Agenda Item E.8
Attachment 1
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2017 Lingcod Stock Assessment

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Contents

Executive Summary

Stock

This assessment applies to lingcod (*Ophiodon elongatus*) off the West Coast of the United States, and is conducted as two separate single stock assessment models, Washington and Oregon in the north, and California in the south. Four fisheries are modeled in the north: commercial trawl (including limited landings in other net gears), commercial fixed gears, and WA and OR recreational fisheries. Three fisheries are modeled in the south: commercial trawl (including limited landings in other net gears), commercial fixed gears, and CA recreational fisheries. Both models start in1889, at the onset of landings.

Landings

Historical commercial catch reconstructions were provided by each state that extend through 1995, 1986, and 1980 for Washington, Oregon, and California, respectively. Recent landings, from 1981 forward, were obtained from PacFIN. However, WDFW and ODFW staff advised that the catch reconstructions be used rather than PacFIN for overlapping years as the reconstructions are regarded as more reliable. Commercial landings were aggregated into two fleets: 1) vessels using primarily trawl gear, but also including other net gear that caught a small fraction of the fish, and 2) vessels using fixed gear such as longline, troll, and hook and line (Tables a and b, Figures a and b). Commercial discards were modeled using discard rate and length composition data to estimate retention curves, while estimates of recreational discards were included in the total landings. Landings declined significantly during 1980 to 2000, with trawl landings dominating the catch in the north, and recreational landings dominating the catch in the south. More recently landings in both regions have been increasing, with the recreational component of the landings growing in the north, and the recreational landings continuing to dominate in the south.

Table a. Recent landings, north. All units are in metric tons.

Years	North Trawl Gear	North Fixed Gears	WA Recreational*	Oregon Recreational	Total Landings
2005	79.32	58.01	78.31	140.84	356.48
2006	115.58	78.63	62.18	107.61	364.01
2007	113.63	71.17	68.21	104.02	357.03
2008	118.79	92.78	70.81	89.34	371.72
2009	93.47	81.47	74.25	78.76	327.95
2010	77.76	47.22	91.43	93.94	310.35
2011	283.43	57.64	117.78	114.99	573.83
2012	373.23	64.87	122.32	155.25	715.68
2013	360.35	78.34	127.32	224	790.01
2014	217.53	82.2	141.58	176.09	617.41
2015	163.4	132.54	271.95	226.17	794.07
2016	262.74	98.31	349.69	154.66	865.4

* Note that the WA recreational landings are entered into SS as numbers of fish, as reported by WDFW, SS then internally converts these landings to weights. The quantities reported for WA landings are the model converted values in metric tons.

Table b. Recent landings, south.

Years	South Trawl Gears	South Fixed Gears	South Recreational	Total Landings
2005	20.23	40.77	387.79	448.78
2006	24.79	36.08	316.87	377.74
2007	42.74	36.47	190.73	269.94
2008	34	36.22	106.96	177.18
2009	31.71	25.04	133.44	190.19
2010	23.05	23.68	107.35	154.08
2011	6.67	26.22	230.24	263.13
2012	16.34	31.46	281.44	329.23
2013	23.61	41.19	432.99	497.78
2014	36.77	70.06	571.82	678.65
2015	42.17	106.32	715.36	863.85
2016	40.21	75.62	647.29	763.12

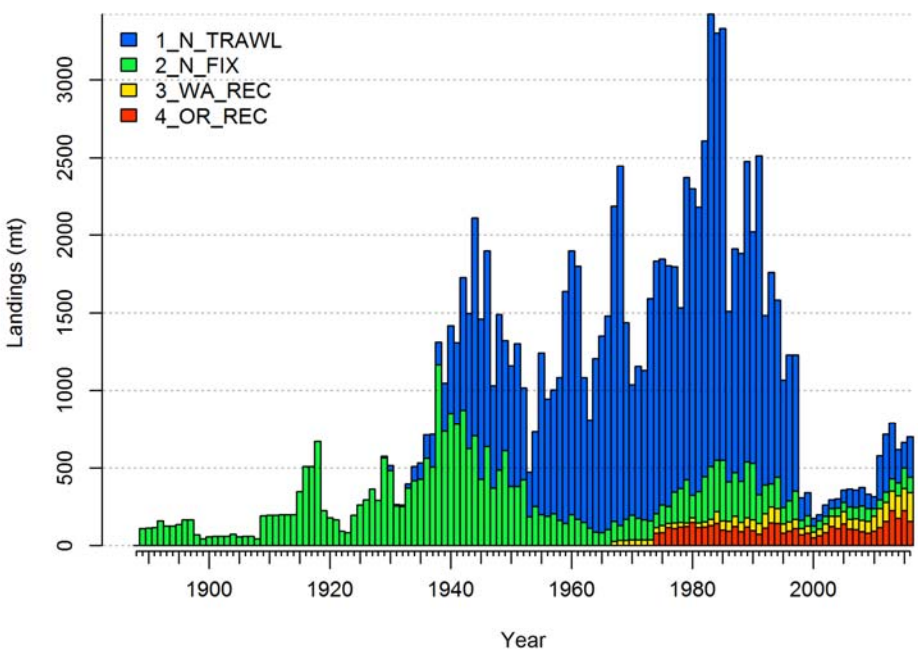

Figure a. North area landings.

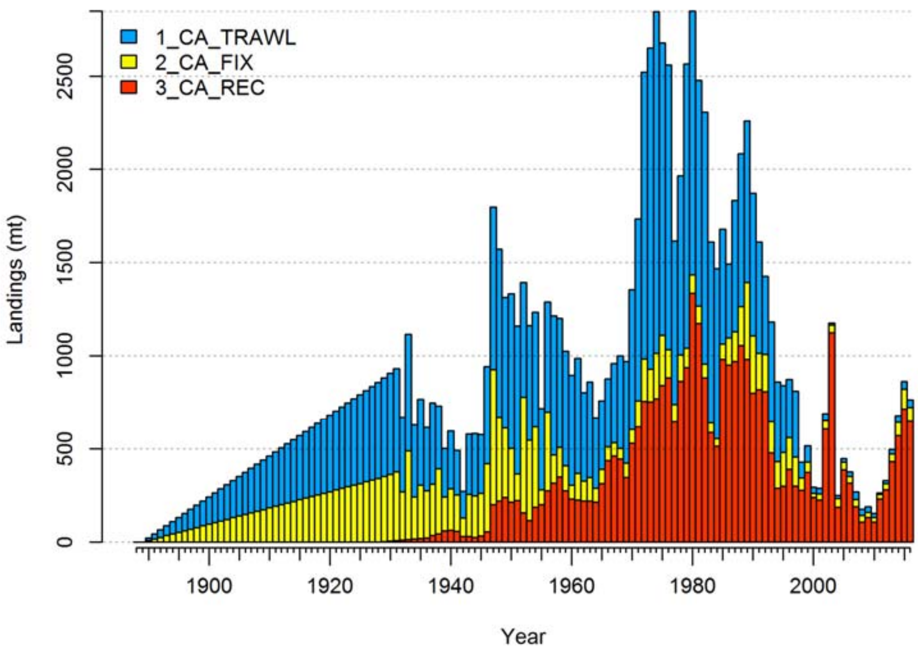

Figure b. South area landings

Data and Assessment

This assessment uses the Stock Synthesis (SS) fisheries stock assessment model, version 3.30.03.07. Lingcod has been modeled using various age-structured forward-projection models since the mid-1990s, with the most recent assessments conducted during 2005 (Jagielo et al. 2005) and 2009 (Hamel et al. 2009). Base model data sets include: landings data from each fleet; commercial discard data from the West Coast Groundfish Observer Program (WCGOP), NMFS Triennial bottom trawl survey, NWFSC bottom trawl survey, the NWFSC Hook and Line survey, PacFIN commercial logbook CPUE, OR nearshore commercial CPUE, both WA and OR recreational CPUE (North Only), commercial, recreational, and research length composition data, and survey age composition data (including CAAL data from the NWFSC bottom trawl survey). Concerns regarding biased sampling of commercial and recreational age composition data compared to the lengths lead to these data being removed from the base models. However, this issue can be addressed prior to the next assessment so that the lingcod age data can be included in the base models. In this assessment the impact of the current age data are show as model sensitivities. A research age and length composition data set from WDFW was also removed from the base model as the data set was limited and uninformative.

A wide range of sensitivity model runs for both the north and south stocks produce similar trajectories of stock decline and recovery, generally agreeing that both north and south lingcod stocks have increased since a low point during the 1990s. Of the key productivity parameters female natural mortality is fixed at the prior, male natural mortality is estimated, and stock-recruit steepness is fixed at 0.7, in keeping with the treatment of h for similar nest guarding species (e.g. Kelp Greenling). In the north, the base model is most sensitive to the inclusion of the fishery age data sets. Including only the Washington and Oregon conditional age-at-length data from the recreational fishery results in a lower estimate of unfished biomass but a similar estimate of stock status. Including only the marginal commercial age composition data results in a higher estimate of unfished biomass but similar stock status. In the south, the model is sensitive to removing the research data set collected by Lam et al., which results in a much higher unfished biomass estimate but a similar estimate of stock status. The south model is highly sensitive to the inclusion of the CA onboard observer index, which suggests a similar unfished stock size but a stock status that is well below the overfished threshold. Selectivity for all fleets and surveys were estimated using the composition data and are all estimated to be dome-shaped during recent years.

Stock Biomass

Tables c and d, and Figures c through f show the trends in spawning biomass and stock depletion. The north base model indicates that the lingcod female spawning biomass off of Washington and Oregon declined rapidly in the 1980s and 1990s, hitting a low during the mid-1990s, and has subsequently recovered to levels above the target reference point. The south base model indicates that the lingcod female spawning biomass off of California declined rapidly in the 1970s and early 1980s, reaching a low point during the 1990s, but that the southern stock has recovered above the minimum stock size threshold and remains in the precautionary zone (i.e. below the target reference point).

Stock status is currently estimated to be above the target reference point (40% of the estimated unfished spawning biomass) at 57.9% (47.9–67.8, 95% asymptotic interval) in the north and in the precautionary zone at 32.9% (12.0–53.9, 95% asymptotic interval) in the south. Unfished spawning biomass was measured at 37,947 mt (25,776–50,172 mt, 95% asymptotic interval) in the north and 20,462 mt (15,406–25,518 mt, 95% asymptotic interval) in the south. Spawning biomass at the beginning of 2017 was estimated to be 21,976 mt (12,517-31,434 mt, 95% asymptotic interval) in the north and 6,742 mt (1,775–11,709 mt, 95% asymptotic interval) in the south. The north stock is estimated to have been below the target reference point from approximately the 1980s through the early 2000s, while the south stock is currently estimated to be in the precautionary zone.

Table c. Recent trend in spawning biomass and stock depletion, north.

Years	Spawning Output	95% Asymptotic Interval	Estimated Depletion (%)	95% Asymptotic Interval
2005	14,711	8,479–20,943	38.7	31.5–46.0
2006	15,569	8,989–22,149	41	33.5–48.5
2007	15,833	9,111–22,556	41.7	34.1–49.3
2008	15,842	9,095–22,589	41.7	34.2–49.2
2009	15,627	8,940–22,314	41.2	33.8–48.5
2010	15,441	8,826–22,056	40.7	33.4–47.9
2011	15,912	9,150–22,674	41.9	34.7–49.1
2012	17,522	10,122–24,923	46.1	38.3–54.0
2013	19,235	11,116–27,355	50.7	42.1–59.2
2014	20,366	11,723–29,009	53.6	44.6–62.7
2015	20,939	12,019–29,858	55.1	45.8–64.5
2016	21,258	12,150–30,365	56	46.4–65.5
2017	21,976	12,517–31,434	57.9	47.9–67.8

Table d. Recent trend in spawning biomass and stock depletion, south.

Years	Spawning Output	95% Asymptotic Interval	Estimated Depletion (%)	95% Asymptotic Interval
2005	4,544	1,571–7,517	22.2	9.2–35.2
2006	4,834	1,551–8,117	23.6	9.4–37.9
2007	4,937	1,477–8,398	24.1	9.2–39.1
2008	4,866	1,376–8,355	23.8	8.7–38.8
2009	4,678	1,282–8,075	22.9	8.3–37.5
2010	4,407	1,169–7,646	21.5	7.7–35.4
2011	4,235	1,145–7,325	20.7	7.5–33.9
2012	4,199	1,180–7,219	20.5	7.7–33.4
2013	4,411	1,325–7,498	21.6	8.5–34.6
2014	4,853	1,515–8,192	23.7	9.6–37.8
2015	5,403	1,647–9,159	26.4	10.6–42.2
2016	6,040	1,696–10,383	29.5	11.2–47.8
2017	6,742	1,775–11,709	32.9	12.0–53.9

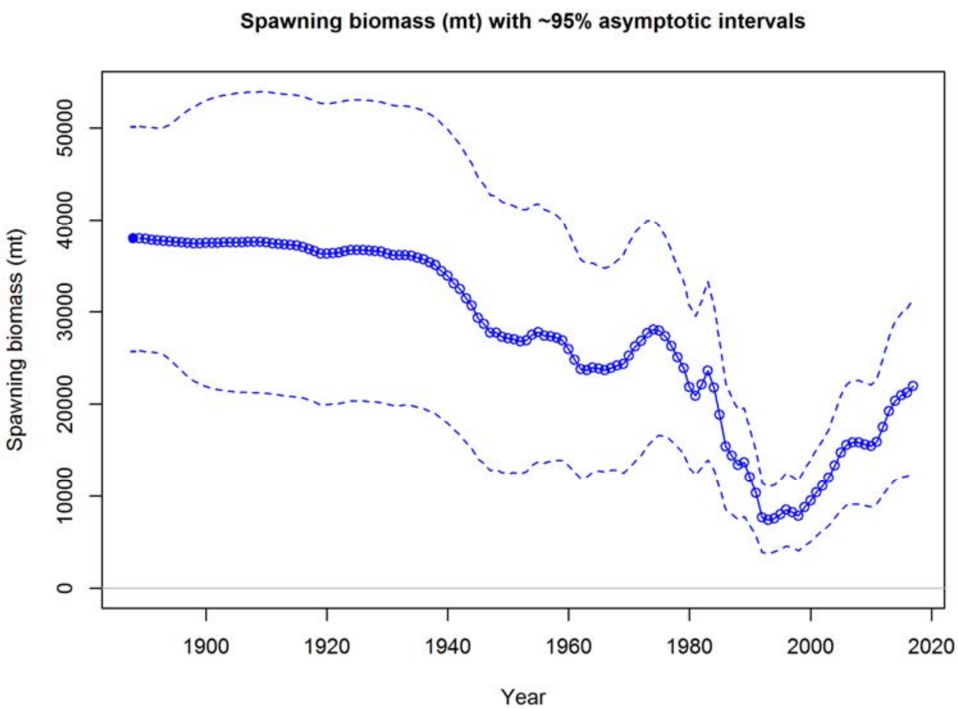

Figure c. Time series of spawning biomass, north.

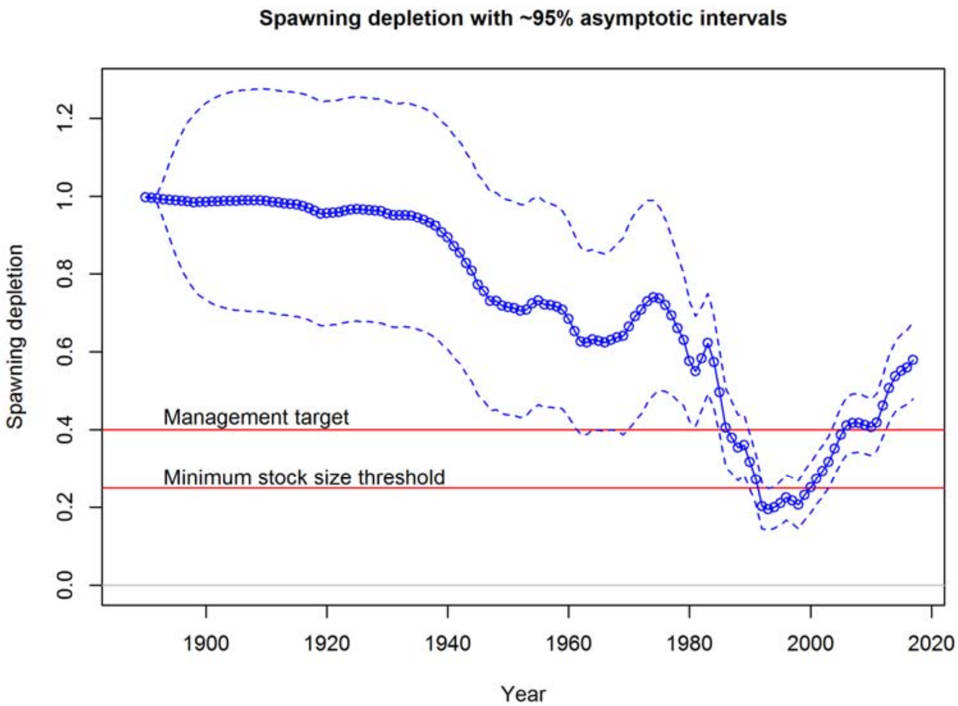

Figure d. Time series of stock depletion, north.

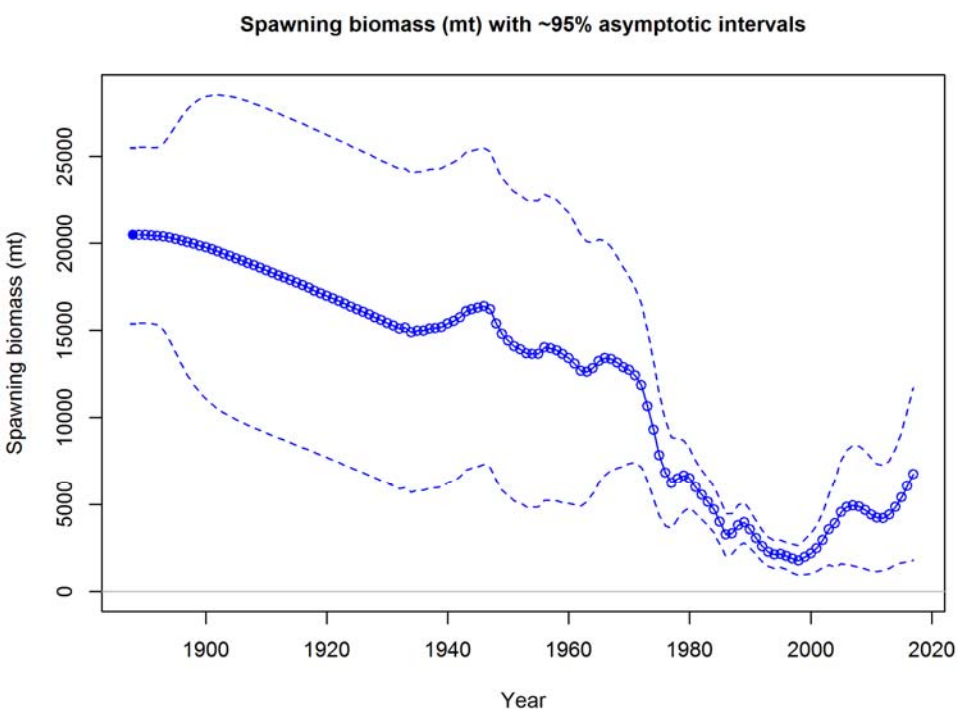

Figure e. Time series of spawning biomass, south.

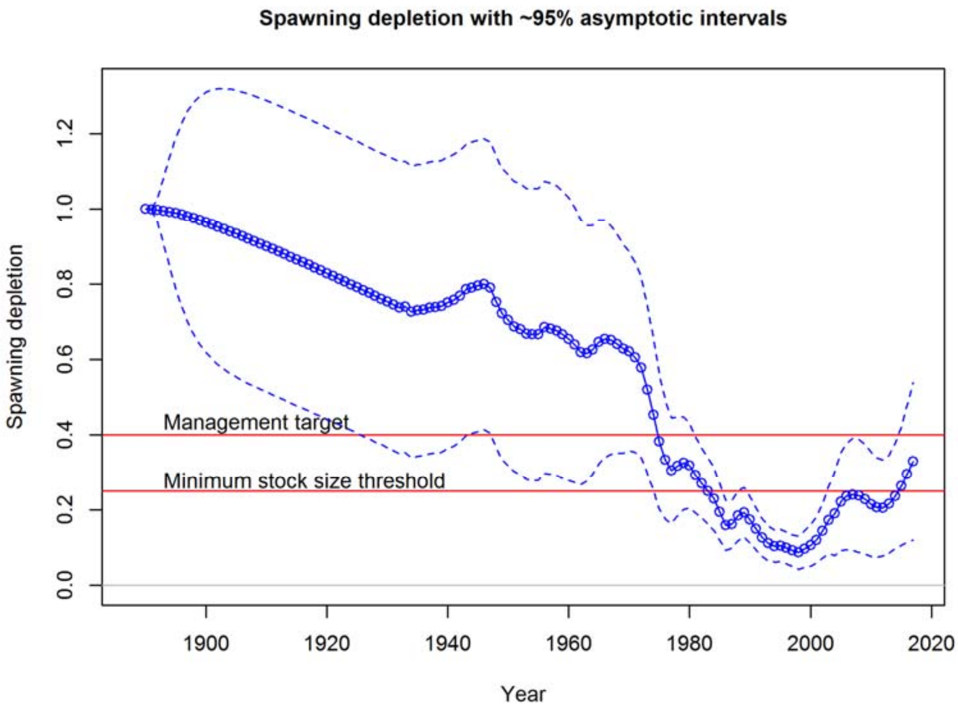

Figure f. Time series of stock depletion, south.

Recruitment

Recruitments in both the north and south were estimated from the model start through 2016 (Tables e and f, Figures g and h). Recruitments from 2017 forward are drawn exclusively from the stock-recruit curve, with corresponding levels of uncertainty. Large recruitment events in the north are estimated to have occurred during 1964-1965, 1969-1970, 1978-1980, 1985, 1990-1991, 2008, 2013 and 2015, while low recruitments were estimated to have occurred during 1986, 1996-1998, 2002-2007, 2011-2012, and 2014. Large recruitment events in the south are estimated to have occurred during 1961, 1973-1974, 1976-1977, and 1984-1985, while low recruitments were estimated to have occurred during 1981-1982, 1992-1993, 1995, 1997- 1998, 2002-2009, and 2014-2016. It is notable that lingcod in the south have not had a recruitment near historical high values since the mid-1980s.

Table e. Recent recruitment, north.

Years	Recruitment (1,000's)	95% Asymptotic Interval	Recruitment Deviations	95% Asymptotic Interval
2005	2,892	1,763–4,742	-0.803	-1.158–-0.447
2006	3,664	2,262–5,935	-0.579	-0.918–-0.241
2007	4,460	2,761–7,203	-0.387	-0.715–-0.058
2008	14,491	9,685–21,681	0.792	0.607–0.977
2009	6,292	3,961–9,996	-0.039	-0.346–0.267
2010	6,671	4,304–10,340	0.022	-0.238–0.281
2011	4,058	2,497–6,593	-0.482	-0.814–-0.150
2012	4,319	2,649–7,042	-0.44	-0.774–-0.107
2013	10,580	6,697–16,714	0.437	0.156–0.718
2014	4,851	2,528–9,307	-0.369	-0.929–0.191
2015	10,322	4,638–22,973	0.33	-0.422–1.082
2016	7,516	2,755–20,502	-0.041	-1.057–0.975
2017	8,037	2,813–22,958	0	-1.078–1.078

Table f. Recent recruitment, south.

Years	Recruitment (1,000's)	95% Asymptotic Interval	Recruitment Deviations	95% Asymptotic Interval
2005	637	329–1,236	-1.453	-1.977–-0.928
2006	454	223–922	-1.814	-2.407–-1.221
2007	792	429–1,461	-1.264	-1.712–-0.816
2008	1,799	1,071–3,021	-0.438	-0.752–-0.125
2009	1,928	1,146–3,244	-0.356	-0.675–-0.037
2010	3,807	2,272–6,379	0.345	0.068–0.623
2011	3,328	1,905–5,814	0.225	-0.095–0.546
2012	3,857	2,117–7,027	0.376	0.022–0.730
2013	5,174	2,805–9,541	0.652	0.284–1.019
2014	2,077	1,084–3,981	-0.294	-0.782–0.194
2015	1,823	834–3,986	-0.459	-1.151–0.233
2016	1,450	499–4,214	-0.854	-1.937–0.230
2017	4,007	1,056–15,200	0	-1.470–1.470

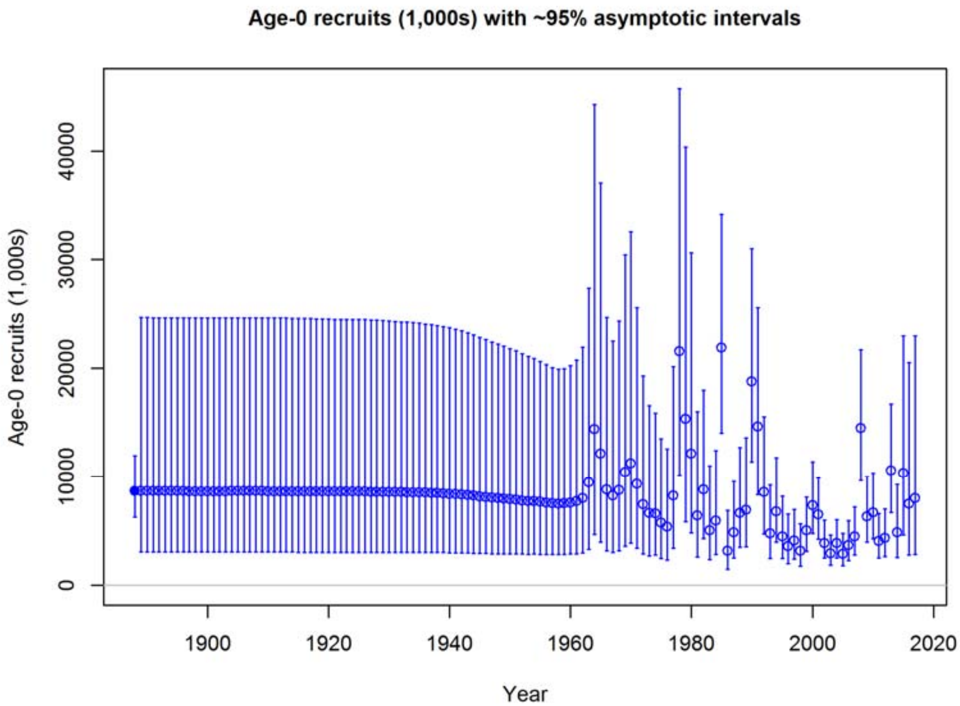

Figure g. Time series of estimated recruitment, north.

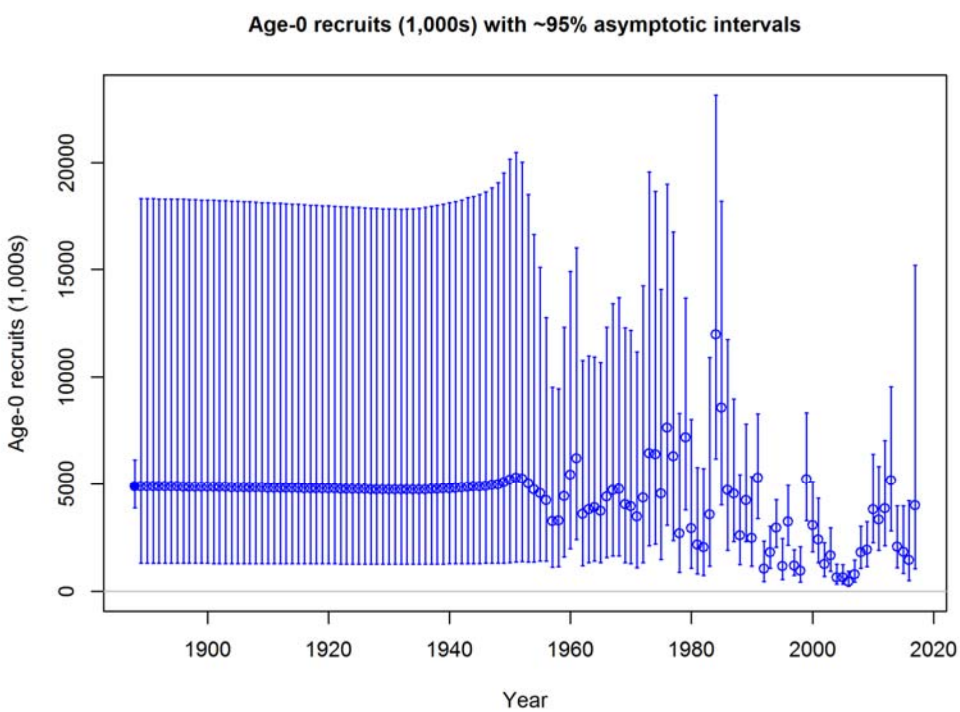

Figure h. Time series of estimated recruitments, south.

Exploitation Status

Historical harvest rates rose steadily through the 1990s, exceeding the target SPR harvest rate for several decades (Tables g and h, Figures i through l). Estimated harvest rates for the north and south models have not exceeded management target levels in recent years (Tables g and h, Figures i through l). However, in the south during the early 2000's it appears that harvest rates exceeded the management target for two years. In recent years, the spawning potential ratio (SPR) for lingcod in both areas has been above the proxy target of 45% (indicating fishing mortality rates are below the target). The full exploitation history in terms of both biomass and relative SPR, (1-SPR)/(1-$SPR_{45\%}$), is portrayed graphically via a phase plot (Figures k and l).

Table g. Recent exploitation status, north. Harvest rate is catch/Age-3+ summary biomass.

Years	Estimated (1-SPR)/(1-SPR_45%) (%)	95% Asymptotic Interval	Harvest Rate (proportion)	95% Asymptotic Interval
2005	0.237	14.83–32.57	0.113	0.066–0.160
2006	0.2662	16.69–36.54	0.122	0.071–0.173
2007	0.2355	14.53–32.56	0.103	0.059–0.146
2008	0.2619	16.21–36.17	0.11	0.063–0.156
2009	0.2444	15.05–33.83	0.099	0.057–0.140
2010	0.193	11.89–26.71	0.08	0.046–0.113
2011	0.2818	17.82–38.55	0.12	0.071–0.169
2012	0.2914	18.47–39.81	0.136	0.080–0.192
2013	0.2865	18.08–39.22	0.139	0.082–0.196
2014	0.2183	13.48–30.17	0.107	0.063–0.152
2015	0.2324	14.35–32.14	0.115	0.067–0.163
2016	0.2504	15.46–34.62	0.115	0.067–0.163

Table h. Recent exploitation status, south. Harvest rate is catch/Age-3+ summary biomass.

Years	Estimated (1-SPR)/(1-SPR_45%) (%)	95% Asymptotic Interval	Harvest Rate (proportion)	95% Asymptotic Interval
2005	0.5096	22.71–79.22	0.304	0.109–0.499
2006	0.4724	20.21–74.26	0.247	0.082–0.413
2007	0.4123	17.02–65.43	0.188	0.057–0.318
2008	0.3333	13.36–53.31	0.129	0.037–0.222
2009	0.4269	18.50–66.88	0.146	0.040–0.252
2010	0.4179	18.62–64.95	0.123	0.033–0.214
2011	0.6601	33.62–98.40	0.205	0.059–0.351
2012	0.7041	37.01–103.81	0.255	0.078–0.432
2013	0.787	42.75–114.66	0.339	0.113–0.564
2014	0.8056	43.05–118.08	0.413	0.141–0.686
2015	0.8299	42.79–123.19	0.467	0.152–0.783
2016	0.6571	28.86–102.55	0.356	0.107–0.606

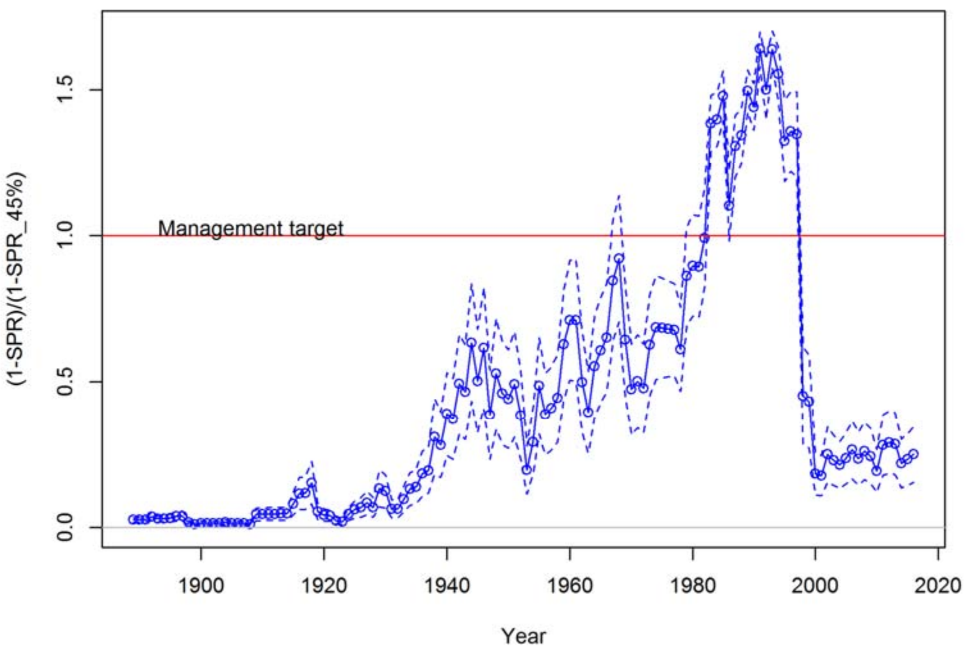

Figure i. Estimated spawning potential ratio (SPR), north. One minus SPR is plotted so that higher exploitation rates occur in the upper portion of the y-axis.

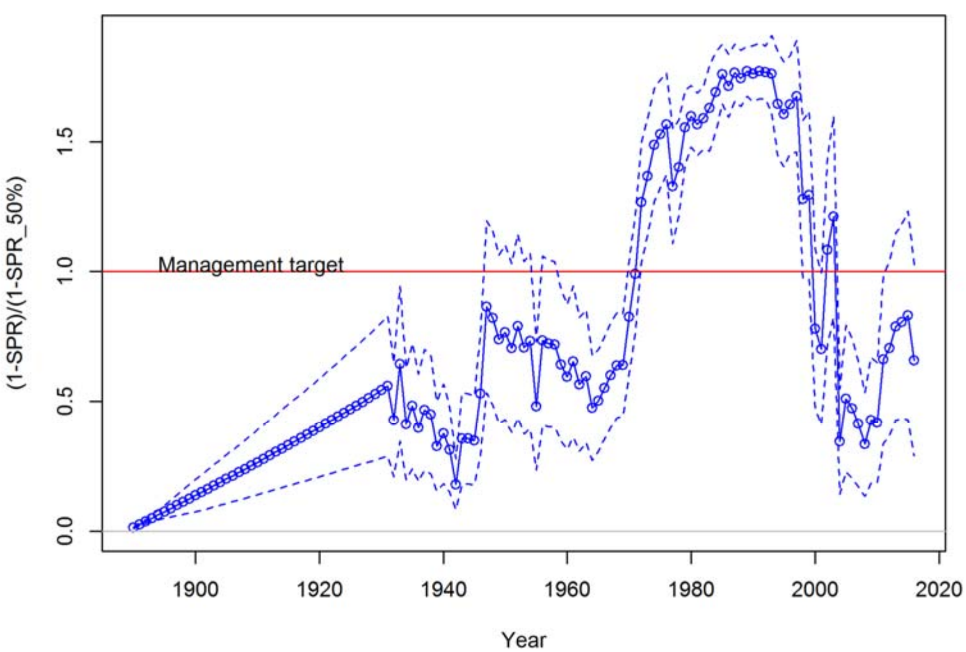

Figure j. Estimated spawning potential ratio (SPR), south. One minus SPR is plotted so that higher exploitation rates occur in the upper portion of the y-axis.

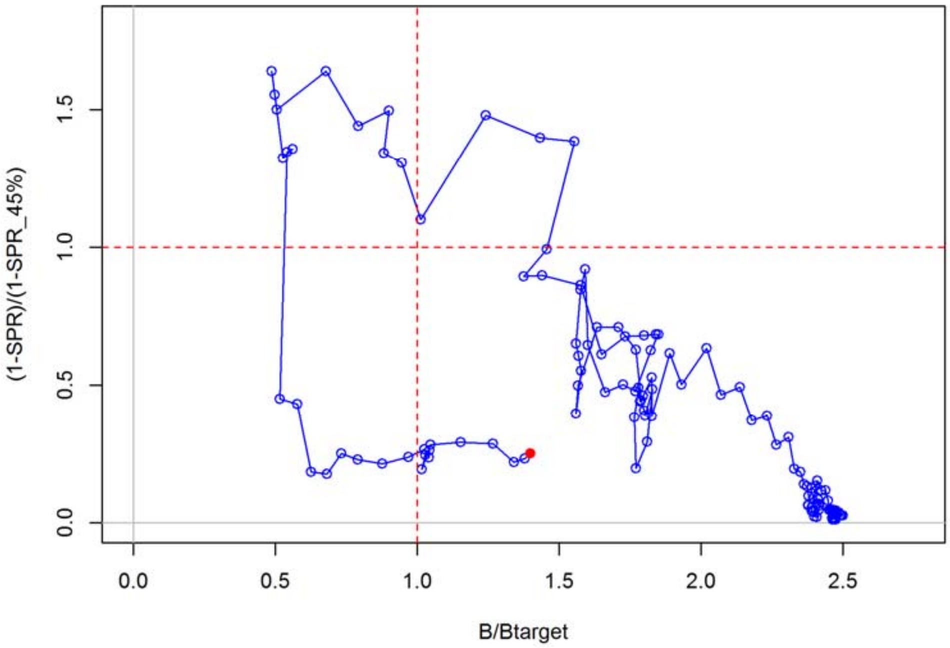

Figure k. Phase plot of estimated relative (1-SPR) vs. relative spawning biomass, north.

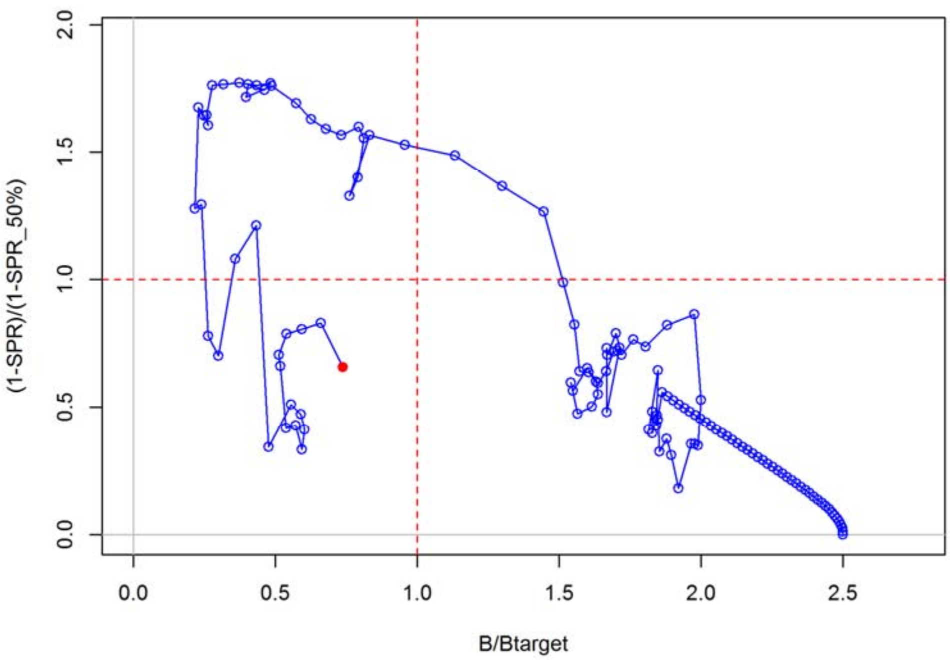

Figure l. Phase plot of estimated relative (1-SPR) vs. relative spawning biomass, south.

Ecosystem Considerations

In this assessment, ecosystem considerations were not explicitly included in the analysis. Lingcod often feed on target species of rockfish, particularly when these species are abundant (e.g., Beaudreau and Essington 2007).

However, there is a paucity of relevant data to provide quantitative information on this effect directly to the assessment. Recently available habitat information was used to select the data used in the onboard observer indices.

Reference Points

The north and south stocks are estimated to have been below the target reference point from approximately the 1980s through the early 2000s. Fishing intensity since approximately 2005 has been below the target for both the north and south stocks (Figures i - l). The phase plots show the interaction of fishing intensity and biomass targets (Figures k and l). The target stock size based on the biomass target (SB40%) is 15,190 10,311–20,069 mt, 95% asymptotic interval) in the north and 8,185 mt (standard deviation 569.7 mt) in the south, which gives catches of 2291.9 mt (standard deviation 58.1 mt) for the north and 1982.1 mt (6,162–10,207, 95% asymptotic standard deviation) for the south (Tables i and j). Equilibrium yield at the proxy FMSY harvest rate is 3,241 mt (2,215–4,268 mt, 95% asymptotic interval) and 1,658 mt (1,299–2,016 mt, 95% asymptotic interval) for the north and south, respectively (Tables i and j).

Table i. Reference points, north. Note that exploitation rate is Catch/(Age-3+ biomass).

	Estimate	95% Asymptotic Interval
Unfished Spawning Biomass (mt)	37,974	25,776–50,172
Unfished Age 3+ Biomass (mt)	56,005	38,126–73,884
Spawning Biomass (2017)	21,976	12,517–31,434
Unfished Recruitment (R0)	8,664	5,870–11,458
Depletion (2017)	57.87	47.94–67.80
Reference Points Based SB40%		
Proxy Spawning Biomass (SB40%)	15,190	10,311–20,069
SPR resulting in SB40%	0.464	0.464–0.464
Exploitation Rate Resulting in SB40%	0.126	0.123–0.129
Yield with SPR Based On SB40% (mt)	3,197	2,184–4,210
Reference Points based on SPR proxy for MSY		
Proxy spawning biomass (SPR45)	14,582	9,898–19,266
SPR45	0.45	NA
Exploitation rate corresponding to SPR45	0.132	0.129–0.135
Yield with SPR45 at SBSPR (mt)	3,241	2,215–4,268
Reference points based on estimated MSY values		
Spawning biomass at MSY (SBMSY)	10,254	6,966–13,542
SPRMSY	0.348	0.345–0.351
Exploitation rate corresponding to SPRMSY	0.187	0.183–0.190
MSY (mt)	3,409	2,329–4,489

Table j. Reference points, south. Note that exploitation rate is Catch/(Age-3+ biomass).

	Estimate	95% Asymptotic Interval
Unfished Spawning Biomass (mt)	20,462	15,406–25,518
Unfished Age 3+ Biomass (mt)	31,547	24,121–38,973
Spawning Biomass (2017)	6,742	1,775–11,709
Unfished Recruitment (R0)	4,881	3,763–5,999
Depletion (2017)	32.95	12.02–53.88
Reference Points Based SB40%		
Proxy Spawning Biomass (SB40%)	8,185	6,162–10,207
SPR resulting in SB40%	0.464	0.464–0.464
Exploitation Rate Resulting in SB40%	0.125	0.116–0.135
Yield with SPR Based On SB40% (mt)	1,732	1,357–2,106
Reference Points based on SPR proxy for MSY		
Proxy spawning biomass (SPR45)	9,003	6,779–11,228
SPR45	0.5	NA
Exploitation rate corresponding to SPR45	0.11	0.102–0.119
Yield with SPR45 at SBSPR (mt)	1,658	1,299–2,016
Reference points based on estimated MSY values		
Spawning biomass at MSY (SBMSY)	5,317	3,997–6,636
SPRMSY	0.339	0.334–0.344
Exploitation rate corresponding to SPRMSY	0.196	0.184–0.208
MSY (mt)	1,868	1,465–2,272

Management Performance

The 2009 stock assessment estimated lingcod to be at 61.9% and 73.7% of unfished spawning stock biomass in the north and south, respectively. Based on the 2009 stock assessment, the most recent 2017 and 2018 ACTs were set to 3066.4 and 2861.2 in the north and 1517.6 and 1392.8 in the south. Note that these values are based on reallocating 8% of the ACT north of 40-10 management line to the south. The value of 8% is based on the 5 year average biomass distribution in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS). Recent coast-wide annual landings have not exceeded the ACL.

Table k. Recent trends in landings and total catch (mt) relative to management guidelines. Total dead catch 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, which are the "official" records for determining whether the ACL has been exceeded.

Years	Spatial Management Strata	Coast-wide OFL	North OFL	South OFL	Coast-wide ABC	North ABC	South ABC	North Landings	North Total Dead	South Landings	South Total Dead
2005	Coast-wide	2,922	NA	NA	2,414	NA	NA	356	502	449	462
2006	Coast-wide	2,716	NA	NA	2,414	NA	NA	364	544	378	390
2007	Coast-wide	6,706	NA	NA	6,706	NA	NA	358	459	270	289
2008	Coast-wide	5,853	NA	NA	5,853	NA	NA	374	480	177	191
2009	Coast-wide	5,278	NA	NA	5,278	NA	NA	331	424	190	202
2010	Coast-wide	4,829	NA	NA	4,829	NA	NA	315	343	154	160
2011	Split at 42º N	4,961	2438	2523	4,432	2,330	2,102	578	611	263	265
2012	Split at 42º N	4,848	2251	2597	4,315	2,151	2,164	717	748	329	334
2013	Lingcod Split at 40º10' N	4,668	3,334	1,334	4,147	3,036	1,111	790	813	498	505
2014	Lingcod Split at 40º10' N	4,438	3,162	1,276	3,941	2,878	1,063	619	632	679	690
2015	Lingcod Split at 40º10' N	4,215	3,010	1,205	3,834	2,830	1,004	662	677	864	877
2016	Lingcod Split at 40º10' N	4,027	2,891	1,136	3,665	2,719	946	702	723	763	774
2017	Lingcod Split at 40º10' N	5,051	3,549	1,502	4,584	3,333	1,251	NA	NA	NA	NA
2018	Lingcod Split at 40º10' N	4,683	3,310	1,373	4,254	3,110	1,144	NA	NA	NA	NA

Unresolved Problems and Major Uncertainties

A few outstanding issue remain for lingcod stock assessment on the west coast of the U.S. First, the commercial age data need to be resampled to ensure that they are representative of the sampled lengths. There is evidence of bias in some years with respect to age sampling. While this issue was not able to be fully resolved at the STAR panel, a resolution is possible for the next lingcod assessment. Future assessments should also investigate implementing a spatial model that is able to explore linkages between the north and south regions as lingcod are a single genetic stock but show differences in biological traits, such as growth and allometry, which may be attributable to physical and ecological differences across this large geographic expanse. There is evidence that the recreational lingcod fishery in California is landing fish from Mexican waters. Landings from Mexican waters need to be removed from the U.S. landings in future lingcod assessments. Finally, it would be useful to explore the availability of transboundary lingcod data (both Canada and Mexico) and how these data could be used in the PFMC stock assessment process. Both of these issues require communications and research activity outside of the PFMC stock assessment cycle. Time limitations during this assessment did not allow for exploration of Canadian lingcod data or inclusion in the assessment model. Mexico may also have relevant lingcod data but this has not been investigated.

Decision Table

The lingcod stock assessments are Category 1 stock assessments (subject to SSC approval), thus projections and decision tables are based on using P*=0.45 and sigma = 0.36, resulting in a multiplier on the OFL of 0.956. This is combined with the 40-10 harvest control rule to calculate OFLs, ABCs and ACLs. The total catches in 2017 and 2018 were assumed to equal the PFMC-adopted ACLs, and the average 2015-2017 exploitation rate was used to distribute catches among the fisheries. Uncertainty in management quantities for the north and south models was characterized using the asymptotic standard deviations for the 2017 spawning biomass from the base model. A fixed value of Ro was used to attain the 2017 spawning biomass values for the lower and upper states of nature, given by the base model mean +/- 1.15*standard deviation. The values for Ro were identified using likelihood profile model runs to produce a plot of Ro versus 2017 spawning biomass. The high catch stream in the decision table is given by the 40-10 control rule. At the request of the GMT representative on the STAR panel the moderate catch streams were set to 40% ACL attainment for the north and 70% ACL attainment in the south. Finally, the low catch stream was set to ~700 mt, a level similar to recent average catches.

Harvest projections are provided in Tables l and m. In the north, current medium-term projections of expected catch, spawning biomass and depletion from the base model project a declining trend through 2028 as recent large cohorts increase in age (note that all projections assume average recruitment from the stock-recruit curve) and the 40-10 control rule ACLs move the stock towards the target reference point. The stock is expected to remain above the target stock size of $SB_{40\%}$ through 2026, assuming average recruitment based on the stock-recruit curve. In the south, current medium term projection of expected catch, spawning biomass and depletion from the base model project a declining trend through the projection period, with the stock remaining just above the minimum stock size threshold $SB_{25\%}$ through the projection period. The lack of increasing stock sizes during the projections is due, in part, to a large number of poor recruitments since 2000 (11 out of 17 years) and a lack of recruitments near historical highs.

Decision tables are provided in Tables n and o. In the north, current medium-term forecasts based on the alternative states of nature project that the stock will fall below the target stock size in only case, in which the current control rule is applied to the low stock state of nature (bottom left corner of the table). All other decision table scenarios keep the stock at or above the target stock size. In the south, current medium-term forecasts based on the alternative states of nature project a range of outcomes from effective extirpation to increases above the target stock size. All of the low state of nature scenarios suggest that the stock is overfished and only in the constant catch scenario does the stock increase into the precautionary zone. The most pessimistic scenario, the application of the 40-10 rule to the low state of nature, suggests that the stock is extirpated from the south by 2024 (bottom left corner of the table). However, all catch scenarios under the high state of nature suggest that the stock will increase to above or near the target reference point. The constant and 75% ACL catches from the base case model allow the stock to increase towards, or exceed the target reference point.

Table l. Model projections, north.

Year	Predicted OFL (mt)	ACL Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Depletion (%)
2017	4,815.82	3,058.30	34,063.80	21,975.70	57.87
2018	4,711.84	2,844.79	33,998.90	21,239.20	55.93
2019	4,690.12	4,497.30	33,538.10	20,944.30	55.15
2020	4,458.62	4,275.36	31,723.50	19,737.80	51.98
2021	4,271.91	4,096.33	30,257.40	18,683.70	49.2
2022	4,126.12	3,956.53	29,105.30	17,821.00	46.93
2023	4,012.88	3,847.95	28,189.10	17,134.60	45.12
2024	3,923.16	3,761.93	27,451.10	16,586.10	43.68
2025	3,850.11	3,691.90	26,847.70	16,141.10	42.51
2026	3,789.18	3,633.48	26,347.50	15,774.10	41.54

Table m. Model projections, south.

Year	Predicted OFL (mt)	ACL Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Depletion (%)
2017	2,523.12	1,517.64	11,609.70	6,741.96	32.95
2018	2,322.09	1,392.80	10,976.00	6,664.33	32.57
2019	2,115.26	1,846.79	10,021.10	6,292.18	30.75
2020	1,940.77	1,604.91	9,403.82	5,630.36	27.52
2021	1,941.60	1,564.67	9,268.10	5,370.23	26.25
2022	1,998.58	1,605.35	9,332.59	5,334.50	26.07
2023	2,049.60	1,651.55	9,407.48	5,359.83	26.19
2024	2,079.88	1,679.93	9,449.77	5,380.20	26.29
2025	2,094.79	1,692.73	9,465.75	5,383.80	26.31
2026	2,101.99	1,697.75	9,470.86	5,379.30	26.29

Research and Data Needs

Most of the research needs listed below entail investigations that need to take place outside of the routine assessment cycle and require additional resources to be completed.

1. Age validation of lingcod aging is needed to verify the level of age bias, if any.
2. A transboundary stock assessment and the management framework to support such assessments would be beneficial.
3. A survey in untrawlable habitat and/or a near shore survey would improve this stock assessment. Other survey techniques could include longline, combined lingcod/sablefish pot survey, or trap surveys.
4. Investigate environmental covariates for recruitment and time-varying growth and availability inshore.
5. The impact of nest-guarding on reproductive output should be investigated. The current assessment focuses on female spawning biomass as the limiting factor in reproductive output, but nest guarding by lingcod males and the availability of nesting habitat may also play roles. A cursory look at the proportion of sex ratio in the catch did not appear to indicate any serious changes for either north or south populations in recent years. However, we do not know what kind of change in sex ratio would indicate a serious change in reproductive success.

6. Investigation of the proportion of fish caught in Mexico and landed in U.S. ports as there is evidence that California recreational fisheries, primarily out of San Diego, are fishing in Mexican waters. These catches should be allocated appropriately between U.S. and Mexican waters.

Rebuilding Projections

Lingcod stocks in the California Current are not overfished and do not require rebuilding analyses.

Table n. Summary of model outputs, north. Uncertainty in management quantities for the north and south models was characterized using the asymptotic standard deviations for the 2017 spawning biomass from the base model. A fixed value of Ro was used to attain the 2017 spawning biomass values for the lower and upper states of nature, given by the base model mean +/- 1.15*standard deviation.

			State of nature					
			Low 2017 Spawning Biomass *Ln(Ro)=8.81*		Base case 2017 Spawning Biomass *Ln(R0) = 9.0669*		High 2017 Spawning Biomass *Ln(Ro)=9.8*	
Probability			0.25		0.5		0.25	
Manage-ment decision	Year	Catch (mt)	Spawning biomass (mt)	Depletion	Spawning biomass (mt)	Depletion	Spawning biomass (mt)	Depletion
~700mt Constant Catch	2019	695	14329	48.7	20944	55.2	51958	65.8
	2020	695	15227	51.8	22150	58.3	54488	69.0
	2021	697	16162	54.9	23337	61.5	56819	71.9
	2022	698	17084	58.1	24474	64.5	58968	74.6
	2023	698	17948	61.0	25527	67.2	60925	77.1
	2024	699	18741	63.7	26487	69.8	62686	79.3
	2025	699	19468	66.2	27357	72.0	64258	81.3
	2026	700	20129	68.4	28140	74.1	65649	83.1
	2027	700	20727	70.5	28840	76.0	66874	84.6
	2028	700	21267	72.3	29466	77.6	67952	86.0
40% of 40:10 Rule	2019	1785	14329	48.7	20944	55.2	51958	65.8
	2020	1698	14540	49.4	21455	56.5	53791	68.1
	2021	1642	14847	50.5	22009	58.0	55488	70.2
	2022	1575	15209	51.7	22585	59.5	57075	72.2
	2023	1533	15603	53.0	23171	61.0	58566	74.1
	2024	1499	16001	54.4	23741	62.5	59942	75.9
	2025	1472	16392	55.7	24287	64.0	61200	77.5
	2026	1449	16773	57.0	24803	65.3	62339	78.9
	2027	1430	17140	58.3	25287	66.6	63364	80.2
	2028	1413	17490	59.5	25740	67.8	64287	81.4
40:10 Rule	2019	4497	14329	48.7	20944	55.2	51958	65.8
	2020	4275	12863	43.7	19738	52.0	52084	65.9
	2021	4096	11601	39.4	18684	49.2	52171	66.0
	2022	3957	10538	35.8	17821	46.9	52295	66.2
	2023	3848	9682	32.9	17135	45.1	52518	66.5
	2024	3762	8963	30.5	16586	43.7	52799	66.8
	2025	3692	8339	28.3	16141	42.5	53118	67.2
	2026	3633	7779	26.4	15774	41.5	53455	67.7
	2027	3584	7266	24.7	15469	40.7	53800	68.1
	2028	3542	6788	23.1	15213	40.1	54149	68.5

Table o. Summary of model outputs, south. Uncertainty in management quantities for the north and south models was characterized using the asymptotic standard deviations for the 2017 spawning biomass from the base model. A fixed value of Ro was used to attain the 2017 spawning biomass values for the lower and upper states of nature, given by the base model mean +/- 1.15*standard deviation.

			State of nature					
			Low Ln(R0) = 8.122		Base case Ln(R0) = 8.493		High Ln(R0) = 8.742	
Management decision	Year	Catch (mt)	Spawning output (mt)	Depletion	Spawning output (mt)	Depletion	Spawning output (mt)	Depletion
Constant 700 mt catch	2019	700	2,725	19%	6,123	30%	8,894	34%
	2020	700	2,628	19%	6,144	30%	9,011	34%
	2021	700	2,739	20%	6,425	32%	9,441	36%
	2022	700	2,975	21%	6,908	34%	10,128	38%
	2023	700	3,248	23%	7,475	37%	10,930	41%
	2024	700	3,527	25%	8,067	40%	11,768	45%
	2025	700	3,810	27%	8,658	42%	12,600	48%
	2026	700	4,099	29%	9,238	45%	13,410	51%
	2027	700	4,395	31%	9,800	48%	14,186	54%
	2028	700	4,697	33%	10,340	51%	14,924	57%
75% ACL catch	2019	1,318	3,152	22%	6,572	32%	9,349	35%
	2020	1,154	2,707	19%	6,222	31%	9,092	34%
	2021	1,135	2,548	18%	6,214	30%	9,228	35%
	2022	1,173	2,524	18%	6,420	31%	9,634	37%
	2023	1,212	2,518	18%	6,696	33%	10,138	38%
	2024	1,237	2,489	18%	6,979	34%	10,662	40%
	2025	1,249	2,437	17%	7,250	36%	11,172	42%
	2026	1,255	2,372	17%	7,511	37%	11,666	44%
	2027	1,258	2,304	16%	7,765	38%	12,140	46%
	2028	1,261	2,232	16%	8,013	39%	12,596	48%
ABC 40-10 Rule	2019	1,757	2,725	19%	6,123	30%	8,894	34%
	2020	1,539	2,041	15%	5,512	27%	8,371	32%
	2021	1,513	1,685	12%	5,293	26%	8,292	31%
	2022	1,564	1,444	10%	5,291	26%	8,489	32%
	2023	1,616	1,179	8%	5,344	26%	8,775	33%
	2024	1,649	850	6%	5,388	26%	9,071	34%
	2025	1,665	NA	NA	5,412	27%	9,351	35%
	2026	1,673	NA	NA	5,425	27%	9,621	36%
	2027	1,678	NA	NA	5,435	27%	9,882	37%
	2028	1,681	NA	NA	5,445	27%	10,138	38%

Table p. Summary of model outputs, north. Note that exploitation rate is Catch/(Age-3+ biomass).

Years	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1-SPR	0.24	0.27	0.24	0.26	0.24	0.19	0.28	0.29	0.29	0.22	0.23	0.25	NA
Exploitation Rate	0.11	0.12	0.1	0.11	0.1	0.08	0.12	0.14	0.14	0.11	0.11	0.11	NA
Age 3+ Biomass (mt)	23,760	23,945	23,974	23,493	23,078	23,041	27,371	29,480	31,302	31,650	31,634	33,759	34,064
Spawning Biomass (mt)	14,711	15,569	15,833	15,842	15,627	15,441	15,912	17,522	19,235	20,366	20,939	21,258	21,976
95% Confidence Interval	8,479–20,943	8,989–22,149	9,111–22,556	9,095–22,589	8,940–22,314	8,826–22,056	9,150–22,674	10,122–24,923	11,116–27,355	11,723–29,009	12,019–29,858	12,150–30,365	12,517–31,434
Recruitment	2,892	3,664	4,460	14,491	6,292	6,671	4,058	4,319	10,580	4,851	10,322	7,516	8,037
95% Confidence Interval	1,763–4,742	2,262–5,935	2,761–7,203	9,685–21,681	3,961–9,996	4,304–10,340	2,497–6,593	2,649–7,042	6,697–16,714	2,528–9,307	4,638–22,973	2,755–20,502	2,813–22,958
Depletion (%)	38.7	41	41.7	41.7	41.2	40.7	41.9	46.1	50.7	53.6	55.1	56	57.9
95% Confidence Interval	31.5–46.0	33.5–48.5	34.1–49.3	34.2–49.2	33.8–48.5	33.4–47.9	34.7–49.1	38.3–54.0	42.1–59.2	44.6–62.7	45.8–64.5	46.4–65.5	47.9–67.8

Table q. Summary of model outputs, south. Note that exploitation rate is Catch/(Age-3+ biomass).

Years	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1-SPR	0.51	0.47	0.41	0.33	0.43	0.42	0.66	0.7	0.79	0.81	0.83	0.66	NA
Exploitation Rate	0.3	0.25	0.19	0.13	0.15	0.12	0.21	0.25	0.34	0.41	0.47	0.36	NA
Age 3+ Biomass (mt)	7,734	8,038	7,849	7,513	7,047	6,591	6,578	6,675	7,594	8,498	9,559	11,049	11,610
Spawning Biomass (mt)	4,544	4,834	4,937	4,866	4,678	4,407	4,235	4,199	4,411	4,853	5,403	6,040	6,742
95% Confidence Interval	1,571–7,517	1,551–8,117	1,477–8,398	1,376–8,355	1,282–8,075	1,169–7,646	1,145–7,325	1,180–7,219	1,325–7,498	1,515–8,192	1,647–9,159	1,696–10,383	1,775–11,709
Recruitment	637	454	792	1,799	1,928	3,807	3,328	3,857	5,174	2,077	1,823	1,450	4,007
95% Confidence Interval	329–1,236	223–922	429–1,461	1,071–3,021	1,146–3,244	2,272–6,379	1,905–5,814	2,117–7,027	2,805–9,541	1,084–3,981	834–3,986	499–4,214	1,056–15,200
Depletion (%)	22.2	23.6	24.1	23.8	22.9	21.5	20.7	20.5	21.6	23.7	26.4	29.5	32.9
95% Confidence Interval	9.2–35.2	9.4–37.9	9.2–39.1	8.7–38.8	8.3–37.5	7.7–35.4	7.5–33.9	7.7–33.4	8.5–34.6	9.6–37.8	10.6–42.2	11.2–47.8	12.0–53.9