2017 Lingcod Stock Assessment

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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 (including all line 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 (including all line gears), and CA recreational fisheries. Both models start during 1889, at the onset of landings.

Landings

Historical commercial landed 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 gear such as longline, troll, and hook and line, hereafter referred to as "fixed gear" vessels (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 Catch
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 Stock Synthesis 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

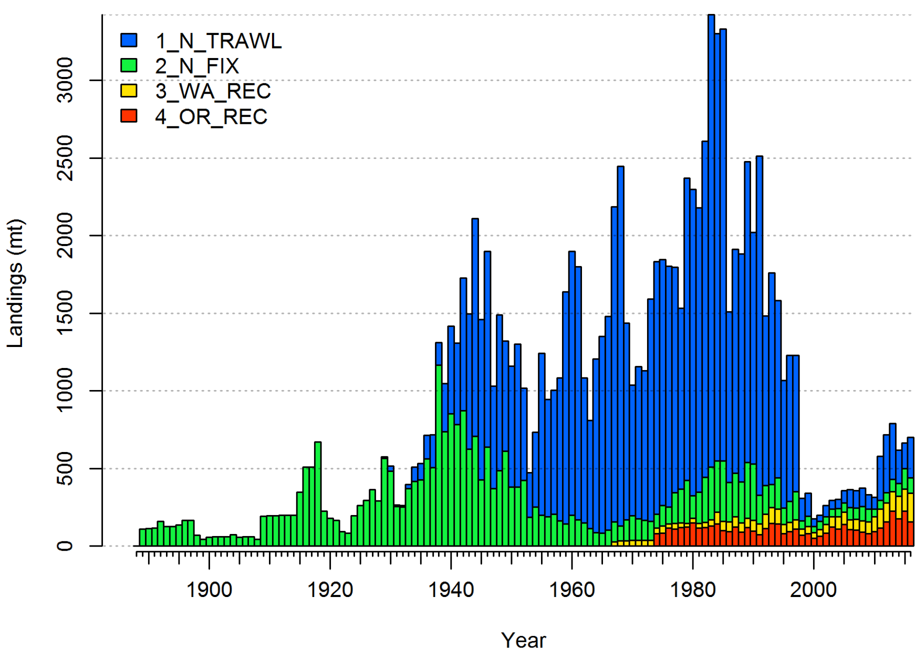

Figure a. North area landings.

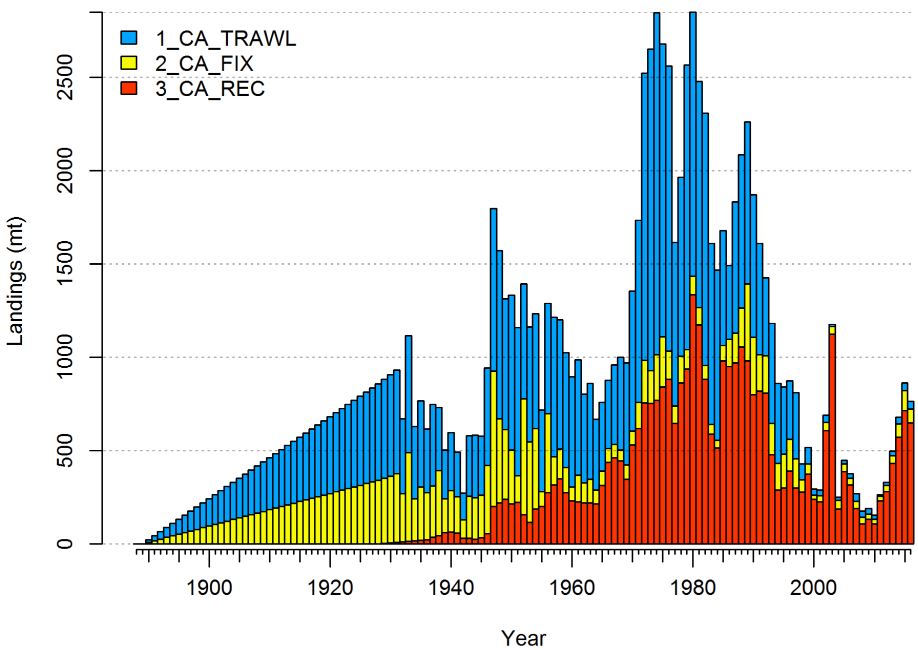

Figure b. South area landings

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 Conditional-age-at-length (CAAL) data from the NWFSC bottom trawl survey). Concerns regarding biased sub-sampling for age-determination from commercial and recreational samples lead to these age composition data being excluded from the base models. In this assessment the impact of the currently available age data are shown in model sensitivity runs. 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.

Of the key productivity parameters female natural mortality is fixed at the median of the prior, male natural mortality is estimated, and stock-recruit steepness is 0.7, in keeping with the treatment of h for similar nest guarding species (e.g. Kelp Greenling). Time-invariant, sex-specific growth is estimated in this assessment, with all SS growth parameters being estimated except for female length at maximum age in the north model. The log of the unexploited recruitment level for the Beverton-Holt stock-recruit function is treated as an estimated parameter. Annual recruitment deviations are estimated beginning in 1889, just prior to reliable length and age composition entering the models. Selectivities are estimated using the double normal pattern for all fleets and surveys. Retention is estimated for the commercial fishing fleets and is fit with time blocks to account for management changes.

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. 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. If the index is included (see south model sensitivities) the estimate of unfished stock size is similar to the base model but stock status that is well below the overfished threshold.

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 (40% of the estimated unfished spawning biomass). 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 (10% of the estimated unfished spawning biomass) 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 at 57.9% (47.9–67.8, 95% asymptotic interval) in the north and in the precautionary zone at 32.1% (11.1–53.1, 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 20,260 mt (15,304–25,215 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 6,509 mt (1,624–11,394 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 (between 25% and 40% of the estimated unfished spawning biomass).

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

Years	Spawning Biomass (mt)	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	4,398	1,475–7,321	21.7	8.7–34.7
2006	4,667	1,443–7,892	23	8.8–37.3
2007	4,757	1,362–8,153	23.5	8.5–38.4
2008	4,681	1,260–8,102	23.1	8.1–38.1
2009	4,496	1,169–7,824	22.2	7.6–36.8
2010	4,232	1,062–7,401	20.9	7.0–34.7
2011	4,065	1,044–7,087	20.1	6.9–33.2
2012	4,032	1,081–6,983	19.9	7.1–32.7
2013	4,242	1,224–7,259	20.9	7.9–34.0
2014	4,674	1,407–7,942	23.1	9.0–37.1
2015	5,209	1,527–8,891	25.7	9.9–41.5
2016	5,827	1,561–10,093	28.8	10.4–47.1
2017	6,509	1,624–11,394	32.1	11.1–53.1

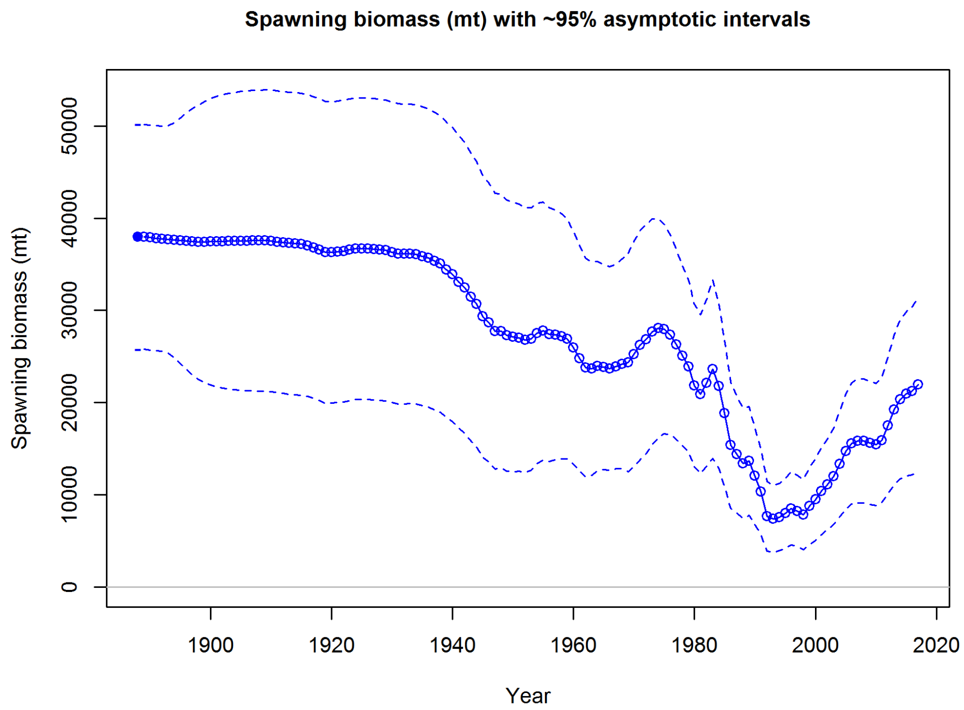

Figure c. Time series of spawning biomass, north.

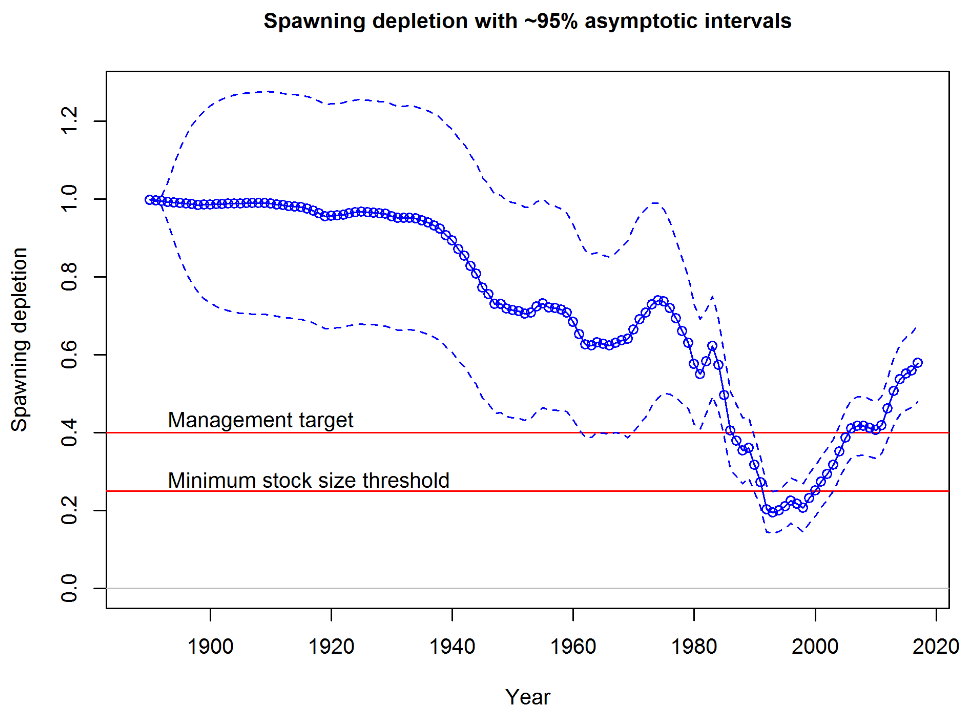

Figure d. Time series of stock depletion, north.

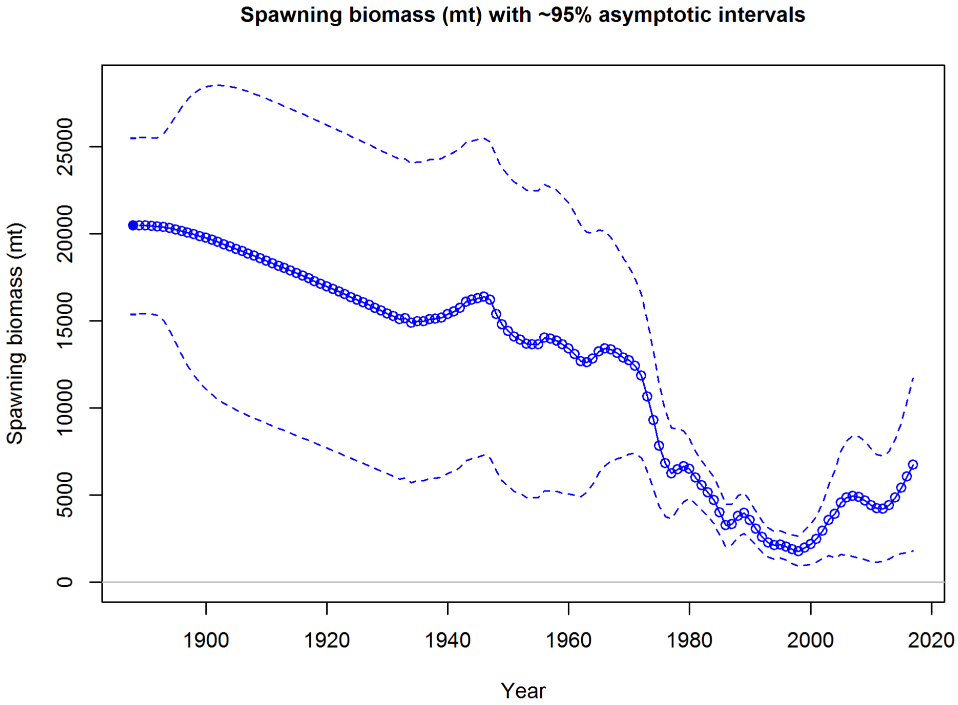

Figure e. Time series of spawning biomass, south.

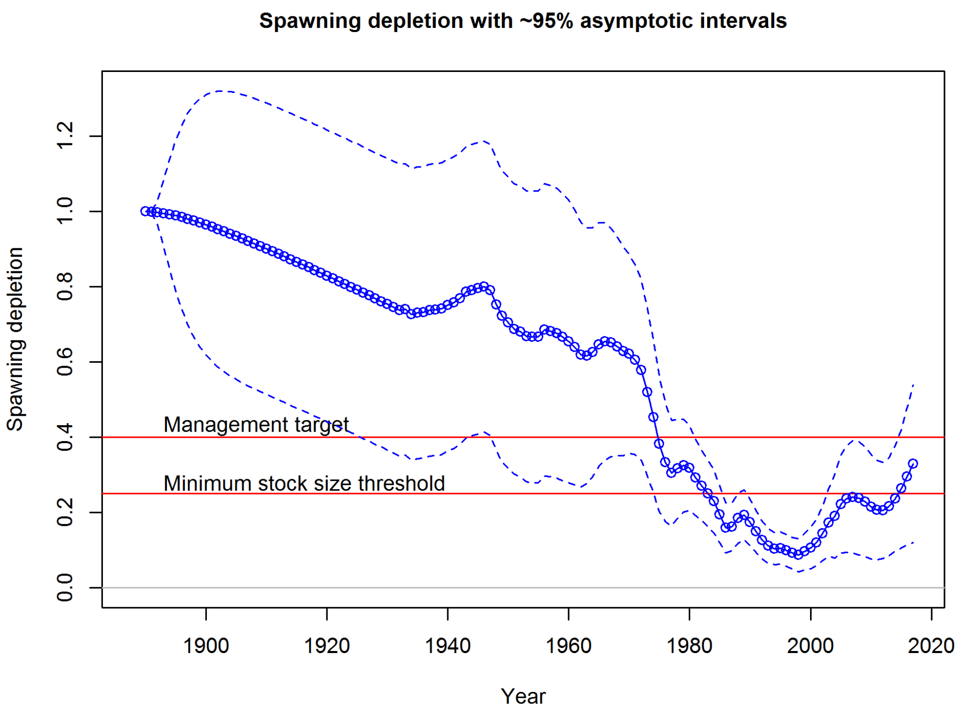

Figure f. Time series of stock depletion, south.

Recruitment

Recruitments in both the north and south were estimated from the model start (1889) 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	620	319–1,204	-1.466	-1.989–-0.942
2006	441	217–898	-1.826	-2.417–-1.235
2007	769	416–1,421	-1.277	-1.723–-0.832
2008	1,752	1,043–2,942	-0.449	-0.759–-0.138
2009	1,884	1,118–3,175	-0.362	-0.678–-0.045
2010	3,727	2,218–6,264	0.342	0.067–0.617
2011	3,255	1,855–5,711	0.221	-0.098–0.540
2012	3,773	2,058–6,917	0.372	0.018–0.726
2013	5,066	2,728–9,408	0.648	0.279–1.017
2014	2,030	1,056–3,901	-0.301	-0.788–0.187
2015	1,783	815–3,902	-0.466	-1.157–0.225
2016	1,425	490–4,143	-0.857	-1.940–0.226
2017	3,953	1,042–15,002	0	-1.470–1.470

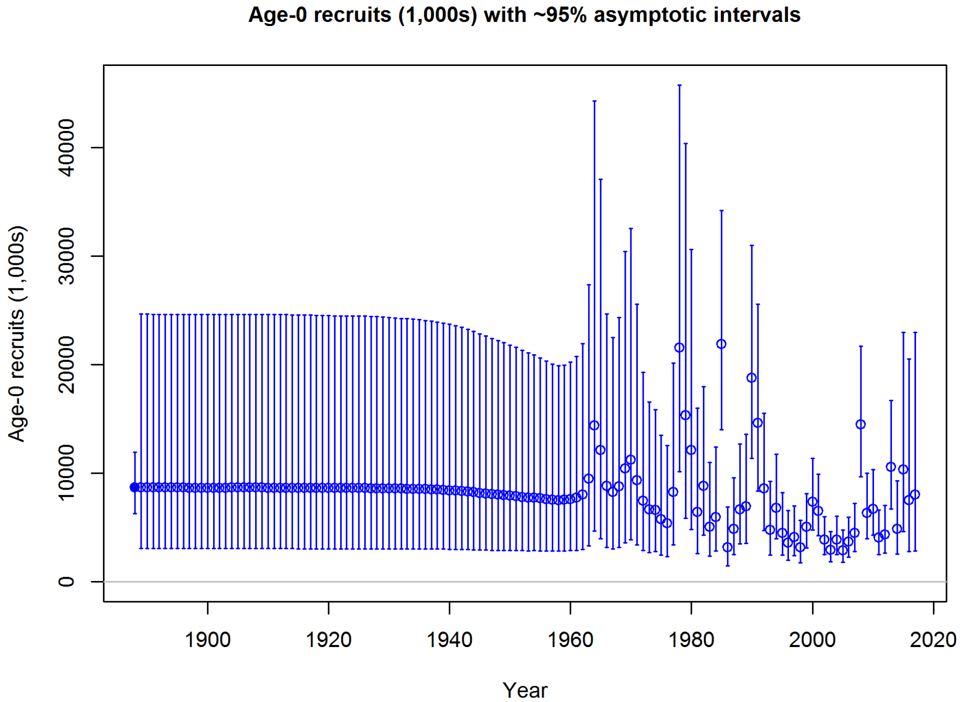

Figure g. Time series of estimated recruitment, north.

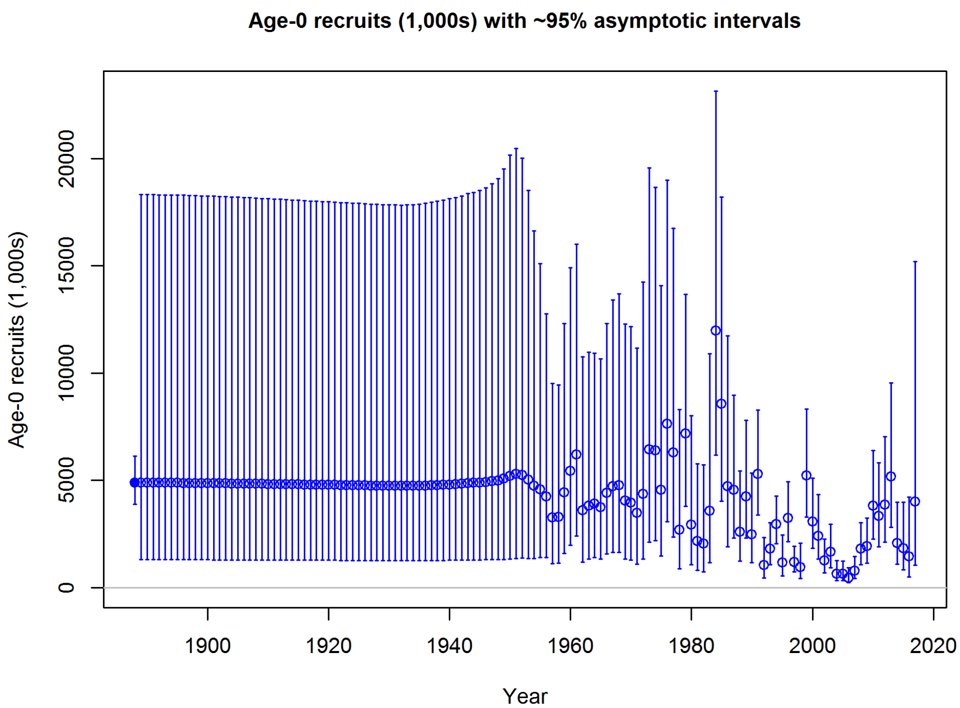

Figure h. Time series of estimated recruitments, south.

Exploitation Status

Historical harvest rates rose steadily through the 1990s, exceeding the target spawning potential ratio (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 2000s it appears that harvest rates exceeded the management target for two years. In recent years, the 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 histories in terms of both biomass and relative SPR, (1-SPR)/(1-$SPR_{45\%}$), are portrayed graphically via phase plots (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	0.4767	20.92–74.42	0.313	0.109–0.518
2006	0.4424	18.60–69.88	0.256	0.081–0.430
2007	0.3865	15.64–61.67	0.194	0.056–0.333
2008	0.3128	12.26–50.29	0.134	0.036–0.232
2009	0.3998	17.05–62.92	0.152	0.039–0.264
2010	0.3911	17.18–61.03	0.128	0.033–0.224
2011	0.6159	31.18–91.99	0.213	0.058–0.368
2012	0.6564	34.36–96.92	0.264	0.077–0.451
2013	0.7323	39.64–106.82	0.35	0.113–0.588
2014	0.7489	39.84–109.95	0.427	0.140–0.714
2015	0.7712	39.51–114.73	0.482	0.151–0.814
2016	0.6118	26.46–95.90	0.368	0.105–0.630

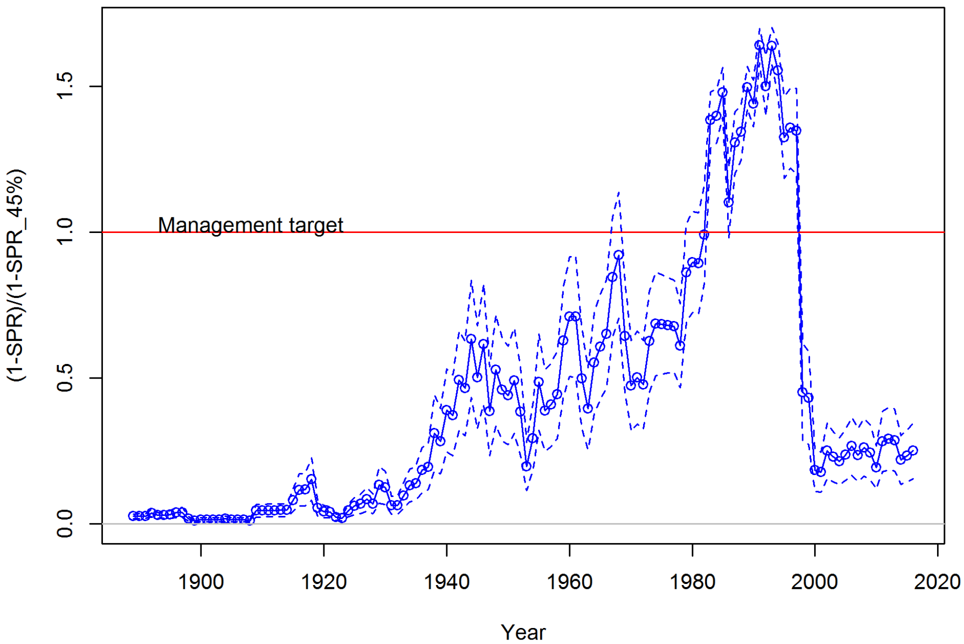

Figure i. Estimated spawning potential ratio (SPR), north. One minus SPR is plotted so that higher exploitation rates occur in the upper portion of the y-axis.

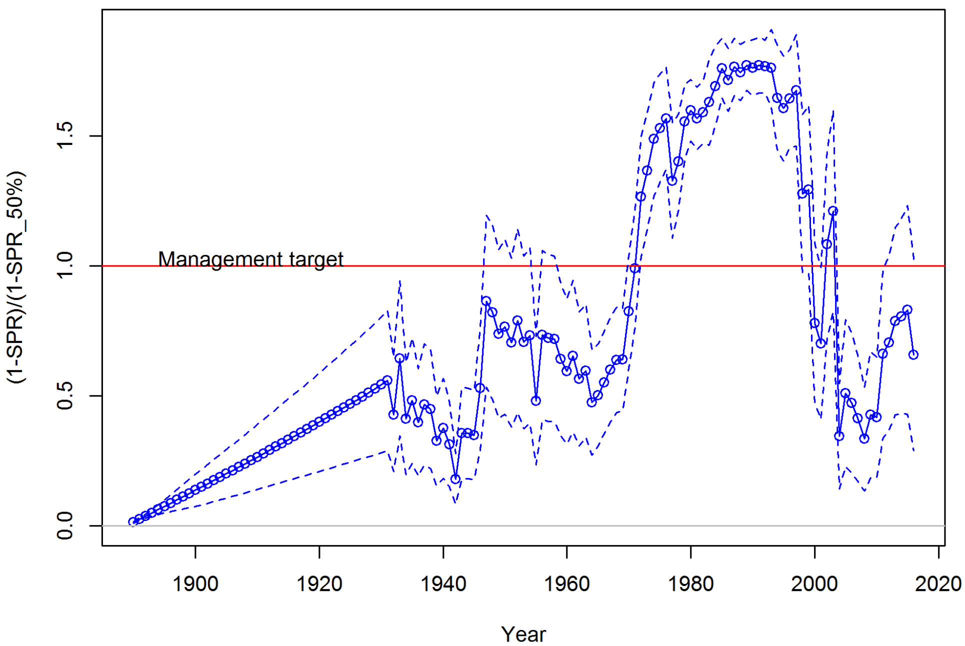

Figure j. Estimated spawning potential ratio (SPR), south. One minus SPR is plotted so that higher exploitation rates occur in the upper portion of the y-axis.

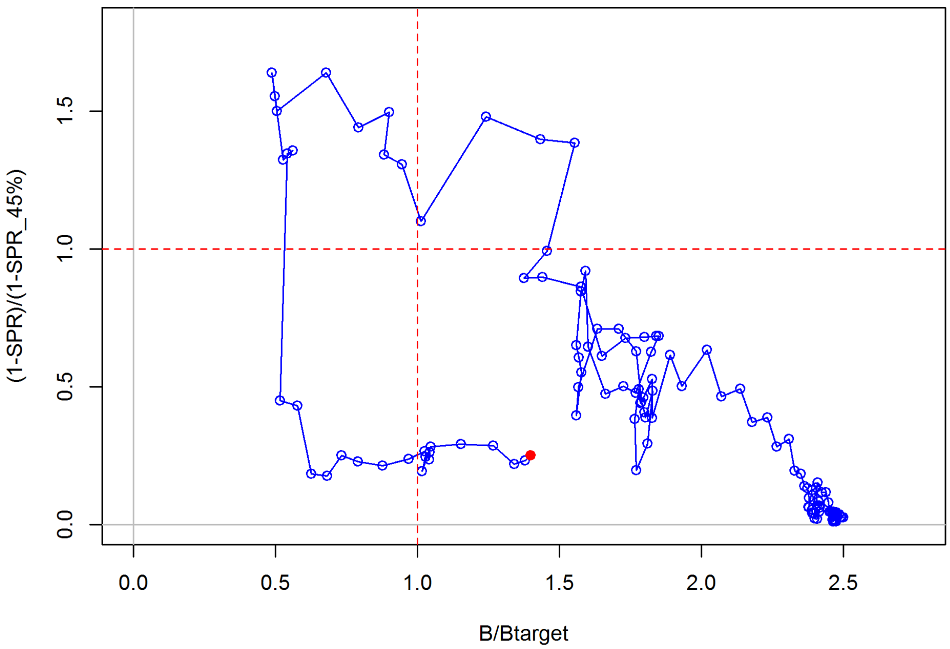

Figure k. Phase plot of estimated relative (1-SPR) vs. relative spawning biomass, north.

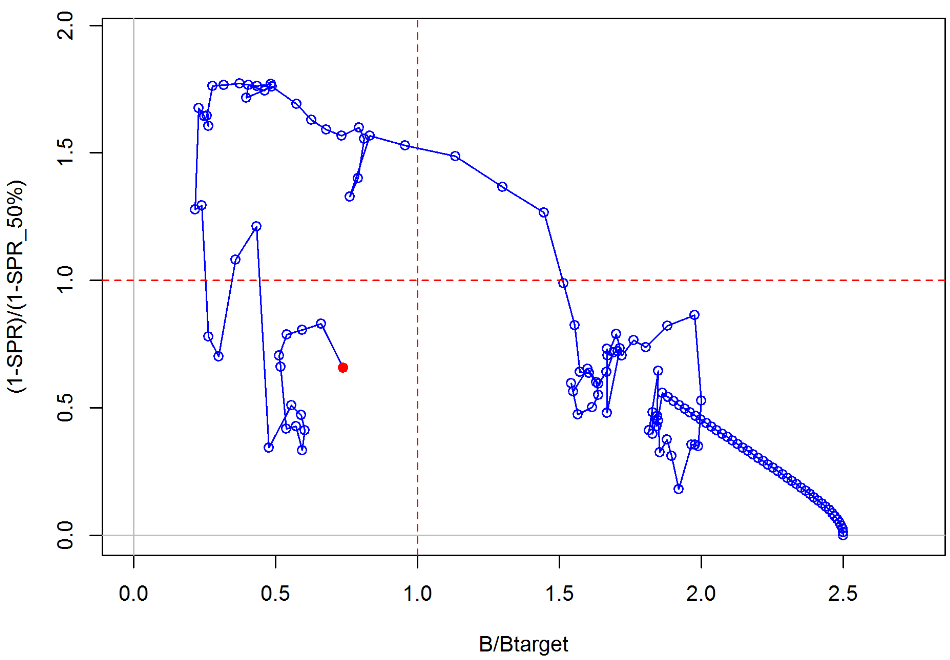

Figure l. Phase plot of estimated relative (1-SPR) vs. relative spawning biomass, south.

Ecosystem Considerations

In this assessment, ecosystem considerations were not explicitly included in the analysis. Lingcod often feed on species of rockfish that are targeted by fisheries, potentially influencing the natural mortality of these rockfish species (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 (SB40%) from approximately the 1980s through the early 2000s. Fishing intensity since approximately 2005 has been below the target (SPR45%) 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 7,780 mt (5,877–9,683 mt 95% asymptotic interval) in the south, which gives catches of 3197 mt (2,184–4,210 mt, 95% asymptotic interval) for the north and 1746 mt (1,372–2,121, 95% asymptotic standard deviation) for the south (Tables i and j). Equilibrium yield at the proxy FMSY harvest rate is 3,409 mt (2,329–4,489 mt, 95% asymptotic interval) and 1,856 mt (1,458–2,253 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)	20,260	15,304–25,215
Unfished Age 3+ Biomass (mt)	31,235	23,914–38,556
Spawning Biomass (2017)	6,509	1,624–11,394
Unfished Recruitment (R0)	4,848	3,747–5,949
Depletion (2017)	32.13	11.14–53.12
Reference Points Based SB40%		
Proxy Spawning Biomass (SB40%)	8,104	6,122–10,086
SPR resulting in SB40%	0.464	0.464–0.464
Exploitation Rate Resulting in SB40%	0.126	0.116–0.135
Yield with SPR Based On SB40% (mt)	1,720	1,351–2,089
Reference Points based on SPR proxy for MSY		
Proxy spawning biomass (SPR45)	7,780	5,877–9,683
SPR45	0.45	NA
Exploitation rate corresponding to SPR45	0.132	0.122–0.142
Yield with SPR45 at SBSPR (mt)	1,746	1,372–2,121
Reference points based on estimated MSY values		
Spawning biomass at MSY (SBMSY)	5,265	3,972–6,559
SPRMSY	0.339	0.334–0.344
Exploitation rate corresponding to SPRMSY	0.197	0.185–0.209
MSY (mt)	1,856	1,458–2,253

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 annual catch targets (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 48% of the CA biomass being in the 40-10 to 42 region. This value 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 annula catch limit (ACL). Table k shows recent management quantities.

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 (Somers et al. 2017), 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	3915
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	3349
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	
2018	Lingcod Split at 40º10' N	4,683	3,310	1,373	4,254	3,110	1,144	NA	NA	NA	

Unresolved Problems and Major Uncertainties

A few outstanding issues remain for lingcod stock assessment on the west coast of the U.S. First, in many cases the commercial age data are not randomly sampled with respect to lengths, there is evidence of bias in some years with respect to age sampling. One option for dealing with this situation includes resampling the ages to ensure that they are representative of the sampled lengths. However, the SSC should agree an acceptable range of options for dealing with this issue prior to the 2019 stock assessment cycle. 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 considers the results of ongoing genetic analyses with respect to lingcod stock structure and that is able to explore linkages between the north and south regions. Current publications on lingcod stock structure suggest that 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 taken from Mexican waters. Landings of lingcod from Mexican waters need to be removed from the U.S. landings in future lingcod assessments. The south model also lacks fishery dependent age data due to a lack of sampling for age structures, which increases uncertainty in the south area model estimates. 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. Given that a majority of the jitter runs were unable to converge to the south base model, this issue should be investigated during future lingcod south assessments. Finally, the south model lacks fishery dependent age data. Obtaining recreational fishery data from California could provide improved information on recent stock trends.

Harvest Projections and Decision Table

The lingcod stock assessments are Category 1 stock assessments, thus projections and decision tables are based on using P*=0.45 and sigma = 0.36, resulting in a multiplier on the over fishing limit (OFL) of 0.956 (PFMC preferred option). Stock projections for the south are also provided for the PFMC default management option, and use an OFL multiplier of 0.913. The OFL multipliers are combined with the 40-10 harvest control rule to calculate OFLs, ABCs and ACLs. The total catches in 2017 and 2018 were set at the PFMC groundfish management team (GMT) requested values of ~ 1000 mt in the north and 750 mt in the south, the average 2015-2017 exploitation rate was used to distribute catches among the fisheries.

Table l shows stock projections of management quantities, as requested by PFMC council staff, for both the stock assessment areas and converted to the management areas under alternative harvest policies requested by the PFMC. Note that the conversion between stock assessment areas and management areas assumes that 20.31% of the CA biomass is in the 40-10 to 42 region. This value is based on the 5 year average biomass distribution in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS).

Standard harvest projections that include both management quantities and trends in stock size and status are provided in Tables m1, m2, and m3. 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 2028, assuming average recruitment based on the stock-recruit curve. In the south, the current medium term projection of expected catch under both harvest policies, shows increasing spawning biomass and depletion from the base model, with the stock remaining in the precautionary zone during the projection period. Note that the difference in final stock status (depletion) between the council preferred and default options is < 1%. The lack of strong increases in 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. Uncertainty in management quantities for the north and south models was characterized using the asymptotic standard deviation for the 2017 spawning biomass from the base model. Specifically, the 2017 spawning biomass for the high and low states of nature are given by the base model mean +/-1.15*standard deviation (the 12.5th and 87.5th percentiles). A search across fixed values of Ro was used to attain the 2017 spawning biomass values for the high and low states of nature. The high catch streams were based on the 40-10 harvest control rule. At the request of the PFMC GMT representative on the STAR panel the moderate catch streams were set to 40% ACL attainment for the north management area and 70% ACL attainment in the south management area. Finally, the low catch stream was set to ~700 mt, a level similar to recent average catches.

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 one case, in which the current control rule is applied to the low stock state of nature (bottom left corner of the table). Note that the catches specified in the above scenario (ranging from 4497 to 3542 mt) are much larger than recent landings (~700 mt). All other decision table scenarios keep the stock near 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 overfished (lower left corner) to well above target stock size (upper right corner). All states of nature from the constant catch scenario, that specifies catches similar to recent levels, suggest that the stock will increase towards, or exceed the target reference point. However, catching the full ACL catches result in stock declines at the low state of nature and modest stock increases under the base case and high state of nature.

Table l. PFMC requested management options: 1) preferred harvest control rule (HCR) (Alt. 1) and 2) default HCRs (No Action Alt.) for 2019 through 2026, all units are in metric tons. Note that the south area ACL has the 40-10 control rule catch reduction applied because the stock is estimated to be in the precautionary zone. The both HCRs implement a GMT request to assume partial attainment of the 2017-2018 ACLs of 1000 mt in the north model area and 750 mt in the south model area and assume full ACL attainment from 2019 forward. The preferred HCR implements buffers of 0.956 in the north and south. The default HCR implements buffers of 0.956 and 0.913, respectively.

Preferred Option								
Year	Area	Buffer	Assessment Areas	Management Areas	Assessment Areas	Management Areas	Assessment Areas	Management Areas
			OFL		ABC		ACL	
2019	North	0.956	4,800	5,110	4,589	4,885	4,589	4,871
2020	North	0.956	4,504	4,768	4,305	4,558	4,305	4,541
2021	North	0.956	4,259	4,537	4,072	4,337	4,072	4,319
2022	North	0.956	4,082	4,392	3,903	4,199	3,903	4,183
2023	North	0.956	3,958	4,294	3,784	4,105	3,784	4,091
2024	North	0.956	3,868	4,217	3,698	4,032	3,698	4,020
2025	North	0.956	3,797	4,154	3,630	3,971	3,630	3,962
2026	North	0.956	3,738	4,100	3,574	3,920	3,574	3,912
2027	North	0.956	3,689	4,054	3,527	3,876	3,527	3,869
2028	North	0.956	3,646	4,014	3,486	3,837	3,486	3,832
2019	South	0.956	1,452	1,143	1,388	1,093	1,320	1,039
2020	South	0.956	1,242	977	1,187	934	1,104	869
2021	South	0.956	1,304	1,026	1,247	981	1,161	914
2022	South	0.956	1,455	1,145	1,391	1,095	1,315	1,034
2023	South	0.956	1,573	1,238	1,504	1,184	1,440	1,133
2024	South	0.956	1,640	1,291	1,568	1,234	1,515	1,192
2025	South	0.956	1,675	1,318	1,602	1,260	1,557	1,225
2026	South	0.956	1,697	1,335	1,622	1,276	1,585	1,247
2027	South	0.956	1,712	1,347	1,637	1,288	1,606	1,264
2028	South	0.956	1,724	1,357	1,648	1,297	1,624	1,278

Default Option								
Year	Area	Buffer	Assessment Areas	Management Areas	Assessment Areas	Management Areas	Assessment Areas	Management Areas
			OFL		ABC		ACL	
2019	North	0.956	4,800	5,110	4,589	4,872	4,589	4,859
2020	North	0.956	4,504	4,770	4,305	4,549	4,305	4,533
2021	North	0.956	4,259	4,539	4,072	4,328	4,072	4,312
2022	North	0.956	4,082	4,395	3,903	4,188	3,903	4,175
2023	North	0.956	3,958	4,297	3,784	4,094	3,784	4,083
2024	North	0.956	3,868	4,222	3,698	4,021	3,698	4,013
2025	North	0.956	3,797	4,159	3,630	3,960	3,630	3,954
2026	North	0.956	3,738	4,105	3,574	3,909	3,574	3,905
2027	North	0.956	3,689	4,059	3,527	3,865	3,527	3,862
2028	North	0.956	3,646	4,020	3,486	3,827	3,486	3,826
2019	South	0.913	1,452	1,143	1,326	1,043	1,265	996
2020	South	0.913	1,249	983	1,141	898	1,066	839
2021	South	0.913	1,315	1,035	1,200	945	1,125	885
2022	South	0.913	1,469	1,156	1,341	1,056	1,277	1,005
2023	South	0.913	1,590	1,252	1,452	1,143	1,402	1,103
2024	South	0.913	1,661	1,307	1,516	1,193	1,478	1,163
2025	South	0.913	1,699	1,337	1,551	1,220	1,523	1,198
2026	South	0.913	1,722	1,355	1,572	1,237	1,552	1,221
2027	South	0.913	1,739	1,368	1,587	1,249	1,575	1,239
2028	South	0.913	1,752	1,379	1,600	1,259	1,594	1,254

Table m1. Model projections, north model area (WA and OR).

Year	Predicted OFL (mt)	ACL Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Depletion (%)
2017	2,162.0	1,000.3	34,063.8	21,975.7	57.9%
2018	2,043.0	997.9	35,946.1	22,593.1	59.5%
2019	4,800.4	4,589.2	37,091.0	23,455.6	61.8%
2020	4,503.5	4,305.5	34,839.0	22,123.7	58.3%
2021	4,259.2	4,071.9	32,975.1	20,863.8	54.9%
2022	4,082.1	3,902.5	31,516.8	19,796.9	52.1%
2023	3,958.3	3,784.2	30,363.9	18,935.4	49.9%
2024	3,867.7	3,697.6	29,437.0	18,238.5	48.0%
2025	3,796.8	3,629.9	28,677.2	17,664.5	46.5%
2026	3,738.5	3,574.1	28,044.0	17,184.0	45.3%
2027	3,689.0	3,526.8	27,511.3	16,778.8	44.2%
2028	3,646.4	3,486.2	27,061.6	16,436.6	43.3%

Table m2. Model projections, buffer 0.956, south model area (CA).

Year	Predicted OFL (mt)	ACL Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Depletion (%)
2017	2,889.0	750.0	11,229.9	6,508.8	32.1%
2018	2,640.0	750.0	11,358.5	6,879.7	34.0%
2019	1,452.3	1,320.3	11,028.3	6,918.5	34.1%
2020	1,241.6	1,103.8	10,855.1	6,560.0	32.4%
2021	1,303.9	1,161.0	11,171.5	6,585.9	32.5%
2022	1,455.5	1,314.5	11,642.2	6,809.7	33.6%
2023	1,573.4	1,439.5	12,035.6	7,038.4	34.7%
2024	1,640.2	1,514.7	12,325.4	7,216.9	35.6%
2025	1,675.4	1,557.2	12,544.1	7,351.3	36.3%
2026	1,696.6	1,585.1	12,722.9	7,461.4	36.8%
2027	1,712.1	1,606.4	12,875.5	7,557.4	37.3%
2028	1,724.2	1,623.9	13,007.5	7,643.1	37.7%

Table m3. Model projections, buffer 0.913, south, south model area (CA).

Year	Predicted OFL (mt)	ACL Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Depletion (%)
2017	2,889.0	750.0	11,229.9	6,508.8	32.1%
2018	2,640.0	750.0	11,358.5	6,879.7	34.0%
2019	1,452.3	1,265.4	11,028.3	6,918.5	34.1%
2020	1,249.3	1,066.2	10,910.9	6,593.5	32.5%
2021	1,314.8	1,125.3	11,261.3	6,641.3	32.8%
2022	1,469.2	1,276.9	11,759.9	6,884.1	34.0%
2023	1,590.5	1,401.5	12,182.8	7,132.3	35.2%
2024	1,660.7	1,478.0	12,502.3	7,330.4	36.2%
2025	1,698.6	1,522.5	12,748.6	7,483.5	36.9%
2026	1,721.8	1,552.1	12,951.9	7,610.5	37.6%
2027	1,738.8	1,574.9	13,125.8	7,721.4	38.1%
2028	1,752.1	1,593.6	13,276.5	7,820.3	38.6%

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 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.
7. Given that a majority of the jitter runs were unable to converge to the south base model, this issue should be investigated during future lingcod south assessments.
8. The south model lacks fishery dependent age data. Obtaining recreational fishery data from California could provide improved information on recent stock trends.

Rebuilding Projections

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

Table n. North model decision table of 12-year projections for alternate states of nature (columns) and management options (rows). Summary of model outputs for the preferred council HCR, north (WA + OR). Uncertainty in management quantities for the north and south models was characterized using the asymptotic standard deviation for the 2017 spawning biomass from the base model. Specifically, the 2017 spawning biomass for the high and low states of nature are given by the base model mean +/-1.15*standard deviation (the 12.5th and 87.5th percentiles). A search across fixed values of Ro was used to attain the 2017 spawning biomass values for the high and low states of nature. The total catches in 2017 and 2018 were set at the GMT requested values of ~ 1000 mt.

			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	
Management 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% ACL	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
ACL	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. South model decision table of 12-year projections for alternate states of nature (columns) and management options (rows). Summary of model outputs for the preferred council HCR, south (CA), using a buffer of 0.956, south. Uncertainty in management quantities for the north and south models was characterized using the asymptotic standard deviation for the 2017 spawning biomass from the base model. Specifically, the 2017 spawning biomass for the high and low states of nature are given by the base model mean +/- 1.15*standard deviation (the 12.5th and 87.5th percentiles). A search across fixed values of Ro was used to attain the 2017 spawning biomass values for the high and low states of nature. The total catches in 2017 and 2018 were set at the GMT requested values of 750 mt in the south.

			State of nature					
			Low 2017 Spawning Biomass *Ln(Ro)=8.122*		Base case 2017 Spawning Biomass *Ln(R0) = 8.493*		High 2017 Spawning Biomass *Ln(Ro)=8.742*	
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	700	4,220	29.8%	6,918	34.1%	9,756	37.0%
	2020	700	4,040	28.5%	6,938	34.2%	9,881	37.5%
	2021	700	4,116	29.1%	7,199	35.5%	10,299	39.1%
	2022	700	4,368	30.8%	7,670	37.9%	10,983	41.7%
	2023	700	4,687	33.1%	8,232	40.6%	11,784	44.7%
	2024	700	5,027	35.5%	8,819	43.5%	12,619	47.9%
	2025	700	5,371	37.9%	9,403	46.4%	13,446	51.0%
	2026	700	5,712	40.3%	9,972	49.2%	14,246	54.0%
	2027	700	6,047	42.7%	10,519	51.9%	15,009	56.9%
	2028	700	6,375	45.0%	11,039	54.5%	15,730	59.7%
~75% ACL	2019	915	4,220	29.8%	6,918	34.1%	9,756	37.0%
	2020	810	3,919	27.7%	6,808	33.6%	9,750	37.0%
	2021	874	3,937	27.8%	7,005	34.6%	10,105	38.3%
	2022	1,006	4,101	29.0%	7,383	36.4%	10,695	40.6%
	2023	1,122	4,256	30.1%	7,774	38.4%	11,325	43.0%
	2024	1,200	4,361	30.8%	8,119	40.1%	11,916	45.2%
	2025	1,238	4,425	31.3%	8,415	41.5%	12,455	47.2%
	2026	1,266	4,472	31.6%	8,683	42.9%	12,954	49.1%
	2027	1,287	4,510	31.8%	8,928	44.1%	13,418	50.9%
	2028	1,305	4,540	32.1%	9,154	45.2%	13,846	52.5%
ACL	2019	1,320	4,220	29.8%	6,918	34.1%	9,756	37.0%
	2020	1,104	3,687	26.0%	6,560	32.4%	9,501	36.0%
	2021	1,161	3,548	25.1%	6,586	32.5%	9,682	36.7%
	2022	1,315	3,566	25.2%	6,810	33.6%	10,117	38.4%
	2023	1,440	3,564	25.2%	7,038	34.7%	10,584	40.1%
	2024	1,515	3503	24.7%	7,217	35.6%	11,009	41.8%
	2025	1,557	3401	24.0%	7,351	36.3%	11,388	43.2%
	2026	1,585	3281	23.2%	7,461	36.8%	11,735	44.5%
	2027	1,606	3153	22.3%	7,557	37.3%	12,055	45.7%
	2028	1,624	3020	21.3%	7,643	37.7%	12,353	46.9%

Table p. Summary of model outputs, north model area (WA and OR). 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/ 1-SPR_45%	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 model area (CA). 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/ 1-SPR_45%	0.48	0.44	0.39	0.31	0.4	0.39	0.62	0.66	0.73	0.75	0.77	0.61	NA
Exploitation Rate	0.31	0.26	0.19	0.13	0.15	0.13	0.21	0.26	0.35	0.43	0.48	0.37	NA
Age 3+ Biomass (mt)	7,485	7,760	7,563	7,229	6,773	6,330	6,321	6,419	7,323	8,207	9,240	10,690	11,230
Spawning Biomass (mt)	4,398	4,667	4,757	4,681	4,496	4,232	4,065	4,032	4,242	4,674	5,209	5,827	6,509
95% Confidence Interval	1,475–7,321	1,443–7,892	1,362–8,153	1,260–8,102	1,169–7,824	1,062–7,401	1,044–7,087	1,081–6,983	1,224–7,259	1,407–7,942	1,527–8,891	1,561–10,093	1,624–11,394
Recruitment	620	441	769	1,752	1,884	3,727	3,255	3,773	5,066	2,030	1,783	1,425	3,953
95% Confidence Interval	319–1,204	217–898	416–1,421	1,043–2,942	1,118–3,175	2,218–6,264	1,855–5,711	2,058–6,917	2,728–9,408	1,056–3,901	815–3,902	490–4,143	1,042–15,002
Depletion (%)	21.7	23	23.5	23.1	22.2	20.9	20.1	19.9	20.9	23.1	25.7	28.8	32.1
95% Confidence Interval	8.7–34.7	8.8–37.3	8.5–38.4	8.1–38.1	7.6–36.8	7.0–34.7	6.9–33.2	7.1–32.7	7.9–34.0	9.0–37.1	9.9–41.5	10.4–47.1	11.1–53.1

Introduction

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. This is the same approach implemented in recent lingcod assessments. Four fisheries are modeled in the north: commercial trawl (including limited landings in other net gears), commercial fixed gears (including all line 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 (including all line gears), and CA recreational fisheries. Both models start during 1889, at the onset of landings. These areas were chosen due to latitudinal trends in weight-length and growth relationships observed in the Northwest Fishery Science Center (NWFSC) survey data, evidence that lingcod do not generally move across large areas (tagging data suggest the scale of movement is at tens of kilometers), little stock connectivity at moderate (~10 km) to large (~1000 km) scales (Marko et al. 2007), and different fleet structures and sampling programs between the states. While there is evidence for a limited demographic connectivity at moderate to large scales (~100-1000 km) along the coast, analysis of genetic variation indicates that lingcod are genetically similar throughout their range (Marko et al. 2007).

Life History and Ecosystem Considerations

Lingcod (*Ophiodon elongatus*, family Hexagrammidae) are large opportunistic top predators in the nearshore demersal ecosystem of the northeast Pacific Ocean and are valued both commercially and recreationally in the U.S. groundfish fishery. They range from Kodiak Island, Alaska down to Baja California, Mexico, though abundance tapers off quickly south of Point Conception (Wilby 1937, Hart 1973). The historical center of abundance is off of British Columbia and Washington State (Hart 1973). While the NWFSC survey catches lingcod up to depths of approximately 450 m, they typically occur at depths of less than 200 meters. 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). Studies using DNA markers (Marko et al. 2007) have found that lingcod are genetically similar throughout their coastal range, suggesting extensive gene flow among populations throughout the West Coast. Through 2010 the lingcod stock was managed as a coast-wide population, during 2011 and 2012 lingcod were managed as having a Northern population (Washington and Oregon), and a Southern population (California), finally during 2013 to present northern and southern lingcod populations have been managed with a break at 40 degrees 10 minutes north latitude.

Lingcod are sexually dimorphic, with females typically attaining larger sizes ($L\infty$ = 131 cm for females and $L\infty$= 93 cm for males sampled off of British Columbia) (Richards et al. 1990). Female lingcod reach maturity at larger sizes, between 3-5 years of age, while males are smaller, grow faster initially (before sexual maturation), and reach maturity earlier at 2 years (Miller and Geibel 1973, Cass et al. 1990). Growth rate and size at maturity has been seen to vary regionally, with lingcod off Washington waters growing slower and maturing at larger sizes (females at 64 cm, males at 52 cm) than lingcod from warmer waters in California (females 59 cm; males 40 cm) (Richards et al. 1990, Silberberg et al. 2001). Given that the age at maturity does not differ significantly between the regions, the observed geographic differences in size at maturation are likely attributed to spatial variation in growth rates.

In the late fall, male lingcod aggregate and become territorial in areas suitable for spawning, these areas are generally in shallower water with rocky high relief habitat. The proportion of male lingcod sampled from offshore trawl landings declines in the late fall, suggesting a pre-spawning departure of males from the trawl grounds (Miller and Geibel 1973 (California), Cass et al. 1990 (British Columbia), Jagielo 1994 (Washington)). Males are in spawning condition earlier in the year than females, and it appears that larger and older females spawn first (Cass et al. 1990). Mature females are rarely seen on the spawning grounds and appear to move into spawning areas for only a brief period to deposit eggs (Giorgi 1981). Spawning behavior has been reported from the intertidal zone to a depth of 126 m (Giorgi 1981, O'Connell 1993). Spawning typically begins in early December, with the observed timing of peak spawning activity ranging from January (Wilby 1937) to early March (La Riviere et al. 1981). However, recent maturity studies suggest that lingcod are batch spawners with ability to spawn year round, with, peak spawning taking place during October – December (pers. comm, Melissa Head, NWFSC). Mature females move in from deeper offshore areas (100-200 m) to shallow (10-40 m) rocky habitats to deposit eggs in favorable nesting sites (Wilby 1937). Mature males will initially select and guard optimal nesting areas, crevices or rocky outcrops with high flow, before the arrival of spawning females. After eggs are deposited, female lingcod will return to depth, leaving the male to guard the eggs until they hatch, usually between 5-7 weeks (Low and Beamish 1978, Miller and Geibel 1973). Nest guarding by males has been shown to be imperative for egg survival by protecting against opportunistic fish predators like perches (Embiotocidae), greenlings (Hexagrammidae), and sculpins (Cottidae) (Jewell 1968). Males appear to be more effective at guarding the nest from predation by vertebrates than by invertebrates (La Riviere et al. 1981, Low and Beamish 1928). In experiments where males were removed from nests, new males sometimes assumed a guardian role, but in one removal experiment, 4 of 7 nests were lost to predators within 22 days. (Low and Beamish, 1978). Ambient oxygen levels (Giorgi 1981), salinity and temperature affect egg survival as well (Cook et al. 2005).

Eggs hatch between January and June (Jewell 1968, Low and Beamish 1978). Upon hatching, the larvae are about 12 mm in total length and become epipelagic until they reach about 70 mm and settle to soft bottom habitats (Phillips and Barraclough 1977, Cass et al. 1990). Larvae in the Strait of Georgia first appear in the plankton in late February. Numbers peak in late April. Larvae were concentrated in the upper 3 m of the water column by day and disperse or migrate to deeper depths at night. Larvae begin to disappear from the upper water column by late May to early June and become demersal at about 70-80 mm and at about 3 months of age. Epipelagic larvae feed on small copepods and copepod eggs, shifting to larger copepods and fish larvae as they grow (Phillips and Barraclough 1977).

At about 3 months old, juveniles settle on sandy bottom areas near eelgrass or kelp beds. Juvenile lingcod will stay on the soft bottom until they grow to at least 350 mm in length, when they move into rocky areas with high relief as protection from large predators (Petrie and Ryer 2006). By age 1 or 2, lingcod move into rocky habitats similar to those occupied as adults, but shallower. 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). Newly settled juveniles have been sampled nearshore in June on sandy bottom areas near eelgrass or kelp beds (Buckley et al. 1984), and have been found at depth ranging from 20m in Canada (Phillips and Barraclough 1977) to 55 m in California (Miller and Geibel, 1973). In Washington, juveniles have been collected from the mouth of the Pysht River in the Strait of Juan de Fuca, from Grays Harbor and Willapa Bay, and from coastal waters nearshore to these embayments (Buckley et al. 1984, Jagielo 1994). Coley et al. (1986) found juvenile lingcod in Grays Harbor in October, over hard bottom shell-cobble habitat near rocks in 9-15 m of water.

Outside of spawning season, male and female lingcod are segregated by depth where females tend to inhabit deeper offshore waters and males inhabit nearshore rocky reefs. Consequently, each sex is vulnerable to different types of fishing gear. The majority of nearshore males (66.3%) are caught using hook-and-line or spearfishing gear, and a majority of deep water females (62.4%) are caught by trawl gear (Miller and Geibel 1973). Miller and Geibel (1973) reported that juvenile lingcod in California are about 35 cm in length (1 year old) when they first move into nearshore rocky areas typical of adult habitat. Surveys off the west coast of Vancouver Island suggest that juveniles move from inshore areas to a wider range of flat bottom areas by September (Cass et al. 1990), and begin to move into habitats of similar relief and substrate as adult lingcod by age 2, but remain at shallower depths. Juvenile lingcod feed on small fishes including herring (*Clupea pallasii*), Pacific sand lance (*Ammodytes hexapterus*), flatfish (*Pleuronectidae*), shiner perch (*Cymatogaster aggregate*), and walleye pollock (*Theragra chalcogramma*), and an assortment of invertebrates including shrimp (*Neomysis macrops*) and prawns (*Pandalus danae*) (Cass et al. 1990).

Phillips and Barraclough (1977) estimated that young-of-the-year (YOY) growth was approximately 1.3 mm/day. Buckley et al. (1984) reported YOY growth from June to September in the Strait of Juan de Fuca also averaged 1.3mm/day. 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).

The movement and migration of lingcod has been extensively studied through tag-recapture methods and acoustic arrays. As adults, lingcod have a high degree of site fidelity and tend to stay within an 8 km home range. In Cape Flattery, Washington, Jagielo (1990) reported that 80.7% of tagged fish were recovered <8 km from their original release site though recaptures came from as far north as Queen Charlotte sound (195 km) and as far south as Cape Falcon (120 km). U.S. and Canadian tagging studies have demonstrated movement between coastal areas off Washington and southwest Vancouver Island. However, 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). Most fish recovered in tagging studies are found near the point of release, but some exceptional movements have been reported. Cass et al. (1990) found that 95% of fish recovered from a tagging study off the west coast of Vancouver Island were recaptured near the point of release. One fish tagged as a juvenile was recovered 510 km to the south in Oregon. Jagielo (1990) reported that only 19% of recoveries were further than 10km from the release point at Cape Flattery, Washington. However, recaptures came from as far north as Queen Charlotte sound (195 km) and as far south as Cape Falcon (120 km). Starr et al. (2005) in Alaska and Greenley (2009) in Central California used acoustic tags for tracking lingcod movement and both observed that while lingcod exhibit high site fidelity with an established location of residence, they frequently leave for brief periods of time (1-5 days) over short distances (2 km) to feed, then return home for a longer duration. Large females generally had shorter residency times, spending more time outside of their tagged site. Additional acoustic studies by Bishop et al. (2010) and Stahl et al. (2014) in Prince William Sound have reported that younger individuals (2-4 year olds, around 50 cm) disperse from nearshore reefs during spawning season, most likely due to displacement by older and larger spawning individuals. Overall, residency times appear vary by sex, size, season, and habitat of residence.

There are no clear stock delineations for lingcod in U.S. waters. No distinct breaks are seen in the fishery landings, catch distributions, or survey data, although latitudinal trends in life history parameters are apparent. Genetic studies have found coastal lingcod populations to be genetically similar throughout their range (Jagielo et al. 1996). More recent analyses indicate limited genetic changes in the stock along the coast, but no distinct stock breaks. Marko et al. (2007) found surprisingly little connectivity between stocks at moderate (~10 km) to large (~1000 km) ranges, suggesting that regionally structured assessments are appropriate.

Lingcod are top order predators of the family Hexagrammidae. Among the Hexagrammidae, the genus Ophiodon is ecologically intermediate between the more littoral genera Hexagrammos, Agrammus and Oxylebius and the more pelagic Pleurogrammus (Rutenberg 1962). Lingcod are opportunistic predators, feeding on a variety of fishes (pelagic and demersal), cephalopods, and crustaceans (Wilby 1937). Juvenile lingcod in soft bottom habitats prey upon small fishes including herring (*Clupea pallasii*), Pacific sand lance (*Ammodytes hexapterus*), flatfish (*Pleuronectidae*), shiner perch (*Cymatogaster aggregata*), and an assortment of invertebrates including shrimp (*Neomysis macrops*) and prawns (*Pandalus danae*) (Cass et al. 1990). As juvenile lingcod begin to move into rocky habitats and exceed 30 cm TL, rockfishes (*Sebastes* spp.) become a more prominent component of their diet, making up 19% of total prey biomass by weight. Rockfish biomass in lingcod diet increases by three-fold for lingcod found inside marine reserves (Beaudreau and Essington 2007). Preliminary observations (B. Brown, Moss Landing Marine Laboratories, personal communication, 6 April 2017) from lingcod stomachs contents sampled from Washington to California in both nearshore and offshore habitats indicate a higher occurrence of bony fishes from Washington and Oregon waters, and a higher occurrence of cephalopods in lingcod from California waters with an overlapping region near southern Oregon. This latitudinal shift in prey composition suggests differences in feeding behavior and the predatory role of lingcod in coastal environments.

Map

Figure 1a shows the geographic scope of the assessment and depicts boundaries for fisheries and data collection strata. The stock assessment is split into two areas, north and south of the California border.

Historical and current fishery

Lingcod fisheries have a long history, with the earliest evidence of lingcod fishing coming 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). More recently, the commercial fishery off of California dates back more than a century, and the fishery off of Washington and Oregon dates back nearly as far. Recorded commercial and recreational take of lingcod began during the 1920s in southern California, then Oregon and Washington later during the 1940s.

Lingcod are harvested commercially by trawl and longline gear, and recreationally by hook-and-line and spear (see executive summary figures a and b). The fishery steadily grew with the rise of the groundfish trawl industry, reaching peak landings during in the early 1980s. Landings decreased during the late 1980s due to population declines and the implementation of seasonal closures and size limits. During 1999 the lingcod fishery was declared overfished coast-wide. With the combination of a federal rebuilding plan implemented during 2003 and favorable ocean conditions for lingcod recruitment, the population was deemed recovered in 2005, four years ahead of the projected recovery time.

In California, the recreational lingcod fishery has substantial landings that have surpassed that of the CA commercial fleet since 1998. At the peak of the lingcod fishery during 1974, 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 (commercial passenger fishing vessel, CPFV, and private/rental boats). Private boat landings (including kayaks) were higher than those from CPFVs. A small fraction of landings are from spear fishers using SCUBA or free diving gear (Lynn 2008).

Catches of lingcod in Oregon and Washington have shifted from the commercial trawl fleet, accounting for 90% of landings during its mid-1980s peak, to a fishery evenly split between commercial and recreational in recent years. Between 1980 and 1996, the majority of lingcod were caught by the bottom trawl fishery (>75%), followed by troll and hook-and-line (between 10-20%), with a small fraction of additional landings from pots and traps, nets, and shrimp trawls (Jagielo et al. 1997). From 1999 to 2016, however, the recreational fishery has contributed about half of all lingcod landings, on average.

Management history and performance

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 of the United States. With implementation of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) in 1976, primary responsibility for management of the groundfish stocks off Washington, Oregon and California shifted from the states to the Pacific Fishery Management Council (PFMC). The U.S. west coast allowable biological catch (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 a quantitative assessment (Jagielo et al. 2000). Trip limits on commercial Lingcod catch were first instituted in 1995, when a 20,000 lbs. /month limit was imposed, and a minimum size was imposed for recreational fisheries of 22 inches. During 1998 to present, individual year ABC and OY levels were set, commercial trip limits became much more restrictive (starting at 1,000 mt/2 months in 1998), and recreational bag limit were set at 2 (or 1) lingcod with minimum sizes ranging from 22 to 30 inches.

PFMC implemented an initial Lingcod 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. The coast-wide ABC was further reduced by 27.1% (700 mt, down from 960 mt). In the commercial fishery sector, harvest guidelines in 2000 were reduced by over 80% from 1998 limits. In order to achieve these low harvest goals, all commercial fishing for lingcod was closed for six months (January to April, and November to December). During the open period between April and November, all commercial vessels were limited to 400 pounds per month, and lingcod landed by non-trawl vessels south of Cape Mendocino had a minimum size limits of 26 inches long, and 24 inches long in all other areas. During the rebuilding period between 2000 and 2005, cumulative trip limits were very low at 800 pounds for every 2 months with frequent closures.

After 2006, the population had rebuilt, and the ABC and trip limits began rising, with a bimonthly limit of 1,200 pounds. Concurrently, Marine Protected Areas (MPAs) in California, Rockfish Conservation Area (RCA) and Cowcod Conservation Area (CCA) were implemented, prohibiting take of all groundfish within specified depths, habitats, and locations.

During 2011, the limited entry trawl sector became a catch share program with 100% observer coverage, while during the period 2002 to 2011 observed trips were chosen by random stratified sampling. The Trawl Catch Share Program requires 100% at-sea observer coverage since all catch of Individual Fishing Quota (IFQ) species must be accounted for to allow fishers and managers to track and monitor their individual quotas.

The first recreational regulations for lingcod were set in 1994, with a bag limit of 3 fish in Washington and Oregon, 5 fish in California, and coast-wide size limit of 22 inches. In 1998, the bag limit in all three states dropped to 2 fish per day at 24 inches, where it largely remained until 2008. Regulations in California fluctuate frequently, where during the stock rebuilding period between 2000 and 2004 the California recreational bag limit dropped to 1 fish per day, and the size limit increased from 26 inches to 30 inches. In 2015, the bag limit was increased to 3 fish per day in California, 2 fish per day in Oregon and Washington, and a size limit of 22 inches. Most recently, the bag limit in California has decreased back to 2 fish per day.

Summaries of regulatory histories for both federal and state management actions are available as supplementary materials to this stock assessment. See table k in the executive summary for a recent history of OFLs, ACLs, landings, and catch (landings plus discards) for each area.

Fisheries off of Alaska, Canada, and Mexico

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 Management Council. The sport fishery is restricted by daily bag and possession limits. Commercial fisheries are restricted by catch and bycatch quotas. Lingcod are a non-target species in the subsistence fishery. No formal lingcod stock assessment has been done in Alaskan waters.

Lingcod in Canada are managed under the Pacific Integrated Goundfish Fishery by the Department of Fisheries and Oceans for take by First Nations and the commercial and recreational sectors. Beginning in 1997, the Canadian commercial groundfish trawl fishery implemented an IVQ (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 lingcod assessment in outer British Columbia waters in 2011, and in the Strait of Georgia in 2014 (DFO, 2016). The 2011 assessment implements a Bayesian surplus production model to assess lingcod stock status within four assessment areas. Overall the stock appears to have remained stable from 1927-1970, declined until 1980, increased until 1990 and has continued to decline since then. However the stock is still estimate to be healthy with respect to reference points. The 2016 assessment implement a two-sex statistical catch-at-age model in a Bayesian model. Results suggest that spawning biomass in 2014 is greater than spawning biomass at the start of the current management regime during 2006, and that the stock is likely in a precautionary management zone.

Southern CA recreational fishers have reported fishing in Mexican waters and landing fish in U.S. ports. This is an issue that requires further investigation. There are no known Mexican stock assessments for lingcod.

2. Data

The following sources of data were used in building this assessment, which is partitioned into two independent assessment areas: a northern area for WA and OR and a southern area for CA:

1. Fishery independent data including bottom trawl survey-based indices of abundance and biological data (age and length) from the NWFSC survey and AFSC Triennial survey.
2. Research length and age composition data from WDFW (north model only) and L. Lam (pers. Comm.)
3. Estimates of fecundity, maturity, length-weight relationships and ageing error from various sources.
4. Commercial landings, length, and age composition data.
5. Estimates of commercial discard length frequencies and fraction discarded in the fishery obtained from the West Coast Groundfish Observer Program (WCGOP).
6. Recreational landings, length, and age composition data.
7. Commercial and recreational fishery CPUE.

Data availability by source and year is presented in Figures 2 and 3 as well as in the more detailed data sections below. A description of each of the specific data sources follows.

Fishery Independent Data: NWFSC WCGBTS trawl survey

Three sources of information are produced from the West Coast Groundfish Bottom Trawl Survey (WCGBTS): an index of relative abundance, length-frequency distributions, and age-frequency distributions. Only years in which this survey included the continental shelf are considered (2003 forward), since lingcod are primarily a shelf species.

The WCGBTS is based on a random-grid design, covering the coastal waters from a depth of 55 m to 1,280 m (Keller et al. 2007). This design 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 that are executed from north to south. Two vessels fish during each pass, and survey tows are conducted from late May to early October each year. This design therefore incorporates both vessel-to-vessel differences in catchability as well as variance associated with selecting a relatively small number (~700) of possible cells from a very large set of possible cells spread from the Mexican to the Canadian border. Much effort has been expended on appropriate analysis methods for this type of data, culminating in the West Coast trawl survey workshop held in Seattle in November, 2006.

Data from the WCGBTS are analyzed using a spatio-temporal delta-model (Thorson et al. 2015), implemented as an R package titled *VAST* (Thorson and Barnett 2017) and publicly available online (https://github.com/James-Thorson/VAST). This method for constructing survey abundance indices was reviewed, endorsed, and recommended by the Pacific Fishery Management Council's Scientific and Statistical Committee (SSC). The particular VAST model applied to the survey data includes spatial and spatio-temporal variation in both encounter probability and positive catch rates, a logit-link for encounter probability, and a log-link for positive catch rates. Vessel-year effects are included for each unique combination of vessel and year in the database, to account for the random selection of commercial vessels used during sampling (Helser et al. 2004, Thorson and Ward 2014). Spatial variation is approximated using 250 knots, and the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016) is used. Further details regarding model structure are available in the user manual (https://github.com/James-Thorson/VAST/blob/master/examples/VAST_user_manual.pdf). To confirm convergence of the model estimation algorithm, we checked that the Hessian matrix is positive definite and that the absolute-value of the final gradient of the log-likelihood with respect to each fixed effect was <0.0001 for each fixed effect. We selected among two alternative model configurations, i.e., treating positive catch rates as following a lognormal or gamma distribution. Following advice from the Science and Statistical Committee, we used the following three diagnostics for model fit:

1. The Quantile-Quantile plot, generated by comparing each observed datum with its predicted distribution under the fitted model, calculating the quantile of that datum, and comparing the distribution of quantiles with its expectation under a null model (i.e., a uniform distribution). This Q-Q plot shows no evidence that the model fails to capture the shape of dispersion shown in the positive catch rate data (Figure 4).
2. A comparison of predicted and observed proportion encountered when binning observations by their predicted encounter probability. This comparison shows no evidence that encounter probabilities are over-estimated for low-encounter-probability observations, or vice versa (Figure 5).
3. A visualization of Pearson residuals for encounter probability and positive catch rates associated with each knot. This comparison shows no evidence of residual spatial patterns for either model component (Figures 6 and 7).

VAST indices were calculated from separate model runs for the both north and south model areas, covering the extent of lingcod observations in the survey, the lognormal model was selected (Table 2 and Figure 8). The survey biomass density (weight per area swept) was a function of year, latititude, longitude, and vessel-year. Note that a single area model run initially used to produce the indices was nearly identical to the separate area VAST model run. Trends for the north and south areas are similar. Note that the VAST indices were compared with the survey design based index, these indices were similar. Additional tables with VAST model output and a comparison with the design based indices are available in Appendix I.

Length bins in 2 cm increments from 10 to 130 cm in the north and 4 to 130 cm in the south were used to summarize the length frequency of the survey catches in each year. The first bin includes all observations less than 10 cm and 4 cm for the north and south, respectively, and the last bin includes all fish larger than 130 cm. The observed length compositions were expanded to account for subsampling tows by expanding each length sample from a tow to represent the entire tow by dividing the total lingcod catch weight by the total weight of lingcod measured for length and multiplying the observed length frequencies by the expansion factor, the resulting length frequencies are then summed. Figures 9 and 10 show the length frequency distributions for the WCGBTS north and south areas. Tables 3 and 4 show sample sizes.

Age-frequency data from the WCGBTS (Figures 11 and 12) were included in the model as conditional age-at-length distributions by sex and year, and therefore were not expanded. Individual length- and age-observations can be thought of as entries in an age-length key (matrix), with age across the columns and length down the rows. The approach consists of tabulating the sums within rows as the standard length-frequency 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. This approach has several benefits for analysis above the standard use of marginal age compositions. 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 conditional age 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. The second major benefit of using conditional age-composition observations is that in addition to being able to estimate the basic growth parameters (L_{minAge}, L_{maxAge}, K) 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. Therefore, to retain objective weighting of the length and age data, and to fully include the uncertainty in growth parameters (and avoid potential bias due to external estimation where size-based selectivity is operating) conditional age-at-length compositions were developed using the WCGBTS age data.

Age distributions included bins from age 0 to age 20+, with the last bin including all fish of greater age. Note that these survey age data are used as CAAL and, therefore, are not expanded. The numbers of fish are used without any adjustment. These data show the growth trajectory of females reaching a maximum size between 120-130 cm and males reaching a maximum size of about 80-90 cm. Tables 5 and 6 show sample sizes.

Fishery Independent Data: Triennial trawl survey

The Triennial Shelf Trawl Survey that was conducted every third year from 1977-2004 is the second source of fishery-independent data regarding the lingcod abundance (Dark and Wilkins 1994). However, the 1977 data were not used due to concerns about the first year of the survey's implementation. The sampling methods used in the survey over the 21-year period are most recently described in Weinberg et al. (2002). The basic design was a series of equally spaced east-west transects from which searches for tows in a specific depth range were initiated. In general, all of the surveys were conducted in the mid-summer through early fall, although survey timing between years was variable. While the AFSC conducted all of the previous triennial surveys, the 2004 survey was conducted by the NWFSC Fishery Resource Analysis and Monitoring (FRAM) division following the AFSC survey protocols. Haul depths ranged from 91–457 m during the 1977 survey with no hauls shallower than 91 m. In all subsequent years the survey sampled depths from 55–366 m. Water hauls (Zimmermann et al., 2003), tows that were not on the bottom, and tows located in Canadian and Mexican waters were also excluded from the analyses for this assessment. Due to changes in survey timing, the triennial data have been split into early (1980-1992) and late (1995-2004) survey time series and treated independently, due to the changes in survey timing and the expected change in stock catchability because of the stock's seasonal onshore-offshore spawning movements.

Spatial variation is approximated using 250 knots, the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016) is used. Further details regarding model structure are available in the user manual (https://github.com/James-Thorson/VAST/blob/master/examples/VAST_user_manual.pdf). To confirm convergence of the model estimation algorithm, we checked that the Hessian matrix was positive definite and that the absolute-value of the final gradient of the log-likelihood with respect to each fixed effect was <0.0001 for each fixed effect. We selected among two alternative model configurations, i.e., treating positive catch rates as following a lognormal or gamma distribution. Following advice from the Science and Statistical Committee, we used the following three diagnostics for model fit:

1. The Quantile-Quantile plot, generated by comparing each observed datum with its predicted distribution under the fitted model, calculating the quantile of that datum, and comparing the distribution of quantiles with its expectation under a null model (i.e., a uniform distribution). This Q-Q plot shows no evidence that the model fails to capture the shape of dispersion shown in the positive catch rate data (Figures 13 and 14).
2. A comparison of predicted and observed proportion encountered when binning observations by their predicted encounter probability. This comparison shows no evidence that encounter probabilities are over-estimated for low-encounter-probability observations, or vice versa (Figures 15 and 16).
3. A visualization of Pearson residuals for encounter probability and positive catch rates associated with each knot. This comparison shows no evidence of residual spatial patterns for either model component (Figures 17-20).

VAST indices were calculated for the north and south areas using two separate model runs, using lognormal models (Table 2 and Figures 21 and 22). The survey biomass density (weight per area swept) was a function of year, latititude, longitude, and vessel-year. The early Triennial survey shows a decline in relative abundance, while the late Triennial shows an increase in relative abundance. Note that a single area model run initially used to produce the indices was nearly identical to the separate area VAST model run. Additional tables with VAST model output are available in Appendix I.

Length bins in 2 cm increments from 10 to 130 cm in the north and 4 to 130 cm in the south were used to summarize the length frequency of the survey catches in each year. The first bin includes all observations less than 10 cm and the last bin includes all fish larger than 130 cm. Length data preparation follow the same methods as applied to the WCBTS data. Figures 23-26 show the length frequency distributions for the Triennial survey. Tables 3 and 4 show the number of tows with lingcod samples.

Age distributions included bins from age 0 to age 20+, with the last bin including all fish of greater age. Age data preparation follow the same methods as the WCBTS length data. The Triennial Shelf Trawl Survey age-frequency data were included in the model as marginal age compositions and are shown in Figures 27-28. Tables 5 and 6 show the number of tows with lingcod samples.

Fishery Independent Data: NWFSC Hook and Line Survey

The lingcod index of abundance from the Hook and Line survey is based on numbers of fish caught in the Southern California Bight. This index uses survey data from 2004-2016 and was created following the methods described in Harms et al. (2010). The final index is averaged over all crew staff and sites. (Note that vessels are confounded with crew staff.) Two vessels were employed for the survey in 2004-12 and three vessels in 2013-16. Data from inside the Cowcod Conservation closed area was not used in this index as this area has not been consistently surveyed through time. A Bayesian delta GLM was used to estimate the probability of capture for a lingcod on each hook as a function of year, site, staff, drop number, hook number, and sea state where sea state covariates (swell height, wave height, and the percentage of daylight passed at the time of each drop) are modeled as polynomial functions. The binomial model with a logit link was used to model the presence/absence of lingcod. The posterior median index values and their associated posterior log-SD are from a converged, 2.5 million draw MCMC. Table 2 and Figure 29 shows the index. Length compositions from this survey were used as numbers of fish, all fish were measured, and were not expanded.

Fishery Independent Data: WDFW Research Compositions

WDFW conducted mark-recapture experiments in the nearshore area at the Cape Flattery from 1986 - 1994. Though study results were published in several journal articles (Jagielo 1991, 1994, and 1999), original data were misplaced. Additional surveys were conducted in the following years using bottom fish troll gear. Biological data collected from these surveys are presented in Figures 30 and 31. These data were ultimately removed from the base model as they did not provide any additional information to the model.

Fishery Independent Data: Lam Research

In collaboration with the NWFSC and Moss Landing Marine Labs, lingcod in nearshore and offshore rocky reef habitats were collected between January 2016 and January 2017 via hook and line on chartered CPFVs. Sixteen latitudinally distinct sampling sites, or ports, were chosen from northern Washington to southern California. 85 to 120 individuals were caught per port (N=1784, 922 Males, 862 Females) using methods identical to those used by the onboard recreational lingcod fishery except that shorts were retained (individuals smaller than the legal-size limit of 22 inches) and areas closed to recreational harvest were occasionally utilized (CDFW Permit #SC-6477, ODFW Permit #20237, WDFW Permit ID Samhouri 16-138). This was to ensure an even distribution of size and age classes from each port for purposes of comparing lingcod von Bertalanffy growth curves by spatially explicit regions. A random stratified subsample by size and sex was selected per region for ageing and genetics analysis. These composition data are used as CAAL, and therefore are not expanded. The Lam research composition data are shown in Figures 32-35.

Fishery Independent Data: Other

The International Pacific Halibut Commission (IPHC) longline survey data were examined for their utility in building a fixed gear index of abundance. However, depth and hook size are not appropriate for lingcod so these data are not used.

A WDFW hook and line survey includes 5-7 years of sampling but methods changed over time as this was a pilot study so these data are not used.

Biological Data: Weight-Length

The weight-length relationship is based on the standard power function: $W = aL^b$ where W is weight in kilograms and L is length in centimeters. Hart (1967) reported the relationship between length and weight as $W = 0.000282406 \cdot L^{3.011}$. The length-weight relationship was estimated by Jagielo (1994) using available survey data and was fit to mean weight-at-length measured in the West Coast survey. Jagielo (1994) estimated the following relationship for males, $W = 0.000003953\ L^{3.2149}$, and females, $W = 0.00000176\ L^{3.3978}$, where W is weight (kg) and L is fork length (cm).

Between 2003 and 2015, lengths and weights were measured for 10789 lingcod on the WCBTS. Data from 2016 and 2017 were not available early enough during the stock assessment cycle to include them in these analyses. Spatial differences were investigated by fitting an overall exponential relationship between length and weight, and then comparing the residuals across latitude and depth using Tukey HSD pairwise multiple comparison tests. Although the parameter estimates for females and males appeared different, functionally the relationships were nearly identical. Residuals of the fit between length and weight showed significant differences among States, but not north and south of Point Conception, California. The relationship between length and weight did not change with depth.

The parameters were re-estimated using data from the WCBTS. New length and weight data from the NWFSC survey for this year's assessment estimate the following length-weight relationships for females, $W=0.00000276L^{3.28}$, and males, $W=0.00000161L^{3.42}$ in the north, and for females, $W=0.000003308L^{3.248}$, and males, $W=0.000002179L^{3.36}$ in the south (Figures 36-37).

Biological Data: Maturity and Fecundity

Richards et al. (1990) examined coast-wide trends in lingcod maturity and observed that male lingcod mature at a smaller size and younger age than female lingcod. They also noted that size at maturity increases with latitude (distance from the equator). Size at 50% maturity was estimated to be 63.6 cm for females and 57.1 cm for males (ages 3.9 and 3.5) off of Vancouver Island, whereas Miller and Geibel (1973) found size at 50% maturity to be 58.8 cm and 39.8 cm (and ages 5 and 2) for females and males off of California. Jagielo (1994) found ages of 50% maturity of 3.4 years for males and 4.6 years for females off Washington. The 2009 stock assessment used values estimated in the previous assessment, with 50% maturity occurring at 68 cm in the north and 60 cm in the south.

This assessment uses an updated functional maturity ogive for lingcod, collected in 2013 – 2016 from the WCGBTS, 2014 – 2016 Oregon Department of Fish and Wildlife (ODFW), 2016 Washington Department of Fish and Wildlife (WDFW), and the 2014, 2016 Southern California Bight Hook and Line Survey of untrawlable habitat (Figures 38 and 39). The functional maturity approach accounts for abortive maturation that has been observed in adolescent females, while previously estimated maturity curves do not. The estimated size at 50% maturity (cm) with 95% confidence intervals for lingcod is 56.693 (1.546) in the north (n=302) and 52.269 (1.940) in the south (n=222).

Fecundity was assumed to be proportional to weight. Hart (1967) found fecundity to be essentially proportional to length cubed.

Biological Data: Natural Mortality

Jagielo 1994 estimated *M* for male and female lingcod using three empirical models based on life history parameters (Hoenig 1983, Alverson and Carney 1975, and Pauly 1980). Estimates of *M* for male lingcod ranged from 0.23 to 0.39, while estimates for female lingcod range 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 0.24-0.34 for females and 0.13-0.23 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.

Hamel (2015) developed a method for combining methods for calculating *M* via meta-analytic approaches to relating the natural mortality rate *M* to other life-history parameters such as longevity, size, growth rate and reproductive effort, to provide a prior on M. In that same journal issue, Then et al. (2015), provided an updated data set of *M* values and covariates estimates of *M* and related life history parameters across a large number of fish species, from which to develop an *M* estimator for fish species in general. They concluded by recommending *M* estimates be based on maximum age alone, based on an updated Hoenig non-linear least squares (nls) estimator M=4.899Amax^(-.916). The approach of basing *M* priors on maximum age (Amax) alone was one that was already being used for west coast rockfish assessments. However, in fitting the alternative model forms relating *M* to the Amax, Then et al. did not consistently apply their transformation. In particular, in real space, one would expect substantial heteroscedasticity in both the observation and process error associated with the observed relationship of *M* to Amax. Therefore, it would be reasonable to fit all models under a log transformation. This was not done. Revaluating the data used in Then et al. (2015) by fitting the one-parameter Amax model under a log-log transformation (such that the slope is forced to be -1 in the transformed space (as in Hamel 2015)), the point estimate for M is: M=5.4/Amax. Note that the data used by Then et al. (2015) include a wide range of genera.

This formula for M provides the median of the prior. The prior is defined as a lognormal with mean ln(5.4/Amax) and a standard error of 0.4384343. Using a Maximum age of 21for females the point estimate and median of the prior for lingcod is 0.257.

Biological Data: Length at age

Lingcod display sexually dimorphic growth. Females grow faster than and reach larger sizes than males. Jagielo (1994) estimated growth using a fixed length at age 1 of 30 cm, and estimated 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 young-of-the-year (age 0) lingcod was 11.99 cm and for age 2 (48.1 cm) for Washington samples, and that growth trajectories diverge considerably by sex after age 3, as female lingcod tend to grow faster and live longer than male lingcod, while male lingcod mature at age 3.

Estimates of growth parameters were investigated and starting values for model inputs were updated using the WCBTS data. Spatial differences were investigated by fitting an overall von Bertalanffy relationship between age and length, and then comparing the residuals across latitude and depth using Tukey HSD pairwise multiple comparison tests. Although the parameters for females and males appeared different, functionally the relationships look similar. Residuals of the fit between age and length showed significant differences among States. Sampled fish were larger at higher latitudes (linear regression of latitude on length, coefficient = 2.087, $t = 54.75$, $df = 10787$, $p < 0.0001$). Unlike with the length-weight relationship, age and length fits did vary with depth. However, patterns were not statistically distinguishable between shallow (<85 m) and mid-shallow (85-110 m), or between mid-deep (140-183 m) and deep (>183 m).

Externally estimated lingcod von Bertalanffy growth parameters using the 2003-2015 WCBTS are: k=0.0173 and Linf=108.6 (females), and k=0.268 and Linf=79.3 (males) for the north, and k=0.191 and Linf=100.9 (female) and k=0.214 and Linf=86.3 (male) for the south. Internally estimate growth curves are shown in figures 40-41.

Biological Data: Ageing precision and bias

A new aging error analysis was derived using the double reads from the NWFSC Cooperative Aging Project (CAP) and Washington State labs using a software designed for that purpose (Punt et al. 2008). Within lab reads for WDFW and CAP had 336 and 811 samples, respectively. Between lab reads had 404 samples. The results used are shown in Figure 47. The software is publicly available at https://github.com/nwfsc-assess/nwfscAgeingEror. The variability in age readings was estimated under an assumption of a linear increase in standard deviation with age. The resulting estimate indicated a standard deviation in age readings increasing from 0.13 years at age 1 by about 1 year of uncertainty per 10 years of age to a standard deviation of 3.16 years at age 25 (Figure 42). Note that all ages are from fin rays.

Using otoliths, McFarlane and King (2001) validated that the observed annuli are generally annual marks, via a mark-recapture study which used oxytetracycline (OTC) injections to leave a distinct mark on the otoliths that could be observed upon recapture of the fish and extraction of the otoliths, their results did find some error in ageing (>5% miss-aged) even for a single year at large, and under research settings, which generally have higher precision than under production ageing conditions. More work needs to be done to identify potential biases in production ageing of lingcod. One of the sources of error in ageing lingcod using otoliths is that the first and second annuli can be re-absorbed as the fish ages. Beamish and Chilton (1977) developed a method that used mean annual diameter measurement to locate the position of the first and second annuli and thus minimize, but not eliminate, error due to this re-absorption. Recent unpublished work suggests that ages produced from fin rays and otoliths are similar.

Fishery Dependent Data: Commercial 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 their catch reconstructions be used rather than PacFIN for overlapping years as the reconstructions are regarded as more reliable. While there is evidence for commercial landings in California prior to 1931, the historical catch reconstruction for lingcod does not address this period. Therefore, in the south, a linear ramp was applied from the start of the model period to the first year of available reconstructed landings data. Estimates of landings in CA from WA and OR waters provided late in the assessment process (pers. Comm. J. Field) were investigated as a model sensitivity run and did not impact the assessment. 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 longline, troll, and hook and line, refered to as fixed gear in this document. Table 1, and Figure 43 shows the commercial landings used in this assessment. Figure 43 also shows comparisons with commercial landings used in the 2009 assessment. Landings have declined significantly during the past two decades, 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.

WDFW’s commercial catch reconstruction focused on pre-1980 landings, especially for time periods without fish ticket data (1889 - 1943). The two main challenges for historical Washington landings data are separating catches from marine waters off of Washington from catches taken off of Alaska, Canada, and in Puget Sound; and determining catches by gear types. The main sources of information include the US Commission of Fish and Fisheries reports, WA Department of Fishery Statistical Bulletins, and the WDFW fish receiving ticket data.

Fishery Dependent Data: Commercial Discards

The WCGOP estimates commercial fishery discard ratios of lingcod for the period between 2003 to present. The WCGOP data are collected by gear type, fishery (e.g., open access, limited entry) and species/management units. The discard ratios were computed as the total estimated discarded weight (in pounds) on observed trips divided by the estimated total catch (discarded and retained). To aggregate these ratios into the fleet modeled in this assessment, each state, fishery and gear combination was weighted by the total estimated catch (discarded and retained weight). Thus, the discard rates used for each commercial fishing fleet represent the weighted estimates from each contributing segment within that fleet. Uncertainty in these values was quantified via bootstrapping the individual observations and then aggregating to the total estimate, providing a distribution of the discard rate. From this distribution a standard error associated with year specific discard ratio estimate was provided.

Annual commercial fishery discard estimates (Figures 44-47) and length compositions for both the trawl and fixed gear fleets in the north and south (Figures 48-51) are provided by the West Coast Groundfish Observer Program (WCGOP) from 2003 forward. Differences in discard rates between the north (lower) and south (higher) as well as the trawl and fixed gear fleets are apparent. Prior to the beginning of the catch shares program discard rates were generally high. However, post catch shares discard rates in the north trawl fishery show a strong decrease while the south trawl fishery exhibits higher discard rates.

Analysis of discard mortality rates have been conducted as part of the PFMC process (via the Groundfish Management Team during April 2008) and reviewed/accepted by the Science and Statistical Committee (during March 2012). Discard mortality rates of 7% for fixed gears and 50% for trawl gears are applied in this assessment.

Fishery Dependent Data: Recreational Landings

Recreational landings for WA and OR were provided by the states. California recreational landings were obtained from John Field for the years 1928-1980, with 1981 – 2004 being taken from the 2009 assessment, and 2005 forward being provided by RecFIN (pers. comm R. Ames). Recreational catches include retained plus estimated discarded dead catch (catch types A and B1) and were aggregated across boat mode (“PC” = party/charter, “PR”=private/rental), year and area. Table 1 and Figures 52-53 show both commercial and recreational landings for this assessment.

Fishery Dependent Data: PacFIN Commercial Logbooks

Two commercial fishery catch-per-unit-effort (CPUE) indices spaning the years 1981-1997 were derived from PacFIN logbook data for this assessment, north and south trawl indices. Significant changes in management beginning in 1998 result in a truncated index, ending during 1997 for both the north and south time series.

Logbook information went through several data quality filters, including filtering to attain the best possible consistent and representative data set through time to estimate a relative abundance trend. Erroneous tow locations outside of the EEZ, on land, or with extreme depths (e.g. in the abyssal plain) were removed from the data set. However, tows with reasonable depths but with map coordinates that correspond to deep areas, such as trenches or unreasonably shallow areas have been identified and removed, as these appear to be miss-reported. Likewise, tows with large differences between logbook reported and map depths have also been identified and removed. Only tows within the EEZ but not within Puget Sound were retained in the data set. This takes care of most of the tows reported to be on land, however there were erroneous tows west of the customary commercial groundfish fishing grounds but still inside the EEZ so another filtering step was needed. The following steps were used to define good tows in the rest of the logbook data based on location and reported depth: 1) polygons representing the customary groundfish fishing grounds (using data from 1981-2015) were identified using a convex hull function ('ahull' in the R alphahull package), and 2) points not in the hull were removed.

Many records in the PacFIN logbooks lack depth data. Estimated depths using GIS data were calculated for each tow using lat/long, with the 'depthMeters' function (R Imap package). Over all years, this increased the percentage of entries with a depth estimates from 85.7% to 99.7%. Note that for those tows recorded only by Fishing Block the centroid of the block is used for the beginning tow lat/long. In cases where depth was recorded in the logbooks, the GIS depth was used to double check reliable reporting of depth. To be retained in the data set 1) the depth reported in PacFIN must be within 500 meters of the GIS depth and 2) the reported depth, or the GIS depth if the reported depth is missing, must be smaller than 1,500 meters. These rules balance depth differences being generously large, since the GIS depth is based on the start of tow coordinates whereas the reported depth is a skipper estimated average depth over the tow, and depth difference being small enough to ferret out erroneous coordinates and depth.

For tows reported by 10-minute fishing blocks before 1997, largely in California, the above rules were not applied since the actual location and depth of a tow can be far different than the centroid of a block. For example, the centroid of a block may be outside of the polygons of the customary catch area, but the tow could be within a polygon. The reported depth, or GIS depth if no depth is recorded, must still be less than 1,500 meters (and greater than zero). Note that before 1997 there appears to be almost no erroneous reporting of blocks. However, from 1997 forward the recording of inaccurate data increased with the request for specific tow locations.

Finally, if a tow was identified as 'midwater' and the GIS bottom depth or the reported bottom depth was smaller than 1,646 meters (900 fathoms) then the tow was identified as good. Nine hundred fathoms is the default depth for midwater tows in the GIS estimated depth since it appears the reported depth may sometimes be the depth of the net (PacFIN has a placeholder to enter type of depth (net, bottom, etc.) but it is not used in more recent years). This depth limit is based on recent year bottom depth limits for midwater tows. The midwater tow filter was used because there are clusters of tows identified in PacFIN as 'midwater' but whose species composition clearly show bottom dwelling species.

The resulting filtered dataset reduces the size of logbook dataset over all years, 1981-1997, by 6.04%. Finally, the data set for analysis for this assessment was limited to vessels that catch the top 90% of the lingcod catch over the duration of the logbook data, essentially removing vessels that rarely caught lingcod. Issues with management constraints on landing due to trip limits have not been explicitly addressed. However, the index has been truncated in 1997 to avoid the series of management measures that had strong impacts on the groundfish fishery beginning in 1998.

The PacFIN logbook data were analyzed using the spatio-temporal delta-model (Thorson et al. 2015), implemented as an R package titled *VAST* (Thorson and Barnett 2017) and publicly available online (https://github.com/James-Thorson/VAST). *VAST* specifically includes spatial and spatio-temporal variation in both encounter probability and positive catch rates, a logit-link for encounter probability, and a gamma-link for positive catch rates. Spatial variation is approximated using 100 knots, the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016) is used. Further details regarding model structure are available in the user manual (https://github.com/James-Thorson/VAST/blob/master/examples/VAST_user_manual.pdf). To confirm convergence of the model estimation algorithm, we confirmed that the Hessian matrix is positive definite and that the absolute-value of the final gradient of the log-likelihood with respect to each fixed effect was <0.0001 for each fixed effect. We selected among two alternative model configurations, i.e., treating positive catch rates as following a lognormal or gamma distribution. Following advice from the Science and Statistical Committee, we used the following three diagnostics for model fit:

1. The Quantile-Quantile plot, generated by comparing each observed datum with its predicted distribution under the fitted model, calculating the quantile of that datum, and comparing the distribution of quantiles with its expectation under a null model (i.e., a Uniform distribution). This Q-Q plot shows that the model generally captures the shape of dispersion shown in the positive catch rate data (Figures 54).
2. A comparison of predicted and observed proportion encountered when binning observations by their predicted encounter probability. This comparison shows that encounter probabilities are acceptable (Figures 55).
3. A visualization of Pearson residuals for encounter probability and positive catch rates associated with each knot. This comparison shows generally small residuals with some spatial patterning, particularly for the southern California. (Figures 56-57).

Tow-by-tow catch rates (CPUE), calculated as pounds per hour, were fitted using VAST using year, vessel, month, depth, and PFMC area, and vessel-year as covariates Both gamma and lognormal models were explored, the gamma model better fit the data. Model diagnostics show adequate fit and general consistency with GLM model assumptions for the positive catch component. Similarly to past analyses (Jagielo 2000), the northern trawl logbook index trend shows a sharply declining stock since 1976, and the southern trawl logbook index indicates a declining stock since 1979 (Table 2 and Figure 58). Both stocks remain at low levels through the end of the time series in 1997. Additional tables with VAST model output are available in Appendix I.

Fishery Dependent Data: OR Fixed Gear Nearshore Commercial Logbook Index

The ODFW has required nearshore commercial fishers (both nearshore permitted vessels and open access vessels) to submit fishing logbooks since 2004. Responses from submitted logbooks have been entered into a central database. Fisher compliance is generally high, averaging around 80%, but has varied through time ranging from 65% in 2007 to 95% in recent years. Although required to provide all requested information in the logbook per fishing gear set, there has been substantial variation in the quantity and quality of information reported in logbooks.

Logbook information went through several data quality filters recommended by ODFW staff to attain the best possible consistent and representative data set through time to estimate a relative abundance trend. Individual observations of catch (kg) and effort (hook hour) were at the trip level, where multi-set trips were aggregated to the trip level. Gear type was restricted to hook-and-line (excluding longline gear) because this method accounted for a majority of sets.

Covariates considered in the full model included month, vessel, port, depth, and people. All covariates were specified as categorical variables, except depth was a continuous variable. Depth was included to account for general differences in bathymetry and fishing depth restrictions. People were included in an attempt to control for the potential oversaturation of hooks at a given fishing location and the interaction that multi-crew trips (# fishers onboard) may have on fishing efficiency. The selection of covariates included in final models were evaluated using standard information criterion for relative goodness of fit (AIC), where a covariate remained in the model if model fit was improved relative to an otherwise identical model without the covariate.

CPUE was modeled using a delta-GLM approach, where the catch occurrence (binomial) component was modeled using a logit link function and the positive catch component was modeled according to a lognormal distribution with a log link function. CPUE was calculated for each trip, where total catch was defined as the sum total of all reported retained catch (in weight) and released catch (numbers converted to weight by applying a median catch weight) and total effort was defined by hook-hours (number of hooks used multiplied by the number of hours fished). A gamma distribution for the positive catch component was also evaluated, but graphical summary diagnostics of model adequacy favored the lognormal distribution.

Model selection of all main effects models identified the full model with covariates month, vessel, port, depth and people as the best fit to the data, along with the categorical year factor of interest for the index. A bootstrap resampling routine was conducted to estimate the standard error (and CV) of the year effects. Standard model diagnostics show adequate fit and general consistency with GLM model assumptions for the positive catch component (Table 2 and Figure 59). Figure 60 shows the index.

Fishery Dependent Data: Commercial Biological Sampling

Sex specific commercial fishery landed length and age compositions (Figures 61-64) were obtained from PacFIN. Annual commercial length- and age-frequency distributions were developed for each state for which observations were available, following the same bin structure as was used for research observations. For each fleet, the raw observations were expanded to the sample level, to allow for any fish that were not measured, then to the trip level to account for the relative size of the landing from which the sample was obtained. Length and age data collected from commercial landings for each region are summarized by the number of port samples, where a port sample consists of fish sampled from a single fishing trip. The number of port samples is the input N for each year and area. Tables 3 to 5 show biological data sample sizes. Note that the early Washington data contain a large proportion of unsexed fish, therefore all samples collection prior to 1993 are included in this assessment as sex combined compositions. Durng this stock assessment cycle it was found that the proportion of unsexed fish prior to 1993 was high in the north model area, leading to the use of sex-combined length compositions prior to 1993 and sex specific length compositions after 1993.

Fishery Dependent Data: WA Dockside Recreational Index

The WDFW provided recreational dockside fisheries data from 1981 to present. In consultation with state representatives, it was determined that the dockside index was more reliable so the MRFSS recreational data were not used. These data went through several data quality filters to identify the best subset of the available data that are likely to be consistent over the time series and provide a representative relative index of abundance once standardized. Analyses were conducted both with and without the Stephens and MacCall (2004) data filter. The Stephens-MacCall method is an objective approach for identifying trip records of catch and effort data when fishing locations are unknown, based on inference regarding the species composition of the catch, and identifying trips to habitats where the target species is likely to occur (Stephens and MacCall 2004). Since recreational fishing trips target a wide variety of species, standardization of the catch rates requires selecting trips that are likely to have fished in the target species habitat. The method of Stephens and MacCall (2004) was used to identify trips with a high probability of catching the target species, based on the species composition of the catch in a given trip. Coefficients from the Stephens-MacCall analysis (a binomial GLM) are positive for species that co-occur with the target species, and negative for species that are not caught with the target species. Covariates considered in the full model included year, month, boat type, area, and a covariate for management that captured management actions likely to impact the fisher (e.g. depth restrictions, bag limits, and size limits). All covariates were specified as categorical variables. The stepwise selection of covariates in main effects models was evaluated using standard information criterion for relative goodness of fit (AIC). Depth was not included in the analysis because it was not uniformly recorded through time; depth data collection began during 2003. The covariates for daily bag limits and allowable landing size of fish represent management changes.

CPUE was modeled using a delta-GLM approach, where the catch occurrence (binomial) component was modeled using a logit link function and the positive catch component was modeled after log-transformation of the response variable, according to a normal distribution with an identity link function. Data are collected at the trip level, with the number of fish landed and the number of anglers on each vessel being recorded. The amount of time fished by each angler is not recorded. Therefore, the units for CPUE are fish landed/angler-trip. A gamma distribution for the positive catch component was also explored, but model selection favored the lognormal model.

Model selection from all main effects models selected the full model with covariates month, boat type, area, and management as important for both the catch occurrence and positive catch component models for all data sets, along with the categorical year factor used for the index of abundance. The management covariate accounts for changes in bag limits and allowable landing size. A bootstrap analysis (N=500) was used to estimate the standard errors (and CVs) of the year effects. Standard model diagnostics show adequate fit and general consistency with GLM model assumptions for the positive catch component (Figure 65). CPUE indices produced both with and without the Stephens-MacCall data filter produced highly similar indices so the index without Stephens-MacCall filtering was used in the stock assessment model (Figure 66).

Fishery Dependent Data: OR Ocean Recreational Boat Sampling (ORBS)

The OR Ocean Recreational Boat Sampling (ORBS) dockside sampling program has a more comprehensive coverage and greater sample sizes (i.e., 50-70 times more trips than the onboard observer program), but somewhat less confidence in the data elements compared to onboard observer programs, as only retained catch and the number of anglers were verified by biologists (all other trip details were angler reported). The onboard and dockside sampling programs are not fully independent as a single fishing trip can be sampled in both the onboard observer program and the dockside within ORBS. In order to provide estimates of total catch and effort for the Oregon sport fisheries, ORBS obtains catch rates from a portion of vessels via a dockside survey, and applies them to total effort counts. During the dockside survey, biologists intercept vessels returning from fishing trips and record catch, effort, and other trip-related details (e.g., grid area fished, target species, depth, port, etc.). Since catch and effort per sampled trip are both obtained, the dockside survey of ORBS was also used to develop an index of abundance for lingcod. Note that, in consultation with state representatives, it was determined that the ORBS sampling was more reliable so the MRFSS recreational data were not used.

Modifications were made to trip hours from the original ORBS dataset to create a standardized unit of effort. Since trip hours in ORBS are not hours fished, but rather the total duration of the trip (as measured from the time the boat crossed into the ocean until the time they were interviewed at the dock), travel times had to be determined and subtracted from trip hours in order to get a standardized measure of fishing effort per trip. Accordingly, a total distance function was created for each trip based on the river miles (distance along the navigable channel from the port to the bar (river mouth)) and ocean miles (i.e., straight distance from the river bar to the ocean grid fished, wrapping around obstructions if needed). Total distance was then converted to travel time based on generalized vessel speeds for private (i.e., 18 mph) and charter boats (i.e., 13 mph) following methods applied by Dick et al. (2015). It is important to note that the original trip hours minus travel hours still does not equal hours fished because it does not account for time needed to move from drift to drift; however, since the number of resets between drifts would be expected to be related to fish abundance (as with catch rates), the modified trips hours was deemed a viable effort unit for the assessment.

Some trips had erroneous trips hours (discrepancies between values entered on paper and then entered electronically later). These were the steps taken to correct the issue:

1. Trip hours is computed automatically by the data logger based on the time the interview is entered electronically
2. If samplers write their interviews on paper and enter them electronically later when they have time (as believed to have happened despite being instructed not to), then the trip hours are inflated.
3. To potentially remove these errors, we computed time intervals between interviews. Pulses of interviews a minute or two apart are very likely to have been from bunches of paper interviews entered electronically in one sitting, as normal interviews are somewhat sporadic and take more than a minute to complete.

The ORBS dockside charter boat spans the years 2001-2016. As with the other trip-based CPUE data sets, analyses were completed with and without the Stephens-MacCall data filtering method that is used to identify trips with a high probability of catching the target species. Prior to using the Stephens-MacCall approach to select relevant trips, a number of other filters were applied to the data to minimize variability in CPUE estimates. Criteria for valid trips included vessels with trip hours <12. Trips targeting tuna and dive trips were excluded from the analysis.

CPUE was modeled using a delta-GLM approach, where the catch occurrence (binomial) component was modeled using a logit link function and the positive catch component was modeled after log-transformation of the response variable, according to a normal distribution with an identity link function. The units for CPUE are fish landed/angler-hours, with covariates being year, month, boat type, bag limits, minimum length regulations, and maximum length regulations. Both lognormal and gamma distributions for the positive catch component were explored, but model selection favored the lognormal model.

Model selection using all main effects models selected the covariates year, month, and boat type as important for both the catch occurrence and positive catch component models for all data sets, along with the categorical year factor used for the index of abundance. A bootstrap analysis (N=500) was used to estimate the standard errors (and CVs) of the year effects. Standard model diagnostics show adequate fit and general consistency with GLM model assumptions for the positive catch component (Figure 67). CPUE indices produced both with and without the Stephens-MacCall data filter produced highly similar indices so the index without Stephens-MacCall filtering was used in the stock assessment model (Table 2 and Figure 68).

Note that the Oregon recreational fishery has been subject to a seasonal depth restriction since 2004, this was 40 fathoms until 2012 and changed to 30 fathoms after 2012. However, this depth restriction was not modeled due to the relatively small change in depths.

Fishery Dependent Data: OR and CA Onboard Observer Recreational Indices

All data elements for the onboard observer indices were verified by a biologist, and thus there was a high degree of certainty in the catch, effort, and locations fished; however, there was limited spatial-temporal coverage and only charter boats were included (not private boats). The goal of the Observer Programs in California and Oregon is to collect data including charter boat fishing locations, catch and discard of observed fish by species, and lengths of discarded fish. Both states sample the Commercial Passenger Fishing Vessel (CPFV), i.e., charter boat or for-hire fleet. The onboard observer programs collect drift-specific information at each fishing stop on an observed trip. At each fishing stop recorded information includes start and end times, start and end location (latitude/longitude), start and/or end depth, number of observed anglers (a subset of the total anglers), and the catch (retained and discarded) by species of the observed anglers.

Data for the onboard observer indices for the recreational CPFV fleet are from four sampling programs. The CDFW conducted an onboard observer program in central California from 1987-1998 (Reilly et al. 1998). These data were previously used in the 2013 data moderate assessments (Cope et al. 2015), at the level of a fishing trip. Since the 2013 assessments, the original data sheets were acquired and data were key punched to the level of fishing stop. One caveat of these data is that locations were recorded at a finer scale than the catch data. We aggregated the relevant location information (time and number of observed anglers) to match the available catch information. Between April 1987 and July 1992 the number of observed anglers was not recorded for each fishing stop, but the number of anglers aboard the vessel is available. We imputed the number of observed anglers using the number of anglers aboard the vessel and the number of observed anglers at each fishing stop from the August 1992- December 1998 data (see Dick et al. 2015, Appendix E for details, p.E-1).

California implemented a statewide onboard observer program in 1999 (Monk et al. 2014). California Polytechnic State University (Cal Poly) has conducted an independent onboard sampling program as of 2003 for boats in Port San Luis and Morro Bay (Stephens et al. 2006), but follows the protocols established in Reilly et al. (1998), and was modified to reflect sampling changes that CDFW has also adopted, e.g., observing fish as they are landed instead of at the level of a fisher's bag. Therefore, the Cal Poly data area incorporated in the same index as the CDFW data from 1999-2014. Cal Poly collects lengths of both retained and discarded fish.

We generated separate relative indices of abundance in California for the 1987-1998 and 1999-2016 datasets due to the number of regulation changes occurring throughout the time period, and the difference in sampling regimes between these periods. Regulatory changes implemented by CDFW during 1999 through 2001 resulted in removal of these years from the index. A regulation of three hooks during 2000 was reduced to (and remains at) two hooks during 2001.

The ODFW initiated an onboard observer program in 2001, which became a yearly sampling program in 2003 (Monk et al. 2013). Both California and Oregon provided onboard sampling data through 2016.

Prior to analyses preliminary data filters were applied. Trips/drifts from the CDFW 1988-1998 database meeting the following criteria were excluded from analyses:

1. Drift associated with a fishing location code that was not assigned to a reef.
2. Drifts identified as having possible erroneous location, observed anglers, or time data.
3. Trips encountering <50% groundfish species (number of fish).
4. Drifts/trips missing any of the following: year, month, district, depth, angler hours, number of lingcod kept or discarded, latitude or longitude, trip-level percentage of catch containing groundfish
5. Drifts with a value of zero for depth or angler hours
6. Drifts missing the number of lingcod encountered (after determining whether this could be reconstructed from the number kept and discarded)
7. Drifts in depths 500 ft. (depth at which relatively few positive observations of lingcod occurred)

Trips/drifts from the CDFW 1999-2014, and Cal Poly databases meeting the following criteria were excluded from analyses:

1. Drifts identified as having possible erroneous location, observed anglers, or time data
2. Drifts/trips missing any of the following: year, month, district, depth, angler hours, number of lingcod kept or discarded, latitude or longitude, trip-level percentage of catch containing groundfish

3. Drifts with a value of zero for depth or angler hours
4. Drifts missing number of lingcod encountered (after determining whether this could be reconstructed from the number kept and discarded)
5. Drifts with locations outside of a polygon representing depths from 0-305m.
6. Drifts within Arcata Bay, Humboldt Bay, South Bay, or San Francisco Bay
7. Drifts occurring > 500m from a reef (distance at which relatively few positive observations of lingcod occurred), for northern or central California (where such habitat data were available)
8. Drifts occurring on a reef with < 3 cumulative positive encounters of lingcod over the period of the time series, for northern or central California (where such habitat data were available)
9. Drifts in southern California occurring outside the area of likely lingcod catch, determined by the convex hull of positive lingcod catch records (alpha = 0.28)
10. Trips encountering ≤ 50% groundfish species
11. Drifts in months with relatively few observations (January and February)
12. Drifts in depths > 400 ft. (depth at which relatively few positive observations of lingcod occurred)
13. Drifts with fish times ≤ 2 minutes or 290 minutes

Trips/drifts from the ODFW database meeting the following criteria were excluded from analyses:

1. Drifts associated with a fishing location code that was not assigned to a reef
2. Drifts identified as having possible erroneous location, observed anglers, or time data
3. Trips encountering < 50% groundfish species (number of fish)
4. Halibut-targeted trips
5. Drifts/trips missing any of the following: year, month, county, depth, angler hours, number of lingcod kept or discarded, latitude or longitude
6. Drifts with a value of zero for depth or angler hours
7. Drifts missing the number of lingcod encountered (after determining whether this could be reconstructed from the number kept and discarded)
8. Drifts where midwater groundfish made up 95% of the catch
9. Drifts occurring > 400m from a reef (distance at which relatively few positive observations of lingcod occurred)
10. Drifts occurring on a reef with < 3 cumulative positive encounters of lingcod over the period of the time series
11. Drifts with fish times ≤ 2 minutes
12. Drifts in months with relatively few observations (March and October)
13. Drifts in depths > 200 ft. (depth at which relatively few positive observations of lingcod occurred)

CPUE was modeled using a delta-GLM approach, where the catch occurrence (binomial) component was modeled using a logit link function and the positive catch component was modeled after log-transformation of the response variable, according to a normal distribution with an identity link function. Data were analyzed at the drift level and catch was taken to be the sum of observed retained and discarded fish, i.e., the number of fish encountered per angler hour. Potential covariates for all indices were year, month, depth, area, and year-area interaction. Both lognormal and gamma distributions for the positive catch component were explored, but model selection favored the lognormal model in all cases. A bootstrap analysis (N=500) was used to estimate the standard errors (and CVs) of the year effects for all models. Standard model diagnostics showed adequate fit and general consistency with GLM model assumptions for the positive catch component (Figures 69-71). The final models included all main effects. Although the model with the year-area interaction had the lowest AIC value, the index was unrealistically erratic and the CVs were very large. Table 2 and Figures 72-73 show the onboard recreational observer indices. Note that the base assessment model does not use both the OR onboard index as well as the OR dockside as they show similar trends. The dockside index is used due to the longer time series.

Fishery Dependent Data: Central CA Recreational Index

A central California (Point Conception to Point Mendocino) PSMFC recreational dockside boat survey, also referred to as MRFSS, index (1980-1997) was included in the 2009 south assessment (Hamel et al. 2009). Data after 1997 were not included due to a succession of changes in management regulations that may have affected the CPUE and length distribution of the catch. This index (Figure 74) is not included in the base model in this document, as other data sets were viewed as more reliable, and was explored in model sensitivity runs during the assessment process.

Fishery Dependent Data: Recreational Biological Sampling

Recreational fishery landed length and age compositions (Tables 3 to 5 and Figures 75-79) were obtained directly from WDFW and ODFW, and from John Field and RecFIN for CA. Note that, in consultation with WDFW and ODFW representatives, it was determined that the state databases were more reliable so the data were not obtained via RecFIN (MRFSS). Additionally, the RecFIN database was undergoing restructuring during this stock assessment cycle, leading to delays in obtaining data. Annual recreational length- and age-frequency distributions were developed for each state for which observations were available, following the same bin structure as was used for research observations. Many of these composition data lack information on the number of fish sampled out of those landed in a given trip, and therefore are used without expansion to the sample level. Unexpanded recreational composition data are commonly used in West Coast stock assessments for the above reason. Input N values were set at the number of fish sampled for each year and data set.

In Oregon the minimum size limits for lingcod have changed from 22 inches during 1995 to 1997 and 2006 to present, but were 24 inches during 1998 to 2006. It has also been reported that recreational fishers in Oregon sometimes release large, assumed to be female fish, so that they can spawn. However other anglers tend to target and retain these large fish.

4. Model

Data changes since 2009 assessment

Changes in data for this assessment include:

1. Expansion of the time period of the assessments back to 1889.
2. Splitting of the 2009 commercial fleet into trawl and fixed gear components.
3. Splitting the 2009 north recreational fleet into OR and WA.
4. Updated landings and length composition data
5. Use of conditional age-at-length data for only the NWFSC survey and the research study by L. Lam.
6. Re-analysis of the commercial fishery CPUE time series with VAST (last investigated during the late 1990s – early 2000s).

7. Addition of an OR commercial nearshore CPUE index.
8. Addition of a WA recreational dockside CPUE index.
9. Addition of an OR ORBS recreational dockside CPUE index.
10. Exploration of an OR charter boat onboard observer recreational CPUE index (in agreement with dockside sampling).
11. Exploration of early and late CA charter boat onboard observer recreational CPUE index (model sensitivity).
12. Addition of the NWFSC hook and line survey CPUE index and length data.
13. Addition of length and age composition data from L. Lam's research study.
14. Exploration of length and age data from a WDFW research study (removed from base model).
15. An updated prior on natural mortality (Hamel).
16. A new maturity relationship based on recent data collections.
17. Updated length weight relationships based on NWFSC survey data.
18. Re-analysis of double read age data for revised estimates of aging variability.
19. Re-analysis of the AFSC Triennial survey index with VAST.
20. Exploration of conditional age-at-length composition data for the WA and OR recreational fisheries (model sensitivity).
21. Exploration of marginal age composition for the commercial fleets (model sensitivity).

History of Modeling Approaches

There have been six assessments of lingcod since 1986 covering part or all of the West Coast of the United States.

Adams (1986) conducted a yield per recruit analysis. Jagielo (1994) conducted an age-structured assessment of the status of the lingcod stock between Cape Falcon in Northern Oregon to 49 ˚N (off of southwest Vancouver Island in British Columbia - PMFC areas 3A, 3B, and 3C, including Canada), using the Stock Synthesis program (Methot, 1990). Data included trawl and recreational catch from 1979-1993 with equilibrium catch before then, triennial shelf survey and trawl CPUE indices, and length and age composition data. The final spawning output levels were estimated to be about 20% of pristine levels, and catch level recommendations ranged between 2500 and 3000 mt based on F40% to F20%.

The 1997 assessment (Jagielo et al.1997) expanded the area south to Cape Blanco (42°50' N), and retained the northern boundary of 49°00'N and the use of the Stock Synthesis model. Depletion in spawning output in this model was below 10% for 1997.

Adams et al. (1999), conducted a length-based, age-structured population model implemented in AD Model Builder (ADMB, Fournier 1996) for the southern area which had not yet been assessed (Eureka, Monterey, and Conception INPFC areas).

Jagielo et al. (2000) conducted age structured models in ADMB for two areas of the US: US Vancouver-Columbia (no longer including Canadian waters) and Eureka, Monterey, Conception INPFC areas. Jagielo et al. (2003) conducted age structured assessments for the two areas using Coleraine. Finally, Jagielo et al. (2005) conducted age structured assessments for the two areas using Stock Synthesis 2 (SS2). They found that the northern stock had recovered substantially from a low point in the 1990s was at 87% depletion, while the southern area had not recovered as well and was at 24% depletion, with a 64% coast-wide depletion.

The 2009 stock assessment, completed in Stock Synthesis 2, divides the Northern (Washington and Oregon) and Southern (California) stocks by state line (Hamel et al. 2009). The point estimate for the spawning stock depletion at the start of 2009 was 61.9% for the North, 73.7% for the South, indicating the stock is recovered. The axis of uncertainty for the decision table provided to managers was natural mortality for the north, with the base model $M = 0.18$ for females and 0.32 for males. The "Low M" alternative uses $M = 0.16$ and 0.285 for females and males respectively, and the "High M" alternative uses $M = 0.20$ and 0.355. The axis of uncertainty for the South model was for the high alternative including age data, and for the low alternative excluding the dockside recreational CPUE index. The 2009 stock assessment removed all age data due to issues with outliers and possible aging bias. The north and south models were made as equivalent as possible by keeping fixed and estimated parameters largely the same for the two assessments. Natural mortality (M) was fixed at 0.18 for females and 0.32 for males in both assessments, while stock-recruitment steepness (h) was fixed at 0.8.

GAP and GMT input

Two meetings were held to prior to the STAR panel to discuss data and modeling issues relevant to this 2017 lingcod stock assessment. The first was with GAP and GMT members during the March 2017 Pacific Fishery Management Council meeting held in Vancouver, WA. The second was at a pre-assessment workshop held during March 2017 at the PFMC offices in Portland, OR. GAP and GMT members were also active participants at the STAR panel review during June 2017. Finally, a series of phone calls with the GMT, PFMC staff, and SSC took place during December 2017 to discuss the treatment of the 2017-2018 ACLs.

Response to 2009 STAR Panel Recommendations

Issues with respect to data that were raised during the 2009 lingcod stock assessment are reviewed below. Actions taken between the 2009 and current assessments are provided below.

1. The need for age validation
    - An age validation study has not been completed for lingcod.
2. Problems noted with NWFSC survey length and age sampling during the 2003 survey.
    - Standard sampling protocols have been instituted for the NWFSC groundfish trawl survey and are reviewed annually.
3. The need for alternative survey methods for untrawlable habitat.
    - No new surveys have been implemented.
4. Evaluate use of IPHC survey for lingcod
    - This data set is not suitable for lingcod due to an inappropriate sampling depth range and hook size.
5. Evaluate usefulness of WA tagging data.
    - This tagging data is from Puget Sound, outside of the scope of the assessment area, and the data reside on paper records that are not readily available for analyses.
6. Investigate reasons for outliers in length-at-age data.
    - Length and age data have been restructured for this assessment and large outliers are no longer a problem. The models were able to fit the composition data well. However, the STAR panel identified concerns with biased sampling of ages with respect to lengths, leading to the removal of the fishery age data from the base model. The inclusion of the recreational age composition data as conditional-age-at-length is able to address the sampling bias, these data were included in the model as a sensitivity run. The amount of commercial age data prohibits the use of conditional compositions, the marginal age compositions are included as a model sensitivity. The sampling bias problem can be addressed for the next lingcod assessment.

7. Look at environmental covariates for recruitment, time-varying growth, and in-shore availability.
    - No studies have been completed since the last assessment.

Issues with respect to the stock assessment modeling raised during the 2009 lingcod stock assessment are reviewed below. Actions taken between the 2009 and current assessments are provided below.

1. The definition of length at age in SS was unclear.
    - SS documentation is now readily available.
2. Evaluate the assumption that fishery CPUE is proportional to stock biomass.
    - During the 2017 model development the proportionality assumption was investigated for all indices. Assuming indices are not proportional to abundance results in similar or more favorable stock trends. While arguments could be made for why each of the indices are not proportional to abundance, this 2017 stock assessment maintains the assumption of proportionality as the indices generally provide similar information on stock trends.
3. Investigate the inability to estimate growth or poor growth estimation
    - The 2017 assessment is able to reliably estimate male growth and female growth in the south but is not able to reliably estimate female L at maximum age in the north model where large fish that were observed historically are not present in the NWFSC conditional length-at-age data. This value is fixed.
4. Investigate the inability to fit the NWFSC survey data
    - This 2017 assessment fits the NWFSC survey data.
5. Sensitivity to recruitment estimation start year
    - This 2017 assessment is able to estimate recruitment from the model start and no longer shows an unrealistically large recruitment at the beginning of the main recruitment deviation period.
6. Consider the impact of male nest guarding on the definition of reproductive output
    - Time did not permit for the investigation of this issue. The PFMC SSC may consider a range of alternative definitions of reproductive output that they may be interested inconsidering in the future.
7. Undertake a Bi-national assessment.
    - Lingcod are a transboundary stock with both Canada and Mexico. However, a legal mandate and management framework for using the advice of a transboundary stock assessment does not exist. Data sharing is currently happening at a scientific level with Canadian scientists.

Responses to the current 2017 STAR Panel are detailed in the 2017 STAR Panel report for lingcod with the following exception. The Panel's requested approach (Request 4.1) for constructing the low and high states of nature in the decision tables would have resulted in states of nature that were less extreme than the uncertainty implied by the standard errors for the base models' estimates of 2017 spawning biomass.

Transition from 2009 to 2017 Stock Assessment Models

This assessment uses SS version V3.30.03.07, and implements two separate assessments for the north and south areas, as did the 2009 assessment. Similarly to the 2009 assessment the two areas are defined by state boundaries with the north area including Washington and Oregon, and the south area including California. The 2009 models were transitioned into SS version 3. 03.05, these transitioned models matched the time series of spawning biomass and stock depletion estimated in the 2009 stock assessment. The 2017 model implements model structural changes including:

1. Disaggregating both the commercial fleets into trawl and fixed gears and the north recreational fleet into WA and OR.

2. This assessment implements plus and minus groups for the data length bins are larger and smaller that those used in 2009.
3. This assessment implements a larger plus group for ages than that used in the 2009 assessment.
4. A broader set of time blocks are used to model selectivity for both commercial and recreational fisheries to better reflect management impacts.

Given structural changes to this model a step-by-step transition to the final accepted base model in not provided, as required by update stock assessments. However, the comparison between the final 2009 and 2017 base models are provided below.

Summary of data for fleets and areas

Commercial fishery removals were divided among four fleets and two assessment models:
1. north trawl gears
2. north fixed gears
3. south trawl gears
4. south fixed gears

Recreational fishery removals were divided into three fleets and two assessment models:
1. north WA
2. north OR
3. south CA

All available data are described in Figures 2 and 3.

Modeling software

This assessment used the Stock Synthesis V3.30.03.07 modeling framework written by Dr. Richard Methot at the NWFSC (Methot and Wetzel, 2013).

Data weighting

Indices of relative abundance all had variance estimates generated as part of the analysis of raw catch data. These variances are converted to standard deviations in log space for use in the model; additional variances for the fishery indices of abundance were estimated inside the model. The number of trawl tows or port samples was used as the initial input sample sizes for length and marginal age compositional data for survey and fishery samples, respectively. The number of fish aged by length class was used as the input sample size for the survey and L. Lam conditional age-at-length compositions, as well as for recreational composition data. Each observation of CAAL composition consists of multiple age-composition vectors, one for each length class.

This assessment follows the iterative re-weighting approach to developing consistency between the input composition sample sizes (or standard errors) and the effective sample sizes based on model fit. This approach attempts to reduce the potential for particular data sources to have a disproportionate effect on total model fit, while creating estimates of uncertainty that are commensurate with the uncertainty inherent in the input data. Iterative re-weighting was applied to all compositional data. Two approaches were considered. One approach, attributed to McAllister and Ianelli (1997), consisted of comparing the mean input sample size for compositional data with the mean effective sample size based on model fit. A single iteration was completed using a multiplicative scalar to tune the input sample sizes for all length- or age-compositions for a given fleet or survey. The second approach, developed by Francis (2011), considers the influence of compositional weights on fits to average lengths or average lengths-at-age.

Sensitivity to the two methods for model tuning of composition data were investigated, it was determined that the model was not sensitive to implementing either Francis (2011) or McAllister and Ianelli (1997). The estimated 2017 stock depletion and unfished spawning biomass for both the north and south models were inside the estimated assympotic standard deviations for these quantitites. Specifically, the difference in estimates of stock depletion for both the north and south models between the two methods was < 2%, the difference in estimates of unfished spawning biomass between the two methods was -2841 mt in the north and 125 mt in the south. As each method provided similar results, the model sensitivity section below focuses on other explorations. The base model in both the pre-STAR and post-STAR models uses the Francis (2011) method.

The value of σ_R, the parameter controlling recruitment variability, was determined using an iterative procedure to ensure that the value of σ_R assumed by the assessment model and the empirical variance in recruitment were self-consistent. This involved setting σ_R to an initial value, fitting the model and calculating the variance of the recruitment deviations for the years for which recruitments are estimated in the model, then replacing the assumed value of σ_R by the calculated value. Very little iterative reweighting was necessary for σ_R.

Priors

Priors were applied only to Male natural mortality based on a meta-analysis completed by Hamel (2015). The prior female natural mortality was fixed at the median of the prior based on a maximum observed age of 21, where M = 0.257. See the discussion of natural mortality in the data section for justification of the estimation of sex specific M.

General model specifications

Stock synthesis has a broad suite of structural options available. Where possible, the ‘default’ or most commonly used approaches are applied to this stock assessment. The assessment is sex-specific, including the estimation of separate growth curves, natural mortality, and selectivity for males and females. Therefore, the assessment only tracks female spawning biomass for use in calculating stock status.

This assessment consists of two independent models that cover the U.S. west coast with time-series of landings beginning in1889. The sex-ratio at birth is fixed at 1:1, although by allowing increased natural mortality for males, size-based selectivity, and dimorphic growth, the sex ratio will vary by age and time. The model starts at equilibrium, assuming an unfished initial age structure.

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. See the SS technical documentation for details (Methot and Wetzel 2013). Estimated likelihood components from the base models can be found in the model output Report.sso files archived with the PFMC.

Electronic model files including the SS executable, data, control, starter, and forecast files are archived with the PFMC.

Estimated and fixed parameters

A full list of all estimated and fixed parameters is provided in Tables 7 and 8. Time-invariant, sex-specific growth is estimated in this assessment, with all SS growth parameters being estimated except for female length at maximum age in the north model l, which was fixed at 110 cm for age 14 fish. The log of the unexploited recruitment level for the Beverton-Holt stock-recruit function is treated as an estimated parameter. Annual recruitment deviations are estimated beginning at the model start, 1889, with the main period of recruitment deviation estimation starting during 1965, just prior to reliable length and age composition entering the models. Female natural mortality is fixed, male natural mortality is estimated, as is commonly done for groundfish stocks that exhibit dimorphic growth such as lingcod. Sex specific size selectivities are estimated, where sex specific data allowed, using the double normal pattern (SS pattern 24) for all fleets and surveys. All surveys as well as the Oregon and California recreational data were modeled using combined male and female selectivity due to either combined sex data, or good fits to the data without sex specific selectivity curves. Retention is estimated for the commercial fishing fleets. In the north model selectivity and retention are estimated with time blocks such that: 1) the fixed gear fleet uses blocks from 1998 to 2010 and 2011 to 2016 to account for management changes (e.g. gear changes and closed areas) and the implementation of the catch shares program, respectively, 2) the trawl fleet uses blocks from 1998 to 2006, 2007 to 2009, 2010 to 2010, and 2011 to 2016 to account for management changes and the implementation of the catch shares program, and 3) the Oregon recreational fleet uses blocks from 1999 to 2016 to account for management changes and observed changes in the composition data. In the south model selectivity and retention are estimated with time blocks such that: 1) the fixed gear fleet uses blocks from 1998 to 2001, 2002 to 2002, 2003 to 2010, and 2011 to 2016 to account for management changes and the implementation of the catch shares program, 2) the trawl fleet uses blocks from 1998 to 2006, 2007 to 2009, 2010 to 2010, and 2011 to 2016 to account for management changes and the implementation of the catch shares program, and 3) the California recreational flees uses blocks from 1959 to 1974, 1975 to 1989, 1990 to 2003, and 2004 to 2016 to account data collection by different agencies and in different regions of the state. See tables 7 and 8 for information on estimated and fixed selectivity parameters. The six parameter double normal selectivy pattern was reduced to three parameters by fixing the width at the peak (P2), the initial selectivity (P5), and final selectivity (P6) to large negative values (-15, -999, and -999, respectively) and estimating the remaining parameters, where the data allowed. The survey catchability parameters are calculated analytically (set as scaling factors) such that the estimate is median unbiased, which is comparable to the way *q* is treated in most groundfish assessments.

2017 Model

Key Assumptions and Structural Choices

All structural choices for stock assessment models are likely to be important under some circumstances. Assessment choices were generally made to 1) be as objective as possible and 2) follow generally accepted methods of approaching similar models and data. The relative effect on assessment results of each of these choices is often unknown; however, an effort is made to explore alternate choices through sensitivity analysis. Major choices in the structuring of this stock assessment model include two separate area models (north and south), splitting the triennial survey into an early and late time period, and estimates of selectivity curves for each fleet and retention curves for the commercial fleets. Length and age bins in this assessment are expanded from those used in the previous two assessments. In the north, length bins range from 10 to 130 in two cm increments, with the first bin containing all fish less than 10 cm and the maximum bin containing all fish ≥ 130 cm. In the south, length bins range from 4 to 130 in two cm increments, with the first bin containing all fish less than 4 cm and the maximum bin containing all fish ≥ 130 cm. Smaller fish are observed in the southern survey area, hence the need for the length bins to start at a smaller size. Age bins for both models range from 0 to 20 in single year increments, with the upper bin serving as a plus group for all fish older than age 20.

Alternate Models Explored

Comparison of key model assumptions include comparisons based on nested models (e.g., asymptotic vs. domed selectivity, constant vs. time-varying selectivity). Many variations on the base case models were explored during this analysis; only the most relevant and recent are reported in this document. Some of these are reported as sensitivity and retrospective analyses. Prior to the STAR panel, detailed exploration was made to evaluate:

1. Estimation of natural mortality with a prior.
   - Estimation of M is possible for both males and females if the commercial age data are retained in the north model. Without the commercial age data the model is not able to estimate female M, but male M can be estimated if the female value is fixed. There is not enough information in the available data to estimate female M in the south model, even if all of the age data are retained. However, similarly to the north model, male M can be estimated if the female value is fixed.
2. Alternative fixed values for female natural mortality.
   - Scale the estimates of unfished biomass up and down as expected (higher M = lower estimate of unfished biomass, and vice versa), retaining similar estimates of current biomass.
3. Alternative fixed values for h.
   - Scale the estimates of current biomass up and down as expected (higher h = faster population recovery and larger current stock size, and vice versa), retaining similar estimates of unfished biomass.
4. Tuning of composition sample sizes.
   - The models were not sensitive to the choice of weighting method, see the data weighting section below for more detail.
5. The period over which recruitment deviations are estimated.
   - Early explorations show that the model estimates of stock depletion are highly sensitive to this choice, the final model follows best practices and estimates recruitment deviations beginning at the start of the model period.
6. Time varying, combined female and male versus sex specific selectivity, and asymptotic versus dome-shaped selectivity for fishing fleets and surveys.
   - Results varied, with fits to the data guiding the modeling of selectivity.
7. The tuning of recruitment variability.
   - Estimates of current stock size from the south model are somewhat sensitive to this value.
8. Commercial age data and aging error estimates.
   - Fits to the commercial and recreational age data were improved compared to those from the 2011 stock assessment. Better fits to the data were due, in part, to the re-bining of the age and length data as well as to the use of age selectivity pattern 11 rather than 10. Age error estimates were similar to the previous stock assessment.
9. Fishery dependent CPUE indices.
   - Six new indices were evaluated for this assessment: Oregon commercial nearshore CPUE, Washington Dockside recreational CPUE, Oregon ORBS CPUE, Oregon charter onboard observer CPUE, California onboard observer CPUE, and Central California onboard observer CPUE. The south model is sensitive to the California onboard observer CPUE.
10. The impact of the 2016 NWFSC survey data and the 2016 research study data from L. Lam on derived model outputs.
    - The south model is sensitive to the Lam research age and length data.
11. Time blocking of retention parameters.

- Time blocking improved the model fits to fishery dependent composition data.

12. Estimation of the added standard deviation parameters for all indices of abundance.
    - Estimating the added standard deviations improved model fits to the fishery dependent indices but not to the fishery independent indices.
13. Removal of individual index data sets.
    - Indices for the north model generally provide similar information with respect to stock size and trends. The south model NWFSC survey index and the California onboard observer index provide different information with respect to the rate of stock increase during the past ~15 years, with the NWFSC survey index being more favorable.
14. Estimation of growth parameters
    - The north model is unable to estimate both female k and the Lenth-at-maxium age so the later was fixed at a value based on the data. This may be due to large lingcod being present in the early fishery dependent data that are never, or rarely, observed in more recent data. All male parameters could be estimated in the north model. All growth parameters could be estimated in the south.

Convergence

Convergence testing through use of over dispersed starting values often requires very extreme values to actually explore new areas of the multivariate likelihood surface. For this reason, a good target for convergence testing is to ‘jitter’ or randomly adjust starting values between reasonable upper and lower bounds by a factor. Jitter is a SS option that allows for the generation of a uniform random deviate equal to the product of the input value and the range between upper and lower parameter bounds for each parameter. These random numbers are then added to initial parameter values in the input files and the model minimization started at these new conditions. The SS jitter option was used to explore the identification of a global best estimate for the base models. In the north none of these trials found a different minimum. A total of 100 jittered model runs, using a jitter value of 0.1 resulted in 76% of the model runs returning to the base case, and the rest went to local minima with larger negative log-likelihood values. In the south, out of a total 300 jitter runs using combinations of jitter values of 0.1 and 0.15 as well as alternative start values for Ro, 4% of the model runs found a slightly better solution (0.22 likelihood units better), 2.7% went back to the base model likelihood, and the rest went to local minima with larger negative log-likelihood values. This indicates the south model has a flat likelihood space, and therefore less informative likelihood profiles, with data that are less informative than the data available for the north model. Given that a majority of the jitter runs were unable to converge to the base model, this issue should be investigated during future lingcod south assessments. A comparison of the south base model and the model that converged to a slightly better solution revealed that their results are virtually identical. The model run with the slightly better solution is presented in this document.

Base Model Results

All r4ss plot files (see the Auxiliary files section of this document) for both the north and south base models are provided in supplementary materials. Parameters, both estimated and fixed are provided in tables 7 and 8. Note that fishery ages were removed from the base case model due to concerns with age sampling not being representative of length sampling. However, these data are used in model sensitivity runs below.

The base case model for the north model fit the indices, lengths and fishery independent ages well (Figures 80-109). Good fits to the indices were, in part, due to strong agreement among various indices, except for a few years during the 1990s when the recreational indices trended up while the commercial index remained low. Fits to the time aggregated length compositions were good except for a limited amount of miss-fitting to the Triennial survey compositions and the Lam research length compositions. The Triennial survey compositions are noisy due to lower sample sizes and most likely to the line transect nature of the survey design. The Lam research data were collected with age and growth studies in mind, and are therefore, not random samples, resulting in greater difficulty in fitting these data. The fits to the age compositions were also generally good, with the exception of some larger residuals in the Lam data.

North model selectivity curves were well estimated for all fleets, with the commercial and recreational fleets using time blocks to capture changes in management that drove corresponding changes in composition data. See the Estimated and Fixed parameters section above for parameterization details. Figure 110 shows the end year selectivity for each fleet. Early selectivity patterns for the trawl, fixed gear commercial fleets are estimated to be asymptotic, while selectivity patterns for recent years were estimated as dome shaped. Estimated growth curves for females and males were reasonable (Figure 111), suggesting that on average females grow to a maximum size of about 120 cm and males grow to a maximum size of about 80cm. Variability in growth was greater for younger fish than for older fish.

Tables 1 and 8, along with Figures 112-116 shows the time trajectories of the estimates of total dead fish (landings plus estimated dead discards), spawning biomass, fishery exploitation rate, recruitment, and depletion in spawning output from the north model. Figures 117-119 show management quantities: equilibrium yield plots and time series of surplus production from the north model. This assessment estimated that the stock size was well over the management target, and has generally been on an upward trajectory since its low point during the 1990s. 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.

The base case model for the south model was able to fit the indices, lengths and fishery independent ages well with the exception of the CA recreational onboard observer index and recent length compositions (Figures 120-144). The model sensitivity run with the CA recreational observer index estimates a large added standard deviation and the length compositions shows strong residual patterns in recent years (Figure 132). Fits to the time aggregated length compositions were good except for a limited amount of miss-fitting to the Triennial Shelf Trawl Survey compositions, and the NWFSC Hook and Line survey length compositions. The Triennial survey compositions were noisy due to smaller sample sizes and most likely to the line transect nature of the survey design. The Hook and Line survey sample sizes were also lower and lingcod were less common in this survey. The fits to the age compositions were also generally good.

South model selectivity curves were well estimated for all fleets, with the commercial and recreational fleets using time blocks to capture changes in management that drove corresponding changes in composition data. See the Estimated and Fixed parameters section above for parameterization details. Figure 144 shows the end year estimated selectivity curves. Early selectivity patterns for the trawl fleet and Triennial survey were estimated to be asymptotic. Fishery selectivity patterns for recent years were estimated as dome shaped. Estimated growth curves for females and males were reasonable (Figure 145), suggesting that on average females grow to a maximum size of about 120 cm and males grow to a maximum size of about 100cm. Similarly to the north model, variability in growth was greater for younger fish than for older fish. Female growth patterns between the north and south models are estimated to be more similar than those for the males, this difference needs to be investigated during the next benchmark lingcod stock assessment.

Tables 1 and 10, along with Figures 146-150, shows the time trajectories of the estimates of total dead fish (landings plus estimated dead discards), spawning biomass, fishery exploitation rate, recruitment, and depletion in spawning output from the south model. Figures 151-153 show management quantities: time series of SPR ratios and the phase plot from the south model. This assessment estimated that the stock is in the precautionary zone, and while it has generally been on an upward trajectory since its low point during the 1990s, the rate of increase is slower than in the north. 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.

Sensitivity Analyses

Sensitivity analyses were performed to determine the sensitivity of the model results to a range of different assumptions. For the most part, conclusions from the models remained generally consistent across the assumptions that were explored.

Results from the north base case sensitivity runs that produced the most extreme results are shown in Table 11, and Figures 154-155 (the table and figures show the same sets of model runs). The sensitivity model runs all produced similar trajectories of stock decline and recovery. In the north, the model is most sensitive to the inclusion of the fishery age data sets. Model runs that add data to the base model (note that the base model uses the NWFSC survey conditional age data) show the impact of adding first only the recreational age data, then only the commercial age data, and finally, both the recreational and commercial age data. 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 pre-STAR model runs, not shown here, fixing *M* at either lower or higher values than the base model resulted in similar estimates of unfished spawning biomass, but stock status changed systematically with the assumed value of *M*: lower values of *M* resulted in lower stock status, although all values resulted in estimates of stock status that were over the management target reference point. Asuming that female and male M are both fixed at 0.257 suggests similar stock status, but a slightly lower unfished spawning biomass.

Results from the south base case sensitivity runs that showed the most extreme results are shown in Table 12, and Figures 156-157 (the table and figures show the same sets of model runs). Many of the sensitivity model runs produced similar trajectories of stock decline and recovery. In the south, the model is sensitive to removing the research age and length data set collected by Lam et al., which results in a much higher unfished biomass estimate but a similar estimate of stock status (Figures 160-161). Note that the Lam data are collected from rocky reef areas that are not accessible to the NWFSC survey, and are the only source of age data from California that characterizes the ages of fish caught by the California recreational fishery. The south model is highly sensitive to the inclusion of the California onboard observer index, which suggests a similar unfished stock size but a stock status that is well below the overfished threshold. While both the California onboard observer index and the NWFSC survey both suggest that the lingcod south stock has been increasing during the past few decades, these data sets provide conflicting information regarding the rate of stock increase. The NWFSC survey, which covers the deeper waters than the California onboard observer index, suggests a faster rate of stock increase than the California onboard observer index, which spans only nearshore waters and suggests a much slower rate of increase. The conflicting information provded by the CA onboard observer index and the NWFSC survey may indicate localized depletion in the regions repeatedly visited by the California recreational fleet. In the pre-STAR model runs, not shown here, fixing *M* at either lower or higher values than the base model resulted in similar estimates of unfished spawning biomass for all runs with stock status changing systematically with the assumed value of *M*: lower values of *M* resulted in lower stock status.

Retrospective Analyses

A retrospective analysis was conducted by comparing the base models with data through 2016 to models sequentially removing up to 7 years of data. The north model does not show a retrospective pattern (Figures 158-159). A retrospective pattern in the south model between 2016 and the rest of the years was identified (Figures 160-161), with investigations showing that this pattern is caused by the addition of the 2016 conditional age-at-length composition data from the Lam research study. Note that the Lam age composition data provide the only source of age data that are representative of the California recreational catches in the south model. The base model that includes the Lam age data suggests a slower rate of stock increase that models without the Lam data. Changes in the estimation of recruit deviations also contributes to this retrospective pattern. The base model estimates that the most recent 3 years have had recruitment well below the long term average from the stock recruitment curve, while the preceding 4 years were well above average.

Historical Assessment Analyses

Comparisons between the base model estimates for spawning biomass and stock depletion from the 2009 assessments suggest similar patterns of stock increases from a low point during the 1990s to present (Figures 162-163). However, the rate of the stock increase is slower and lower in magnitude than those estimated/projected in the 2009 assessment, particularly for the south. The 2017 south model shows a strong divergence from the 2009 assessment beginning during the early 2000s.

Likelihood profiles

Likelihood profiles for log unfished recruitment and female natural mortality were completed to investigate the information in the data with respect to these parameters. (Figures 164-167).

Given the removal of the commercial marginal age data from the north base model, there is no longer adequate information in the data to produce informative M or h profiles. North model likelihood profiles for log R_o show a strong conflict between the length and age data with respect to the value of unfished recruitment, with the length data suggesting a higher value and the age data suggesting a lower value. In the north the OR recreational index, NWFSC conditional age data, WA recreational lengths and Trawl commercial length data sets most strongly inform stock scale. In aggregate plausible values for log unfished recruitment range from about 8.7 to 9.8. South model likelihood profiles are uninformative with repsect to both M and h. Log R_o likelihood profiles show a strong influence of the recruitment estimates, with plausible values ranging from about 8.3 to 8.7. In the south Lam research data, the indices (except the hook and line index), the late triennial length data, and the commercial trawl data most strongly inform stock scale.

Rebuilding Parameters

Both the north and south lingcod stocks are estimated to be above the minimum stock size threshold, therefore a rebuilding plan is not necessary.

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. The phase plots show the interaction of fishing intensity and biomass targets. 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 32.1% (11.1–53.1, 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 20,260 mt (15,304–25,215 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 6,509 mt (1,624–11,394 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. 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 7,780 mt (5,877–9,683 mt 95% asymptotic interval) in the south, which gives catches of 3197 mt (2,184–4,210 mt, 95% asymptotic interval) for the north and 1746 mt (1,372–2,121, 95% asymptotic standard deviation) for the south (Tables i and j). Equilibrium yield at the FMSY proxy harvest rate (F45) is 3,409 mt (2,329–4,489 mt, 95% asymptotic interval) and 1,856 mt (1,458–2,253 mt, 95% asymptotic interval) for the north and south, respectively.

Harvest Projections and Decision Tables

The lingcod stock assessments are Category 1 stock assessments, thus projections and decision tables are based on using P*=0.45 and sigma = 0.36, resulting in a multiplier on the over fishing limit (OFL) of 0.956 (PFMC preferred option). Stock projections for the south are also provided for the PFMC default management option, and uses an OFL multiplier of 0.913. The OFL multipliers are combined with the 40-10 harvest control rule to calculate OFLs, ABCs and ACLs. The total catches in 2017 and 2018 were set at the PFMC groundfish management team (GMT) requested values of ~ 1000 mt in the north and 750 mt in the south, the average 2015-2017 exploitation rate was used to distribute catches among the fisheries. All stock projections and decision tables (Tables 13-16) are based on the stock assessment model areas: north (WA and OR) and south (CA).

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 (Table 13). The stock is expected to remain above the target stock size of $SB_{40\%}$ through 2028, assuming average recruitment based on the stock-recruit curve. In the south, the current medium term projection of expected catch under both harvest policies, shows increasing spawning biomass and depletion from the base model, with the stock remaining in the precautionary zone during the projection period (Table 14). Note that the difference in final stock status (depletion) between the council preferred and default options is < 1%. The lack of strong increases in 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.

Uncertainty in management quantities for the north and south models decision tables (Tables 15 - 16) was characterized using the asymptotic standard deviation for the 2017 spawning biomass from the base model. Specifically, the 2017 spawning biomass for the high and low states of nature are given by the base model mean +/-1.15*standard deviation (the 12.5th and 87.5th percentiles). A search across fixed values of Ro was used to attain the 2017 spawning biomass values for the high and low states of nature. The high catch streams were based on the 40-10 harvest control rule. At the request of the PFMC GMT representative on the STAR panel the moderate catch streams were set to 40% ACL attainment for the north management area and 70% ACL attainment in the south management area. Finally, the low catch stream was set to ~700 mt, a level similar to recent average catches.

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 one case, in which the current control rule is applied to the low stock state of nature (bottom left corner of the table). Note that the catches specified in the above scenario (ranging from 4497 to 3542 mt) are much larger than recent landings (~700 mt). All other decision table scenarios keep the stock near 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 overfished (lower left corner) to well above target stock size (upper right corner). All states of nature from the constant catch scenario, that specifies catches similar to recent levels, suggest that the stock will increase towards, or exceed the target reference point. However, catching the full ACL catches results in stock declines at the low state of nature and modest stock increases under the base case and high state of nature.

Regional Management Considerations

Regional management considerations are to some extent addressed by the two area assessments. Reallocation of catches from the south model area to the northern managment area based on the 40-10 management line can be done using the 5 year average percentage of survey biomass in either the region from the 40-10 management line to the OR/CA border or the section of CA between the 40-10 management line and 42 degrees. These values were obtained using VAST model runs with the above spatial delineations, and result in values of 8% of the coast wide survey biomass, or 21.31% of the CA biomass being in the 40-10 to 42 region. Note that the proportion of the survey biomass estimated to be between the 40-10 management line and 42 degrees has declined over time.

Research 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.
7. Given that a majority of the jitter runs were unable to converge to the south base model, this issue should be investigated during future lingcod south assessments.
8. The south model lacks fishery dependent age data. Obtaining recreational fishery data from California could provide improved information on recent stock trends.

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List of Auxiliary Files

Lingcod North Model:
\4_North_Base\Ling.dat
\4_North_Base\Ling.ctl
\4_North_Base\forecast.ss
\4_North_Base\starter.ss
\4_North_Base\natage_f.csv
\4_North_Base\natage_m.csv
\4_North_Base\Report.sso
r4ss plots folder: \4_North_Base\plots\

Lingcod South Model
\5_South_Base\Ling.dat
\5_South_Base\Ling.ctl
\5_South_Base\forecast.ss
\5_South_Base\starter.ss
\5_South_Base\natage_f.csv
\5_South_Base\natage_m.csv
\5_South_Base\Report.sso
r4ss plots folder: \5_South_Base\plots\

Table 1. Landings from 1889-2016. Note that the columns North and South "Total Dead" include model estimates of dead discarded fish.

Year	North Trawl Gears	North Fixed Gears	WA Recrea-tional	OR Recrea-tional	North Total Landings	North Total Dead	South Trawl Gears	South Fixed Gears	South Recrea-tional	South Total Landings	South Total Dead
1889	0.0	109.0	0.0	0.0	109.0	110.5	0.0	0.0	0.0	0.0	0.0
1890	0.0	112.7	0.0	0.0	112.7	114.2	13.2	8.7	0.0	22.0	25.1
1891	0.0	115.5	0.0	0.0	115.5	117.1	26.5	17.5	0.0	43.9	50.2
1892	0.0	158.4	0.0	0.0	158.4	160.5	39.7	26.2	0.0	65.9	75.4
1893	0.0	125.4	0.0	0.0	125.4	127.1	52.9	35.0	0.0	87.9	100.5
1894	0.0	125.4	0.0	0.0	125.4	127.1	66.1	43.7	0.0	109.8	125.6
1895	0.0	136.8	0.0	0.0	136.8	138.6	79.4	52.4	0.0	131.8	150.8
1896	0.0	164.5	0.0	0.0	164.5	166.7	92.6	61.2	0.0	153.7	176.0
1897	0.0	165.0	0.0	0.0	165.0	167.2	105.8	69.9	0.0	175.7	201.2
1898	0.0	71.0	0.0	0.0	71.0	71.9	119.0	78.6	0.0	197.7	226.3
1899	0.0	45.2	0.0	0.0	45.2	45.8	132.3	87.4	0.0	219.6	251.6
1900	0.0	57.3	0.0	0.0	57.3	58.1	145.5	96.1	0.0	241.6	276.8
1901	0.0	58.6	0.0	0.0	58.6	59.4	158.7	104.9	0.0	263.6	302.1
1902	0.0	59.9	0.0	0.0	59.9	60.7	171.9	113.6	0.0	285.5	327.3
1903	0.0	61.2	0.0	0.0	61.2	62.0	185.2	122.3	0.0	307.5	352.6
1904	0.0	73.3	0.0	0.0	73.3	74.2	198.4	131.1	0.0	329.5	378.0
1905	0.0	57.8	0.0	0.0	57.8	58.6	211.6	139.8	0.0	351.4	403.3
1906	0.0	59.1	0.0	0.0	59.1	59.9	224.8	148.6	0.0	373.4	428.7
1907	0.0	60.4	0.0	0.0	60.4	61.2	238.1	157.3	0.0	395.4	454.0
1908	0.0	44.9	0.0	0.0	44.9	45.5	251.3	166.0	0.0	417.3	479.5
1909	0.0	193.6	0.0	0.0	193.6	196.2	264.5	174.8	0.0	439.3	504.9
1910	0.0	194.9	0.0	0.0	194.9	197.5	277.7	183.5	0.0	461.2	530.4
1911	0.0	196.2	0.0	0.0	196.2	198.8	291.0	192.2	0.0	483.2	555.8
1912	0.0	197.5	0.0	0.0	197.5	200.1	304.2	201.0	0.0	505.2	581.4
1913	0.0	198.7	0.0	0.0	198.7	201.4	317.4	209.7	0.0	527.1	606.9
1914	0.0	200.0	0.0	0.0	200.0	202.7	330.6	218.5	0.0	549.1	632.5
1915	0.0	348.7	0.0	0.0	348.7	353.4	343.9	227.2	0.0	571.1	658.1
1916	0.0	508.4	0.0	0.0	508.4	515.3	357.1	235.9	0.0	593.0	683.7
1917	0.0	509.7	0.0	0.0	509.7	516.6	370.3	244.7	0.0	615.0	709.4
1918	0.0	669.4	0.0	0.0	669.4	678.6	383.5	253.4	0.0	637.0	735.0
1919	0.0	223.8	0.0	0.0	223.8	226.8	396.8	262.2	0.0	658.9	760.8
1920	0.0	177.5	0.0	0.0	177.5	179.9	410.0	270.9	0.0	680.9	786.5
1921	0.0	165.9	0.0	0.0	165.9	168.2	423.2	279.6	0.0	702.9	812.3
1922	0.0	93.2	0.0	0.0	93.2	94.5	436.5	288.4	0.0	724.8	838.1
1923	0.0	82.4	0.0	0.0	82.4	83.5	449.7	297.1	0.0	746.8	864.0
1924	0.0	195.8	0.0	0.0	195.8	198.5	462.9	305.8	0.0	768.7	889.9

1925	0.0	260.5	0.0	0.0	260.5	264.0	476.1	314.6	0.0	790.7	915.8
1926	0.0	294.8	0.0	0.0	294.8	298.8	489.4	323.3	0.0	812.7	941.8
1927	0.0	362.4	0.0	0.0	362.4	367.3	502.6	332.1	0.0	834.6	967.8
1928	0.0	290.6	0.0	0.0	290.6	294.6	515.8	340.8	0.0	856.6	993.9
1929	8.0	566.3	0.0	0.0	574.3	586.3	529.0	349.5	2.9	881.4	1022.9
1930	31.8	483.3	0.0	0.0	515.1	539.0	542.3	358.3	5.8	906.3	1051.9
1931	7.2	256.4	0.0	0.0	263.6	271.0	555.5	367.0	8.6	931.1	1081.0
1932	10.2	251.5	0.0	0.0	261.7	270.7	399.2	258.6	11.5	669.3	777.3
1933	27.8	368.8	0.0	0.0	396.7	417.0	626.9	474.1	14.4	1115.4	1287.7
1934	91.6	417.5	0.0	0.0	509.1	565.0	388.3	225.1	17.3	630.7	735.5
1935	106.7	426.9	0.0	0.0	533.6	598.1	459.7	286.3	20.2	766.1	890.9
1936	149.8	562.1	0.0	0.0	711.9	802.1	341.2	252.5	23.1	616.8	710.8
1937	212.5	504.6	0.0	0.0	717.1	841.4	438.4	273.8	35.8	747.9	866.8
1938	145.6	1166.1	0.0	0.0	1311.7	1408.4	337.0	350.4	43.3	730.7	826.7
1939	311.1	735.3	0.0	0.0	1046.4	1229.8	260.4	182.6	59.8	502.8	573.9
1940	564.0	853.0	0.0	0.0	1417.0	1745.9	312.4	222.2	62.8	597.4	682.5
1941	525.6	781.9	0.0	0.0	1307.5	1617.4	238.5	196.1	58.0	492.6	558.3
1942	855.8	870.3	0.0	0.0	1726.1	2231.8	141.6	100.1	30.8	272.6	310.8
1943	872.4	624.5	0.0	0.0	1496.9	2017.4	324.8	226.7	29.5	580.9	668.2
1944	1403.6	705.2	0.0	0.0	2108.8	2958.8	336.5	222.5	24.2	583.1	672.8
1945	1031.7	425.9	0.0	0.0	1457.6	2095.0	315.8	228.8	32.3	576.8	661.4
1946	1259.0	638.9	0.0	0.0	1897.9	2692.9	520.6	365.9	55.5	942.0	1080.9
1947	658.1	371.8	0.0	0.0	1029.9	1452.9	869.5	725.1	201.5	1796.1	2033.4
1948	1002.7	486.0	0.0	0.0	1488.7	2139.1	900.7	450.3	219.6	1570.6	1810.0
1949	708.9	612.3	0.0	0.0	1321.2	1788.7	700.4	373.0	239.4	1312.8	1502.9
1950	779.4	379.5	0.0	0.0	1158.9	1670.9	829.1	287.9	215.1	1332.0	1556.0
1951	919.9	380.4	0.0	0.0	1300.3	1905.7	792.7	143.9	222.3	1158.9	1372.7
1952	593.8	423.0	0.0	0.0	1016.8	1410.5	614.6	619.7	158.2	1392.6	1578.9
1953	288.2	184.0	0.0	0.0	472.2	662.1	614.6	430.5	116.7	1161.8	1344.8
1954	483.1	251.3	0.0	0.0	734.4	1049.1	614.6	429.7	187.9	1232.3	1416.5
1955	1041.1	199.2	0.0	0.0	1240.3	1909.8	436.6	79.5	201.2	717.2	839.5
1956	757.8	187.5	0.0	0.0	945.2	1431.5	591.8	423.5	274.3	1289.6	1462.5
1957	801.3	204.2	0.0	0.0	1005.4	1517.4	747.0	151.0	317.2	1215.2	1415.4
1958	920.1	161.7	0.0	0.0	1081.8	1667.3	692.2	160.3	348.9	1201.4	1380.9
1959	1493.7	144.2	0.0	0.0	1637.9	2589.8	615.6	133.6	275.1	1024.3	1177.3
1960	1699.8	197.4	0.0	0.0	1897.2	2993.3	591.3	74.6	229.9	895.8	1038.1
1961	1629.0	169.5	0.0	0.0	1798.4	2867.1	617.7	141.7	227.1	986.5	1142.0
1962	935.3	149.0	0.0	0.0	1084.4	1709.4	475.7	105.9	221.4	803.1	931.7
1963	697.9	111.4	0.0	0.0	809.3	1281.5	513.3	125.8	221.2	860.2	1006.8
1964	1118.4	88.0	0.0	0.0	1206.3	1973.5	378.9	75.1	214.6	668.6	775.3
1965	1265.6	83.9	0.0	0.0	1349.5	2245.7	368.2	77.5	313.5	759.2	858.2
1966	1376.6	102.2	0.0	0.0	1478.8	2522.0	364.0	74.2	438.3	876.5	970.1
1967	2030.0	127.1	29.2	0.0	2186.2	3873.3	426.7	69.5	462.9	959.1	1066.4

1968	2315.9	96.6	35.6	0.0	2448.1	4503.1	496.4	57.4	446.7	1000.5	1126.2
1969	1267.1	135.3	35.4	0.0	1437.7	2564.4	545.5	76.3	347.5	969.3	1112.3
1970	843.0	158.8	35.3	0.0	1037.1	1753.1	748.5	73.4	531.8	1353.8	1553.8
1971	981.5	138.3	35.4	0.0	1155.2	1947.2	973.1	140.3	618.9	1732.4	1995.6
1972	963.5	128.7	35.5	0.0	1127.8	1883.9	1539.4	226.9	756.4	2522.7	2938.5
1973	1431.6	123.7	35.6	0.0	1590.9	2737.6	1721.4	176.0	753.0	2650.4	3123.8
1974	1626.9	89.3	35.4	80.4	1832.0	3106.9	1833.7	244.0	768.5	2846.1	3402.9
1975	1584.9	133.1	41.7	84.8	1844.6	3035.6	1569.1	268.9	841.1	2679.1	3242.0
1976	1552.7	109.3	23.2	116.8	1802.0	2904.0	1527.2	152.1	881.3	2560.6	3191.1
1977	1451.1	198.8	31.3	110.2	1791.3	2766.8	875.3	92.5	646.7	1614.5	2008.0
1978	1163.4	218.9	26.1	118.9	1527.2	2273.5	957.6	144.3	862.1	1963.9	2410.8
1979	1948.6	276.0	22.4	121.7	2368.5	3614.7	1525.8	104.4	935.9	2566.1	3264.2
1980	1973.8	144.0	29.0	149.8	2296.6	3744.7	1413.5	98.6	1335.4	2847.5	3467.0
1981	1831.9	200.3	31.9	117.5	2181.6	3874.5	1212.2	92.1	1173.0	2477.3	2994.1
1982	2163.0	291.9	35.1	119.6	2609.7	4957.1	1350.8	74.1	882.0	2306.9	2850.3
1983	2914.1	337.8	43.2	129.0	3424.1	9221.2	967.3	52.2	589.0	1608.6	2174.0
1984	2752.5	330.4	71.9	143.9	3298.6	8012.9	910.3	42.0	514.0	1466.4	2025.7
1985	2781.0	388.8	55.1	98.9	3323.8	7601.0	614.0	82.4	981.0	1677.4	2266.4
1986	1098.1	252.4	56.6	92.4	1499.4	3165.8	394.3	146.1	950.0	1490.4	2047.9
1987	1442.9	279.2	60.0	122.9	1905.0	4478.0	703.2	159.4	969.0	1831.6	2712.9
1988	1467.5	263.8	57.0	90.5	1878.8	5004.3	819.0	211.0	1054.0	2083.9	2855.2
1989	1937.0	357.5	59.1	120.0	2473.6	6433.6	867.0	412.8	980.0	2259.9	2936.9
1990	1493.8	360.8	68.4	96.9	2019.9	4754.9	763.3	309.1	799.0	1871.4	2434.3
1991	2186.6	184.9	66.4	73.5	2511.4	6577.1	597.7	192.7	820.0	1610.4	2082.6
1992	1092.0	185.0	89.8	112.4	1479.2	4213.6	419.5	199.3	808.0	1426.8	1808.9
1993	1363.1	148.1	107.9	145.9	1764.9	7214.6	536.9	165.8	479.0	1181.7	1621.0
1994	1140.9	201.9	102.9	142.5	1588.1	5902.1	429.4	142.4	289.0	860.8	1177.6
1995	824.4	103.5	65.6	79.6	1073.0	3639.2	361.9	179.9	300.0	841.9	1085.4
1996	942.8	134.6	61.8	93.2	1232.3	3675.4	312.0	169.6	391.0	872.6	1091.9
1997	875.8	182.5	59.4	110.8	1228.5	3278.3	351.8	158.7	299.0	809.6	1073.3
1998	145.6	53.6	38.4	70.0	307.6	610.2	85.4	65.2	279.0	429.6	551.3
1999	149.5	65.1	45.5	79.7	339.8	627.0	89.5	52.7	375.0	517.2	638.1
2000	48.0	40.8	34.7	51.2	174.7	261.4	33.0	22.7	240.0	295.6	337.7
2001	39.6	53.3	43.5	61.8	198.1	268.2	28.6	34.1	226.0	288.6	328.2
2002	74.5	48.9	56.5	82.4	262.2	401.1	37.2	44.0	608.0	689.2	745.7
2003	56.3	49.4	66.5	122.5	294.6	410.9	12.4	38.8	1125.0	1176.3	1191.9
2004	60.3	53.3	79.0	108.7	301.4	426.5	16.7	45.7	188.0	250.4	265.8
2005	79.3	58.0	78.3	140.8	356.5	501.9	20.2	40.8	387.8	448.8	462.0
2006	115.6	78.6	62.2	107.6	364.0	544.3	24.8	36.1	316.9	377.7	390.5
2007	113.6	71.2	68.2	104.0	357.0	459.3	42.7	36.5	190.7	269.9	289.3
2008	118.8	92.8	70.8	89.3	371.7	480.2	34.0	36.2	107.0	177.2	190.8
2009	93.5	81.5	74.3	78.8	328.0	424.1	31.7	25.0	133.4	190.2	202.4
2010	77.8	47.2	91.4	93.9	310.4	342.7	23.1	23.7	107.4	154.1	159.9

2011	283.4	57.6	117.8	115.0	573.8	611.1	6.7	26.2	230.2	263.1	265.2
2012	373.2	64.9	122.3	155.3	715.7	747.5	16.3	31.5	281.4	329.2	333.9
2013	360.4	78.3	127.3	224.0	790.0	812.7	23.6	41.2	433.0	497.8	505.2
2014	217.5	82.2	141.6	176.1	617.4	632.3	36.8	70.1	571.8	678.7	689.9
2015	163.4	132.5	272.0	226.2	794.1	677.3	42.2	106.3	715.4	863.9	877.4
2016	262.7	98.3	349.7	154.7	865.4	722.7	40.2	75.6	647.3	763.1	773.7

* 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 2. Indices of abundance for the 2017 lingcod stock assessment.

Year	Fleet	Value	Standard Error	Units
1981	North Trawl	2861.5	0.370	mt
1982	North Trawl	2742.8	0.360	mt
1983	North Trawl	1442.0	0.358	mt
1984	North Trawl	710.3	0.384	mt
1985	North Trawl	637.5	0.335	mt
1986	North Trawl	533.4	0.353	mt
1987	North Trawl	1264.0	0.068	mt
1988	North Trawl	806.7	0.066	mt
1989	North Trawl	879.0	0.065	mt
1990	North Trawl	766.7	0.067	mt
1991	North Trawl	716.2	0.066	mt
1992	North Trawl	447.0	0.067	mt
1993	North Trawl	462.1	0.067	mt
1994	North Trawl	497.7	0.067	mt
1995	North Trawl	499.2	0.068	mt
1996	North Trawl	519.5	0.068	mt
1997	North Trawl	530.3	0.070	mt
2004	North Fixed Gear	7.3	0.139	mt
2005	North Fixed Gear	8.2	0.131	mt
2006	North Fixed Gear	9.2	0.137	mt
2007	North Fixed Gear	8.2	0.145	mt
2008	North Fixed Gear	7.2	0.135	mt
2009	North Fixed Gear	8.4	0.136	mt
2010	North Fixed Gear	11.1	0.131	mt
2011	North Fixed Gear	10.0	0.126	mt
2012	North Fixed Gear	9.5	0.124	mt
2013	North Fixed Gear	8.4	0.128	mt
2014	North Fixed Gear	7.8	0.129	mt
2015	North Fixed Gear	9.0	0.131	mt
2016	North Fixed Gear	6.7	0.145	mt
1981	Washington Recreational	1.03	0.069	numbers
1982	Washington Recreational	1.07	0.071	numbers
1983	Washington Recreational	0.88	0.063	numbers
1984	Washington Recreational	0.97	0.056	numbers
1985	Washington Recreational	0.73	0.048	numbers
1986	Washington Recreational	0.63	0.037	numbers
1987	Washington Recreational	0.75	0.038	numbers

1988	Washington Recreational	0.74	0.052	numbers
1989	Washington Recreational	0.88	0.045	numbers
1990	Washington Recreational	0.61	0.027	numbers
1991	Washington Recreational	0.68	0.026	numbers
1992	Washington Recreational	0.92	0.027	numbers
1993	Washington Recreational	1.02	0.041	numbers
1994	Washington Recreational	1.16	0.051	numbers
1995	Washington Recreational	0.71	0.021	numbers
1996	Washington Recreational	0.59	0.023	numbers
1997	Washington Recreational	0.63	0.024	numbers
1998	Washington Recreational	0.36	0.081	numbers
1999	Washington Recreational	0.44	0.075	numbers
2000	Washington Recreational	0.37	0.070	numbers
2001	Washington Recreational	0.46	0.039	numbers
2002	Washington Recreational	0.54	0.034	numbers
2003	Washington Recreational	0.64	0.025	numbers
2004	Washington Recreational	0.75	0.028	numbers
2005	Washington Recreational	0.61	0.027	numbers
2006	Washington Recreational	0.50	0.058	numbers
2007	Washington Recreational	0.52	0.038	numbers
2008	Washington Recreational	0.55	0.035	numbers
2009	Washington Recreational	0.59	0.033	numbers
2010	Washington Recreational	0.75	0.024	numbers
2011	Washington Recreational	0.97	0.029	numbers
2012	Washington Recreational	0.95	0.030	numbers
2013	Washington Recreational	0.87	0.030	numbers
2014	Washington Recreational	0.84	0.019	numbers
2015	Washington Recreational	0.85	0.033	numbers
2016	Washington Recreational	1.07	0.053	numbers
1986	Oregon Dockside Recreational	0.08	0.032	numbers
1987	Oregon Dockside Recreational	0.09	0.032	numbers
1988	Oregon Dockside Recreational	0.08	0.030	numbers
1989	Oregon Dockside Recreational	0.08	0.026	numbers
1990	Oregon Dockside Recreational	0.07	0.028	numbers
1991	Oregon Dockside Recreational	0.08	0.032	numbers
1992	Oregon Dockside Recreational	0.11	0.024	numbers
1993	Oregon Dockside Recreational	0.15	0.019	numbers
1994	Oregon Dockside Recreational	0.15	0.018	numbers
1995	Oregon Dockside Recreational	0.07	0.023	numbers
1996	Oregon Dockside Recreational	0.07	0.025	numbers
1997	Oregon Dockside Recreational	0.07	0.024	numbers

1998	Oregon Dockside Recreational	0.04	0.027	numbers
1999	Oregon Dockside Recreational	0.06	0.026	numbers
2000	Oregon Dockside Recreational	0.04	0.028	numbers
2001	Oregon Dockside Recreational	0.03	0.028	numbers
2002	Oregon Dockside Recreational	0.04	0.028	numbers
2003	Oregon Dockside Recreational	0.08	0.023	numbers
2004	Oregon Dockside Recreational	0.06	0.029	numbers
2005	Oregon Dockside Recreational	0.08	0.019	numbers
2006	Oregon Dockside Recreational	0.07	0.021	numbers
2007	Oregon Dockside Recreational	0.06	0.026	numbers
2008	Oregon Dockside Recreational	0.04	0.024	numbers
2009	Oregon Dockside Recreational	0.04	0.027	numbers
2010	Oregon Dockside Recreational	0.06	0.020	numbers
2011	Oregon Dockside Recreational	0.07	0.022	numbers
2012	Oregon Dockside Recreational	0.10	0.017	numbers
2013	Oregon Dockside Recreational	0.10	0.018	numbers
2014	Oregon Dockside Recreational	0.10	0.017	numbers
2015	Oregon Dockside Recreational	0.09	0.016	numbers
2016	Oregon Dockside Recreational	0.07	0.019	numbers
1980	North Early Triennial	7399.7	0.289	mt
1983	North Early Triennial	12507.6	0.240	mt
1986	North Early Triennial	6684.1	0.264	mt
1989	North Early Triennial	6055.0	0.254	mt
1992	North Early Triennial	2799.6	0.253	mt
1995	North Late Triennial	4478.9	0.282	mt
1998	North Late Triennial	4010.4	0.277	mt
2001	North Late Triennial	7536.9	0.227	mt
2004	North Late Triennial	19659.7	0.237	mt
2003	North NWFSC Survey	16276.5	0.157	mt
2004	North NWFSC Survey	14189.4	0.164	mt
2005	North NWFSC Survey	12203.8	0.166	mt
2006	North NWFSC Survey	16478.9	0.155	mt
2007	North NWFSC Survey	12132.7	0.159	mt
2008	North NWFSC Survey	10161.5	0.159	mt
2009	North NWFSC Survey	8656.3	0.157	mt
2010	North NWFSC Survey	10147.6	0.149	mt
2011	North NWFSC Survey	14782.9	0.140	mt
2012	North NWFSC Survey	15955.2	0.159	mt
2013	North NWFSC Survey	18031.8	0.158	mt
2014	North NWFSC Survey	15293.3	0.145	mt
2015	North NWFSC Survey	16837.8	0.148	mt

2016	North NWFSC Survey	15254.6	0.149	mt
1981	South Trawl	1450.2	0.078	mt
1982	South Trawl	1231.9	0.079	mt
1983	South Trawl	625.0	0.077	mt
1984	South Trawl	460.2	0.075	mt
1985	South Trawl	285.5	0.074	mt
1986	South Trawl	327.5	0.081	mt
1987	South Trawl	463.6	0.073	mt
1988	South Trawl	392.4	0.071	mt
1989	South Trawl	482.1	0.074	mt
1990	South Trawl	534.7	0.082	mt
1991	South Trawl	329.7	0.074	mt
1992	South Trawl	310.1	0.075	mt
1993	South Trawl	298.5	0.073	mt
1994	South Trawl	312.7	0.077	mt
1995	South Trawl	298.8	0.080	mt
1996	South Trawl	223.1	0.074	mt
1997	South Trawl	233.9	0.076	mt
1980	South Early Triennial	9724.1	0.540	mt
1983	South Early Triennial	6897.9	0.572	mt
1986	South Early Triennial	5410.0	0.576	mt
1989	South Early Triennial	8570.9	0.444	mt
1992	South Early Triennial	2349.1	0.563	mt
1995	South Late Triennial	3315.1	0.535	mt
1998	South Late Triennial	2527.2	0.531	mt
2001	South Late Triennial	8809.3	0.477	mt
2004	South Late Triennial	13764.1	0.445	mt
2003	South NWFSC Trawl Survey	6285.7	0.156	mt
2004	South NWFSC Trawl Survey	7431.6	0.173	mt
2005	South NWFSC Trawl Survey	5805.6	0.158	mt
2006	South NWFSC Trawl Survey	6455.6	0.195	mt
2007	South NWFSC Trawl Survey	3524.4	0.196	mt
2008	South NWFSC Trawl Survey	2786.7	0.174	mt
2009	South NWFSC Trawl Survey	2806.2	0.155	mt
2010	South NWFSC Trawl Survey	2611.8	0.157	mt
2011	South NWFSC Trawl Survey	3078.3	0.153	mt
2012	South NWFSC Trawl Survey	5251.7	0.166	mt
2013	South NWFSC Trawl Survey	6746.0	0.189	mt
2014	South NWFSC Trawl Survey	7345.4	0.139	mt
2015	South NWFSC Trawl Survey	5935.3	0.148	mt
2016	South NWFSC Trawl Survey	7753.0	0.155	mt

2004	South Hook and Line Survey	0.020	0.520	numbers
2005	South Hook and Line Survey	0.015	0.510	numbers
2006	South Hook and Line Survey	0.004	0.739	numbers
2007	South Hook and Line Survey	0.017	0.484	numbers
2008	South Hook and Line Survey	0.003	0.579	numbers
2009	South Hook and Line Survey	0.007	0.491	numbers
2010	South Hook and Line Survey	0.004	0.555	numbers
2011	South Hook and Line Survey	0.013	0.458	numbers
2012	South Hook and Line Survey	0.023	0.435	numbers
2013	South Hook and Line Survey	0.030	0.426	numbers
2014	South Hook and Line Survey	0.020	0.432	numbers
2015	South Hook and Line Survey	0.023	0.390	numbers
2016	South Hook and Line Survey	0.022	0.447	numbers
1987	California Recreational Observer	0.28	0.202	numbers
1988	California Recreational Observer	0.26	0.131	numbers
1989	California Recreational Observer	0.25	0.125	numbers
1990	California Recreational Observer	0.26	0.164	numbers
1991	California Recreational Observer	0.20	0.161	numbers
1992	California Recreational Observer	0.19	0.129	numbers
1993	California Recreational Observer	0.14	0.129	numbers
1994	California Recreational Observer	0.16	0.125	numbers
1995	California Recreational Observer	0.27	0.122	numbers
1996	California Recreational Observer	0.25	0.133	numbers
1997	California Recreational Observer	0.26	0.128	numbers
1998	California Recreational Observer	0.25	0.143	numbers
2002	California Recreational Observer	0.32	0.076	numbers
2003	California Recreational Observer	0.30	0.045	numbers
2004	California Recreational Observer	0.27	0.047	numbers
2005	California Recreational Observer	0.21	0.054	numbers
2006	California Recreational Observer	0.17	0.057	numbers
2007	California Recreational Observer	0.10	0.066	numbers
2008	California Recreational Observer	0.09	0.075	numbers
2009	California Recreational Observer	0.08	0.068	numbers
2010	California Recreational Observer	0.12	0.052	numbers
2011	California Recreational Observer	0.19	0.045	numbers
2012	California Recreational Observer	0.21	0.042	numbers
2013	California Recreational Observer	0.21	0.046	numbers
2014	California Recreational Observer	0.21	0.049	numbers
2015	California Recreational Observer	0.22	0.048	numbers
2016	California Recreational Observer	0.26	0.048	numbers

Table 3. Length samples sizes for the north.

Year	Fleet/Survey	Units (Used in Model)	Model Input Sample Size	Number of Fish
1986	Early Triennial	N tows	32	203
1989	Early Triennial	N tows	90	286
1992	Early Triennial	N tows	56	441
1995	Late Triennial	N tows	84	246
1998	Late Triennial	N tows	99	385
2001	Late Triennial	N tows	144	940
2004	Late Triennial	N tows	91	507
2003	NWFSC WCGBTS	N tows	90	669
2004	NWFSC WCGBTS	N tows	88	567
2005	NWFSC WCGBTS	N tows	98	511
2006	NWFSC WCGBTS	N tows	119	687
2007	NWFSC WCGBTS	N tows	116	449
2008	NWFSC WCGBTS	N tows	111	535
2009	NWFSC WCGBTS	N tows	103	432
2010	NWFSC WCGBTS	N tows	128	1078
2011	NWFSC WCGBTS	N tows	139	1143
2012	NWFSC WCGBTS	N tows	121	939
2013	NWFSC WCGBTS	N tows	99	552
2014	NWFSC WCGBTS	N tows	128	1192
2015	NWFSC WCGBTS	N tows	116	757
2016	NWFSC WCGBTS	N tows	122	859
1971	Fixed Gears	N port samples	14	61
1978	Fixed Gears	N port samples	32	150
1979	Fixed Gears	N port samples	11	9
1980	Fixed Gears	N port samples	38	28
1981	Fixed Gears	N port samples	20	51
1982	Fixed Gears	N port samples	77	134
1983	Fixed Gears	N port samples	25	58
1986	Fixed Gears	N port samples	46	37
1987	Fixed Gears	N port samples	50	361
1988	Fixed Gears	N port samples	48	158
1989	Fixed Gears	N port samples	53	137
1990	Fixed Gears	N port samples	53	208
1991	Fixed Gears	N port samples	51	202
1992	Fixed Gears	N port samples	91	68
1993	Fixed Gears	N port samples	92	381
1994	Fixed Gears	N port samples	80	620

1995	Fixed Gears	N port samples	72	382
1996	Fixed Gears	N port samples	58	301
1997	Fixed Gears	N port samples	73	318
1998	Fixed Gears	N port samples	63	223
1999	Fixed Gears	N port samples	66	108
2000	Fixed Gears	N port samples	87	290
2001	Fixed Gears	N port samples	110	402
2002	Fixed Gears	N port samples	140	312
2003	Fixed Gears	N port samples	122	266
2004	Fixed Gears	N port samples	163	569
2005	Fixed Gears	N port samples	70	189
2006	Fixed Gears	N port samples	104	322
2007	Fixed Gears	N port samples	179	706
2008	Fixed Gears	N port samples	136	439
2009	Fixed Gears	N port samples	130	308
2010	Fixed Gears	N port samples	190	493
2011	Fixed Gears	N port samples	170	697
2012	Fixed Gears	N port samples	202	928
2013	Fixed Gears	N port samples	231	956
2014	Fixed Gears	N port samples	265	1210
2015	Fixed Gears	N port samples	326	2225
2016	Fixed Gears	N port samples	311	1660
1965	Trawl Gears	N port samples	4	572
1966	Trawl Gears	N port samples	3	730
1967	Trawl Gears	N port samples	5	1034
1968	Trawl Gears	N port samples	38	10037
1969	Trawl Gears	N port samples	16	4463
1970	Trawl Gears	N port samples	20	4562
1971	Trawl Gears	N port samples	14	3600
1972	Trawl Gears	N port samples	4	907
1973	Trawl Gears	N port samples	3	561
1974	Trawl Gears	N port samples	6	1421
1975	Trawl Gears	N port samples	16	4083
1978	Trawl Gears	N port samples	32	848
1979	Trawl Gears	N port samples	11	725
1980	Trawl Gears	N port samples	38	2271
1981	Trawl Gears	N port samples	20	1426
1982	Trawl Gears	N port samples	77	3086
1983	Trawl Gears	N port samples	25	832
1984	Trawl Gears	N port samples	19	756
1985	Trawl Gears	N port samples	22	912
1986	Trawl Gears	N port samples	46	1257
1987	Trawl Gears	N port samples	50	823

1988	Trawl Gears	N port samples	48	1005
1989	Trawl Gears	N port samples	53	1211
1990	Trawl Gears	N port samples	53	1084
1991	Trawl Gears	N port samples	51	1026
1992	Trawl Gears	N port samples	91	2427
1993	Trawl Gears	N port samples	92	2373
1994	Trawl Gears	N port samples	80	2627
1995	Trawl Gears	N port samples	72	1505
1996	Trawl Gears	N port samples	58	1188
1997	Trawl Gears	N port samples	73	1416
1998	Trawl Gears	N port samples	63	1151
1999	Trawl Gears	N port samples	66	1425
2000	Trawl Gears	N port samples	87	646
2001	Trawl Gears	N port samples	110	727
2002	Trawl Gears	N port samples	140	840
2003	Trawl Gears	N port samples	122	856
2004	Trawl Gears	N port samples	163	611
2005	Trawl Gears	N port samples	70	632
2006	Trawl Gears	N port samples	104	741
2007	Trawl Gears	N port samples	179	1207
2008	Trawl Gears	N port samples	136	1171
2009	Trawl Gears	N port samples	130	1126
2010	Trawl Gears	N port samples	190	872
2011	Trawl Gears	N port samples	170	882
2012	Trawl Gears	N port samples	202	1045
2013	Trawl Gears	N port samples	231	1584
2014	Trawl Gears	N port samples	265	930
2015	Trawl Gears	N port samples	326	819
2016	Trawl Gears	N port samples	311	1013
2004	Fixed Gears Discards	N tows	105	527
2005	Fixed Gears Discards	N tows	94	569
2006	Fixed Gears Discards	N tows	199	823
2007	Fixed Gears Discards	N tows	143	490
2008	Fixed Gears Discards	N tows	148	562
2009	Fixed Gears Discards	N tows	142	452
2010	Fixed Gears Discards	N tows	181	631

2011	Fixed Gears Discards	N tows	213	958
2012	Fixed Gears Discards	N tows	227	985
2013	Fixed Gears Discards	N tows	190	962
2014	Fixed Gears Discards	N tows	190	855
2015	Fixed Gears Discards	N tows	211	779
2004	Trawl Gears Discards	N tows	409	1705
2005	Trawl Gears Discards	N tows	480	2778
2006	Trawl Gears Discards	N tows	197	712
2007	Trawl Gears Discards	N tows	87	271
2008	Trawl Gears Discards	N tows	70	212
2009	Trawl Gears Discards	N tows	201	619
2010	Trawl Gears Discards	N tows	69	195
2011	Trawl Gears Discards	N tows	352	1418
2012	Trawl Gears Discards	N tows	353	1668
2013	Trawl Gears Discards	N tows	269	1089
2014	Trawl Gears Discards	N tows	298	1197
2015	Trawl Gears Discards	N tows	224	695
1979	WA Recreational	N fish	13	
1980	WA Recreational	N fish	235	
1981	WA Recreational	N fish	98	
1982	WA Recreational	N fish	72	
1983	WA Recreational	N fish	43	
1986	WA Recreational	N fish	359	
1987	WA Recreational	N fish	336	
1988	WA Recreational	N fish	279	
1989	WA Recreational	N fish	296	
1990	WA Recreational	N fish	239	
1991	WA Recreational	N fish	310	
1992	WA Recreational	N fish	522	

1993	WA Recreational	N fish	542
1994	WA Recreational	N fish	674
1995	WA Recreational	N fish	1,025
1996	WA Recreational	N fish	812
1997	WA Recreational	N fish	441
1998	WA Recreational	N fish	461
1999	WA Recreational	N fish	431
2000	WA Recreational	N fish	479
2001	WA Recreational	N fish	619
2002	WA Recreational	N fish	951
2003	WA Recreational	N fish	1,085
2004	WA Recreational	N fish	1,081
2005	WA Recreational	N fish	1,277
2006	WA Recreational	N fish	897
2007	WA Recreational	N fish	936
2008	WA Recreational	N fish	453
2009	WA Recreational	N fish	672
2010	WA Recreational	N fish	517
2011	WA Recreational	N fish	409
2012	WA Recreational	N fish	392
2013	WA Recreational	N fish	354
2014	WA Recreational	N fish	697
2015	WA Recreational	N fish	501
2016	WA Recreational	N fish	832
2001	OR Recreational	N fish	1164
1980	OR Recreational	N fish	108
1981	OR Recreational	N fish	54
1982	OR Recreational	N fish	254
1983	OR Recreational	N fish	101
1984	OR Recreational	N fish	241
1985	OR Recreational	N fish	345
1986	OR Recreational	N fish	140
1987	OR Recreational	N fish	250
1988	OR Recreational	N fish	286
1989	OR Recreational	N fish	295
1993	OR Recreational	N fish	948
1994	OR Recreational	N fish	955
1995	OR Recreational	N fish	434
1996	OR Recreational	N fish	564
1997	OR Recreational	N fish	596
1998	OR Recreational	N fish	446
1999	OR Recreational	N fish	451
2000	OR Recreational	N fish	314

2002	OR Recreational	N fish	2413
2003	OR Recreational	N fish	2908
2004	OR Recreational	N fish	1764
2005	OR Recreational	N fish	2912
2006	OR Recreational	N fish	4463
2007	OR Recreational	N fish	4934
2008	OR Recreational	N fish	5352
2009	OR Recreational	N fish	4531
2010	OR Recreational	N fish	5451
2011	OR Recreational	N fish	6154
2012	OR Recreational	N fish	6992
2013	OR Recreational	N fish	7105
2014	OR Recreational	N fish	5554
2015	OR Recreational	N fish	6388
2016	OR Recreational	N fish	4951
1996	WDFW Research	N fish	857
1997	WDFW Research	N fish	809
2001	WDFW Research	N fish	168
2002	WDFW Research	N fish	166
2003	WDFW Research	N fish	174
2016	Lam Research	N fish	744

Table 4. Length samples sizes for the south.

Year	Fleet/Survey	Units (Used in Model)	Model Input Sample Size	Number of Fish
1989	Early Triennial	N tows	72	406
1992	Early Triennial	N tows	32	190
1995	Late Triennial	N tows	55	252
1998	Late Triennial	N tows	64	246
2001	Late Triennial	N tows	102	515
2004	Late Triennial	N tows	90	474
2003	NWFSC WCGBTS	N tows	95	661
2004	NWFSC WCGBTS	N tows	82	800
2005	NWFSC WCGBTS	N tows	98	586
2006	NWFSC WCGBTS	N tows	52	325
2007	NWFSC WCGBTS	N tows	53	196
2008	NWFSC WCGBTS	N tows	79	625
2009	NWFSC WCGBTS	N tows	118	675
2010	NWFSC WCGBTS	N tows	107	852
2011	NWFSC WCGBTS	N tows	127	710
2012	NWFSC WCGBTS	N tows	129	1248
2013	NWFSC WCGBTS	N tows	90	791
2014	NWFSC WCGBTS	N tows	135	1732
2015	NWFSC WCGBTS	N tows	129	1081
2016	NWFSC WCGBTS	N tows	108	894
1978	Fixed Gears	N port samples	25	23
1979	Fixed Gears	N port samples	29	8
1982	Fixed Gears	N port samples	27	25
1983	Fixed Gears	N port samples	38	12
1985	Fixed Gears	N port samples	11	14
1986	Fixed Gears	N port samples	9	3
1987	Fixed Gears	N port samples	14	32
1988	Fixed Gears	N port samples	30	54
1989	Fixed Gears	N port samples	17	16
1993	Fixed Gears	N port samples	86	280
1994	Fixed Gears	N port samples	36	128
1995	Fixed Gears	N port samples	52	144
1996	Fixed Gears	N port samples	96	253
1997	Fixed Gears	N port samples	98	213
1998	Fixed Gears	N port samples	42	101
1999	Fixed Gears	N port samples	113	304
2000	Fixed Gears	N port samples	40	101
2001	Fixed Gears	N port samples	74	183
2002	Fixed Gears	N port samples	41	85
2003	Fixed Gears	N port samples	26	37

2004	Fixed Gears	N port samples	43	77
2005	Fixed Gears	N port samples	24	14
2006	Fixed Gears	N port samples	50	43
2007	Fixed Gears	N port samples	99	109
2008	Fixed Gears	N port samples	83	65
2009	Fixed Gears	N port samples	68	56
2010	Fixed Gears	N port samples	78	85
2011	Fixed Gears	N port samples	53	96
2012	Fixed Gears	N port samples	57	101
2013	Fixed Gears	N port samples	59	94
2014	Fixed Gears	N port samples	65	178
2015	Fixed Gears	N port samples	110	447
2016	Fixed Gears	N port samples	154	483
1978	Trawl Gears	N port samples	25	116
1979	Trawl Gears	N port samples	29	195
1980	Trawl Gears	N port samples	59	1616
1982	Trawl Gears	N port samples	27	286
1983	Trawl Gears	N port samples	38	371
1984	Trawl Gears	N port samples	17	238
1985	Trawl Gears	N port samples	11	56
1986	Trawl Gears	N port samples	9	82
1987	Trawl Gears	N port samples	14	114
1988	Trawl Gears	N port samples	30	207
1989	Trawl Gears	N port samples	17	102
1993	Trawl Gears	N port samples	86	1046
1994	Trawl Gears	N port samples	36	631
1995	Trawl Gears	N port samples	52	391
1996	Trawl Gears	N port samples	96	410
1997	Trawl Gears	N port samples	98	951
1998	Trawl Gears	N port samples	42	263
1999	Trawl Gears	N port samples	113	313
2000	Trawl Gears	N port samples	40	160
2001	Trawl Gears	N port samples	74	201
2002	Trawl Gears	N port samples	41	261
2003	Trawl Gears	N port samples	26	141
2004	Trawl Gears	N port samples	43	264
2005	Trawl Gears	N port samples	24	161
2006	Trawl Gears	N port samples	50	312
2007	Trawl Gears	N port samples	99	459
2008	Trawl Gears	N port samples	83	427
2009	Trawl Gears	N port samples	68	233
2010	Trawl Gears	N port samples	78	290
2011	Trawl Gears	N port samples	53	129

2012	Trawl Gears	N port samples	57	129
2013	Trawl Gears	N port samples	59	365
2014	Trawl Gears	N port samples	65	332
2015	Trawl Gears	N port samples	110	476
2016	Trawl Gears	N port samples	154	797
2004	Fixed Gears Discards	N tows	167	609
2005	Fixed Gears Discards	N tows	104	355
2006	Fixed Gears Discards	N tows	82	225
2007	Fixed Gears Discards	N tows	97	254
2008	Fixed Gears Discards	N tows	36	97
2009	Fixed Gears Discards	N tows	77	298
2010	Fixed Gears Discards	N tows	56	162
2011	Fixed Gears Discards	N tows	133	447
2012	Fixed Gears Discards	N tows	146	499
2013	Fixed Gears Discards	N tows	119	511
2014	Fixed Gears Discards	N tows	92	343
2015	Fixed Gears Discards	N tows	158	554
2004	Trawl Gears Discards	N tows	73	568
2005	Trawl Gears Discards	N tows	177	733
2006	Trawl Gears Discards	N tows	47	140
2007	Trawl Gears Discards	N tows	38	134
2008	Trawl Gears Discards	N tows	47	125
2009	Trawl Gears Discards	N tows	39	124
2010	Trawl Gears Discards	N tows	31	85
2011	Trawl Gears Discards	N tows	132	437
2012	Trawl Gears Discards	N tows	116	383
2013	Trawl Gears Discards	N tows	141	552
2014	Trawl Gears Discards	N tows	222	902
2015	Trawl Gears Discards	N tows	215	807
2004	NWFSC Hook and Line	N fish	32	
2005	NWFSC Hook and Line	N fish	37	
2006	NWFSC Hook and Line	N fish	14	
2007	NWFSC Hook and Line	N fish	26	
2008	NWFSC Hook and Line	N fish	13	
2009	NWFSC Hook and Line	N fish	19	
2010	NWFSC Hook and Line	N fish	15	
2011	NWFSC Hook and Line	N fish	31	
2012	NWFSC Hook and Line	N fish	28	
2013	NWFSC Hook and Line	N fish	94	
2014	NWFSC Hook and Line	N fish	91	
2015	NWFSC Hook and Line	N fish	85	
2016	NWFSC Hook and Line	N fish	106	
1987	CA Recreational, J. Field	N fish	284	

1988	CA Recreational, J. Field	N fish	1072
1989	CA Recreational, J. Field	N fish	1070
1990	CA Recreational, J. Field	N fish	223
1991	CA Recreational, J. Field	N fish	359
1992	CA Recreational, J. Field	N fish	718
1993	CA Recreational, J. Field	N fish	566
1994	CA Recreational, J. Field	N fish	589
1995	CA Recreational, J. Field	N fish	952
1996	CA Recreational, J. Field	N fish	1091
1997	CA Recreational, J. Field	N fish	1290
1998	CA Recreational, J. Field	N fish	424
1975	CA Recreational, Southern CA	N fish	140
1976	CA Recreational, Southern CA	N fish	235
1977	CA Recreational, Southern CA	N fish	165
1978	CA Recreational, Southern CA	N fish	292
1986	CA Recreational, Southern CA	N fish	45
1987	CA Recreational, Southern CA	N fish	122
1988	CA Recreational, Southern CA	N fish	279
1989	CA Recreational, Southern CA	N fish	313
1959	CA Recreational, Monterey Bay	N fish	262
1960	CA Recreational, Monterey Bay	N fish	368
1961	CA Recreational, Monterey Bay	N fish	350
1962	CA Recreational, Monterey Bay	N fish	512
1963	CA Recreational, Monterey Bay	N fish	591
1964	CA Recreational, Monterey Bay	N fish	592
1966	CA Recreational, Monterey Bay	N fish	459
1967	CA Recreational, Monterey Bay	N fish	375
1968	CA Recreational, Monterey Bay	N fish	468
1969	CA Recreational, Monterey Bay	N fish	375
1970	CA Recreational, Monterey Bay	N fish	453
1971	CA Recreational, Monterey Bay	N fish	344
1972	CA Recreational, Monterey Bay	N fish	370
2004	CA Recreational, RecFIN	N fish	1426
2005	CA Recreational, RecFIN	N fish	4642
2006	CA Recreational, RecFIN	N fish	4477
2007	CA Recreational, RecFIN	N fish	3347
2008	CA Recreational, RecFIN	N fish	2695
2009	CA Recreational, RecFIN	N fish	2754
2010	CA Recreational, RecFIN	N fish	1908
2011	CA Recreational, RecFIN	N fish	4578
2012	CA Recreational, RecFIN	N fish	5770
2013	CA Recreational, RecFIN	N fish	7901
2014	CA Recreational, RecFIN	N fish	9017

2015	CA Recreational, RecFIN	N fish	12834
2016	CA Recreational, RecFIN	N fish	10337
1993	CA Recreational, MRFSS	N fish	664
1994	CA Recreational, MRFSS	N fish	406
1995	CA Recreational, MRFSS	N fish	397
1996	CA Recreational, MRFSS	N fish	787
1997	CA Recreational, MRFSS	N fish	166
1998	CA Recreational, MRFSS	N fish	341
1999	CA Recreational, MRFSS	N fish	721
2000	CA Recreational, MRFSS	N fish	242
2001	CA Recreational, MRFSS	N fish	153
2002	CA Recreational, MRFSS	N fish	848
2003	CA Recreational, MRFSS	N fish	1431
2016	Lam Research	N fish	1042

Table 5. Input age sample sizes for the north model.

Year	Fleet/Survey	Units (Used in Model)	Model Input Sample Size	Number of Fish
1995	Triennial Late	N tows	74	200
1998	Triennial Late	N tows	91	292
2001	Triennial Late	N tows	96	586
2004	Triennial Late	N tows	85	424
2003	NWFSC WCGBTS	N tows	81	414
2004	NWFSC WCGBTS	N tows	85	419
2005	NWFSC WCGBTS	N tows	96	444
2006	NWFSC WCGBTS	N tows	119	485
2007	NWFSC WCGBTS	N tows	91	326
2008	NWFSC WCGBTS	N tows	108	428
2010	NWFSC WCGBTS	N tows	99	265
2011	NWFSC WCGBTS	N tows	118	274
2012	NWFSC WCGBTS	N tows	97	196
2014	NWFSC WCGBTS	N tows	86	173
2013	NWFSC WCGBTS	N tows	96	183
2015	NWFSC WCGBTS	N tows	100	192
2016	NWFSC WCGBTS	N tows	90	164
1978	Fixed Gears	N tows	16	147
1979	Fixed Gears	N tows	11	9
1980	Fixed Gears	N tows	33	24
1981	Fixed Gears	N tows	19	32
1982	Fixed Gears	N tows	22	52
1983	Fixed Gears	N tows	18	41
1986	Fixed Gears	N tows	40	34
1987	Fixed Gears	N tows	47	336
1988	Fixed Gears	N tows	43	145
1989	Fixed Gears	N tows	40	129

1990	Fixed Gears	N tows	45	204
1991	Fixed Gears	N tows	49	195
1992	Fixed Gears	N tows	90	24
1993	Fixed Gears	N tows	89	285
1994	Fixed Gears	N tows	69	306
1995	Fixed Gears	N tows	68	271
1996	Fixed Gears	N tows	54	265
1997	Fixed Gears	N tows	43	284
1998	Fixed Gears	N tows	36	150
1999	Fixed Gears	N tows	34	100
2000	Fixed Gears	N tows	29	119
2001	Fixed Gears	N tows	40	92
2002	Fixed Gears	N tows	49	41
2003	Fixed Gears	N tows	63	69
2004	Fixed Gears	N tows	51	99
2005	Fixed Gears	N tows	35	61
2006	Fixed Gears	N tows	45	93
2007	Fixed Gears	N tows	57	73
2008	Fixed Gears	N tows	45	40
2009	Fixed Gears	N tows	37	26
2010	Fixed Gears	N tows	26	25
2011	Fixed Gears	N tows	35	50
2012	Fixed Gears	N tows	37	55
2013	Fixed Gears	N tows	44	91
2014	Fixed Gears	N tows	40	196
2015	Fixed Gears	N tows	14	33
2016	Fixed Gears	N tows	22	28
1978	Trawl Gears	N tows	16	68
1979	Trawl Gears	N tows	11	695
1980	Trawl Gears	N tows	33	1939
1981	Trawl Gears	N tows	19	1391
1982	Trawl Gears	N tows	22	607
1983	Trawl Gears	N tows	18	475
1984	Trawl Gears	N tows	11	429
1985	Trawl Gears	N tows	14	458
1986	Trawl Gears	N tows	40	988
1987	Trawl Gears	N tows	47	741
1988	Trawl Gears	N tows	43	821
1989	Trawl Gears	N tows	40	787
1990	Trawl Gears	N tows	45	887
1991	Trawl Gears	N tows	49	999
1992	Trawl Gears	N tows	90	2399
1993	Trawl Gears	N tows	89	2328

1994	Trawl Gears	N tows	69	1529
1995	Trawl Gears	N tows	68	1423
1996	Trawl Gears	N tows	54	1108
1997	Trawl Gears	N tows	43	674
1998	Trawl Gears	N tows	36	706
1999	Trawl Gears	N tows	34	750
2000	Trawl Gears	N tows	29	390
2001	Trawl Gears	N tows	40	626
2002	Trawl Gears	N tows	49	696
2003	Trawl Gears	N tows	63	786
2004	Trawl Gears	N tows	51	494
2005	Trawl Gears	N tows	35	532
2006	Trawl Gears	N tows	45	629
2007	Trawl Gears	N tows	57	824
2008	Trawl Gears	N tows	45	761
2009	Trawl Gears	N tows	37	562
2010	Trawl Gears	N tows	26	261
2011	Trawl Gears	N tows	35	391
2012	Trawl Gears	N tows	37	448
2013	Trawl Gears	N tows	44	448
2014	Trawl Gears	N tows	40	232
2015	Trawl Gears	N tows	14	91
2016	Trawl Gears	N tows	22	170
1979	WA recreational	N fish	13	
1980	WA recreational	N fish	226	
1981	WA recreational	N fish	14	
1982	WA recreational	N fish	19	
1983	WA recreational	N fish	39	
1986	WA recreational	N fish	342	
1987	WA recreational	N fish	276	
1988	WA recreational	N fish	250	
1989	WA recreational	N fish	227	
1990	WA recreational	N fish	207	
1991	WA recreational	N fish	247	

1992	WA recreational	N fish	499
1993	WA recreational	N fish	530
1994	WA recreational	N fish	449
1995	WA recreational	N fish	643
1996	WA recreational	N fish	461
1997	WA recreational	N fish	441
1998	WA recreational	N fish	416
1999	WA recreational	N fish	432
2000	WA recreational	N fish	394
2001	WA recreational	N fish	560
2002	WA recreational	N fish	650
2003	WA recreational	N fish	619
2004	WA recreational	N fish	570
2005	WA recreational	N fish	566
2006	WA recreational	N fish	398
2007	WA recreational	N fish	483
2008	WA recreational	N fish	430
2009	WA recreational	N fish	335
2010	WA recreational	N fish	385
2011	WA recreational	N fish	296
2012	WA recreational	N fish	234
2013	WA recreational	N fish	344
2014	WA recreational	N fish	688
2015	WA recreational	N fish	487

2016	WA recreational	N fish	768
1999	OR recreational	N fish	178
2000	OR recreational	N fish	264
2001	OR recreational	N fish	791
2002	OR recreational	N fish	859
2003	OR recreational	N fish	803
2004	OR recreational	N fish	647
2005	OR recreational	N fish	540
2006	OR recreational	N fish	799
2007	OR recreational	N fish	788
2008	OR recreational	N fish	740
2012	OR recreational	N fish	260
2014	OR recreational	N fish	259
2015	OR recreational	N fish	259
2016	OR recreational	N fish	260
1996	WDFW Research	N fish	511
1997	WDFW Research	N fish	498
2001	WDFW Research	N fish	100
2002	WDFW Research	N fish	100
2003	WDFW Research	N fish	100
2016	Lam Research	N fish	573

Table 6. . Input age sample sizes for the south model.

Year	Fleet/Survey	Units (Used in Model)	Model Input Sample Size	Number of Fish
2003	NWFSC WCGBTS	N tows	91	461
2004	NWFSC WCGBTS	N tows	76	408
2005	NWFSC WCGBTS	N tows	90	396
2006	NWFSC WCGBTS	N tows	52	212
2007	NWFSC WCGBTS	N tows	53	157
2008	NWFSC WCGBTS	N tows	77	410
2010	NWFSC WCGBTS	N tows	95	253
2011	NWFSC WCGBTS	N tows	96	245
2012	NWFSC WCGBTS	N tows	105	214
2013	NWFSC WCGBTS	N tows	68	141
2014	NWFSC WCGBTS	N tows	114	295
2015	NWFSC WCGBTS	N tows	103	203
2016	NWFSC WCGBTS	N tows	88	202
1993	Fixed Gears	N tows	22	48
1994	Fixed Gears	N tows	20	39
1998	Fixed Gears	N tows	14	38
2004	Fixed Gears	N tows	12	15
1993	Trawl Gears	N tows	22	769
1994	Trawl Gears	N tows	20	568
1995	Trawl Gears	N tows	12	270
1996	Trawl Gears	N tows	17	334
1997	Trawl Gears	N tows	43	873
1998	Trawl Gears	N tows	14	219
2001	Trawl Gears	N tows	14	183
2002	Trawl Gears	N tows	15	247
2003	Trawl Gears	N tows	13	98
2004	Trawl Gears	N tows	12	138
1995	Late Triennial	N tows	49	199

1998	Late Triennial	N tows	52	204
2001	Late Triennial	N tows	48	216
2004	Late Triennial	N tows	83	358
2016	Lam Research	N fish	414	

Table 7. North base model parameters.

SS Parameter Name	Fixed Value or Estimate	Minimum Bound	Maximum Bound	Standard Deviation	Prior Type
NatM_p_1_Fem_GP_1	0.257	0.05	0.4	Fixed	Log_Norm
L_at_Amin_Fem_GP_1	17.2792	4	60	0.735161	No_prior
L_at_Amax_Fem_GP_1	110	40	130	Fixed	No_prior
VonBert_K_Fem_GP_1	0.128177	0.01	0.5	0.004204	No_prior
CV_young_Fem_GP_1	0.143666	0.01	0.5	0.0106661	No_prior
CV_old_Fem_GP_1	0.0606102	0.01	0.5	0.00990003	No_prior
Wtlen_1_Fem	0.00000276	-3	3	Fixed	No_prior
Wtlen_2_Fem	3.28	-3	5	Fixed	No_prior
Mat50%_Fem	56.7	-3	100	Fixed	No_prior
Mat_slope_Fem	-0.269	-5	5	Fixed	No_prior
Eggs/kg_inter_Fem	1	-3	3	Fixed	No_prior
Eggs/kg_slope_wt_Fem	0	-3	3	Fixed	No_prior
NatM_p_1_Mal_GP_1	0.304947	0.15	0.45	0.00660155	Log_Norm
L_at_Amin_Mal_GP_1	14.8756	10	60	1.02119	No_prior
L_at_Amax_Mal_GP_1	76.7131	40	110	0.98677	No_prior
VonBert_K_Mal_GP_1	0.301253	0.01	1	0.0154737	No_prior
CV_young_Mal_GP_1	0.156754	0.01	0.5	0.0140373	No_prior
CV_old_Mal_GP_1	0.0722656	0.01	0.5	0.00693014	No_prior
Wtlen_1_Mal	0.00000161	-3	3	Fixed	No_prior
Wtlen_2_Mal	3.42	-5	5	Fixed	No_prior
RecrDist_GP_1	0	-3	3	Fixed	No_prior
RecrDist_Area_1	0	-3	3	Fixed	No_prior
RecrDist_Bseas_1	1	0	999	Fixed	No_prior
CohortGrowDev	0	0	0	Fixed	No_prior
FracFemale_GP_1	0.5	0.000001	0.999999	Fixed	No_prior
SR_LN(R0)	9.0669	5	15	0.164548	No_prior
SR_BH_steep	0.7	0.2	1	Fixed	No_prior
SR_sigmaR	0.55	0	2	Fixed	No_prior
SR_regime	0	-5	5	Fixed	No_prior
SR_autocorr	0	0	2	Fixed	No_prior
LnQ_base_1_N_TRAWL(1)	-1.16572	-15	15	Fixed	No_prior
Q_extraSD_1_N_TRAWL(1)	0.0663834	0.001	2	0.0347138	No_prior
LnQ_base_2_N_FIX(2)	-7.08317	-15	15	Fixed	No_prior
Q_extraSD_2_N_FIX(2)	0.120872	0.001	2	0.054318	No_prior
LnQ_base_3_WA_REC(3)	-8.56169	-15	15	Fixed	No_prior
Q_extraSD_3_WA_REC(3)	0.261407	0.001	2	0.0416452	No_prior
LnQ_base_4_OR_REC(4)	-11.0514	-15	15	Fixed	No_prior
Q_extraSD_4_OR_REC(4)	0.216863	0.001	2	0.0339093	No_prior

LnQ_base_5_N_TRI_Early(5)	-0.733503	-15	15	Fixed	No_prior
LnQ_base_6_N_TRI_Late(6)	-0.645328	-15	15	Fixed	No_prior
LnQ_base_7_N_NWFSC(7)	-0.30414	-15	15	Fixed	No_prior
SizeSel_P1_1_N_TRAWL(1)	6.51E+01	14	120	1.45192	No_prior
SizeSel_P2_1_N_TRAWL(1)	-15	-20	4	Fixed	No_prior
SizeSel_P3_1_N_TRAWL(1)	6	-1	15	Fixed	No_prior
SizeSel_P4_1_N_TRAWL(1)	14	-1	15	Fixed	No_prior
SizeSel_P5_1_N_TRAWL(1)	-10	-5	9	Fixed	No_prior
SizeSel_P6_1_N_TRAWL(1)	-999	-5	9	Fixed	No_prior
Retain_P1_1_N_TRAWL(1)	86.3558	10	100	4.59286	No_prior
Retain_P2_1_N_TRAWL(1)	10.6771	0.1	12	1.22738	No_prior
Retain_P3_1_N_TRAWL(1)	8.24742	0.001	12	65.7569	No_prior
Retain_P4_1_N_TRAWL(1)	0.808175	-10	10	1.2112	No_prior
DiscMort_P1_1_N_TRAWL(1)	0	-1	1	Fixed	No_prior
DiscMort_P2_1_N_TRAWL(1)	0.0001	-1	1	Fixed	No_prior
DiscMort_P3_1_N_TRAWL(1)	0.5	0.001	1	Fixed	No_prior
DiscMort_P4_1_N_TRAWL(1)	0	-2	2	Fixed	No_prior
SzSel_Male_Peak_1_N_TRAWL(1)	-1.39219	-30	15	Fixed	No_prior
SzSel_Male_Ascend_1_N_TRAWL(1)	0.20461	-15	15	0.164678	No_prior
SzSel_Male_Descend_1_N_TRAWL(1)	-2.67287	-15	15	0.421588	No_prior
SzSel_Male_Final_1_N_TRAWL(1)	0	-15	15	Fixed	No_prior
SzSel_Male_Scale_1_N_TRAWL(1)	1	-15	15	Fixed	No_prior
SizeSel_P1_2_N_FIX(2)	86.0596	14	100	1.83103	No_prior
SizeSel_P2_2_N_FIX(2)	-15	-20	10	Fixed	No_prior
SizeSel_P3_2_N_FIX(2)	6.57729	-10	9	0.154424	No_prior
SizeSel_P4_2_N_FIX(2)	5.18328	-1	9	0.365862	No_prior
SizeSel_P5_2_N_FIX(2)	-999	-5	9	Fixed	No_prior
SizeSel_P6_2_N_FIX(2)	-999	-5	9	Fixed	No_prior
Retain_P1_2_N_FIX(2)	58.6395	10	100	0.412502	No_prior
Retain_P2_2_N_FIX(2)	6.84265	0.1	10	1.55369	No_prior
Retain_P3_2_N_FIX(2)	5.1616	0.001	6	20.1646	No_prior
Retain_P4_2_N_FIX(2)	-1.3	-2	6	Fixed	No_prior
DiscMort_P1_2_N_FIX(2)	0	-1	1	Fixed	No_prior
DiscMort_P2_2_N_FIX(2)	0.0001	-1	1	Fixed	No_prior
DiscMort_P3_2_N_FIX(2)	0.07	0.001	1	Fixed	No_prior
DiscMort_P4_2_N_FIX(2)	0	-2	2	Fixed	No_prior
SzSel_Male_Peak_2_N_FIX(2)	-28	-30	20	Fixed	No_prior
SzSel_Male_Ascend_2_N_FIX(2)	-1.40909	-15	15	0.249416	No_prior
SzSel_Male_Descend_2_N_FIX(2)	1.67931	-15	15	0.573604	No_prior
SzSel_Male_Final_2_N_FIX(2)	0	-15	15	Fixed	No_prior
SzSel_Male_Scale_2_N_FIX(2)	1	-15	15	Fixed	No_prior
SizeSel_P1_3_WA_REC(3)	72.581	35	100	1.12761	No_prior
SizeSel_P2_3_WA_REC(3)	-15	-20	10	Fixed	No_prior

SizeSel_P3_3_WA_REC(3)	4.9258	-1	9	0.140439	No_prior
SizeSel_P4_3_WA_REC(3)	6.27983	-1	9	0.15761	No_prior
SizeSel_P5_3_WA_REC(3)	-999	-5	9	Fixed	No_prior
SizeSel_P6_3_WA_REC(3)	-999	-5	9	Fixed	No_prior
SzSel_Male_Peak_3_WA_REC(3)	-8.64984	-15	15	1.22297	No_prior
SzSel_Male_Ascend_3_WA_REC(3)	-5.05E-01	-15	15	0.18074	No_prior
SzSel_Male_Descend_3_WA_REC(3)	-0.145975	-15	15	Fixed	No_prior
SzSel_Male_Final_3_WA_REC(3)	0	-15	15	Fixed	No_prior
SzSel_Male_Scale_3_WA_REC(3)	1	-15	15	Fixed	No_prior
SizeSel_P1_4_OR_REC(4)	58.66	35	100	0.436011	No_prior
SizeSel_P2_4_OR_REC(4)	-15	-20	4	Fixed	No_prior
SizeSel_P3_4_OR_REC(4)	4.62899	-4	9	0.210642	No_prior
SizeSel_P4_4_OR_REC(4)	8.10352	-1	9	1.06127	No_prior
SizeSel_P5_4_OR_REC(4)	-999	-5	9	Fixed	No_prior
SizeSel_P6_4_OR_REC(4)	-999	-5	9	Fixed	No_prior
SizeSel_P1_5_N_TRI_Early(5)	94.7887	14	120	5.00852	No_prior
SizeSel_P2_5_N_TRI_Early(5)	-15	-20	4	Fixed	No_prior
SizeSel_P3_5_N_TRI_Early(5)	7.06894	-1	9	0.15714	No_prior
SizeSel_P4_5_N_TRI_Early(5)	6	-1	9	Fixed	No_prior
SizeSel_P5_5_N_TRI_Early(5)	-999	-5	9	Fixed	No_prior
SizeSel_P6_5_N_TRI_Early(5)	-999	-5	9	Fixed	No_prior
SizeSel_P1_6_N_TRI_Late(6)	57.3908	14	110	9.90742	No_prior
SizeSel_P2_6_N_TRI_Late(6)	-15	-20	4	Fixed	No_prior
SizeSel_P3_6_N_TRI_Late(6)	6.16568	-1	9	0.685511	No_prior
SizeSel_P4_6_N_TRI_Late(6)	8	-1	15	Fixed	No_prior
SizeSel_P5_6_N_TRI_Late(6)	-999	-5	9	Fixed	No_prior
SizeSel_P6_6_N_TRI_Late(6)	-999	-5	9	Fixed	No_prior
SizeSel_P1_7_N_NWFSC(7)	61.2144	35	120	6.0047	No_prior
SizeSel_P2_7_N_NWFSC(7)	-15	-20	4	Fixed	No_prior
SizeSel_P3_7_N_NWFSC(7)	6.45783	-1	9	0.344327	No_prior
SizeSel_P4_7_N_NWFSC(7)	7.05119	-1	9	0.618844	No_prior
SizeSel_P5_7_N_NWFSC(7)	-999	-5	9	Fixed	No_prior
SizeSel_P6_7_N_NWFSC(7)	-999	-5	9	Fixed	No_prior
SizeSel_P1_8_N_Lam_Research(8)	82.4813	35	100	2.91143	No_prior
SizeSel_P2_8_N_Lam_Research(8)	-15	-20	4	Fixed	No_prior
SizeSel_P3_8_N_Lam_Research(8)	5.82225	-1	9	0.287732	No_prior
SizeSel_P4_8_N_Lam_Research(8)	5.55355	-1	9	0.691088	No_prior
SizeSel_P5_8_N_Lam_Research(8)	-999	-5	9	Fixed	No_prior
SizeSel_P6_8_N_Lam_Research(8)	-999	-5	9	Fixed	No_prior
SzSel_Male_Peak_8_N_Lam_Research(8)	-18.8698	-30	40	3.92398	No_prior
SzSel_Male_Ascend_8_N_Lam_Research(8)	-1.00808	-15	15	0.493042	No_prior
SzSel_Male_Descend_8_N_Lam_Research(8)	-1.52421	-15	15	0.915959	No_prior
SzSel_Male_Final_8_N_Lam_Research(8)	0	-15	15	Fixed	No_prior

SzSel_Male_Scale_8_N_Lam_Research(8)	1	-15	15	Fixed	No_prior
AgeSel_P1_1_N_TRAWL(1)	0.1	0	1	Fixed	No_prior
AgeSel_P2_1_N_TRAWL(1)	100	0	101	Fixed	No_prior
AgeSel_P1_2_N_FIX(2)	0.1	0	1	Fixed	No_prior
AgeSel_P2_2_N_FIX(2)	100	0	101	Fixed	No_prior
AgeSel_P1_3_WA_REC(3)	0.1	0	1	Fixed	No_prior
AgeSel_P2_3_WA_REC(3)	100	0	101	Fixed	No_prior
AgeSel_P1_4_OR_REC(4)	0.1	0	1	Fixed	No_prior
AgeSel_P2_4_OR_REC(4)	100	0	101	Fixed	No_prior
AgeSel_P1_5_N_TRI_Early(5)	0.1	0	1	Fixed	No_prior
AgeSel_P2_5_N_TRI_Early(5)	100	0	101	Fixed	No_prior
AgeSel_P1_6_N_TRI_Late(6)	0.1	0	1	Fixed	No_prior
AgeSel_P2_6_N_TRI_Late(6)	100	0	101	Fixed	No_prior
AgeSel_P1_7_N_NWFSC(7)	0.1	0	1	Fixed	No_prior
AgeSel_P2_7_N_NWFSC(7)	100	0	101	Fixed	No_prior
AgeSel_P1_8_N_Lam_Research(8)	0.1	0	1	Fixed	No_prior
AgeSel_P2_8_N_Lam_Research(8)	100	0	101	Fixed	No_prior
SizeSel_P4_1_N_TRAWL(1)_BLK3repl_1973	10	-1	15	Fixed	No_prior
SizeSel_P4_1_N_TRAWL(1)_BLK3repl_1983	6.78718	-1	15	0.222518	No_prior
SizeSel_P4_1_N_TRAWL(1)_BLK3repl_1993	6.25786	-1	15	0.215587	No_prior
SizeSel_P4_1_N_TRAWL(1)_BLK3repl_2003	6.27301	-1	15	0.171979	No_prior
SizeSel_P4_1_N_TRAWL(1)_BLK3repl_2011	8.3592	-1	15	0.587714	No_prior
Retain_P1_1_N_TRAWL(1)_BLK2repl_1998	82.1169	10	100	1.05352	No_prior
Retain_P1_1_N_TRAWL(1)_BLK2repl_2007	73.2902	10	100	3.23625	No_prior
Retain_P1_1_N_TRAWL(1)_BLK2repl_2010	59.9287	10	100	2.90061	No_prior
Retain_P1_1_N_TRAWL(1)_BLK2repl_2011	55.0591	10	100	0.89431	No_prior
Retain_P2_1_N_TRAWL(1)_BLK2repl_1998	7.58008	0.1	12	Fixed	No_prior
Retain_P2_1_N_TRAWL(1)_BLK2repl_2007	5.27153	0.1	12	1.27383	No_prior
Retain_P2_1_N_TRAWL(1)_BLK2repl_2010	4.28695	0.1	12	1.28567	No_prior
Retain_P2_1_N_TRAWL(1)_BLK2repl_2011	2.21665	0.1	12	0.301165	No_prior
Retain_P3_1_N_TRAWL(1)_BLK2repl_1998	7	0.001	12	Fixed	No_prior
Retain_P3_1_N_TRAWL(1)_BLK2repl_2007	1.81886	0.001	12	1.22386	No_prior
Retain_P3_1_N_TRAWL(1)_BLK2repl_2010	9.88871	0.001	12	40.5791	No_prior
Retain_P3_1_N_TRAWL(1)_BLK2repl_2011	11.4486	0.001	12	14.1079	No_prior
Retain_P2_2_N_FIX(2)_BLK1repl_1998	1.69917	0.1	10	0.427384	No_prior
Retain_P2_2_N_FIX(2)_BLK1repl_2011	1.44337	0.1	10	0.326083	No_prior
Retain_P3_2_N_FIX(2)_BLK1repl_1998	0.646927	0.001	6	0.0921431	No_prior
Retain_P3_2_N_FIX(2)_BLK1repl_2011	0.777991	0.001	6	0.118112	No_prior
SizeSel_P3_4_OR_REC(4)_BLK4repl_1999	2.0846	-4	9	0.261511	No_prior
SizeSel_P4_4_OR_REC(4)_BLK4repl_1999	6.78122	-1	9	0.120623	No_prior
Early_RecrDev_1889	-8.29E-06	-4	4	0.549998	No_prior
Early_RecrDev_1890	-9.73E-06	-4	4	0.549998	No_prior
Early_RecrDev_1891	-1.14E-05	-4	4	0.549997	No_prior

Early_RecrDev_1892	-1.34E-05	-4	4	0.549997	No_prior
Early_RecrDev_1893	-1.57E-05	-4	4	0.549996	No_prior
Early_RecrDev_1894	-1.85E-05	-4	4	0.549995	No_prior
Early_RecrDev_1895	-2.17E-05	-4	4	0.549995	No_prior
Early_RecrDev_1896	-2.54E-05	-4	4	0.549994	No_prior
Early_RecrDev_1897	-2.99E-05	-4	4	0.549992	No_prior
Early_RecrDev_1898	-3.50E-05	-4	4	0.549991	No_prior
Early_RecrDev_1899	-4.11E-05	-4	4	0.54999	No_prior
Early_RecrDev_1900	-4.83E-05	-4	4	0.549988	No_prior
Early_RecrDev_1901	-5.67E-05	-4	4	0.549986	No_prior
Early_RecrDev_1902	-6.66E-05	-4	4	0.549983	No_prior
Early_RecrDev_1903	-7.81E-05	-4	4	0.54998	No_prior
Early_RecrDev_1904	-9.16E-05	-4	4	0.549977	No_prior
Early_RecrDev_1905	-0.000107502	-4	4	0.549973	No_prior
Early_RecrDev_1906	-0.000126073	-4	4	0.549968	No_prior
Early_RecrDev_1907	-0.00014776	-4	4	0.549963	No_prior
Early_RecrDev_1908	-0.000173018	-4	4	0.549957	No_prior
Early_RecrDev_1909	-0.000202412	-4	4	0.549949	No_prior
Early_RecrDev_1910	-0.000236601	-4	4	0.549941	No_prior
Early_RecrDev_1911	-0.000276649	-4	4	0.54993	No_prior
Early_RecrDev_1912	-0.000323833	-4	4	0.549919	No_prior
Early_RecrDev_1913	-0.000379556	-4	4	0.549905	No_prior
Early_RecrDev_1914	-0.000445305	-4	4	0.549888	No_prior
Early_RecrDev_1915	-0.000522416	-4	4	0.549869	No_prior
Early_RecrDev_1916	-0.000612247	-4	4	0.549847	No_prior
Early_RecrDev_1917	-0.000717075	-4	4	0.549821	No_prior
Early_RecrDev_1918	-0.000839304	-4	4	0.54979	No_prior
Early_RecrDev_1919	-0.00098161	-4	4	0.549755	No_prior
Early_RecrDev_1920	-0.00114836	-4	4	0.549714	No_prior
Early_RecrDev_1921	-0.00134346	-4	4	0.549665	No_prior
Early_RecrDev_1922	-0.00157093	-4	4	0.54961	No_prior
Early_RecrDev_1923	-0.00183697	-4	4	0.549544	No_prior
Early_RecrDev_1924	-0.00214696	-4	4	0.549469	No_prior
Early_RecrDev_1925	-0.00250764	-4	4	0.549382	No_prior
Early_RecrDev_1926	-0.0029247	-4	4	0.549283	No_prior
Early_RecrDev_1927	-0.00340201	-4	4	0.549169	No_prior
Early_RecrDev_1928	-0.00394451	-4	4	0.549041	No_prior
Early_RecrDev_1929	-0.00455869	-4	4	0.548898	No_prior
Early_RecrDev_1930	-0.00524492	-4	4	0.548738	No_prior
Early_RecrDev_1931	-0.00600884	-4	4	0.548561	No_prior
Early_RecrDev_1932	-0.00685808	-4	4	0.548366	No_prior
Early_RecrDev_1933	-0.00779123	-4	4	0.548151	No_prior
Early_RecrDev_1934	-0.00880488	-4	4	0.547918	No_prior

Early_RecrDev_1935	-0.00988879	-4	4	0.547666	No_prior
Early_RecrDev_1936	-0.0110366	-4	4	0.547395	No_prior
Early_RecrDev_1937	-0.0122602	-4	4	0.547102	No_prior
Early_RecrDev_1938	-0.0135861	-4	4	0.546781	No_prior
Early_RecrDev_1939	-0.0150278	-4	4	0.546428	No_prior
Early_RecrDev_1940	-0.0166601	-4	4	0.546028	No_prior
Early_RecrDev_1941	-0.018528	-4	4	0.54557	No_prior
Early_RecrDev_1942	-0.0207092	-4	4	0.545037	No_prior
Early_RecrDev_1943	-0.0231671	-4	4	0.544431	No_prior
Early_RecrDev_1944	-0.0259318	-4	4	0.543747	No_prior
Early_RecrDev_1945	-0.0289267	-4	4	0.542999	No_prior
Early_RecrDev_1946	-0.032347	-4	4	0.542144	No_prior
Early_RecrDev_1947	-0.036135	-4	4	0.541186	No_prior
Early_RecrDev_1948	-0.0405452	-4	4	0.540058	No_prior
Early_RecrDev_1949	-0.045297	-4	4	0.53881	No_prior
Early_RecrDev_1950	-0.0504055	-4	4	0.537434	No_prior
Early_RecrDev_1951	-0.0558341	-4	4	0.535939	No_prior
Early_RecrDev_1952	-0.0617691	-4	4	0.534278	No_prior
Early_RecrDev_1953	-0.0686024	-4	4	0.532363	No_prior
Early_RecrDev_1954	-0.0763008	-4	4	0.530236	No_prior
Early_RecrDev_1955	-0.0843999	-4	4	0.528058	No_prior
Early_RecrDev_1956	-0.0924383	-4	4	0.525924	No_prior
Early_RecrDev_1957	-0.0996281	-4	4	0.523854	No_prior
Early_RecrDev_1958	-0.102984	-4	4	0.522284	No_prior
Early_RecrDev_1959	-0.0981789	-4	4	0.521887	No_prior
Early_RecrDev_1960	-0.0814344	-4	4	0.522956	No_prior
Early_RecrDev_1961	-0.0560938	-4	4	0.525441	No_prior
Early_RecrDev_1962	-0.0134097	-4	4	0.534253	No_prior
Early_RecrDev_1963	0.151146	-4	4	0.570116	No_prior
Early_RecrDev_1964	0.569575	-4	4	0.620572	No_prior
Main_RecrDev_1965	0.397961	-4	4	0.607036	No_prior
Main_RecrDev_1966	0.0806491	-4	4	0.548273	No_prior
Main_RecrDev_1967	0.00970694	-4	4	0.535256	No_prior
Main_RecrDev_1968	0.071374	-4	4	0.548875	No_prior
Main_RecrDev_1969	0.24436	-4	4	0.586152	No_prior
Main_RecrDev_1970	0.315525	-4	4	0.587433	No_prior
Main_RecrDev_1971	0.130581	-4	4	0.542762	No_prior
Main_RecrDev_1972	-0.0879856	-4	4	0.499105	No_prior
Main_RecrDev_1973	-0.202848	-4	4	0.471683	No_prior
Main_RecrDev_1974	-0.207162	-4	4	0.445857	No_prior
Main_RecrDev_1975	-0.339358	-4	4	0.429062	No_prior
Main_RecrDev_1976	-0.396377	-4	4	0.423033	No_prior
Main_RecrDev_1977	0.0421129	-4	4	0.452172	No_prior

Main_RecrDev_1978	1.01551	-4	4	0.367826	No_prior
Main_RecrDev_1979	0.688301	-4	4	0.503626	No_prior
Main_RecrDev_1980	0.471598	-4	4	0.473827	No_prior
Main_RecrDev_1981	-0.147859	-4	4	0.456643	No_prior
Main_RecrDev_1982	0.162026	-4	4	0.330891	No_prior
Main_RecrDev_1983	-0.395793	-4	4	0.369514	No_prior
Main_RecrDev_1984	-0.219659	-4	4	0.348767	No_prior
Main_RecrDev_1985	1.12052	-4	4	0.150813	No_prior
Main_RecrDev_1986	-0.773403	-4	4	0.376465	No_prior
Main_RecrDev_1987	-0.313901	-4	4	0.307952	No_prior
Main_RecrDev_1988	0.0177971	-4	4	0.281477	No_prior
Main_RecrDev_1989	0.0625185	-4	4	0.298435	No_prior
Main_RecrDev_1990	1.09926	-4	4	0.174602	No_prior
Main_RecrDev_1991	0.89873	-4	4	0.206537	No_prior
Main_RecrDev_1992	0.469799	-4	4	0.24313	No_prior
Main_RecrDev_1993	-0.0998084	-4	4	0.297292	No_prior
Main_RecrDev_1994	0.253991	-4	4	0.208656	No_prior
Main_RecrDev_1995	-0.185328	-4	4	0.253348	No_prior
Main_RecrDev_1996	-0.426062	-4	4	0.266245	No_prior
Main_RecrDev_1997	-0.288299	-4	4	0.209215	No_prior
Main_RecrDev_1998	-0.529664	-4	4	0.24195	No_prior
Main_RecrDev_1999	-0.102115	-4	4	0.171674	No_prior
Main_RecrDev_2000	0.254389	-4	4	0.128027	No_prior
Main_RecrDev_2001	0.0985555	-4	4	0.12159	No_prior
Main_RecrDev_2002	-0.441287	-4	4	0.138512	No_prior
Main_RecrDev_2003	-0.739109	-4	4	0.152109	No_prior
Main_RecrDev_2004	-0.489804	-4	4	0.139117	No_prior
Main_RecrDev_2005	-0.802912	-4	4	0.181366	No_prior
Main_RecrDev_2006	-0.579431	-4	4	0.172627	No_prior
Main_RecrDev_2007	-0.386578	-4	4	0.167785	No_prior
Main_RecrDev_2008	0.791705	-4	4	0.0943627	No_prior
Main_RecrDev_2009	-0.0394556	-4	4	0.156173	No_prior
Main_RecrDev_2010	0.0216739	-4	4	0.132544	No_prior
Main_RecrDev_2011	-0.482224	-4	4	0.169282	No_prior
Main_RecrDev_2012	-0.440383	-4	4	0.170053	No_prior
Main_RecrDev_2013	0.436919	-4	4	0.143494	No_prior
Main_RecrDev_2014	-0.368906	-4	4	0.285757	No_prior
Main_RecrDev_2015	0.330138	-4	4	0.383649	No_prior
Late_RecrDev_2016	-0.0408081	-4	4	0.518396	No_prior

Table 8. South base model parameters.

SS Parameter Name	Fixed Value or Estimate	Minimum Bound	Maximum Bound	Standard Deviation	Prior Type
NatM_p_1_Fem_GP_1	0.257	0.05	0.3	Fixed	Log_Norm
L_at_Amin_Fem_GP_1	18.0172	10	60	0.335569	No_prior
L_at_Amax_Fem_GP_1	93.4891	40	130	1.313	No_prior
VonBert_K_Fem_GP_1	0.129188	0.01	0.5	0.0101582	No_prior
CV_young_Fem_GP_1	0.149984	0.01	0.5	0.00896961	No_prior
CV_old_Fem_GP_1	0.0704911	0.01	0.5	0.00949212	No_prior
Wtlen_1_Fem	3.308E-06	-3	3	Fixed	No_prior
Wtlen_2_Fem	3.248	-3	5	Fixed	No_prior
Mat50%_Fem	52.3	-3	100	Fixed	No_prior
Mat_slope_Fem	-0.219	-5	5	Fixed	No_prior
Eggs/kg_inter_Fem	1	-3	3	Fixed	No_prior
Eggs/kg_slope_wt_Fem	0	-3	3	Fixed	No_prior
NatM_p_1_Mal_GP_1	0.318869	0.15	0.4	0.0144209	Log_Norm
L_at_Amin_Mal_GP_1	18.1283	10	60	0.407732	No_prior
L_at_Amax_Mal_GP_1	83.8504	40	110	2.618	No_prior
VonBert_K_Mal_GP_1	0.16	0.01	1	0.0207978	No_prior
CV_young_Mal_GP_1	0.136616	0.01	0.5	0.0102783	No_prior
CV_old_Mal_GP_1	0.0874206	0.01	0.5	0.0146184	No_prior
Wtlen_1_Mal	2.179E-06	-3	3	Fixed	No_prior
Wtlen_2_Mal	3.36	-5	5	Fixed	No_prior
RecrDist_GP_1	0	-3	3	Fixed	No_prior
RecrDist_Area_1	0	-3	3	Fixed	No_prior
RecrDist_Bseas_1	1	0	999	Fixed	No_prior
CohortGrowDev	0	0	0	Fixed	No_prior
FracFemale_GP_1	0.5	0.000001	0.999999	Fixed	No_prior
SR_LN(R0)	8.49309	5	15	0.11683	No_prior
SR_BH_steep	0.7	0.2	1	Fixed	No_prior
SR_sigmaR	0.75	0	2	Fixed	No_prior
SR_regime	0	-5	5	Fixed	No_prior
SR_autocorr	0	0	2	Fixed	No_prior
LnQ_base_1_CA_TRAWL(1)	-1.53461	-15	15	Fixed	No_prior
Q_extraSD_1_CA_TRAWL(1)	0.0459027	0.001	2	0.02565	No_prior
LnQ_base_4_CA_TRI_Early(4)	-0.16492	-15	15	Fixed	No_prior
LnQ_base_5_CA_TRI_Late(5)	0.222239	-15	15	Fixed	No_prior
LnQ_base_6_CA_NWFSC(6)	0.151513	-15	15	Fixed	No_prior
LnQ_base_7_CA_HookLine(7)	-11.6401	-15	15	Fixed	No_prior
SizeSel_P1_1_CA_TRAWL(1)	60.1518	14	100	2.26135	No_prior
SizeSel_P2_1_CA_TRAWL(1)	-15	-6	4	Fixed	No_prior

SizeSel_P3_1_CA_TRAWL(1)	7	-5	15	Fixed	No_prior
SizeSel_P4_1_CA_TRAWL(1)	13.0712	-5	15	36.8752	No_prior
SizeSel_P5_1_CA_TRAWL(1)	-999	-5	9	Fixed	No_prior
SizeSel_P6_1_CA_TRAWL(1)	-999	-5	9	Fixed	No_prior
Retain_P1_1_CA_TRAWL(1)	60.4119	10	100	3.39629	No_prior
Retain_P2_1_CA_TRAWL(1)	9	0.1	15	Fixed	No_prior
Retain_P3_1_CA_TRAWL(1)	2	0.001	1	Fixed	No_prior
Retain_P4_1_CA_TRAWL(1)	0	-2	2	Fixed	No_prior
DiscMort_P1_1_CA_TRAWL(1)	0	-1	1	Fixed	No_prior
DiscMort_P2_1_CA_TRAWL(1)	1.00E-04	-1	1	Fixed	No_prior
DiscMort_P3_1_CA_TRAWL(1)	0.5	0.001	1	Fixed	No_prior
DiscMort_P4_1_CA_TRAWL(1)	0	-2	2	Fixed	No_prior
SzSel_Male_Peak_1_CA_TRAWL(1)	-3.40204	-30	15	4.14287	No_prior
SzSel_Male_Ascend_1_CA_TRAWL(1)	3.16188	-15	15	0.921592	No_prior
SzSel_Male_Descend_1_CA_TRAWL(1)	-1.24978	-15	15	0.577689	No_prior
SzSel_Male_Final_1_CA_TRAWL(1)	0	-15	15	Fixed	No_prior
SzSel_Male_Scale_1_CA_TRAWL(1)	1	-15	15	Fixed	No_prior
SizeSel_P1_2_CA_FIX(2)	85.5639	14	100	1.26771	No_prior
SizeSel_P2_2_CA_FIX(2)	-15	-6	4	Fixed	No_prior
SizeSel_P3_2_CA_FIX(2)	7.53682	-5	15	0.696182	No_prior
SizeSel_P4_2_CA_FIX(2)	5.59902	-5	15	0.793539	No_prior
SizeSel_P5_2_CA_FIX(2)	-999	-5	9	Fixed	No_prior
SizeSel_P6_2_CA_FIX(2)	-999	-5	9	Fixed	No_prior
Retain_P1_2_CA_FIX(2)	51.6181	10	100	1.89667	No_prior
Retain_P2_2_CA_FIX(2)	2.36616	0.1	10	0.682729	No_prior
Retain_P3_2_CA_FIX(2)	1	0.001	1	Fixed	No_prior
Retain_P4_2_CA_FIX(2)	0	-2	2	Fixed	No_prior
DiscMort_P1_2_CA_FIX(2)	0	-1	1	Fixed	No_prior
DiscMort_P2_2_CA_FIX(2)	0.0001	-1	1	Fixed	No_prior
DiscMort_P3_2_CA_FIX(2)	0.07	0.001	1	Fixed	No_prior
DiscMort_P4_2_CA_FIX(2)	0	-2	2	Fixed	No_prior
SzSel_Male_Peak_2_CA_FIX(2)	-22	-30	20	Fixed	No_prior
SzSel_Male_Ascend_2_CA_FIX(2)	-1.66525	-15	15	0.283987	No_prior
SzSel_Male_Descend_2_CA_FIX(2)	0.284651	-15	15	0.375479	No_prior
SzSel_Male_Final_2_CA_FIX(2)	0	-15	15	Fixed	No_prior
SzSel_Male_Scale_2_CA_FIX(2)	1	-15	15	Fixed	No_prior
SizeSel_P1_3_CA_REC(3)	62.5	35	100	Fixed	No_prior
SizeSel_P2_3_CA_REC(3)	-15	-16	1	Fixed	No_prior
SizeSel_P3_3_CA_REC(3)	5.8	-1	15	Fixed	No_prior
SizeSel_P4_3_CA_REC(3)	7.2	-1	15	Fixed	No_prior
SizeSel_P5_3_CA_REC(3)	-999	-5	9	Fixed	No_prior
SizeSel_P6_3_CA_REC(3)	-999	-5	9	Fixed	No_prior
SizeSel_P1_4_CA_TRI_Early(4)	38.7654	10	100	4.40268	No_prior

SizeSel_P2_4_CA_TRI_Early(4)	-15	-6	4	Fixed	No_prior
SizeSel_P3_4_CA_TRI_Early(4)	5.39489	-1	15	0.532214	No_prior
SizeSel_P4_4_CA_TRI_Early(4)	14.2259	-1	15	18.5576	No_prior
SizeSel_P5_4_CA_TRI_Early(4)	-999	-5	9	Fixed	No_prior
SizeSel_P6_4_CA_TRI_Early(4)	-999	-5	9	Fixed	No_prior
SizeSel_P1_5_CA_TRI_Late(5)	24.9651	14	70	1.92705	No_prior
SizeSel_P2_5_CA_TRI_Late(5)	-15	-6	4	Fixed	No_prior
SizeSel_P3_5_CA_TRI_Late(5)	1.18281	-5	15	1.84467	No_prior
SizeSel_P4_5_CA_TRI_Late(5)	10.3673	-1	15	2.09671	No_prior
SizeSel_P5_5_CA_TRI_Late(5)	-999	-5	9	Fixed	No_prior
SizeSel_P6_5_CA_TRI_Late(5)	-999	-5	9	Fixed	No_prior
SizeSel_P1_6_CA_NWFSC(6)	2.70E+01	5	30	6.17249	No_prior
SizeSel_P2_6_CA_NWFSC(6)	-15	-12	4	Fixed	No_prior
SizeSel_P3_6_CA_NWFSC(6)	4.82267	-1	15	1.36051	No_prior
SizeSel_P4_6_CA_NWFSC(6)	7.91397	-1	15	0.355013	No_prior
SizeSel_P5_6_CA_NWFSC(6)	-999	-5	9	Fixed	No_prior
SizeSel_P6_6_CA_NWFSC(6)	-999	-5	9	Fixed	No_prior
SizeSel_P1_7_CA_HookLine(7)	65.7369	35	100	4.48331	No_prior
SizeSel_P2_7_CA_HookLine(7)	-15	-6	4	Fixed	No_prior
SizeSel_P3_7_CA_HookLine(7)	5.46627	-6	15	0.488622	No_prior
SizeSel_P4_7_CA_HookLine(7)	6.8853	-6	15	0.790743	No_prior
SizeSel_P5_7_CA_HookLine(7)	-999	-5	9	Fixed	No_prior
SizeSel_P6_7_CA_HookLine(7)	-999	-5	9	Fixed	No_prior
SzSel_Male_Peak_7_CA_HookLine(7)	-9.8533	-30	40	7.23756	No_prior
SzSel_Male_Ascend_7_CA_HookLine(7)	-0.101812	-15	15	0.779511	No_prior
SzSel_Male_Descend_7_CA_HookLine(7)	-1.98247	-15	15	1.18987	No_prior
SzSel_Male_Final_7_CA_HookLine(7)	0	-15	15	Fixed	No_prior
SzSel_Male_Scale_7_CA_HookLine(7)	1	-15	15	Fixed	No_prior
SizeSel_P1_8_CA_Lam_Research(8)	90.9412	35	100	0.0304565	No_prior
SizeSel_P2_8_CA_Lam_Research(8)	-15	-6	4	Fixed	No_prior
SizeSel_P3_8_CA_Lam_Research(8)	6.5544	-6	15	0.0778421	No_prior
SizeSel_P4_8_CA_Lam_Research(8)	-5.6	-6	15	Fixed	No_prior
SizeSel_P5_8_CA_Lam_Research(8)	-999	-5	9	Fixed	No_prior
SizeSel_P6_8_CA_Lam_Research(8)	-999	-5	9	Fixed	No_prior
SzSel_Male_Peak_8_CA_Lam_Research(8)	-27.4041	-30	40	Fixed	No_prior
SzSel_Male_Ascend_8_CA_Lam_Research(8)	-1.19576	-15	15	0.103804	No_prior
SzSel_Male_Descend_8_CA_Lam_Research(8)	9.66269	-15	15	0.238694	No_prior
SzSel_Male_Final_8_CA_Lam_Research(8)	0	-15	15	Fixed	No_prior
SzSel_Male_Scale_8_CA_Lam_Research(8)	1	-15	15	Fixed	No_prior
AgeSel_P1_1_CA_TRAWL(1)	0.1	0	1	Fixed	No_prior
AgeSel_P2_1_CA_TRAWL(1)	100	0	101	Fixed	No_prior
AgeSel_P1_2_CA_FIX(2)	0.1	0	1	Fixed	No_prior
AgeSel_P2_2_CA_FIX(2)	100	0	101	Fixed	No_prior

AgeSel_P1_3_CA_REC(3)	0.1	0	1	Fixed	No_prior
AgeSel_P2_3_CA_REC(3)	100	0	101	Fixed	No_prior
AgeSel_P1_4_CA_TRI_Early(4)	0.1	0	1	Fixed	No_prior
AgeSel_P2_4_CA_TRI_Early(4)	100	0	101	Fixed	No_prior
AgeSel_P1_5_CA_TRI_Late(5)	0.1	0	1	Fixed	No_prior
AgeSel_P2_5_CA_TRI_Late(5)	100	0	101	Fixed	No_prior
AgeSel_P1_6_CA_NWFSC(6)	0.1	0	1	Fixed	No_prior
AgeSel_P2_6_CA_NWFSC(6)	100	0	101	Fixed	No_prior
AgeSel_P1_7_CA_HookLine(7)	0.1	0	1	Fixed	No_prior
AgeSel_P2_7_CA_HookLine(7)	100	0	101	Fixed	No_prior
AgeSel_P1_8_CA_Lam_Research(8)	0.1	0	1	Fixed	No_prior
AgeSel_P2_8_CA_Lam_Research(8)	100	0	101	Fixed	No_prior
SizeSel_P3_1_CA_TRAWL(1)_BLK3repl_1973	7	-5	15	Fixed	No_prior
SizeSel_P3_1_CA_TRAWL(1)_BLK3repl_1983	7.52422	-5	15	1.06219	No_prior
SizeSel_P3_1_CA_TRAWL(1)_BLK3repl_1993	7.09913	-5	15	1.13626	No_prior
SizeSel_P3_1_CA_TRAWL(1)_BLK3repl_2003	3.37165	-5	15	0.940105	No_prior
SizeSel_P3_1_CA_TRAWL(1)_BLK3repl_2011	2.95757	-5	15	0.92669	No_prior
SizeSel_P4_1_CA_TRAWL(1)_BLK3repl_1973	14.405	-5	15	14.9785	No_prior
SizeSel_P4_1_CA_TRAWL(1)_BLK3repl_1983	6.27737	-5	15	0.370226	No_prior
SizeSel_P4_1_CA_TRAWL(1)_BLK3repl_1993	6.75968	-5	15	0.363754	No_prior
SizeSel_P4_1_CA_TRAWL(1)_BLK3repl_2003	6.43832	-5	15	0.27952	No_prior
SizeSel_P4_1_CA_TRAWL(1)_BLK3repl_2011	7.98343	-5	15	0.573227	No_prior
Retain_P1_1_CA_TRAWL(1)_BLK2repl_1998	66.6014	10	100	0.890228	No_prior
Retain_P1_1_CA_TRAWL(1)_BLK2repl_2007	67.3433	10	100	1.5386	No_prior
Retain_P1_1_CA_TRAWL(1)_BLK2repl_2010	56.4308	10	100	3.61753	No_prior
Retain_P1_1_CA_TRAWL(1)_BLK2repl_2011	56.5342	10	100	0.676295	No_prior
Retain_P2_1_CA_TRAWL(1)_BLK2repl_1998	3.5	0.1	10	Fixed	No_prior
Retain_P2_1_CA_TRAWL(1)_BLK2repl_2007	2.88695	0.1	10	1.10367	No_prior
Retain_P2_1_CA_TRAWL(1)_BLK2repl_2010	0.717526	0.1	10	2.02997	No_prior
Retain_P2_1_CA_TRAWL(1)_BLK2repl_2011	1.41886	0.1	10	0.399397	No_prior
SizeSel_P3_2_CA_FIX(2)_BLK1repl_1998	8.1	-5	15	Fixed	No_prior
SizeSel_P3_2_CA_FIX(2)_BLK1repl_2002	5.21908	-5	15	0.402242	No_prior
SizeSel_P3_2_CA_FIX(2)_BLK1repl_2003	6.72597	-5	15	0.112117	No_prior
SizeSel_P3_2_CA_FIX(2)_BLK1repl_2011	6.41842	-5	15	0.0960195	No_prior
SizeSel_P4_2_CA_FIX(2)_BLK1repl_1998	6.4	-5	15	Fixed	No_prior
SizeSel_P4_2_CA_FIX(2)_BLK1repl_2002	6.26952	-5	15	2.32721	No_prior
SizeSel_P4_2_CA_FIX(2)_BLK1repl_2003	4.75209	-5	15	0.396613	No_prior
SizeSel_P4_2_CA_FIX(2)_BLK1repl_2011	4.6785	-5	15	0.419886	No_prior
Retain_P1_2_CA_FIX(2)_BLK1repl_1998	61.3714	10	100	2.01447	No_prior
Retain_P1_2_CA_FIX(2)_BLK1repl_2002	30.3033	10	100	418.065	No_prior
Retain_P1_2_CA_FIX(2)_BLK1repl_2003	59.735	10	100	0.484091	No_prior
Retain_P1_2_CA_FIX(2)_BLK1repl_2011	59.5812	10	100	0.406052	No_prior
Retain_P2_2_CA_FIX(2)_BLK1repl_1998	2.46793	0.1	10	0.93287	No_prior

Retain_P2_2_CA_FIX(2)_BLK1repl_2002	2.06227	0.1	10	40.4422	No_prior
Retain_P2_2_CA_FIX(2)_BLK1repl_2003	0.9633	0.1	10	0.331465	No_prior
Retain_P2_2_CA_FIX(2)_BLK1repl_2011	1.03193	0.1	10	0.267353	No_prior
SizeSel_P1_3_CA_REC(3)_BLK4repl_1959	67.9434	20	100	5.37741	No_prior
SizeSel_P1_3_CA_REC(3)_BLK4repl_1975	69.8087	20	100	5.96763	No_prior
SizeSel_P1_3_CA_REC(3)_BLK4repl_1990	62.9961	20	100	1.31172	No_prior
SizeSel_P1_3_CA_REC(3)_BLK4repl_2004	62.6001	20	100	0.571921	No_prior
SizeSel_P3_3_CA_REC(3)_BLK4repl_1959	5.79739	-1	15	0.403138	No_prior
SizeSel_P3_3_CA_REC(3)_BLK4repl_1975	5.60189	-1	15	0.442773	No_prior
SizeSel_P3_3_CA_REC(3)_BLK4repl_1990	3.9863	-1	15	0.28373	No_prior
SizeSel_P3_3_CA_REC(3)_BLK4repl_2004	3.93701	-1	15	0.134673	No_prior
SizeSel_P4_3_CA_REC(3)_BLK4repl_1959	7.10632	-1	15	0.780214	No_prior
SizeSel_P4_3_CA_REC(3)_BLK4repl_1975	6.58471	-1	15	1.30567	No_prior
SizeSel_P4_3_CA_REC(3)_BLK4repl_1990	6.53554	-1	15	0.443927	No_prior
SizeSel_P4_3_CA_REC(3)_BLK4repl_2004	5.85501	-1	15	0.123925	No_prior
Early_RecrDev_1889	2.12E-05	-4	4	0.750007	No_prior
Early_RecrDev_1890	2.48E-05	-4	4	0.750008	No_prior
Early_RecrDev_1891	2.91E-05	-4	4	0.75001	No_prior
Early_RecrDev_1892	3.40E-05	-4	4	0.750012	No_prior
Early_RecrDev_1893	3.97E-05	-4	4	0.750013	No_prior
Early_RecrDev_1894	4.63E-05	-4	4	0.750016	No_prior
Early_RecrDev_1895	5.39E-05	-4	4	0.750018	No_prior
Early_RecrDev_1896	6.28E-05	-4	4	0.750021	No_prior
Early_RecrDev_1897	7.30E-05	-4	4	0.750025	No_prior
Early_RecrDev_1898	8.49E-05	-4	4	0.750028	No_prior
Early_RecrDev_1899	9.85E-05	-4	4	0.750033	No_prior
Early_RecrDev_1900	0.0001142	-4	4	0.750038	No_prior
Early_RecrDev_1901	0.0001322	-4	4	0.750044	No_prior
Early_RecrDev_1902	0.0001529	-4	4	0.750051	No_prior
Early_RecrDev_1903	0.0001766	-4	4	0.750059	No_prior
Early_RecrDev_1904	0.0002038	-4	4	0.750067	No_prior
Early_RecrDev_1905	0.0002349	-4	4	0.750078	No_prior
Early_RecrDev_1906	0.0002705	-4	4	0.750089	No_prior
Early_RecrDev_1907	0.000311	-4	4	0.750102	No_prior
Early_RecrDev_1908	0.0003572	-4	4	0.750117	No_prior
Early_RecrDev_1909	0.0004097	-4	4	0.750134	No_prior
Early_RecrDev_1910	0.0004693	-4	4	0.750153	No_prior
Early_RecrDev_1911	0.000537	-4	4	0.750175	No_prior
Early_RecrDev_1912	0.0006135	-4	4	0.750199	No_prior
Early_RecrDev_1913	0.0007	-4	4	0.750226	No_prior
Early_RecrDev_1914	0.0007976	-4	4	0.750257	No_prior
Early_RecrDev_1915	0.0009075	-4	4	0.750292	No_prior
Early_RecrDev_1916	0.001031	-4	4	0.750331	No_prior

Early_RecrDev_1917	0.0011698	-4	4	0.750375	No_prior
Early_RecrDev_1918	0.0013254	-4	4	0.750423	No_prior
Early_RecrDev_1919	0.0014995	-4	4	0.750478	No_prior
Early_RecrDev_1920	0.0016941	-4	4	0.750539	No_prior
Early_RecrDev_1921	0.001911	-4	4	0.750607	No_prior
Early_RecrDev_1922	0.0021526	-4	4	0.750683	No_prior
Early_RecrDev_1923	0.0024213	-4	4	0.750768	No_prior
Early_RecrDev_1924	0.0027204	-4	4	0.750863	No_prior
Early_RecrDev_1925	0.0030539	-4	4	0.750969	No_prior
Early_RecrDev_1926	0.0034268	-4	4	0.751088	No_prior
Early_RecrDev_1927	0.0038461	-4	4	0.751222	No_prior
Early_RecrDev_1928	0.0043211	-4	4	0.751375	No_prior
Early_RecrDev_1929	0.0048601	-4	4	0.751547	No_prior
Early_RecrDev_1930	0.0054751	-4	4	0.751743	No_prior
Early_RecrDev_1931	0.006183	-4	4	0.751968	No_prior
Early_RecrDev_1932	0.0069894	-4	4	0.752223	No_prior
Early_RecrDev_1933	0.0079242	-4	4	0.752517	No_prior
Early_RecrDev_1934	0.0089845	-4	4	0.752846	No_prior
Early_RecrDev_1935	0.0102305	-4	4	0.753224	No_prior
Early_RecrDev_1936	0.0116709	-4	4	0.753653	No_prior
Early_RecrDev_1937	0.0133066	-4	4	0.754127	No_prior
Early_RecrDev_1938	0.0151185	-4	4	0.75464	No_prior
Early_RecrDev_1939	0.0170557	-4	4	0.755179	No_prior
Early_RecrDev_1940	0.0190943	-4	4	0.75574	No_prior
Early_RecrDev_1941	0.0211821	-4	4	0.756324	No_prior
Early_RecrDev_1942	0.0232544	-4	4	0.756928	No_prior
Early_RecrDev_1943	0.0253655	-4	4	0.757582	No_prior
Early_RecrDev_1944	0.0277066	-4	4	0.758344	No_prior
Early_RecrDev_1945	0.0308137	-4	4	0.759385	No_prior
Early_RecrDev_1946	0.0355939	-4	4	0.760986	No_prior
Early_RecrDev_1947	0.0437417	-4	4	0.763614	No_prior
Early_RecrDev_1948	0.0576591	-4	4	0.767786	No_prior
Early_RecrDev_1949	0.0798517	-4	4	0.773639	No_prior
Early_RecrDev_1950	0.108638	-4	4	0.779593	No_prior
Early_RecrDev_1951	0.132264	-4	4	0.780565	No_prior
Early_RecrDev_1952	0.132704	-4	4	0.769547	No_prior
Early_RecrDev_1953	0.0968287	-4	4	0.745075	No_prior
Early_RecrDev_1954	0.0431488	-4	4	0.711629	No_prior
Early_RecrDev_1955	0.0175178	-4	4	0.667	No_prior
Early_RecrDev_1956	-0.057168	-4	4	0.606811	No_prior
Early_RecrDev_1957	-0.314688	-4	4	0.586356	No_prior
Early_RecrDev_1958	-0.303036	-4	4	0.578669	No_prior
Early_RecrDev_1959	0.0045348	-4	4	0.559851	No_prior

Early_RecrDev_1960	0.218806	-4	4	0.552258	No_prior
Early_RecrDev_1961	0.36011	-4	4	0.52211	No_prior
Early_RecrDev_1962	-0.176478	-4	4	0.611223	No_prior
Early_RecrDev_1963	-0.106791	-4	4	0.58762	No_prior
Early_RecrDev_1964	-0.083655	-4	4	0.578318	No_prior
Main_RecrDev_1965	-0.119508	-4	4	0.575524	No_prior
Main_RecrDev_1966	0.0430721	-4	4	0.573591	No_prior
Main_RecrDev_1967	0.117906	-4	4	0.58707	No_prior
Main_RecrDev_1968	0.136868	-4	4	0.596375	No_prior
Main_RecrDev_1969	-0.015224	-4	4	0.62605	No_prior
Main_RecrDev_1970	-0.034797	-4	4	0.637985	No_prior
Main_RecrDev_1971	-0.149565	-4	4	0.657531	No_prior
Main_RecrDev_1972	0.0898686	-4	4	0.671659	No_prior
Main_RecrDev_1973	0.503394	-4	4	0.635975	No_prior
Main_RecrDev_1974	0.524871	-4	4	0.610283	No_prior
Main_RecrDev_1975	0.225248	-4	4	0.633625	No_prior
Main_RecrDev_1976	0.784525	-4	4	0.515311	No_prior
Main_RecrDev_1977	0.621637	-4	4	0.54178	No_prior
Main_RecrDev_1978	-0.237976	-4	4	0.619552	No_prior
Main_RecrDev_1979	0.743926	-4	4	0.346592	No_prior
Main_RecrDev_1980	-0.146061	-4	4	0.543405	No_prior
Main_RecrDev_1981	-0.421763	-4	4	0.526511	No_prior
Main_RecrDev_1982	-0.448712	-4	4	0.554865	No_prior
Main_RecrDev_1983	0.142928	-4	4	0.607842	No_prior
Main_RecrDev_1984	1.38475	-4	4	0.327295	No_prior
Main_RecrDev_1985	1.11394	-4	4	0.388798	No_prior
Main_RecrDev_1986	0.611666	-4	4	0.491557	No_prior
Main_RecrDev_1987	0.567913	-4	4	0.353135	No_prior
Main_RecrDev_1988	-0.044518	-4	4	0.383252	No_prior
Main_RecrDev_1989	0.435291	-4	4	0.309686	No_prior
Main_RecrDev_1990	-0.051498	-4	4	0.389181	No_prior
Main_RecrDev_1991	0.772003	-4	4	0.217794	No_prior
Main_RecrDev_1992	-0.776586	-4	4	0.426591	No_prior
Main_RecrDev_1993	-0.151044	-4	4	0.256245	No_prior
Main_RecrDev_1994	0.38017	-4	4	0.171727	No_prior
Main_RecrDev_1995	-0.556563	-4	4	0.370371	No_prior
Main_RecrDev_1996	0.503299	-4	4	0.176095	No_prior
Main_RecrDev_1997	-0.459391	-4	4	0.218168	No_prior
Main_RecrDev_1998	-0.643238	-4	4	0.3874	No_prior
Main_RecrDev_1999	1.00449	-4	4	0.17151	No_prior
Main_RecrDev_2000	0.423661	-4	4	0.179387	No_prior
Main_RecrDev_2001	0.118172	-4	4	0.212518	No_prior
Main_RecrDev_2002	-0.619267	-4	4	0.211028	No_prior

Main_RecrDev_2003	-0.42168	-4	4	0.189805	No_prior
Main_RecrDev_2004	-1.3895	-4	4	0.253875	No_prior
Main_RecrDev_2005	-1.46568	-4	4	0.266992	No_prior
Main_RecrDev_2006	-1.82608	-4	4	0.301387	No_prior
Main_RecrDev_2007	-1.27735	-4	4	0.227446	No_prior
Main_RecrDev_2008	-0.448689	-4	4	0.158455	No_prior
Main_RecrDev_2009	-0.361738	-4	4	0.161566	No_prior
Main_RecrDev_2010	0.341975	-4	4	0.140507	No_prior
Main_RecrDev_2011	0.22132	-4	4	0.162776	No_prior
Main_RecrDev_2012	0.372112	-4	4	0.180638	No_prior
Main_RecrDev_2013	0.64811	-4	4	0.188251	No_prior
Main_RecrDev_2014	-0.300687	-4	4	0.24863	No_prior
Main_RecrDev_2015	-0.466013	-4	4	0.352361	No_prior
Late_RecrDev_2016	-0.857053	-4	4	0.55246	No_prior

Table 9. Time series of population estimates from the north base case.

Year	Total Biomass (mt)	Spawning Biomass	Total Biomass 3+ (mt)	Deple-tion (%)	Age-0 Recruits	Total Landings (mt)	(1-SPR)/ (1-SPR_45%)	Relative Exploitation Rate
1889	58,746	37,974	56,005	100	8,664	110	0.025	0.002
1890	58,640	37,904	55,899	99.8	8,662	114	0.026	0.002
1891	58,540	37,834	55,799	99.6	8,660	117	0.027	0.002
1892	58,449	37,768	55,708	99.5	8,659	160	0.037	0.003
1893	58,327	37,682	55,587	99.2	8,656	127	0.029	0.002
1894	58,253	37,625	55,513	99.1	8,655	127	0.029	0.002
1895	58,189	37,576	55,450	99	8,654	139	0.032	0.002
1896	58,124	37,527	55,385	98.8	8,652	167	0.038	0.003
1897	58,041	37,466	55,302	98.7	8,651	167	0.038	0.003
1898	57,968	37,411	55,230	98.5	8,649	72	0.017	0.001
1899	57,997	37,424	55,259	98.6	8,650	46	0.011	0.001
1900	58,051	37,457	55,314	98.6	8,650	58	0.013	0.001
1901	58,089	37,482	55,352	98.7	8,651	59	0.014	0.001
1902	58,122	37,504	55,385	98.8	8,652	61	0.014	0.001
1903	58,150	37,524	55,412	98.8	8,652	62	0.014	0.001
1904	58,173	37,540	55,435	98.9	8,652	74	0.017	0.001
1905	58,180	37,547	55,442	98.9	8,652	59	0.013	0.001
1906	58,200	37,562	55,462	98.9	8,652	60	0.014	0.001
1907	58,217	37,574	55,479	98.9	8,653	61	0.014	0.001
1908	58,230	37,584	55,492	99	8,653	45	0.01	0.001
1909	58,255	37,603	55,517	99	8,653	196	0.045	0.004
1910	58,133	37,523	55,395	98.8	8,651	198	0.045	0.004
1911	58,020	37,446	55,282	98.6	8,648	199	0.045	0.004
1912	57,918	37,373	55,181	98.4	8,646	200	0.046	0.004
1913	57,827	37,307	55,090	98.2	8,644	201	0.046	0.004
1914	57,746	37,247	55,010	98.1	8,642	203	0.047	0.004
1915	57,675	37,194	54,940	97.9	8,640	353	0.08	0.006
1916	57,469	37,051	54,735	97.6	8,635	515	0.116	0.009
1917	57,130	36,816	54,397	97	8,628	517	0.117	0.009
1918	56,826	36,598	54,094	96.4	8,622	679	0.153	0.013
1919	56,403	36,298	53,673	95.6	8,613	227	0.053	0.004
1920	56,461	36,314	53,734	95.6	8,612	180	0.042	0.003
1921	56,573	36,376	53,848	95.8	8,612	168	0.039	0.003
1922	56,692	36,450	53,967	96	8,612	94	0.022	0.002
1923	56,871	36,569	54,146	96.3	8,612	84	0.019	0.002
1924	57,040	36,687	54,315	96.6	8,613	198	0.046	0.004
1925	57,078	36,720	54,353	96.7	8,610	264	0.061	0.005
1926	57,041	36,702	54,316	96.7	8,606	299	0.068	0.006

1927	56,968	36,658	54,244	96.5	8,601	367	0.084	0.007
1928	56,831	36,569	54,108	96.3	8,594	295	0.068	0.005
1929	56,774	36,530	54,053	96.2	8,588	586	0.133	0.011
1930	56,443	36,307	53,724	95.6	8,576	539	0.124	0.010
1931	56,186	36,124	53,470	95.1	8,565	271	0.064	0.005
1932	56,213	36,131	53,500	95.1	8,558	271	0.063	0.005
1933	56,241	36,146	53,531	95.2	8,550	417	0.097	0.008
1934	56,126	36,066	53,419	95	8,539	565	0.131	0.011
1935	55,877	35,888	53,173	94.5	8,525	598	0.139	0.011
1936	55,617	35,698	52,916	94	8,510	802	0.184	0.015
1937	55,185	35,387	52,489	93.2	8,492	841	0.195	0.016
1938	54,757	35,067	52,066	92.3	8,472	1,408	0.311	0.027
1939	53,825	34,422	51,141	90.6	8,441	1,230	0.283	0.024
1940	53,160	33,917	50,483	89.3	8,413	1,746	0.389	0.035
1941	52,086	33,107	49,420	87.2	8,373	1,617	0.371	0.033
1942	51,245	32,459	48,589	85.5	8,334	2,232	0.492	0.046
1943	49,924	31,454	47,282	82.8	8,281	2,017	0.464	0.043
1944	48,942	30,677	46,314	80.8	8,232	2,959	0.634	0.064
1945	47,189	29,334	44,580	77.2	8,159	2,095	0.502	0.047
1946	46,416	28,701	43,823	75.6	8,107	2,693	0.616	0.061
1947	45,170	27,752	42,599	73.1	8,039	1,453	0.386	0.034
1948	45,202	27,741	42,646	73.1	8,003	2,139	0.528	0.050
1949	44,597	27,294	42,062	71.9	7,947	1,789	0.46	0.043
1950	44,355	27,133	41,831	71.5	7,900	1,671	0.44	0.040
1951	44,233	27,049	41,727	71.2	7,853	1,906	0.491	0.046
1952	43,880	26,805	41,389	70.6	7,797	1,410	0.384	0.034
1953	43,989	26,910	41,512	70.9	7,748	662	0.196	0.016
1954	44,763	27,504	42,302	72.4	7,713	1,049	0.293	0.025
1955	45,070	27,781	42,624	73.2	7,661	1,910	0.486	0.045
1956	44,490	27,400	42,060	72.2	7,585	1,431	0.388	0.034
1957	44,346	27,330	41,932	72	7,528	1,517	0.408	0.036
1958	44,083	27,179	41,691	71.6	7,497	1,667	0.443	0.040
1959	43,656	26,903	41,281	70.8	7,522	2,590	0.628	0.063
1960	42,368	25,975	40,001	68.4	7,610	2,993	0.711	0.075
1961	40,802	24,808	38,423	65.3	7,750	2,867	0.71	0.075
1962	39,527	23,804	37,115	62.7	8,036	1,709	0.498	0.046
1963	39,551	23,697	37,072	62.4	9,466	1,282	0.395	0.035
1964	40,248	23,965	37,562	63.1	14,411	1,974	0.552	0.053
1965	40,921	23,834	37,557	62.8	12,128	2,246	0.607	0.060
1966	42,315	23,700	37,973	62.4	8,822	2,522	0.651	0.066
1967	43,976	23,934	40,419	63	8,231	3,873	0.846	0.096
1968	44,175	24,198	41,441	63.7	8,770	4,503	0.921	0.109
1969	43,314	24,325	40,671	64.1	10,435	2,564	0.644	0.063

1970	44,009	25,254	41,106	66.5	11,207	1,753	0.473	0.043
1971	45,464	26,221	42,121	69	9,315	1,947	0.502	0.046
1972	46,765	26,869	43,390	70.8	7,471	1,884	0.477	0.043
1973	47,866	27,706	45,077	73	6,652	2,738	0.626	0.061
1974	47,543	28,098	45,252	74	6,600	3,107	0.685	0.069
1975	46,189	27,974	44,102	73.7	5,746	3,036	0.683	0.069
1976	44,327	27,349	42,316	72	5,380	2,904	0.68	0.069
1977	42,150	26,318	40,347	69.3	8,249	2,767	0.677	0.069
1978	40,072	25,071	38,054	66	21,554	2,274	0.611	0.060
1979	39,617	23,935	36,002	63	15,340	3,615	0.862	0.100
1980	40,150	21,874	33,880	57.6	12,100	3,745	0.897	0.111
1981	42,192	20,898	37,662	55	6,425	3,874	0.894	0.103
1982	44,266	22,142	40,893	58.3	8,798	4,957	0.992	0.121
1983	44,311	23,613	42,130	62.2	5,062	9,221	1.384	0.219
1984	38,560	21,768	36,121	57.3	5,922	8,013	1.398	0.222
1985	32,771	18,857	31,023	49.7	21,909	7,601	1.479	0.245
1986	27,683	15,390	24,718	40.5	3,141	3,166	1.101	0.128
1987	28,390	14,369	23,019	37.8	4,866	4,478	1.306	0.195
1988	27,730	13,418	26,604	35.3	6,629	5,004	1.343	0.188
1989	25,794	13,688	24,141	36	6,928	6,434	1.497	0.267
1990	21,939	12,040	19,787	31.7	18,786	4,755	1.441	0.240
1991	20,403	10,314	17,348	27.2	14,615	6,577	1.64	0.379
1992	18,841	7,667	13,500	20.2	8,559	4,214	1.501	0.312
1993	20,771	7,391	16,772	19.5	4,749	7,215	1.639	0.430
1994	19,317	7,567	17,006	19.9	6,802	5,902	1.555	0.347
1995	17,686	8,006	16,085	21.1	4,476	3,639	1.324	0.226
1996	17,295	8,527	15,378	22.5	3,598	3,675	1.357	0.239
1997	16,180	8,234	14,860	21.7	4,079	3,278	1.347	0.221
1998	14,893	7,848	13,746	20.7	3,149	610	0.45	0.044
1999	15,971	8,772	14,746	23.1	5,024	627	0.432	0.043
2000	16,911	9,521	15,752	25.1	7,374	261	0.184	0.017
2001	18,409	10,371	16,641	27.3	6,482	268	0.177	0.016
2002	20,311	11,129	18,068	29.3	3,858	401	0.251	0.022
2003	22,225	12,015	20,392	31.6	2,927	411	0.229	0.020
2004	23,788	13,331	22,636	35.1	3,861	426	0.214	0.019
2005	24,752	14,711	23,760	38.7	2,892	502	0.237	0.021
2006	25,094	15,569	23,945	41	3,664	544	0.266	0.023
2007	24,955	15,833	23,974	41.7	4,460	459	0.235	0.019
2008	24,784	15,842	23,493	41.7	14,491	480	0.262	0.020
2009	25,227	15,627	23,078	41.2	6,292	424	0.244	0.018
2010	26,973	15,441	23,041	40.7	6,671	343	0.193	0.015
2011	29,373	15,912	27,371	41.9	4,058	611	0.282	0.022
2012	31,384	17,522	29,480	46.1	4,319	748	0.291	0.025

2013	32,650	19,235	31,302	50.7	10,580	813	0.286	0.026
2014	33,473	20,366	31,650	53.6	4,851	632	0.218	0.020
2015	34,564	20,939	31,634	55.1	10,322	677	0.232	0.021
2016	35,708	21,258	33,759	56	7,516	723	0.25	0.021
2017	37,110	21,976	34,064	57.9	8,037	4,838	1.058	0.142
2018	34,730	20,113	32,319	53	7,911	4,510	1.06	0.140
2019	32,939	18,809	30,415	49.5	7,811	4,080	1.035	0.134
2020	31,746	17,970	29,260	47.3	7,741	3,954	1.035	0.135
2021	30,793	17,268	28,336	45.5	7,677	3,855	1.035	0.136
2022	30,017	16,699	27,581	44	7,623	3,773	1.035	0.137
2023	29,376	16,235	26,959	42.8	7,577	3,704	1.035	0.137
2024	28,843	15,851	26,443	41.7	7,537	3,645	1.035	0.138
2025	28,397	15,532	26,011	40.9	7,502	3,594	1.035	0.138
2026	28,021	15,266	25,647	40.2	7,473	3,550	1.035	0.138

Table 10. Time series of population estimates from the south base case.

Year	Total Biomass (mt)	Spawning Biomass	Total Biomass 3+ (mt)	Deple-tion (%)	Age-0 Recruits	Total Catch (mt)	(1-SPR)/ (1-SPR_45%)	Relative Exploitation Rate
1889	32,781	20,260	31,235	100.0	4,848	0	0.000	0
1890	32,781	20,260	31,235	100.0	4,848	25.1	0.011	0.0008
1891	32,757	20,243	31,211	99.9	4,848	50.2	0.023	0.0016
1892	32,709	20,211	31,165	99.8	4,847	75.4	0.034	0.0024
1893	32,641	20,165	31,097	99.5	4,846	100.5	0.046	0.0032
1894	32,555	20,105	31,012	99.2	4,845	125.6	0.057	0.0041
1895	32,452	20,033	30,909	98.9	4,843	150.8	0.068	0.0049
1896	32,334	19,951	30,792	98.5	4,841	176.0	0.079	0.0057
1897	32,204	19,860	30,663	98.0	4,838	201.1	0.091	0.0066
1898	32,062	19,762	30,523	97.5	4,836	226.3	0.102	0.0074
1899	31,912	19,656	30,374	97.0	4,833	251.6	0.114	0.0083
1900	31,753	19,545	30,217	96.5	4,830	276.8	0.125	0.0092
1901	31,588	19,429	30,053	95.9	4,827	302.1	0.137	0.0101
1902	31,416	19,308	29,883	95.3	4,824	327.3	0.148	0.0110
1903	31,239	19,184	29,707	94.7	4,820	352.6	0.160	0.0119
1904	31,058	19,056	29,528	94.1	4,817	377.9	0.171	0.0128
1905	30,873	18,926	29,344	93.4	4,813	403.3	0.183	0.0137
1906	30,684	18,793	29,157	92.8	4,809	428.7	0.195	0.0147
1907	30,493	18,657	28,967	92.1	4,806	454.0	0.206	0.0157
1908	30,298	18,520	28,775	91.4	4,802	479.5	0.218	0.0167
1909	30,101	18,381	28,580	90.7	4,798	504.9	0.230	0.0177
1910	29,902	18,241	28,382	90.0	4,794	530.4	0.242	0.0187
1911	29,701	18,099	28,183	89.3	4,790	555.8	0.254	0.0197
1912	29,497	17,956	27,981	88.6	4,786	581.4	0.266	0.0208
1913	29,292	17,812	27,778	87.9	4,781	606.9	0.278	0.0218
1914	29,085	17,666	27,573	87.2	4,777	632.5	0.291	0.0229
1915	28,877	17,520	27,367	86.5	4,773	658.1	0.303	0.0240
1916	28,667	17,372	27,159	85.7	4,768	683.7	0.315	0.0252
1917	28,455	17,224	26,949	85.0	4,764	709.3	0.327	0.0263
1918	28,243	17,075	26,739	84.3	4,760	735.0	0.340	0.0275
1919	28,028	16,925	26,526	83.5	4,755	760.8	0.352	0.0287
1920	27,813	16,774	26,313	82.8	4,751	786.5	0.365	0.0299
1921	27,596	16,622	26,098	82.0	4,746	812.3	0.378	0.0311
1922	27,378	16,469	25,882	81.3	4,742	838.1	0.390	0.0324
1923	27,158	16,316	25,665	80.5	4,737	864.0	0.403	0.0337
1924	26,938	16,162	25,447	79.8	4,733	889.9	0.416	0.0350
1925	26,716	16,007	25,227	79.0	4,729	915.8	0.429	0.0363
1926	26,493	15,852	25,006	78.2	4,724	941.8	0.442	0.0377

1927	26,269	15,696	24,784	77.5	4,720	967.8	0.455	0.0391
1928	26,043	15,539	24,561	76.7	4,716	993.9	0.468	0.0405
1929	25,817	15,382	24,337	75.9	4,712	1022.9	0.483	0.0420
1930	25,586	15,222	24,108	75.1	4,708	1051.9	0.497	0.0436
1931	25,352	15,059	23,876	74.3	4,704	1081.0	0.512	0.0453
1932	25,114	14,895	23,640	73.5	4,701	777.3	0.392	0.0329
1933	25,197	14,942	23,720	73.7	4,707	1287.7	0.590	0.0543
1934	24,793	14,669	23,321	72.4	4,700	735.5	0.378	0.0315
1935	24,956	14,768	23,479	72.9	4,711	890.9	0.442	0.0379
1936	24,974	14,776	23,496	72.9	4,718	710.8	0.365	0.0303
1937	25,173	14,902	23,689	73.6	4,731	866.8	0.428	0.0366
1938	25,217	14,930	23,732	73.7	4,741	826.7	0.412	0.0348
1939	25,298	14,977	23,808	73.9	4,752	573.9	0.299	0.0241
1940	25,626	15,190	24,129	75.0	4,771	682.5	0.344	0.0283
1941	25,836	15,327	24,334	75.7	4,787	558.3	0.286	0.0229
1942	26,154	15,535	24,645	76.7	4,806	310.8	0.165	0.0126
1943	26,697	15,892	25,179	78.4	4,831	668.2	0.326	0.0265
1944	26,862	16,002	25,340	79.0	4,846	672.8	0.326	0.0266
1945	27,002	16,095	25,477	79.4	4,865	661.4	0.320	0.0260
1946	27,139	16,184	25,608	79.9	4,892	1080.9	0.484	0.0422
1947	26,857	15,996	25,325	79.0	4,924	2033.4	0.790	0.0803
1948	25,661	15,201	24,136	75.0	4,959	1810.0	0.751	0.0750
1949	24,762	14,592	23,235	72.0	5,042	1502.9	0.676	0.0647
1950	24,255	14,228	22,709	70.2	5,170	1556.0	0.701	0.0685
1951	23,803	13,890	22,229	68.6	5,248	1372.7	0.646	0.0618
1952	23,643	13,735	22,035	67.8	5,214	1578.9	0.723	0.0717
1953	23,371	13,489	21,742	66.6	4,990	1344.8	0.647	0.0619
1954	23,399	13,468	21,793	66.5	4,704	1416.5	0.670	0.0650
1955	23,355	13,462	21,825	66.4	4,561	839.5	0.441	0.0385
1956	23,821	13,839	22,361	68.3	4,229	1462.5	0.672	0.0654
1957	23,547	13,768	22,150	68.0	3,249	1415.4	0.661	0.0639
1958	23,109	13,655	21,878	67.4	3,266	1380.9	0.658	0.0631
1959	22,456	13,458	21,446	66.4	4,410	1177.2	0.588	0.0549
1960	21,891	13,220	20,777	65.3	5,420	1038.1	0.545	0.0500
1961	21,568	12,906	20,107	63.7	6,187	1142.0	0.599	0.0568
1962	21,454	12,512	19,700	61.8	3,581	931.7	0.518	0.0473
1963	21,719	12,460	20,009	61.5	3,817	1006.8	0.547	0.0503
1964	21,908	12,656	20,768	62.5	3,896	775.3	0.434	0.0373
1965	22,204	13,078	21,001	64.6	3,759	858.2	0.460	0.0409
1966	22,256	13,261	21,043	65.5	4,410	970.1	0.504	0.0461
1967	22,105	13,204	20,867	65.2	4,724	1066.4	0.549	0.0511
1968	21,879	12,998	20,467	64.2	4,778	1126.2	0.582	0.0550
1969	21,695	12,753	20,212	62.9	4,071	1112.3	0.584	0.0550

1970	21,593	12,610	20,161	62.2	3,964	1553.8	0.751	0.0771
1971	21,062	12,306	19,807	60.7	3,502	1995.6	0.901	0.1008
1972	20,033	11,755	18,853	58.0	4,392	2938.4	1.152	0.1559
1973	18,085	10,566	16,957	52.2	6,482	3123.8	1.244	0.1842
1974	16,235	9,221	14,768	45.5	6,414	3402.9	1.353	0.2304
1975	14,562	7,786	12,693	38.4	4,553	3242.0	1.392	0.2554
1976	13,367	6,777	11,677	33.5	7,654	3191.1	1.426	0.2733
1977	12,611	6,207	11,063	30.6	6,316	2007.9	1.207	0.1815
1978	13,318	6,460	11,194	31.9	2,690	2410.8	1.273	0.2154
1979	13,571	6,633	12,000	32.7	7,194	3264.2	1.413	0.2720
1980	12,956	6,495	11,819	32.1	2,923	3467.0	1.453	0.2933
1981	11,877	5,989	10,183	29.6	2,157	2994.1	1.424	0.2940
1982	10,843	5,546	10,071	27.4	2,042	2850.3	1.445	0.2830
1983	9,508	5,126	8,907	25.3	3,581	2174.0	1.481	0.2441
1984	8,428	4,685	7,769	23.1	11,971	2025.7	1.538	0.2607
1985	7,996	3,985	6,476	19.7	8,569	2266.4	1.600	0.3500
1986	8,105	3,240	5,375	16.0	4,746	2047.9	1.559	0.3810
1987	8,889	3,302	6,933	16.3	4,556	2712.9	1.605	0.3913
1988	8,990	3,776	7,768	18.6	2,595	2855.2	1.585	0.3676
1989	8,410	3,948	7,391	19.5	4,243	2936.9	1.610	0.3973
1990	7,284	3,554	6,496	17.5	2,489	2434.3	1.602	0.3747
1991	6,268	3,051	5,330	15.1	5,288	2082.6	1.611	0.3907
1992	5,585	2,585	4,746	12.8	1,035	1808.9	1.606	0.3812
1993	5,063	2,264	4,029	11.2	1,802	1621.0	1.602	0.4024
1994	4,533	2,109	4,207	10.4	2,937	1177.6	1.497	0.2799
1995	4,341	2,145	3,775	10.6	1,155	1085.4	1.461	0.2875
1996	4,123	2,021	3,464	10.0	3,212	1091.9	1.495	0.3152
1997	3,941	1,865	3,457	9.2	1,167	1073.3	1.526	0.3105
1998	3,751	1,753	3,039	8.7	932	551.3	1.167	0.1814
1999	3,986	1,936	3,668	9.6	5,099	638.1	1.183	0.1740
2000	4,377	2,124	3,750	10.5	2,984	337.7	0.717	0.0901
2001	5,350	2,411	3,957	11.9	2,336	328.2	0.646	0.0829
2002	6,522	2,879	5,640	14.2	1,217	745.7	0.996	0.1322
2003	7,236	3,457	6,598	17.1	1,606	1191.8	1.117	0.1806
2004	7,315	3,781	6,896	18.7	632	265.8	0.322	0.0385
2005	7,913	4,398	7,485	21.7	620	462.0	0.477	0.0617
2006	7,961	4,667	7,760	23.0	441	390.5	0.442	0.0503
2007	7,745	4,757	7,563	23.5	769	289.3	0.387	0.0383
2008	7,397	4,681	7,229	23.1	1,752	190.8	0.313	0.0264
2009	7,103	4,496	6,773	22.2	1,884	202.4	0.400	0.0299
2010	6,899	4,232	6,330	20.9	3,727	159.8	0.391	0.0253
2011	7,079	4,065	6,321	20.1	3,255	265.2	0.616	0.0420
2012	7,566	4,032	6,419	19.9	3,773	333.9	0.656	0.0520

2013	8,405	4,242	7,323	20.9	5,066	505.2	0.732	0.0690
2014	9,521	4,674	8,207	23.1	2,030	689.9	0.749	0.0841
2015	10,593	5,209	9,240	25.7	1,783	877.4	0.771	0.0950
2016	11,316	5,827	10,690	28.8	1,425	773.7	0.612	0.0724
2017	11,768	6,509	11,230	32.1	3,953	1517.6	0.925	0.1351
2018	11,276	6,424	10,605	31.7	3,939	1392.8	0.938	0.1313
2019	10,906	6,055	9,647	29.9	3,874	1077.1	0.899	0.1116
2020	11,048	5,855	9,798	28.9	3,837	953.5	0.890	0.0973
2021	11,570	6,012	10,338	29.7	3,867	1063.5	0.897	0.1029
2022	12,166	6,329	10,941	31.2	3,923	1241.9	0.912	0.1135
2023	12,662	6,621	11,424	32.7	3,972	1374.7	0.924	0.1203
2024	13,044	6,848	11,789	33.8	4,008	1453.2	0.932	0.1233
2025	13,348	7,028	12,079	34.7	4,035	1500.8	0.938	0.1243
2026	13,604	7,182	12,324	35.4	4,057	1535.5	0.943	0.1246

Table 11. Sensitivity table, north model

Label	Final Base	2009 M and h	Add Conditional Recreational Ages	Add Marginal Commercial Ages	Add Conditional Recreational and Commercial Marginal Ages	Ro8.81	Ro9.8	SigmaR = 0.6	Female Length at Amax = 108	Female Length at Amax = 112	M=0.257
TOTAL_like	1381.18	1460.79	1862.19	2132.47	1643.16	1382.57	1382.37	1380.58	1379.05	1383.98	1409.93
Survey_like	-104.98	-107.55	-108.33	-110.58	-106.94	-104.37	-105.14	-104.99	-105.33	-104.60	-103.03
Discard_like	-48.87	-54.24	-48.59	-42.23	-42.77	-49.42	-48.69	-48.78	-48.69	-49.04	-48.11
Length_comp_like	1078.79	1166.08	1099.79	1107.09	1095.20	1080.92	1077.83	1077.29	1076.05	1081.52	1090.64
Age_comp_like	454.94	455.13	921.89	1179.33	696.09	453.93	456.46	455.08	455.42	455.08	468.32
Parm_priors_like	0.39	0.49	0.26	0.31	0.42	0.38	0.40	0.38	0.37	0.40	0.15
NatM_p_1_Fem_GP_1	0.26	0.18	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
L_at_Amin_Fem_GP_1	17.28	16.92	16.11	16.43	17.42	17.15	17.37	17.28	16.92	17.63	17.11
L_at_Amax_Fem_GP_1	110	110	110	110	110	110	110	110	108	112	110
VonBert_K_Fem_GP_1	0.13	0.13	0.14	0.14	0.13	0.13	0.13	0.13	0.14	0.12	0.13
CV_young_Fem_GP_1	0.14	0.15	0.16	0.15	0.14	0.14	0.14	0.14	0.15	0.14	0.14
CV_old_Fem_GP_1	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
NatM_p_1_Mal_GP_1	0.30	0.32	0.28	0.29	0.31	0.30	0.31	0.30	0.30	0.31	0.26
L_at_Amin_Mal_GP_1	14.88	12.05	15.52	15.39	15.24	15.13	14.59	14.87	14.76	14.99	15.98
L_at_Amax_Mal_GP_1	76.71	75.15	74.90	76.36	78.51	76.97	76.41	76.69	76.40	77.03	76.27
VonBert_K_Mal_GP_1	0.30	0.35	0.29	0.28	0.28	0.30	0.31	0.30	0.31	0.30	0.29
CV_young_Mal_GP_1	0.16	0.19	0.15	0.14	0.15	0.16	0.16	0.16	0.16	0.16	0.14
CV_old_Mal_GP_1	0.07	0.07	0.09	0.09	0.06	0.07	0.07	0.07	0.07	0.07	0.09
SR_LN(R0)	9.07	8.29	8.85	9.13	9.22	8.81	9.80	9.08	9.14	9.00	8.93
SR_BH_steep	0.70	0.80	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
SPRratio_2009	0.24	0.42	0.29	0.25	0.24	0.32	0.12	0.25	0.22	0.26	0.26
SPRratio_2017	0.80	1.31	1.04	0.92	0.91	1.14	0.54	0.97	0.90	1.01	0.83
F_2009	0.10	0.14	0.12	0.10	0.09	0.13	0.04	0.10	0.09	0.11	0.11

F_2017	0.48	0.90	0.74	0.60	0.59	0.87	0.28	0.65	0.58	0.69	0.51
Bratio_2009	0.41	0.35	0.41	0.39	0.38	0.39	0.45	0.40	0.42	0.41	0.39
Bratio_2017	0.58	0.51	0.58	0.56	0.55	0.54	0.64	0.56	0.59	0.57	0.56
SSB_Unfished_thousand_mt	37.97	43.16	32.06	42.23	44.29	29.42	79.02	38.32	39.52	36.80	33.62
TotBio_Unfished	58746	52676	49588	64887	68085	45659	121813	59289	62089	56099	57333
SmryBio_Unfished	56005	51330	47401	62034	64939	43538	116108	56522	59131	53535	54814
Recr_Unfished_millions	8.66	3.99	7.00	9.27	10.11	6.70	18.03	8.74	9.32	8.11	7.59
SSB_Btgt_thousand_mt	15.19	17.27	12.82	16.89	17.72	11.77	31.61	15.33	15.81	14.72	13.45
SPR_Btgt	0.46	0.44	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
Fstd_Btgt	0.13	0.09	0.13	0.13	0.12	0.13	0.13	0.13	0.13	0.12	0.13
TotYield_Btgt_thousand_mt	3.20	2.05	2.73	3.51	3.66	2.49	6.60	3.23	3.46	2.98	3.12
SSB_SPRtgt_thousand_mt	14.58	17.84	12.31	16.22	17.01	11.30	30.34	14.72	15.18	14.13	12.91
Fstd_SPRtgt	0.13	0.09	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13
TotYield_SPRtgt_thousand_mt	3.24	2.02	2.77	3.56	3.71	2.53	6.69	3.27	3.51	3.02	3.16
SSB_MSY_thousand_mt	10.25	9.83	8.73	11.42	11.93	7.95	21.30	10.35	10.69	9.92	9.23
SPR_MSY	0.35	0.28	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Fstd_MSY	0.19	0.16	0.19	0.19	0.18	0.19	0.19	0.19	0.19	0.18	0.19
TotYield_MSY_thousand_mt	3.41	2.28	2.90	3.74	3.91	2.66	7.04	3.44	3.69	3.18	3.31
RetYield_MSY	3269	2206	2783	3580	3738	2551	6737	3300	3536	3048	3169

Table 12. Sensitivity table, south model

Label	Final Base	Add Recreational Onboard Observer Index as Proportional to Biomass	Add Recreational Onboard Observer Index as Not Proportional to Biomass	Add Commercial Marginal Ages	SigmaR = 0.7	SigmaR = 0.8	No Lam Composition Data	M=0.257	Ro=8.122	Ro=8.742
TOTAL_like	1362.02	1347.58	1417.13	1392.60	1362.41	1361.97	1255.67	1372.79	1378.73	1363.22
Survey_like	-49.07	-64.16	-57.68	-48.60	-48.88	-49.02	-49.96	-51.41	-51.2419	-47.9431
Discard_like	-7.88	-7.39	-2.90	-7.68	-7.94	-7.78	-8.52	-8.05	-7.3553	-8.0045
Length_comp_like	971.09	966.23	1011.59	973.72	972.88	969.13	938.71	984.15	983.317	971.939
Age_comp_like	438.38	439.97	453.94	465.54	438.24	438.61	367.41	440.83	439.892	437.985
Parm_priors_like	0.47	0.57	0.58	0.47	0.46	0.49	0.66	0.15	0.3608	0.4795
NatM_p_1_Fem_GP_1	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.257	0.257
L_at_Amin_Fem_GP_1	18.02	17.91	17.91	18.03	18.03	17.99	18.07	17.95	17.9454	18.0504
L_at_Amax_Fem_GP_1	93.49	92.70	92.36	93.09	93.59	93.28	96.51	92.92	93.6468	93.6443
VonBert_K_Fem_GP_1	0.13	0.14	0.14	0.13	0.13	0.13	0.12	0.14	0.1317	0.1273
CV_young_Fem_GP_1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1505	0.1495
CV_old_Fem_GP_1	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.0736	0.0701
NatM_p_1_Mal_GP_1	0.32	0.33	0.34	0.32	0.32	0.32	0.35	0.26	0.3007	0.3202
L_at_Amin_Mal_GP_1	18.13	17.99	17.95	18.12	18.15	18.10	18.13	18.60	18.165	18.1198
L_at_Amax_Mal_GP_1	83.85	81.96	81.70	82.90	84.16	83.44	87.92	90.70	85.3556	83.8369
VonBert_K_Mal_GP_1	0.16	0.17	0.18	0.17	0.16	0.16	0.14	0.11	0.1507	0.1605
CV_young_Mal_GP_1	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.1363	0.1367
CV_old_Mal_GP_1	0.09	0.08	0.08	0.09	0.09	0.09	0.08	0.11	0.0908	0.0873
SR_LN(R0)	8.49	8.45	8.40	8.52	8.48	8.51	8.74	8.46	8.122	8.742
SR_BH_steep	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.7	0.7
SPRratio_2009	0.43	0.66	0.90	0.41	0.38	0.49	0.32	0.29	0.5708	0.3484
SPRratio_2017	1.13	1.49	1.78	1.10	1.04	1.25	0.90	0.72	1.4452	0.9698
F_2009	0.15	0.27	0.43	0.14	0.13	0.18	0.09	0.09	0.1998	0.116
F_2017	0.68	1.19	2.15	0.65	0.59	0.81	0.47	0.47	1.0806	0.5259
Bratio_2009	0.23	0.14	0.09	0.23	0.27	0.19	0.28	0.31	0.2283	0.2252
Bratio_2017	0.33	0.20	0.12	0.34	0.38	0.27	0.38	0.43	0.2849	0.3397
SSB_Unfished_thousand_mt	20.46	19.04	18.06	20.64	20.29	20.58	29.04	19.47	14.242	26.362
TotBio_Unfished	33103	29602	28010	33331	33083	33002	43779	43226	24463.4	42440.4

SmryBio_Unfished	31547	28128	26588	31740	31542	31429	41828	41645	23370.3	40449.5
Recr_Unfished_millions	4.88	4.66	4.46	5.00	4.82	4.94	6.22	4.73	3.3678	6.2604
SSB_Btgt_thousand_mt	8.19	7.62	7.22	8.25	8.12	8.23	11.62	7.79	5.697	10.545
SPR_Btgt	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.4643	0.4643
Fstd_Btgt	0.13	0.13	0.13	0.13	0.12	0.13	0.12	0.11	0.1241	0.1245
TotYield_Btgt_thousand_mt	1.73	1.62	1.55	1.77	1.72	1.75	2.12	1.92	1.259	2.207
SSB_SPRtgt_thousand_mt	9.00	8.38	7.95	9.08	8.93	9.05	12.78	7.48	6.267	11.599
Fstd_SPRtgt	0.11	0.11	0.12	0.11	0.11	0.11	0.10	0.11	0.1092	0.1097
TotYield_SPRtgt_thousand_mt	1.66	1.55	1.48	1.69	1.64	1.67	2.02	1.95	1.205	2.112
SSB_MSY_thousand_mt	5.32	4.98	4.73	5.38	5.27	5.35	7.45	4.98	3.706	6.844
SPR_MSY	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.3395	0.3389
Fstd_MSY	0.20	0.20	0.20	0.20	0.20	0.20	0.19	0.18	0.1953	0.1954
TotYield_MSY_thousand_mt	1.87	1.74	1.66	1.90	1.85	1.88	2.29	2.08	1.358	2.381
RetYield_MSY	1840	1719	1639	1874	1826	1856	2259	2047	1338.12	2345.23

Table 13. Model projections, north model area (WA+OR).

Year	Predicted OFL (mt)	ABC Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Depletion (%)
2017	2,162.0	1,000.3	34,063.8	21,975.7	57.9%
2018	2,043.0	997.9	35,946.1	22,593.1	59.5%
2019	4,800.4	4,589.2	37,091.0	23,455.6	61.8%
2020	4,503.5	4,305.5	34,839.0	22,123.7	58.3%
2021	4,259.2	4,071.9	32,975.1	20,863.8	54.9%
2022	4,082.1	3,902.5	31,516.8	19,796.9	52.1%
2023	3,958.3	3,784.2	30,363.9	18,935.4	49.9%
2024	3,867.7	3,697.6	29,437.0	18,238.5	48.0%
2025	3,796.8	3,629.9	28,677.2	17,664.5	46.5%
2026	3,738.5	3,574.1	28,044.0	17,184.0	45.3%
2027	3,689.0	3,526.8	27,511.3	16,778.8	44.2%
2028	3,646.4	3,486.2	27,061.6	16,436.6	43.3%

Table 14a. Model projections, south model area (CA), for the preferred PFMC management option.

Year	Predicted OFL (mt)	ABC Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Depletion (%)
2017	2,889.0	750.0	11,229.9	6,508.8	32.1%
2018	2,640.0	750.0	11,358.5	6,879.7	34.0%
2019	1,452.3	1,320.3	11,028.3	6,918.5	34.1%
2020	1,241.6	1,103.8	10,855.1	6,560.0	32.4%
2021	1,303.9	1,161.0	11,171.5	6,585.9	32.5%
2022	1,455.5	1,314.5	11,642.2	6,809.7	33.6%
2023	1,573.4	1,439.5	12,035.6	7,038.4	34.7%
2024	1,640.2	1,514.7	12,325.4	7,216.9	35.6%
2025	1,675.4	1,557.2	12,544.1	7,351.3	36.3%
2026	1,696.6	1,585.1	12,722.9	7,461.4	36.8%
2027	1,712.1	1,606.4	12,875.5	7,557.4	37.3%
2028	1,724.2	1,623.9	13,007.5	7,643.1	37.7%

Table 14b. Model projections, south model area (CA), for the default PFMC management option.

Year	Predicted OFL (mt)	ABC Catch (mt)	Age 3+ Biomass (mt)	Spawning Biomass (mt)	Depletion (%)
2017	2,889.0	750.0	11,229.9	6,508.8	32.1%
2018	2,640.0	750.0	11,358.5	6,879.7	34.0%
2019	1,452.3	1,265.4	11,028.3	6,918.5	34.1%
2020	1,249.3	1,066.2	10,910.9	6,593.5	32.5%
2021	1,314.8	1,125.3	11,261.3	6,641.3	32.8%
2022	1,469.2	1,276.9	11,759.9	6,884.1	34.0%
2023	1,590.5	1,401.5	12,182.8	7,132.3	35.2%
2024	1,660.7	1,478.0	12,502.3	7,330.4	36.2%
2025	1,698.6	1,522.5	12,748.6	7,483.5	36.9%
2026	1,721.8	1,552.1	12,951.9	7,610.5	37.6%
2027	1,738.8	1,574.9	13,125.8	7,721.4	38.1%
2028	1,752.1	1,593.6	13,276.5	7,820.3	38.6%

Table 15. North model decision table of 12-year projections for alternate states of nature (columns) and management options (rows). Summary of model outputs for the preferred council HCR, north. Uncertainty in management quantities for the north and south models was characterized using the asymptotic standard deviation for the 2017 spawning biomass from the base model. Specifically, the 2017 spawning biomass for the high and low states of nature are given by the base model mean +/-1.15*standard deviation (the 12.5th and 87.5th percentiles). A search across fixed values of Ro was used to attain the 2017 spawning biomass values for the high and low states of nature.

			State of nature					
			Low 2017 Spawning Biomass *Ro=8.81*		Base case 2017 Spawning Biomass		High 2017 Spawning Biomass *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
~700 mt 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% ACL	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
ACL	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 16. South model decision table of 12-year projections for alternate states of nature (columns) and management options (rows). Summary of model outputs for the preferred council HCR using a buffer of 0.956, south. Uncertainty in management quantities for the north and south models was characterized using the asymptotic standard deviation for the 2017 spawning biomass from the base model. Specifically, the 2017 spawning biomass for the high and low states of nature are given by the base model mean +/-1.15*standard deviation (the 12.5th and 87.5th percentiles). A search across fixed values of Ro was used to attain the 2017 spawning biomass values for the high and low states of nature.

			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	4,220	29.8%	6,918	34.1%	9,756	37.0%
	2020	700	4,040	28.5%	6,938	34.2%	9,881	37.5%
	2021	700	4,116	29.1%	7,199	35.5%	10,299	39.1%
	2022	700	4,368	30.8%	7,670	37.9%	10,983	41.7%
	2023	700	4,687	33.1%	8,232	40.6%	11,784	44.7%
	2024	700	5,027	35.5%	8,819	43.5%	12,619	47.9%
	2025	700	5,371	37.9%	9,403	46.4%	13,446	51.0%
	2026	700	5,712	40.3%	9,972	49.2%	14,246	54.0%
	2027	700	6,047	42.7%	10,519	51.9%	15,009	56.9%
	2028	700	6,375	45.0%	11,039	54.5%	15,730	59.7%
~75% ACL	2019	915	4,220	29.8%	6,918	34.1%	9,756	37.0%
	2020	810	3,919	27.7%	6,808	33.6%	9,750	37.0%
	2021	874	3,937	27.8%	7,005	34.6%	10,105	38.3%
	2022	1,006	4,101	29.0%	7,383	36.4%	10,695	40.6%
	2023	1,122	4,256	30.1%	7,774	38.4%	11,325	43.0%
	2024	1,200	4,361	30.8%	8,119	40.1%	11,916	45.2%
	2025	1,238	4,425	31.3%	8,415	41.5%	12,455	47.2%
	2026	1,266	4,472	31.6%	8,683	42.9%	12,954	49.1%
	2027	1,287	4,510	31.8%	8,928	44.1%	13,418	50.9%
	2028	1,305	4,540	32.1%	9,154	45.2%	13,846	52.5%
ACL	2019	1,320	4,220	29.8%	6,918	34.1%	9,756	37.0%
	2020	1,104	3,687	26.0%	6,560	32.4%	9,501	36.0%
	2021	1,161	3,548	25.1%	6,586	32.5%	9,682	36.7%
	2022	1,315	3,566	25.2%	6,810	33.6%	10,117	38.4%
	2023	1,440	3,564	25.2%	7,038	34.7%	10,584	40.1%
	2024	1,515	3503	24.7%	7,217	35.6%	11,009	41.8%
	2025	1,557	3401	24.0%	7,351	36.3%	11,388	43.2%
	2026	1,585	3281	23.2%	7,461	36.8%	11,735	44.5%
	2027	1,606	3153	22.3%	7,557	37.3%	12,055	45.7%
	2028	1,624	3020	21.3%	7,643	37.7%	12,353	46.9%

Figures

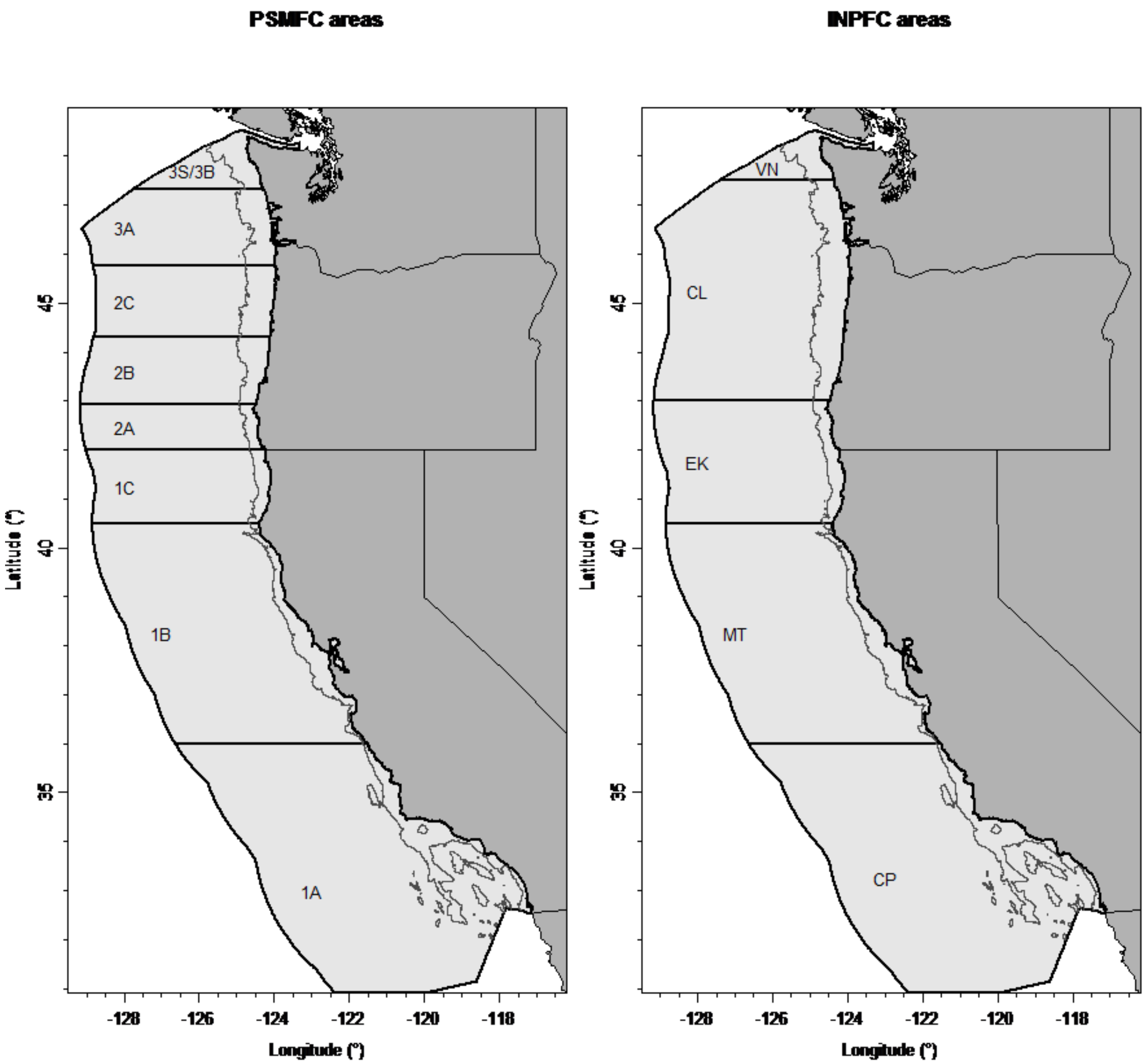


Figure 1. Map showing Pacific States Marine Fish Commission (PSMFC) and International North Pacific Fisheries Commission (INPFC) boundaries. The INPFC area abbreviations are Vancouver (VN), Columbia (CL), Eureka (EK), Monterrey (MT), and Concepcion (CP). The solid gray line off the coast is the 300 fathom depth contour. The stock assessment is split north and south of the California border.

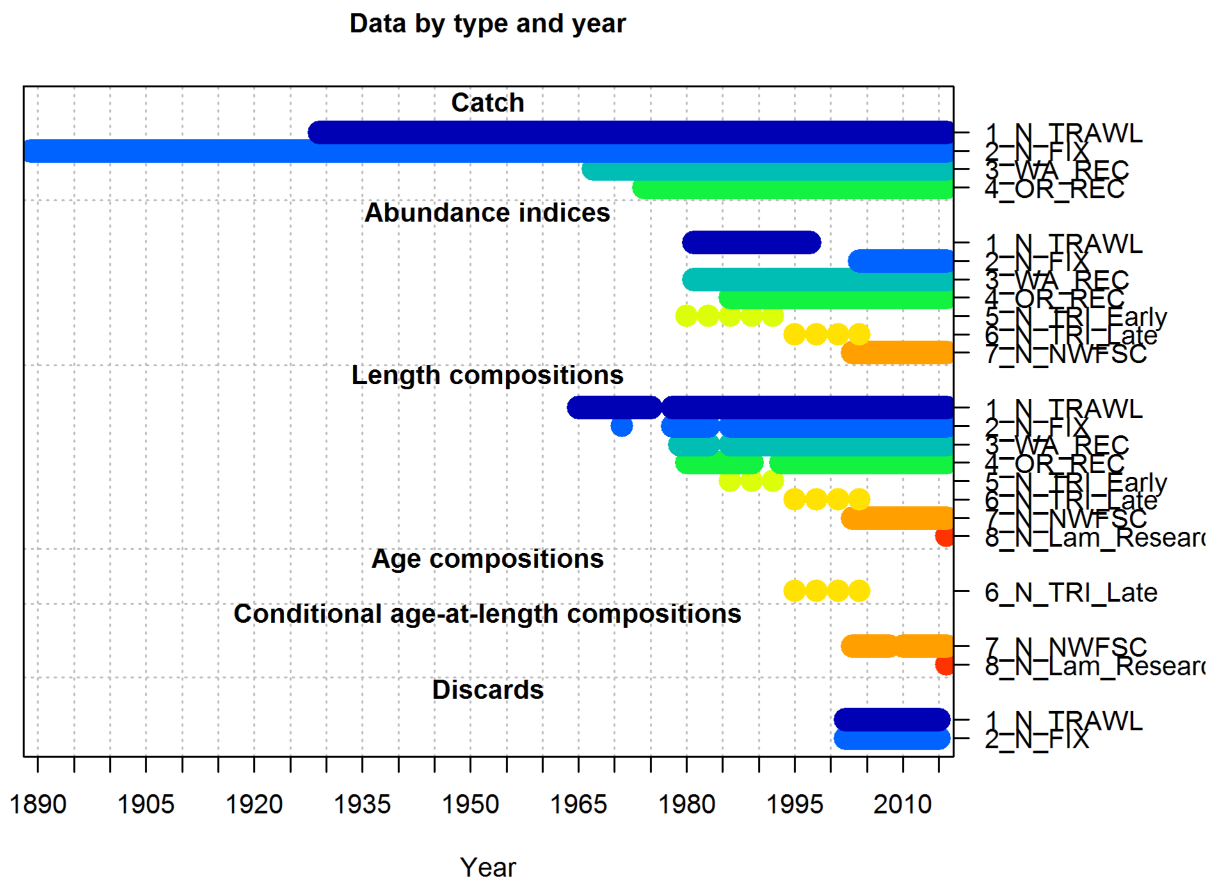


Figure 2. Data used in the north stock assessment.

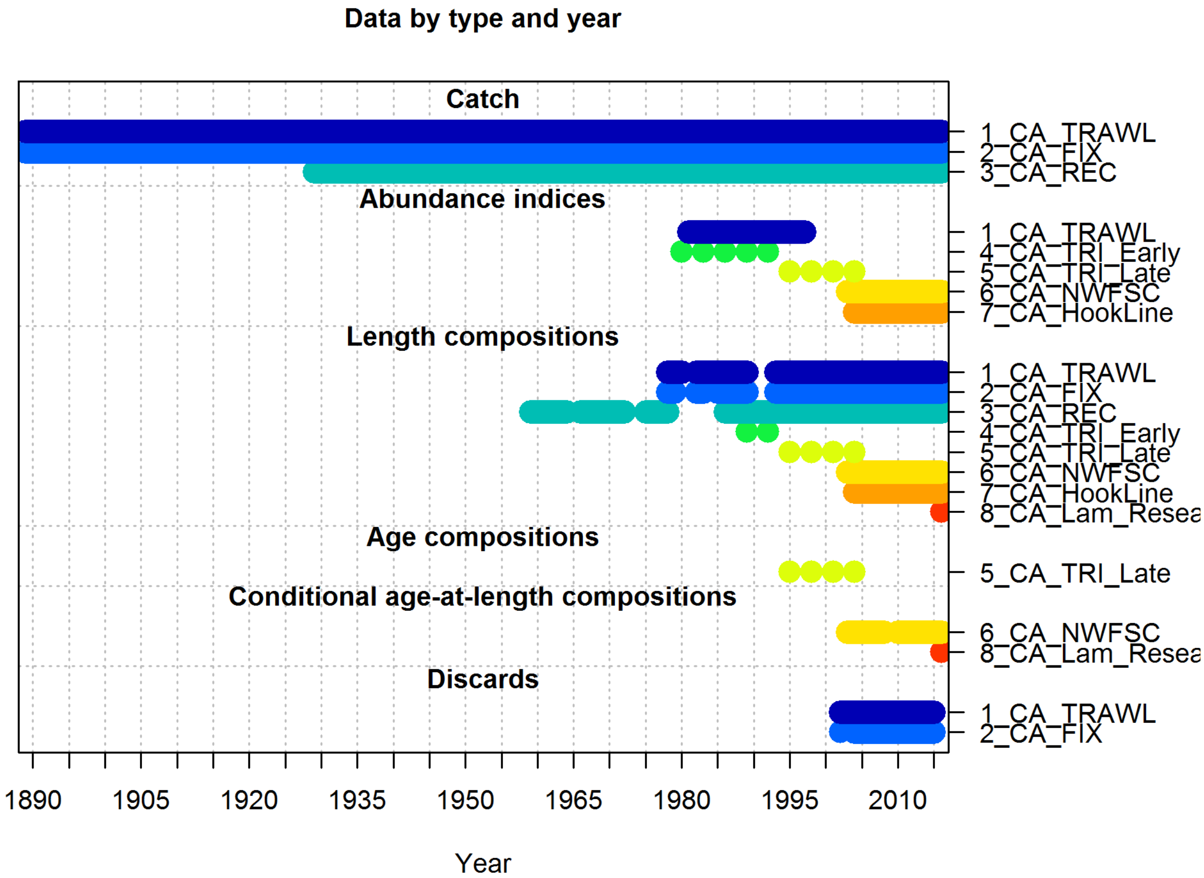


Figure 3. Data used in the south assessment.

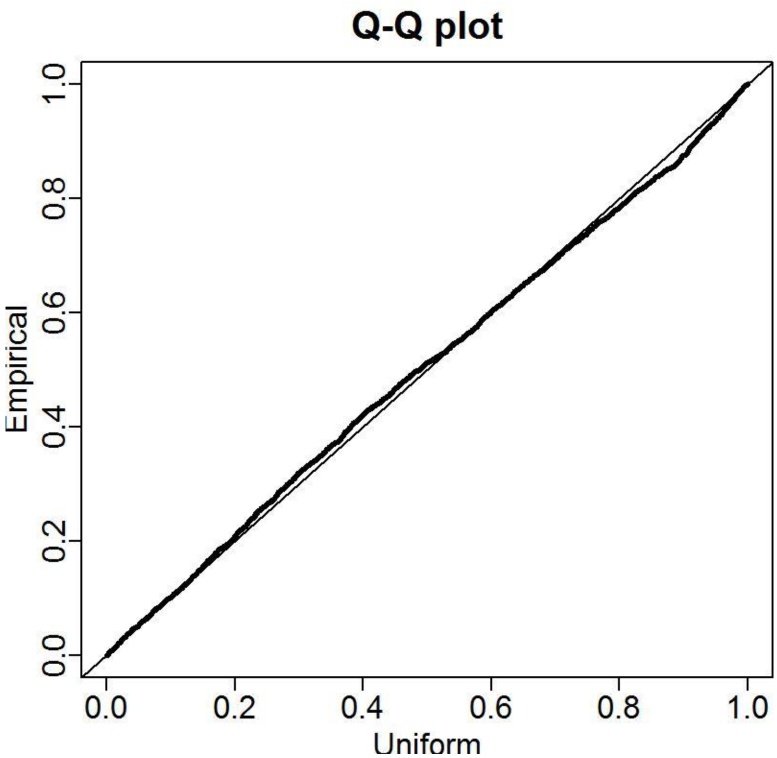


Figure 4. NWFSC survey index VAST Q-Q plot.

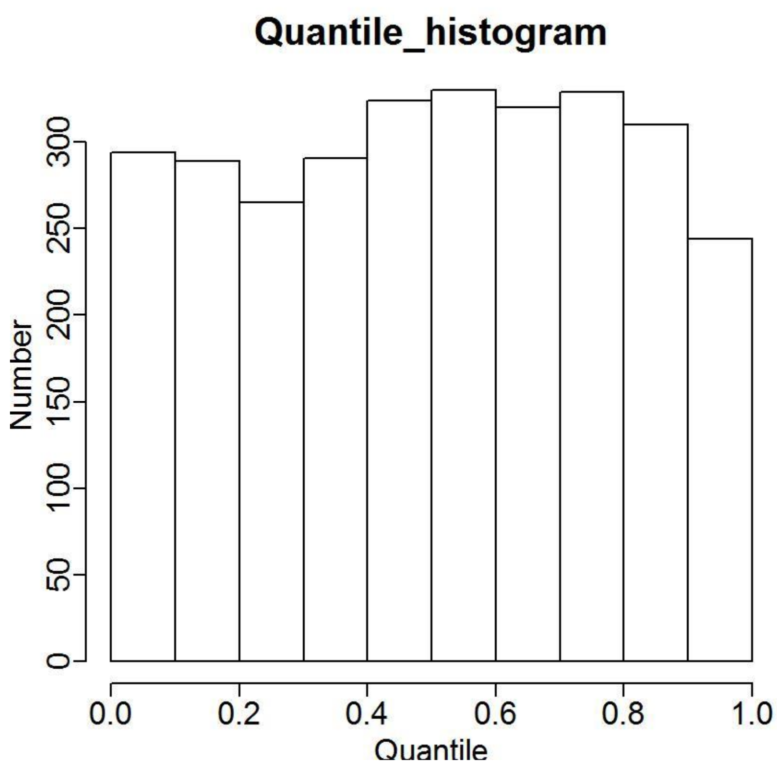


Figure 5. NWFSC survey index VAST binned by predicted encounter probability.

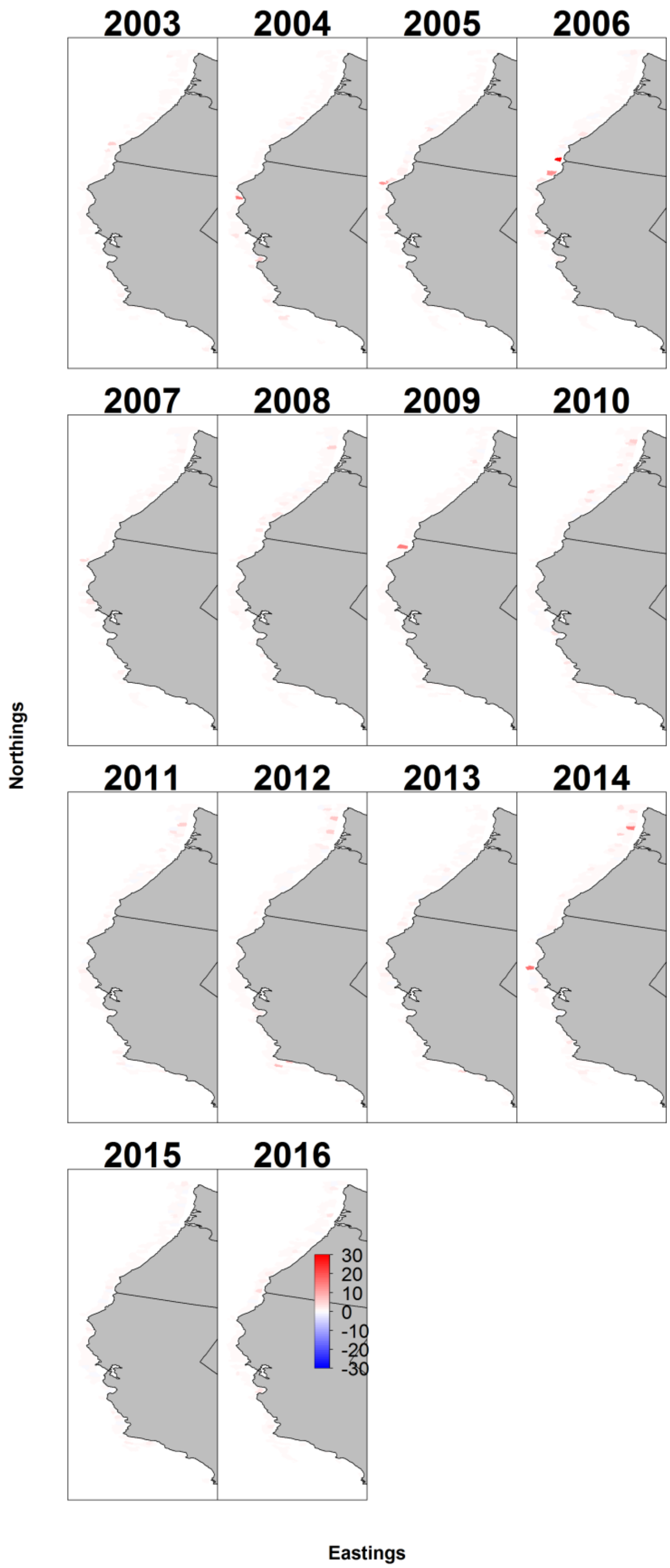


Figure 6. NWFSC survey index encounter probability Pearson residuals.

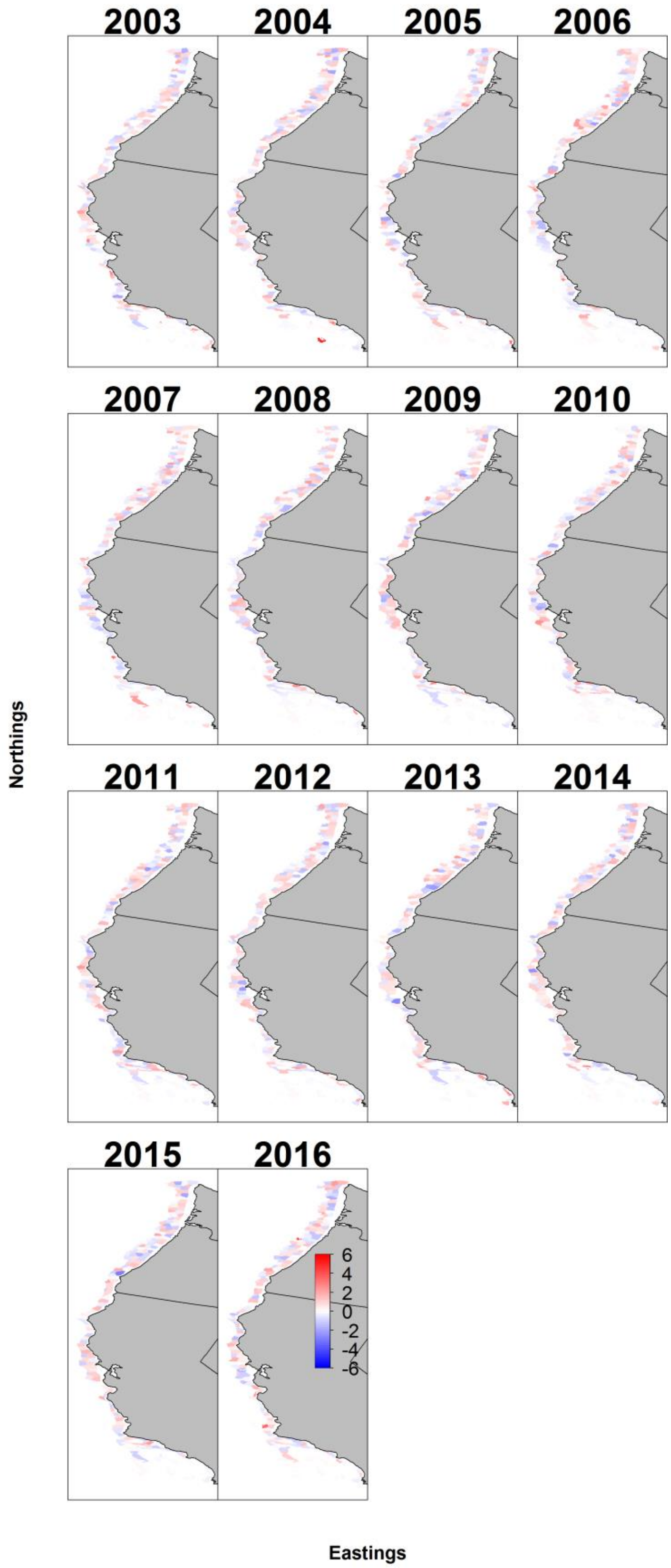


Figure 7. NWFSC survey index positive catch rate probability Pearson residuals.

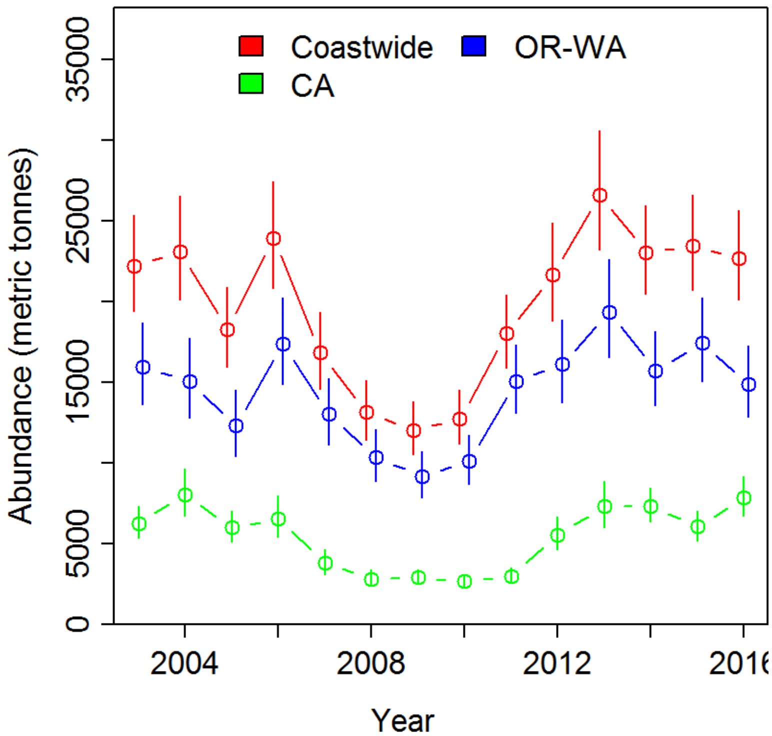


Figure 8. NWFSC coast-wide, north (WA and OR), and south (CA) survey indices.

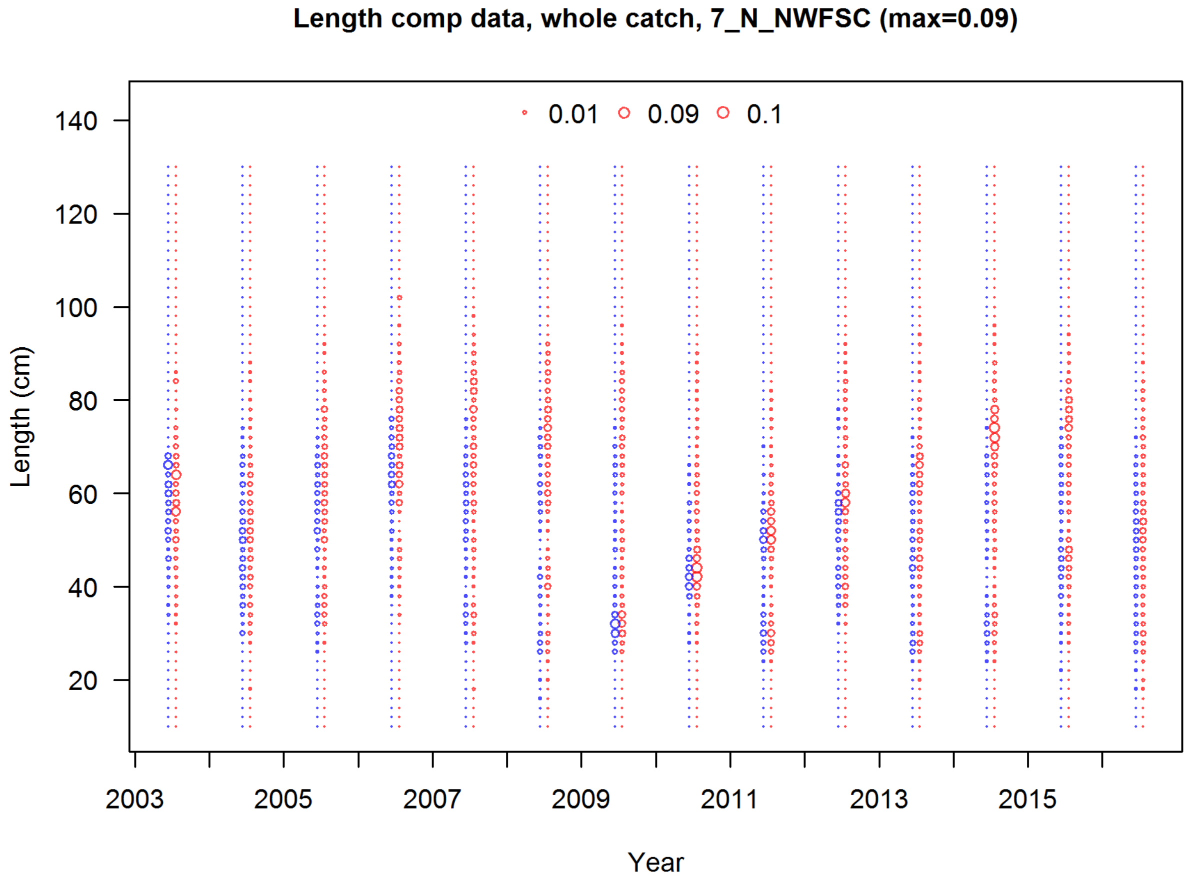


Figure 9. NWFSC survey length composition data, north.

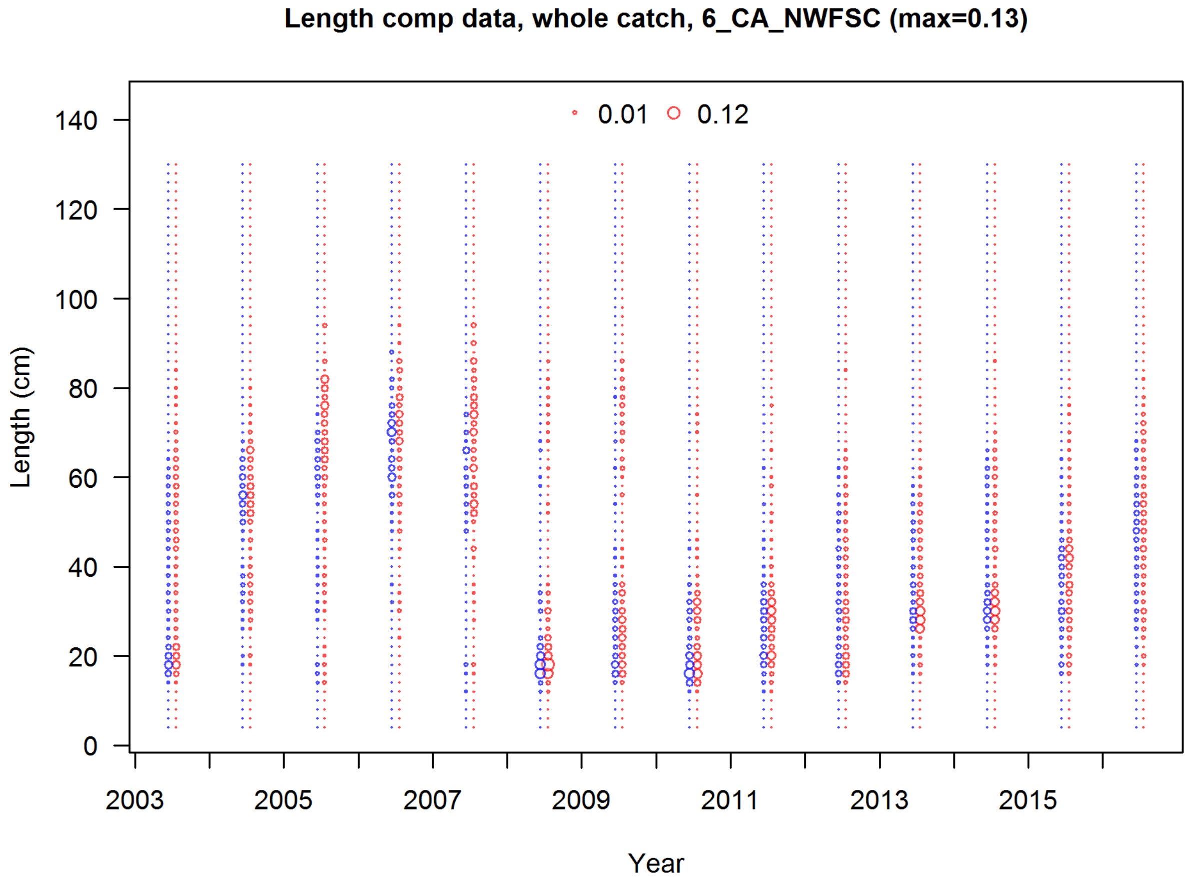


Figure 10. NWFSC survey length composition data, south.

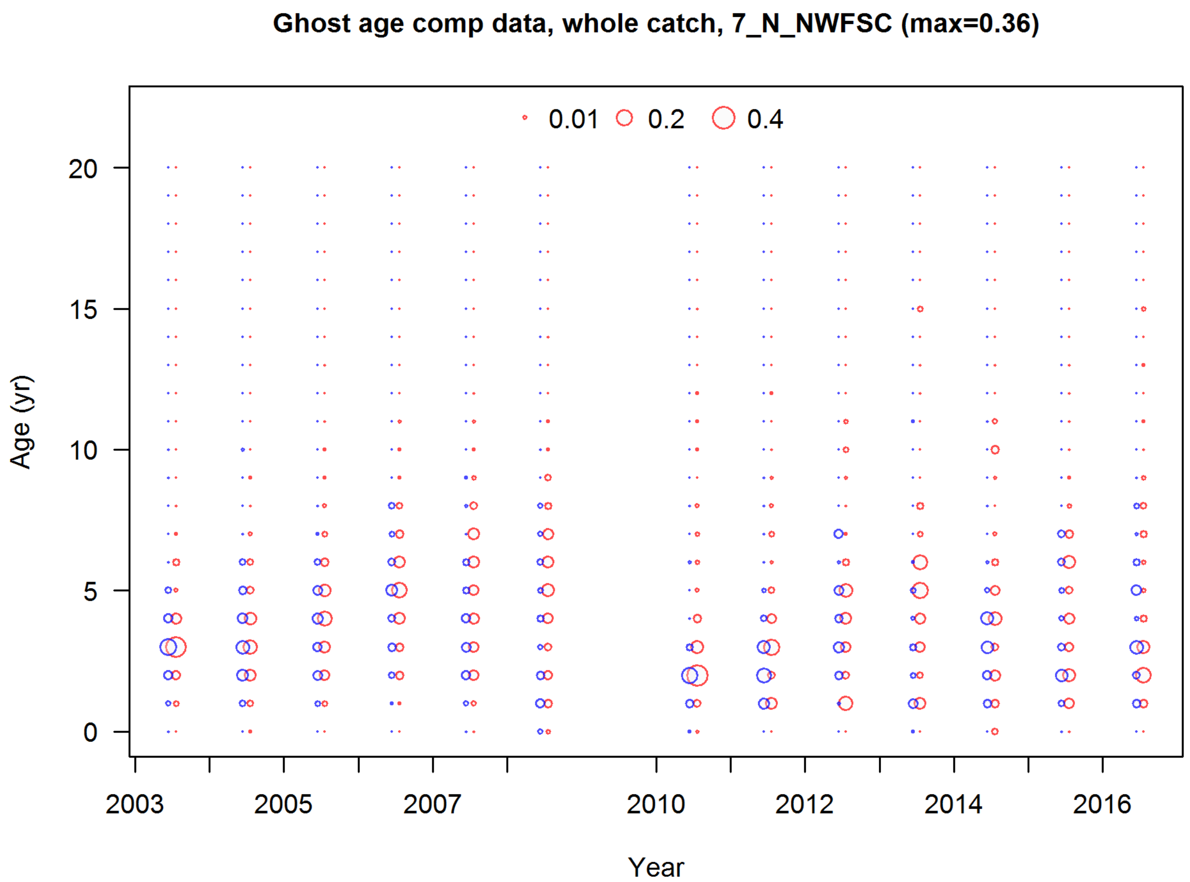


Figure 11. NWFSC survey marginal age composition data, north.

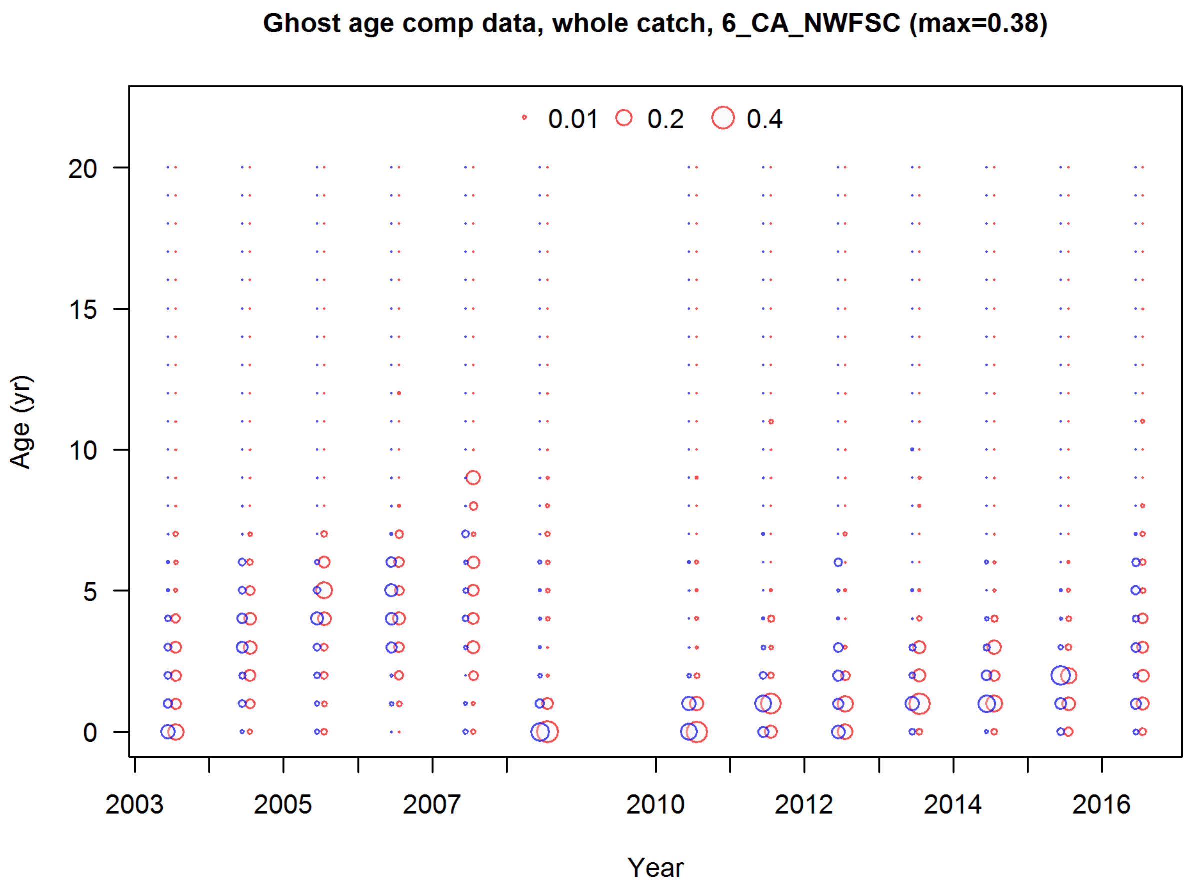


Figure 12. NWFSC survey marginal age composition data, south.

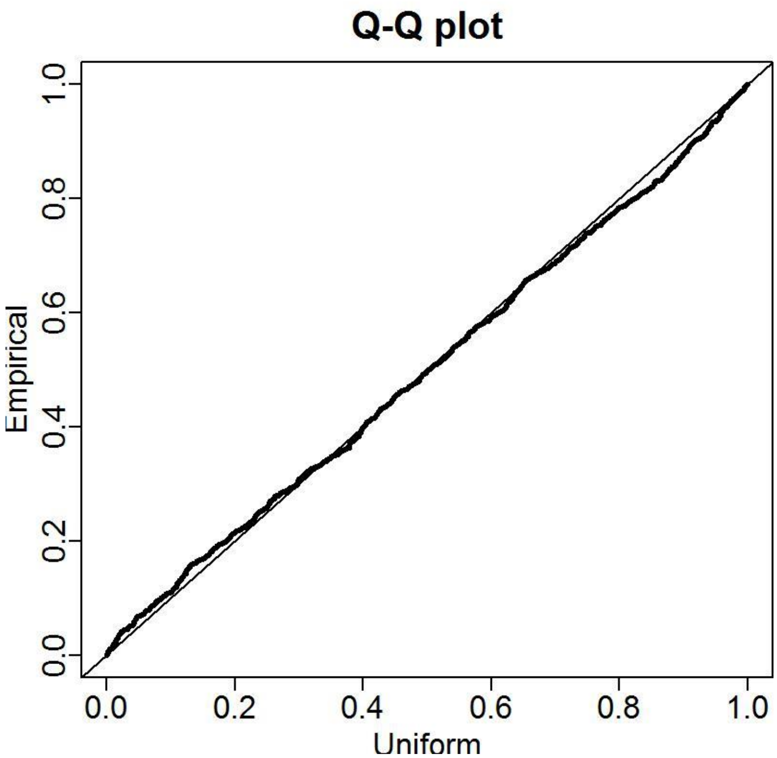


Figure 13. Triennial survey early index VAST Q-Q plot.

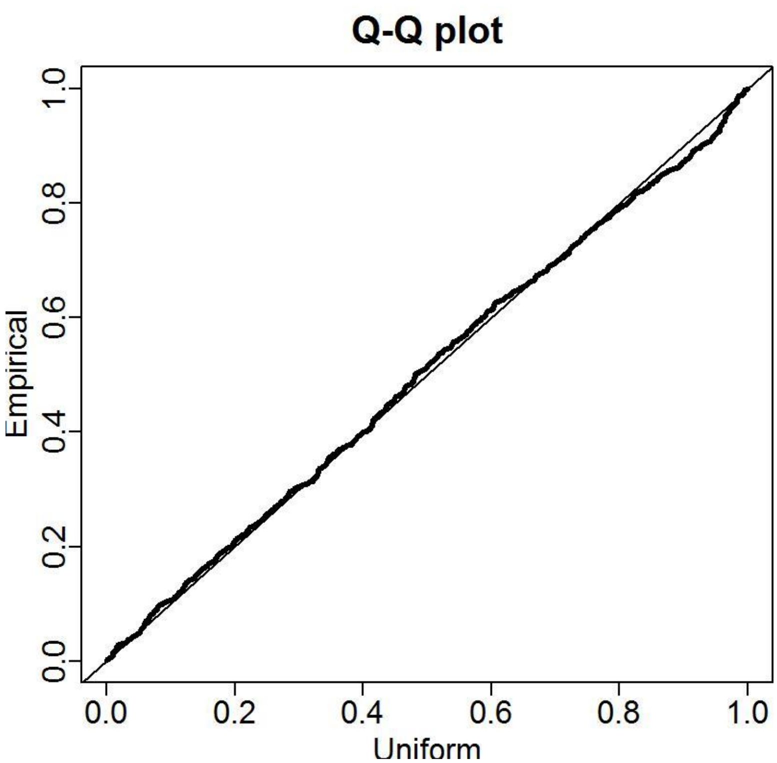


Figure 14. Triennial survey late index VAST Q-Q plot.

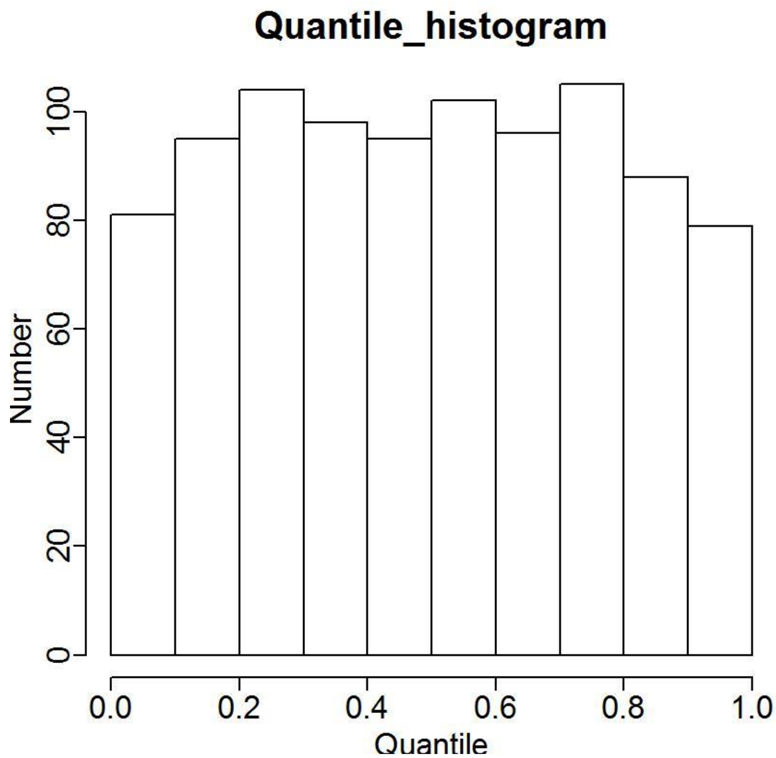


Figure 15. Triennial survey early binned index VAST binned by predicted encounter probability.

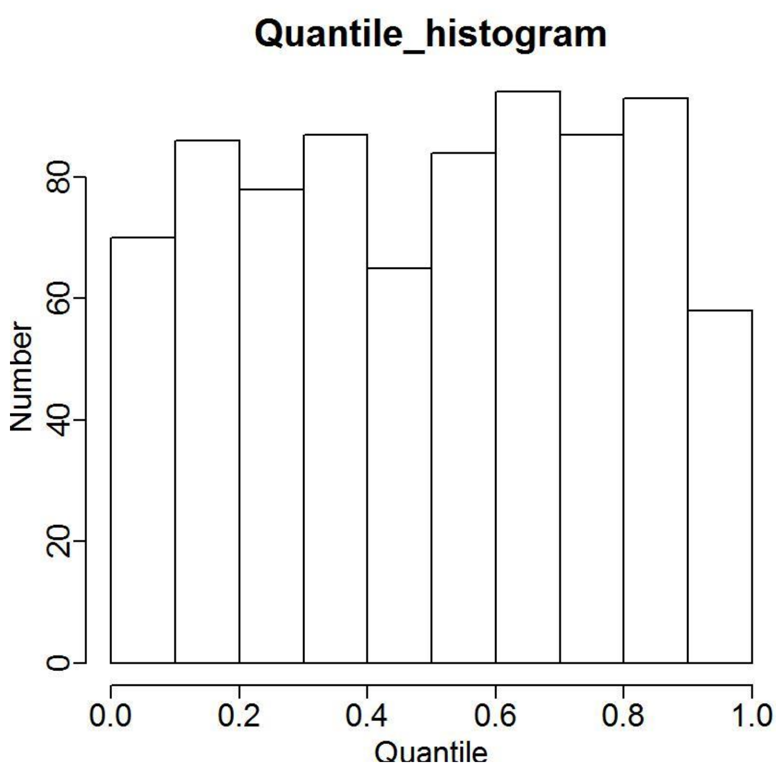


Figure 16. Figure 15. Triennial survey late binned index VAST binned by predicted encounter probability.

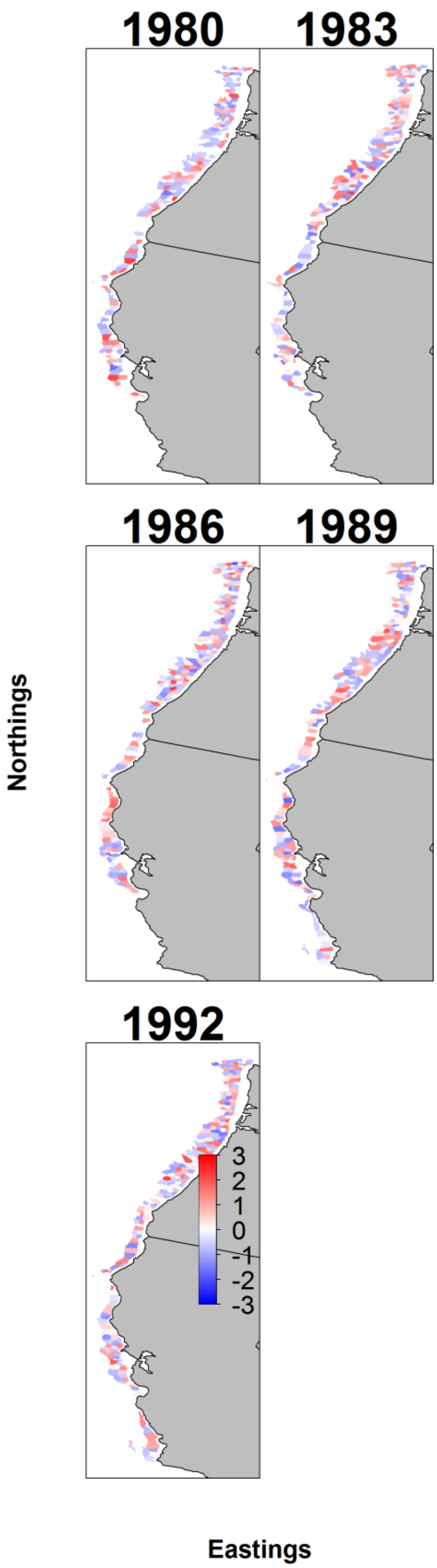


Figure 17. Triennial early survey index encounter probability Pearson residuals.

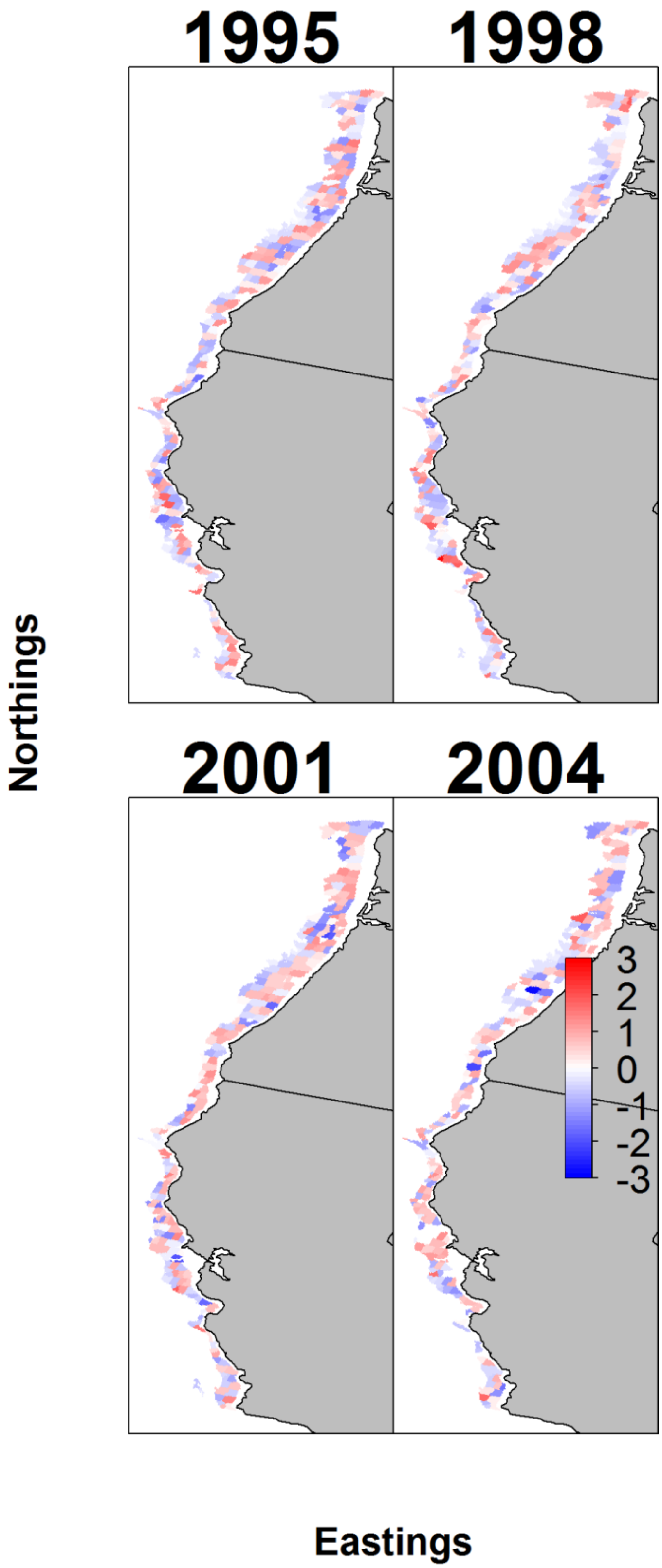


Figure 18. Triennial late survey index encounter probability Pearson residuals.

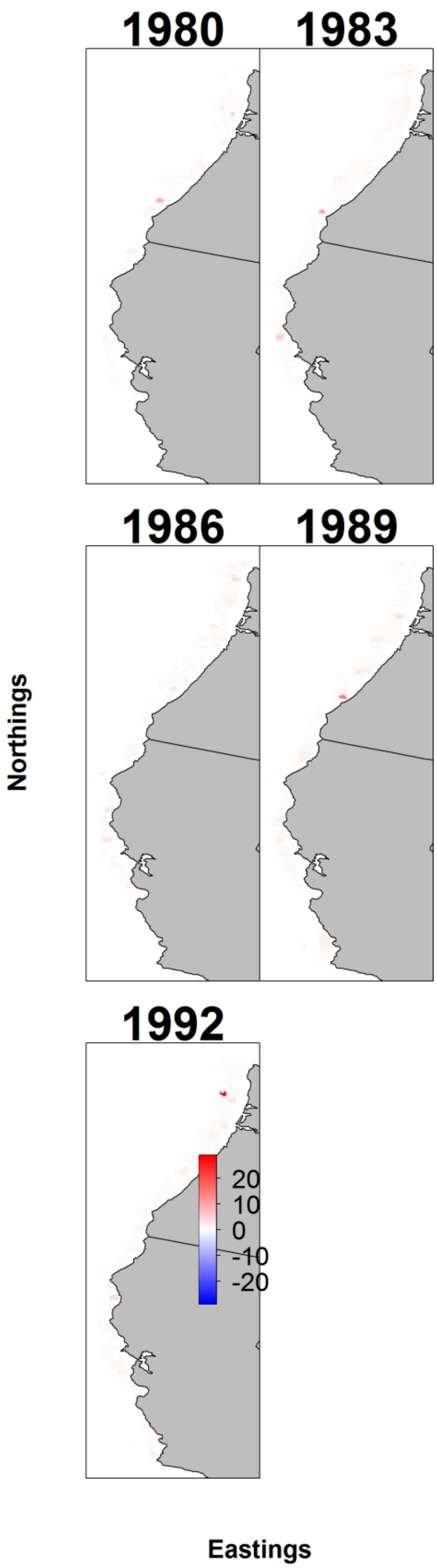


Figure 19. Triennial early survey index positive catch rate probability Pearson residuals.

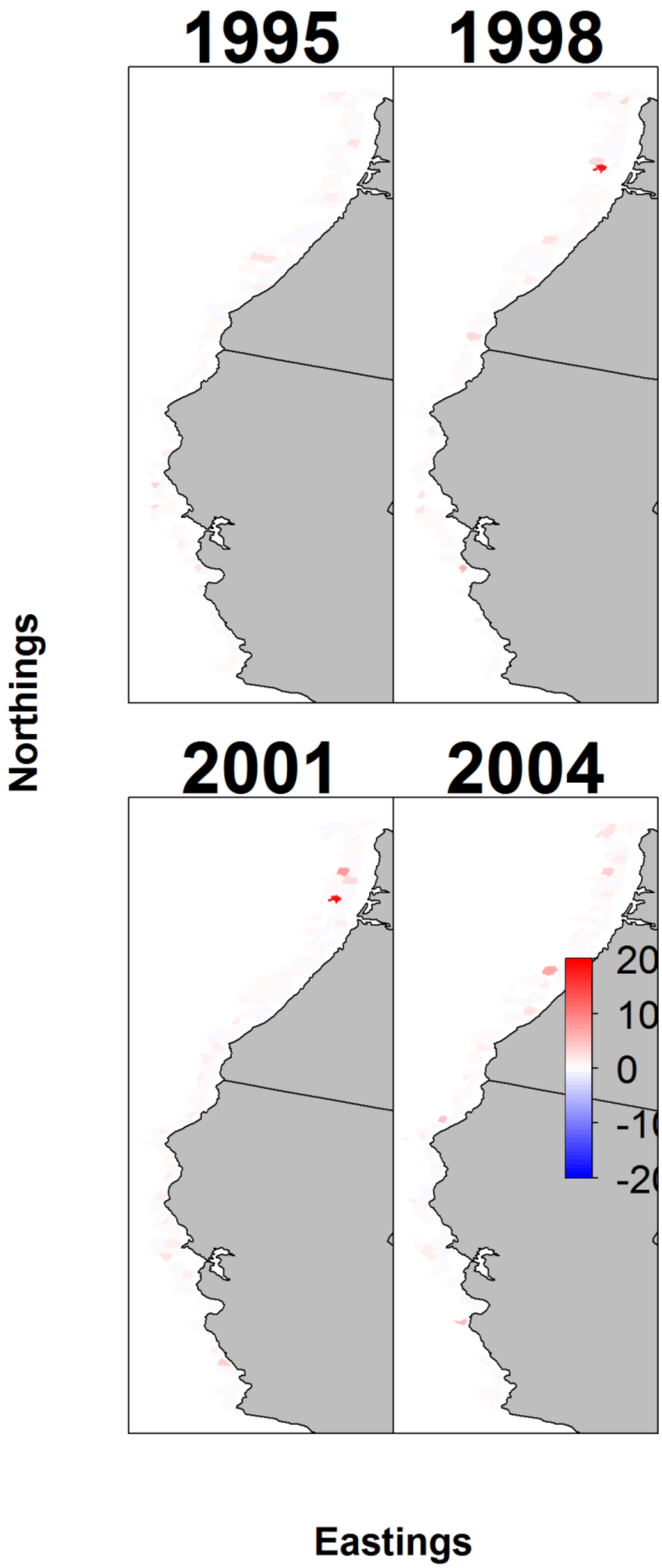


Figure 20. Triennial late survey index positive catch rate probability Pearson residuals.

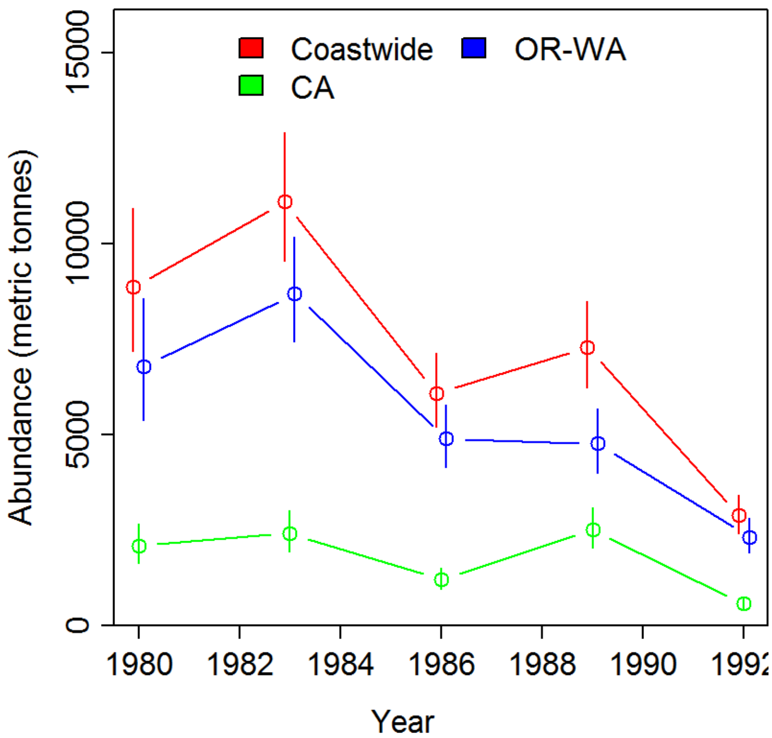


Figure 21. Triennial early coast-wide, north (WA and OR), and south (CA) survey indices.

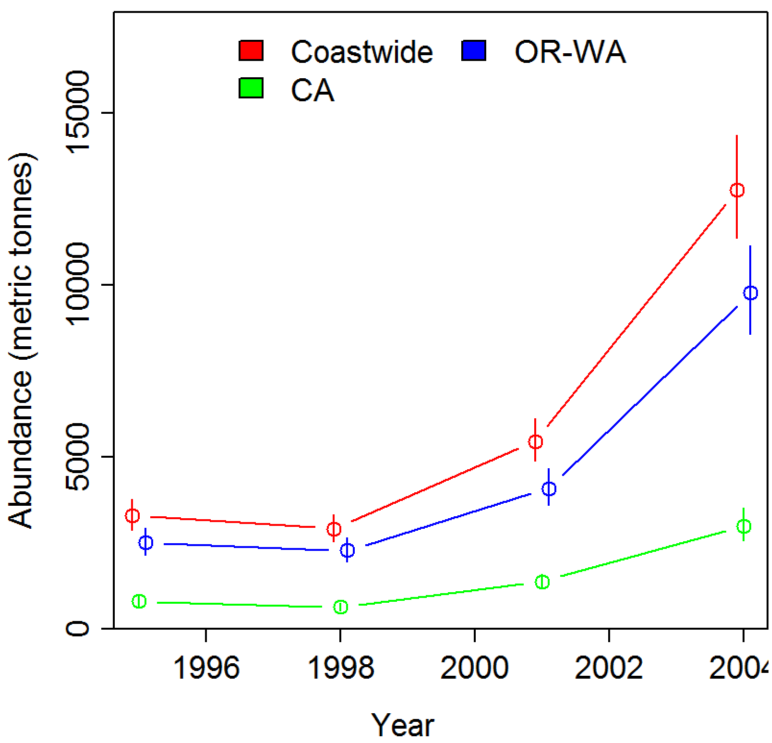


Figure 22. Triennial late coast-wide, north (WA and OR), and south (CA) survey indices.

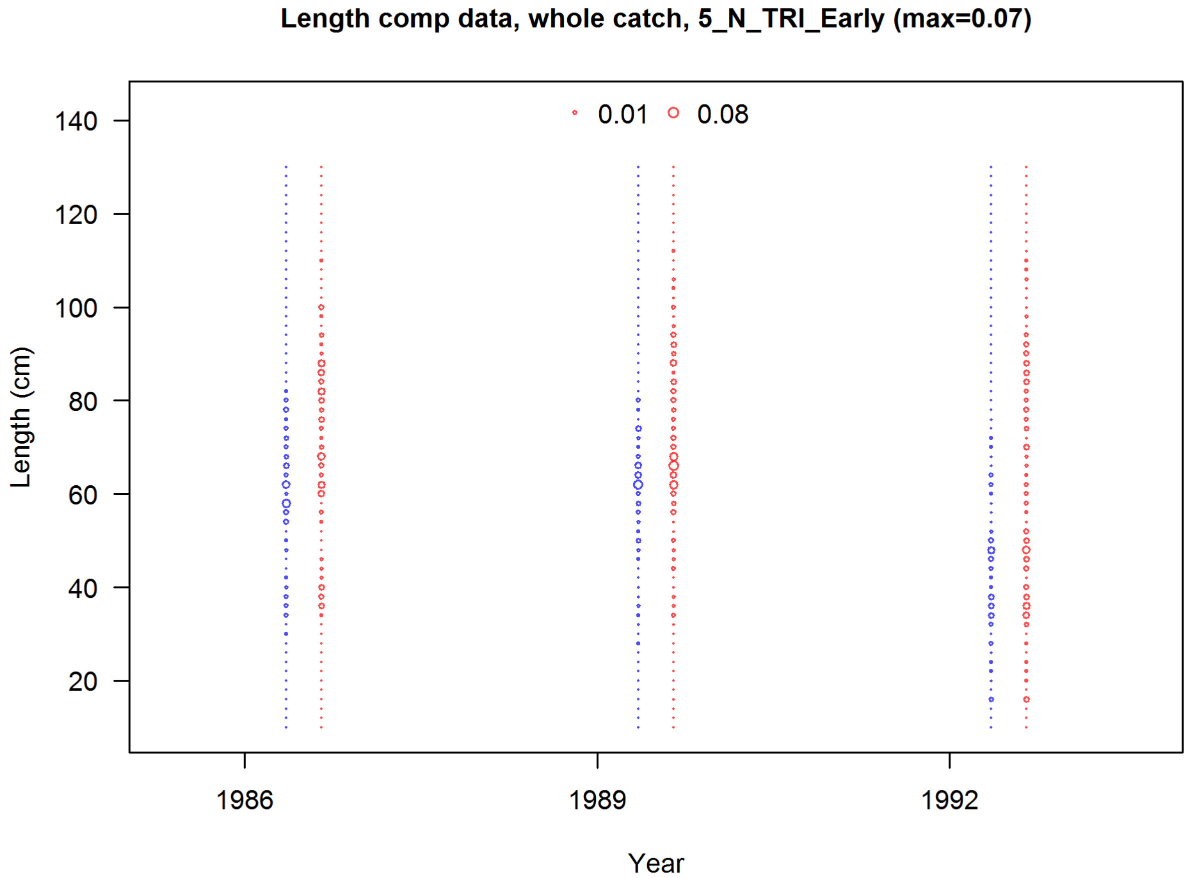


Figure 23. Triennial early survey composition data, north.

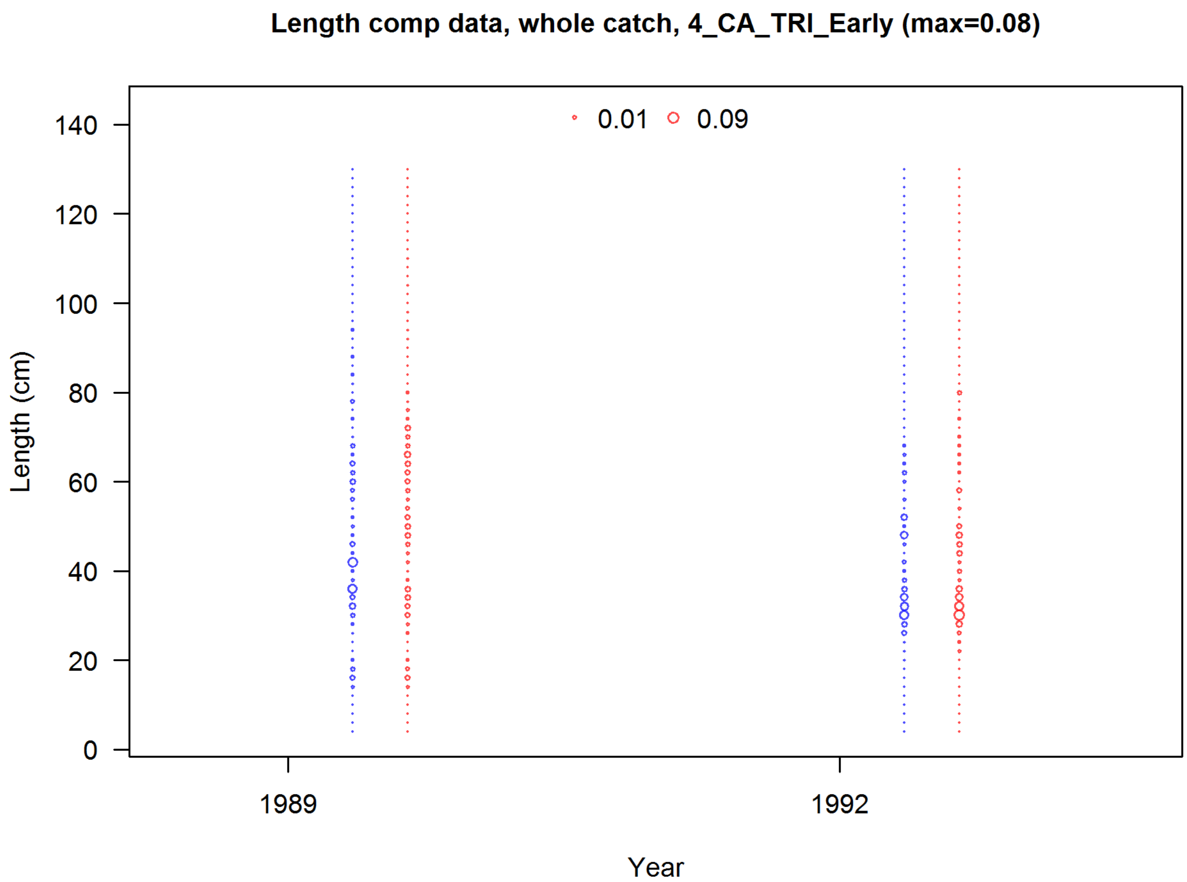


Figure 24. Triennial early survey composition data, south.

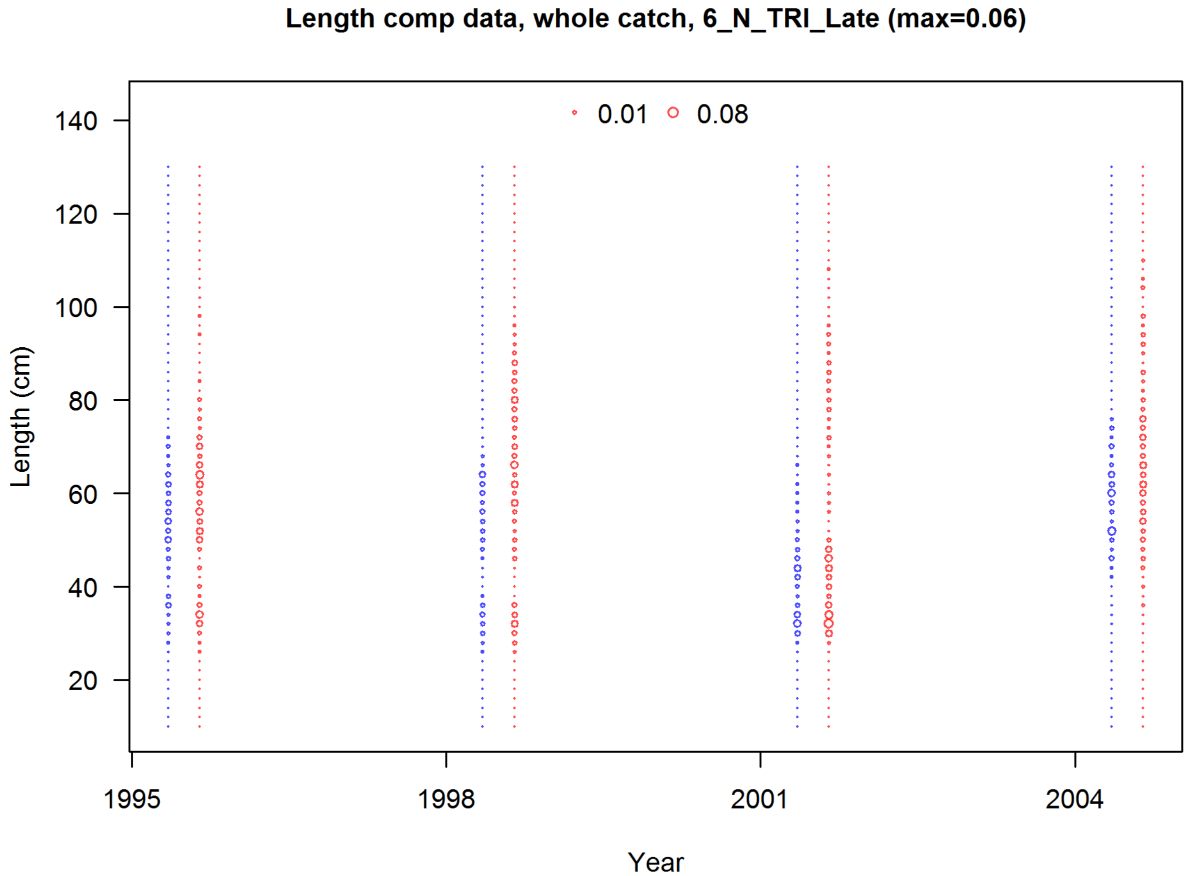


Figure 25. Triennial late survey composition data, north.

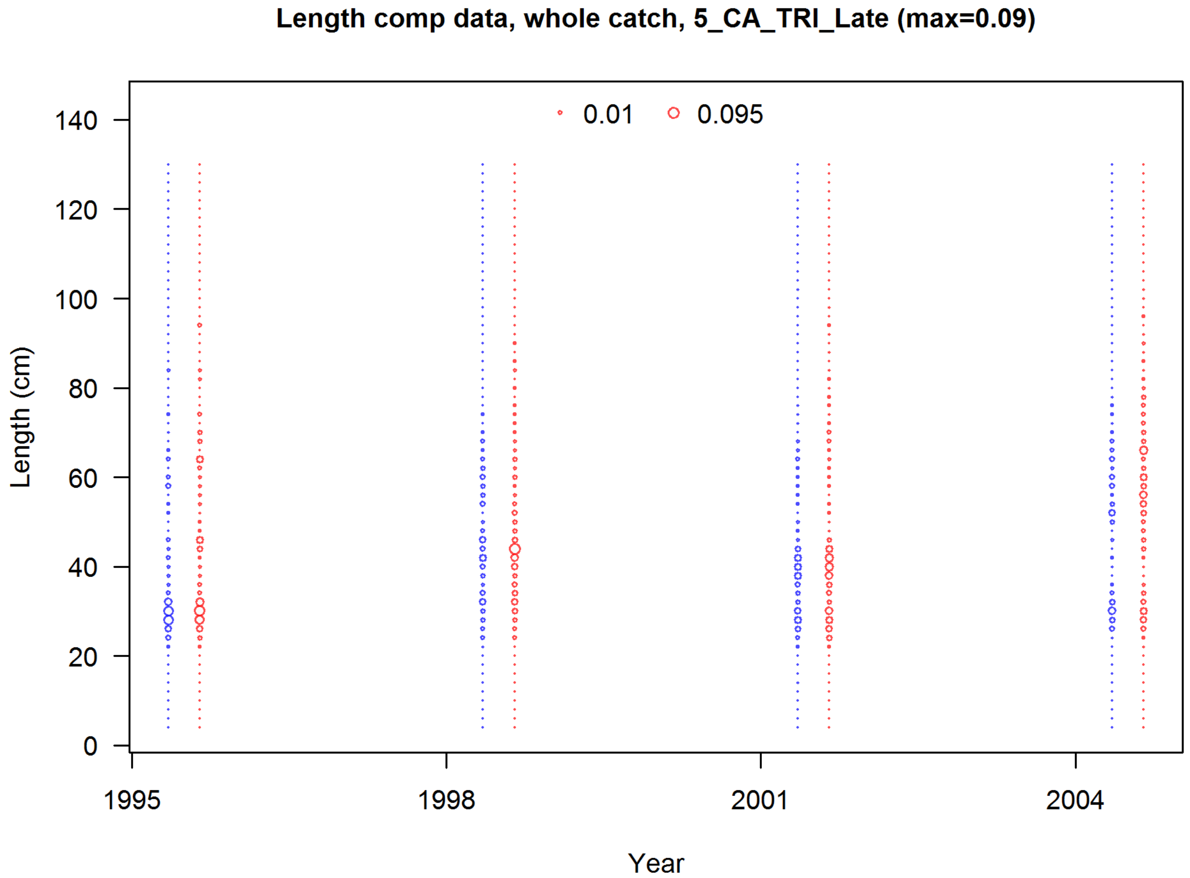


Figure 26. Triennial late survey composition data, south.

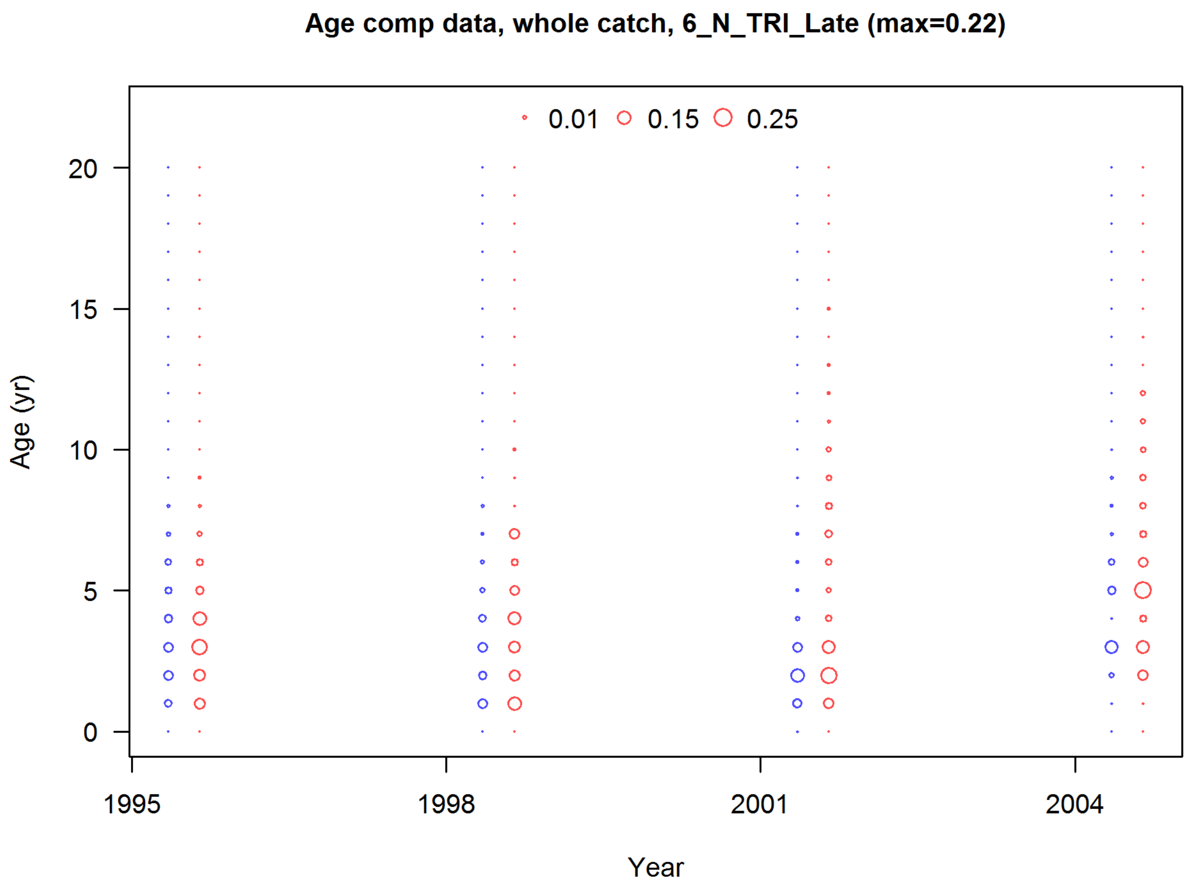


Figure 27. Triennial late age composition data, north.

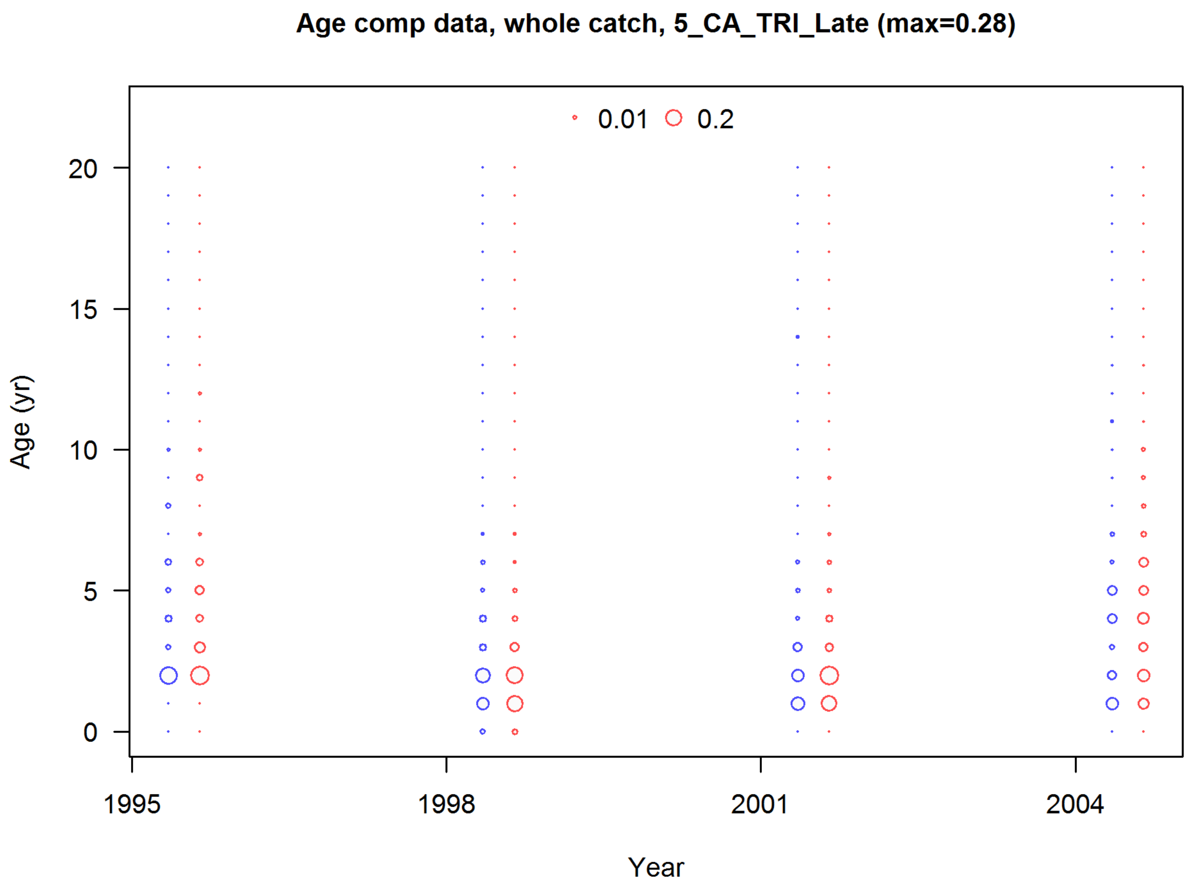


Figure 28. Triennial survey late age composition data, south.

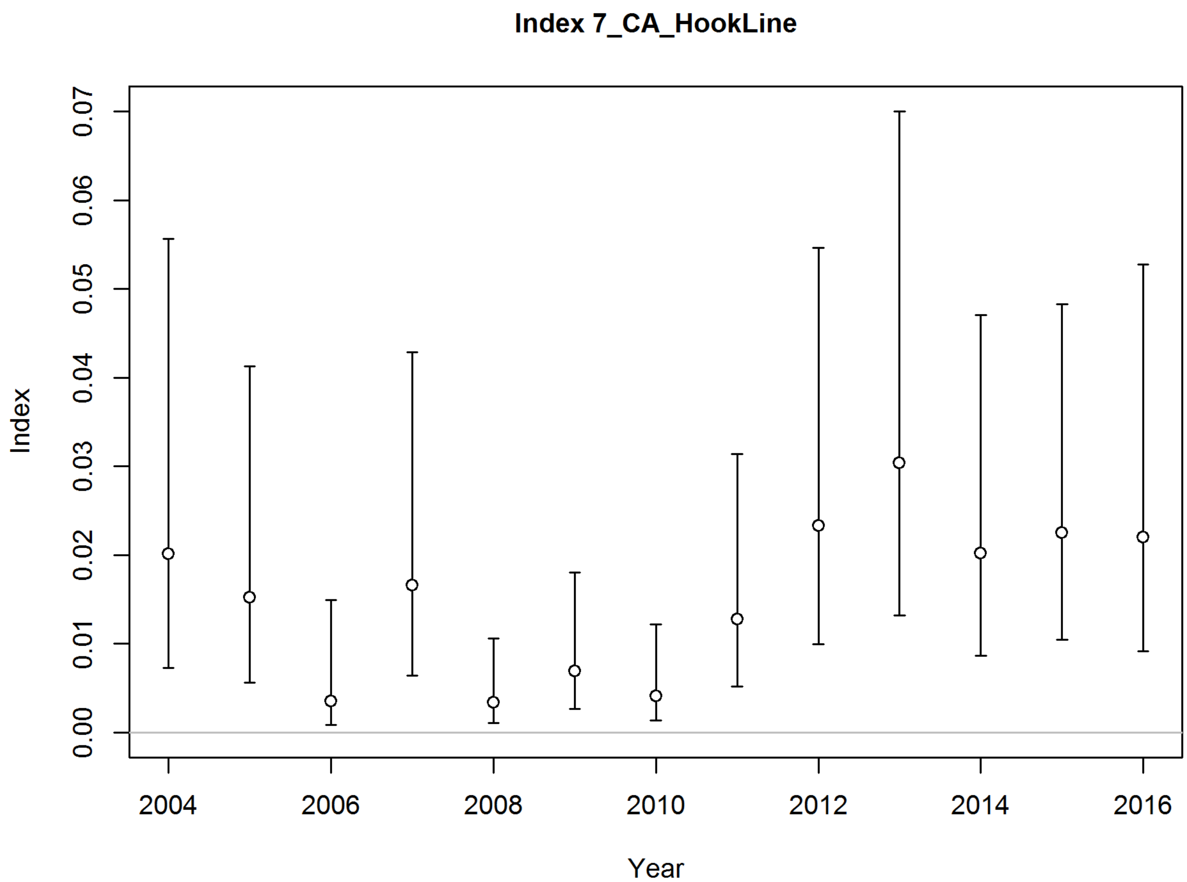


Figure 29. Southern CA Hook and Line survey posterior median index values (MCMC) with 95% prediction intervals.

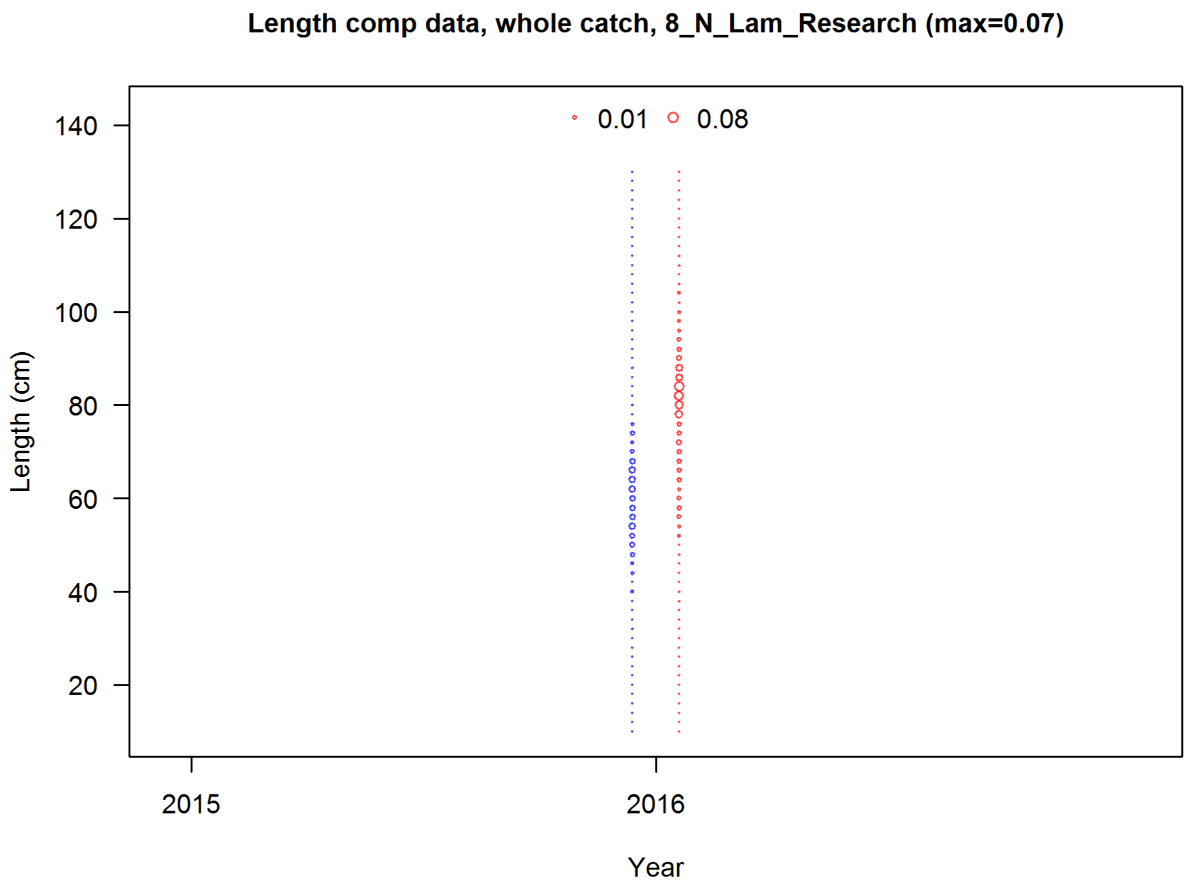


Figure 30. WA research length compositions, north.

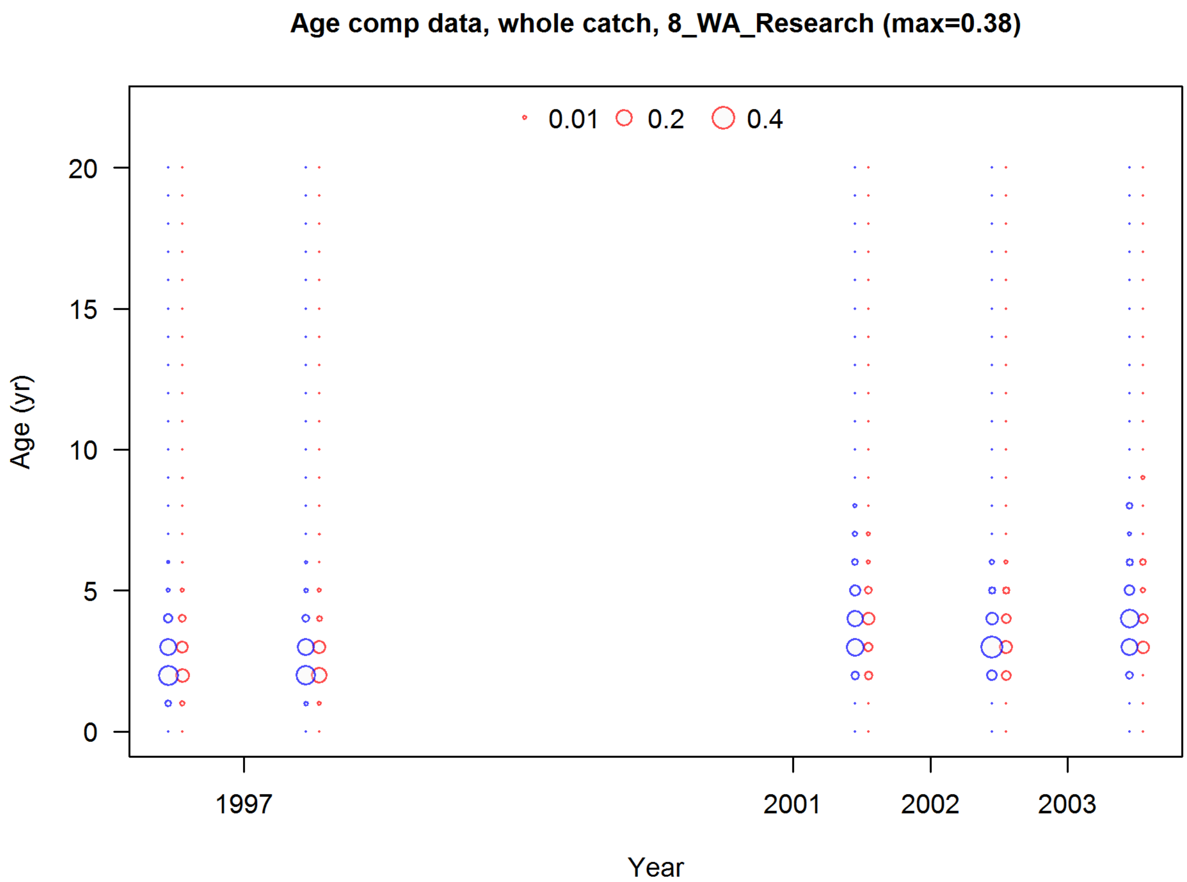


Figure 31. WA research age compositions, north.

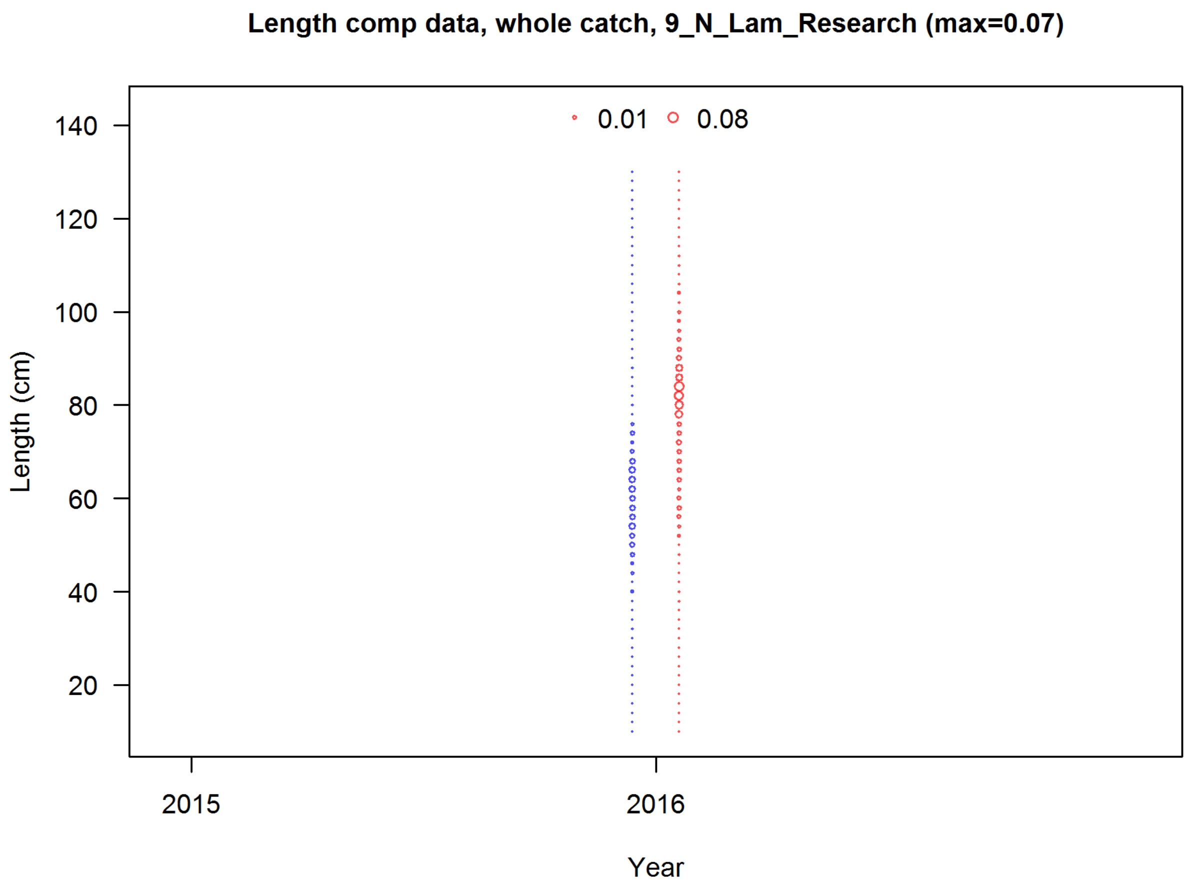


Figure 32. Lam research lengths, north.

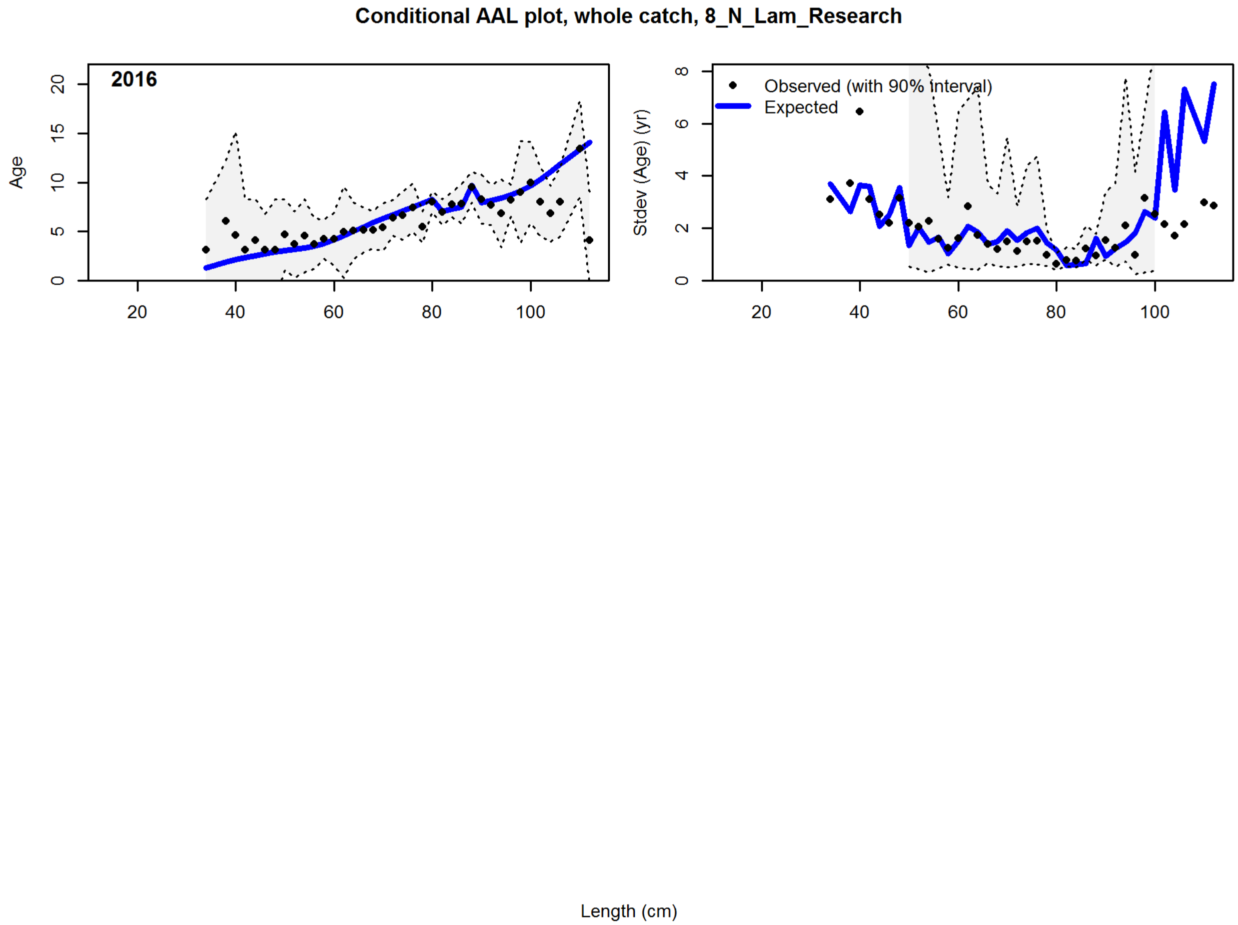


Figure 33. Lam research age compositions, north.

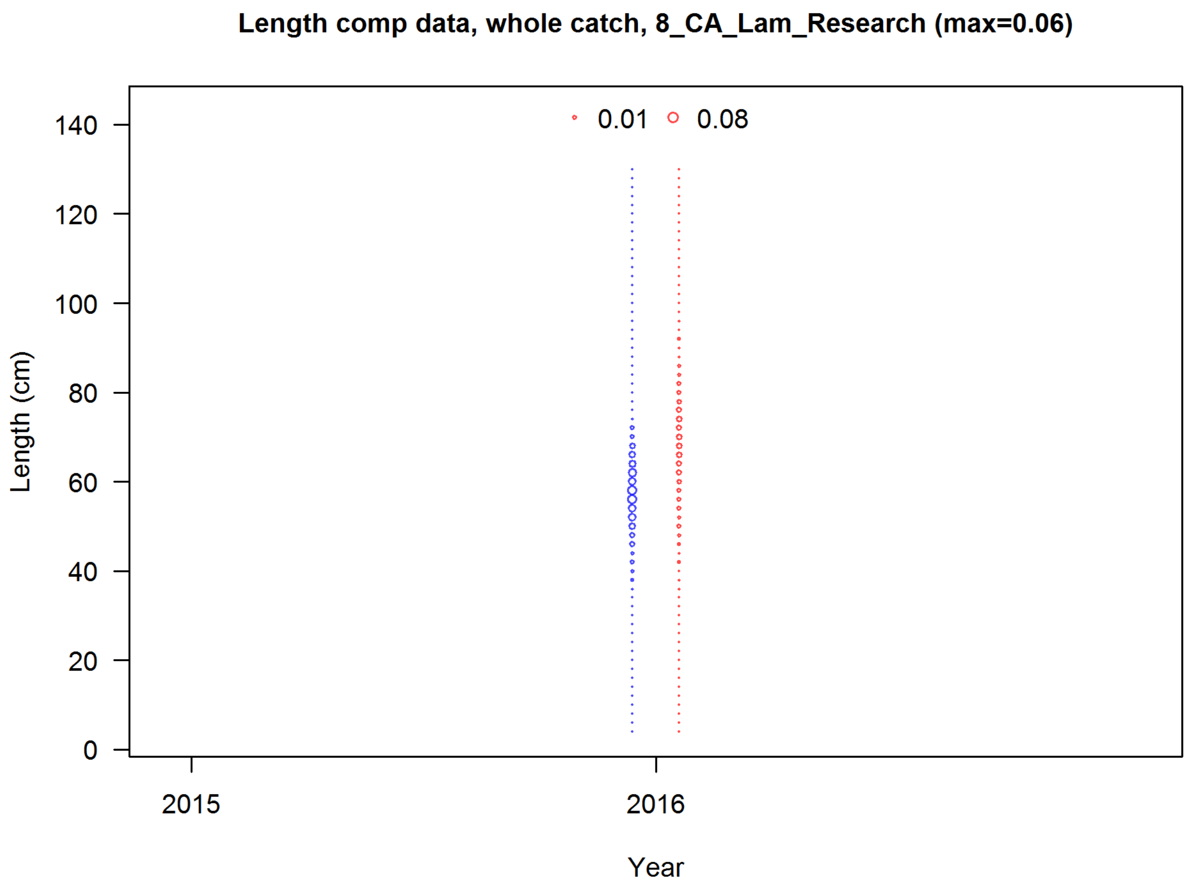


Figure 34. Lam research length compositions, south.

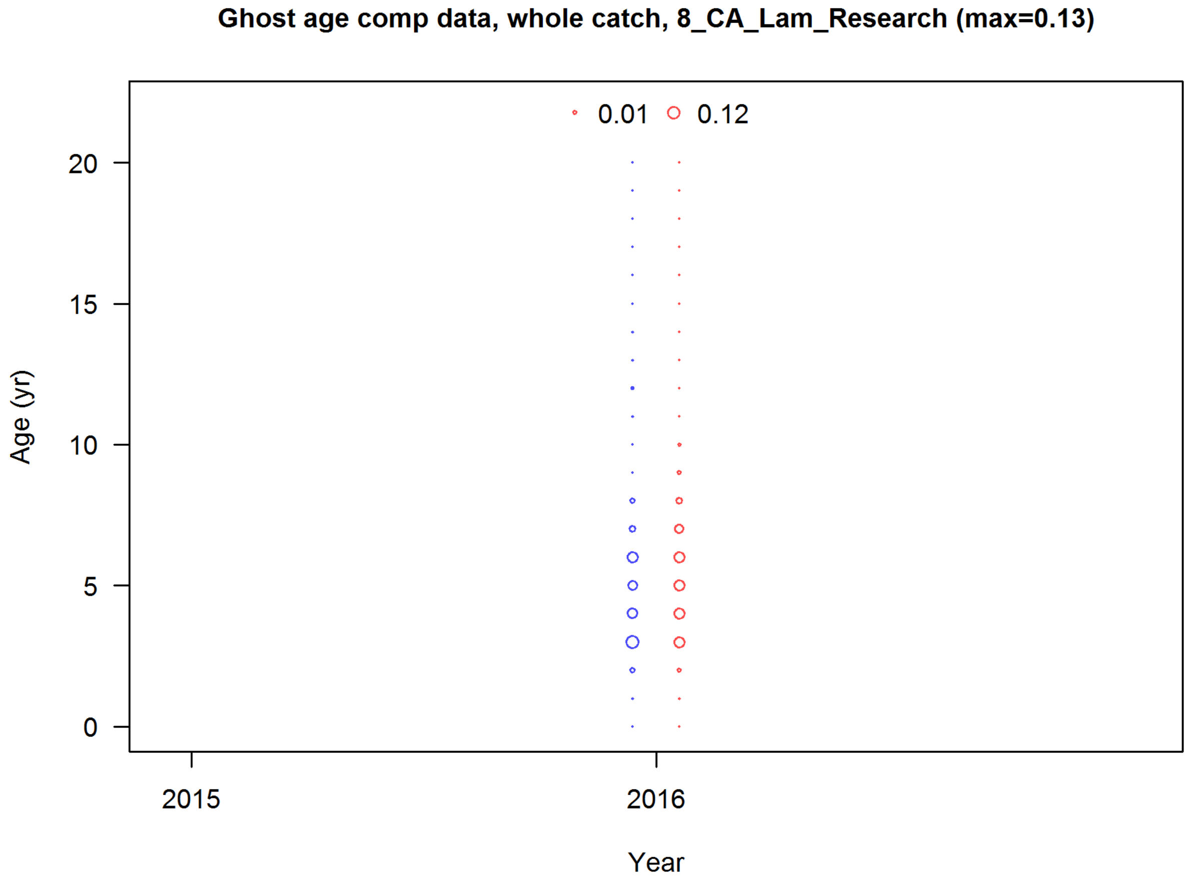


Figure 35. Lam research age compositions, south.

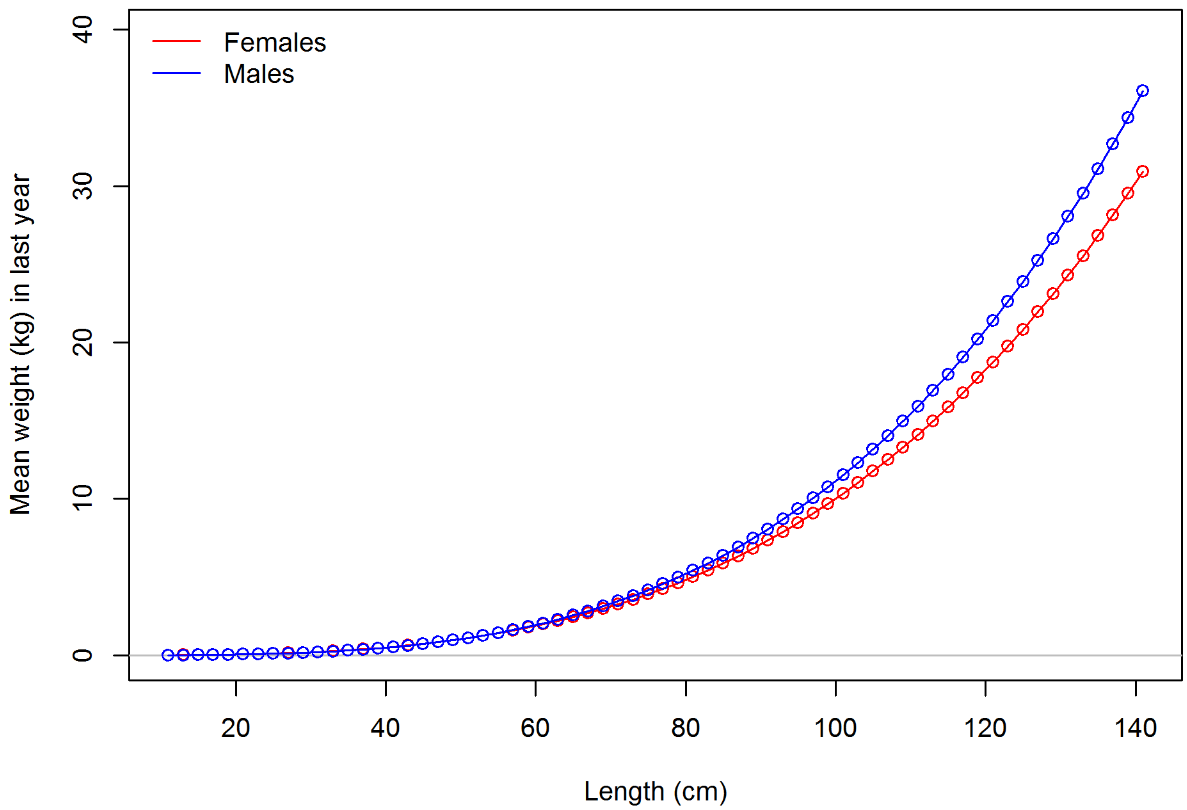


Figure 36. Length-weight relationship, north.

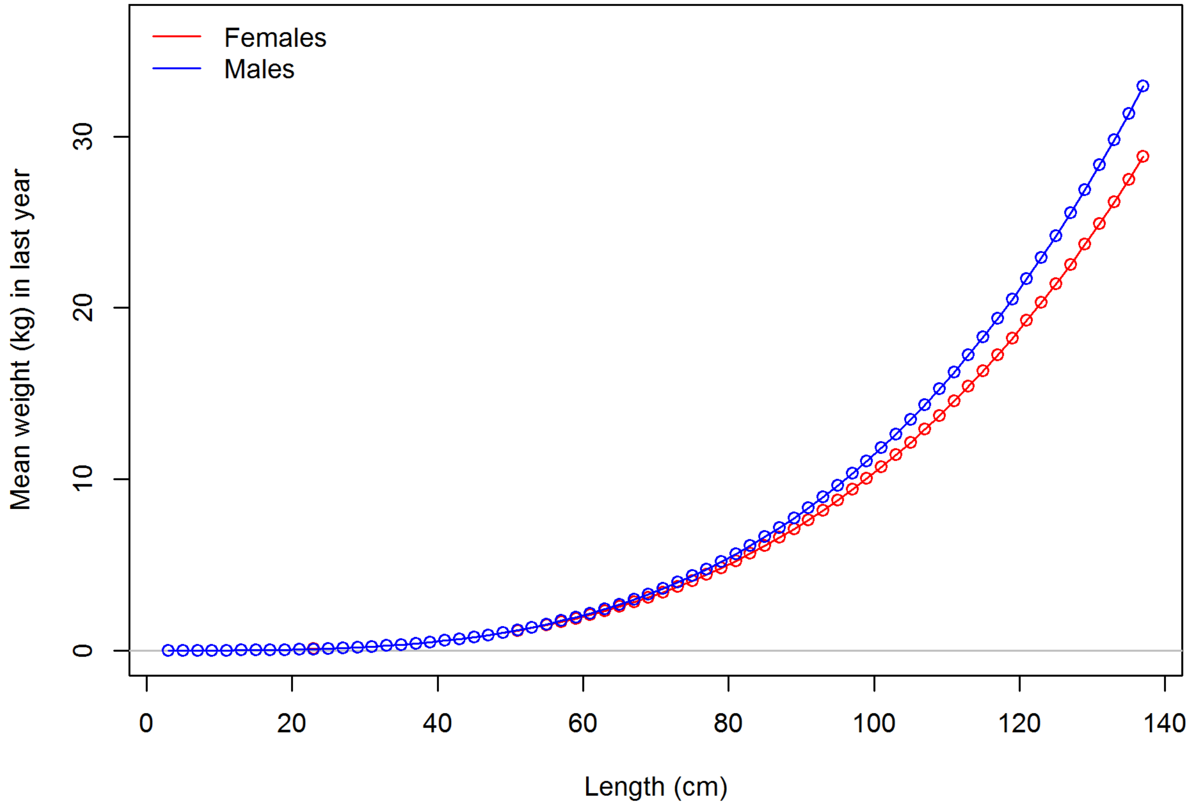


Figure 37. Length-weight relationship, south.

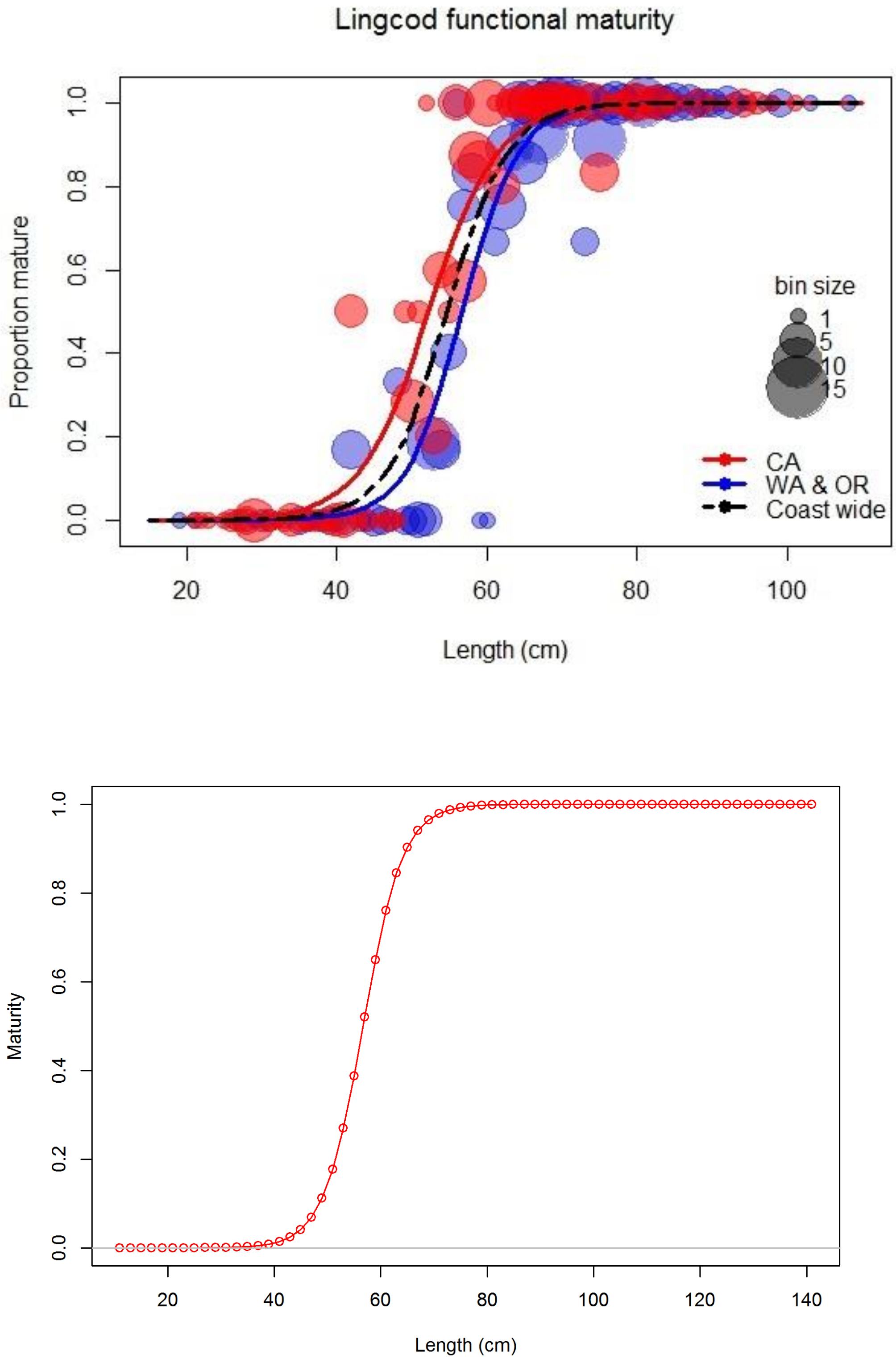


Figure 38. Maturity ogives, the top panel shows the data used to fit maturity ogives for both the north and south regions, the bottom panel shows the input to the north model.

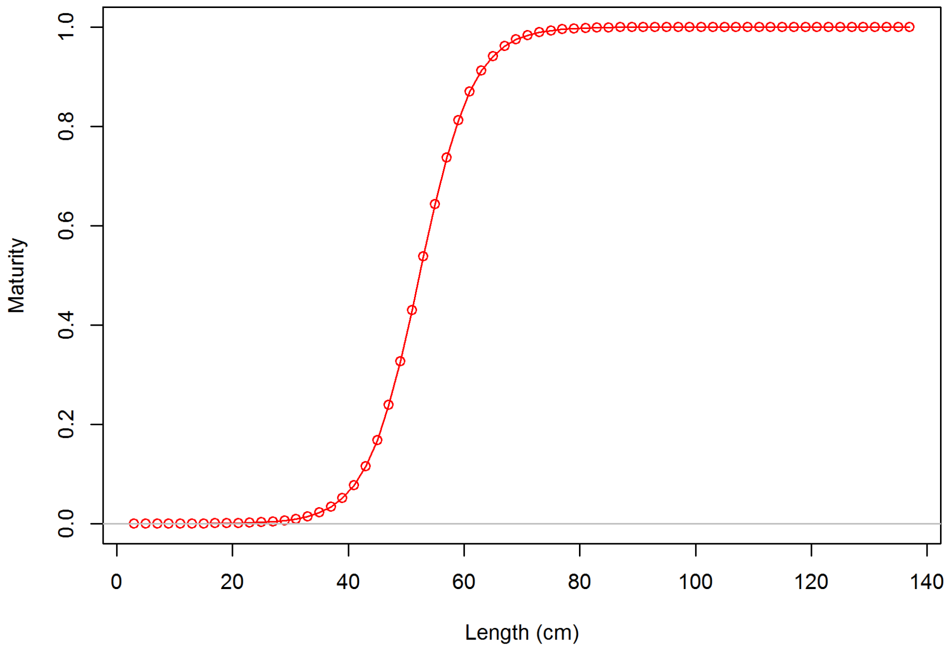


Figure 39. Maturity ogive input to the south.

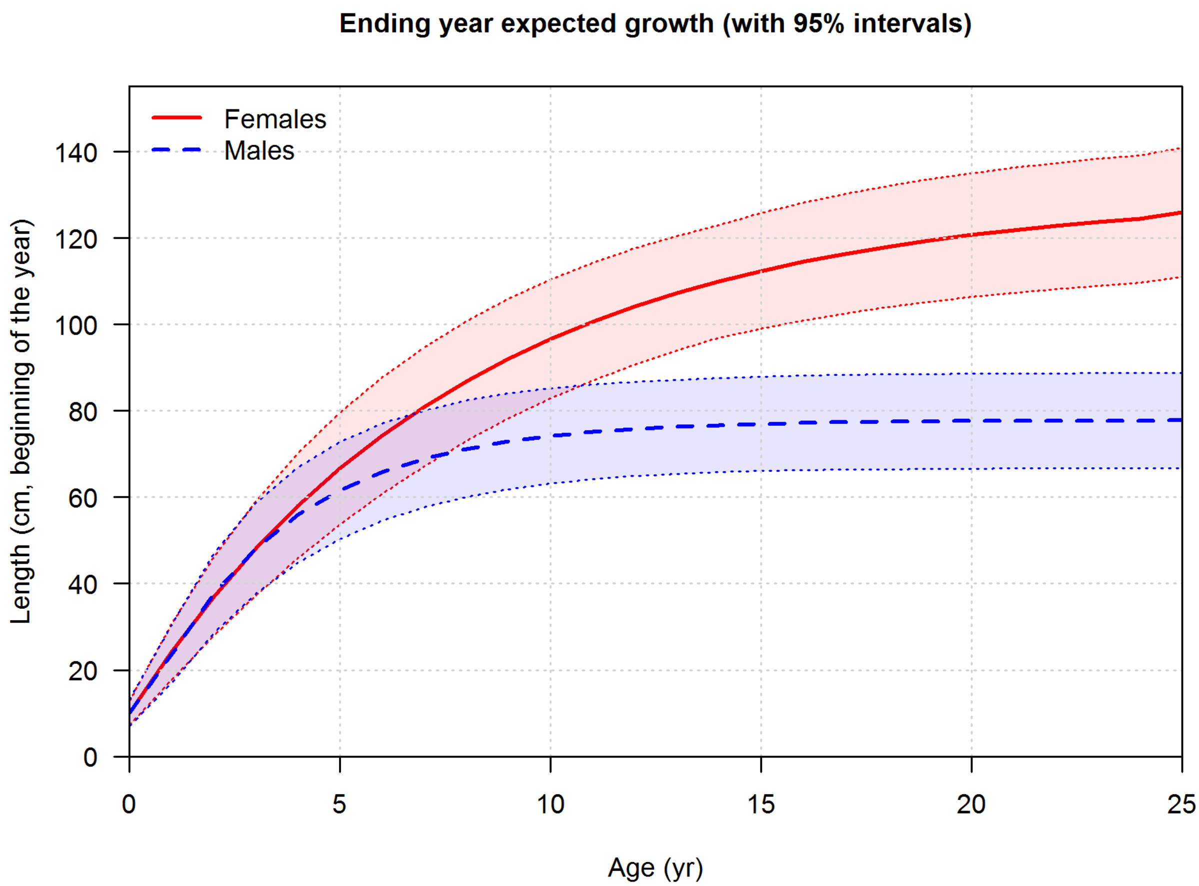


Figure 40. Model estimated growth, north.

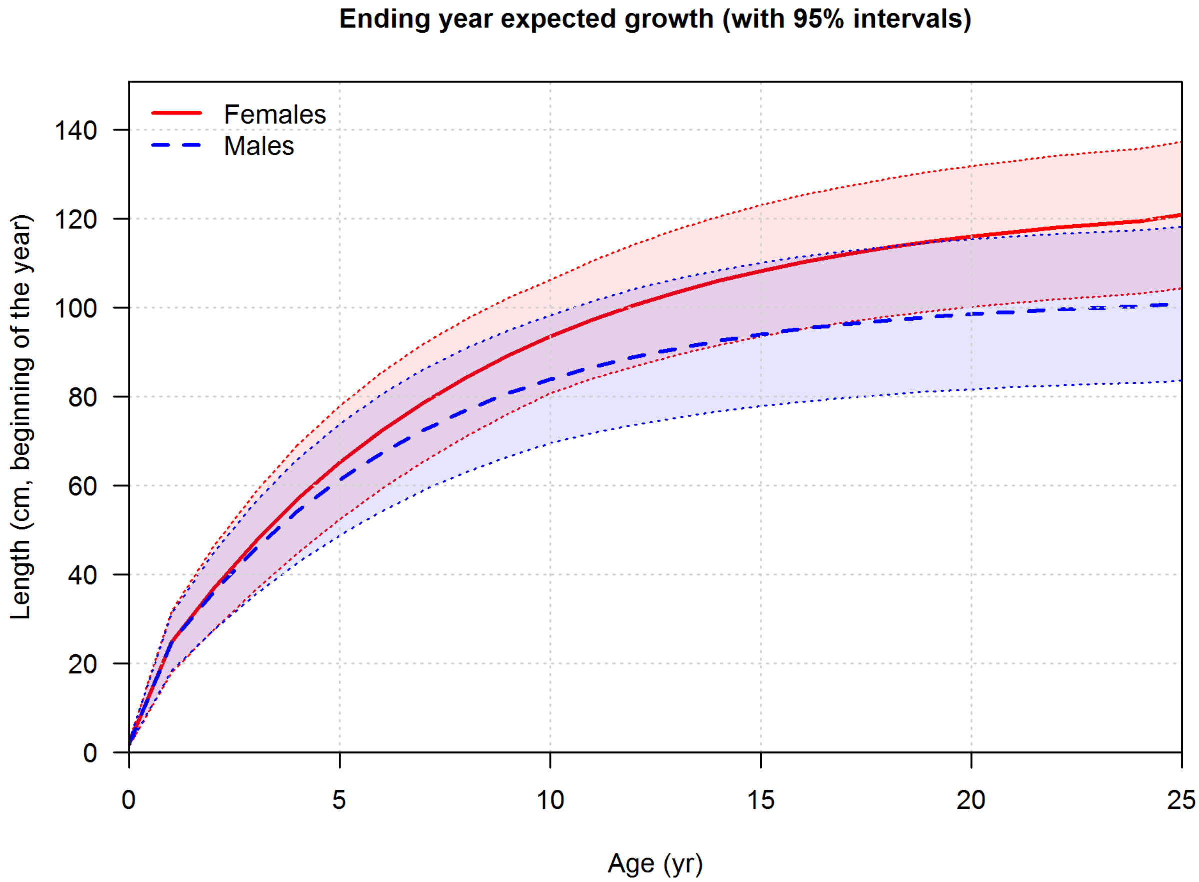


Figure 41. Model estimated growth, south

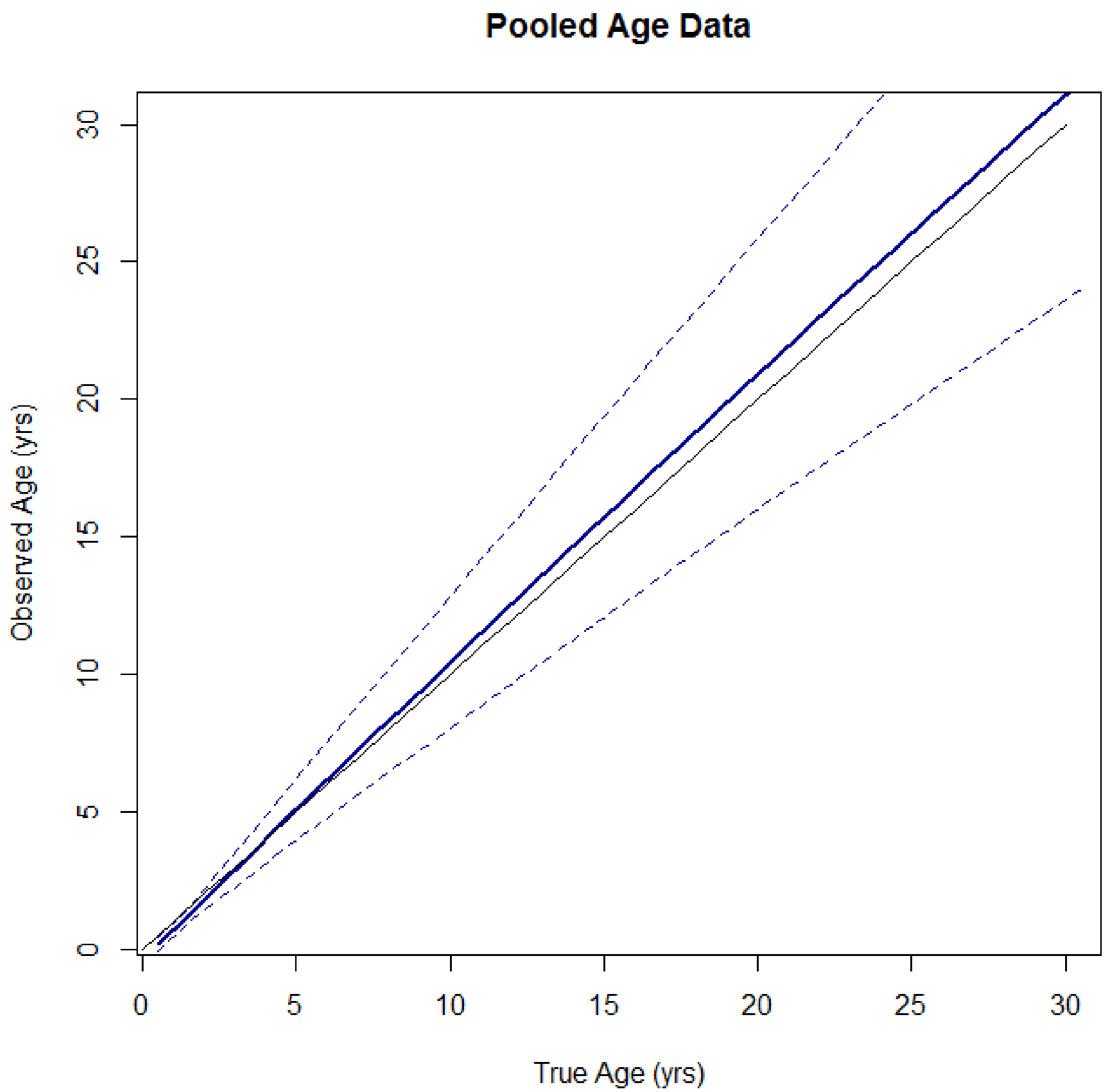


Figure 42. Aging error bias between labs and variability. The difference between the black 1:1 line (WDFW Lab) and the blue line (CAP) labs shows that the two labs age similarly, with the CAP lab aging fish as slightly older at older ages.

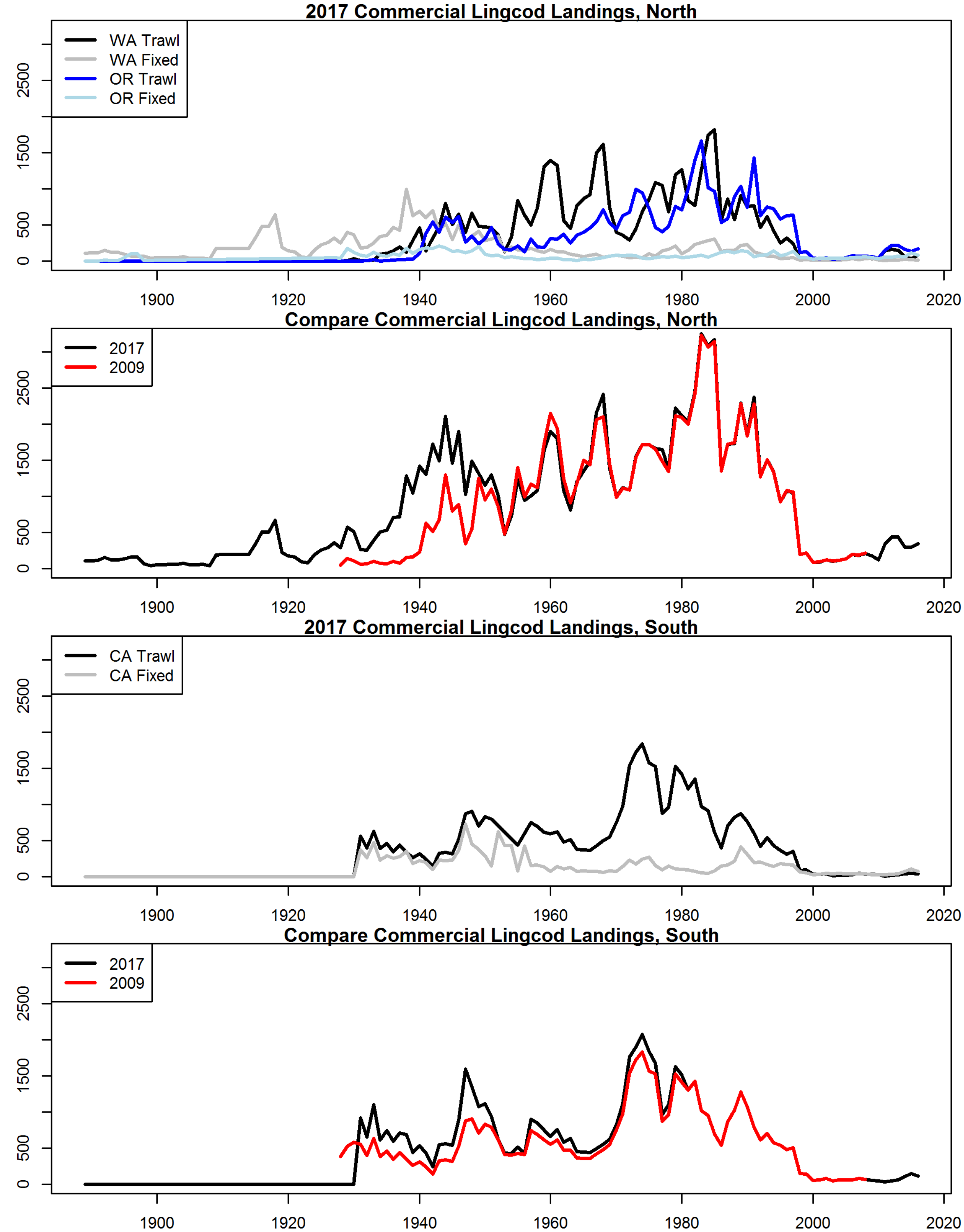


Figure 43. Commercial trawl and fixed gear fleets landings for the north and the south, along with comparison between landings used in the 2009 assessment and current assessment. Note that this figure only includes recorded data and not the assumed early catch ramp for CA used in the base model of this assessment.

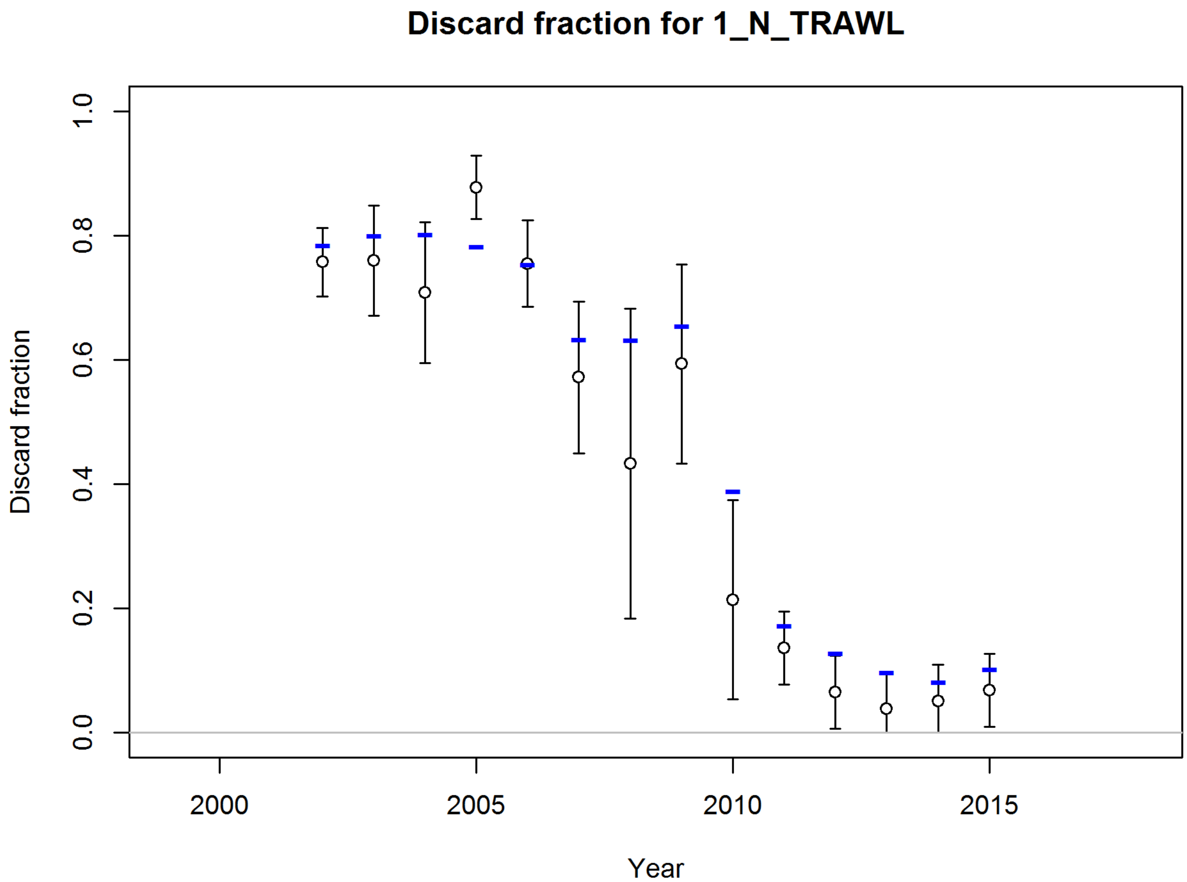


Figure 44. Discard fraction (circles) and the bootstrap uncertainty (vertical lines), trawl fleet, north. The blue horizontal lines are model fits to data.

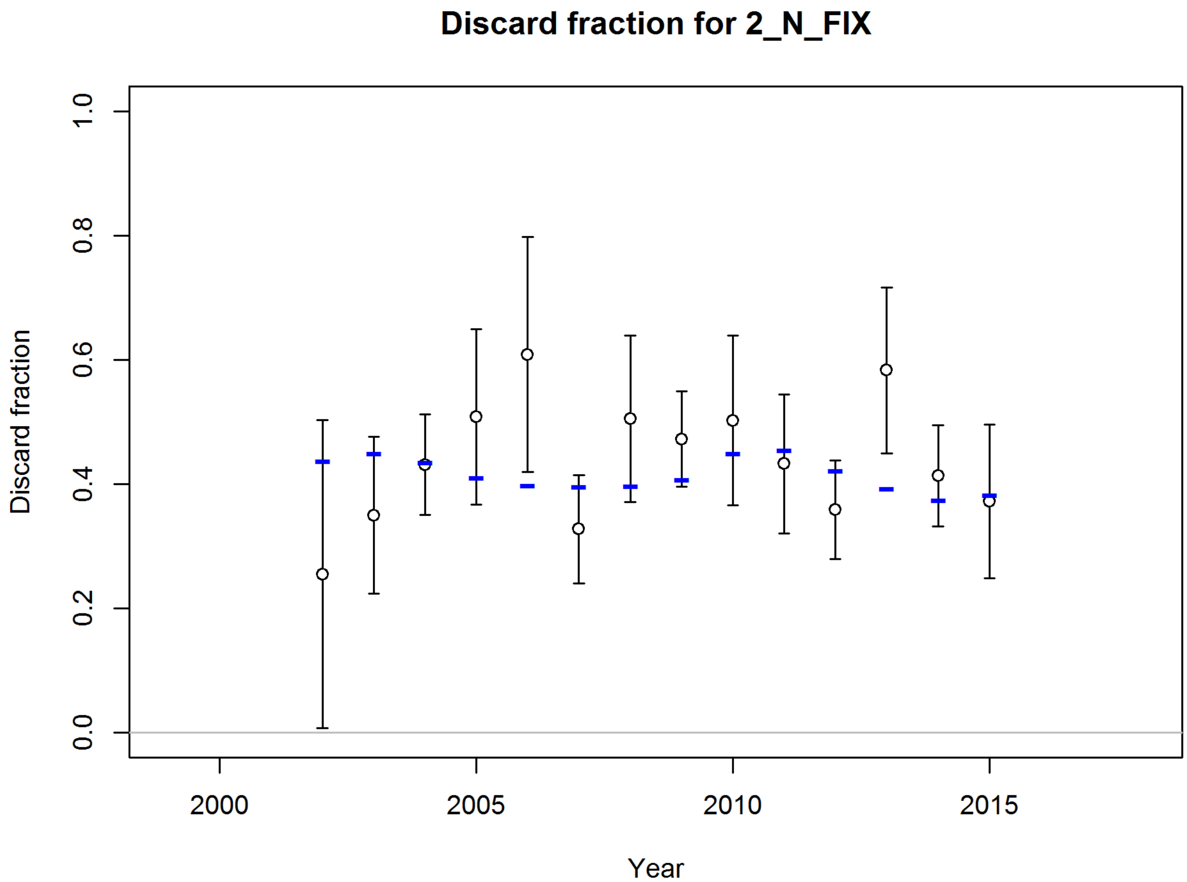


Figure 45. Discard fraction (circles) and the bootstrap uncertainty (vertical lines), fixed gear fleet, north. The blue horizontal lines are model fits to data.

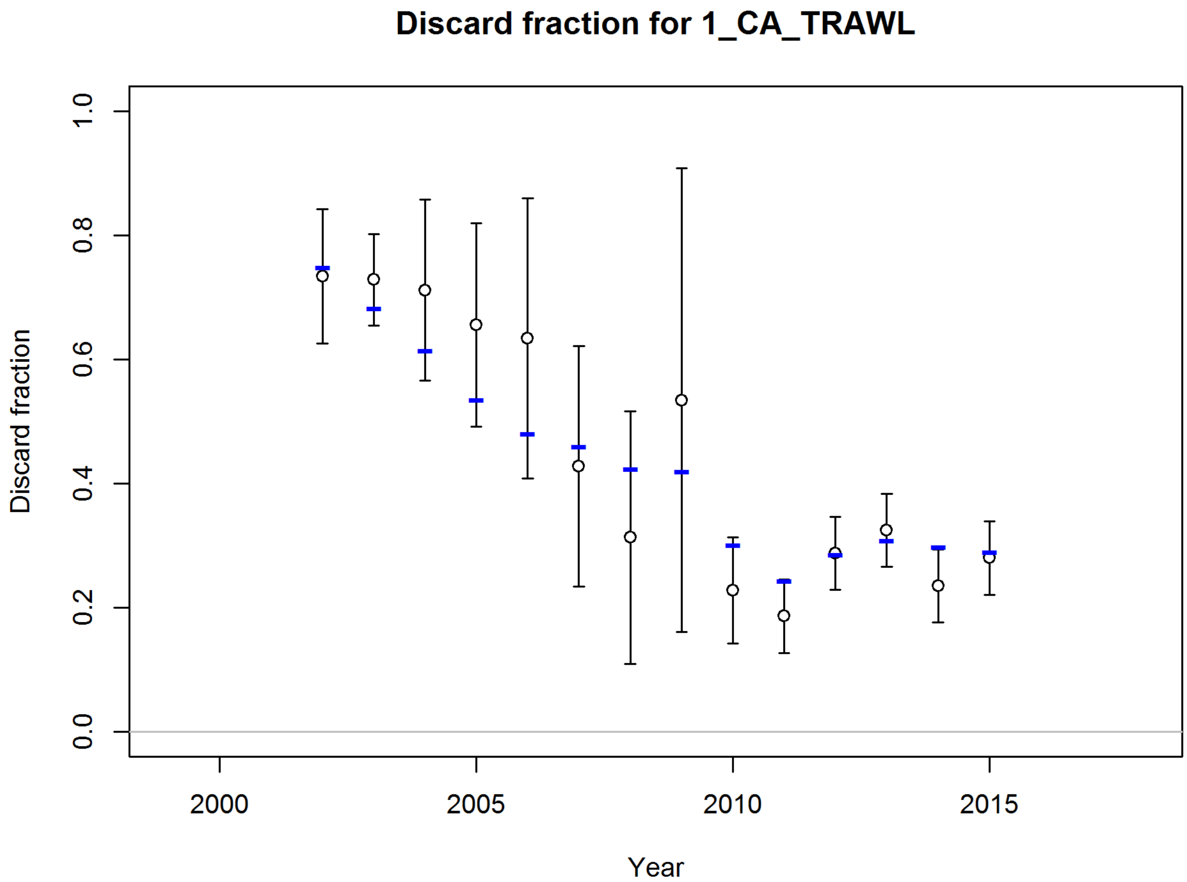


Figure 46. Discard fraction (circles) and the bootstrap uncertainty (vertical lines), trawl fleet, south. The blue horizontal lines are model fits to data.

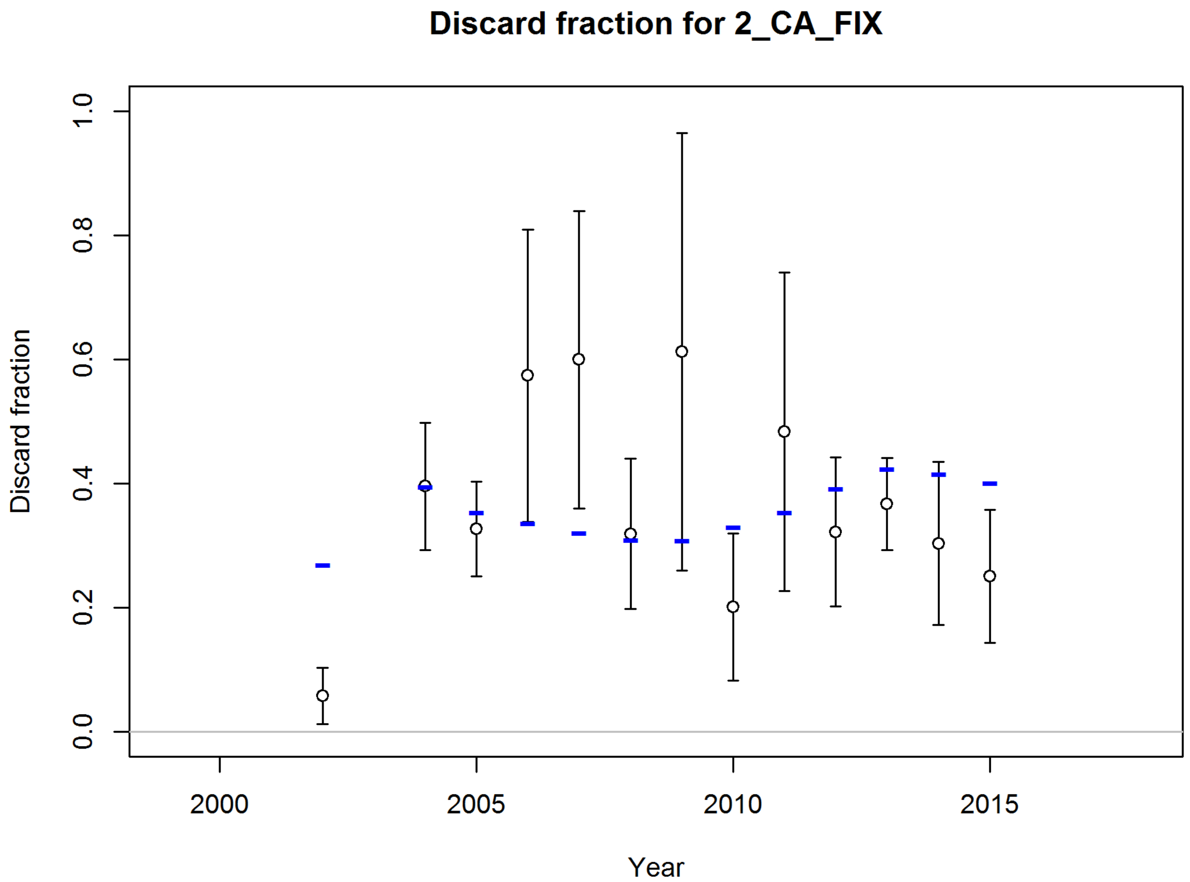


Figure 47. Discard fraction (circles) and the bootstrap uncertainty (vertical lines), fixed gear fleet, south. The blue horizontal lines are model fits to data.

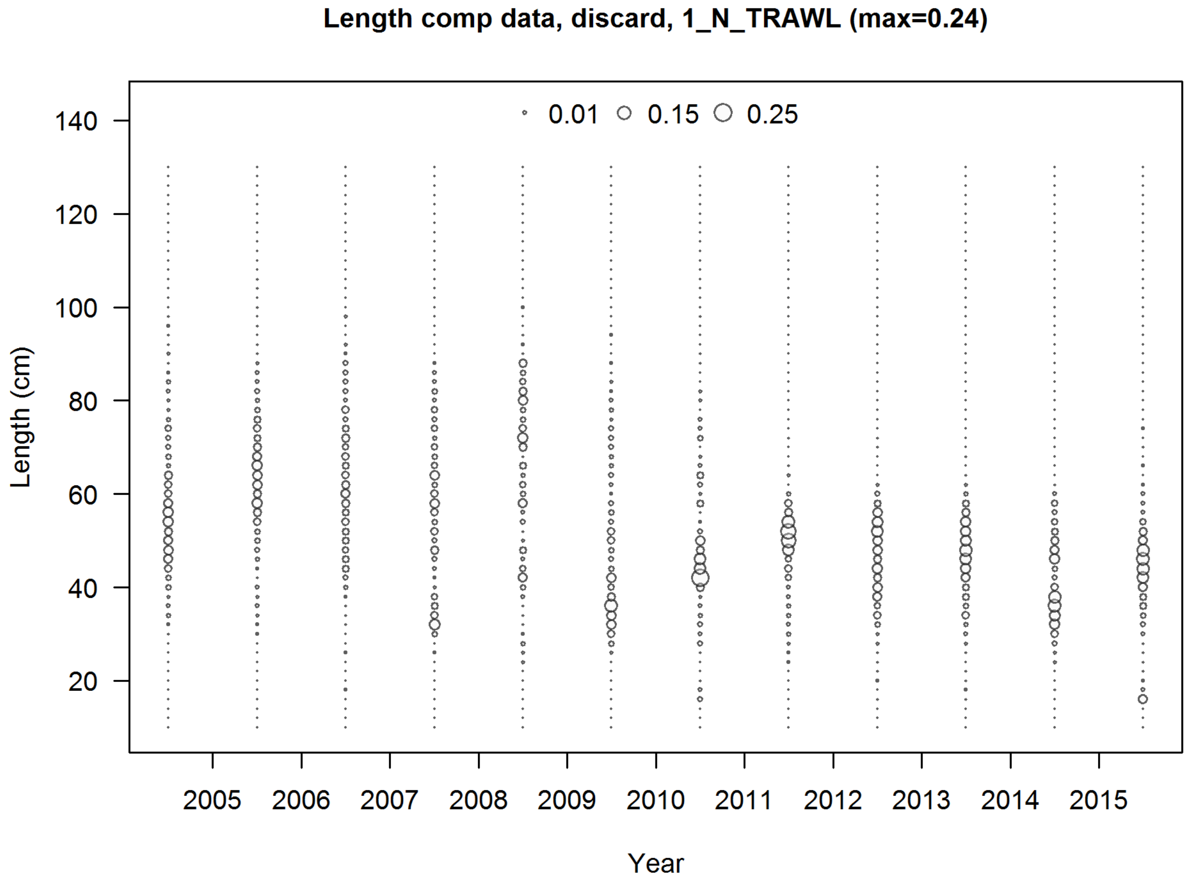


Figure 48. Discard length compositions, trawl fleet, north.

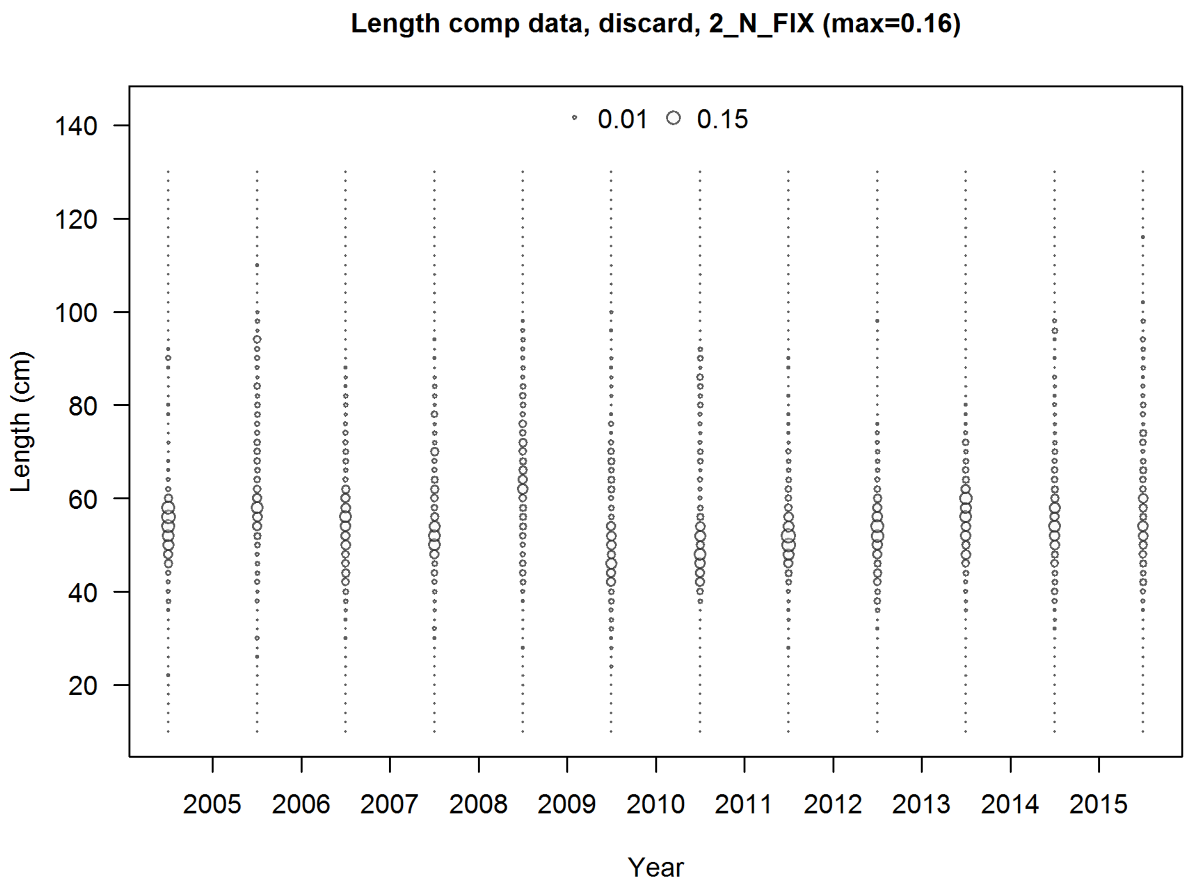


Figure 49. Discard length compositions, fixed gear fleet, north.

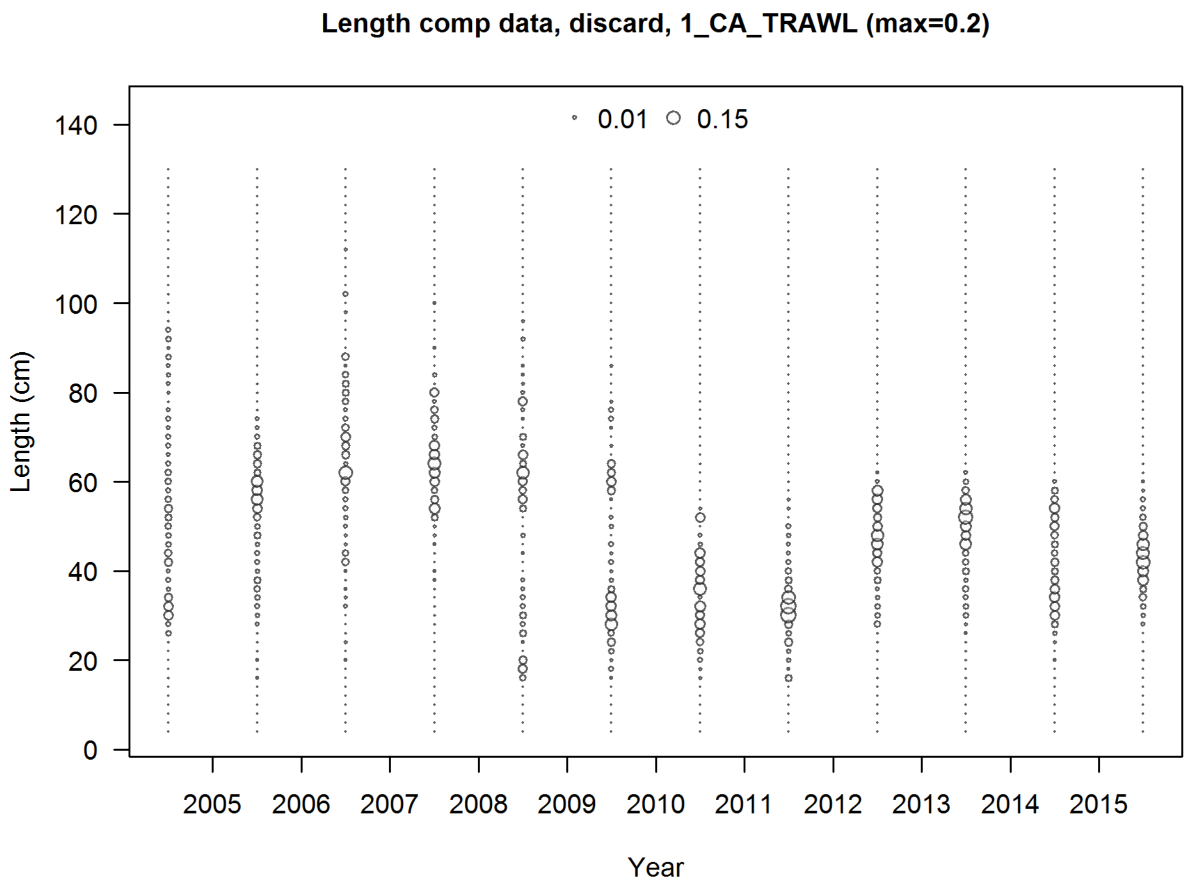


Figure 50. Discard length compositions, trawl, south.

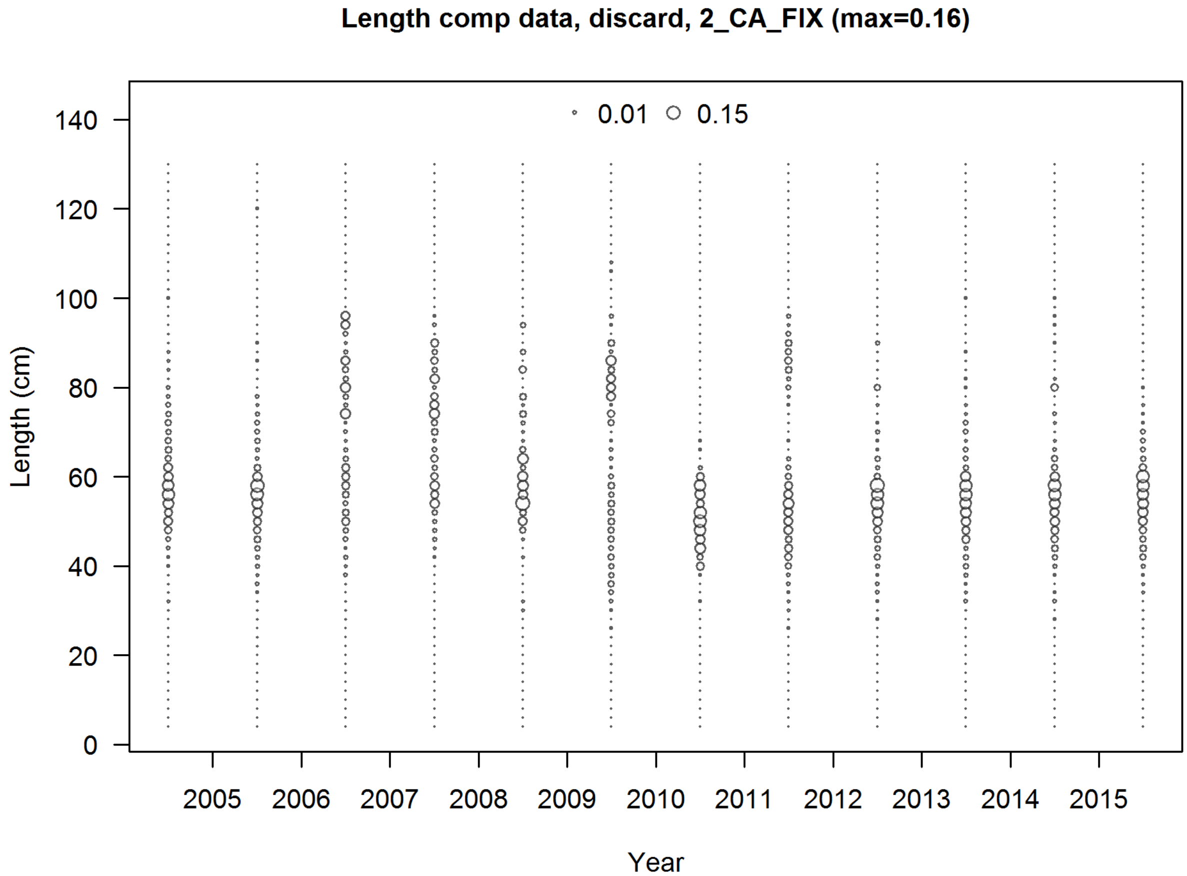


Figure 51. Discard length compositions, fixed gear fleet, south.

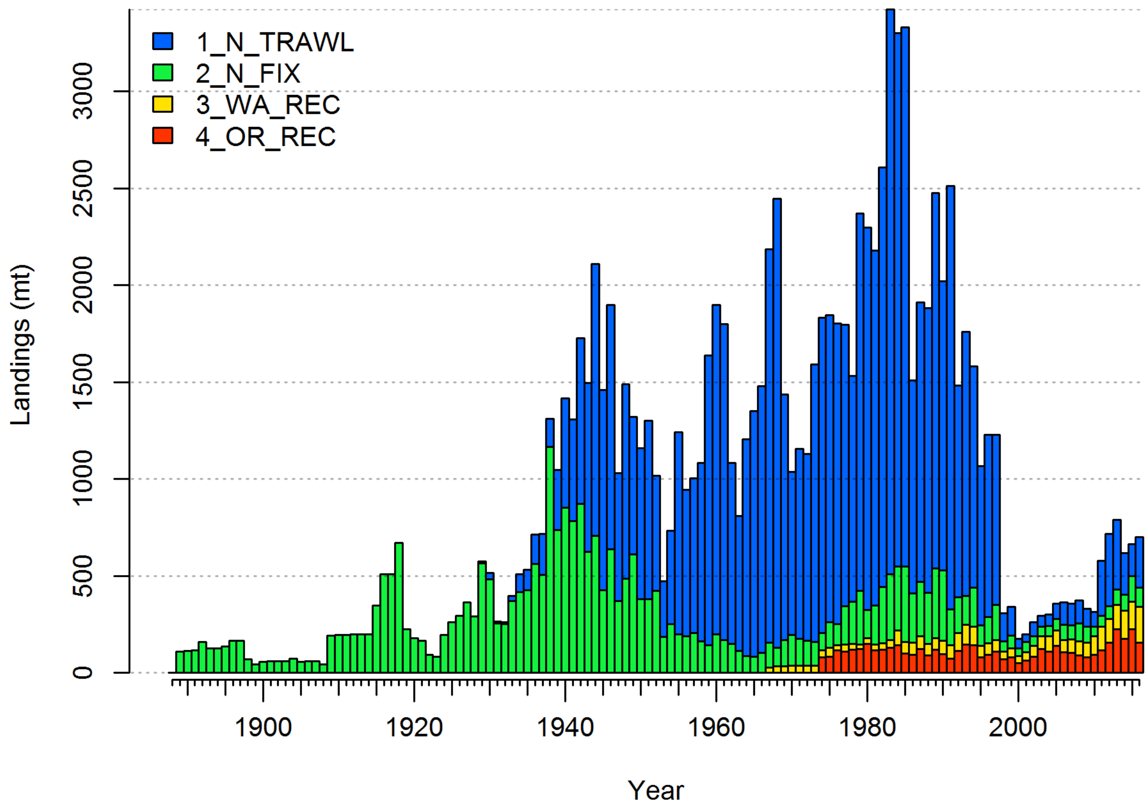


Figure 52. Commercial and recreational landings, north.

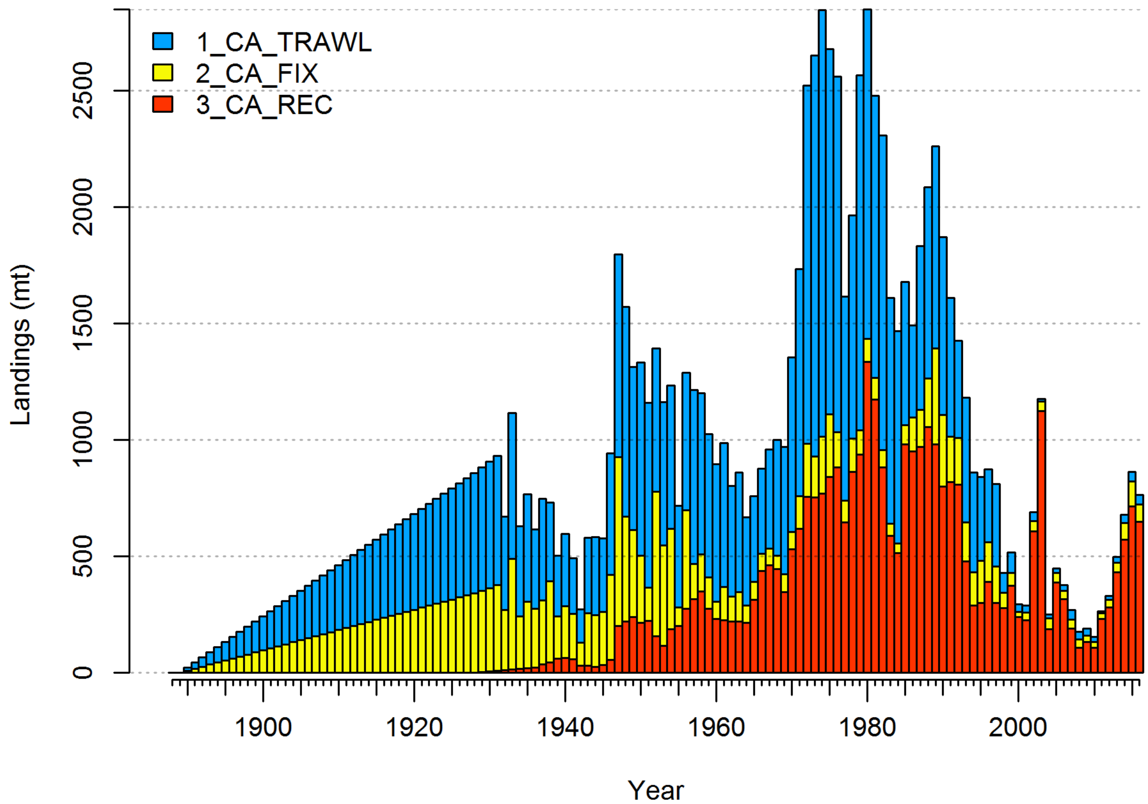


Figure 53. Commercial and recreational landings, south.

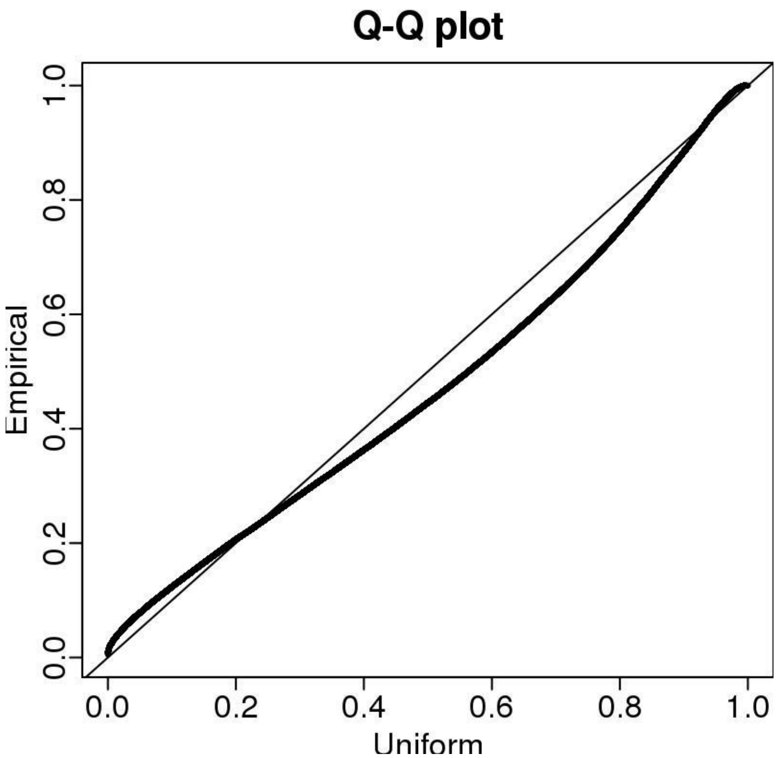


Figure 54. PacFIN logbook CPUE index VAST Q-Q plot.

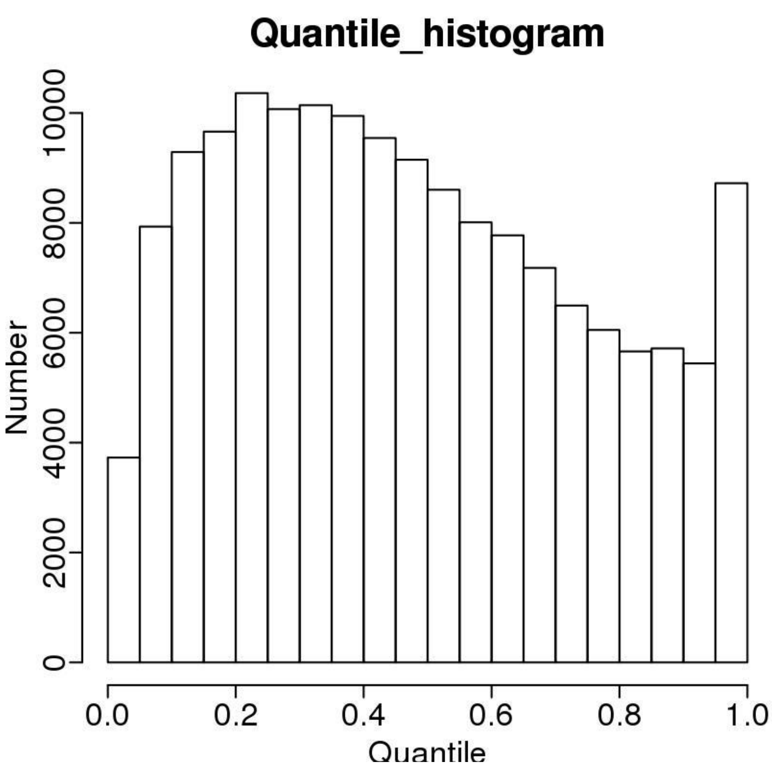


Figure 55. PacFIN logbook CPUE index VAST binned by predicted encounter probability.

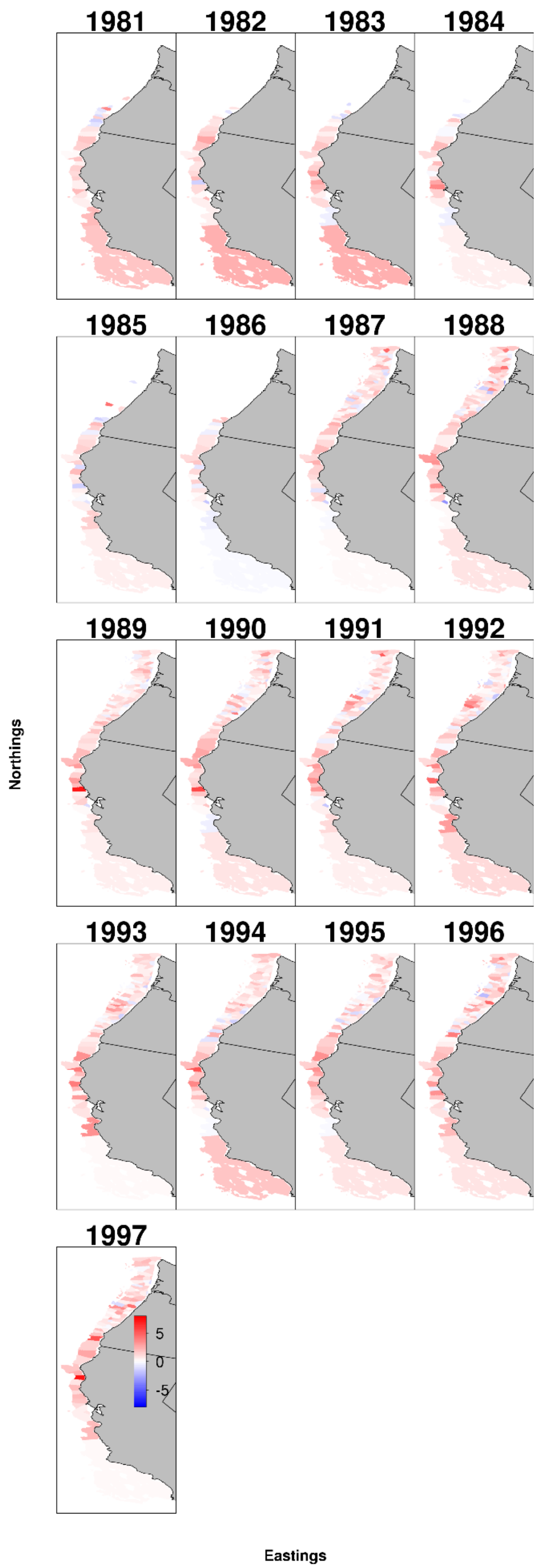


Figure 56. PacFIN logbook CPUE index encounter probability Pearson residuals.

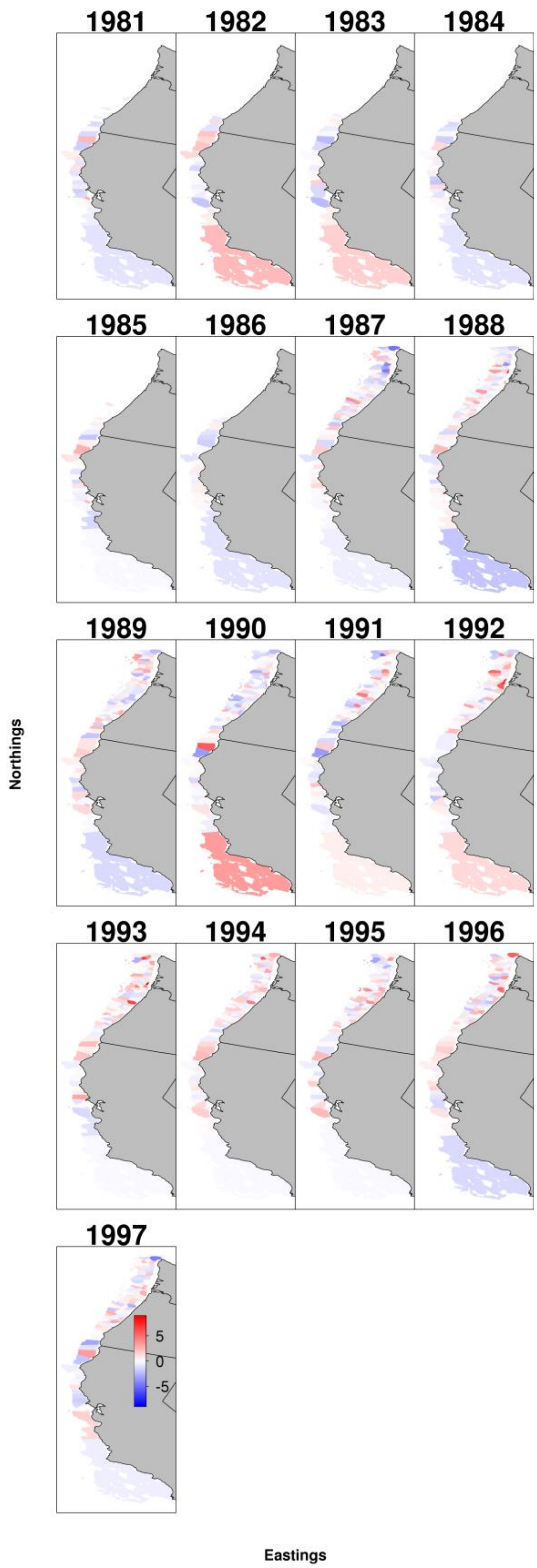


Figure 57. PacFIN logbook CPUE index VAST positive catch rate probability Pearson residuals.

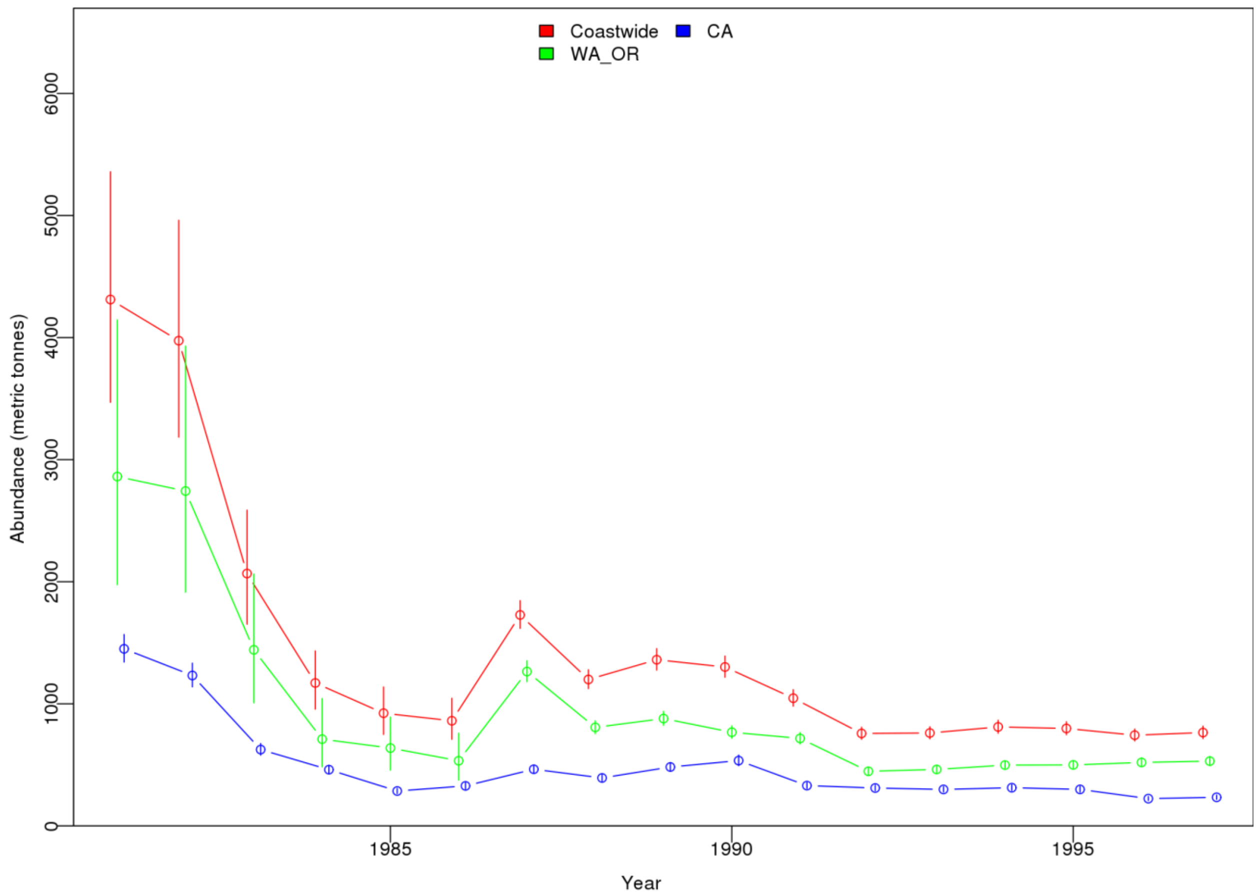


Figure 58. PacFIN logbook CPUE VAST indices.

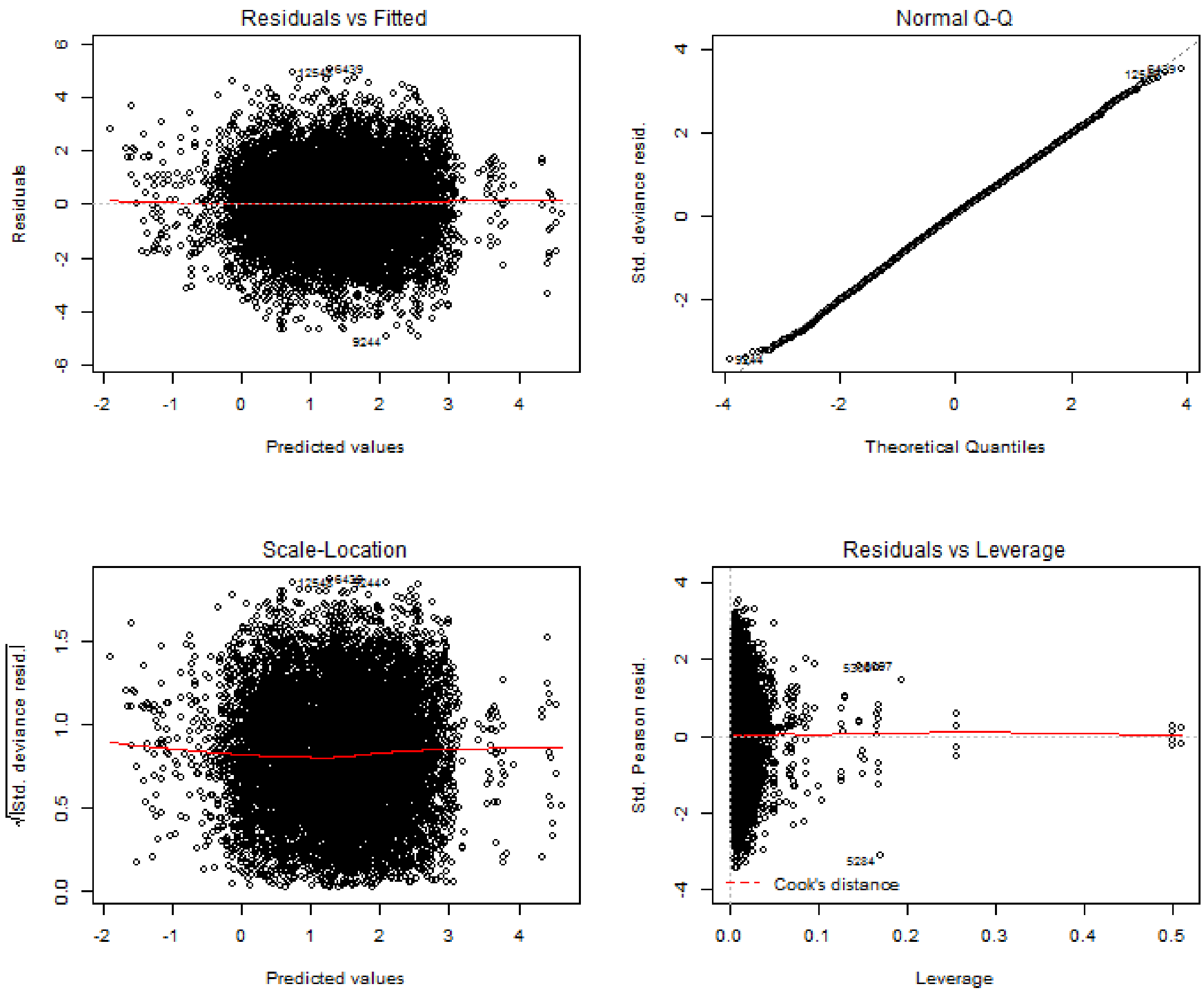


Figure 59. OR commercial nearshore logbook CPUE GLM diagnostics.

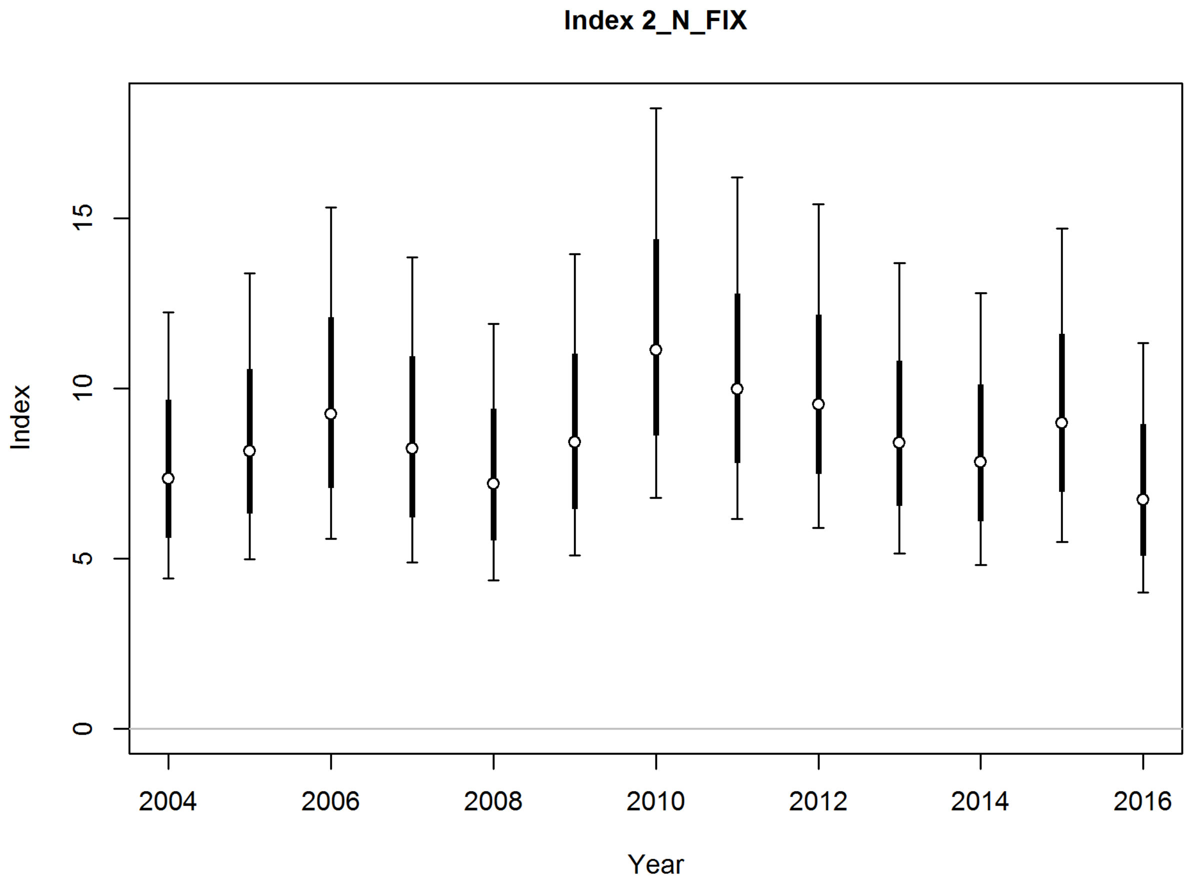


Figure 60. OR nearshore commercial logbook index.

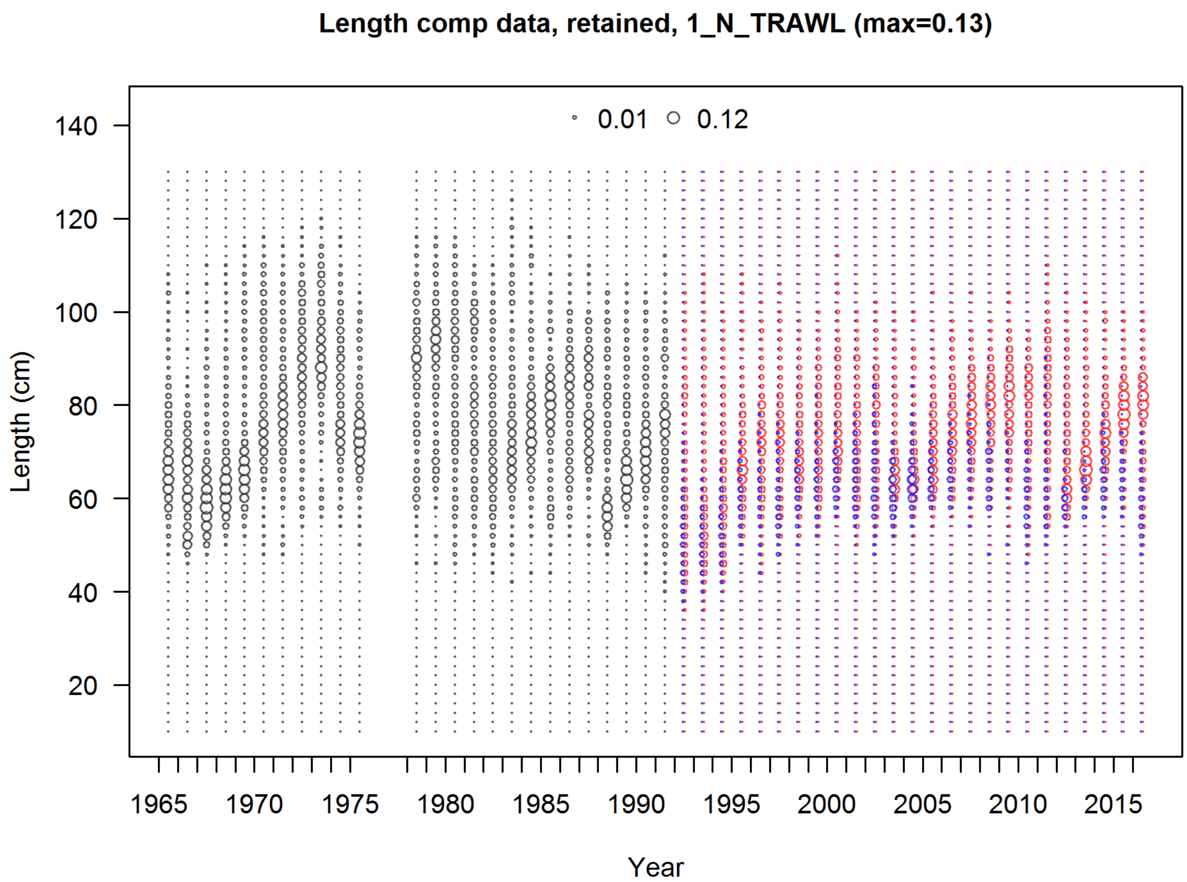


Figure 61. Commercial trawl length compositions, north. Grey circles represent unsexed composition, red and blue circles represent females and males, respectively.

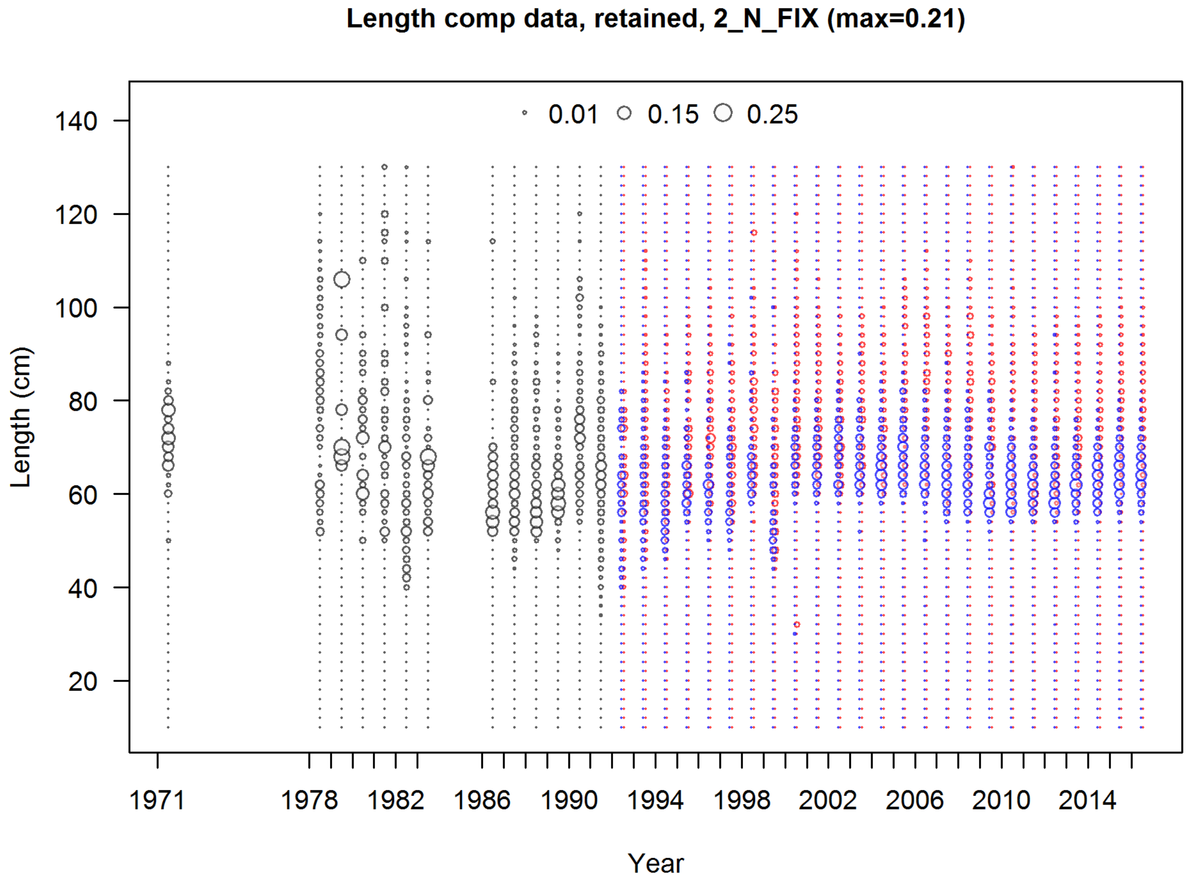


Figure 62. Commercial fixed gear length compositions, north. Grey circles represent unsexed composition, red and blue circles represent females and males, respectively.

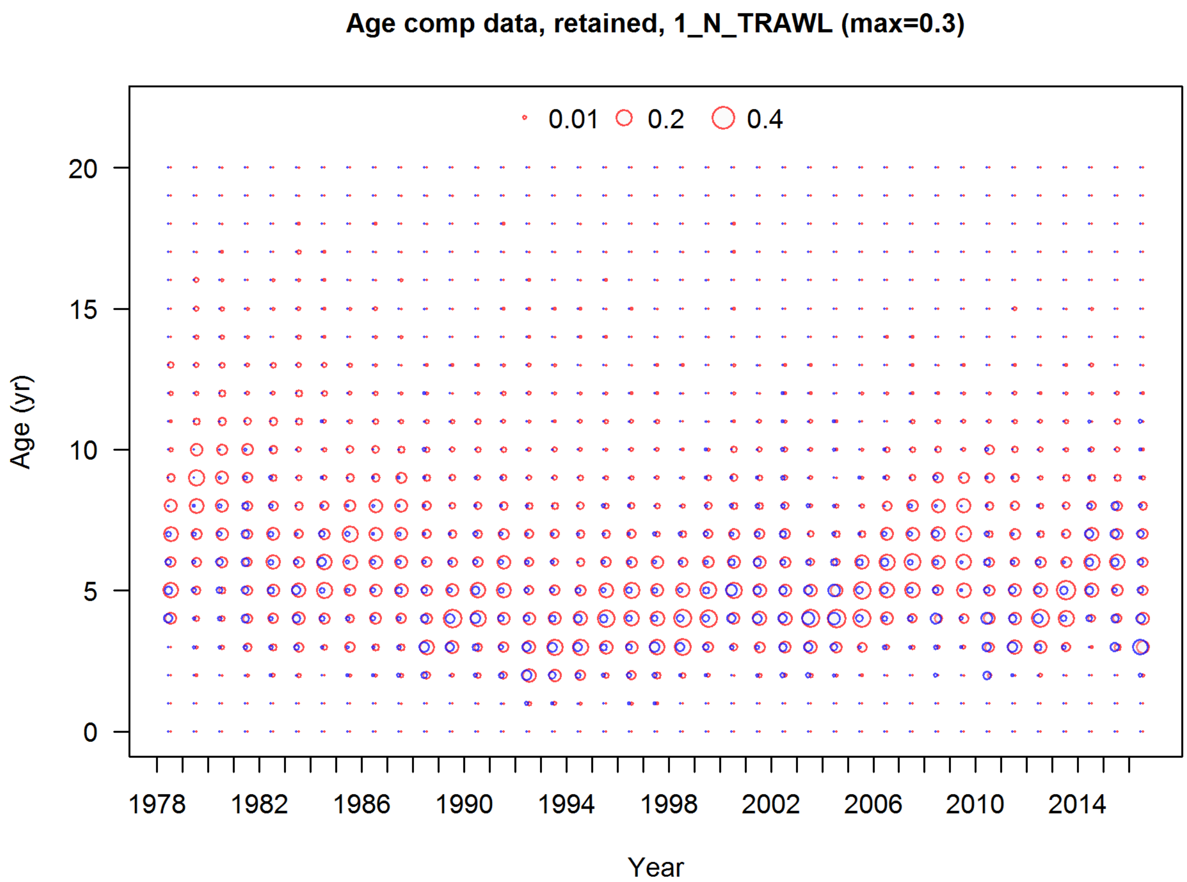


Figure 63. Commercial trawl age compositions, north.

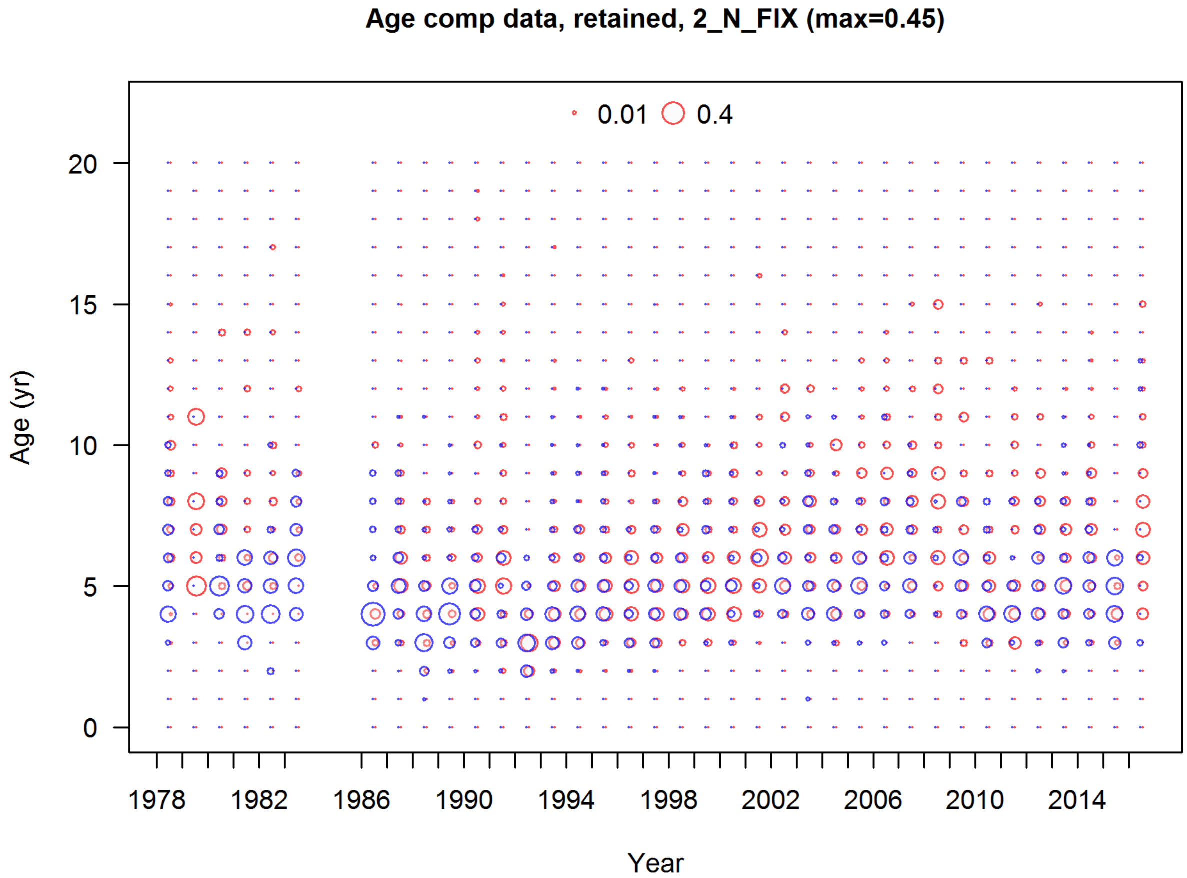


Figure 64. Commercial fixed gear age compositions, north.

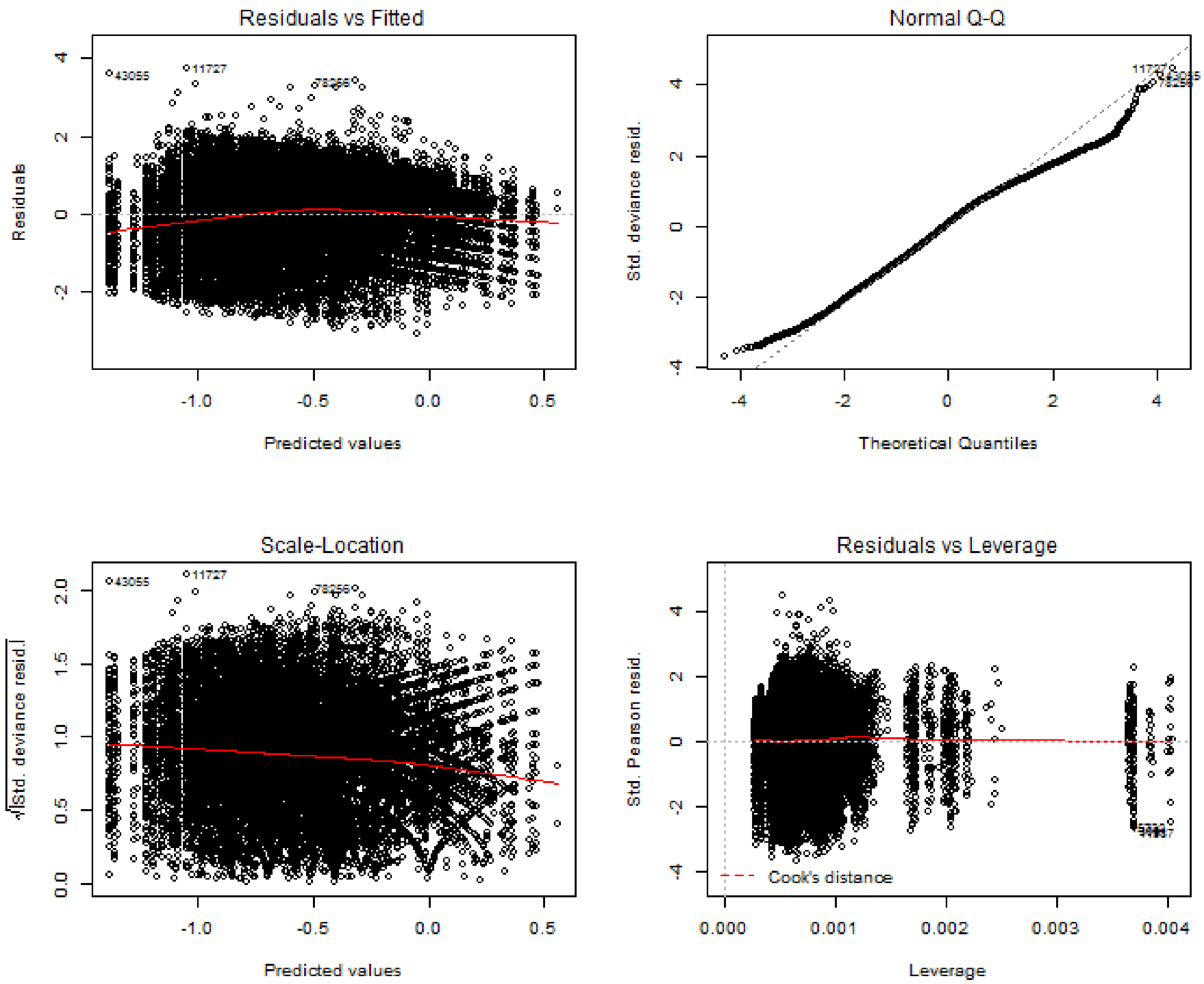


Figure 65. WA recreational dockside CPUE GLM diagnostics.

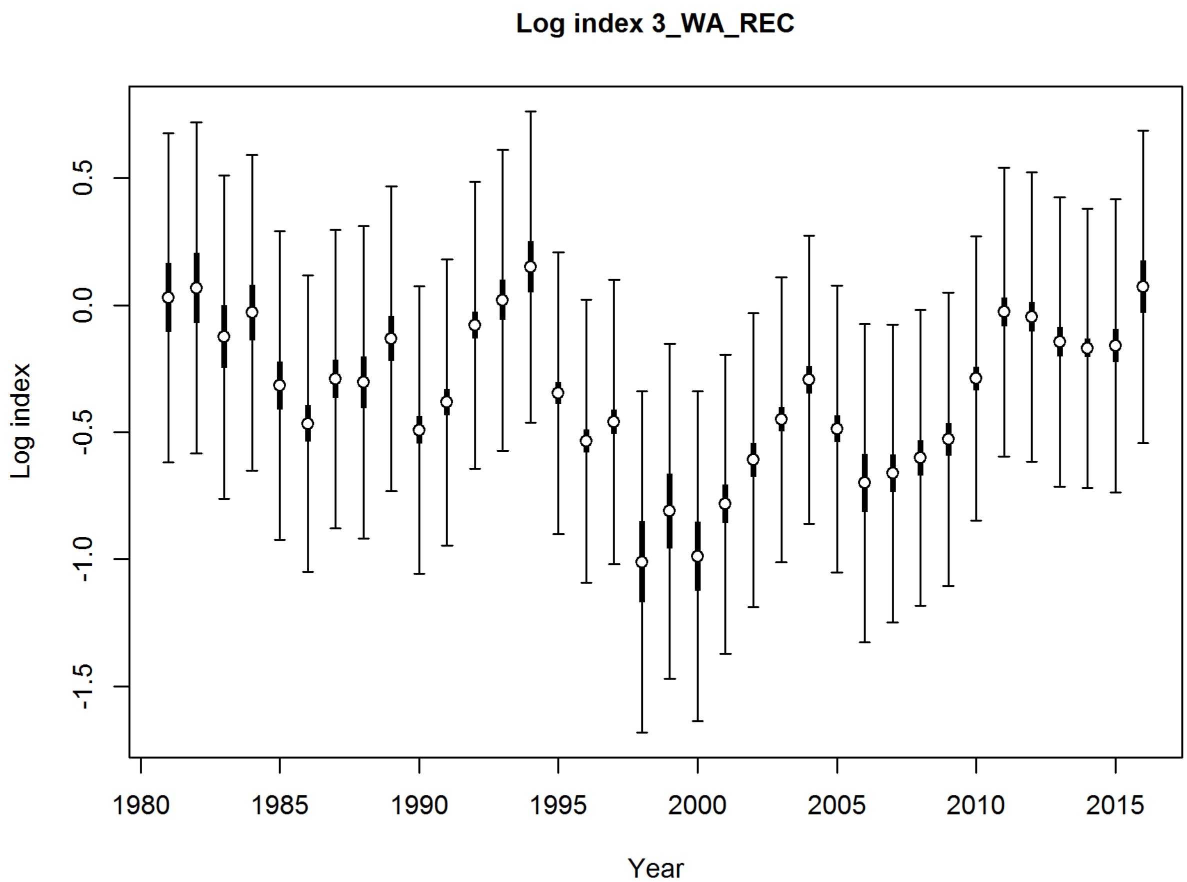


Figure 66. WA recreational dockside CPUE index.

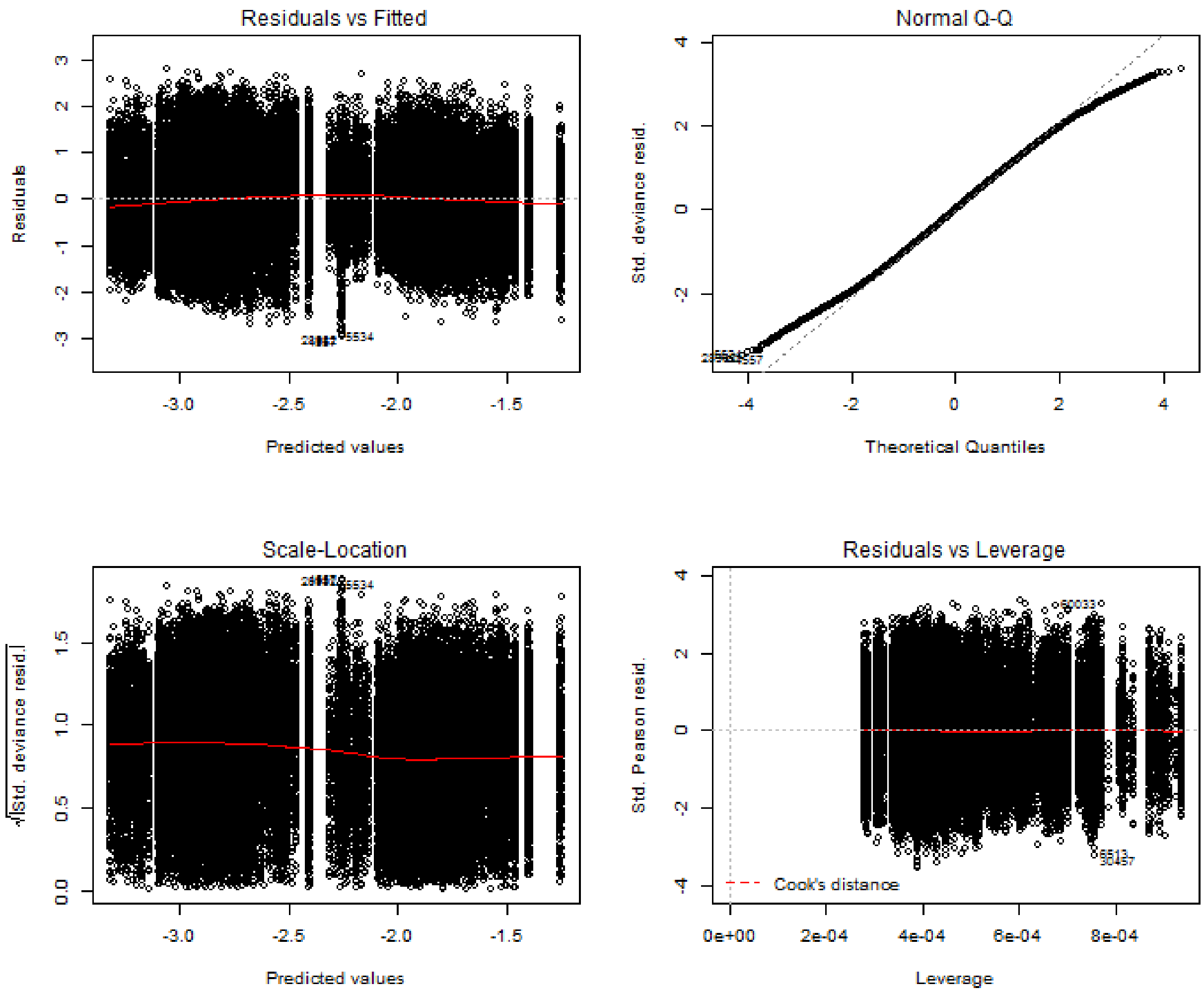


Figure 67. OR recreational dockside CPUE index GLM diagnostics.

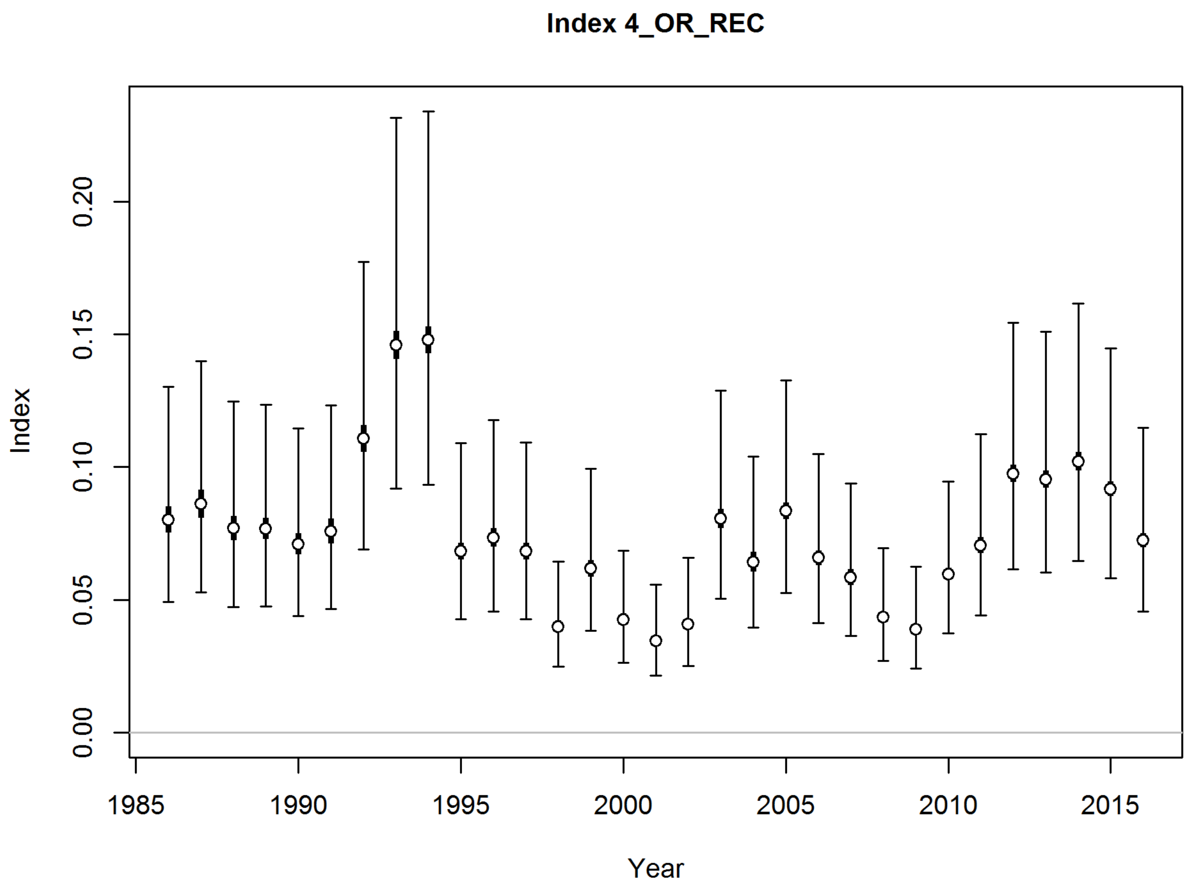


Figure 68. OR recreational dockside CPUE index.

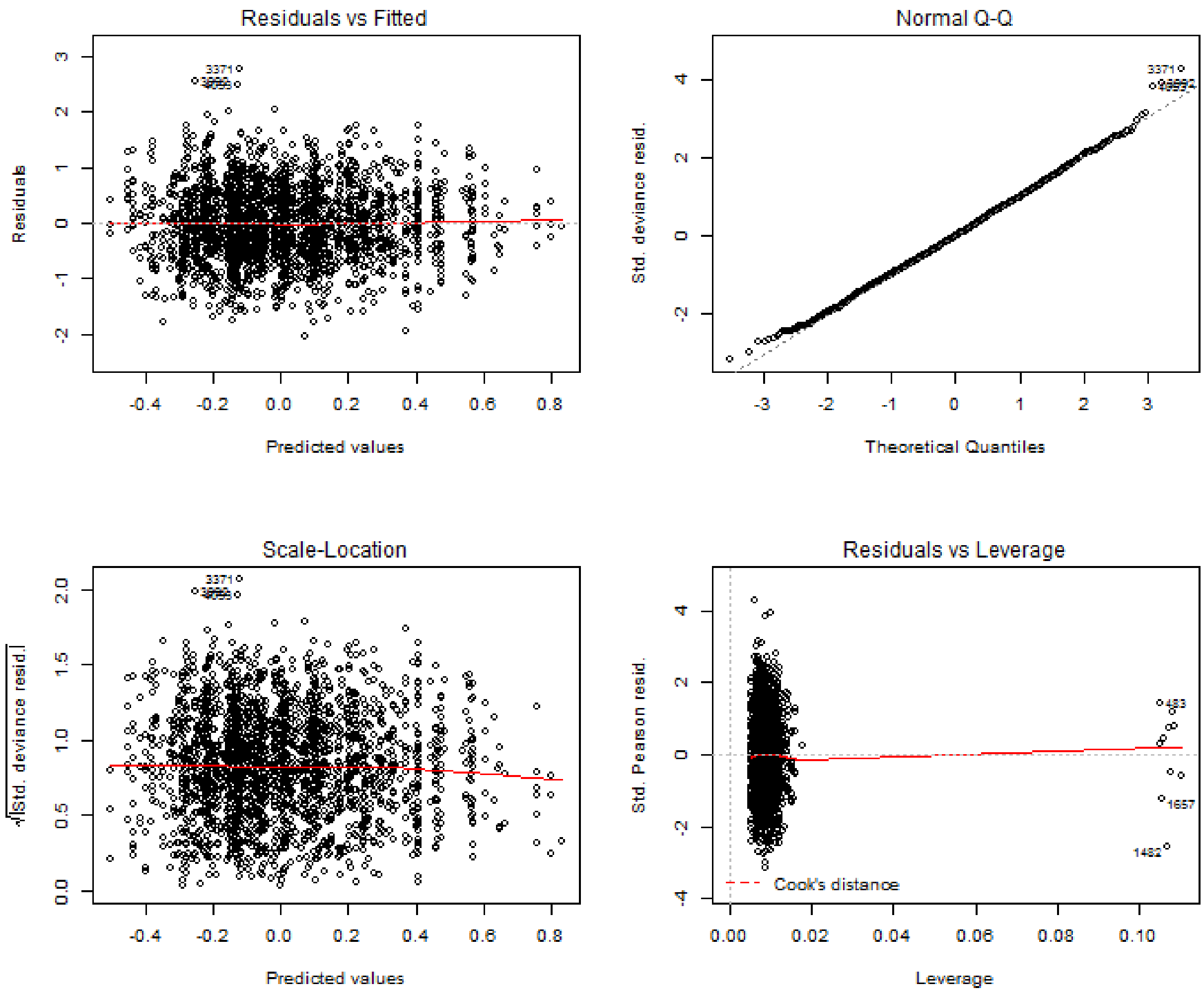


Figure 69. OR onboard observer CPUE index GLM diagnostics.

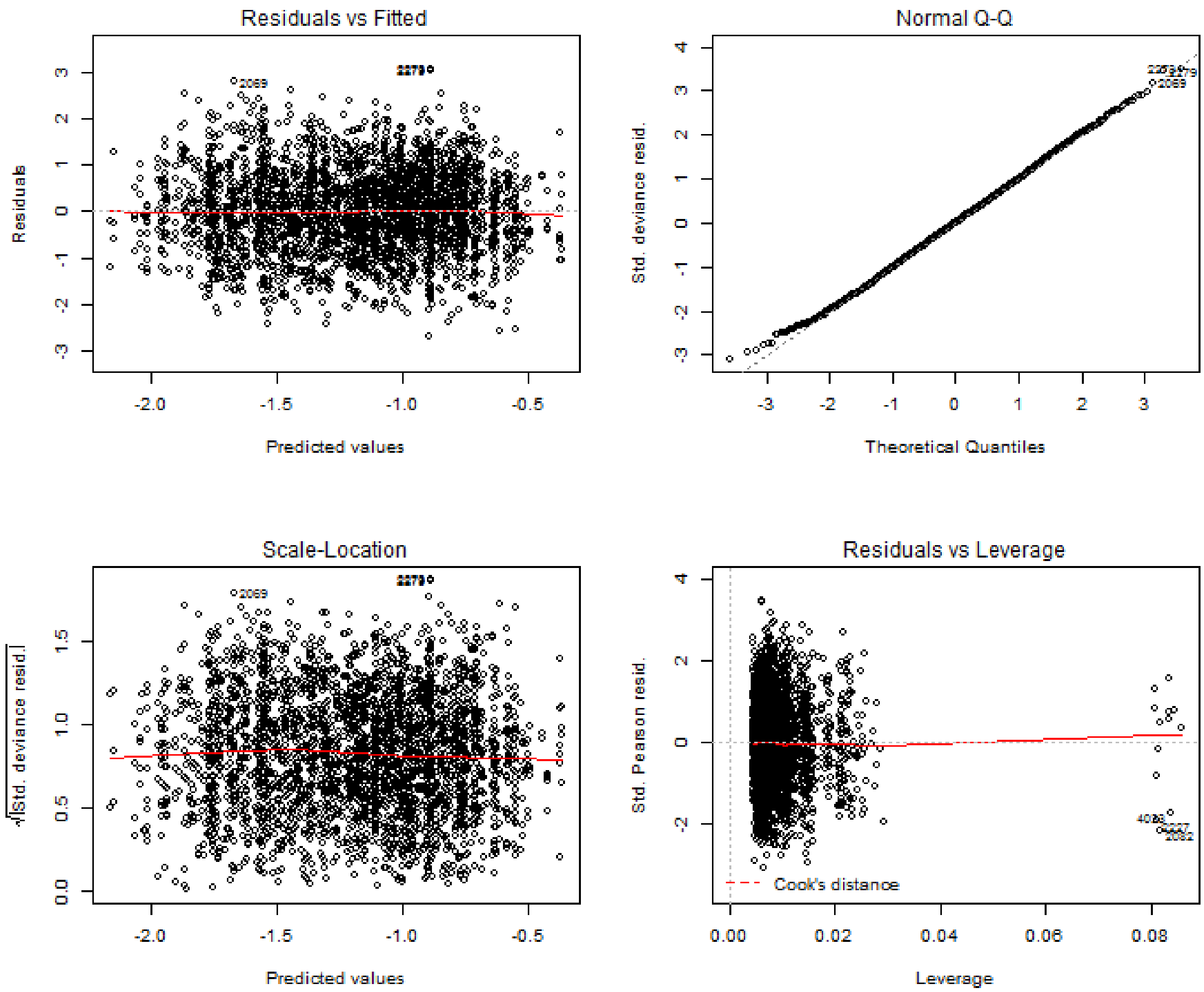


Figure 70. CA early recreational onboard observer CPUE index diagnostics.

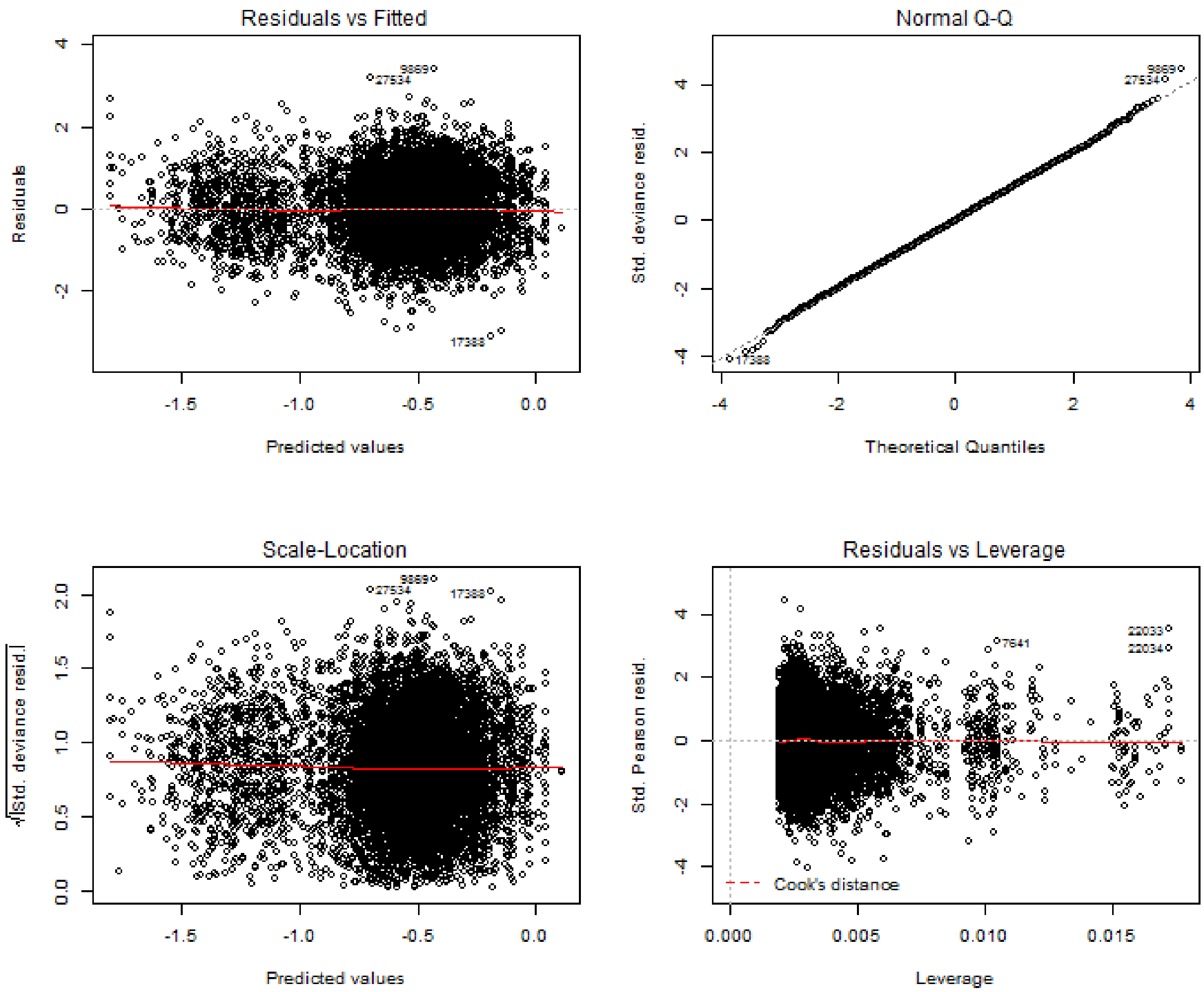


Figure 71. CA late onboard observer CPUE index diagnostics.

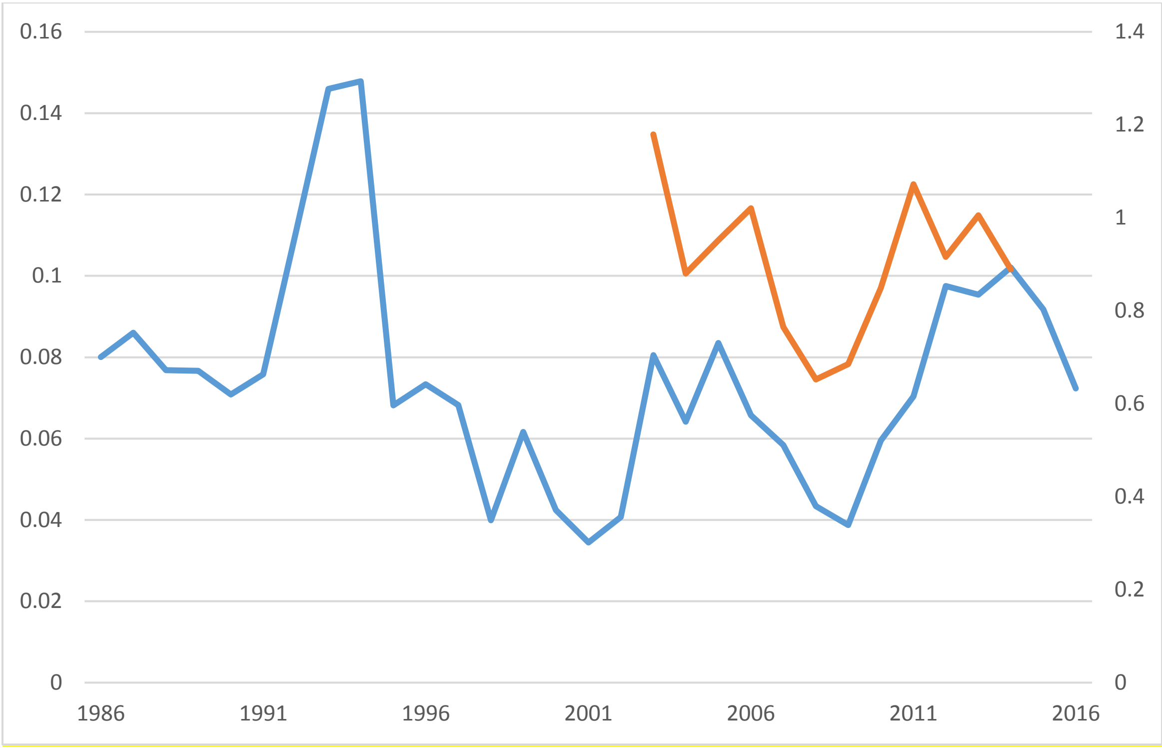


Figure 72. OR onboard observer recreational CPUE index (red, y-axis 2) compared to the OR dockside index (blue, y-axis 1).

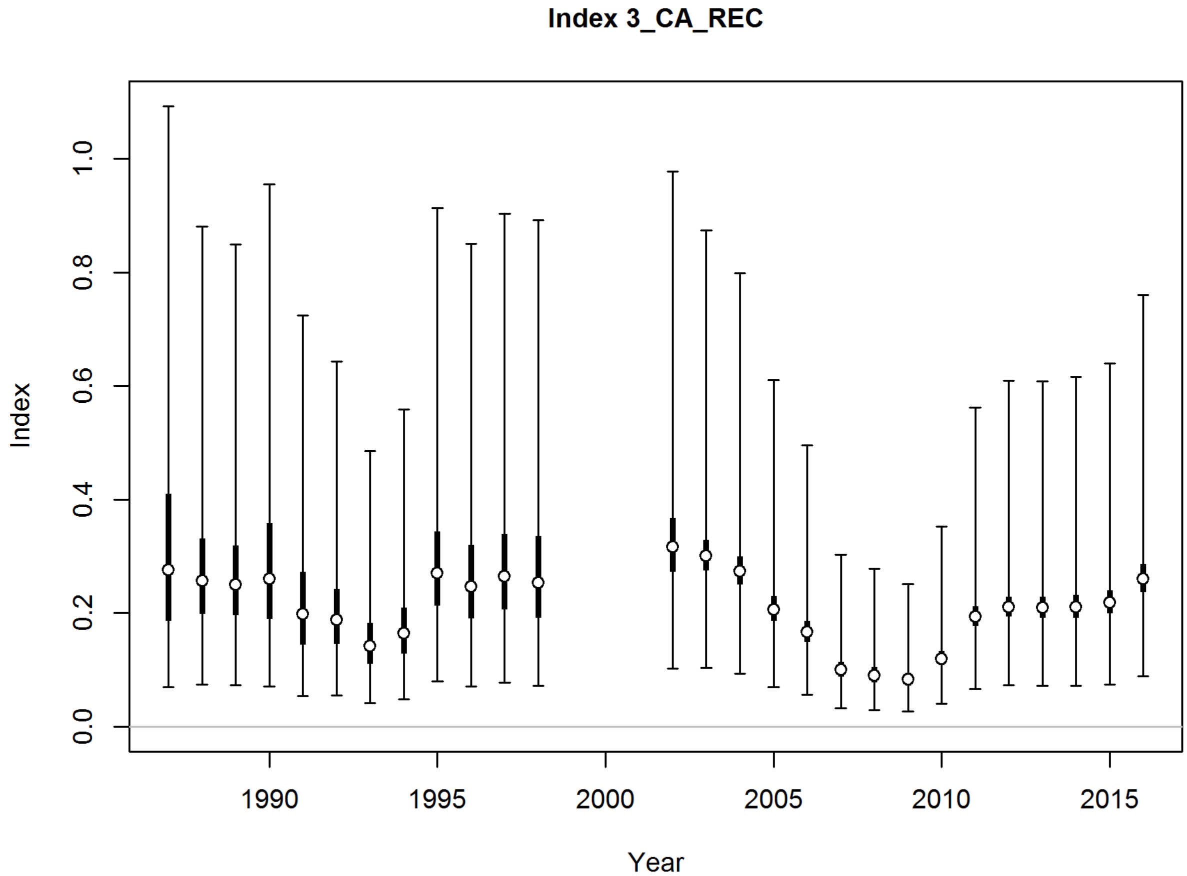


Figure 73. CA early and late onboard observer recreational CPUE indices.

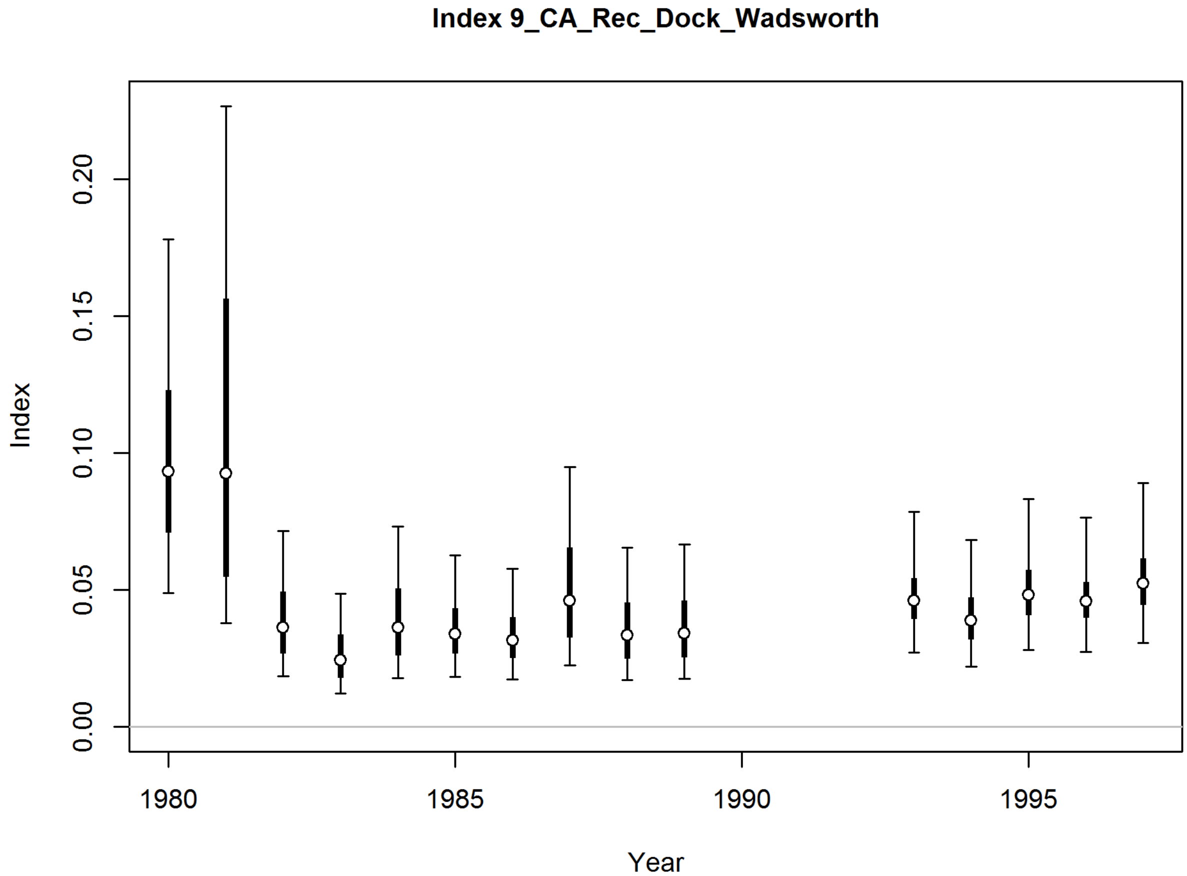


Figure 74. CA recreational dockside CPUE index.

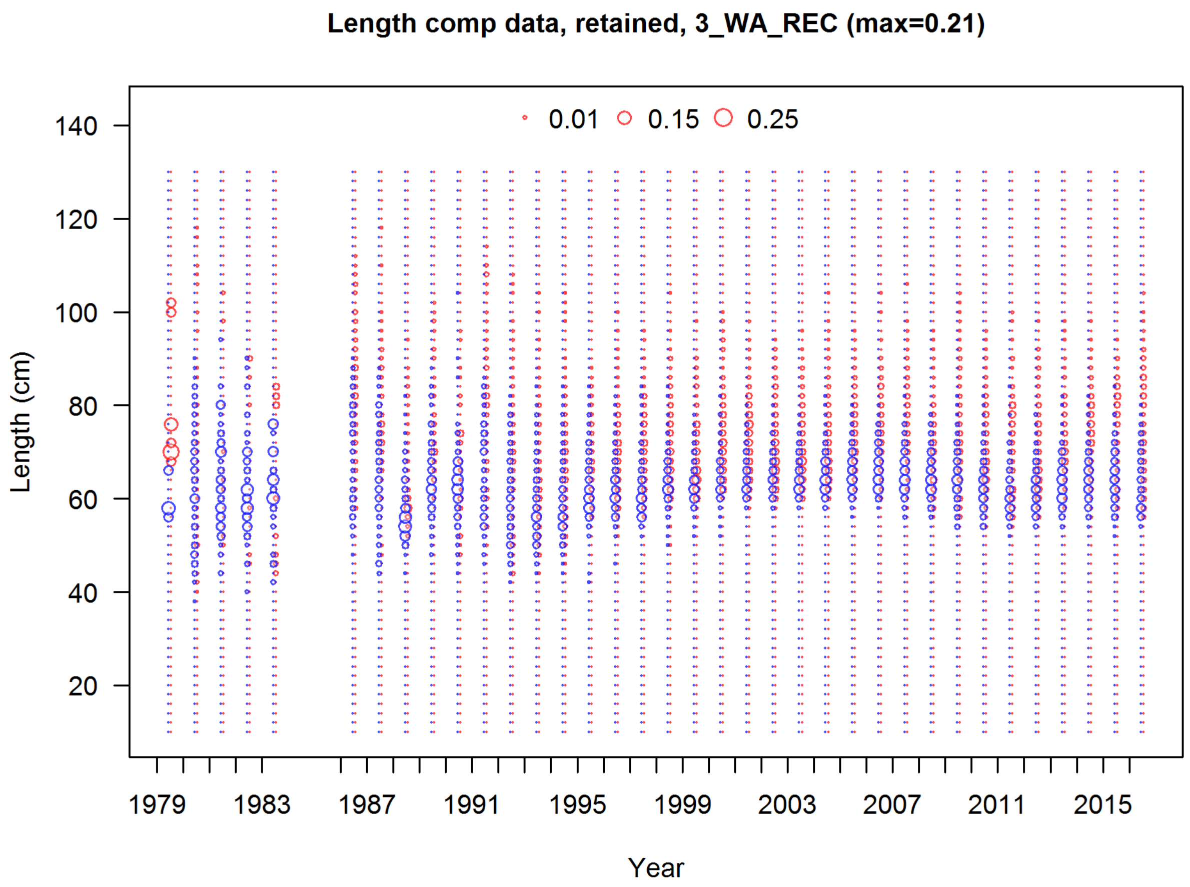


Figure 75. WA recreational length data.

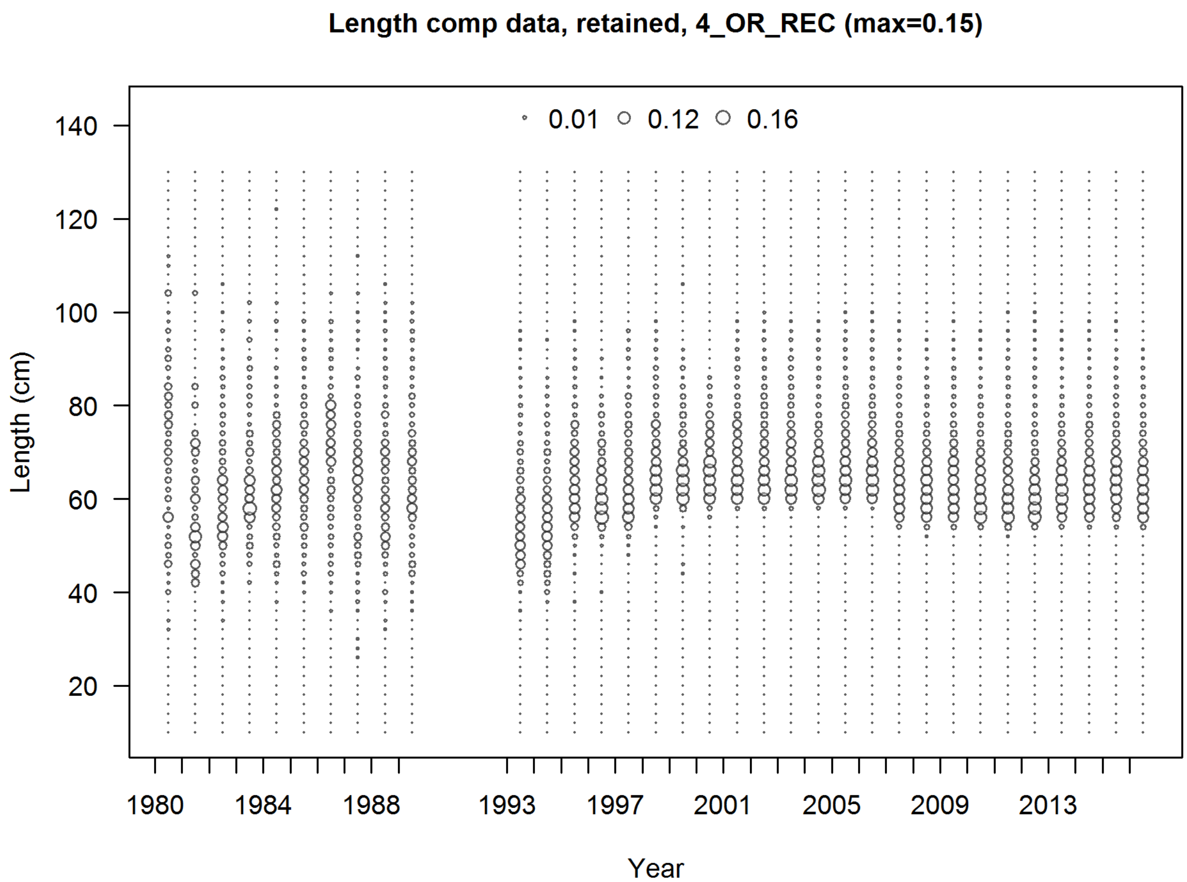


Figure 76. OR recreational length composition data.

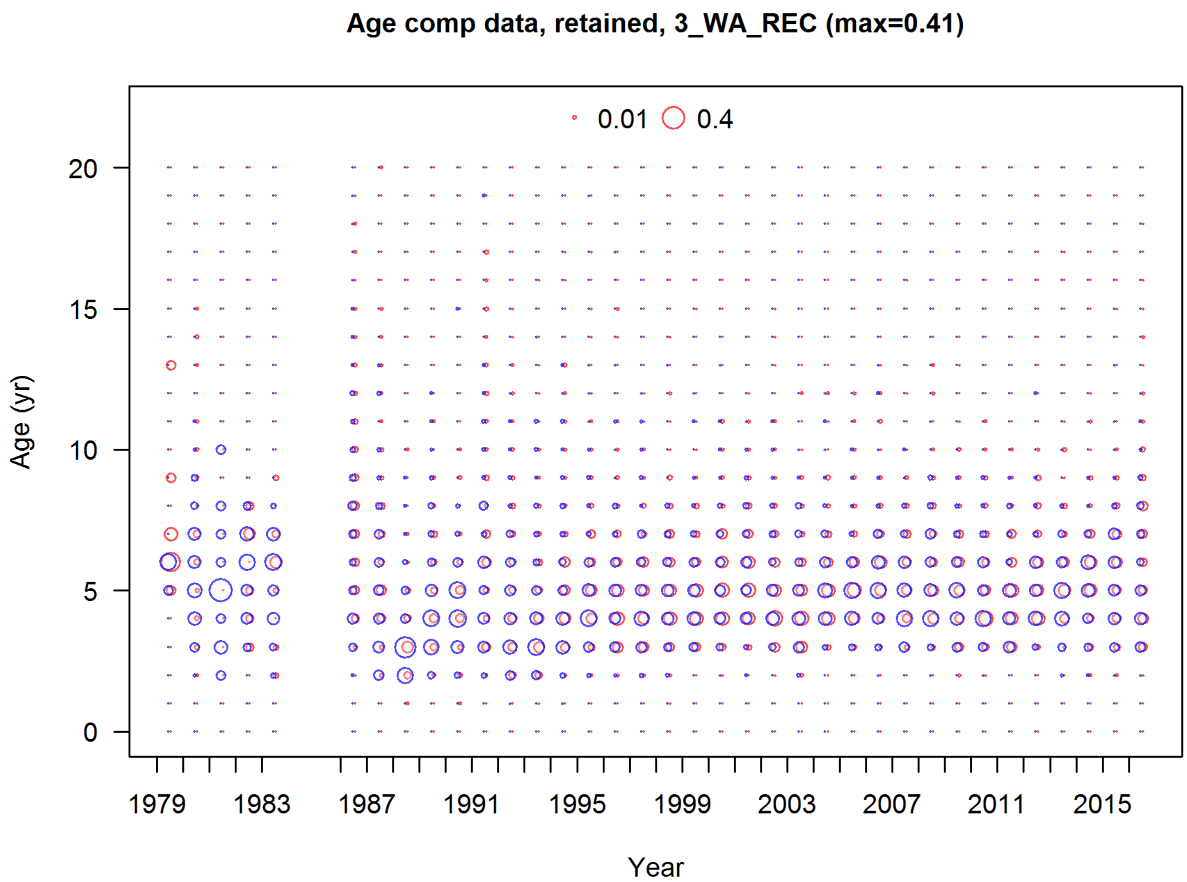


Figure 77. WA recreational age data.

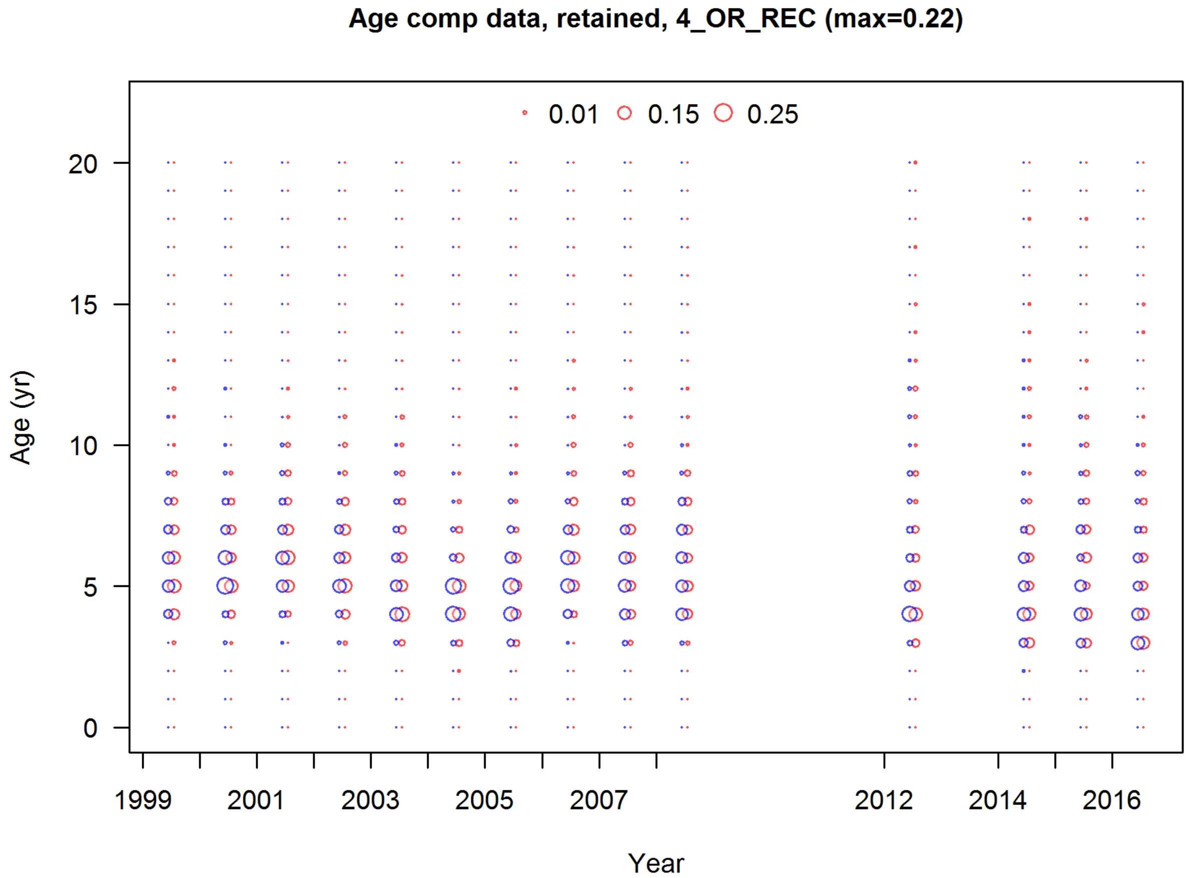


Figure 78. OR recreational age composition data.

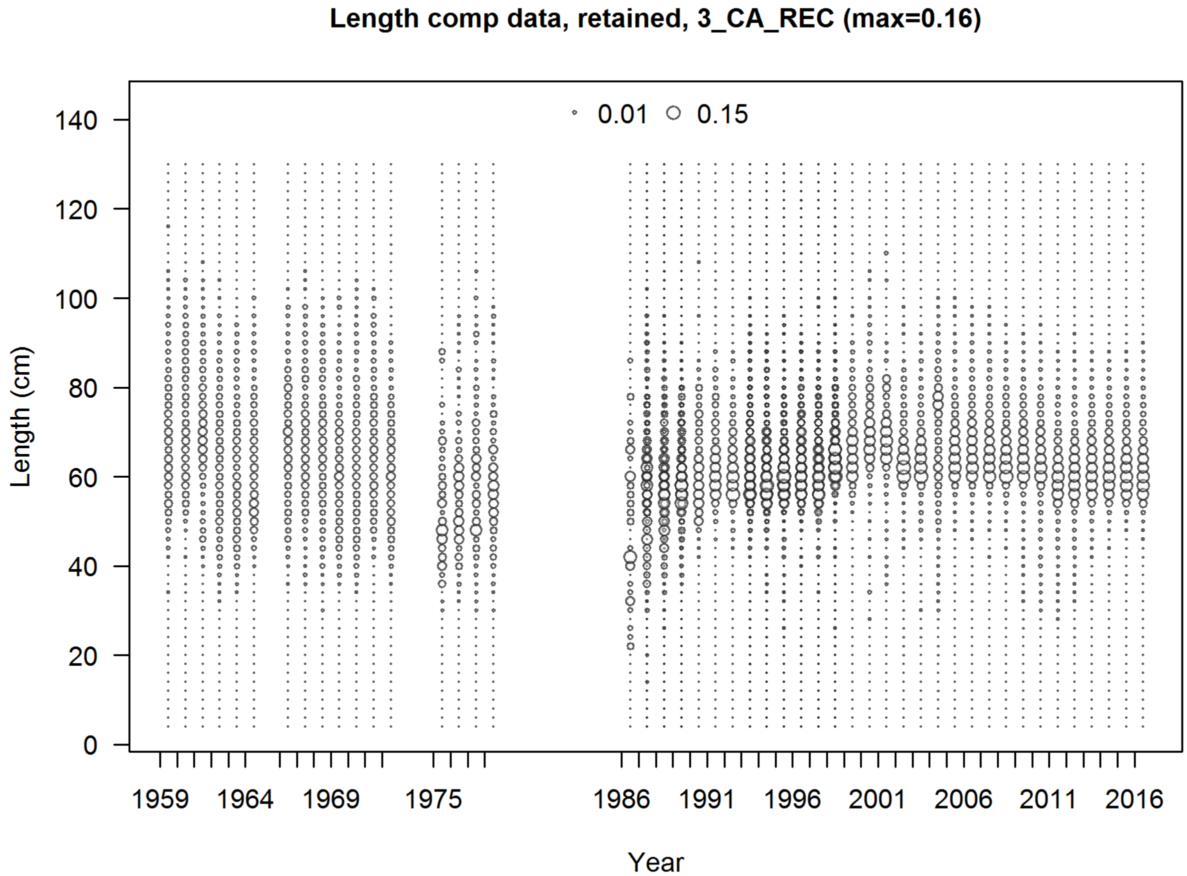


Figure 79. CA recreational length data.

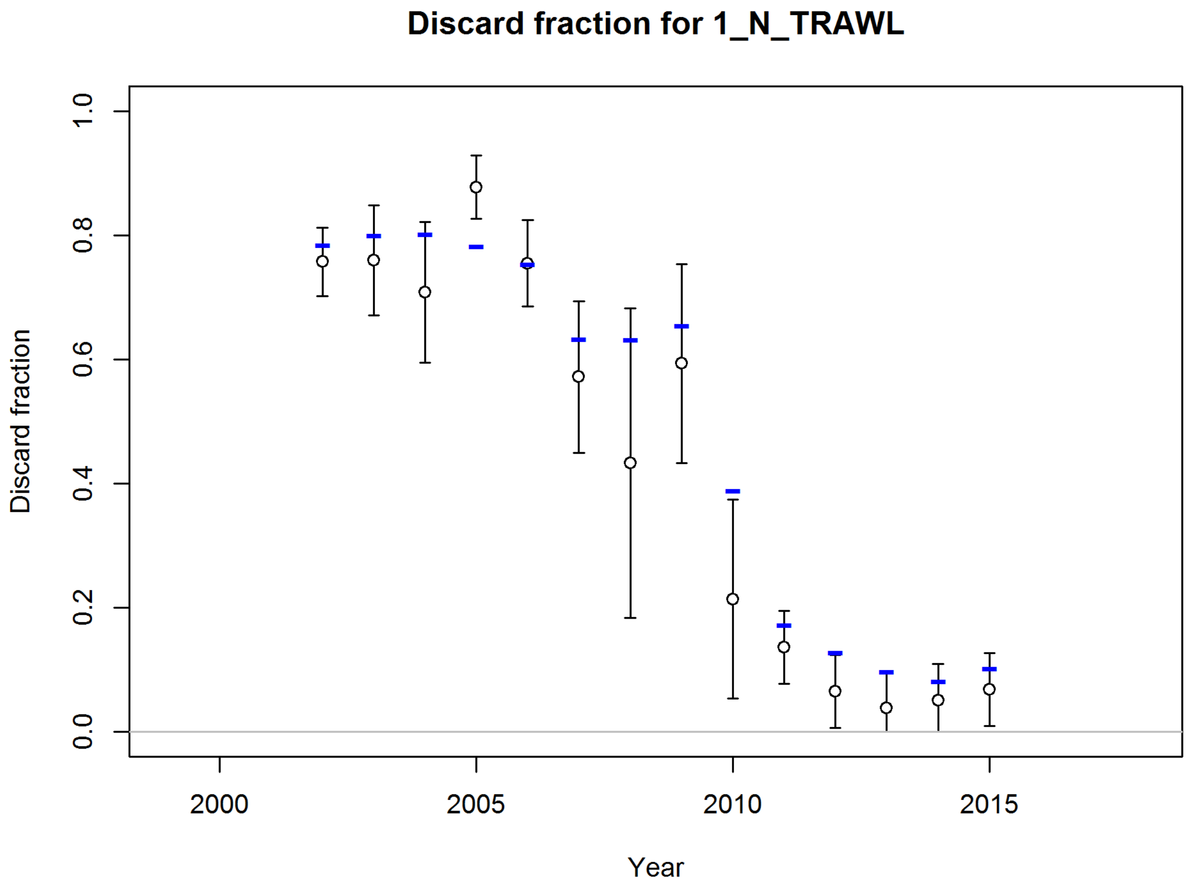


Figure 80. Discard fraction trawl fits, north. Blue horizontal dashes are model fits.

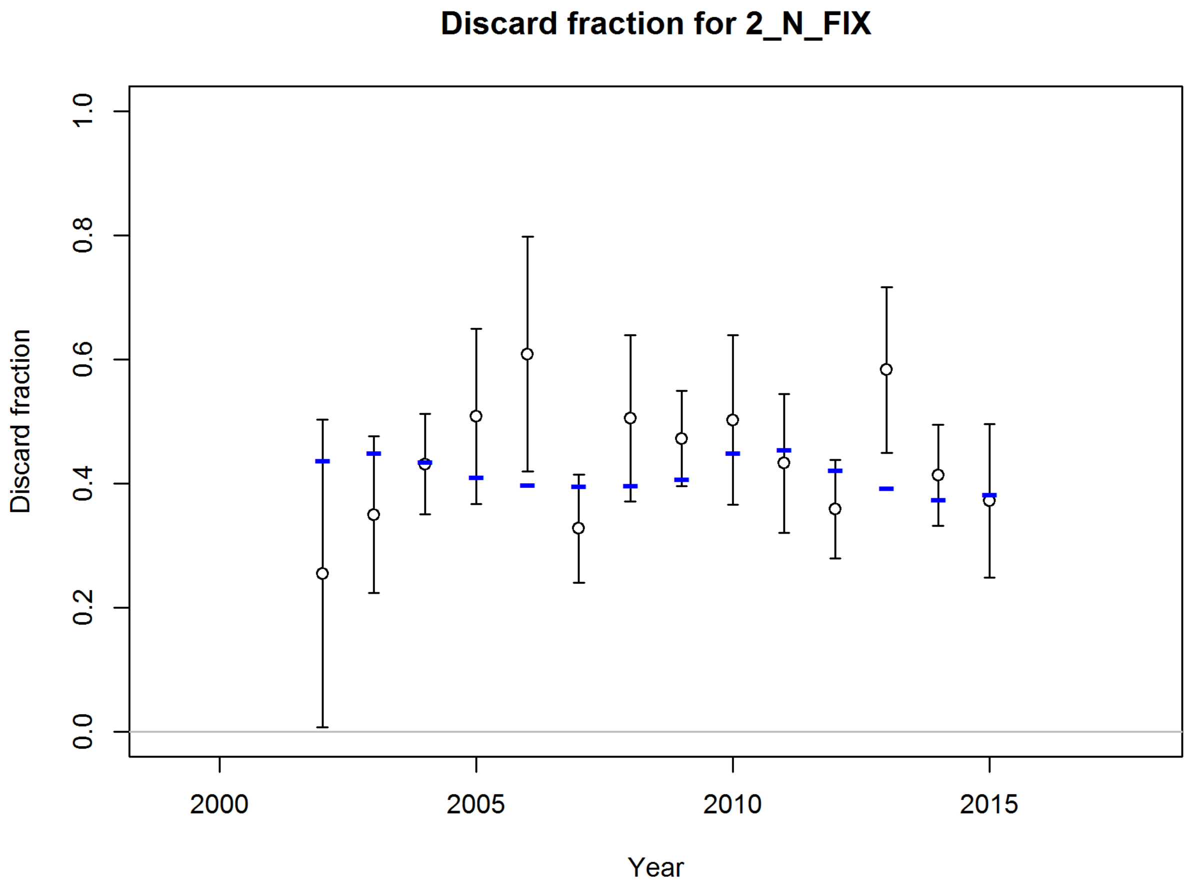


Figure 81. Discard fraction fixed gear fits, north. Blue horizontal dashes are model fits.

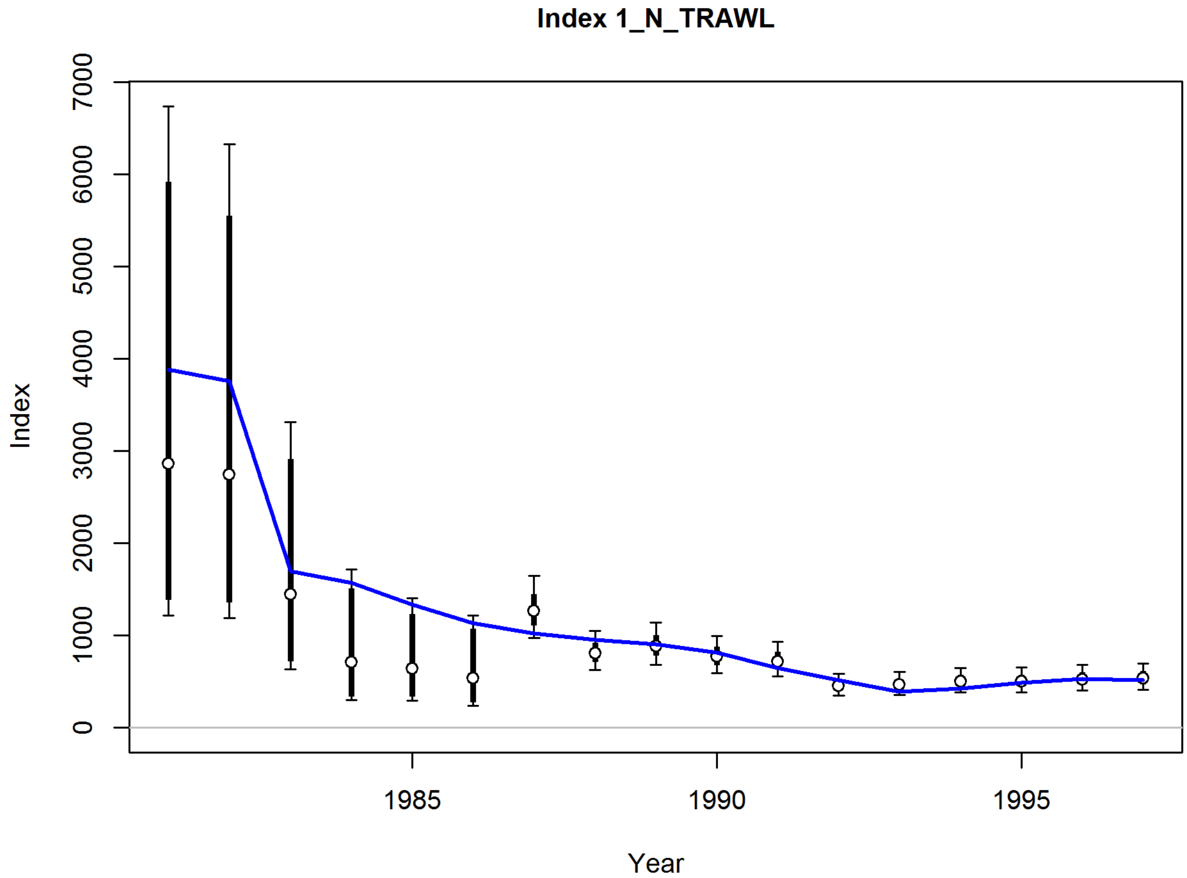


Figure 82. Trawl fleet index fit, north. Thick bars indicate the input standard deviations; light bars represent the estimated added standard deviations.

Figure 83. Fixed gear index fit, north. Thick bars indicate the input standard deviations; light bars represent the estimated added standard deviations.

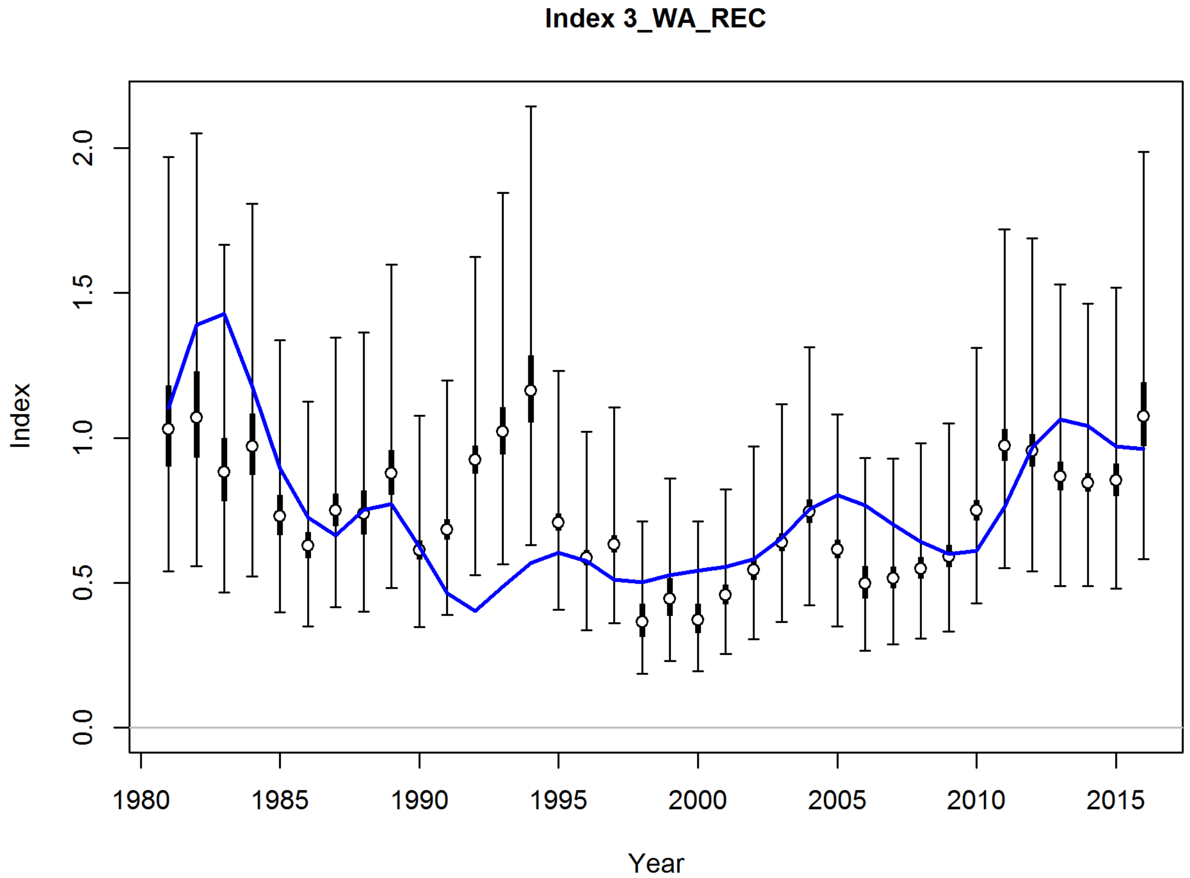


Figure 84. WA recreational CPUE index fit. Thick bars indicate the input standard deviations; light bars represent the estimated added standard deviations.

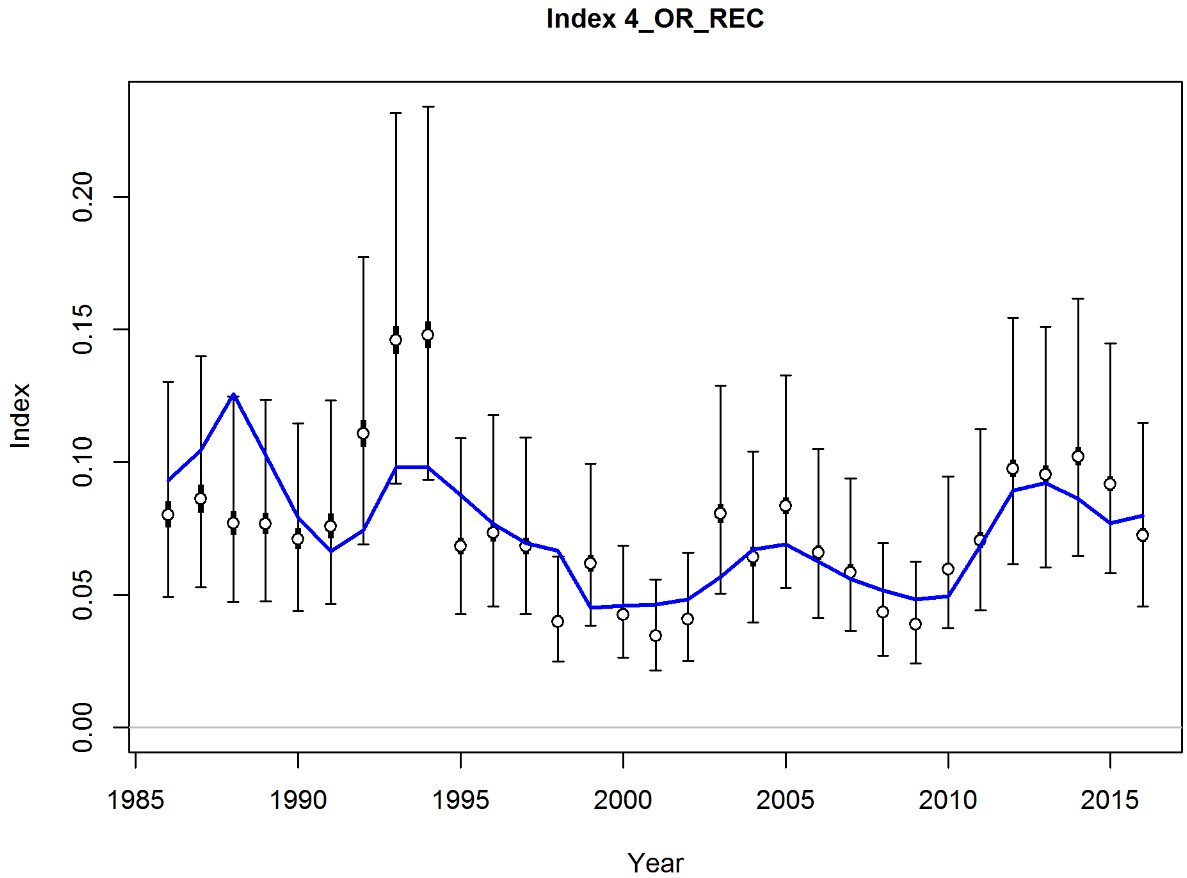


Figure 85. OR recreational CPUE index fit. Thick bars indicate the input standard deviations; light bars represent the estimated added standard deviations.

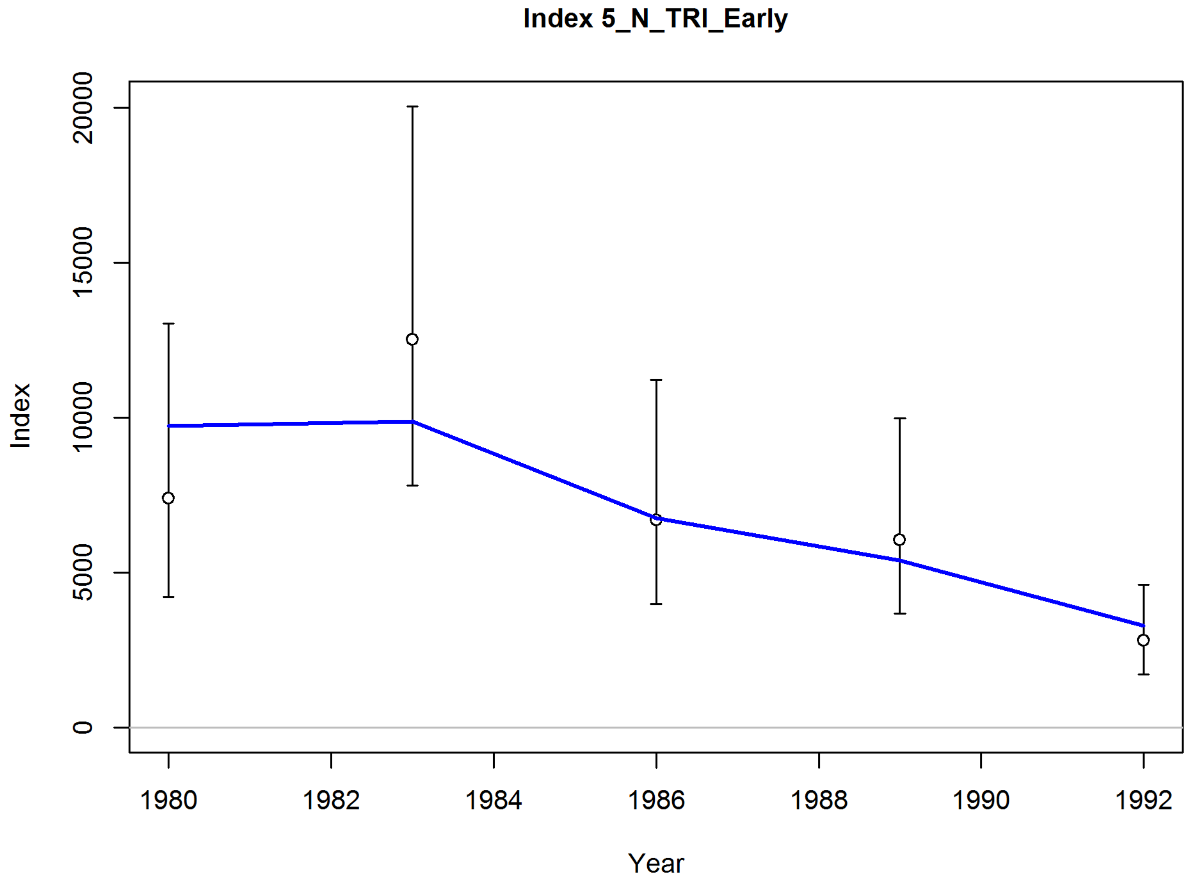


Figure 86. Triennial survey early fit.

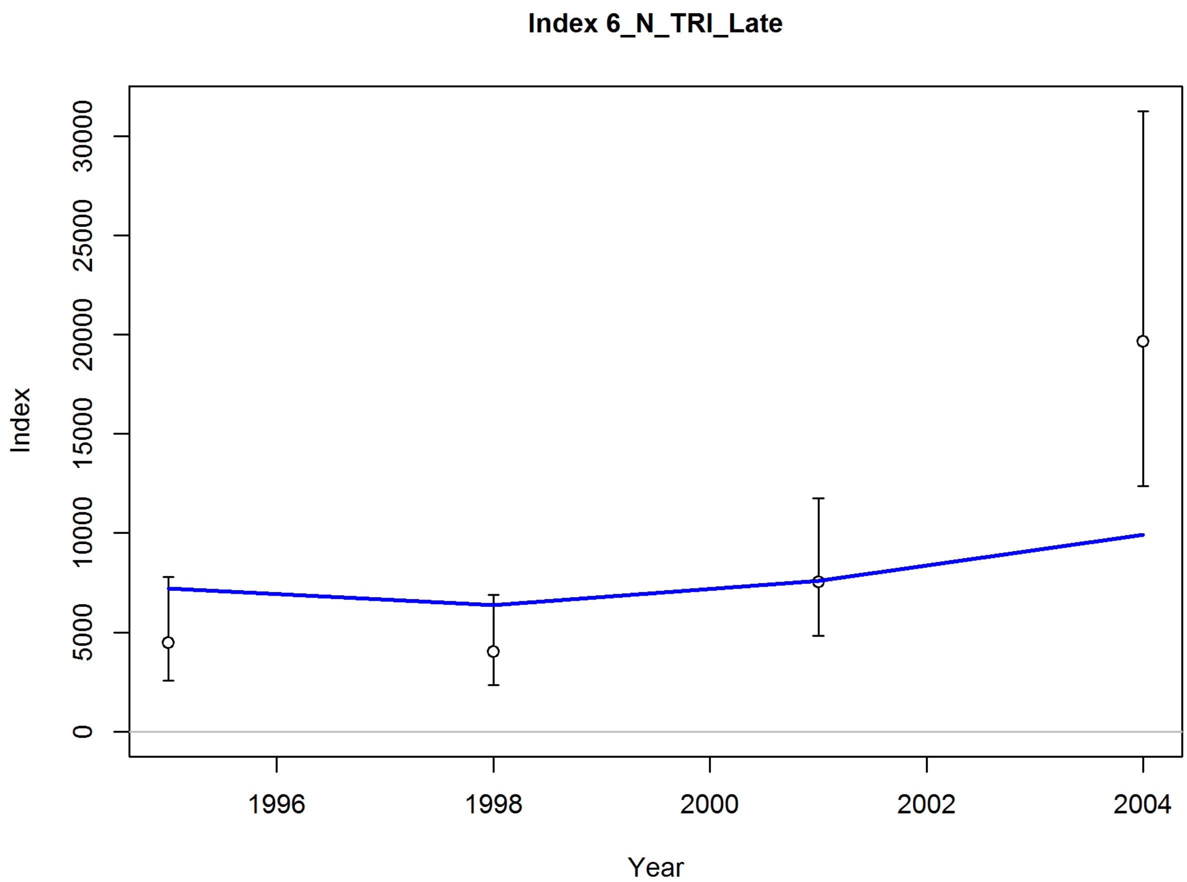


Figure 87. Triennial survey late fit.

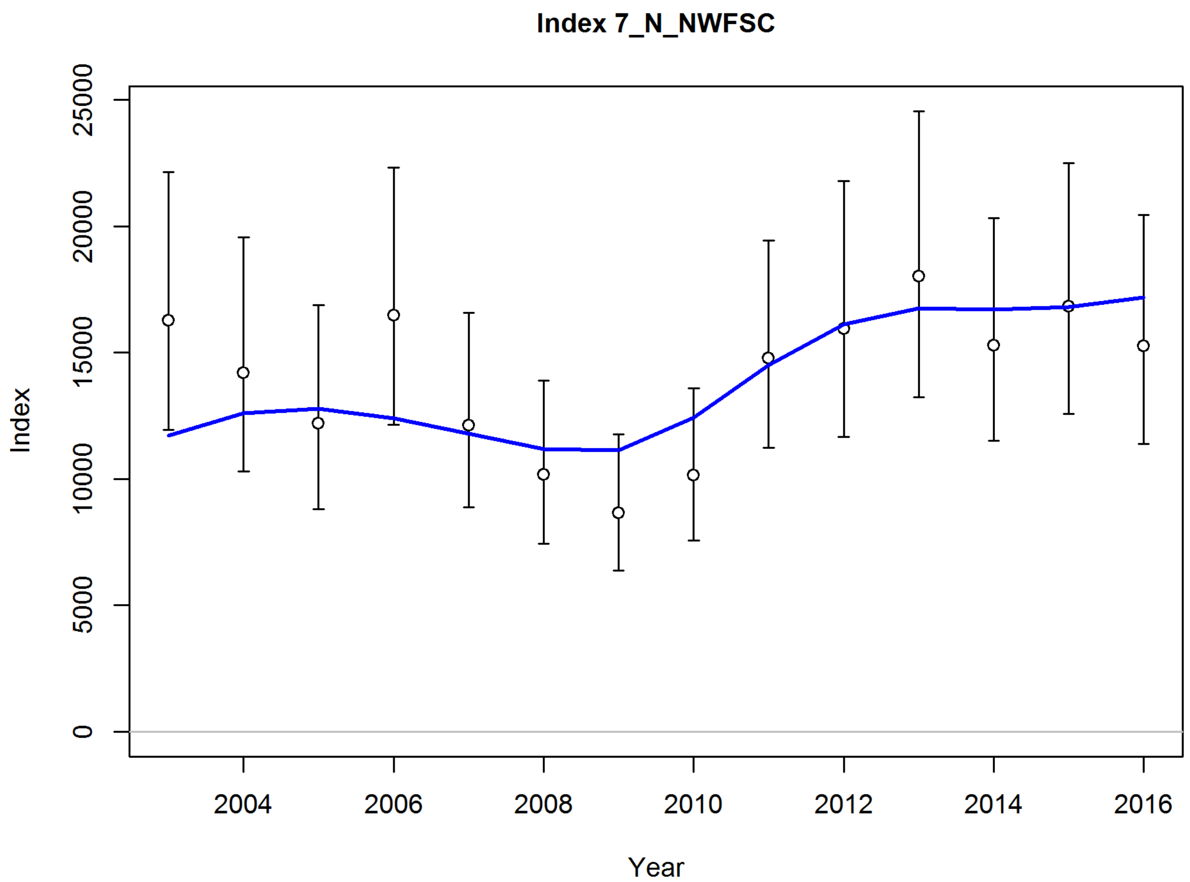


Figure 88. NWFSC survey fit.

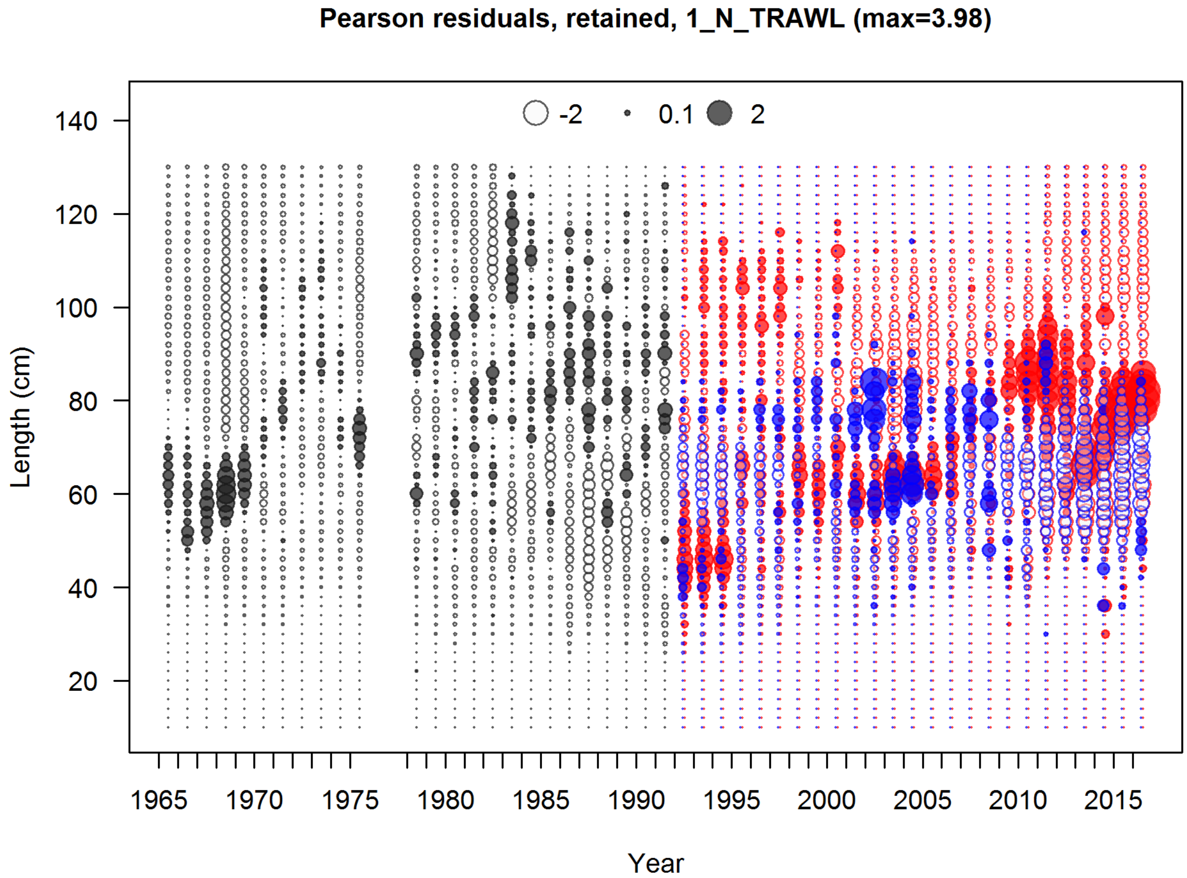


Figure 89. Commercial trawl length data Pearson residuals, north. Grey circles represent sex-combined compositions, while red and blue circles represent female and male compositions, respectively.

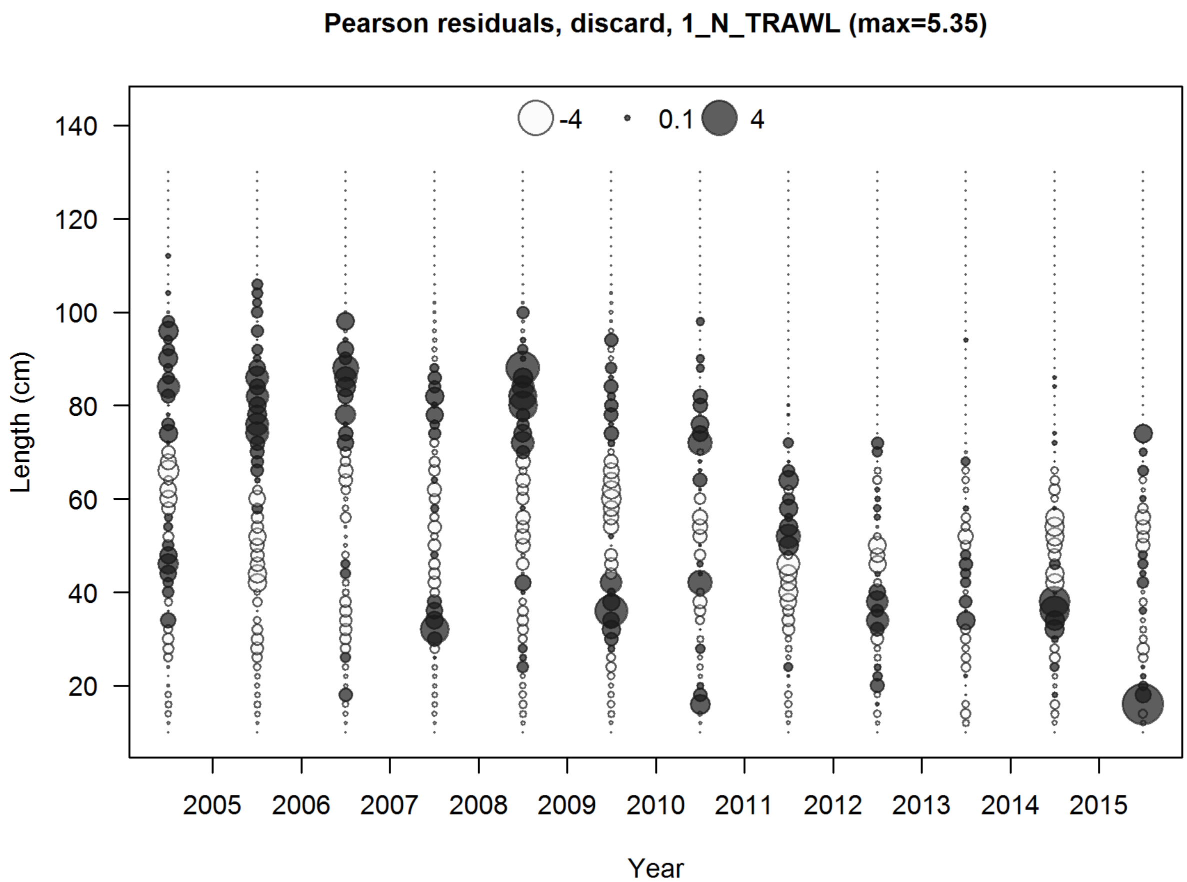


Figure 90. Commercial sex combined trawl discard length data Pearson residuals, north.

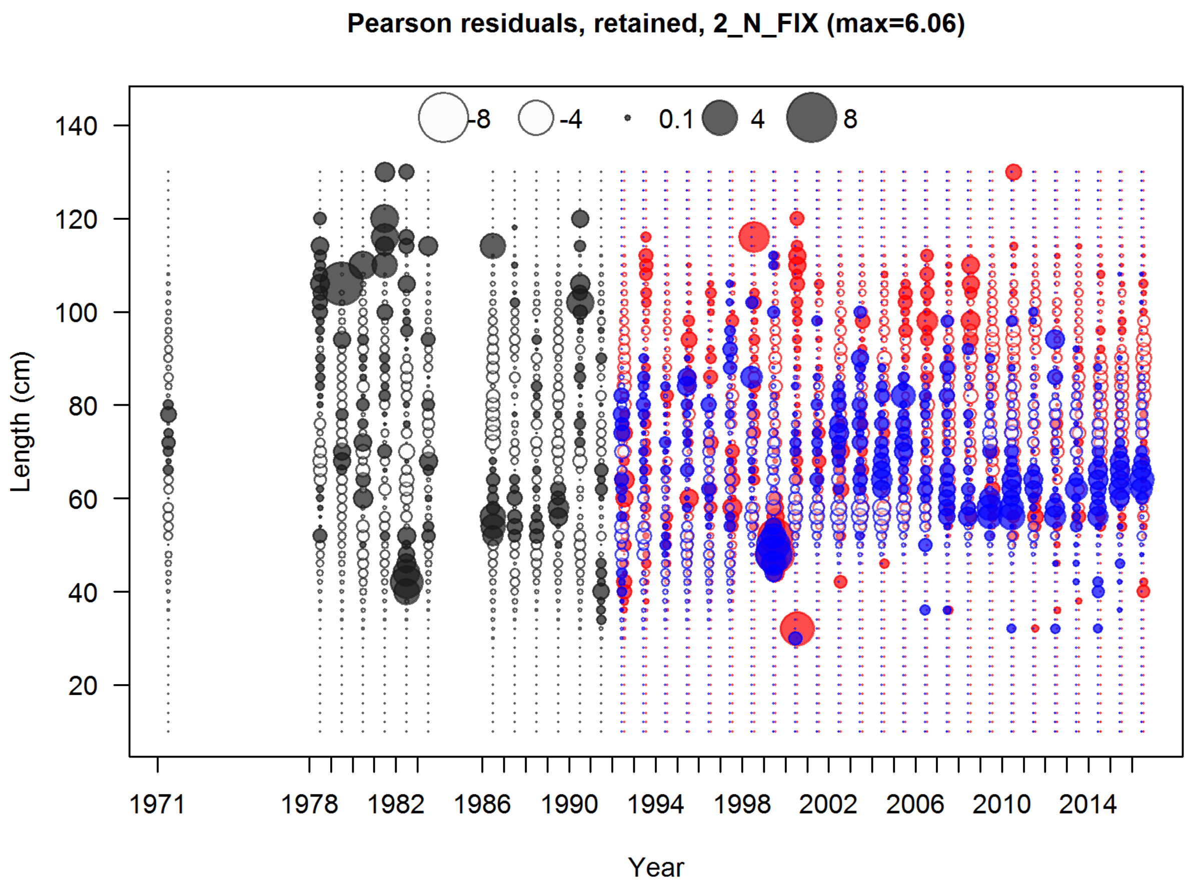


Figure 91. Commercial fixed gear fleet length data Pearson residuals, north. Grey circles represent sex-combined compositions, while red and blue circles represent female and male compositions, respectively.

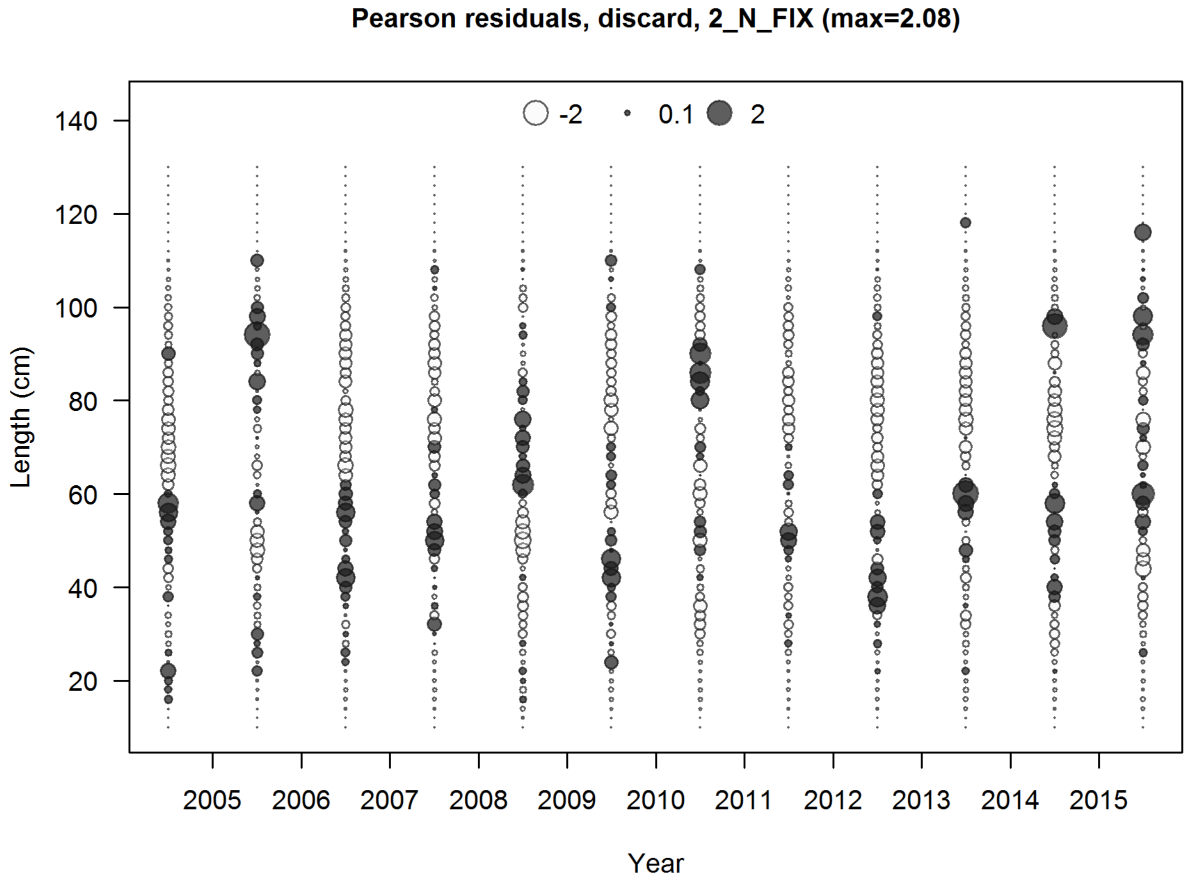


Figure 92. Commercial sex combined fixed gear discard length data Pearson residuals, north.

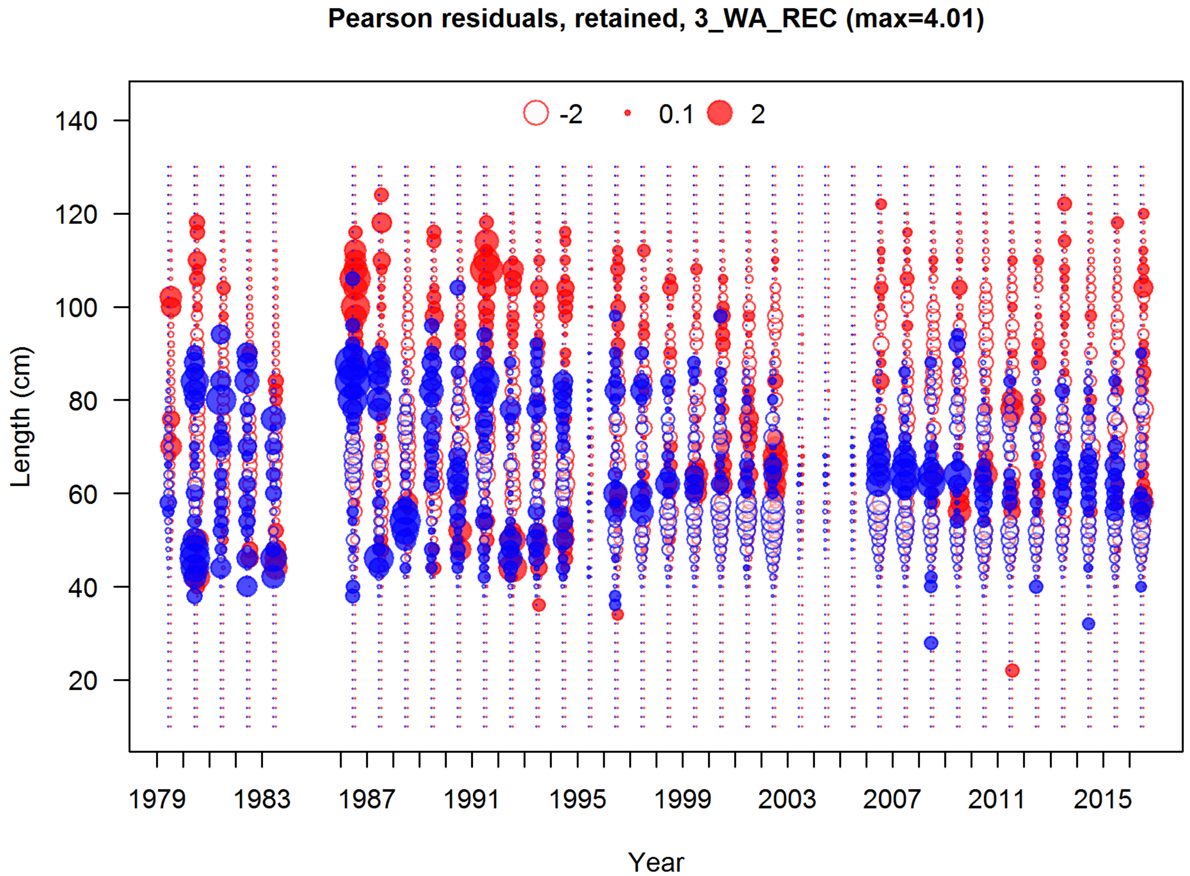


Figure 93. WA sex specific recreational length data Pearson residuals.

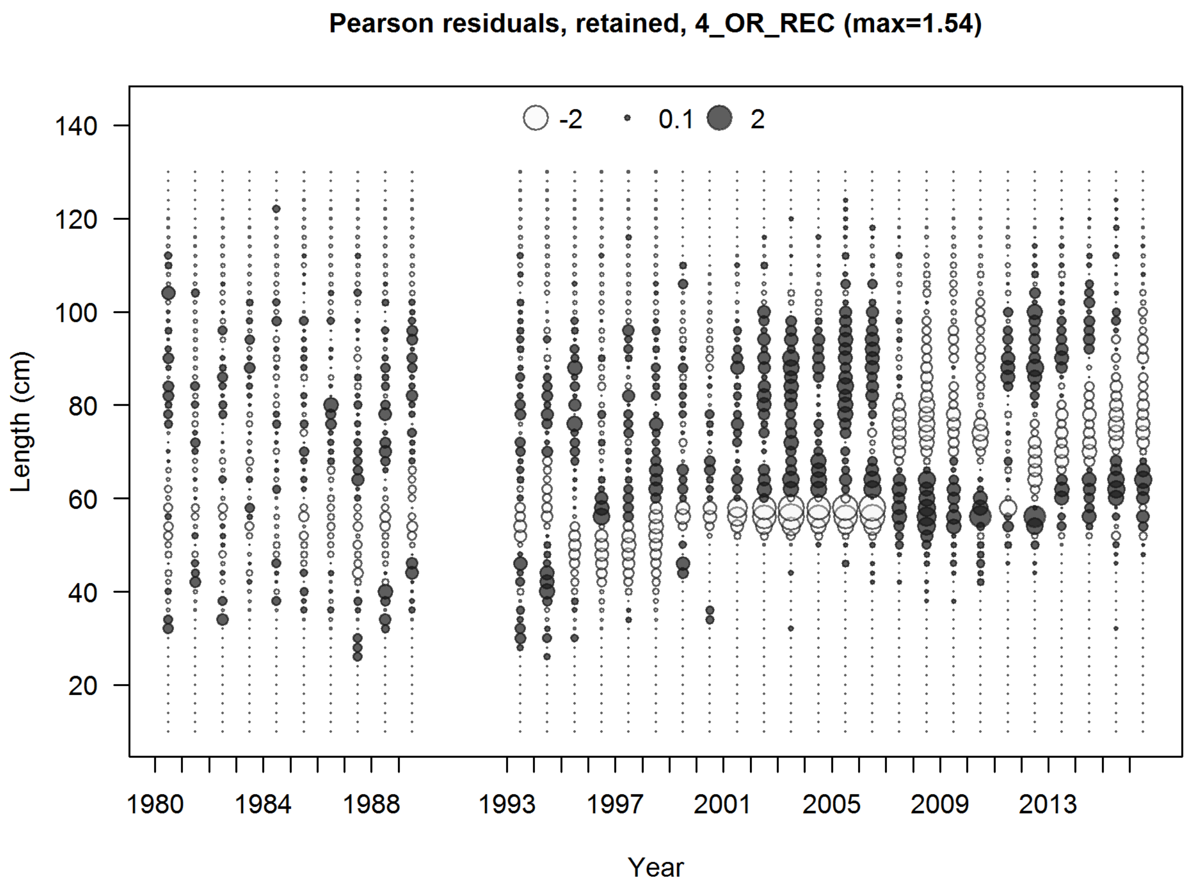


Figure 94. OR sex combined recreational length data Pearson residuals.

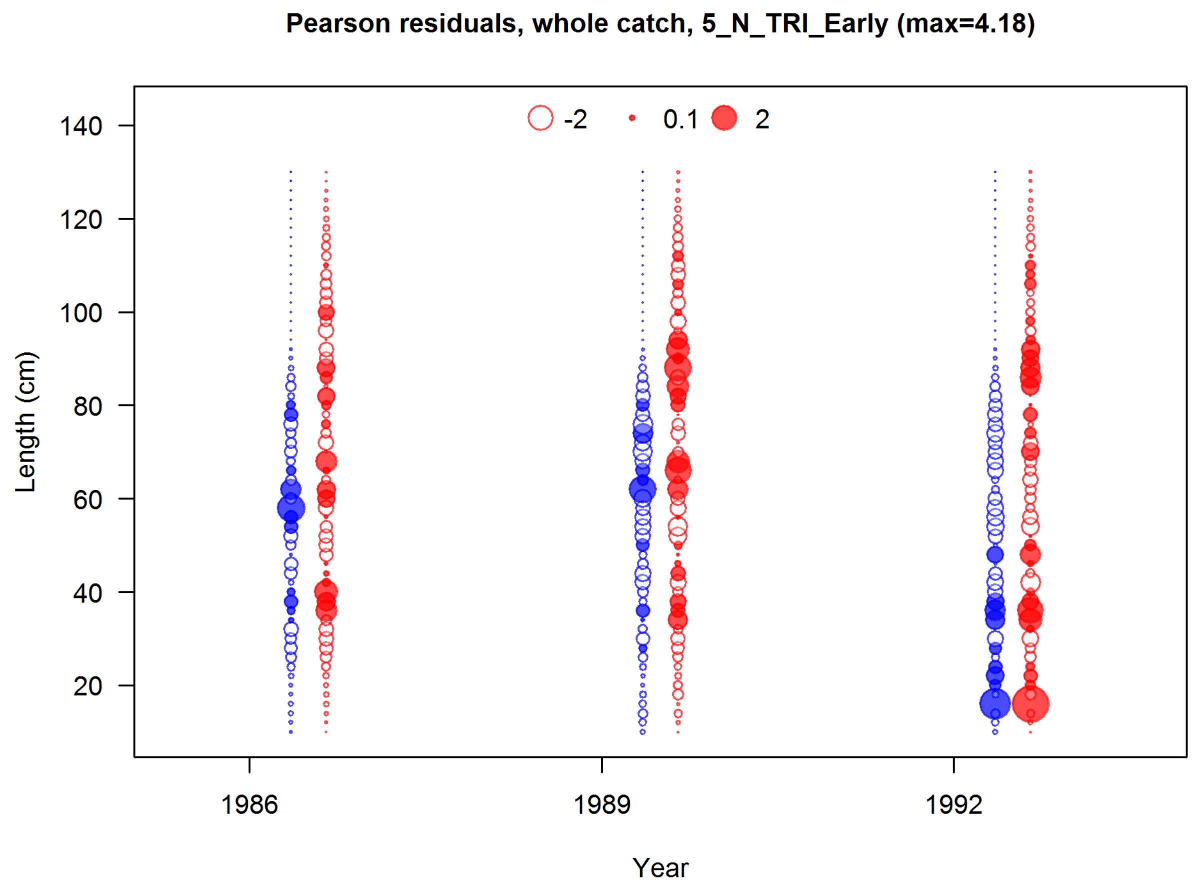


Figure 95. Triennial early sex specific length data Pearson residuals, north.

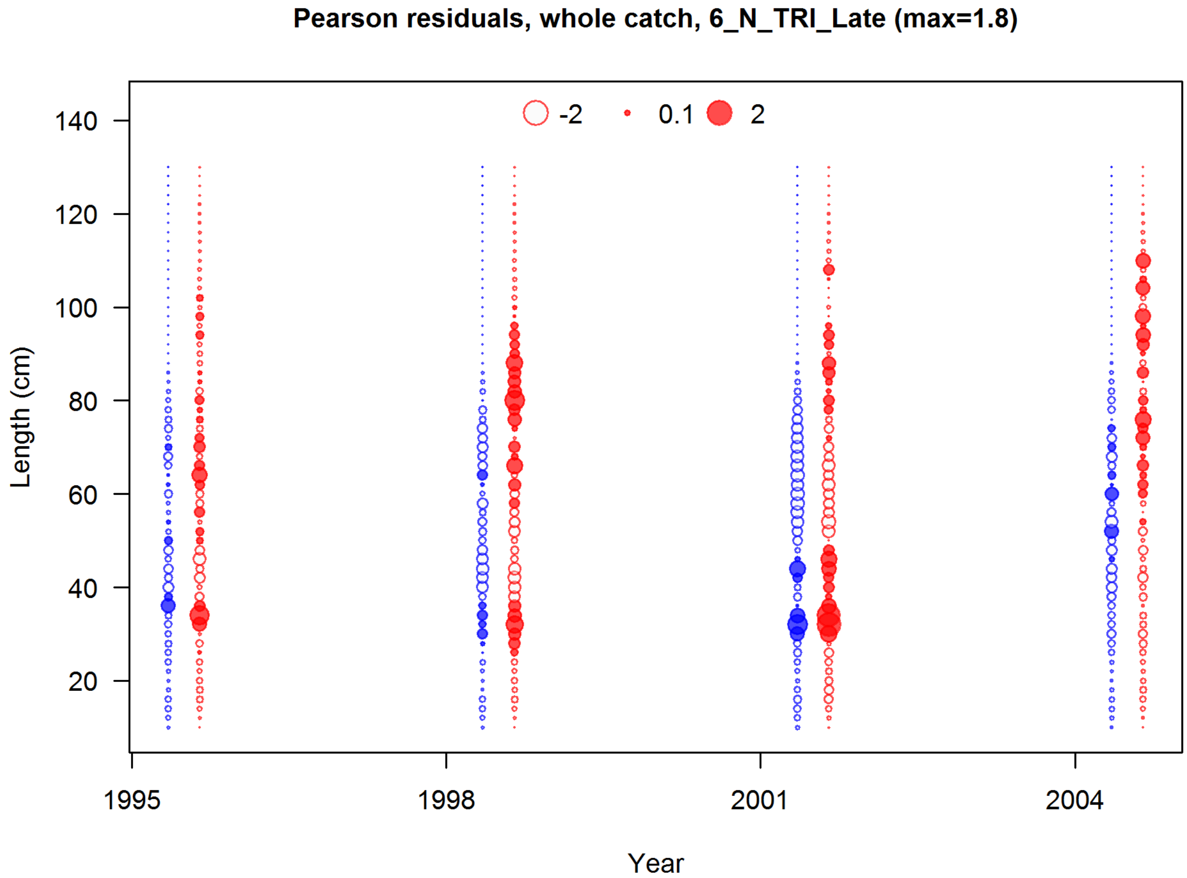


Figure 96. Triennial survey late sex specific length data Pearson residuals, north.

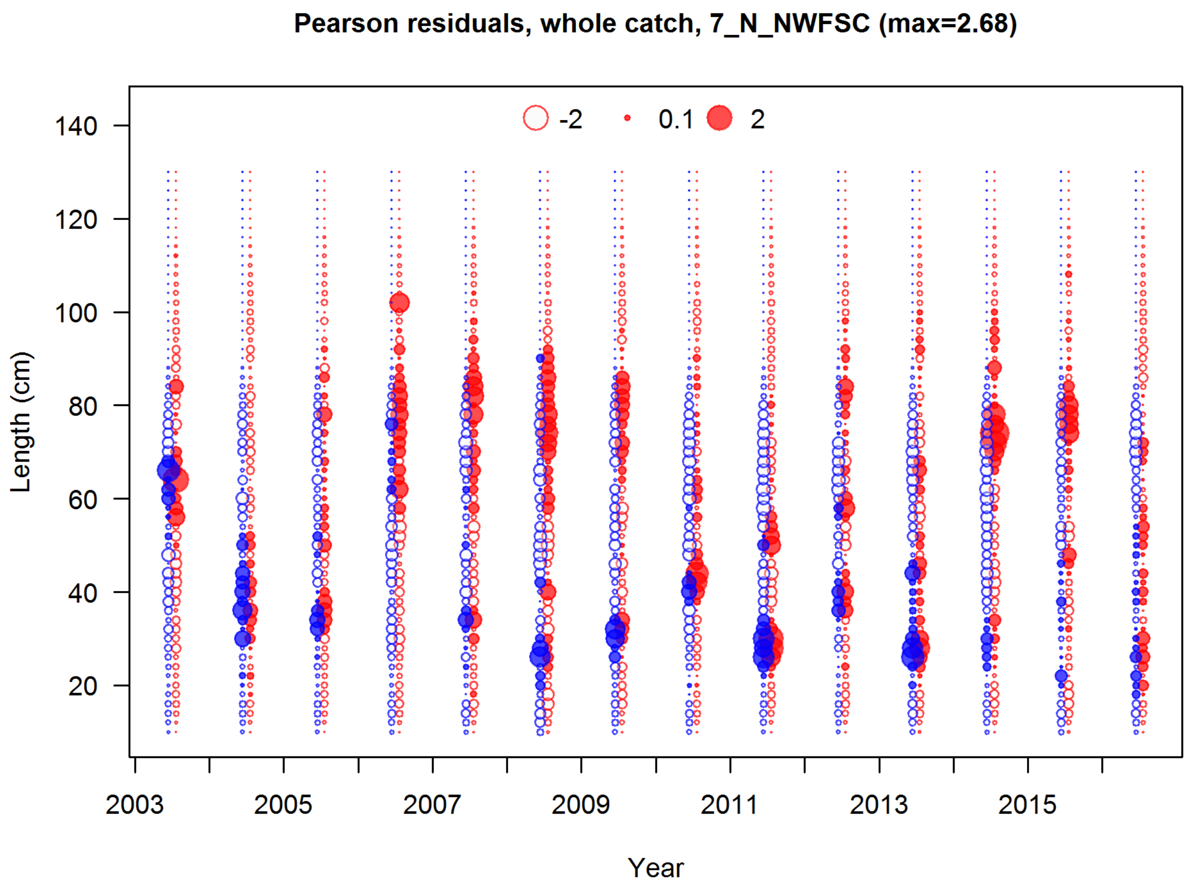


Figure 97. NWFSC survey sex specific length data Pearson residuals, north.

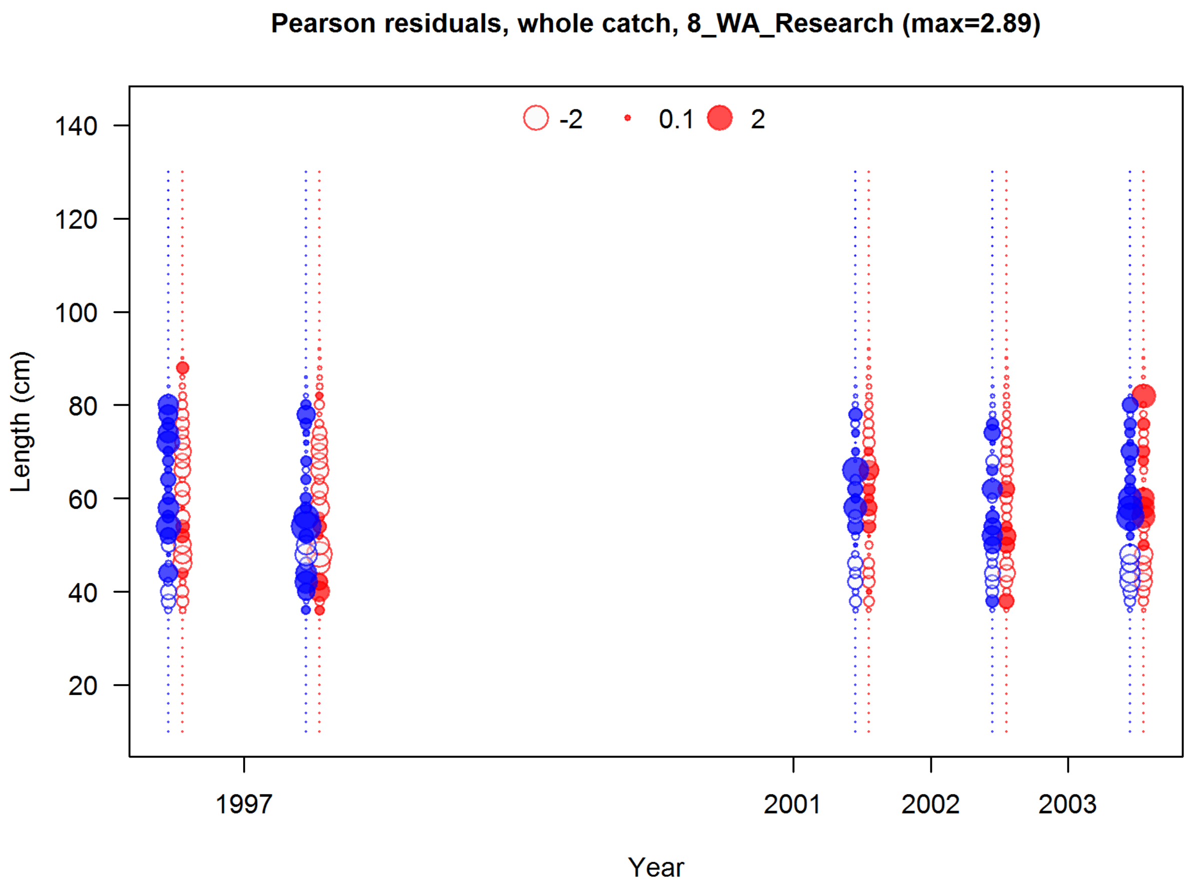


Figure 98. WA research sex specific length data Pearson residuals from the pre-STAR model. The final base model does not include these data.

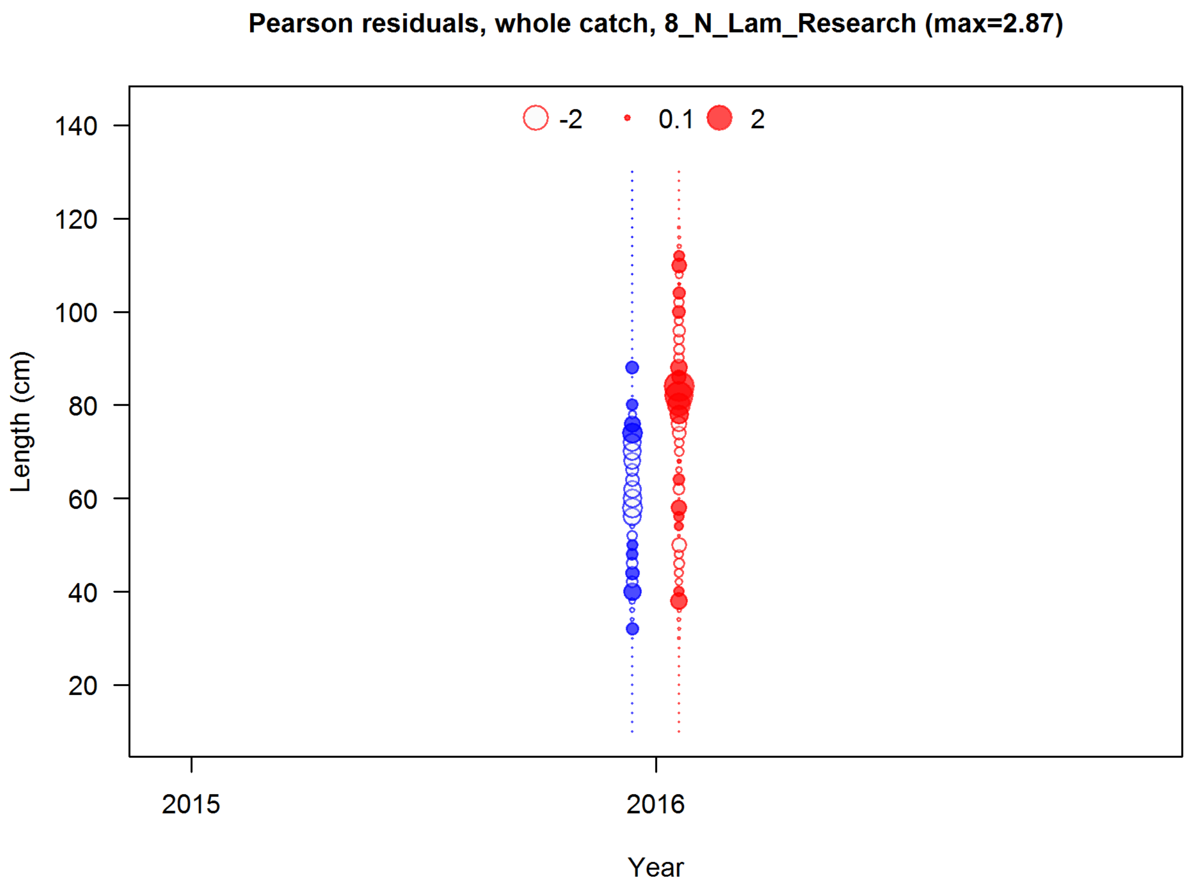


Figure 99. Lam sex specific research length data Pearson residuals, north.

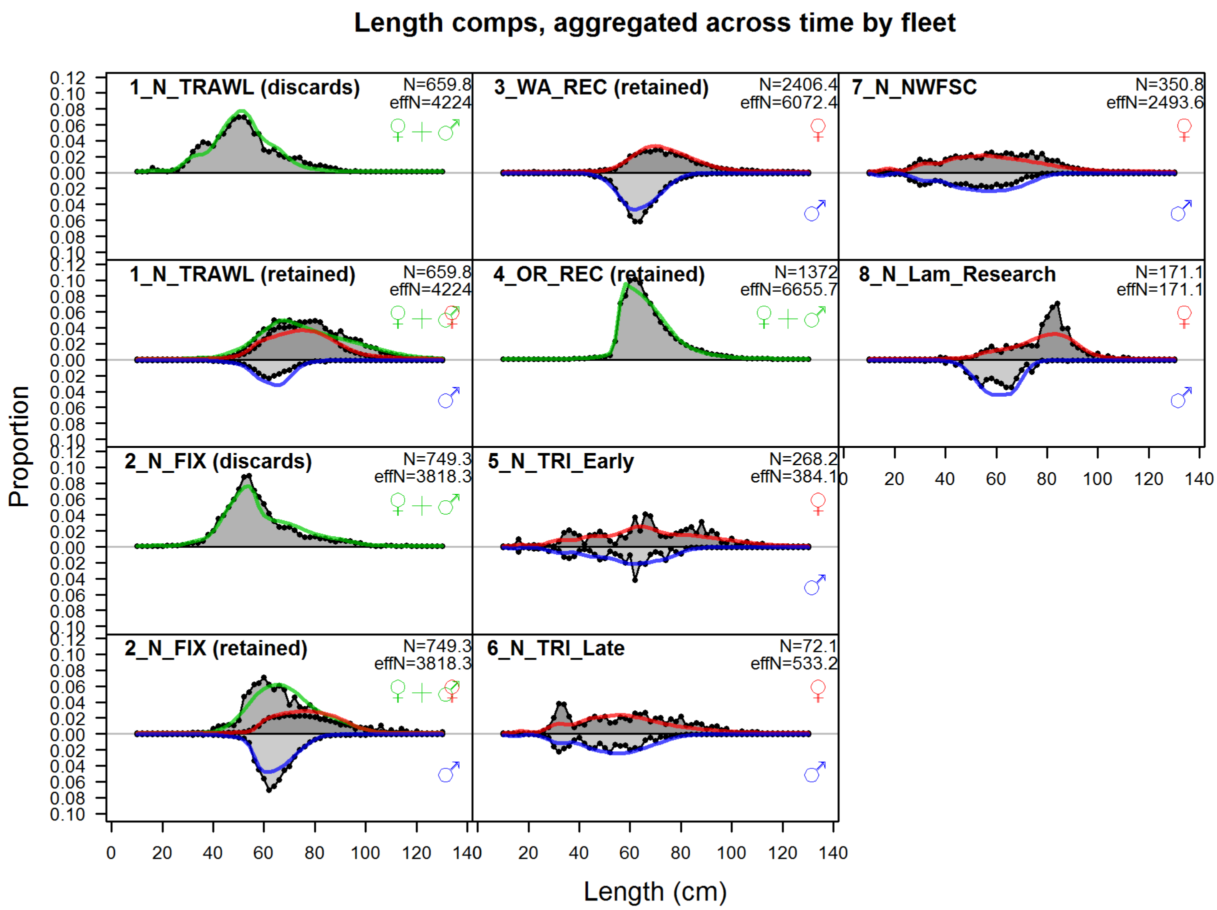


Figure 100. North model length composition data fits aggregated across time by fleet.

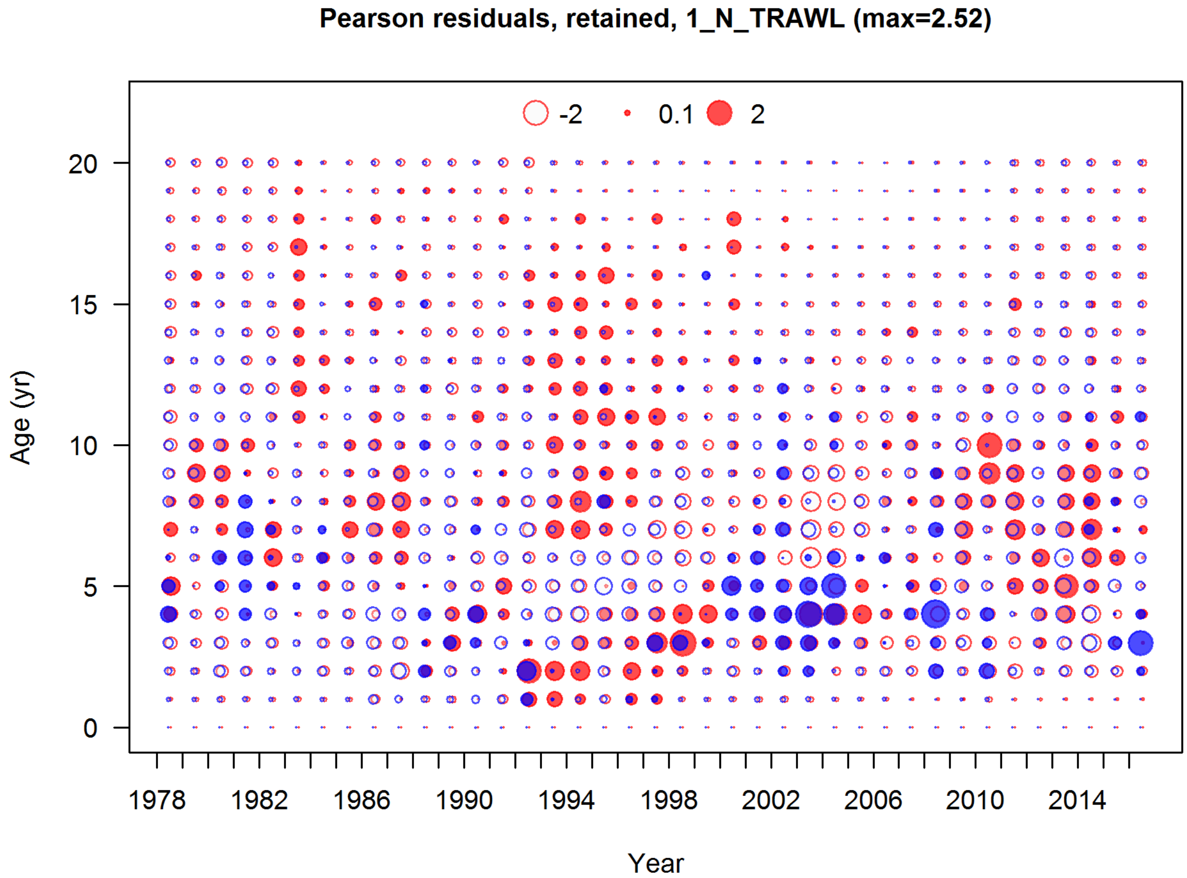


Figure 101. Commercial sex specific trawl age data Pearson residuals, north, from model sensitivity run that included these data.

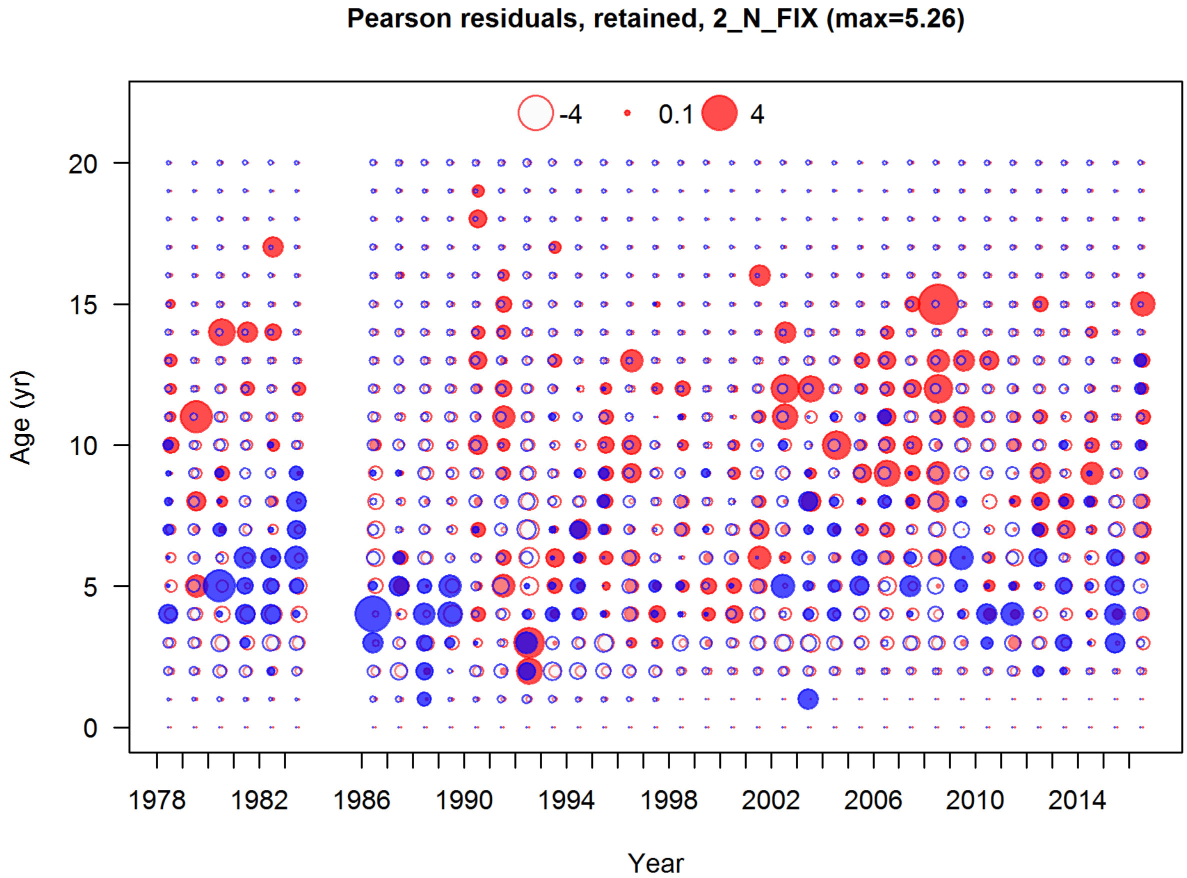


Figure 102. Commercial sex specific fixed gear age data Pearson residuals, north, from a model sensitivity run with these data.

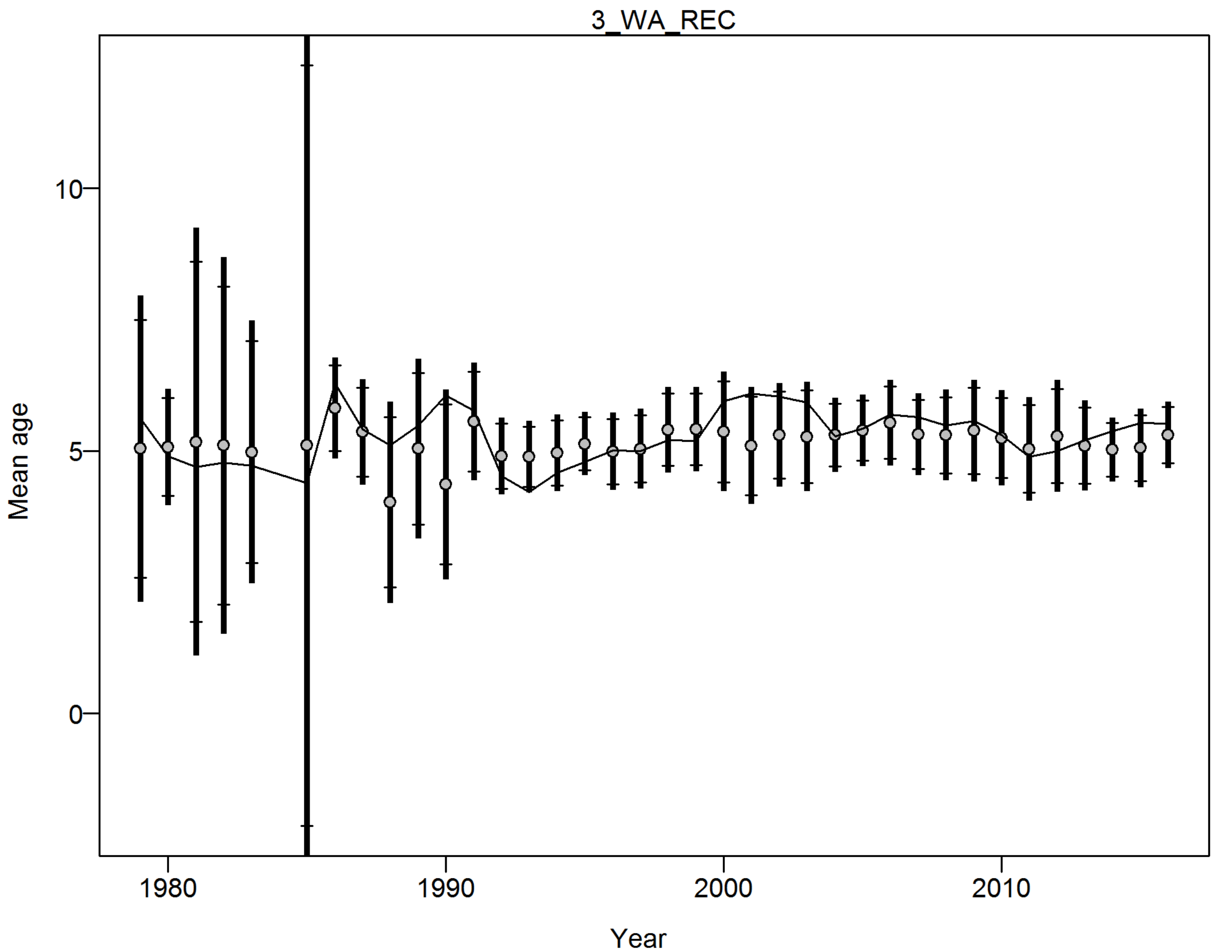


Figure 103. Fits to WA recreational age data from a model sensitivity to these data.

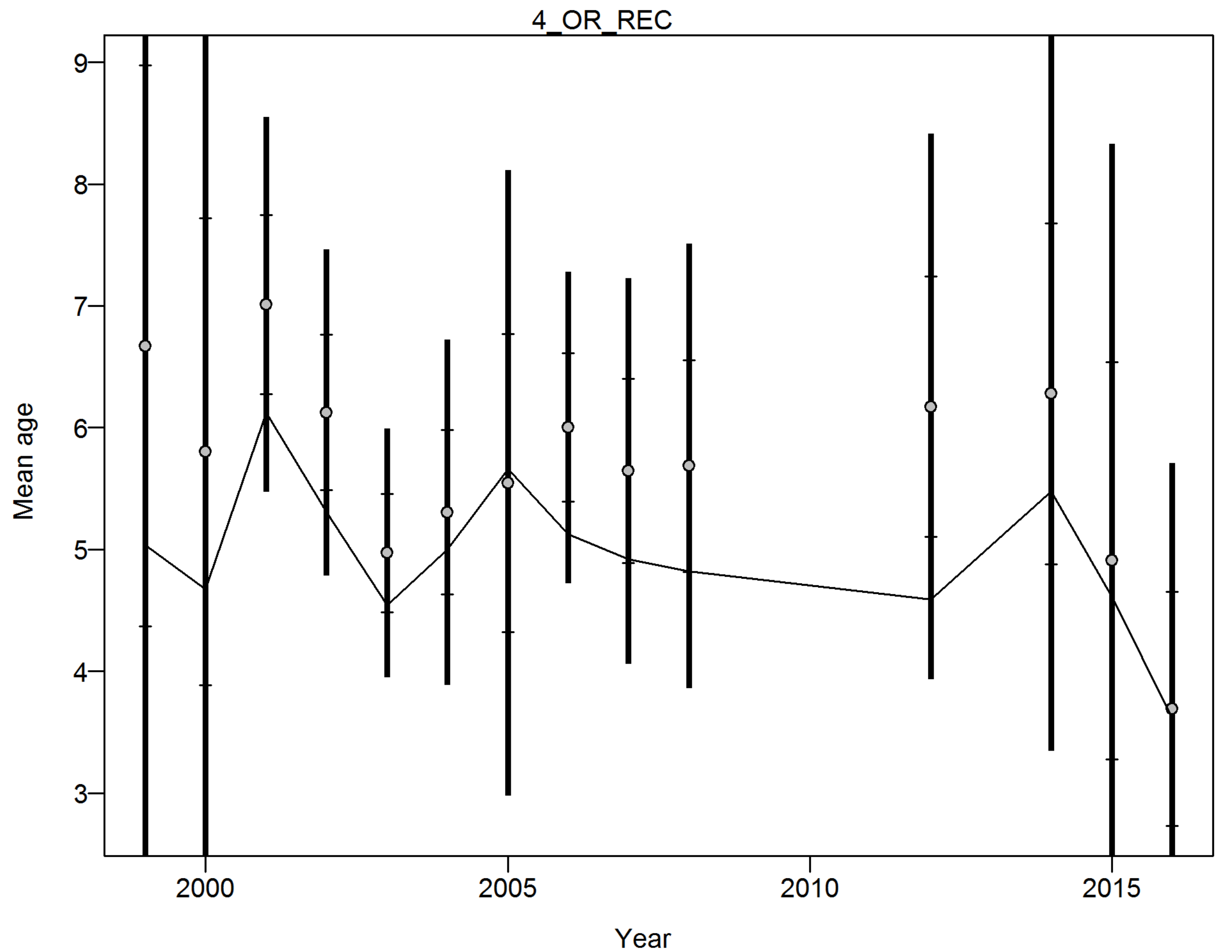


Figure 104. Fits to OR recreational age data from a model sensitivity run with these data.

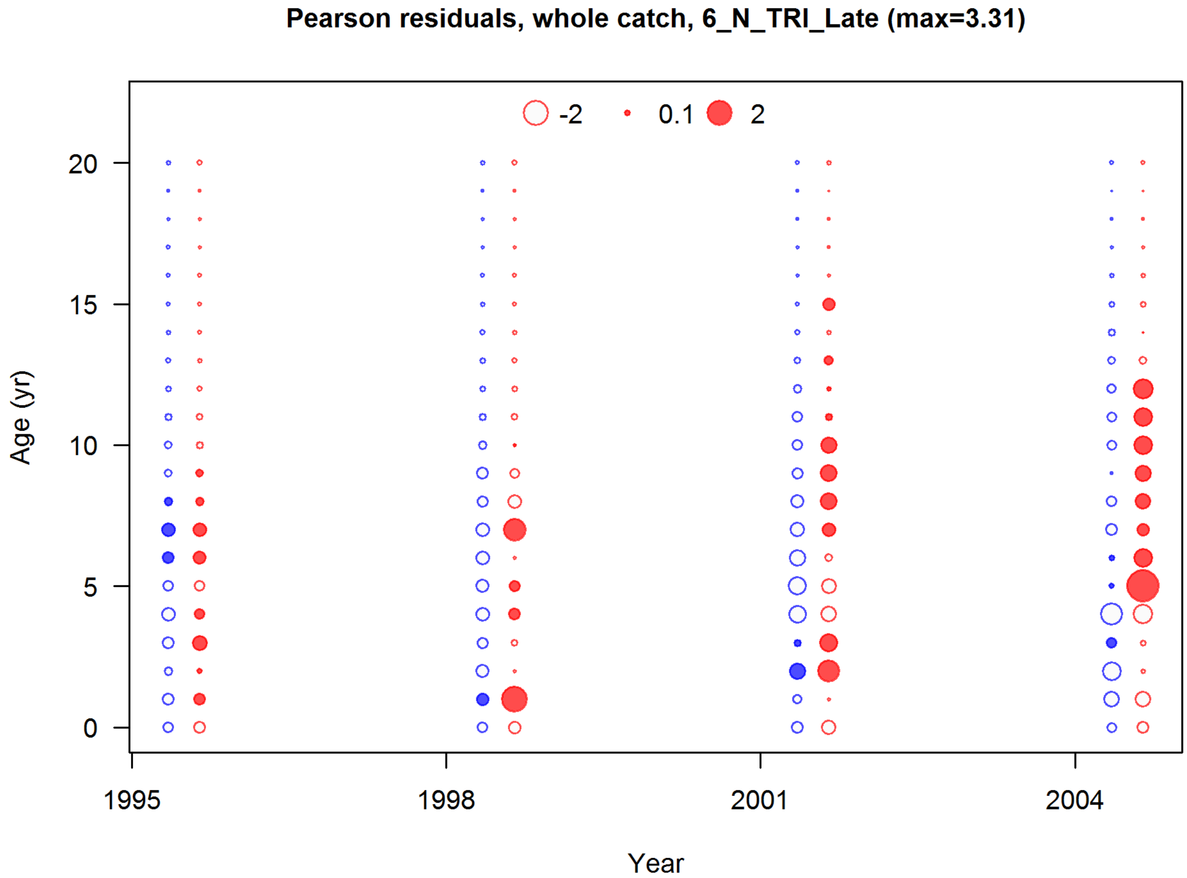


Figure 105. Triennial late survey sex specific age data Pearson residuals, north.

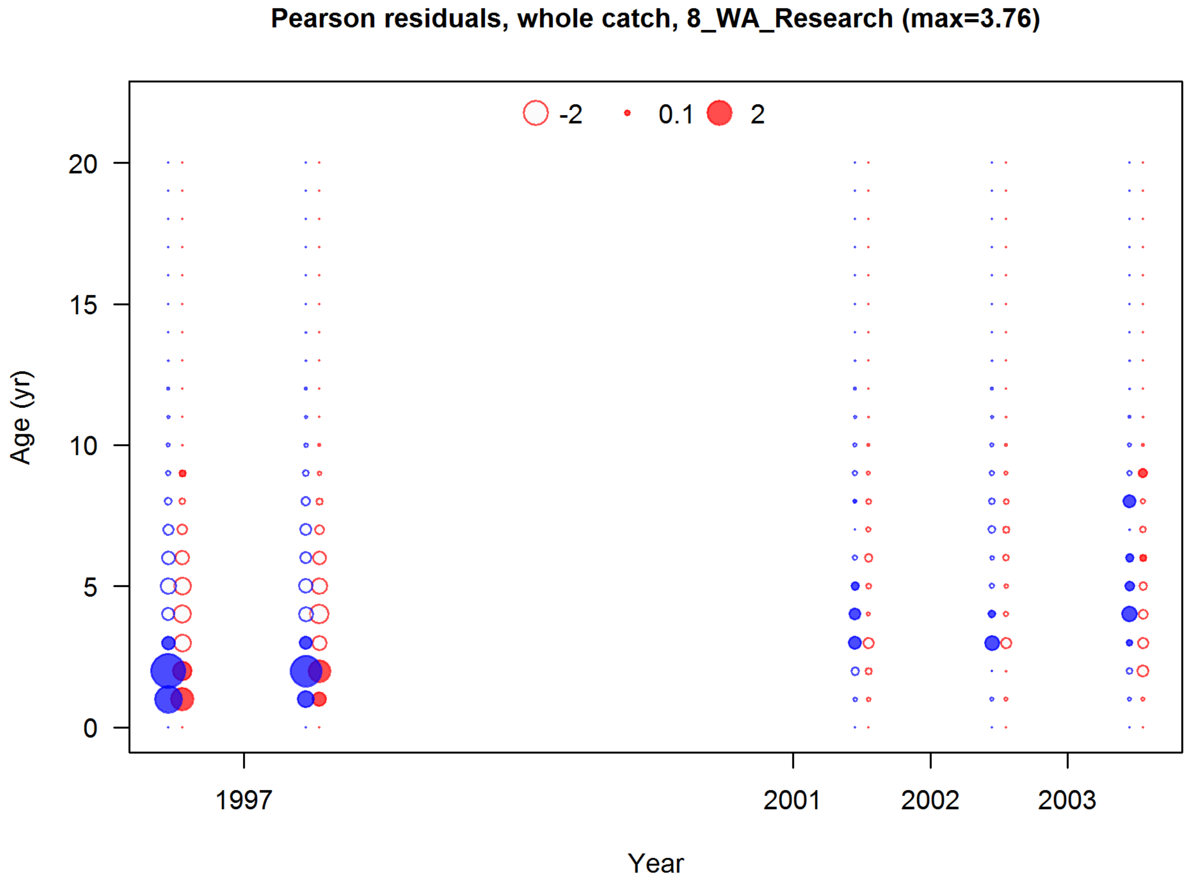


Figure 106. WA research sex specific age data Pearson residuals from a sensitivity run with these data.

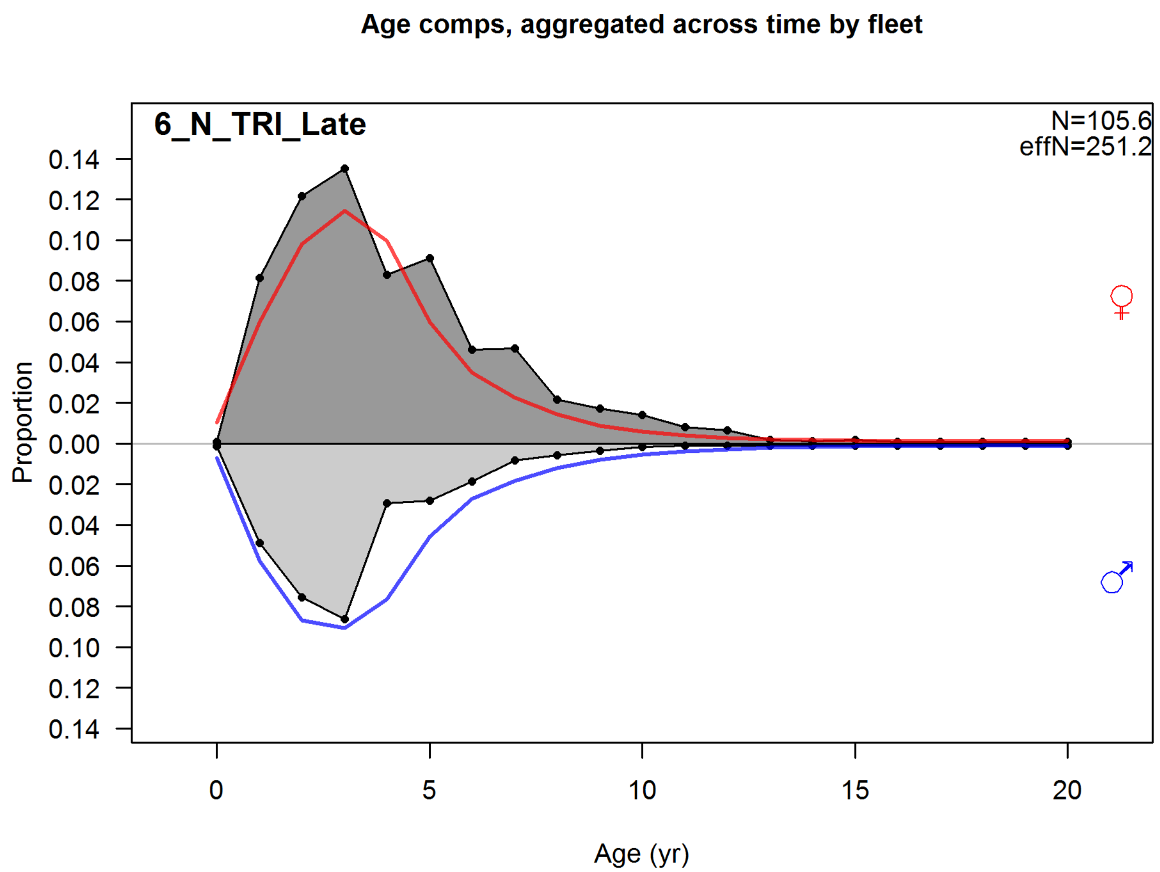


Figure 107. Age composition fits aggregated across time and by fleet for the north.

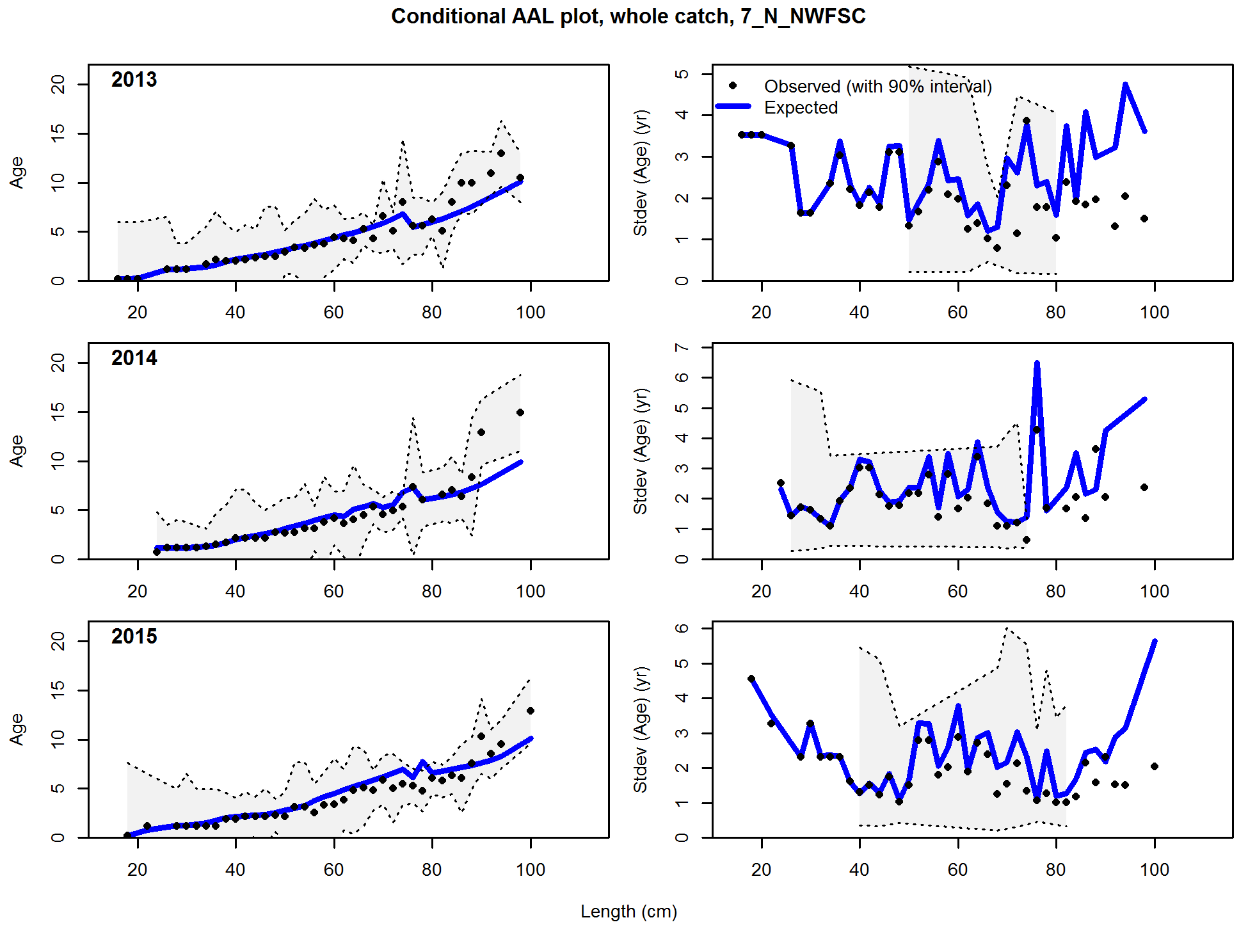


Figure 108. Conditional age-at-length (AAL) fits for the NWFSC survey data.

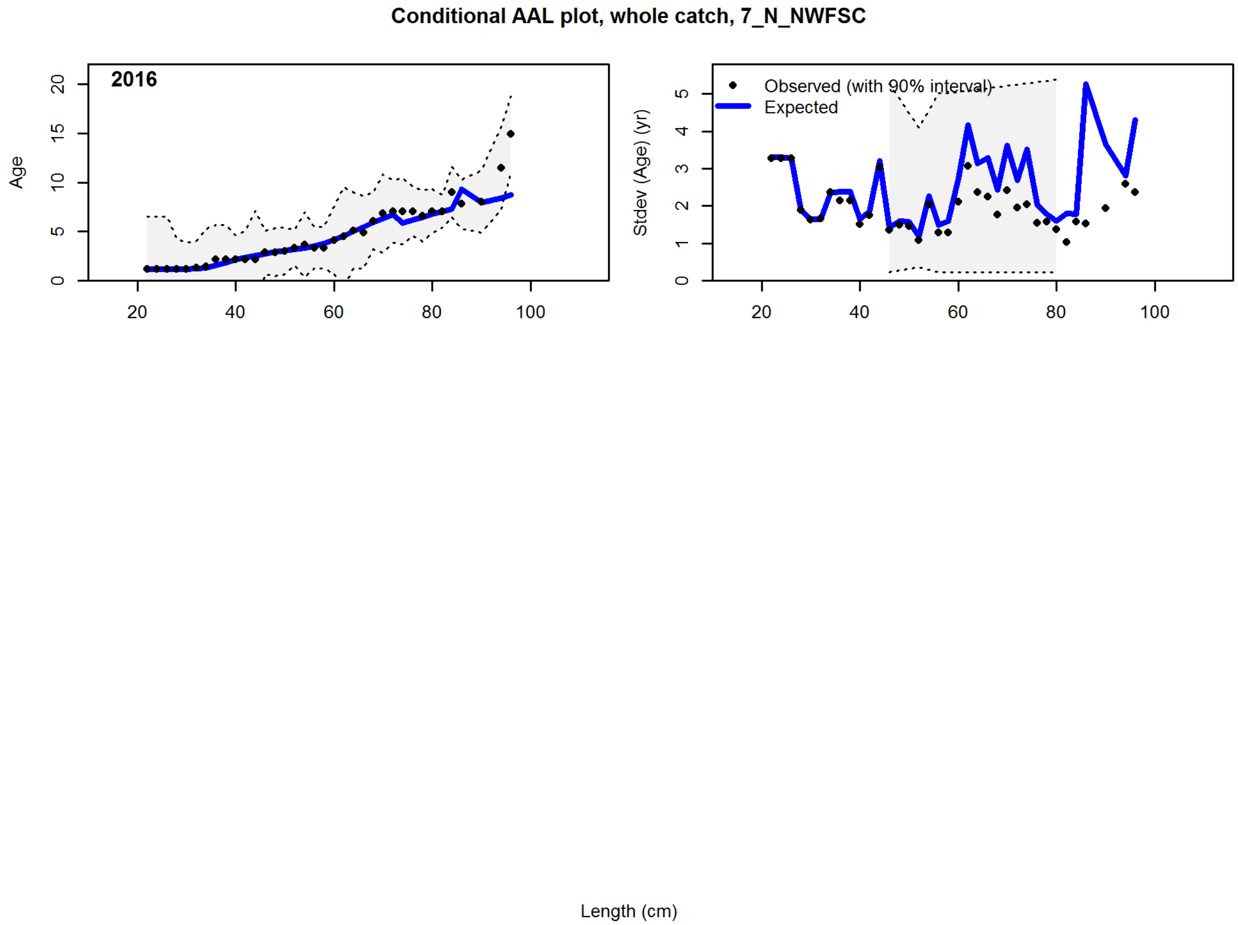


Figure 109. Conditional age-at-length (AAL) fits for Lam research data.

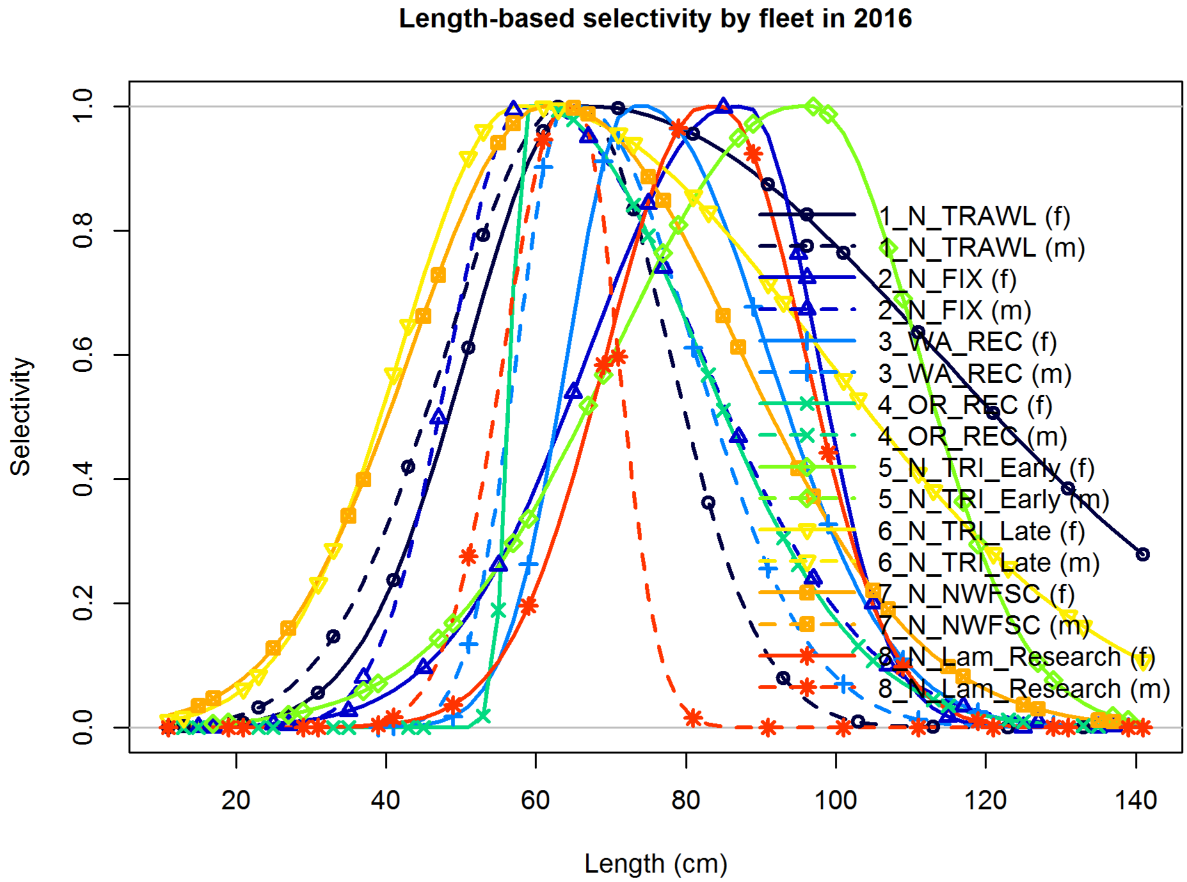


Figure 110. End year selectivity for each north model fleet. Go to the Auxiliary files r4ss plots folder for the north model run, open the SS Output html file, and go to the "sel" tab to see individual selectivity plots for each fleet as well as plots of retention curves for the commercial fleets.

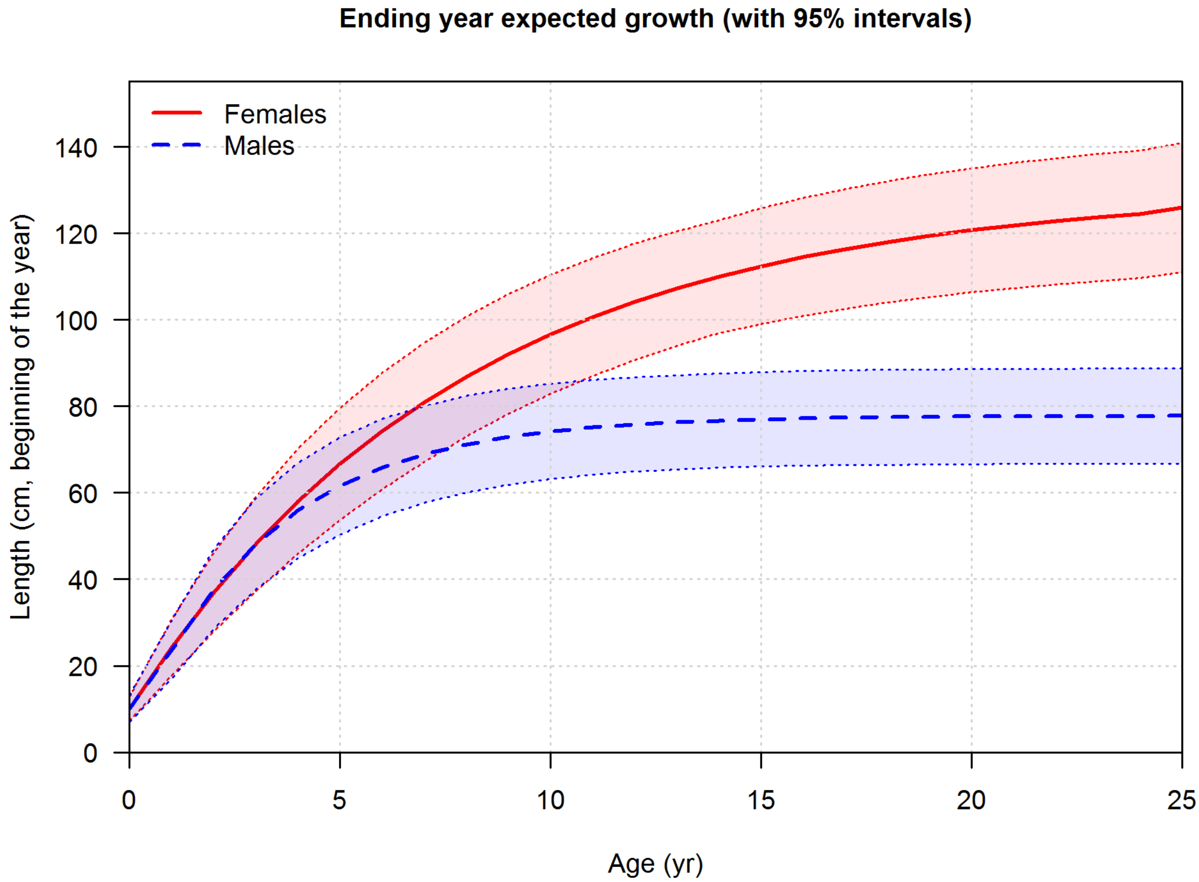


Figure 111. Estimated growth curves, north.

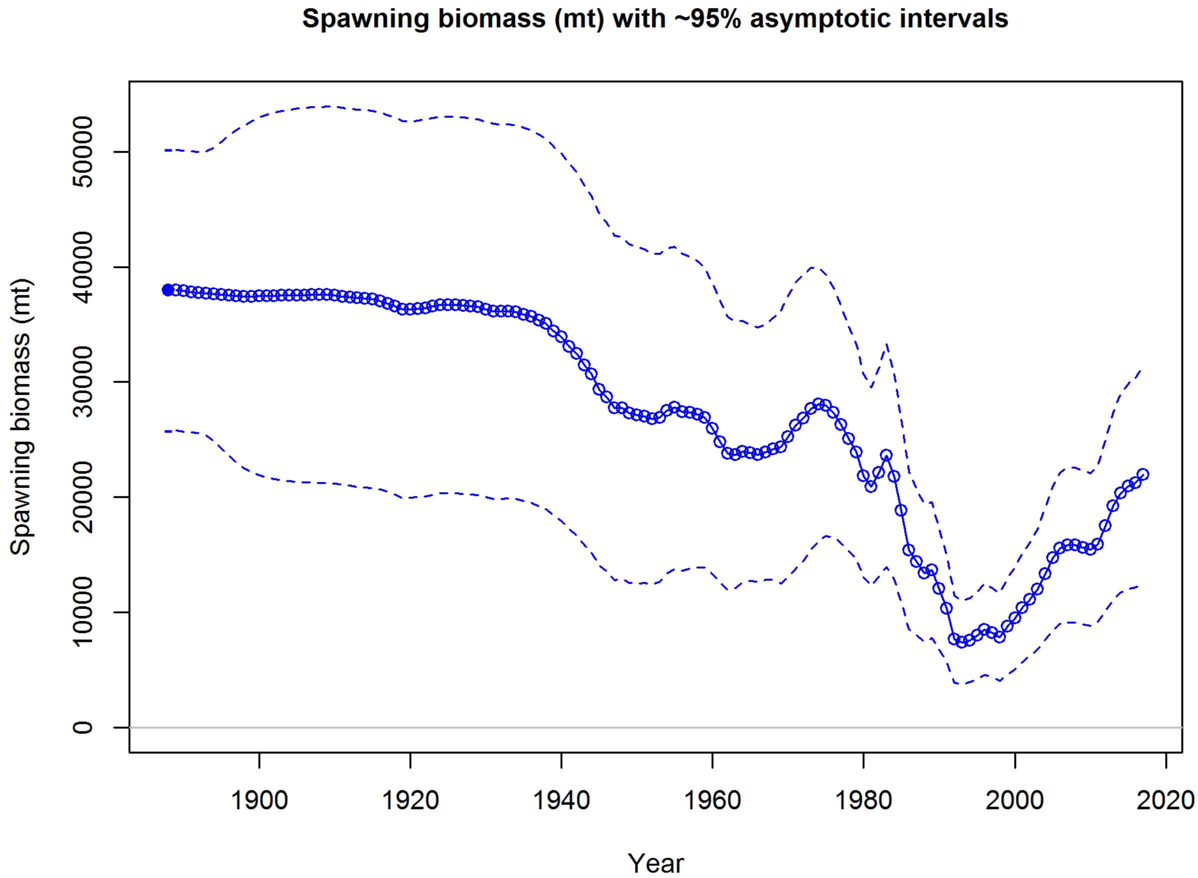


Figure 112. Time series of estimate spawning biomass, north.

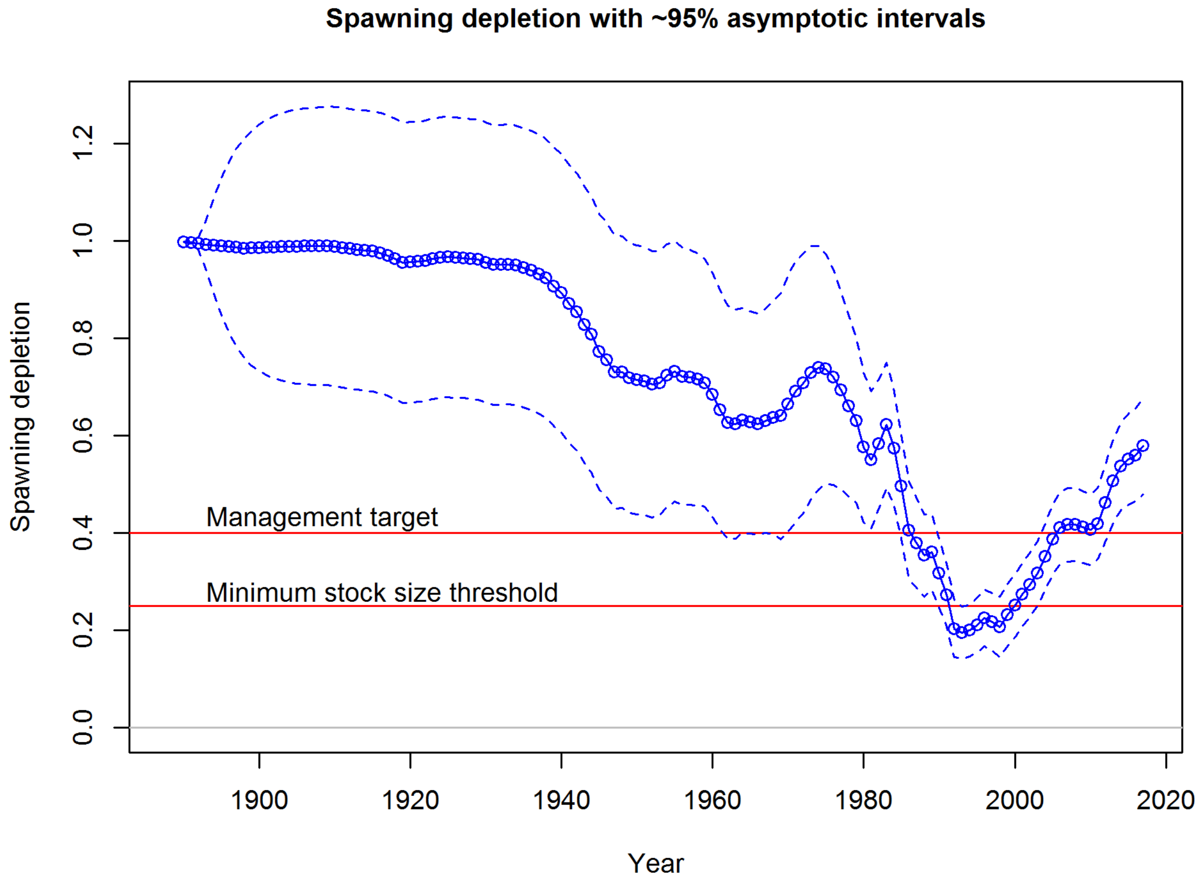


Figure 113. Time series of stock depletion, north.

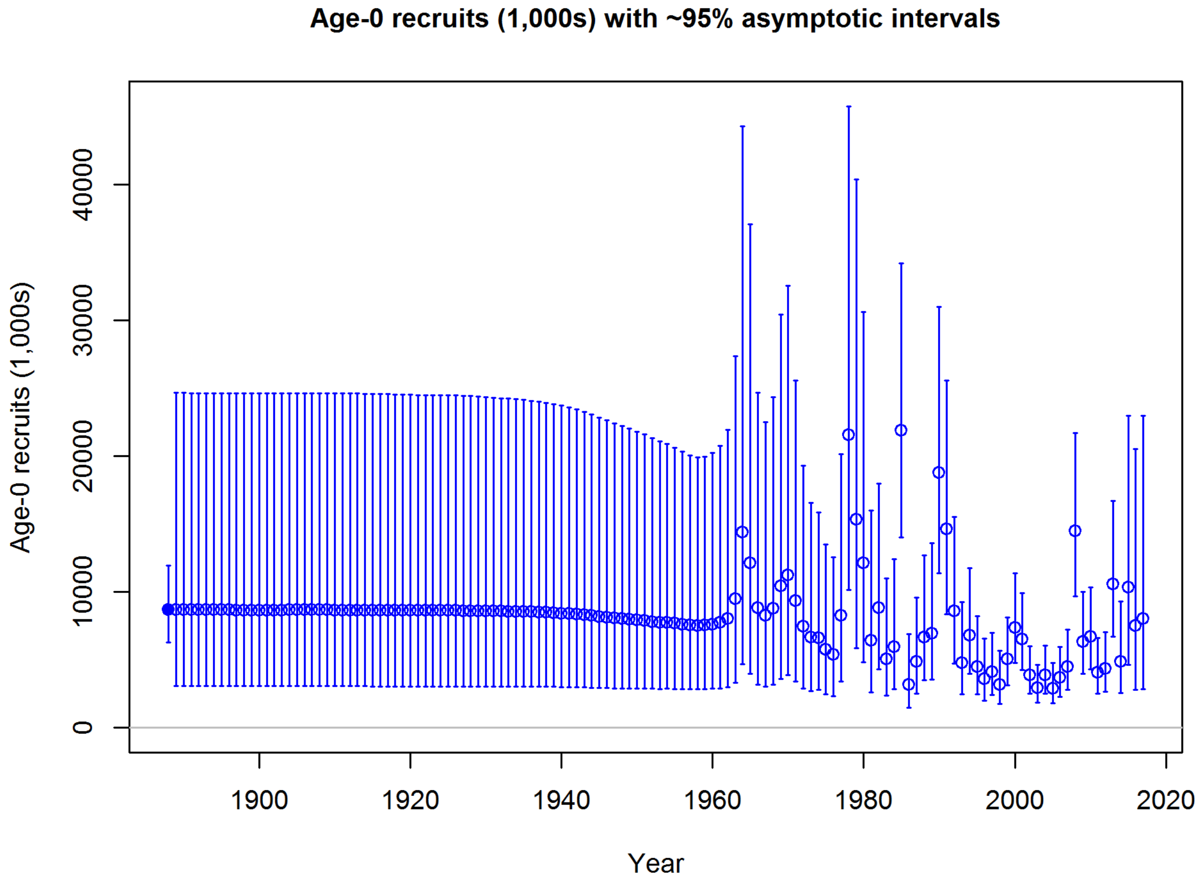


Figure 114. Time series of estimated recruits, north.

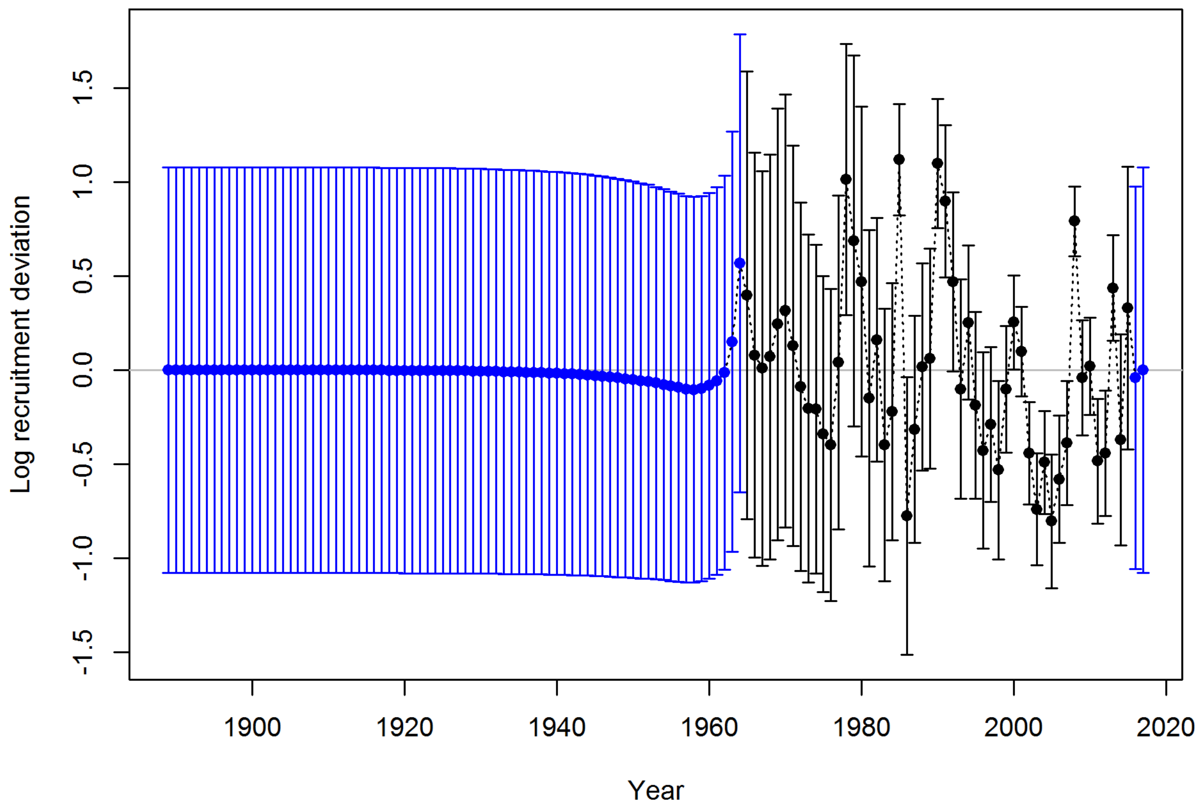


Figure 115. Estimated recruitment deviations, north.

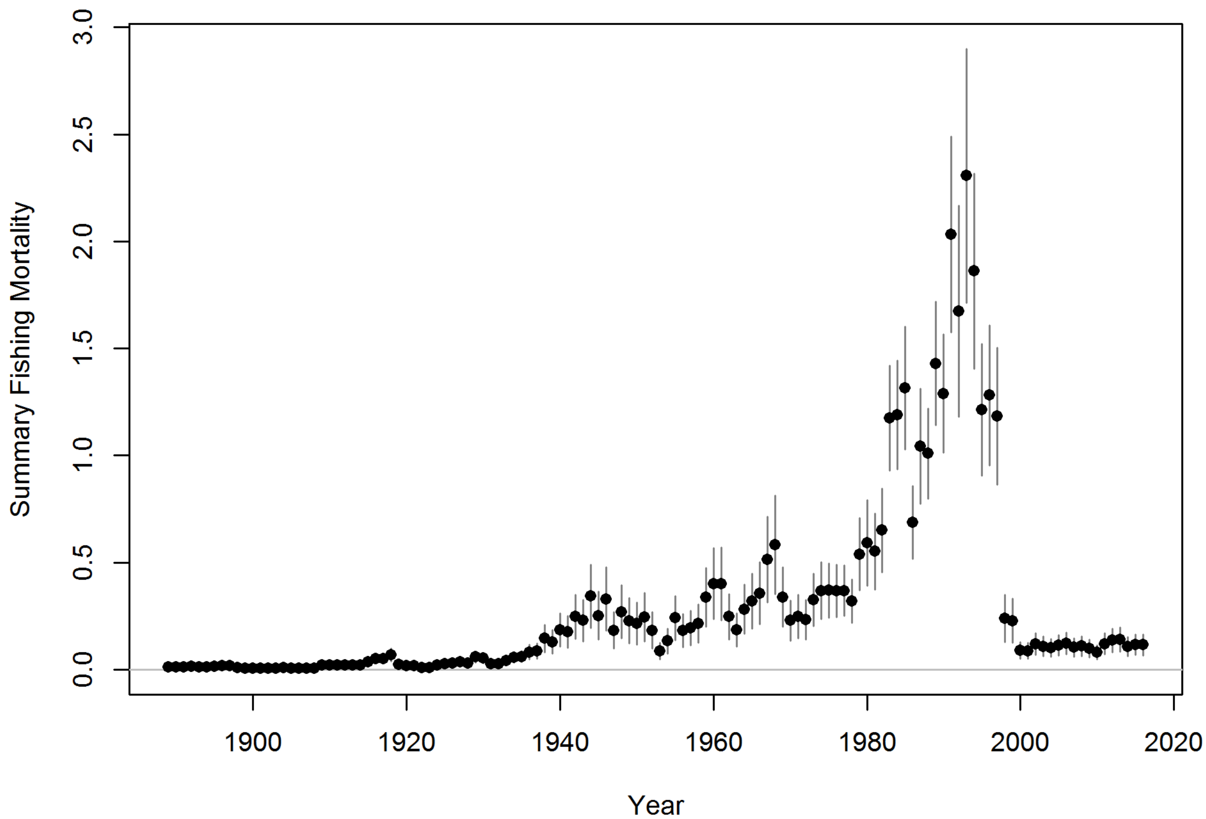


Figure 116. Time series of estimated Summary Fishing Mortality (F), north.

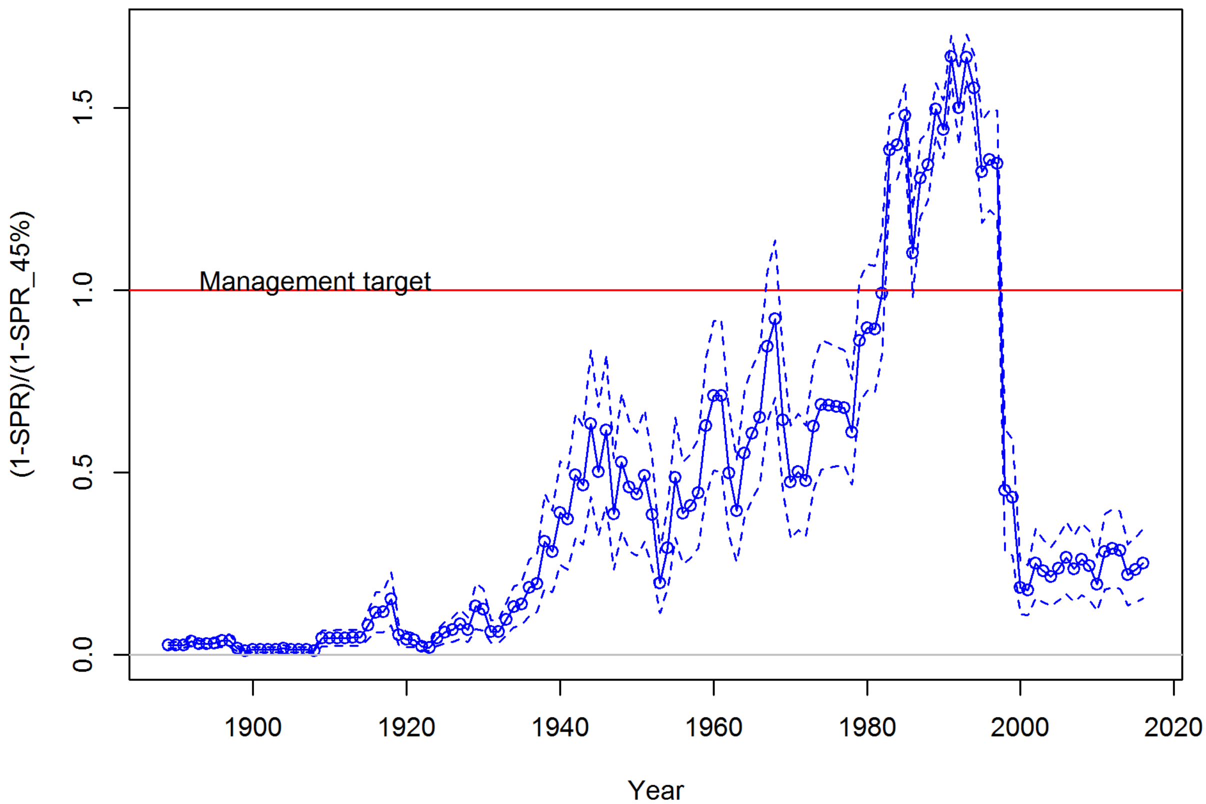


Figure 117. Time series of SPR ratio, north.

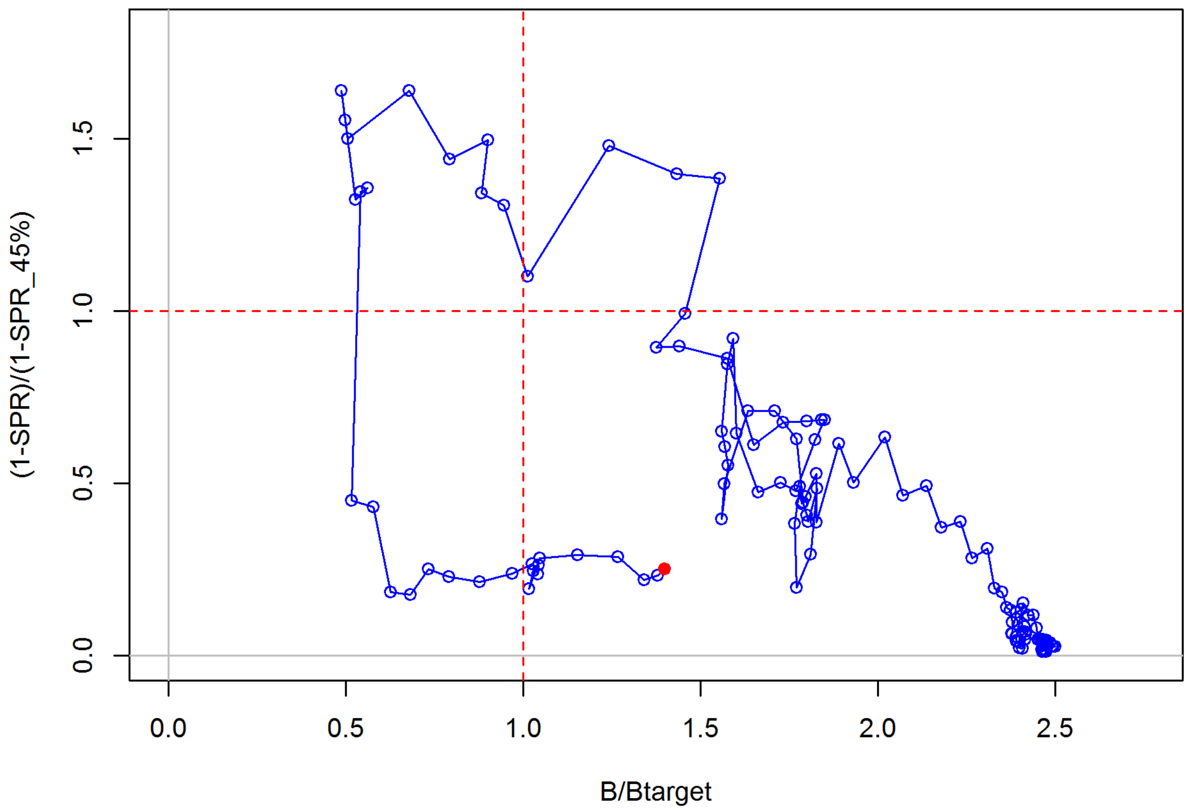


Figure 118. Phase plot of biomass ratio v. SPR ratio.

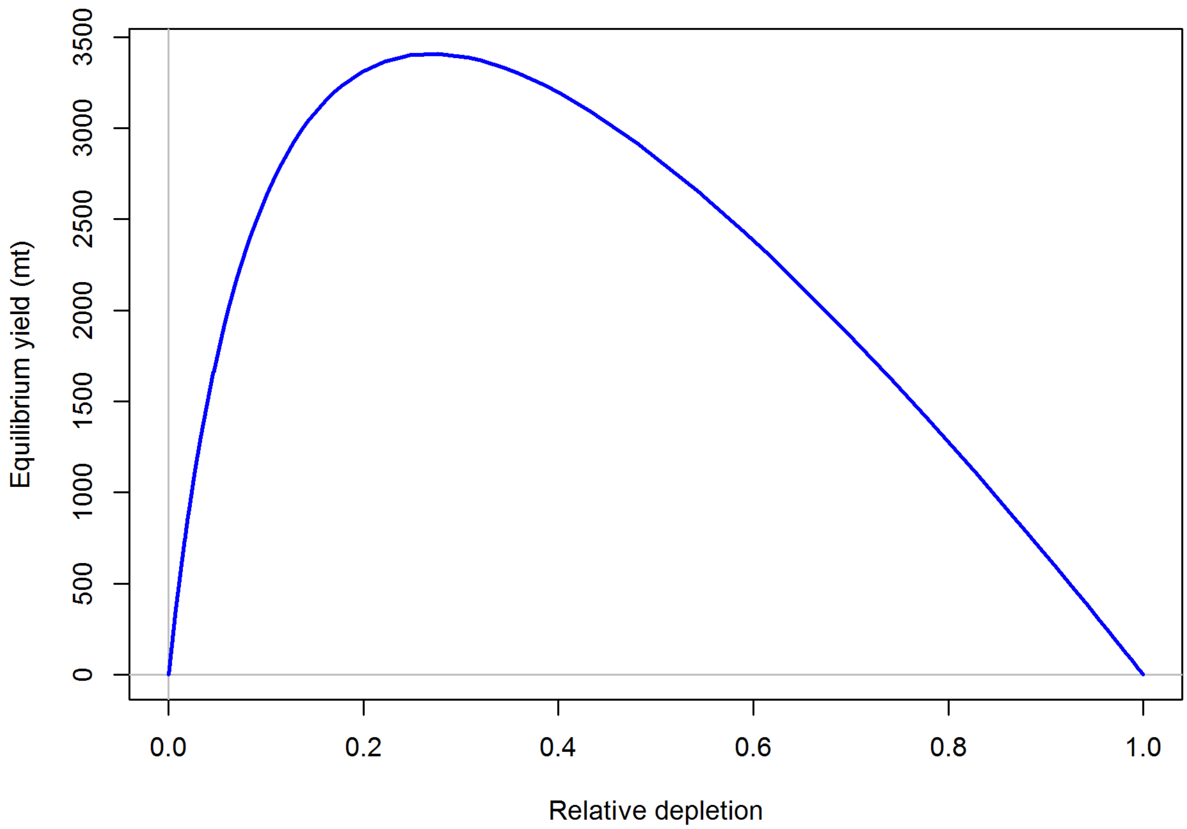


Figure 119. Equilibrium yield curve, north.

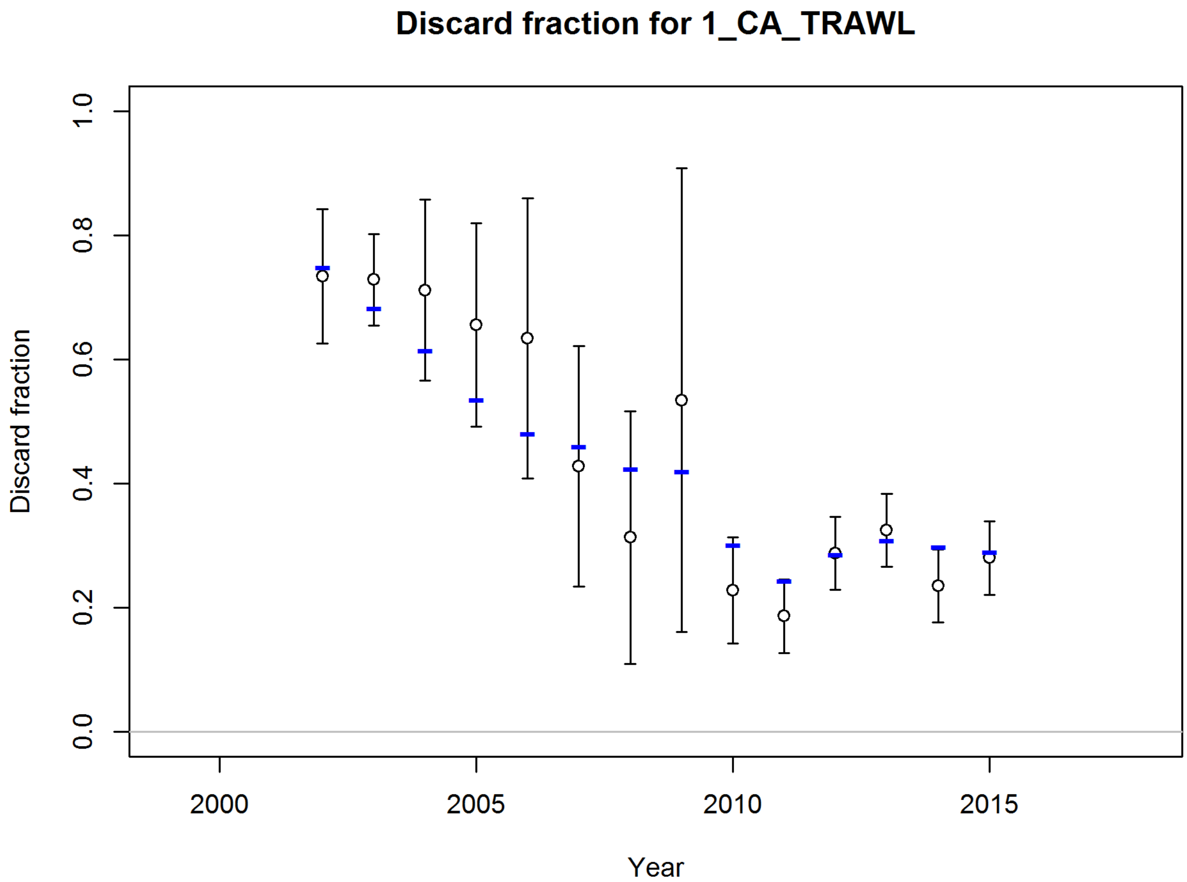


Figure 120. Commercial trawl discard fraction fits, south. Blue horizontal dashed lines are model fits.

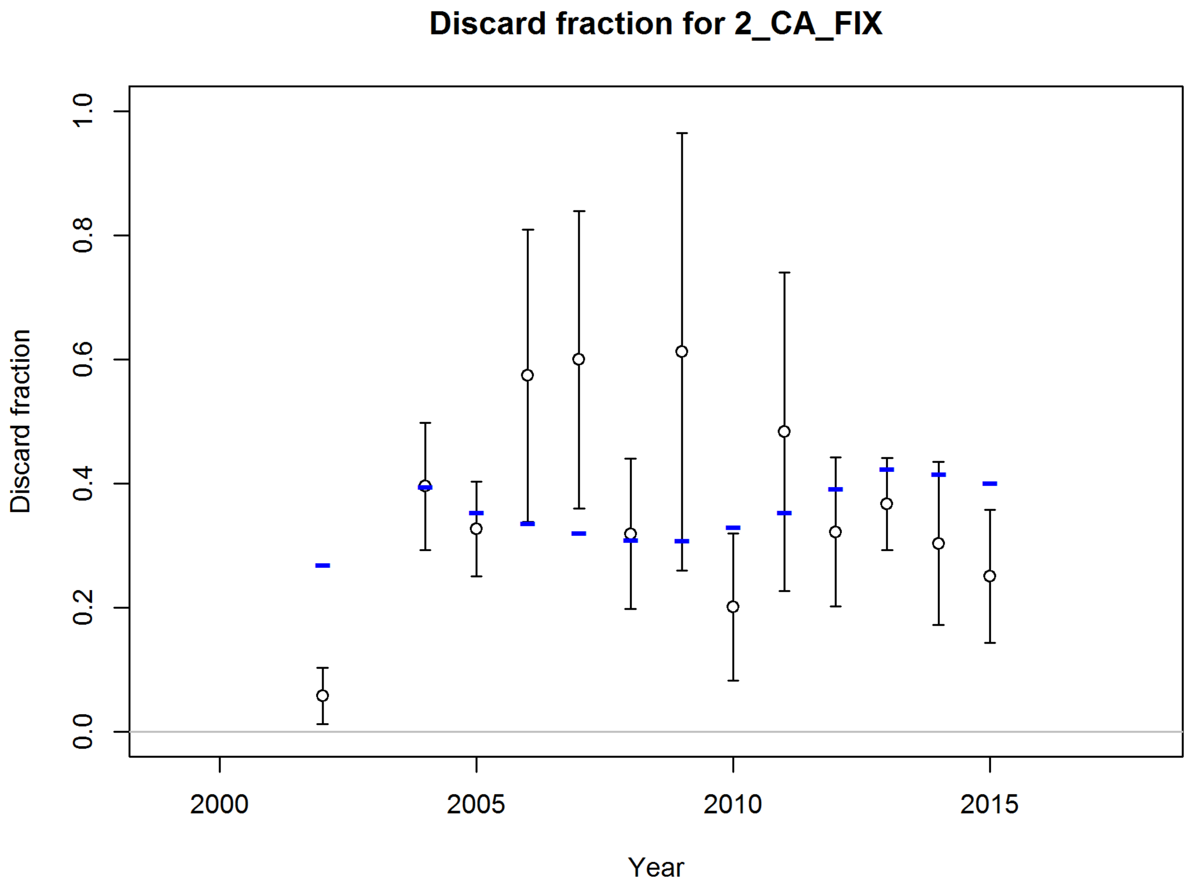


Figure 121. Commercial fixed gear discard fraction fits, south. Blue horizontal dashed lines are model fits.

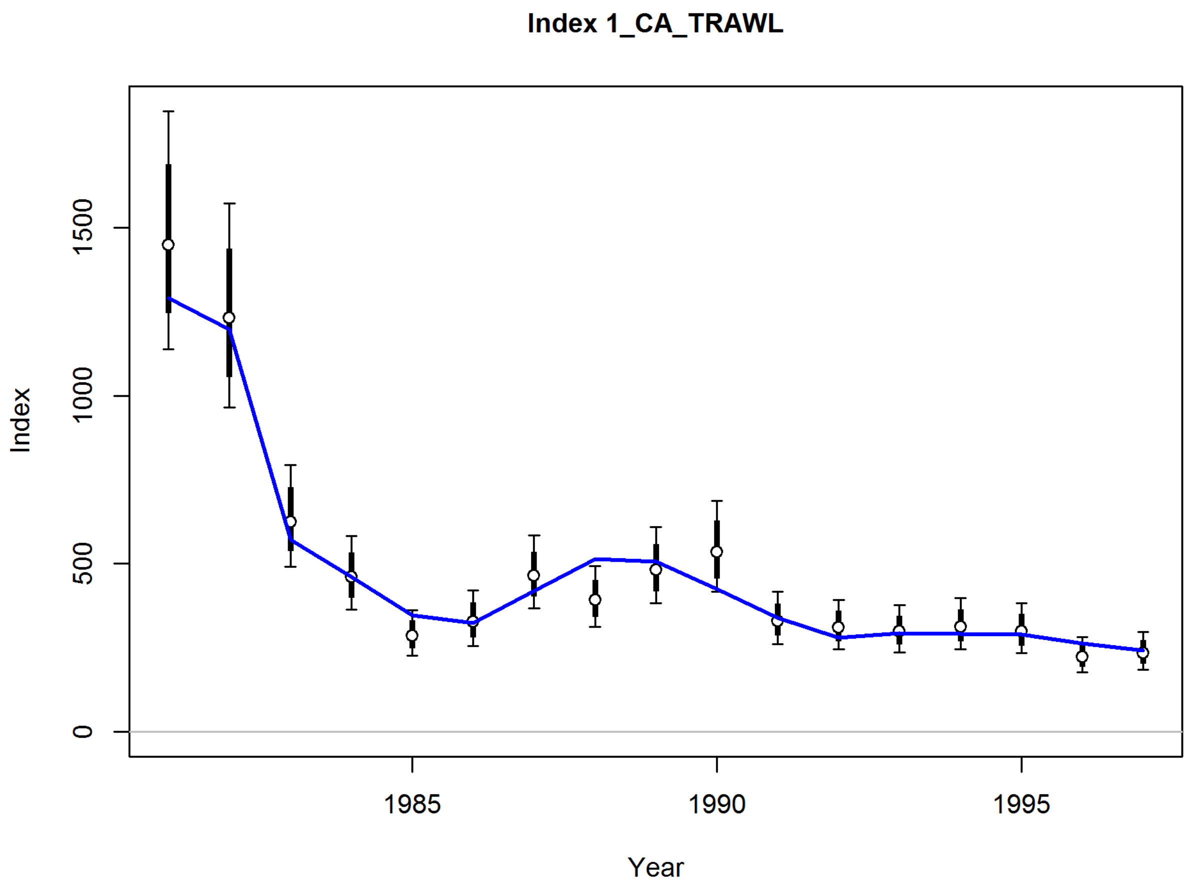


Figure 122. Commercial trawl CPUE fit, south. Thick bars indicate the input standard deviations; light bars represent the estimated added standard deviations.

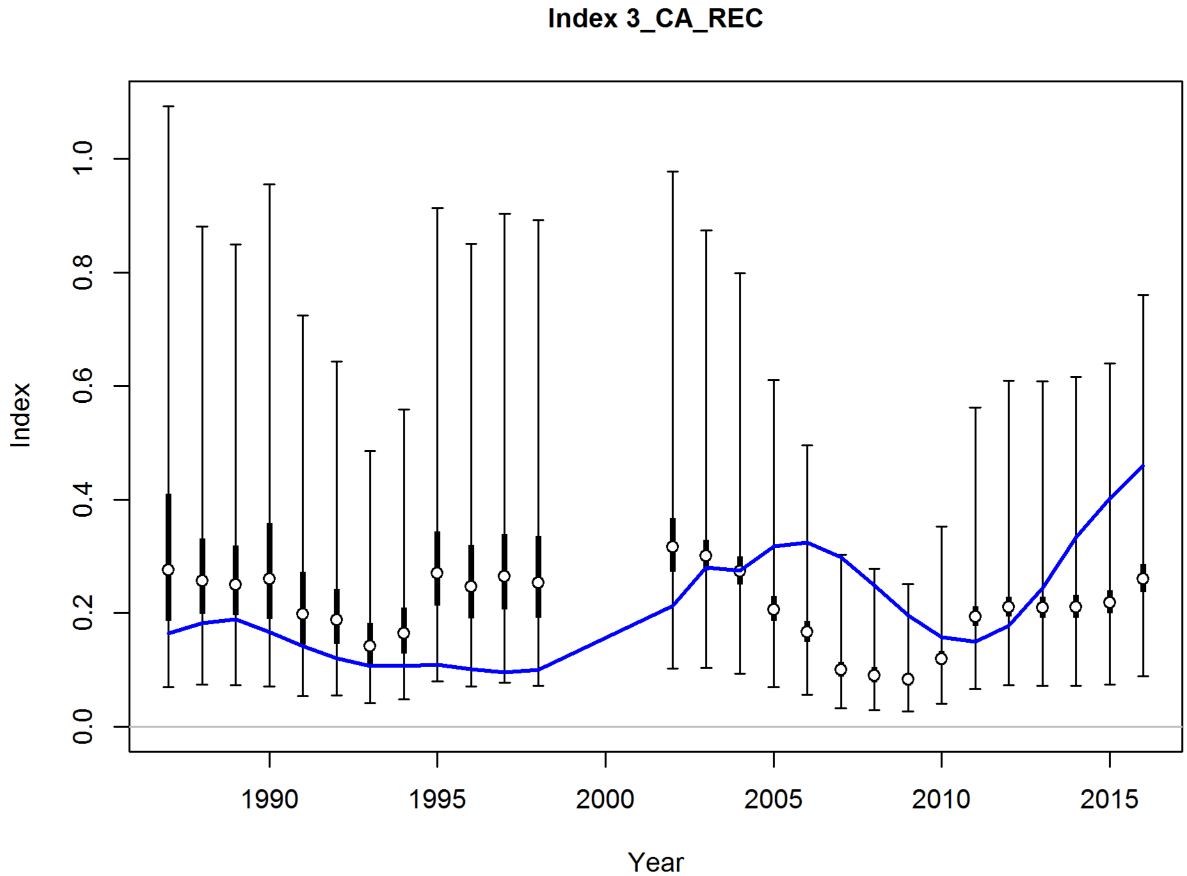


Figure 123. Recreation onboard observer CPUE fit, south, from a model sensitivity run with these data. Thick bars indicate the input standard deviations; light bars represent the estimated added standard deviations.

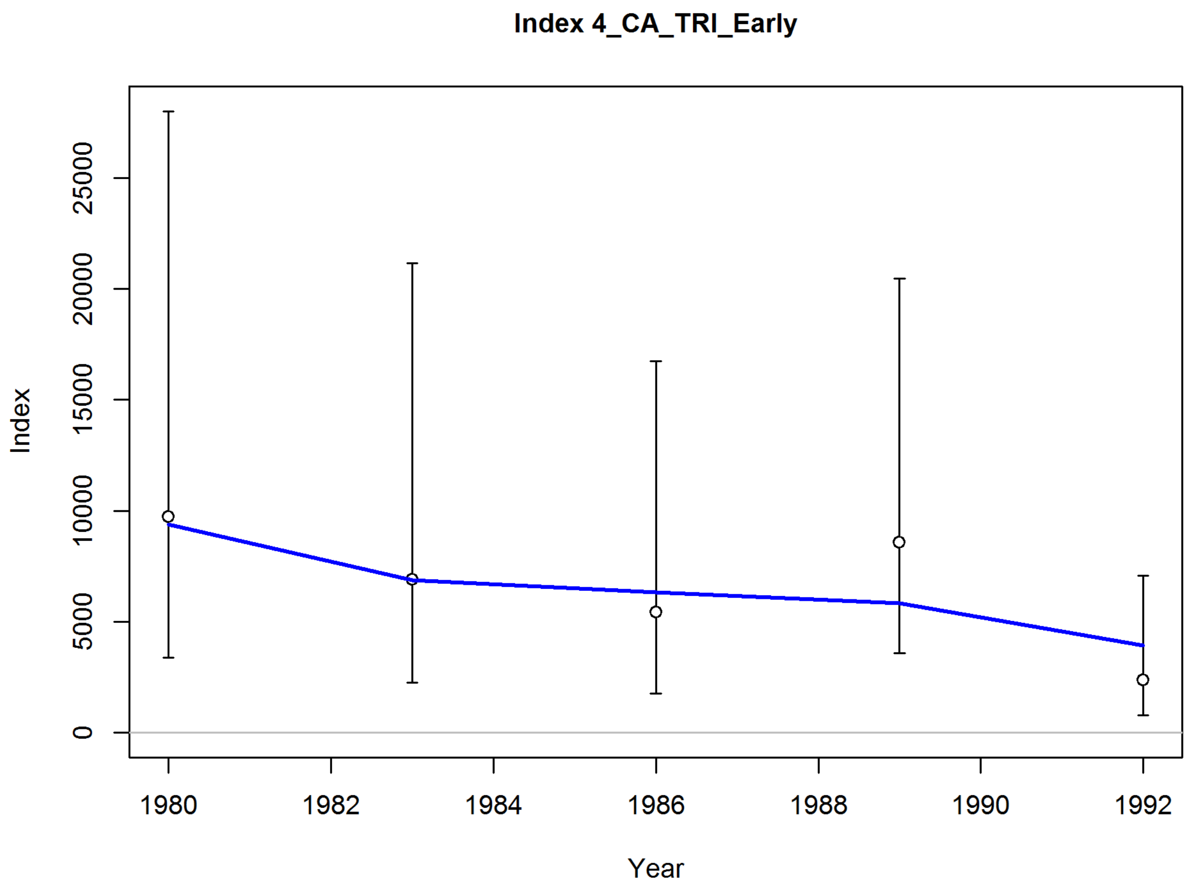


Figure 124. Triennial survey CPUE fit, south.

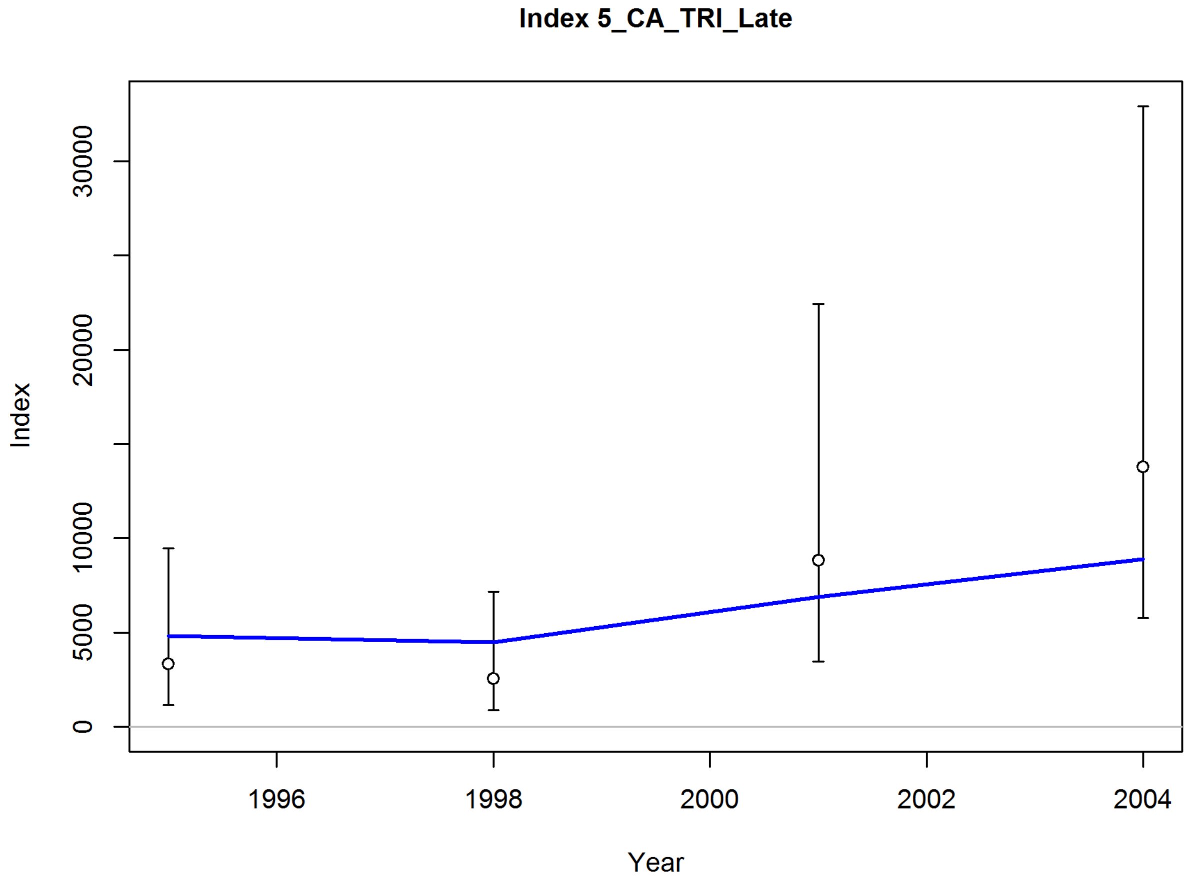


Figure 125. Triennial survey late CPUE fit, south.

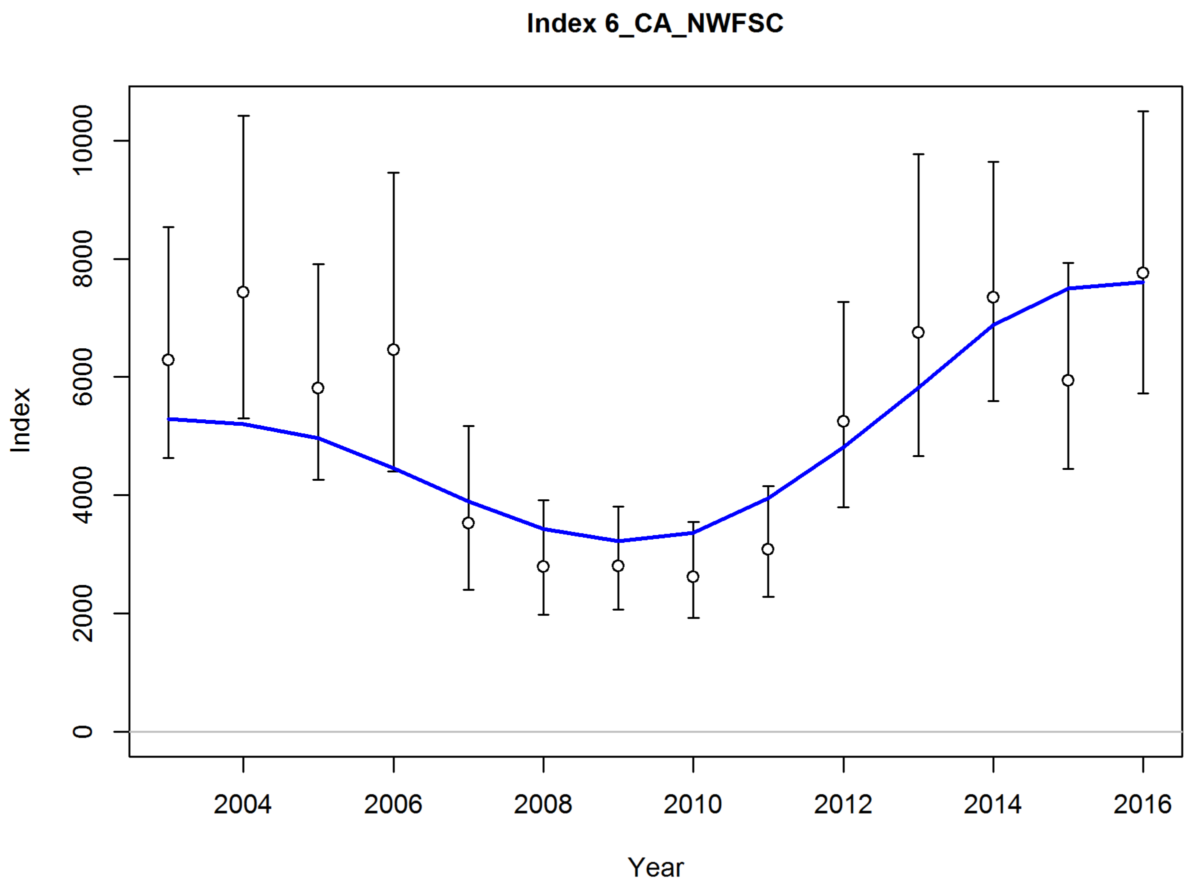


Figure 126. NWFSC survey index fit, south.

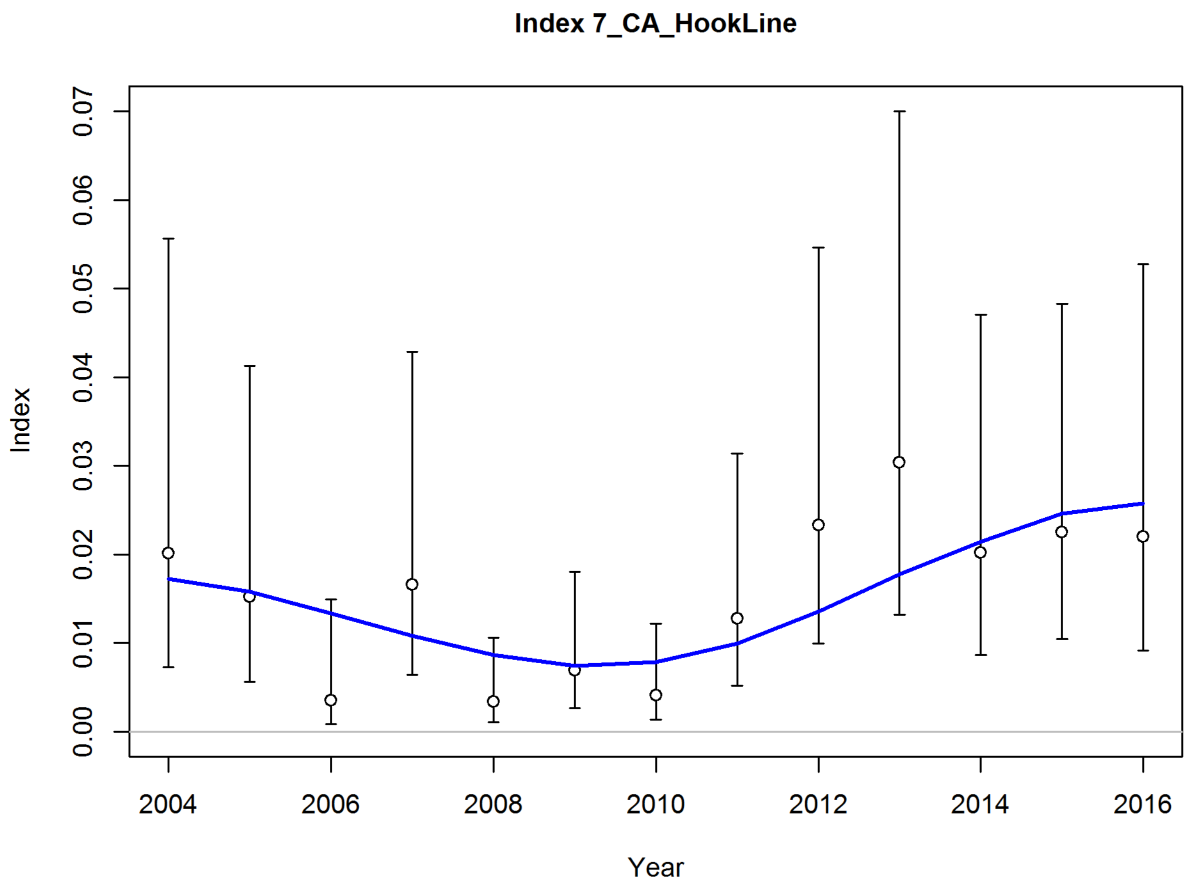


Figure 127. NWFSC Hook and Line survey fit.

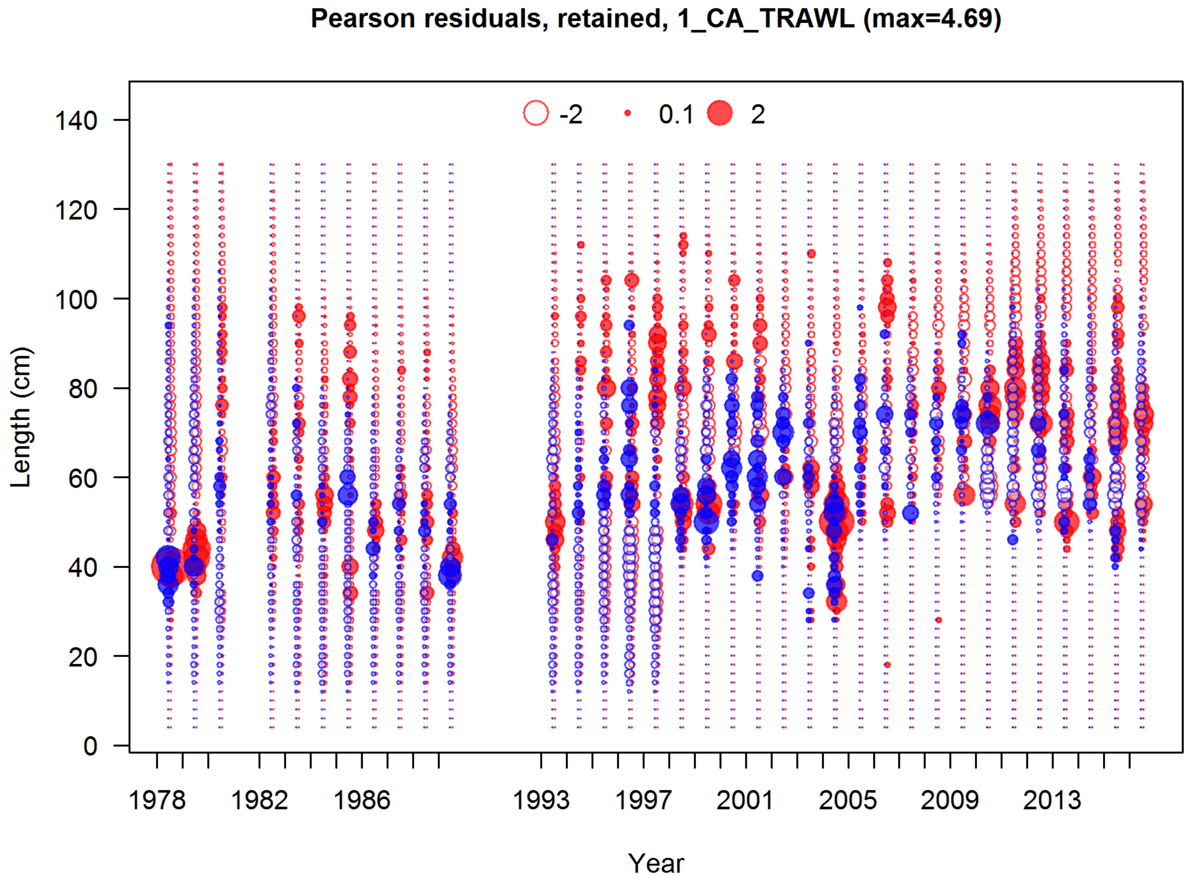


Figure 128. Commercial trawl sex specific length data Pearson residuals, south.

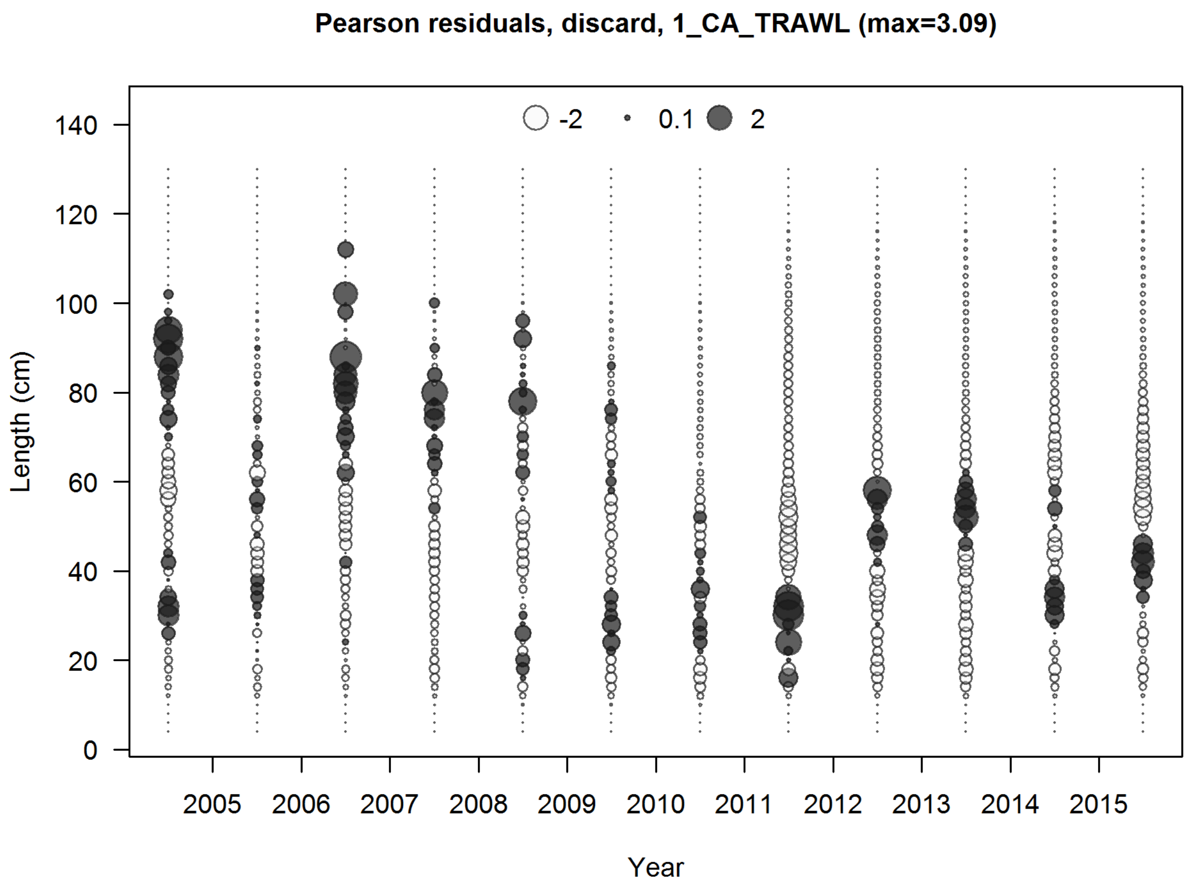


Figure 129. Commercial trawl sex combined discard length data Pearson residuals, south.

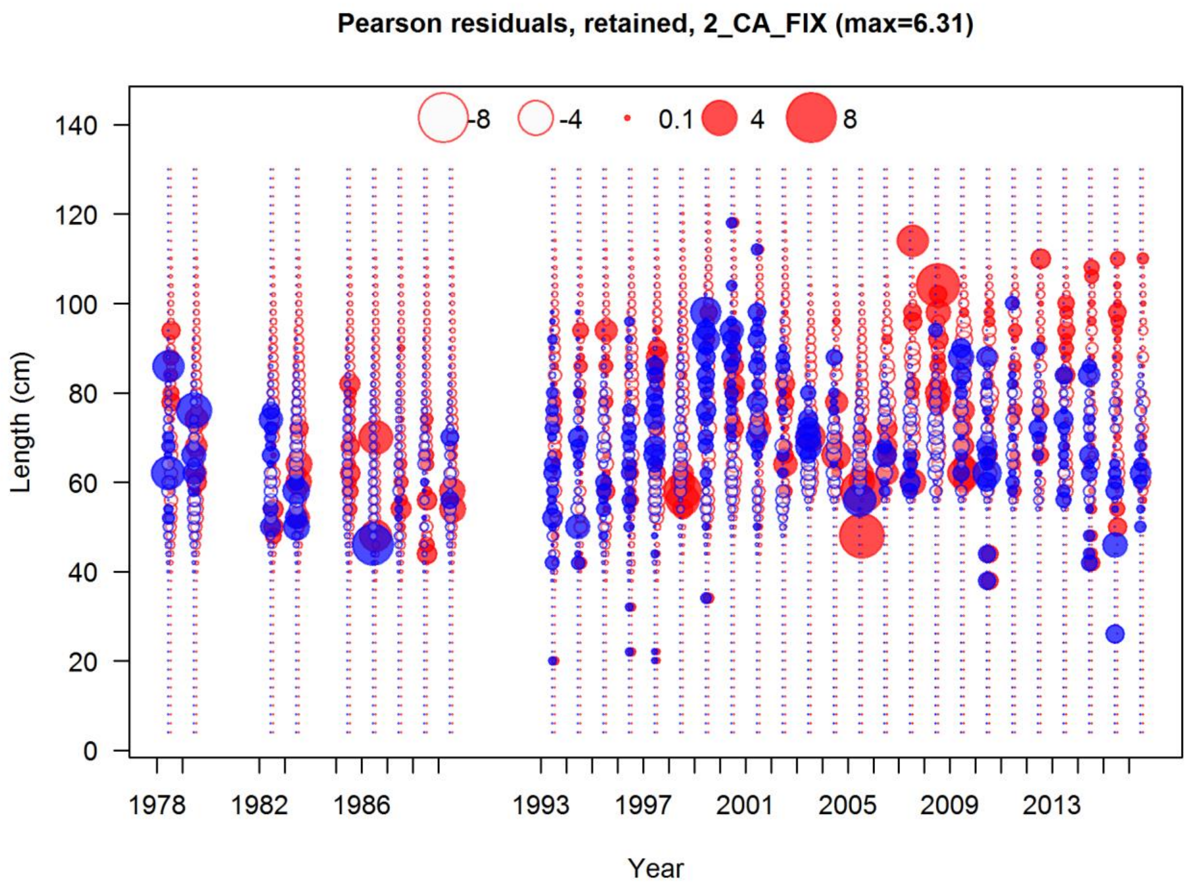


Figure 130. Commercial fixed gear sex specific length data Pearson residuals, south.

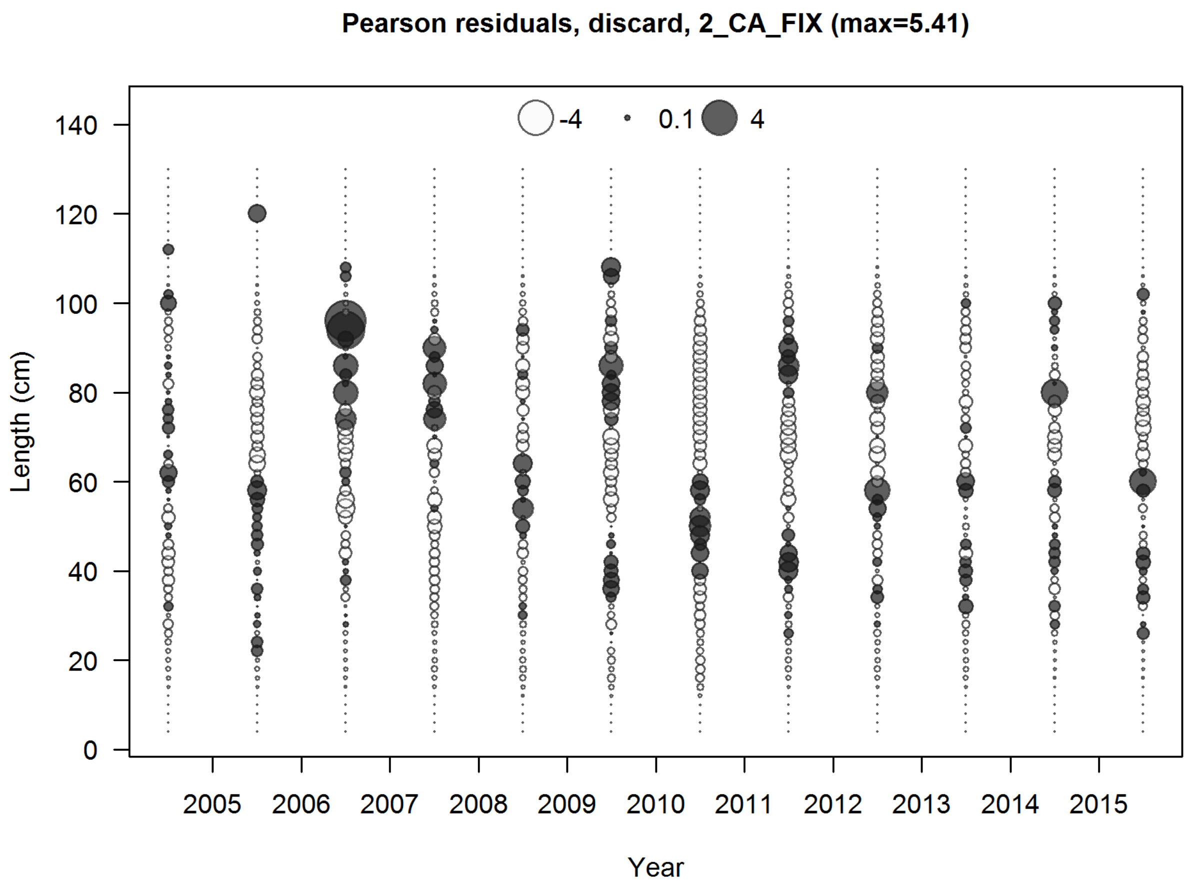


Figure 131. Commercial fixed gear sex combined discard length data Pearson residuals, south.

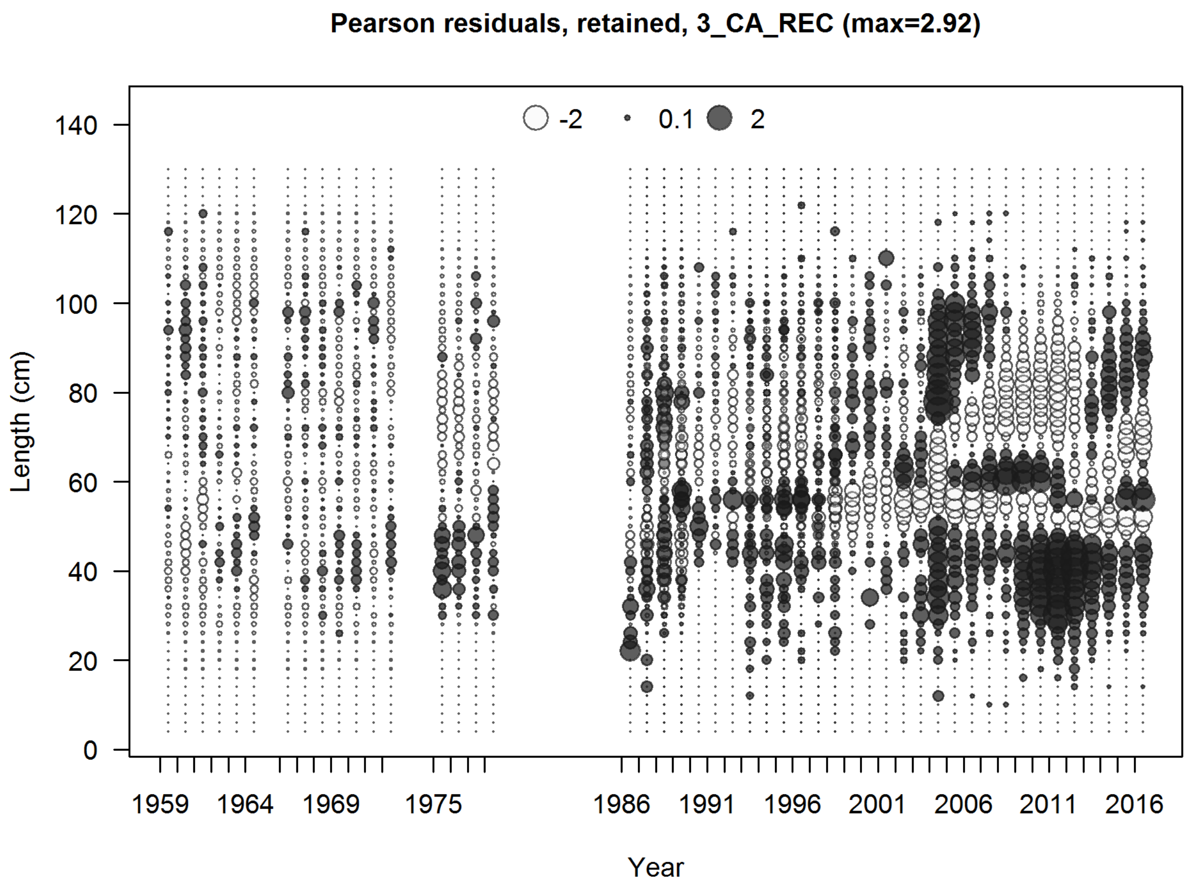


Figure 132. Recreational sex combined length data Pearson residuals, south.

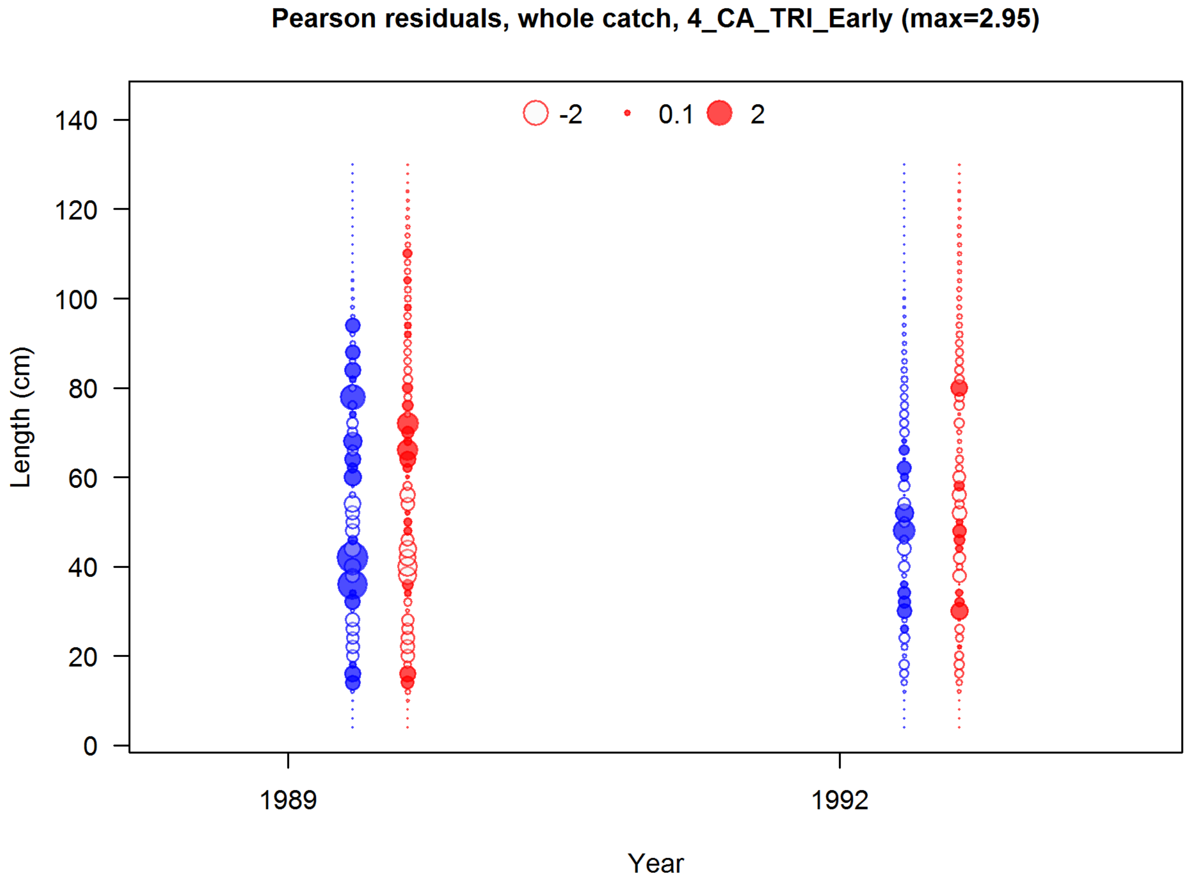


Figure 133. Triennial survey early sex specific length data Pearson residuals, south.

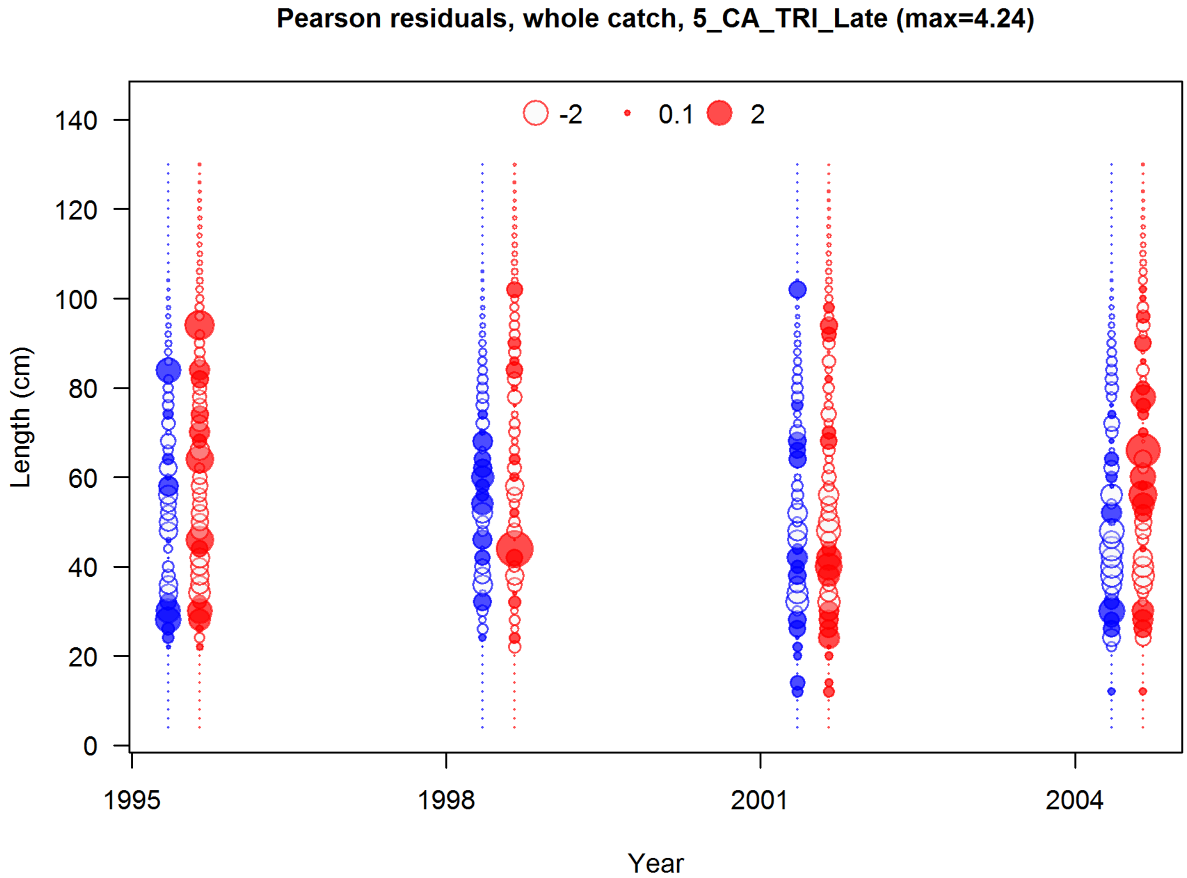


Figure 134. Triennial survey sex specific length data Pearson residuals, south.

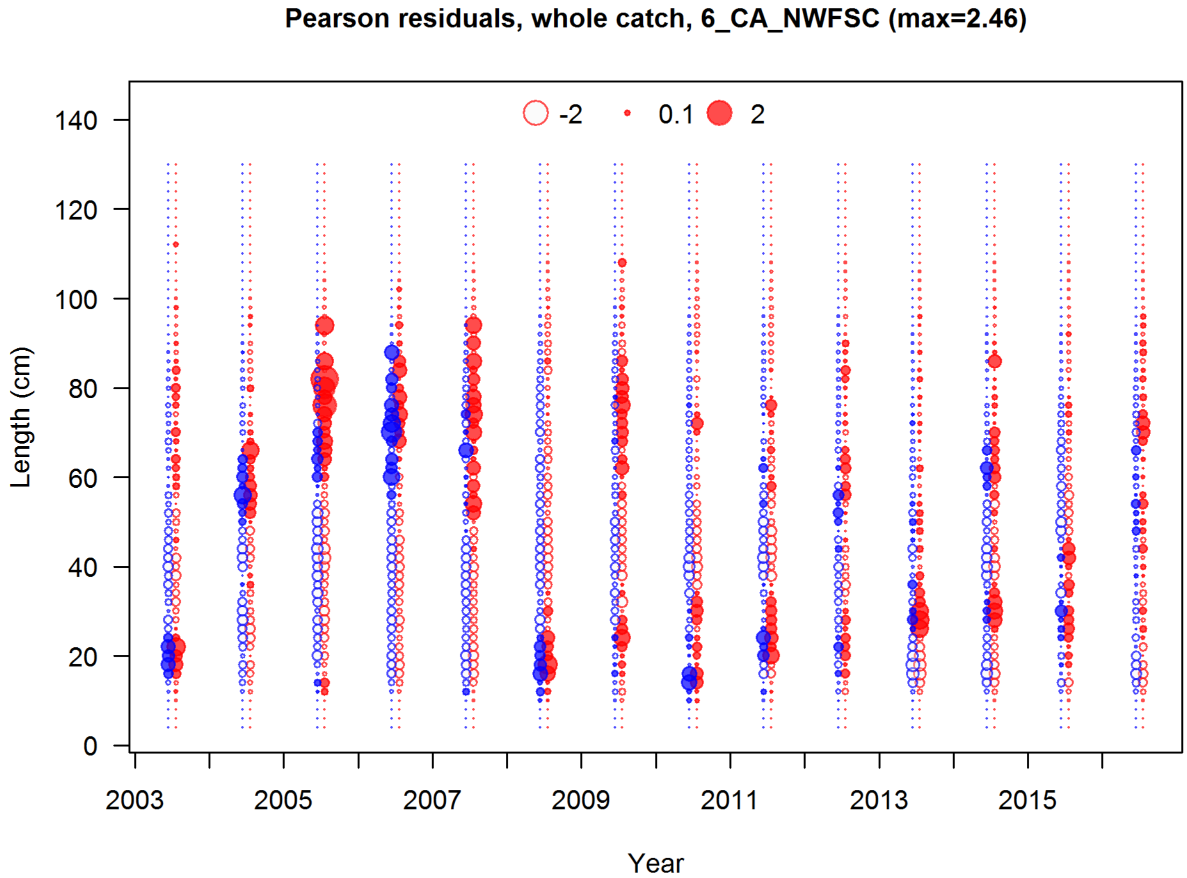


Figure 135. NWFSC survey sex specific length data Pearson residuals, south.

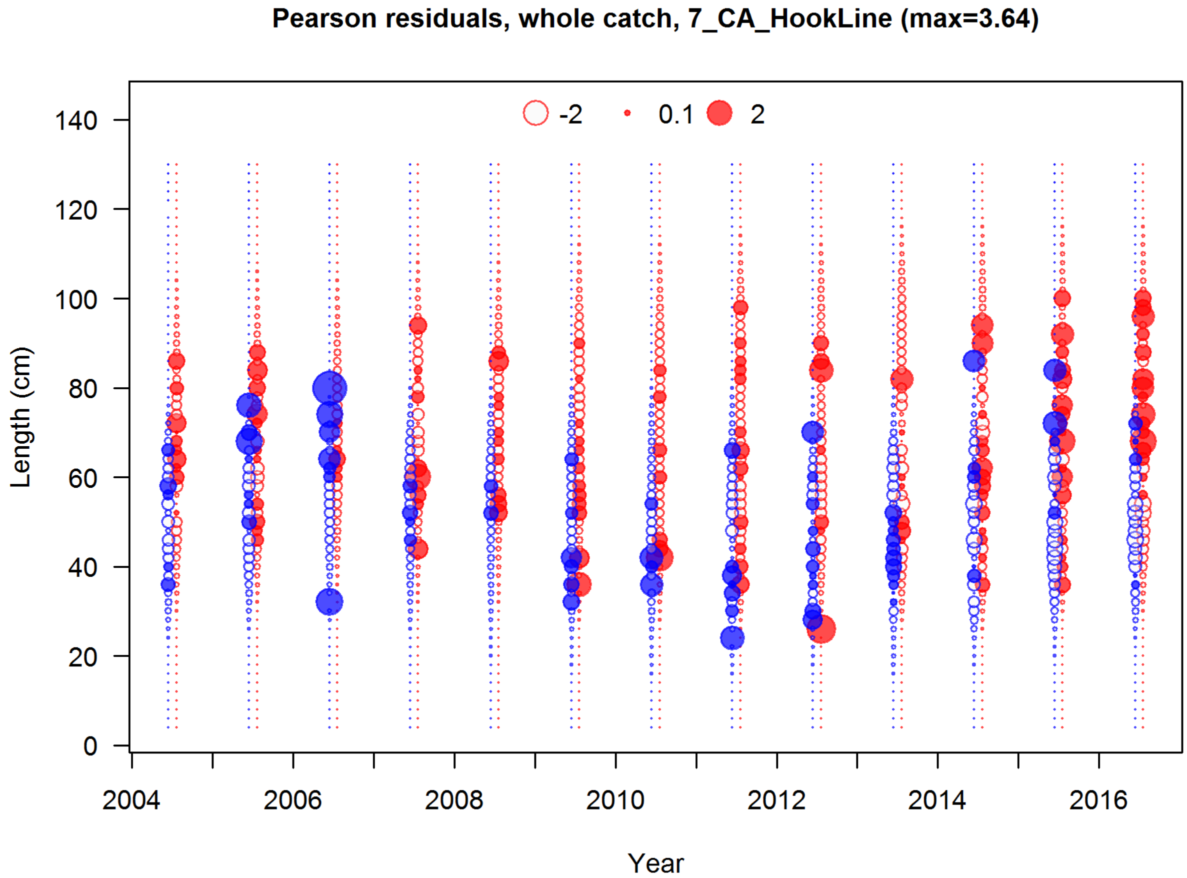


Figure 136. NWFSC hook and line survey sex specific length data Pearson residuals, south.

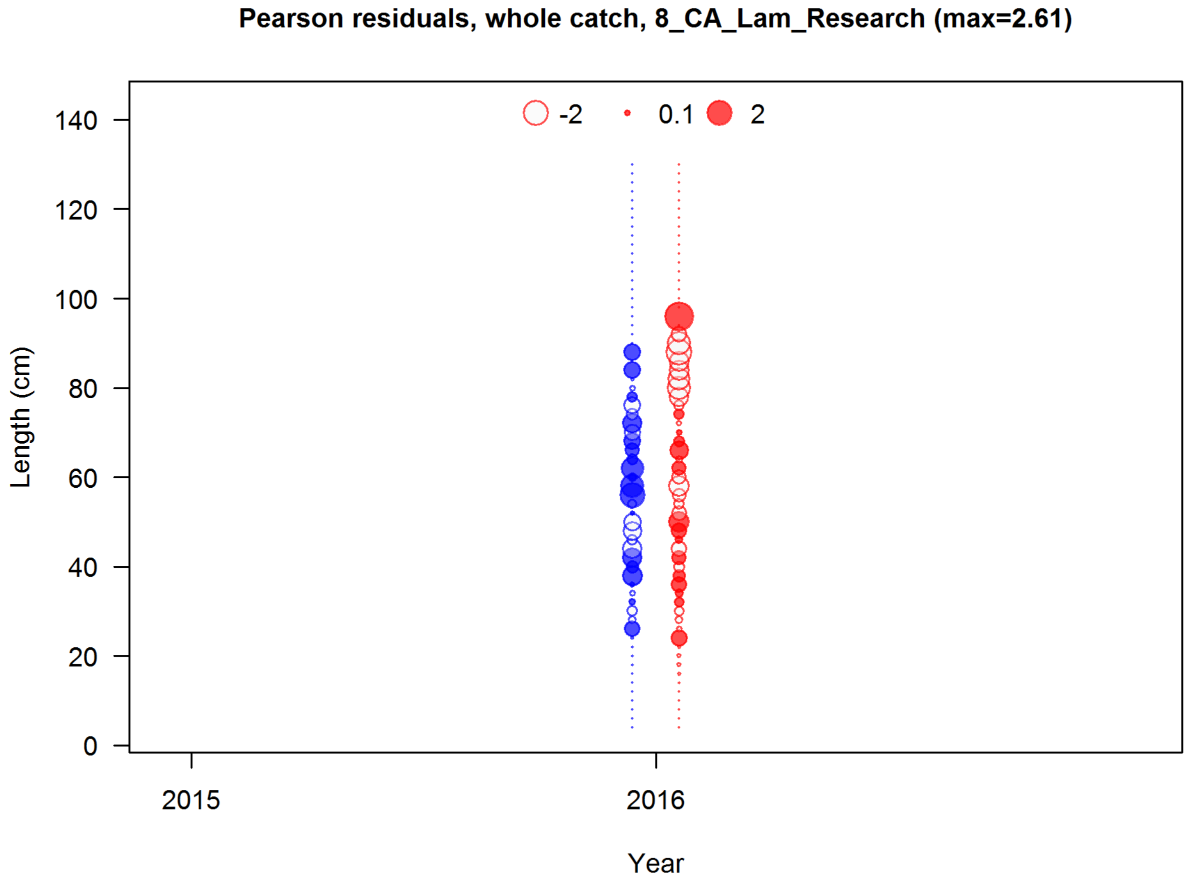


Figure 137. Lam sex specific research length data Pearson residuals, south.

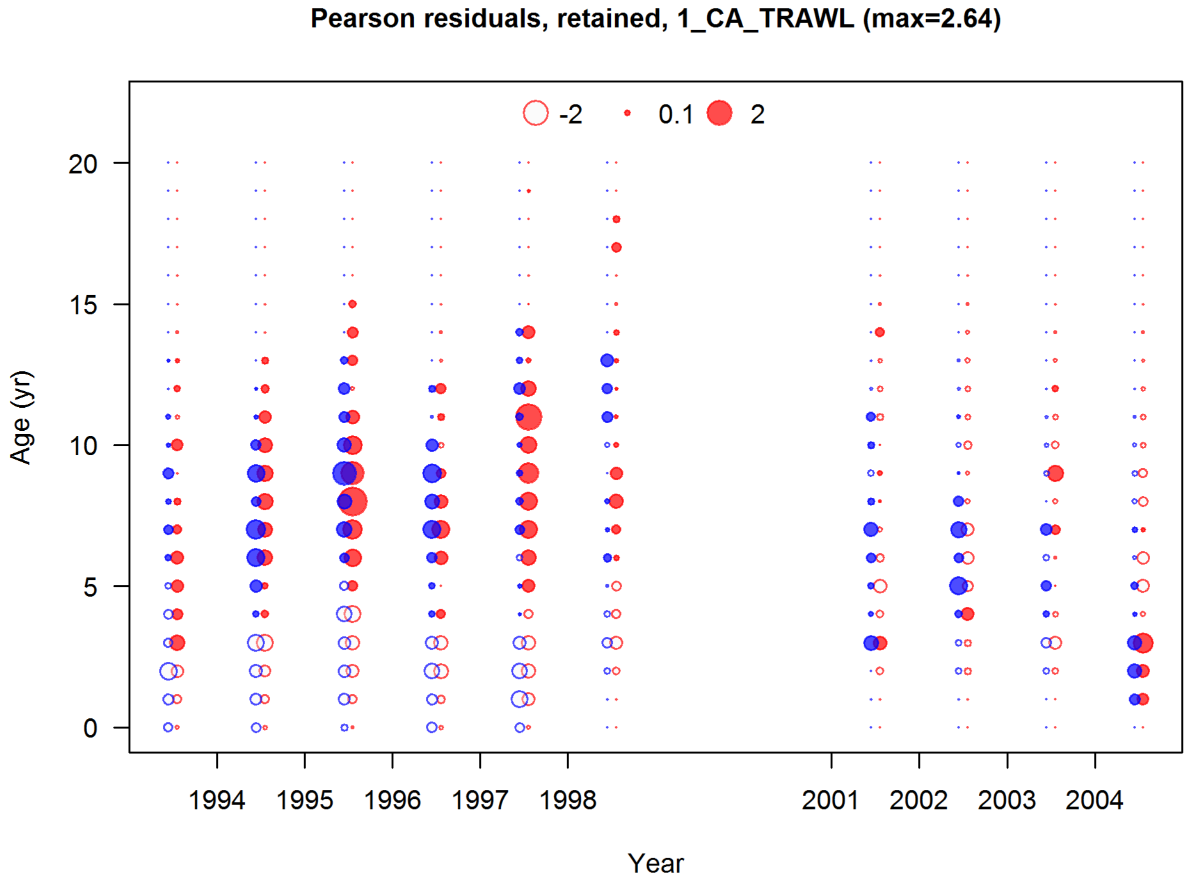


Figure 138. Commercial trawl sex specific age data Pearson residual, south, from a model sensitivity run with these data.

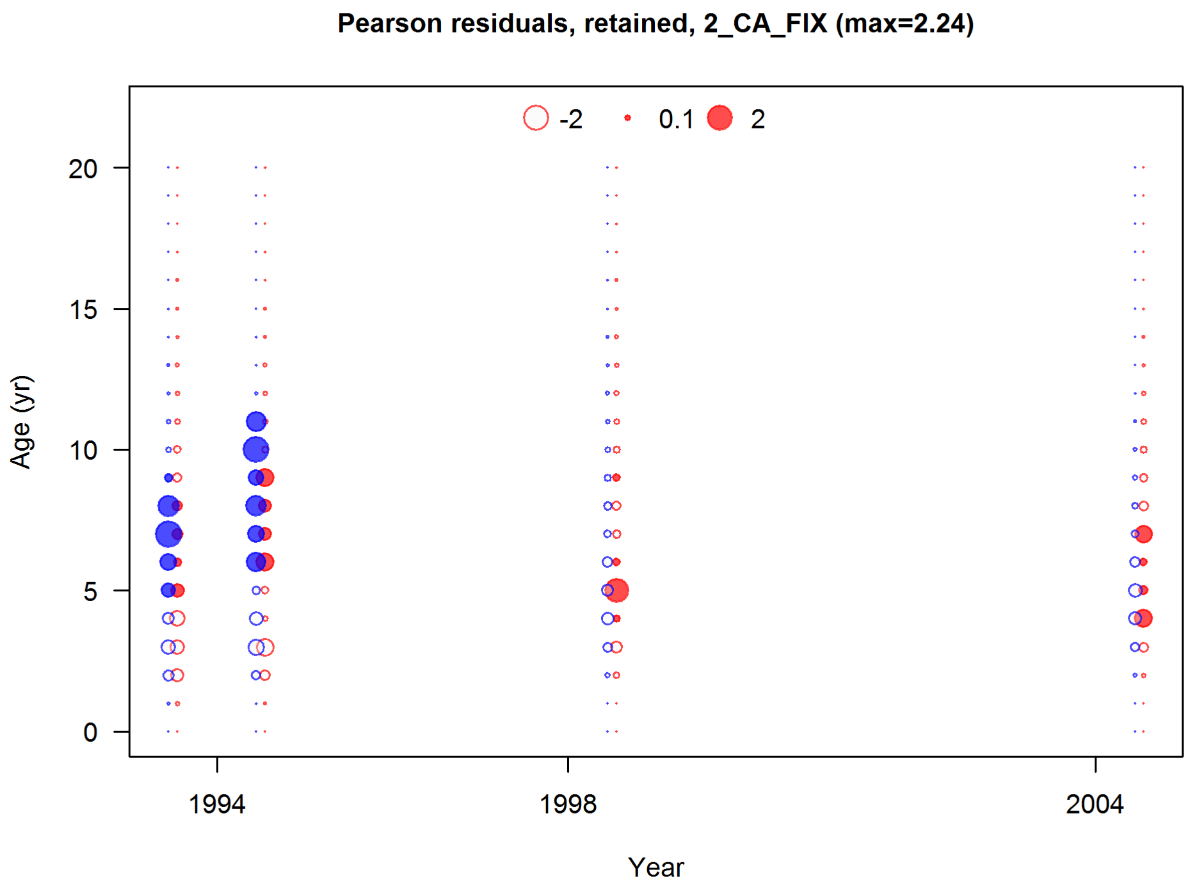


Figure 139. Commercial fixed gear sex specific age data Pearson residuals, south, from a model sensitivity run with these data.

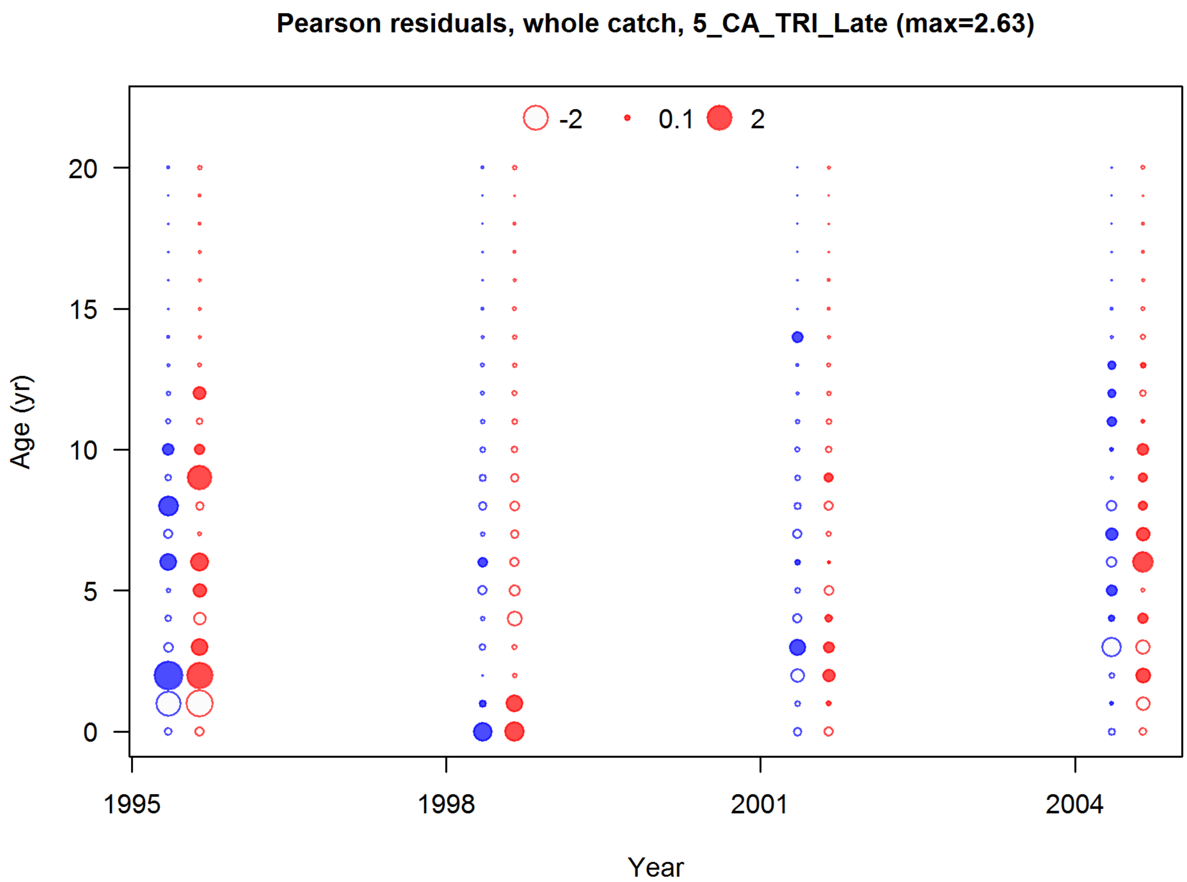
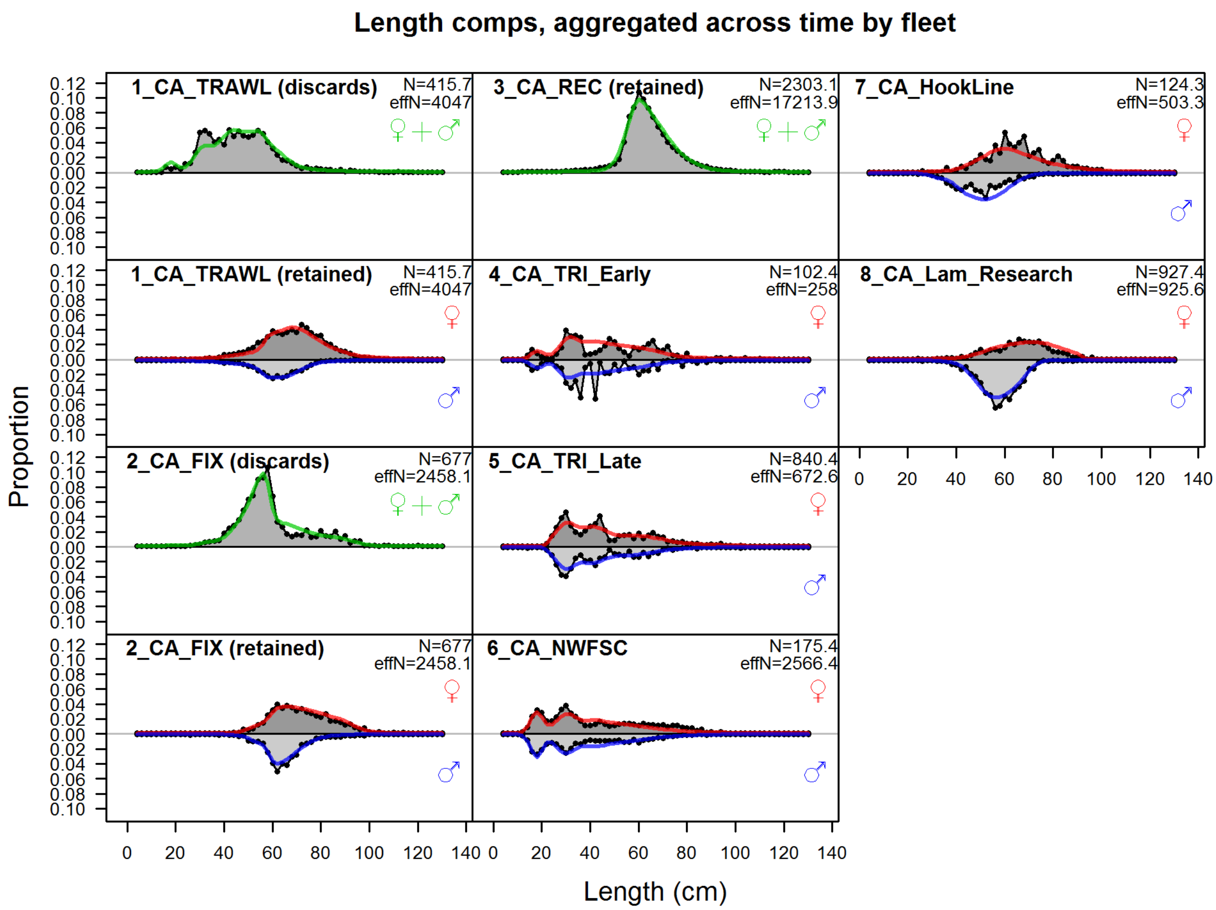


Figure 140. Triennial survey late sex specific age data Pearson residuals, south.



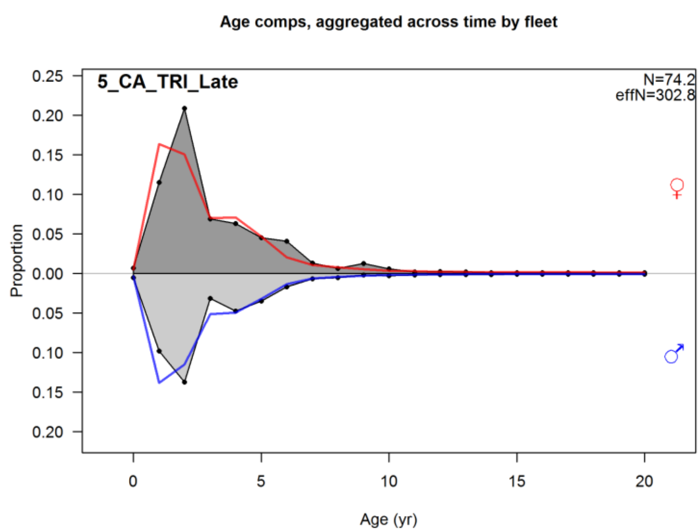


Figure 141. Length (top panel) and age (bottom panel) composition data fits aggregated across time for each fleet, south.

comp_condAALfit_Andre_plotsflt6mkt0_page4.png

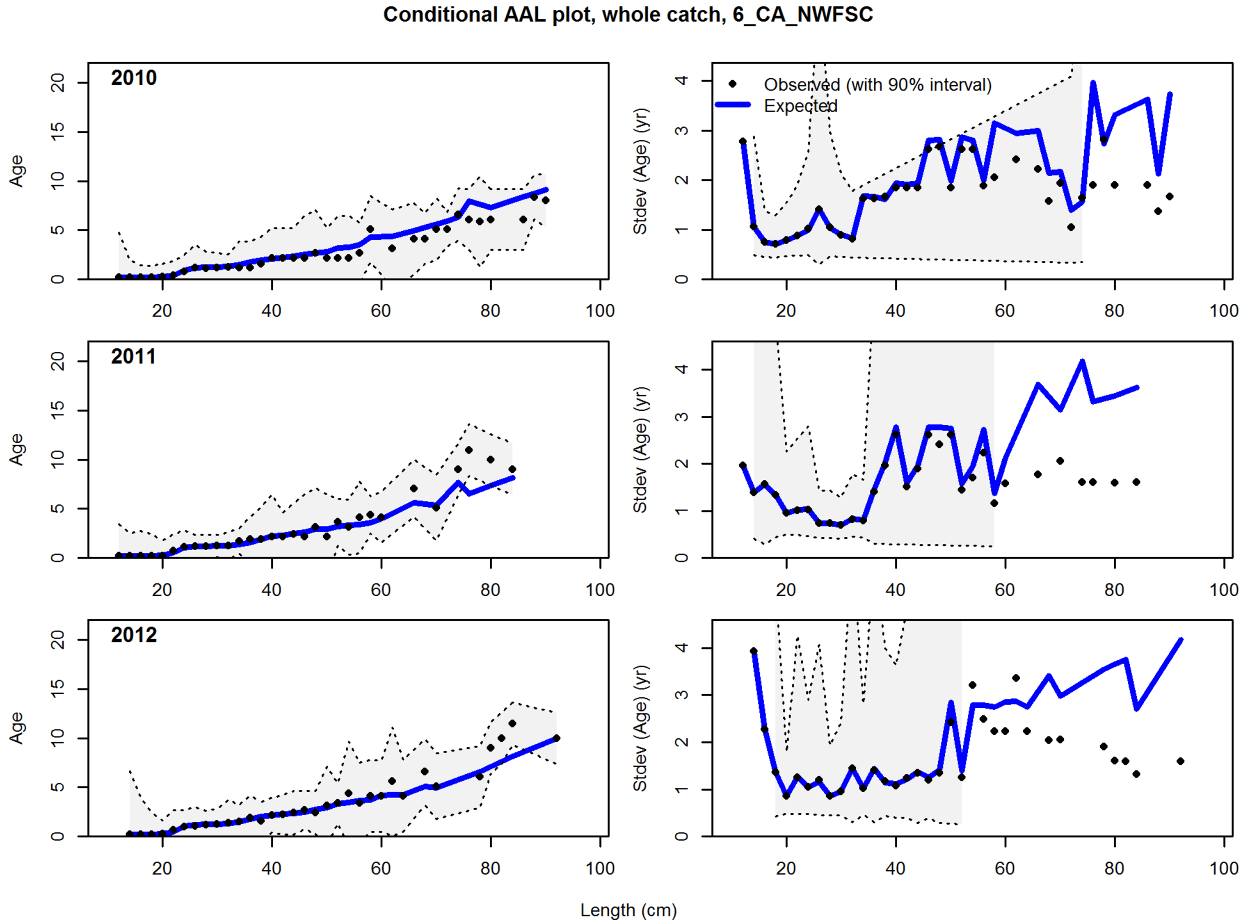


Figure 142. NWFSC conditional age-at-length (AAL) fits, south.

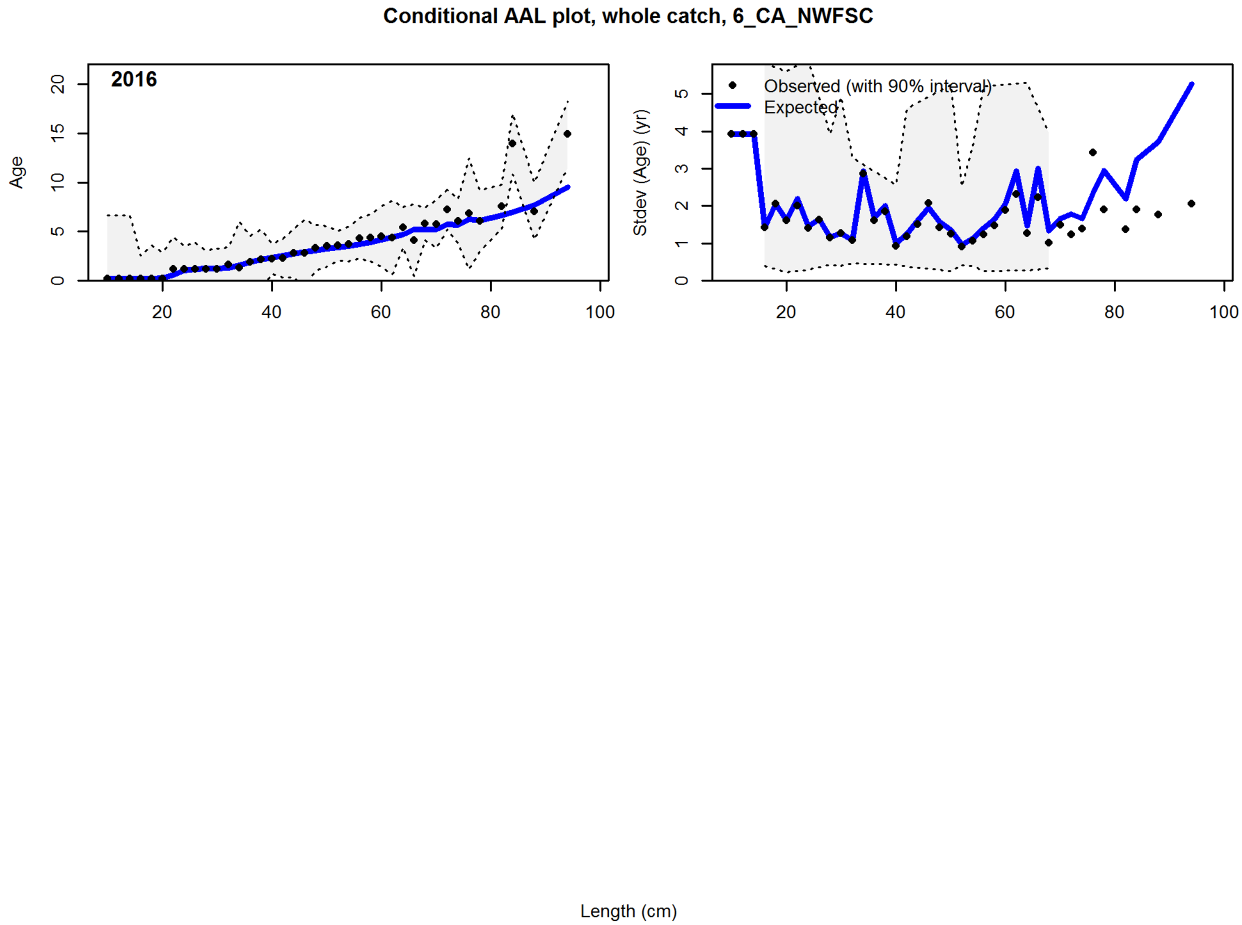


Figure 143. Lam research conditional age-at-length (AAL) fits, south.

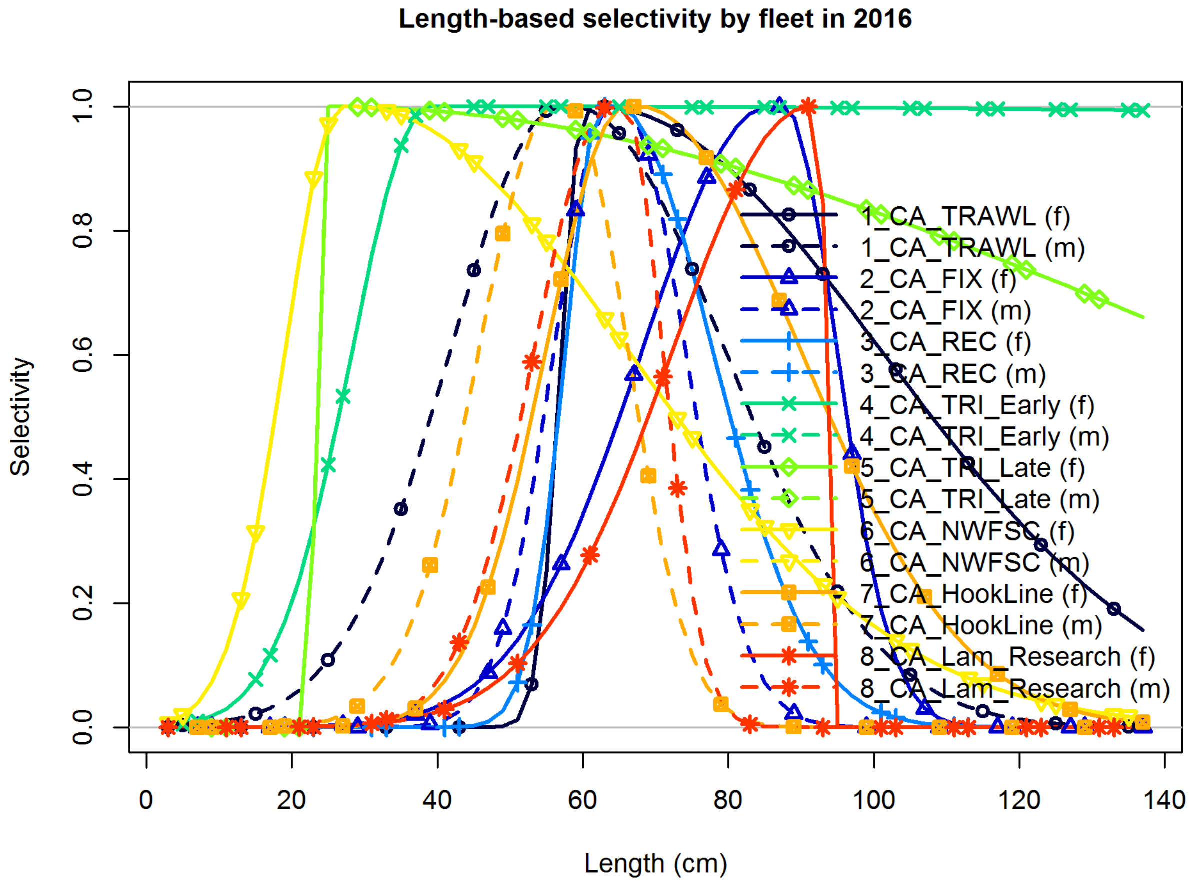


Figure 144. Estimated end year selectivity curves for each fleet, south. Go to the Auxiliary files r4ss plots folder for the south model run, open the SS Output html file, and go to the "sel" tab to see individual selectivity plots for each fleet as well as plots of retention curves for the commercial fleets.

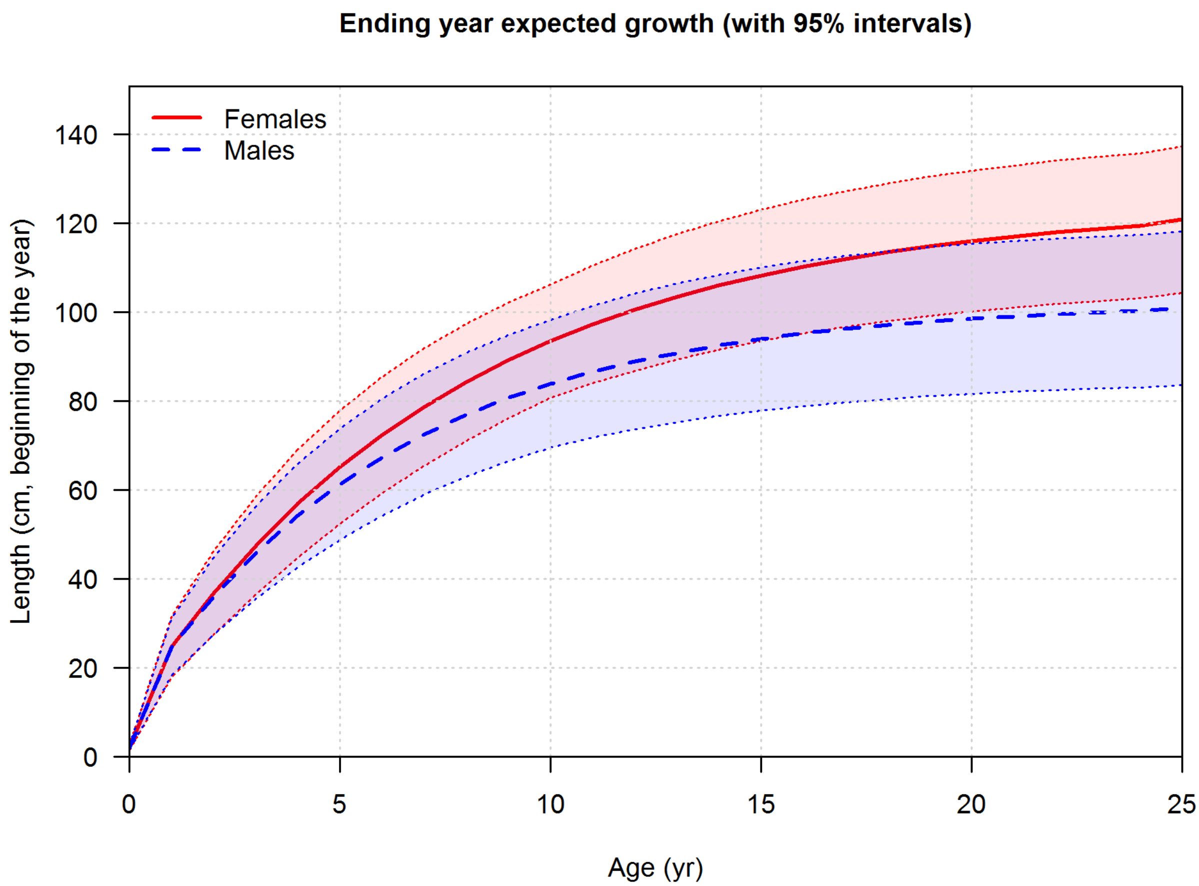


Figure 145. Estimated growth curves, south.

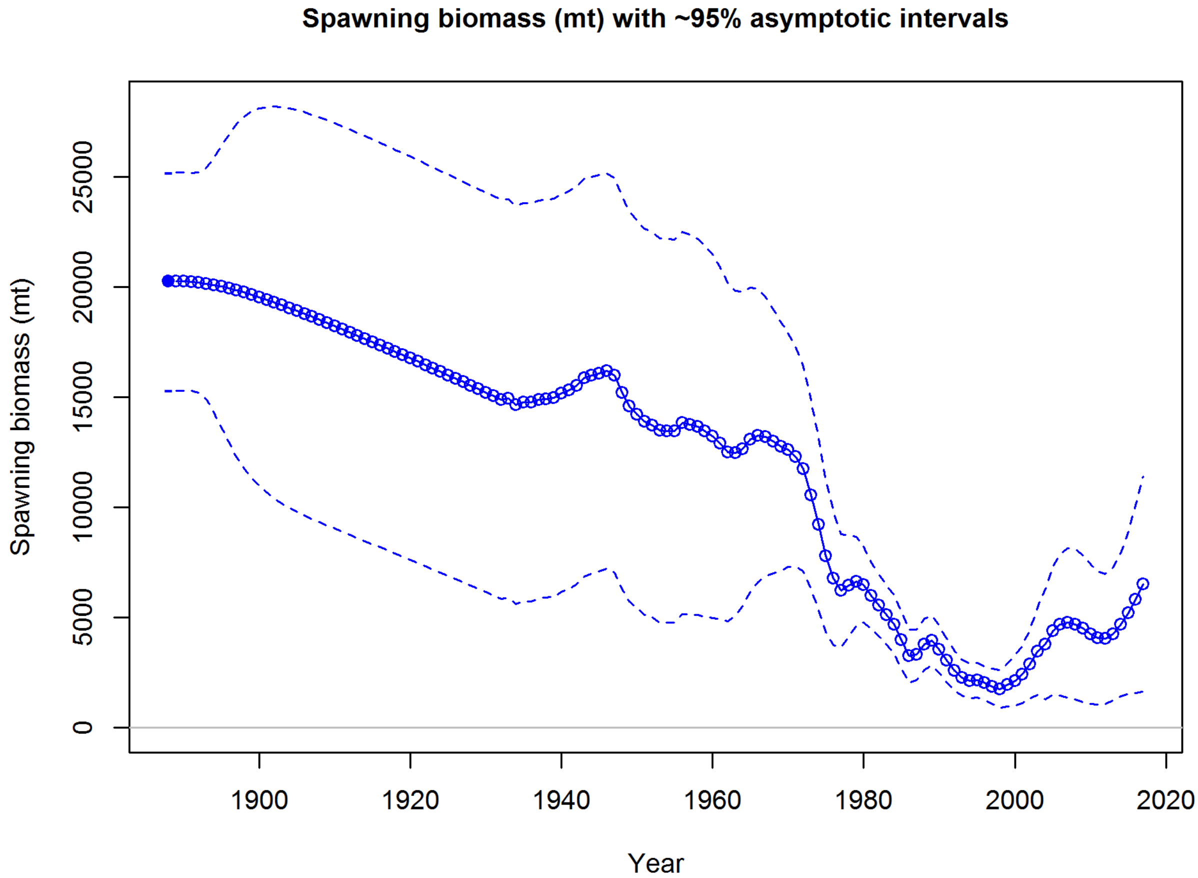


Figure 146. Time series of estimate spawning biomass, south.

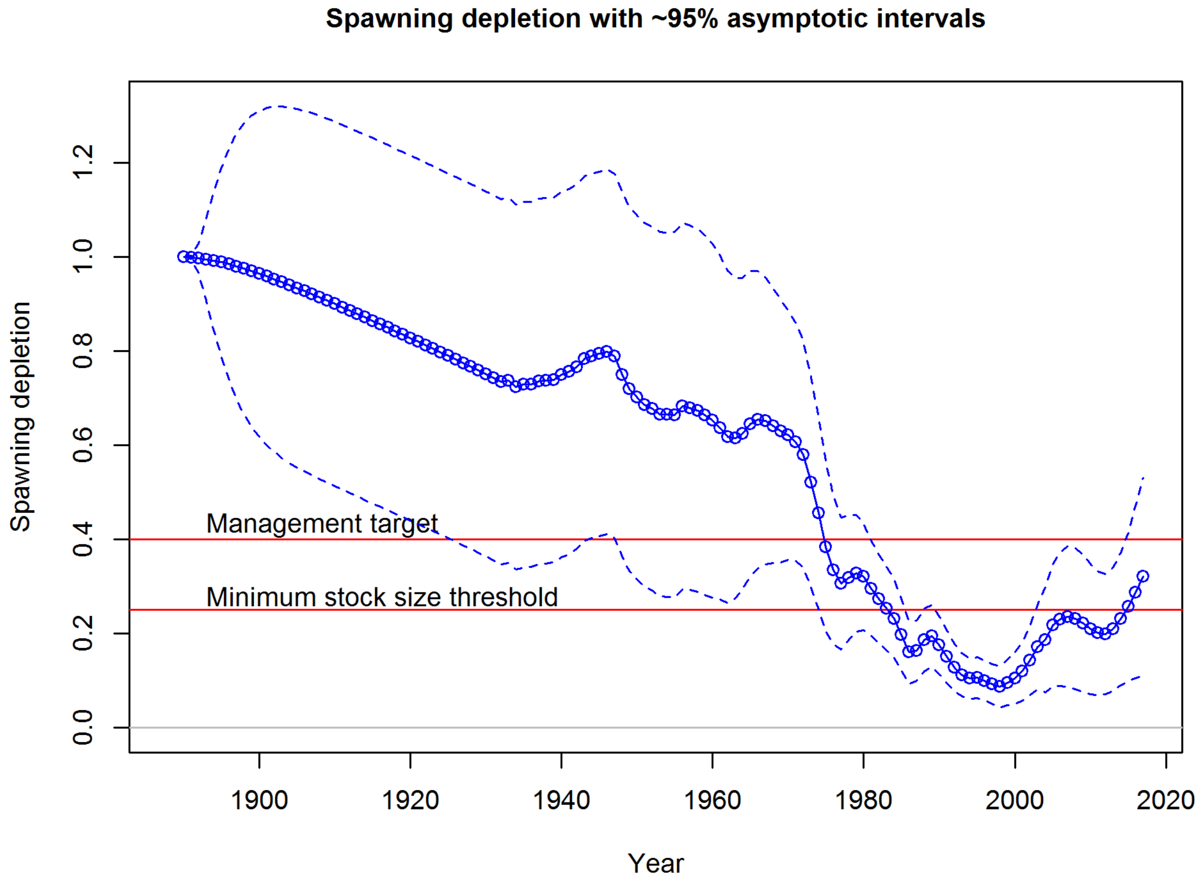


Figure 147. Time series of estimated stock depletion, south.

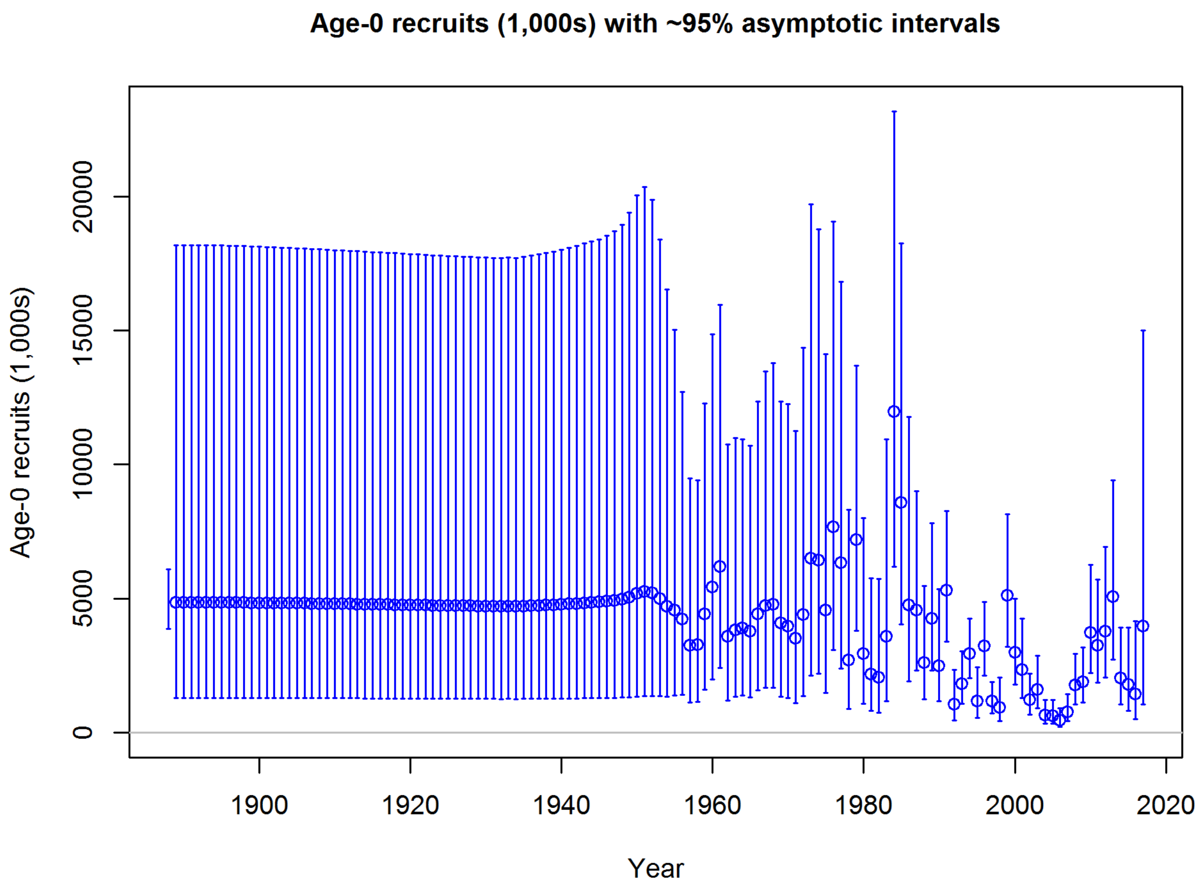


Figure 148. Time series of estimated age-0 recruits, south.

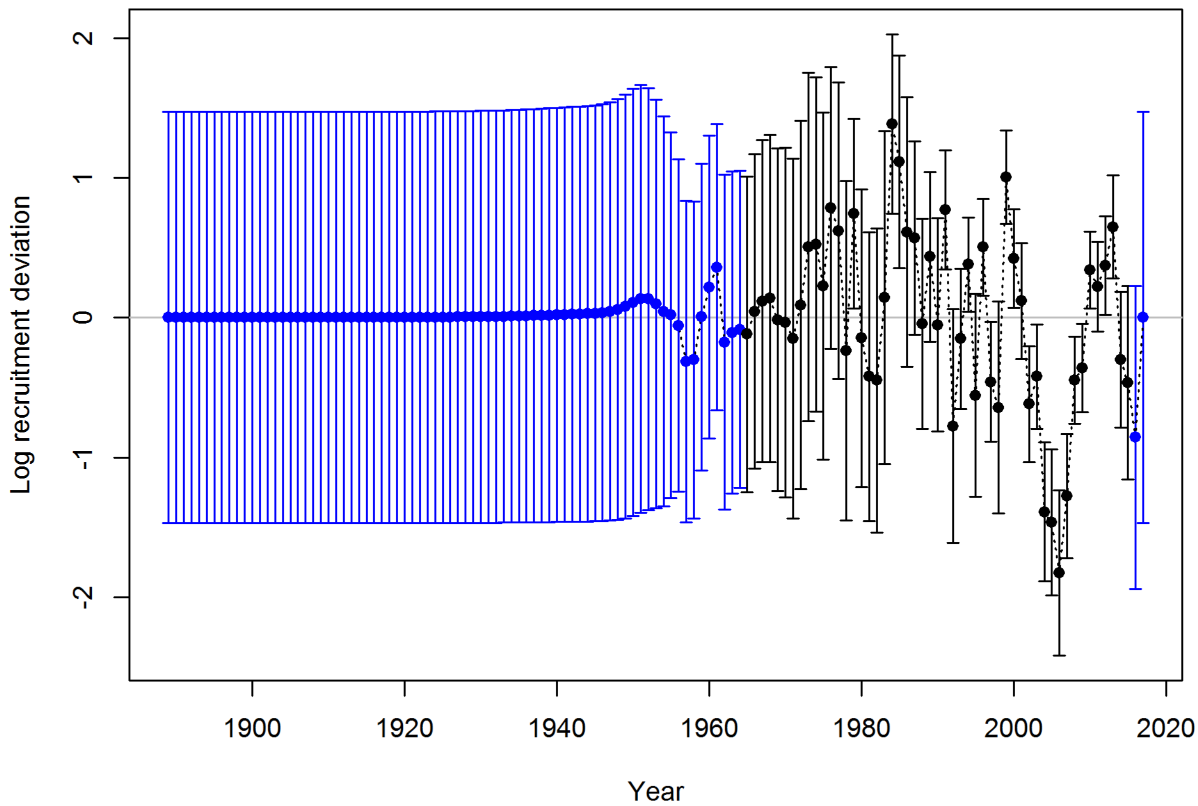


Figure 149. Time series of estimated recruitment deviations, south.

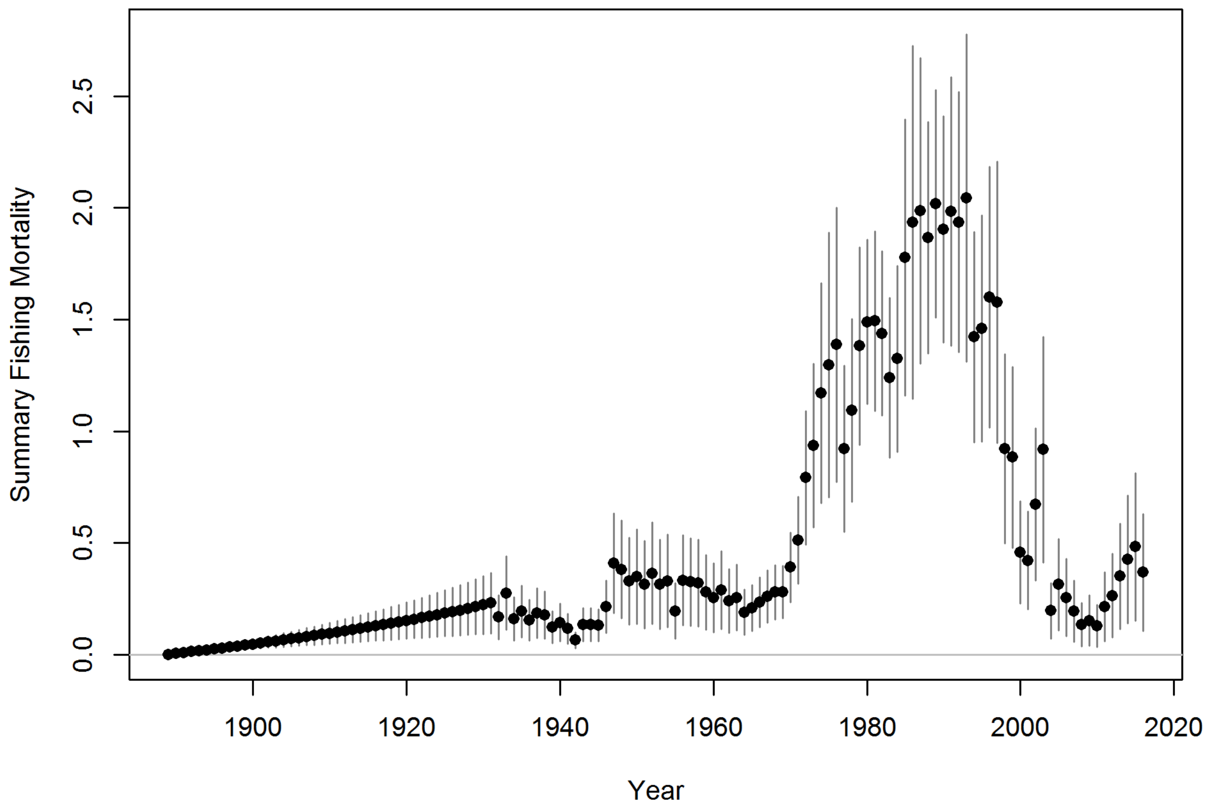


Figure 150. Time series estimated summary fishing mortality (F), south.

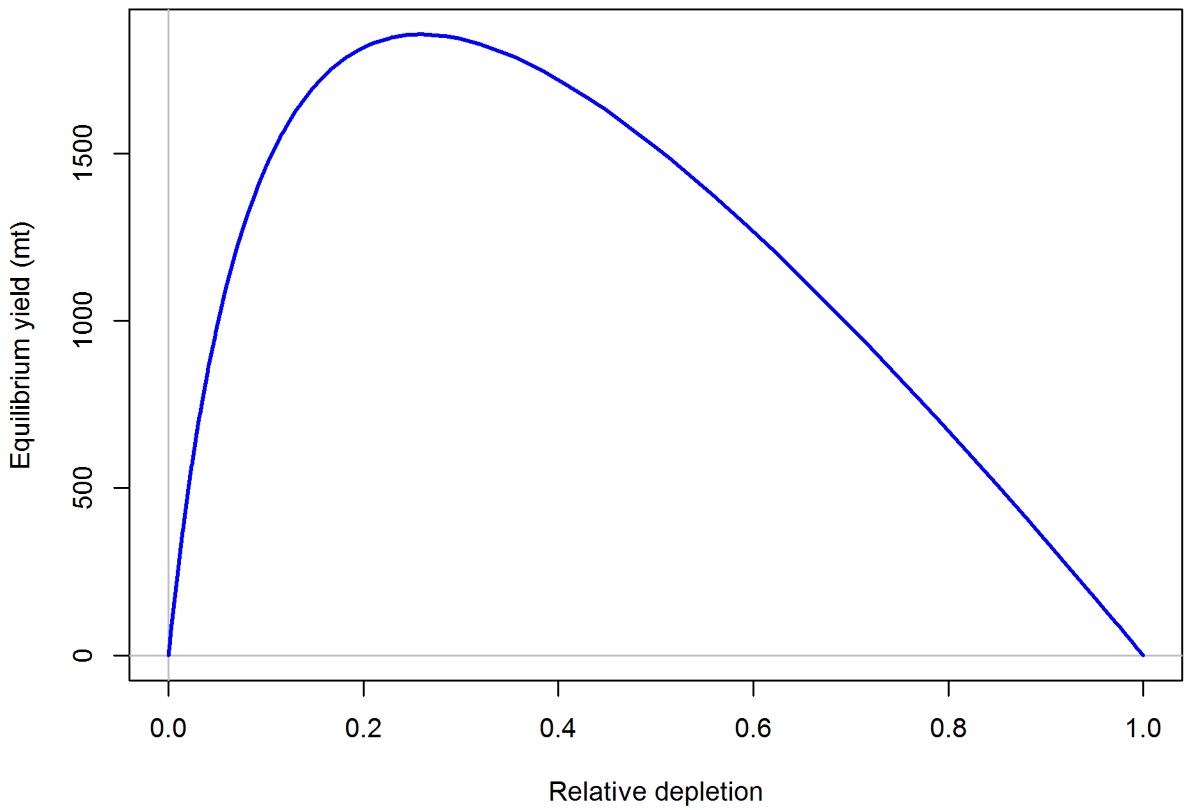


Figure 151. Equilibrium yield curve, south.

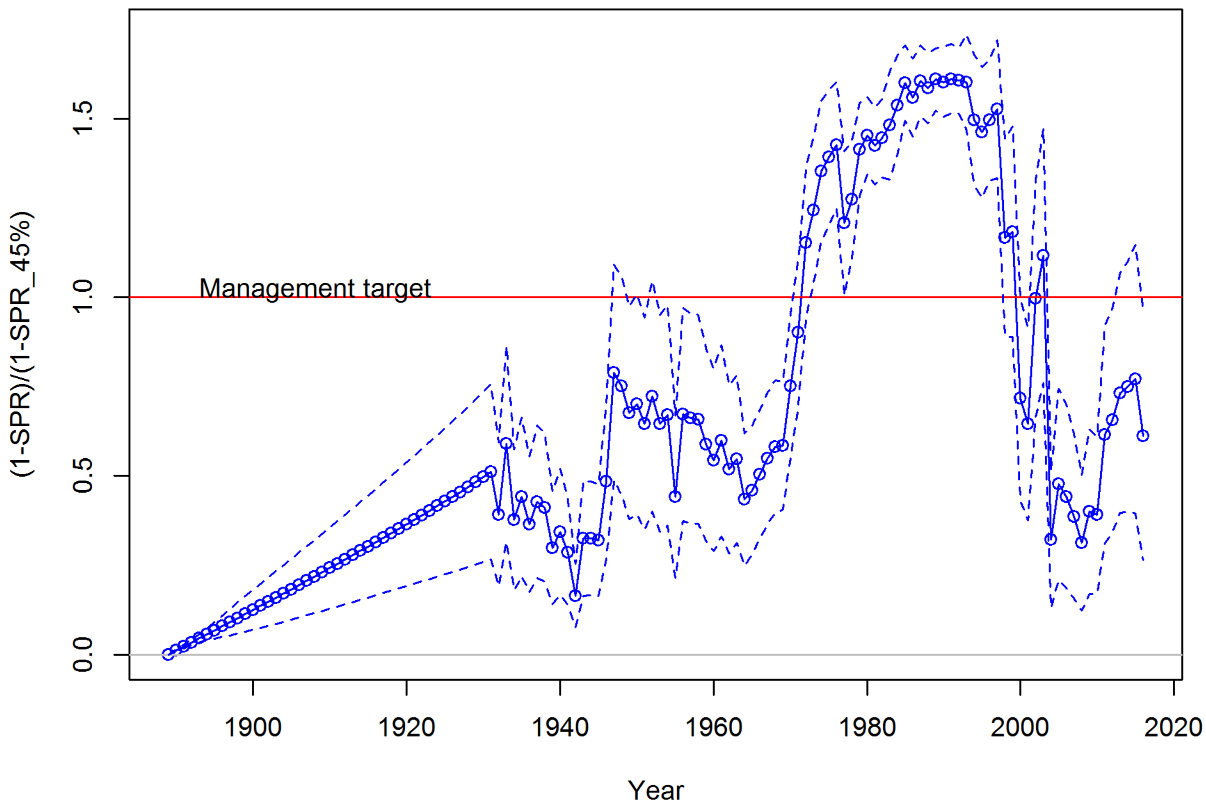


Figure 152. Time series of SPR ratio, south.

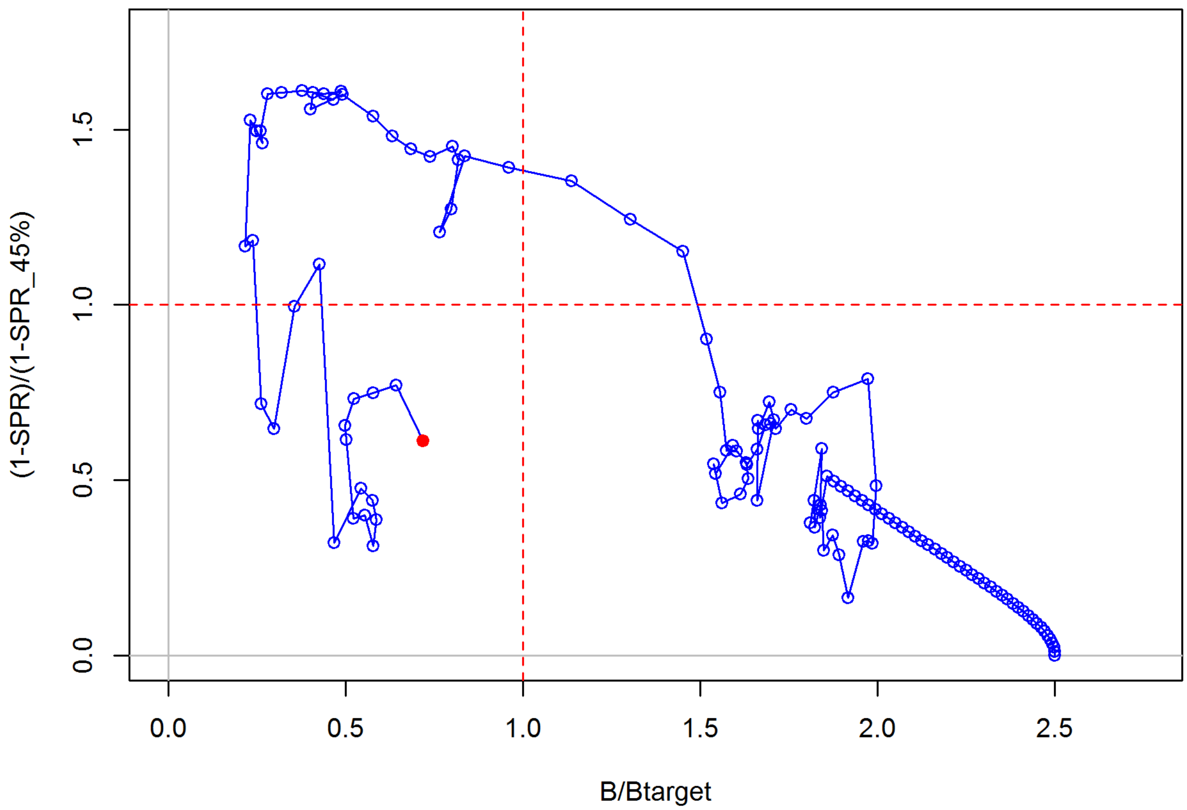


Figure 153. Phase plot of biomass ratio v SPR ratio, south.

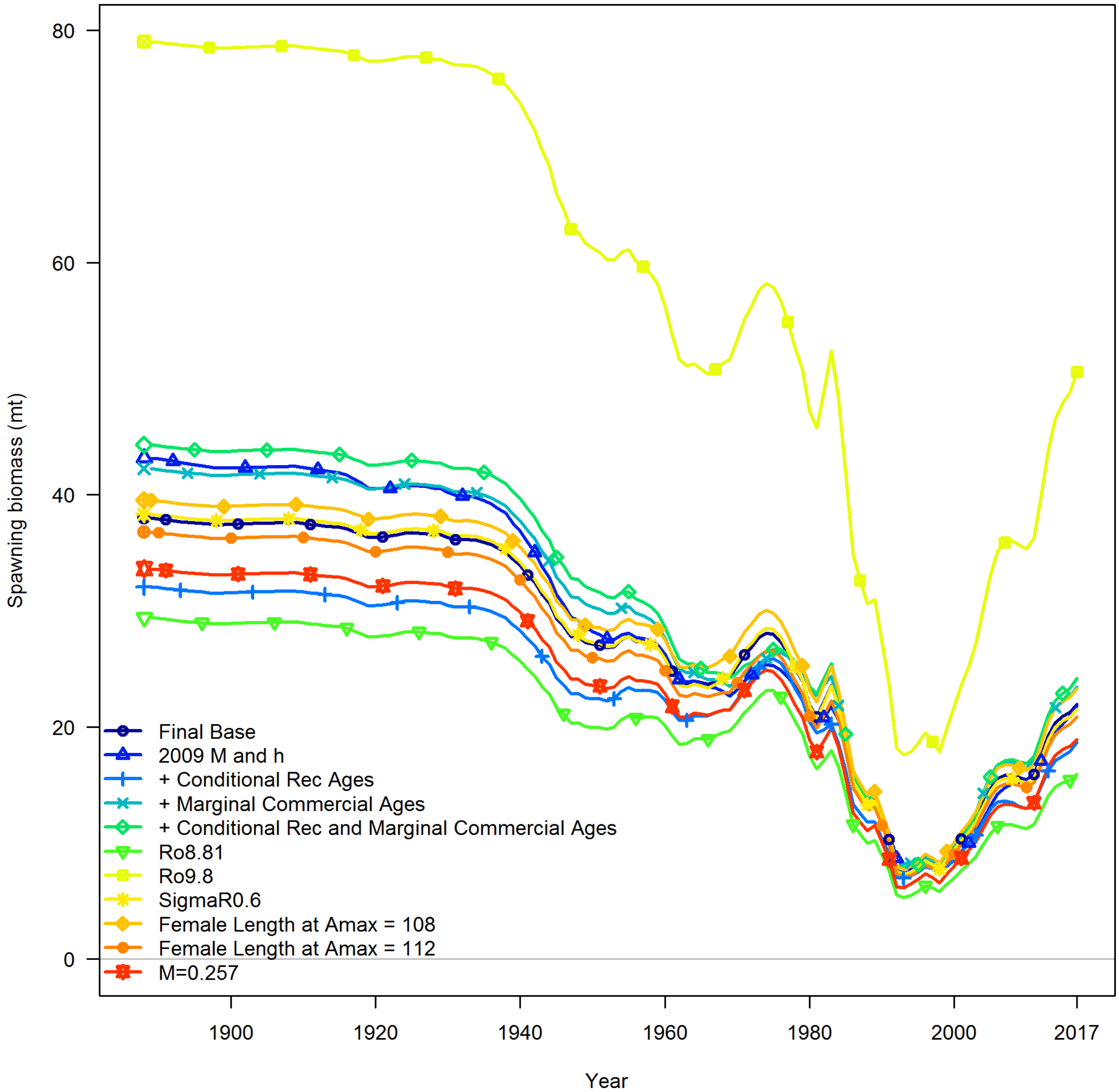


Figure 154. Sensitivity in spawning biomass to north model sensitivity runs. The run 2009 M and h sets these values to those used in the 2009 stock assessment. The run + Conditional Rec Ages includes both WA and OR recreational age data as CAAL compositions. The run + Marginal Commercial Ages includes all commercial age data as prepared for the STAR panel version of this assessment. The run + Conditional Rec and Marginal Commercial Ages adds all fishery age data into the model. The runs Ro8.81 and Ro9.8 fix the parameter for unfished recruitment at each value; these runs bracket the base model. The run SigmaR0.6 fixed the input parameter for recruitment variability to 0.6. The runs Female Length at Amax = 108 and Female Length at Amax = 112 fix the values for this parameter at 108 cm and 112 cm, respectively. The run M=0.257 fixes male M to the value of female M (0.257) rather than estimating male M.

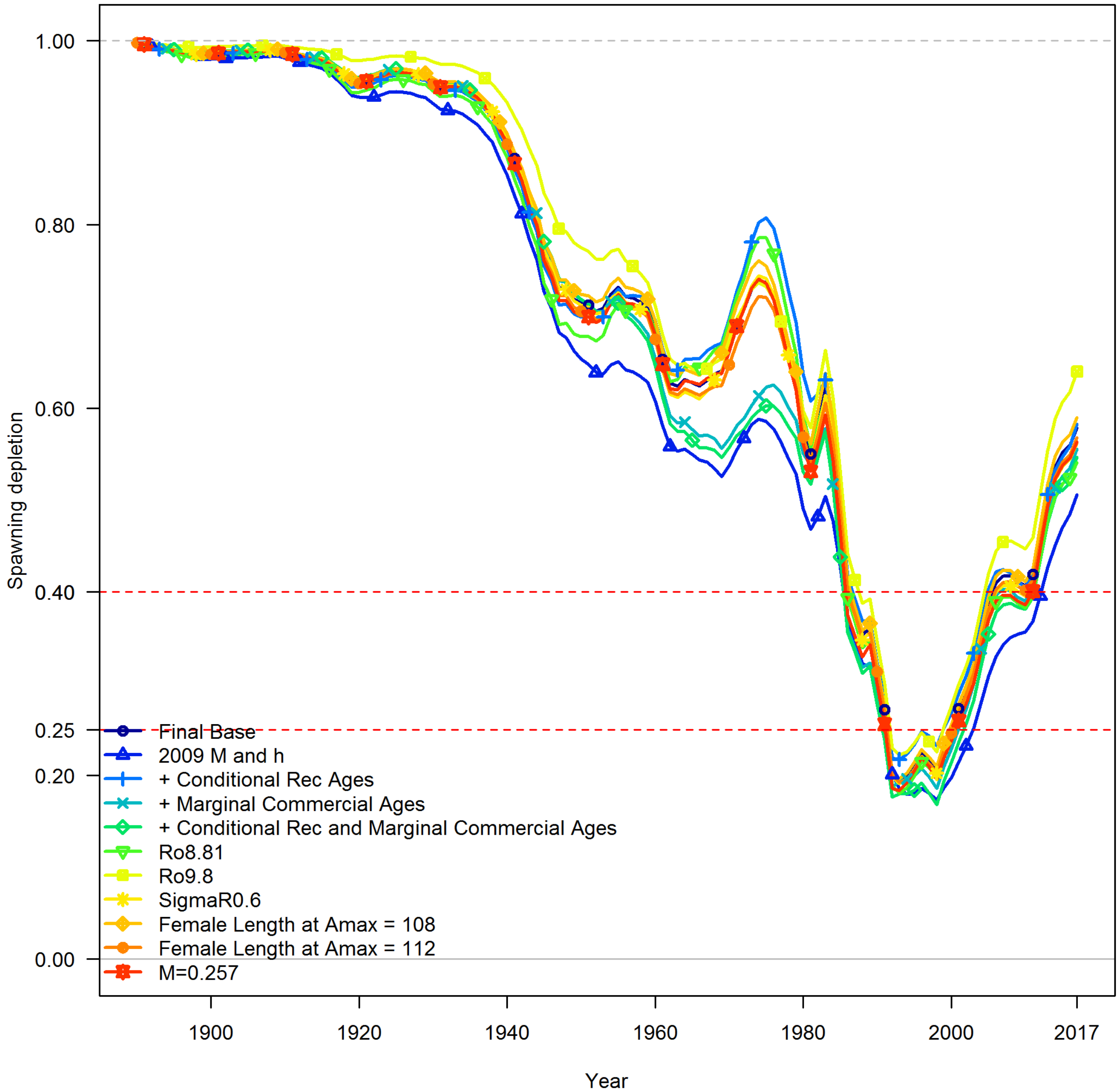


Figure 155. Sensitivity in stock depletion to north model sensitivity runs. The run 2009 M and h sets these values to those used in the 2009 stock assessment. The run + Conditional Rec Ages includes both WA and OR recreational age data as CAAL compositions. The run + Marginal Commercial Ages includes all commercial age data as prepared for the STAR panel version of this assessment. The run + Conditional Rec and Marginal Commercial Ages adds all fishery age data into the model. The runs Ro8.81 and Ro9.8 fix the parameter for unfished recruitment at each value; these runs bracket the base model. The run SigmaR0.6 fixed the input parameter for recruitment variability to 0.6. The runs Female Length at Amax = 108 and Female Length at Amax = 112 fix the values for this parameter at 108 cm and 112 cm, respectively. The run M=0.257 fixes male M to the value of female M (0.257) rather than estimating male M.

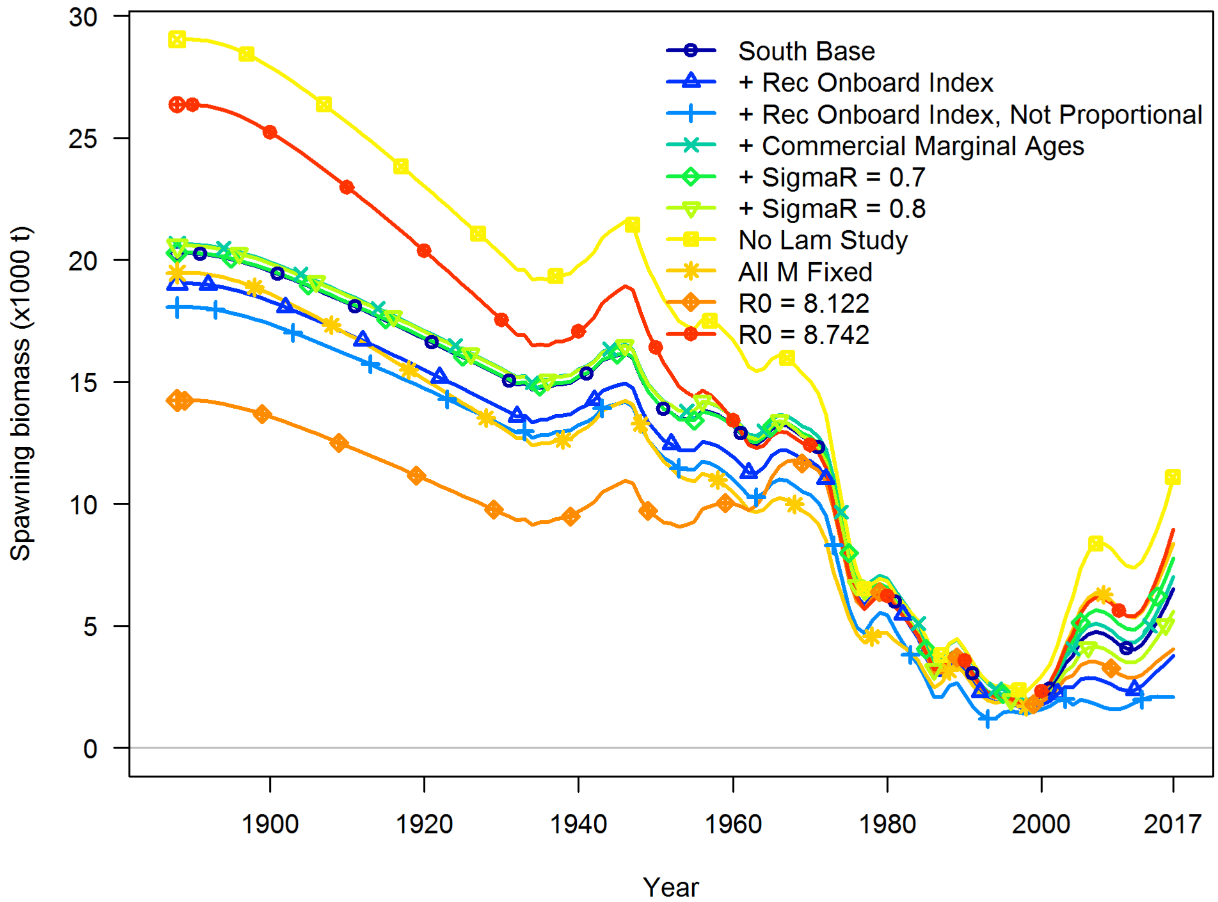


Figure 156. Sensitivity in spawning biomass to south model sensitivity runs. The run + Rec Onboard Index adds the CA recreational onboard observer index to the model as proportional to biomass. The run + Rec Onboard Index, Not Proportional adds the CA recreational onboard observer index to the model with a parameter that allows the index to be fit as not proportional to biomass. The run + Commercial Marginal Ages add the commercial age data as prepared for the pre-STAR draft assessment back into the model. The runs SigmaR = 0.7 and SigmaR = 0.8 change the fixed value for recruitment variability to 0.7 and 0.8, respectively. The run No Lam Study removes the Lam research CAAL and length composition data from the model. The run M=0.257 fixes male M to the value of female M (0.257) rather than estimating male M.

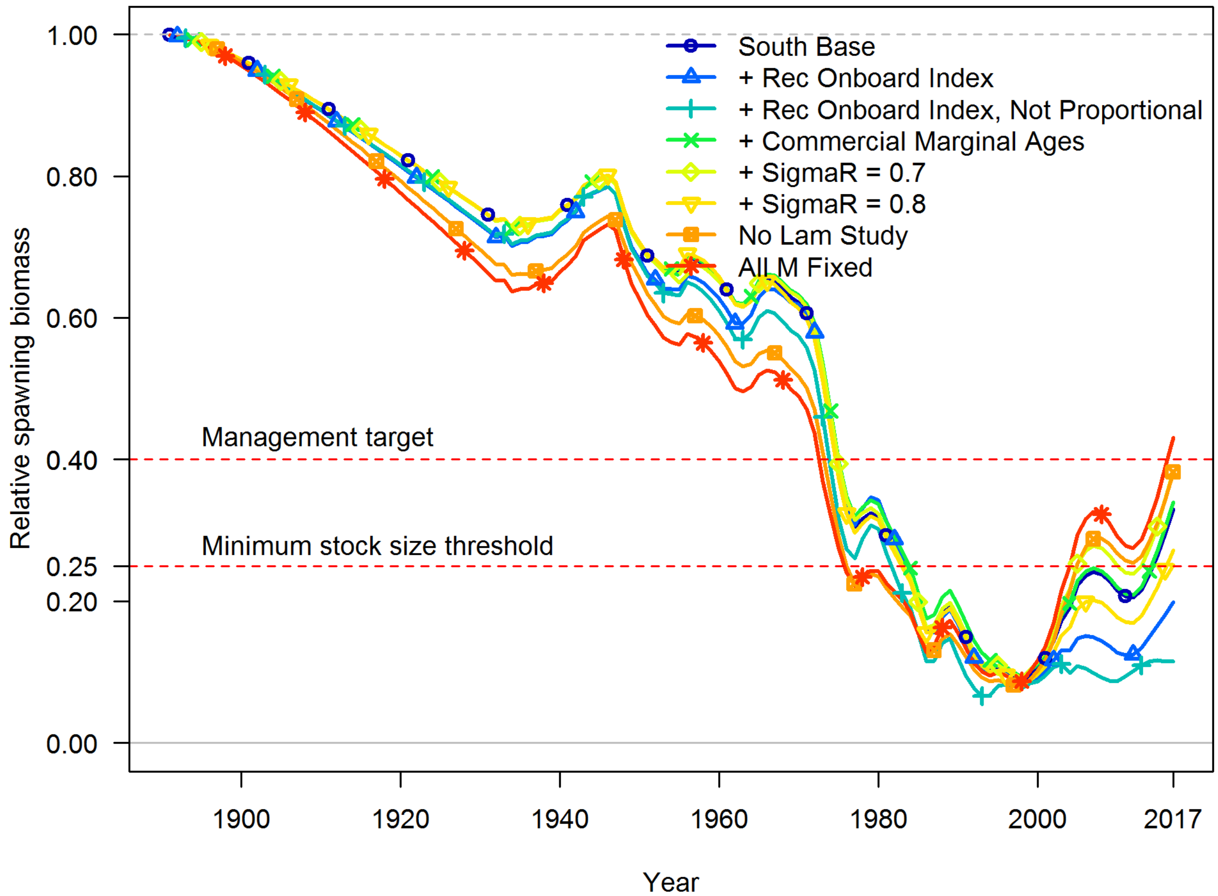


Figure 157. Sensitivity in stock depletion to south model sensitivity runs. The run + Rec Onboard Index adds the CA recreational onboard observer index to the model as proportional to biomass. The run + Rec Onboard Index, Not Proportional adds the CA recreational onboard observer index to the model with a parameter that allows the index to be fit as not proportional to biomass. The run + Commercial Marginal Ages add the commercial age data as prepared for the pre-STAR draft assessment back into the model. The runs SigmaR = 0.7 and SigmaR = 0.8 change the fixed value for recruitment variability to 0.7 and 0.8, respectively. The run No Lam Study removes the Lam research CAAL and length composition data from the model. The run M=0.257 fixes male M to the value of female M (0.257) rather than estimating male M.

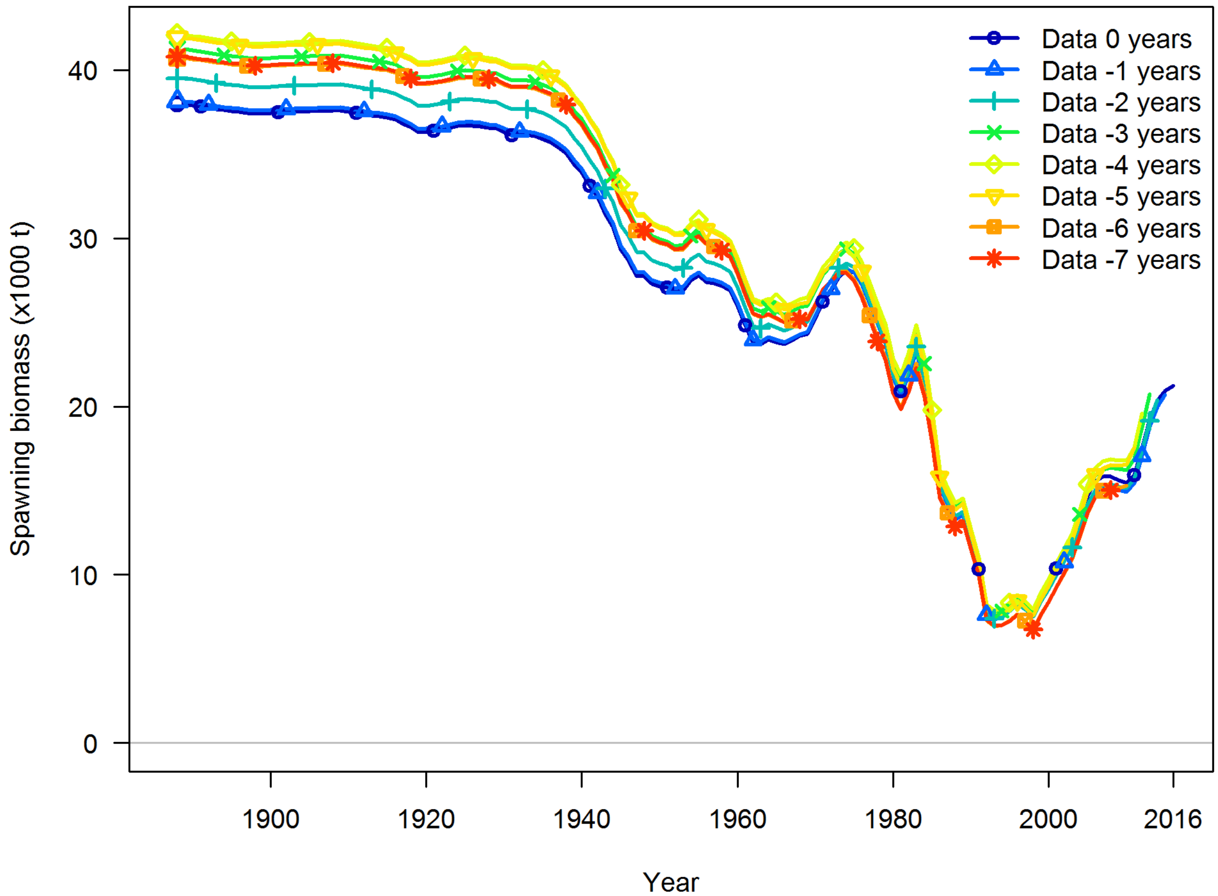


Figure 158. North base spawning biomass retrospective model runs.

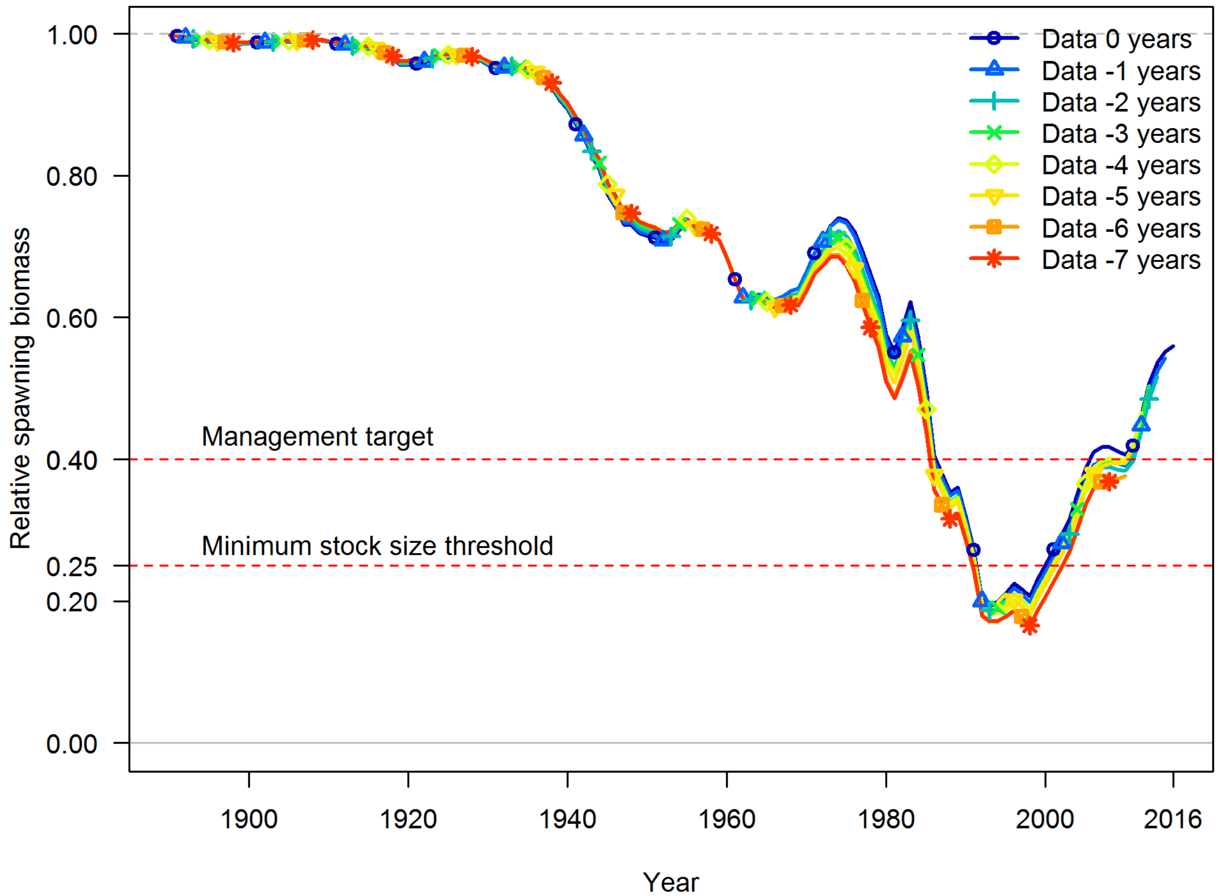


Figure 159. North base stock depletion retrospective model runs.

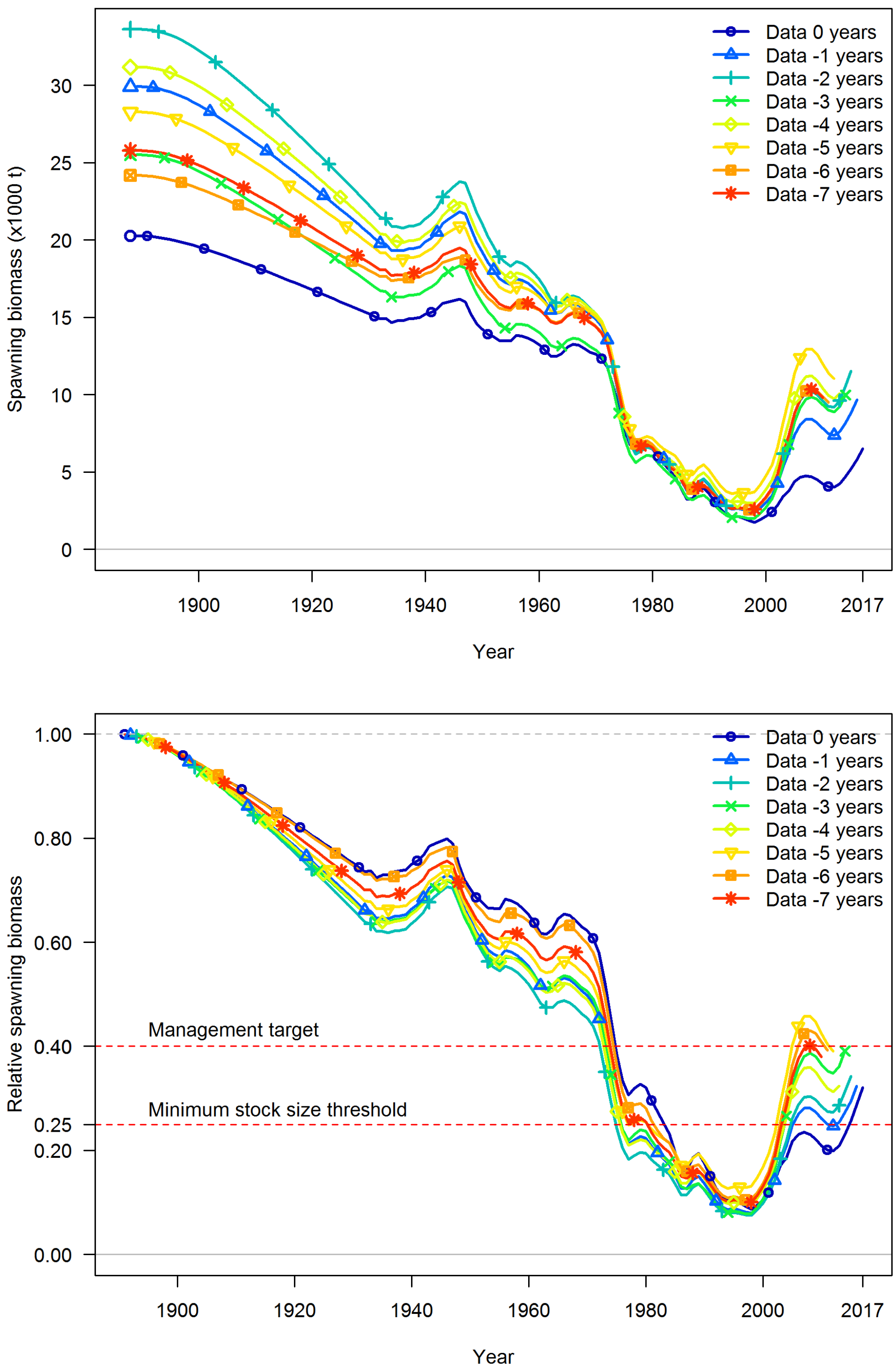


Figure 160. South base spawning biomass retrospective with (top panel) and without (bottom panel) the Lam data set.

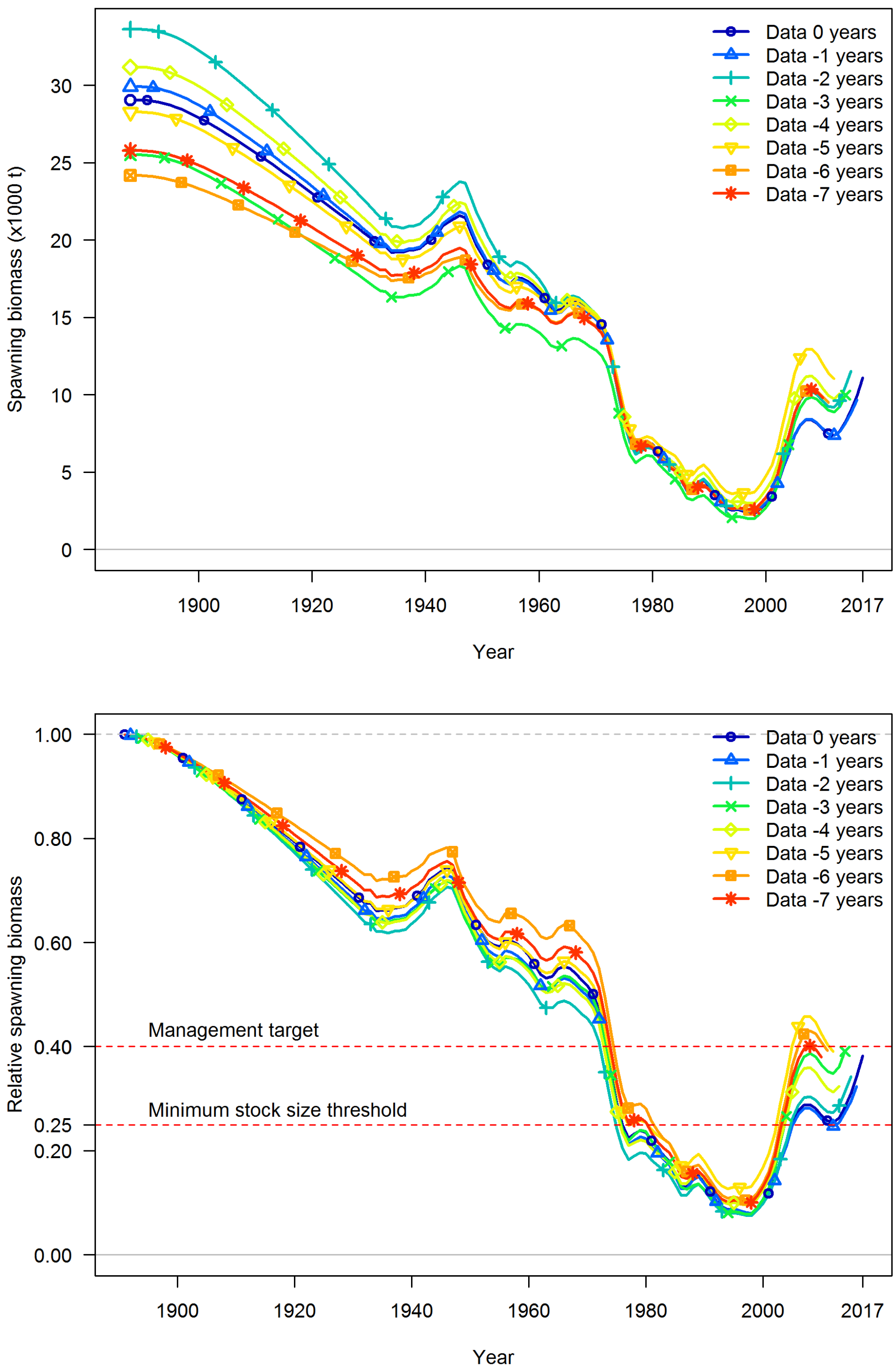


Figure 161. South base stock depletion retrospective with (top panel) and without (bottom panel) the Lam data set.

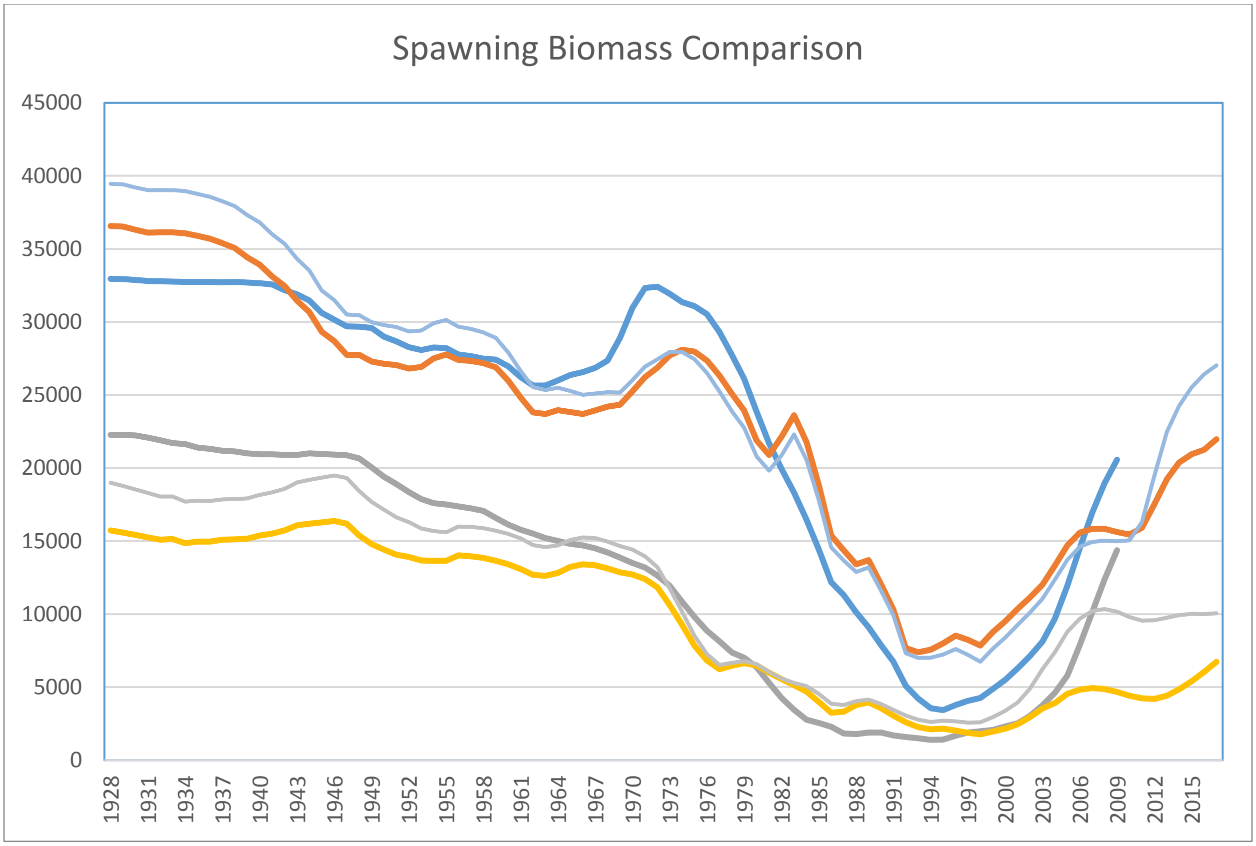


Figure 162. Comparison of spawning biomass trends between the 2009 and 2017 models. The 2009 north, 2017 north, 2009 south, and 2017 south models are show in blue, red, grey and yellow, respectively. The retrospective model runs that remove seven years of data are for the north (thin blue line) and south (thin grey line).

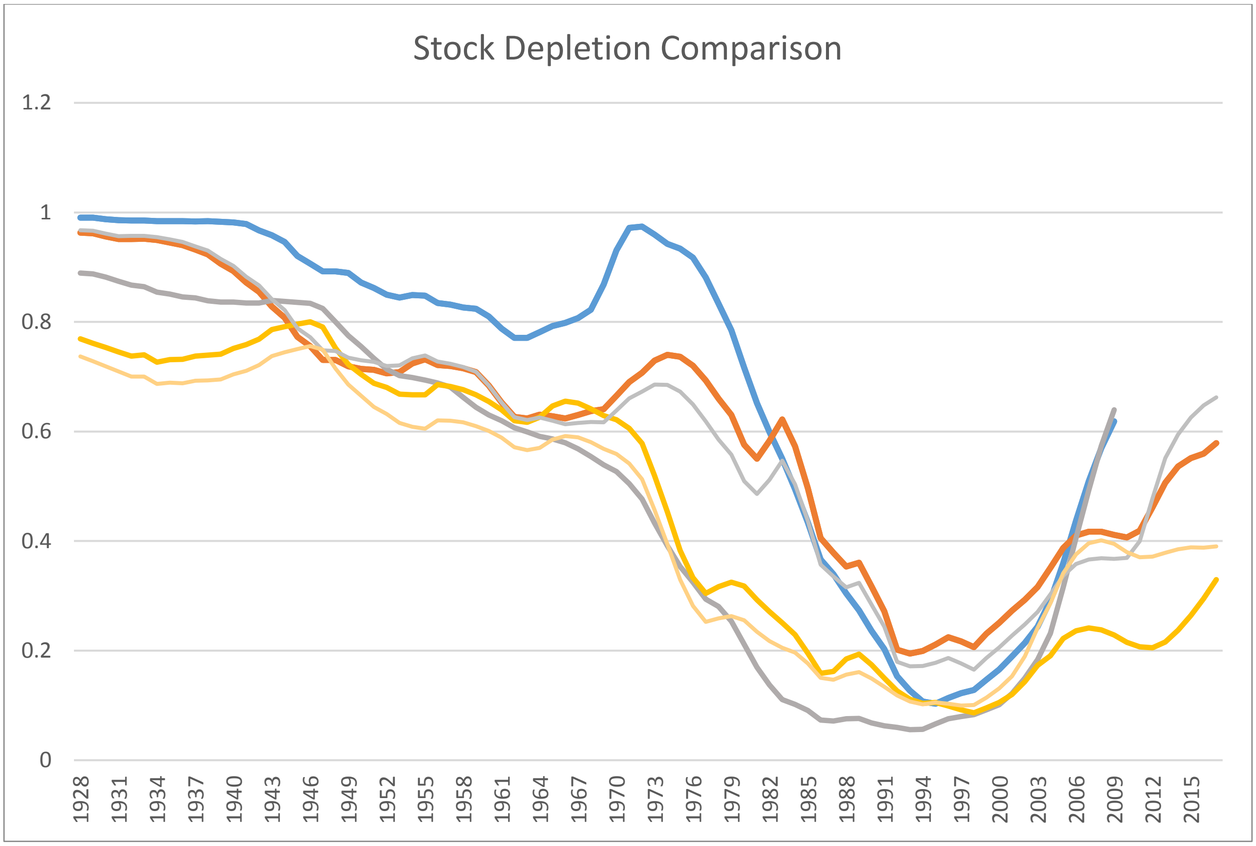


Figure 163. Comparison of stock depletion from the 2009 and 2017 models. The 2009 north, 2017 north, 2009 south, and 2017 south models are show in blue, red, grey and yellow, respectively. The retrospective model runs that remove seven years of data are for the north (thin blue line) and south (thin yellow line).

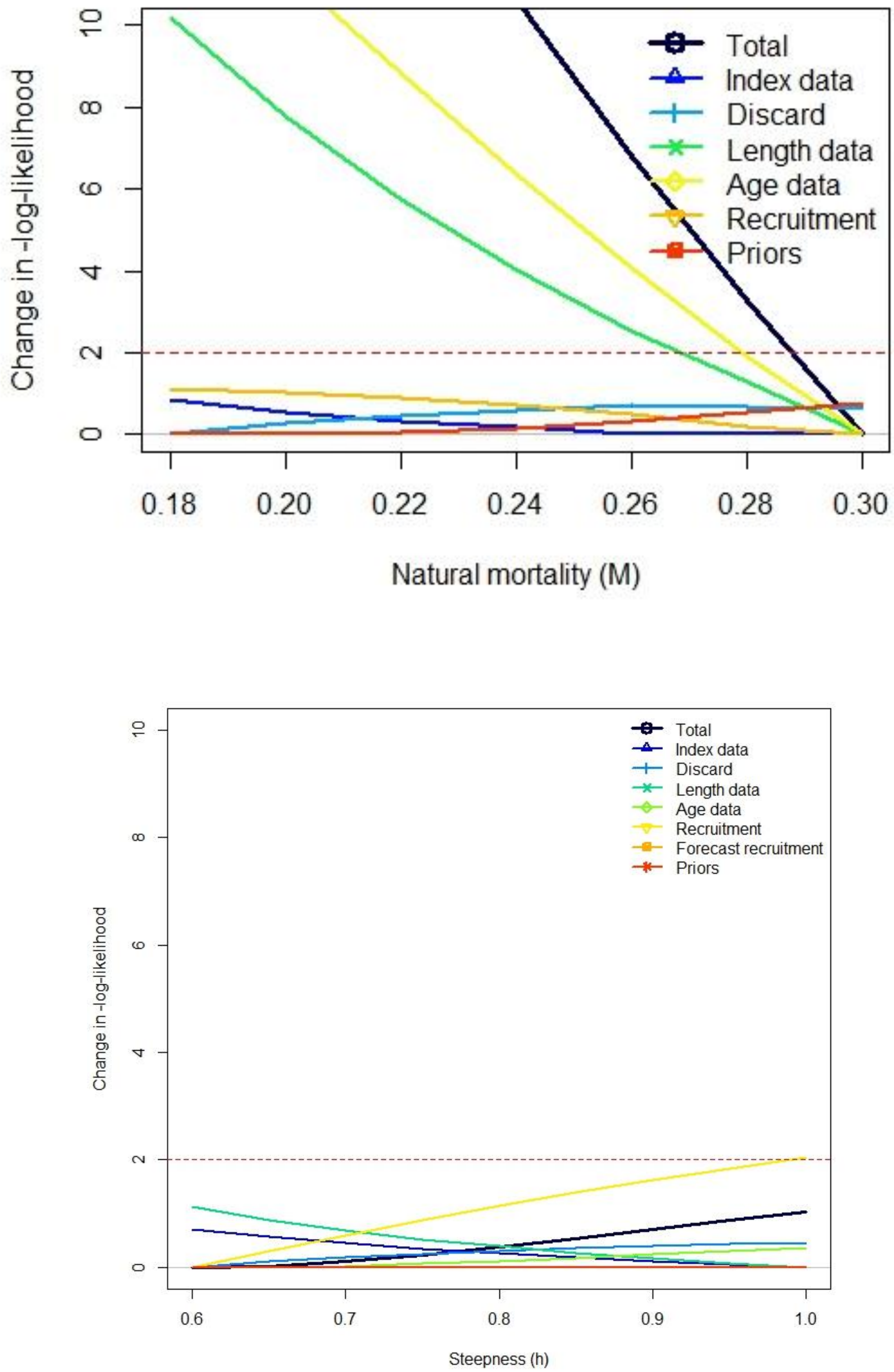


Figure 164. Female natural mortality (top panel) and stock-recruit steepness (bottom panel) likelihood profiles, north.

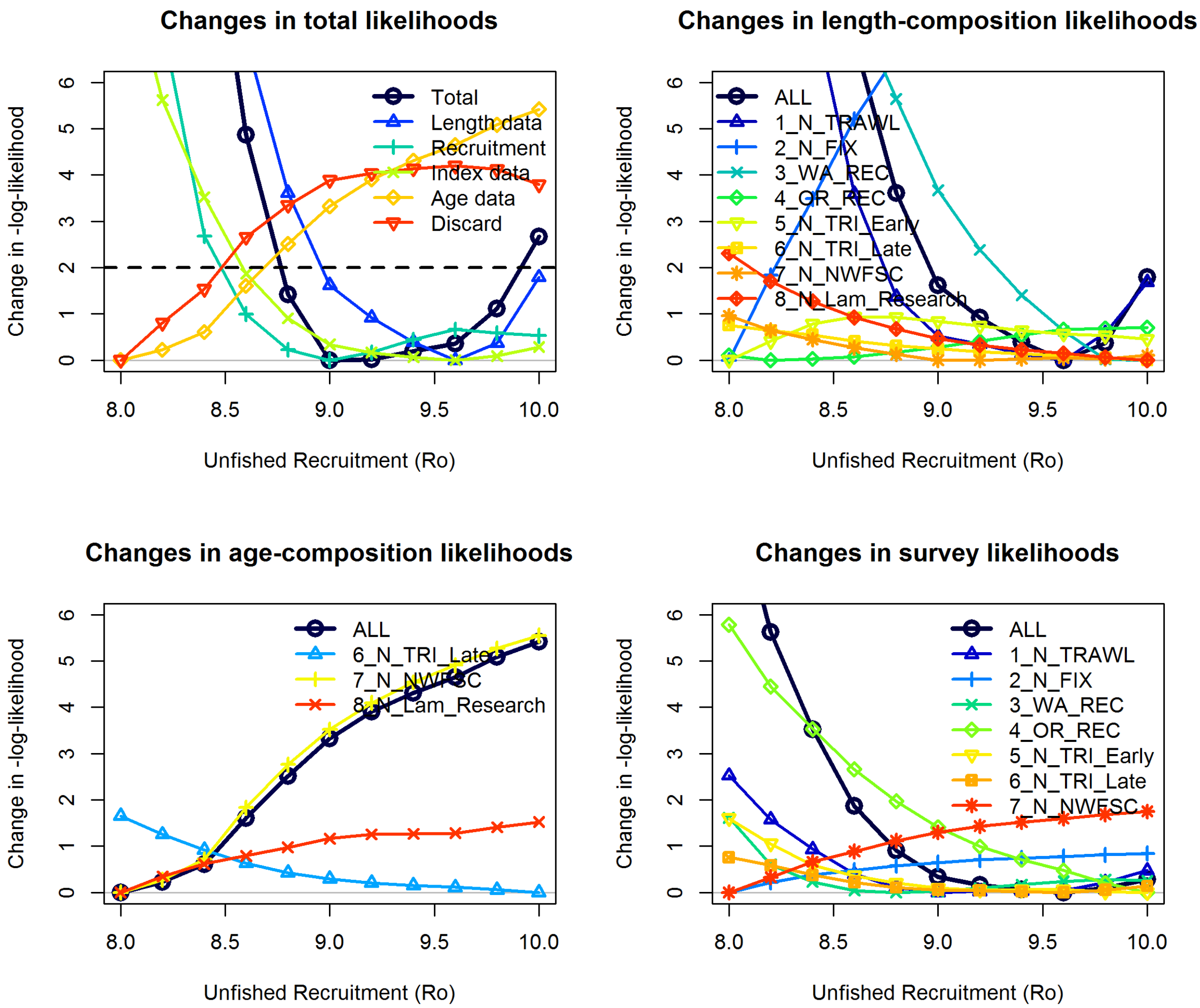


Figure 165. Estimated log unfished recruitment likelihood profile, north.

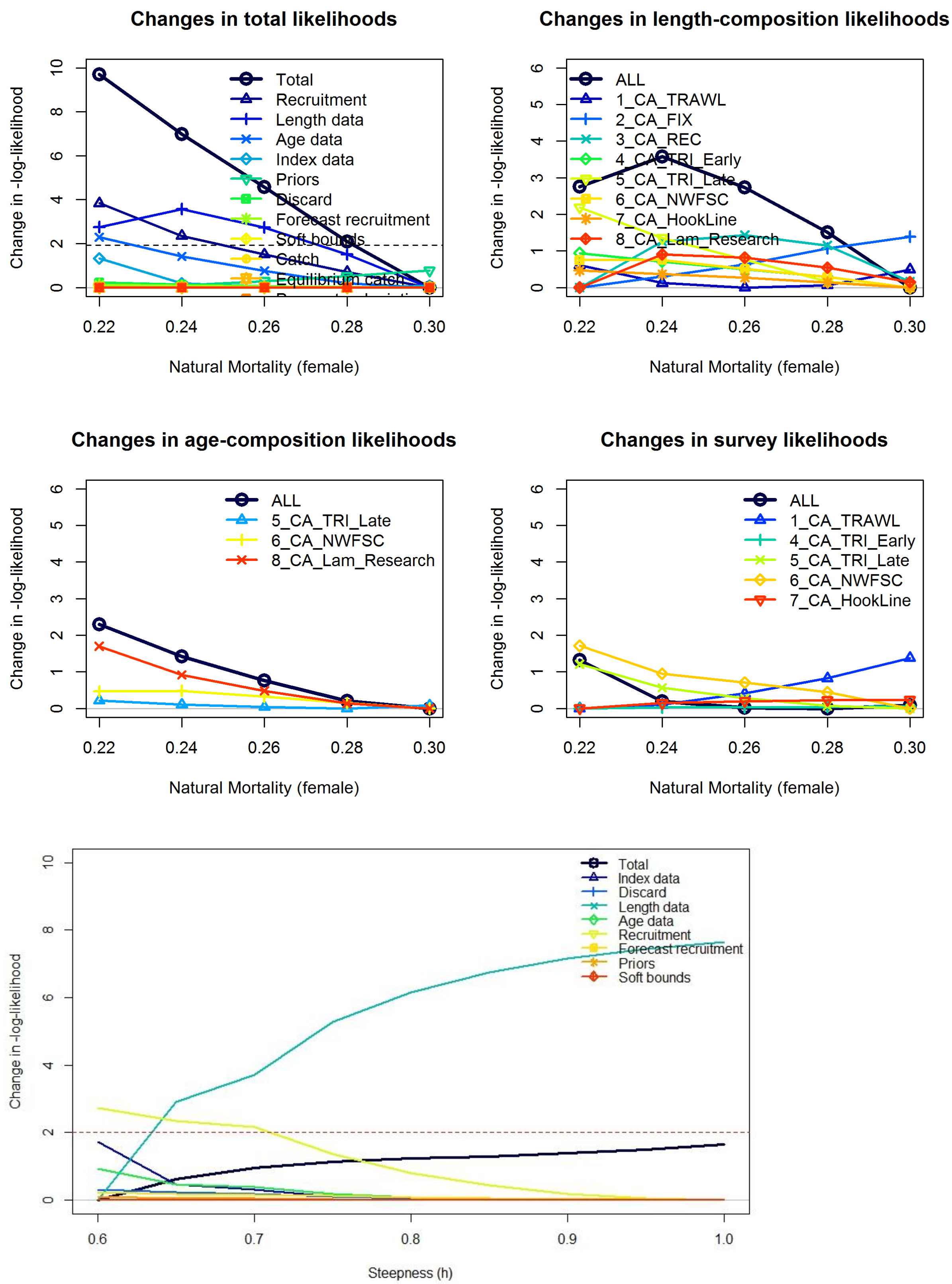


Figure 166. Female natural mortality (top panels) and stock-recruit steepness (bottom panel) likelihood profiles, south.

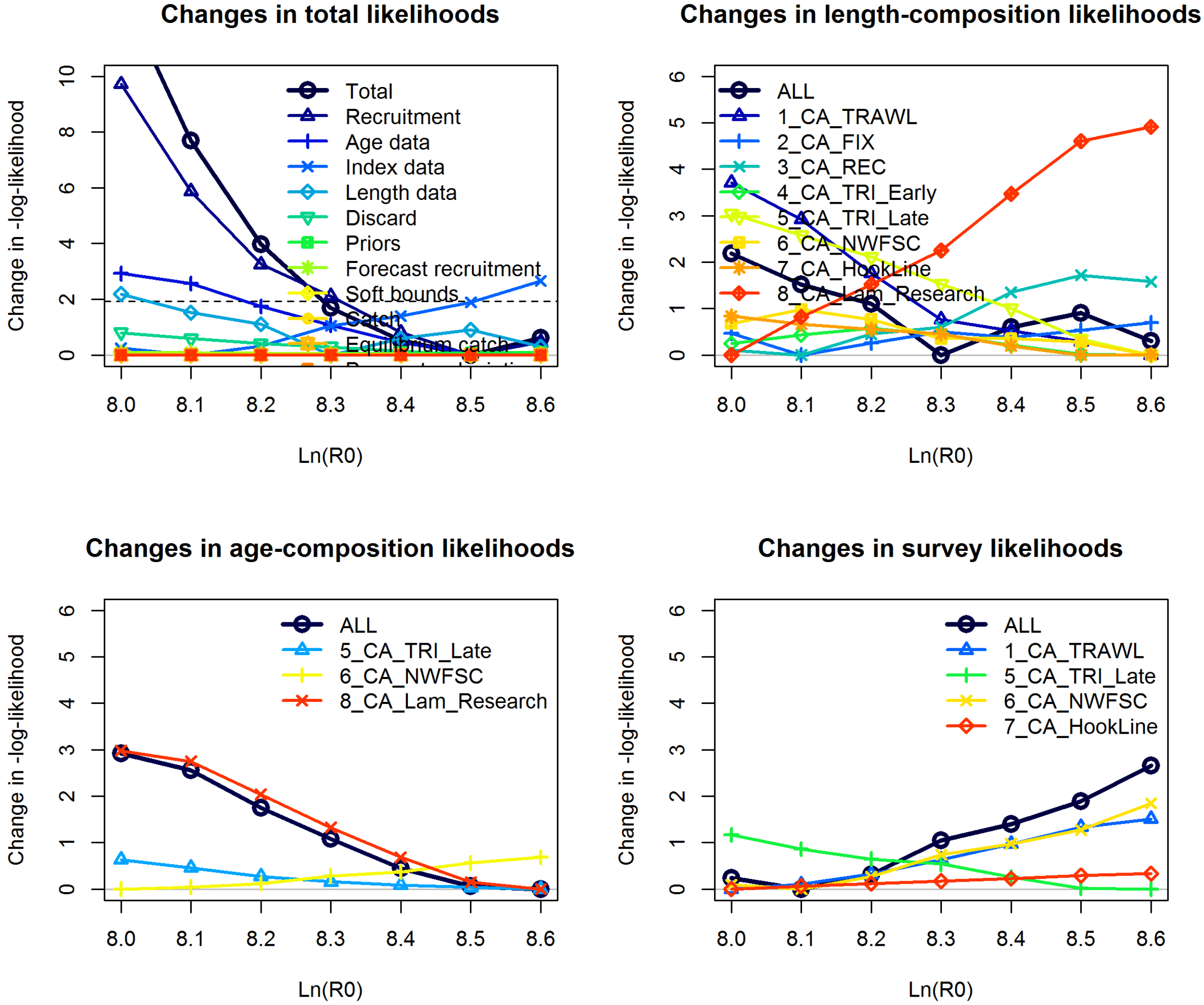


Figure 167. Estimated log unfished recruitment likelihood profile, south.

Appendix 1.

This appendix includes tables documenting VAST model specifications for the data sets analyzed using the VAST software as well as a comparison of the VAST and design based indices for the NWFSC survey data. For more detailed descriptions of the VAST modeling framework, see the User Manual available at: https://github.com/James-Thorson/VAST/blob/master/examples/VAST_user_manual.pdf

Table A1. Specifications and gradients for the VAST model runs.

Survey Data Set	NWFSC North	NWFSC South	Triennial North Early	Triennial North Late	Triennial South Early	Triennial South Late	PacFIN Logbooks
Number of knots	250	250	250	250	250	250	100
Maximum gradient	0.000589	0.000448	< 1e-06	< 1e-06	< 1e-06	< 1e-06	0.564
Is hessian positive definite?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was bias correction used?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distribution for measurement errors	Lognormal	Lognormal	Lognormal	Lognormal	Lognormal	Lognormal	Gamma
Spatial effect for encounter probability	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatio-temporal effect for encounter probability	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatial effect for positive catch rate	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatio-temporal effect for positive catch rate	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table A2. Summary of coefficients for the NWFSC survey and PacFIN trawl logbook VAST model runs.

	NWFSC North and South, Individually		PacFIN Trawl Logbooks	
Coefficient_name	Number_of_coefficients	Type	Number_of_coefficients	Type
beta1_ct	14	Fixed	11	Fixed
beta2_ct	14	Fixed	11	Fixed
L_epsilon1_z	1	Fixed	1	Fixed
L_epsilon2_z	1	Fixed	1	Fixed
L_omega1_z	1	Fixed	1	Fixed
L_omega2_z	1	Fixed	1	Fixed
L1_z	1	Fixed		
L2_z	1	Fixed	1	Fixed
lambda1_k	1	Fixed		
lambda2_k	1	Fixed		
ln_H_input	2	Fixed	2	Fixed
logkappa1	1	Fixed	1	Fixed
logkappa2	1	Fixed	1	Fixed
logSigmaM	1	Fixed	1	Fixed
Epsiloninput1_sft	3724	Random	1276	Random
Epsiloninput2_sft	3724	Random	1276	Random
eta1_vf	8	Random		
eta2_vf	8	Random	162	Random
Omegainput1_sf	266	Random	116	Random
Omegainput2_sf	266	Random	116	Random

Table A3. Summary of coefficients for the Triennial survey VAST model runs.

		Number_of_coefficients			
Coefficient_name	Type	Triennial North Early	Triennial North Late	Triennial South Early	Triennial South Late
beta1_ct	Fixed	5	4	5	4
beta2_ct	Fixed	5	4	5	4
L_epsilon1_z	Fixed	1	1	1	1
L_epsilon2_z	Fixed	1	1	1	1
L_omega1_z	Fixed	1	1	1	1
L_omega2_z	Fixed	1	1	1	1
L1_z	Fixed	1	1	1	1
L2_z	Fixed	1	1	1	1
ln_H_input	Fixed	2	2	2	2
logkappa1	Fixed	1	1	1	1
logkappa2	Fixed	1	1	1	1
logSigmaM	Fixed	1	1	1	1
Epsiloninput1_sft	Random	3458	2660	3458	2660
Epsiloninput2_sft	Random	3458	2660	3458	2660
eta1_vf	Random	7	6	7	6
eta2_vf	Random	7	6	7	6
Omegainput1_sf	Random	266	266	266	266
Omegainput2_sf	Random	266	266	266	266

Table A4. NWFSC VAST model based and design based indices.

Year	Region	Design Based Index	Design Based SE Log Biomass	Design Based Standardized	VAST Index	VAST SE Log Biomass	VAST Standardized
2003	North	35,067.7	0.487	2.100	15,952.8	0.157	0.510
2004	North	10,430.9	0.168	0.261	15,042.7	0.164	0.210
2005	North	8,170.4	0.182	-0.144	12,285.6	0.165	-0.699
2006	North	25,215.6	0.455	2.908	17,362.1	0.153	0.974
2007	North	9,159.0	0.126	0.033	13,013.9	0.156	-0.459
2008	North	11,959.4	0.210	0.535	10,328.9	0.157	-1.345
2009	North	7,122.3	0.185	-0.331	9,159.6	0.157	-1.730
2010	North	11,914.3	0.203	0.527	10,077.5	0.149	-1.428
2011	North	16,522.6	0.221	1.352	15,031.1	0.140	0.206
2012	North	21,489.0	0.277	2.241	16,093.6	0.160	0.556
2013	North	11,900.8	0.206	0.524	19,347.4	0.157	1.629
2014	North	30,058.6	0.340	3.775	15,705.2	0.146	0.428
2015	North	14,887.1	0.174	1.059	17,435.5	0.148	0.999
2003	South	6,459.0	0.157	-0.450	6,242.0	0.160	0.408
2004	South	17,950.0	0.385	1.607	8,044.0	0.180	1.309
2005	South	16,372.5	0.535	1.325	5,971.0	0.160	0.273
2006	South	17,128.2	0.554	1.460	6,558.3	0.197	0.566
2007	South	8,345.4	0.623	-0.112	3,797.6	0.201	-0.813
2008	South	2,512.1	0.178	-1.156	2,806.4	0.177	-1.309
2009	South	5,599.6	0.533	-0.604	2,876.6	0.157	-1.273
2010	South	2,452.1	0.151	-1.167	2,641.5	0.159	-1.391
2011	South	2,432.5	0.258	-1.171	2,989.3	0.153	-1.217
2012	South	8,243.1	0.340	-0.131	5,538.2	0.179	0.056
2013	South	8,458.4	0.227	-0.092	7,282.7	0.197	0.928
2014	South	13,725.6	0.314	0.851	7,337.1	0.141	0.955
2015	South	6,959.6	0.217	-0.360	6,037.0	0.151	0.306

Figure A4. Comparison of design based and VAST indices for the NWFSC survey data, north and south. The blue line is the design-based index; the red line is the VAST index.