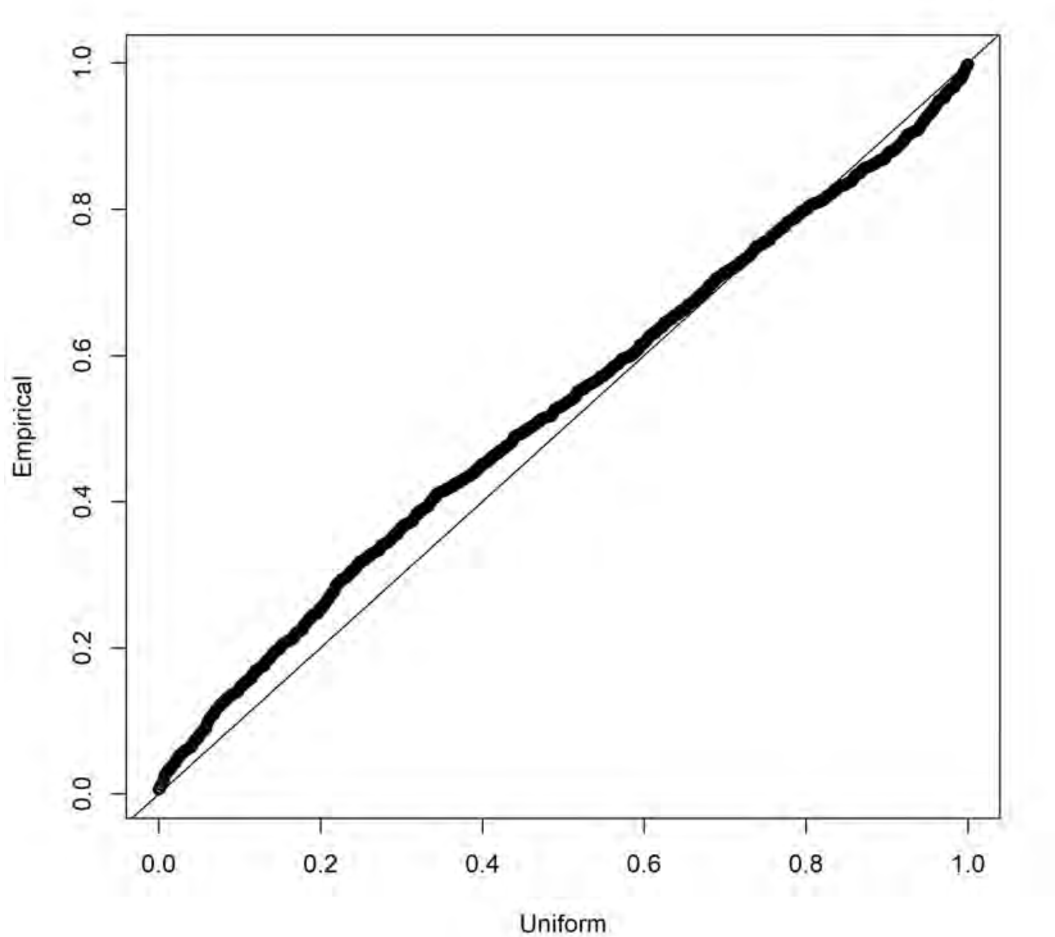

Figure 24: Quantile-Quantile (QQ) plot of the theoretical quantiles versus the standardized quantiles given fits to the data for the index-standardization process for the WCGBT Survey.

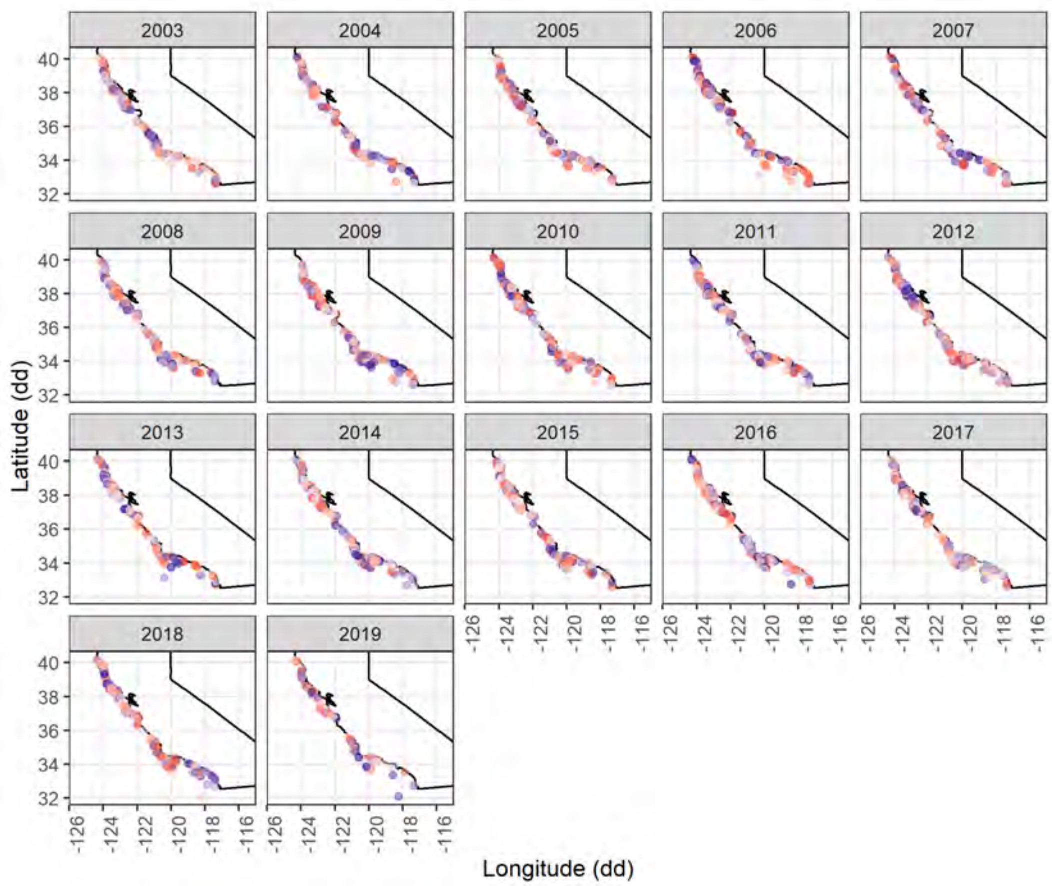

Figure 25: Map of standardized residuals by year (panels) from the index-standardization process for the WCGBT Survey. Dark blue are the lowest value, white are closest to the mean, and red are the highest values.

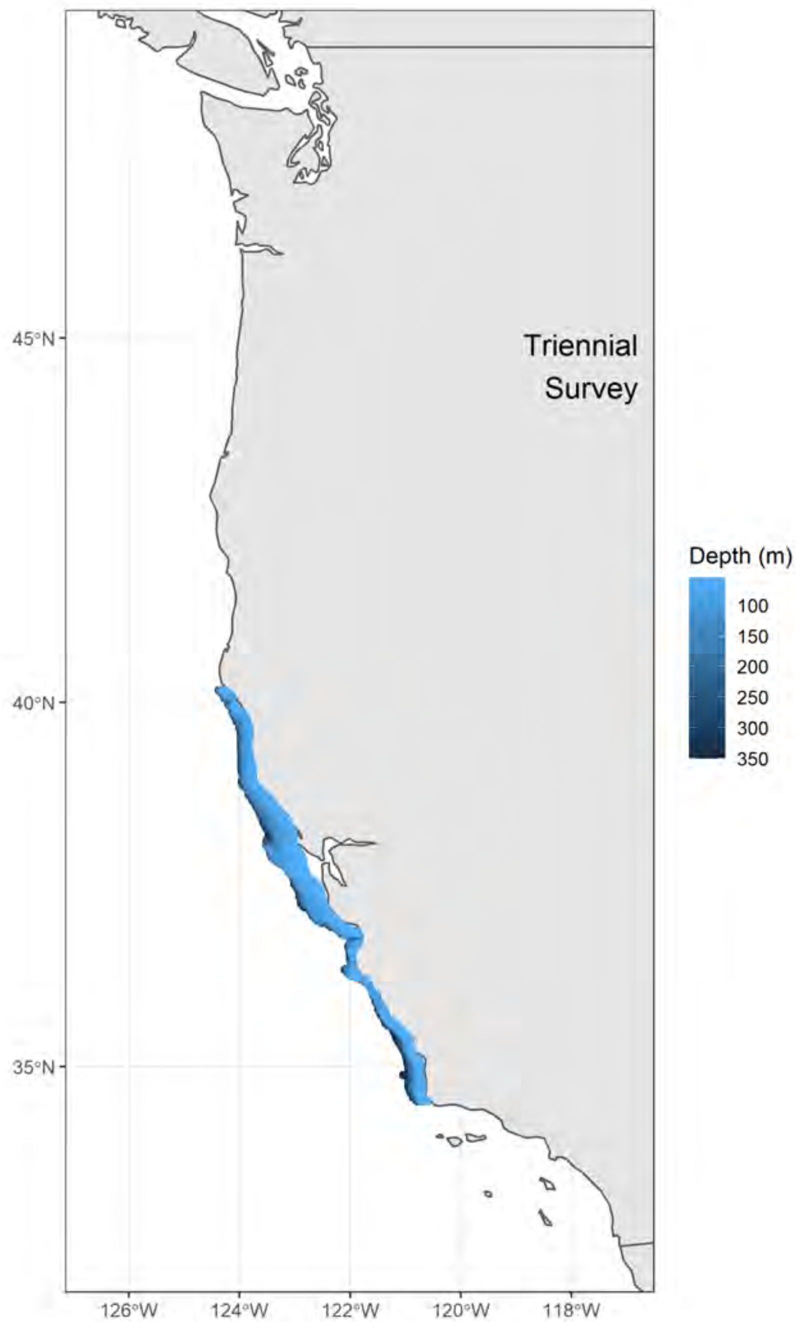

Figure 26: Map of the area modeled by the index-standardization process for the index-standardization process for the Triennial Survey.

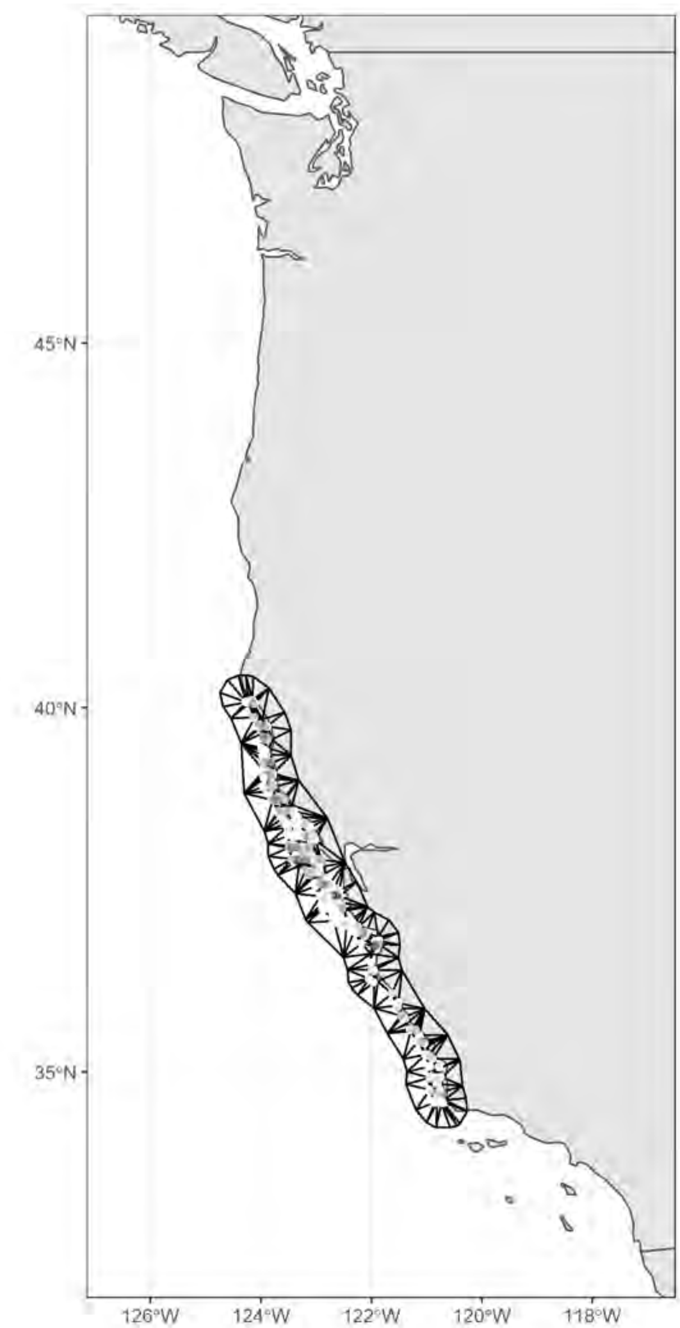

Figure 27: Map of knot locations used to approximate the spatial field for the index-standardization process for the Triennial Survey.

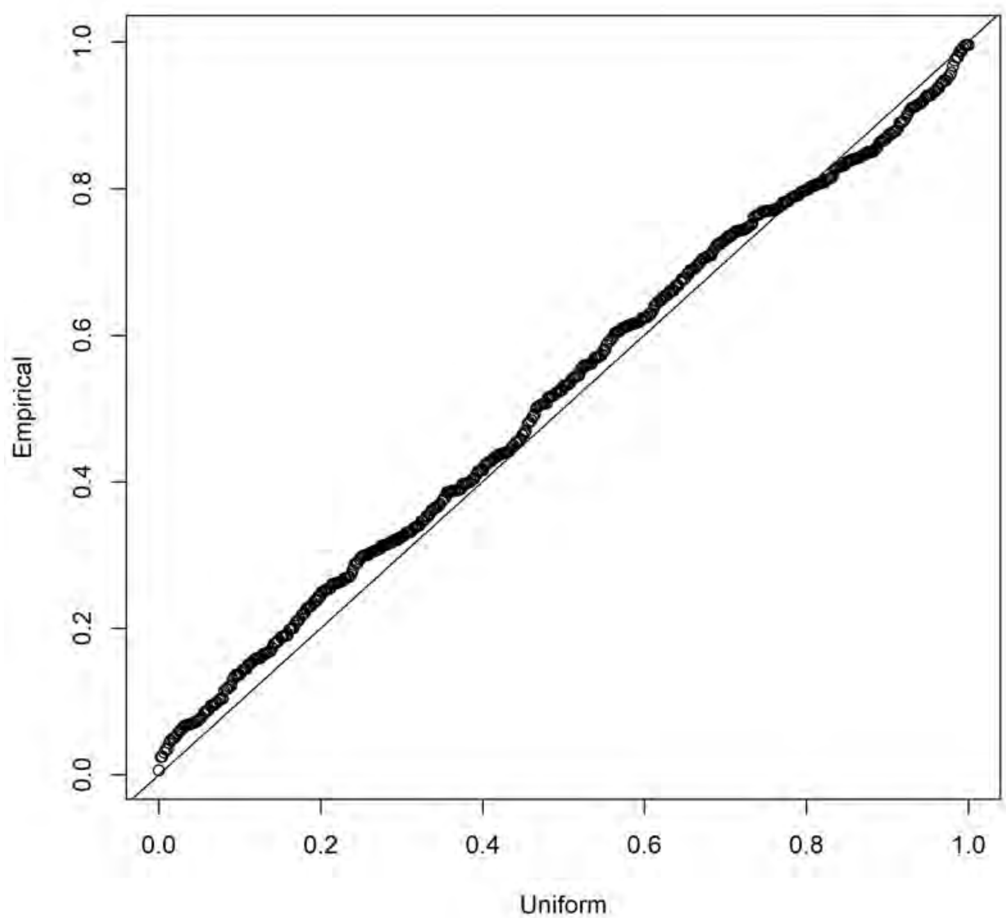

Figure 28: Quantile-Quantile (QQ) plot of the theoretical quantiles versus the standardized quantiles given fits to the data for the index-standardization process for the Triennial Survey.

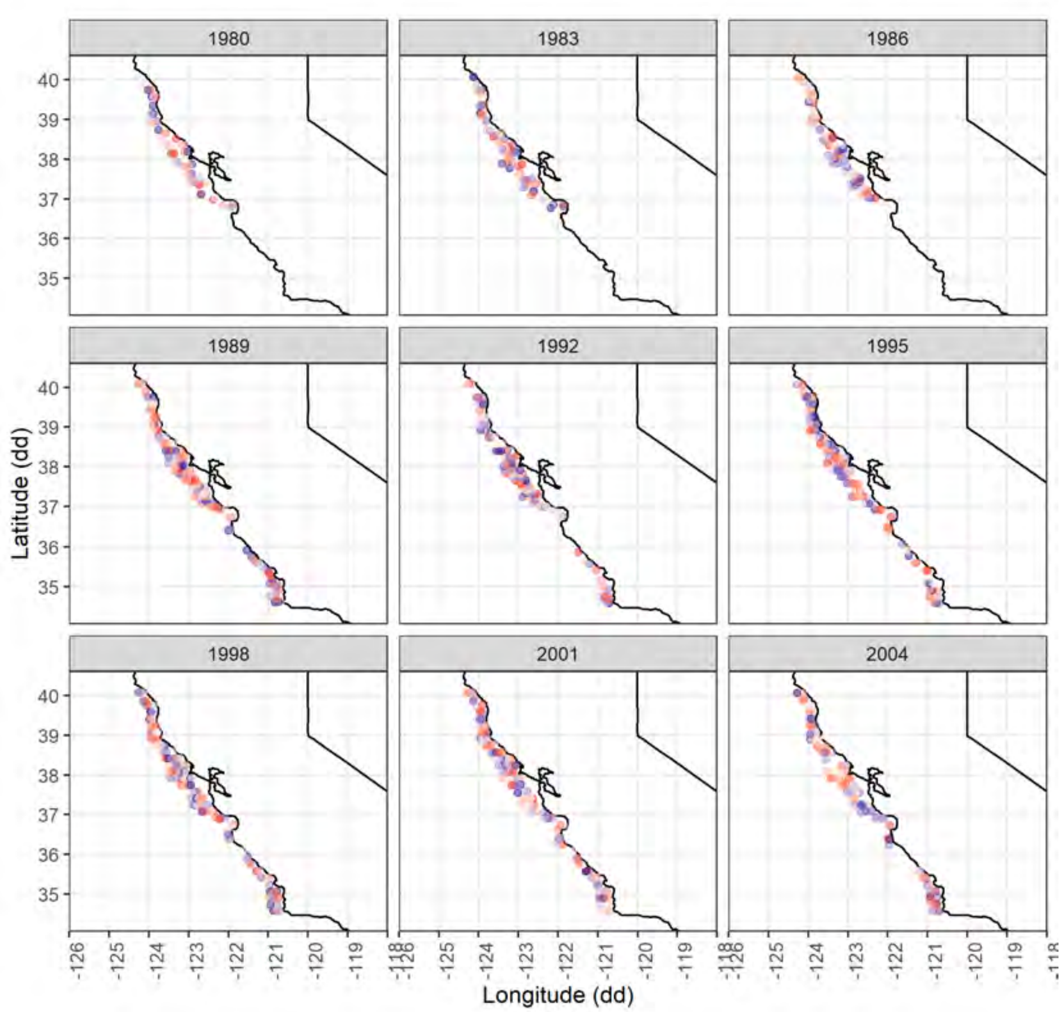

Figure 29: Map of standardized residuals by year (panels) from the index-standardization process for the Triennial Survey. Dark blue are the lowest value, white are closest to the mean, and red are the highest values.

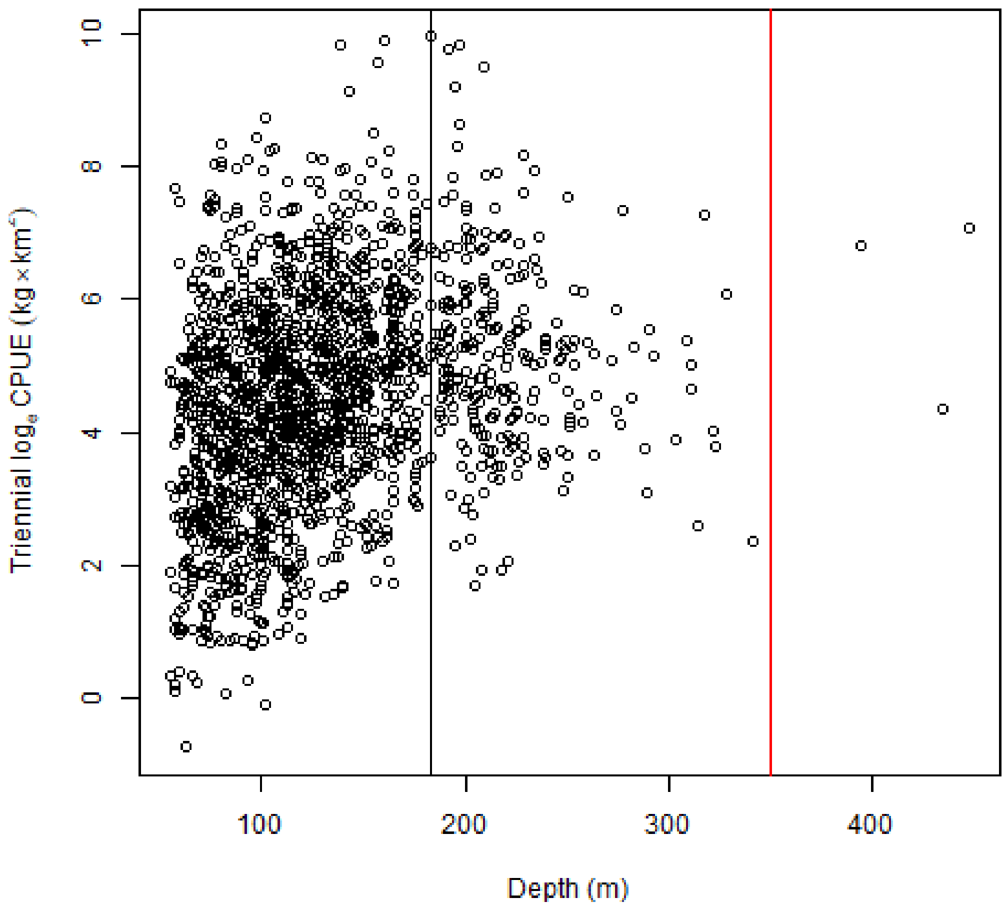

Figure 30: Raw catch per unit effort in by depth in the triennial survey. The black vertical line indicate split in depth strata at 183 m, and red vertical line shows end of depth strata at 350 m.

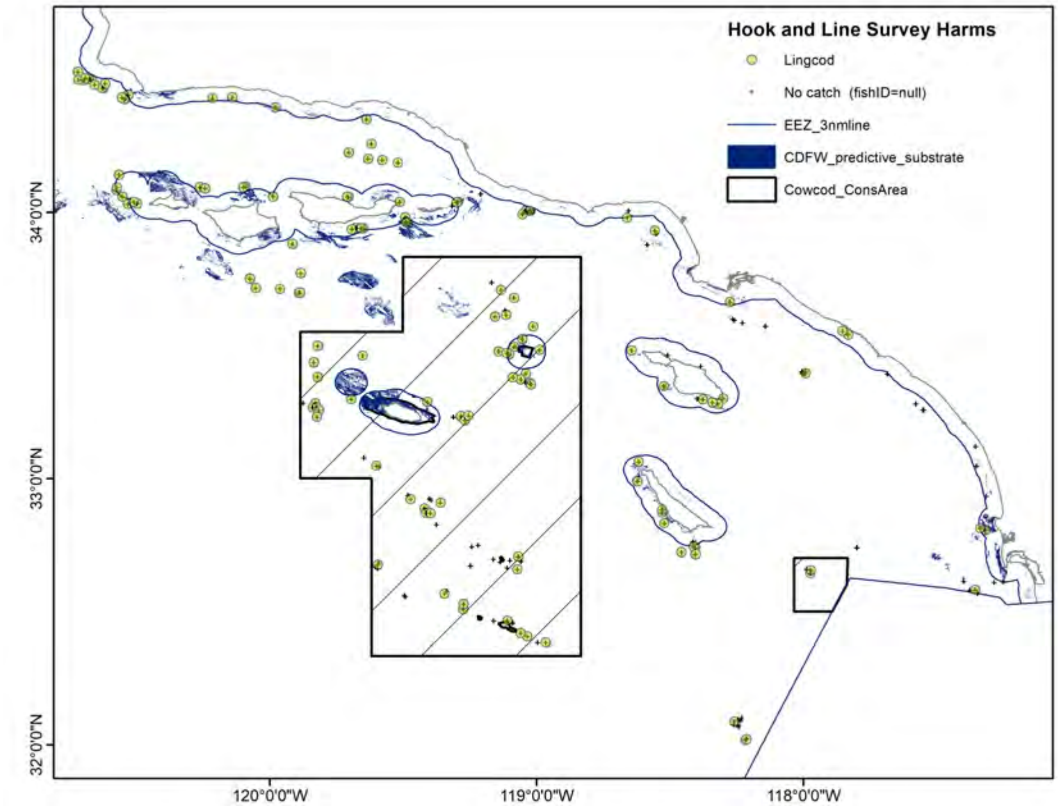

Figure 31: Map of the NWFSC hook-and-line survey site with circle indicating location at which lingcod rockfish were observed at least once.

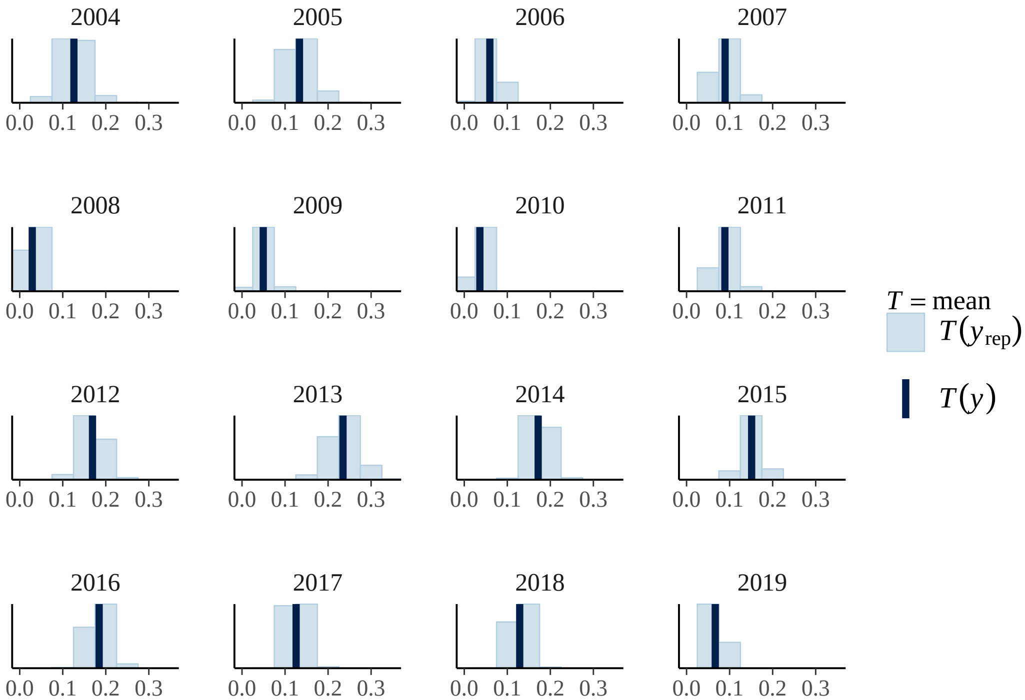

Figure 32: Posterior predictive draws of the mean by year with a vertical line of the raw data average.

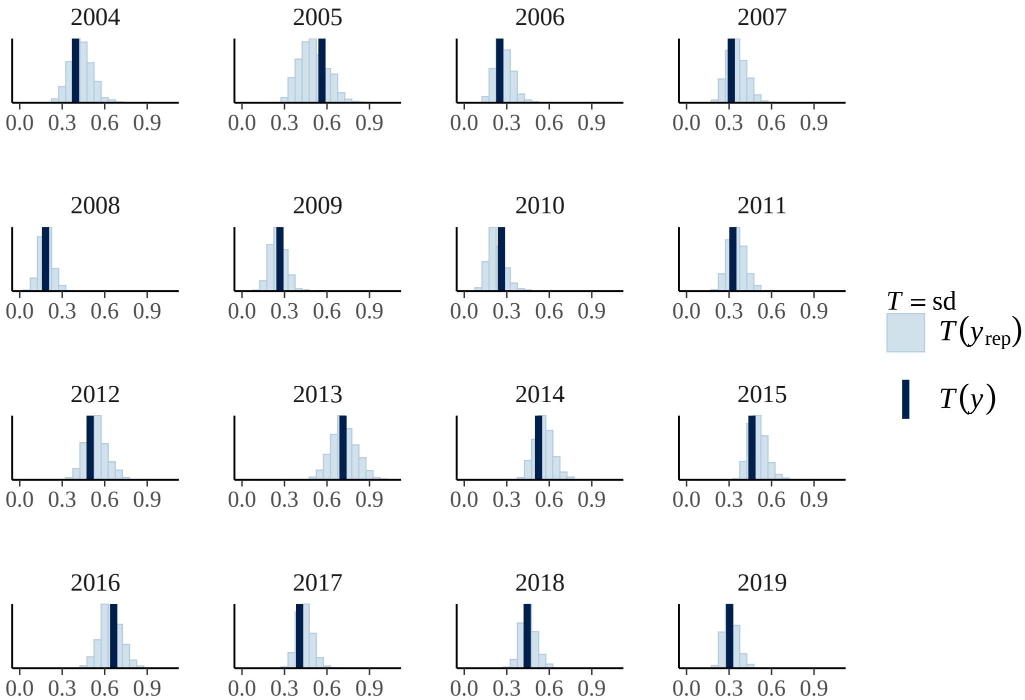

Figure 33: Posterior predictive draws of the standard deviation by year with a vertical line representing the observed average.

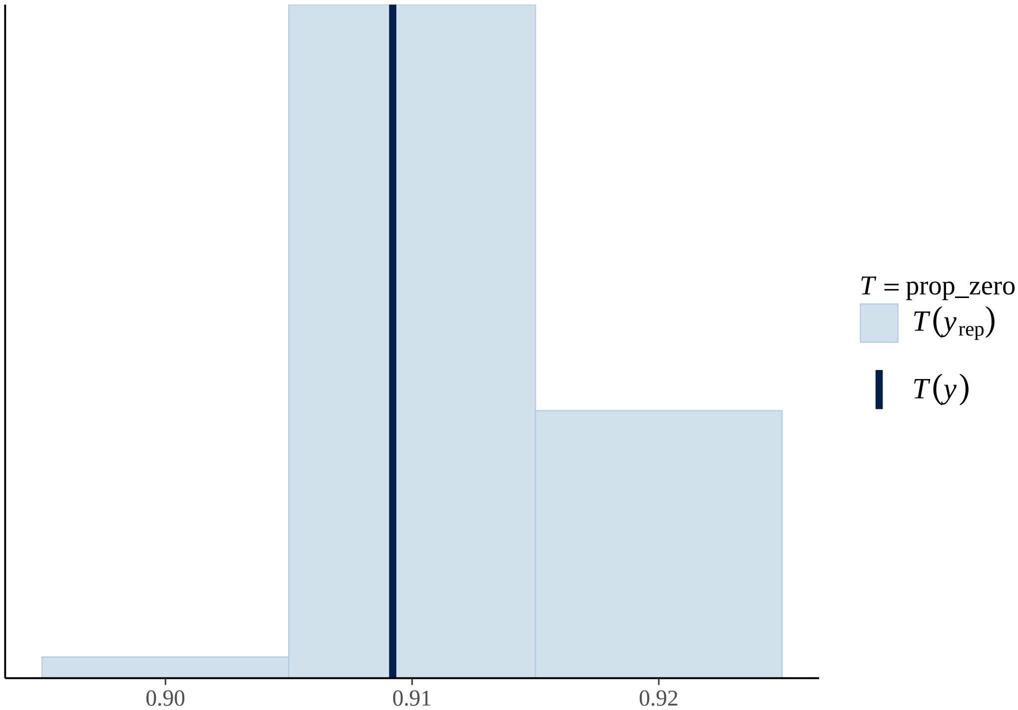

Figure 34: Posterior predictive distribution of the proportion of zero observations in replicate data sets generated by the logit normal model with a vertical line representing the observed average.

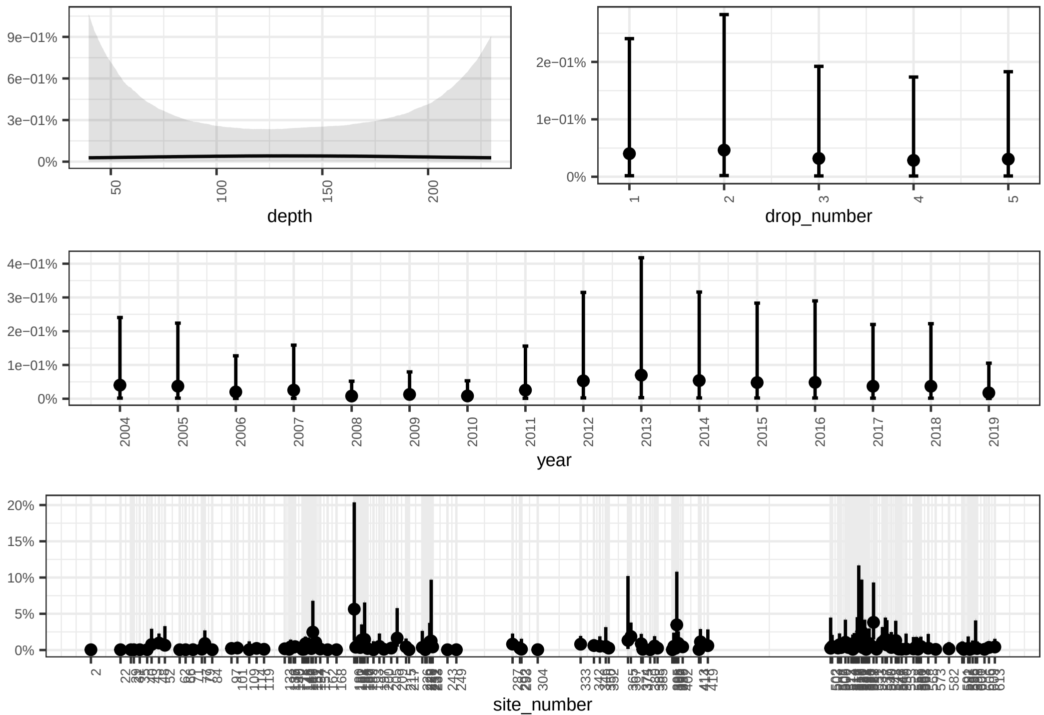

Figure 35: Marginal effects from the final model logit normal model.

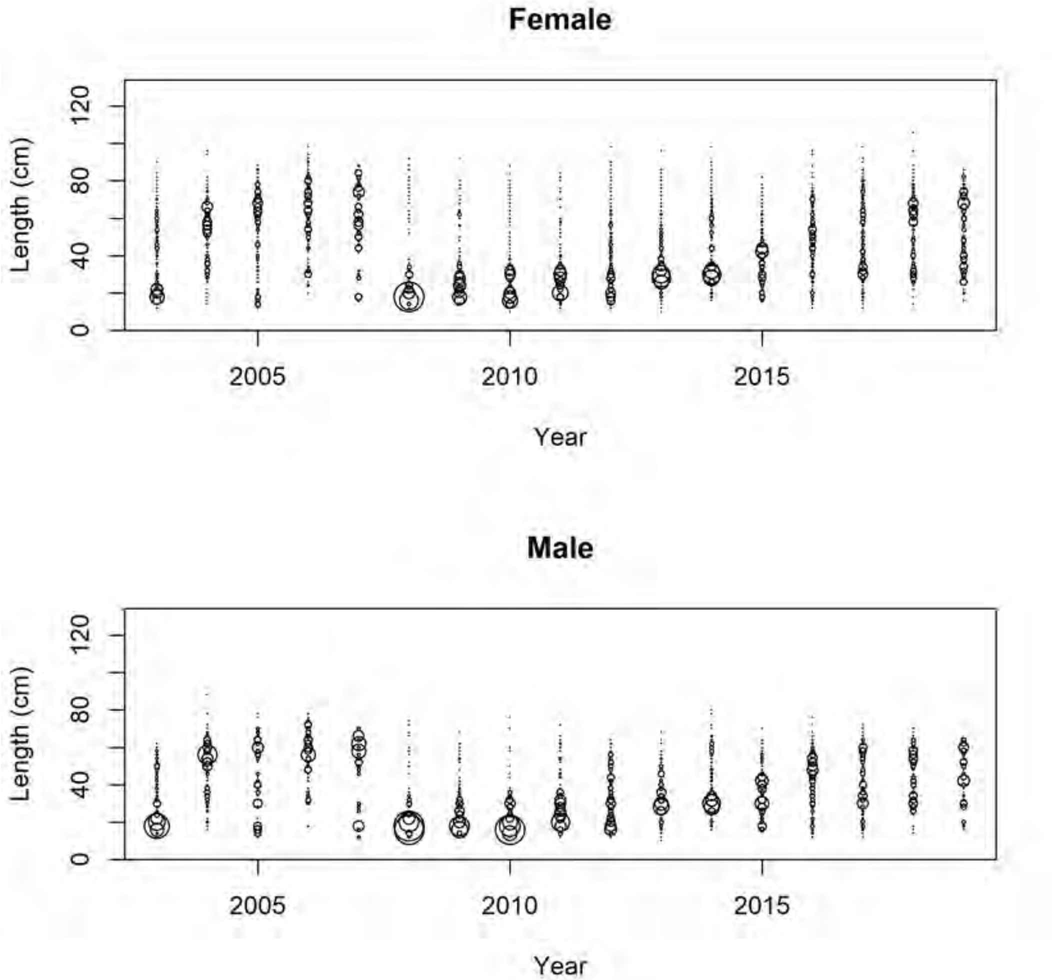

Figure 36: Length-composition data for males and females in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS).

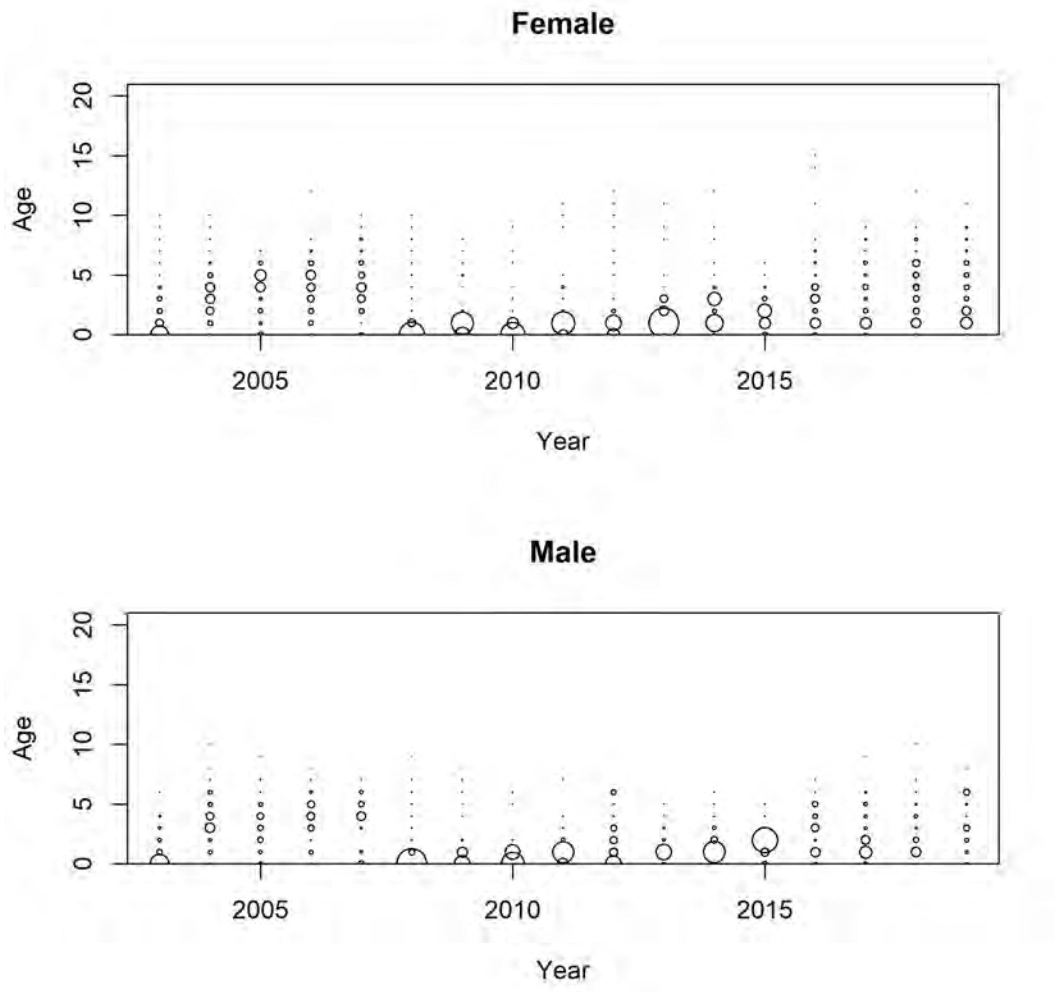

Figure 37: Age-composition data for males and females in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS).

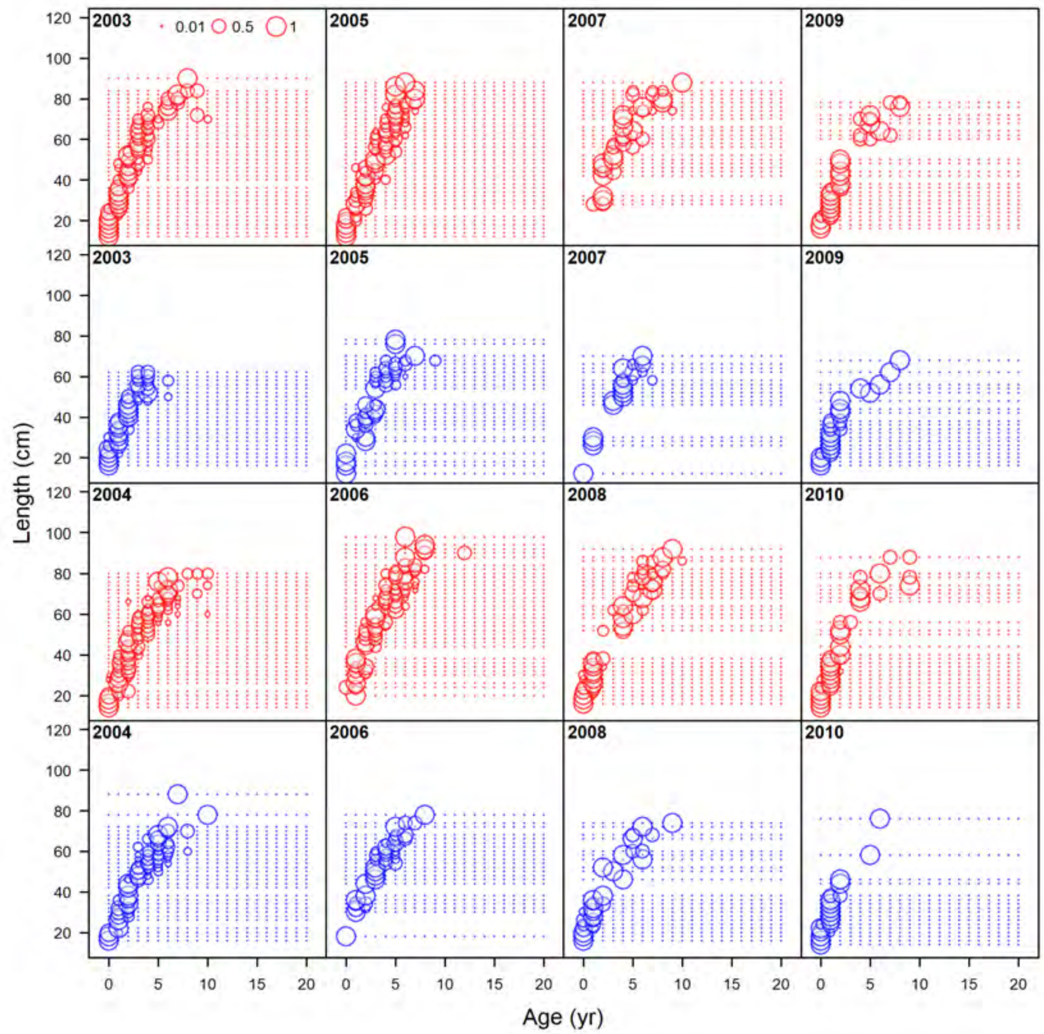

Figure 38: Conditional age-at-length data, whole catch, WCGBT Survey (max=0.98) (plot 1 of 3).

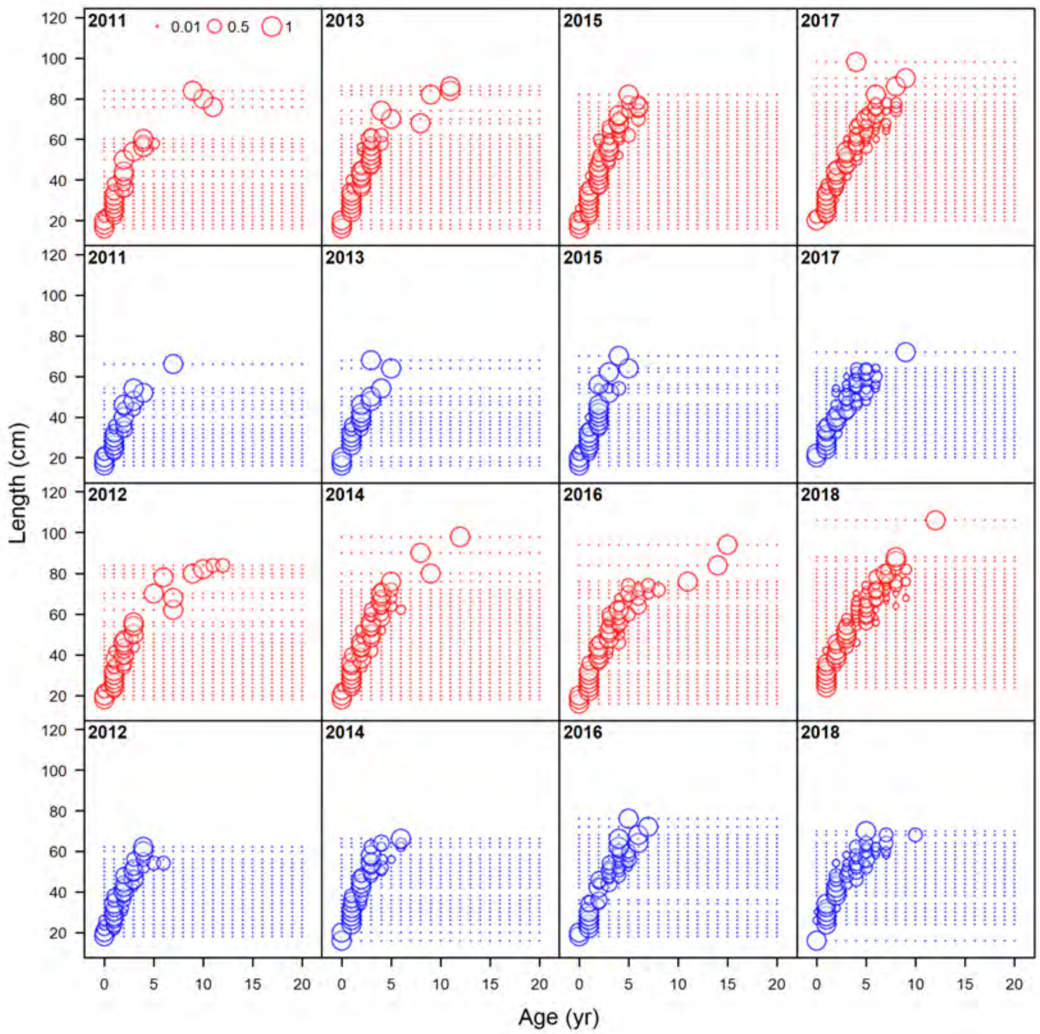

Figure 39: Conditional age-at-length data, whole catch, WCGBT Survey (max=0.98) (plot 2 of 3).

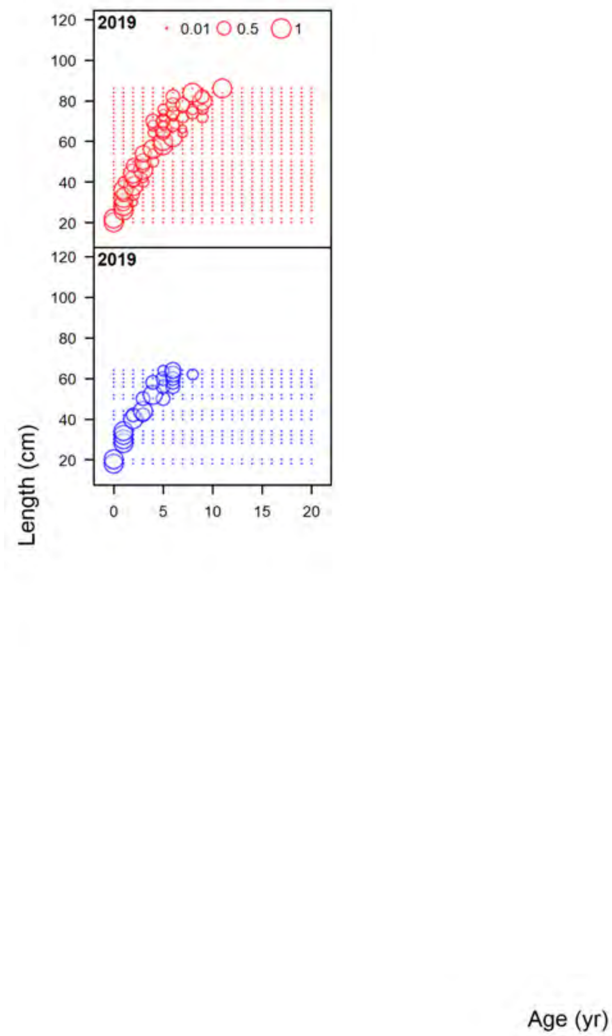

Figure 40: Conditional age-at-length data, whole catch, WCGBT Survey (max=0.98) (plot 3 of 3).

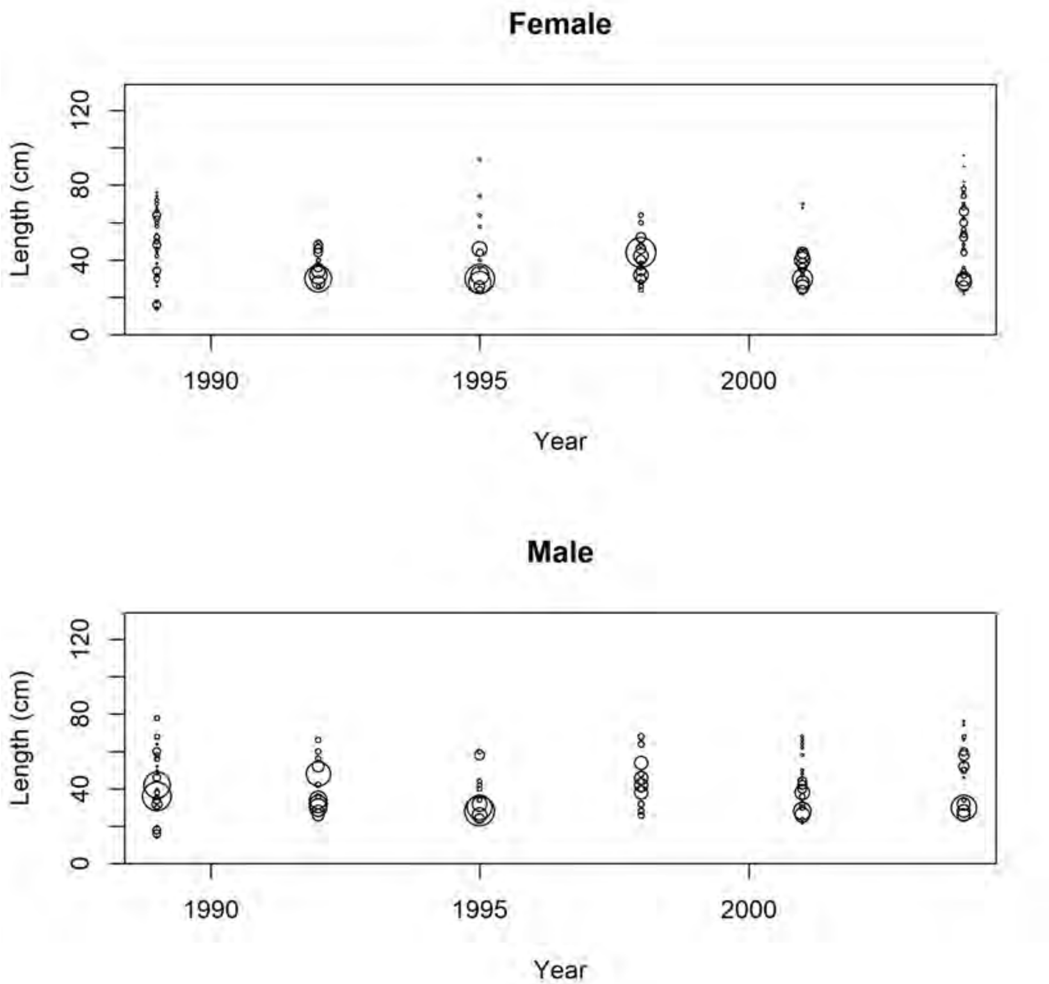

Figure 41: Length-composition data for males and females in the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey).

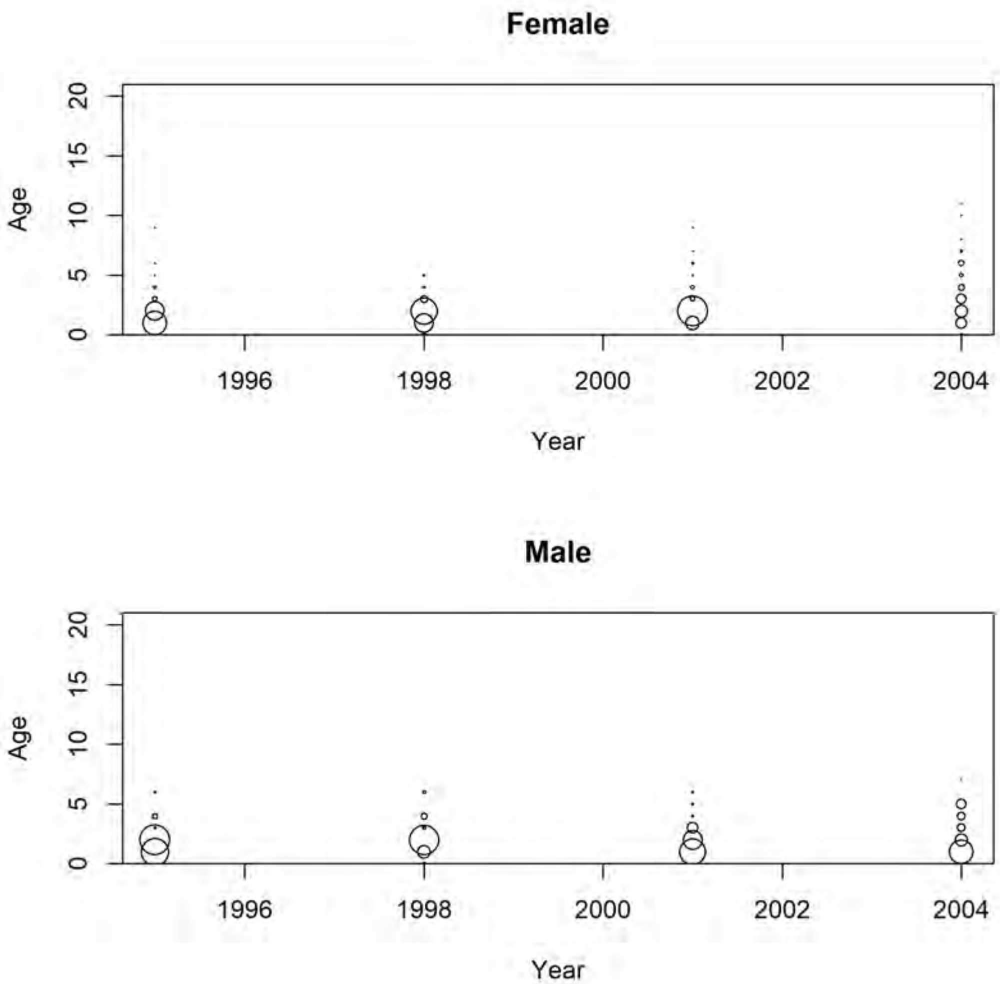

Figure 42: Age-composition data for males and females in the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey).

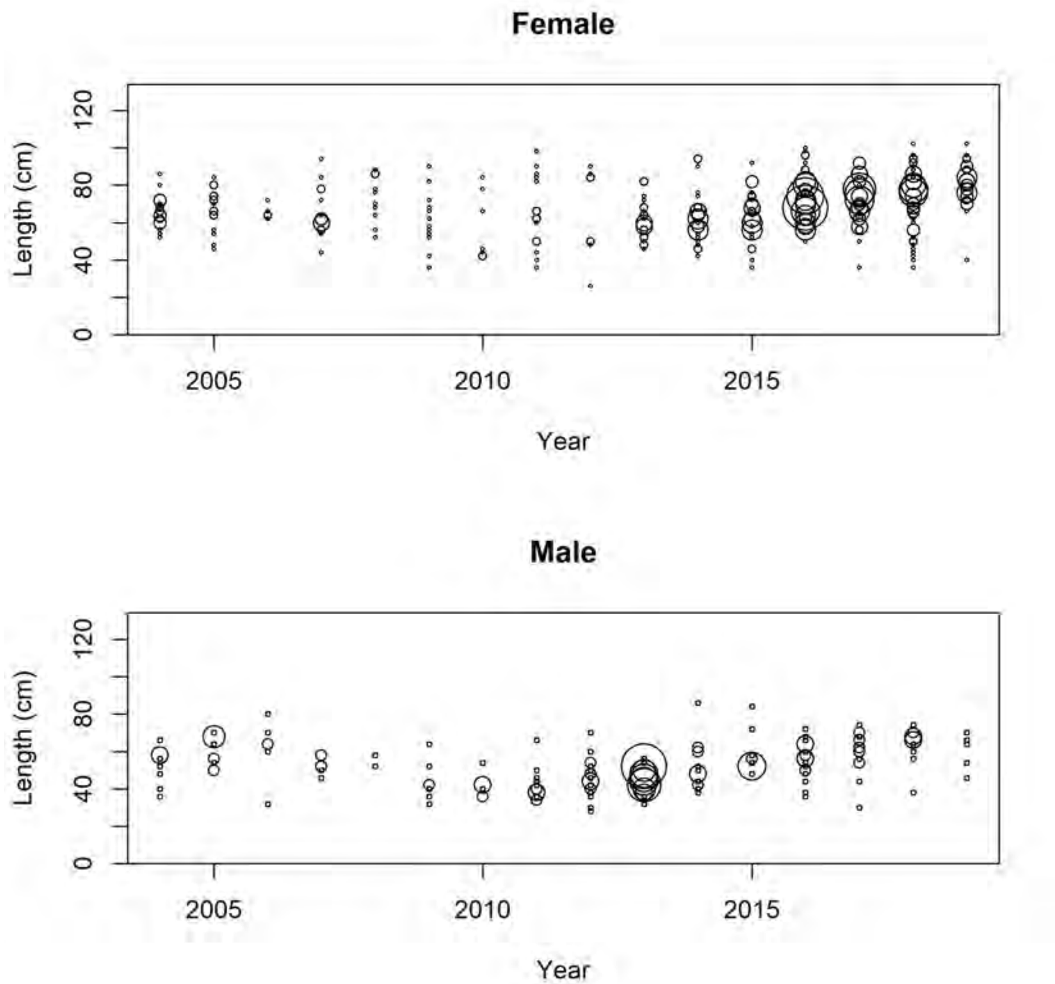

Figure 43: Length-composition data for males and females in the NWFSC Hook and Line Survey (Hook and Line Survey).

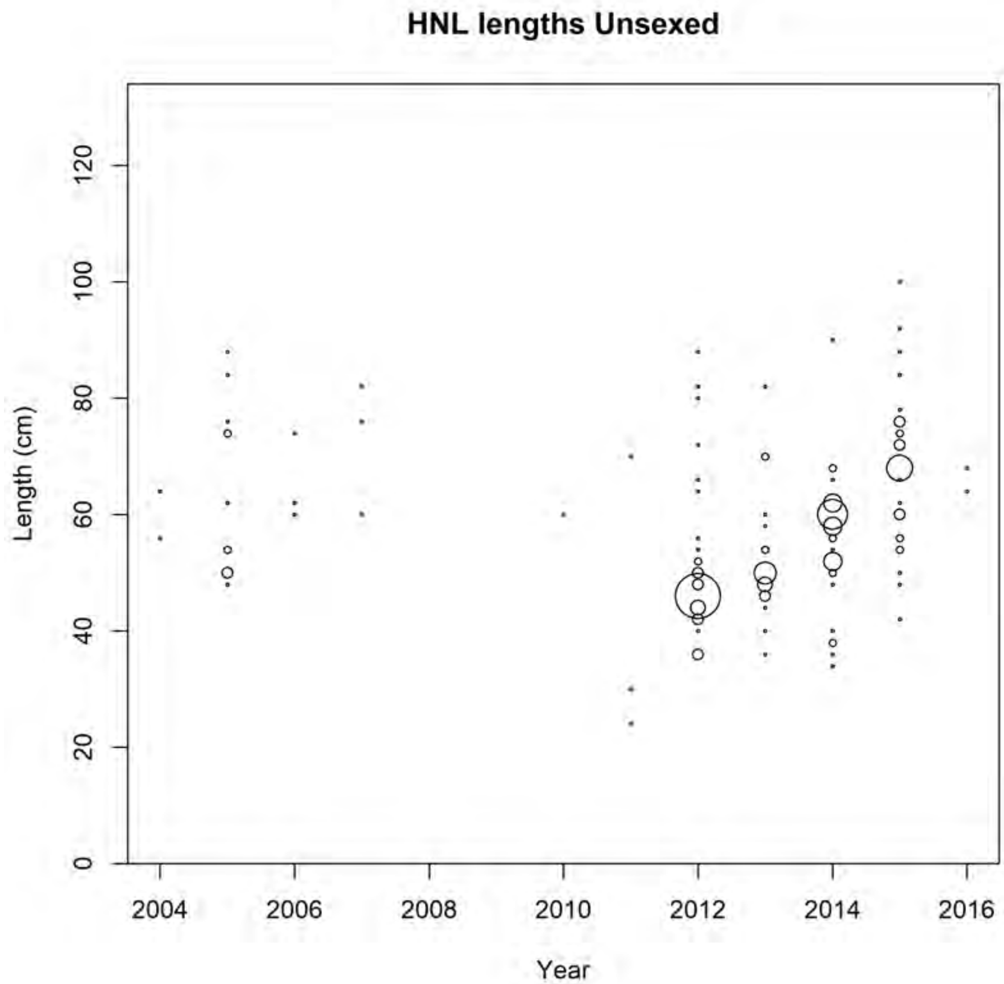

Figure 44: Length-composition data for unsexed fish in the NWFSC Hook and Line Survey (Hook and Line Survey).

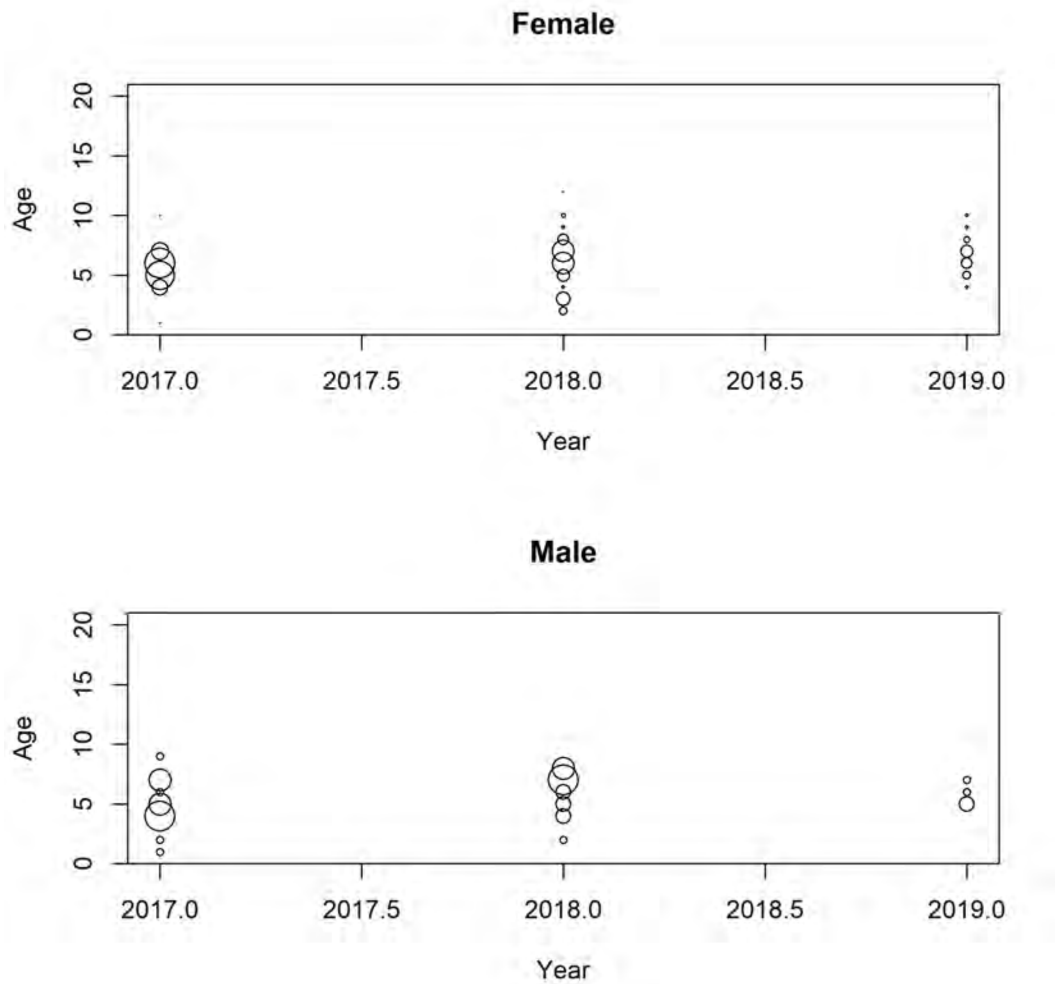

Figure 45: Age-composition data for males and females in the NWFSC Hook and Line Survey (Hook and Line Survey).

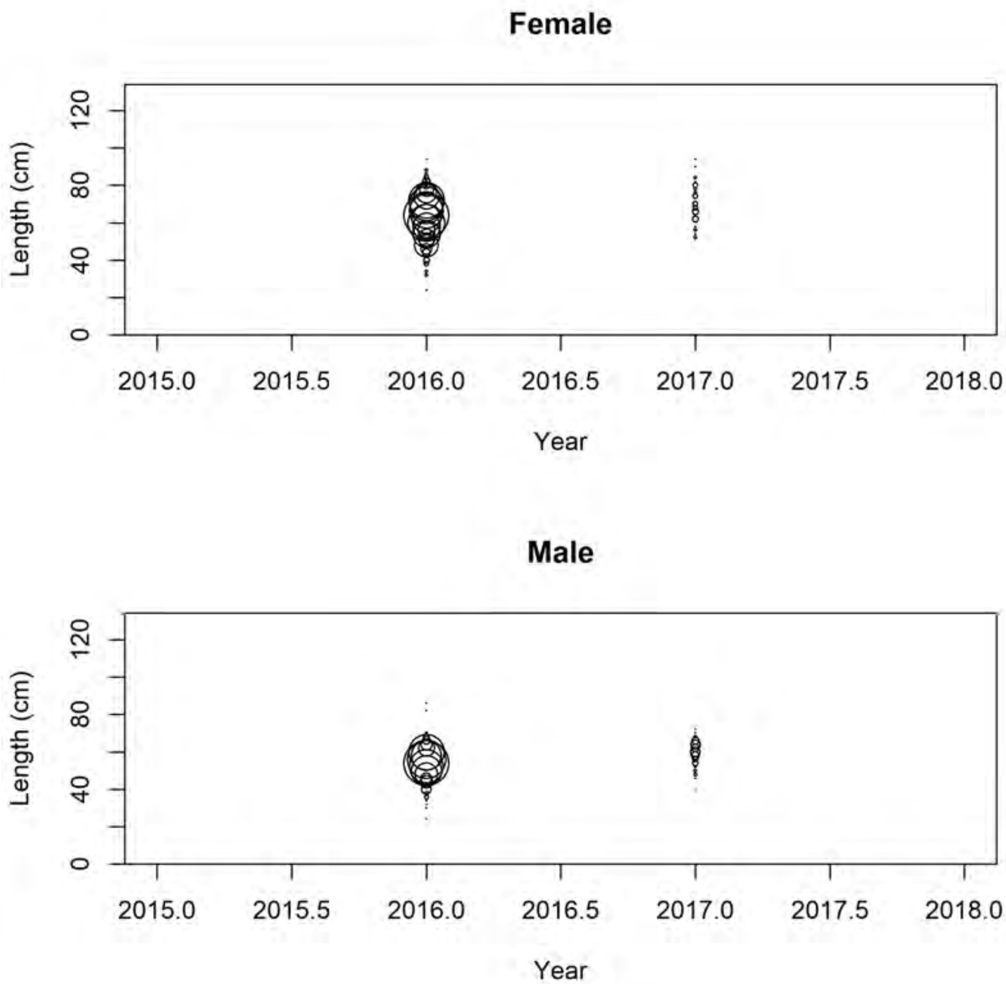

Figure 46: Length-composition data for male and females from Lam Research data.

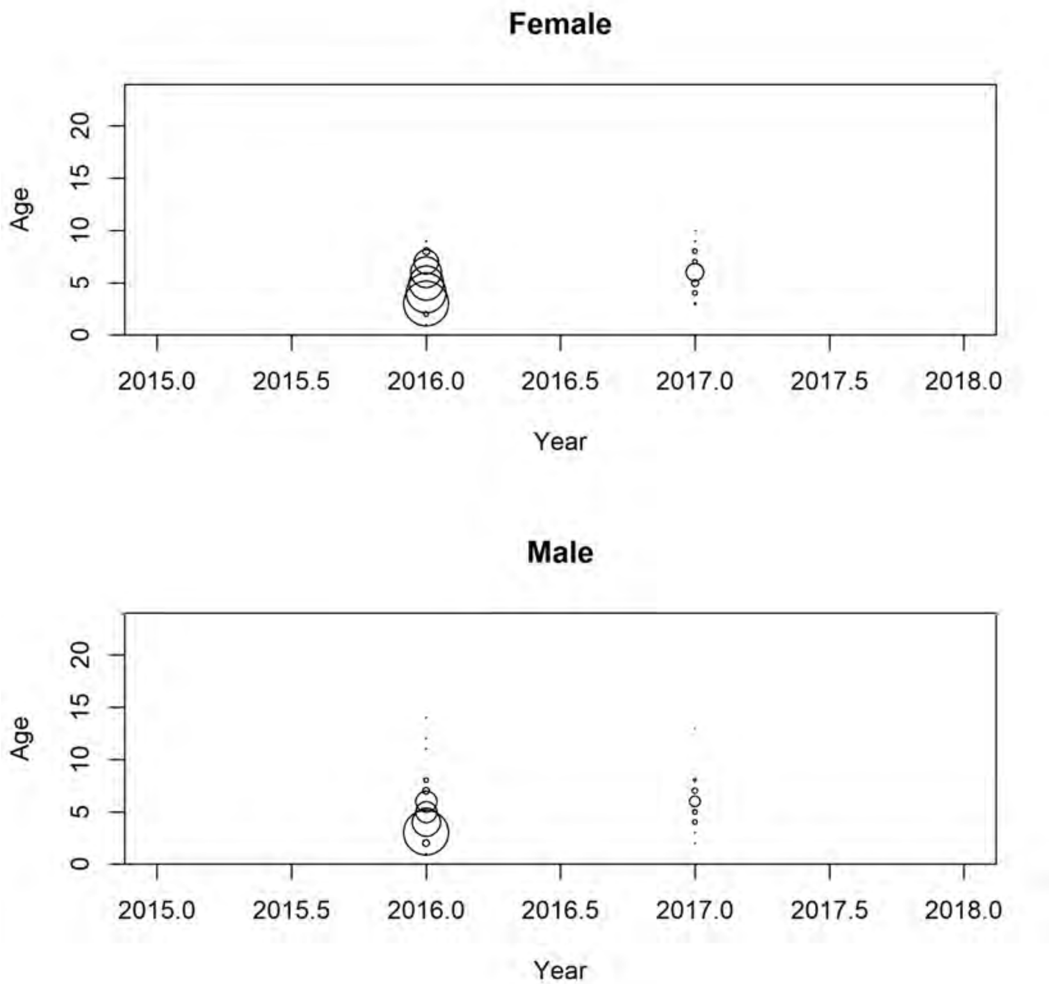

Figure 47: Age-composition data for male and females from Lam Research data.

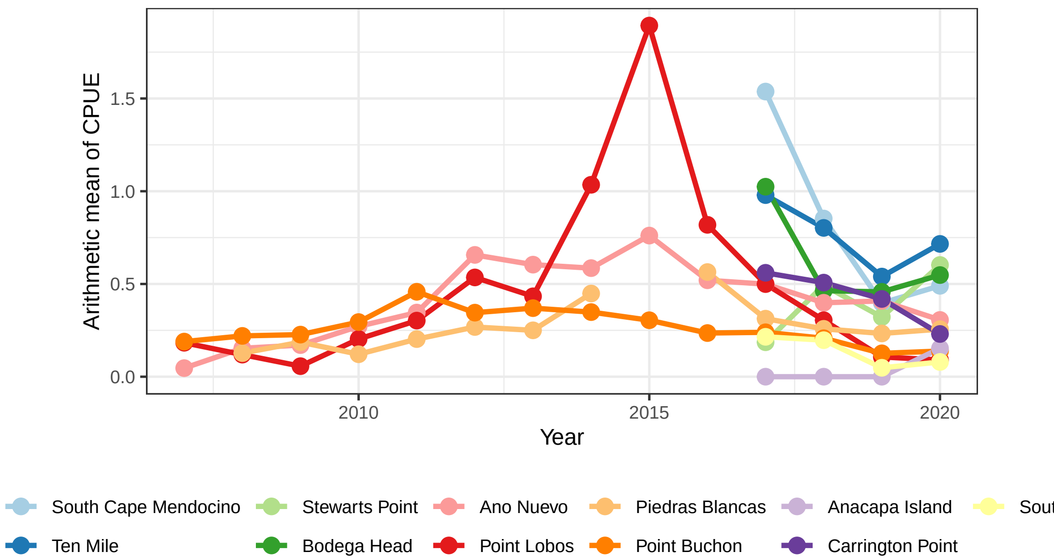

Figure 48: Arithmetic mean of catch per unit effort (CPUE) by region for lingcod from the filtered California Collaborative Fisheries Research Program (CCFRP) data.

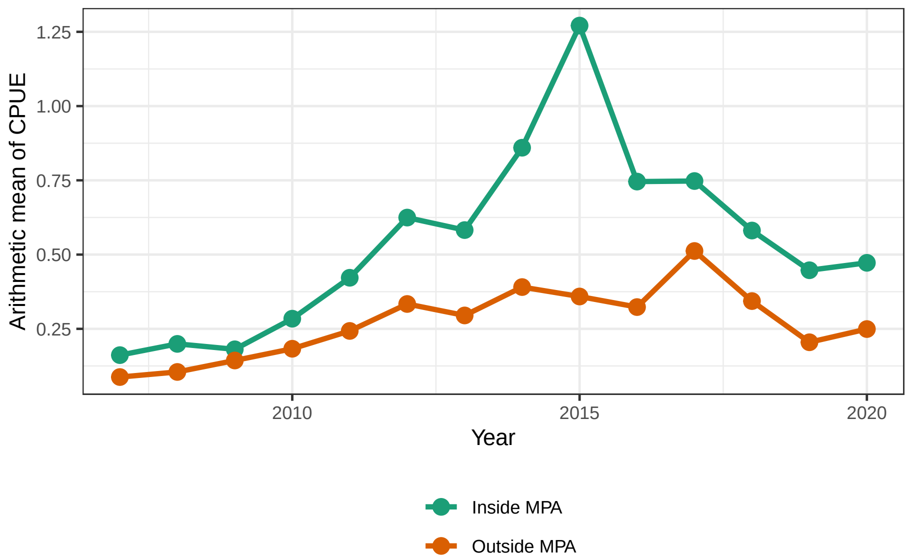

Figure 49: Arithmetic mean of catch per unit effort (CPUE) inside (green) and outside (orange) Marine Protected Area (MPA) sample sites for lingcod from the filtered California Collaborative Fisheries Research Program (CCFRP) data.

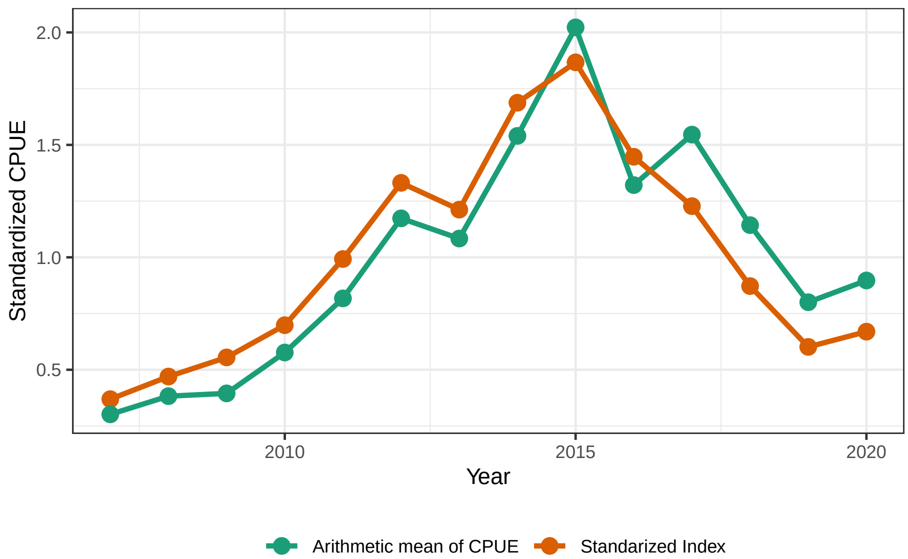

Figure 50: Standardized index and arithmetic mean of the catch per unit effort (CPUE) from the filtered California Collaborative Fisheries Research Program (CCFRP) data. Each timeseries is scaled to its respective mean.

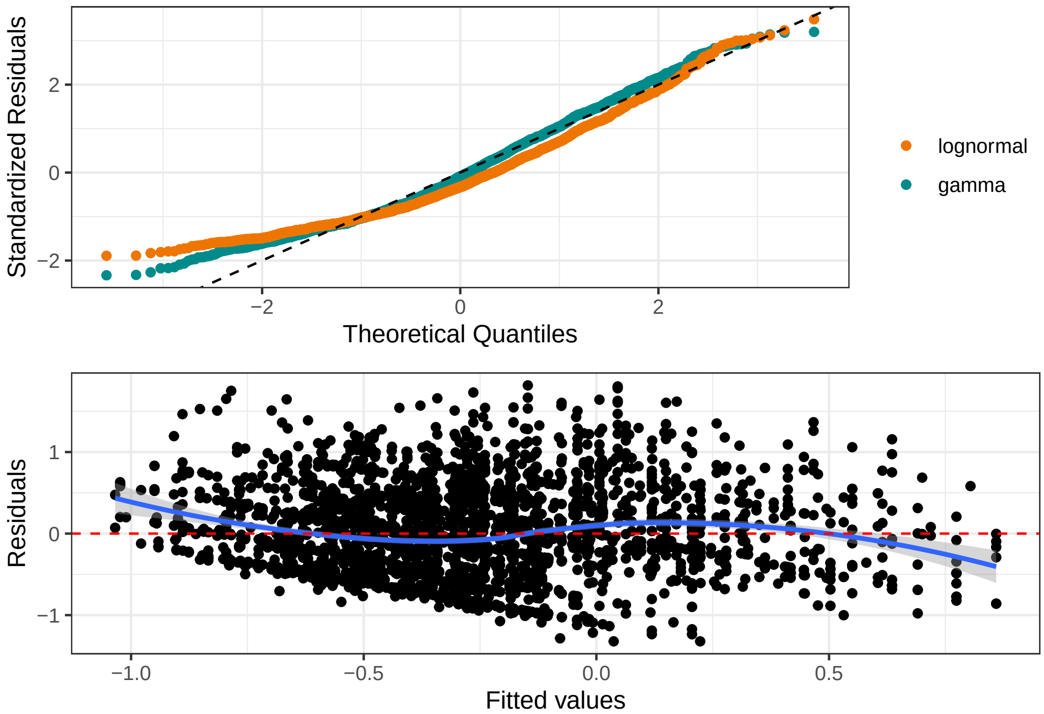

Figure 51: A comparison of the observed to theoretical quantiles (Q-Q plot; top panel) suggesting the Lognormal distribution (orange) provides a better fit to the positive observations than a Gamma distribution (green). Residuals versus observations for the final, Lognormal, model (bottom panel) exhibit some trends in the extremes of the distribution (blue line is a smoother).

7.2 Biology figures

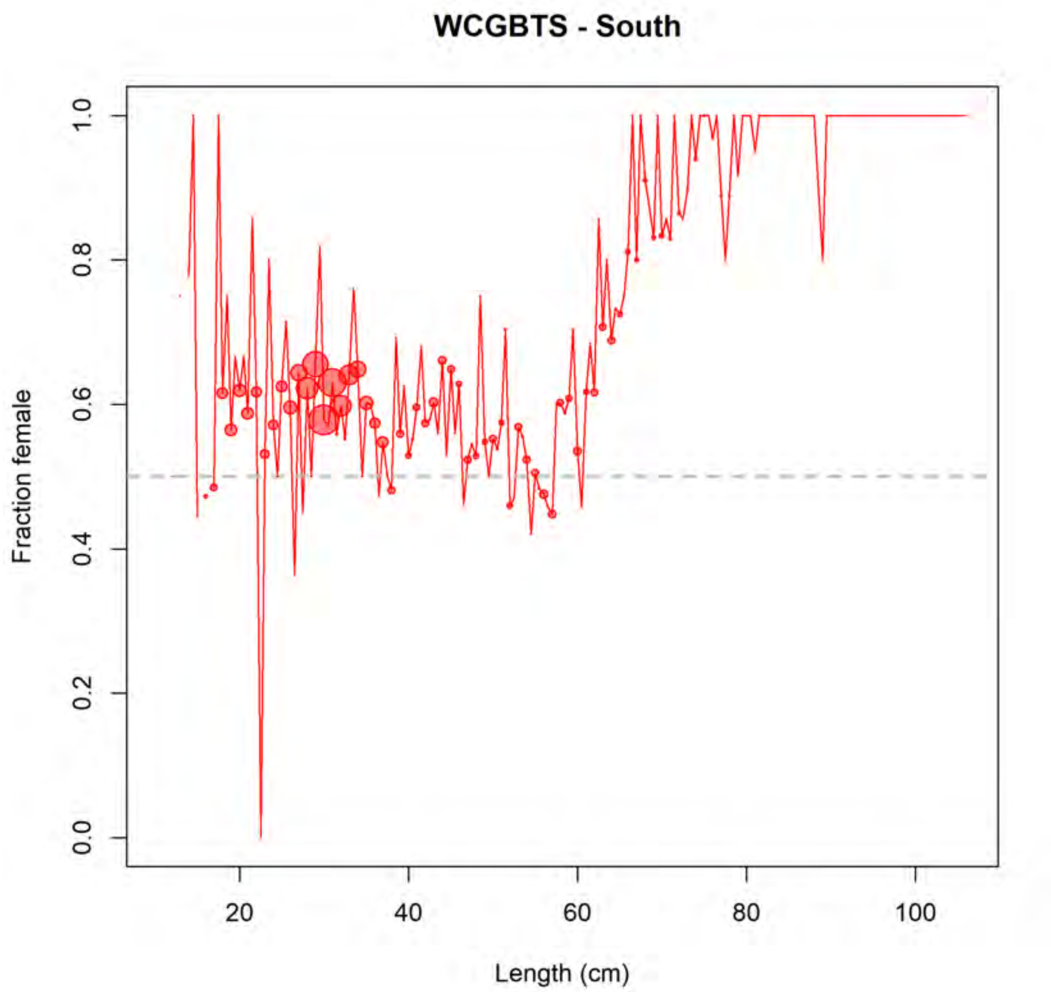

Figure 52: Fraction of the biological data from the WCGBTS subset to just the area included in this assessment that are female by length (cm).

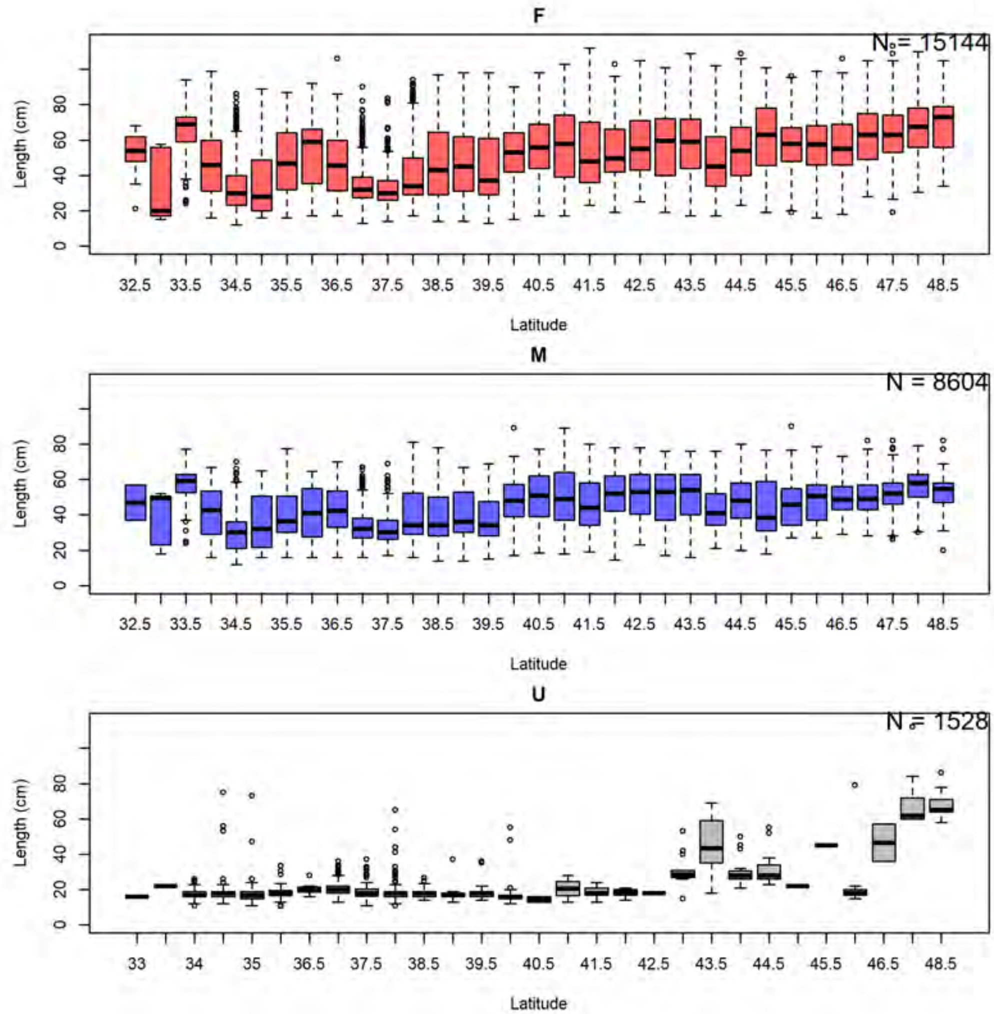

Figure 53: Histograms of lengths for female (top panel), male (middle panel) and unsexed (bottom panel) fish by latitude, in half degree increments. Samples sizes (N) for each sex are displayed in the upper left of each panel. Histograms show the median (solid bar), quartiles (colored boxes), 1.5 times 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).

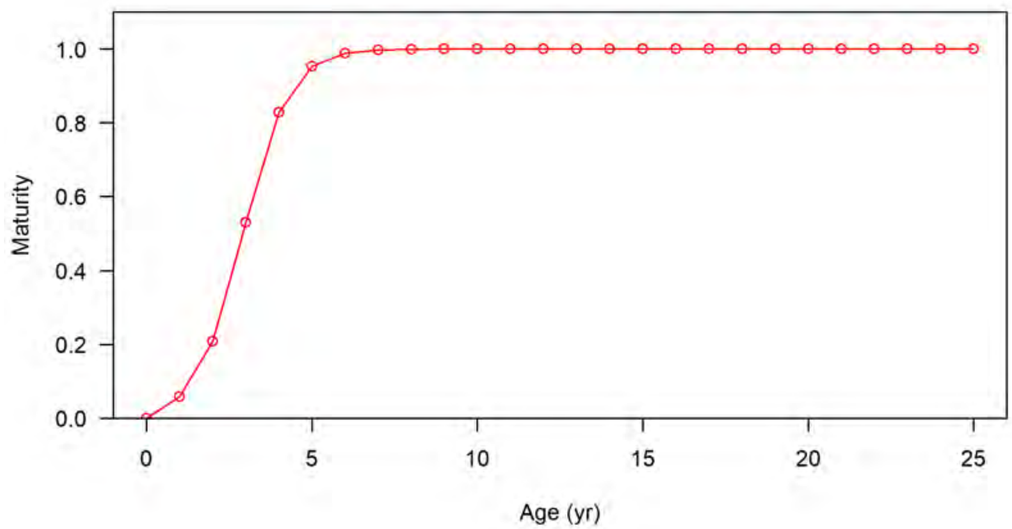

Figure 54: Maturity at age.

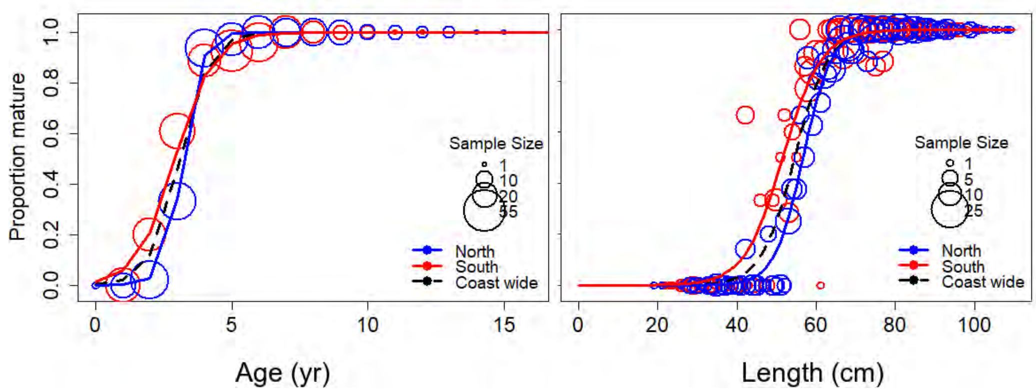

Figure 55: Proportion mature versus age (left panel; years) and length (right panel; cm) from fishery-independent and -dependent data sources. See Section 2.3.2 for details on the analysis.

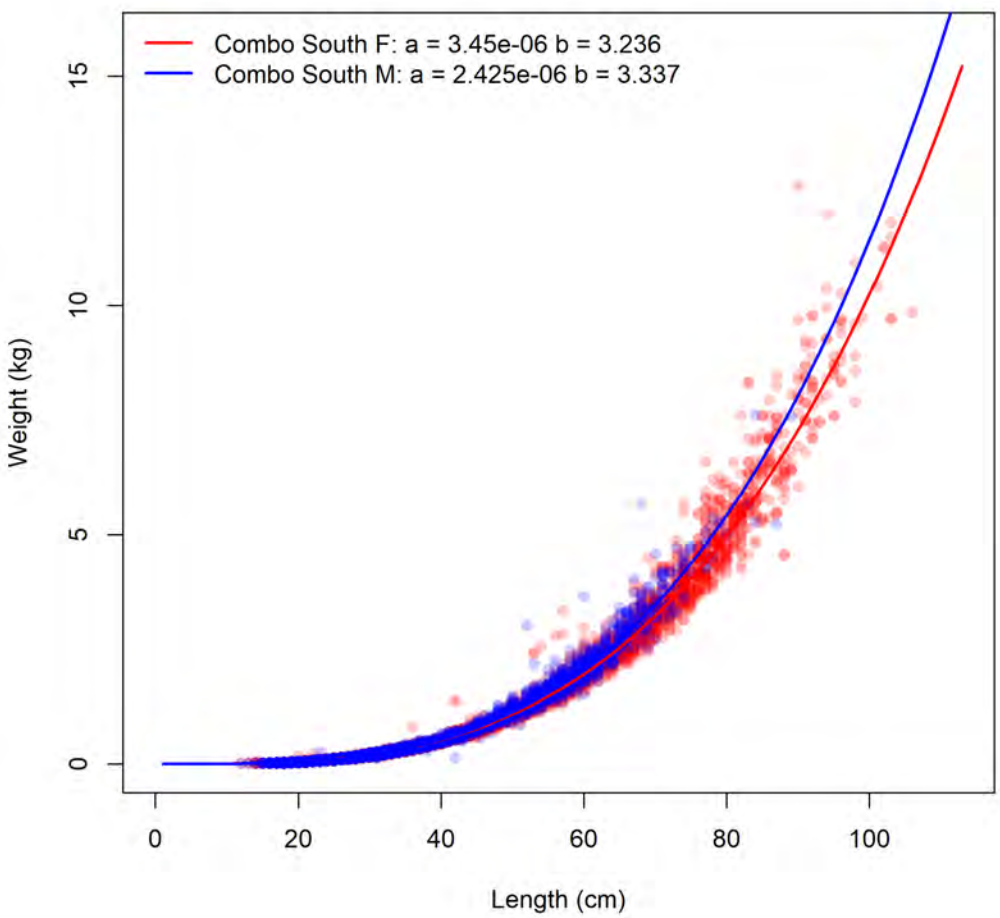

Figure 56: Weight-length relationship for males and females from the WCGBTS.

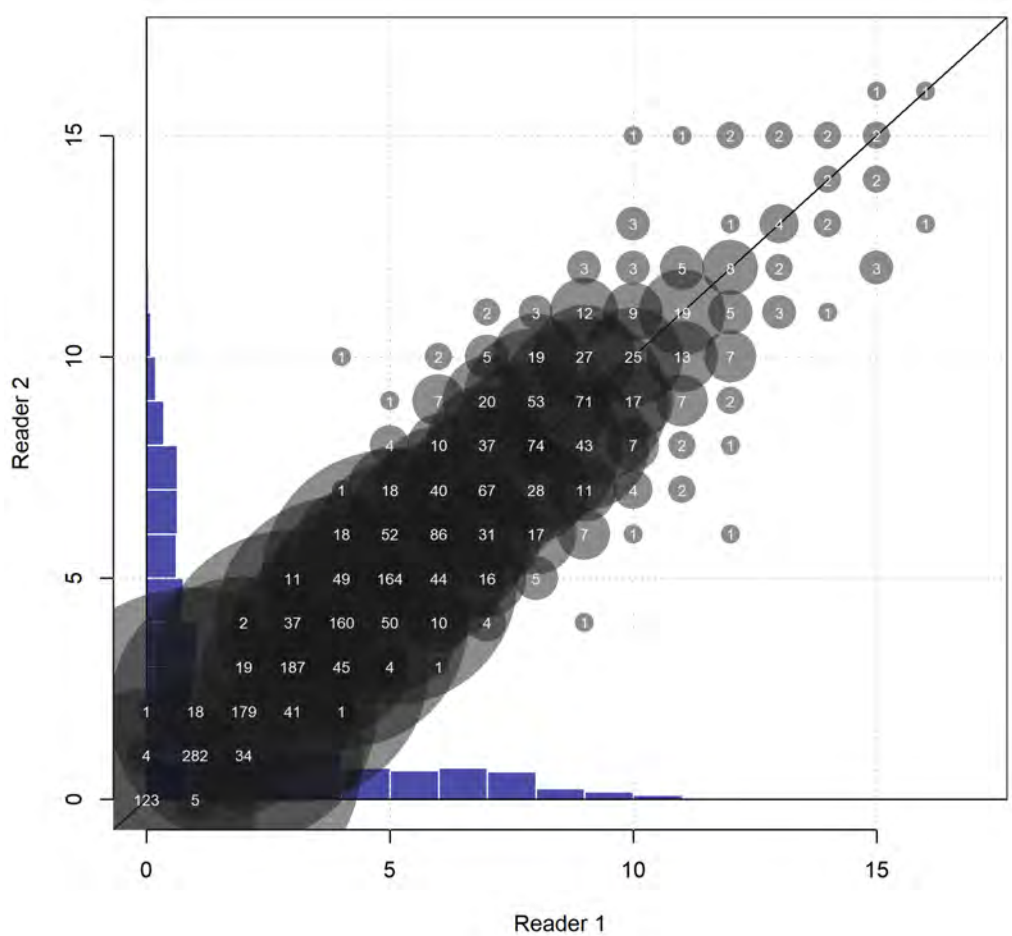

Figure 57: Comparison of age estimates from the double reads. Sample sizes associated with each combination of ages are shown by the size circles and the values within the circles. The blue histograms show the distribution of ages. This represents all double reads pooled together so 'Reader 1' and 'Reader 2' are generic and descriptions do not represent specific individuals.

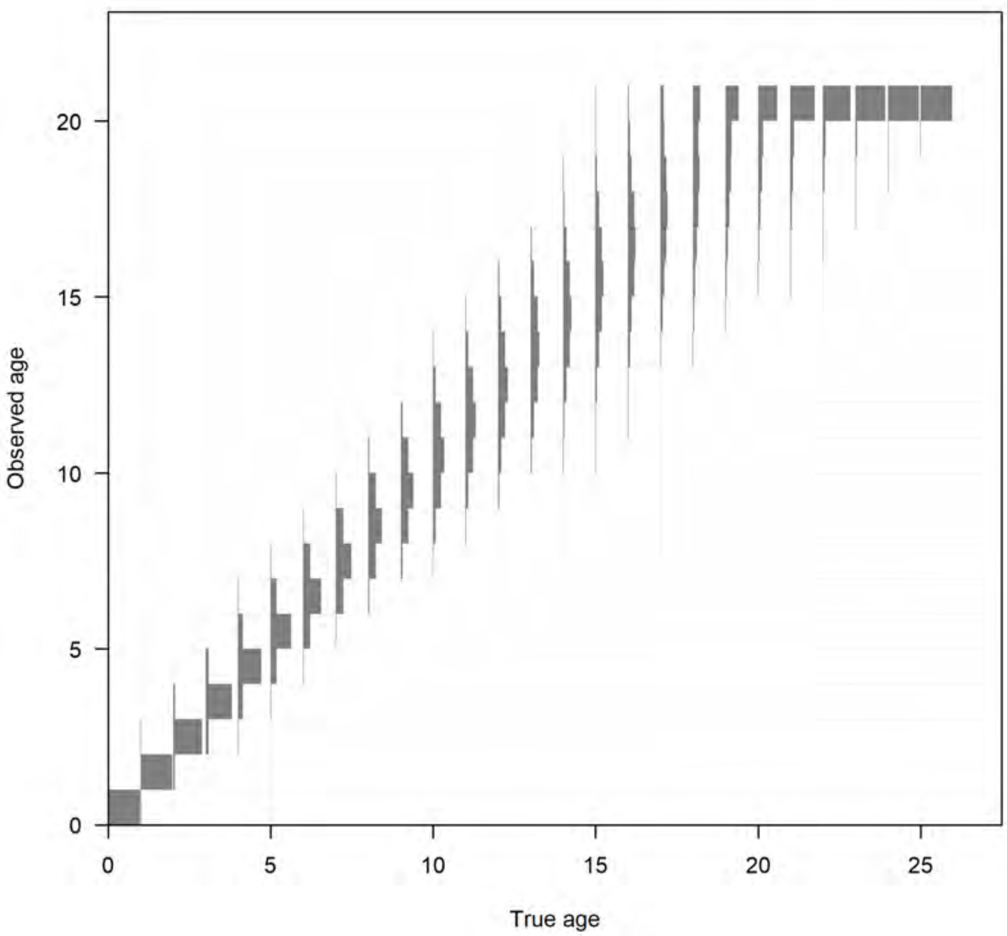

Figure 58: Distribution of observed age at true age for ageing error type 1.

7.3 Model results figures

7.3.1 Selectivity

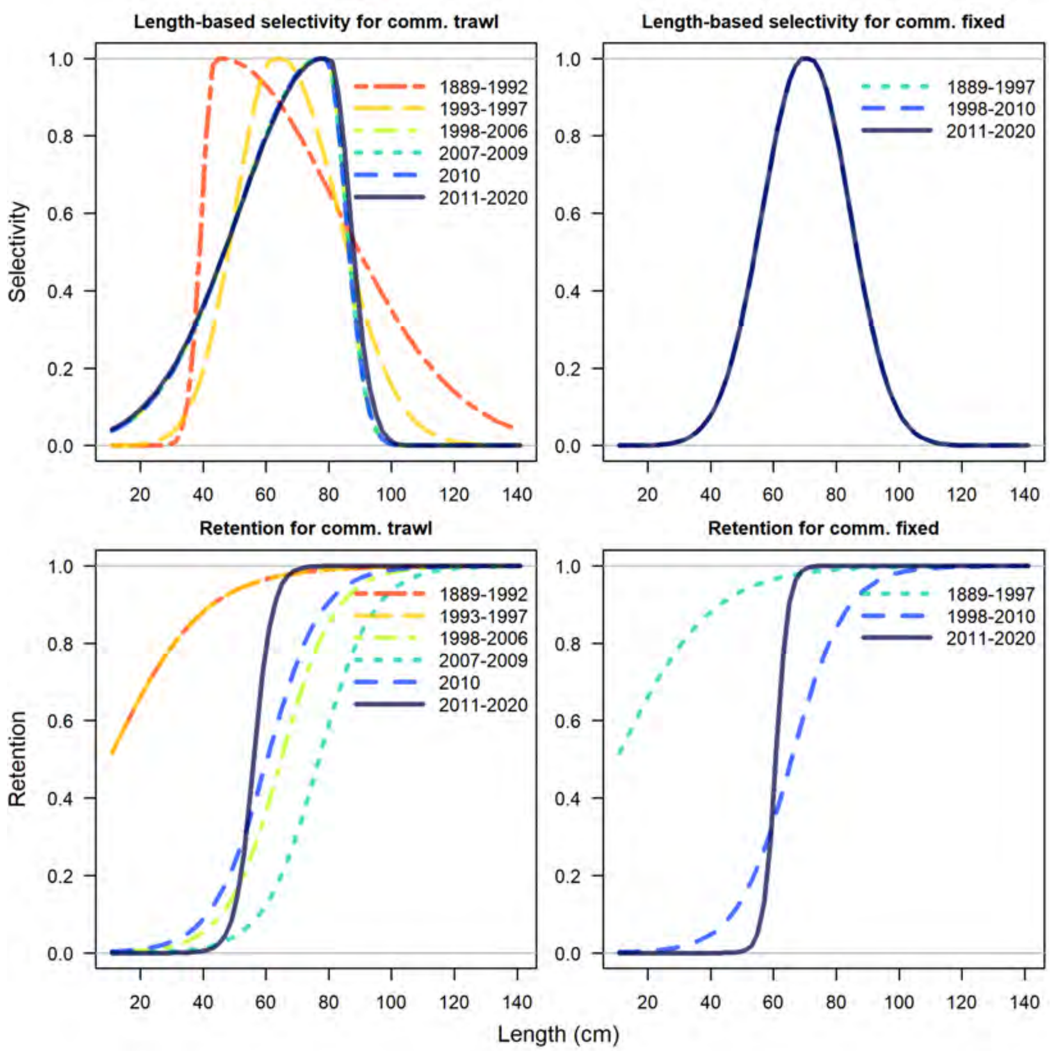

Figure 59: Time-varying selectivity (top) and retention (bottom) for the commercial trawl and fixed-gear fleets.

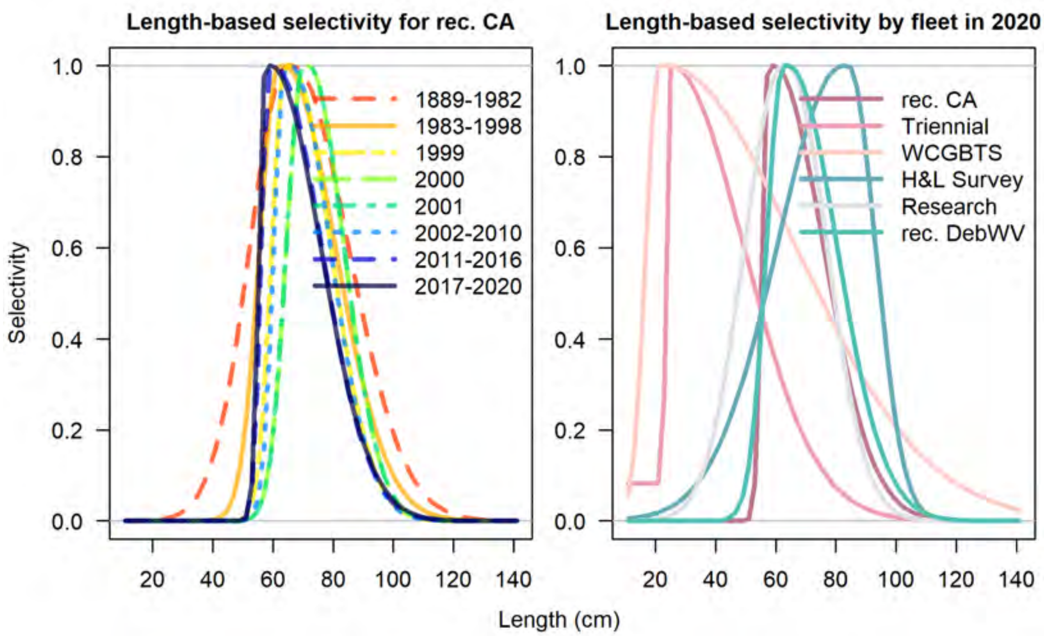

Figure 60: Time-varying selectivity for the California recreational fleet and comparison of selectivity among the different non-commercial fleet.

7.3.2 Fits to data

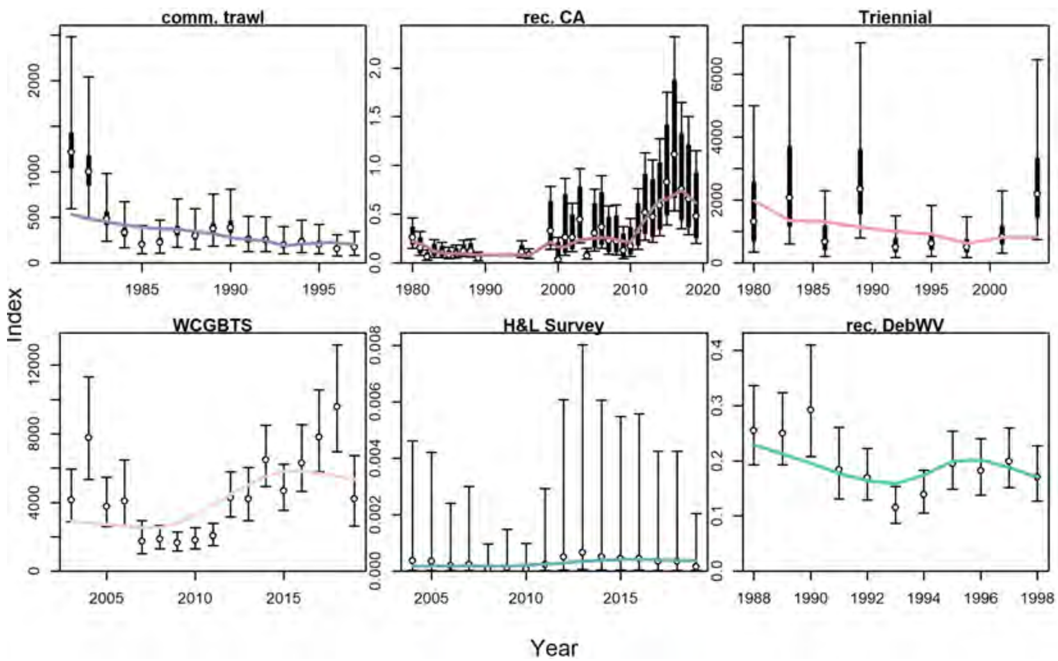

Figure 61: Index fits for all fleets. Lines indicate 95% uncertainty interval around estimated values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of an estimated additional uncertainty parameter which is added to the standard error of all years within an index.

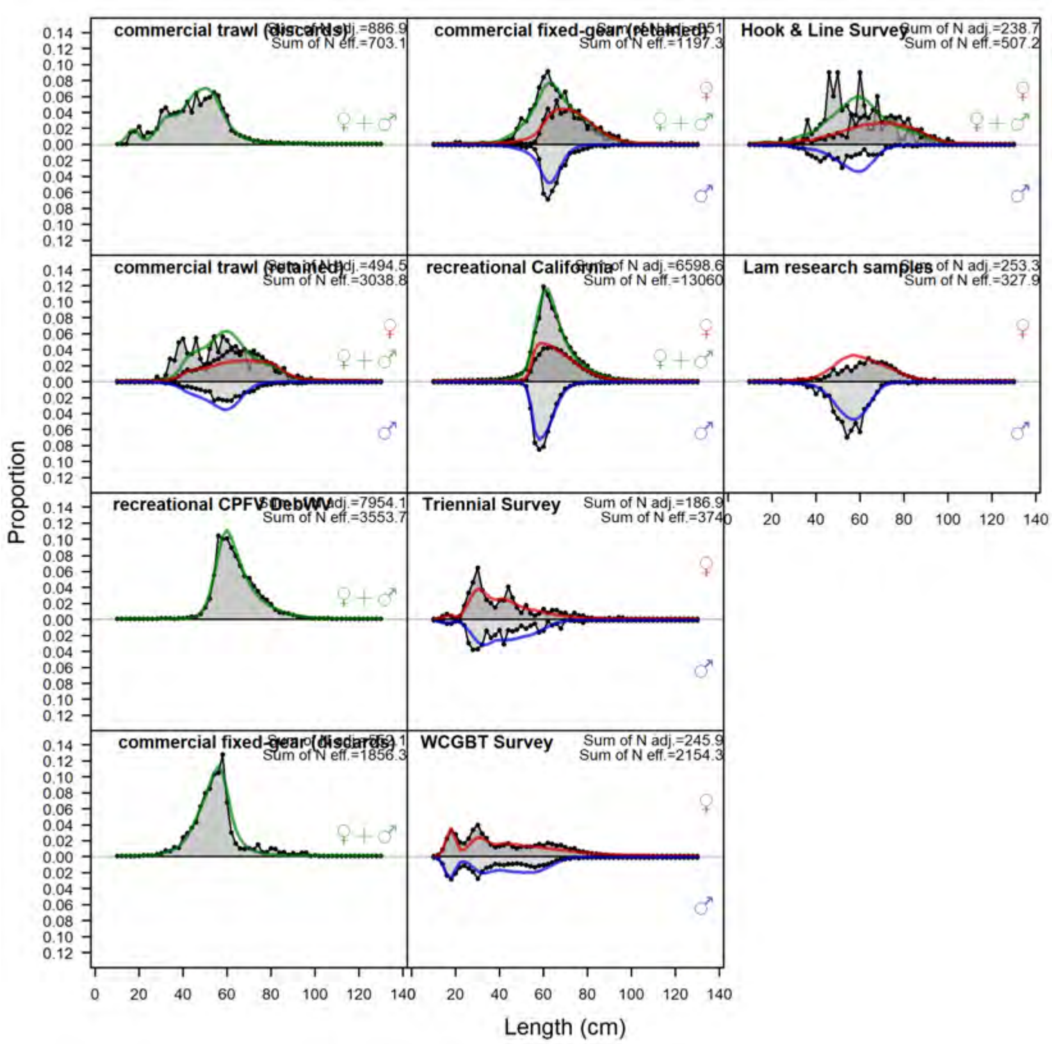

Figure 62: Length comps, aggregated across time by fleet. Labels 'retained' and 'discard' indicate discarded or retained sampled for each fleet. Panels without this designation represent the whole catch.

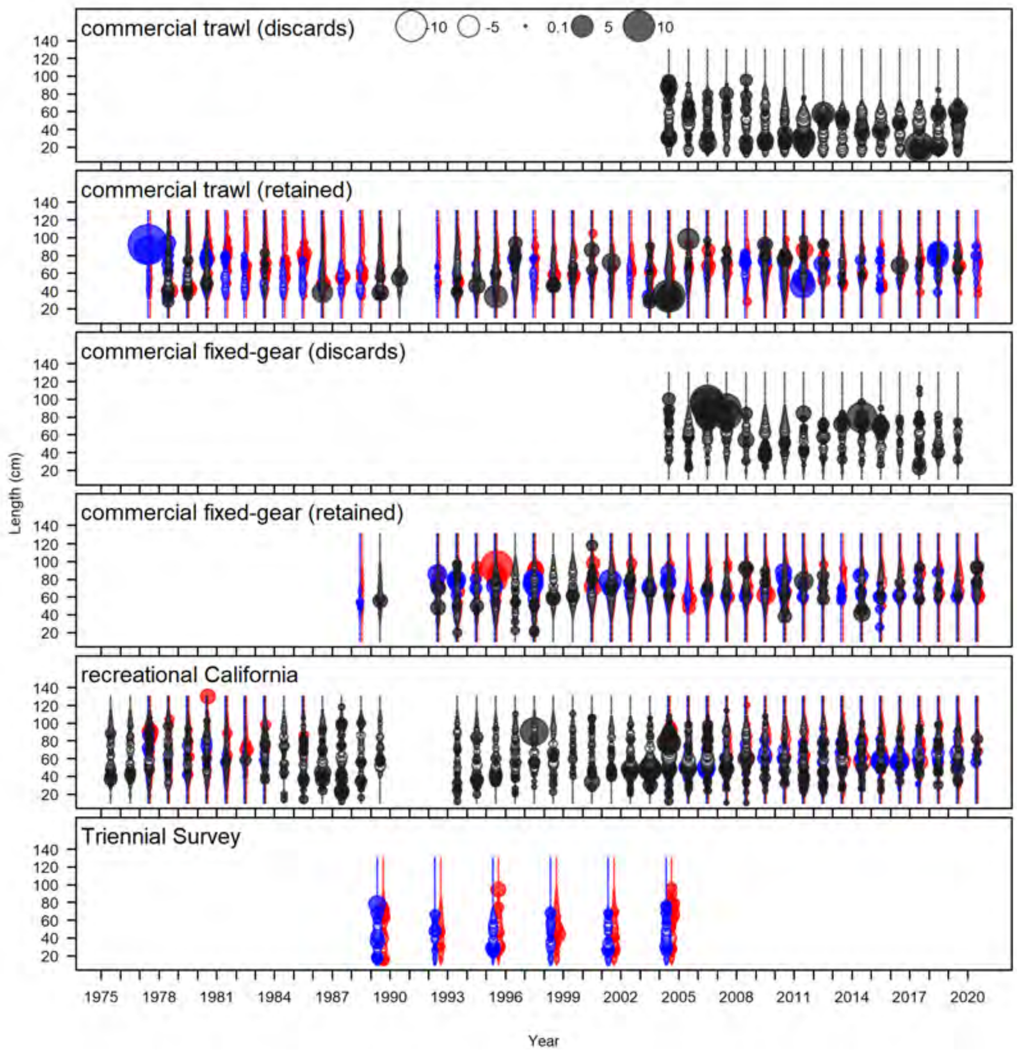

Figure 63: Pearson residuals, comparing across fleets (plot 1 of 2) Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

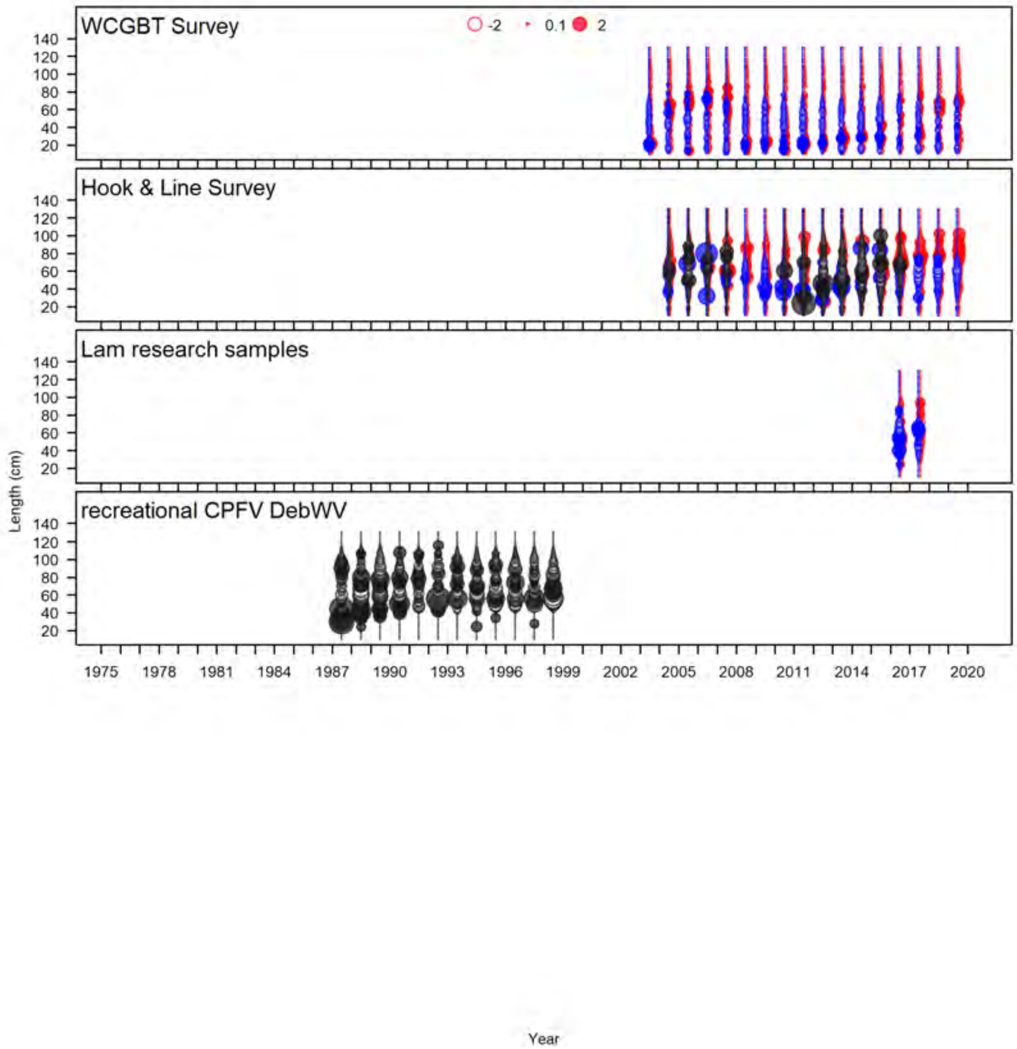

Figure 64: Pearson residuals, comparing across fleets (plot 2 of 2).

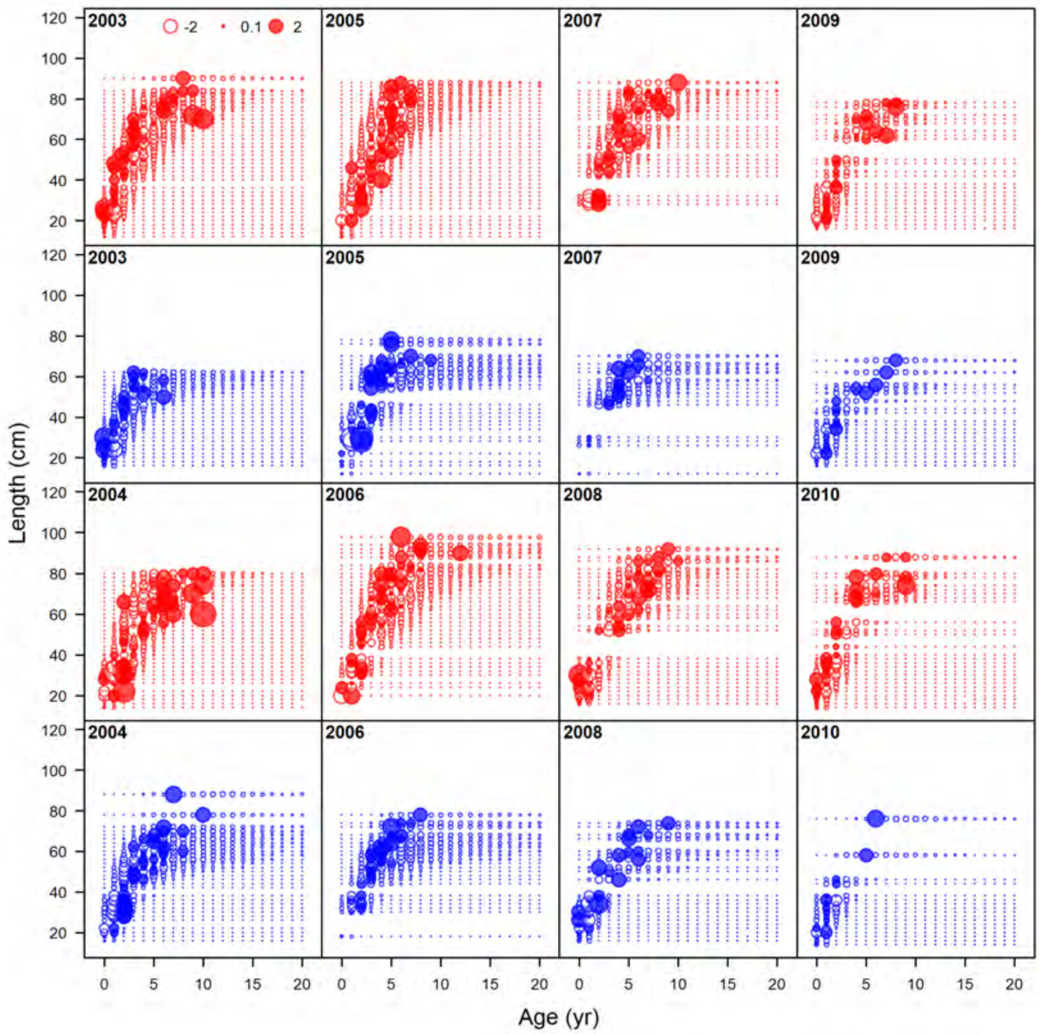

Figure 65: Pearson residuals, whole catch, WCGBT Survey (max=21.08) (plot 1 of 3).

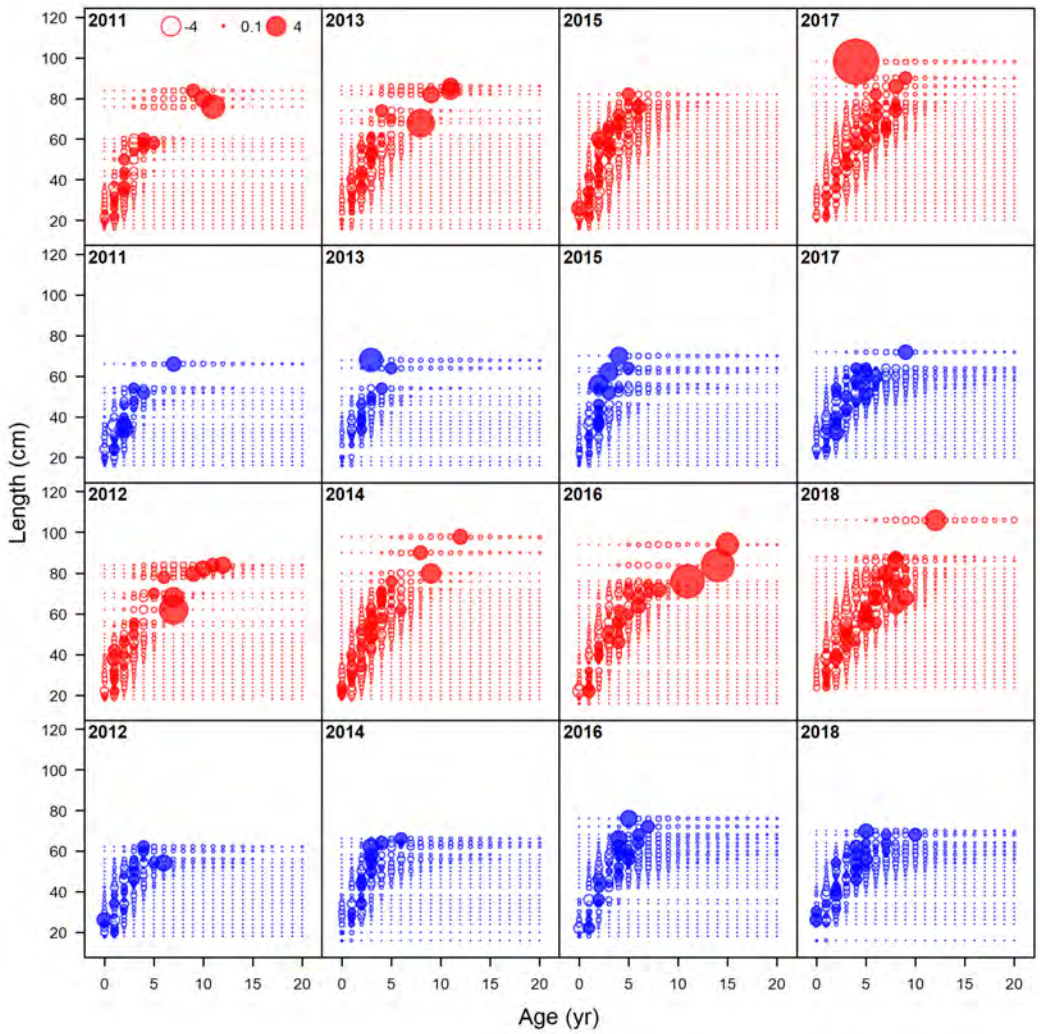

Figure 66: Pearson residuals, whole catch, WCGBT Survey (max=21.08) (plot 2 of 3).

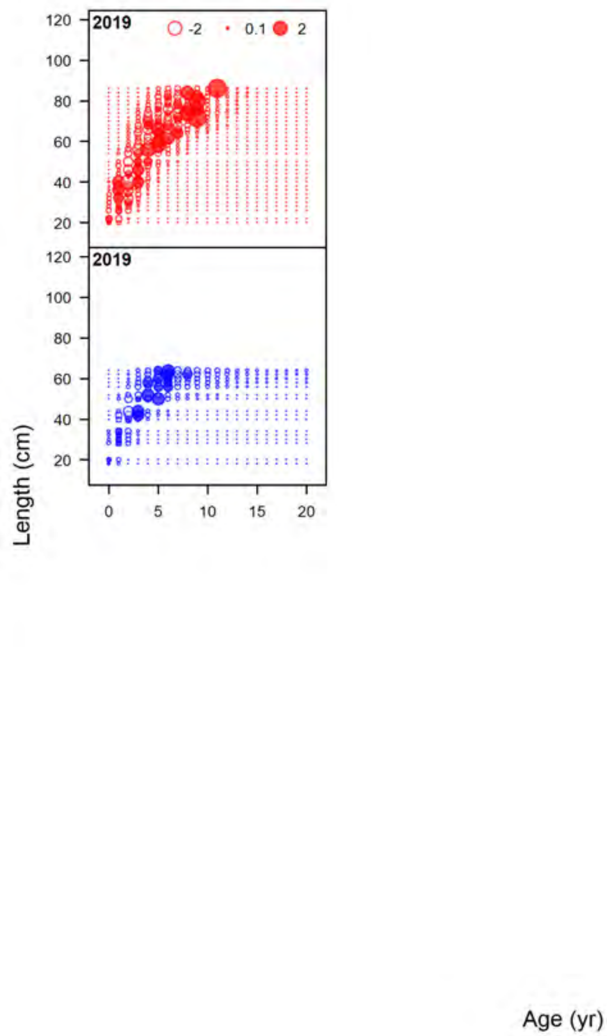

Figure 67: Pearson residuals, whole catch, WCGBT Survey (max=21.08) (plot 3 of 3).

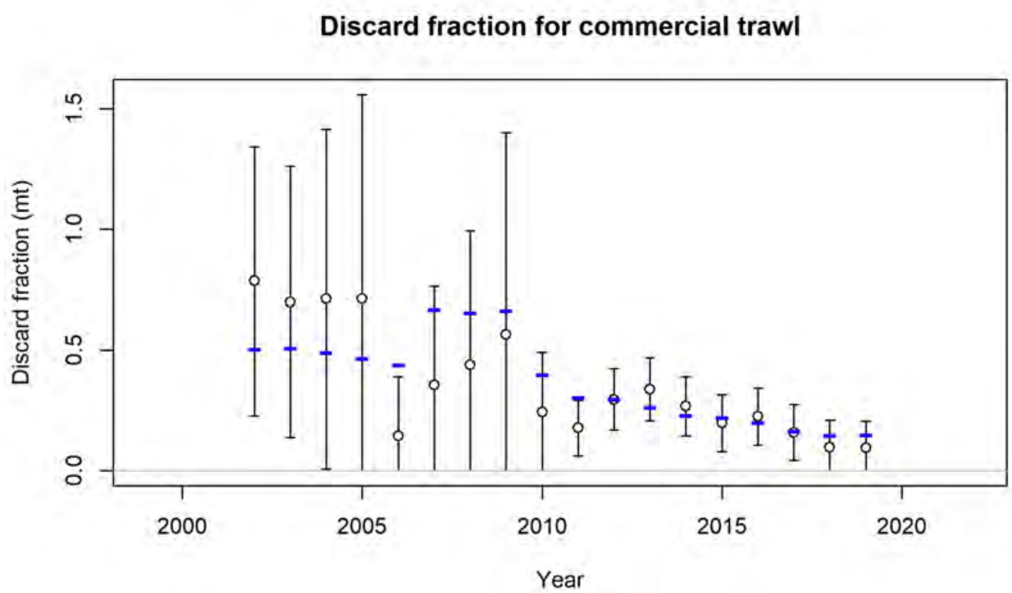

Figure 68: Discard fraction for commercial trawl.

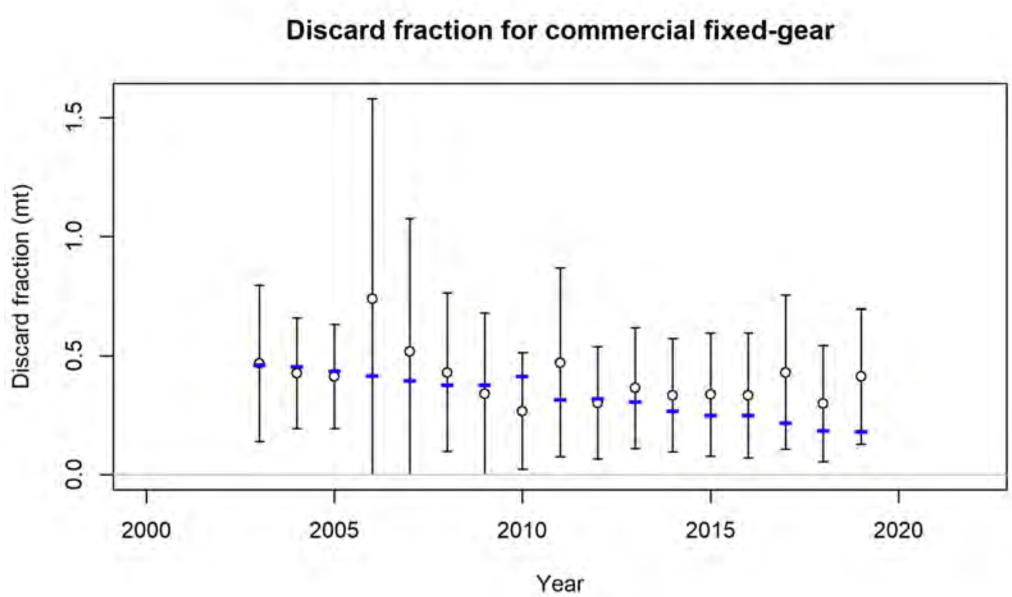

Figure 69: Discard fraction for commercial fixed-gear.

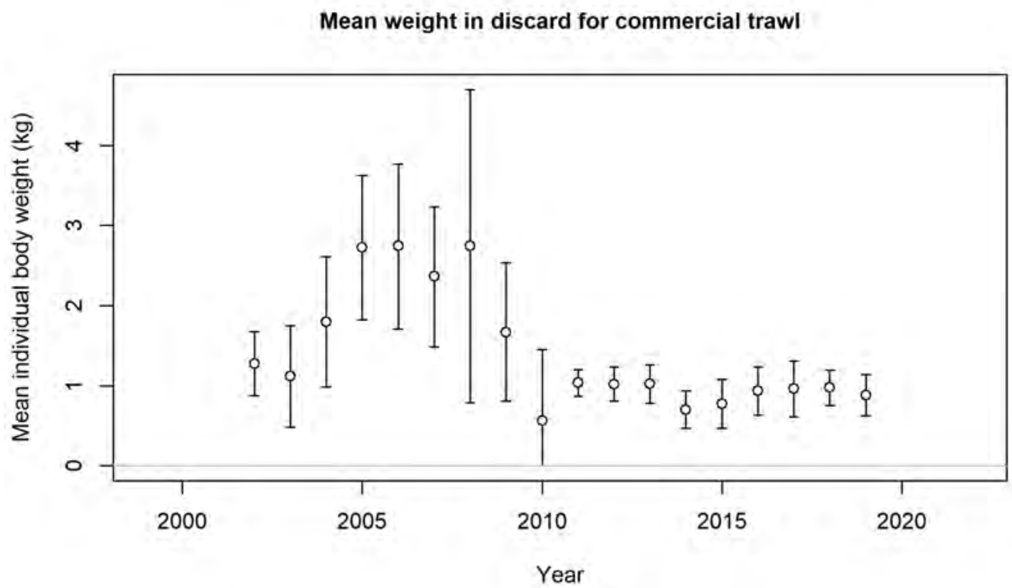

Figure 70: Mean weight in discard for commercial trawl.

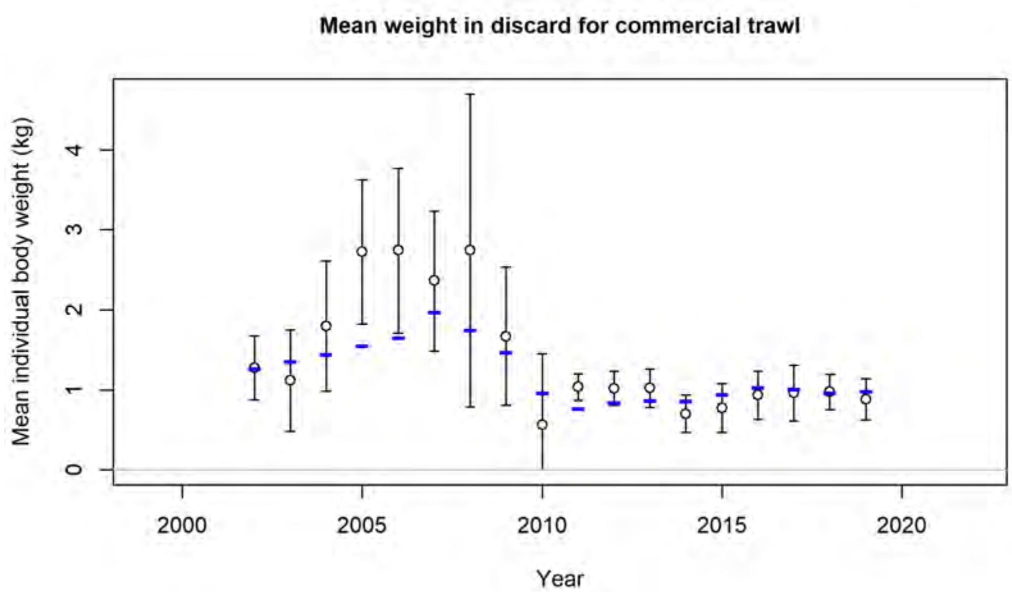

Figure 71: Mean weight in discard for commercial trawl.

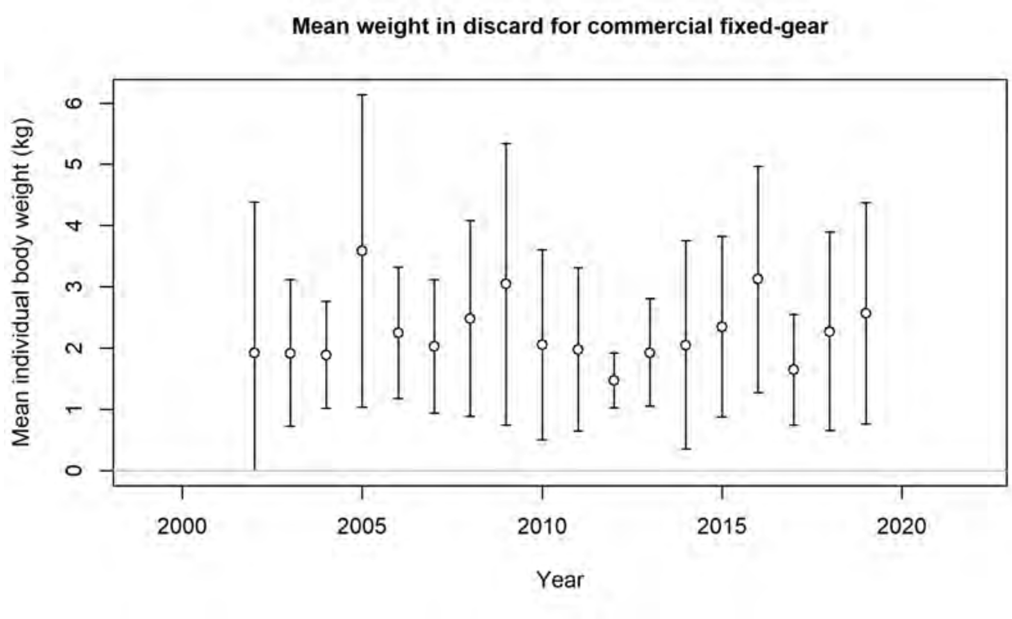

Figure 72: Mean weight in discard for commercial fixed-gear.

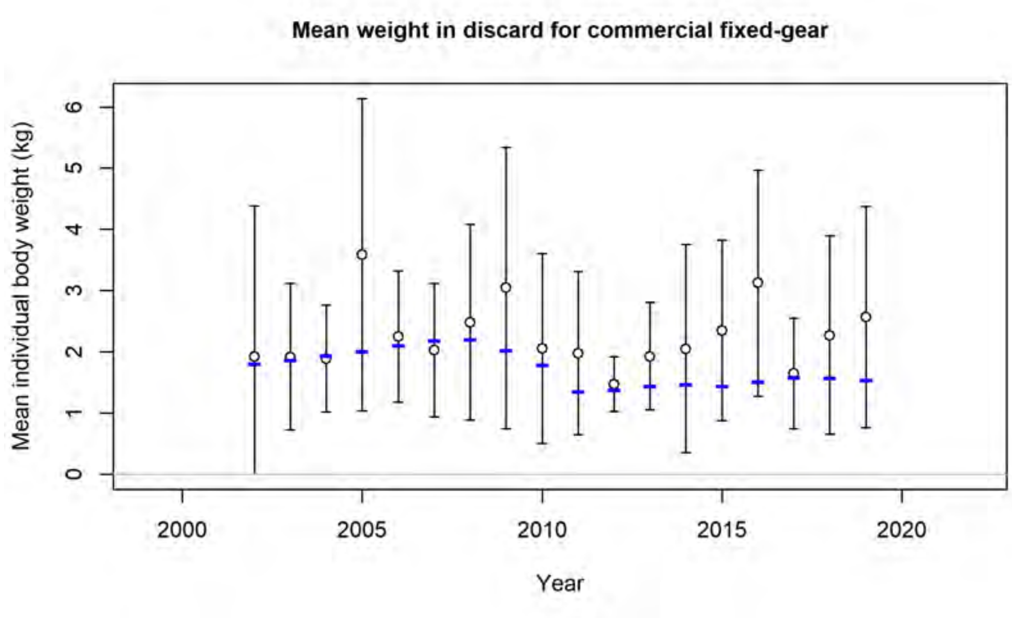

Figure 73: Mean weight in discard for commercial fixed-gear.

7.3.3 Time series figures

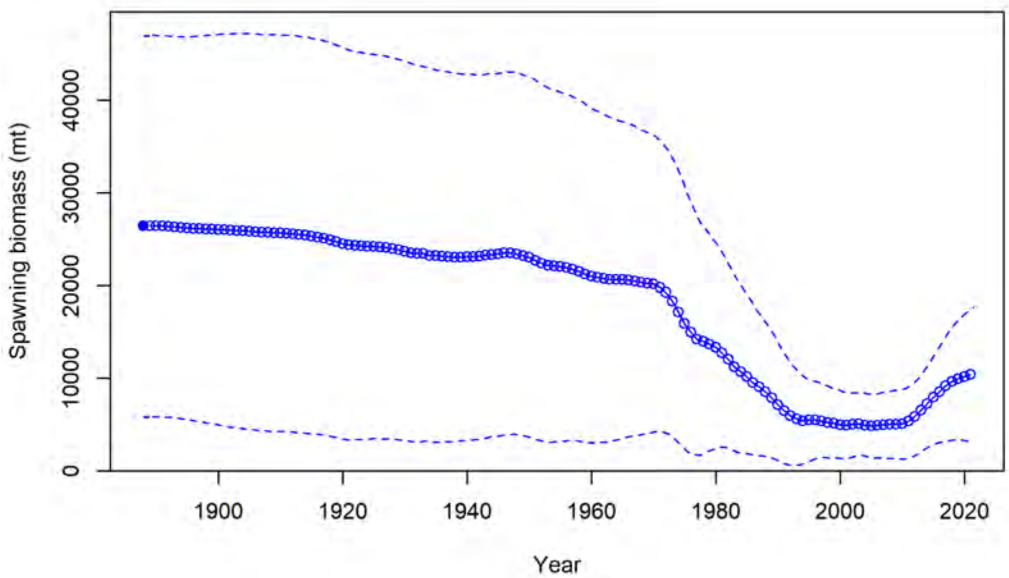

Figure 74: Spawning biomass (mt) with ~95% asymptotic intervals.

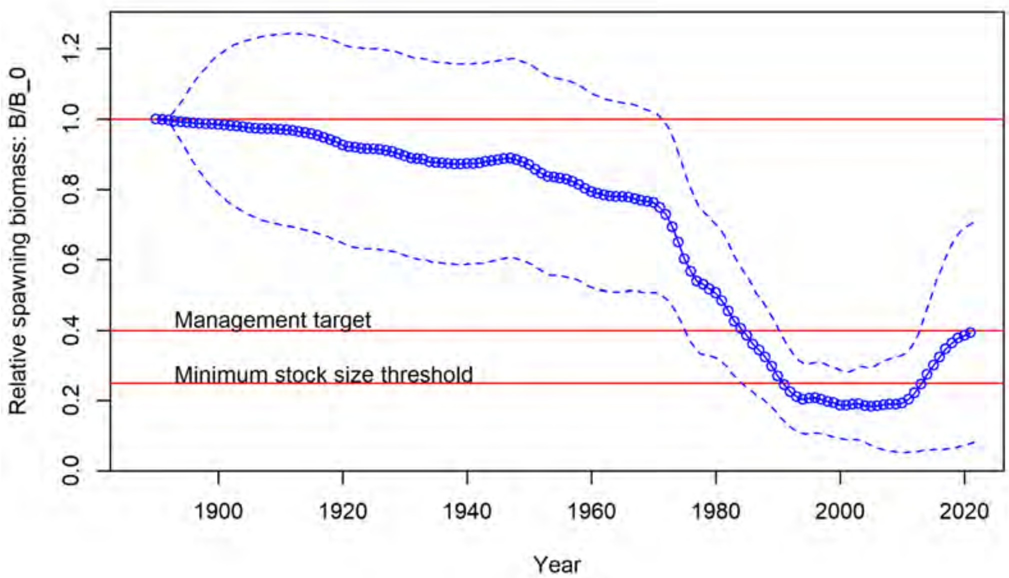

Figure 75: Relative spawning biomass: B/B_0 with ~95% asymptotic intervals.

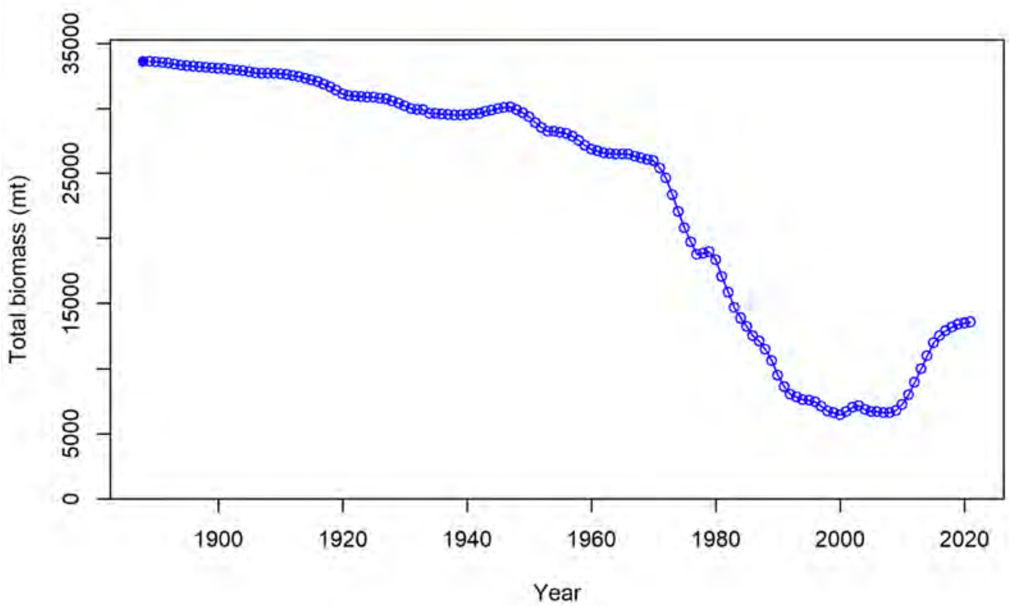

Figure 76: Total biomass (mt).

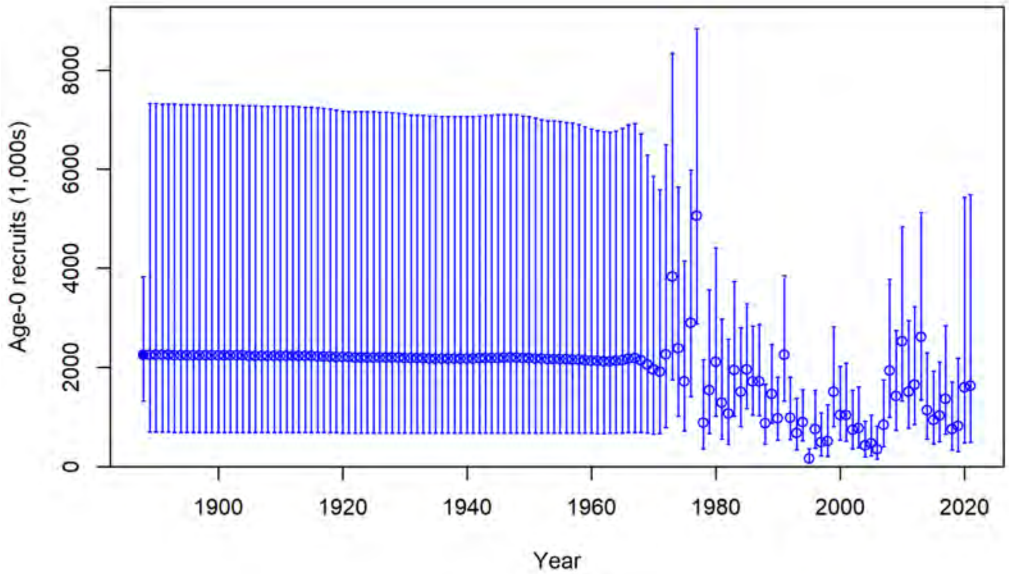

Figure 77: Age-0 recruits (1,000s) with ~95% asymptotic intervals.

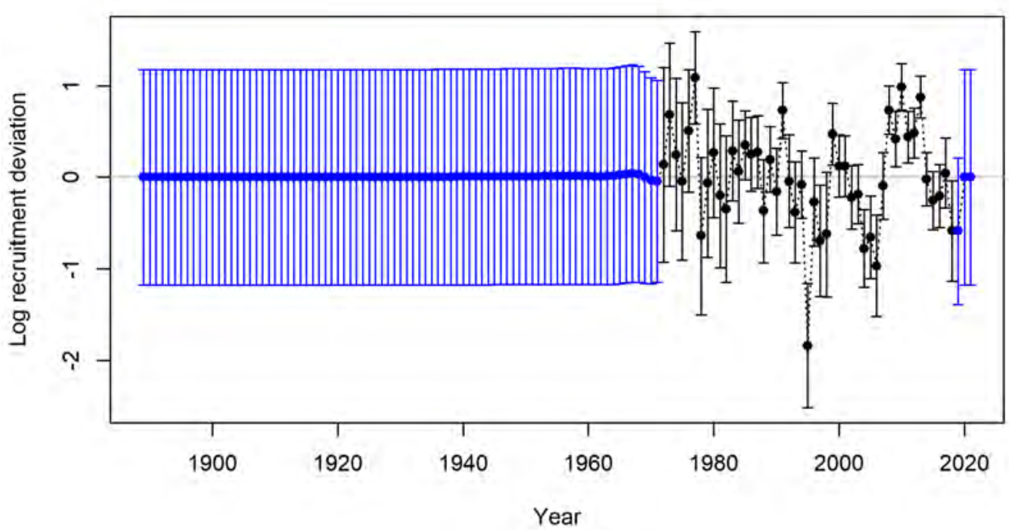

Figure 78: Recruitment deviations with 95% intervals.

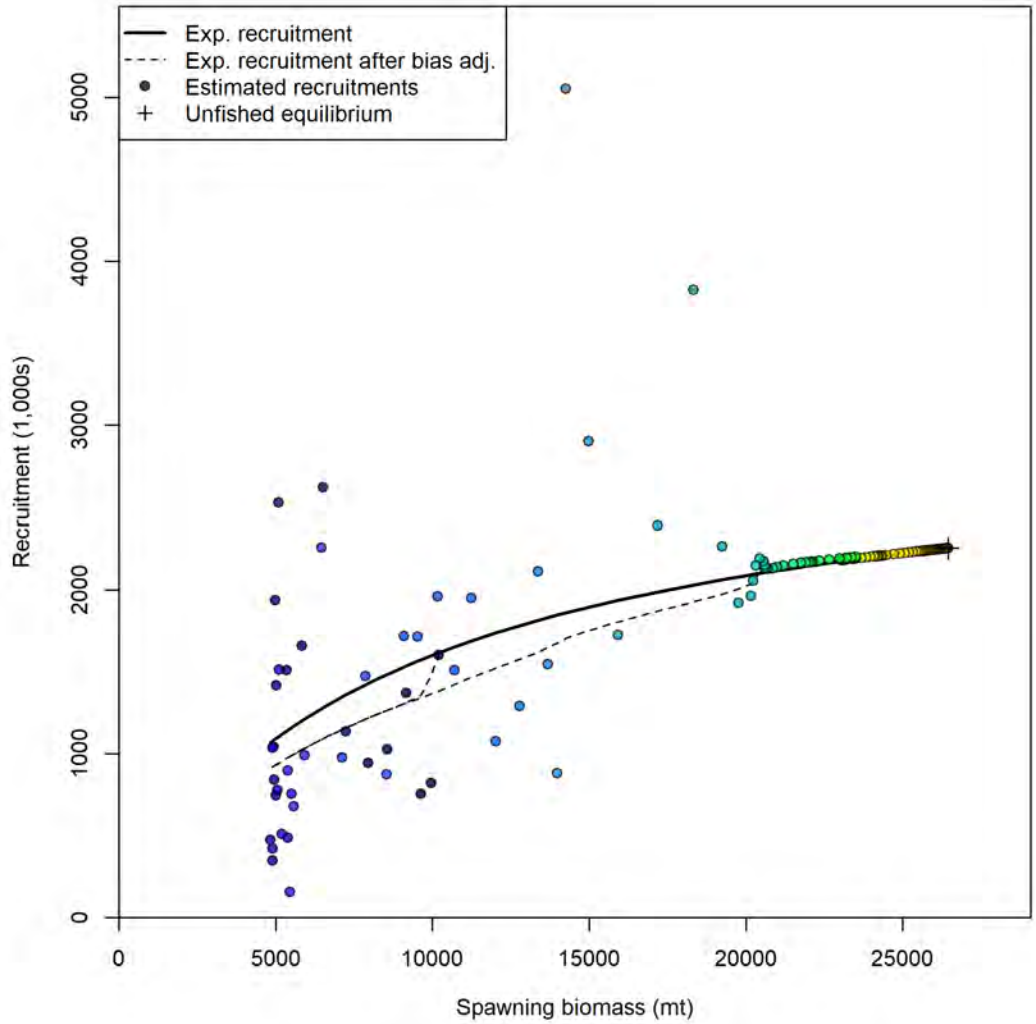

Figure 79: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

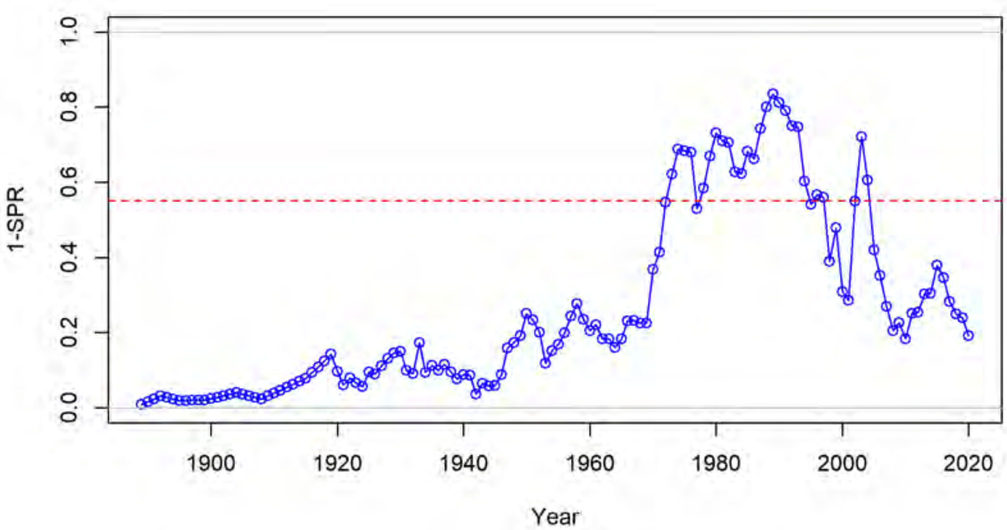

Figure 80: Timeseries of 1-SPR.

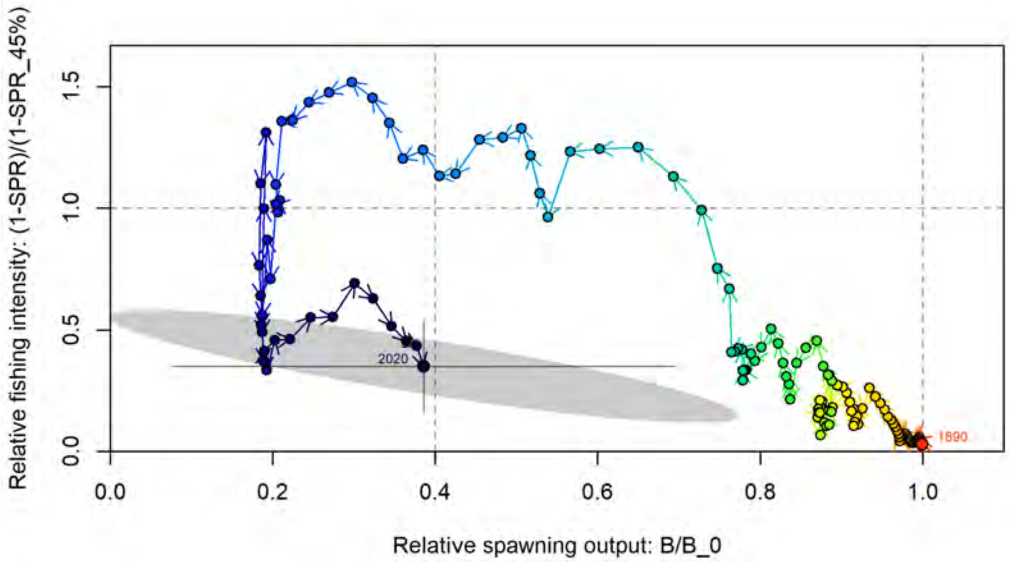

Figure 81: Phase plot of biomass ratio vs. SPR ratio. Each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show 95% intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95% region which accounts for the estimated correlation between the two quantities: -0.873. 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).

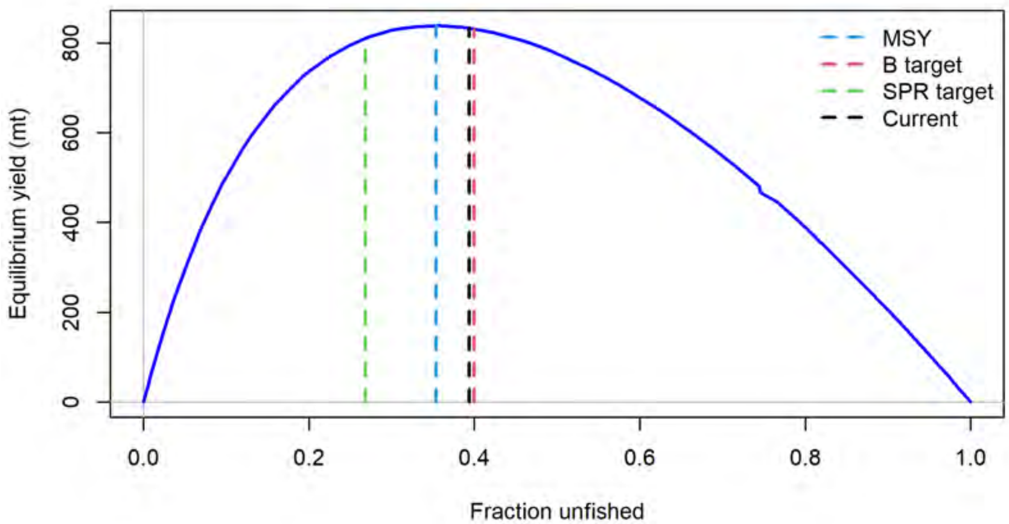

Figure 82: Yield curve with reference points.

7.3.4 Sensitivity analyses and retrospectives

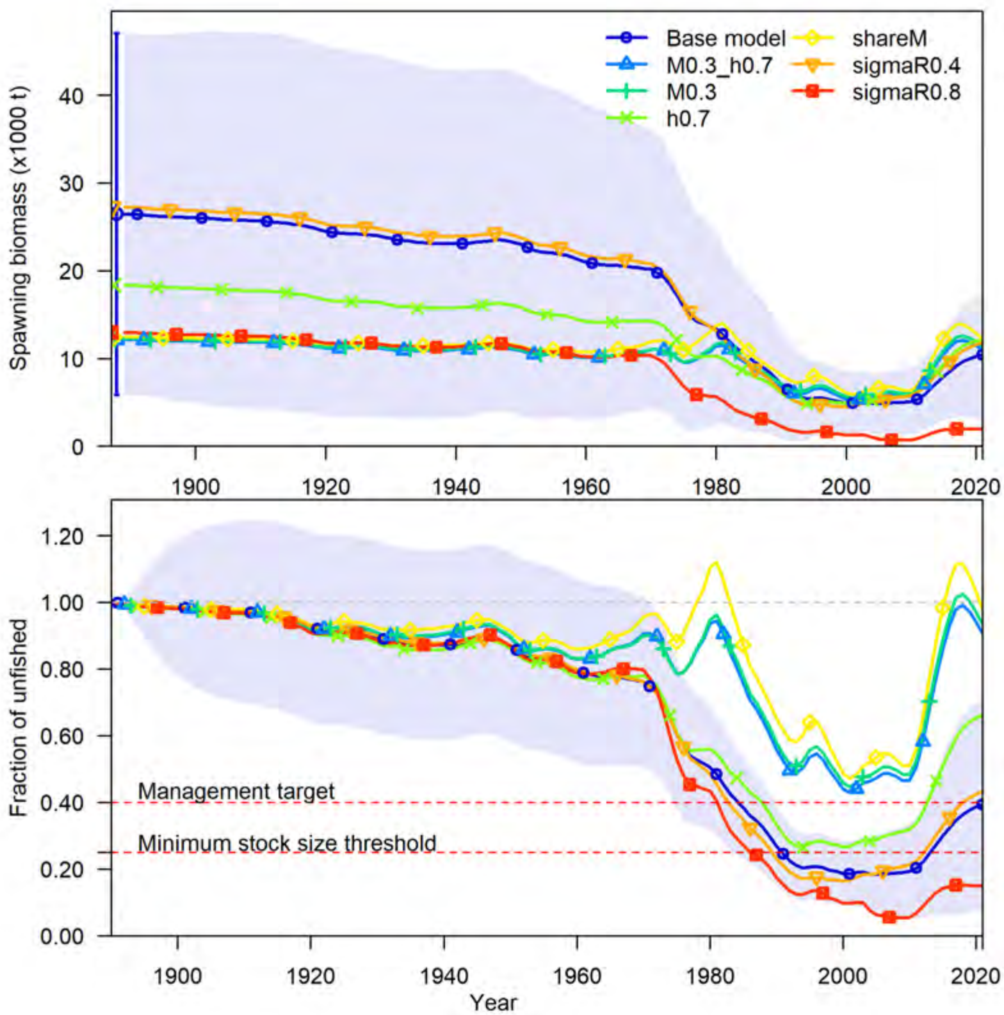

Figure 83: Time series of spawning biomass (top) and fraction of unfished (bottom) for the sensitivity analyses related to biology and recruitment.

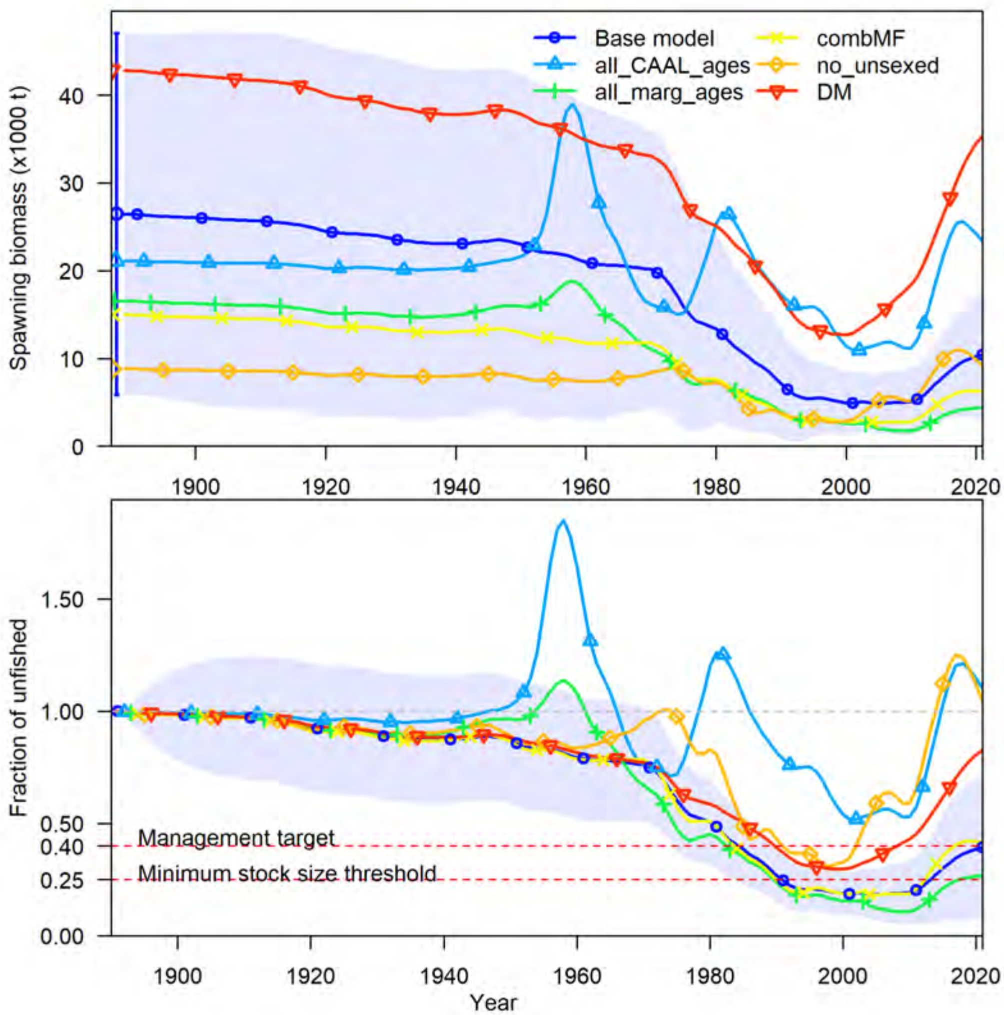

Figure 84: Time series of spawning biomass (top) and fraction of unfished (bottom) for the sensitivity analyses related to composition data.

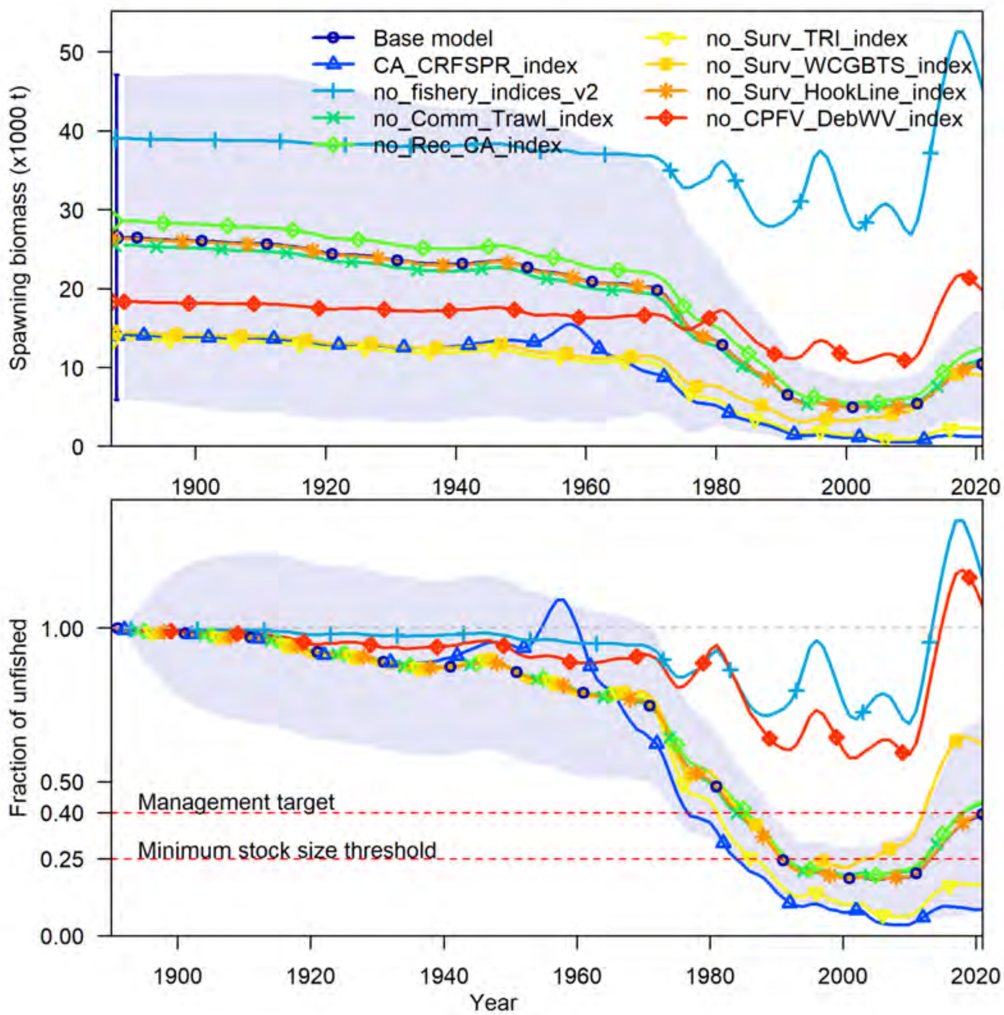

Figure 85: Time series of spawning biomass (top) and fraction of unfished (bottom) for the sensitivity analyses related to indices of abundance.

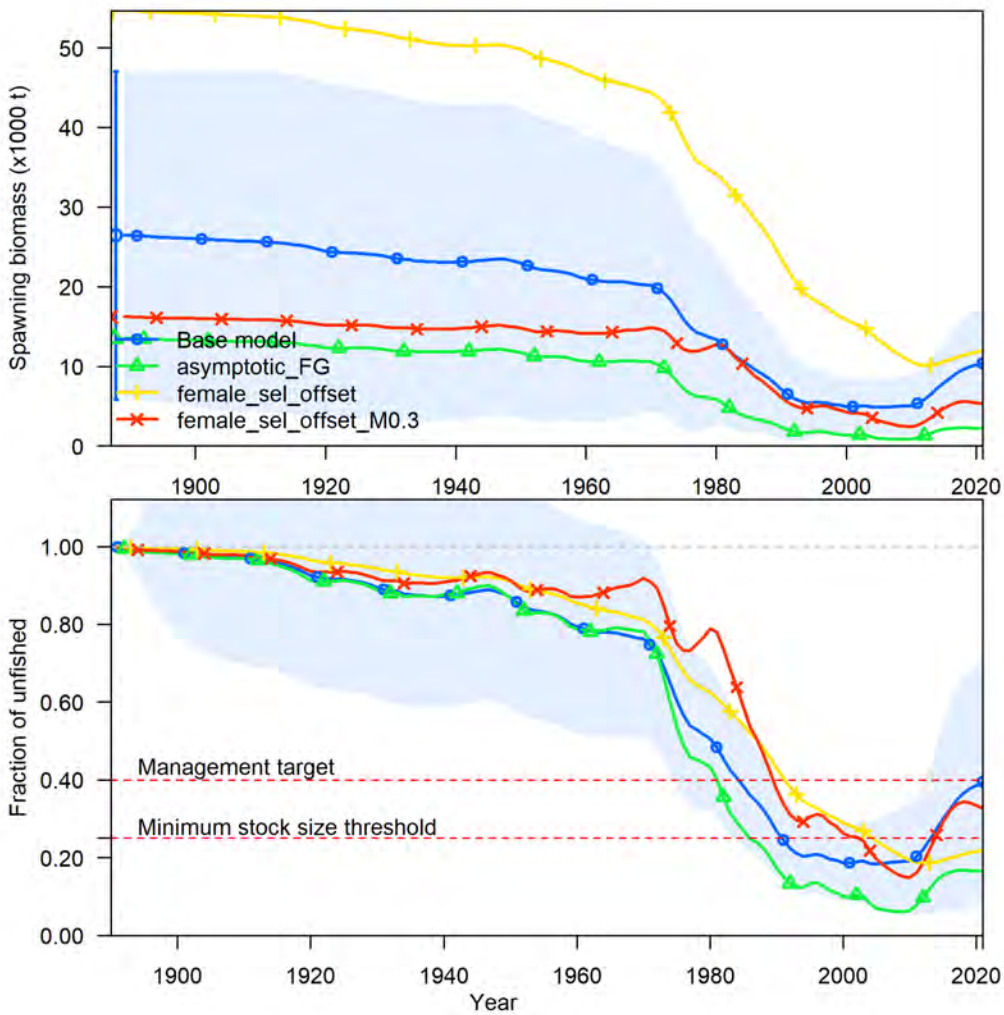

Figure 86: Time series of spawning biomass (top) and fraction of unfished (bottom) for the sensitivity analyses related to .

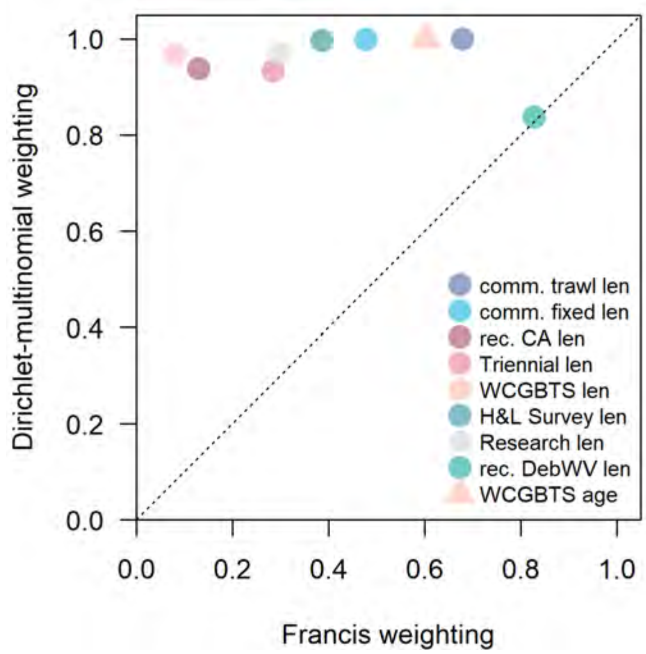

Figure 87: Weights applied to the length- and age-composition data by the Francis weighting used in the base model vs the Dirichlet-multinomial weighting used in a sensitivity analyses.

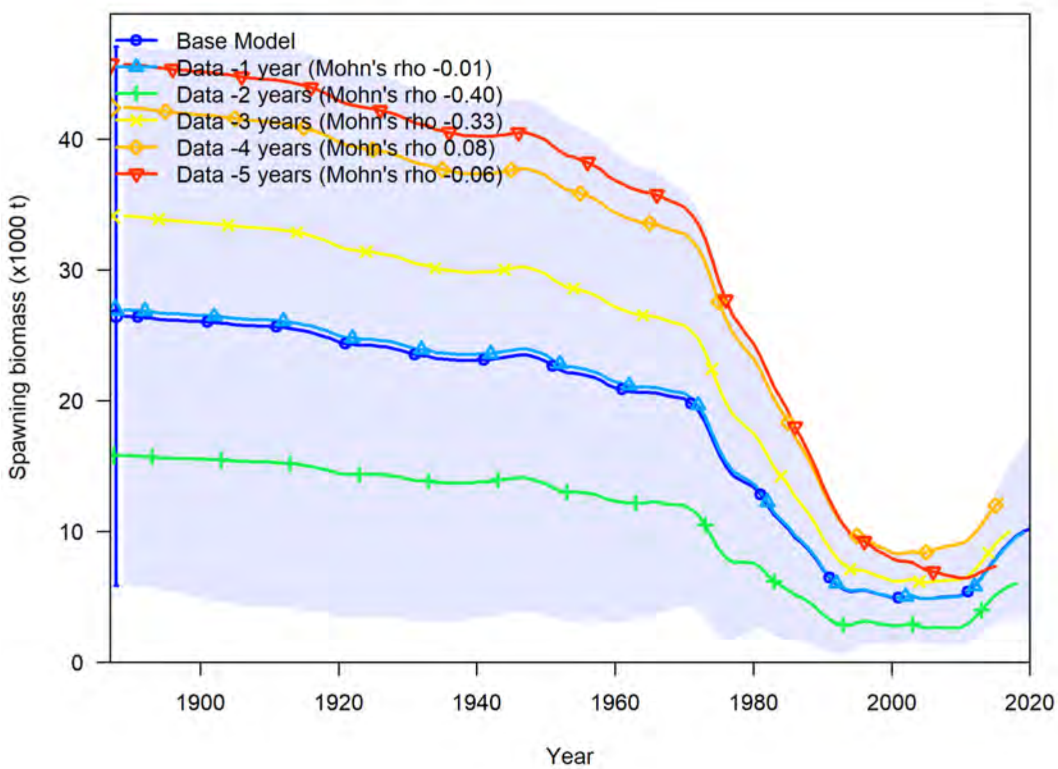

Figure 88: Change in the spawning biomass when the most recent 5 years of data are removed sequentially.

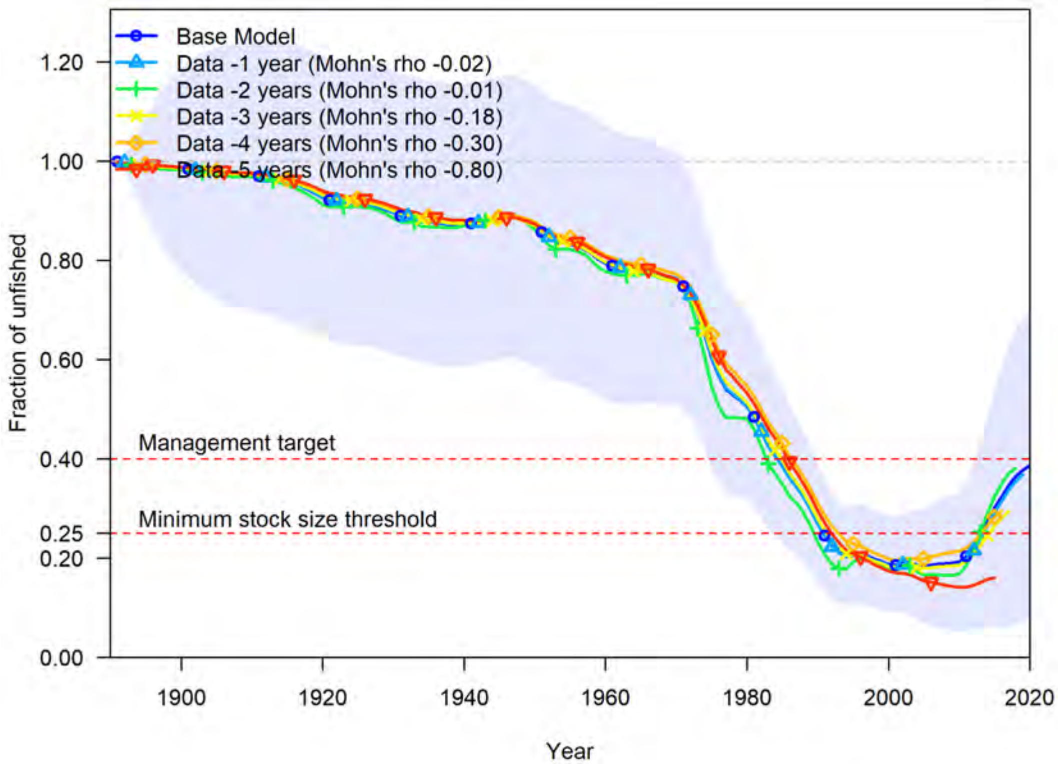

Figure 89: Change in the fraction unfished when the most recent 5 years of data are removed sequentially.

7.3.5 Likelihood profiles

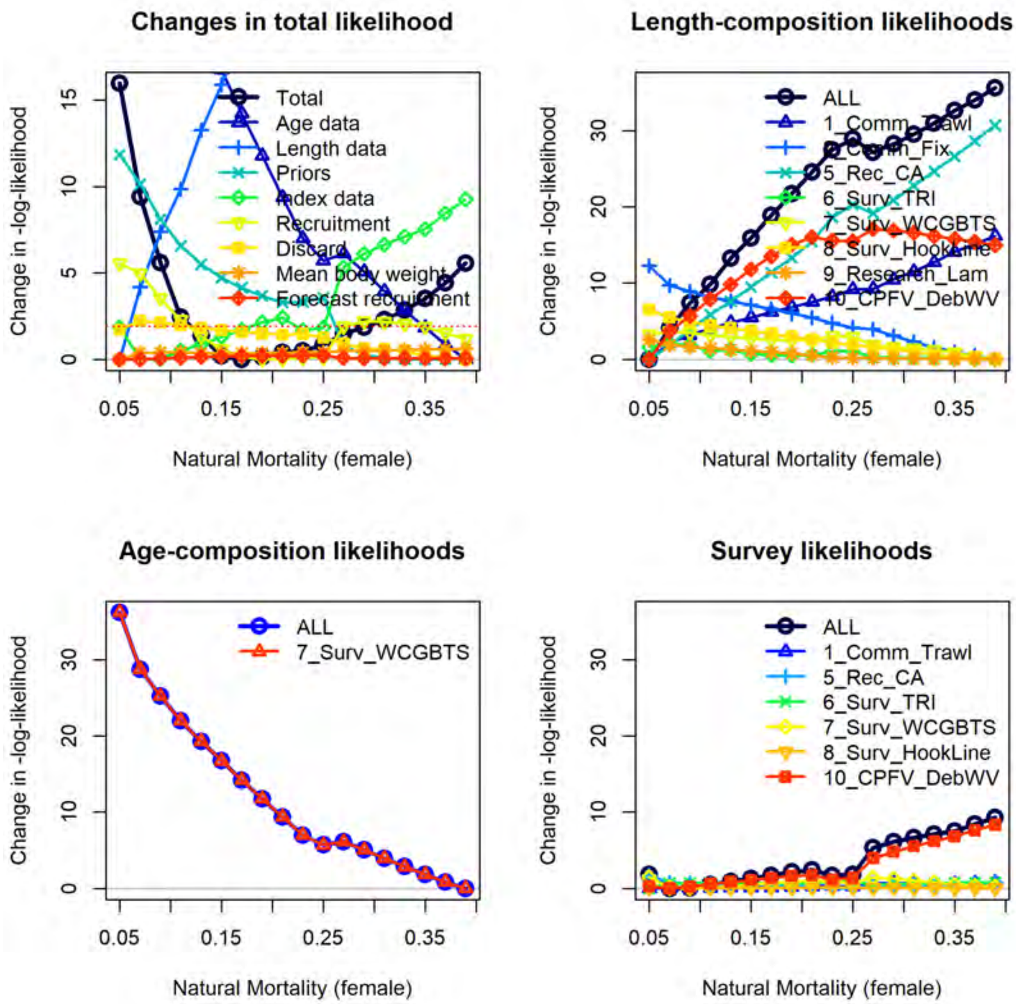

Figure 90: Change in the negative log-likelihood across a range of female M values.

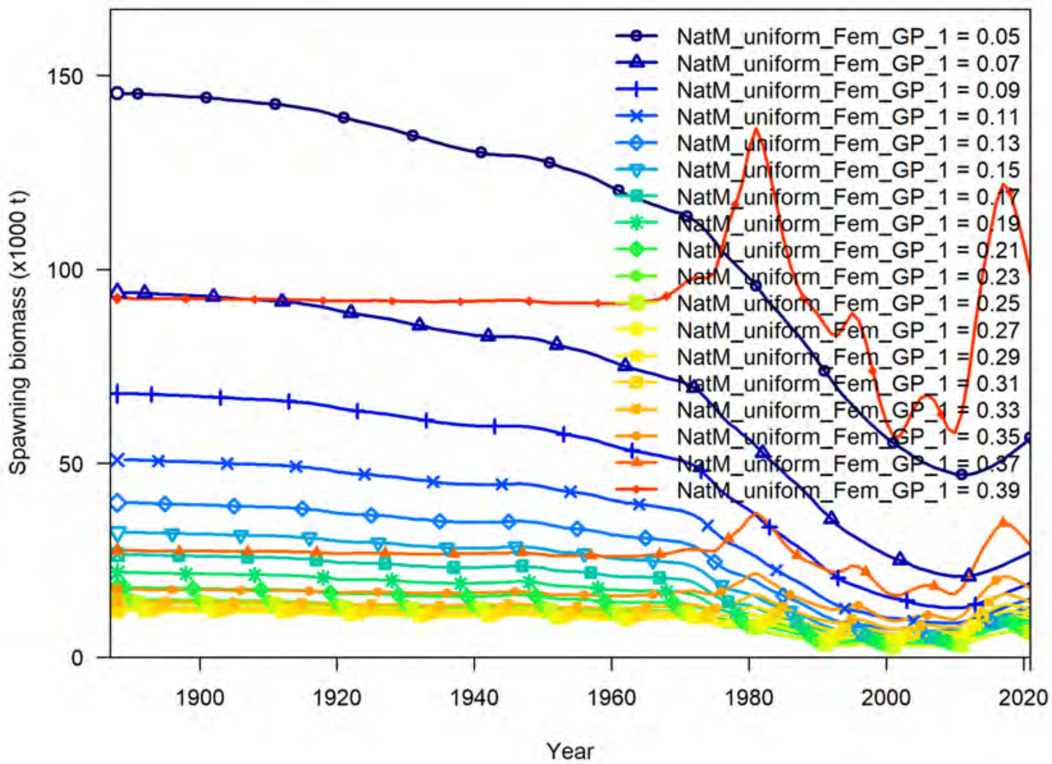

Figure 91: Change in the spawning biomass across a range of female M values.

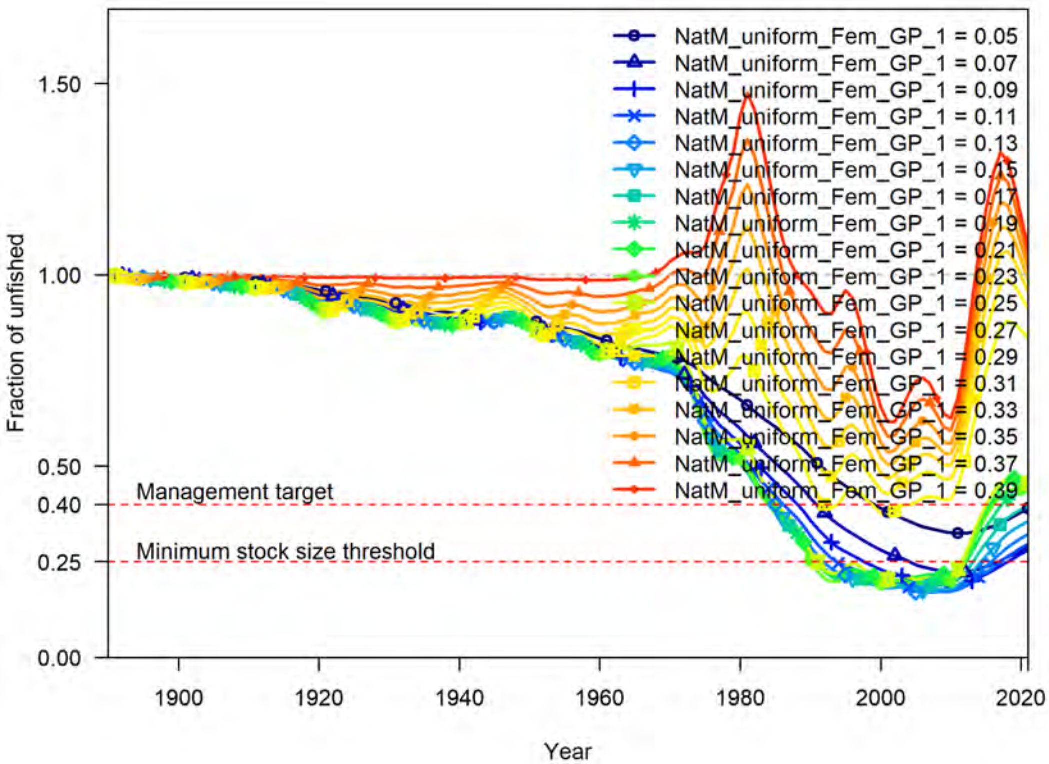

Figure 92: Change in the fraction of unfished across a range of female M values.

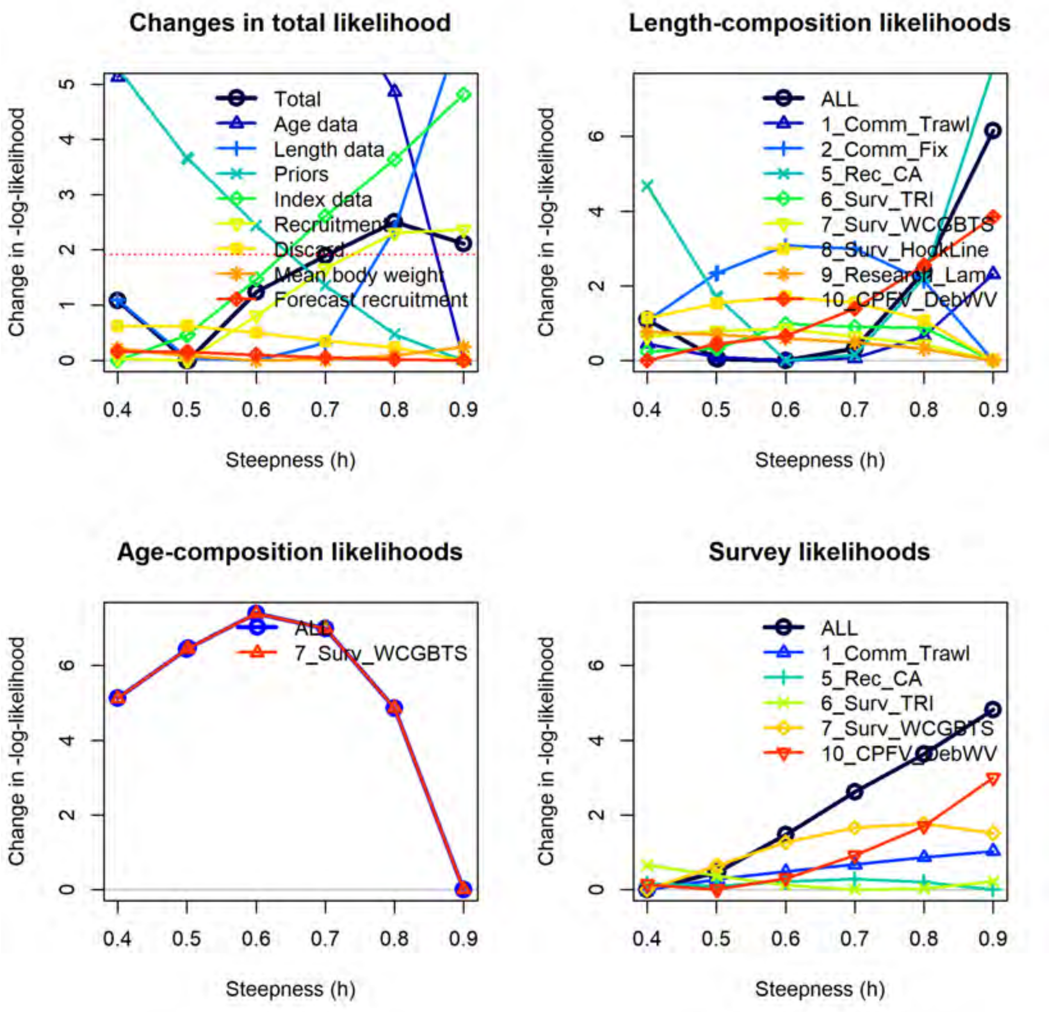

Figure 93: Change in the negative log-likelihood across a range of steepness values.

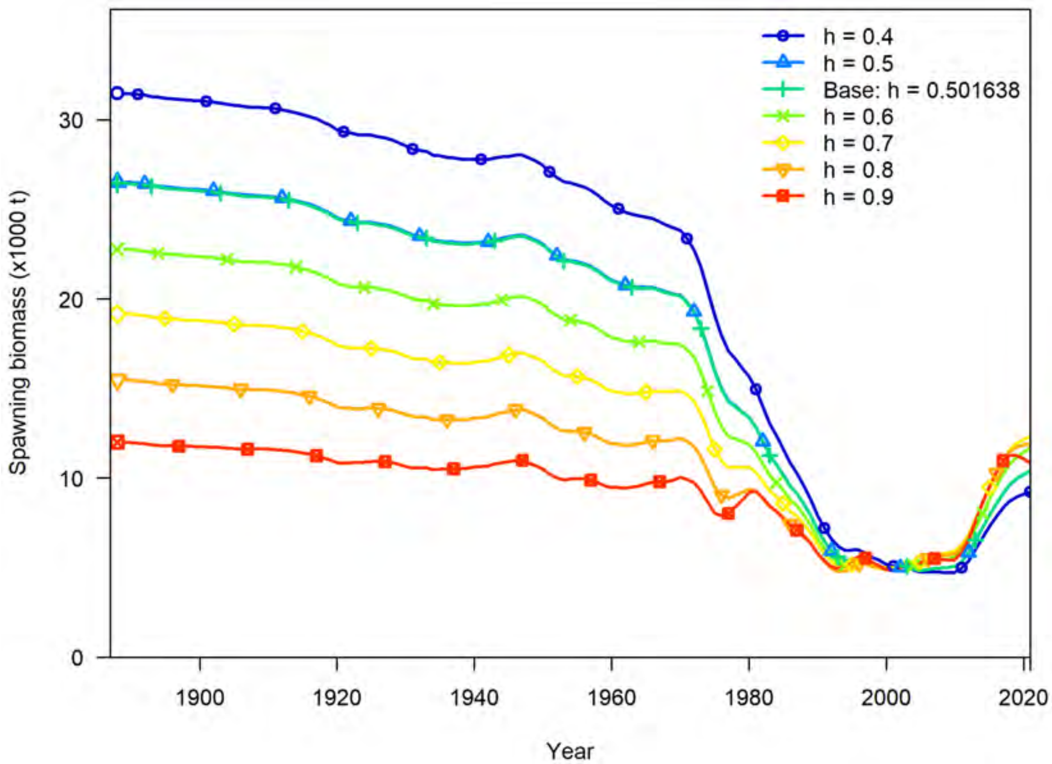

Figure 94: Change in the spawning biomass across a range of steepness values.

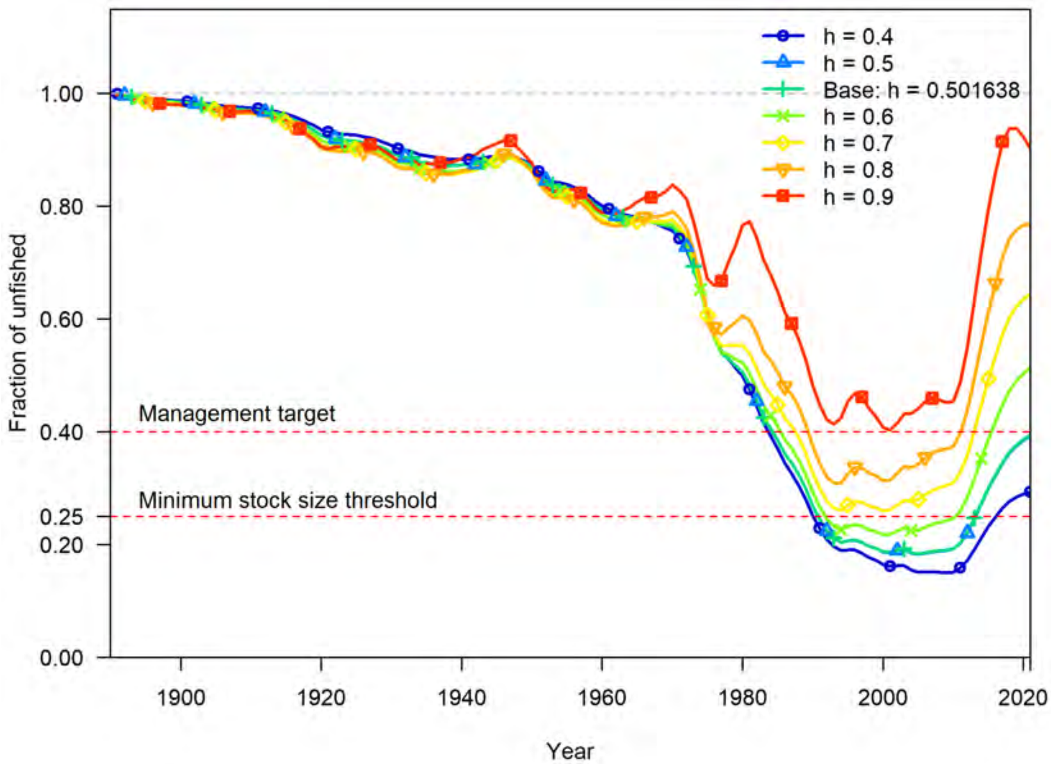

Figure 95: Change in the fraction of unfished across a range of steepness values.

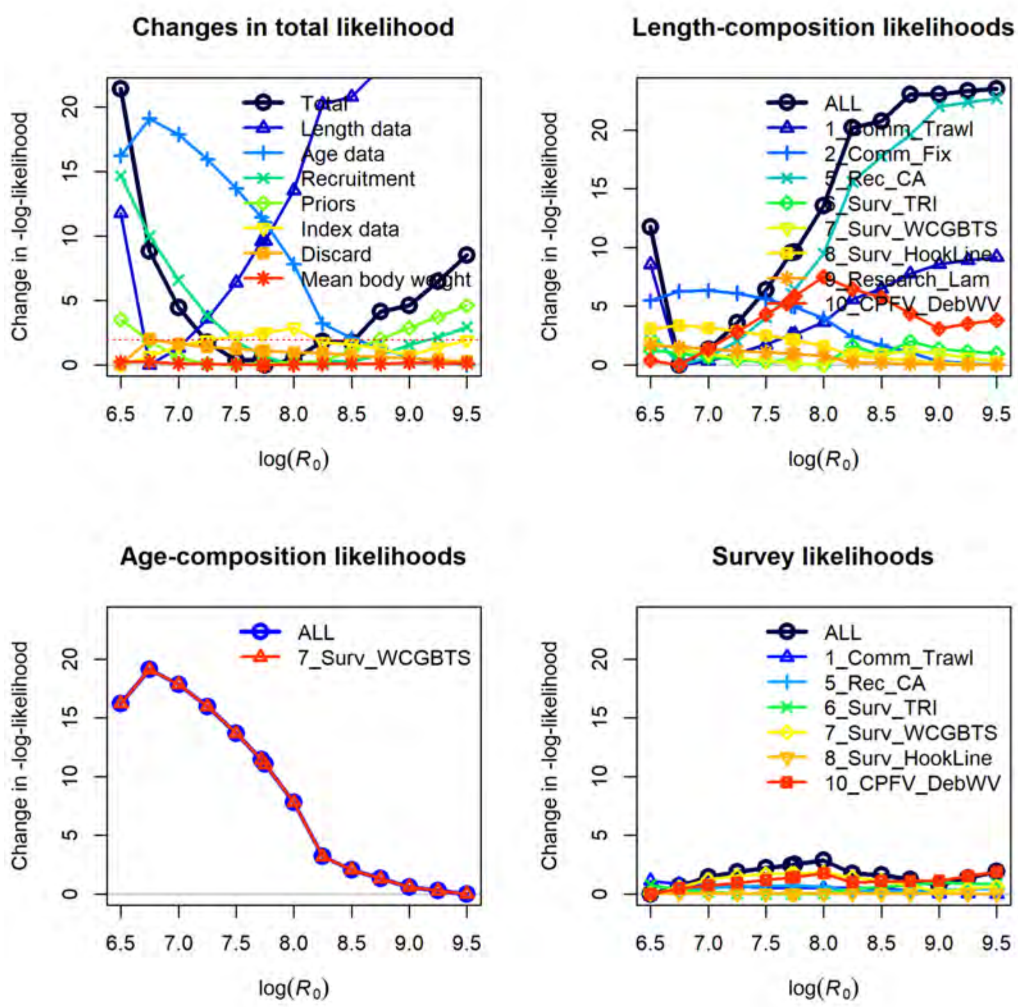

Figure 96: Change in the negative log-likelihood across a range of $log(R0)$ values.

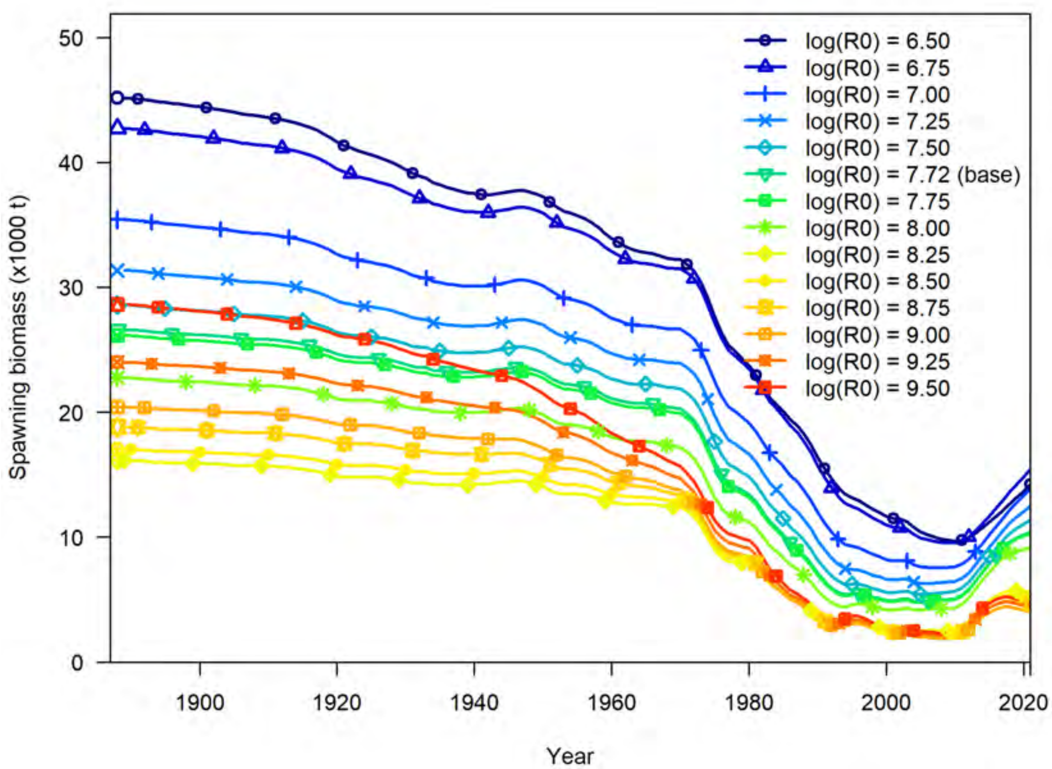

Figure 97: Change in the spawning biomass across a range of $log(R0)$ values.

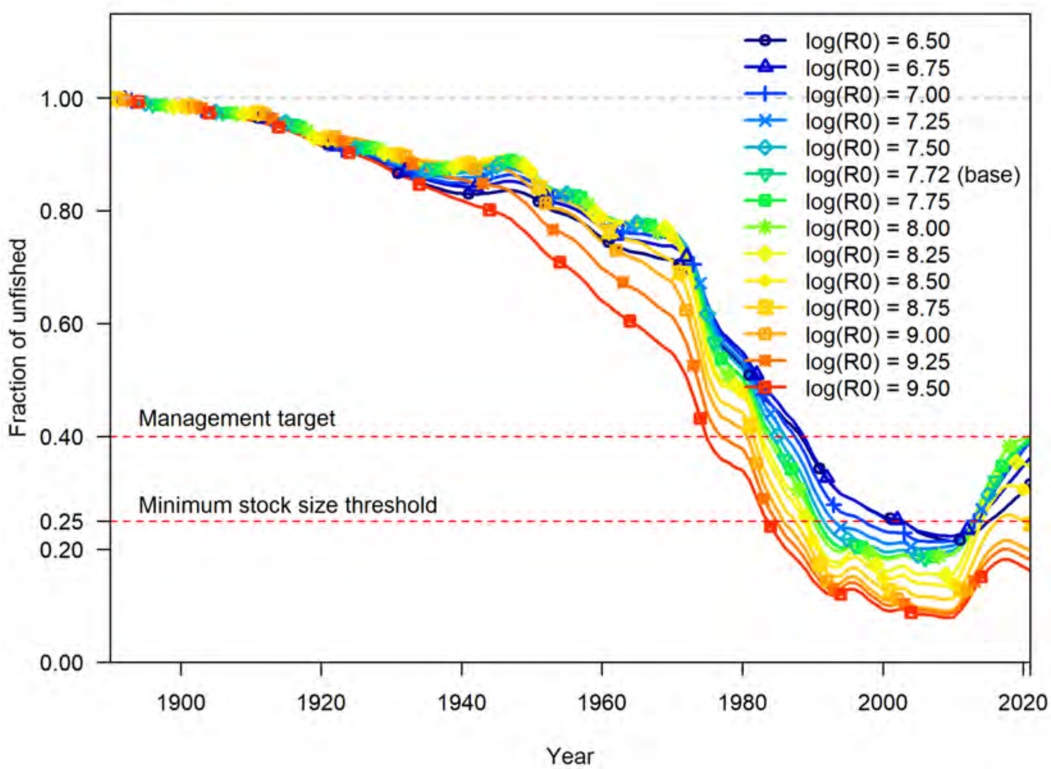

Figure 98: Change in the fraction of unfished across a range of $log(R0)$ values.

7.3.6 Reference points and forecasts

7.3.7 Comparisons of north and south models

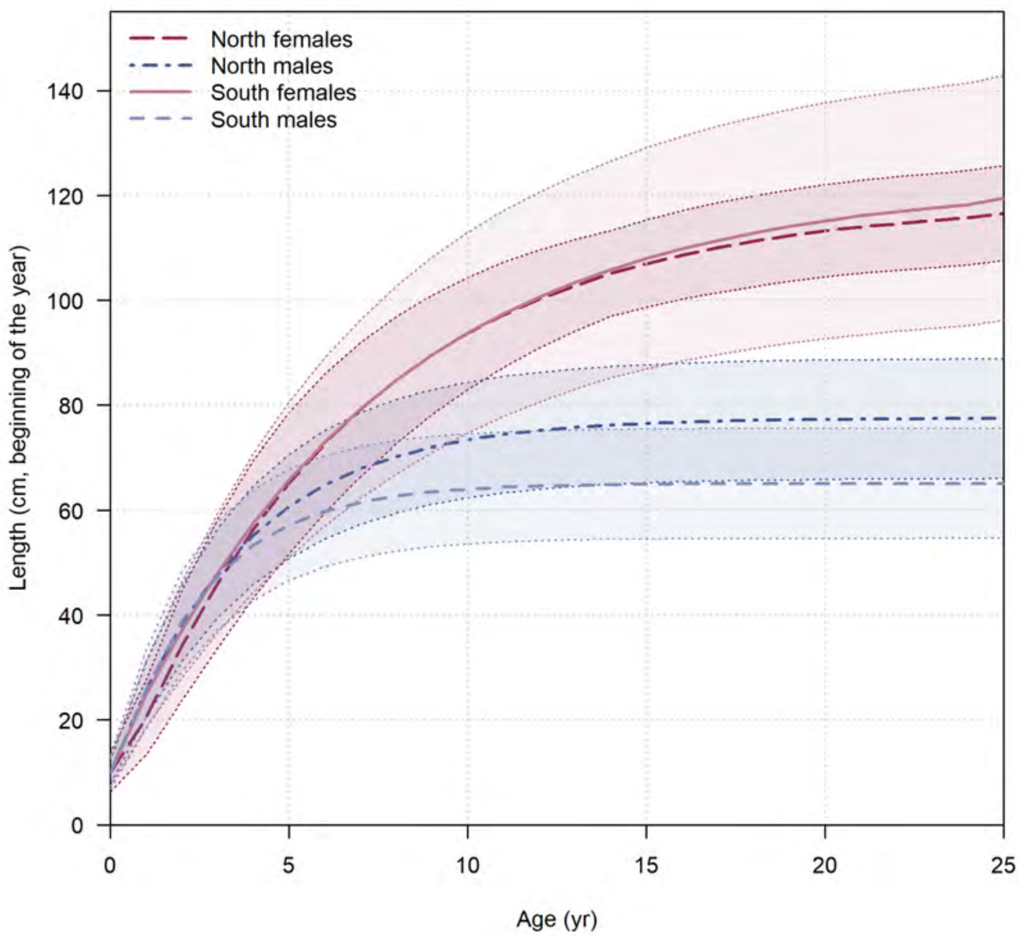

Figure 99: Comparison of estimated growth curves and variability in growth for the north and south base models.

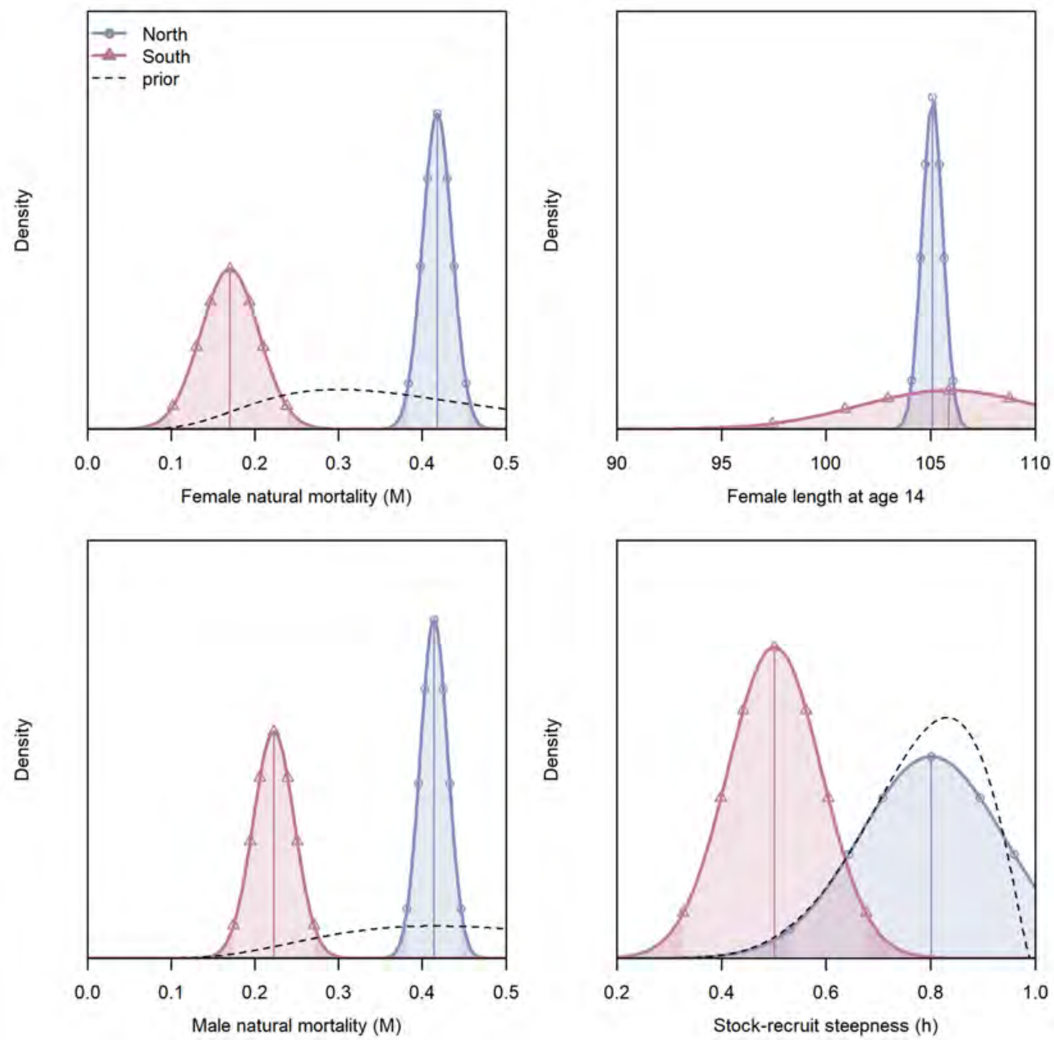

Figure 100: Comparison estimates for parameters of interest from each model with normal approximation to posterior based on asymptotic standard error with priors shown in black.

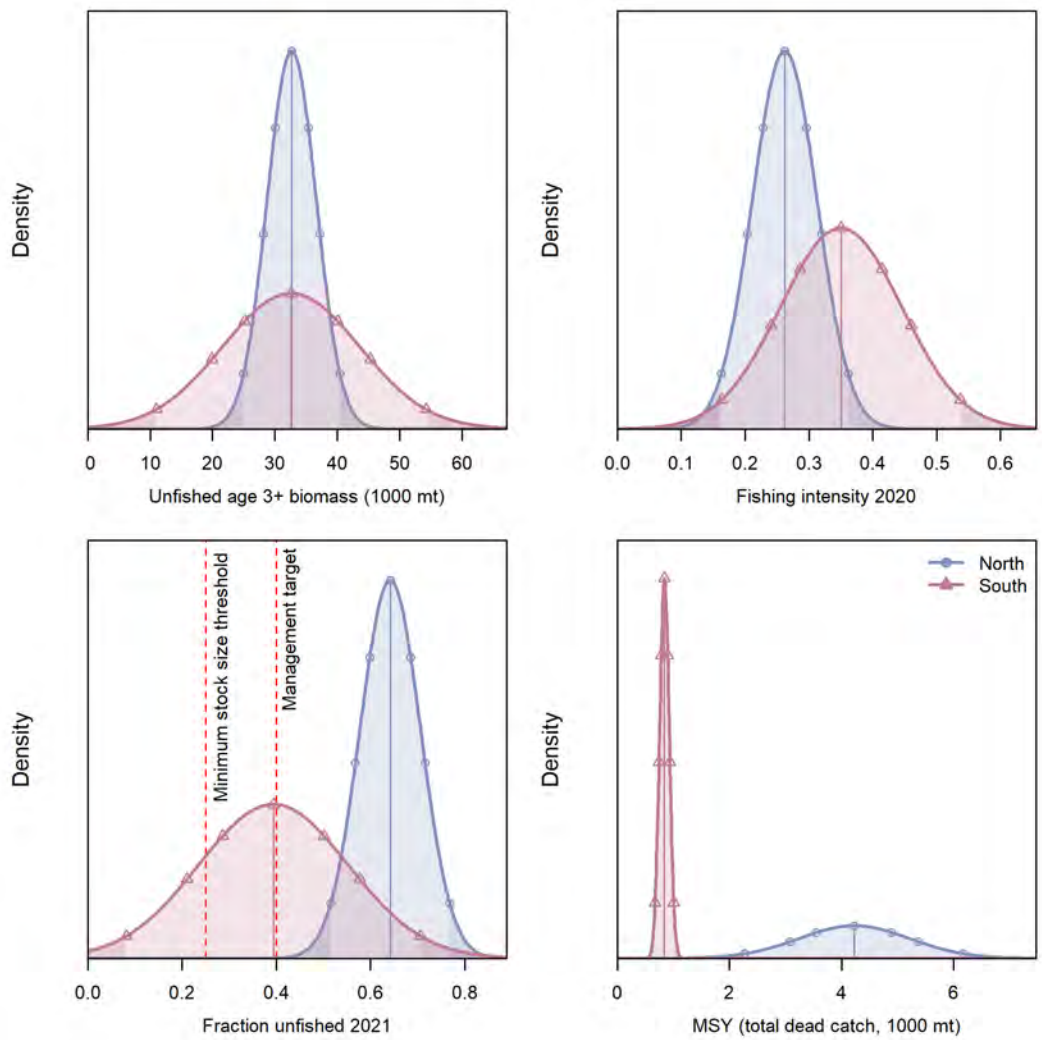

Figure 101: Comparison estimates for quantities of interest from each model with normal approximation to posterior based on asymptotic standard error.

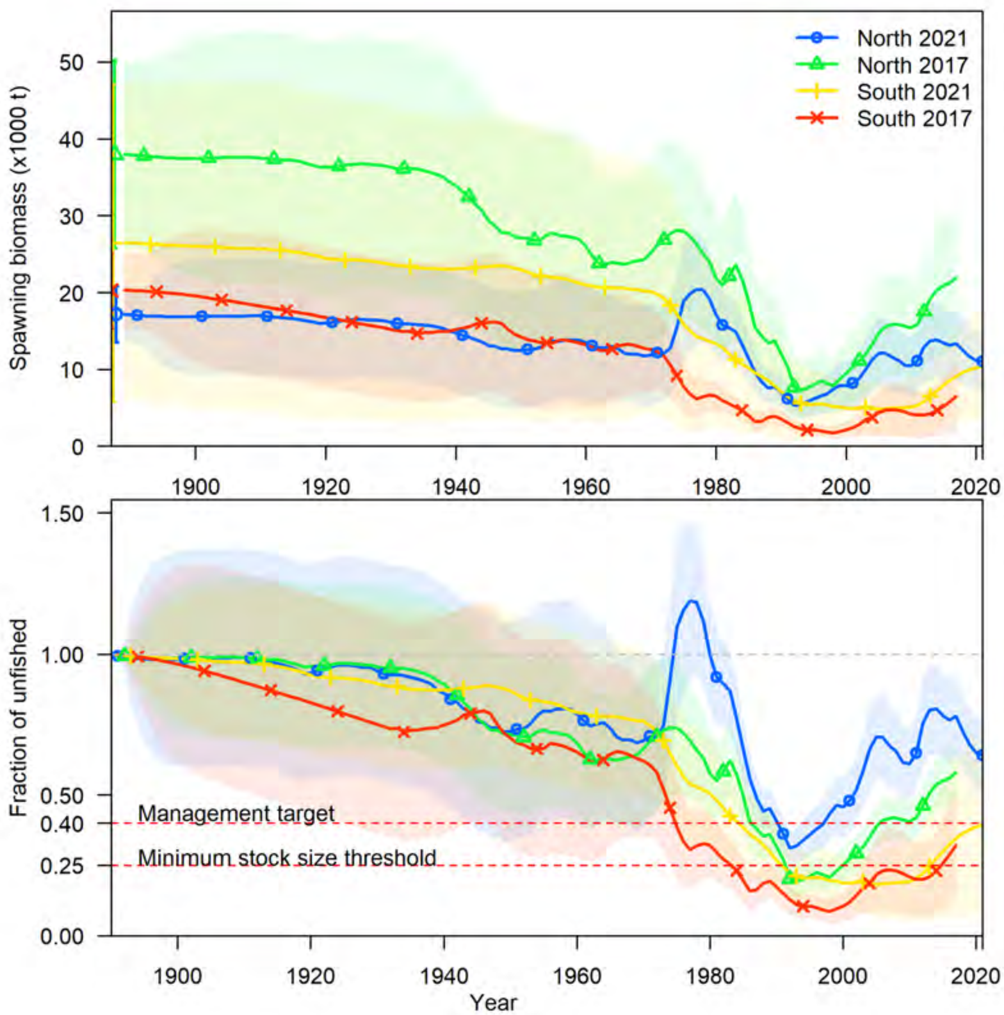

Figure 102: Time series of spawning biomass (top) and fraction of unfished (bottom) from the 2021 and 2017 base models for north and south. Note that the 2017 models had a break at 42°00'N instead of 40°10'N used in the 2021 models.