Agenda Item C.6
Attachment 1
September 2021

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

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August 2021

Correct citation for this publication:

Taylor, I.G., K.F. Johnson, B.J. Langseth, A. Stephens, L.S. Lam, M.H. Monk, A.D. Whitman, M.A. Haltuch. 2021. Status of lingcod (*Ophiodon elongatus*) along the northern U.S. west coast in 2021. Pacific Fishery Management Council, Portland, Oregon. xvi p.

Contents

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Executive summary

Stock

This assessment reports the status of lingcod (*Ophiodon elongatus*) off the northern U.S. west coast using data through 2020. Lingcod were modeled as two stocks and this document contains summary information about the species as a whole and detailed information for the northern stock. Stocks were split at 40°10'N based on the results of a genetic analysis. This boundary also happens to be the boundary used for the management of commercial catches. Models for lingcod do not include catches from the Alaskan, Canadian, or Mexican populations and assume that these flanking populations do not contribute to the stock being assessed here.

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 and recent landings (Table i) were available from PacFIN and RecFIN. Commercial discards were modeled using discard rates and length compositions, which facilitated the estimation of retention curves. Recreational catches included estimates of dead discards in the catch data (Table i). Discard mortality was assumed to be 50% for commercial trawl and 7% for commercial fixed-gear and recreational fleets.

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 summed across fleets, and the total mortality including discards which were estimated internal to the model for the commercial fleets.

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

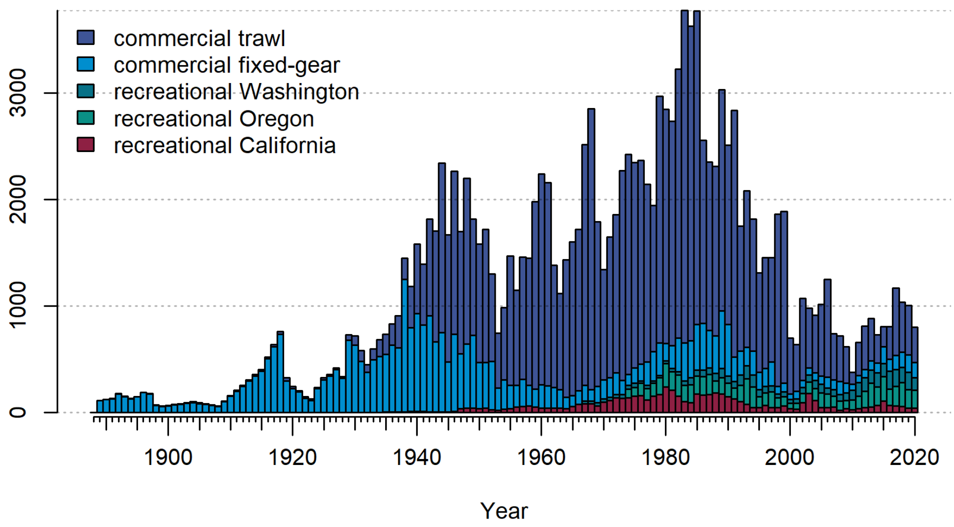

Figure i: Landings plus dead discards (mt) by fleet as input and estimated in the base model.

Data and assessment

This assessment uses the Stock Synthesis fisheries stock assessment model version 3.30.17.01. 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). 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; length and age compositions, available from the previous sources as well as research done by L. Lam.

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

Age data were explored using conditional-age-at-length rather than marginal ages and length data were modeled as sex-specific compositions for fish that were sexed and as combined-sex compositions for fish that were measured but not sexed. Unsexed fish that were aged 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. Main annual recruitment deviations started in 1960, just prior to the availability of reliable length- and age-composition data. Selectivity for each fleet was modeled using a double-normal function of length that allowed for dome or asymptotic shapes that were supported by the data. Time blocks were used for selectivity and retention to account for management changes.

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

Stock biomass and dynamics

The stock biomass is currently trending downwards, though the rate of the decline is highly uncertain (Table ii; Figure ii). And, although it is currently declining, it estimated to have been above the management target since the late 1990s and never to have been below 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	11147	7126	15168	0.650	0.518	0.781
2012	12969	8282	17656	0.756	0.603	0.909
2013	13732	8807	18656	0.800	0.640	0.960
2014	13843	8932	18754	0.807	0.648	0.965
2015	13408	8746	18070	0.781	0.633	0.930
2016	13143	8619	17667	0.766	0.623	0.909
2017	13377	8802	17951	0.780	0.635	0.924
2018	12433	8168	16697	0.725	0.590	0.859
2019	11658	7642	15673	0.679	0.552	0.807
2020	11183	7288	15078	0.652	0.527	0.777
2021	11010	7143	14877	0.642	0.515	0.768

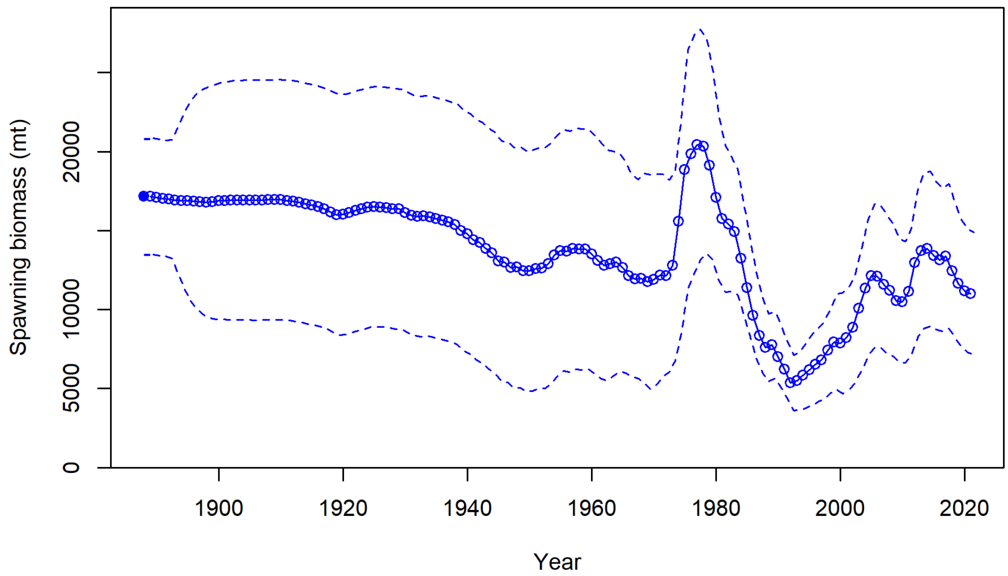

Figure ii: Estimated time series of spawning output (circles and line are maximum likelihood estimates; light broken lines are 95% intervals) for the base model.

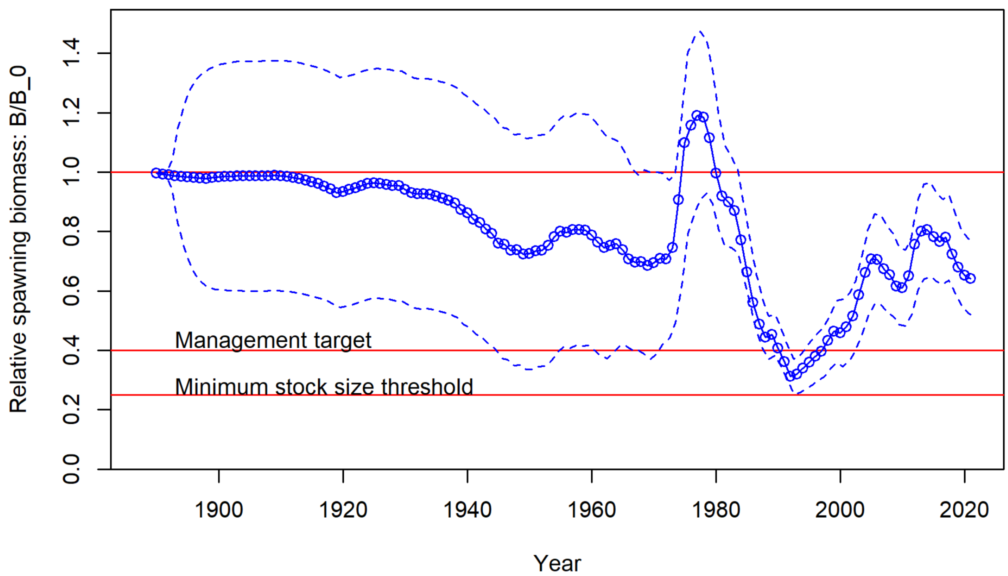

Figure iii: Estimated time series of fraction of unfished spawning output (circles and line are maximum likelihood estimates; light broken lines are 95% intervals) for the base model.

Recruitment

Lingcod appear to have moderate variability in estimates of recruitment with recruitment variability (σ_R) fixed at 0.6 (Figures iv and v). Given the pandemic and the lack of recent survey information, there was little information in the data to estimate recruitment in 2019. Thus, 2019 and 2020 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). If the survey in 2019 would have been conducted, then 2019 recruitment perhaps would have been less uncertain. Lingcod are not seen as age-0 fish in any data set in appreciable quantities, and thus, the terminal year of recruitment is never estimated. 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 iii: Estimated recent trend in recruitment and recruitment deviations and the 95 percent intervals.

Year	Recruit- ment	Lower interval	Upper interval	Recruit- ment deviations	Lower interval	Upper interval
2011	10611	6232	18067	-0.250	-0.460	-0.041
2012	10832	6421	18273	-0.243	-0.442	-0.044
2013	21762	13156	35999	0.450	0.300	0.601
2014	7629	4459	13052	-0.599	-0.840	-0.357
2015	10034	5986	16819	-0.322	-0.526	-0.118
2016	13159	7804	22188	-0.050	-0.257	0.158
2017	9854	5661	17153	-0.340	-0.629	-0.051
2018	18745	10567	33253	0.309	-0.026	0.644
2019	7823	3231	18942	-0.637	-1.444	0.170
2020	16198	5131	51141	0.000	-1.176	1.176
2021	16175	5123	51066	0.000	-1.176	1.176

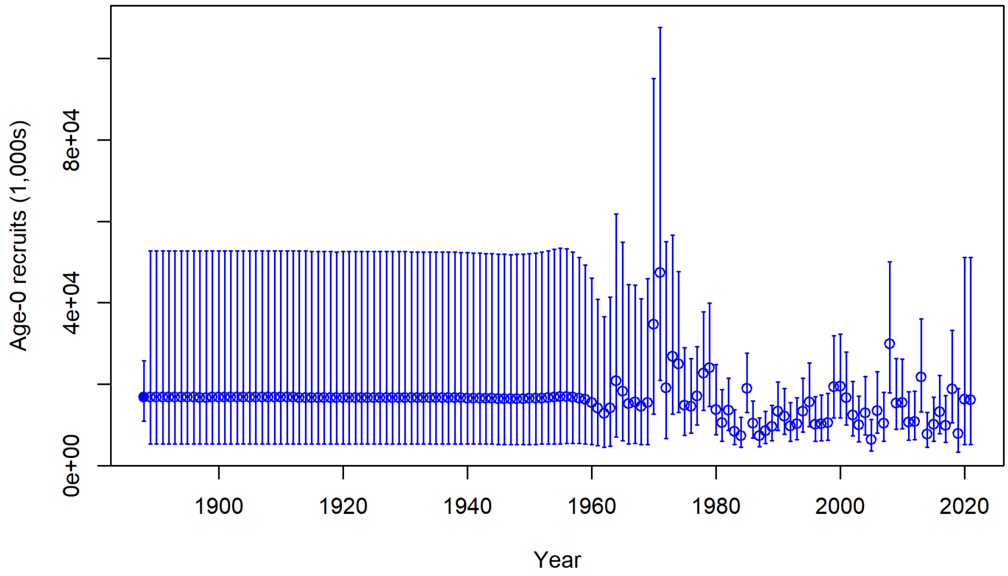

Figure iv: Estimated time series of age-0 recruits (1000s) for the base model with 95 percent intervals.

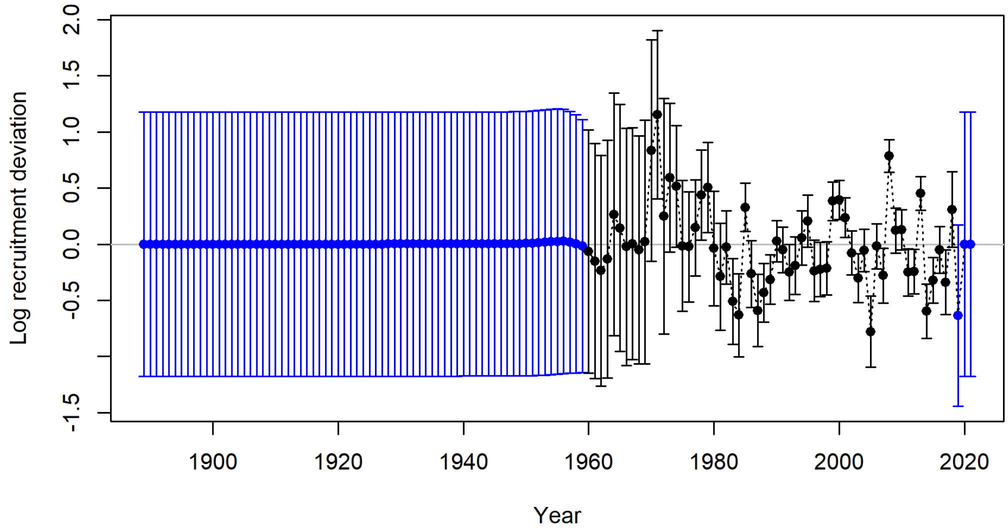

Figure v: Estimated time series of recruitment deviations.

Exploitation status

The harvest rate was estimated to have never been above the target proxy harvest rate (Table iv; Figure vi). Recent estimates of fishing intensity indicate stability within the fishery and are close to pre-1950 estimates. The relative fishing intensity is estimated to have peaked in 1991 at a value of (1 - SPR)/(1-SPR45%) = 0.93.

Table iv: Estimated recent trend in relative fishing intensity and exploitation rate with associated 95% intervals. Fishing intensity is (1-SPR)/(1-SPR45%), where SPR is the spawning potential and SPR45% = 0.45 is the SPR target. Exploitation rate is annual total dead catch divided by age 3+ biomass.

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

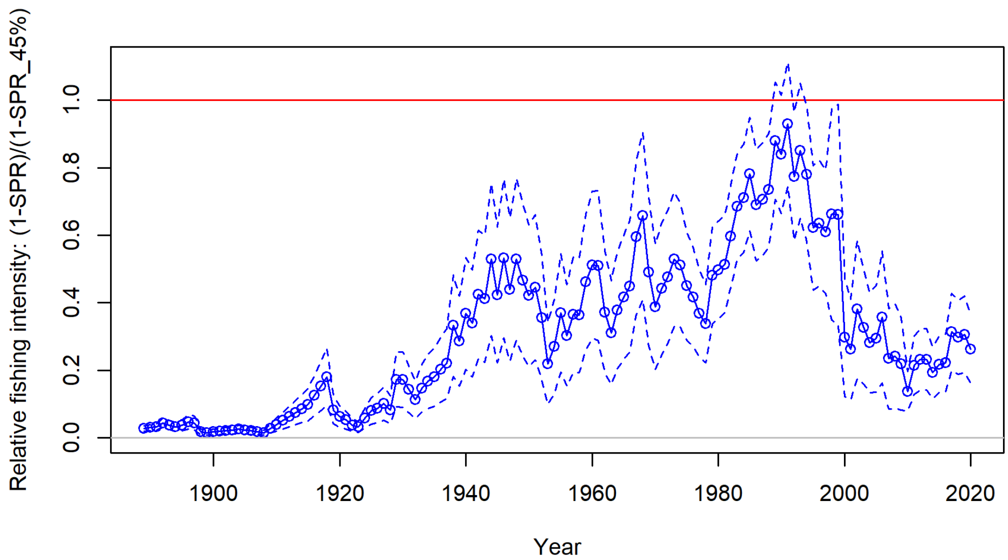

Figure vi: Estimated relative fishing intensity = (1-SPR)/(1-SPR45%) with 95% intervals, where SPR is the spawning potential and SPR45% = 0.45 is the SPR target. The red horizontal line at 1.0 indicates fishing intensity equal to the target and values above this reflect harvest in excess of the proxy 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 2021 spawning biomass relative to unfished equilibrium biomass (fraction unfished) was estimated to be well above the management target at 0.6416; even the lower interval was estimated to be above the target (Table vi; Figures vii and viii).

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

Reference point	Estimate	Lower interval	Upper interval
Unfished Spawning Biomass (mt)	17159.8	13486.6903	20832.9097
Unfished Age 3+ Biomass (mt)	32693	24945.2232	40440.7768
Unfished Recruitment (R0)	16734.6	9454.059	24015.141
Spawning Biomass (mt) (2021)	11010.2	7142.9167	14877.4833
Fraction Unfished (2021)	0.6416	0.5154	0.7679
Reference Points Based SB40%	-	-	-
Proxy Spawning Biomass (mt) SB40%	6863.91	5394.6661	8333.1539
SPR Resulting in SB40%	0.4372	0.3741	0.5002
Exploitation Rate Resulting in SB40%	0.2322	0.1794	0.2849
Yield with SPR Based On SB40% (mt)	3707.56	2395.7424	5019.3776
Reference Points Based on SPR Proxy for MSY	-	-	-
Proxy Spawning Biomass (mt) (SPR45)	7098.53	5534.9041	8662.1559
SPR45	0.45	NA	NA
Exploitation Rate Corresponding to SPR45	0.2224	0.2043	0.2404
Yield with SPR45 at SB SPR (mt)	3644.93	2488.9178	4800.9422
Reference Points Based on Estimated MSY Values	-	-	-
Spawning Biomass (mt) at MSY (SB MSY)	3675.78	1155.1095	6196.4505
SPR MSY	0.2629	0.0618	0.4639
Exploitation Rate Corresponding to SPR MSY	0.4301	0.0889	0.7713
MSY (mt)	4222.53	2271.0742	6173.9858

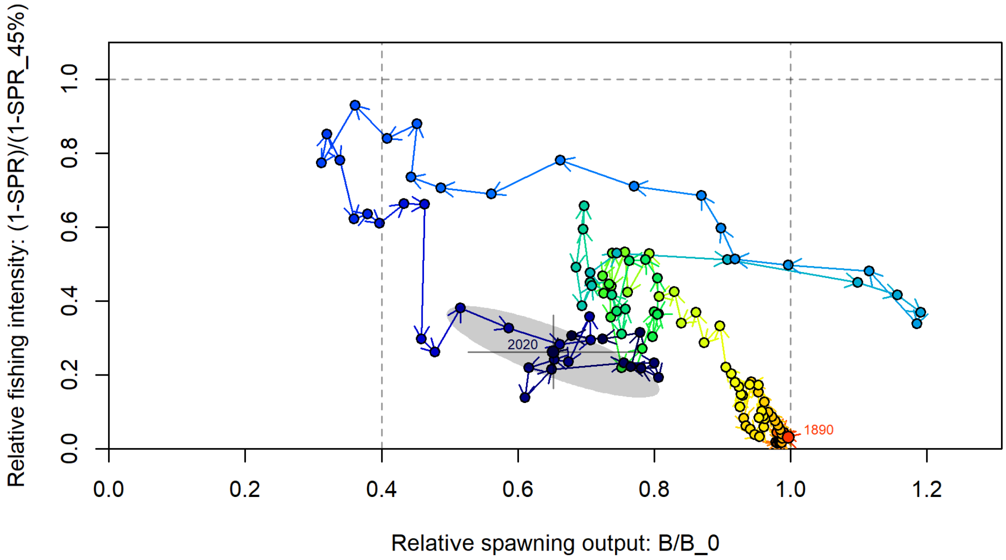

Figure vii: Phase plot of biomass ratio vs. spawning potential ratio (SPR) ratio. Each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show 95% intervals based on the asymptotic uncertainty for each dimension.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

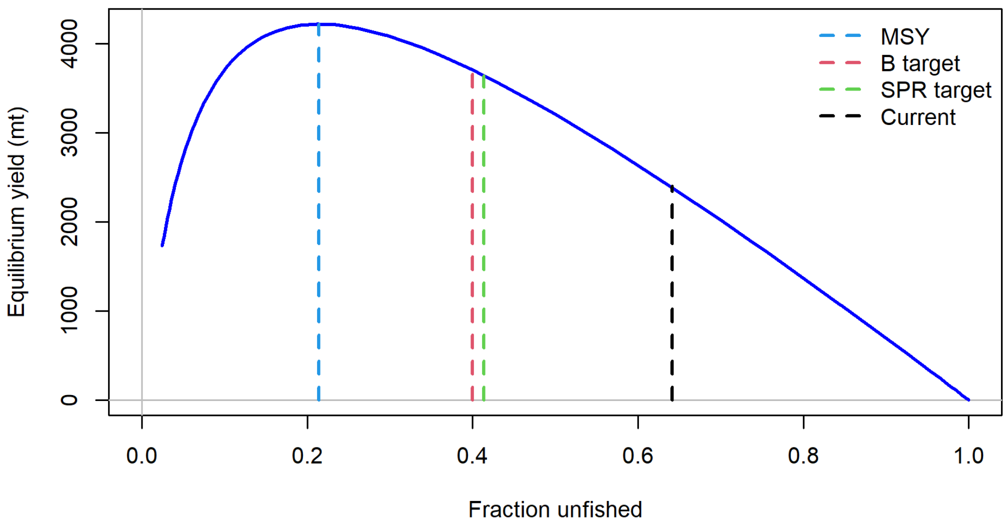

Figure viii: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivities.

Management performance

In the last ten years, the annual catch limit has been below the overfishing limit and acceptable biological catch (Table vi). Furthermore, 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 (OFL), the acceptable biological catches (ABCs), the annual catch limits (ACLs), the total landings, and total mortality (mt).

Year	OFL	ABC	ACL	Landings	Total mortality
2011	2438	2330	2330	631.14	657.19
2012	2251	2151	2151	784.03	811.65
2013	3334	3036	3036	860.19	881.28
2014	3162	2878	2878	716.13	728.86
2015	3010	2830	2830	796.16	808.29
2016	2891	2719	2719	789.45	806.49
2017	3549	3333	3333	1,144.47	1,172.02
2018	3310	3110	3110	1,014.26	1,035.71
2019	5110	4884	4871	980.92	1,004.75
2020	4768	4558	4541	783.66	803.86

Unresolved problems and major uncertainties

The base-model configuration was developed with the goal of balancing parsimony with realism and 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.

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

Three alternative catch streams were created for the decision table (Table viii). The first option uses recent average catch as provided by the Groundfish Management Team, the second option uses a P^* of 0.40, and the third option uses a P^* of 0.45. These P^* values are combined with the category 2 default $\sigma = 1.0$ in calculating the buffer between OFL and 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 Pstar of 0.45 and the category 2 default sigma = 1.0. ACLs additionally include the 40:10 adjustment for projections which fall below the B40 reference point.

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

Table viii: Decision table summary of 10-year projections based on recent average catch for the first two years of the projection, alternative states of nature (columns), and management assumptions (asm.; rows) based on recent average catch and annual catch limits (ACLs) defined using an estimate of uncertainty (i.e., P^*) of 0.40 and 0.45. Catch and resulting fraction unfished are colored relatively with lighter colors representing lower values. Italicized values indicate years where the full catch could not be removed from the low state of nature due to insufficient selected biomass.

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

Scientific uncertainty

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

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

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

Regional management considerations

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

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

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

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

Research and data needs

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

- Sex-specific selectivity is likely given the life history of lingcod, but 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 asympototic 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 prior to the review of this assessment suggested that information on natural mortality at age was lacking for the southern stock. 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.

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