Status of Cowcod (*Sebastes levis*) in 2019

Photo: R. Lea

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<u>Glossary of Acronyms:</u>

ABC: Acceptable Biological Catch
ACL: Annual Catch Limit
ACT: Annual Catch Target
CAAL: Conditional age at length
CalCOFI: California Cooperative Oceanic Fisheries Investigations
CALCOM: California Cooperative Groundfish Survey
CCGS: California Cooperative Groundfish Survey
CDFW (CDFG): California Department of Fish and Wildlife (formerly Fish and Game)
CPFV: Commercial Passenger Fishing Vessel (aka “party” or “charter” boats)
CPUE: Catch-per-unit-effort
CRFS: California Recreational Fisheries Survey
FED: Fisheries Ecology Division
INPFC: International North Pacific Fisheries Commission
LACSD: Los Angeles County Sanitation District
MRFSS: Marine Recreational Fisheries Statistics Survey
NMFS: National Marine Fisheries Service
NOAA: National Oceanic and Atmospheric Administration
NWFSC: Northwest Fisheries Science Center
OCSD: Orange County Sanitation District
ODFW: Oregon Department of Fish and Wildlife
OFL: Overfishing Limit
PacFIN: Pacific Fisheries Information Network
PFMC: Pacific Fishery Management Council
PSMFC: Pacific States Marine Fisheries Commission
RecFIN: Recreational Fisheries Information Network
SPR: Spawning Potential Ratio
SS: Stock Synthesis
STAR: Stock Assessment Review (Panel)
STAT: Stock Assessment Team
SWFSC: Southwest Fisheries Science Center
WCGBT: NWFSC West Coast Groundfish Bottom Trawl (WCGBT) Survey.
WCGOP: West Coast Groundfish Observer Program
YOY: Young-of-the-year

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Executive Summary

Stock

This is an assessment of *Sebastes levis* ("Cowcod") in the Southern California Bight (SCB), defined as U.S. waters off California and south of Point Conception (34° 27' North latitude). Waters north and south of the SCB are not considered in the assessment due to sparse data. A separate analysis to estimate sustainable yield for areas north of Point Conception is included as an appendix. Hess et al. (2014) used genetic tools to study cowcod population structure from California to Oregon. Specifically, they tested the hypothesis that a phylogeographic boundary exists at Point Conception. Their results supported a hypothesis of two primary lineages with a geographic boundary falling in the vicinity (slightly south) of Point Conception. Both lineages co-occur in the SCB with no clear pattern of depth stratification or spatial structure within the Bight. Within lineages, there is evidence for considerable gene flow across the Point Conception boundary. Cowcod found north of Point Conception consist primarily of a single lineage, also found in northern areas of the SCB. No information is available regarding dispersal between U.S. and Mexican waters.

Catches

Commercial catches of cowcod declined in the 1930s and 1940s due to changes in targeting (effort shifts to shark and sardine fisheries) and the Second World War. Post-war increases in commercial and recreational landings through the early 1980s were followed by rapid declines in catch through the 1990s (Figure A). The stock was declared overfished in 2000 and retention of cowcod was prohibited from January 2001 until January 2011. Since then, a small quota has been allocated to the trawl fishery as part of the Pacific Groundfish Trawl Rationalization Program, but retention remains prohibited in all other sectors. Recreational and commercial catch estimates in this assessment are identical to those in the previous assessment for years prior to 2001. Commercial catches since 2001 and recreational catches since 2005 were updated with the latest available estimates, resulting in only minor changes since the last assessment. Reported total annual removals for cowcod over the last ten years have not exceeded 2 mt, averaging 1.3 mt per year (Table A).

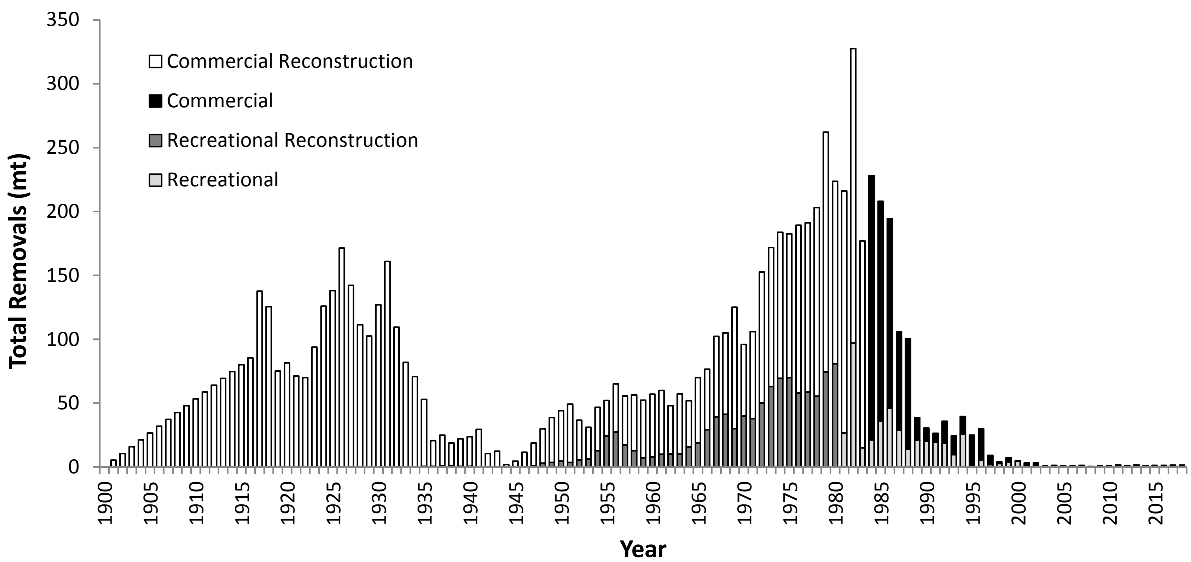

Figure A. Estimated commercial and recreational removals of cowcod in the Southern California Bight, 1900-2018.

Table A: Recent cowcod removals (mt) in the Southern California Bight. Sources: RecFIN (recreational) and WCGOP (GEMM Report). Commercial catch in 2018 was estimated at 1 mt for the assessment.

Year	Recreational	Commercial	Total
2009	0.21	0.66	0.86
2010	0.40	0.42	0.81
2011	1.28	0.17	1.45
2012	0.72	0.32	1.04
2013	1.38	0.41	1.79
2014	0.66	0.43	1.09
2015	0.44	0.97	1.41
2016	0.68	0.61	1.29
2017	0.51	0.95	1.46
2018	0.58	1.00	1.58

Data and assessment

The previous full assessment of cowcod was based on a Bayesian surplus production model (XDB-SRA; Dick and MacCall 2013). The 2019 assessment uses a statistical catch at age model (Stock Synthesis, version 3.30.13.09) that is fit to six fishery-independent data sources: four time-series of relative abundance (CalCOFI larval abundance survey, Sanitation District trawl surveys, NWFSC West Coast Groundfish Bottom Trawl (WCGBT) survey, and NWFSC Hook-and-Line survey), as well as two visual survey estimates of abundance conducted by the SWFSC in 2002 and 2012. The 2002 abundance estimate is based on a SWFSC submersible survey of rocky habitat in the Cowcod Conservation Areas (CCA), and is related to cowcod abundance in the SCB using a prior distribution for catchability. The 2012 absolute abundance estimate is new to this assessment, and is based on a SWFSC ROV survey stratified by habitat and depth, both inside and outside the CCA. The model is also fit to length composition data from the recreational fishery, NWFSC WCGBT survey, NWFSC Hook-and-Line survey, and Sanitation District surveys. Age composition data from the commercial and recreational fisheries, as well as from the NWFSC WCGBT and Hook-and-Line surveys were included by length bin (conditional age-at-length) to help inform growth. Recruitment deviations were not estimated, as individual year-class strengths were not discernable given the data and model.

The previous assessment (Dick and MacCall, 2013) found increasing trends in all four fishery-independent time series. Updates of these indices do not show increasing trends after 2013 in all cases. The current base model is most consistent with the high-productivity alternatives presented in the 2013 assessment, largely due to a higher estimated rate of natural mortality (M = 0.088 [yr^{-1}], versus M = 0.055 in previous assessments). Age data in the assessment are limited in sample size and temporal coverage, with evidence of bias between readers for ages from the fishery (1970s and 1980s) and more recent NWFSC surveys (2003 to 2018). The two SWFSC visual surveys provide independent estimates of cowcod biomass in 2002 and 2012. These estimates are consistent with model predictions based on the other data sets alone (i.e. when excluding the visual surveys from the likelihood). Therefore, while the surveys themselves are not informative about relative stock status, they provide valuable information about population scale. Very little information is available about trends in recent stock abundance from fishery-dependent sources due to regulatory restrictions (retention being prohibited in most sectors since 2001).

Stock biomass

The base case model suggests that spawning output initially decreased until the early 1930s, then increased as effort targeting cowcod declined. The model also suggests a rapid decline in spawning output from the 1970s to mid-1980s, falling below the Minimum Stock Size Threshold (MSST; 25% of unfished spawning output) from 1983 through 2000, dropping to a low of 9% of unfished biomass in 1989. Since then, the base model suggests the stock has increased to 57% of unfished equilibrium biomass (SB_0) in 2019, with a 95% asymptotic interval (hereafter "interval") of 42% to 72% (Table B, Figures B and C). The 2013 assessment predicted stock status in 2013 to be 34% of unfished biomass, with a 95% credible interval of 15%-66%. For comparison, the current base model estimates stock depletion in 2013 was at 47% of unfished (i.e. within the range of uncertainty in the 2013 assessment), but predicts a faster rate of increase due to changes in estimated productivity of the stock (e.g. natural mortality, as noted above). Unfished spawning output in the base model is 285 billion eggs, with a 95% interval of 235-334. Unfished age 10+ biomass (males and females combined) is estimated at 3564 mt (95% interval of 2939-4189 mt).

Table B: Recent trend in spawning output and stock depletion (percentage of unfished spawning output)

Year	Spawning Output (eggs x 10^9)	95% Asymptotic Interval	Estimated Depletion (%)	95% Asymptotic Interval
2007	103	72–134	36.2	23.2–49.2
2008	108	76–140	37.9	24.6–51.3
2009	113	81–145	39.7	26.1–53.4
2010	118	86–151	41.5	27.6–55.4
2011	123	90–156	43.3	29.2–57.4
2012	128	95–161	45.1	30.8–59.4
2013	133	100–166	46.9	32.4–61.3
2014	138	105–172	48.6	34.0–63.2
2015	143	110–177	50.4	35.7–65.0
2016	148	115–181	52.1	37.4–66.8
2017	153	120–186	53.8	39.0–68.6
2018	158	125–191	55.5	40.7–70.3
2019	163	130–195	57.1	42.4–71.9

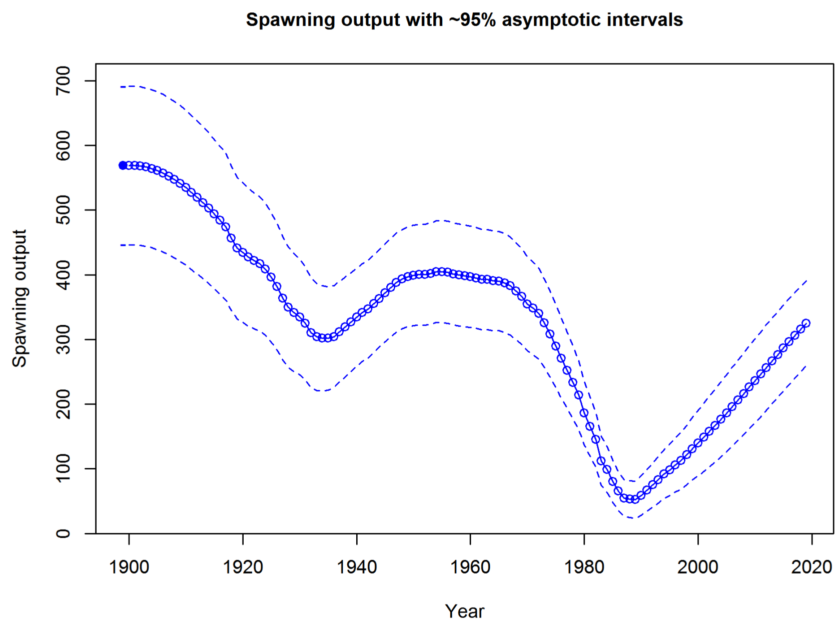

Figure B: Spawning output trajectory with asymptotic 95% intervals. Spawning output as shown is twice the actual value due to the use of a single-sex model.

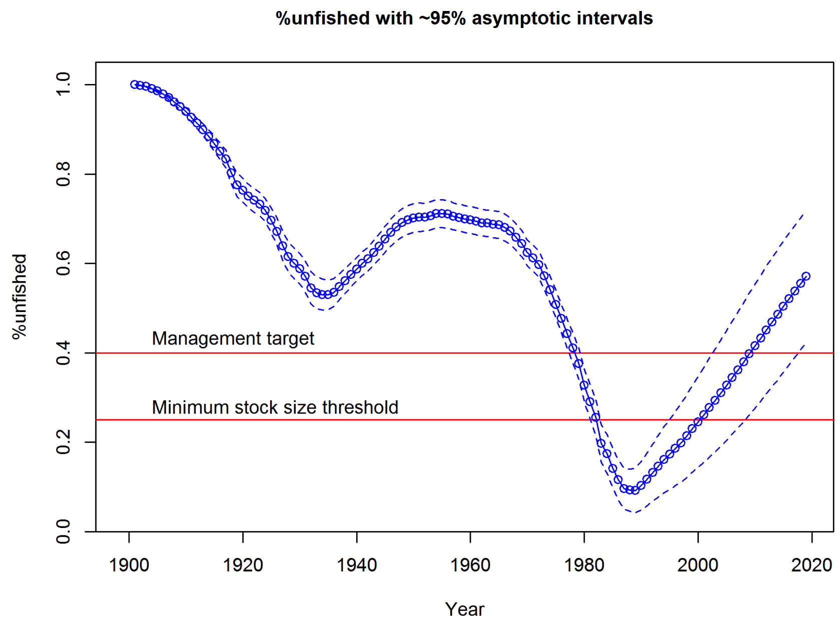

Figure C. Spawning output relative to unfished spawning output (aka "depletion," solid line) with 95% intervals (dashed lines) for the base case assessment model.

Recruitment

Attempts to estimate annual recruitment deviations were not successful, so the base model assumes deterministic recruitment (Figure D, Table C) following a Beverton-Holt stock recruitment relationship with steepness fixed at 0.72 (the prior mean). Alternative, 3-parameter stock-recruitment relationships were explored as part of the transition from the XDB-SRA model (see section 2.2.4). Unfished recruitment in the base model is estimated at 180000 age-0 fish.

Figure D: Time series of deterministic recruitment with 95% asymptotic confidence intervals.

Table C: Recent deterministic recruitment estimates from the 2019 base model.

Year	Recruitment	95% Asymptotic Interval
2007	154	93–254
2008	155	94–256
2009	157	95–258
2010	158	96–260
2011	160	98–261
2012	161	99–262
2013	162	100–264
2014	163	101–265
2015	164	101–266
2016	165	102–267
2017	166	103–268
2018	167	104–269
2019	168	104–269

Exploitation status

The annual (equilibrium) SPR harvest rate (1-SPR) for cowcod has been less than 4% of target for over a decade (Table D). Historically, the SPR harvest rate reached target levels by 1920-1930, and later regularly exceeded the target for roughly 30 years, from the mid-1960s to the mid-1990s (Figure E). As a percentage of age-10+ biomass (i.e. exploitation rate), harvest rates peaked at around 40% in the 1980s, but have declined to levels below 1% since retention of cowcod was prohibited in 2001 (Figure F). Exploitation history relative to the target SPR harvest rate (0.5) and the target spawning output (40% of unfished spawning output) is shown in Figure G. The estimated $SPR_{50\%}$-based proxy for maximum sustainable yield (MSY) is 73 mt per year, which corresponds to an annual harvest rate of roughly 4% of age 10+ biomass (Figure H, Table E).

Table D. Recent trend in spawning potential ratio (entered as 1-SPR / 1-SPR50%) and Harvest Rate (catch / age 10+ biomass) for cowcod.

Years	Estimated (1-SPR)/(1-SPR_50%) (%)	95% Asymptotic Interval	Harvest Rate (proportion)	95% Asymptotic Interval
2007	3.7	2.14–5.18	0.001	0.001–0.001
2008	1.3	0.81–1.87	0	0.000–0.000
2009	2.1	1.26–2.94	0.001	0.000–0.001
2010	1.9	1.19–2.64	0.001	0.000–0.001
2011	3.3	2.13–4.47	0.001	0.001–0.001
2012	2.3	1.47–3.10	0.001	0.000–0.001
2013	3.8	2.49–5.12	0.001	0.001–0.001
2014	2.2	1.47–3.02	0.001	0.000–0.001
2015	2.8	1.80–3.71	0.001	0.001–0.001
2016	2.5	1.66–3.32	0.001	0.001–0.001
2017	2.7	1.80–3.60	0.001	0.001–0.001
2018	2.9	1.93–3.77	0.001	0.001–0.001
2019	3.6	2.44–4.67	0.001	0.001–0.001

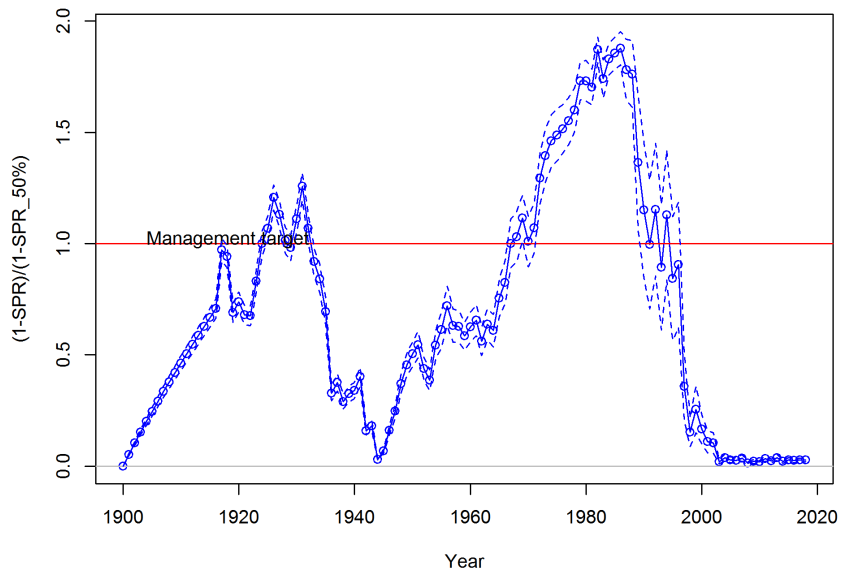

Figure E. Estimated spawning potential ratio (SPR) for the base case model with approximate 95% asymptotic confidence intervals. One minus SPR is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the $SPR_{50\%}$.

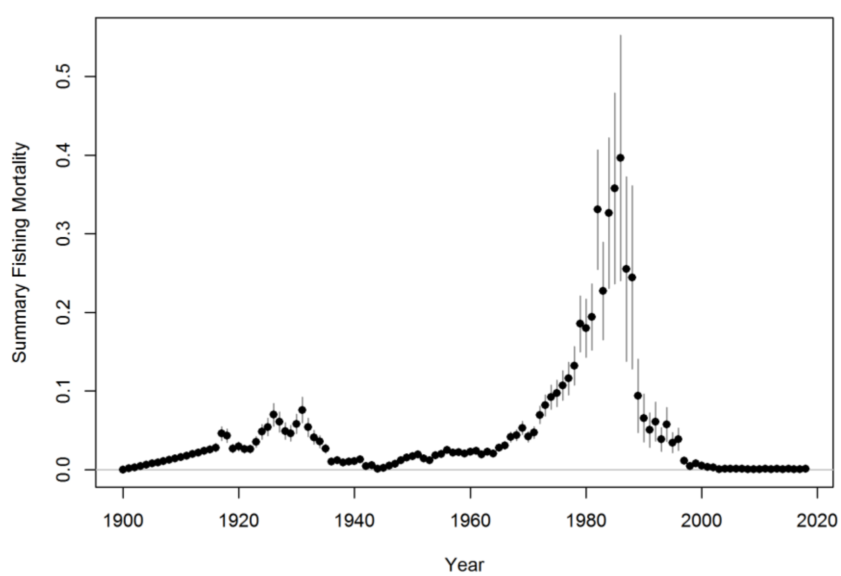

Figure F. Time-series of estimated summary harvest rate (total catch divided by age-10 and older biomass) for the base case model with approximate 95% asymptotic confidence intervals (grey lines).

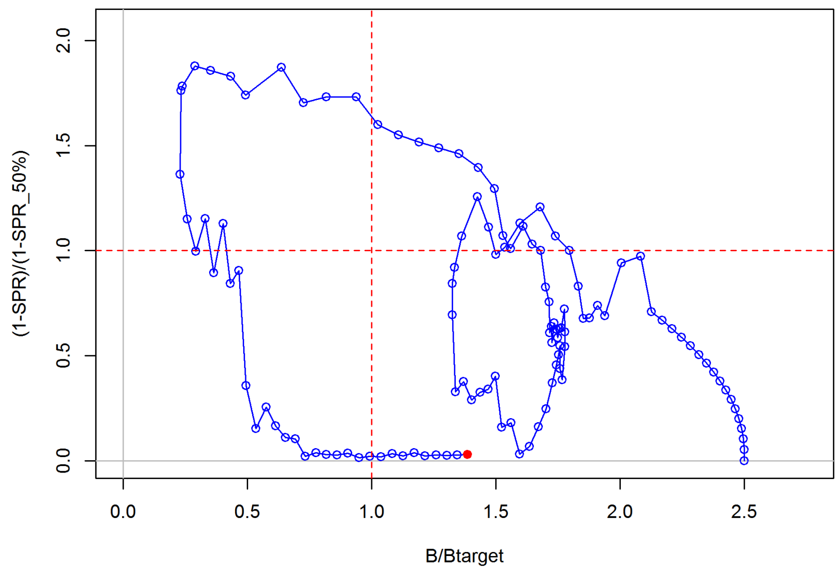

Figure G. Phase plot of estimated relative (1-SPR) vs. relative spawning output for the base case model. The vertical axis is "relative (1-SPR)" or (1-SPR) divided by 0.5 (the SPR target). Relative depletion (B/Btarget) is the annual spawning output divided by the spawning output corresponding to 40% of the unfished spawning output. The red point indicates the year 2018.

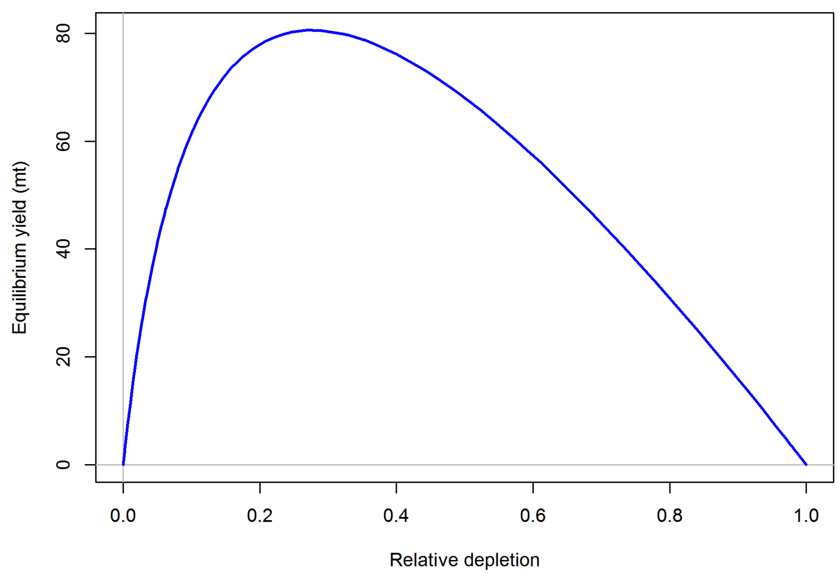

Figure H. Equilibrium yield curve (derived from reference point values reported in Table E) for the base case model. Depletion is relative to unfished spawning output.

Ecosystem considerations

No environmental correlations or food web considerations were considered explicitly in the model. However, alternative 3-parameter stock-recruitment relationships were explored in addition to the 2-parameter Beverton-Holt model (see sections 1.4 and 2.2.4). These implicitly consider a "cultivation effect" whereby adults crop down forage species that are potential competitors/predators of their own juveniles. Also, habitat associations were considered during development of length-based selectivity curves for the visual surveys. The 2002 submersible survey sampled high-relief, rocky habitats. Based on evidence supporting ontogenetic movement of cowcod from low-relief to high-relief substrate, both the observed and predicted biomasses for the submersible survey were linked to 40+ cm individuals. In contrast, the 2012 ROV survey sampled a wider range of habitats, and was associated with predictions of age 1+ biomass.

Reference points

Reference points and management quantities for the 2019 cowcod base case model are listed in Table E. In 2019, spawning output relative to unfished spawning output ("depletion") is estimated at 57% (~95% asymptotic intervals = 42%-72%). Unfished spawning output was estimated at 285 billion eggs (~95% asymptotic intervals = 235-334; Table E), and spawning output at the beginning of 2019 was estimated to be 163 billion eggs (~95% asymptotic intervals = 130-195). The target spawning output ($SB_{40\%}$) is 114 billion eggs, compared to an equilibrium spawning output of 127 billion eggs associated with the proxy $SPR_{50\%}$ harvest rate. Yield at the SPR proxy biomass and harvest rate (i.e. proxy MSY) is 73 mt per year (~95% asymptotic intervals = 63-83 mt), corresponding to a harvest of 4.3% of age 10+ biomass per year.

Table E. Summary of reference points for the base case model.

Quantity	Estimate	95% Asymptotic Interval
Unfished Spawning Output (eggs x 10^9)	285	235–334
Unfished Age 10+ Biomass (mt)	3,564	2,939–4,189
Spawning Output in 2019 (eggs x 10^9)	163	130–195
Unfished Recruitment (R_0, 1000s of age-0 fish)	180	100–260
Depletion (2019 spawning output / unfished spawning output, %)	57	42–72
Reference Points Based $SB_{40\%}$		
Proxy Spawning Biomass ($SB_{40\%}$)	114	94–134
SPR resulting in $SB_{40\%}$	0.458	0.458–0.458
Exploitation Rate Resulting in $SB_{40\%}$	0.05	0.036–0.064
Yield with SPR Based On $SB_{40\%}$ (mt)	76	66–87
Reference Points based on SPR proxy for MSY		
Proxy spawning biomass (SPR_{50})	127	105–149
SPR_{50}	0.5	NA
Exploitation rate corresponding to SPR_{50}	0.043	0.031–0.055
Yield with SPR_{50} at SB_{SPR} (mt)	73	63–83
Reference points based on estimated MSY values		
Spawning biomass at MSY (SB_{MSY})	79	63–95
SPR_{MSY}	0.347	0.337–0.358
Exploitation rate corresponding to SPR_{MSY}	0.074	0.051–0.098
MSY (mt)	81	69–92

Management performance

Total mortality of cowcod has been well below catch targets and limits since 2009 (Table F).

Table F. Annual estimates of total mortality, overfishing limit (OFL), acceptable biological catch (ABC), annual catch limit (ACL), and annual catch target (ACT) for cowcod, 2009-2018. Units are metric tons for total mortality and harvest specifications.

Year	OFL	ABC	ACL	ACT	Total Mortality	Source of Total Mortality Estimate
2018	71	64	10	4	1.58	Approximation (approved by GMT)
2017	70	63	10	4	1.46	WCGOP GEMM Report + RecFIN
2016	68	62	10	--	1.29	WCGOP GEMM Report + RecFIN
2015	67	60	10	--	1.41	WCGOP GEMM Report + RecFIN
2014	12	9	3	--	1.09	WCGOP GEMM Report + RecFIN
2013	11	9	3	--	1.79	WCGOP GEMM Report + RecFIN
2012	13	8	3	--	1.04	WCGOP GEMM Report + RecFIN
2011	13	8	3	--	1.45	WCGOP GEMM Report + RecFIN
2010	--	14	4*	--	0.81	WCGOP GEMM Report + RecFIN
2009	--	13	4*	--	0.86	WCGOP GEMM Report + RecFIN

* The OFL/ABC/ACL framework was adopted in 2011; values in ACL column for 2009-10 are Optimum Yields.

Unresolved problems and major uncertainties

A major issue and uncertainty associated with the cowcod assessment is the lack of data, particularly age data, adequate to estimate recruitment deviations, growth, and natural mortality. The assessment would greatly benefit from improved collection of age data from both commercial and recreational fisheries, as well as from ongoing fishery-independent surveys. These data are needed to improve our understanding of these processes, all of which influence estimates of productivity and yield. Validation of current ageing methods is also needed for this species.

The base model estimates current spawning output to be above target in 2019, and therefore estimates of OFL and ABC may exceed the SPR proxy for MSY (i.e. >73 mt) in the short term. Uncertainty in current stock status and productivity is greatly underestimated by the base model due to lack of sufficient information in estimating natural mortality, the form and parameters of the stock recruitment relationship, recruitment variability, and historical fishery selectivity. As noted in the main text, catch uncertainty affects the precision of population scale (and therefore yield), and is not accounted for in the current assessment (see research recommendations). Therefore, the STAT recommends that target yields be set well below the MSY proxy until data become available to better inform stock productivity and status.

Decision table

Projections of OFL (mt), ABC (mt), age 10+ biomass (mt), spawning output (billions of eggs), and depletion (% of unfished spawning output) are shown for the default harvest control rule in Table G. Catch estimates for 2019 and 2020 are based on GMT recommendations (M. Mandrup, CDFW; pers. comm.), with 0.6 mt for commercial and 2.5 mt for recreational fleets. Projections assume a constant allocation among fleets equal to the recommended catch for 2019 and 2020 (19.35% commercial, 80.65% recreational) for 2021 and beyond.

Table G. Projection of OFL, assumed default harvest control rule catch (ABC = ACL when stock is above 40% SSB_0), age 10+ biomass, spawning output and relative spawning output as a percentage of unfished spawning output ("depletion") using the cowcod base case model with 2019-2020 catches set equal to GMT recommendations. Assumed ABC catches are based on a tier 2 sigma value of 1.0 with a 'p-star' value of 0.45. Catches for 2019 and 2020 recommended by the STAR panel GMT representative. OFLs and ABCs for 2019 and 2020 were set during the previous management cycle, and therefore not reported here.

Year	Assumed Catch (mt)	OFL (mt)	ABC (mt)	Age 10+ biomass (mt)	Spawning Output (eggs x 10^9)	Depletion (%)
2019	3.1	--	--	2125	325	57.1%
2020	3.1	--	--	2180	334	58.7%
2021	83.0	95.0	83.0	2233	343	60.3%
2022	81.3	93.9	81.3	2210	340	59.7%
2023	79.7	93.0	79.7	2188	337	59.2%
2024	78.1	92.0	78.1	2166	334	58.7%
2025	76.7	91.2	76.7	2146	331	58.1%
2026	75.3	90.4	75.3	2127	328	57.6%
2027	74.1	89.7	74.1	2111	325	57.2%
2028	72.9	89.1	72.9	2095	323	56.7%
2029	71.7	88.5	71.7	2082	321	56.4%
2030	70.7	88.1	70.7	2071	319	56.0%

High and low states of nature for a decision table (Table H) were agreed upon during the STAR panel review. The low state of nature set commercial length at 50% selectivity ($L_{50\%}$) at 35 cm with an M of 0.055 (the value of M used in the previous assessment) and the high state of nature at a selectivity of 55 cm with M = 0.098 (the median of the Hamel prior on M given a maximum age of 55). The base model assumed a commercial fleet length at 50% selectivity of 45.6 cm, equal to the maturity ogive, and estimated M = 0.088. Alternative management strategies (catch streams) were identified as the default ABC harvest control rule under each state of nature. Proxy MSY yields vary by state of nature. The base model's SPR proxy for MSY is 73 mt, while the proxy MSY yields given the low and high states of nature are 58 mt and 86 mt, respectively.

Table H. Decision table summarizing 12-year projections (2019 – 2030) for cowcod according to three alternative states of nature varying natural mortality and commercial fishery selectivity (length at 50% selectivity). Columns range over low, medium, and high state of nature, and rows range over different assumptions of total catch levels corresponding to the forecast catches from each state of nature. Catches in 2019 and 2020 were proposed by the GMT representative. Catch is in mt, spawning output is in billions of eggs, and depletion is the percentage of spawning output relative to unfished spawning output. Outcomes below target spawning output (40% of unfished spawning output) are shaded in gray.

			State of nature					
			Low		Base case		High	
			M=0.055, $L_{50\%}$=35 cm		M=0.088, $L_{50\%}$=45.6 cm		M=0.098, $L_{50\%}$=55cm	
Management decision	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
Low Catch	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	45.6	330	38.1%	343	60.3%	434	77.8%
	2022	45.7	335	38.6%	346	60.7%	434	77.8%
	2023	45.8	339	39.1%	348	61.1%	434	77.7%
	2024	45.8	343	39.6%	350	61.5%	433	77.6%
	2025	45.9	347	40.0%	351	61.7%	432	77.4%
	2026	45.7	351	40.5%	353	62.0%	431	77.2%
	2027	45.6	354	40.9%	354	62.1%	430	77.0%
	2028	45.4	358	41.3%	355	62.3%	428	76.8%
	2029	45.3	361	41.6%	355	62.5%	427	76.5%
	2030	45.2	364	42.0%	356	62.6%	425	76.2%
Base Catch	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	83.0	330	38.1%	343	60.3%	434	77.8%
	2022	81.3	329	38.0%	340	59.7%	429	76.9%
	2023	79.7	328	37.8%	337	59.2%	423	75.9%
	2024	78.1	326	37.6%	334	58.7%	418	74.9%
	2025	76.7	324	37.3%	331	58.1%	412	73.9%
	2026	75.3	321	37.0%	328	57.6%	407	72.9%
	2027	74.1	318	36.7%	325	57.2%	401	71.9%
	2028	72.9	315	36.4%	323	56.7%	396	71.0%
	2029	71.7	312	36.0%	321	56.4%	391	70.1%
	2030	70.7	309	35.6%	319	56.0%	387	69.3%
High Catch	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	128.0	330	38.1%	343	60.3%	434	77.8%
	2022	123.1	323	37.2%	334	58.7%	422	75.6%
	2023	118.7	314	36.3%	325	57.1%	410	73.5%
	2024	114.5	306	35.3%	316	55.5%	399	71.6%
	2025	110.7	297	34.2%	307	54.0%	389	69.8%
	2026	107.1	288	33.2%	299	52.5%	380	68.2%
	2027	104.0	279	32.2%	291	51.1%	372	66.7%
	2028	100.9	270	31.1%	283	49.8%	365	65.3%
	2029	98.1	261	30.1%	276	48.5%	358	64.1%
	2030	95.7	253	29.1%	270	47.4%	352	63.0%

Scientific uncertainty

The estimated asymptotic standard error of the natural logarithm of spawning output in 2018 was 0.11, although this estimate of uncertainty is biased low (see "Unresolved problems and major uncertainties" section). ABC catches in the current draft are based on a tier 2 sigma value of 1.0 with a 'p-star' value of 0.45.

Research and data needs

Specific recommendations for the next cowcod assessment:

1. Evaluating how to structure the NWFSC Hook-and-Line survey index given its expansion into the CCA, also independent analysis of information content in NWFSC Hook-and-Line survey.
2. There are a number of improved data collection efforts that would benefit the next assessment of cowcod:
    - Continue to conduct the NWFSC Hook-and-Line survey which was an important source of fishery independent data for cowcod.
    - Repeated (although not necessarily annual) absolute abundance estimates for cowcod from visual surveys are important to understanding the stock size and status of the stock.
    - Given the lack of biological data for cowcod, it is critical to improve and expand collection of length and age data for fishery and fishery independent data sources.
    - The majority of ages available for cowcod were read by a single age reader. As data collection increases having additional age double reads and age validation information would be beneficial.
    - Rockfish species, particularly in southern California waters, have been observed to produce multiple broods within a single year. Collecting biological data to better understand the potential fecundity for cowcod across size and is important to understanding the reproductive potential of the population.
3. Increased spatio-temporal sampling around Pt Conception to identify stock boundaries.

General recommendations for all assessments:

1. Continued and improved data collection for West Coast groundfish stocks. The NWFSC Hook-and-Line survey offers important data on species that may be infrequently encountered by the NWFSC WCGBTS.
2. Examine uncertainties around historical catch data and methods for incorporating into the assessment.
3. Explore alternate stock recruitment relationships.

Table I. Summary table of the base model results. *OFLs and ACLs prior to 2011 are ABC and OY estimates, respectively.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Estimated total catch (mt)	0.86	0.81	1.45	1.04	1.79	1.09	1.41	1.29	1.46	1.58	NA
OFL (mt)	13*	14*	13	13	11	12	67	68	70	71	
ACL (mt)	4*	4*	3	3	3	3	10	10	10	10	
1-SPR	0.011	0.010	0.017	0.011	0.019	0.011	0.014	0.012	0.014	0.014	NA
Exploitation rate (catch/ age 10+ biomass)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	NA
Age 10+ biomass (mt)	1510	1574	1639	1702	1765	1827	1888	1949	2009	2067	2125
Spawning Output	113	118	123	128	133	138	143	148	153	158	163
~95% Confidence Interval	81–145	86–151	90–156	95–161	100–166	105–172	110–177	115–181	120–186	125–191	130–195
Recruitment	157	158	160	161	162	163	164	165	166	167	168
~95% Confidence Interval	95–258	96–260	98–261	99–262	100–264	101–265	101–266	102–267	103–268	104–269	104–269
Depletion (%)	39.7	41.5	43.3	45.1	46.9	48.6	50.4	52.1	53.8	55.5	57.1
~95% Confidence Interval	26.1–53.4	27.6–55.4	29.2–57.4	30.8–59.4	32.4–61.3	34.0–63.2	35.7–65.0	37.4–66.8	39.0–68.6	40.7–70.3	42.4–71.9

1 Introduction

1.1 Basic Information

Cowcod, *Sebastes levis*, is a member of the family Scorpaenidae with a distribution from Newport, Oregon, to central Baja California, Mexico (Love et al., 2002). They are most common from Cape Mendocino (California, USA) to northern Baja California, Mexico, in depths from 50-300 m. Hess et al. (2014) used genetic and otolith microchemistry tools to study cowcod population structure from California to Oregon. Specifically, they tested the hypothesis that a phylogeographic boundary exists at Point Conception, California (34° 27′ N. latitude). Their results supported a hypothesis of two primary lineages with a geographic boundary falling slightly south of Point Conception. Both lineages co-occur in the Southern California Bight (SCB), with no clear pattern of depth stratification or spatial structure within the Bight. Within lineages, there is evidence for considerable gene flow across the Point Conception boundary. Cowcod found north of Point Conception consist primarily of a single lineage, also found in northern areas of the SCB. For management purposes, Hess et al. identified Point Conception as a reasonable proxy for a stock boundary, pending higher resolution spatial sampling of the region. This assessment assumes a single, well-mixed stock in the SCB, specifically U.S. waters between Point Conception and the U.S.-Mexico border. No assessment has been conducted of cowcod in Mexican waters (see Research and Data Needs section).

1.2 Map

Assumed stock boundaries for the 2019 cowcod assessment are shown in Figure 1.

1.3 Life History

As with other *Sebastes*, fertilization for cowcod is internal and the number of developing ova ranges from roughly 200,000 to 2,000,000 with a strong positive relationship between female body size and fecundity (Love et al. 1990, 2002). Evidence of multiple broods (up to 3 broods per female per year) was reported by Love et al. (1990), with increasing frequency of multiple brooding for larger (>55 cm) fish and also in more southern latitudes. Larval and pelagic juvenile stages of cowcod are described in detail by Moser (1996), who estimated length at parturition to be 5mm. Cowcod pelagic juveniles are quite distinctive among rockfishes and easier to visually identify due to pronounced vertical bars and yellow fins (Figure 2). CalCOFI ichthyoplankton surveys conducted since 1951 have captured larval cowcod from November through June in southern California, with peak densities observed from January-March (Moser et al. 2001). Cowcod juveniles settle roughly 100 days after parturition at total lengths of 5-6 cm (Johnson et al. 2001). The number of recruits is highly variable between years and is linked to environmental conditions in the California Current during the planktonic phase (Ralston et al. 2013, Schroeder et al. 2019). Love et al. (1990) reported that 50% of cowcod mature by 41 cm fork length (43 cm total length), but see section 2.1.3.3 for revised estimates developed for this assessment.

Cowcod adults are easily distinguished from other rockfish. They have a distinct set of characteristics such as a large head, relatively small eyes, dark vertical bars (on juveniles), and a deeply-incised dorsal fin which may have inspired the common name “roosterfish” used up until the early twentieth century (Love et al. 2002). Cowcod are one of the largest *Sebastes*, growing to fork lengths of at least 90 cm (94 cm total length). Previous studies and newly available data suggest that growth does not differ by sex (Love et al. 1990; section 2.1.3.2 of this document). Cowcod have been estimated to live at least 55 years (Butler et al. 1999).

1.4 Ecosystem Considerations

This assessment does not explicitly incorporate environmental correlations or food web interactions into the assessment model, but a brief description of trophic interactions and habitat associations is provided below.

Early life history stages of cowcod eat copepods, mysids, and amphipods, gradually progressing to fishes, squids, and octopi as adults (Love et al. 2002). Adult cowcod share a trophic position with lingcod as the top-level groundfish predators in rocky habitat. A food web effect is implicitly considered in a Pella-Tomlinson-Fletcher production function, in which adults crop down forage species that are potential competitors/predators of their own juveniles. This phenomenon, termed a "cultivation effect" was explored by Walters and Kitchell (2001) who concluded that this phenomenon is widespread (occurring in approximately one-third of the cases examined) and that it should not be ignored. Specifically, they suggested that spawning stock abundance goals should generally be no less than 50% of unfished spawning biomass. MacCall (2002) independently obtained similar results from a simple simulation of "cultivation effect" recruitment dynamics of a cowcod-like predator-prey system, where resulting predator $B_{MSY}/B_0 \approx 0.6$. Although the Pella-Tomlinson-Fletcher model is not explicitly available in the Stock Synthesis framework, the STAT explores alternative 3-parameter stock-recruitment relationships in addition to the 2-parameter Beverton-Holt model (see section 2.2.4). Finally, Baskett et al. (2006) developed a community interactions model that incorporated life history characteristics of both dwarf (e.g. Pygmy) and large, piscivorous (e.g. Yelloweye, but Cowcod would presumably be a comparable candidate) rockfish to consider rocky reef community interactions under varying exploitation histories and with variable habitat areas protected from fishing (e.g. marine reserves). They found that initial conditions and protected area size contributed to the equilibrium state, which in turn varied between states in which the overfished, piscivorous species dominates and one in which the lower trophic level species dominates.

Habitat associations for cowcod vary by size and age. Cowcod have been taken in depths between 40-491m (Love et al. 2002). Johnson et al. (2001) described the size, age (in days), and depth distribution of YOY cowcod to soft, benthic habitats in Monterey Bay, California. Due to gear restrictions, this study did not adequately cover the range of habitat associations for juveniles. Love and Yoklavich (2008) also described habitat of juvenile rockfish based on data from 303 dive surveys. Based on the combined results of these two studies, pelagic juveniles recruit to a variety of low-relief habitats between depths of 40 to 277 meters, moving to higher relief substrate as they grow. Fish 25 cm and greater have a positive and significant association with higher relief substrate, with 40-45 cm fish (sub-adults and young adults) associated strongly with complex, high-relief rock. Love and Yoklavich (2008) reported YOY cowcod (5-10 cm fish, total length) between depths of 52-277 m, while juveniles as a group (defined as fish smaller than 45cm total length) were found between depths of 52-330 m. Adult cowcod associate with high-relief, rocky outcrops, are typically sedentary and solitary, and remain within a few meters of the ocean floor (Love et al. 2002).

1.5 Fishery Information

Historically, the majority of commercial cowcod landings in California have been to ports south of Point Conception (Figure 3). Hook and line gear dominated the fishery prior to 1944, with trawl landings becoming increasingly common in Santa Barbara county and northward after introduction of the "balloon trawl" to California in 1943 (Lenarz 1987). Prior to 1968, no trawl gear could be processed south of Ventura County (Frey 1971), and once set net gear was introduced in the 1970s, net gears became the primary source of cowcod landings in southern and central California by the mid-1980s (Figure 4). Net landings declined in the 1990s due to increasing public concern regarding bycatch of marine mammals and seabirds, followed by the passage of Proposition 132. Retention of cowcod was prohibited in 2001, and since then removals have been very small by historical standards, the vast majority of which have been regulatory discards. Since 2011, a small commercial quota has been allocated to the trawl fleet operating mainly north of Point Conception as part of the trawl rationalization program.

Miller et al. (2014) described the spatial and temporal development of the California groundfish fishery. They analyzed a spatially-explicit database of landings in California dating back to 1933, finding that groundfish fishing effort has shifted from shallow, coastal areas to deeper depths and greater distances from port over time. Implications of their research to the current assessment include the possibility that commercial catch reconstructions, such as those developed by Dick et al. (2007) and Ralston et al. (2010), may overestimate the magnitude of historical cowcod catch. Sampling of commercial species compositions in Southern California began in 1983, a time when the groundfish fleet was already fishing in deeper depths. Both historical reconstructions used these data to represent species compositions of total rockfish catch during earlier periods of the fishery, and as a result may overestimate the percentage of cowcod in earlier fisheries that operated closer to port and in shallower depths. Sensitivities to the magnitude of historical catch reconstructions are presented in section 2.6.1.

The Commercial Passenger Fishing Vessel (CPFV; aka 'party' and 'charter' boat) fleet began ca. 1919 in California, although recreational fishing effort for fishes other than Tunas, other gamefish and salmon was minimal until about 1930. The CPFV fleet numbered about 200 vessels in 1939 (Croker, 1939, cited in Young, 1969). After a hiatus in most operations during WWII, the fleet increased to about 590 vessels by 1953, then declined to approximately 256 vessels around 1963. The 1970s saw an increase in rockfish-directed effort, primarily during winter months in southern California. Over the period 1980-2000, CPFVs landed about 70% of the recreational catch, with private boats landing the remaining 30% (RecFIN). The large size of cowcod made them prized by recreational fishermen, and they were often reported as the 'jackpot' (heaviest) fish on CPFV trips from 1966 until retention of cowcod was prohibited in 2001 (Bellquist and Semmens, 2016). Cowcod have always been a small fraction of the recreational catch, amounting to less than 1% of the total rockfish catch in onboard CPFV surveys from the 1960s-1980s (Miller and Gotshall, 1965; Collins and Crooke, unpublished manuscript; Ally et al. 1991). However, Bellquist and Semmes (2016) found a steady decline in the size of trophy cowcod over the period 1966-2000, consistent with high levels of exploitation (Pearson and Ralston, 1990; Ralston et al. 1990).

1.6 Summary of Management History

Commercial Fisheries
Prior to the first cowcod assessment in 1999, cowcod were managed as part of the Pacific Fishery Management Council's (PFMC) "remaining rockfish" complex. The Acceptable Biological Catch (ABC) for remaining rockfish in the combined Conception, Monterey, and Eureka areas was initially 9500 mt, and was reduced to 7000 mt in 1994 (Rogers, 1996). Butler et al. (1999) reported an ABC of 4731 mt (OY = 2705 mt) for 1999, and that catches of cowcod were unlikely to have been affected by historical trip and monthly limits for the complex. Beginning in 2000, a cowcod ABC of 5 mt was adopted for the Conception INPFC area, which was added to an ABC of 19 mt for the Monterey area (based on average landings from 1983-1997). Catch targets and limits (OFL/ABC/ACL/ACT) since 2009 are shown in Table 1. Since 2011, a small allocation of cowcod has been retained by the rationalized trawl fishery. A database of Federal commercial fishing regulations was constructed by D. Pearson (SWFSC, retired), and is now maintained as part of the PacFIN database. A table of Federal commercial regulations affecting cowcod from January 2000 to January 2019 is provided as Appendix A.

Recreational Fisheries
Prior to 2000, cowcod were originally counted toward 20-fish, and subsequently 15-fish, bag limits for rockfish. The 15 rockfish bag limit continued through 1999. Following the first assessment, a bag limit of

1 cowcod was enacted for 2000. Since January, 2001, retention of cowcod has been prohibited for recreational anglers.

Cowcod Conservation Areas (CCA)
In 2001, two area closures ("Cowcod Conservation Areas") were implemented to reduce fishing mortality of cowcod, originally prohibiting bottom-fishing deeper than 20 fm. Effective 2019, retention of nearshore and shelf rockfish (excluding cowcod) is allowed in depths shallower than 40 fm. The larger of the two areas (CCA West) is a 4200 square mile area west of Santa Catalina and San Clemente Islands. A smaller area (CCA East) is about 40 miles offshore of San Diego, and covers about 100 square miles.

Rockfish Conservation Areas (RCA)
In 2002 the PFMC established trawl- and non-trawl area closures known as the Rockfish Conservation Areas. These closed areas are gear-specific, and have seasonally changing boundaries to help reduce fishing mortality.

1.7 Management Performance

Since 2009, total mortality of cowcod has been well below catch limits, and has not exceeded catch targets (Table 1). Total OFLs and ABCs for cowcod are derived from the stock assessment for southern California, plus the yield associated with applying the assessment MSY proxy harvest rate to the biomass estimated using a data-limited model for northern California (Table 2); see Appendix C of Dick and MacCall (2013) for details. The recreational and commercial fleets have taken roughly equal amounts south of Cape Mendocino (40 10 N lat) over the same time period, for all years combined (Table 3).

1.8 Fisheries off Mexico

An examination of the most recent (2017) Carta Nacional Pesquera revealed no mention of the genus *Sebastes*. To the STAT's knowledge, no assessment of cowcod has been attempted in waters off Mexico.

2 Assessment

2.1 Data

The STAT presented proposed analyses and data sources for the 2019 cowcod assessment during the PFMC Pre-Assessment Workshop for 2019 Groundfish Stock Assessments, hosted March 25-26, 2019, in Portland, OR. Topics addressed included progress on research priorities, data sources and types, stock structure, fleet structure, key model parameters (e.g. natural mortality), and potential challenges.

Time series of commercial and recreational removals for Southern California were distributed to GMT (M. Mandrup) and GAP (G. Richter) representatives for review on June 5, 2019. Ms. Mandrup confirmed the adequacy of the catch time series, and also provided updated regulatory histories for cowcod in recent years.

2.1.1 Fishery-Dependent Data

A complete summary of estimated cowcod removals (commercial and recreational) in the Southern California Bight, by year and data source, is provided in Table 4 and Table 5. Figure 4 shows the time series of commercial and recreational landings, 1900-2018. Data and methods used to derive these estimates are described in this section.

2.1.1.1 Commercial Landings and Discard

Commercial Landings, 1900-1968

Commercial landings of cowcod prior to 1969 were reconstructed for the 2007 cowcod assessment (Dick et al., 2007). Subsequently, Ralston et al. (2010) developed a reconstruction of commercial landings for California. Dick et al. (2009) compared the reconstructed landings used in 2007 to those of Ralston et al., noting that Ralston et al. stratified historical catch across the boundary of the Monterey and Conception INPFC areas (36° N. latitude), rather than at the assumed cowcod stock boundary (Point Conception, 34° 27′ N. latitude). For this reason, the current assessment uses the reconstruction of Dick et al. (2007). Relevant text with updated links, as well as tables and figures from the 2007 and 2009 cowcod assessments are included below for convenience.

Butler et al. (1999) developed a time series of historical landings of cowcod by the commercial fisheries (1916-1981) using a ratio estimator applied to published landings of total rockfish in California (CDF&G Fish Bulletin No. 149, 1970). Since their assessment, other sources of information have become available that provided us an opportunity to revise the historical landings. As described below, the STAT used this information to develop a ratio estimator stratified by port complex and gear group, based on the earliest available data from the SCB.

In his "Rockfish Review" (CDF&G Fish Bulletin No. 105, 1958), J.B. Phillips provided a record of total rockfish landings by region (Southern, Central, and Northern California) for the period 1916-1956 (Table 6). These data combine the genus *Sebastolobus* (thornyheads) with *Sebastes*, and include rockfish caught in foreign waters (Mexico) but landed at U.S. ports. The regional data show that the relative proportion of California's commercial rockfish landed in each area has changed dramatically over time (Figure 6). This result prompted the STAT to develop a ratio estimator that tracks rockfish landings in the SCB rather than statewide rockfish landings.

The NMFS SWFSC Environmental Research Division (ERD) currently hosts a data server (ERDDAP; https://coastwatch.pfeg.noaa.gov/erddap/index.html) with commercial landings originally published in the CDF&G Fish Bulletin series (Dataset ID = "erdCAMarCatSY"). Similar to the data from Fish Bulletin No. 105, rockfish landings in this dataset include thornyheads (up to 1977); however, the ERDDAP data exclude fish caught in foreign waters. The STAT queried ERDDAP using the R library "rerddap" to obtain total rockfish landings by region for the period 1928-1968 (Table 6). The 6 geographic regions in ERDDAP are San Diego (San Diego County), Los Angeles (Los Angeles and Orange Counties), Santa Barbara (San Luis Obispo Santa Barbara, and Ventura Counties), Monterey (Santa Cruz and Monterey Counties), San Francisco (Sonoma, Marin, San Mateo and San Francisco Counties, plus San Francisco Bay), and Eureka (Del Norte, Humboldt and Mendocino Counties). The "Southern" area described by Phillips (CDF&G Fish Bulletin No. 105, 1958) is spatially equivalent to the San Diego, Los Angeles, and Santa Barbara regions in ERDDAP. The "Central" area is spatially equivalent to ERDDAP's Monterey and San Francisco areas, and the "Northern" area is equivalent to the ERDDAP's Eureka region. When the ERDDAP data from Southern California are spatially aggregated to mimic the Southern rockfish landings in Fish Bulletin No. 105, the ERDDAP landings are consistently smaller than the Fish Bulletin landings. This is expected, because the ERDDAP data only include fish caught in U.S. waters. To account for this difference, the STAT calculated annual estimates of foreign-caught rockfish (Table 7) as the difference between the sum of the ERDDAP landings in the San Diego, Los Angeles, and Santa Barbara regions and the "Southern" landings in Fish Bulletin No. 105. To estimate the amount of foreign-caught rockfish prior to 1928, the STAT used a ratio estimator based on the years 1928-1933. This estimate (0.74%) was applied as a correction factor to the Fish Bulletin Southern-area data for years 1916-1927.

The “Santa Barbara” region as defined in the Fish Bulletin series (and ERDDAP) includes San Luis Obispo (SLO) County, which is north of Point Conception and is therefore outside the stock boundary as defined in this assessment. Therefore, it was necessary to adjust the rockfish landings in this region to exclude catches north of Point Conception. Beginning in 1949, CDF&G’s Fish Bulletin series reported port-specific rockfish landings for the Santa Barbara region. The STAT entered these data and observed that in the mid-1950s rockfish landings in the Santa Barbara region increased dramatically due to landings at Morro Bay and Avila (Figure 7, Table 7). We subtracted the rockfish landed at these two ports to create an “adjusted Santa Barbara” region that reflects rockfish catch within the assumed stock boundary (Figure 8, Table 7). In doing so, we assume that annual rockfish landings are zero at other ports north of Point Conception but within the Santa Barbara region (e.g. San Simeon). This is unlikely to have a major effect on our results due to the relative size of landings at Morro Bay and Avila compared to other ports in the region. For the years 1928-1949, we extrapolated Morro Bay and Avila landings using a ratio estimator based on the fraction of rockfish in the Santa Barbara region landed at each port during the years 1949-1951 (Table 7). The rockfish catch in Avila was not reported in 1952-53 or 1958-61, so we calculated ratio estimates for these years using catches in proximal years (Table 7).

To extend our time series of rockfish landings in the Los Angeles, San Diego, and adjusted Santa Barbara regions back to 1916, we subtracted our estimates of foreign-caught rockfish from the total rockfish landings in the Southern area. We then used a ratio estimator based on landings from 1928-1933 to estimate the fraction of rockfish caught in each region during the period 1916-1927. For example, we divided the sum of rockfish landings in the Los Angeles region from 1928-1933 by the sum of rockfish landings in the San Diego, Los Angeles, and adjusted Santa Barbara regions during the same years. We assume that this percentage (64.6%) of rockfish caught in the Southern area and landed in the Los Angeles region is constant from 1916-1927. By the same method, ratio estimates for the San Diego and adjusted Santa Barbara regions were 33.4% and 0.97%, respectively. The final time series of historical rockfish landings by region, 1916-1968, is illustrated in Figure 8.

The final step in deriving the historical commercial landings was to determine the fraction (by weight) of the rockfish landings that was cowcod. We based our estimates on 5-year averages from the earliest years for which we have actual samples (1984-1988) in all port complexes (Table 8). Gear types were chosen to be consistent with the historical fisheries. Hook & line was the dominant gear group for rockfish prior to 1944 (CDF&G Fish Bulletin No. 126, 1964), and prior to 1968 it was illegal to process a trawl net south of Ventura County (Frey, 1971). Therefore, we estimated the percentage of rockfish that was cowcod in the Los Angeles and San Diego regions from their respective hook and line fisheries. In Santa Barbara the trawl fishery developed in the mid-1940s, so we based our estimates on the combination of line and trawl gears beginning in 1944, and on the hook and line fishery for years prior to 1944. The annual fraction of cowcod in rockfish landings was variable, but without trend, in the San Diego hook and line fishery, whereas the fraction in the Los Angeles and Santa Barbara fisheries showed steep declines during the 1980s (Figure 9).

The 1984-88 ratio estimate of the fraction of cowcod in the Los Angeles hook & line fishery is large relative to other fisheries and relative to subsequent years in the same fishery. Most of the strata were well-sampled during this period (Table 9), but it is unknown whether estimates based on these five years are representative of previous years.

Estimated commercial catches of cowcod from Ralston et al. (2010) are slightly larger than those reported by Dick et al. (2007). This is not unexpected, because the estimates in Ralston et al. represent landings in the Conception INPFC area (south of 36° N. latitude) rather than the area south of Point Conception (Figure 10). This assessment uses the reconstruction from Dick et al. (2007), as it best matches the available evidence regarding stock structure in cowcod. Final estimates of commercial landings were assumed to increase linearly from 0 mt in 1900 to the reconstructed estimate in 1916. See the "Evaluation of Uncertainty" section for effects of alternative commercial catch reconstructions on model outputs.

Commercial Landings, 1969-1983

In September 2005, the California Cooperative Groundfish Survey (CCGS) incorporated newly acquired commercial landings statistics from 1969-77 into the CALCOM database. The data consisted of landing receipts ("fish tickets"), including mixed species categories for rockfish. In order to assign landings to individual species, the earliest available species composition samples were applied to the fish ticket data by port, gear, and quarter. These 'ratio estimator' landings are coded (internally) as market category 977 in the CALCOM database, and are used in this and past assessments as the best available landings for the time period. See Appendix A of Dick et al. 2007 and Pearson et al. (2008; pp. 8 and 15-16) for further details.

Commercial port samples for the Santa Barbara, Los Angeles, and San Diego port complexes are not available prior to 1984, so landings estimates for Southern California from 1969-1983 are based on the same ratio estimator approach, with species composition derived from data collected in 1984-86. These estimates also corrected for a re-definition of market category 265 ("yelloweye rockfish") around 1981-82, as described in Appendix A of Dick et al. 2007 and Pearson et al. 2008.

Commercial Landings, 1984-2000

Commercial landings estimates for California are derived from two primary data sources: total landed pounds reported on landing receipts ("fish tickets") and samples of species compositions (by weight) within landed strata. Landing receipts from commercial vessels are submitted to CDFW, while sampling of species compositions and biological information has been conducted by the California Cooperative Groundfish Survey (CCGS) since 1978. Biological sampling includes data such as length, sex, maturity, and age (from otolith collections). Species composition and biological samples that are collected by port samplers are maintained in the CALCOM database (recently relocated to the PSMFC).

As described by Pearson et al. (2008), commercial fish are sorted into two types of market categories: single species and group categories. As of 2008, there were 421 defined market categories in California. Historically, single species categories such as the "cowcod" market category (245) often contained other species (Table 10). For rockfish in general, the majority of historical landings have been in group market categories (Pearson et al. 2008). This was also true during the periods of highest exploitation rates for cowcod as well, when less than 1/3 of landed cowcod were sorted into the "cowcod" market category (245) over the period 1984-2000 (Table 11, Figure 11). In more recent years, small amounts (<3 mt) of cowcod have been landed almost entirely in the cowcod market category (245), primarily by the trawl fleet north of Point Conception (CALCOM, 2019).

The number of samples per stratum for species composition data has declined over time due to a proliferation of strata, in part due to an increase in the number of market categories in which fish are landed (Pearson et al. 2008). Species composition samples collected by the CCGS are used to "expand" landings (in weight) by year, quarter, port complex, gear group, market category, and disposition (landed live or dead) to species-level landings per stratum. The "expansion" process is described by Pearson et al. (2008). Due to the highly stratified sampling design, a large number of landed strata remain unsampled, and data gaps are filled through a system of 'borrowing' rules. Limitations in funding, along with the proliferation of strata over time, have resulted in a very low average number of samples per stratum in recent years. For species that are rarely encountered or retained, such as cowcod, this may result in highly imprecise estimates of removals.

Commercial Discard, 1900 – 2000

Discards in years prior to 2001 are assumed to be zero in the commercial fleet. Discard was likely to be very small relative to retained catch, as cowcod was a highly desirable species. Sensitivity analyses of the base model to uncertainty in landings (see Section 2.6) span a range of removals that far exceed potential differences associated with commercial discard.

Commercial Landings and Discard, 2001-2018

The West Coast Groundfish Observer Program (WCGOP) prepares the Groundfish Expanded Mortality Multiyear ("GEMM") Report, which includes total estimated mortality of cowcod (landings plus discard with discard mortality rates applied) for the years 2002 to 2017. Total mortality for 2001 is assumed equal to the 2002 estimate from WCGOP (2.7 mt), and since no estimate is yet available for 2018, an estimate of 1 mt was proposed by the STAT and was considered reasonable by the GMT representative.

Quantifying Uncertainty in Commercial Landings

Recent research at the SWFSC (Grunloh et al., in prep.) has focused on a model-based, Bayesian estimator for species compositions. Predicted compositions are combined with landing receipt data (assumed to be a census) to estimate catch for sampled and unsampled strata, along with uncertainty estimates. The goal of this research is to improve estimates of landed catch in sparsely-sampled fisheries, and to quantify uncertainty in landed catch. Preliminary results, presented during a methodological review sponsored by the PFMC in 2018, suggested that CVs of statewide landings range from 10% to 50% for the rockfish species that made up 90% of the commercial catch in California over the period 1984-1990 (Table 12).Species that were less frequently sampled in California, such as Cowcod, Pacific Ocean Perch, and Bronzespotted rockfish, had annual CVs for statewide landings in the range of 40% to 80%. As expected, finer levels of stratification (e.g. landings by gear group) result in less precise estimates (Table 13).

Commercial length composition data

Catch-weighted length compositions from the commercial fisheries were obtained from CALCOM (Table 14). The net fisheries had the largest sample size and appeared to select fish between 34 and 94 cm fork length (Table 15, Figure 12). Hook-and-line gear appeared to capture a similar range of sizes. Compositions aggregated across gears (to increase sample sizes) varied considerably among years and showed no clear modal progression in well-sampled years (Figure 13). Due to inconsistencies in the commercial length comp data, previous assessment authors (Piner et al. 2005 and Dick et al. 2007, 2009) fixed length at 50% selectivity for the commercial fishery equal to that of the maturity ogive. Sensitivity of the base model to this assumption is explored in Section 2.6.

Commercial age composition data

Butler et al. (1999) aged 129 cowcod sampled from the commercial fishery from 1982-1986. Two of these ages did not have corresponding length measurements and were excluded from analyses in this assessment (Table 16). A small quota of cowcod was allocated to the trawl fleet beginning in 2011, and almost 200 otoliths have been collected since 2012 (Table 17). These otoliths were not aged due to time constraints.

2.1.1.2 Recreational Landings and Discard

Recreational Landings, 1928-1980

The estimates of recreational landings from Ralston et al. (2010) were used in this assessment without modification. Ralston et al. partitioned estimates of total rockfish catch to species using CDFW block-specific species composition data and average weight data from onboard CPFV sampling programs conducted in the SCB during the 1970s and 1980s. Similar to the commercial catch reconstructions, the recreational composition data mainly reflect fishing practices (e.g. distance from shore, species targeting) in the mid-to-late 1970s, and may not represent catch composition or average weights in earlier years.

Based on a sample of over 2000 CPFV trips by onboard observers in southern California from 1985-1987, Ally et al. (1991) did not observe any released cowcod. This is consistent with a highly-prized sport fish, and no adjustments were made to the Ralston et al. reconstruction to account for discarded catch.

Recreational Landings, 1981-2004

The Marine Recreational Fisheries Statistics Survey (MRFSS) estimated recreational catch in California from 1980-2003. Ralston et al. (2010) discussed inconsistencies in the estimates for 1980, and presented alternative estimates. Per their recommendation we use the revised estimate for 1980. Beginning in 1981, recreational landings (and angler-reported dead discards) in the current assessment are based a query of MRFSS estimates, available from RecFIN (J. Edwards, PSMFC, pers. comm.). Specifically, missing removals were taken to be the combined weight (mt) of catch types A (sampler-examined catch) and B1 (unobserved dead fish).

Occasionally in the MRFSS data, catch in numbers were reported for a stratum but no average weight was estimated. These strata have estimates of catch in numbers, but no corresponding catch in weight. Estimates of catch in weight were obtained by borrowing average weight information from adjacent years. Also, years with missing data (e.g. interruptions in sampling due to lack of funding) were estimated using linear interpolation. Linear interpolation for years 1989-92 were based on 2-year averages for 1987-88 and 1993-94.

Retention of cowcod was prohibited for recreational anglers beginning in 2001. Mortality estimates after 2000 are very small by historical standards, but also erratic and highly imprecise. MRFSS estimates of removals in 2001 were set equal to 2002, and catch in weight for 2003 was estimated as the reported catch in numbers for 2003 times the average weight of cowcod in 2002. CDFW transitioned to a new survey (CRFS) in 2004. CRFS estimates of recreational catch from 2004 are not currently available on the RecFIN website due to pending revisions. The current assessment uses the same estimated catch for 2004 that was reported by Dick and MacCall (2013).

Recreational Landings, 2005-2018

Mortality estimates for the period 2005-2018 were queried from the RecFIN website (www.recfin.org). Reported estimates are for southern California, all modes, and filtered to exclude fish caught in Mexican waters. Total recreational mortality estimates provided to RecFIN are also adjusted using species- and depth-specific discard mortality rates.

Recreational length composition data

Length data from the recreational fishery are sparse, with only 262 lengths available from RecFIN for the MRFSS survey period (1980-2003) in southern California (125 lengths in northern California). Some reported lengths prior to 1993 may be converted estimates from weight measurements, further reducing the sample sizes. A query of biological data from the CRFS survey data on RecFIN (2004-2018) generated 143 lengths over all years for southern California (CRFS districts 1 & 2), and only 21 lengths for northern California.

The best available length composition data for cowcod are from onboard CPFV observers in the mid-1970s (Table 18; Collins and Crooke, unpublished manuscript). These data consist of about 300 cowcod lengths per year from 1975-1977, with an additional ~100 fish from 1974 and 1978 (combined). Additional onboard observer data collected from 1986-1989 contained 183 cowcod from 89 trips (Ally et al. 1991). The 1980s composition data were extremely variable among years (Figure 14) and were not used in the final model.

Recreational age composition data

Butler et al. (1999) aged 131 otoliths collected from the recreational fishery between 1975 and 1981. It's likely that the majority of these structures were collected by the onboard observer program described by Collins and Crooke (unpublished manuscript). After excluding fish with no length information, 129 age/length combinations remained, although 3 of the years (1979-1981) had a total of 4 fish (Table 16).

2.1.2 Fishery-Independent Data

2.1.2.1 NWFSC West Coast Groundfish Bottom Trawl (WCGBT) Survey

For the 2013 cowcod assessment, Dick and MacCall developed an index of small (<1 kg) cowcod abundance using 2003-2012 data from the WCGBT survey. The population dynamics model for that assessment tracked mature adult biomass with an implicit knife-edge selectivity curve. Since the WCGBT survey captured mainly small cowcod, the authors lagged the index by 4 years (the average age of small fish captured by the survey). The binomial index was considered proportional to adult abundance 4 years earlier (1999-2008).

For the current assessment, the STAT downloaded WCGBT Survey data (2003-2018) from the NWFSC data warehouse using the "nwfscSurvey" R library. Specifically, the "PullCatch.fn" and "PullBio.fn" functions were used to obtain catch by haul and biological data for cowcod. The catch query produced 10365 tows, 4731 of which were south of Cape Mendocino and 1863 of which were south of Point Conception. Cowcod are a relatively rare component of the survey catch, with a total of 300 positive tows coastwide (2.9% of all tows), 291 of which were south of Cape Mendocino. South of Point Conception, 133 of tows were positive for cowcod, making up 7.1% of all tows in the Southern California Bight and reflecting their more southerly distribution (Table 19).

As noted by Dick and MacCall (2013), the size and age distribution of cowcod in the WCGBT Survey catch is made up primarily of smaller fish, with 243 (94%) of the southern California cowcod having lengths <50 cm and a similar distribution in northern California (Table 20, Figure 15). Otoliths from the trawl survey were read by SWFSC personnel (D. Pearson and S. Beyer), with the large majority of fish being aged at less than 10 years old, i.e. primarily juveniles (Table 21, Figure 16). Length and age data collected by the NWFSC WCGBT Survey complement the range of sizes captured by the NWFSC hook-and-line survey. Together, they provide important information about growth for cowcod (see Section 2.1.3.2).

Rather than using time lags to match the abundance of juveniles to mature biomass (as was done in 2013) the age-structured model (Stock Synthesis) can explicitly define the vulnerable portion of the population as juveniles, fitting to the observed size and age composition data as well as to the time series of relative abundance. The STAT considered four alternative methods to develop an index of juvenile (<50 cm) abundance:

1. A design-based index
2. A non-spatial run using VAST
3. Another VAST run that estimates spatial autocorrelation
4. A binomial GLM with year and depth effects

Methods 1-3 use CPUE (number of <50 cm fish per square kilometer) as a response variable, while method 4 uses presence/absence of <50 cm fish per tow. All four methods were applied to tows south of 34.5° North latitude (the closest available stratification to Point Conception).

Design-based index
A large fraction of the WCGBT Survey tows occur outside of typical depths for juvenile cowcod. The design-based index was stratified by three depth strata (55-155, 155-250, and 250-350 meters) which included 132 of the 133 positive tows in southern California, and a total of 840 tows (16% positive) from 2003-2018. Total tows and number of positive tows by year and depth stratum are shown in Table 22. The function "Biomass.fn" in the R package "nwfscSurvey" was used expand catch rates by stratum area. The usual response variable ('cpue_kg_km2') was replaced with numbers of <50 cm fish per square km. The majority of juveniles were found in the shallow and intermediate depth ranges, and the aggregate index is variable with highest mean abundances in 2010, 2012, and 2014 (Figure 17).

VAST indices
Spatial and non-spatial indices were developed using the complete data set for southern California. Direct comparisons between VAST outputs and the design-based and binomial GLM methods are therefore difficult. Constraining the VAST data set to depths between 55 and 350 meters would likely introduce artifacts in the spatial model, so a design-based index was fit to the complete data set for comparison. A non-spatial version of VAST was found to exactly replicate the annual arithmetic mean, as is expected for a model without other covariates. Turning on the spatial autocorrelation feature resulted in slightly higher estimates for the early years of the index, but a lower estimate for 2014. A comparison of both VAST runs to the arithmetic mean and design-based index showed similar patterns, including high inter-annual variability (Figure 18). The STAT recommends further research into the possibility of developing an index for cowcod using VAST.

Binomial GLM
Given the large amount of interannual variability, the STAT chose to develop an index using a binomial GLM. This approach was used in the 2013 assessment and produces a similar trend (Figure 19). The design-based index generates a high estimate in 2014 based on a single tow that captured 22 juvenile cowcod in the 250-350m depth stratum. The majority of hauls catch 1 or 2 cowcod, and a binomial model produces a less variable index that matches the general low-high-low pattern abundance shared across all the standardization models. Variable selection for year and depth effects in the binomial model selected only depth effects for this model based on AIC, but the year effect was retained for purposes of generating the index (Table 23). The index and associated precision estimates are provided as Table 24.

2.1.2.2 Sanitation District Surveys

Authors of the first cowcod assessment (Butler et al., 1999) developed an index using data from the Orange County and Los Angeles County Sanitation Districts. This index was deleted from subsequent assessments (Piner et al., 2005; Dick et al. 2007, 2009) due to an apparent lack of new information. Research recommendations from the 2009 assessment identified the sanitation district index and other fishery-independent indices as potential indicators of stock recovery, given that the closure of the fishery had eliminated fishery-dependent sources of information. The Sanitation District trawl surveys were re-introduced by Dick and MacCall (2013) in view of more recent data indicating an increase in cowcod abundance, and are updated here with the most recent information available.

Orange County Sanitation District Trawl Survey

The Orange County Sanitation District conducts benthic trawl surveys at fixed stations on the shelf roughly between the cities of Newport Beach and Seal Beach, CA (Figure 20). Four stations have been surveyed every year, and one station has been sampled in all years except one. Four stations were sampled for 28 or more consecutive years, but were either started or discontinued in the middle of the time series. In 2011, 6 new stations were added, with an additional 3 in 2012. Four stations were sampled for 3 years or less. Sampling was conducted on a quarterly basis from 1970 through 1984, but subsequently reallocated to quarters 1 and 3, with twice the number of hauls per quarter.

Stations T15-T25, TBC, and TC, were excluded from our analysis because they were occupied in fewer than four years. Data from quarter 2 were removed, because total sampling effort was reallocated to quarters 1 & 3 beginning in 1986. Since peak parturition for cowcod in Southern California occurs in January (Love et al., 1990) and is followed by a pelagic juvenile stage lasting several months, it is unlikely that cowcod observed in 1st quarter hauls represent production from that year. Therefore, data from the 1st quarter of each year were reassigned to the 4th quarter of the previous year. In the 2013 assessment, fourth quarter observations were removed from the O.C. data, which was inconsistent with the treatment of the Los Angeles County Sanitation District data. In the 2019 assessment, data from quarter 1 are combined with fourth quarter data from the previous year, resulting in slightly larger sample sizes prior to 1985. The re-coding of the year effect reduced sample sizes for the first year and the last year, and data from these two “shift-years” (1969 and 2018) were not included in the final analysis.

The final data set from the Orange County Sanitation District includes 938 hauls conducted at 8 stations over 48 years, with 80 cowcod observed in 43 positive hauls (4.6% positive; Table 25). Average size of cowcod caught in the OCSD trawls was 13 cm, consistent with an advanced stage young-of-the-year and 1-year-olds (Figure 21).

Los Angeles County Sanitation District Trawl Survey

The Los Angeles County Sanitation District has sampled 3 depths (23m, 61m, and 137m) along four cross-shelf transects since 1972 (Figure 20). In 1991, a fourth station was added to each transect at 305m. Quarterly trawl data were obtained from LACSD. As described above for the Orange County data, samples from quarter 2 were removed and samples from quarter 1 were combined with quarter 4 samples in the previous year. Average size of cowcod in the selected hauls was 13 cm, similar to the Orange County data. Piner et al. (2005) described the survey gear specifications as “otter trawls with a 7.6 m headrope with a 1.25-1.3cm cod end mesh. Trawl speed was 1.5-2.5 knots and durations were ~10min.”

The final data set from the Los Angeles County Sanitation District consisted of 958 hauls conducted at 8 stations (stations T0-61, T0-137, T1-61, T1-137, T4-61, T4-137, T5-61, and T5-137). A total of 141 cowcod were observed in 96 positive hauls (10% positive; Table 26). All stations were sampled annually, excluding 1978 and 2003. A single haul was completed at each station in almost every year, with three exceptions (station T1-61 in 1975 and 1976, and station T5-61 in 1975). The lack of replication within quarter precludes testing for differences in trends among stations.

Combined LA/OC Sanitation District Trawl Survey Index
The proportion of hauls that encountered cowcod in the two surveys shows a similar pattern over time, with a lower overall fraction positive and earlier decline in the Orange County data (Figure 22).

As noted for the CalCOFI survey in previous assessments, the Sanitation District data are imprecise for any given year, but appear to track long-term trends. The absence of cowcod in some years also presents a problem for analysis using binomial models. For these reasons, we binned the data into eight, roughly 5-year time blocks: 1970-75, 1976-80, 1981-85, 1986-90, 1991-95, 1996-2000, 2001-05, 2006-10, 2011-15, 2016-2018 (note 3-year terminal block).

We fit a binomial GLM to the combined data set, with block-year, station, and quarter as factors. Analysis of deviance and stepwise AIC model selection supported the inclusion of all variables in the final model, and excluded two-way interaction terms between block-year, site, and quarter (Table 27). The final index was estimated from the back-transformed year coefficients of the binomial GLM. The average of the coefficients for each covariate were included in the back-transformation to scale the index to an 'average' proportion positive across the factor levels for station and quarter (i.e. a "least-squares mean" estimate). The GLM index (Table 28), which accounts for differences among stations and quarters, shows a slightly faster decline between the first two block-years, and a less rapid increase after block-year 1993 (Figure 23). Given the limited spatial coverage relative to other surveys, the STAT explores including parameters for added variance in the assessment model.

2.1.2.3 NWFSC Hook-and-Line Survey

Since 2004, the NWFSC has conducted an annual hook-and-line survey targeting shelf rockfish at fixed stations ('sites') in the Southern California Bight (Figure 24). During each site visit, three deckhands simultaneously deploy 5-hook sampling rigs (this is referred to as a single 'drop') for a maximum of 5 minutes per line, but individual lines may be retrieved sooner at the angler's discretion (e.g. to avoid losing fish). Five drops are attempted at each site for a maximum possible catch of 75 fish per site per year (3 anglers × 5 hooks × 5 drops). Further details regarding the sampling frame, site selection, and survey methodology are described by Harms et al. (2008).

Similar to the 2013 assessment, sites considered for an abundance index were limited to those that have caught at least 1 cowcod over the period 2004-2018 (solid circles in Figure 24). From 2004 through 2013, sampling was conducted only outside the Cowcod Conservation Areas. Beginning in 2014, 40 sites inside the CCAs were sampled, and roughly another 40 sites have been added in subsequent years inside the CCAs. The survey currently has 201 sites (79 inside and 122 outside the CCAs) and at least one cowcod has been caught at 94 sites to date (46 inside, and 48 outside). Sampling effort over time and across all sites that caught at least one cowcod was close to the target, averaging 68 hooks per site (Table 29, Table 30) and a slightly lower average in 2004 (~50 hooks), the first year of the survey.

The STAT initially explored alternative time series of relative abundance for the 2019 cowcod assessment, considering alternative response variables, probability distributions, and design matrices:

1. Catch in weight (continuous response) per drop, adjusted for the number of anglers fishing
2. Catch in numbers (integer response) per drop, adjusted for the number of anglers fishing
3. Presence/absence (binary response, i.e. presence/absence of cowcod per hook)

Preliminary analyses showed that trends in the annual proportion of positive hooks were very similar to trends in catch rate (number of cowcod per angler drop; Figure 25, upper and middle panels). The similarity is due to the fact that roughly 89% of positive angler drops catch only one cowcod. The maximum number of cowcod caught by a single angler on a drop was 4 (given 5 hooks per line), which occurred only twice during 12476 angler drops over the period 2004-2018 at the 94 ‘positive’ sites. The time series of catch rate in biomass (kg cowcod per angler drop) was similar to the other two response types, except for a larger difference between areas (Figure 25, bottom panel). This is due to a difference in mean weight per fish inside the CCAs (Figure 26).

Following consultation with NWFSC staff (J. Harms and J. Wallace) who work regularly with the hook-and-line survey data and have more thoroughly investigated indices of abundance (Harms et al. 2010), it was agreed that the traditional, hook-level presence/absence approach would be used pending further research into alternative standardization methods. Two indices were provided to the STAT (J. Wallace, NWFSC, pers. comm.) for the pre-STAR panel draft to describe changes in cowcod abundance outside the CCA (2004-2018) and inside the CCA (2014-2018).

The pre-STAR panel cowcod indices of abundance were based on numbers of fish provided by the Northwest Fisheries Science Center’s Hook and Line survey in the Southern California Bight. Both of the final yearly indices were averaged over all vessels and sites and created following the methods put forth in Harms et al. (2010) after those methods were updated to create models with more parsimony and selected based on the AIC criterion. Note that crew staff were nested within vessels, which led to the exclusion of crew effects from the final models. Two vessels were employed for the survey in 2004-12 and three vessels in 2013-18.

The “outside CCA” index (Figure 27, Figure 28) used survey data from 2004-2018, and considered the following variables in the binomial GLM with logit link:

NumCow ~ Year + Vessel + SiteName + DropNum + HookNum + poly(Depth,2)

Where poly(…, X) identifies the Xth degree polynomials for continuous variables, and a colon (‘:’) represents an interaction term. Year, vessel, site name, drop number, and hook number are treated as categorical covariates in the linear predictor.

The pre-STAR panel “inside CCA” index (Figure 29, Figure 30) was based on a separate (independent) binomial GLM, with a covariate structure identical to “outside” index of abundance. The posterior median index values and their associated posterior log-SDs were from converged, 2.5 million draw MCMC runs. MCMC diagnostics provided to the STAT included autocorrelation plots and trace plots for the year effects. The simulated draws had little to no correlation at lags greater than 1, and showed no signs of poor mixing based on visual examination of the trace plots.

During the STAR panel review, the Hook-and-Line data were re-analyzed to create a single binomial GLM index using data inside and outside the CCAs (see Request 8a, section 2.4). The final index (Table 31) includes year, site, and hook number covariates. Selectivity for the combined-area index is informed by survey composition data from 2014-2018, and survey composition data from 2004-2013 is fit as a ‘dummy’ fleet, i.e. not linked to the relative abundance index (labeled “early comps” in relevant figures and tables). See STAR panel request #13 in section 2.4 for details.

The Hook-and-line survey also collects biological information such as sex, size (length, weight), maturity, gonads, otoliths, and fin clips. A total of 569 cowcod lengths were available from the survey, and average length inside the CCA is larger than outside the CCA (Table 32, Figure 31). For this assessment, a total of 428 ages were read by SWFSC personnel (D. Pearson and S. Beyer) through 2017. Ages for 2018 were not completed due to time constraints (Table 33, Figure 32). See Section 2.1.3 regarding maturity and fecundity data collected by the hook-and-line survey and made available for this assessment.

2.1.2.4 California Cooperative Oceanic Fisheries Investigations (CalCOFI) Ichthyoplankton Survey

Raw CalCOFI Survey sample data for 1951-2017 were provided by A. Thompson (NMFS, SWFSC) producing data from 19997 ichthyoplankton tows, of which 252 were positive for cowcod larvae. The data were filtered (A. Thompson, pers. comm.) to include only core stations ("76.7 49", "76.7 51", "76.7 55", "76.7 60","80 51", "80 55", "80 60","81.8 46.9","83.3 40.6", "83.3 42", "83.3 51", "83.3 55", "83.3 60", "86.7 33", "86.7 35", "86.7 40", "86.7 45", "86.7 50", "86.7 55","90 28", "90 30", "90 35", "90 37", "90 45", "90 53", "93.3 26.7", "93.3 28", "93.3 30", "93.3 35", "93.3 40", "93.3 45", "93.3 50").

The bulk of positive stations are in southern California waters (63 sites in southern California vs. 25 in northern California), and the STAT limited its analysis of the CalCOFI data to the southern California region. The data set filtered to include only positive stations in southern California contained 8232 tows, of which 202 were positive observations (Figure 33). The monthly distribution of southern California CalCOFI sampling and the proportion of positive tows shows that cowcod larvae are most abundant from January through March, increasing as early as November and extending as late as June or July (Figure 34).

Seasonality was represented in the index by filtering and grouping data into the two periods of highest cowcod abundance, January-March and April-June. Stations with inconsistent sampling coverage over time (i.e. fewer than 30 years in the time series) were also excluded. The final index was based on a total of 4367 tows (152 positive) at 31 stations from January to June over the period 1951-2018 (Table 34). Sampling in recent years has been limited to April, which misses the period of highest abundance for cowcod and many other winter-spawning species. Due to high-frequency interannual variability in the proportion of positive tows (Figure 35), data were binned into 'super years' as follows: 1951-55, 1956-60, 1961-65, 1966-70, 1971-75, 1976-96 (a single estimate based on these 21 years was repeated as 4 identical points in 1979, 1984, 1989, and 1994 to account for the extended period of zeros), 1997-2001, 2002-2006, 2007-2011, 2012-2016, and 2017-2018 (2-year terminal block).

Model selection using AIC best supported a binomial GLM with super-year, 3-month period, and line-station effects (Table 35). During the STAR panel, it was noted that the number of years assigned to each super year was not consistent across the time series (see STAR panel request #14, section 2.4). The STAT agreed that this approach could underweight the period of low proportion positive tows, and adopted the recommendation from the request. The change in the index had only a minor effect on spawning output. The final 2019 CalCOFI index for cowcod is shown in Table 36.

Cowcod larvae were regularly encountered before 1983 and after 1998, but were very rare from 1983 to 1998 (Figure 35). During the past two decades there has been a clear increase in cowcod occurrences relative to the 1980s and 1990s. The long string of zero (13 sampled years) and near-zero (4 years) observations from 1975 to 1998 is difficult to treat in an assessment model. Clearly, cowcod larval production was very low during this period, indicative of a depleted spawning population. However, 1983 to 1998 was also a warm period of low oceanic productivity, which may have contributed to reduced fecundity. Variability in fecundity is a source of error that is not adequately addressed by simple sampling statistics, but may justify added variance in the assessment model.

2.1.2.5 SWFSC Submersible Survey of the Cowcod Conservation Areas

Yoklavich et al. (2007) describe a line-transect survey of cowcod abundance in 2002 conducted from a submersible inside the Cowcod Conservation Areas (CCAs). They estimated cowcod biomass inside the CCAs at 524 mt (CV=0.26). The survey area encompassed eight offshore banks having characteristics consistent with known cowcod habitat (75-300 m depth, mixed sediment and rock substrata). 94 dives were completed over 28 days, See Yoklavich et al. (2007) for additional details regarding the survey design. Yoklavich (pers. comm.) estimated the percentage of total biomass that was mature (95.5% of total biomass, or 501 mt) based on a cut-off of 40 cm. This estimate was used in the base model with a fixed selectivity curve at 40 cm.

The cowcod biomass estimate from the survey represents fish inside the CCAs (the survey area), and therefore must be expanded to represent the biomass in the entire SCB. Since the 2005 cowcod assessment, the biomass estimate has been treated as a relative index with an informative prior on the catchability coefficient (q) reflecting uncertainty in the expansion factor. Methods previously used to derive a prior for q are in Appendix IV of Piner et al. (2005). In summary, CPFV catch rates by statistical block were used as a proxy for relative density in the SCB. The density proxies for blocks inside and outside the CCA were multiplied by "habitat" area (70-300 m depth) and summed to estimate the proportion of cowcod inside vs. outside the CCAs. The results of that analysis suggested that the CCAs contained ¾ of the biomass in the SCB ($q \cong 0.75$). Piner et al. (2005) specified a normal prior on log(q) with mean -0.2863 and standard deviation of 0.5. This is correct for a lognormally distributed variable with median equal to 0.75. The pre-STAR assessment treated 0.75 as the mean of the lognormal distribution, resulting in a normal distribution for log(q) with a mean -0.41135 and standard deviation of 0.5. The change in central tendency had little effect due to the diffuse prior on q.

During the STAR panel, a revised prior for catchability of the submersible survey was developed based on biomass estimates inside and outside the CCAs from the 2012 SWFSC ROV survey (see STAR panel request #10). The STAT and STAR panel agreed that this prior was based on the best available data to describe the proportion of cowcod abundance inside the CCAs. The resulting prior was a normal distribution for log(q) with a mean equal to -0.5029 and standard deviation of 0.1475.

2.1.2.6 SWFSC Remotely Operated Vehicle (ROV) Survey of Cowcod in the Southern California Bight

The SWFSC Fishery Resource Division (FRD) conducted a survey of potential cowcod habitat between Point Conception and the U.S. – Mexico border from October through December of 2012 (Stierhoff et al. 2013). One of the primary goals of the survey was estimate absolute abundance and biomass of cowcod in 2012 to better inform population trends and scale. FRD scientists completed 167 visual transects of 500m target length over the course of 4 cruise legs using a high-definition, high-voltage ROV. The visual transects were distributed across 18 sites from 67 to 268 m depth and across a variety of seabed types following a stratified random sampling design (Figure 36). A total of 189 cowcod were observed during the survey, ranging from 8.6 cm to 78.6 cm total length. The STAT and Dr. Kevin Stierhoff (SWFSC, Chief Scientist of the ROV survey) used these data to develop a new index of 2012 absolute abundance for cowcod. Information relevant to the development of the index is included below; see Steirhoff et al. (2013) for additional details regarding survey methodology and design.

The ROV survey recorded transect-level counts and areas by depth zone (70-100m, 100-160m, 160-300m), substrate type (see Stierhoff et al. 2013 for a complete listing), and location (inside CCA, outside CCA). Total lengths (cm) were measured with the assistance of parallel reference lasers, and lengths were converted to weight using the weight-length relationship from Love et al. (1990). For purposes of developing the biomass index, seabed types were reclassified into 2 categories ('soft' and 'hard', roughly corresponding to low- and high-relief, respectively). Total survey areas [km^2] associated with each stratum were estimated using GIS software. A summary of sample sizes, transect distances, number of cowcod observed, mean densities, and total areas by stratum are provided as Table 37.

The SWFSC ROV biomass index was developed in 4 steps:

1. Estimation of average density (cowcod per km^2) by stratum
2. Multiplication of densities by total area, yielding abundance by stratum
3. Multiplication of abundance by average weights, yielding biomass by stratum
4. Summation of biomass across all strata

The ROV data set presented some challenges for estimating cowcod biomass. These include a lack of transects in one stratum (70-100m, soft substrate outside the CCAs; Table 37), requiring an approach that can impute density for unsampled strata. Due to the rarity of cowcod, the transect data have a high proportion of zeros (55% of transects observed no cowcod), and in some sampled strata no cowcod were observed in any transects. Although densities may be lower in these strata, it is unlikely that no cowcod would occur in these strata (i.e. an estimate of zero is unrealistic) and the lack of positive observations is likely due to small sample sizes. With respect to estimation of average weight (needed to convert abundance to biomass), very few fish were measured over soft substrate (n=7), and none were measured over soft substrate outside of the CCAs. This required consideration of alternative data sources to inform average weights for soft substrates, as described below.

The STAT adopted a model-based estimator for cowcod density. This approach allows for imputation of density in unsampled strata and can account for the large proportion of zeros in the data. Counts of cowcod per unit area were modeled using a negative binomial regression with a log link function. The model included categorical covariates for depth, substrate, and location (inside/outside CCAs), as well as an offset term to adjust for variation in the amount of area sampled per transect. Model selection based on AIC found that a main-effects only model was indistinguishable (i.e. AIC difference was < 2) from the ‘best’ model that included an interaction between substrate type and depth (Table 38). The STAT chose the simple, additive structure of a main effects model because of the high level of support from AIC relative to other models as well as the need to impute density for one unsampled stratum. Visual examination of simulated quantile residuals (Dunn and Smyth 1998; implemented using the R package “DHARMa”) suggested the main-effects model was able to adequately reproduce the observed data set (Figure 37, Figure 38). Final model parameters were estimated in a Bayesian framework using the R package ‘rstanarm.’ Diffuse prior distributions were used for the regression coefficients and dispersion parameter, such that posterior medians closely matched MLE estimates using the glm.nb() function in the R library MASS (Table 39). Simulating posterior draws using the Bayesian model facilitated computation of variance estimates for functions of model parameters (e.g. the sum across strata of the product of density, area, and average weight) while retaining the covariance structure of the joint posterior. Diagnostic tests did not suggest a failure to converge, indicated the Monte Carlo standard errors to be small relative to the standard errors of the marginal posterior distributions, and produced adequate effective sample sizes with little autocorrelation in posterior simulations.

Given the ontogenetic movement of cowcod from low- to high-relief substrate, it was important to consider potential data sources to inform estimates of average weight for use in biomass calculations. Length samples (n=182) were available from the ROV to estimate mean weight over hard substrate and by depth stratum, however very few size measurements were taken by the ROV survey over ‘soft’ substrate (n = 7, all depth strata combined). Data from similar ROV cruises in recent years (2007-2011; n=69) were used to augment existing length samples and to estimate average weight for hard substrate, but only 2 additional samples were available for soft substrate. To better inform average weights for the soft / low-relief (i.e. ‘trawlable’) strata, the STAT used size composition data from the NWFSC WCGBT Survey (n = 700; Table 37). Trawl observations deeper than 300m were excluded from the analysis to match the depth limits of the ROV survey. Averages weights in the trawl survey data increase with depth, and are consistent with reported sizes of juvenile and sub-adult cowcod (<40cm; <1 kg). Estimated mean weights [kg] and log-scale standard errors by depth bin and substrate type are provided in Table 40.

To compute distributions of abundance and biomass by stratum, simulated draws of mean density were multiplied by total area to estimate abundance (number of cowcod) in each stratum. These draws were then multiplied by draws from mean weight distributions (with means and variances estimated from their respective sources), which propagated uncertainty in mean weight into biomass estimates. Summation across the 12 survey strata produced estimates of total cowcod abundance and biomass in 2012 (Table 41, Table 42). Inclusion of average weight data reduced the log-scale standard error of the biomass index to 0.291, relative to the standard error of the abundance index (0.444).

2.1.3 Biological Data

Biological characteristics reported in this assessment do not take into account differences between cowcod stocks, as described by Hess et al. (2014). See Section 6 for research recommendations on this topic.

2.1.3.1 Natural Mortality

Previous assessments have compared several estimates of the natural mortality rate (M [yr^{-1}]) for cowcod. Dick et al. (2007) reported results of three methods based on information available at the time (Table 43). Two of the methods estimate total mortality (Z = M+F), namely those of Hoenig (1983) and a catch-curve assuming an age at full recruitment of 12 years. The third method (Beverton 1992) aims to estimate only natural mortality, and produces the lowest of the three estimates (M=0.045 yr^{-1}). The methods of Hoenig and Beverton rely solely on an estimate of maximum age (55 years), which remains unchanged for this assessment. However, the observed maximum age may not be representative of an unfished population because the earliest available age data are from the 1970s, a period of high exploitation rates for cowcod. The oldest fish was taken from a sample collected in 1985. Although a relatively large number of otoliths have been collected by the NWFSC surveys since 2003, the oldest observed individual was roughly 40 years old, captured by the hook-and-line survey.

There is evidence of bias between current age readers and those that contributed to the original cowcod assessment (see section 2.1.3.2). The best model to account for this bias was a linear correction assuming that current readers' ages were, on average, 91.6% of the ages estimated for the 1999 cowcod assessment. The STAT calculated bias-corrected ages using the original age data (assuming current readers are unbiased) and repeated the catch curve analysis (Figure 39). Assuming full recruitment at age 12, the slope of the catch curve changed from -0.055 (the original value) to -0.060 using the bias-corrected ages. This provides an estimate of total mortality (Z=0.06) that is within 10% of the original estimate (Z=0.055). Although the oldest fish was not included in the set of cross-read otoliths, the bias-corrected maximum age is 50.4 years (55 × 0.916).

Current best practices for U.S. West Coast stock assessments include a recommendation to estimate a prior probability distribution for M. The prior distribution is

$$M \sim Lognormal\left(\log_e\left(\frac{5.4}{Tmax}\right), 0.438\right)$$

where *Tmax* = 55 years for cowcod. A lognormal distribution with these parameters has a median of 0.098. Maximum ages of 50 and 60 years old produce median estimates of 0.108 and 0.090 yr^{-1}, respectively. Previous cowcod assessments derived a prior distribution based on Hoenig's (1983) geometric mean regression (for all groups) for total mortality (Z = M + F). Predictions of total mortality as a function of maximum age using Hoenig's method are lower than the current prior for natural mortality (Figure 40).

Based on the results of this and previous assessments, the cowcod population in the Southern California Bight experienced its highest rates of fishing mortality during the 1970s and 1980s (Butler et al. 1999; Dick et al. 2007, 2009; Dick and MacCall, 2013). Although the severity of the decline varies among assessments, this pattern of fishing mortality rates is consistent. Due to the truncation of size and age structure in heavily exploited fish populations, it is possible that the bias-corrected maximum age of roughly 50 years does not represent maximum age for an unfished cowcod population. For this reason, the STAT chose to retain the previous assessment's estimate of 55 years for maximum age (*Tmax*) to calculate the median of the prior distribution ($M = 0.098$ yr^{-1}). This may still be a conservative estimate of maximum age, given the date of capture and history of exploitation for this stock.

2.1.3.2 Growth

Cowcod are among the largest species in the genus *Sebastes* (94 cm max. length). The model used for the previous full assessment (Dick and MacCall 2013) did not explicitly account for growth. For this assessment, we revisit the relationships between weight [kg] at length [cm], and length at age [years], given the latest available data.

Weight at length

Love et al. (1990) found a roughly cubic relationship between cowcod weight [grams] and total length [cm], with parameter values a=0.01009 and b=3.09332 for the power function $W=aL^b$. They found no difference in weight at length between sexes.

The NWFSC Hook-and-Line survey has collected length and weight data for 580 cowcod caught in the SCB from 2004-2018. Lengths were measured in fork length [cm] and weights in kg. The NWFSC WCGBT Survey collects similar data, and 706 cowcod lengths and weights were available. We fit the combined data from the two surveys (natural log transformed to linearize the power function), and compared the estimated mean weight at length to the results reported by Love et al. (1990). This comparison required conversion from fork length to total length, for which we used the relationship reported by Echeverria and Lenarz (1984):

$$[\text{Total Length, mm}] = 1.055 \times [\text{Fork Length, mm}] - 3.335$$

The estimated relationship between weight and total length reported by Love et al. is very similar to the relationship derived from the NWFSC survey data (Figure 41). For this assessment, we use the values estimated from the NWFSC survey data, as additional data will become available in the future, and also because data from Love et al. (1990) are no longer available (M. Love, pers. comm.). Since the majority of length data in the current assessment were originally in units of fork length, the STAT estimated the following weight-length parameters for use in the assessment:

$$W = (9.6788 \times 10^{-6})L^{3.1462}$$

Units are kg whole weight and cm fork length, and the coefficient (a) was back-transformed and bias-corrected following Miller (1984).

Length at age

Dick et al. (2007) estimated parameters of the von Bertalanffy growth function external to the population dynamics model (L_∞ = 870 mm total length, k = 0.052 yr^{-1}, and t_0 = -1.94 years). The most recent full assessment of cowcod (Dick and MacCall, 2013) used a biomass dynamics model that did not explicitly characterize growth. For this assessment, SWFSC age readers generated over 450 new cowcod age estimates from otoliths collected by the NWFSC WCGBT and Hook-and-Line surveys.

Previous authors have reported growth as being the same for cowcod males and females (Butler et al. 1999), and this is consistent with results based on the newly available data. Fitting to the NWFSC survey data (trawl and hook-and-line), predictions of a combined-sex von Bertalanffy growth equation (L_∞ = 81.8 cm, k = 0.073 yr^{-1}, and t_0 = -2.05 yr) are nearly indistinguishable from separate fits by sex (Figure 43).

Length at age data collected for the first cowcod assessment appear to show smaller fish at age (older fish at a given size) when superimposed on against the NWFSC survey data (Figure 44). Lengths from the Butler et al. data set were converted from total length to fork length (see Dick et al. 2009 for details) prior to plotting the data. While evidence of bias between current readers (D. Pearson and S. Beyer) and readers from the first assessment partially explains the shift, other factors (e.g. differences in selectivity and/or growth) may also contribute to the differences in size at age.

Analysis of ageing error

Otoliths collected by the NWFSC surveys were read by Don Pearson (NMFS, retired) and Sabrina Beyer (UCSC / NMFS). To evaluate between-reader ageing error, 358 otoliths were aged twice based on blind reads (Figure 45). Among-reader error was also evaluated based on independent reads by D. Pearson and the consensus ages used by Butler et al. 1999. There is some evidence of bias between the ages used in previous assessments (i.e. the Butler et al. ages) and D. Pearson, with D. Pearson estimating ages that are roughly 10% younger than the consensus ages from Butler et al., on average (Figure 46).

Two ageing error matrices (Pearson vs. Beyer, and Pearson vs. consensus Butler) were estimated using the R package "nwfscAgeingError." Considering 9 candidate models, the best fit model for the Pearson/Beyer ageing error assumes a linear (but negligible) bias and curvilinear CV (Figure 47). The best fit model, also out of 9 candidate models, for the Pearson/Butler ageing error matrix assumed a linear bias of about 10% (consensus Butler ages being older than Pearson's), and a constant CV (Figure 48).

2.1.3.3 Maturity

Estimates of the proportion of mature female cowcod at length were reported by Wyllie-Echeverria (1987) and Love et al. (1990). Wyllie-Echeverria (1987) estimated length at 50% maturity (L_{MAT}) at 32 cm total length (TL), smaller than other studies and based on a small sample size (n=41). Love et al. (1990) reported L_{MAT} = 43cm TL and observed 100% maturity for females 52 cm TL and larger in their sample (n=194). The 2007 and 2009 cowcod assessments used a maturity ogive consistent with Love et al. (1990) with L_{MAT} = 43 cm TL and 99% maturity at 52 cm TL (41.1 cm and 49.6 cm fork length, respectively). Since the 2013 assessment used a biomass dynamic model with a lagged production function, the implicit maturity assumption was knife-edged at age 11 (roughly 43 cm TL based on the age-length relationship in prior assessments).

For the current assessment, Melissa Head (NWFSC, pers. comm.) determined maturity for 174 female cowcod caught by recent fishery-independent surveys (Table 44). Two types of maturity determinations were provided, 'biological maturity' and 'functional maturity.' The former category includes "juveniles exhibiting dummy runs (early vitellogenesis or yolk granules present in a small proportion of oocytes, some in early stages of cellular decay) and skip spawners (adults foregoing spawning in a given year)" (M. Head, pers. comm.), while the latter excludes such cases. Separate logistic regressions were fit to each type of maturity determination as a function of fork length (Figure 50), estimating L_{MAT} at 41.4 cm (biological maturity) and 45.6 cm (functional maturity), with slopes of -0.3452 and -0.3939, respectively.

The biological maturity determination based on the new survey data is most consistent with maturity curves from previous assessments (Figure 51). However, this determination type may overestimate the proportion of spawning females at length, given the above definition. The STAT evaluated the effect of characterizing maturity at length using either the biological or functional determination types (see Section 2.6).

The proportion of females classified as mature may be sensitive to the month of capture. Cowcod females less than 50 cm were less likely to be classified as mature when captured in June and July, relative to those captured in September and October (Table 45). Further research is needed to determine which sampling months minimize ambiguities in maturity determinations.

2.1.3.4 Fecundity

This assessment makes the assumption that fecundity is a power function of female body length, $F = aL^b$. Values for the exponent (b = 3.44) and coefficient (a = 4.79e-07) were estimated from ovaries collected by the NWFSC hook-and-line survey and analyzed by N. Kashef and D. Stafford (UCSC / NMFS SWFSC). Since the exponent of the fecundity-length relationship is greater than the exponent of the fecundity-weight relationship, weight-specific fecundity (eggs or larvae per gram female body weight) also increases with size. A meta-analysis of rockfish fecundity by Dick et al. (2017) did not include species-level parameter estimates for cowcod, as it is not affiliated with a subgenus described by Hyde et al. (2007). The hierarchical analysis by Dick et al. produced an out-sample-prediction for the *Sebastes* (genus-level) exponent that was higher ($b \cong 4$). The estimate for cowcod in the base model is based on a small sample size (n=39 fish) but the available data span a reasonable range of sizes (57-84 cm FL). The 95% asymptotic confidence interval for the exponent parameter (2.8 – 4.1) contains the genus-level point estimate reported by Dick et al. (2017).

Previous age-structured assessments for cowcod used the fecundity-length relationship reported by Love et al. (1990). Fits to the new data suggest lower average fecundity at size (Figure 52). However, the estimated exponent (b = 3.44) implies a slightly faster increase in weight-specific fecundity with size, relative to the exponent reported by Love et al. (b = 3.15).

The fecundity-length relationship in the base model is assumed to represent total annual egg production. If the estimated relationship instead describes only one of multiple broods released during the year, then the model will underestimate total egg production. More importantly, if the frequency of multiple brooding is size- or age-dependent, then reductions in spawning output due to truncation of the population's size and age structure will be underestimated.

Although most species of *Sebastes* produce a single brood, many *Sebastes* closer to the southern end of their range have long been known to produce more than one brood in a given spawning season, some as many as two to three broods (Moser 1966, Moser 1967, MacGregor 1970, Love et al. 1990). This has been observed to happen more frequently for southerly distributed species, such as cowcod, bocaccio (*S. paucispinis*), speckled (*S. ovalis*), squarespot (*S. hopkinsi*), and rosy rockfish (*S. rosaceus*), although it has been recorded, possibly with increasing frequency over time, in central California waters for species such as chilipepper (*S. goodei*) and as well (Beyer et al. 2014, Lefebvre et al. 2018). In ovaries examined macroscopically, multiple broods can be identified as those containing residual larvae and/or fertilized eggs from a primary brood together with developing oocytes from an upcoming secondary brood (Beyer et al. 2015, Lefebvre et al. 2018). Lefebvre et al. (2018) also examined ovaries from both single and multiple brooding chilipepper rockfish histologically, by evaluating when ovaries contained postovulatory follicle complexes (POFs), residual larvae or eyed larvae (primary brood) and non-atretic late developing vitellogenic stage oocytes (upcoming secondary brood).   The latter study also quantified the probability of producing a second brood in that species by size and region, clearly demonstrating that larger individuals were more likely to produce a second brood, and that the second brood was likely comparable in size to broods produced by single-brooding individuals (when accounting for individual size). Importantly, this study was dependent on obtaining specimens during the peak of the spawning season, it is currently very difficult to evaluate either macroscopically, microscopically or histologically the likelihood that a given individual is producing more than one brood outside the peak of the spawning season for that species. Collectively, these studies challenge previous classifications of all *Sebastes* as “determinate” spawners (either the “total” or “batch” variety) and identify at least some species as indeterminate spawners.

In the Levebvre et al. (2018) analysis, the probability of producing a second brood at a given size did change between regions (Southern California Bight and Central California), and the number of multiple brooders appeared to be greater in the years of that study relative to historical studies, but the data were too sparse to clearly identify environmental drivers or correlates.   However, recent laboratory studies of rosy rockfish (*S. rosaceus*) have shown that this species is capable of producing as many as three to five broods in a spawning season, and fish produced and released more broods under warmer conditions with abundant food supplies. Thus, environmental factors likely drive the frequency and number of multiple broods in wild populations, but accurately quantifying the mechanisms and conditions related to such production will require considerably more monitoring, evaluation and analysis. Such studies should be continued, given that key stock assessment metrics, such as estimates of spawning stock biomass, depend on accurate data about the species reproductive strategies and reproductive output. For example, He et al. (2015) demonstrated that if size-dependent fecundity is not specified in an assessment, but such a relationship exists in a real population, assessment models will be biased to estimating a more optimistic stock status than actually exists (He et al. 2015), a finding echoed in a meta-analysis by Barneche et al. (2018). Thus, improved data on the frequency of multiple brooding by size, region and ideally under varying environmental conditions will be critical both to better parameterization of reproductive output, as well as more accurate interpretation of relative abundance time series that are directly linked to reproductive output, particularly the CalCOFI larval abundance time series.

Sensitivity analyses to alternative models for annual fecundity are presented in section 2.6.

2.1.4 Data Sets Considered But Not Used in Assessment

2.1.4.1 SWFSC Pelagic Juvenile Rockfish Index

Since 1983, the SWFSC has conducted an annual midwater trawl survey for pelagic juvenile rockfish and other groundfish in the Central California region of the California Current (Ralston et al. 2013 and references therein). Due to concerns about mesoscale abundance patterns and a need for greater spatial representation in the data, including some apparent strong differences in spatial distribution patterns in the early 2000s (Hastie and Ralston 2007, Ralston and Stewart 2013), this survey was expanded to a broader spatial scale in the 2001-2004 period, and since 2004 most years have coastwide data from a combination of SWFSC, NWFSC and Cooperative Research surveys (see Field et al. 2017 for more complete details regarding coastwide pre-recruit data, and Sakuma et al. 2016, Friedman et al. 2018 for additional details and alternative applications of survey data).   Pre-recruit indices have been incorporated into several stock assessments, including the most recent assessments for chilipepper, bocaccio, shortbelly, widow, canary and blue/deacon rockfish. However, without exception these data have only been used in assessments that estimate recruitment variability, as they are considered to represent the setting of recruitment following the impacts of density-independent environmental influences on year class strength. Consequently, they would not be an appropriate index to incorporate into a model with deterministic recruitment. Despite this, they are generally consistent with population increases, although the trends seen in cowcod are also consistent with those seen in a broader assemblage of pelagic juvenile rockfish, for which a considerable fraction of the variability in pelagic juvenile abundance appears to be oceanographic factors associated with transport, and more specifically the source waters, of the California Current that are presumed to be associated with greater density- independent survival of pelagic larvae (Ralston et al. 2013, Schroeder et al. 2019).

Cowcod are a relatively infrequently encountered species in the survey, particularly in the longer-term (core) area data, although they are more frequently encountered in the Southern California Bight, and have been more frequently encountered in recent years relative to the early years of this survey. Thus, we provide a short summary of available data, and the resulting trend from an index developed from these data. Table 46 shows the total sample size (number of trawls) available for analysis since 1983, with the number of those trawls that had one or more juvenile cowcod and the percent frequency of occurrence, for the Southern California Bight (south of Point Conception, the stock assessment area for this assessment) and the central California region (between Point Conception and Cape Mendocino). Cowcod have never been encountered in the nearly 1000 trawls conducted north of Mendocino in this survey. Figure 53 shows the percent frequency occurrence data graphically, indicating that the percent frequency occurrence of pelagic juvenile cowcod in central California was higher in the mid- to late-1980s relative to the early 1980s, very low during most of the 1990s, and has been increasing sharply in most years since 2009. Similarly, in the Southern California Bight, where the percent frequency of occurrence tends to be greater, there has been an ongoing increase in the percent frequency of occurrence since survey data began to be collected in that region (2004). Figure 54 shows the relative abundance indices generated when year effects are estimated in a delta-GLM model, noting that most of the covariates used in the typical models (Julian day bin, latitude and depth bins) had to be dropped in the southern California model due to the sparseness of the data, and even then only seven of the 14 years in which data were collected had sufficient data (minimum of two positive tows) to estimate a year effect. A "coastwide" model, which included all of the data collected south of Cape Mendocino was able to estimate year effects for ten of the 15 years of coastwide data collection (recall that one of those years did not include data south of Point Conception), and include most of the covariates, and generally led to similar results and patterns as inferred by the percentage frequency occurrence data alone. Both models had very high amounts of error, which is consistent with the high degree of sparseness in the data.

2.1.4.2 Historical Groundfish Trawl Surveys

Cowcod were described as rare in the AFSC Triennial Shelf Trawl Survey, with density estimates below 0.5 fish per hectare in all years and spatial strata (Butler et al. 1999). Moreover, that survey did not sample waters south of Point Conception. 16 otoliths from the 2004 triennial Shelf survey were aged by D. Pearson (SWFSC, retired) in 2013. Average length was 30 cm, and average age was 4 years. The slope trawl survey in 2002 collected otoliths from 15 cowcod with an average length of 30 cm. These fish were aged by Don Pearson in 2013 and had an average age of 4 years.

2.1.4.3 Central California Onboard CPFV Observer Program, 1987-1998

The STAT considered data sources that might inform trends in abundance for the area north of Point Conception. CDFW conducted onboard sampling of CPFVs in Central California from 1987-1998, but observed only 77 cowcod over the 11-year period. A relational database was constructed to facilitate analysis of these data and is documented by Monk et al. (2016). As cowcod were infrequently encountered, and this survey too was limited to waters north of Point Conception, it was not utilized in this model.

2.1.4.4 CDFW Onboard CPFV Observer Program, 1999-2018

Monk et al. (2014) constructed and describe a relational database of onboard CPFV sampling data conducted by CDFW from 1999 – 2011. This data set includes retained and discarded catch for a subset of anglers by species, fishing stop (“drift”), fishing time (effort), lengths of discarded fish, and GPS coordinates. This database has been updated through 2018, and was queried for drifts encountering cowcod. In northern CA, 168 cowcod were caught on 138 drifts out of 43543 total (0.32%). In northern California, 27 cowcod were caught on 23 drifts out of 24307 total (0.11%). Low catch rates are due to depth restrictions designed in part to reduce bycatch of cowcod. This data source should be monitored for trends in CPUE if the fishery is expanded into deeper depths that constitute cowcod habitat.

2.2 Model

2.2.1 History of Modeling Approaches Used for this Stock

The first stock assessment of cowcod (Butler et al. 1999) used Schnute’s (1985) generalization of Deriso’s (1980) delay-difference model. The assessment was tuned to three indices of abundance (the CalCOFI ichthyoplankton survey, CPUE from CPFV logbook data, and demersal trawl surveys conducted by the Los Angeles and Orange County Sanitation Districts). Butler et al. estimated spawning biomass in 1998 to be about 7% of the unfished level.

The next assessment (Piner et al., 2005) was an age-structured production model coded in Stock Synthesis (Methot and Wetzel, 2013). The assessment considered updated versions of the three indices used in the first assessment, as well as RecFIN CPUE indices and a visual transect survey of the Cowcod Conservation Areas. The CalCOFI, RecFIN, and Sanitation District indices were excluded from the final analysis, as were all length composition data. The number of zero observations in the indices presented a problem for the assumed lognormal error structure, and the composition data were highly variable and poorly fit by the model. The final model was tuned to the CPFV logbook index and the visual transect survey, estimating unfished recruitment given deterministic recruitment and fixed values of steepness and natural mortality.

In 2007, Dick et al. used a similar age-structured model, and fit it to a slightly revised CPFV logbook index. Commercial and recreational landings were modeled as separate fleets and selectivity curves were updated, as were the growth curve, spatial stratification of the CPFV logbook index, and historical commercial catch estimates. Dick et al. (2009) prepared an update to the 2007 assessment, which included a revision to the historical (1928-1980) recreational catch time series based on California’s catch reconstruction effort (Ralston et al. 2010). The 2007 and 2009 models included no data to inform trends in biomass after the 2002 visual survey (Yoklavich et al. 2007), and the 2009 assessment noted that the rate of stock recovery was entirely dependent which data sets were included (CPFV CPUE and/or the SWFSC visual survey) and the assumed value of steepness. Low, mid, and high states of nature in the 2009 assessment resulted in stock status estimates of 4%, 5%, and 21%, respectively (Dick et al. 2009).

The most recent full assessment of cowcod was conducted in 2013 by Dick and MacCall (2013). Following recommendations from the previous STAR panel, the authors revisited several fishery-independent surveys to inform recent trends in abundance. The CalCOFI and Sanitation District indices were updated and included in the final base model, as were the NWFSC trawl and hook-and-line surveys.

After a thorough re-investigation of the CPFV logbook data (both the monthly block-summary and trip-based data formats) it was determined that this fishery-dependent index was extremely influential but also sensitive to alternative methods for standardization of effective effort for cowcod. The STAT and panel agreed to remove the index, resulting in a final model that was fit to four, fishery-independent relative abundance trends (CalCOFI, Sanitation Districts, NWFSC Hook-and-Line, and NWFSC WCGBT) and one estimate of absolute abundance (inside the CCAs) in 2002 based on the SWFSC submersible visual survey. The data were fit using a Bayesian surplus production model (XDB-SRA). Stock status in 2013 was estimated to be between 15% and 66% of unfished biomass, with a median estimate of 34%. Projections assuming a1.5 mt constant catch per year predicted median stock status in 2019 would be roughly 25%, 41%, or 64% of unfished biomass (low, base, and high states of nature, respectively).

2.2.2 Response to STAR Panel Recommendations from the 2013 assessment

1. Investigate the stock structure of cowcod in adjacent areas, especially the population in waters off Mexico.

No progress has been made on this recommendation, but analysis of fin clips collected by ongoing surveys could help inform stock structure, including individuals in Mexican waters.

2. Re-investigate the CPFV data to attempt to produce a CPUE time series to be used as an index of relative abundance. The CPFV data have a historical basis for inclusion and produce a time-series that has a smaller interannual variability than other indices.

Several attempts were made during the 2013 assessment to develop indices using both the aggregated (monthly block summary) and trip-level CPUE databases. Indices based on the aggregated data were discarded due to hyperdepletion patterns that could not be fit by the model dynamics. Likewise, no satisfactory method to standardize indices based on the trip-level data was found (Dick and MacCall, 2013). Filters using species composition data to identify effective effort removed an excessive number of positive trips (discarding over ¾ of all positives), and could not reliably identify trips targeting cowcod.

3. Age-at-maturity and other life history parameters are inherently uncertain for cowcod and require further investigation. Future assessments should consider incorporating the uncertainty associated with age at 50% maturity.

This assessment updates the size-at-maturity ogive based on data collected during the NWFSC trawl and hook-and-line surveys. Relative to previous estimates provided by Love et al. (1990), size at 50% maturity has increased by roughly 4 cm fork length. Uncertainty in maturity is not easily implemented in Stock Synthesis. The ability to specify multivariate priors (e.g. correlated slopes and intercepts of a logistic regression) would facilitate propagation of uncertainty in maturity into model outputs.

4. Investigate methods to include uncertainty in historical catches in the modeling.

Options for propagating uncertainty in catch are limited in the current implementation of Stock Synthesis, but catch uncertainty for cowcod is likely to be large. Historically, cowcod was landed in many mixed-species market categories for which limited samples exist. Recently, retention of cowcod has been prohibited in several sectors, and estimates of total discard are highly uncertainty, in part due to management measures implemented to reduce total mortality. However, it is likely that recent fishing mortality is very low relative to historical removals. The current assessment uses a bracketing approach to evaluate low and high estimates of removals. The range of catch levels was determined by preliminary estimates of uncertainty from the work of Grunloh et al. (in prep.).

5. Evaluate the methods used to reconstruct historical catches of cowcod and other rockfish.

A model to improve historical commercial catch estimates and quantify uncertainty (Grunloh et al., in prep.) has been reviewed during a Council-sponsored methodology review. Members of the cowcod STAT are currently involved in responding to requests from that review panel.

6. The STAT team expressed the most confidence in the NWFSC Hook-and-Line and visual surveys. The STAT team and STAR Panel recommend continuing these indices into the future and extending the NWFSC Hook-and-Line survey into the CCAs.

The current assessment includes both the NWFSC Hook-and-Line survey and the SWFSC visual (submersible) survey. The Hook-and-Line survey is extended through 2018, and the index includes stations inside the CCAs (2014-2018). Trends inside and outside the CCAs were compared and the final index assumes no interaction between year and area.

7. Priors for model parameters, based on rockfish, should be developed.

The current assessment uses the recommended rockfish priors for steepness and natural mortality. A revised prior for the catchability coefficient of the 2002 submersible survey was developed based on in-situ observations from a 2012 ROV survey rather than recreational CPUE as in past assessments.

2.2.3 New Modeling Approaches

The 2013 cowcod assessment tracked the dynamics of aggregate, mature biomass using a Bayesian surplus production model (Dick and MacCall, 2013). The production function was a modification of the 3-parameter Pella-Tomlinson model (Pella and Tomlinson, 1969), allowing for peak productivity at biomass levels greater than ½ of unfished biomass. Mature fish were treated as equally vulnerable to all fleets and surveys and biological processes such as growth were wrapped into an aggregate production function. To accommodate the characteristics of the production model, surveys that selected sub-adult fish (NWFSC trawl survey) or larvae (CalCOFI) were either treated as time-lagged indices of abundance or assumed proportional to larval production to best match the mature biomass tracked by the model.

This assessment attempts to describe cowcod population dynamics using an age-structured, statistical catch at age model (Stock Synthesis; Methot and Wetzel, 2013). This framework allows the STAT to include updated information about growth, maturity, and fecundity in the model. Also, size- and age-based selectivity functions were used to better match relative abundance indices to vulnerable segments of the population. An effort was made to explore alternative stock-recruitment relationships, including the 3-parameter stock recruitment relationships made available in recent versions of Stock Synthesis. The 3-parameter models could potentially mimic the flexibility of the production function used in the 2013 (XDB-SRA) assessment. Specifically, the Shepherd (1982) and “Ricker-Power” functions (as described by Punt and Cope, 2019) are considered in addition to the traditional Beverton-Holt and Ricker models.

2.2.4 Transition to the Current Stock Assessment

The last full assessment of cowcod (Dick and MacCall, 2013) modeled the dynamics of mature biomass using XDB-SRA, a Bayesian surplus production model that places a prior on terminal depletion rather than initial biomass. Therefore, it is not possible to exactly replicate the results of that model using a statistical catch at age model such as Stock Synthesis (SS). However, SS can be configured as an age-structured production model, with deterministic recruitment, fixed growth, and other simplifications to reduce model complexity. The STAT used this general approach to 'bridge' between the two modeling frameworks.

The first step taken was to develop a single-sex model with deterministic recruitment and biological parameters (growth and maturity) fixed at the values used in the last age-structured cowcod model (Dick et al. 2009). Fecundity was assumed proportional to female spawning biomass. Productivity and scale parameters were estimated in XDB-SRA (natural mortality (M), F_{MSY} / M, B_{MSY} / B_0, and terminal biomass relative to unfished) so analogous parameters were estimated in Stock Synthesis using a Beverton-Holt stock-recruitment relationship (M, steepness, and $\ln(R_0)$). Additive variance parameters were estimated for the CalCOFI and Sanitation District indices, as in XDB-SRA, but were not required in SS for the other abundance time series (NWFSC WCGBT and Hook-and-Line surveys). The sixth, and last parameter, was a prior on catchability for the 2002 SWFSC visual survey.

Abundance indices in the bridge model were entered exactly as they were reported in the 2013 assessment. Since the biomass dynamics model implicitly assumes knife-edge selectivity and maturity, all indices were set to units of biomass with selectivity fixed equal to the maturity ogive. Catches were pulled from the original 2013 data files and were identical in terms of total removals. However, to facilitate later steps in the transition process the commercial and recreational fleets were entered separately with mirrored selectivity curves (fixed equal to maturity).

Estimated time series of biomass and biomass relative to unfished (aka 'depletion') are remarkably similar in the two models (Figure 55, Figure 56, and Model 1 in Table 47). Uncertainty intervals are also of similar magnitude, but were derived using very different approaches (Sampling Importance Resampling in XDB-SRA versus the inverse Hessian in SS). Although the two models are very similar in terms of scale and status, the XDB-SRA model does not decline as low as the SS model. Relative biomass in the SS model also increases at a faster rate following the lowest point in the time series. This may be related to the differences in the production functions (a modified Pella-Tomlinson model vs. Beverton-Holt), effects of age structure, and/or growth. Also, differences may occur because the XDB-SRA biomass "time series" is the median of thousands of simulated trajectories, whereas the Stock Synthesis output is a single population trajectory derived from the best-fit parameter values. Regardless of the exact cause, the overall scale, trajectories, and uncertainty estimates from the two models are sufficiently similar that the STAT considers the bridge model in SS to be an adequate representation of the previous stock assessment.

Next, a series of models were run to evaluate the influence of fixing important parameters (M and h) and updating biological parameters and functions with current information. Table 47 shows key parameters and derived quantities for the following models:

1. Bridge model (as described above)
2. Same as #1, but fixing M at 0.055, the mean of the 2013 prior.
3. Same as #1, but fixing steepness at 0.72, the mean of the 2019 prior.
4. Same as #1, but fixing growth at external estimates fitted to NWFSC survey data
5. Same as #4, but using the revised, functional maturity ogive
6. Same as #5, but with updated fecundity (no longer proportional to mature female biomass) *[Note: model #6 has entirely updated (but fixed) biological parameters; still fit to 2013 data]*
7. Begin replacing indices with updated versions: replace *only* the NWFSC WCGBT Survey (selectivity unchanged from bridge model)

8. Replace only the Sanitation Districts index (selectivity unchanged from bridge model)
9. Replace only the NWFSC hook-and-line index (selectivity unchanged from bridge model)
10. Replace only the CalCOFI index (selectivity unchanged from bridge model)
11. Replace ALL indices (selectivity unchanged from bridge model)

Figure 57 compares time series of spawning biomass for Models 1-11. Units of spawning biomass change from mature biomass to egg production with the updated fecundity relationship in Models 6-11, so spawning output for these models is on a different scale from Models 1-5. Within sets of models using the same spawning units (Models 1-5 and Models 6-11), the scale of the population is very consistent. The exception is Model 2, which fixes M = 0.055 (Figure 57). This fixed value is far from the estimated values of M in all the other runs (Table 47). Spawning output relative to unfished output ('depletion') is directly comparable among all models (Figure 58). Again, Model 2 is a clear outlier, with less variable dynamics over time (consistent with lower M) and a more depleted stock at the end of the time series.

As noted above, the XDB-SRA model uses a modified version of the 3-parameter Pella-Tomlinson production function. Differences between XDB-SRA and SS may be related to the use of a Beverton-Holt stock-recruitment relationship (SRR) in SS, which has 2 parameters and for which reference points such as B_{MSY}/B_0 and F_{MSY}/M are tightly linked to steepness (Mangel et al. 2013). To evaluate this, the STAT evaluated 3-parameter stock-recruitment relationships using the pre-STAR base model. Specifically, likelihood multipliers ("lambdas") were set equal to zero for all composition data (lengths and ages) in the model. Growth parameters were fixed at the internally estimated values from the fit to the complete data set, and M was estimated in addition to the stock-recruitment parameters. Added variance was estimated for the CalCOFI and Sanitation District indices, as before. No prior was used for the shape parameter in either the Shepherd or Ricker-Power models.

Trends in spawning output were very similar for the three models, especially the Beverton-Holt and Shepherd models (Figure 59). The Beverton-Holt model is a special case of the Shepherd (with shape parameter equal to 1), and the estimated shape parameter was 0.864 with standard deviation 0.32. Virgin spawning output was slightly lower for the Ricker-Power model, which had the largest uncertainty intervals for both SB_0 and terminal spawning output (Figure 59). The Ricker-Power model also displayed the greatest uncertainty in stock depletion, with a 95% asymptotic interval in the terminal year that ranged from less than 25% of unfished spawning output to over 100% (Figure 60). Uncertainty in depletion was similar for the Beverton-Holt and Shepherd models, with a slightly less precise estimate associated with the Shepherd model, likely because of the extra estimated parameter. Although the proposed base model uses the Beverton-Holt SRR, it is worth noting how much uncertainty in terminal biomass increases under the Ricker-Power model, simply with the addition of a single parameter in the deterministic stock-recruitment relationship. Also interesting to note is that the recent rate of increase in spawning output was not reduced by the addition of a 3^{rd} parameter in the stock recruitment relationship, i.e. this does not appear to explain the slower rate of increase in the XDB-SRA model. Finally, the peak of the yield curve (B_{MSY}/B_0) occurs around 27-28% of unfished spawning output under the Beverton-Holt and Shepherd models, but the Ricker-Power model estimates the peak at 42% of the unfished state (Table 48). Changes in total likelihood are small, however, among the three models and estimates of derived quantities such as B_{MSY}/B_0 are likely to be imprecise in the 3-parameter models.

2.2.5 Model Specifications

The assessment is structured as a single, combined sex population spanning U.S. waters from the U.S.-Mexico border to Point Conception, California. The assessment model operates on an annual time step covering the period 1900 to 2018 (not including forecast years) and assumes an unfished equilibrium population prior to 1900. Population dynamics are modeled for ages 0 through 60, with age-60 being the accumulator age ("plus group"). The maximum observed age was 55 years old. Population bins were set every 1 cm from 6 to 98 cm, and data bins were set every 2 cm from 6 to 98 cm. The model is conditioned on catch from two fleets, commercial and recreational, and is informed by six fishery-independent abundance indices (two demersal trawl surveys, one hook-and-line survey, one ichthyoplankton survey, and two visual survey abundance estimates). Size and age data are primarily available from recent years, but include sporadic length compositions ranging from 1973-2018 and ages from 1975-2017. Recruitment is related to spawning output using a deterministic Beverton-Holt stock recruitment relationship. Growth was modeled across a range of ages from 0 through 60. All catch was assumed to be known without error.

Fishing fleets were specified for recreational and commercial sectors. Fleet selectivity was assumed to be logistic for the commercial fleet and dome shaped for the recreational fleet. Surveys were assigned logistic or double-normal, length-based selectivity curves with the exception of the CalCOFI survey which was linked to fecundity. Descending logistic curves, combined with specified age ranges, were used for the two demersal trawl surveys (NWFSC WCGBT and Sanitation District). This allowed the model to better match the smaller size distribution in these surveys. Sensitivity to selectivity assumptions was explored during model development and relative to the base model.

The time-series of data used in the assessment are summarized in Figure 61. Sample sizes for length and age compositions are also summarized (Table 14, Table 15, Table 16, Table 18, Table 20, Table 21, Table 32, and Table 33). For yearly length-composition data, initial sample sizes for recreational fleets were set at the number of sampled trips. Survey length compositions sample sizes were set at the number of fish, as the number of tows was often similar to the number of fish in a given year. Conditional age-at-length data were used in the assessment model to inform estimation of growth and to alleviate the potential lack of independence among dual age and length-composition information for the same sample. Age-at-length composition sample sizes were set at the number of aged fish in each population bin. Length and age composition sample sizes were then tuned in the base assessment model using the Francis weighting method (Francis 2011). The Francis method resulted in down-weighting of all composition data, with the exception of length compositions for the NWFSC Hook-and-Line Survey (Table 49). The weight for this data source was not increased, as the input sample sizes were based on the number of fish. Alternative approaches to weighting were explored through sensitivity evaluations.

Likelihood weights (or emphasis factors) can also be specified in Stock Synthesis (i.e., "lambdas"). In this assessment, there was no clear reason to down-weight (up-weight) particular data sources relative to each other, so all were assumed to have equal emphasis in the base case model.

Prior distributions were specified for natural mortality (see section 2.1.3.1 for more details), steepness, and catchability for the 2002 SWFSC submersible survey of the CCAs. A lognormal prior for natural mortality was applied when estimating natural mortality (mean = -2.321, standard deviation = 0.438). A beta prior (mean=0.72, SD=0.16) was applied when estimating steepness of the stock recruitment curve. The steepness prior was developed from a west coast groundfish meta-analysis (Dorn 2002). A normal prior was specified for log(q) of the submersible survey based on estimates of biomass inside and outside the CCAs from the 2012 ROV survey.

Likelihood components that were minimized in the overall fitting procedure include fleet-specific catch, length compositions, conditional age-at-length compositions, survey indices, parameter priors, and parameter soft-bounds. Initial model explorations utilized individual and combined likelihood values to assist in model development.

This assessment used a recent version of Stock Synthesis 3 (version 3.30.13.09), which was compiled by Rick Methot (NOAA-NWFSC) on June 30, 2019. The basic population dynamic equations used in Stock Synthesis 3 can be found in Methot and Wetzel (2013). The relevant input files necessary to run the stock assessment can be found on the Pacific Fisheries Management council website (http://www.pcouncil.org/groundfish/stock-assessments/).

2.2.6 Model Parameters

The population dynamics model has many parameters, some estimated using the available data in the assessment and some fixed at values either external to the assessment or informed by the available data. A summary of all estimated and fixed parameter values, including associated properties, are listed in Table 50.

A total of 22 parameters were estimated in the base model. Initial (equilibrium) recruitment was estimated. Natural mortality was estimated and informed by a prior distribution. Time-invariant growth parameters (Brody growth coefficient, lengths at age 2 and age 35, and CV old/young) using the Schnute parameterization of the von Bertalanffy growth function were estimated. The CV of the distribution of length-at-age, CV(L), in the base model is estimated at the lower and upper ages specified in the Schnute parameterization of von Bertalanffy growth, and a linear interpolation between these 2 parameters is a function of length at age. Length-based selectivity was assumed to be asymptotic for the commercial fleet and domed for the recreational fleet. Length-based selectivity for all surveys was assumed to be logistic or double-normal, except for the CalCOFI ichthyoplankton survey for which selectivity mirrors fecundity. All selectivity parameters were assumed to be time-invariant. Coefficients of variation were estimated for the CalCOFI and Sanitation District abundance indices, due to unexplained variability in fecundity in the case of CalCOFI, and limited spatial coverage in the case of the Sanitation District surveys.

The base model fixes the Beverton-Holt steepness parameter at 0.72, which is the prior mean. Parameters for fecundity were fixed at new estimates based on ovaries collected during the NWFSC hook-and-line survey.

2.3 Base Model Selection and Evaluation

2.3.1 Key Assumptions and Structural Choices

Many of the key assumptions and structural choices made in this assessment were evaluated through sensitivity analysis (section 2.6). For consistency, model structural choices were made that were likely to result in the most parsimonious treatment of the available data, either a priori determined or through the evaluation of model goodness of fit. The major structural choices in this assessment were the use of a single closed area (U.S. waters off California from the U.S.-Mexico border to Point Conception) to adequately describe population dynamics of cowcod in the Southern California Bight, and that natural mortality rates can be adequately estimated from available data.

The amount of length and age composition data is limited for cowcod, and the STAT's primary goals in fitting to these data were 1) to estimate a reasonable growth curve, and 2) to estimate selectivity curves such that the available indices of abundance represent appropriate size and age classes within the population. Alternative model configurations (e.g. models fit only to indices) were explored during model development to better understand the influence of composition data on the model dynamics, and whether or not the composition data conflicted with or otherwise de-emphasized trends in the indices of abundance.

Major structural assumptions included fixing the steepness stock recruitment parameter. Natural mortality was estimated using the prior distribution following methods of Hamel (2015). Selectivity was assumed to be asymptotic following a logistic curve for the commercial fleet and all survey fleets except CalCOFI (which was linked to fecundity). The recreational fleet was allowed to estimate dome-shaped selectivity. There was insufficient information in the commercial length data to produce reasonable estimates for selectivity. The model was sensitive to size at which 50% of fish become vulnerable to commercial gears, and the base model assumes commercial selectivity roughly matches the maturity ogive.

2.3.2 Evaluation of Model Parameters

Model parameters were evaluated for stability, precision, along likelihood profile gradients (section 2.6), and against the main assumptions in the base case model (section 2.3.1). Stability was examined by ensuring that model parameters were not up against a lower or upper bound (Table 50), and that the addition or removal of parameters associated with selectivity did not substantially improve model fit. Parameter precision was also monitored by looking at estimated standard deviations to assess the variability associated with point estimates.

2.3.3 Residual Analysis

Residuals from length and age composition fits to the model were explored during model development. In general, annual fits to time-aggregated length composition information were adequate (Figure 62). The distributions of small, younger fish observed in the demersal trawl surveys (WCGBT Survey and Sanitation-District) appeared to be well-represented by the base model's combination of length-based, descending logistic curves and a fully selected subset of ages. The exception to this is the commercial length compositions, which were ultimately removed from the base model (Figure 63). Attempts to fit selectivity to the commercial data resulted in unstable estimates and curves that shifted between selecting either excessively large or small individuals, depending on the model configuration. Previous assessments have had similar issues with the commercial length data, and also chose to fix selectivity equal to maturity (Piner et al. 2005; Dick et al. 2007). Sensitivities to this assumption are explored in section 2.6. Given the small sample sizes, examination of fits to annual (disaggregated) length compositions is not very informative (Figure 64, Figure 65, Figure 66, Figure 67), except in the cases of the 1970s recreational fishery data (Figure 68). The model was not inconsistent with mean lengths in the various data sets, but it also did not closely track changes in mean length over time (Figure 69, Figure 70).

Although internally estimated growth curves from the model seem reasonable when compared to external fits (Figure 49) and ageing error matrices are used to adjust for apparent bias between readers, the model still shows some lack of fit to the conditional age at length data from the commercial fishery (Figure 71). Other sources such as the 1970 onboard CPFV observer data appear to be well reproduced by the model (Figure 72). Predicted ages at length for the NWFSC hook-and-line CAAL data (Figure 73, Figure 74) seem to have a slight bias in the opposite direction of the commercial data, with the model attempting to 'split the difference' in growth between the two data sets.

2.3.4 Convergence

Model convergence was checked for all models during development of a base model by ensuring that the final gradient of the likelihood surface was less than 0.00001 and produced asymptotic standard deviations. All estimated parameter values were also checked to ensure they were not hitting a minimum or maximum bound. A total of 200 jittered runs were performed for the base model. The lowest likelihoods of each jittered run matched the base case likelihood in over 98% of the runs with no jittered runs finding a better solution (Table 51).

2.4 Response to STAR Panel Recommendations

Request 1: Develop a catch curve for (outside) NWFSC Hook-and-Line survey and compare to historic commercial catch curve from bias-corrected ages.
Rationale*:* It seems from catch curves that the value of M cannot be as high as estimated given the structure of the model
Response: The STAT had previously estimated a catch curve Z value using the bias corrected ages from the Butler 1999 assessment. The estimated slope, the Z value, was 0.060. For comparison, a catch curve was estimated using the NWFSC Hook-and-Line data from outside the CCA (Figure 75). The estimated Z value using these data was 0.145, much higher than the Z value based on the Butler ages. The STAT team noted that the results are a bit counter-intuitive. Reducing the catch curve for the NWFSC Hook-and-Line data to cover only fish between 16 and 25 in age, the resulting Z is 0.084. The STAT team expressed some concern that the model is estimating the stock to be more productive than it is (through values of both steepness and natural mortality) which is impacting the rate of decline and the recent rate of increase in the stock. However, without the ability to estimate recruitment deviations, and the potential for dome-shaped selectivity the hook and line survey, the values from the hook and line survey have the potential to be overestimating Z.

Request 2: Rerun base model with two blocks of growth split at 1995 or as STAT determines appropriate.
Rationale*:* To assess whether the different growth patterns over the time period can improve the fit to the age-comp data.
Response: Exploring an early and late block on growth resulted in slightly lower spawning output in the early period but a larger spawning output in recent year, relative to the pre-STAR base model, with the stock nearing unfished in 2019 (Figure 76). The estimate of natural mortality increased marginally to 0.092 from 0.085. A larger difference was seen in estimates of Lmin, Lmax, and *k*, between the early and late periods. Blocking growth improved the overall model fit (lower NLL) through a better fit in the age data. However, the estimates of growth are confounded with potential changes in selectivity, recruitment deviations, and other life-history parameters. The constant growth model is preferable due to the confounding of growth and selectivity from a modeling perspective, and it is best to address the uncertainty in growth though crudely through different levels of constant growth, in the sensitivity analysis.

Request 3: Conduct a retrospective back to 2011. Also, do this retrospective dropping the ROV survey data point. In both cases, remove inside CCA NWFSC Hook-and-Line survey.
Rationale*:* To see the dependence of the ROV survey.
Response: Comparing the model when the ROV survey is included or excluded, in both cases with the Hook-and-Line data from inside the CCA removed, resulted in similar estimates of spawning output (Figure 77). The retrospective run with the ROV datum included did not result in a pattern as data years were removed. The 2011 retrospective run where the ROV datum was removed did result in a visible increase in the uncertainty estimate, implying that this datum point is contributing to the certainty in the

scale in the population, but far less so to the scale itself. The retrospective run where the ROV datum is removed from the current pre-STAR base model resulted in a similar stable retrospective pattern.

Request 4: Fix growth at external estimate and turn all ages into marginal ages. Set Lambda for lengths and ages at 0.5 for fleet with both lengths and ages. Reweight. Also, plot marginals when you fit to the conditionals.
Rationale*:* Explore the impact of how the age data is treated in the model (conditional or marginal) on R_0 and M and the overall time series estimate.
Response: The spawning output trajectory was similar between the pre-STAR base model and this run with growth fixed at external values (Figure 78-left panel). However, the log(R_0) was estimated at a different value between these runs. The run that fixed growth parameters at the external estimated values resulted in a lower estimate in log(R_0) (Figure 78-right panel). The estimate of natural mortality declined to 0.077 from the 0.085 in the pre-STAR base model. Essentially, fish grow faster and live longer using the external growth estimates with a reduction in R_0 compensating for the increased productivity. Overall, the trajectories of the models with the two approaches to treating age data were quite similar in terms of spawning output and productivity.

Request 5: Allow the model to estimate annual recruitment deviations starting in 2001. Complete for base model and for model from request 4 (above).
Rationale*:* There may be adequate information to inform recruitment strengths in more recent years.
Response: The STAT team estimated a main period of recruitment between 2003 – 2015, with early deviations starting in 1993 where the parameters were fixed at external estimates (Table 52 and Figure 79, Model4). The STAT team also presented the pre-STAR base model which internally estimated growth with the same set-up for estimation of recruitment deviations (Table 52 and Figure 79, Estimated1). In both models recruitment variation (sigmaR) was set equal to 0.40. The model with annual recruitment deviations estimated a large positive deviation in 2009. The STAT team noted that allowing the model to estimate recent recruitment deviations resulted in a lower estimate of natural mortality of 0.074, but a larger *k*, compared to the pre-STAR base model. Overall this suggest that there is little evidence that year class strength can be estimated reliably, at least not until growth can be better resolved.

Request 6: Use the Francis-weighting approach for 3 iterations and compare result with harmonic mean weighting approach for 3 iterations and the Dirichlet approaches. Provide table of final weights.
Rationale*:* To examine interactions between data weighting approaches, estimation of growth, and estimates of biomass.
Response: The Dirichlet weights went to 1 and the model did not converge. The McAllister-Ianelli harmonic mean data weighting approach wanted to up-weight the recreational length samples but was capped at 1 because the input sample size was equal to the number of fish. The Francis weighting with multiple iterations had 3 fleets for which weights did not appear to be converging (Recreational, NWFSC WCGBTS, and the NWFSC Hook-and-Line ages). The weighting approaches resulted in similar population trajectories and growth estimates, however, the internally estimated growth rate parameter, *k*, was lower in all models compared to the external estimate based on the data (Table 53). The model parameters are largely insensitive to the weighting method used.

Request 7: Contact John Wallace and check for any interaction between the inside and outside NWFSC Hook-and-Line indices.
Rationale*:* Single index would be preferable from the assessment perspective.
Response: The STAT contacted J. Wallace (NWFSC) to inquire about interactions between the inside and outside hook-and-line indices. Mr. Wallace indicated that he had not evaluated interactions between year and location (inside/outside).

The STAT used the NWFSC Hook-and-Line survey data from 2014-2018 to test for an interaction between year and location (inside/outside CCA). Some sites did not catch a cowcod over the period 2014-2018, and these were excluded from further analyses. Prior to fitting a model, the STAT plotted the proportion positive by year and location (Figure 80).

Next, a binomial GLM was fitted to the data with covariates identical to the index in the draft assessment. Another GLM was fitted with a categorical covariate for location (inside/outside CCA), as well as an interaction term between the Year covariate and location. Specifically, the binomial GLM was fit using the glm() function in R:

```
NumCow ~ Year + CCA.factor + Year:CCA.factor + Vessel + SiteName +
         DropNum + HookNum + poly(Depth.m, 2)
```

The STAT team found small significance to this potential interaction term (AIC and BIC have opposite weak support for this interaction term). Given the weak evidence of an interaction, it is likely that a more parsimonious model that treated the two indices as a single index representative of the whole population should reduce uncertainty. (As noted in Request 8a, below, the final Hook and Line index included only year, site, and hook number effects.)

Request 8: Combine inside and outside comps in the indices for NWFSC Hook-and-Line survey and add a time block in selectivity to account for recent years.
Rationale*:* More realistic way to treat the information from the NWFSC Hook-and-Line survey
Response: The STAT realized after the request was made that an additive effect for CCA is confounded with site effects in the model, as each site can only occur inside or outside the CCAs. The STAT considers model structures for the NWFSC Hook-and-Line index a priority for future research, as this survey targets cowcod (untrawlable) habitat and provides useful information about growth. Hierarchical structures for the linear predictor should be evaluated, e.g. allowing sites to be nested within areas (inside/outside CCA).
To account for possible changes in selectivity with the addition of sites inside the CCA, a time block was added to the base model, retaining both indices (inside and outside) as they were in the base model. A time block was defined for the period 2014-2018. Another difference was the use of 3-parameter selectivity curves for both time periods, allowing for domed shapes and estimating size at peak selectivity, the slope of the ascending limb, and the slope of the descending limb. The “-999” option was used for terminal selectivity, estimating this quantity based on the decay rate of the (estimated) descending limb.
Major differences between this model and the base include much slower growth and larger asymptotic size, to the point that the size distribution of older fish is truncated. Natural mortality decreases relative to the pre-STAR base (estimated M=0.067 vs. 0.085), and spawning output increases by roughly a third. Stock status declined from roughly 60% to 50% of unfished in 2019. The model with dome-shaped selectivity assumes larger, older fish are present, but not selected in the survey, whereas the model with asymptotic selectivity assumes that larger fish have not survived.

Request 8a: Analyze the entire set of NWFSC Hook-and-Line data using site effect as a proxy for inside vs outside CCA. Maintain time block with asymptotic selectivity in second time block allowing for dome-shaped selectivity in the first time block.
Rational: This will address the intent of Request 8 above, despite the inability to fit the index model to inside vs outside explicitly.
Response to the amended request: A revised NWFSC Hook-and-Line index was fit to the complete data set (including sites inside and outside the CCA). Stepwise AIC model selection identified a model with Year, Site, and Hook Number effects as the best model. Although there is evidence of changes in mean

depth fished at some sites across years (Figure 81), depth fished at most sites is consistent over time. The AIC difference for depth (squared) was less than 2, after accounting for site, and therefore depth (and depth^2) was excluded as a factor in developing the final index.

The revised index is similar to the previous 'outside CCA' index (Figure 82), with smaller log-scale standard errors, due in part to the inclusion of additional data from 2014-2018.

The model was fit to the new, combined NWFSC Hook-and-Line index, with selectivity forced to be asymptotic in the 2014-2018 time block. Unfished spawning output increases while current spawning output levels remain similar, resulting in a slightly more depleted stock in terms of relative spawning output (Figure 83). The model with the combined NWFSC Hook-and-Line index and asymptotic selectivity in the 2014-2018 time period has similar growth to the pre-STAR base, and does not result in truncated length distributions for the older fish as was seen in Request 8.

Estimates of growth parameters show values for *k* (0.053 in the pre-STAR base versus 0.050) and smaller size at age 35 that are similar to the pre-STAR base. The estimate of natural mortality decreased slightly relative to the pre-STAR base model (0.085 vs. 0.081).
There was concern from the STAR panel regarding the decision to model two periods of selectivity. The index is being modeled as one continuous process (inside and outside), but adding a selectivity block indicates that there are two processes are being modeled despite the single index calculation. However, the data does seem to support this change in selectivity when composition data from all years are included given that there is a higher proportion of larger fish from the CCA samples compared to the earlier years with data just from outside the CCA. This was further investigated under request 13.

Request 9: Turn off prior on submersible survey q
Rationale*:* The STAR panel is interested in the influence of the prior on the estimate of q and the overall assessment. .
Response: The pre-STAR base model estimates a catchability parameter (q) with a prior distribution developed during the STAR panel for the 2005 cowcod assessment. This quantity represents the proportion of cowcod biomass inside the CCAs, relative to the entire Southern California Bight.
The effect of the prior was evaluated by comparing the 'float' option in Stock Synthesis rather than estimating a parameter for q. The float option calculates an analytical solution for q. Given the large uncertainty in the prior, removing it had a minor effect on stock depletion in 2019 (3.6% change), and affected estimates of natural mortality in the third decimal place (0.0845 in the pre-STAR base versus 0.0868). The catchability estimate with a prior (red triangle at 0.45, Figure 84) was shifted toward the prior mode relative to the analytical solution (blue triangle at 0.37, Figure 84). The estimate of q without the prior made a small difference in the overall model, and the negative log-likelihood between models were similar with the largest difference arising from the prior likelihood contribution. In regard to the estimated trajectory this change only slightly altered the recovery trajectory in recent years (rather than shifting the whole time-series either up or down).

Request 10: Develop prior for submersible survey q based on the proportion of biomass inside the CCA relative to the total area estimated from the ROV survey.
Rationale*:* This is the best information we have on the proportion inside the CCA and would provide a more appropriate and informative prior than the one currently used.
Response: The prior for catchability for the SWFSC submersible survey used in the pre-STAR base model is based on an analysis of CPFV logbook CPUE from 1990 to 2000 (see Piner et al. 2005 for details). An index of abundance based on the logbook data was rejected during the 2013 cowcod assessment because catch rates were sensitive to alternative methods for determining effective effort for cowcod. The SWFSC ROV survey provides a direct estimate of the

proportion of cowcod biomass inside and outside the CCAs in 2012. Use of these data to inform a prior for catchability assumes that the relative distribution of biomass was the same in 2002 when the submersible survey was conducted.
Using the model-based abundance estimate for the SWFSC ROV Survey, posterior draws (10^5) of biomass estimates for strata inside the CCAs were summed and divided by the sum of posterior draws in all strata (inside and outside the CCAs). This produced a distribution for the ratio of biomass inside the CCAs to total biomass in the SCB (solid black line, Figure 85). A lognormal distribution with the same mean and variance (dashed black line, Figure 85) is used as an alternative prior for the catchability coefficient for the SWFSC submersible survey. The original prior (red line, Figure 85) is less precise and more skewed, with a larger mean but a smaller mode than the prior derived from the ROV survey.

Parameter estimates, derived quantities, and likelihood components were similar for the model with the submersible survey catchability with and without the original prior and the estimate based on the revised prior (i.e. derived from ROV survey). Stock status in 2019 based on the revised catchability prior is 53.9%, or 3.8% lower than the base and 7.4% lower than the estimate without a prior (i.e. effectively removing the submersible survey, Figure 86). The STAT supports this new approach for defining the prior on q for the submersible survey.

Request 11: Conduct a series of drop 1 out as well as include only 1 index (and associated composition data) at a time sensitivities, in contrast to previous sensitivities which dropped only compositional data.
Rationale*:* To check the influence of each individual index data source.
Response: The model was relatively insensitive to dropping a single index at a time (Figure 87). Dropping either the CalCOFI (slower recovery trajectory) or the submersible indices (faster recovery trajectory) resulted in the largest differences. For the 1 index at a time sensitivities (Figure 88), the unfished spawning output is estimated much lower but a faster increase in recent years when only using the NWFSC WCGBTS, NWFSC Hook-and-Line, or CalCOFI indices due to higher estimates of natural mortality. Fits to only the NWFSC WCGBTS and Hook-and-Line survey indices did not meet the convergence (gradient) threshold. In these single index runs, growth was fixed at the full model estimates due to the lack of data to estimate growth in most of these sensitivities. The STAT team reported that, given that steepness is fixed, the model estimates of M and R_0 adjust in each run to result in a stock trajectory that fits both the ROV and submersible data points. This at least partially explains the high correlation between M and R_0 parameters in the model. The STAT team showed a run where only the submersible index was used which was a single parameter model, R_0, with M and q fixed. This run fits the submersible perfectly, but also is fitting the ROV data point (as a ghost fleet). Additionally, the visual fits to the other indices (as ghost fleets) are relatively similar to the full base model with M and growth estimated as well.

Request 12: Create the "Piner plot" for R_0 across the index likelihood components.
Rationale*:* This plot will provide information about the influence of each index on the estimated scale of the population.
Response: The majority of the information in the estimation of $\log(R_0)$ is coming from the ROV and the CalCOFI surveys. Each survey is supporting values of $\log(R_0)$ that range between 5-5.5 (Figure 89).

Request 13: Remove composition data prior to 2014 from the combined NWFSC Hook-and-Line survey comps and put in a new dummy fleet. Also, remove time block on NWFSC Hook-and-Line selectivity.
Rationale*:* NWFSC Hook-and-Line survey index as developed should have a single selectivity over entire time period. However, do not want to lose information on lengths and ages from earlier portion.
Response: The selectivity for the 2014-2018 period was set at asymptotic reaching full selectivity at approximately 75 cm while the early comp fleet assumed a dome-shaped selectivity peaking at slightly smaller sizes (Figure 90, left panel). This adjustment to the treatment of the data resulted in a similar

trajectory to the previous model with only a minor change in unfished spawning output (Figure 90, right panel). This treatment seems to be a better compromise than the pre-STAR-base model where the survey is treated as two separate indices.

Request 14: For CalCOFI index, replicate the index representing a ~20yr time period and place at 5yr intervals, i.e. remove the 1986 point and replace with identical values at 1979, 1984, 1989, and 1994. Use the average SE across all the other points.
Rationale*:* The current point at 1986 currently represents 19 years whereas the other super years represent 5 years. Thus this point is currently underweighted.
Response: The STAT team recalculated the index and input this in to the model from request 13 This change in the treatment of the CalCOFI data only resulted in a minor change to the spawning output. The model estimates a similar fit to the new index relative to the fits from previous model runs, but from a process perspective it is the more reasonable approach.

2.5 Base-Model(s) Results

The cowcod base case model estimated reasonable growth parameters (k, length at minimum and maximum age, and CV young/old; Table 50). Internally estimated growth parameters suggest slightly slower growth and larger asymptotic size than external estimates fit to the same data (Figure 49).

Fits to the indices vary in quality. The CalCOFI index is one of the better time series fits, which is unusual for such a long time series (>65 years; Figure 91). The NWFSC Hook-and-Line, NWFSC WCGBT, and sanitation district surveys fit poorly, with little correlation between the expected and observed values (Figure 92, Figure 93, and Figure 94). The two SWFSC visual surveys, spaced a decade apart, are both centered near the model's biomass predictions (Figure 95). Since the biomass estimates from both surveys have low precision, they are not highly influential, but as independent estimates of biomass, they help validate the predicted scale of the populations as well as the rate of increase since 2002.

Length-based selectivity curves were estimated for 5 fleets/surveys: the recreational fishery, the Sanitation District surveys, the NWFSC WCGBT survey and 2 time periods from the Hook-and-Line survey (before and after sampling inside the CCAs began) (Figure 96). CalCOFI selectivity was linked to the fecundity relationship, as this index is intended to track spawning output. The length composition data from 2004-2013 for the NWFSC Hook-and-Line survey were fit as a 'dummy' fleet, and allowed to take a dome shape due to the lack of sampling inside the CCA where fish of larger size were observed. Selectivity for the Hook-and-Line index was informed by composition data from the years 2014-2018 and forced to be asymptotic (see STAR panel request #13). Selectivity for the commercial fleet was fixed to mimic the maturity ogive, due to the previously mentioned difficulties in fitting to the commercial composition data. However, the length at 50% selectivity for the commercial fleet was included along with natural mortality in defining the major axes of uncertainty in the decision table. Selectivity of the submersible survey was also fixed, with size at 50% vulnerability set to 40cm, as this was the minimum size incorporated into the existing biomass estimate. The two demersal trawl surveys had both length- and age-based selectivity curves (Figure 96, Figure 97, Figure 98), derived from the range of commonly observed ages in the catch, as well as the effects of ontogenetic movement into untrawlable habitat with increasing size. All selectivity curves were considered to be time-invariant. Changes in selectivity due to depth restrictions in recent years are not an issue, as recent mortality of cowcod is already so small that fine-scale adjustments will have little impact on assessment results. Collection of length and age composition data will be critical to understand selectivity of the fisheries when removals increase.

Cowcod spawning output in California was estimated to be 163 billion eggs in 2019 (~95% asymptotic intervals: 130-195; Table 54), which equates to a depletion level of 57% (~95% asymptotic intervals:

42%-72%; Table 54, Figure 99, Figure 100) in 2019. “Depletion” in this assessment is the ratio of the estimated spawning output in a particular year relative to estimated unfished, equilibrium spawning output. Cowcod spawning output south of Point Conception declined rapidly throughout the 1970s and 1980s to a level well below the Minimum Stock Size Threshold (MSST). Given the drop in catches after 1988, the current base model allows for a much more rapid recovery than previous assessments (Table 55, Figure 100). Recruitment in the base model is fixed at the prior mean, a higher value than was assumed in previous assessments. The combination of higher steepness and higher natural mortality rate largely explains differences in perceived stock status relative to previous assessments. Since recruitment is deterministic, the estimated recruitment time series is simply a transformation of spawning output (Figure 101, Figure 102).

Equilibrium SPR “exploitation rates” [(1-SPR) / (1-SPR50%)] reached and briefly exceeded target levels as early as the mid-1920s and 1930, falling due to shifts in effort and WWII. Increases in fishing effort after WWII led to exploitation rates above target during most of the 1970s and 1980s, rapidly declining in the late 1990s and nearing zero after the overfished declaration in 2000 (Figure 103, Figure 104). The equilibrium yield curve is shifted left, a characteristic of the Beverton-Holt stock-recruitment relationship, and the fixed value of steepness (h=0.72) largely determines the peak of the curve (28% of unfished spawning output; Figure 105).

The base model predicts the most optimistic view to date about the rate of stock recovery for cowcod. This is largely determined by the assumed values for natural mortality and steepness. Steepness is fixed at the prior mean (h=0.72), a value higher than what was assumed in previous assessments. Natural mortality is estimated to be larger (M=0.088) than values used in previous assessments (M=0.055). The base model estimates a value for M given the available age composition data. These data come from years of heavy exploitation or during the subsequent recovery. The model may not distinguish between a population with shorter life spans (high M, fewer old individuals), and one with lower M that has a truncated size and age structure due to a history of heavy fishing.

On the other hand, the base model is consistent with two SWFSC absolute abundance estimates from visual surveys spaced a decade apart (2002 and 2012). These surveys not only serve as independent estimates of the scale of the cowcod population, they also agree with the rate of increase implied by the base model. This suggests to the STAT that it is not possible to rule out the rate of increase predicted by the current base model. However, the STAT considers current stock status and the rate of increase (i.e. forecasts of stock status and yield) to be highly uncertain quantities, and strongly advises caution when setting catch limits for cowcod based on this assessment.

2.6 Evaluation of Uncertainty

2.6.1 Sensitivity to Assumptions, Data, and Weighting

These analyses (section 2.6.1) were conducted using the pre-STAR panel base model, but the post-STAR panel base model is very similar to the pre-STAR base and conclusions are likely to be qualitatively similar. The STAT evaluated sensitivity of the Cowcod base model to specific data sources using a ‘one-off’ approach (remove one data source relative to the base model) to clearly identify the impact of a single piece of information or structural assumption. Specifically, the STAT evaluated models that *excluded* the following data:

- Commercial Fishery CAAL data
- Recreational CAAL and lengths

- NWFSC WCGBT Survey CAAL and lengths
- NWFSC Hook-and-Line CAAL and lengths
- Sanitation District lengths
- All composition data; fixing growth and selectivity

Other sensitivity tests include:

- Alternative methods of data-weighting for composition data (Francis vs. McAllister-Ianelli)
- Changing size at 50% selectivity for the commercial fleet over a range of values
- Fixing steepness and natural mortality at values used in the last age-structured assessment
- Sensitivity to fecundity, accounting for multiple broods (2 broods max.)
- Scaling historical removals (pre-1969) to ½ and double the estimates used in the base model
- Effect of alternative maturity ogives on model results ("functional" vs. "biological" maturity)

Effects of removing individual composition data sources
The pre-STAR base case model was relatively stable with respect to population scale except for the two cases when the commercial CAAL data were removed (Figure 106), but relative trends in biomass varied little across all runs (Figure 107). Removal of the commercial, NWFSC WCGBT Survey, and NWFSC Hook-and-Line CAAL data seemed to have the greatest effects on growth parameters (Table 56). Similar to the analyses using age-structured production models (see section 2.2.4), uncertainty in stock status increases dramatically with estimation of both steepness and M, rather than just M (Figure 108).

See also STAR panel request #11 in section 2.4 for 'drop-1' and 'leave-only-1' sensitivity analyses by data source. Unlike the sensitivity described above, which focused on composition data, both indices and associated composition data were included/excluded for request #11.

Sensitivity to alternative data-weighting methods
Scale and current status of spawning output in the Cowcod model are not very sensitive to the approach used to weight composition data (Figure 109). The pre-STAR base model used the Francis method to weight length composition data, and the comparison suggests that this approach generates the largest estimates of uncertainty (Figure 109). Francis weights resulted in a slightly less depleted stock relative to the equal weight scenario (all weights = 1) and the McAllister-Ianelli method. See also STAR panel request #6 for further sensitivity analyses related to data weighting methods.

Influence of the assumed selectivity curve for the commercial fleet
As noted in the drop-one analysis, above, the pre-STAR base model was sensitive to the commercial composition (CAAL) data. Since the marginal commercial length compositions are of poor quality, and the commercial fleet is the largest source of historical removals, the STAT decided to evaluate how the model changes with selectivity for this fleet. Results show that natural mortality estimates are inversely correlated with size at 50% selectivity, and estimated scale of the population increases as selectivity is shifted "to the right" (i.e. as the model selects larger fish) (Table 57, Figure 110). Since the change in selectivity has a simple scaling effect, estimates of stock status relative to unfished spawning output are less affected by selectivity (Figure 111).

Fixing steepness and natural mortality at values from previous assessments
The pre-STAR base model predicted that the cowcod stock in the Southern California Bight is much less depleted than previous assessments. To illustrate the influence of the Beverton-Holt steepness parameter and natural mortality rate on the model outcome, the STAT fixed both parameters at the values adopted for the 2007 and 2009 cowcod assessments (h = 0.6 and M = 0.055). Profiles over h and M (see the

“Parameter Uncertainty” section, below) also show how influential these parameters are on the current model outcomes.

With steepness and natural mortality parameters fixed at their pre-2010 values, the model predicts that cowcod will be at 35% of unfished spawning output in 2019 (Table 58, Figure 112, Figure 113). Stock status under the same model was 17% and 25% of unfished spawning output in 2000 and 2009, respectively.

Preliminary exploration of the effects of size-dependent multiple brooding

Given that several authors have reported multiple brooding in cowcod, we estimate the effect on total fecundity of a hypothetical size-dependent multiple brooding effect. The percentage of females producing 2 broods (versus 1) was modeled as a function of length (the “MB ogive”; Figure 114). In this sensitivity, 50% of cowcod were assumed to produce multiple broods at roughly 1.1 times the size at 50% maturity, based on the relative positions of the two ogives for chilipepper rockfish in southern California (*S. goodei*; see Lefebvre et al. 2018). The slope of the MB ogive was assumed equal to chilipepper in the southern CA region. Potential Annual Fecundity (PAF) at length was then defined as Brood Fecundity (the base model fecundity relationship) multiplied by (1 + proportion of multiple brooders at length). The derived estimates of PAF at length were fit using an allometric relationship, producing the following relationship:

$$PAF = (5.558 \times 10^{-7}) L^{3.5603}$$

In this hypothetical case, total annual fecundity is roughly doubled, but with little change in the fecundity-length exponent due to the similarity of the maturity ogive and the multiple brooding ogive. This assumption effectively doubles the estimates of spawning output, but leaves stock status unchanged as the difference between the weight-length exponent and fecundity-length exponent in both models is relatively small and the model is able to make a minor adjustment to the rate of natural mortality to compensate (Figure 115, Table 59).

During the STAR panel review, it was suggested that uncertainty in the percentage of females producing multiple broods could be bracketed by also considering the results for central California from Lefebvre et al. (2018), rather than limiting the analysis to the southern California results. The “MB ogive” (or “% MB” in the figures) for the central California area increases at larger sizes (Figure 116), which increases the exponent of the PAF-at-length relationship to roughly 4.3, and implies a faster increase in weight-specific fecundity with length (Dick et al. 2017).

$$PAF = (1.540 \times 10^{-8}) L^{4.3472}$$

The model with a shifted multiple-brood ogive (relative to maturity) is also somewhat similar to the base model in terms of stock depletion (Figure 117), but the increase in the estimated value of natural mortality is much more pronounced (M=0.094 versus M=0.088 in the base model). It appears that the model is able to increase M to offset the effects of size-dependent relative fecundity on stock status. Both processes (natural mortality and fecundity) are used to establish the “replacement line” of the stock-recruitment relationship, and are therefore confounded in the model. Since the cowcod base model relies on limited age data, it is unknown whether this shift in M is reasonable or simply the most efficient way to improve the fit given the set of estimable parameters available to the model during the fitting process. Given the paucity of age data, increases in M resulted in only a minor degradation of fit to age compositions (Table 59).

Both of these alternatives limit the maximum number of multiple broods to 2 per year per female, and are based on observations of chilipepper rockfish. Additional research on size-dependent fecundity and the rate of natural mortality is needed to better understand the implications of size-dependent fecundity for cowcod and other rockfish species (see research recommendations).

Uncertainty in historical catch reconstructions
As described in section 1.5, existing historical catch reconstructions may overestimate landings of cowcod because the earliest available species composition data reflect a time period when the commercial and recreational fisheries had moved farther from port and fished deeper waters than the historical fishery. The STAT fit the pre-STAR base model conditioning on catches that were ½ the values used in the pre-STAR base model prior to 1969. To also understand how the model responds to a larger catch stream, a scenario in which historical catches were double the base model values was also run.

The assumed magnitude of historical catch has a greater effect on the scale of initial spawning output than it does on current spawning output (Figure 118). If historical catches overestimate cowcod catch, then the probability that the stock is above target increases (Figure 119). Harvest rates under all three scenarios are considerably lower than peak rates estimated during the 1980s, which are relatively stable under all three historical harvest scenarios (Figure 120). Estimates of growth parameters are stable under each catch history, but estimated natural mortality rates increase to M=0.090 under the lower catch scenario, and decreases to M=0.067 under the higher catch scenario (Table 60).

Functional vs. Biological Maturity
The pre-STAR base model describes the proportion of mature females as a function of length, based on the "functional" maturity classification described in section 2.1.3.3. A model fit using the biological maturity ogive produces very similar results to the pre-STAR base model which uses the functional maturity relationship (Table 61, Figure 121, Figure 122).

2.6.2 Parameter Uncertainty

Likelihood profiles were performed on the post-STAR panel base model across three major sources of uncertainty: natural mortality (M), steepness (h), and initial recruitment (R0).

The profile over female natural mortality (M) with steepness fixed at 0.72 was conducted across a range of values (0.04 – 0.14 yr^{-1}) (Figure 123). All data types are consistent in preferring M values between roughly 0.07 and 0.1 (Figure 123). The model could have difficulty distinguishing between a stock with higher natural mortality (one possibility when there are fewer old fish) and a stock with lower M that was previously depleted (i.e. with fewer older individuals due to fishing). The oldest age observed by the NWFSC hook-and-line survey to date is around 40 years. The value of M has a much larger effect on stock status than it does on terminal biomass in the model (Figure 124, Figure 125). The range of depletion estimates for 2019 across likely values of M spans stock sizes just above the Minimum Stock Size Threshold to above 80% of unfished biomass (Figure 125). Note that when M is fixed at 0.055 (i.e. near the estimated value and prior mean of the 2013 assessment), the stock is below the management target in 2019.

Profiles over the Beverton-Holt steepness parameter (h) indicated that different values of steepness produced better fits, depending on the data type (Figure 126). The age data (in aggregate) are best fit by either high or low steepness values, and length data prefer higher values. The indices favor values in the range of 0.7, but changes in total likelihood are minor in all cases, suggesting that steepness is not well informed by the available data. Steepness has a strong effect on the rate of increase in spawning output after the stock fell to its lowest levels in the 1980s (Figure 127). However, stock status in 2019 is not greatly affected by the value of steepness (Figure 128), perhaps because M is estimated in each profile run, and is negatively correlated with steepness in the model.

The profile over the unfished equilibrium recruitment parameter (R_0) indicated that all data types preferred a similar value, except for the age data (Figure 129). Terminal values of spawning output are sensitive to the value of R_0 (Figure 130), but stock status relative to unfished spans a huge range of values, from below the MSST to almost unexploited levels (Figure 131). Natural mortality and R_0 are highly correlated in the base model (correlation >0.98).

2.6.3 Retrospective Analysis

A retrospective analysis was conducted on the post-STAR base model by sequentially removing 1 through 4 years of data from the base model starting with 2018. The model's estimate of unfished spawning output is sensitive to removal of NWFSC Hook-and-Line composition data (2014-2018), as these data inform asymptotic selectivity for the index (Figure 132). Earlier years of composition data from the Hook-and-Line survey are fit using a dome-shaped selectivity function, because the survey had not yet begun sampling inside the CCAs, where larger average fish sizes have been observed (see section 2.1.2.3).

2.6.4 Historical Analysis

As noted in section 2.2.4, both age-structured and surplus production (biomass dynamic) models have been used to assess the status of cowcod. This makes direct comparison of biomass time series difficult due to differences in model assumptions and units of spawning biomass. For this comparison, biomass from the 1999 assessment (Table 10 in Butler et al. 1999) is compared to summary biomass from the 2009 assessment, where the summation is over ages 11+ and is roughly equivalent to mature biomass under the previous growth and maturity schedules. The production function in the 2013 assessment used a time lag of 11 years, based on the best available maturity schedule at the time, and therefore biomass is implicitly age 11+ mature & vulnerable biomass. Comparisons from the post-STAR base model are based on age 10+ biomass, as this is roughly age at 50% maturity based on revised (2019) growth and maturity schedules. The 2005 assessment was excluded due to an error in the selectivity curve that was corrected in the 2007 assessment. Since the 2009 assessment was simply an update of the 2007 assessment, only the 2009 assessment is shown for clarity in the figures. The 2019 post-STAR base model was also run using M=0.055 and h=0.6, to illustrate how rates of increase in the base model are consistent with previous models under previous assumptions of stock productivity.

Unfished biomass (mature males and females) varies from roughly 3000-5000 mt among models (Figure 133). These point estimates fall within the 95% interval for unfished age 11+ biomass reported by Dick and MacCall (2013), and estimates of the overall scale of the population seem to be consistent. All models have also predicted a highly depleted stock in the late 1980s and early 1990s (Figure 134). The major difference between assessments has been the predicted rate of increase following this decline. Following the closure of the fishery, limited data have been available to inform assessment models about progress in stock recovery.

3 Reference Points

Trends in spawning output (billions of eggs or larvae) suggest a strong decline throughout the 1970s and early 1980s, followed by a rapid increase beginning in the 1990s (Figure 99). The predicted distribution of stock status in 2019 is centered above target biomass (40% of unfished spawning output) with an increasing trend. The southern California stock is estimated to be at 57% (~95% asymptotic intervals = 42%-72%) in 2019 (Figure 100). Unfished spawning output was estimated at 285 billion eggs (~95% asymptotic intervals = 235-334 million eggs; Table 54), and spawning output at the beginning of 2019 was estimated to be 163 billion eggs (~95% asymptotic intervals = 130–195 billion eggs; Table 54). Fishing intensity was near the $SPR_{50\%}$ target rate as early as the 1920s and 1930s, but dropped before and during WWII (Figure 103). Fishing intensity peaked in the 1980s, but declined prior to the closure and has remained negligible for nearly twenty years. The phase plot shows the relationship between fishing intensity and stock size, both relative to their target values of equilibrium $F(SPR_{50\%})$ and 40% of unfished biomass, respectively (Figure 104). The equilibrium yield curve is shifted left, as expected from the high fixed steepness, showing a more productive stock than the $SPR_{50\%}$ reference point would suggest (Figure 105, Table 54). The target stock size based on the biomass target ($SB_{40\%}$) is 114 billion eggs, which corresponds to a yield of 76 mt. Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $F(SPR_{50\%})$ is 73 mt.

4 Harvest Projections and Decision Tables

Projections of OFL (mt), ABC (mt), age 10+ biomass (mt), spawning output (billions of eggs), and depletion (% of unfished spawning output) are shown for the default harvest control rule in Table 62. Catch estimates for 2019 and 2020 are based on GMT recommendations (M. Mandrup, CDFW; pers. comm.), with 0.6 mt for commercial and 2.5 mt for recreational fleets. Projections assume a constant allocation among fleets equal to the recommended catch for 2019 and 2020 (19.35% commercial, 80.65% commercial).

High and low states of nature for a decision table (Table 63) were agreed upon during the STAR panel review. The low state of nature set commercial length at 50% selectivity ($L_{50\%}$) at 35 cm with an M of 0.055 (the value of M used in the previous assessment) and the high state of nature at a selectivity of 55 cm with M = 0.098 (the median of the Hamel prior on M given a maximum age of 55). The base model assumed a commercial fleet length at 50% selectivity of 45.6 cm, equal to the maturity ogive, and estimated M = 0.088. Alternative management strategies (catch streams) were identified as the default ABC harvest control rule under each state of nature. Proxy MSY yields vary by state of nature. The base model’s SPR proxy for MSY is 73 mt, while the proxy MSY yields given the low and high states of nature are 58 mt and 86 mt, respectively.

5 Regional Management Considerations

The majority of cowcod biomass is estimated to be in the SCB, but majority of catch (although very minimal, overall) is currently taken by commercial fisheries north of Point Conception. As catch limits for cowcod increase over time, yield relative to regional abundance should be monitored. Otherwise, spatial variation in fishing mortality rates could cause a reduction in maximum sustainable yield for the assessed area (e.g. Ralston and O’Farrell 2008). Currently, OFL contributions from the northern California region are highly uncertain, as they are based on a data-poor methods (DB-SRA) rather than a stock assessment.

6 Research Needs

Specific recommendations for the next cowcod assessment:

1. Evaluating how to structure the NWFSC Hook-and-Line survey index given its expansion into the CCA, also independent analysis of information content in NWFSC Hook-and-Line survey.
2. There are a number of improved data collections that would be beneficial to the next assessment of cowcod.
    - Continue to conduct the NWFSC Hook-and-Line survey which was an important source of fishery independent data for cowcod.
    - Having multiple absolute abundance observations for cowcod from visual survey are important to understanding the stock size and status of the stock.
    - Given the lack of biological data for cowcod, it is critical to improve and expand collection of length and age data for fishery and fishery independent data sources.
    - The majority of ages available for cowcod were read by a single age reader. As data collection increases having additional age double reads and age validation information would be beneficial.
    - Rockfish species, particularly in southern California waters, have been observed to produce multiple broods within a single year. Collecting biological data to better understand the potential fecundity for cowcod across size and is important to understanding the reproductive potential of the population
3. The WCGBTS provides some abundance information for smaller cowcod. Adding sampling within the CCA while continuing with a sampling intensity of over 700 cells per year (a four-vessel survey, as opposed to the two-vessel survey conducted in 2019) would provide improved information on the abundance of these size and age classes.
4. Increased spatiotemporal sampling around Pt. Conception would aid in identifing stock boundaries.

General recommendations for all assessments:

1. Continued and improved data collection for West Coast groundfish stocks. The NWFSC Hook-and-Line survey offers important data on species that may be infrequently encountered by the NWFSC WCGBTS. Expanding the WCGBTS into the CCAs would improve index and compositional information for a number of stocks in the Southern California Bight.
2. Work with Mexico to get information on the densities and compositions of stocks in their waters, in particular in areas directly south of the California-Mexico border, would improve our understanding of ranges, dynamics and status of stocks which extend into Mexico.
3. Examine uncertainties around historical catch data and methods for incorporating into the assessment.
4. Explore alternate stock recruitment relationships.

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9 Auxiliary Files

Stock Synthesis files:

`ss.exe (version V3.30.13.09-opt, compiled 2019-06-30)`

`cowcod2019.ctl`

`cowcod2019.dat`

`forecast.ss`

`starter.ss`

`Report.sso`

10 Tables

Table 1: Annual estimates of total mortality, overfishing limit (OFL), acceptable biological catch (ABC), annual catch limit (ACL), and annual catch target (ACT) for cowcod in U.S. waters south of 40° 10′ N. latitude, 2009-2018. Units are metric tons for total mortality and harvest specifications.

Year	OFL	ABC	ACL	ACT	Total Mortality	Source of Total Mortality Estimate
2018	71	64	10	4	1	Approximation (approved by GMT)
2017	70	63	10	4	1.46	WCGOP GEMM Report + RecFIN
2016	68	62	10	--	1.29	WCGOP GEMM Report + RecFIN
2015	67	60	10	--	1.41	WCGOP GEMM Report + RecFIN
2014	12	9	3	--	1.09	WCGOP GEMM Report + RecFIN
2013	11	9	3	--	1.79	WCGOP GEMM Report + RecFIN
2012	13	8	3	--	1.04	WCGOP GEMM Report + RecFIN
2011	13	8	3	--	1.45	WCGOP GEMM Report + RecFIN
2010	--	14	4*	--	0.81	WCGOP GEMM Report + RecFIN
2009	--	13	4*	--	0.86	WCGOP GEMM Report + RecFIN

* The OFL/ABC/ACL framework started in 2011; values in ACL column for 2010-11 are Optimum Yields.

Table 2: OFL and ABC contributions, by region, to the total OFL and ABC for cowcod. Values for southern California are based on the 2013 assessment, and values from 40 10' N lat to 36 N lat are derived from the Fmsy proxy for southern California applied to biomass estimates from the data-limited model for northern California. See Appendix C of Dick and MacCall (2013) for details.

	40 10' to 36 N lat		South of 36 N lat	
	2017	2018	2017	2018
OFL	11.6	12.0	57.9	59.4
ABC	9.7	10.0	52.9	54.2

Table 3: Total mortality (mt) by fleet, 2009 – 2018. Sources: WCGOP and RecFIN.

Year	Commercial	Recreational	Total
2009	0.66	0.21	0.86
2010	0.42	0.40	0.81
2011	0.17	1.28	1.45
2012	0.32	0.72	1.04
2013	0.41	1.38	1.79
2014	0.43	0.66	1.09
2015	0.97	0.44	1.41
2016	0.61	0.68	1.29
2017	0.95	0.51	1.46
2018	1.00	0.58	1.58

Table 4: Estimated cowcod removals (1900-1959) in the Southern California Bight, by year and data source

Year	Dick et al. 2007 Comm. Recon.	CALCOM	WCGOP GEMM Report	Ralston et al. Rec. Recon.	RecFIN	Total Commercial	Total Recreational	TOTAL
1900	0.01					0.01		0.01
1901	5.34					5.34		5.34
1902	10.68					10.68		10.68
1903	16.01					16.01		16.01
1904	21.35					21.35		21.35
1905	26.68					26.68		26.68
1906	32.02					32.02		32.02
1907	37.35					37.35		37.35
1908	42.68					42.68		42.68
1909	48.02					48.02		48.02
1910	53.35					53.35		53.35
1911	58.69					58.69		58.69
1912	64.02					64.02		64.02
1913	69.35					69.35		69.35
1914	74.69					74.69		74.69
1915	80.02					80.02		80.02
1916	85.36					85.36		85.36
1917	137.73					137.73		137.73
1918	125.59					125.59		125.59
1919	75.10					75.10		75.10
1920	81.57					81.57		81.57
1921	71.26					71.26		71.26
1922	70.11					70.11		70.11
1923	93.94					93.94		93.94
1924	125.94					125.94		125.94
1925	138.15					138.15		138.15
1926	171.48					171.48		171.48
1927	142.30					142.30		142.30
1928	111.30			0.05		111.30	0.05	111.35
1929	102.48			0.11		102.48	0.11	102.59
1930	126.78			0.16		126.78	0.16	126.94
1931	160.80			0.22		160.80	0.22	161.02
1932	109.27			0.27		109.27	0.27	109.54
1933	81.64			0.33		81.64	0.33	81.97
1934	70.36			0.38		70.36	0.38	70.74
1935	52.56			0.44		52.56	0.44	53.00
1936	20.19			0.44		20.19	0.44	20.63
1937	24.22			0.66		24.22	0.66	24.88
1938	18.08			0.63		18.08	0.63	18.71
1939	21.50			0.51		21.50	0.51	22.01
1940	23.28			0.41		23.28	0.41	23.69
1941	29.10			0.38		29.10	0.38	29.48
1942	10.40			0.20		10.40	0.20	10.60
1943	12.18			0.19		12.18	0.19	12.37
1944	1.83			0.16		1.83	0.16	1.99
1945	4.38			0.21		4.38	0.21	4.59
1946	11.30			0.36		11.30	0.36	11.66
1947	17.58			1.18		17.58	1.18	18.76
1948	26.87			3.05		26.87	3.05	29.92
1949	35.05			3.63		35.05	3.63	38.68
1950	39.37			4.63		39.37	4.63	44.00
1951	45.57			3.62		45.57	3.62	49.19
1952	31.05			5.62		31.05	5.62	36.67
1953	24.88			6.33		24.88	6.33	31.21
1954	34.05			12.76		34.05	12.76	46.81
1955	27.62			24.43		27.62	24.43	52.05
1956	37.80			27.37		37.80	27.37	65.17
1957	38.43			17.25		38.43	17.25	55.68
1958	43.54			12.82		43.54	12.82	56.36
1959	45.09			7.21		45.09	7.21	52.30

Table 5: Estimated cowcod removals (1960-2018) in the Southern California Bight, by year and data source.

Year	Dick et al. 2007 Comm. Recon.	CALCOM	WCGOP GEMM Report	Ralston et al. Rec. Recon.	RecFIN	Total Commercial	Total Recreational	TOTAL
1960	49.18			7.87		49.18	7.87	57.05
1961	50.05			9.99		50.05	9.99	60.04
1962	37.92			10.11		37.92	10.11	48.03
1963	47.21			10.13		47.21	10.13	57.34
1964	36.07			15.82		36.07	15.82	51.89
1965	50.97			19.11		50.97	19.11	70.08
1966	47.41			29.22		47.41	29.22	76.63
1967	63.22			39.15		63.22	39.15	102.37
1968	63.87			41.15		63.87	41.15	105.02
1969		95.00		30.13		95.00	30.13	125.13
1970		55.93		39.92		55.93	39.92	95.85
1971		68.07		38.03		68.07	38.03	106.10
1972		102.52		50.10		102.52	50.10	152.62
1973		108.81		62.98		108.81	62.98	171.79
1974		114.28		69.38		114.28	69.38	183.66
1975		112.49		70.06		112.49	70.06	182.55
1976		131.38		57.97		131.38	57.97	189.35
1977		132.46		58.77		132.46	58.77	191.23
1978		147.77		55.41		147.77	55.41	203.18
1979		187.55		74.60		187.55	74.60	262.15
1980		142.65		80.98		142.65	80.98	223.63
1981		189.42			26.55	189.42	26.55	215.97
1982		230.52			96.99	230.52	96.99	327.51
1983		161.92			15.13	161.92	15.13	177.05
1984		206.66			21.22	206.66	21.22	227.88
1985		172.12			35.99	172.12	35.99	208.11
1986		148.37			45.99	148.37	45.99	194.36
1987		76.64			29.14	76.64	29.14	105.78
1988		86.62			13.91	86.62	13.91	100.53
1989		17.87			20.79	17.87	20.79	38.66
1990		10.41			20.06	10.41	20.06	30.46
1991		7.10			19.32	7.10	19.32	26.42
1992		17.22			18.58	17.22	18.58	35.80
1993		14.85			9.68	14.85	9.68	24.54
1994		13.63			26.01	13.63	26.01	39.65
1995		23.30			1.75	23.30	1.75	25.05
1996		24.58			5.36	24.58	5.36	29.93
1997		7.30			1.85	7.30	1.85	9.15
1998		1.21			2.81	1.21	2.81	4.03
1999		3.47			3.77	3.47	3.77	7.24
2000		0.45			4.49	0.45	4.49	4.94
2001			2.72		0.49	2.72	0.49	3.20
2002			2.72		0.49	2.72	0.49	3.20
2003			0.18		0.48	0.18	0.48	0.66
2004			0.81		0.45	0.81	0.45	1.27
2005			0.68		0.32	0.68	0.32	1.01
2006			0.92		0.05	0.92	0.05	0.97
2007			1.16		0.24	1.16	0.24	1.40
2008			0.26		0.27	0.26	0.27	0.53
2009			0.66		0.21	0.66	0.21	0.86
2010			0.42		0.40	0.42	0.40	0.81
2011			0.17		1.28	0.17	1.28	1.45
2012			0.32		0.72	0.32	0.72	1.04
2013			0.41		1.38	0.41	1.38	1.79
2014			0.43		0.66	0.43	0.66	1.09
2015			0.97		0.44	0.97	0.44	1.41
2016			0.61		0.68	0.61	0.68	1.29
2017			0.95		0.51	0.95	0.51	1.46
2018			1.00		0.58	1.00	0.58	1.58

Table 6: Regional rockfish landings (metric tons) from CDF&G Fish Bulletin No. 105 (1958) and the NMFS SWFSC ERD ERDDAP Data Server (https://coastwatch.pfeg.noaa.gov/erddap/index.html).

	CDF&G Fish Bulletin No. 105			ERDDAP Data Server					
year	Southern	Central	Northern	San Diego	Los Angeles	Santa Barbara	Monterey	San Francisco	Eureka
1916	966.62	1258.10	6.48						
1917	1559.70	1953.81	12.74						
1918	1422.29	2286.85	29.72						
1919	850.46	1591.24	6.84						
1920	923.72	1622.13	9.28						
1921	806.94	1339.01	13.91						
1922	794.00	1151.53	10.37						
1923	1063.85	1244.55	3.39						
1924	1426.24	715.81	9.29						
1925	1564.44	895.04	30.12						
1926	1941.86	1448.95	29.71						
1927	1611.49	1230.84	56.40						
1928	1373.50	1489.87	48.65	554.76	769.85	46.65	1037.07	452.80	48.65
1929	1389.53	1231.60	116.94	641.80	687.26	44.60	744.37	487.23	116.94
1930	1415.63	1747.90	113.84	477.91	906.13	21.15	1281.84	466.06	113.84
1931	1617.81	1635.24	48.06	400.30	1182.35	30.91	1162.02	473.23	48.06
1932	1135.48	1380.64	40.48	298.47	797.37	34.76	929.54	451.10	40.48
1933	907.47	1250.11	14.12	252.63	588.30	46.54	734.27	515.84	14.12
1934	857.00	1178.65	52.70	129.53	510.38	127.60	762.08	413.50	57.76
1935	741.23	1377.44	72.72	77.85	373.92	177.65	975.39	402.05	72.72
1936	424.05	1579.23	85.01	69.72	122.80	181.88	1188.37	390.87	85.01
1937	460.65	1425.30	60.52	65.18	156.84	166.26	954.94	470.30	60.52
1938	309.18	1092.21	248.39	33.82	126.04	72.76	838.72	253.49	248.15
1939	389.66	779.56	342.66	92.01	140.83	91.19	602.61	176.25	341.65
1940	396.32	958.58	264.72	66.63	153.11	136.40	752.37	206.21	264.06
1941	470.11	867.78	206.88	42.15	202.95	131.57	662.24	205.29	206.26
1942	192.96	329.34	123.36	10.13	74.46	38.27	297.51	31.76	123.36
1943	226.43	402.58	623.90	5.17	89.07	38.61	310.60	91.98	623.75
1944	43.38	363.18	2506.52	4.63	10.34	22.14	331.89	31.28	2505.76
1945	92.92	617.92	5315.58	4.56	26.97	44.95	533.96	84.16	5313.17
1946	161.19	608.31	4293.16	8.71	79.60	48.78	508.01	100.30	4005.49
1947	185.46	785.98	2883.46	8.79	131.60	26.85	690.04	95.94	2496.14
1948	287.68	886.56	1792.71	24.12	200.08	36.11	748.25	122.98	1594.18
1949	412.09	847.60	1492.66	36.64	258.88	61.88	611.25	236.35	1274.85
1950	427.87	1555.09	1698.35	33.67	294.00	85.96	1106.22	448.88	1555.57
1951	470.81	2440.55	2074.55	14.55	328.93	121.63	1440.72	999.83	2051.35
1952	366.25	3301.04	1195.31	9.47	218.59	108.15	1676.93	1624.11	1089.52
1953	298.74	3845.54	1402.36	14.71	179.44	88.66	1953.92	1891.82	1335.43
1954	583.02	3702.04	1448.42	14.10	247.22	263.09	2348.59	1353.71	1262.75
1955	1810.39	2595.75	1346.19	48.45	199.07	1532.34	1886.96	708.79	1224.17
1956	1481.43	3882.16	1414.68	35.07	257.45	1168.67	2547.45	1334.71	1304.76
1957				32.08	227.86	1522.51	2481.72	1278.15	1675.42
1958				141.03	228.89	1425.89	2656.71	1902.85	1609.67
1959				94.83	264.46	671.00	2130.96	2232.76	1365.33
1960				89.91	238.78	1280.67	1616.42	1492.34	1299.30
1961				98.52	174.94	1052.77	1464.21	1007.77	884.82
1962				70.09	172.42	916.79	1294.95	902.29	808.21
1963				112.15	220.54	1180.38	1118.88	1069.85	1331.18
1964				87.01	207.47	718.63	986.50	793.93	767.33
1965				132.79	248.71	786.04	1187.70	714.95	1081.89
1966				136.44	226.38	1026.92	1535.84	731.57	821.78
1967				167.07	250.56	1313.09	1155.41	388.93	1074.81
1968				126.06	242.67	1187.51	1086.20	264.96	1271.15

Table 7: Data and derived quantities used to develop ratio estimates of total rockfish landings in the SCB. Gray shading indicates ratio estimate (see text for details). "Ratio years" shows the range of years over which ratio estimates were calculated. Sources include the ERDDAP Data Server and several volumes of the CDF&G Fish Bulletin (FB) series.

	FB 105	NMFS ERD live-access server			foreign catch	Major SLO Ports		Source of	adjusted	ratio
year	Southern	San Diego	Los Angeles	Santa Barbara	landed in U.S.	Morro Bay	Avila	SLO catch	Santa Barbara	years
1916	966.62	330.18	620.06		7.11			ratio	9.27	1928-33
1917	1559.70	532.76	1000.51		11.47			ratio	14.96	1928-33
1918	1422.29	485.83	912.36		10.46			ratio	13.64	1928-33
1919	850.46	290.50	545.55		6.26			ratio	8.16	1928-33
1920	923.72	315.52	592.54		6.80			ratio	8.86	1928-33
1921	806.94	275.63	517.63		5.94			ratio	7.74	1928-33
1922	794.00	271.21	509.33		5.84			ratio	7.61	1928-33
1923	1063.85	363.39	682.43		7.83			ratio	10.20	1928-33
1924	1426.24	487.18	914.90		10.49			ratio	13.68	1928-33
1925	1564.44	534.38	1003.54		11.51			ratio	15.00	1928-33
1926	1941.86	663.30	1245.65		14.29			ratio	18.62	1928-33
1927	1611.49	550.45	1033.73		11.86			ratio	15.45	1928-33
1928	1373.50	554.76	769.85	46.65	2.24	17.44	13.90	ratio	15.31	1949-51
1929	1389.53	641.80	687.26	44.60	15.86	16.68	13.28	ratio	14.64	1949-51
1930	1415.63	477.91	906.13	21.15	10.44	7.91	6.30	ratio	6.94	1949-51
1931	1617.81	400.30	1182.35	30.91	4.25	11.56	9.21	ratio	10.14	1949-51
1932	1135.48	298.47	797.37	34.76	4.88	13.00	10.35	ratio	11.41	1949-51
1933	907.47	252.63	588.30	46.54	19.99	17.40	13.86	ratio	15.27	1949-51
1934	857.00	129.53	510.38	127.60	89.49	47.72	38.01	ratio	41.88	1949-51
1935	741.23	77.85	373.92	177.65	111.81	66.43	52.92	ratio	58.30	1949-51
1936	424.05	69.72	122.80	181.88	49.65	68.02	54.18	ratio	59.69	1949-51
1937	460.65	65.18	156.84	166.26	72.37	62.17	49.52	ratio	54.56	1949-51
1938	309.18	33.82	126.04	72.76	76.56	27.21	21.67	ratio	23.88	1949-51
1939	389.66	92.01	140.83	91.19	65.63	34.10	27.16	ratio	29.93	1949-51
1940	396.32	66.63	153.11	136.40	40.18	51.01	40.63	ratio	44.76	1949-51
1941	470.11	42.15	202.95	131.57	93.44	49.20	39.19	ratio	43.18	1949-51
1942	192.96	10.13	74.46	38.27	70.11	14.31	11.40	ratio	12.56	1949-51
1943	226.43	5.17	89.07	38.61	93.57	14.44	11.50	ratio	12.67	1949-51
1944	43.38	4.63	10.34	22.14	6.27	8.28	6.60	ratio	7.27	1949-51
1945	92.92	4.56	26.97	44.95	16.45	16.81	13.39	ratio	14.75	1949-51
1946	161.19	8.71	79.60	48.78	24.10	18.24	14.53	ratio	16.01	1949-51
1947	185.46	8.79	131.60	26.85	18.22	10.04	8.00	ratio	8.81	1949-51
1948	287.68	24.12	200.08	36.11	27.37	13.50	10.76	ratio	11.85	1949-51
1949	412.09	36.64	258.88	61.88	54.69	20.62	22.95	FB 80	18.30	
1950	427.87	33.67	294.00	85.96	14.24	41.23	28.68	FB 86	16.05	
1951	470.81	14.55	328.93	121.63	5.71	38.91	28.63	FB 89	54.08	
1952	366.25	9.47	218.59	108.15	30.04	32.53	25.91	FB 95, ratio	49.72	1949-51
1953	298.74	14.71	179.44	88.66	15.94	56.38	5.04	FB 102, ratio	27.23	1954-56
1954	583.02	14.10	247.22	263.09	58.61	183.91	43.30	FB 102	35.88	
1955	1810.39	48.45	199.07	1532.34	30.52	1393.82	119.73	FB 105	18.79	
1956	1481.43	35.07	257.45	1168.67	20.23	1026.90	69.94	FB 105	71.83	
1957		32.08	227.86	1522.51		1298.20	71.55	FB 108	152.76	
1958		141.03	228.89	1425.89		1136.08	88.64	FB 108, ratio	201.17	1954-57
1959		94.83	264.46	671.00		470.07	36.68	FB 111, ratio	164.25	1954-57
1960		89.91	238.78	1280.67		910.70	71.06	FB 117, ratio	298.92	1954-57
1961		98.52	174.94	1052.77		550.97	42.99	FB 121, ratio	458.81	1954-57
1962		70.09	172.42	916.79		602.72	56.92	FB 125	257.15	
1963		112.15	220.54	1180.38		652.24	230.78	FB 129	297.36	
1964		87.01	207.47	718.63		467.92	114.14	FB 132	136.56	
1965		132.79	248.71	786.04		453.99	40.04	FB 135	292.00	
1966		136.44	226.38	1026.92		666.11	82.68	FB 138	278.13	
1967		167.07	250.56	1313.09		721.16	96.73	FB 144	495.20	
1968		126.06	242.67	1187.51		612.31	34.81	FB 149	540.39	

Table 8: Estimated percentages (by weight) of cowcod in rockfish landings based on 5-year averages (1984-1988). Estimates for the Los Angeles, San Diego, and Santa Barbara (1916-1943) strata are from their respective hook-and-line fisheries. The estimate for the Santa Barbara (1944-1968) stratum is based on the combined trawl and hook-and-line fisheries.

Region (time period)	% cowcod, 1984-88
Santa Barbara (1916-1943)	4.95%
Santa Barbara (1944-1968)	5.56%
Los Angeles (1916-1968)	12.85%
San Diego (1916-1968)	2.10%

Table 9: Number of port samples and number of sampled rockfish (RF) by stratum (year, gear, port complex) for the five earliest-sampled years in the SCB (1984-1988).

Year	SB Hook & Line		SB Trawl		LA Hook & Line		SD Hook & Line	
	# samp.	# RF	# samp.	# RF	# samp.	# RF	# samp.	# RF
1984	11	297	11	366	16	510	17	467
1985	23	632	6	196	39	1113	18	739
1986	43	1335	6	267	38	1226	71	2635
1987	3	99	6	288	37	1422	55	2003
1988	15	537	1	46	9	316	25	848

Table 10: Percentage by weight of species landed in market category 245 (the "cowcod" market category), north and south of Point Conception, 1984-2000. Commercial sampling of ports south of Point Conception was very limited prior to 1984.

Rockfish Species	No_CA	So_CA	All_CA
Cowcod	84.2%	85.5%	85.3%
Bronzespotted	0.1%	8.9%	7.4%
Vermilion	0.5%	3.2%	2.7%
Chilipepper	10.6%	0.7%	2.4%
Yelloweye	0.0%	0.7%	0.6%
Bocaccio	2.8%	0.0%	0.5%
Pinkrose	0.1%	0.4%	0.4%
Canary	0.0%	0.3%	0.3%
Greenspotted	0.3%	0.2%	0.2%
Other	1.6%	0.1%	0.4%
Grand Total	100.0%	100.0%	100.0%

Table 11: Percentage of commercial cowcod landings by market category and region (north/south of Point Conception) in California (1984-2000).

Market Category	NoCA	SoCA	Statewide
959	34.1%	45.9%	42.1%
245	14.1%	32.7%	26.7%
250	33.3%	17.1%	22.3%
956	6.2%	2.8%	3.9%
254	7.1%	0.0%	2.3%
960	3.4%	1.4%	2.1%
Other	1.8%	0.1%	0.7%
Total	100%	100%	100%

Table 12: Annual coefficients of variation (CV) for landed catch of species making up roughly 90% of rockfish landings in California (shaded columns), 1984-1990. Less common species (cowcod, POP, and Bronzespotted rockfish) are shown for comparison.

	CV of Species-Year Landings Distribution											
YEAR	WDOW	BCAC	CLPR	BANK	YTRK	BLGL	DBRK	CNRY	SNOS	CWCD	POP	BRNZ
1984	8%	14%	17%	24%	48%	38%	37%	45%	24%	49%	77%	75%
1985	6%	12%	15%	22%	39%	32%	31%	41%	20%	40%	66%	58%
1986	7%	12%	16%	22%	41%	29%	32%	42%	21%	42%	66%	58%
1987	9%	15%	19%	26%	52%	31%	37%	49%	26%	55%	76%	69%
1988	8%	13%	16%	23%	45%	22%	28%	42%	22%	47%	59%	63%
1989	10%	14%	17%	25%	49%	25%	32%	44%	26%	48%	66%	64%
1990	8%	14%	17%	25%	47%	26%	30%	42%	23%	51%	60%	72%

Table 13: Annual coefficients of variation (CV) for statewide cowcod landings by year and gear group, based on results from a model-based approach to catch estimation (Grunloh et al., in prep.).

Year	CV.trawl	CV.line	CV.net
1984	73%	54%	70%
1985	73%	48%	60%
1986	94%	52%	57%
1987	122%	47%	64%
1988	86%	48%	80%
1989	86%	47%	102%
1990	90%	49%	99%

Table 14: Samples sizes (number of fish and number of samples) for Southern California expanded commercial length composition data by year, gear group, port complex, and market category. Current length expansion procedure for California excludes strata with fewer than 10 fish. Source: CALCOM, 2019.

year	gear_grp	port_complex	mark_cat	num.fish	num.samp
1983	NET	OSD	245	117	5
1983	NET	OSD	250	66	7
1983	NET	OSD	959	22	4
1983	TWL	OSB	250	14	3
1984	HKL	OLA	250	14	2
1984	HKL	OLA	956	10	1
1984	HKL	OLA	959	31	3
1984	HKL	OSB	959	13	4
1984	NET	OLA	250	12	1
1984	NET	OLA	956	12	1
1984	NET	OLA	959	89	10
1984	NET	OSB	959	31	3
1984	NET	OSD	245	67	5
1984	NET	OSD	250	66	10
1984	NET	OSD	959	29	7
1984	TWL	OSB	245	17	1
1984	TWL	OSB	250	24	2
1985	HKL	OLA	250	10	2
1985	HKL	OLA	959	72	8
1985	HKL	OSB	959	15	1
1985	NET	OLA	250	65	10
1985	NET	OLA	956	21	4
1985	NET	OLA	959	265	23
1985	NET	OSB	959	14	8
1985	NET	OSD	245	14	1
1985	NET	OSD	250	17	9
1985	NET	OSD	959	10	2
1986	HKL	OLA	959	11	7
1986	NET	OLA	959	235	19
1986	NET	OSD	245	139	10
1986	NET	OSD	960	16	1
1987	HKL	OLA	959	28	7
1987	NET	OLA	959	106	12
1987	NET	OSD	245	14	1
1987	NET	OSD	250	18	5
1988	HKL	OSB	959	25	2
1988	HKL	OSD	956	17	1
1988	NET	OLA	959	16	2
1989	HKL	OSB	245	24	1
1989	NET	OLA	959	10	2
1992	HKL	OSD	250	18	1
1992	NET	OSD	959	32	3
1995	NET	OSB	245	22	2
1996	HKL	OSB	959	12	8
1996	NET	OSB	959	11	2
1997	HKL	OSB	959	15	8

Table 15: Samples sizes (number of fish and number of samples) for expanded commercial length composition data by year and gear group in Southern California. Current length expansion procedure for California excludes strata with fewer than 10 fish. Source: CALCOM, 2019.

	NUMBER OF FISH			NUMBER OF SAMPLES				
YEAR	HKL	NET	TWL	HKL	NET	TWL	TOTAL FISH	TOTAL SAMPLES
1983		205	14		16	3	219	19
1984	68	306	41	10	37	3	415	50
1985	97	406		11	57		503	68
1986	11	390		7	30		401	37
1987	28	138		7	18		166	25
1988	42	16		3	2		58	5
1989	24	10		1	2		34	3
1992	18	32		1	3		50	4
1995		22			2		22	2
1996	12	11		8	2		23	10
1997	15			8			15	8
Grand Total	315	1536	55	56	169	6	1906	231

Table 16: Otoliths collected from commercial and recreational fleets by Butler et al. (1999). Fish with missing length information were excluded from analyses.

	Commercial				Recreational				
Year	Male	Female	Unknown	Comm. Total	Male	Female	Unknown	Rec. Total	Grand Total
1975					0	0	17	17	17
1976					2	7	51	60	60
1977					10	10	9	29	29
1978					10	7	2	19	19
1979					0	0	1	1	1
1980					1	0	0	1	1
1981					1	0	1	2	2
1982	2	2	0	4					4
1983	1	2	0	3					3
1984	20	13	0	33					33
1985	25	30	1	56					56
1986	15	16	0	31					31
Grand Total	**63**	**63**	**1**	**127**	**24**	**24**	**81**	**129**	**256**

Table 17: Additional commercial otoliths collected since 2011, when a small quota was allocated to the trawl fleet. These otoliths have not been aged due to time constraints.

Year	Otoliths
2012	8
2013	34
2014	24
2015	56
2016	60
2017	16
Grand Total	**198**

Table 18: Number of sampled trips and measured fish from onboard CPFV observer surveys in southern California, 1975-1978 (Collins and Crooke, unpublished manuscript).

Year	Number of Trips	Number of Fish Lengths
1975	74	293
1976	121	363
1977	75	453
1978	66	354
Total	**336**	**1463**

Table 19: Total tows and positive tows for cowcod in the NWFSC WCGBT Survey, by year and region (North of 40 10' N lat., Point Conception to Cape Mendocino, and the Southern California Bight).

	North of 4010		Pt. Conception to Cape Mendocino		Southern CA		Coastwide	
Year	Tows	Positive Tows	Tows	Postive Tows	Tows	Positive Tows	Total Tows	Total Pos. Tows
2003	343	1	127	3	72	3	542	7
2004	253	0	134	16	84	5	471	21
2005	356	2	163	13	118	6	637	21
2006	339	0	177	5	125	6	641	11
2007	389	0	173	3	125	6	687	9
2008	352	0	207	2	120	9	679	11
2009	357	0	202	7	122	7	681	14
2010	376	1	203	11	135	18	714	30
2011	373	0	198	12	124	8	695	20
2012	379	0	187	13	132	11	698	24
2013	281	0	124	5	64	7	469	12
2014	367	0	190	11	125	11	682	22
2015	338	0	211	8	119	9	668	17
2016	379	1	179	20	134	11	692	32
2017	385	0	192	10	130	7	707	17
2018	367	4	201	19	134	9	702	32
Grand Total	5634	9	2868	158	1863	133	10365	300

Table 20: Number of cowcod lengths by area, year, and size class from the NWFSC WCGBT Survey.

	Southern California		Northern California	
Year	<50 cm	50+ cm	<50 cm	50+ cm
2003	6	2	5	0
2004	12	0	51	1
2005	11	0	18	1
2006	19	0	5	1
2007	15	5	5	0
2008	12	0	3	1
2009	7	2	8	6
2010	42	1	13	4
2011	12	0	16	1
2012	37	3	28	5
2013	13	1	12	0
2014	43	0	34	0
2015	17	1	12	0
2016	18	6	39	2
2017	12	2	17	3
2018	21	6	85	4
Total	297	29	351	29

Table 21: Number of cowcod ages by area, year, and sex from the NWFSC WCGBT Survey.

		Sex			
Area	Year	Female	Male	Unknown	Total
Northern CA	2003	1	4	0	5
	2004	14	7	0	21
	2005	7	5	2	14
	2006	4	2	0	6
	2007	2	2	0	4
	2008	0	2	2	4
	2009	8	6	0	14
	2010	7	4	6	17
	2011	9	8	0	17
	2012	17	16	0	33
	2013	7	1	1	9
	2014	19	15	0	34
	2015	8	4	0	12
	2017	6	11	3	20
NoCA Total		109	87	14	210
Southern CA	2003	5	3	0	8
	2004	2	1	0	3
	2005	4	6	1	11
	2006	10	9	0	19
	2007	10	7	0	17
	2008	4	7	1	12
	2009	2	3	3	8
	2010	8	25	8	41
	2011	2	7	3	12
	2012	14	25	1	40
	2013	0	7	7	14
	2014	20	20	1	41
	2015	4	14	0	18
	2017	4	10	0	14
SoCA Total		89	144	25	258
Grand Total		198	231	39	468

Table 22: Number of NWFSC WCGBT Survey tows and positive tows used for the southern California design-based index. Depth strata are 55-155m, 155-250m, and 250-350m.

	Number of Tows			Positive Tows		
Year	shallow	mid	deep	shallow	mid	deep
2003	19	9	7	1	2	0
2004	21	8	9	2	3	0
2005	29	5	15	4	2	0
2006	27	13	8	3	2	1
2007	34	13	11	5	1	0
2008	34	11	5	5	4	0
2009	32	20	11	3	3	1
2010	32	16	13	13	5	0
2011	32	14	10	7	1	0
2012	31	21	8	3	7	1
2013	17	7	7	4	3	0
2014	25	23	8	1	7	3
2015	28	21	7	3	4	2
2016	34	16	10	6	5	0
2017	28	17	15	3	4	0
2018	34	16	9	2	5	1

Table 23: Binomial GLM model selection based on the NWFSC WCGBT Survey data.

Model description	AIC	AIC – min(AIC)
Intercept only	705.2	25.0
Year	719.9	39.7
DepthBin	680.2	0
Year + DepthBin	694.8	14.6
Year + DepthBin + Year:DepthBin	701.1	20.8

Table 24: Binomial GLM index of relative abundance based on the NWFSC WCGBT Survey.

Year	Index	log.SE
2003	0.0813	0.488
2004	0.1199	0.4297
2005	0.1284	0.3881
2006	0.1033	0.4043
2007	0.0731	0.4411
2008	0.1547	0.3372
2009	0.0714	0.4115
2010	0.2488	0.246
2011	0.1219	0.3558
2012	0.1292	0.329
2013	0.1761	0.3825
2014	0.1475	0.3092
2015	0.1211	0.3436
2016	0.1242	0.3466
2017	0.0988	0.3832
2018	0.0958	0.3811

Table 25: Number of hauls (a) and number of hauls catching at least one cowcod (b) by shift-year and station for Orange County Sanitation District trawl data that were incorporated into the combined Los Angeles/Orange County Sanitation District index.

(a) Number of Hauls

	Station								
Shift-Year	T1	T2	T3	T4	T5	T10	T12	T14	Total
1970	3	3	3	3	3	0	0	0	15
1971	3	3	3	2	3	0	0	0	14
1972	3	3	3	3	3	0	0	0	15
1973	3	3	3	3	3	0	0	0	15
1974	3	3	3	3	3	0	0	0	15
1975	3	3	3	3	3	0	0	0	15
1976	3	3	3	3	3	0	0	0	15
1977	3	3	3	3	3	0	0	0	15
1978	3	3	3	3	3	0	0	0	15
1979	3	3	3	3	3	3	0	0	18
1980	3	3	3	3	3	3	0	0	18
1981	3	3	3	3	3	3	0	0	18
1982	3	3	3	3	3	3	0	0	18
1983	3	3	3	3	3	3	0	0	18
1984	3	3	3	3	3	3	0	0	18
1985	4	4	4	4	0	4	0	0	20
1986	4	4	4	4	0	4	0	0	20
1987	4	4	4	4	0	4	0	0	20
1988	4	4	4	4	0	4	0	0	20
1989	4	4	4	4	0	4	0	0	20
1990	4	4	4	4	0	4	0	0	20
1991	6	4	4	4	0	4	0	0	22
1992	6	4	4	4	0	4	0	0	22
1993	6	4	4	4	0	4	0	0	22
1994	4	4	2	4	0	2	0	0	16
1995	4	4	4	4	0	4	0	0	20
1996	4	4	4	4	0	4	0	0	20
1997	4	4	4	4	0	4	0	2	22
1998	5	4	4	0	0	4	5	4	26
1999	6	4	4	3	0	4	6	4	31
2000	6	4	4	0	0	4	6	4	28
2001	6	4	5	0	0	4	6	4	29
2002	6	4	6	0	0	4	6	4	30
2003	6	4	6	0	0	4	6	4	30
2004	6	4	6	0	0	4	6	4	30
2005	6	4	6	0	0	4	6	4	30
2006	6	4	6	0	0	4	6	4	30
2007	6	4	6	0	0	4	6	4	30
2008	6	3	6	0	0	3	6	3	27
2009	6	4	6	0	0	4	6	4	30
2010	6	4	6	0	0	4	6	4	30
2011	2	2	2	0	0	2	2	2	12
2012	2	1	0	0	0	1	2	1	7
2013	2	0	0	0	0	0	2	0	4
2014	2	1	0	0	0	1	2	1	7
2015	2	1	0	0	0	1	2	1	7
2016	2	1	0	0	0	1	2	1	7
2017	2	1	0	0	0	1	2	1	7
Total	194	155	168	99	45	126	91	60	938

(b) Number of Positive Hauls

	Station									Percent
Shift-Year	T1	T2	T3	T4	T5	T10	T12	T14	Total	Positive
1970	0	1	1	2	0	0	0	0	4	26.7%
1971	0	2	1	1	1	0	0	0	5	35.7%
1972	0	0	0	2	1	0	0	0	3	20.0%
1973	2	0	1	1	1	0	0	0	5	33.3%
1974	0	0	0	0	0	0	0	0	0	0.0%
1975	0	0	0	0	0	0	0	0	0	0.0%
1976	0	0	0	0	0	0	0	0	0	0.0%
1977	0	0	1	0	0	0	0	0	1	6.7%
1978	0	0	0	0	0	0	0	0	0	0.0%
1979	0	0	0	0	0	0	0	0	0	0.0%
1980	0	0	0	0	0	0	0	0	0	0.0%
1981	0	0	0	0	0	0	0	0	0	0.0%
1982	0	0	0	0	0	0	0	0	0	0.0%
1983	0	0	0	0	0	0	0	0	0	0.0%
1984	0	0	0	0	0	1	0	0	1	5.6%
1985	0	0	0	0	0	0	0	0	0	0.0%
1986	0	0	0	0	0	0	0	0	0	0.0%
1987	0	0	0	0	0	0	0	0	0	0.0%
1988	0	0	0	0	0	1	0	0	1	5.0%
1989	0	0	0	0	0	0	0	0	0	0.0%
1990	0	0	0	0	0	1	0	0	1	5.0%
1991	0	0	0	0	0	0	0	0	0	0.0%
1992	0	0	0	0	0	0	0	0	0	0.0%
1993	0	0	0	0	0	0	0	0	0	0.0%
1994	0	0	0	0	0	0	0	0	0	0.0%
1995	0	0	0	0	0	0	0	0	0	0.0%
1996	0	0	0	0	0	0	0	0	0	0.0%
1997	0	0	0	0	0	0	0	0	0	0.0%
1998	0	0	0	0	0	0	0	0	0	0.0%
1999	0	0	0	0	0	1	0	2	3	9.7%
2000	0	0	0	0	0	0	1	2	3	10.7%
2001	0	0	0	0	0	1	0	0	1	3.4%
2002	0	0	0	0	0	2	0	1	3	10.0%
2003	0	0	0	0	0	0	0	0	0	0.0%
2004	0	0	0	0	0	1	0	0	1	3.3%
2005	0	0	0	0	0	0	0	1	1	3.3%
2006	0	0	0	0	0	0	0	0	0	0.0%
2007	0	0	0	0	0	0	0	0	0	0.0%
2008	0	0	0	0	0	0	0	0	0	0.0%
2009	0	0	0	0	0	1	0	1	2	6.7%
2010	0	0	3	0	0	1	0	1	5	16.7%
2011	0	0	1	0	0	0	0	0	1	8.3%
2012	0	0	0	0	0	0	0	0	0	0.0%
2013	0	0	0	0	0	0	0	0	0	0.0%
2014	0	0	0	0	0	1	0	0	1	14.3%
2015	0	0	0	0	0	0	0	0	0	0.0%
2016	0	0	0	0	0	1	0	0	1	14.3%
2017	0	0	0	0	0	0	0	0	0	0.0%
Total	2	3	8	6	3	12	1	8	43	4.6%

Table 26: Number of hauls (a) and number of hauls catching at least one cowcod (b) by shift-year and station for Los Angeles County Sanitation District trawl data that were incorporated into the combined Los Angeles/Orange County Sanitation District index.

(a) Number of Hauls

	Site								
Shift-Year	T0-61	T0-137	T1-61	T1-137	T4-61	T4-137	T5-61	T5-137	Total
1972	1	1	1	1	2	2	2	1	11
1973	1	1	1	1	1	1	1	1	8
1974	1	1	1	1	1	1	1	1	8
1975	1	1	2	1	1	1	2	1	10
1976	1	1	2	1	1	1	1	1	9
1977	3	3	3	3	3	3	3	3	24
1978	1	1	1	1	1	1	1	1	8
1979	3	3	3	3	3	3	3	3	24
1980	3	3	3	3	3	3	3	3	24
1981	3	3	3	3	3	3	3	3	24
1982	3	3	3	3	3	3	3	3	24
1983	3	3	3	3	3	3	3	3	24
1984	3	3	3	3	3	3	3	3	24
1985	3	3	3	3	3	3	3	3	24
1986	3	3	3	3	3	3	3	3	24
1987	3	3	3	3	3	3	3	3	24
1988	3	3	3	3	3	3	3	3	24
1989	3	3	3	3	3	3	3	3	24
1990	3	3	3	3	3	3	3	3	24
1991	3	3	3	3	3	3	3	3	24
1992	3	3	3	3	3	3	3	3	24
1993	3	3	3	3	3	3	3	3	24
1994	3	3	3	3	3	3	3	3	24
1995	3	3	3	3	3	3	3	3	24
1996	3	3	3	3	3	3	3	3	24
1997	3	3	3	3	3	3	3	3	24
1998	3	3	3	3	3	3	3	3	24
1999	3	3	3	3	3	3	3	3	24
2000	3	3	3	3	3	3	3	3	24
2001	3	3	3	3	3	3	3	3	24
2002	2	2	2	2	2	2	2	2	16
2003	1	1	1	1	1	1	1	1	8
2004	3	3	3	3	3	3	3	3	24
2005	3	3	3	3	3	3	3	3	24
2006	3	3	3	3	3	3	3	3	24
2007	3	3	3	3	3	3	3	3	24
2008	3	3	3	3	3	3	3	3	24
2009	3	3	3	3	3	3	3	3	24
2010	3	3	3	3	3	3	3	3	24
2011	3	3	3	3	3	3	3	3	24
2012	2	2	2	2	2	2	2	2	16
2013	2	2	2	2	2	2	2	2	16
2014	2	2	2	2	2	2	2	2	16
2015	2	2	2	2	2	2	2	2	16
2016	2	2	2	2	2	2	2	2	16
2017	2	2	2	2	2	2	2	2	16
2018	2	2	2	2	2	2	2	2	16
Total	119	119	121	119	120	120	121	119	958

(b) Number of Positive Hauls

	Site									Percent
Shift-Year	T0-61	T0-137	T1-61	T1-137	T4-61	T4-137	T5-61	T5-137	Total	Positive
1972	0	1	1	0	1	0	0	1	4	36.4%
1973	1	1	0	1	0	1	0	1	5	62.5%
1974	0	0	0	0	0	0	0	1	1	12.5%
1975	1	1	0	1	0	0	0	1	4	40.0%
1976	0	0	0	0	0	0	0	0	0	0.0%
1977	0	0	0	1	0	0	1	2	4	16.7%
1978	0	0	0	0	0	0	0	1	1	12.5%
1979	0	0	0	0	0	0	0	2	2	8.3%
1980	0	2	0	0	0	1	0	0	3	12.5%
1981	0	1	0	0	0	0	0	0	1	4.2%
1982	0	0	0	0	0	0	0	2	2	8.3%
1983	0	0	0	0	0	0	0	0	0	0.0%
1984	0	1	0	0	0	0	0	0	1	4.2%
1985	0	0	0	0	0	0	0	0	0	0.0%
1986	0	0	0	2	0	0	0	2	4	16.7%
1987	0	0	0	0	0	1	0	0	1	4.2%
1988	0	1	0	0	0	0	0	0	1	4.2%
1989	0	0	0	0	0	0	0	0	0	0.0%
1990	0	0	0	0	0	0	0	0	0	0.0%
1991	0	0	0	0	0	0	0	0	0	0.0%
1992	0	0	0	0	0	0	0	0	0	0.0%
1993	0	0	0	0	0	0	0	0	0	0.0%
1994	0	0	0	0	0	0	0	1	1	4.2%
1995	0	0	0	0	0	0	0	0	0	0.0%
1996	0	0	0	0	0	1	0	0	1	4.2%
1997	0	0	0	0	0	0	0	0	0	0.0%
1998	0	0	0	0	0	0	0	0	0	0.0%
1999	0	0	0	0	0	1	0	0	1	4.2%
2000	0	2	0	0	0	1	0	1	4	16.7%
2001	0	0	1	0	0	0	0	0	1	4.2%
2002	0	0	0	0	0	0	0	1	1	6.3%
2003	0	0	0	0	0	0	0	0	0	0.0%
2004	0	0	0	0	0	0	0	1	1	4.2%
2005	0	0	0	0	0	0	0	0	0	0.0%
2006	0	0	0	0	0	0	0	0	0	0.0%
2007	0	0	1	0	0	0	0	0	1	4.2%
2008	0	1	0	0	1	0	1	1	4	16.7%
2009	0	1	1	1	1	0	0	2	6	25.0%
2010	2	2	2	2	3	2	3	1	17	70.8%
2011	1	1	0	2	1	0	0	1	6	25.0%
2012	0	1	1	0	0	0	0	0	2	12.5%
2013	0	0	0	2	0	1	0	2	5	31.3%
2014	0	0	0	2	0	1	0	2	5	31.3%
2015	0	1	0	0	0	0	0	0	1	6.3%
2016	0	0	0	0	0	0	0	1	1	6.3%
2017	0	0	0	0	0	0	0	1	1	6.3%
2018	0	0	0	1	0	1	0	1	3	18.8%
Total	5	17	7	15	7	11	5	29	96	10.0%

Table 27: AIC model selection for the combined Los Angeles/Orange County Sanitation District index.

Model	AIC	AIC - min(AIC)
Intercept Only	996.0	184.4
Block Year	904.2	92.6
Block Year + Shift Quarter	892.0	80.4
Block Year + Site	817.0	5.5
Shift Quarter + Site	927.1	115.5
Block Year + Shift Quarter + Site	811.6	0.0
Block Year + Shift Quarter + Site + BlockYear:ShiftQuarter	829.0	17.4
Block Year + Shift Quarter + Site + BlockYear:Site	922.8	111.2
Block Year + Shift Quarter + Site + ShiftQuarter:Site	818.9	7.3

Table 28: Index of abundance for the combined Los Angeles/Orange County Sanitation District index.

Block year	Index	log.SE
1973	0.3057	0.2066
1978	0.0468	0.3377
1983	0.0142	0.4589
1988	0.0222	0.3761
1993	0.0032	0.7855
1998	0.0312	0.3118
2003	0.0259	0.3570
2008	0.1029	0.2112
2013	0.1138	0.2556
2017	0.0578	0.4343

Table 29: NWFSC Hook-and-Line Survey sampling effort (number of hooks per site and year) for sites <u>outside</u> the Cowcod Conservation Areas, 2004-2018.

	Year															
Site Number	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
2	50	70	48	74	70	75	75	75	73	70	75	75	75	50	49	1004
6	50		50		70	75	75	70	70	75	75	75	75	75	50	885
15		75	50	65	75	75	65	75	75	75	75	50	50	70	75	950
17	49	49	22	70	75	69	75		67	59	75	73	75	74	44	876
18	47	72	50	68	75	75	75		70	74	75	75	69	49	44	918
21			50	74	68	73	75		75	50	75	49	75	50	50	764
24			49	75	67	72	75		70	68	49	75	69	73	49	791
27		50	20	70	75	75	75		74	75	75	75	75	73	50	862
29	50	75	50	70	74	74	75		64	64	74	75	53	75	57	930
31	50	50	20	65	70	67	65		65	65	74	50	69	73	45	828
33	50	50	25	74	75	69	75	75	75	75	74	74	69	74	75	1009
36	50	50	50	70	69	75	70	75	65	75	75	73	70	70	75	1012
43	50	64	50	70	74	70	75	75	73	75	73	75	75	48	72	1019
52	45	44	25	74	75	75	65	65	75	75	50	75	75	74	65	957
77	47				73	74	75	75	75	65	75	70	75	74	44	822
79	43	75	45	65	75	75	75	74	75	68	75	72	75	62	43	997
119	50		50	75	75		75	75	75	74	75	74	75	74	50	897
136	50		50	75	74	75	74	75	75	70	75	74	50	75	40	932
137	45	70	24	74	70	75	74	69	70	75	75	75	50	74	50	970
139	50	74		73	68	75	75	74	74	74	74	75	75	49	75	985
147	43	47	49	69	74	71	75	68	75	75	74	75	75	50	75	995
148	50				75	75	75	75	75	74	73	75	74	73	75	869
149	50				74	73	75	75	75	74	67	75	75	73	75	861
151	47	74	43	75	75	75	74	75	74	75	73	75	74	74	74	1057
154	50	25	10	74	71	75	75	75	70	75	61	50	49	75	65	900
168		75	25	74	75	75	75	60	70	74	50	75	75	50	70	923
181		49		74	73	75	75	69	74	75	65	75	68	50	74	896
182	50	72		73	69	69	69	73	75	75	62	75	69	48	73	952
185	46	71		75	72	75	70	70	75	64	46	75	75	75	75	964
186	43	74		73	75	75	75	75	72	75	47	75	75	74	74	982
200		68	50	75	73	75	75	75	75	75	70	75	75	75	75	1011
205	50	49	24	74	75	75	75	75	75	73	75	65	75	45	75	980
209		75	48	75	74	75	75	75	71	75	75	75	70	44	74	981
215		71	46	75	73	74	75	74	73	74	74	72	61	40	75	957
231	45				57	75	70	73	63	62	75	73	75	69	67	804
232	50				73	74	75	69	75	74	70	74	74	62	61	831
243	50	50	25	75	75	75	75	75	75	75	75	75	73	75	73	1021
291	49	50	25	75	69	75	75	60	75	75	75	70	63	75	75	986
342		69	48	68	30	74	75	75	74	64	50	50	74	75	74	900
346	48	75	48	74	74	71	74	74	70	72	73	74	75	39	70	1011
350		72	47	75	64	62	75	73	63	73	74	74	75		65	892
352	50	73	49	70	74	70	65	74	74	69	75	70	74	75	73	1035
375		75	50	74	69	63	73	75	75	75	66	75	74	34	74	952
377		75	50	73	75	69	70		75	73	74	75	50	72	50	881
385			49	75	75	75	75	75	75	74	75	75	75	74	75	947
413			50	75	70	70	70	75	60		75		45	65	74	729
414		29	49	75	63	74	75	70	74	74	73	73	75	75	63	942
418					55	74	70	68	75	70	75	75	49	75	75	761
Total	1497	2186	1513	2976	3398	3431	3518	2902	3467	3364	3360	3354	3315	3047	3100	44428

Table 30: NWFSC Hook-and-Line Survey sampling effort (number of hooks per site and year) for sites inside the Cowcod Conservation Areas, 2014-2018.

	Year					
Site Number	2014	2015	2016	2017	2018	Total
501	75	75	72	74	75	371
502	75	75	72	72	62	356
503	75	74	74	68	73	364
506		72	75	75	55	277
507		65	75	75	60	275
508		75	75	75	75	300
509	75	75	70	73	50	343
512	45	74	75	73	75	342
514	74	75	75	55	75	354
518	75	74	74	74	75	372
520			75	60	75	210
525		73	75	70	75	293
526	73	63	69	75	71	351
527	70	70	75	74	75	364
531	66	68	62	68	74	338
543			75	69	70	214
546		75	70	65	68	278
547		75	70	50	75	270
548		60	70	70	64	264
549		75	75	45	65	260
551		71		74	63	208
553		75		75	75	225
554		75		70	74	219
557		70	70	39	74	253
558		75		70	74	219
559			69	74	75	218
560		66	70	73	74	283
561		74	74	70	75	293
563		60	70	72	48	250
564		75		74	75	224
566	25	75	49	75	50	274
568	23	74	74	74	71	316
569	75	75	61	74	74	359
573	75	70	73	75	74	367
574	75	70	75	74	68	362
575	24	75	50	70	55	274
581		75		75	74	224
582		69		68	72	209
584		74		58	70	202
586		67		72	54	193
590	25	75		73	75	248
592	25	75	75	75	75	325
597	74	75	74	61	48	332
598	25	74	74	75	75	323
609	74	75	74	69	75	367
611	75	75	70	61	70	351
Total	1298	3107	2555	3180	3174	13314

Table 31: Index of relative abundance based on the NWFSC Hook and Line Survey.

year	index	log.SE
2004	0.48899	0.38699
2005	1.14777	0.26378
2006	0.76577	0.32491
2007	1.12058	0.23175
2008	0.78425	0.23063
2009	1.00754	0.20588
2010	0.68203	0.23809
2011	0.89026	0.22914
2012	1.21863	0.19292
2013	1.0512	0.20347
2014	0.61832	0.2017
2015	1.80202	0.12369
2016	0.77779	0.1653
2017	1.00905	0.15107
2018	1.63579	0.12788

Table 32: Number of cowcod lengths by year and sex from the NWFSC Hook and Line Survey.

Year	**Sex**			**Total**
	Female	**Male**	**Unknown**	
2004	4	1	0	5
2005	8	9	0	17
2006	6	4	0	10
2007	16	7	0	23
2008	9	13	0	22
2009	11	19	0	30
2010	6	15	0	21
2011	14	10	0	24
2012	9	26	1	36
2013	15	16	0	31
2014	11	19	0	30
2015	41	69	0	110
2016	17	31	0	48
2017	30	32	0	62
2018	39	61	0	100
Total	**236**	**332**	**1**	**569**

Table 33: Number of cowcod ages by year and sex from the NWFSC Hook and Line Survey.

Year	Sex			Total
	Female	Male	Unknown	
2003	1	0	0	1
2004	4	2	0	6
2005	8	9	0	17
2006	6	5	0	11
2007	15	7	0	22
2009	11	19	0	30
2010	6	15	0	21
2011	13	9	0	22
2012	8	26	1	35
2013	15	16	0	31
2014	8	16	0	24
2015	48	54	0	102
2016	17	29	0	46
2017	29	31	0	60
Grand Total	189	238	1	428

Table 34: Number of tows by year and month used in the southern California CalCOFI ichthyoplankton survey index.

	month							month					
year	1	2	3	4	5	6	year	1	2	3	4	5	6
1951	15	15	11	17	16	16	1989	30	0	0	30	0	0
1952	13	13	13	19	22	36	1990	0	0	31	30	0	0
1953	18	22	18	22	31	26	1991	31	0	31	0	0	0
1954	22	21	19	22	21	21	1992	0	29	0	30	0	0
1955	17	16	17	17	21	22	1993	31	0	0	31	0	0
1956	16	17	16	18	21	21	1994	30	0	31	0	0	0
1957	0	18	17	18	21	22	1995	30	0	0	31	0	0
1958	15	16	22	22	22	22	1996	0	31	0	28	0	0
1959	20	21	15	21	21	21	1997	0	31	0	27	0	0
1960	21	19	19	21	19	20	1998	0	29	8	31	8	12
1961	24	0	0	22	0	0	1999	30	0	0	31	0	0
1962	23	0	23	0	0	0	2000	31	0	0	31	0	0
1963	23	0	0	25	0	0	2001	29	0	0	31	0	0
1964	28	0	0	25	0	0	2002	30	0	0	30	0	0
1965	25	0	0	25	0	0	2003	0	30	0	31	0	0
1966	19	23	0	29	24	25	2004	30	0	0	31	0	0
1967	0	0	0	0	0	25	2005	27	0	0	31	0	0
1968	24	0	0	0	0	25	2006	0	29	0	31	0	0
1969	25	27	0	24	25	0	2007	31	0	0	24	0	0
1972	22	25	25	0	8	0	2008	30	0	0	26	0	0
1975	27	0	34	0	29	0	2009	31	0	31	0	0	0
1978	35	0	35	35	32	0	2010	30	0	0	30	0	0
1979	27	27	0	27	27	0	2011	31	0	0	30	0	0
1981	29	0	0	56	29	0	2012	0	30	30	0	0	0
1982	0	0	26	0	0	0	2013	31	0	0	29	0	0
1983	0	0	27	0	0	0	2014	0	17	0	35	0	0
1984	28	0	29	27	15	14	2015	31	0	0	30	0	0
1985	0	27	0	0	28	0	2016	31	0	0	30	0	0
1986	0	29	0	0	29	0	2017	0	0	0	31	0	0
1987	0	0	28	0	30	0	2018	0	0	0	29	0	0
1988	30	0	0	0	30	0							

Table 35: AIC model selection for the CalCOFI ichthyoplankton index.

Model	AIC	AIC - min(AIC)
Intercept only	1321.5	125.1
SuperYear	1270.1	73.7
Period	1299.7	103.3
LineStation	1274.8	78.4
SuperYear + Period	1244.4	48.0
SuperYear + LineStation	1224.4	28.0
SuperYear + Period + LineStation	1196.4	0.0

Table 36: Updated 2019 CalCOFI index of abundance for cowcod in the Southern California Bight. See STAR panel request #14 regarding index values for 1979-1994.

Super Year	index	log.SE
1953	0.02391	0.22640
1958	0.01725	0.26617
1963	0.02345	0.31946
1968	0.07300	0.20324
1974	0.03786	0.29607
1979	0.00622	0.32
1984	0.00622	0.32
1989	0.00622	0.32
1994	0.00622	0.32
1999	0.00937	0.42077
2004	0.01801	0.33948
2009	0.02583	0.28137
2014	0.02557	0.28798
2018	0.05232	0.52866

Table 37: Summary of 2012 ROV survey data by stratum (Source: Stierhoff et al. 2013), and cowcod mean weights and sample sizes from the NWFSC WCGBT Survey. Distances are in meters, areas in square kilometers, and weights in kilograms. ROV weights for soft substrate (n=9; italicized) were replaced with depth-based mean weights from the trawl survey (n=700).

								ROV		NWFSC Trawl	
CCA	Depth	Substrate	N.transects	Sum.Distance	Sum.Cowcod	Avg.Density	Area.km2	N.Lengths	Mean.Weight	N.Lengths	Mean.Weight
Outside	70-100m	Soft	0	0	0	--	1580	0	--	42	0.27
Outside	70-100m	Hard	9	4212	2	204.0	126	5	1.73	--	--
Outside	100-160m	Soft	1	443	0	0.0	1162	0	--	289	0.63
Outside	100-160m	Hard	26	11675	27	650.2	183	45	2.36	--	--
Outside	160-300m	Soft	2	774	0	0.0	1944	0	--	369	0.97
Outside	160-300m	Hard	3	1511	0	0.0	174	15	2.47	--	--
Inside	70-100m	Soft	2	685	0	0.0	370	*2*	*1.68*	--	--
Inside	70-100m	Hard	19	7549	14	495.0	231	18	1.81	--	--
Inside	100-160m	Soft	2	788	0	0.0	658	*3*	*3.66*	--	--
Inside	100-160m	Hard	67	31496	121	1000.4	257	137	2.04	--	--
Inside	160-300m	Soft	5	2185	4	435.8	900	*4*	*0.18*	--	--
Inside	160-300m	Hard	24	10269	18	462.9	169	31	2.44	--	--

Table 38: Model selection for cowcod density using the SWFSC ROV survey data. Model structures with gray background are within 2 AIC points of the 'best' model. A main-effects model with all three covariates (in bold) was selected for density estimation (see text for details).

Covariates included in the model for cowcod density	AIC	AIC - min(AIC)
Intercept only	470.7	10.9
Depth	463.6	3.8
Substrate	468.7	8.9
CCA	469.2	9.3
Depth + Substrate	463.7	3.9
Depth + CCA	460.2	0.4
Substrate + CCA	466.9	7.0
Depth + Substrate + CCA	**460.4**	**0.6**
Depth + Substrate + CCA + Depth:CCA	461.5	1.6
Depth + Substrate + CCA + Substrate:CCA	461.1	1.3
Depth + Substrate + CCA + Depth:Substrate	459.8	0.0

Table 39: Comparison of parameter estimates from maximum likelihood and Bayesian regression coefficients for ROV survey density model.

Parameter	Posterior Median	MLE
(Intercept)	4.545	4.595
z.stratum100-160m	0.914	0.906
z.stratum160-300m	0.192	0.188
rock.stratumHard	0.851	0.815
cca1	0.600	0.592

Table 40: Estimates of the mean weight by stratum used in the ROV survey 2012 biomass index.

Source	Depth	Substrate	N	mean [kg]	log.SE
Trawl	70-100m	Soft	42	0.271	0.261
ROV	70-100m	Hard	23	1.794	0.377
Trawl	100-160m	Soft	289	0.630	0.085
ROV	100-160m	Hard	182	2.120	0.107
Trawl	160-300m	Soft	369	0.966	0.067
ROV	160-300m	Hard	46	2.449	0.237

Table 41: Model-based abundance estimates [# of cowcod] for 2012, by stratum and for all strata combined, based on the ROV survey.

Stratum							
CCA	Depth	Substrate	Mean	Median	Lower HDI	Upper HDI	log.SE
Outside	70-100m	Soft	203275	148845	7814	544215	0.817
Outside	70-100m	Hard	30667	27870	9053	58846	0.440
Outside	100-160m	Soft	356620	273696	17299	909014	0.759
Outside	100-160m	Hard	105358	101048	50717	166829	0.289
Outside	160-300m	Soft	283998	222855	19652	710882	0.733
Outside	160-300m	Hard	51869	46626	13732	100708	0.459
Inside	70-100m	Soft	84299	63465	4079	220689	0.782
Inside	70-100m	Hard	99514	93259	38383	173798	0.360
Inside	100-160m	Soft	360768	283148	25230	902383	0.729
Inside	100-160m	Hard	263769	258665	175175	360131	0.180
Inside	160-300m	Soft	229848	187733	20291	542763	0.672
Inside	160-300m	Hard	87780	82552	36851	150478	0.343
TOTAL ABUNDANCE [# fish]			2157765	1868091	710449	4293391	0.444

Table 42: Model-based biomass estimates [mt] for 2012, by stratum and for all strata combined, based on the ROV survey.

Stratum							
CCA	Depth	Substrate	Mean	Median	Lower HDI	Upper HDI	log.SE
Outside	70-100m	Soft	55.1	39.0	1.8	153.5	0.859
Outside	70-100m	Hard	55.0	46.5	8.9	121.7	0.580
Outside	100-160m	Soft	224.7	171.9	10.8	575.4	0.763
Outside	100-160m	Hard	223.4	213.1	101.8	363.9	0.308
Outside	160-300m	Soft	274.2	214.6	19.4	690.9	0.736
Outside	160-300m	Hard	127.0	110.8	27.8	265.3	0.516
Inside	70-100m	Soft	22.9	16.6	0.9	62.3	0.826
Inside	70-100m	Hard	178.2	155.2	39.5	374.6	0.523
Inside	100-160m	Soft	227.5	177.8	14.9	570.7	0.734
Inside	100-160m	Hard	559.4	546.0	338.2	791.7	0.209
Inside	160-300m	Soft	222.0	180.8	20.3	527.3	0.676
Inside	160-300m	Hard	215.1	196.6	68.2	402.1	0.418
TOTAL BIOMASS [mt]			2384.5	2212.1	1225.2	3904.2	0.291

Table 43: Estimates of the annual natural mortality rate reported by Dick et al. 2007.

Method	M	Z	range (if available)
Hoenig (1983); GM regression for all groups		0.072	n/a
Catch curve; age at full recruitment = 12		0.055	(0.038, 0.072)
Beverton (1992); Tmax = 55	0.045		(0.027, 0.064)

Table 44: Summary of maturity data from NWFSC fishery-independent surveys.

Survey	N	min(fork length)	mean(fork length)	max(fork length)
NWFSC Hook-and-Line Survey	121	26.0	63.0	80.0
NWFSC Trawl Survey	53	17.5	34.2	62.0

Table 45: Proportion of female cowcod classified as mature by size class, month of capture, and maturity type. Females less than 50 cm captured in September and October are more likely to be classified as mature than females captured in June and July.

length.bin	month	Sample size	mean length (cm)	prop. Mature (biological)	prop. Mature (functional)
LessThan50cm	6	11	36.0	0.091	0.091
	7	13	28.4	0.077	0.000
	9	31	34.9	0.323	0.161
	10	4	37.5	0.500	0.250
50plus	7	1	53.5	1.000	1.000
	9	64	64.0	1.000	1.000
	10	50	65.8	1.000	0.980
Grand Total		174	54.2	0.741	0.695

Table 46: Sample size (number of pelagic midwater trawls) and number of positive hauls for pelagic juvenile young-of-the-year (YOY) cowcod from SWFSC rockfish recruitment survey.

	Central CA			Southern California Bight		
	positives	tows	%FO	positives	tows	%FO
1983	0	44	0			
1984	0	51	0			
1985	2	96	0.03			
1986	1	124	0.01			
1987	14	141	0.1			
1988	11	134	0.09			
1989	1	100	0.02			
1990	1	136	0.01			
1991	0	120	0			
1992	0	91	0			
1993	4	96	0.05			
1994	0	95	0			
1995	0	94	0			
1996	0	94	0			
1997	0	84	0			
1998	0	89	0			
1999	0	90	0			
2000	1	97	0.02			
2001	1	131	0.01			
2002	2	127	0.02			
2003	1	156	0.01			
2004	1	171	0.01	2	35	0.06
2005	0	178	0	4	40	0.11
2006	0	201	0	0	38	0
2007	0	194	0	1	28	0.04
2008	0	115	0	0	33	0
2009	1	161	0.01	0	26	0
2010	5	112	0.05	2	21	0.1
2011	1	69	0.02	(no survey data)		
2012	3	78	0.04	1	16	0.07
2013	9	101	0.09	1	28	0.04
2014	21	122	0.18	4	18	0.23
2015	37	114	0.33	5	38	0.14
2016	2	95	0.03	2	38	0.06
2017	2	61	0.04	8	21	0.39
2018	0	87	0	4	33	0.13

Table 47: Age-structured production models configured in Stock Synthesis. See text for model descriptions.

	Bridge Model Number										
Quantity	**1**	**2**	**3**	**4**	**5**	**6****	**7**	**8**	**9**	**10**	**11**
# Parameters	6	5	5	6	6	6	7***	6	7***	6	8
NegLogLike TOTAL	-12.376	-11.339	-12.352	-12.272	-12.304	-12.319	-10.040	-12.437	-20.302	-13.757	-19.589
NLL Catch	3.5E-08	2.3E-08	3.5E-08	3.0E-08	2.9E-08	2.9E-08	3.2E-08	3.3E-08	2.2E-08	2.2E-08	1.8E-08
NLL Survey	-12.340	-12.178	-12.356	-12.260	-12.273	-12.279	-10.003	-12.404	-20.329	-13.808	-19.714
NLL Length	0	0	0	0	0	0	0	0	0	0	0
NLL Age	0	0	0	0	0	0	0	0	0	0	0
NLL Priors	-0.035	0.839	0.004	-0.012	-0.031	-0.040	-0.037	-0.033	0.027	0.051	0.125
Max. Gradient	1.13E-06	1.07E-06	4.89E-06	2.80E-06	4.90E-07	1.50E-06	1.04E-06	8.61E-06	3.20E-06	6.38E-07	4.97E-08
Warnings	0	0	0	0	0	0	0	0	0	0	0
M	0.095	0.055*	0.099	0.094	0.094	0.095	0.101	0.101	0.094	0.089	0.094
ln_R0	5.35	4.38	5.43	4.95	4.98	4.99	5.08	5.07	5.00	4.91	4.98
h	0.755	0.841	0.72*	0.743	0.754	0.760	0.814	0.824	0.746	0.726	0.802
k	0.052*	0.052*	0.052*	0.0727*	0.0727*	0.0727*	0.0727*	0.0727*	0.0727*	0.0727*	0.0727*
L @ A1	16.2*	16.2*	16.2*	20.87*	20.87*	20.87*	20.87*	20.87*	20.87*	20.87*	20.87*
L @ A2	75.6*	75.6*	75.6*	76.31*	76.31*	76.31*	76.31*	76.31*	76.31*	76.31*	76.31*
SB0	1557	2166	1532	1593	1525	261	242	241	266	280	264
Depletion 2013	0.414	0.328	0.399	0.444	0.432	0.419	0.493	0.500	0.445	0.404	0.521
Depletion 2019	0.531	0.422	0.512	0.570	0.559	0.547	0.629	0.636	0.568	0.521	0.645

* fixed parameter

** SB in model 6 changed to represent egg production rather than female mature biomass

*** additional variance parameter needed for revised NWFSC indices

Table 48: Likelihoods, parameter estimates, and derived quantities from age-structured production models using alternative stock-recruitment relationships.

Quantity		Beverton-Holt	Ricker-Power	Shepherd
TOTAL LIKELIHOOD		-22.077	-22.392	-22.151
	Survey	-22.265	-22.541	-22.261
	Parm_priors	0.188	0.148	0.110
NatM_p_1_Fem_GP_1		0.103	0.104	0.111
SR_LN(R0)		5.4694	5.3794	5.6795
SR_BH_steep		0.699	NA	NA
SR_RkrPower_steep		NA	0.667	NA
SR_RkrPower_gamma		NA	0.996	NA
SR_steepness		NA	NA	0.774
SR_Shepherd_c		NA	NA	0.864
Q_extraSD_SANITATION(4)		0.620	0.591	0.611
Q_extraSD_CALCOFI(6)		0.185	0.188	0.187
LnQ_base_SWFSC_SUB_SURVEY(7)		-0.680	-0.675	-0.670
Bratio_2019		0.600	0.683	0.571
SSB_unfished		496.1	434.1	488.2
B_MSY/SSB_unfished		0.28	0.42	0.27

Table 49: Relative weights used for fitting compositional data in the Cowcod base model.

Data Source	Likelihood Component	Weighting Method	Relative Weight
Recreational Fishery	Lengths	Francis	0.399
NWFSC WCGBT Survey	Lengths	Francis	0.217
Sanitation District Surveys	Lengths	Francis	0.120
NWFSC Hook-and-Line Index	Lengths	Francis	1.000
NWFSC Hook-and-Line Early Comps	Lengths	Francis	0.404
Commercial Fishery	Conditional Age-at-Length	Francis	0.490
Recreational Fishery	Conditional Age-at-Length	Francis	0.391
NWFSC WCGBT Survey	Conditional Age-at-Length	Francis	0.510
NWFSC Hook-and-Line Index	Conditional Age-at-Length	Francis	0.315
NWFSC Hook-and-Line Early Comps	Conditional Age-at-Length	Francis	0.227

Table 50: Description of parameters used in the Cowcod base case assessment model.

Parameter	Number Estimated	Bounds (low, high)	Prior (Mean, SD) - Type	Value	SE
Biology					
Natural mortality (*M*)	1	(0.01,0.4)	(-2.321,0.438) - Lognormal	0.088	0.011
Ln (R_0)	1	(3,10)	-	5.193	0.227
Steepness (*h*)	0	(0.201,0.999)	(0.72,0.16) - Full Beta	0.720	--
Growth					
Length at age 2	1	(5,30)	-	19.75	0.781
Length at age 35	1	(50,90)	-	73.95	1.257
von Bertalnaffy k	1	(0.01,0.25)	-	0.055	0.005
CV of length at age 2	1	(0.05,0.4)	-	0.169	0.015
CV of length at age 35	1	(0.05,0.4)	-	0.078	0.009
Indices					
Extra SD - Sanitation Districts	1	(0,1)	-	0.629	0.221
Extra SD - CalCOFI	1	(0,1)	-	0.227	0.096
Selectivity					
<u>Recreational</u>					
Length at peak	1	(20,80)	-	42.999	2.943
Ascending width	1	(-9,12)	-	4.658	0.425
Decending width	1	(-9,30)	-	7.111	0.709
<u>NWFSC Combo Trawl Survey</u>					
Inflection Size	1	(10,47)	-	27.487	25.687
Width	1	(-50,-1)	-	-36.786	28.321
<u>Sanitation District Surveys</u>					
Inflection Size	1	(8,40)	-	15.313	7.088
Width	1	(-40,-1)	-	-12.229	10.210
<u>NWFSC Hook-and-Line Survey</u>					
Length at peak	1	(20,96)	-	78.214	5.155
Ascending width	1	(-9,12)	-	5.901	0.225
<u>NWFSC Hook-and-Line Early Comps (ghost fleet)</u>					
Length at peak	1	(20,80)	-	69.030	3.717
Ascending width	1	(-9,12)	-	5.217	0.338
Decending width	1	(-9,12)	-	6.940	4.847
Catchability					
ln(q); SWFSC Submersible Survey	1	(-25, 25)	(-0.5029, 0.148) - Normal	-0.579	0.135

Table 51: Summary of results from 200 jittered runs using the base model.

VarLabel	Value
MinLike	819.4
MaxLike	866.37
DiffLike	46.97
MinMGC	7.54E-08
MaxMGC	1.1468
DepletionAtMinLikePercent	57.14
DepletionAtMaxLikePercent	17.6233
DiffDepletionPercent	-39.5167
NJitter	200
PropRunAtMinLike	0.985
PropRunAtMaxLike	0.005

Table 52: Comparison of the estimated parameters between the pre-STAR base model, that model with estimated recruit deviations, and the model structure from request 4 with recruitment deviations.

Label	Base	RecrDevsEstimated1	RecrDevsEstimatedModel4
Female M	0.085	0.082	0.074
Steepness	0.72	0.72	0.72
lnR0	5.153	5.091	4.761
Total biomass (mt)	4144.02	4194.87	4135.26
Depletion	0.577	0.57	0.563
SPR ratio	1	1	1
Female Lmin	19.965	20.016	19.614
Female Lmax	73.846	74.092	79.444
Female K	0.053	0.052	0.073

Table 53: Comparison of estimated parameters based on the alternative data weighting methods.

Parameter	pre-STAR base	Francis x3	MI x3	Dirichlet-Multinomial
NatM_p_1_Fem_GP_1	0.084514	0.084651	0.087714	0.086598
L_at_Amin_Fem_GP_1	19.9654	20.0589	19.4637	19.521
L_at_Amax_Fem_GP_1	73.8461	73.5107	76.0385	75.6077
VonBert_K_Fem_GP_1	0.052649	0.04341	0.050874	0.053044
CV_young_Fem_GP_1	0.171793	0.182174	0.174796	0.174112
CV_old_Fem_GP_1	0.075653	0.068188	0.077824	0.077063
SR_LN(R0)	5.15292	5.25277	5.14934	5.12136
SR_BH_steep	0.72	0.72	0.72	0.72
Bratio_2019	0.577234	0.592511	0.557932	0.54803
SSB_unfished	598.394	611.224	593.907	593.133

Table 54: Summary of reference points for Cowcod base case model in the Southern California Bight.

Quantity	Estimate	95% Asymptotic Interval
Unfished Spawning Output (eggs x 10^9)	285	235–334
Unfished Age 10+ Biomass (mt)	3,564	2,939–4,189
Spawning Output in 2019 (eggs x 10^9)	163	130–195
Unfished Recruitment (R_0, 1000s of age-0 fish)	180	100–260
Depletion (2019 spawning output / unfished spawning output, %)	57	42–72
Reference Points Based $SB_{40\%}$		
Proxy Spawning Biomass ($SB_{40\%}$)	114	94–134
SPR resulting in $SB_{40\%}$	0.458	0.458–0.458
Exploitation Rate Resulting in $SB_{40\%}$	0.05	0.036–0.064
Yield with SPR Based On $SB_{40\%}$ (mt)	76	66–87
Reference Points based on SPR proxy for MSY		
Proxy spawning biomass (SPR_{50})	127	105–149
SPR_{50}	0.5	NA
Exploitation rate corresponding to SPR_{50}	0.043	0.031–0.055
Yield with SPR_{50} at SB_{SPR} (mt)	73	63–83
Reference points based on estimated MSY values		
Spawning biomass at MSY (SB_{MSY})	79	63–95
SPR_{MSY}	0.347	0.337–0.358
Exploitation rate corresponding to SPR_{MSY}	0.074	0.051–0.098
MSY (mt)	81	69–92

Table 55: Time-series of population estimates from the Cowcod base case model.

Year	Total Biomass (mt)	Spawning Biomass (eggs x10^9)	Depletion	Age-0 Recruits (000s)	Total Catch (mt)	Relative Exploitation Rate	SPR
1900	3,976	569	1.00	180	0.0	0.00	1.00
1901	3,976	569	1.00	180	5.3	0.00	0.97
1902	3,971	568	1.00	180	10.7	0.00	0.95
1903	3,961	567	1.00	180	16.0	0.00	0.92
1904	3,946	564	0.99	180	21.4	0.01	0.90
1905	3,927	561	0.99	180	26.7	0.01	0.88
1906	3,904	557	0.98	180	32.0	0.01	0.85
1907	3,876	552	0.97	179	37.4	0.01	0.83
1908	3,845	547	0.96	179	42.7	0.01	0.81
1909	3,809	541	0.95	179	48.0	0.01	0.79
1910	3,770	535	0.94	179	53.4	0.02	0.77
1911	3,728	528	0.93	179	58.7	0.02	0.75
1912	3,682	520	0.91	178	64.0	0.02	0.73
1913	3,634	512	0.90	178	69.4	0.02	0.71
1914	3,582	503	0.88	178	74.7	0.02	0.69
1915	3,528	494	0.87	177	80.0	0.03	0.67
1916	3,471	484	0.85	177	85.4	0.03	0.65
1917	3,411	474	0.83	176	137.7	0.05	0.51
1918	3,305	457	0.80	176	125.6	0.04	0.53
1919	3,214	442	0.78	175	75.1	0.03	0.66
1920	3,175	435	0.76	175	81.6	0.03	0.63
1921	3,132	427	0.75	174	71.3	0.03	0.66
1922	3,101	422	0.74	174	70.1	0.03	0.66
1923	3,073	417	0.73	174	93.9	0.04	0.58
1924	3,023	409	0.72	173	125.9	0.05	0.50
1925	2,946	396	0.70	173	138.2	0.05	0.47
1926	2,861	382	0.67	172	171.5	0.07	0.40
1927	2,747	363	0.64	171	142.3	0.06	0.43
1928	2,665	350	0.61	170	111.4	0.05	0.49
1929	2,615	341	0.60	169	102.6	0.05	0.51
1930	2,576	335	0.59	168	126.9	0.06	0.44
1931	2,515	325	0.57	168	161.0	0.08	0.37
1932	2,426	310	0.55	166	109.5	0.05	0.47
1933	2,387	304	0.53	166	82.0	0.04	0.54
1934	2,376	302	0.53	166	70.7	0.04	0.58
1935	2,377	302	0.53	166	53.0	0.03	0.65
1936	2,394	304	0.53	166	20.6	0.01	0.84
1937	2,442	312	0.55	167	24.9	0.01	0.81
1938	2,485	319	0.56	167	18.7	0.01	0.86
1939	2,533	327	0.57	168	22.0	0.01	0.84
1940	2,576	334	0.59	168	23.7	0.01	0.83
1941	2,616	341	0.60	169	29.5	0.01	0.80
1942	2,650	347	0.61	169	10.6	0.00	0.92

Table 54 (continued): Time-series of population estimates from the Cowcod base case model.

Year	Total Biomass (mt)	Spawning Biomass (eggs x10^6)	Depletion	Age-0 Recruits	Total Catch (mt)	Relative Exploitation Rate	SPR
1943	2,700	355	0.62	170	12.4	0.01	0.91
1944	2,747	363	0.64	171	2.0	0.00	0.98
1945	2,801	372	0.65	171	4.6	0.00	0.97
1946	2,852	381	0.67	172	11.7	0.00	0.92
1947	2,894	388	0.68	172	18.8	0.01	0.88
1948	2,927	393	0.69	172	29.9	0.01	0.81
1949	2,948	397	0.70	173	38.7	0.02	0.77
1950	2,960	399	0.70	173	44.0	0.02	0.75
1951	2,966	400	0.70	173	49.2	0.02	0.73
1952	2,966	400	0.70	173	36.7	0.01	0.78
1953	2,977	402	0.71	173	31.2	0.01	0.81
1954	2,993	405	0.71	173	46.8	0.02	0.73
1955	2,993	405	0.71	173	52.1	0.02	0.69
1956	2,986	404	0.71	173	65.2	0.03	0.64
1957	2,967	401	0.71	173	55.7	0.02	0.68
1958	2,957	400	0.70	173	56.4	0.02	0.69
1959	2,946	398	0.70	173	52.3	0.02	0.71
1960	2,941	397	0.70	173	57.1	0.02	0.69
1961	2,930	395	0.69	173	60.0	0.02	0.67
1962	2,918	393	0.69	172	48.0	0.02	0.72
1963	2,917	393	0.69	172	57.3	0.02	0.68
1964	2,907	391	0.69	172	51.9	0.02	0.70
1965	2,903	390	0.69	172	70.1	0.03	0.62
1966	2,881	387	0.68	172	76.6	0.03	0.59
1967	2,853	383	0.67	172	102.4	0.04	0.50
1968	2,801	375	0.66	171	105.0	0.04	0.48
1969	2,746	366	0.64	171	125.1	0.05	0.44
1970	2,675	355	0.62	170	95.9	0.04	0.50
1971	2,632	348	0.61	169	106.1	0.05	0.46
1972	2,581	340	0.60	169	152.6	0.07	0.35
1973	2,487	325	0.57	168	171.8	0.08	0.30
1974	2,377	308	0.54	166	183.7	0.09	0.27
1975	2,257	289	0.51	164	182.6	0.10	0.26
1976	2,141	271	0.48	163	189.4	0.11	0.24
1977	2,022	252	0.44	160	191.2	0.12	0.22
1978	1,906	233	0.41	158	203.2	0.13	0.20
1979	1,781	214	0.38	155	262.2	0.19	0.13
1980	1,605	186	0.33	150	223.6	0.18	0.13
1981	1,467	165	0.29	145	216.0	0.19	0.15
1982	1,344	145	0.26	140	327.5	0.33	0.06
1983	1,118	112	0.20	129	177.1	0.23	0.13
1984	1,038	99	0.17	123	227.9	0.33	0.09
1985	917	80	0.14	113	208.1	0.36	0.07

Table 54 (continued): Time-series of population estimates from the Cowcod base case model.

Year	Total Biomass (mt)	Spawning Biomass (eggs x10^6)	Depletion	Age-0 Recruits	Total Catch (mt)	Relative Exploitation Rate	SPR
1986	814	66	0.12	103	194.4	0.40	0.06
1987	724	54	0.10	94	105.8	0.26	0.11
1988	710	53	0.09	92	100.5	0.24	0.12
1989	700	52	0.09	92	38.7	0.09	0.32
1990	741	59	0.10	98	30.5	0.07	0.42
1991	786	67	0.12	104	26.4	0.05	0.50
1992	834	75	0.13	110	35.80	0.06	0.42
1993	871	83	0.15	115	24.5	0.04	0.55
1994	919	92	0.16	120	39.6	0.06	0.44
1995	950	98	0.17	123	25.1	0.03	0.58
1996	995	106	0.19	126	29.9	0.04	0.55
1997	1,035	113	0.20	129	9.2	0.01	0.82
1998	1,095	122	0.21	133	4.0	0.00	0.92
1999	1,160	131	0.23	136	7.2	0.01	0.87
2000	1,222	140	0.25	139	4.9	0.01	0.92
2001	1,287	149	0.26	141	3.2	0.00	0.94
2002	1,354	158	0.28	144	3.2	0.00	0.95
2003	1,421	167	0.29	146	0.7	0.00	0.99
2004	1,491	177	0.31	148	1.3	0.00	0.98
2005	1,560	186	0.33	150	1.0	0.00	0.99
2006	1,630	196	0.34	152	1.0	0.00	0.99
2007	1,701	206	0.36	154	1.4	0.00	0.98
2008	1,770	216	0.38	155	0.5	0.00	0.99
2009	1,840	226	0.40	157	0.9	0.00	0.99
2010	1,910	236	0.42	158	0.8	0.00	0.99
2011	1,979	246	0.43	160	1.5	0.00	0.98
2012	2,046	257	0.45	161	1.0	0.00	0.99
2013	2,114	267	0.47	162	1.8	0.00	0.98
2014	2,179	277	0.49	163	1.1	0.00	0.99
2015	2,245	287	0.50	164	1.4	0.00	0.99
2016	2,309	296	0.52	165	1.3	0.00	0.99
2017	2,372	306	0.54	166	1.5	0.00	0.99
2018	2,434	316	0.55	167	1.6	0.00	0.99
2019	2,494	325	0.57	168	--	--	--

Table 56: "Drop-one" sensitivity results. Column names identify the fleet for which all comp data were removed in a given run. Likelihoods are not directly comparable due to changes in the data structure. Notable deviations are shaded in gray (e.g. removal of the commercial composition data causes M and k to increase significantly relative to other data configurations).

		FLEET / SURVEY WITH COMPS REMOVED				
	ALL DATA	COMM.	REC.	COMBO	HKL	SANITATION
Likelihood: TOTAL	767.54	591.07	652.33	540.60	456.95	763.98
Survey	-22.32	-21.79	-22.27	-22.30	-22.18	-22.32
Length_comp	186.44	185.82	176.02	135.52	67.80	182.79
Age_comp	603.04	426.99	498.14	426.97	410.85	603.12
Parm_priors	0.387	0.043	0.444	0.406	0.480	0.389
Parm_softbounds	0.0015	0.0023	0.0010	0.0027	0.0078	0.0009
Natural Mortality Rate	0.083	0.096	0.085	0.087	0.080	0.084
Length at age 2, cm	19.9	19.3	19.8	13.2	21.4	19.7
Length at age 35, cm	73.5	71.6	74.1	74.1	72.9	73.4
von Bertalanffy k	0.054	0.077	0.057	0.057	0.036	0.055
CV of length at age 2	0.172	0.140	0.175	0.243	0.180	0.170
CV of length at age 35	0.076	0.086	0.074	0.067	0.041	0.077
ln(R0)	5.132	5.229	5.143	5.256	5.198	5.135
Beverton-Holt steepness (fixed)	0.72	0.72	0.72	0.72	0.72	0.72
Q_extraSD_SANITATION(4)	0.642	0.604	0.648	0.647	0.644	0.642
Q_extraSD_CALCOFI(6)	0.183	0.195	0.183	0.184	0.186	0.183
Q_extraSD_NWFSC_HKL_INSIDE_CCA(8)	0.067	0.064	0.068	0.068	0.068	0.067
Size_DblN_peak_REC_FISHERY(2)	43.087	43.088	43.087	42.228	43.873	43.103
Size_DblN_ascend_se_REC_FISHERY(2)	4.713	4.726	4.713	4.598	4.772	4.714
Size_DblN_descend_se_REC_FISHERY(2)	5.301	4.402	5.301	5.999	13.669	5.248
Size_DblN_end_logit_REC_FISHERY(2)	0.200	0.960	0.200	-0.431	-6.786	0.208
Size_inflection_NWFSC_TWL(3)	24.500	36.230	28.589	24.500	6.285	26.241
Size_95%width_NWFSC_TWL(3)	-38.336	-23.778	-33.608	-38.336	-48.026	-37.028
Size_inflection_SANITATION(4)	15.333	15.067	15.450	34.950	15.443	15.333
Size_95%width_SANITATION(4)	-12.007	-12.850	-11.961	-3.224	-10.570	-12.007
Size_DblN_peak_NWFSC_HKL_OUTSIDE_CCA(5)	74.422	88.937	73.695	71.919	74.422	74.501
Size_DblN_ascend_se_NWFSC_HKL_OUTSIDE_CCA(5)	5.718	6.217	5.698	5.633	5.718	5.723
Bratio_2019	0.580	0.582	0.604	0.600	0.541	0.582
SSB_unfished	599.3	495.4	600.1	588.4	632.4	598.6
Totbio_unfished	4143.1	3538.3	4134.9	4025.4	4453.7	4138.4
SmryBio_unfished	3744.5	3073.2	3722.3	3743.3	4052.2	3741.9
Recr_unfished	169.3	186.5	171.2	191.8	181.0	169.8
Dead_Catch_SPR	72.7	76.3	74.3	73.5	69.6	72.8
B_MSY/SSB_unfished	0.281	0.280	0.282	0.279	0.277	0.281
OFLCatch_2019	91.9	96.6	97.3	95.3	83.0	92.2

Table 57: Estimated parameters, derived quantities, and likelihood components for 5 model runs with commercial selectivity ranging from 35 cm to 55 cm.

Label	Sel35	Sel40	Sel45 (Base)	Sel50	Sel55
Female M	0.1	0.093	0.083	0.077	0.07
Steepness	0.72	0.72	0.72	0.72	0.72
lnR0	5.512	5.347	5.13	4.974	4.812
Total biomass (mt)	3979.71	4028.32	4142.72	4242.05	4371.73
Depletion	0.572	0.582	0.579	0.58	0.583
SPR ratio	1	1	1	1	1
Female Lmin	19.927	19.906	19.871	19.838	19.779
Female Lmax	72.828	73.181	73.477	73.459	73.251
Female K	0.053	0.053	0.054	0.056	0.058
Negative log-likelihood					
TOTAL	763.489	765.545	767.727	769.864	772.852
Catch	0	0	0	0	0
Survey	-22.157	-22.228	-22.14	-21.986	-21.719
Length_comp	185.781	186.15	186.438	186.453	186.434
Age_comp	599.734	601.394	603.042	604.834	607.316
Recruitment	0	0	0	0	0
Parm_priors	0.129	0.227	0.386	0.561	0.82
Parm_softbounds	0.003	0.002	0.002	0.001	0.001

Table 58: Comparison of likelihoods, parameters, and derived quantities from the current base model and a model that fixes both steepness and natural mortality at values used in the 2007 and 2009 cowcod assessments. Stock status in 2019 drops from 58% in the current base to 35%.

Quantity	Base Model	M=0.055, h=0.6
Female M	0.083	0.055
Steepness	0.72	0.6
lnR0	5.13	4.514
Total biomass (mt)	4142.72	5249.73
Depletion	0.579	0.352
SPR ratio	1	0.972
Female Lmin	19.871	19.591
Female Lmax	73.477	73.119
Female K	0.054	0.062
Negative log-likelihood		
TOTAL	767.727	777.463
Catch	0	0
Survey	-22.14	-20.151
Length_comp	186.438	187.746
Age_comp	603.042	608.869
Recruitment	0	0
Parm_priors	0.386	0.998
Parm_softbounds	0.002	0.001

Table 59: Sensitivity to fecundity based on assumption of size-dependent multiple brooding (2 broods max.).

Label	Post-STAR base	Multiple brood ogive similar to maturity ogive	Multiple brood ogive shifted relative to maturity
NatM_p_1_Fem_GP_1	0.088	0.089	0.094
L_at_Amin_Fem_GP_1	19.7	19.7	19.7
L_at_Amax_Fem_GP_1	74.0	73.9	73.6
VonBert_K_Fem_GP_1	0.055	0.055	0.055
CV_young_Fem_GP_1	0.169	0.169	0.169
CV_old_Fem_GP_1	0.078	0.078	0.079
SR_LN(R0)	5.193	5.212	5.328
SR_BH_steep	0.72	0.72	0.72
Q_extraSD_SANITATION(4)	0.629	0.629	0.627
Q_extraSD_CALCOFI(6)	0.227	0.226	0.224
LnQ_base_SWFSC_SUB_SURVEY(7)	-0.579	-0.581	-0.592
Bratio_2019	0.571	0.571	0.565
SSB_unfished	569.1	1089.5	796.3
Totbio_unfished	3976.2	3966.2	3915.4
SmryBio_unfished	3564.0	3548.4	3461.8
SSB_SPR	253.9	486.1	355.3
Dead_Catch_SPR	72.8	72.8	72.7
B_MSY/SSB_unfished	0.28	0.28	0.26
OFLCatch_2019	90.7	90.5	88.9
TOTAL	819.40	819.47	819.86
Survey	-10.47	-10.47	-10.47
Length_comp	183.4	183.4	183.3
Age_comp	646.3	646.4	646.8
Parm_priors	0.164	0.165	0.185
Parm_softbounds	0.0043	0.0044	0.0053

Table 60: Sensitivity to historical catches (pre-1969), with alternatives of ½ catch and 2x catch relative to the base

Label	base	1/2 pre-1969 catch	2x pre-1969 catch
Natural Mortality	0.083	0.090	0.067
Length at Age 2	19.9	19.9	19.9
Length at Age 35	73.5	73.7	73.3
von Bert k	0.054	0.053	0.056
CV(L) at Age 2	0.172	0.172	0.173
CV(L) at Age 35	0.076	0.076	0.076
ln(R0)	5.130	5.191	5.007
B-H steepness	0.72	0.72	0.72
Sanitation Districts extra SD	0.6414	0.6517	0.6128
CalCOFI extra SD	0.1831	0.1814	0.2064
ln(Q) SWFSC Submersible Survey	-0.8091	-0.8117	-0.7944
SSB 2019 / SSB unfished	0.5794	0.6312	0.4368
SSB unfished	599.3	523.0	887.1
Total Biomass unfished	4142.7	3704.6	5799.4
Summary Biomass unfished	3744.5	3301.6	5404.3
SSB (SPR target equilibrium)	267.4	233.3	395.8
Yield (SPR target at equilibrium)	72.6	68.9	85.5
SSB_MSY / SSB_unfished	0.28	0.28	0.29
OFLCatch_2019	91.6	93.4	84.1
TOTAL Negative Log Likelihood	767.727	766.236	772.004
Survey NLL	-22.140	-22.012	-21.886
Length_comp NLL	186.438	186.544	186.558
Age_comp NLL	603.042	601.364	606.657
Parm_priors NLL	0.386	0.339	0.673
Parm_softbounds NLL	0.002	0.002	0.001

Table 61: Sensitivity to types of maturity determination (functional vs. biological).

Label	base (functional maturity)	biological maturity
NatM_p_1_Fem_GP_1	0.083	0.080
L_at_Amin_Fem_GP_1	19.9	19.9
L_at_Amax_Fem_GP_1	73.5	73.8
VonBert_K_Fem_GP_1	0.054	0.054
CV_young_Fem_GP_1	0.172	0.172
CV_old_Fem_GP_1	0.076	0.076
SR_LN(R0)	5.130	5.033
SR_BH_steep	0.72	0.72
Q_extraSD_SANITATION(4)	0.6414	0.6409
Q_extraSD_CALCOFI(6)	0.1831	0.1845
LnQ_base_SWFSC_SUB_SURVEY(7)	-0.8091	-0.7569
Bratio_2019	0.579	0.565
SSB_unfished	599.3	639.3
Totbio_unfished	4142.7	4179.2
SmryBio_unfished	3744.5	3809.8
SSB_SPR	267.4	285.2
Dead_Catch_SPR	72.6	71.4
B_MSY/SSB_unfished	0.28	0.29
OFLCatch_2019	91.6	89.0
TOTAL	767.727	767.487
Survey	-22.140	-22.071
Length_comp	186.438	186.268
Age_comp	603.042	602.935
Parm_priors	0.386	0.353
Parm_softbounds	0.002	0.002

Table 62: Projection of OFL, assumed default harvest control rule catch (ABC = ACL above 40% SSB), age 10+ biomass, spawning output and depletion using the cowcod base case model with 2019-2020 catches set equal to recommendations from the GMT. ABC catches are based on a tier 2 sigma value of 1.0 with a 'p-star' value of 0.45. *Catches for 2019 and 2020 recommended by the STAR panel GMT representative.

Year	Predicted OFL (mt)	ABC Catch (mt)	Age 10+ biomass (mt)	Spawning Output (eggs x 10^9)	Depletion (%)
2019	90.7	3.1*	2125	325	57.1%
2020	92.9	3.1*	2180	334	58.7%
2021	95.0	83.2	2233	343	60.3%
2022	93.9	81.5	2210	340	59.7%
2023	93.0	79.9	2188	337	59.2%
2024	92.0	78.4	2166	334	58.7%
2025	91.2	76.9	2146	331	58.1%
2026	90.4	75.5	2127	328	57.6%
2027	89.6	74.3	2111	325	57.1%
2028	89.0	73.1	2095	323	56.7%
2029	88.5	71.9	2082	321	56.3%
2030	88.0	70.9	2071	319	56.0%

Table 63: Decision table summarizing 12-year projections (2019 – 2030) for cowcod according to three alternative states of nature varying natural mortality and commercial fishery selectivity (length at 50% selectivity). Columns range over low, medium, and high state of nature, and rows range over different assumptions of total catch levels corresponding to the forecast catches from each state of nature. Catches in 2019 and 2020 were proposed by the GMT representative. Catch is in mt, spawning output is in billions of eggs, and depletion is the percentage of spawning output relative to unfished spawning output. Outcomes below target spawning output (40% of unfished spawning output) are shaded in gray..

			State of nature					
			Low		Base case		High	
			M=0.055, $L_{50\%}$=35 cm		M=0.088, $L_{50\%}$=45.6 cm		M=0.098, $L_{50\%}$=55cm	
Management decision	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	45.7	330	38.1%	343	60.3%	434	77.8%
	2022	45.8	335	38.6%	346	60.7%	434	77.8%
Low	2023	45.9	339	39.1%	348	61.1%	434	77.7%
Catch	2024	45.9	343	39.6%	350	61.4%	433	77.6%
	2025	45.9	347	40.0%	351	61.7%	432	77.4%
	2026	45.8	351	40.5%	353	61.9%	431	77.2%
	2027	45.7	354	40.9%	354	62.1%	429	77.0%
	2028	45.5	358	41.2%	355	62.3%	428	76.7%
	2029	45.4	361	41.6%	355	62.5%	427	76.5%
	2030	45.3	364	42.0%	356	62.6%	425	76.2%
	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	83.2	330	38.1%	343	60.3%	434	77.8%
	2022	81.5	329	38.0%	340	59.7%	429	76.9%
Base	2023	79.9	328	37.8%	337	59.2%	423	75.9%
Catch	2024	78.4	326	37.6%	334	58.7%	418	74.9%
	2025	76.9	324	37.3%	331	58.1%	412	73.9%
	2026	75.5	321	37.0%	328	57.6%	407	72.9%
	2027	74.3	318	36.7%	325	57.1%	401	71.9%
	2028	73.1	315	36.3%	323	56.7%	396	71.0%
	2029	71.9	312	36.0%	321	56.3%	391	70.1%
	2030	70.9	309	35.6%	319	56.0%	386	69.2%
	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	128.4	330	38.1%	343	60.3%	434	77.8%
	2022	123.5	322	37.2%	334	58.7%	422	75.6%
High	2023	119.0	314	36.2%	325	57.1%	410	73.5%
Catch	2024	114.9	306	35.2%	316	55.5%	399	71.6%
	2025	111.0	297	34.2%	307	54.0%	389	69.8%
	2026	107.5	288	33.2%	299	52.5%	380	68.1%
	2027	104.3	279	32.1%	291	51.1%	372	66.6%
	2028	101.3	270	31.1%	283	49.7%	364	65.3%
	2029	98.5	261	30.1%	276	48.5%	357	64.1%
	2030	96.0	252	29.1%	269	47.3%	351	63.0%

11 Figures

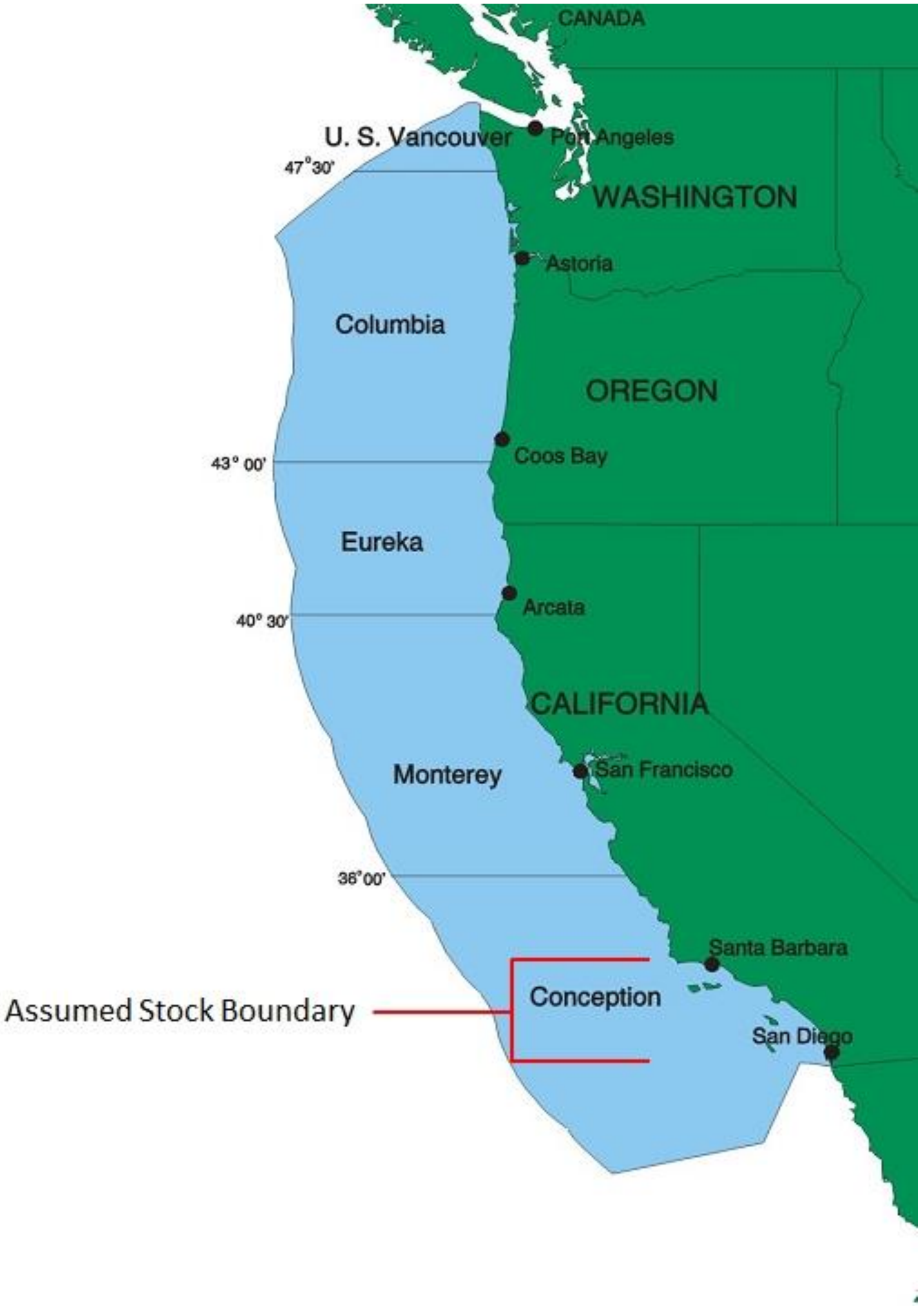


Figure 1: Assumed stock boundary (U.S. waters off California, south of 34° 27′ N. latitude) for the 2019 cowcod base model, showing INPFC areas.

Figure 2: Young of the year pelagic juvenile cowcod. Source: Sakuma et al. 2013. Photo credit: Dale Roberts and Keith Sakuma, SWFSC.

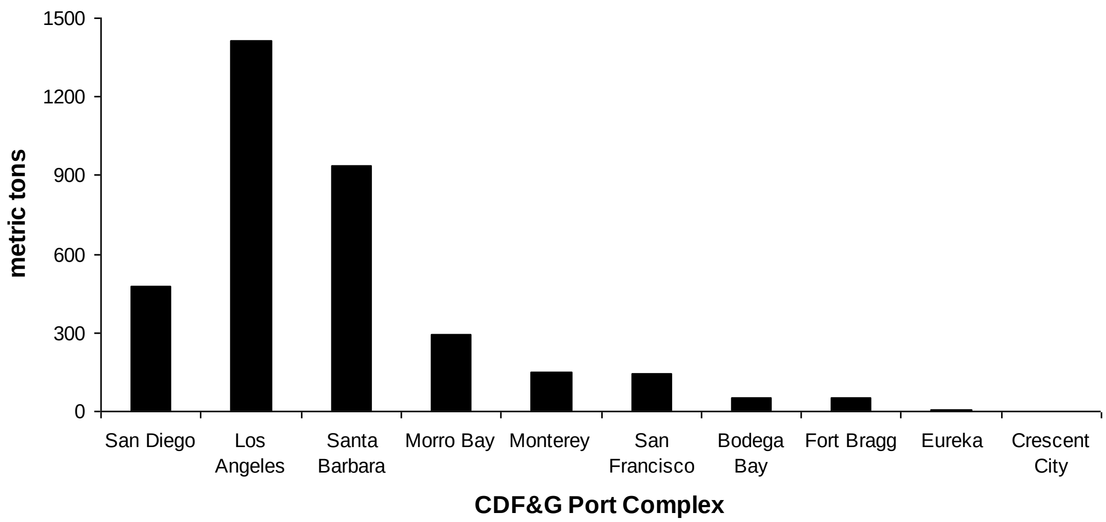


Figure 3: Cowcod landings by port complex, 1969-2005. Landings since 2005 have been on the order of 1-3 mt per year. Roughly 80% of catch has been landed in the San Diego, Los Angeles, and Santa Barbara port complexes. Source: CALCOM.

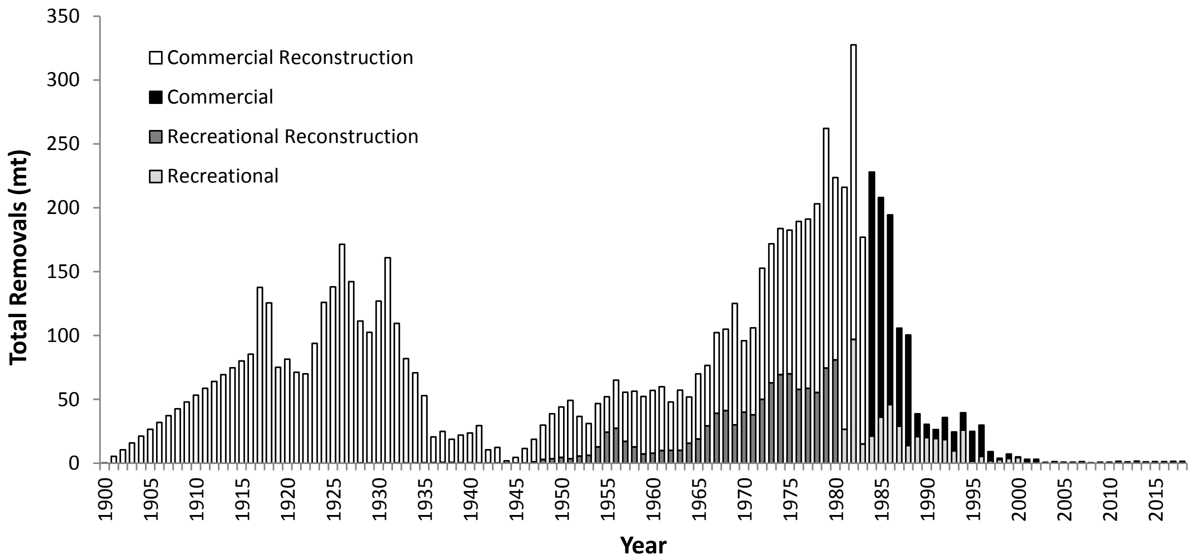


Figure 4: Estimated commercial and recreational removals of cowcod in the Southern California Bight, 1900-2018.

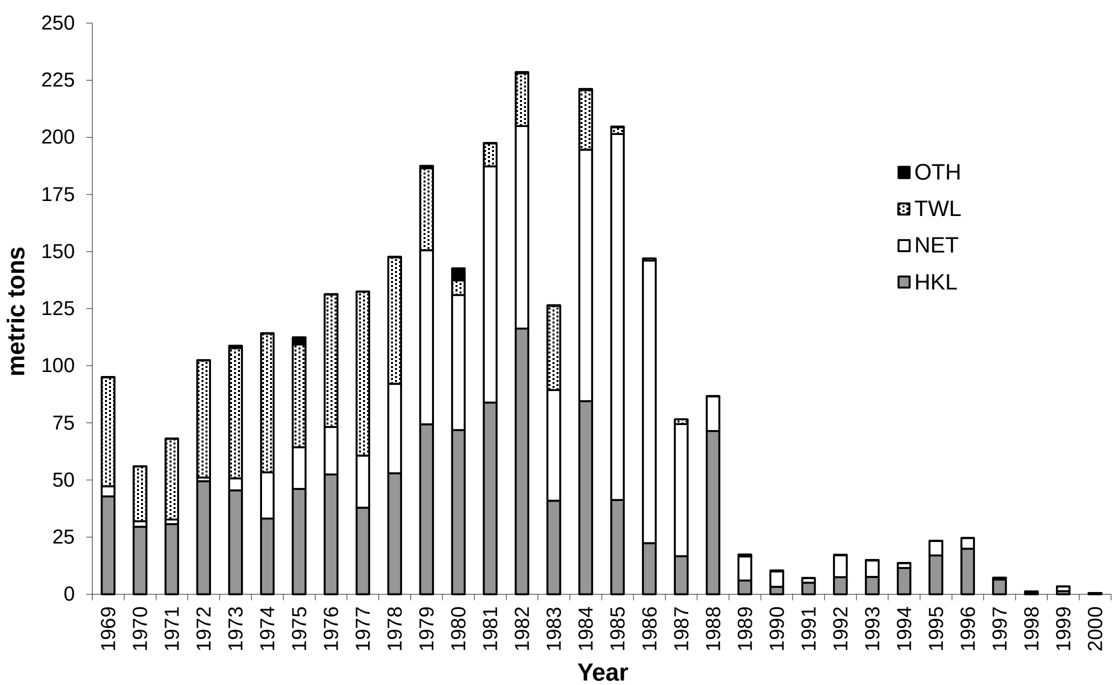


Figure 5: Commercial landings of cowcod by year and gear, 1969-2000. Source: CALCOM.

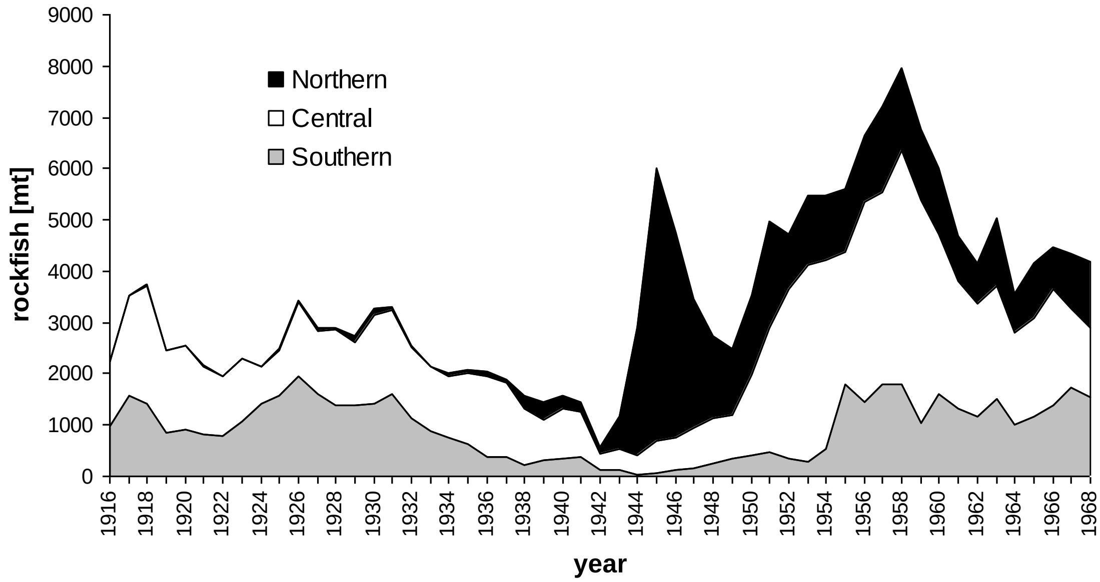


Figure 6: Total commercial rockfish landings by area in California, 1916-1968. See text for definition of regions. Data from 1916-1927 are from CDF&G Fish Bulletin No. 105 (1958), and data after 1927 are from the NMFS SWFSC ERD ERDDAP Data Server.

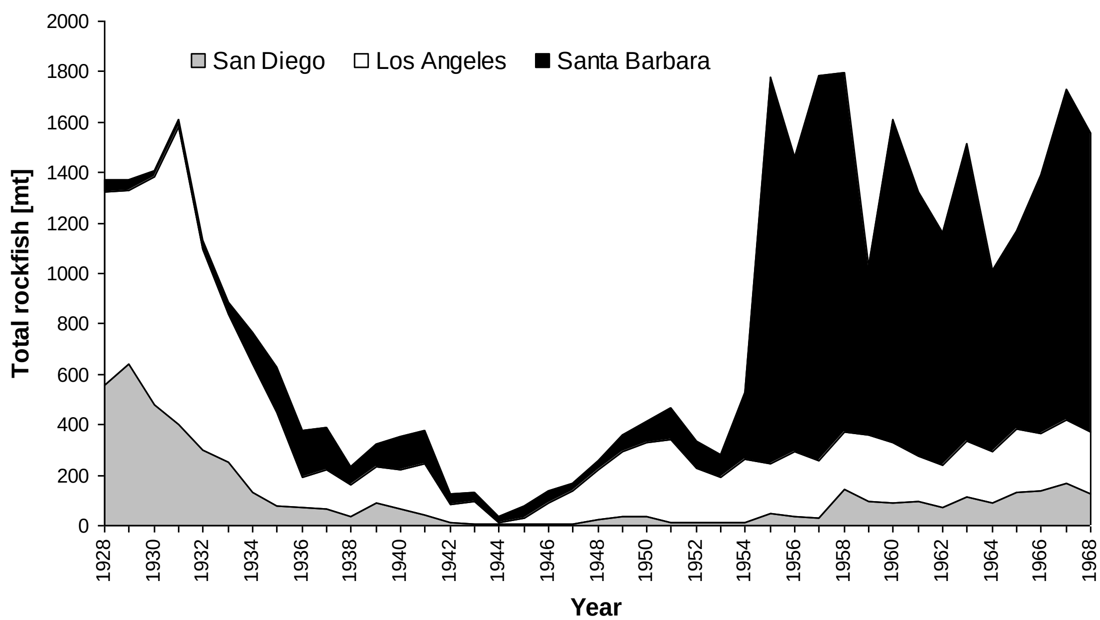


Figure 7: Total commercial rockfish landings in Southern California, 1928-1968, from ERDDAP. Landings include thornyheads (genus *Sebastolobus*) and exclude foreign catch. Increased catch in the Santa Barbara region (1954+) is largely due to landings at Morro Bay and Avila.

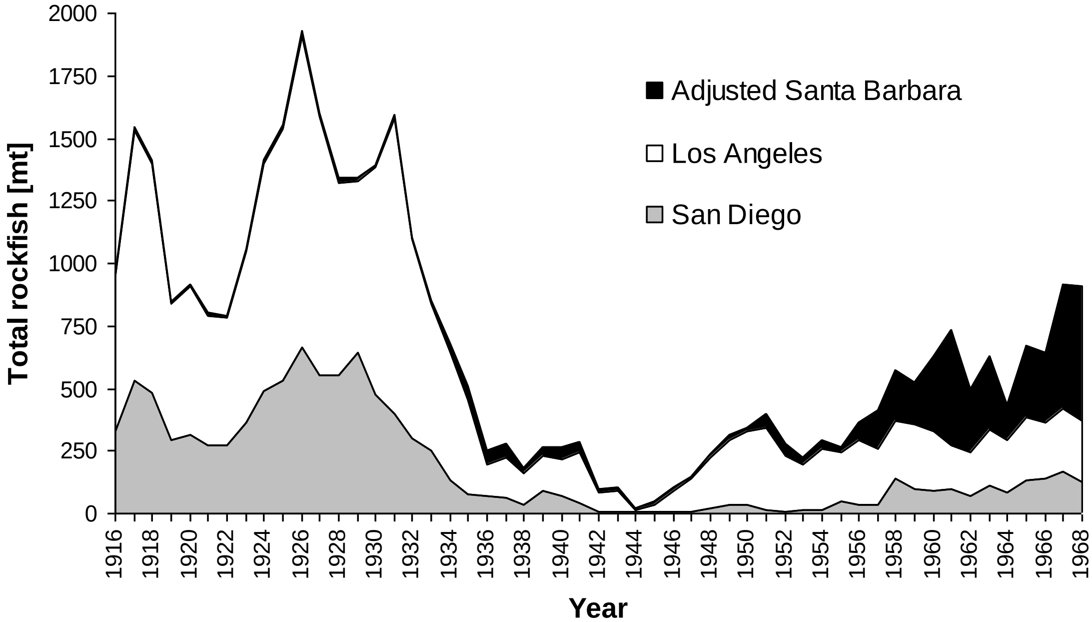
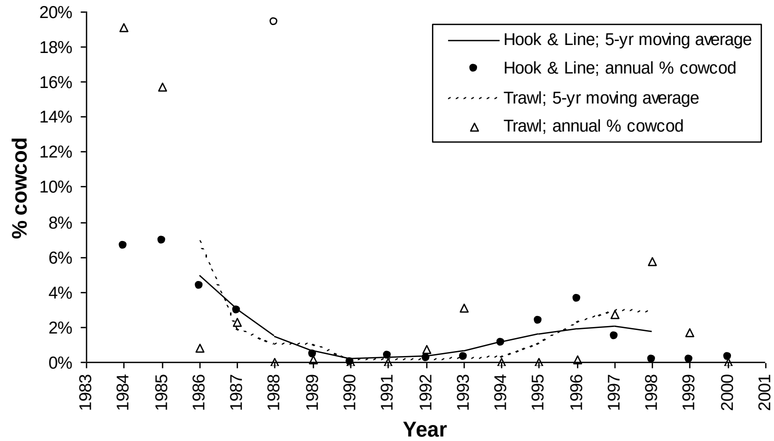
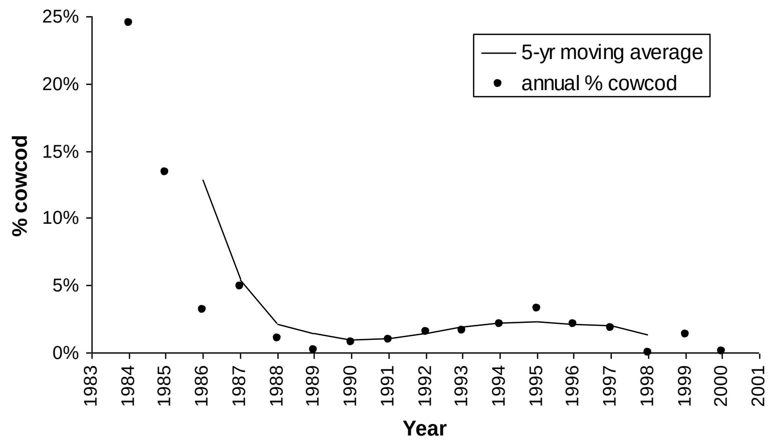


Figure 8: Total commercial rockfish landings in Southern California by region, 1916-1968. Catch in the Santa Barbara region has been adjusted to exclude landings at Morro Bay and Avila.

Santa Barbara Fisheries



Los Angeles Hook & Line Fishery



San Diego Hook & Line Fishery

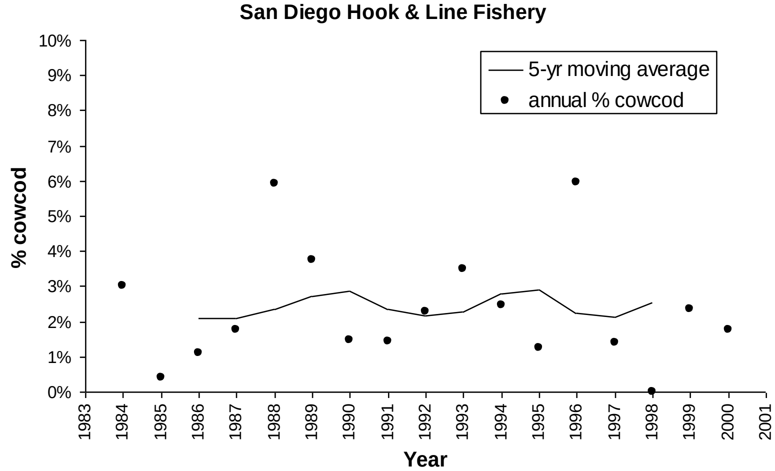


Figure 9: Percent cowcod in rockfish landings, 1984-2000, by year, port, and gear. Moving averages for the Santa Barbara hook & line fishery do not include data from 1988 (open circle).

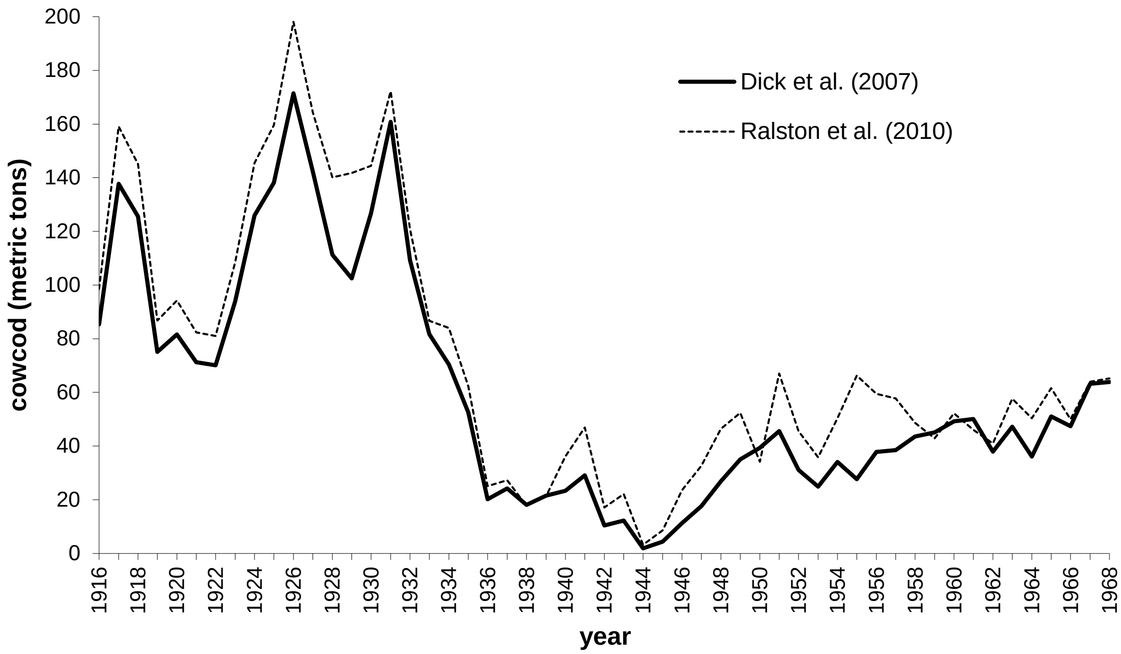


Figure 10: Comparison of historical commercial catch reconstructions for cowcod. Estimates by Ralston et al. (2010) represent catch in the Conception INPFC area. Dick et al. (2007) estimated cowcod catches for U.S. waters south of Point Conception.

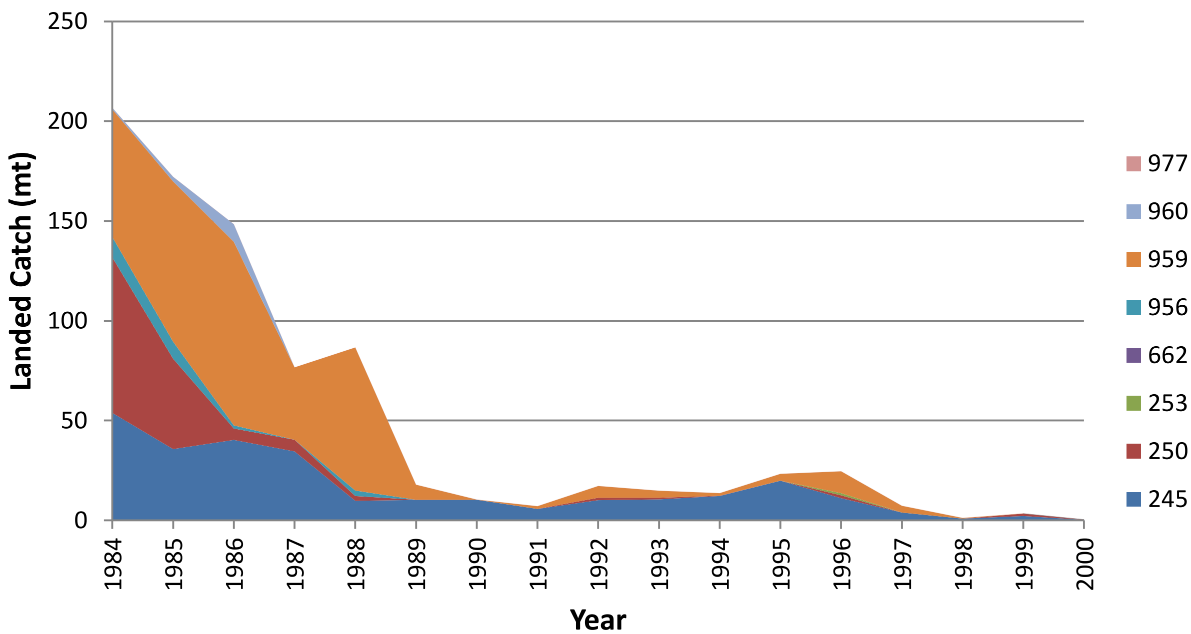


Figure 11: Landings of cowcod (mt) by year and market category. Less than 1/3 of cowcod landings from 1984-2000 were sorted into market category 245 (the "cowcod" market category).

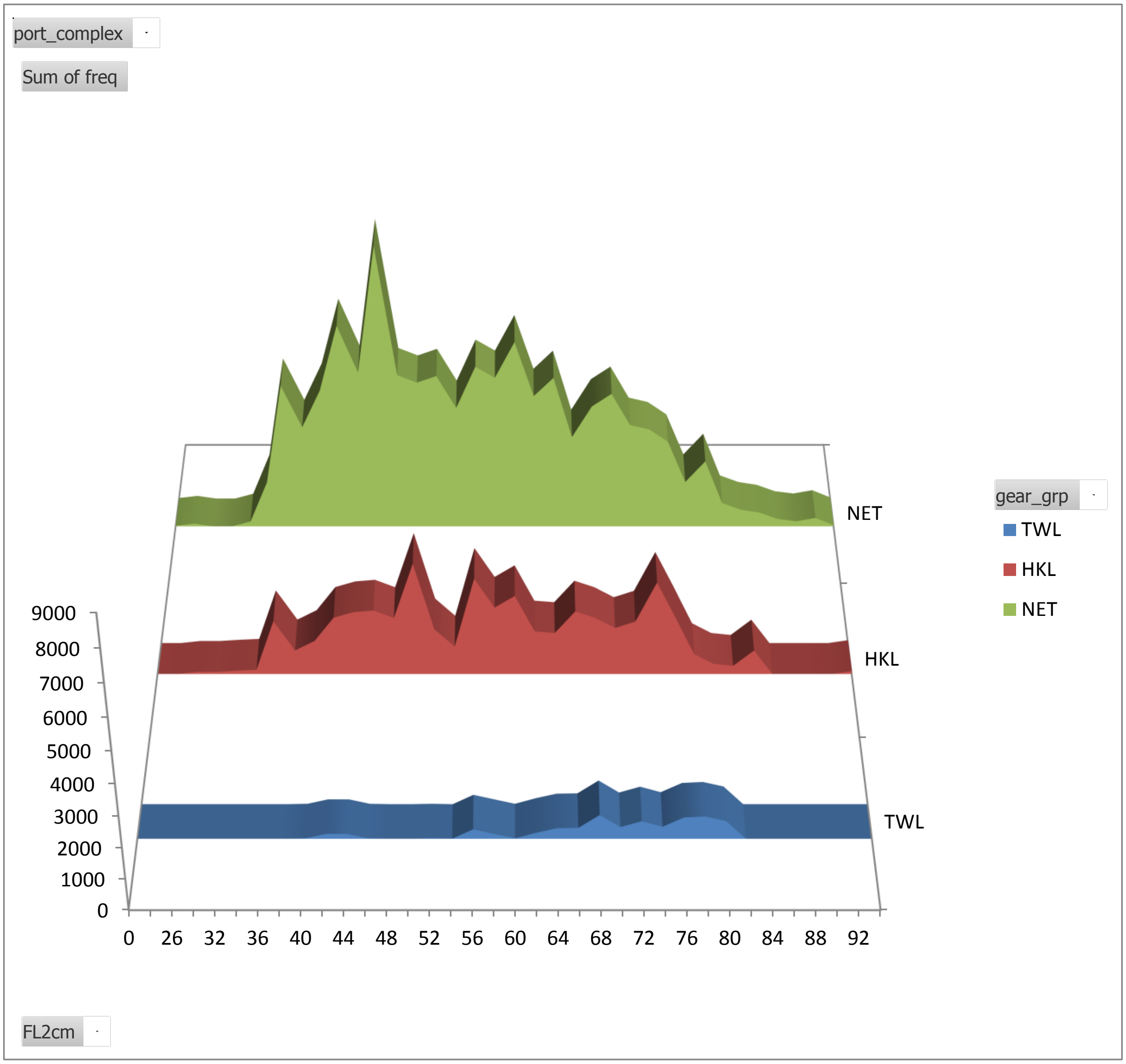


Figure 12: Commercial length compositions by gear group (TWL = trawl, HKL = hook and line, NET = combined net gears) for years with highest sample sizes (1983-1987). Source: CALCOM, 2019.

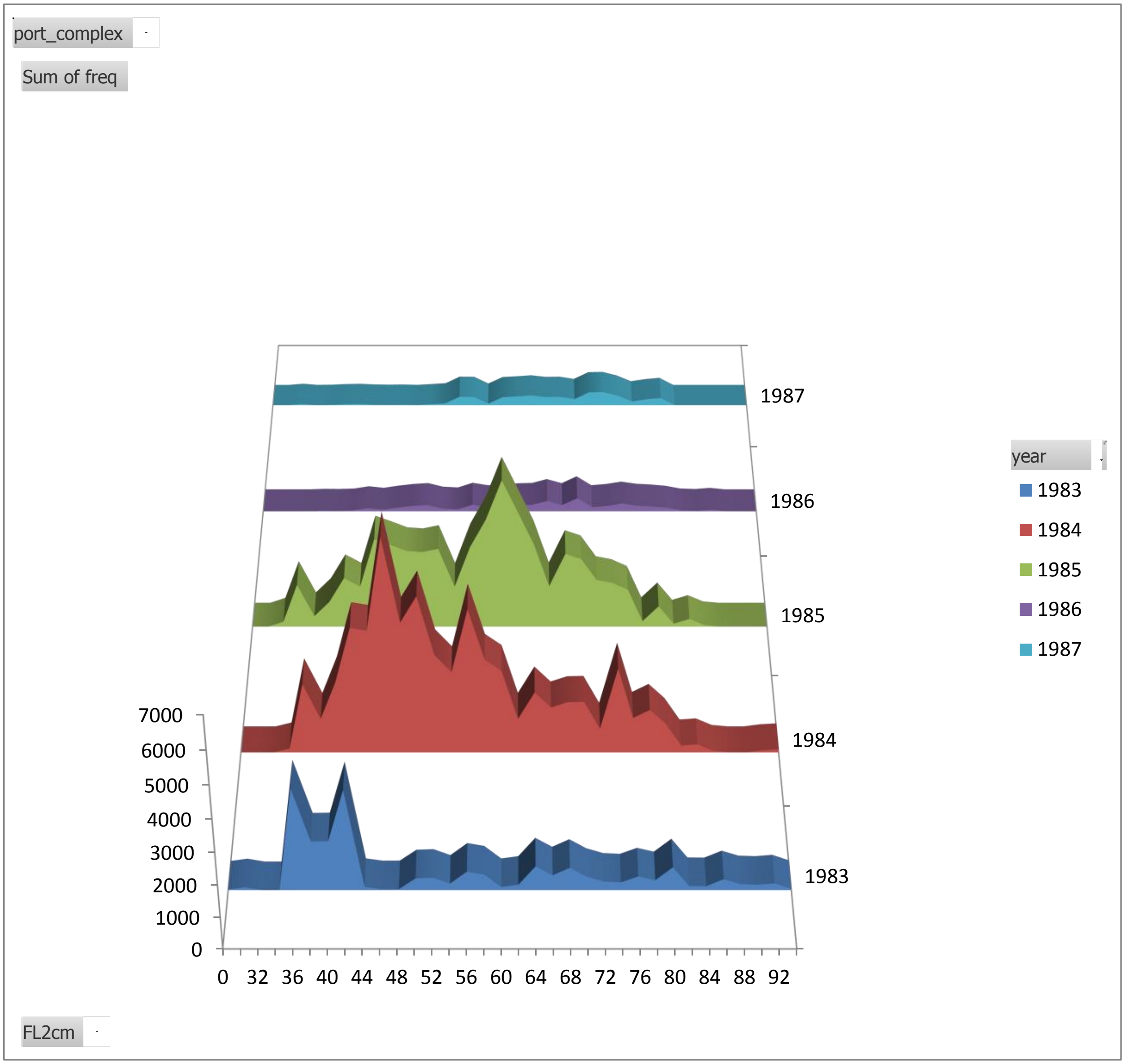


Figure 13: Commercial length compositions for years with highest sample sizes (1983-1987), all gears combined. Source: CALCOM.

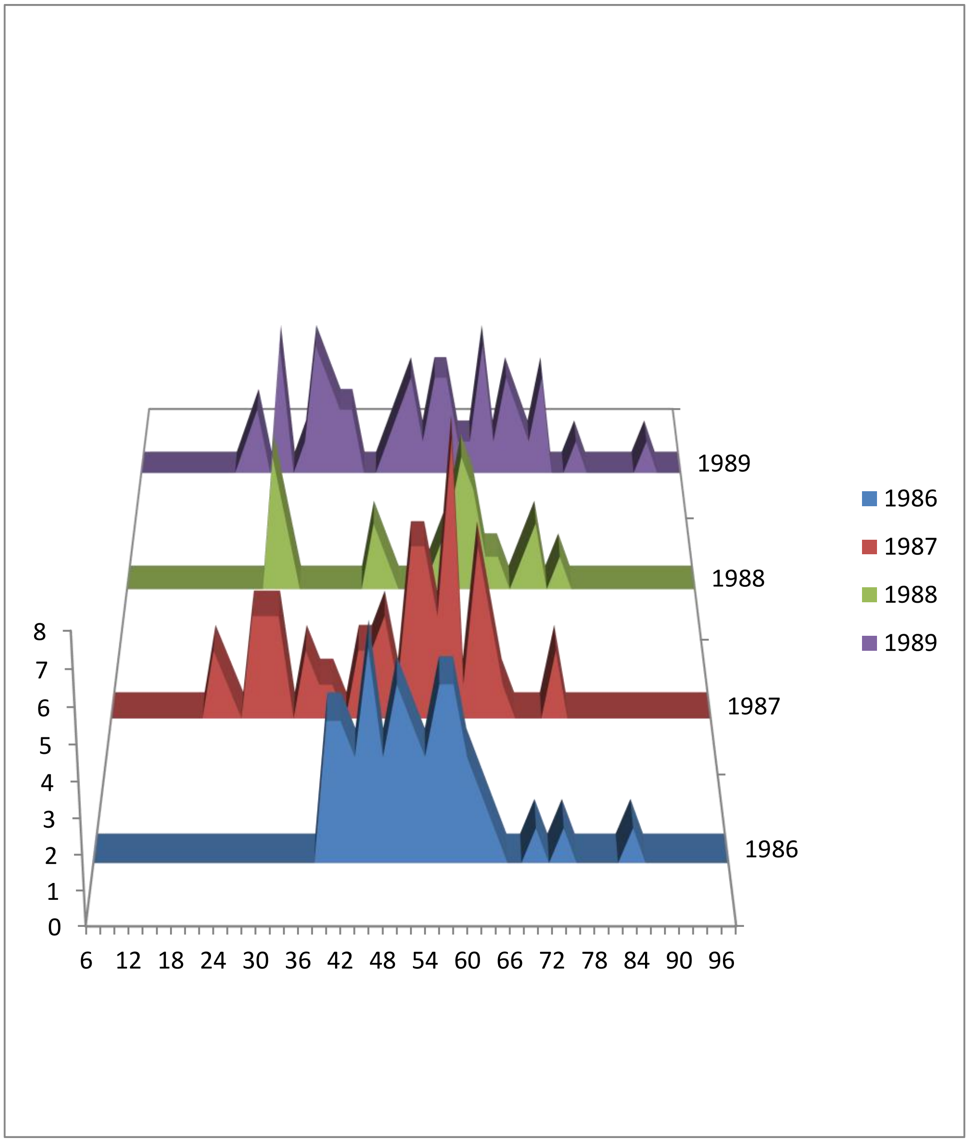


Figure 14: Length composition data (frequency of fish by 2-cm length bin) from onboard CPFV observers in southern California (Ally et al. 1991). Data were converted from total length to fork length.

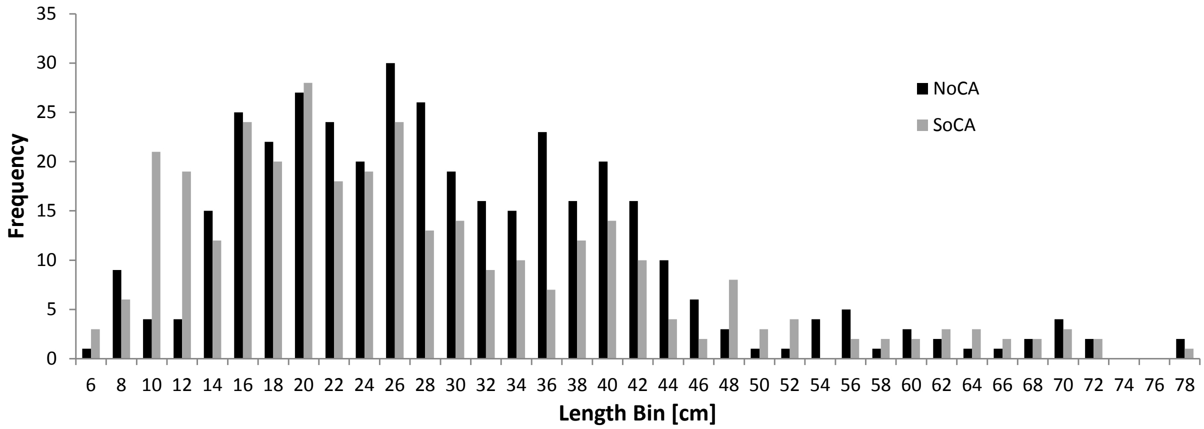


Figure 15: NWFSC WCGBT Survey length frequency distribution by area, all available years combined (2003-2017).

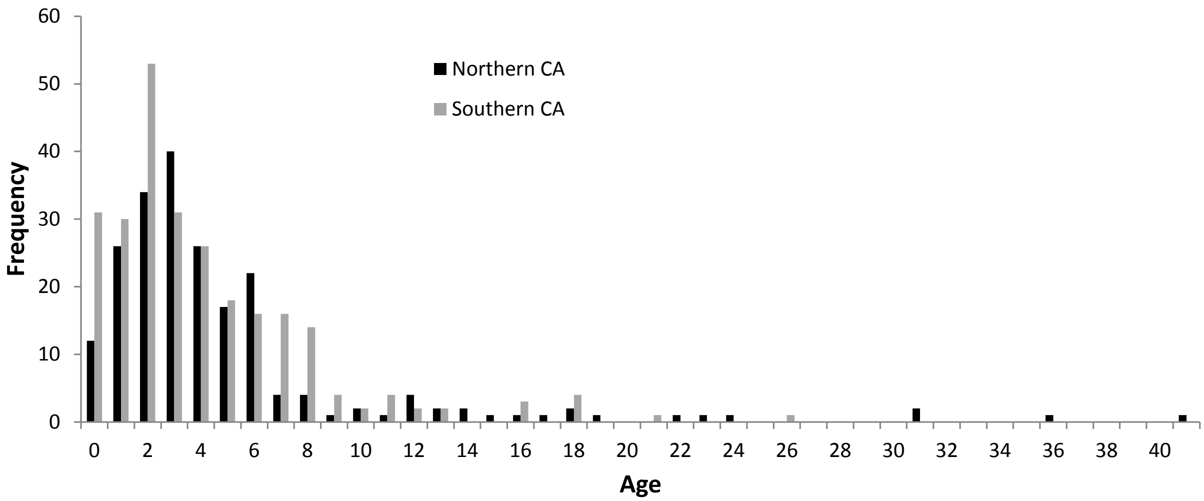


Figure 16: NWFSC WCGBT Survey age frequency distribution by area, all available years combined (2003-2017).

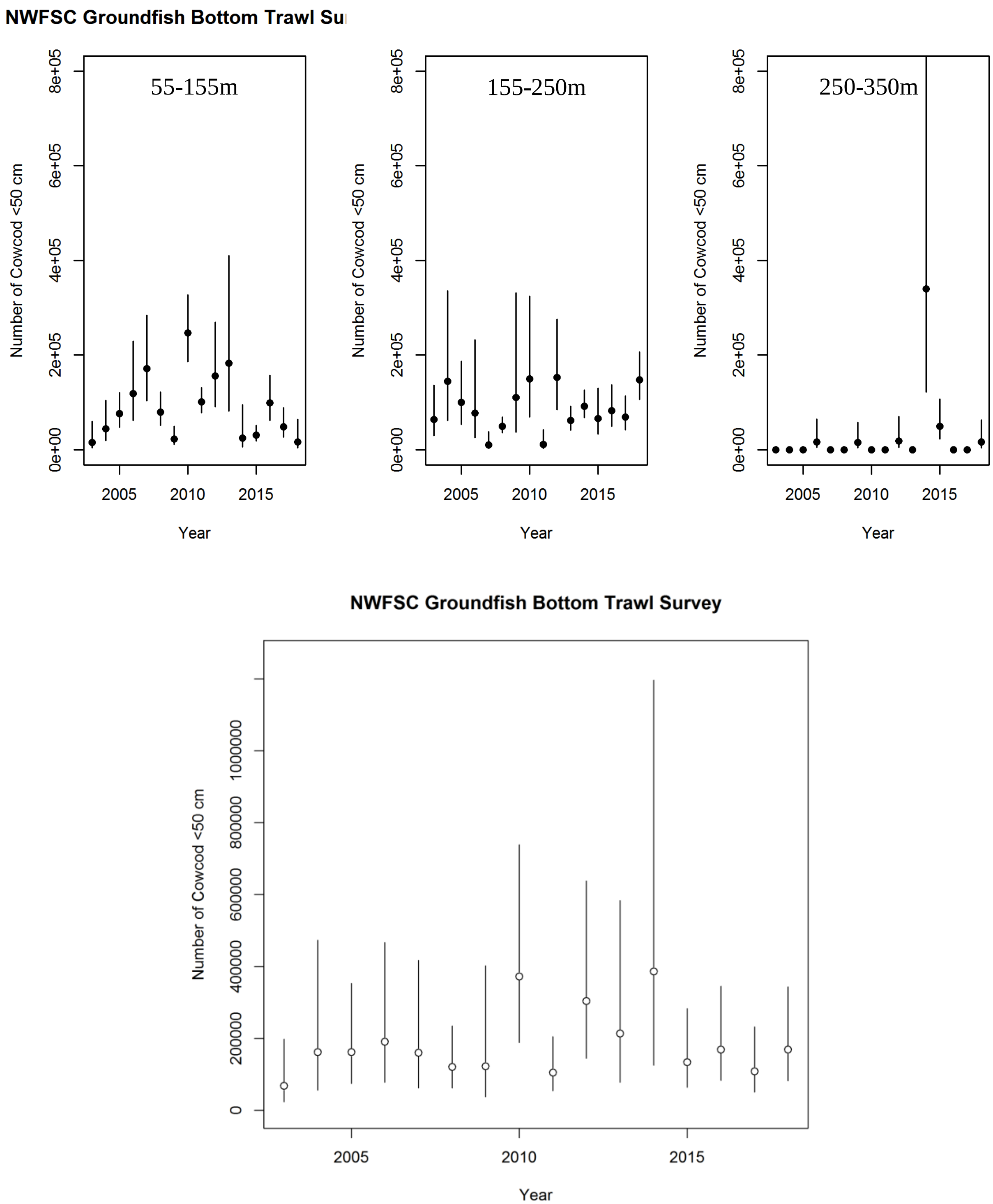


Figure 17: Design-based index for the NWFSC WCGBT Survey. Upper panels: estimated abundance by depth stratum. Lower panel: aggregated index, 55-350m.

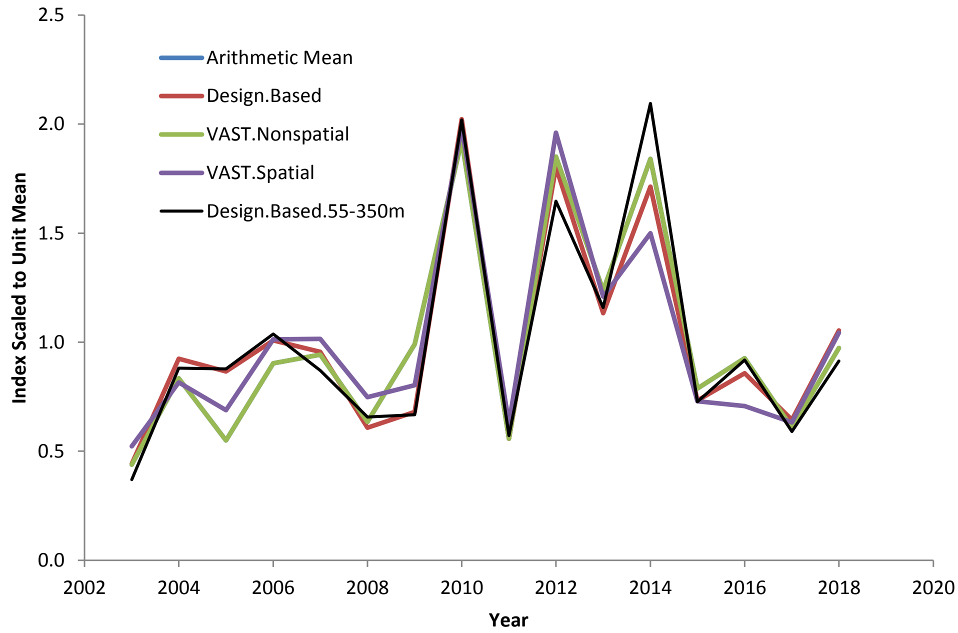


Figure 18: Comparison of indices derived from the NWFSC WCGBT Survey data for Southern California. Response variable is number of fish per square km. The arithmetic mean by year is identical to the VAST nonspatial model (blue line is hidden by the green line). All indices were scaled to a mean of 1 to facilitate comparison of trends.

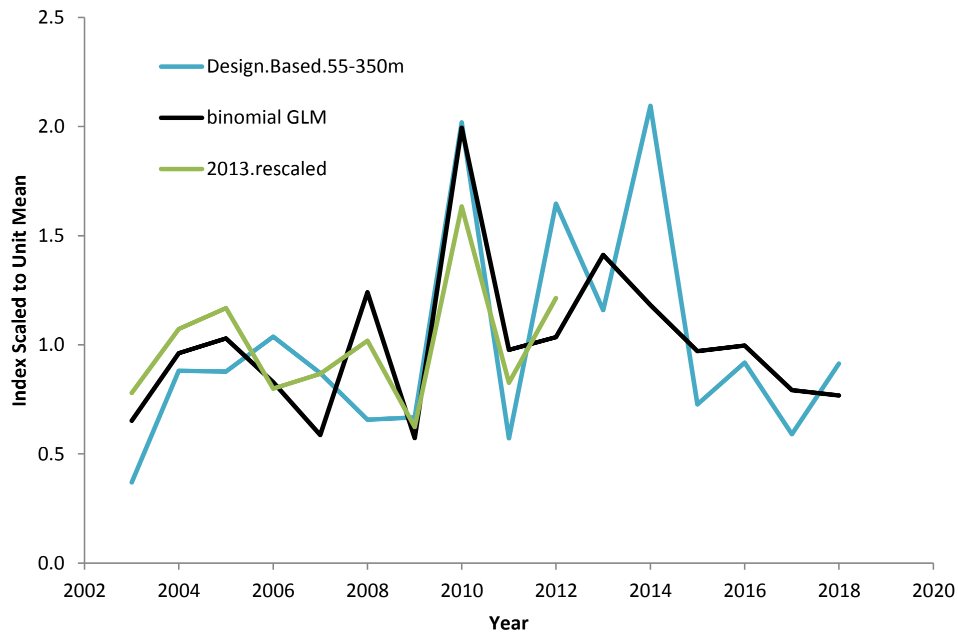


Figure 19: Binomial indices of abundance based on NWFSC WCGBT Survey data. The index from the 2013 assessment (green line) is less variable than a similar model applied to the data through 2019 (black line). A design-based swept area index derived from the same data (blue line) is shown for comparison. All indices have been scaled to a unit mean for comparison.

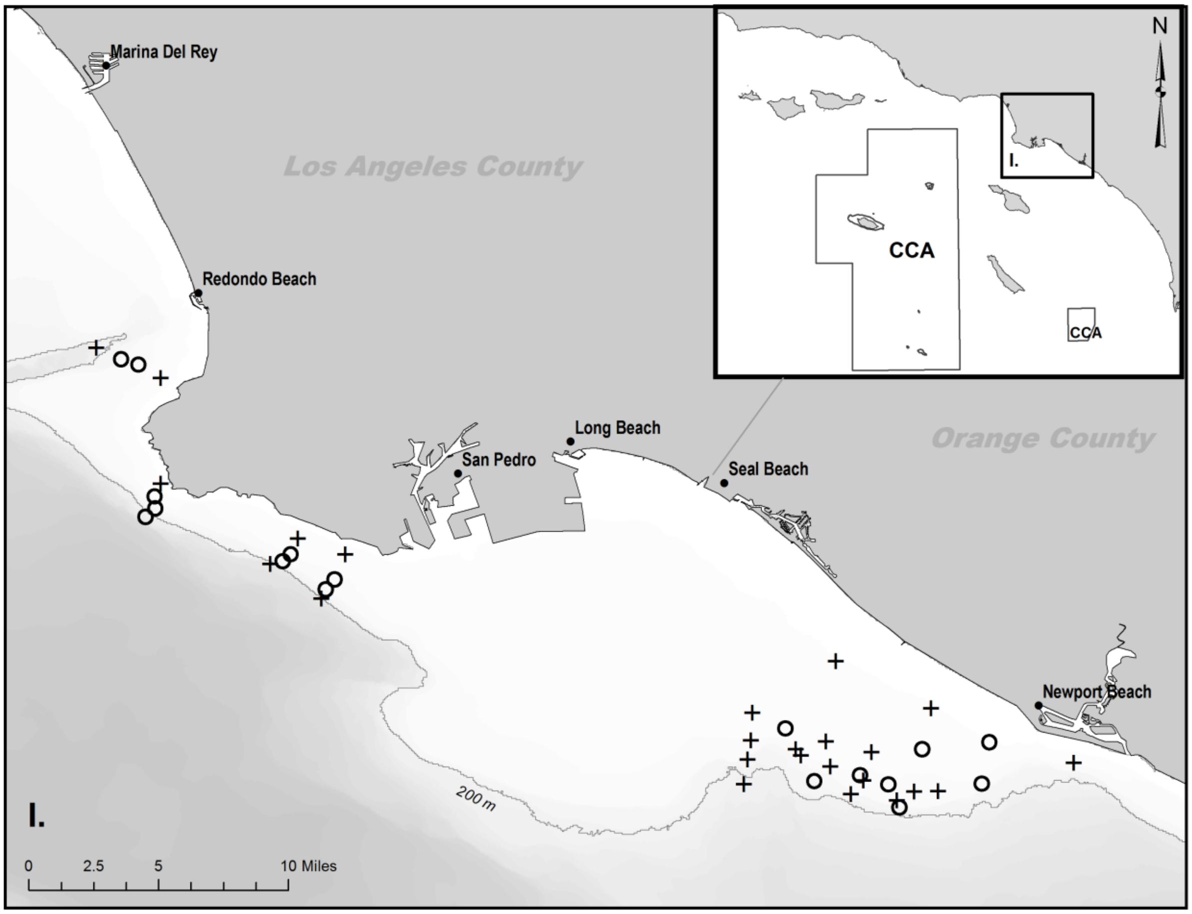


Figure 20: Location of trawls conducted by the Los Angeles and Orange County Sanitation Districts. Circles indicate stations where cowcod have been taken. Plus signs indicate stations where cowcod have not been taken.

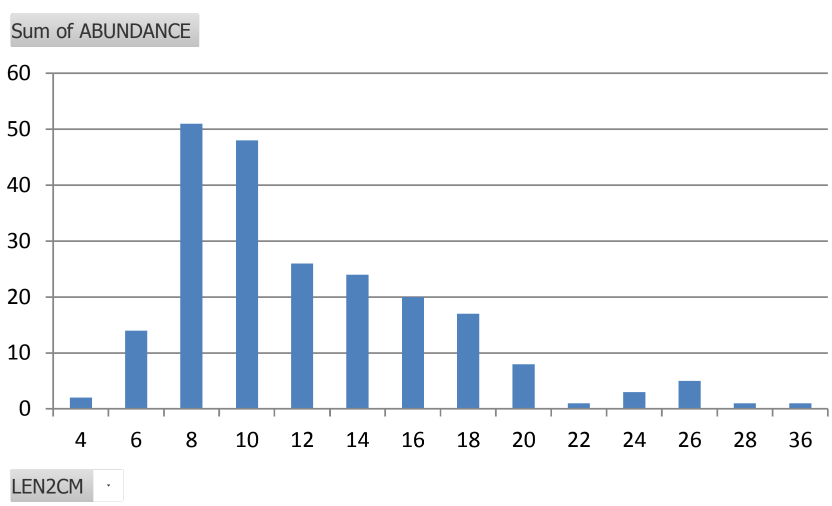


Figure 21: Length frequency distribution (number of fish per 2cm bin, N=221) of cowcod caught by the Los Angeles and Orange County Sanitation District trawl surveys, quarter 1, 3, and 4 of 'shift years' 1970-2018.

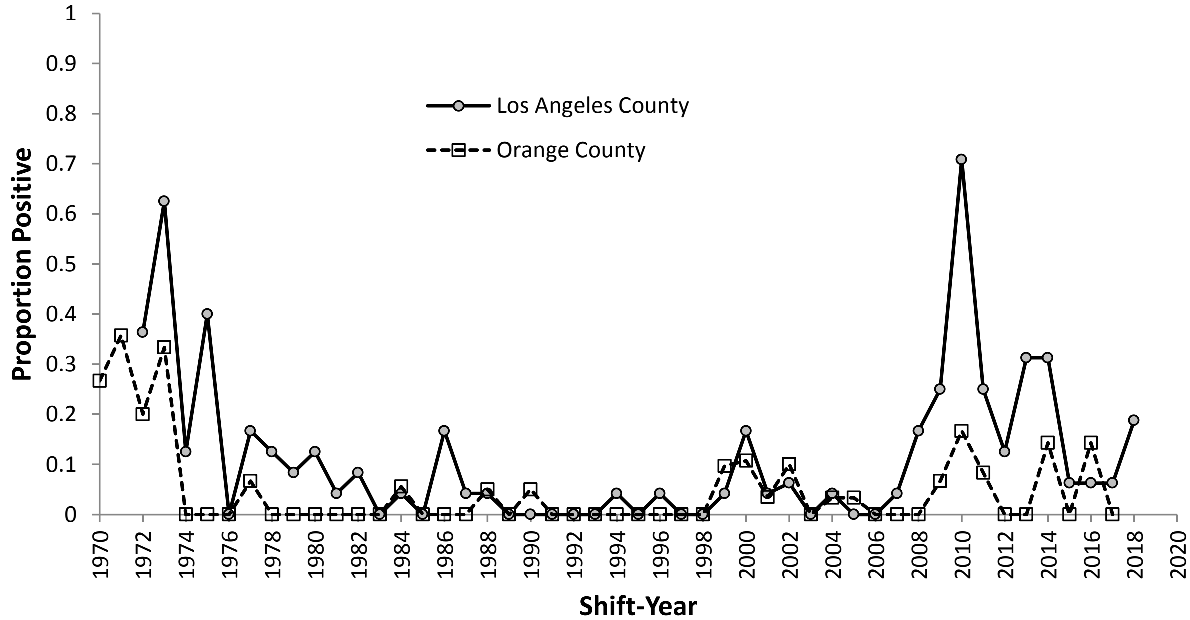


Figure 22: Proportion of hauls positive for cowcod by year and survey in the Los Angeles County (LA) and Orange County (OC) Sanitation District surveys.

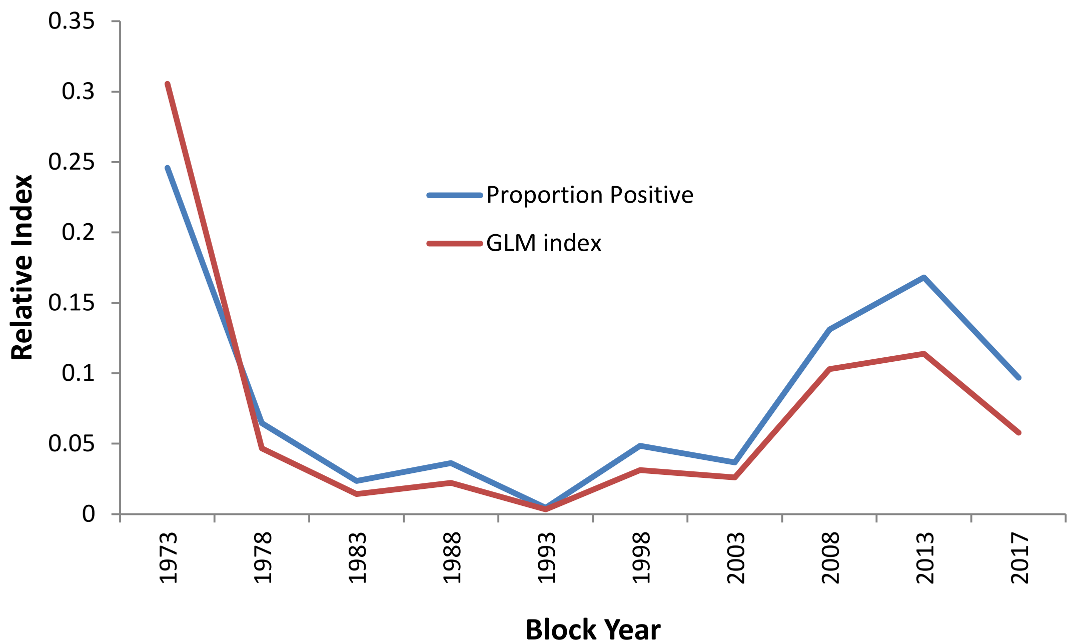


Figure 23: Comparison of the combined LA/OC Sanitation District GLM index (with station and quarter effects) to the proportion of positive hauls in a given year (not accounting for station or quarter effects).

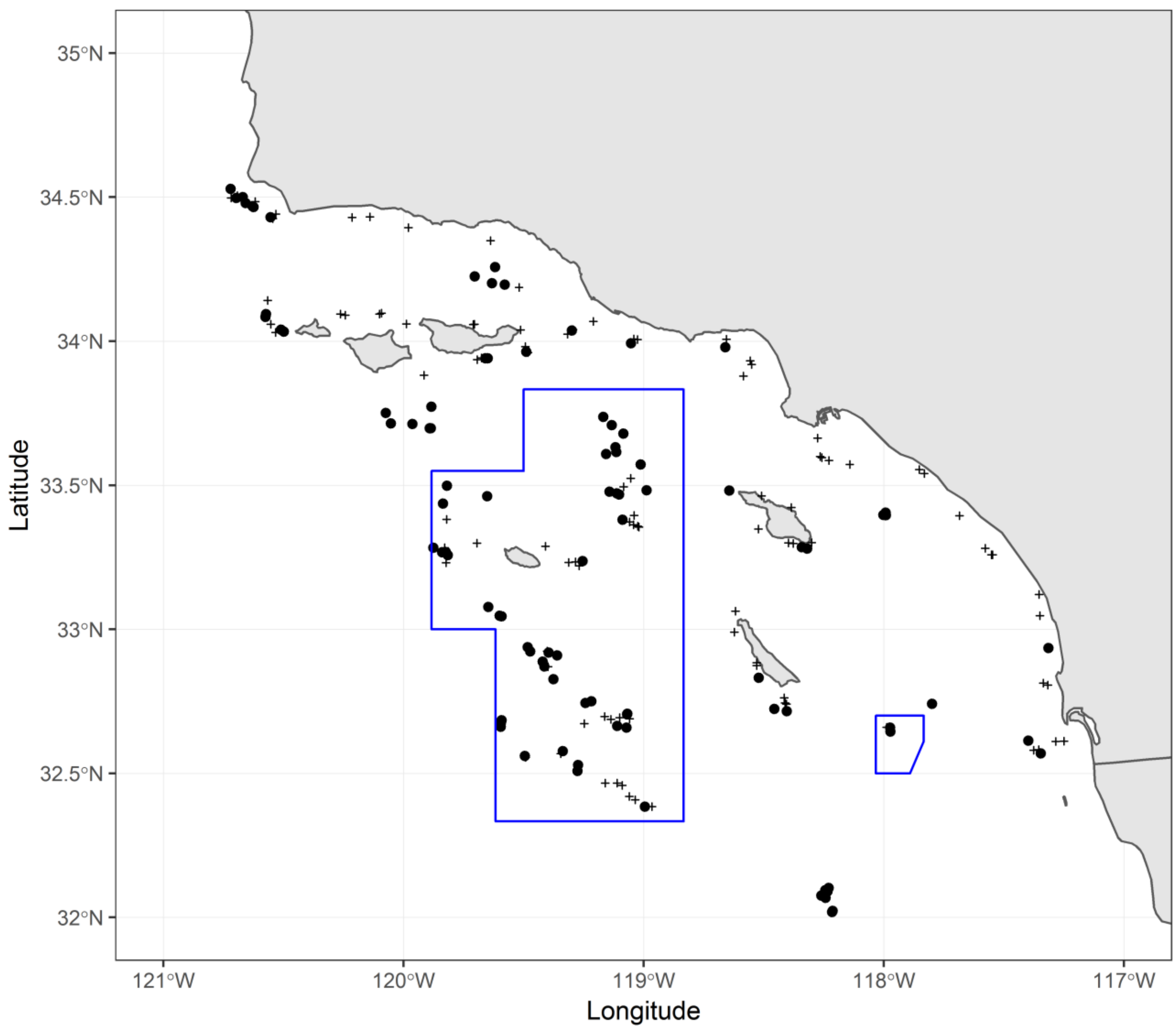


Figure 24: NWFSC Hook-and-Line survey sites, 2004-2018. Solid circles indicate sites at which at least one cowcod has been caught; plus signs indicate sights where no cowcod have been caught. Sampling of sites within the Cowcod Conservation Areas (CCAs; blue polygons) began in 2014.

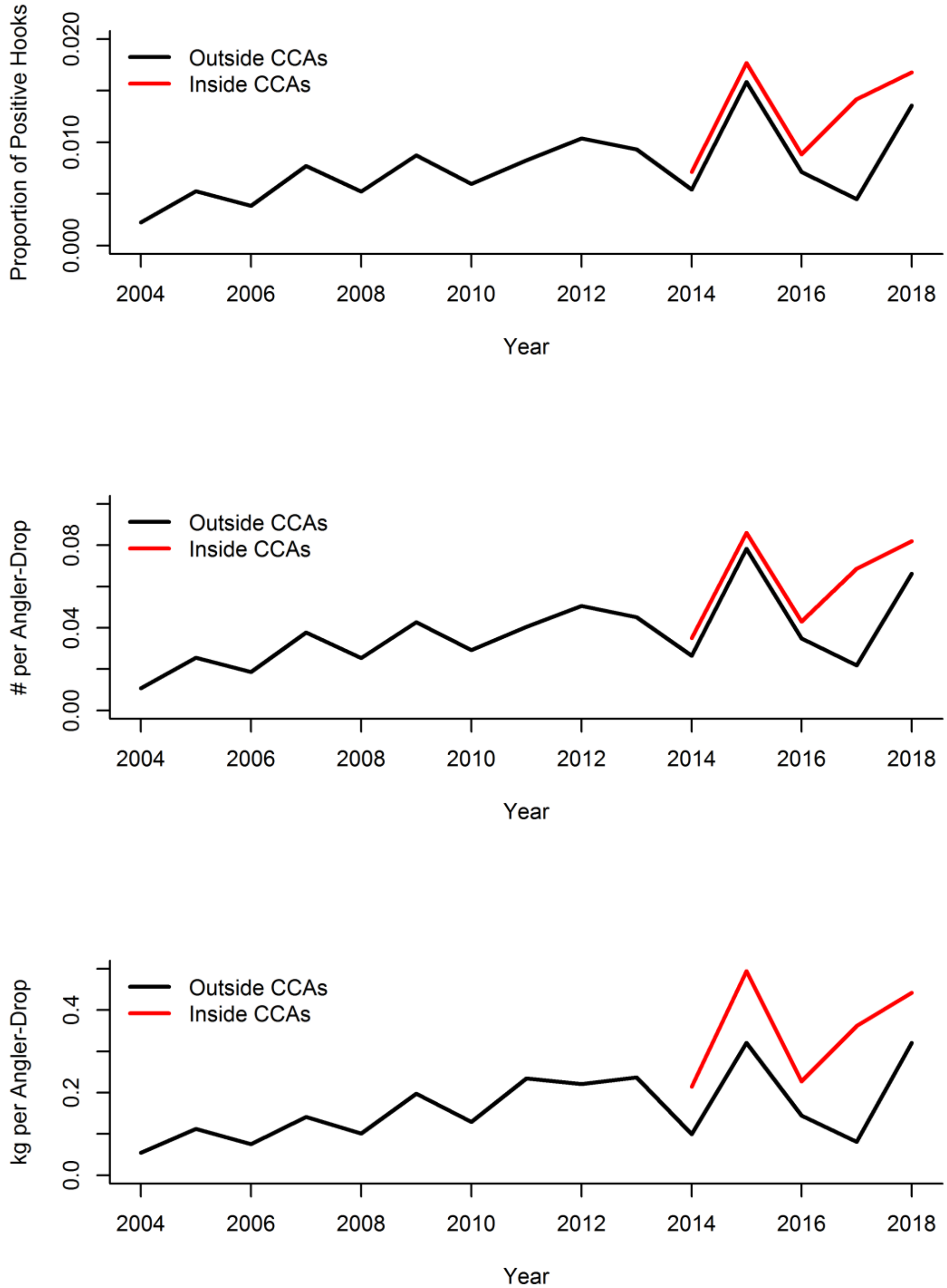


Figure 25: The proportion of positive hooks (upper panel), the mean catch (in numbers) of cowcod per angler drop (middle panel), and the mean catch (in kilograms) of cowcod per angler drop (lower panel) by year and area from the NWFSC Hook-and-Line Survey. Data include all sites that have caught at least one cowcod, 2004-2018, and exclude site visits with <60 valid hooks.

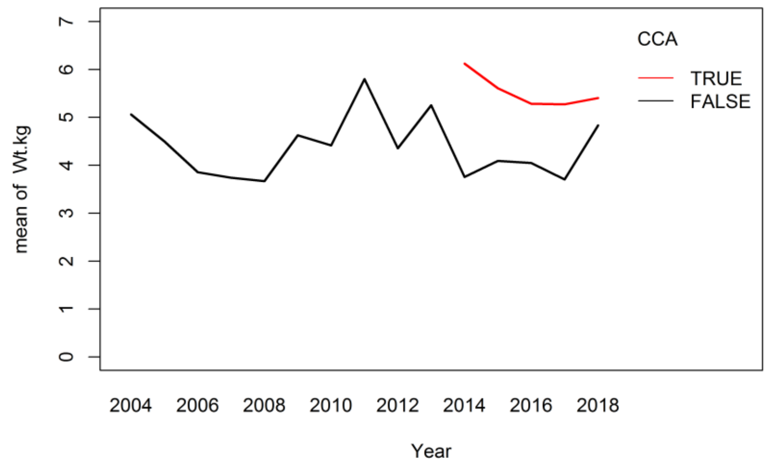


Figure 26: Mean weight [kg per fish] of cowcod caught by the NWFSC Hook-and-Line Survey, by year and area. TRUE and FALSE indicate fish caught inside and outside the CCAs, respectively.

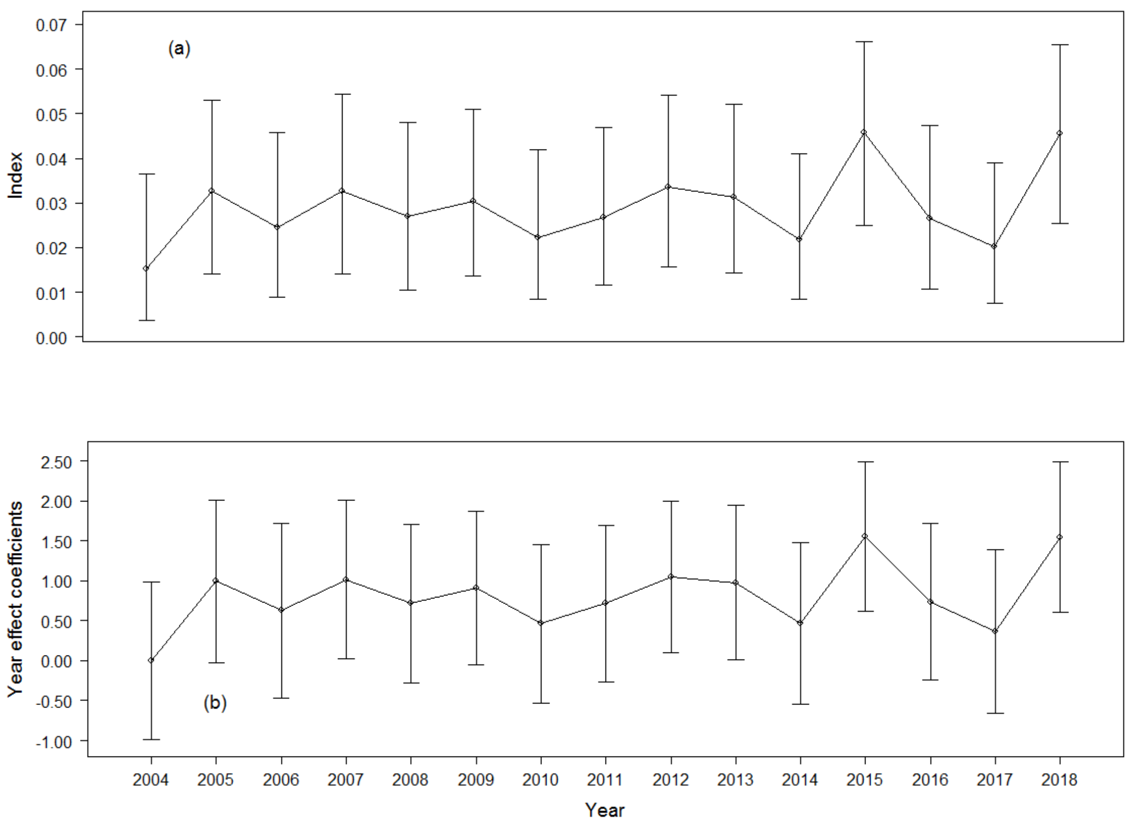


Figure 27: Pre-STAR panel NWFSC hook-and-line survey index of abundance, outside the CCAs, 2004-2018. Upper panel is the back-transformed proportion positive, and lower panel is the year effects from the binomial GLM (reference year = 2004).

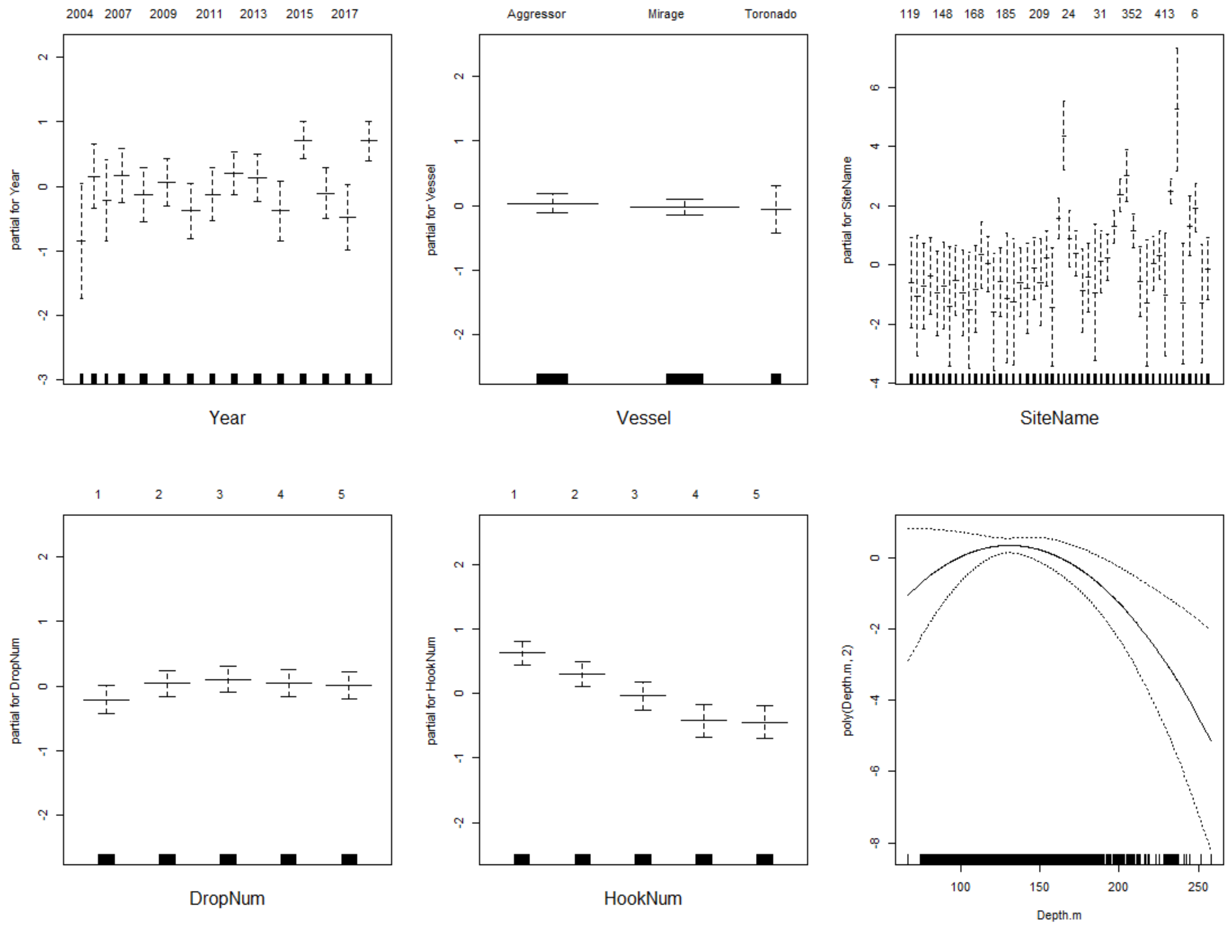


Figure 28: Partial residual plots for covariates in the pre-STAR panel NWFSC hook-and-line survey index of abundance, outside the CCAs, 2004-2018.

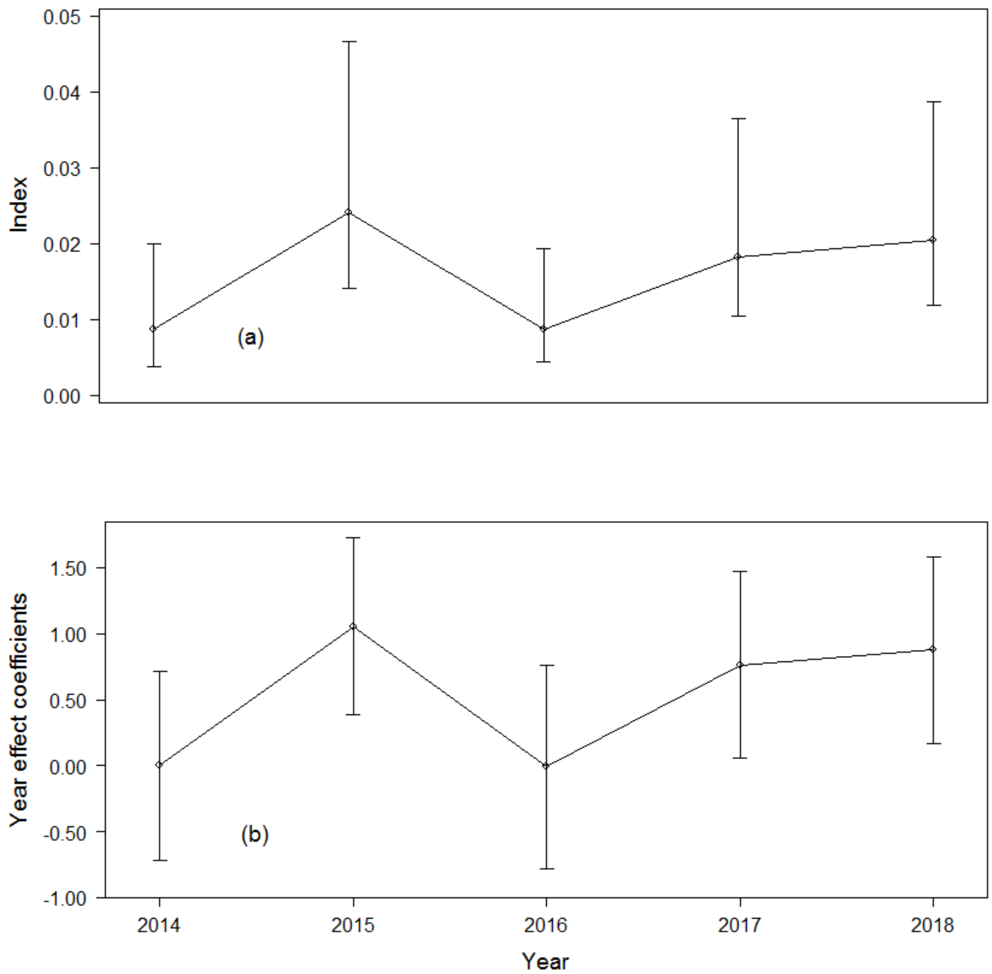


Figure 29: Pre-STAR panel NWFSC hook-and-line survey index of abundance, inside the CCAs, 2014-2018. Upper panel is the back-transformed proportion positive, and lower panel is the year effects from the binomial GLM (reference year = 2014).

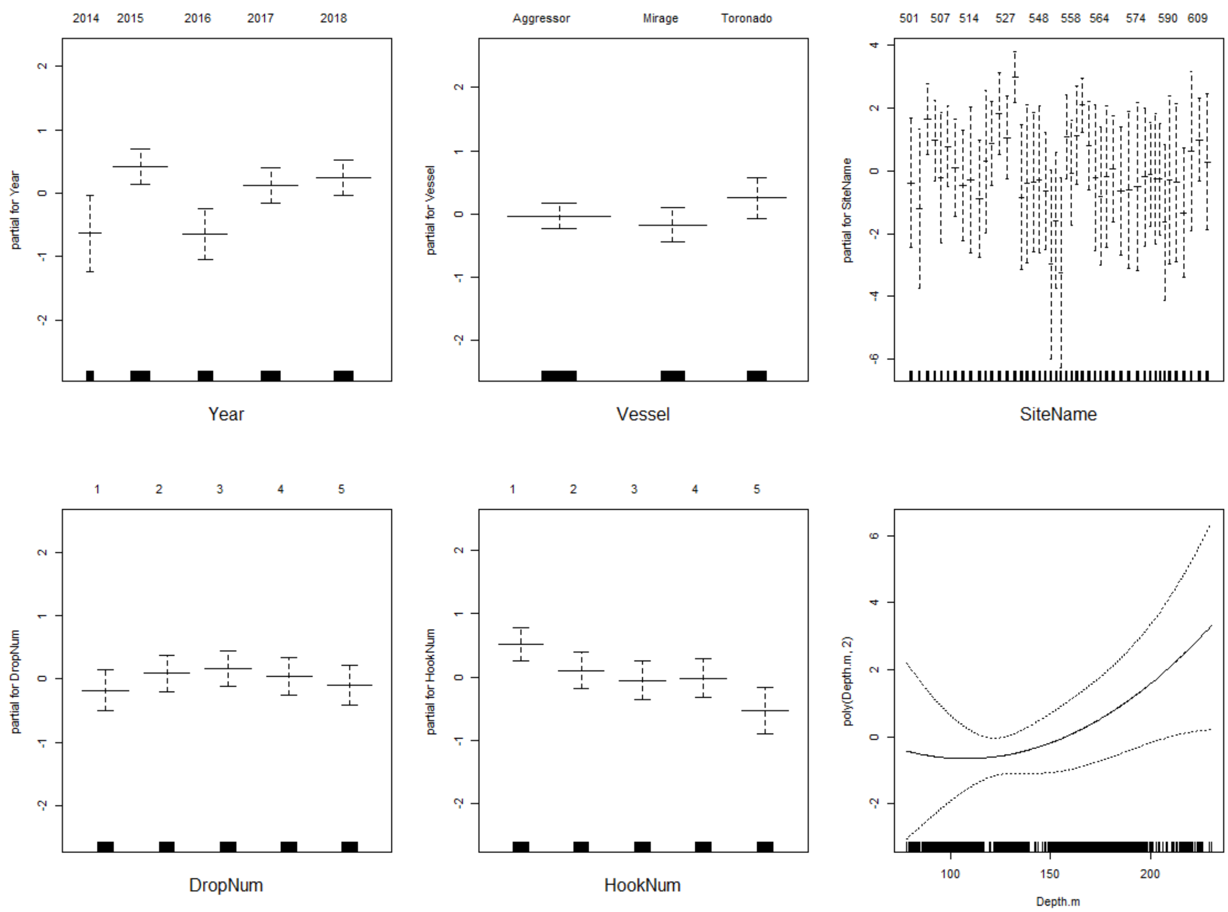


Figure 30: Pre-STAR panel partial residual plots for covariates in the NWFSC hook-and-line survey index of abundance, inside the CCAs, 2014-2018.

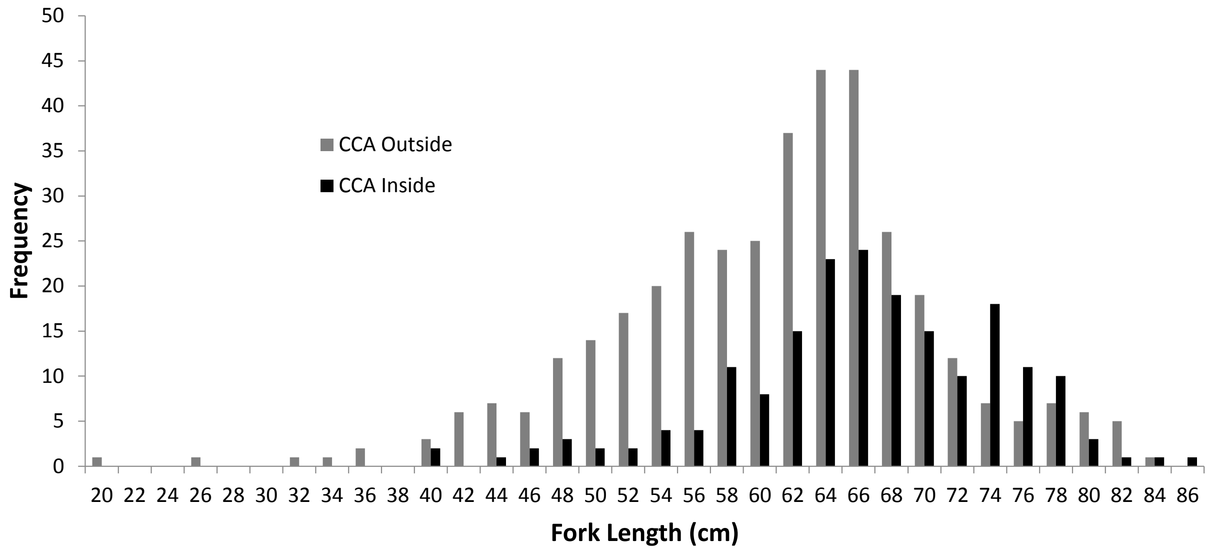


Figure 31: NWFSC Hook-and-Line Survey length frequency distribution inside and outside the CCAs, all available years combined (2004-2018 outside, 2014-2018 inside).

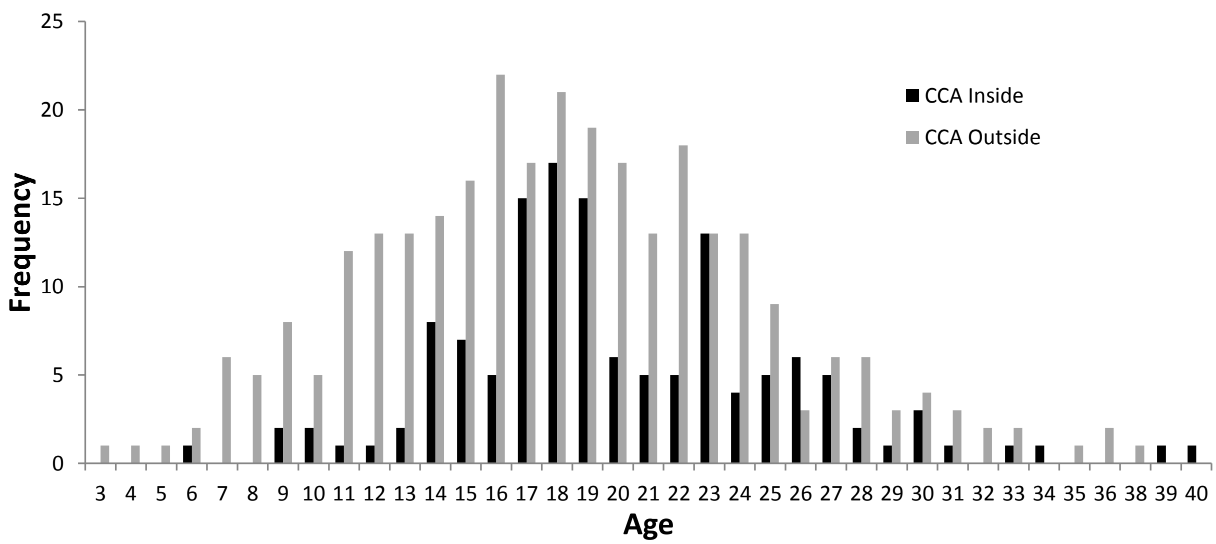


Figure 32: NWFSC Hook-and-Line Survey age frequency distribution inside and outside the CCAs, all available years combined.

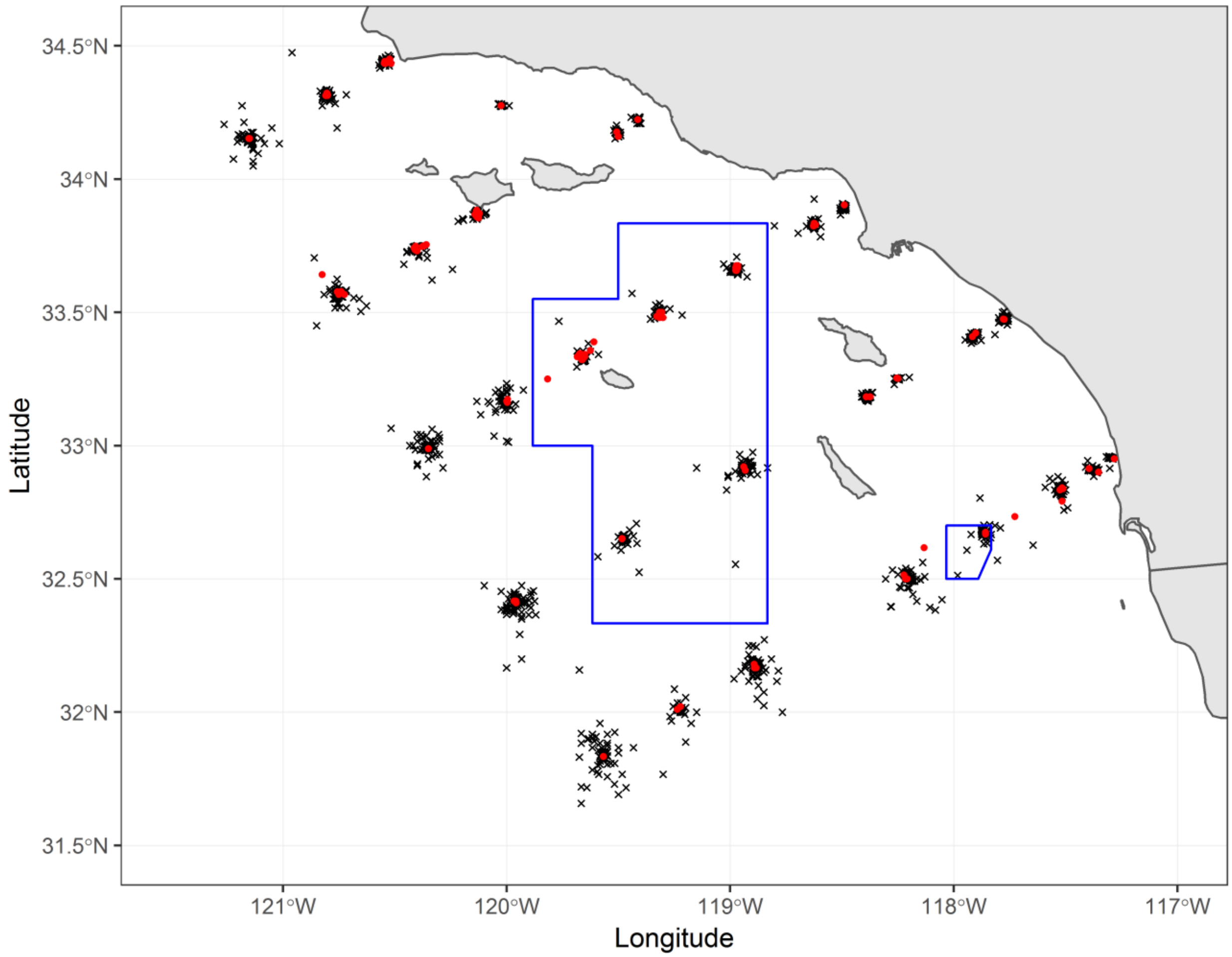


Figure 33: Locations of CalCOFI tows retained for the index of abundance (red = cowcod observed, black = no cowcod observed). The boundaries of the cowcod conservation areas are shown for reference (blue polygons).

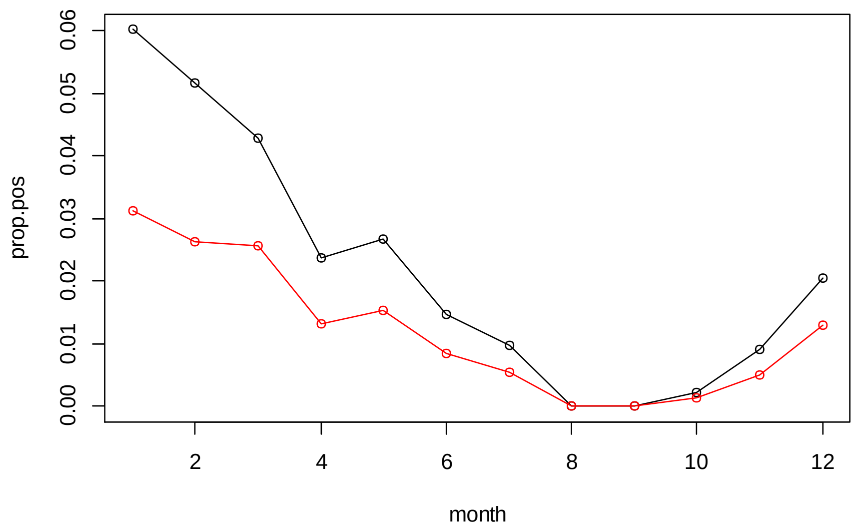


Figure 34: Proportion of positive tows by month in all CalCOFI ichthyoplankton data for southern California (red line); the trend is similar, with a higher proportion positive, in a data set filtered to include only sites that have observed cowcod (black line).

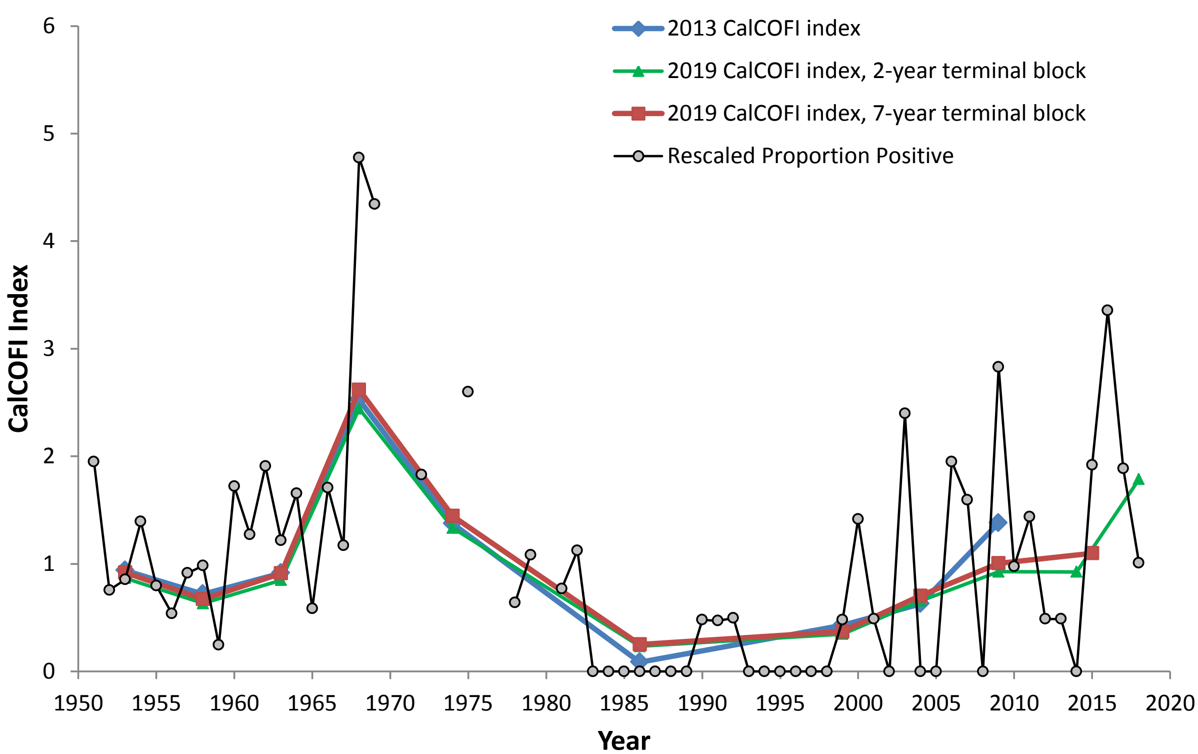


Figure 35: CalCOFI Ichthyoplankton "Super-Year" Indices for Southern California with comparison to the observed proportion positive by year. See STAR Panel request #14 regarding replication of the 1976-1996 super-year in the final index.

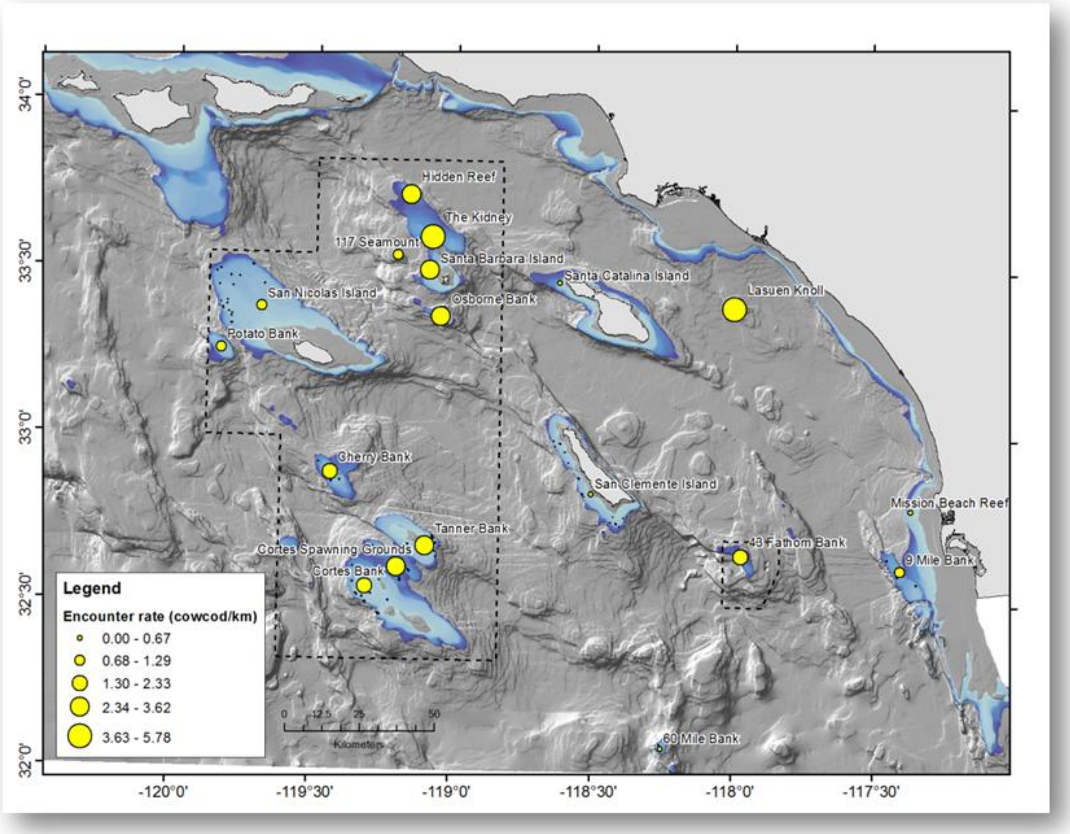


Figure 36: Encounter rates of cowcod from the 2012 Southern California Bight Cowcod Assessment Survey (Steirhoff et al. 2013). 167 transects were surveyed by remotely operated vehicle at 18 sites.

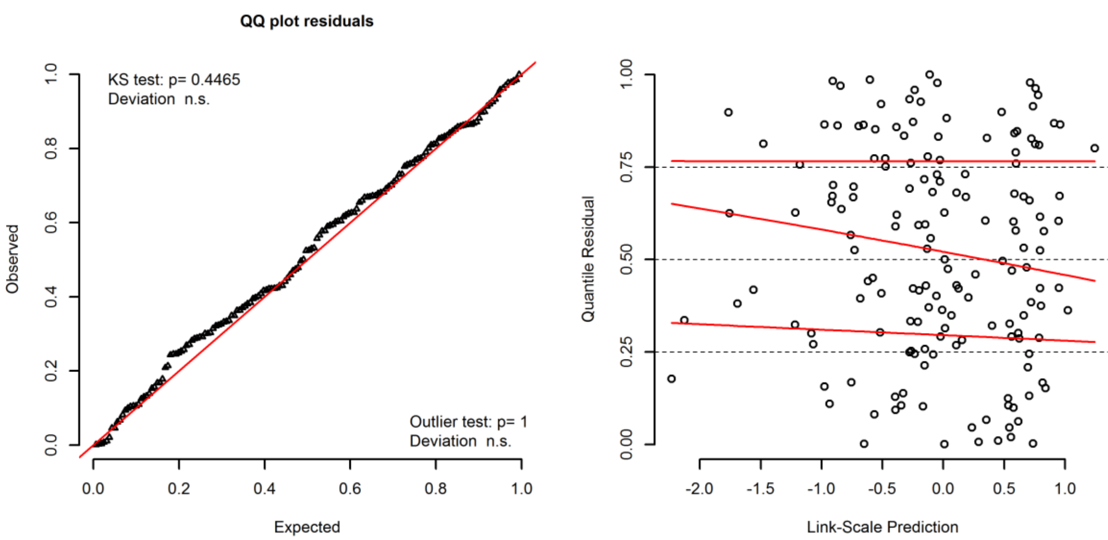


Figure 37: Quantile-quantile plot of residuals from the negative binomial regression model for cowcod density (left panel) and standardized quantile residuals versus log-scale predictions (right panel).

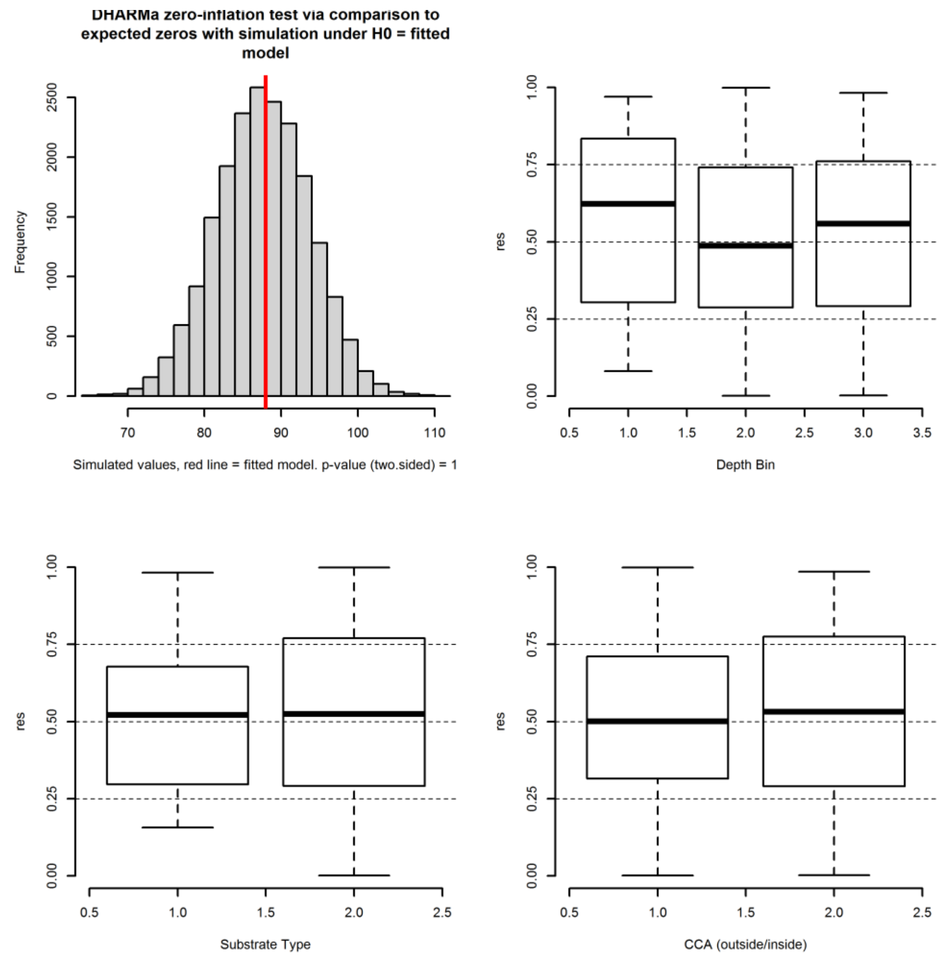


Figure 38: Comparison of the number of observed zeros in the ROV survey data relative to simulated data sets from the negative binomial regression (upper left panel); quantile residuals versus categorical covariates (other three panels).

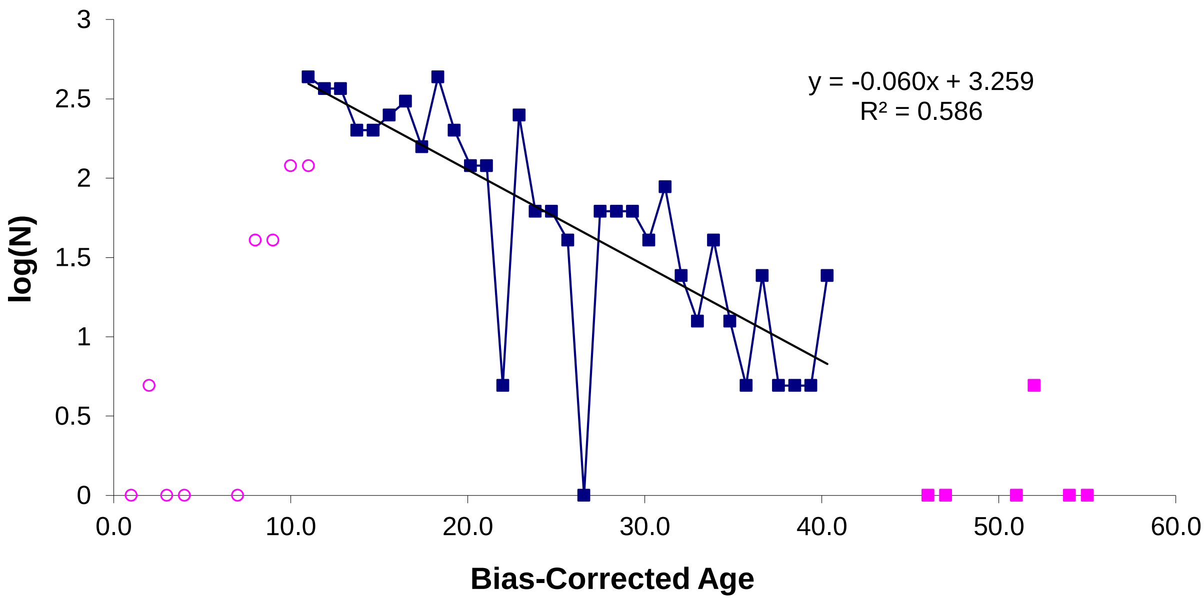


Figure 39: Revised catch curve analysis using age data from the 1999 cowcod assessment. Ages were bias-corrected based on the assumption that current age readers are unbiased, using the best-fit model for ageing error. Bias-corrected age at full recruitment was 11 years old (12 years, unbiased age).

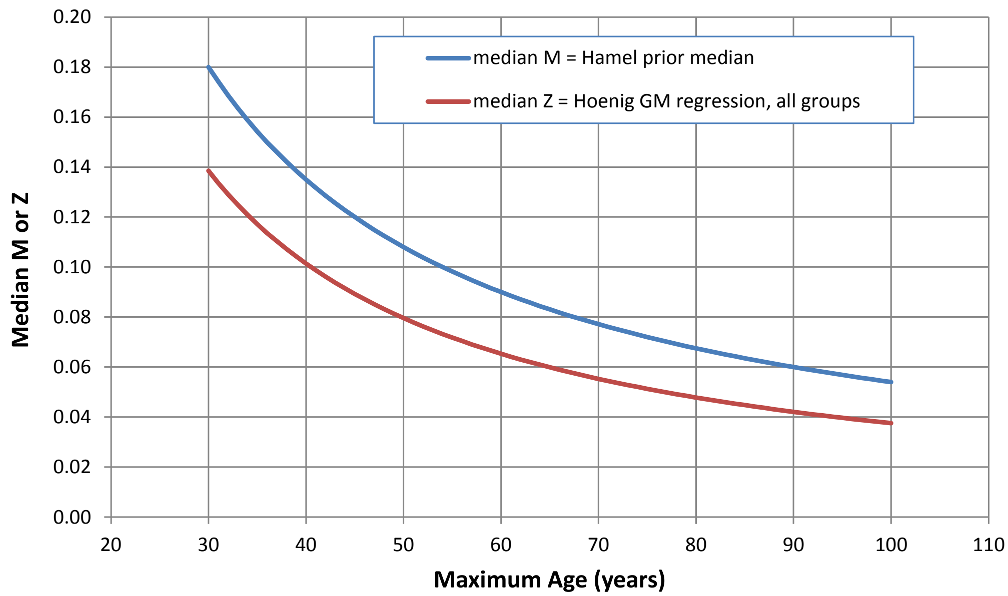


Figure 40: Comparison of median natural mortality (M) predictions from the current prior distribution and predictions for total mortality (Z) from Hoenig's (1983) geometric mean regression for all groups.

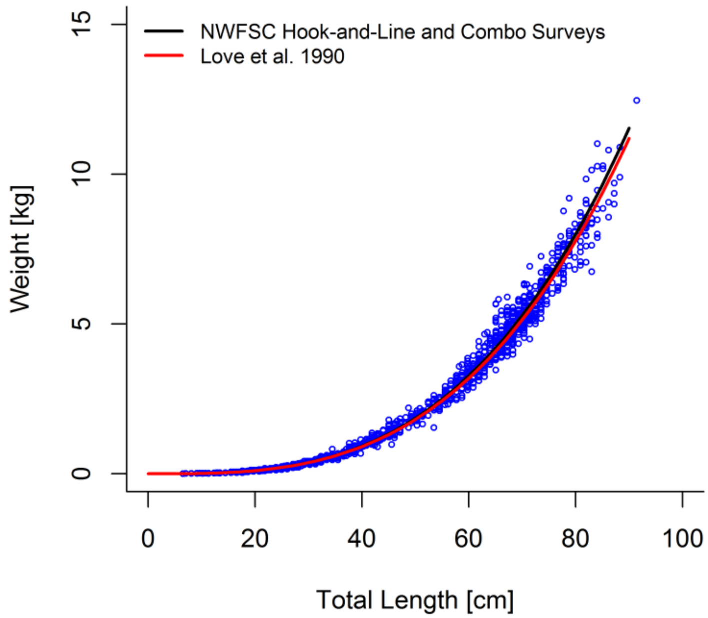


Figure 41: Weight at length data (blue circles) from the NWFSC Hook-and-Line and WCGBT surveys, following conversion to from fork length to total length. The fitted relationship based on the NWFSC data (black line) is very similar to the relationship reported by Love et al. (1990; red line).

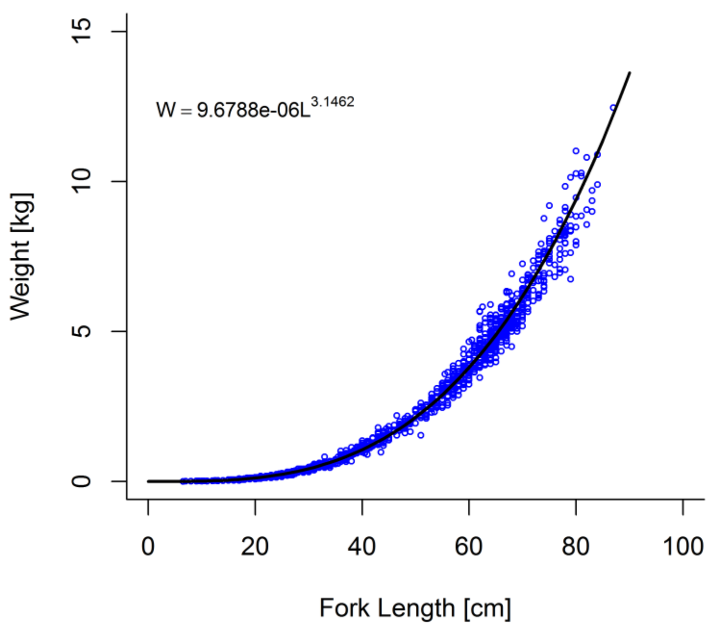


Figure 42: Weight at length relationship used in this assessment (note units of fork length).

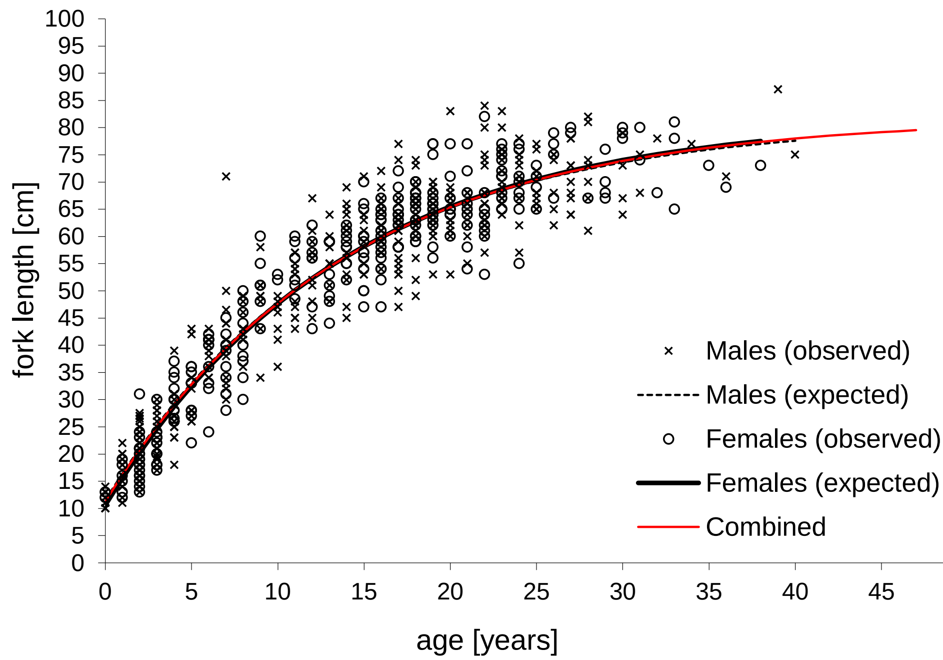


Figure 43: Length at age based on combined data from the NWFSC Hook and Line and WCGBT surveys. WCBT Survey data were filtered to include only hauls south of Point Conception. Predictions from gender-specific von Bertalanffy curves are visually and statistically indistinguishable from the combined-sex curve.

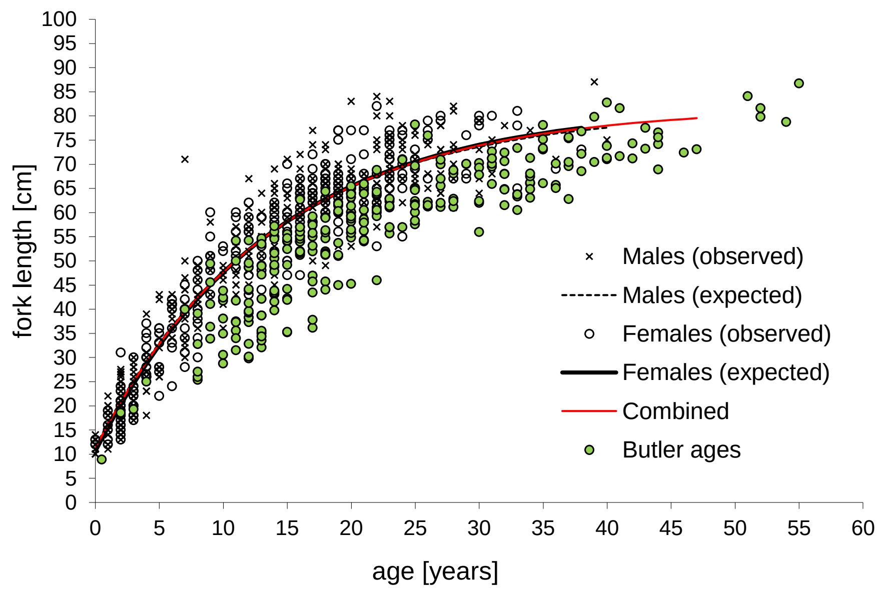


Figure 44: Comparison of length at age estimates from the NWFSC surveys and data collected for the first cowcod assessment (Butler et al. 1999). Lengths from the Butler data were converted from total length to fork length (see Dick et al. 2009 for details regarding previous length conversions). While evidence of bias between current readers (D. Pearson and S. Beyer) and readers from the first assessment partially explains the shift, other factors (e.g. differences in selectivity and/or growth) may also contribute to the differences in size at age.

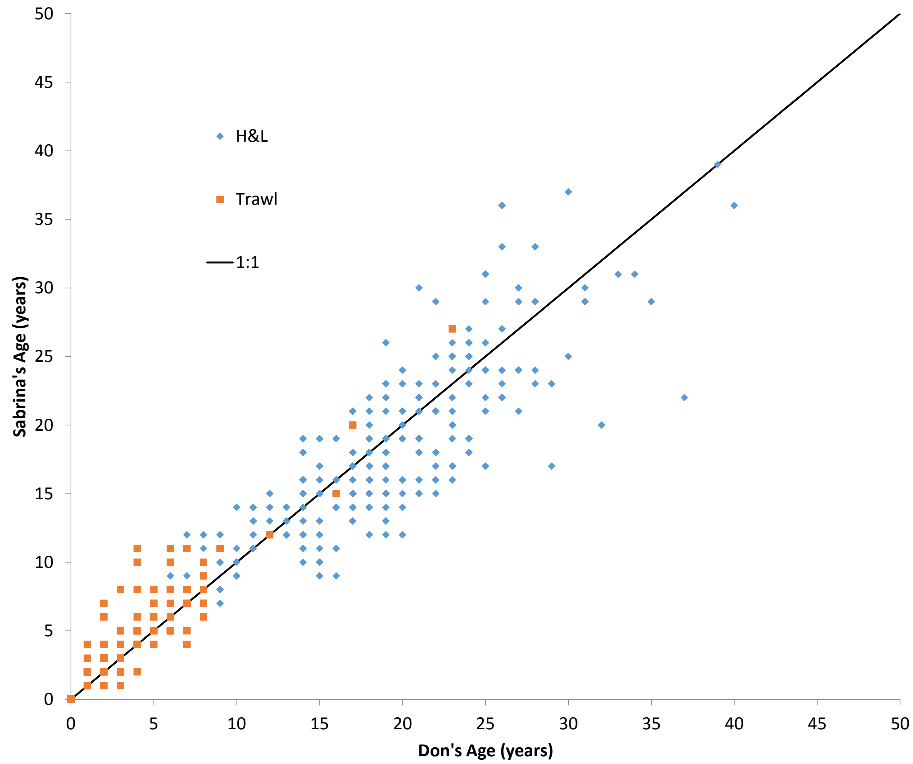


Figure 45: Between-reader ageing agreement (D. Pearson, NMFS, retired; S. Beyer, NMFS / UCSC)

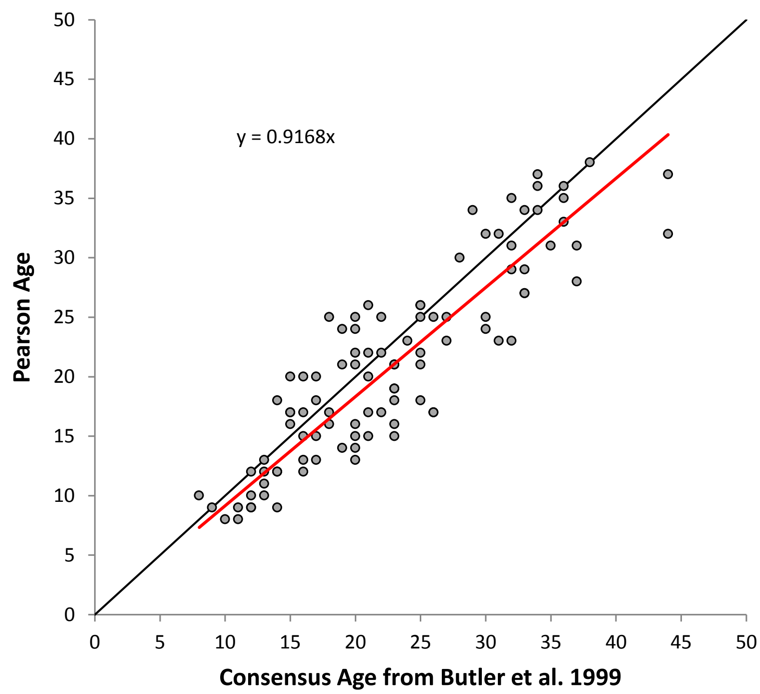


Figure 46: Between-reader ageing agreement (D. Pearson, NMFS, retired; vs. consensus age from Butler et al. 1999)

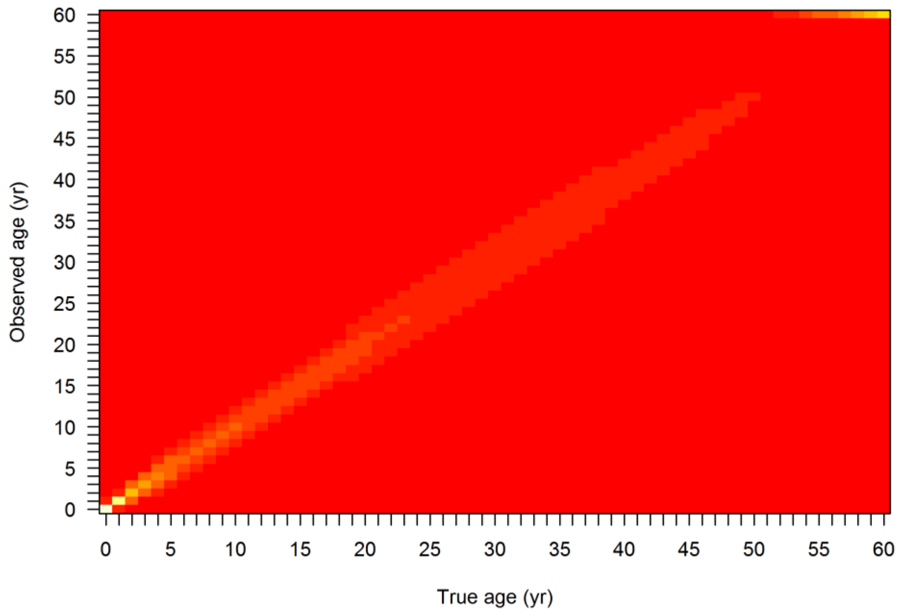


Figure 47: Heat plot of ageing error matrix produced by the nwfscAgeingError best-fit model for Pearson vs. Beyer ages.

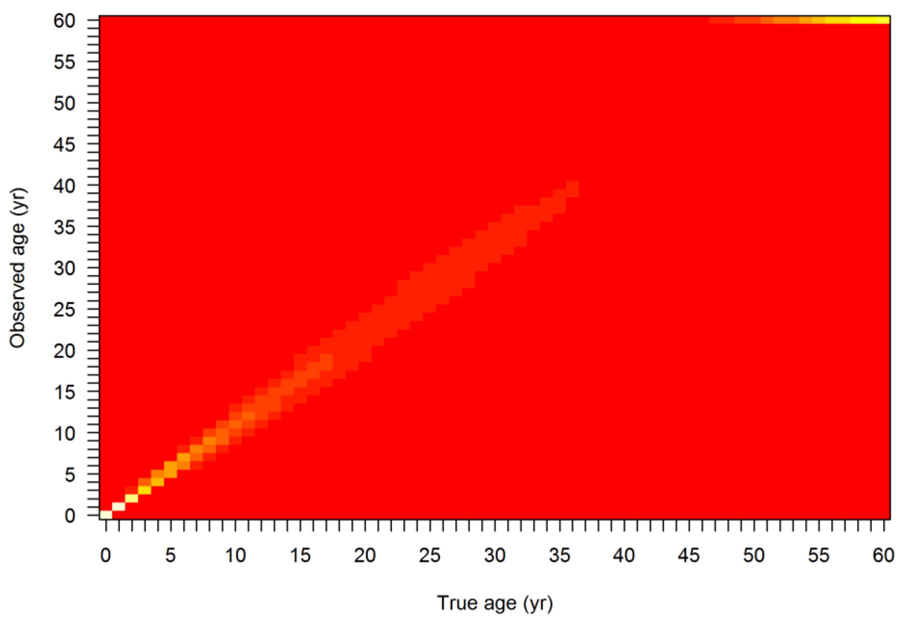


Figure 48: Heat plot of ageing error matrix produced by the nwfscAgeingError best-fit model for Pearson vs. Butler ages.

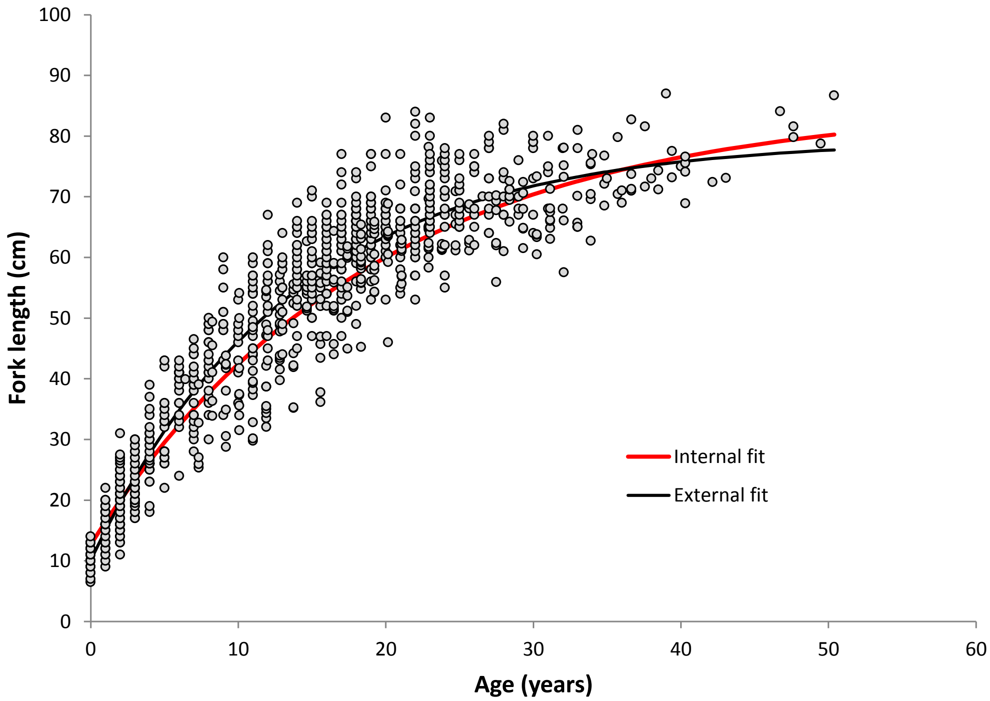


Figure 49: Length at age from all age data in the base model, sexes combined, including bias-corrected ages from Butler et al (1999; ‘sport’ and commercial). An external fit to the data results in slightly faster growth and smaller asymptotic size (black line) relative to the growth curve estimated in the base model (red line).

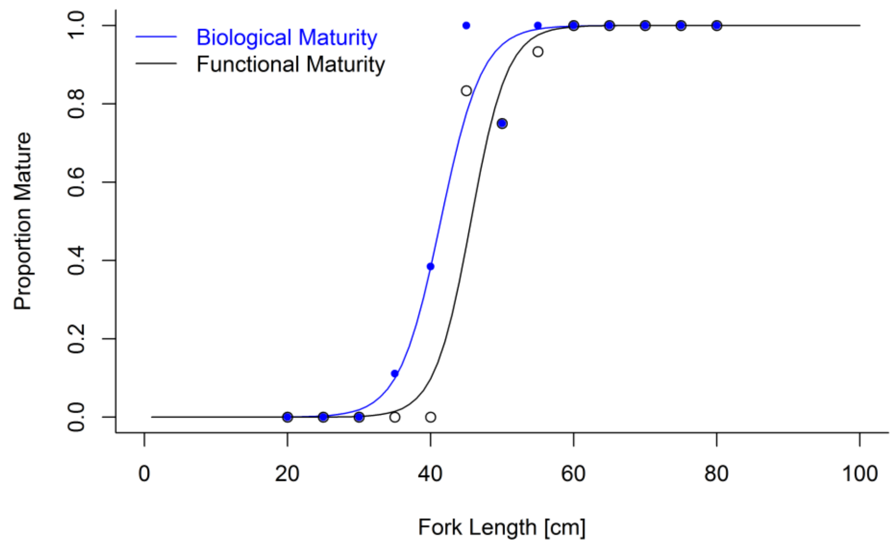


Figure 50: Proportion of mature female cowcod as a function of length and type of maturity determination, based on NWFSC survey data. Lines are predicted proportions from fitted logistic regressions. Circles are observed proportions within 5cm length bins for biological maturity (solid, blue circles) and functional maturity (black, open circles).

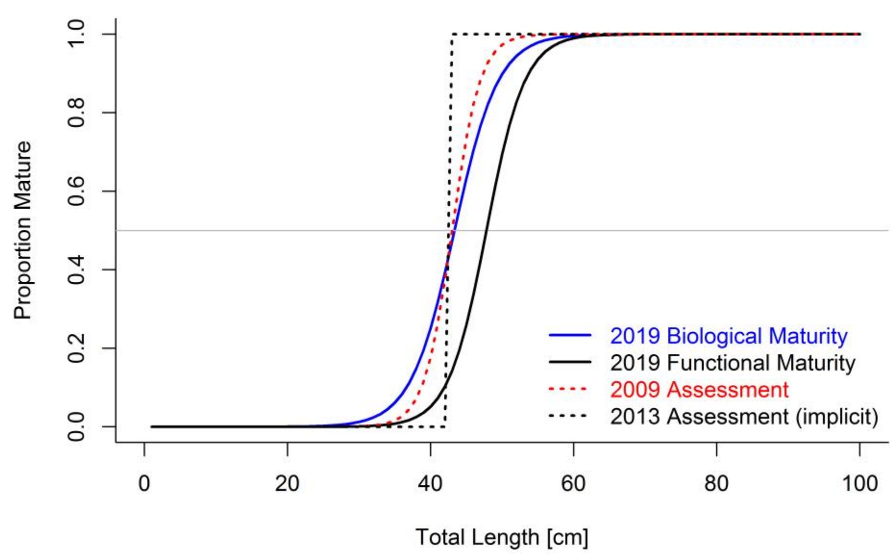


Figure 51: Comparison of maturity at length from the current (2019) and previous assessments. Lengths from all sources were converted to the same measurement type (total length) for this comparison.

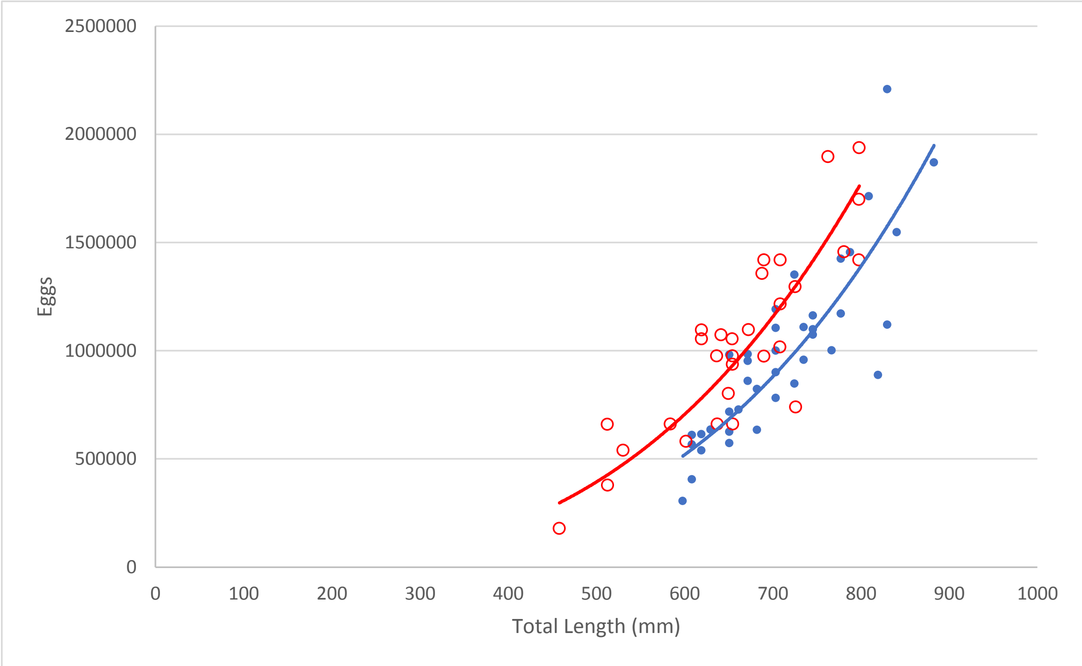


Figure 52: Comparison of two studies reporting cowcod fecundity at length. Red, open circles are fecundity estimates from Love et al. (1990). Blue, solid circles are new estimates collected by the NWFSC hook-and-line survey, and processed for this assessment (estimates courtesy of N. Kashef and D. Stafford, UCSC / NMFS).

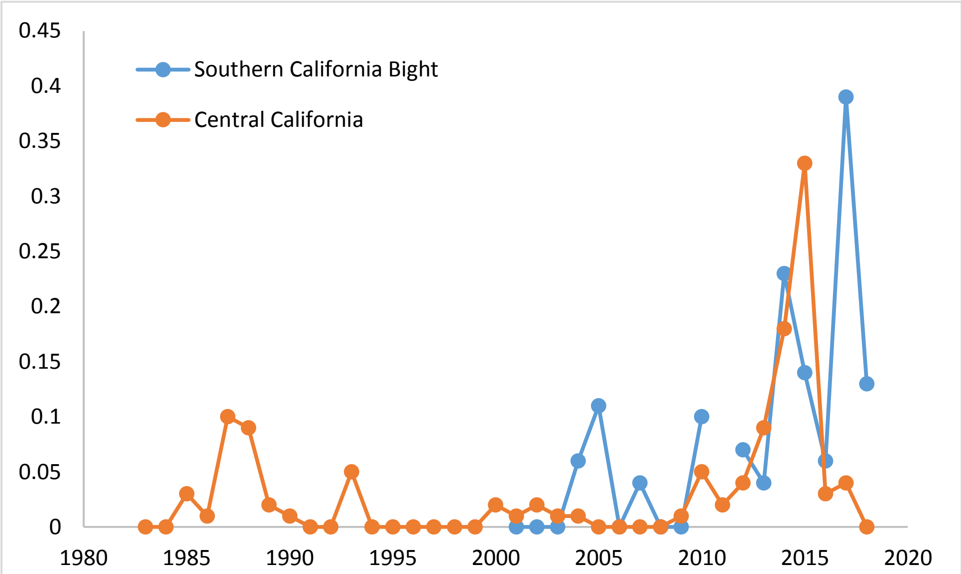


Figure 53: Percentage frequency of occurrence of pelagic juvenile cowcod in pelagic midwater trawls in the Central California region (Cape Mendocino to Point Conception) and in the Southern California Bight (south of Point Conception).

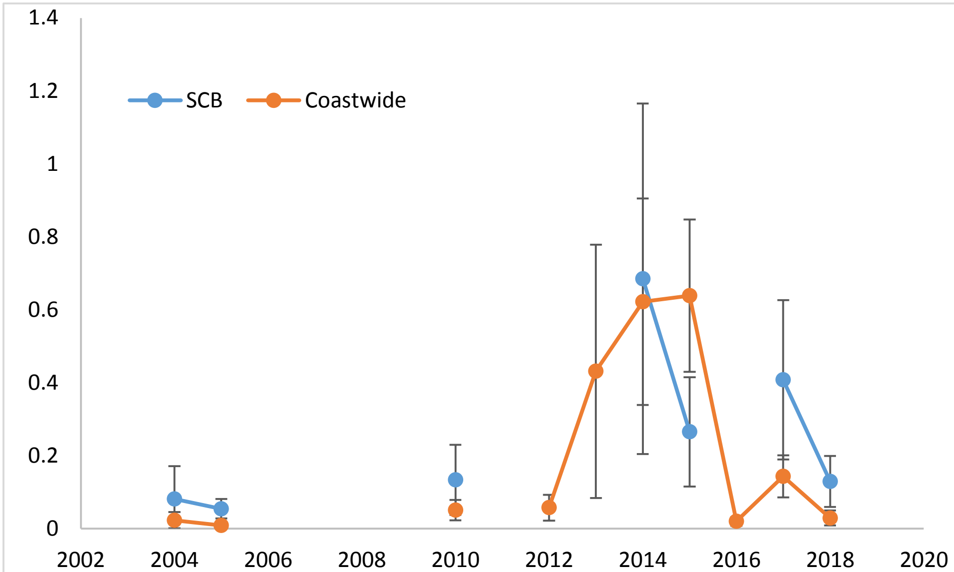


Figure 54: Delta-GLM estimates of pelagic juvenile cowcod abundance for the Southern California Bight (SCB) and for coastwide midwater trawl survey data (both Central and Southern California).

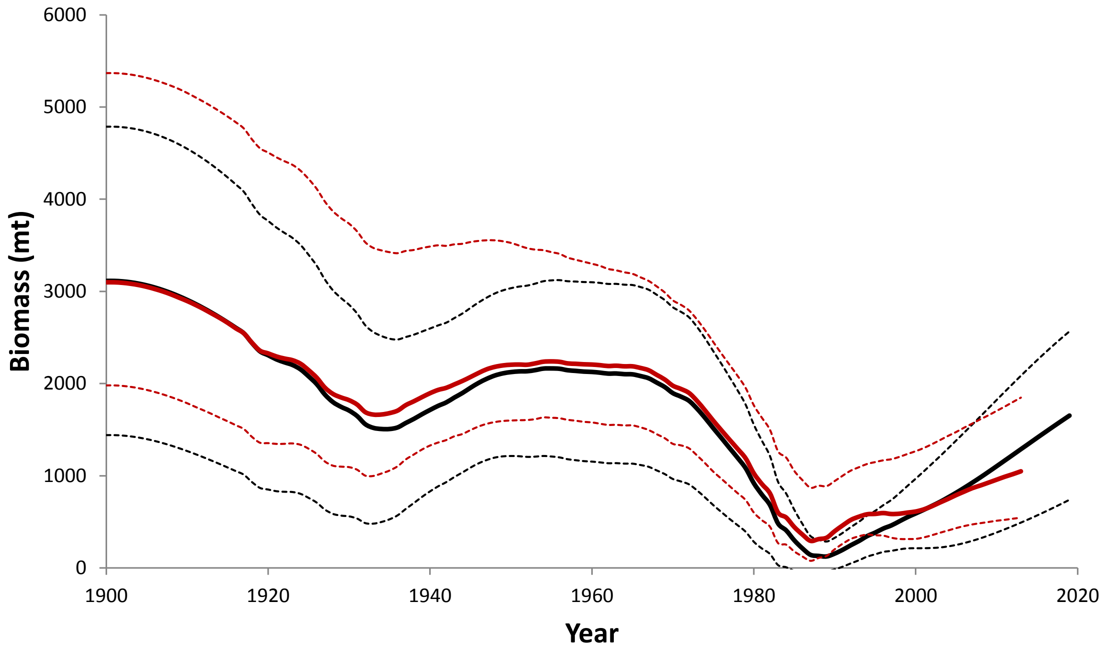


Figure 55: Comparison of 2013 biomass time series estimated using XDB-SRA (solid red line, with 95% highest density intervals) to an age-structured production model configured using Stock Synthesis (solid black line, with 95% asymptotic intervals).

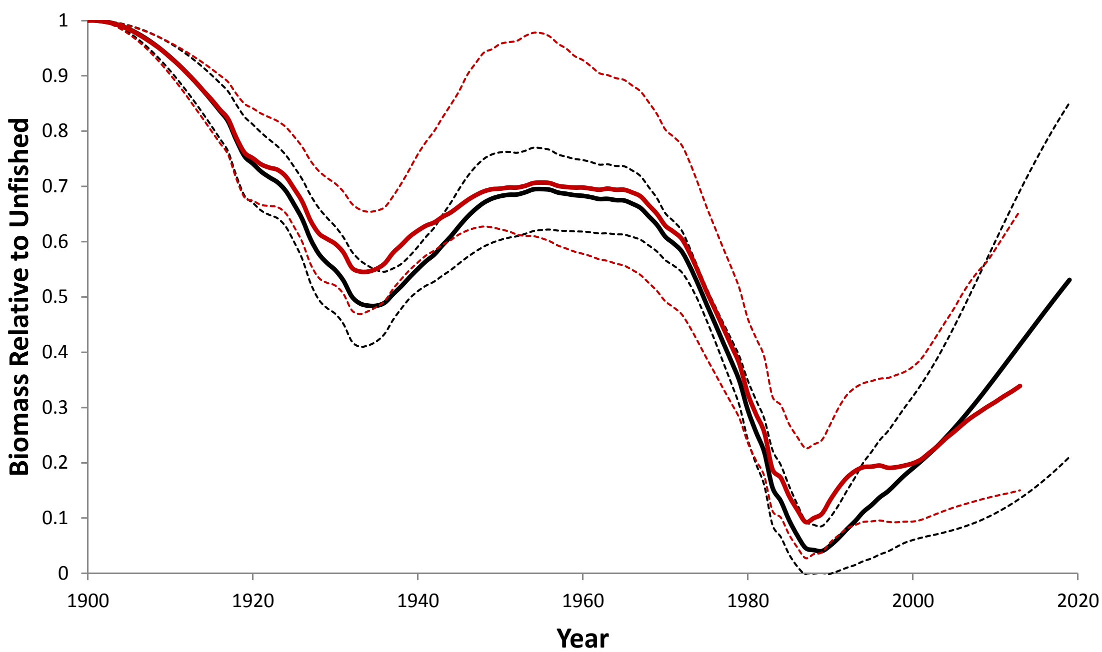


Figure 56: Comparison of 2013 relative biomass time series (B / B_0) estimated using XDB-SRA (solid red line, with 95% highest density intervals) to age-structured production model configured using Stock Synthesis (solid black line, with 95% asymptotic intervals).

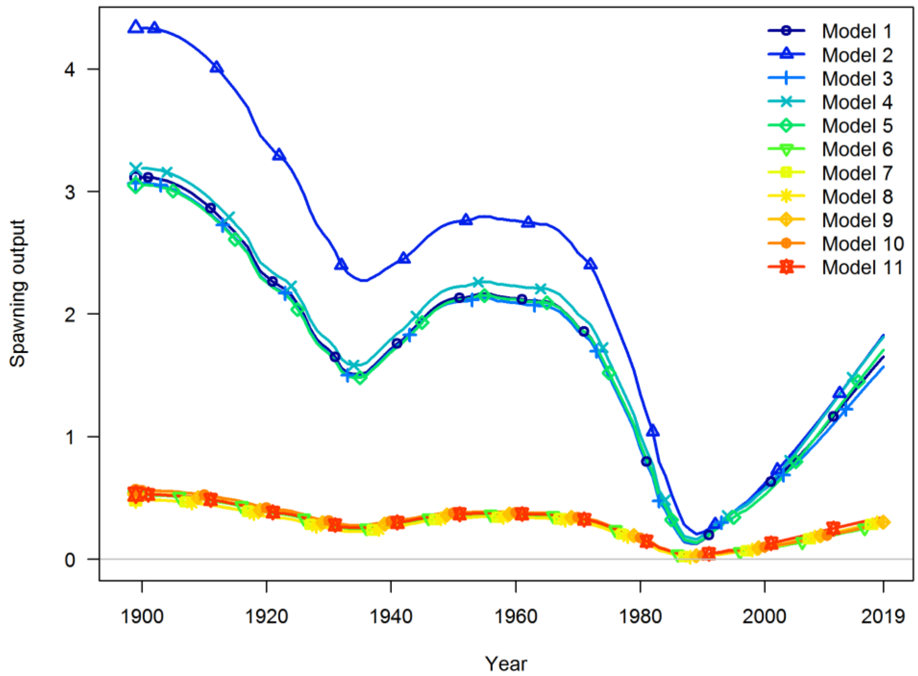


Figure 57: Spawning output (note change in units between Models 1-5 and 6-11) for incremental changes to the bridge model. See text for details.

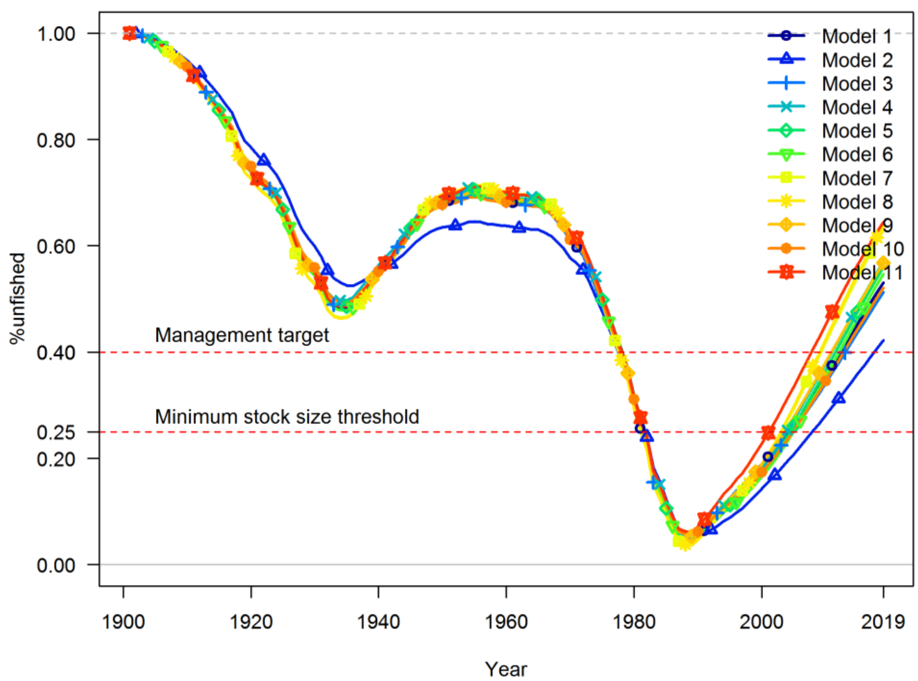


Figure 58: Spawning output relative to unfished given incremental changes to the bridge model. See text for details.

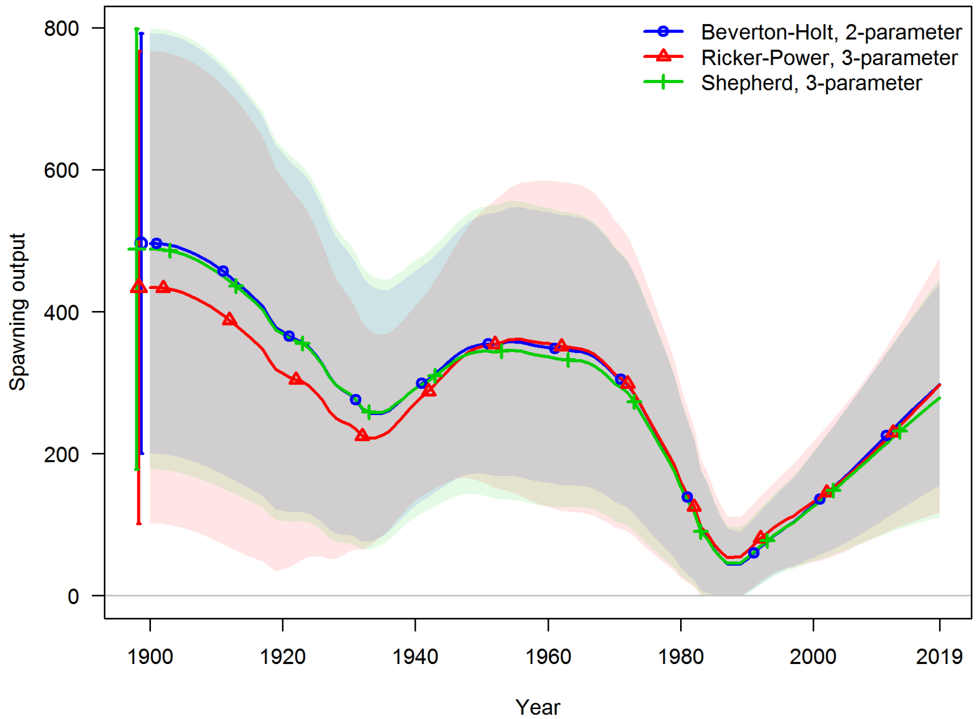


Figure 59: Comparison of spawning output trajectories based on a 2-parameter Beverton-Holt stock-recruitment relationship and two 3-parameter models (Ricker-Power and Shepherd).

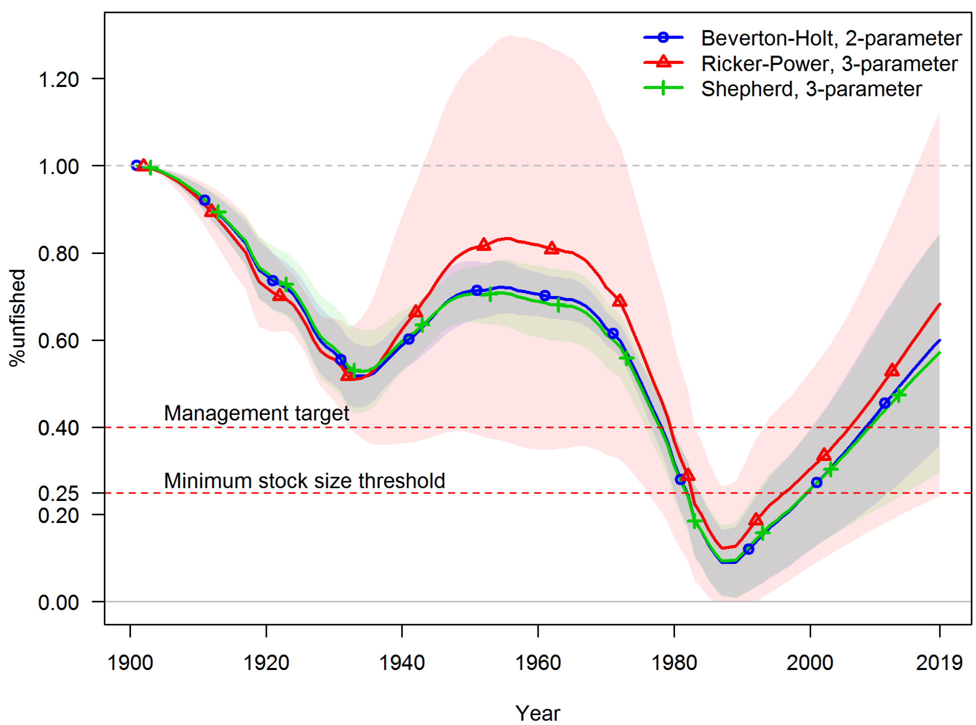


Figure 60: Comparison of relative spawning output trajectories based on a 2-parameter Beverton-Holt stock-recruitment relationship and two 3-parameter models (Ricker-Power and Shepherd).

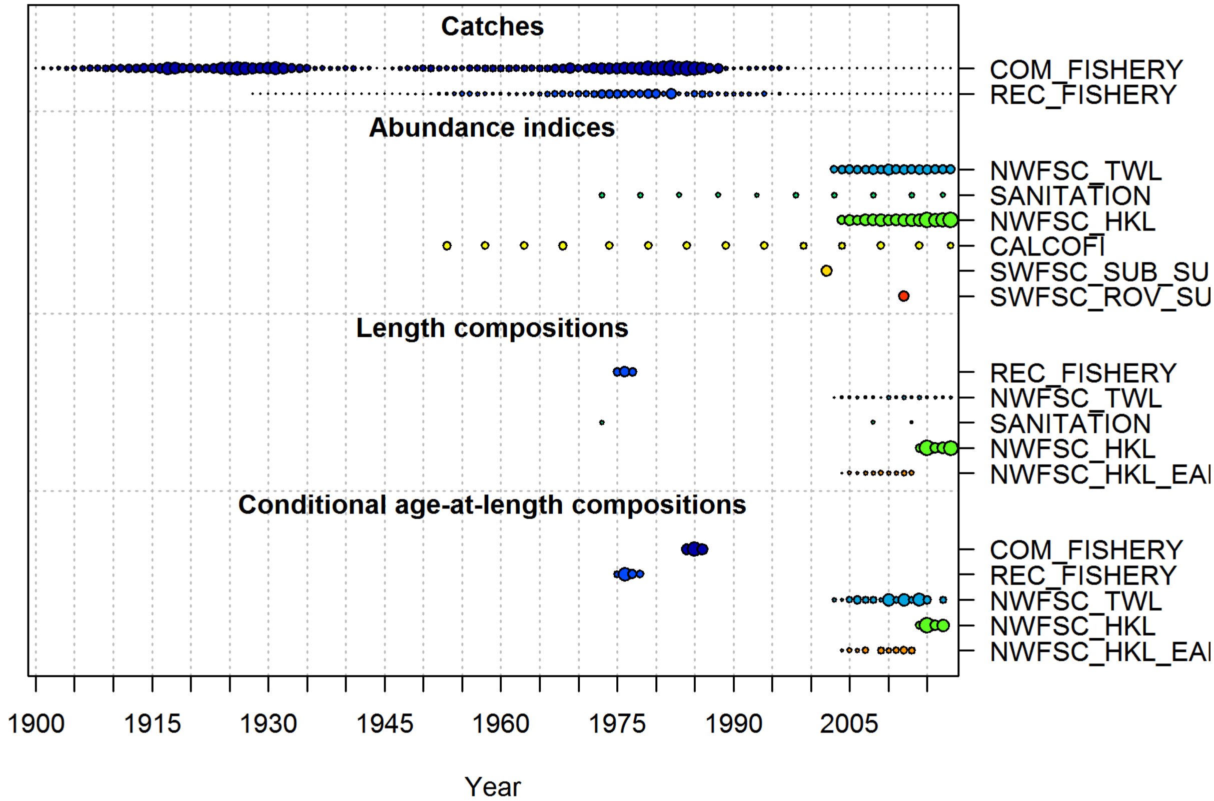


Figure 61: Summary of data sources in the Cowcod base case model

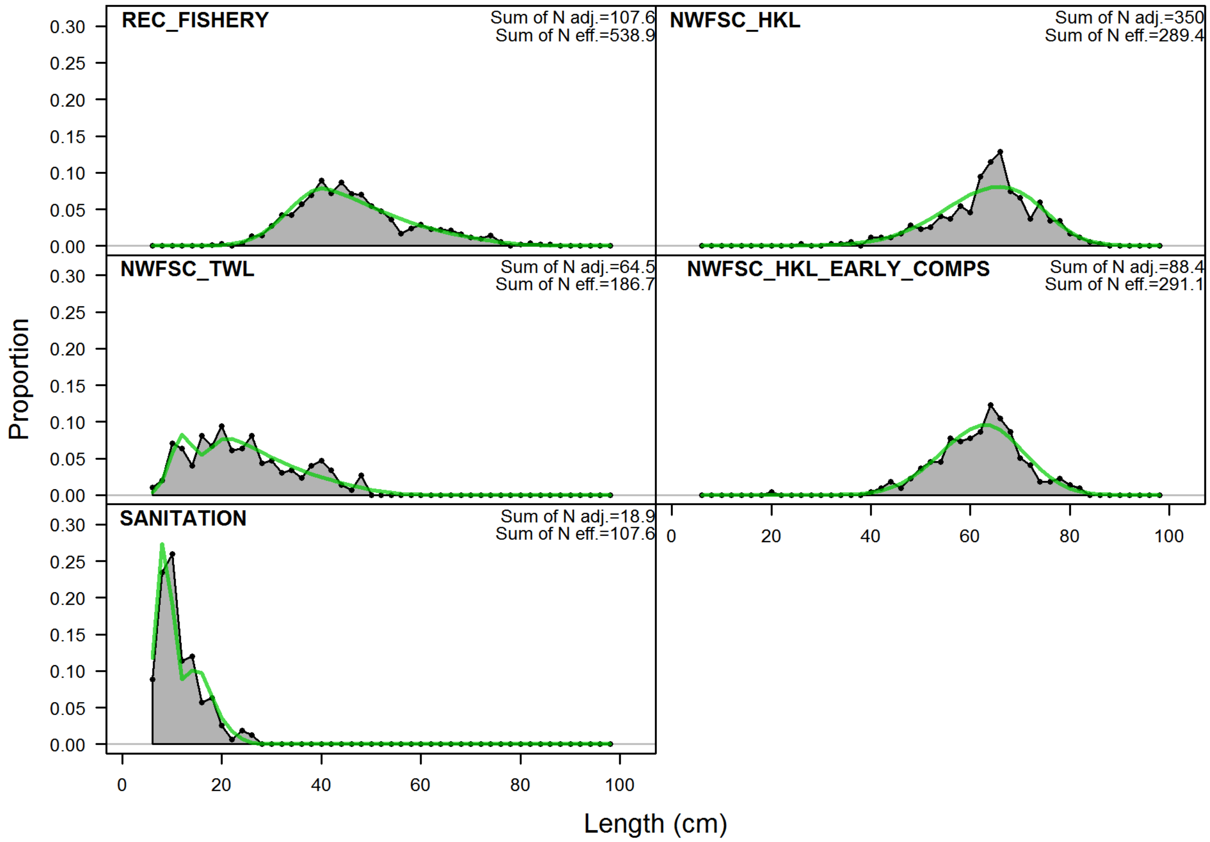


Figure 62: Fits to time-aggregated length composition data.

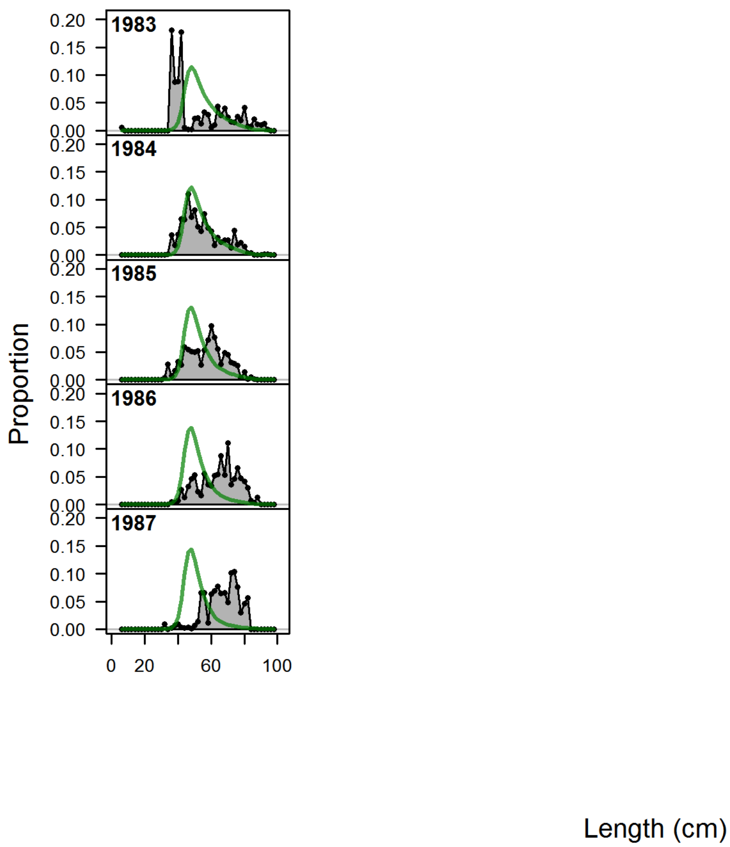


Figure 63: Lack of fit to commercial length composition data. These data were ultimately excluded from the base model, and commercial selectivity curves set equal to maturity at length.

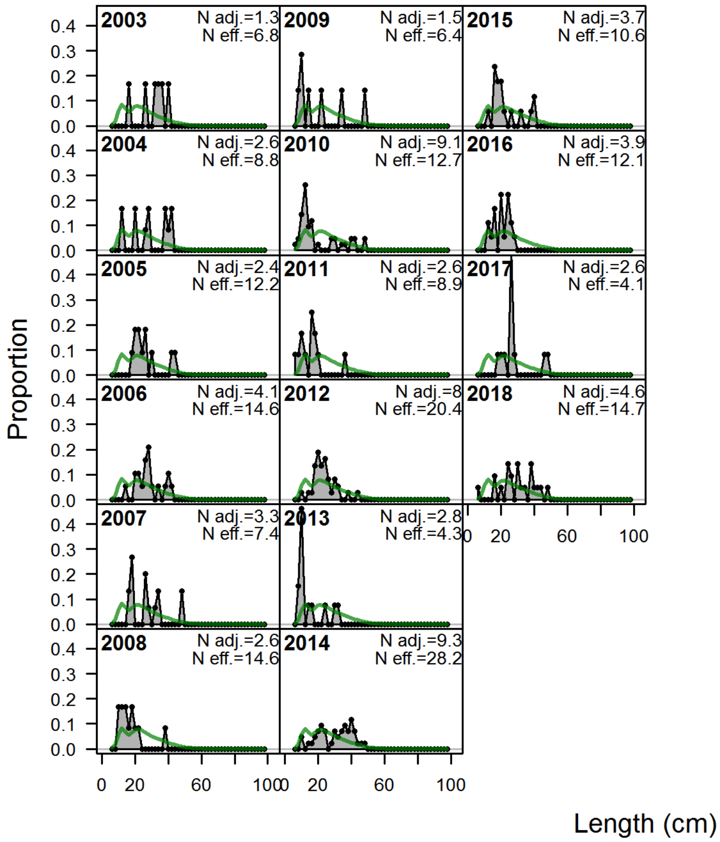


Figure 64: Fits to annual length composition data from the NWFSC WCGBT Survey.

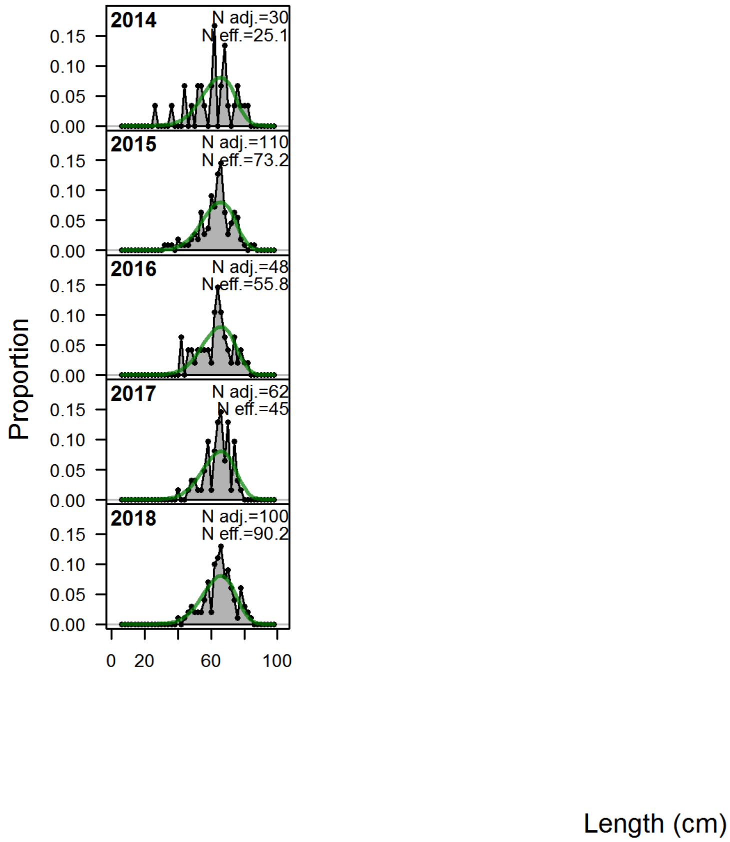


Figure 65: Fits to annual length composition data from the NWFSC hook-and-line survey. Composition data from years prior to 2014 were fit as a 'dummy' fleet (see STAR panel requests 8, 8a, and 13 for details).

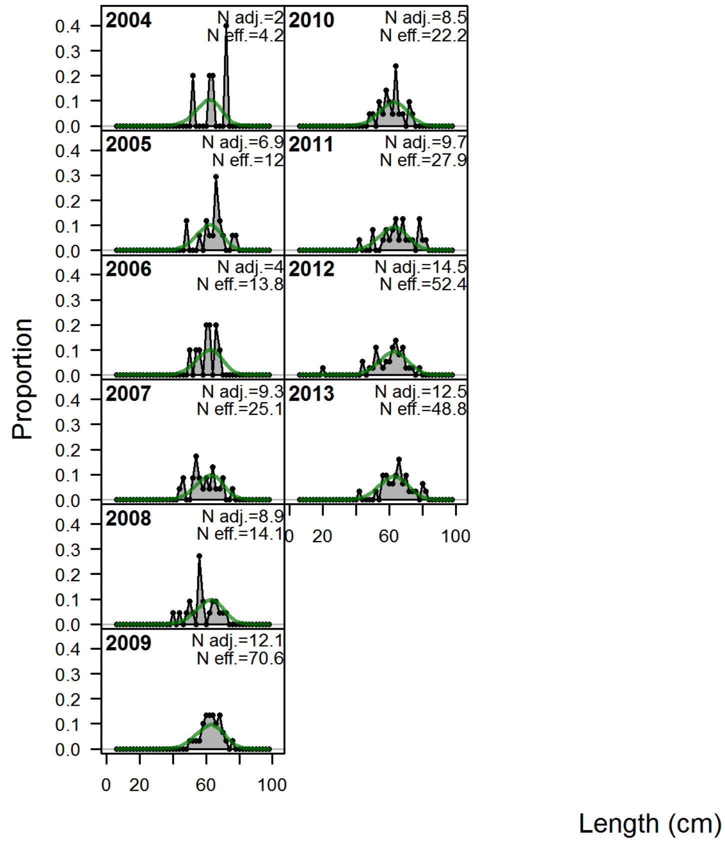


Figure 66: Fits to annual length composition data from the NWFSC hook-and-line survey, 2004-2013, treated as a 'dummy' fleet in the base model. See STAR panel requests 8, 8a, and 13 for details.

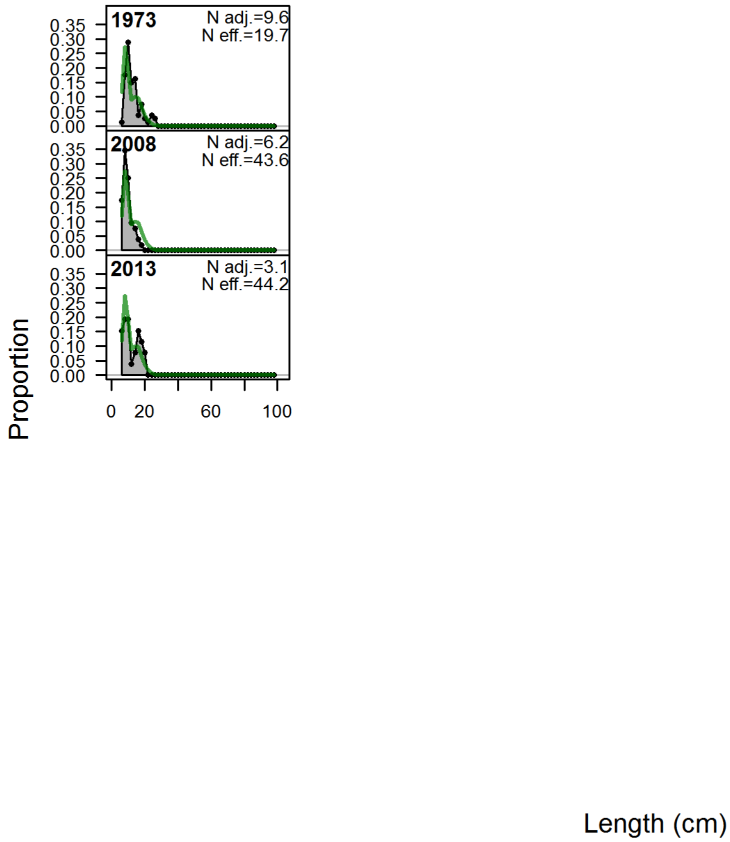


Figure 67: Fits to annual length composition data from the Sanitation District Surveys.

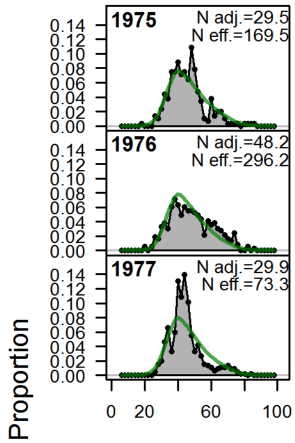


Figure 68: Fits to annual length composition data from the 1970s onboard CPFV observer data.

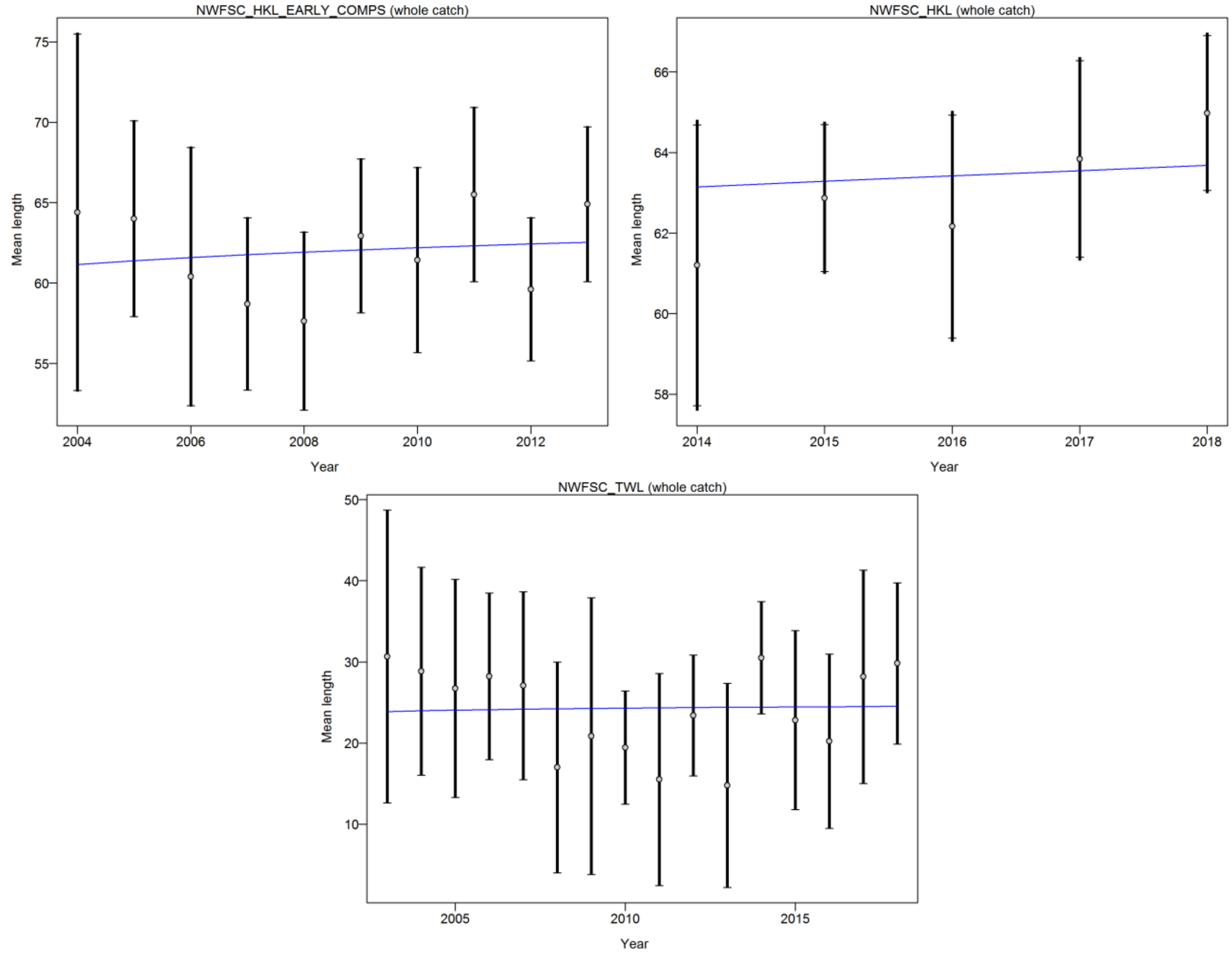


Figure 69: Fits to mean length from NWFSC surveys (upper left panel: Hook-and-Line early comps 'ghost' fleet; upper right panel: Hook-and-Line comps 2014-2018; lower panel: WCGBT comps).

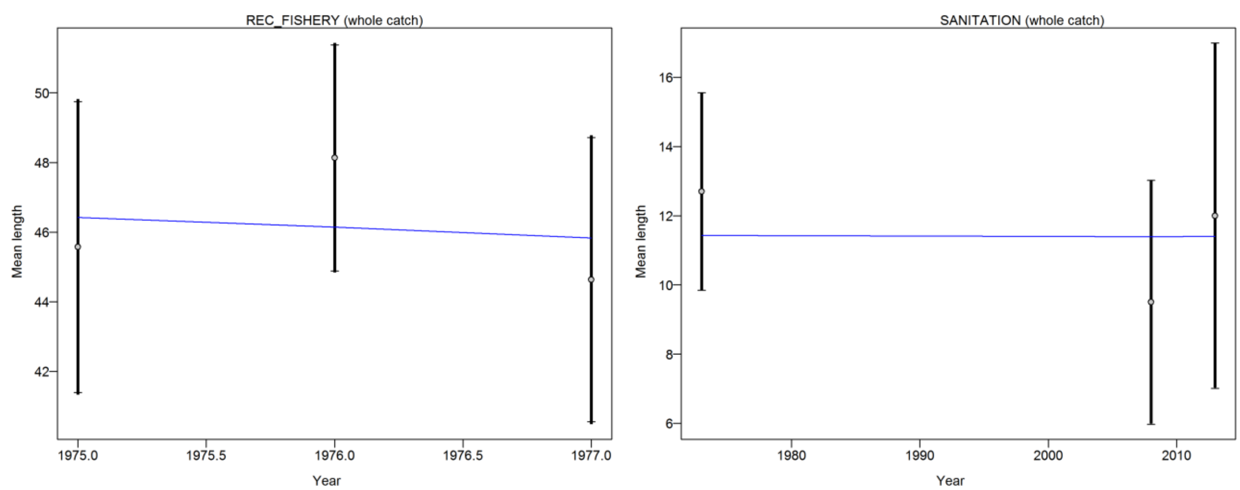


Figure 70: Fits to mean length from the 1970s recreational onboard observer data and the sanitation district surveys.

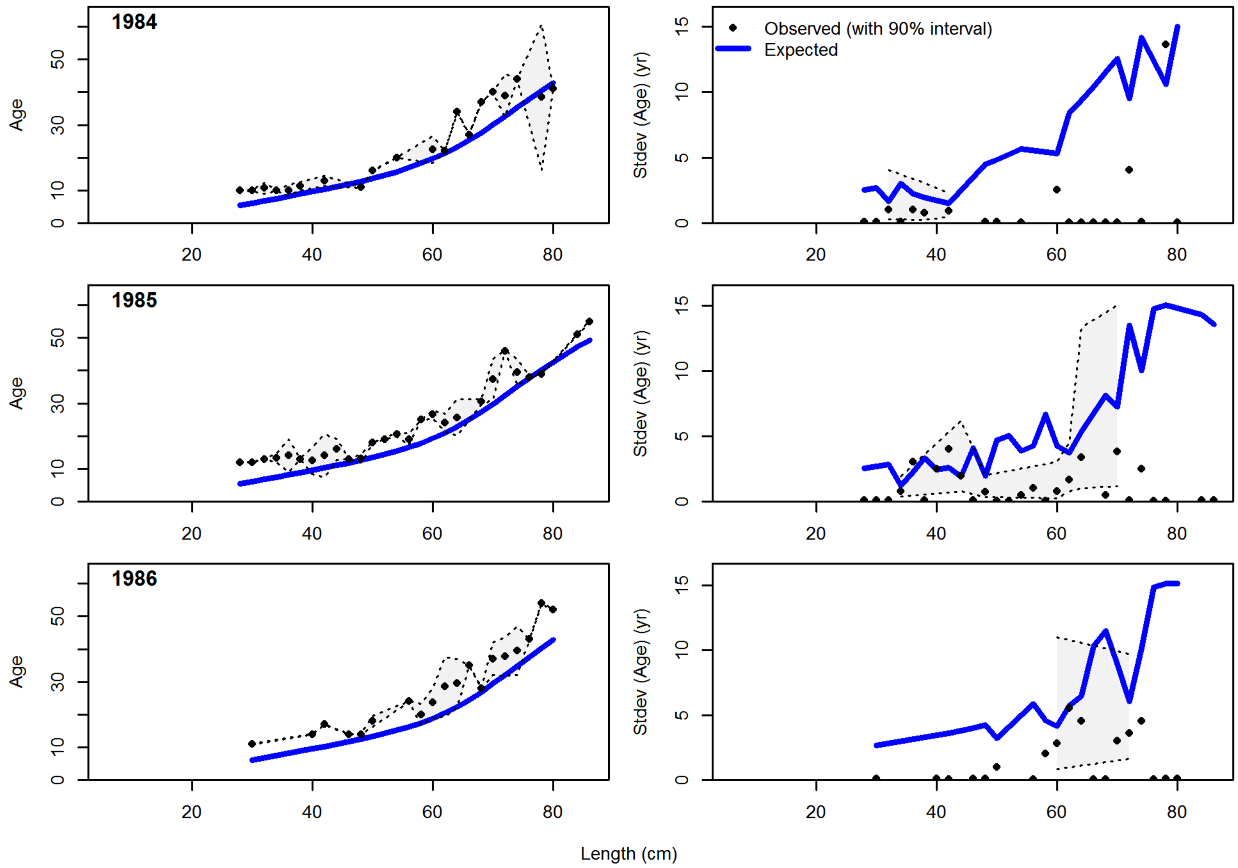


Figure 71: Fits to conditional age at length data from the commercial fishery showing residual bias (predicting fish that are young for their size).

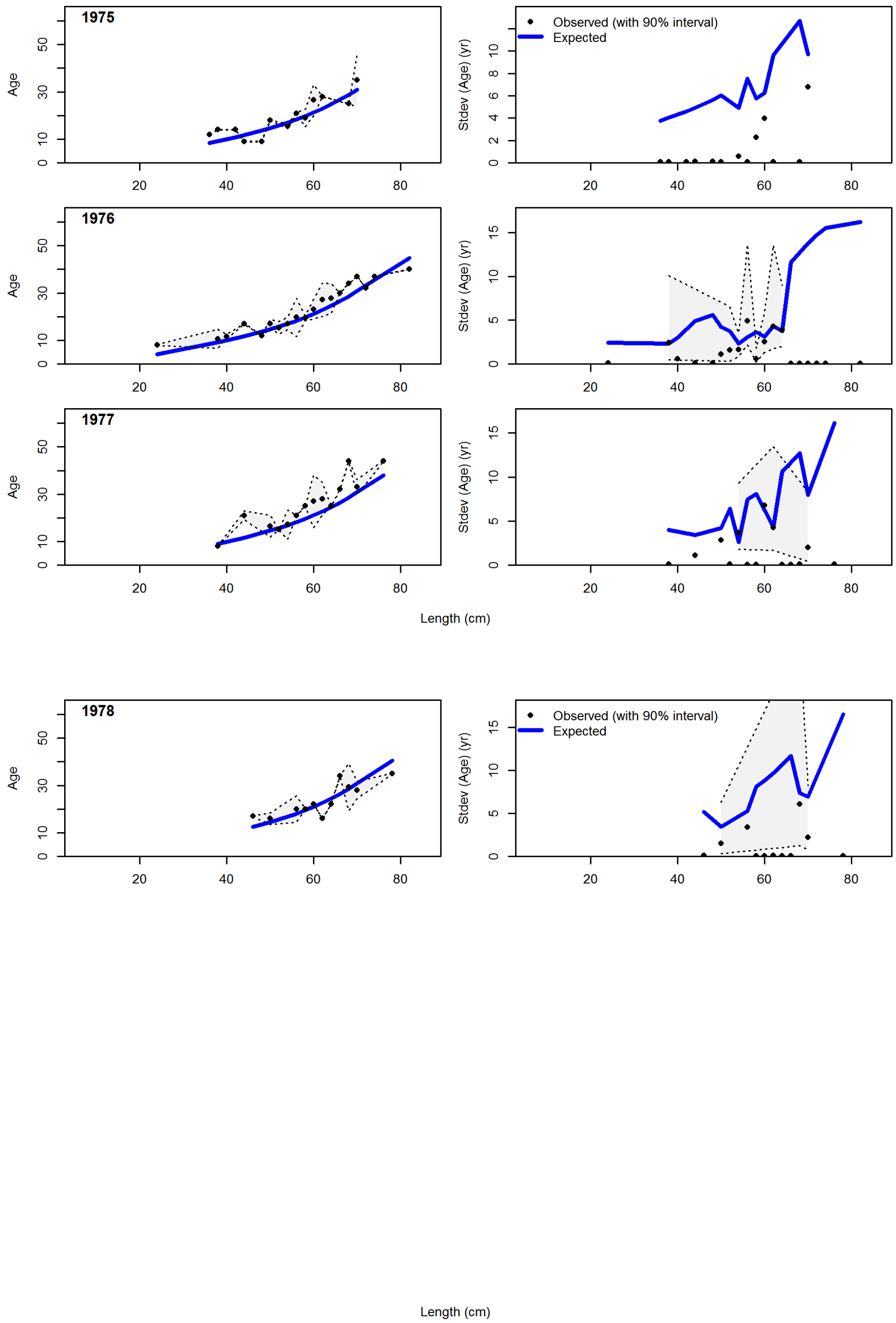


Figure 72: Fits to conditional age at length data from the 1970s onboard CPFV observer data.

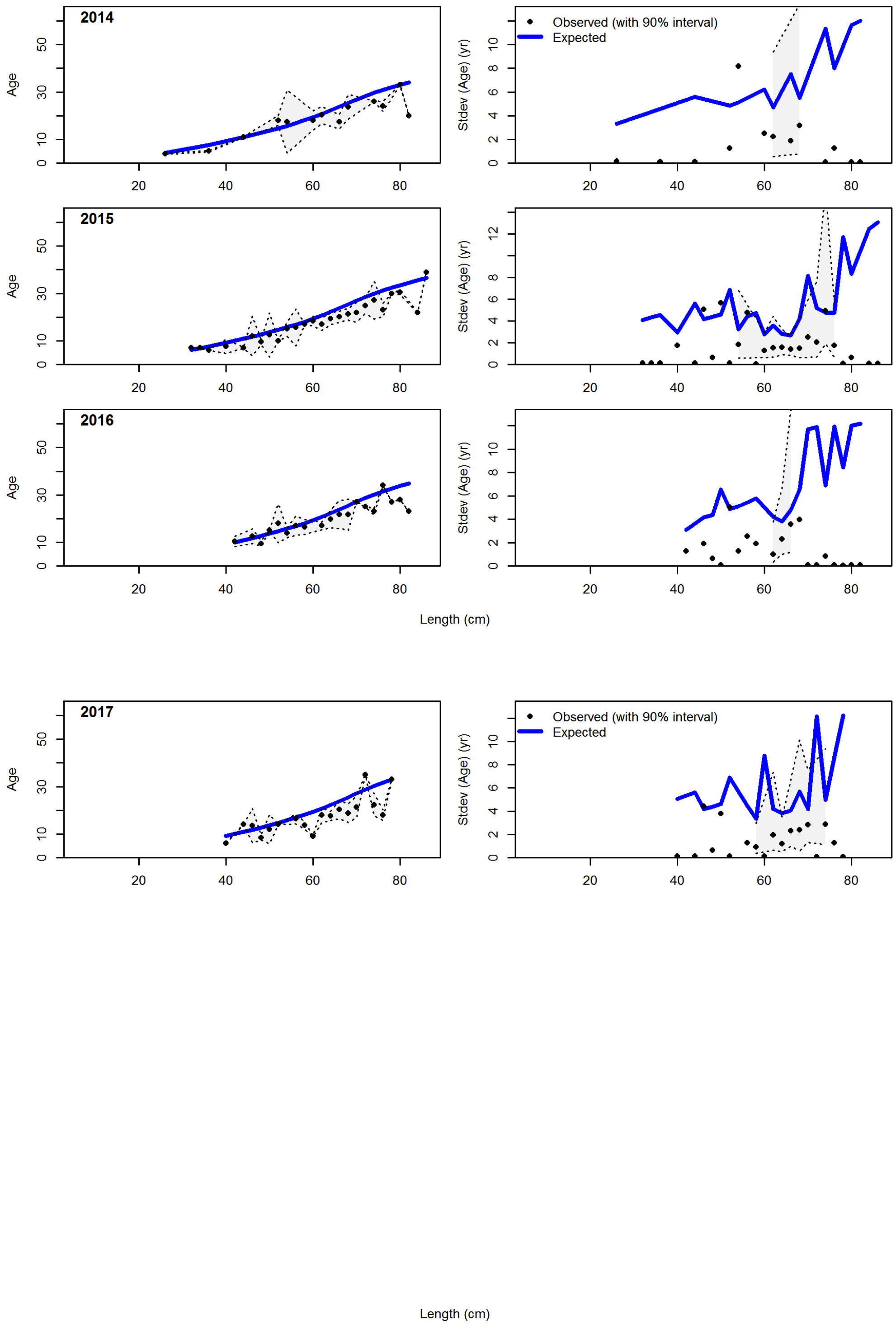


Figure 73: Fits to conditional age at length data (NWFSC hook-and-line survey, 2014-2017) showing a slight bias in predicted age at length, but in the opposite direction of bias in the commercial data.

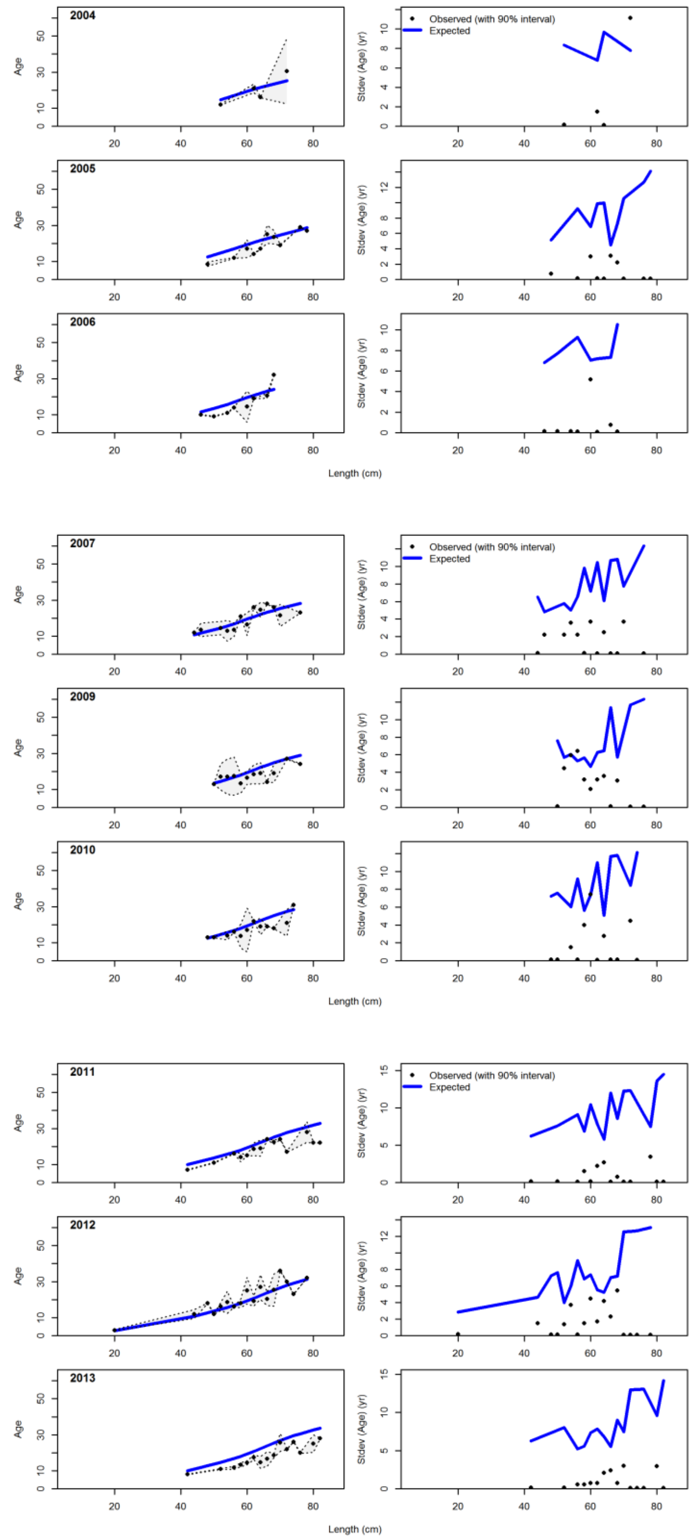


Figure 74: Fits to conditional age at length data (NWFSC hook-and-line survey 'early comps') showing a slight bias in predicted age at length, but in the opposite direction of bias in the commercial data.

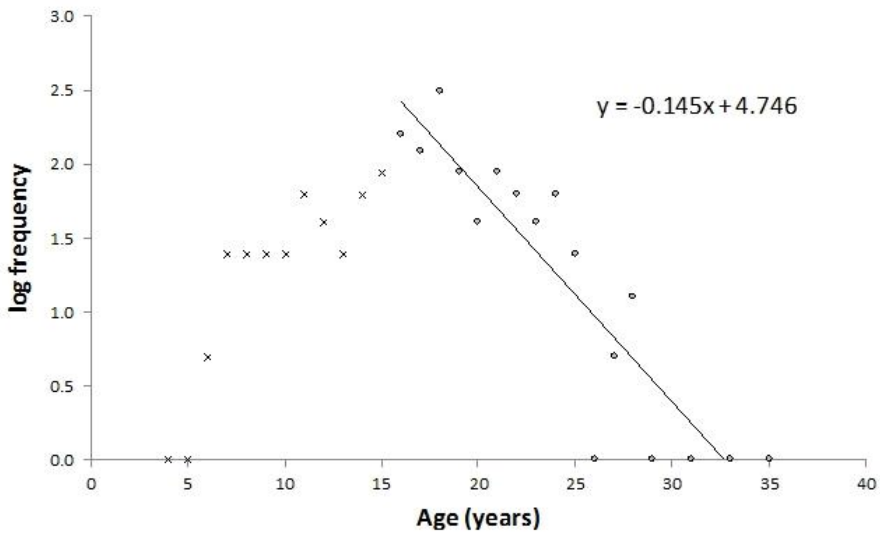


Figure 75: Catch curve analysis for the NWFSC Hook-and-Line survey age data.

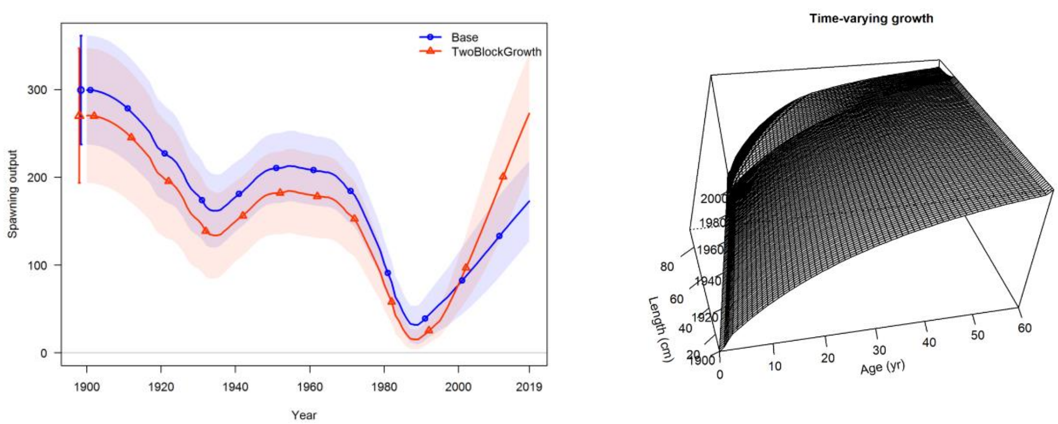


Figure 76: The estimated spawning biomass based on two estimated growth curves (left panel, pre-2000 and post) compared to the base model and the estimated time-varying growth (right panel).

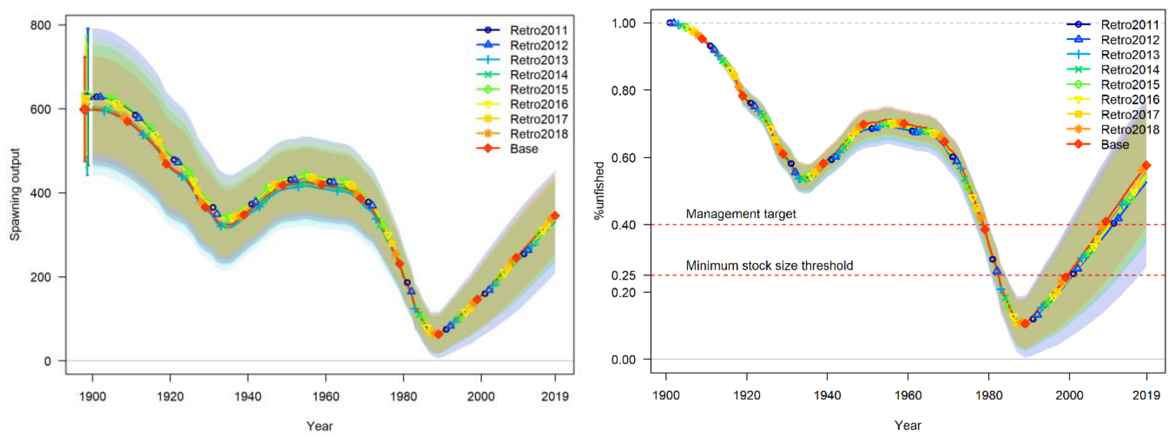


Figure 77: Retrospective pattern in spawning biomass (left panel) and the relative spawning biomass (right panel) when yearly data are removed

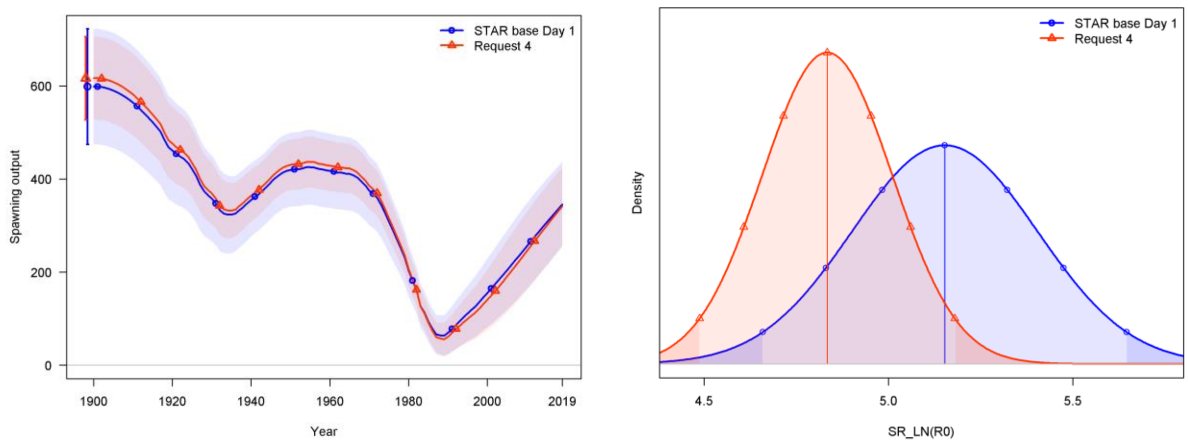


Figure 78: Comparison of the estimated spawning output between externally or internally estimating the growth parameters (left panel) and the difference in the estimated log(R0) between the two approaches (right panel).

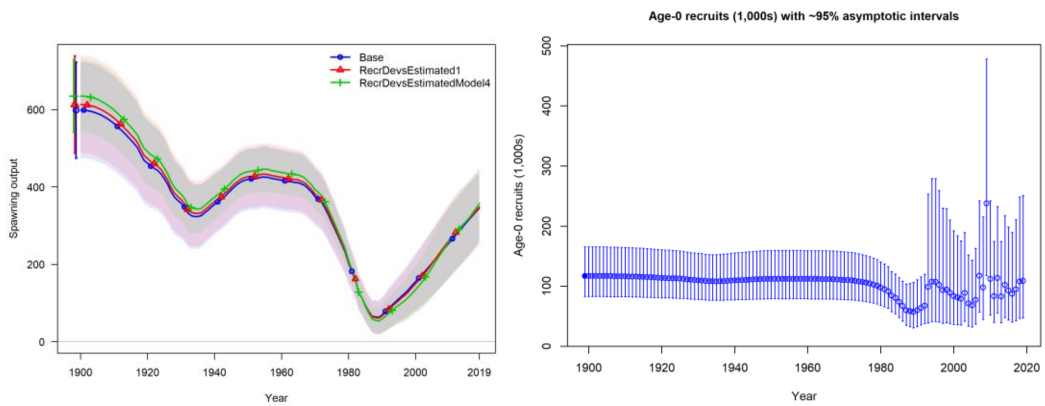


Figure 79: Comparison of the estimated spawning output trajectories (left panel) and the annual estimated recruitment deviations from Model 4 (right panel).

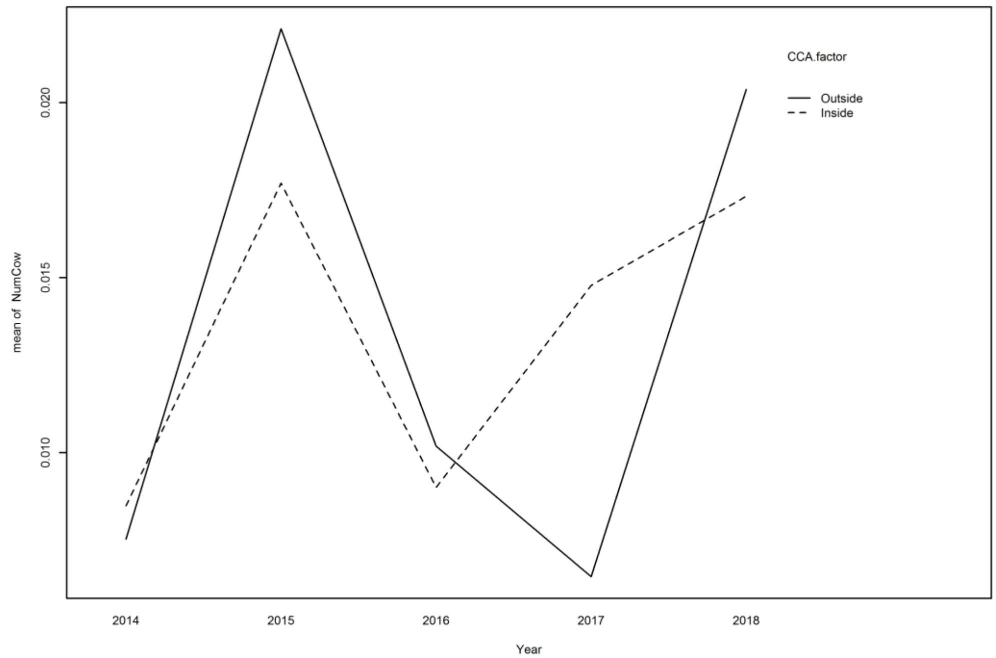


Figure 80: The proportion of positive hooks from the NWFSC Hook-and-Line survey, by year and location (inside/outside the CCAs). Sampling within the CCA began in 2014, so previous years of the survey are not shown.

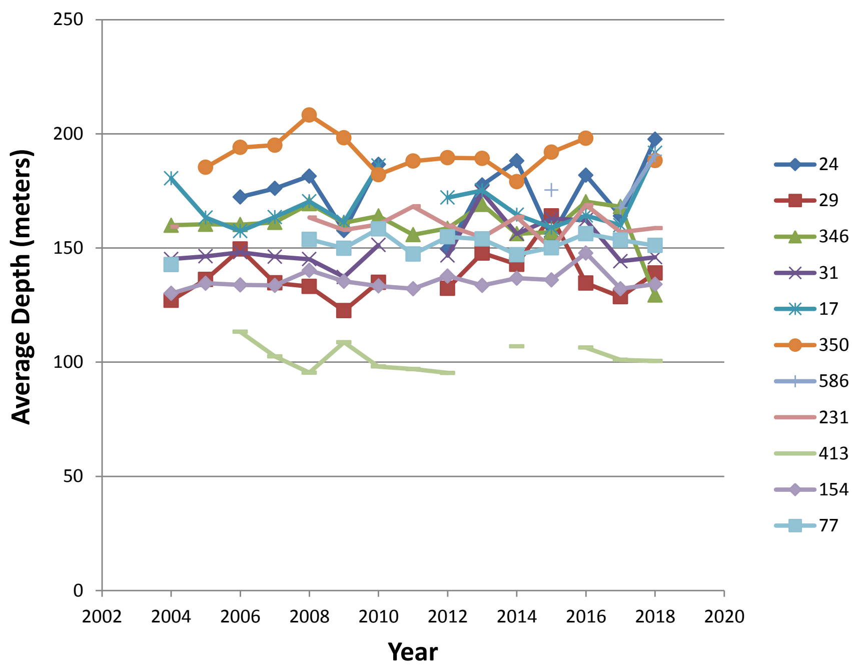


Figure 81: Changes in mean depth fished by site across years (variability among individual drops will be greater).

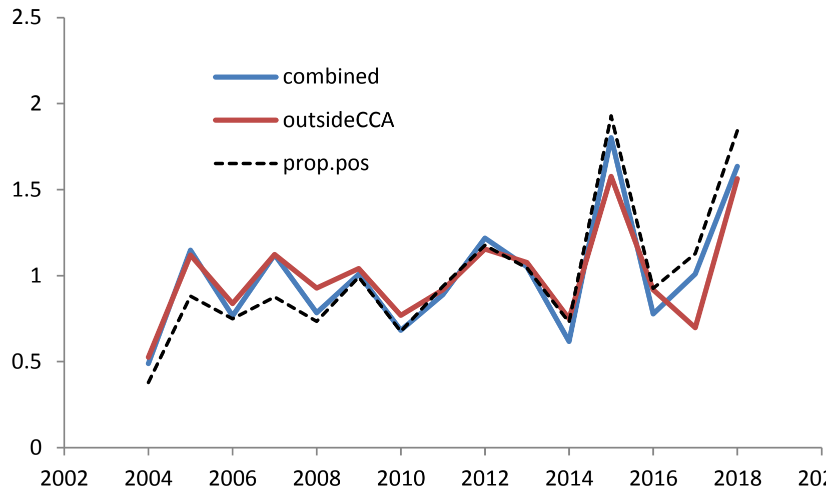


Figure 82: Revised NWFSC Hook-and-Line index (blue line) compared to the outside CCA index from the pre-STAR base model (red line) and annual proportions of positive tows (dashed black line; no standardization for site and hook numbers effects).

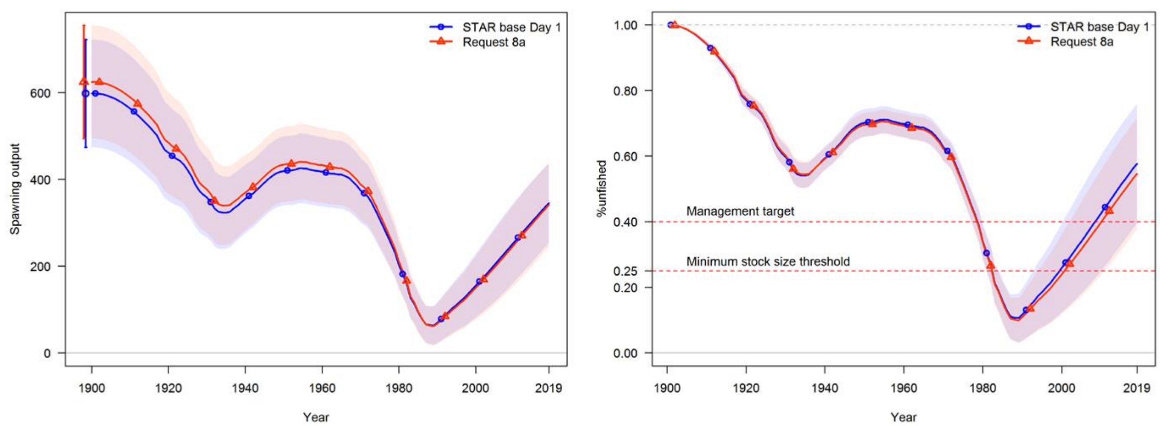


Figure 83: Comparison of spawning output trajectory (left panel) and the relative spawning output (right panel).

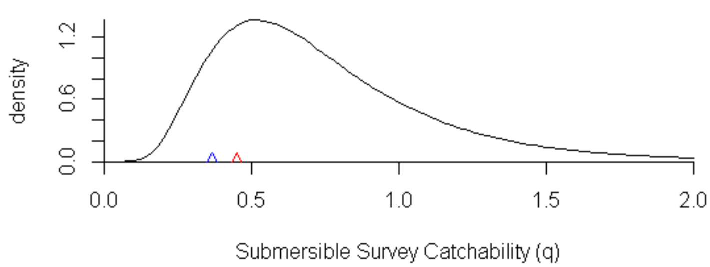


Figure 84: Comparison of the value of q between using a prior on q (red triangle) versus the analytical solution of q without a prior (blue triangle).

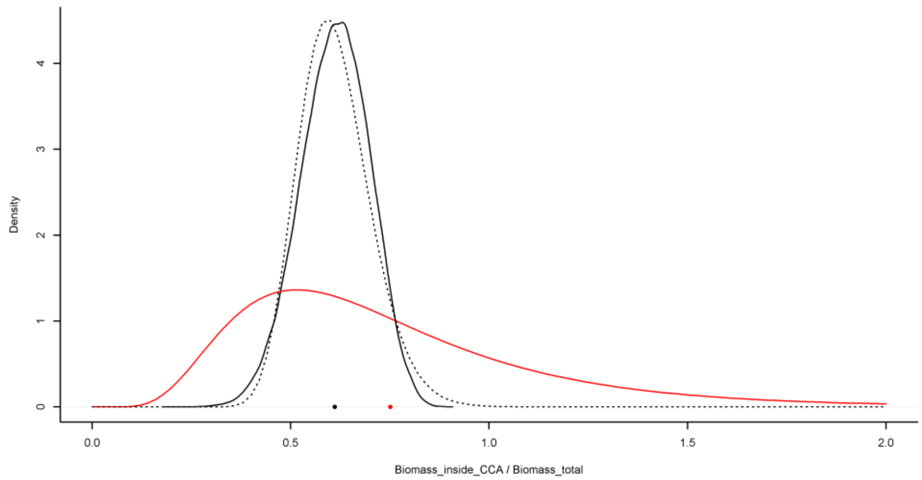


Figure 85: Comparison of q priors for the SWFSC 2002 submersible survey. The red line is the original prior, with a mean of 0.751 (red circle). The solid black line is the posterior density (mean = 0.61, black circle) for catchability derived from the SWFSC 2012 ROV survey. The dashed black line is a lognormal approximation of the posterior with the same mean and log-scale standard deviation.

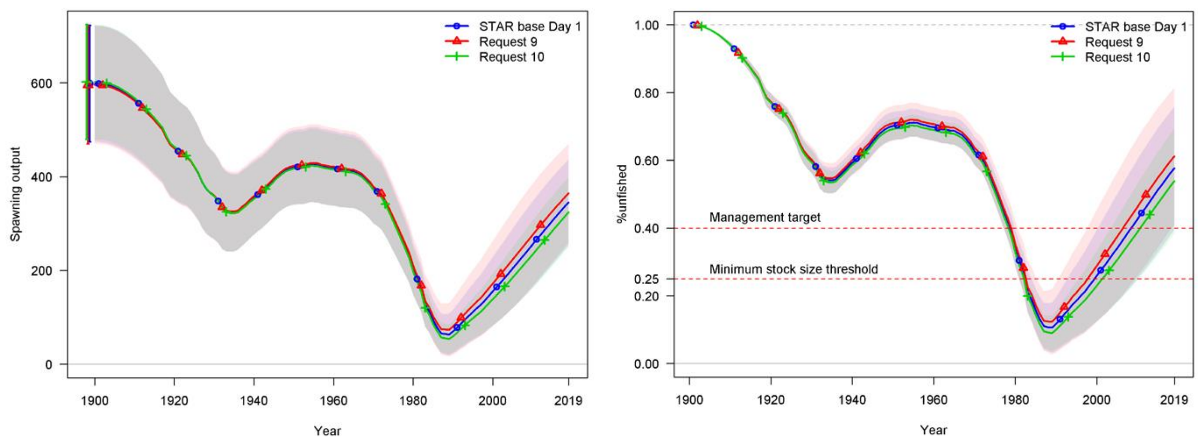


Figure 86: Comparison of the estimated spawning output (left panel) and relative spawning output (right panel) for three alternative priors on catchability for the SWFSC submersible survey. Request 10 uses the prior derived from the SWFSC ROV survey biomass estimates inside and outside the CCA.

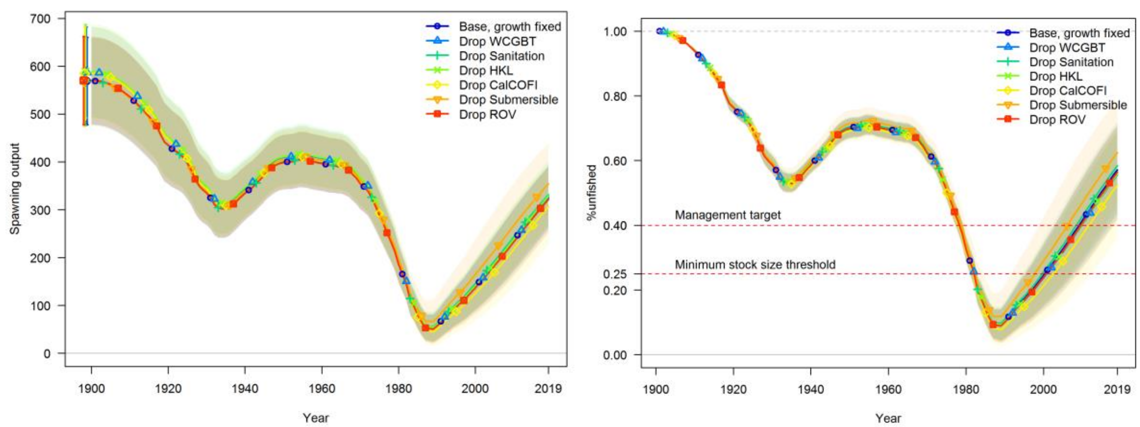


Figure 87: Estimates of spawning output (left panel) and the relative spawning output based on the drop-one analysis.

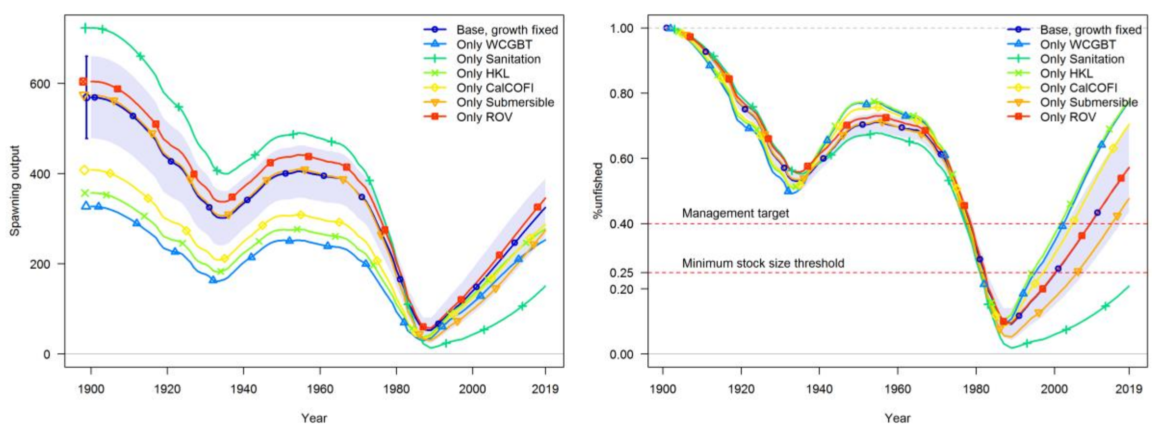


Figure 88: Estimates of spawning output (left panel) and the relative spawning output based on the include-only-1 analysis.

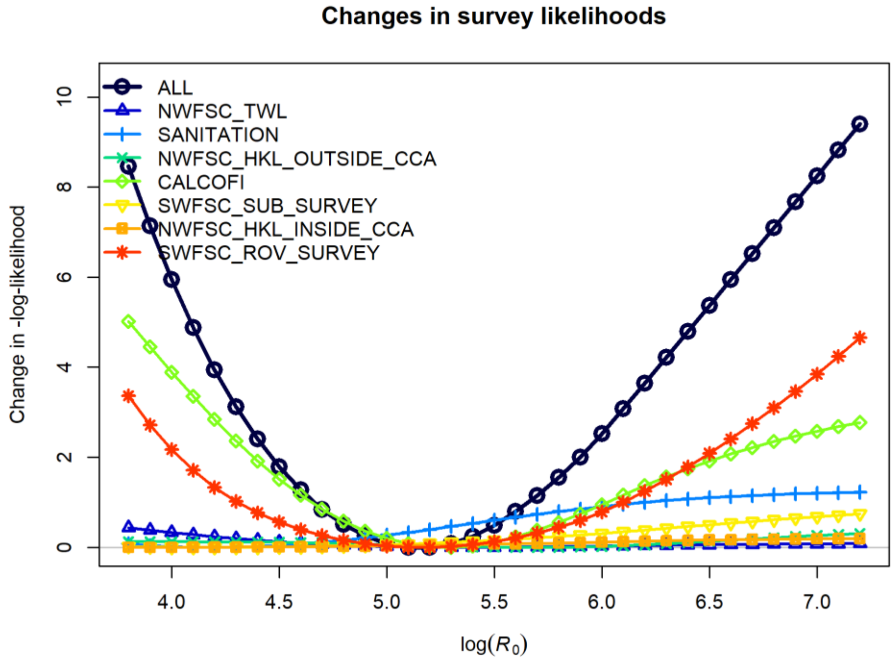


Figure 89: Contribution to the estimated log(R0) value based on the change in the log-likelihood across the survey indices included in the draft cowcod assessment.

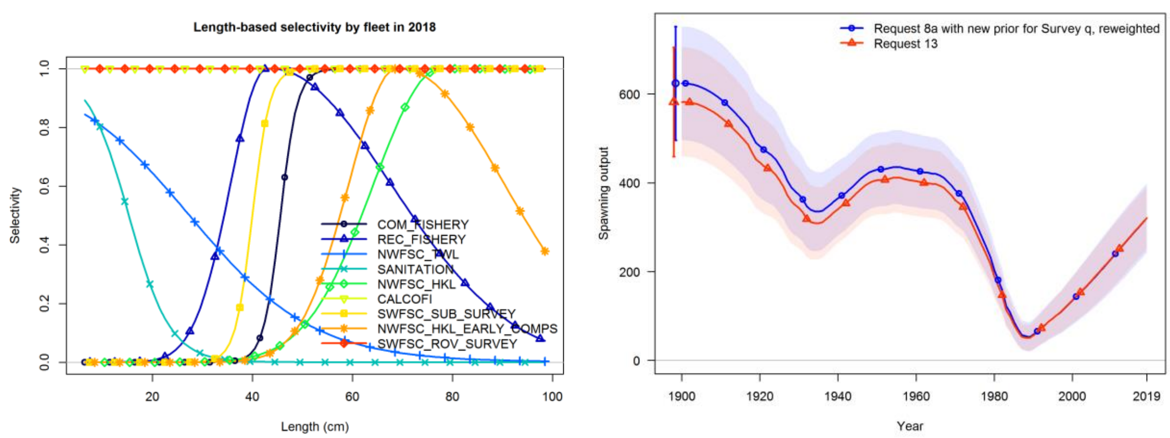


Figure 90: The estimated selectivity (left panel) between the early NWFS Hook-and-Line survey with only outside CCA data (orange line) and the late NWFSC Hook-and-Line survey (green line) which included length data collected inside and outside the CCA. Comparison of the estimated spawning output between the model with the revised treatment of q for the submersible survey (labeled Request 8a) and with the single NWFSC Hook-and-Line index with asymptotic selectivity (right panel).

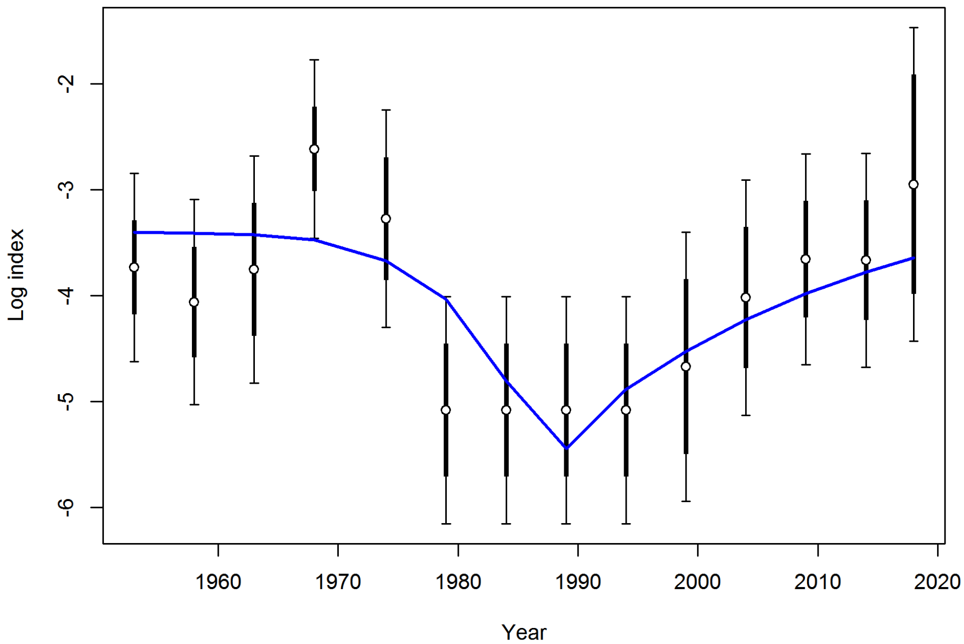


Figure 91: Base model fit to the log-scale CalCOFI index. Thick bars are input variances. Thin bars include additive variance estimates.

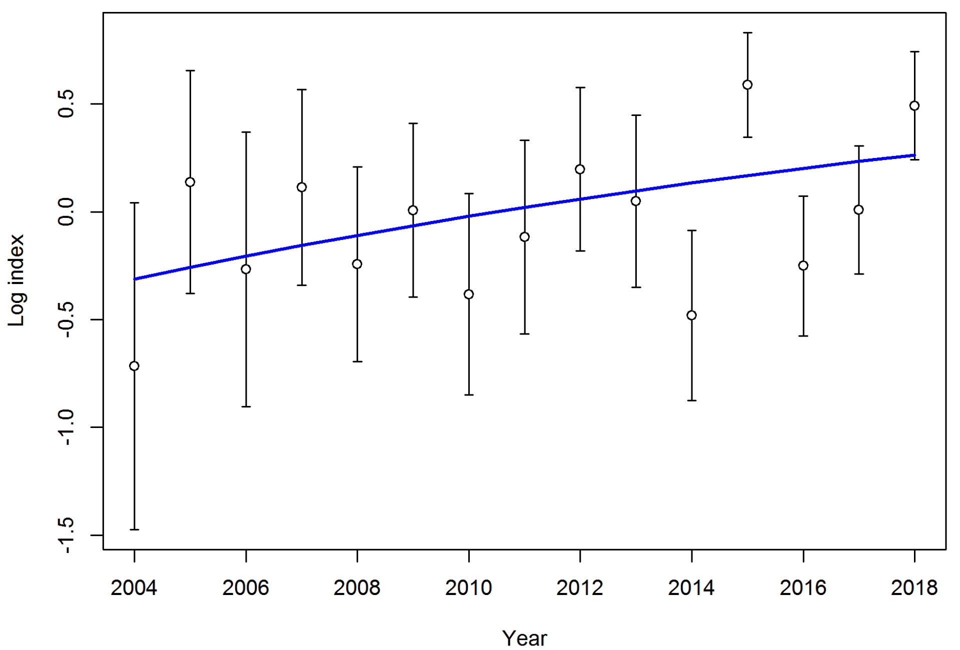


Figure 92: Base model fit to the log-scale NWFSC hook-and-line survey, 2004-2018.

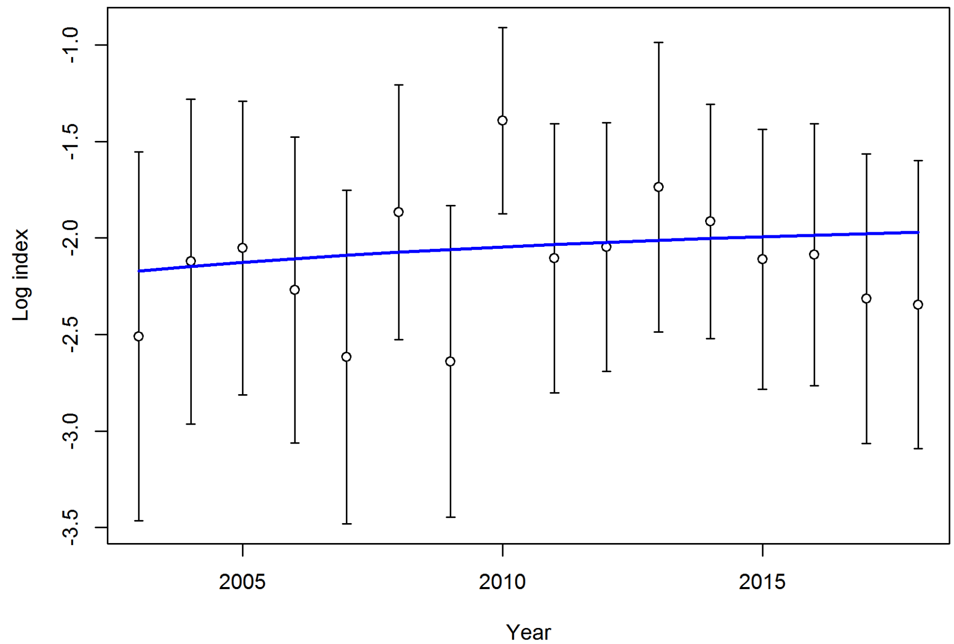


Figure 93: Base model fit to the log-scale NWFSC WCGBT Survey, 2003-2018

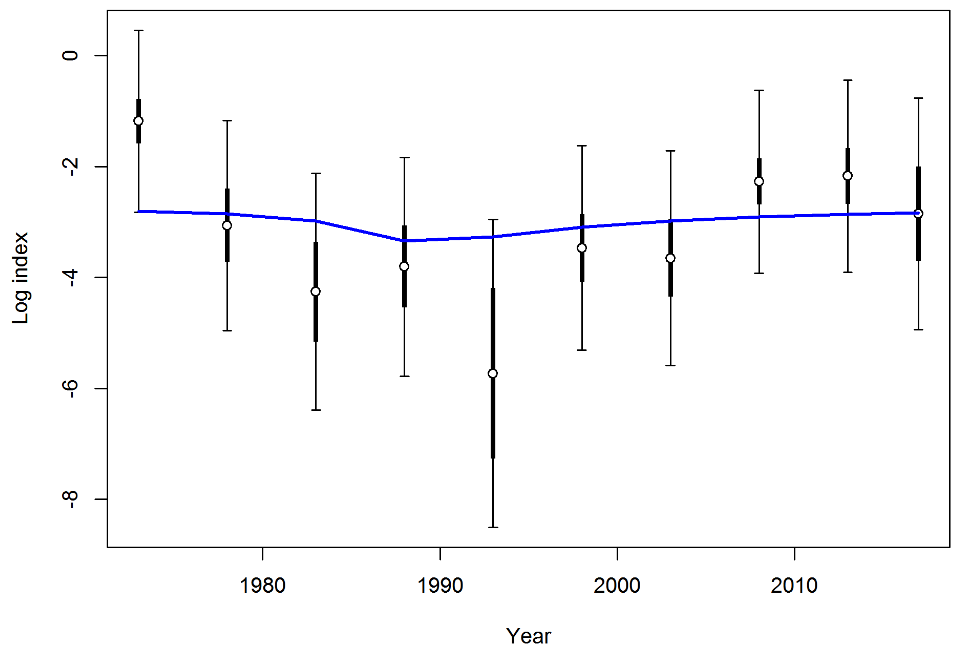


Figure 94: Base model fit to the log-scale Sanitation District trawl surveys.

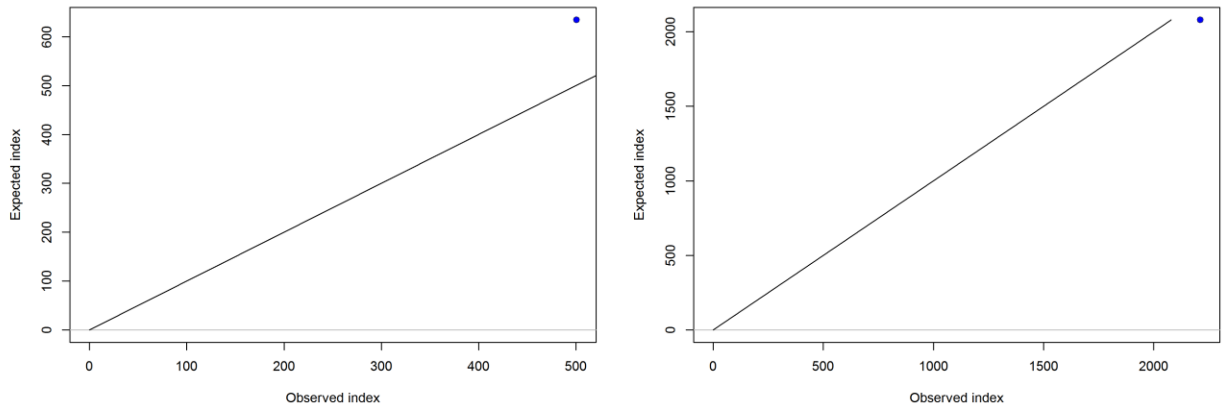


Figure 95: Expected vs. observed values for both SWFSC visual surveys: the 2002 submersible survey (left panel), and the 2012 ROV survey (right panel). Diagonal lines are 1:1.

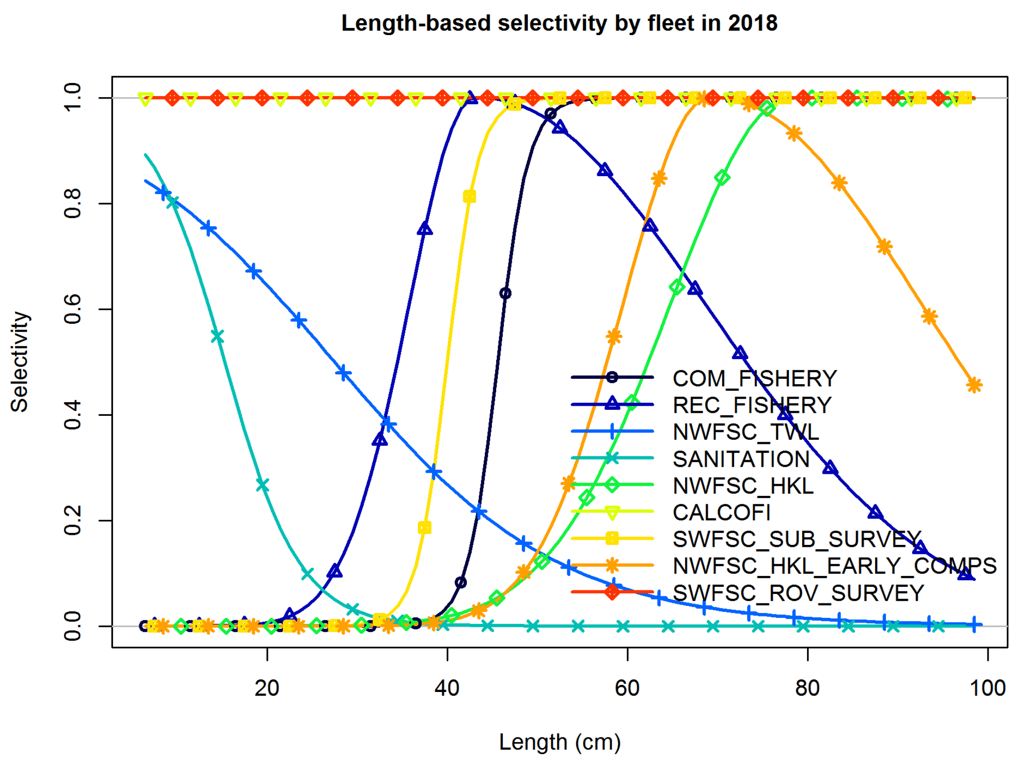


Figure 96: Length-based selectivity curves by fleet for the cowcod base model.

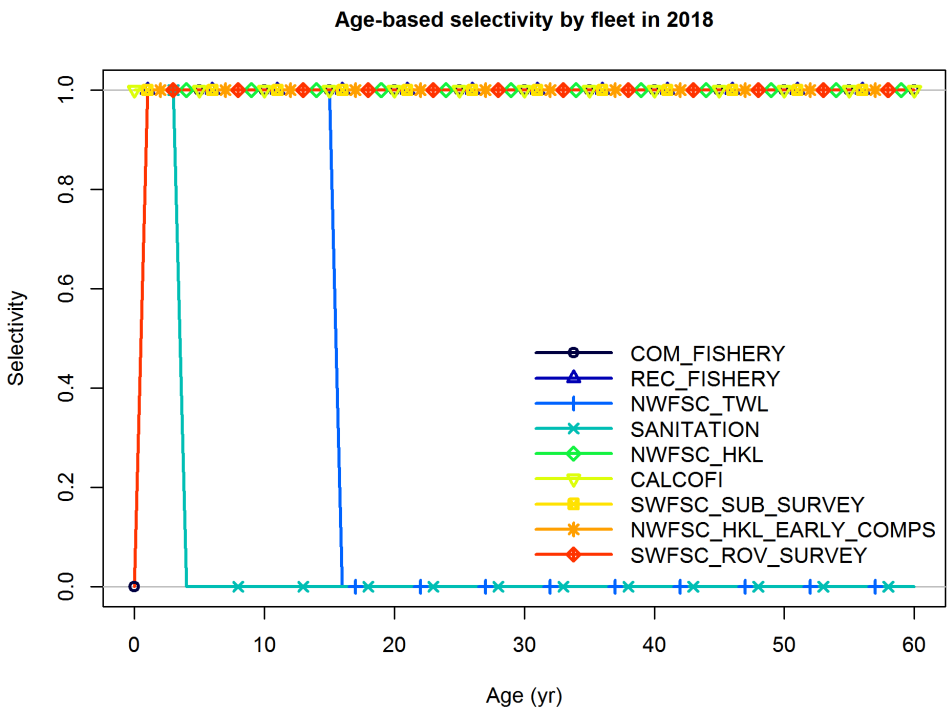


Figure 97: Age-based selectivity curves by fleet for the cowcod base model.

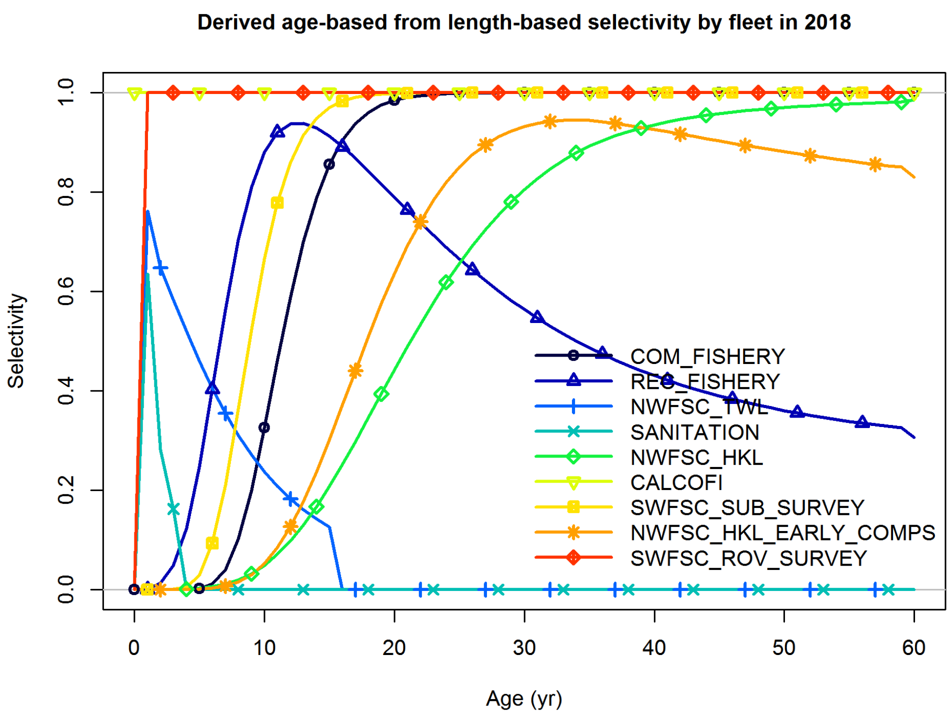


Figure 98: Derived age-based from length-based selectivity curves by fleet for the cowcod base model.

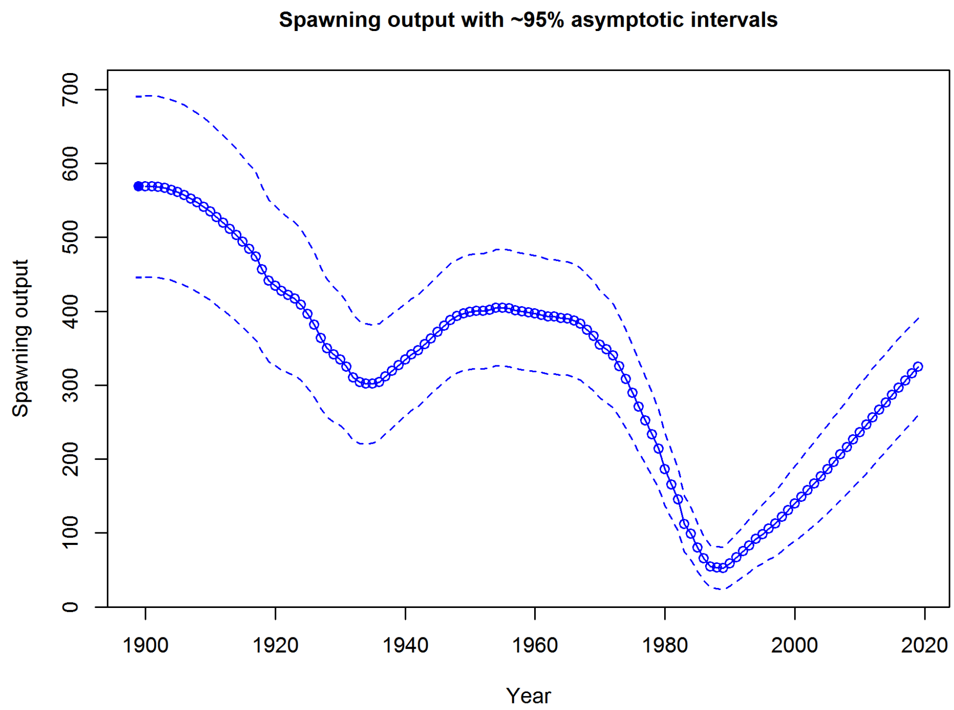


Figure 99: Estimated time series of spawning output (billions of eggs/larvae) from the base case Cowcod model with ~95% confidence intervals. Values are plotted as twice the actual amount due to the use of a single-sex model.

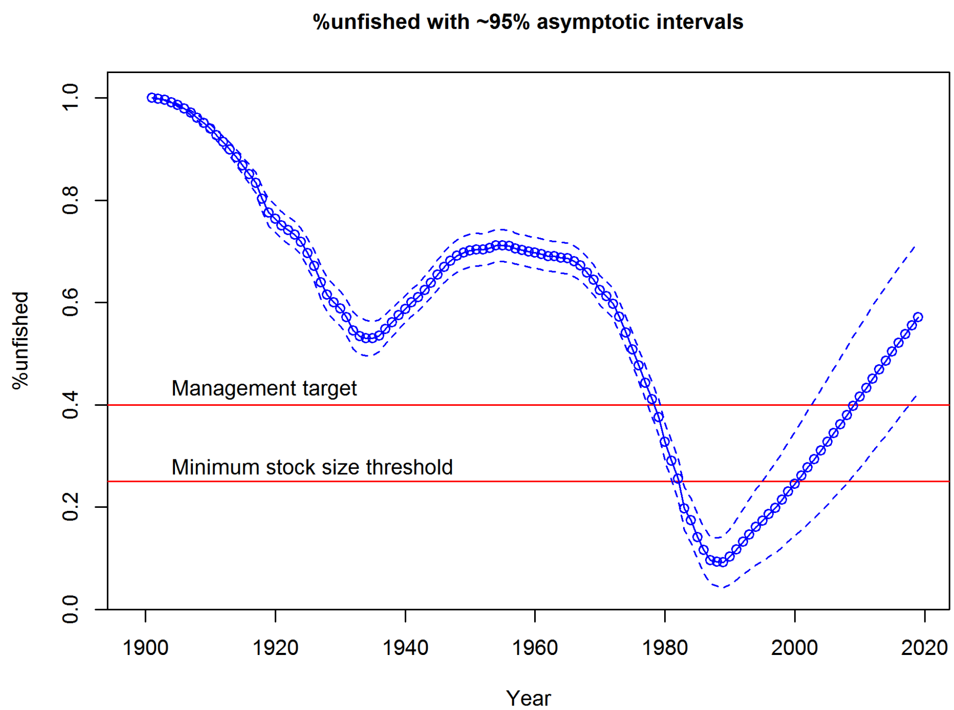


Figure 100: Estimated spawning output relative to unfished levels ("depletion") for the Cowcod base case model with ~95% asymptotic confidence intervals.

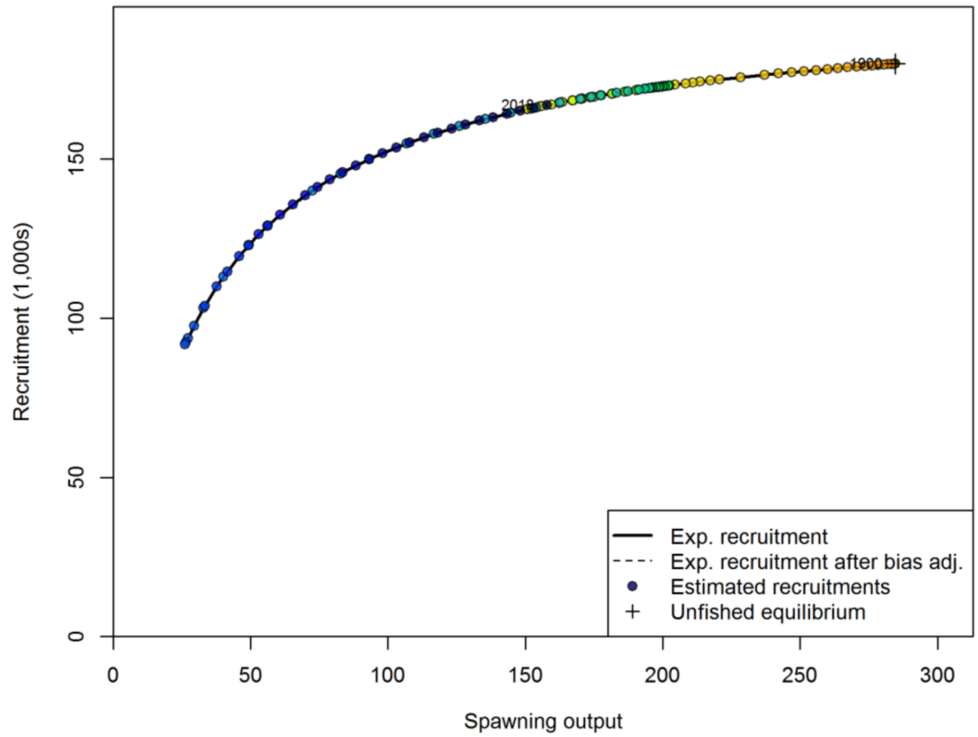


Figure 101: Beverton-Holt stock recruitment relationship in the base model, with steepness fixed at 0.72.

Figure 102: Time series of Age-0 recruits in the base model.

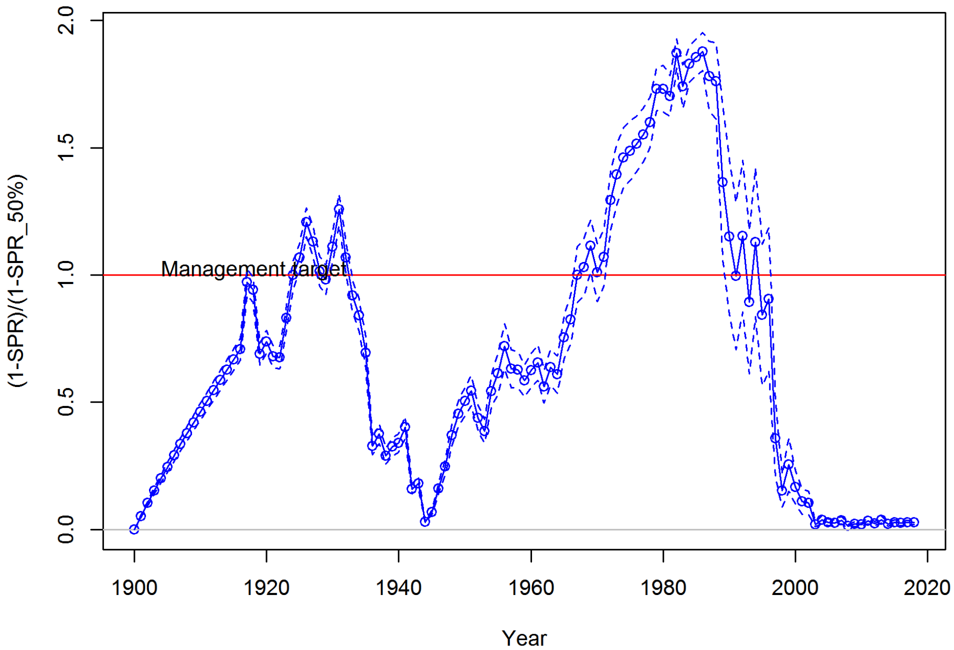


Figure 103: Time series of exploitation rates, defined as [(1-SPR) / (1-SPR$_{50\%}$)].

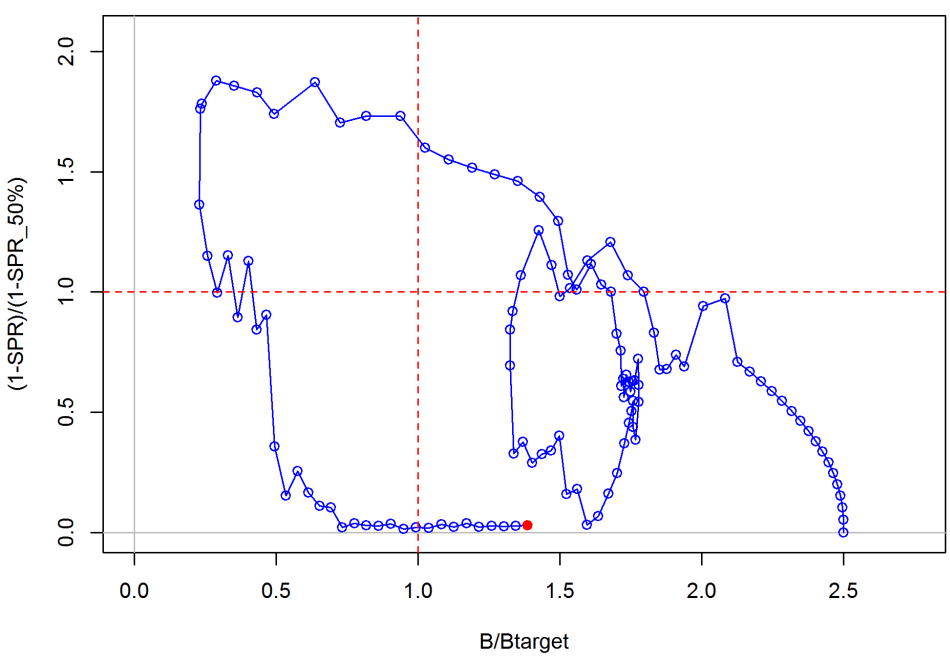


Figure 104: Phase plot of fishing intensity relative to target (50% SPR) versus biomass relative to target (40% of unfished spawning output).

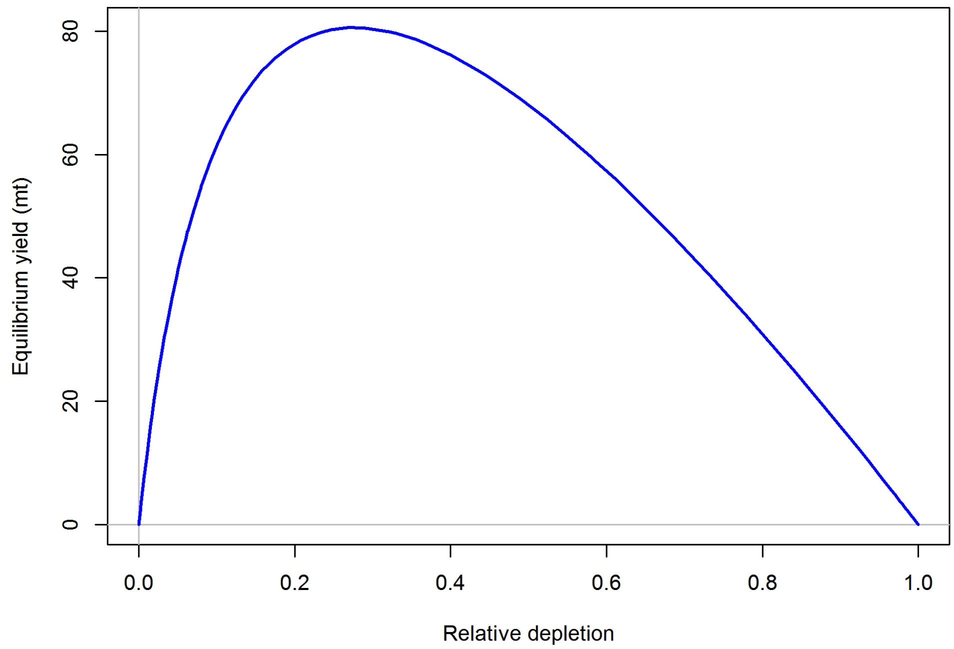


Figure 105: Equilibrium yield curve from the base model (steepness fixed at 0.72).

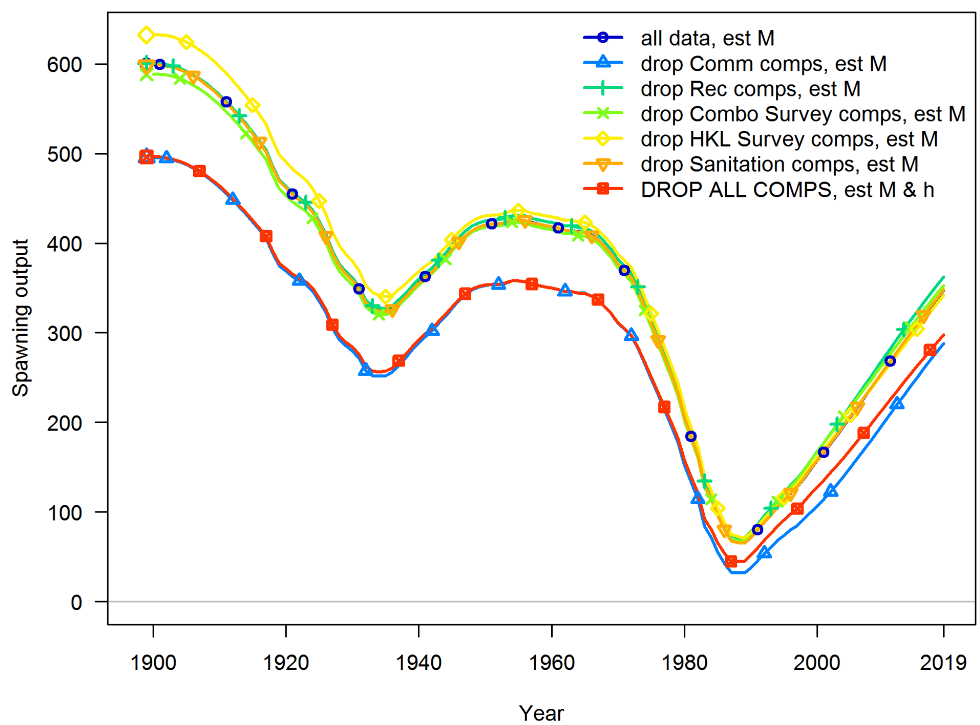


Figure 106: Effect of "Drop One" sensitivity (composition data only) on estimates of spawning output relative to the pre-STAR base model.

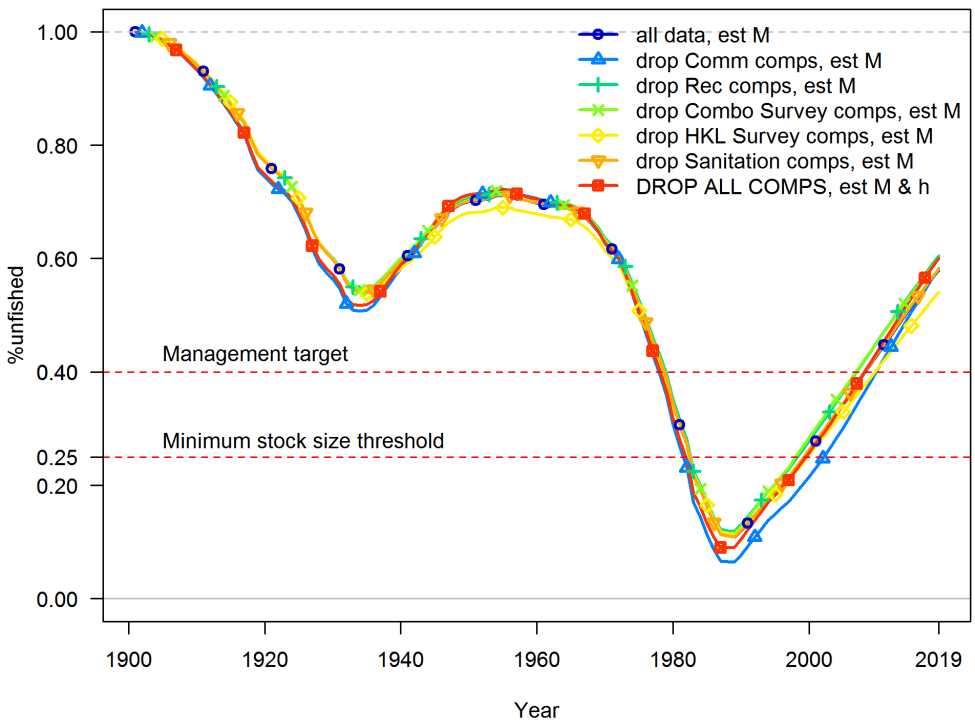


Figure 107: Effect of "Drop One" sensitivity (composition data only) on estimates of spawning output and associated uncertainty relative to the pre-STAR base model.

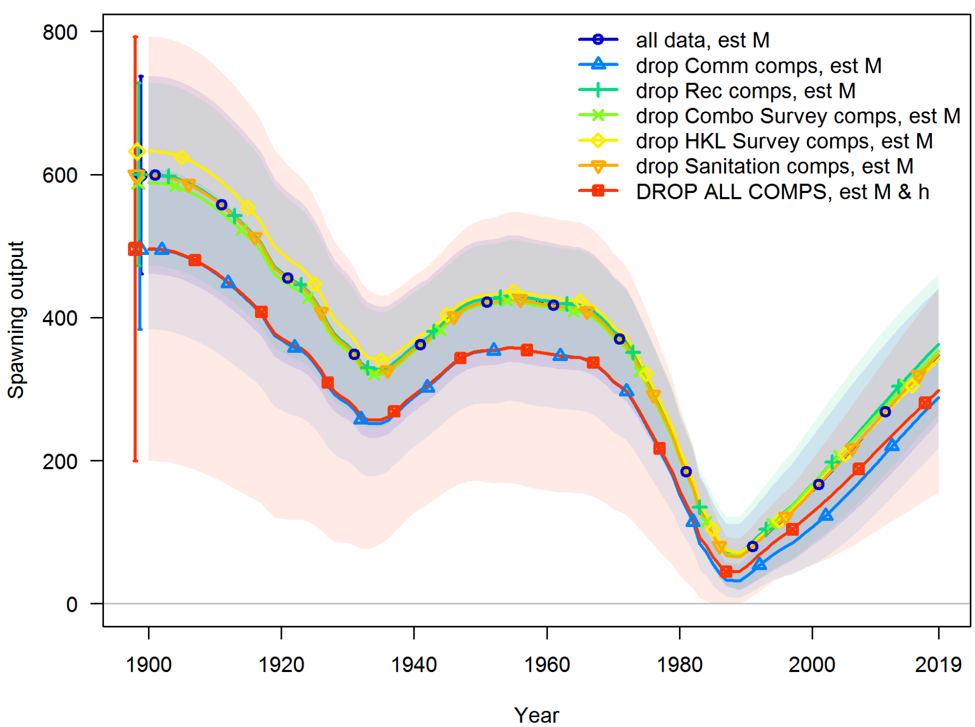


Figure 108: Effect of "Drop One" sensitivity (composition data only) on uncertainty in spawning output relative to the pre-STAR base model.

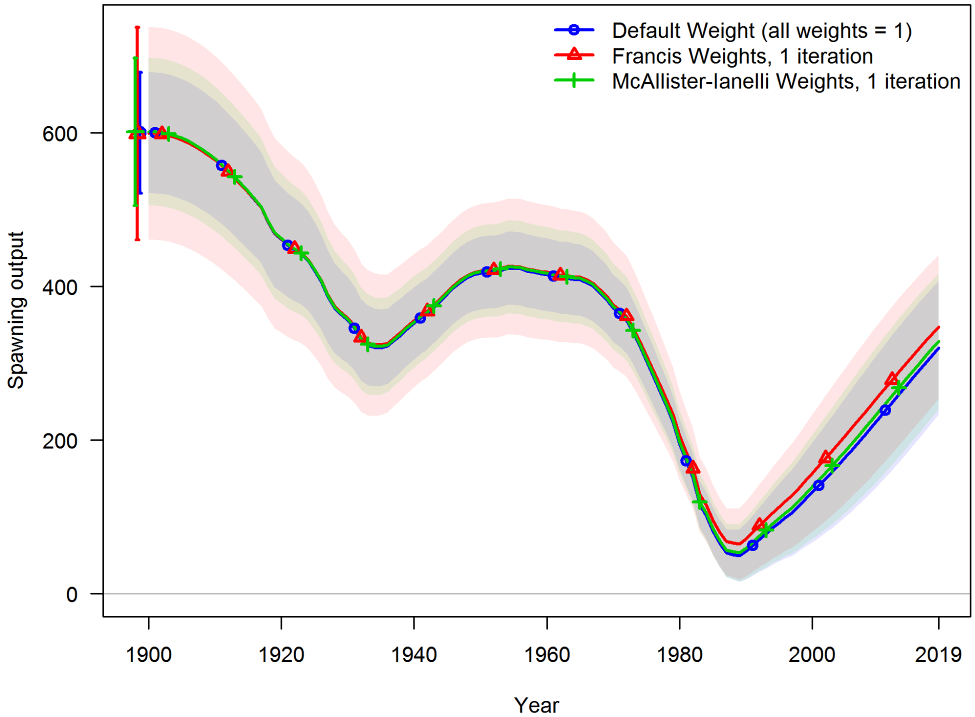


Figure 109: Effect of alternative data weighting methods on estimates of spawning output using pre-STAR base model.

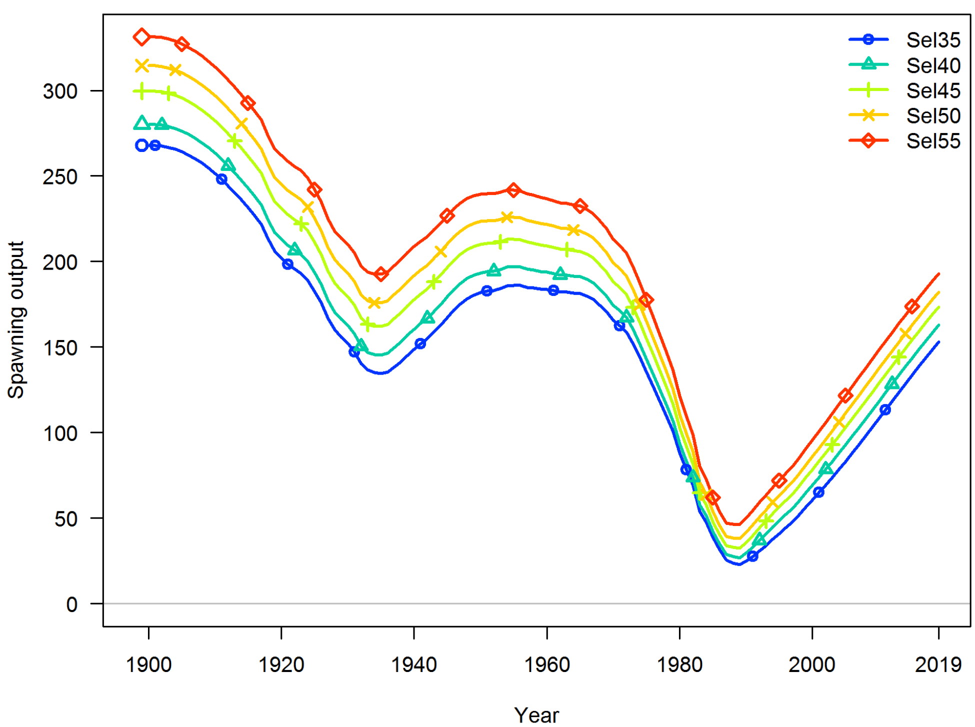


Figure 110: Estimated trend in spawning output as a function of the length at which 50% of fish become vulnerable to commercial fishing gear. Sensitivity conducted on pre-STAR base model.

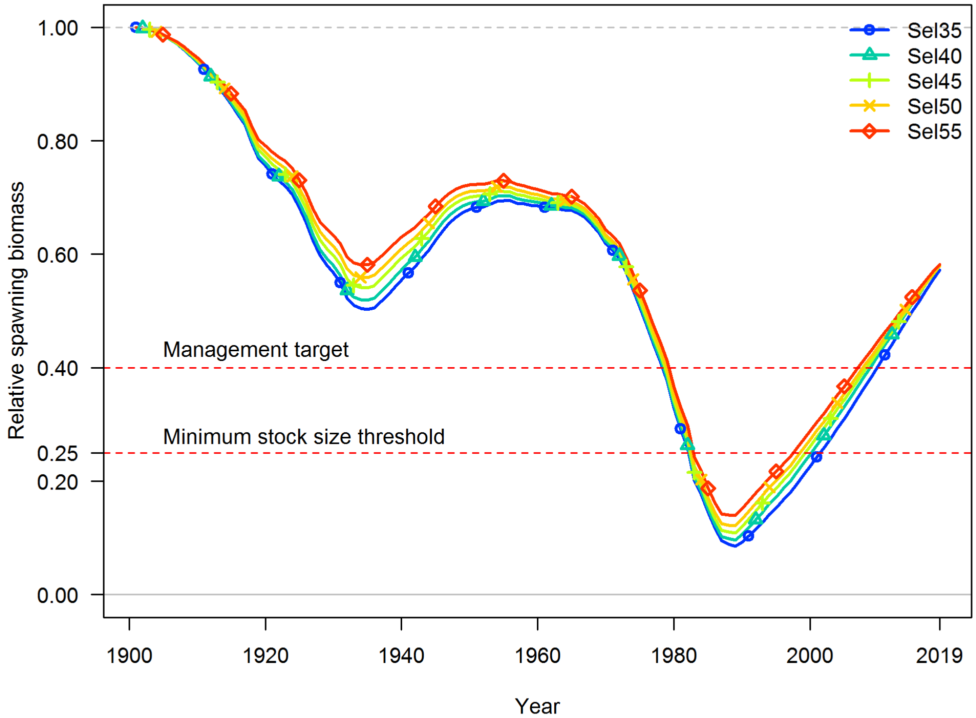


Figure 111: Estimated trend in relative spawning output as a function of the length at which 50% of fish become vulnerable to commercial fishing gear. Sensitivity conducted on pre-STAR base model.

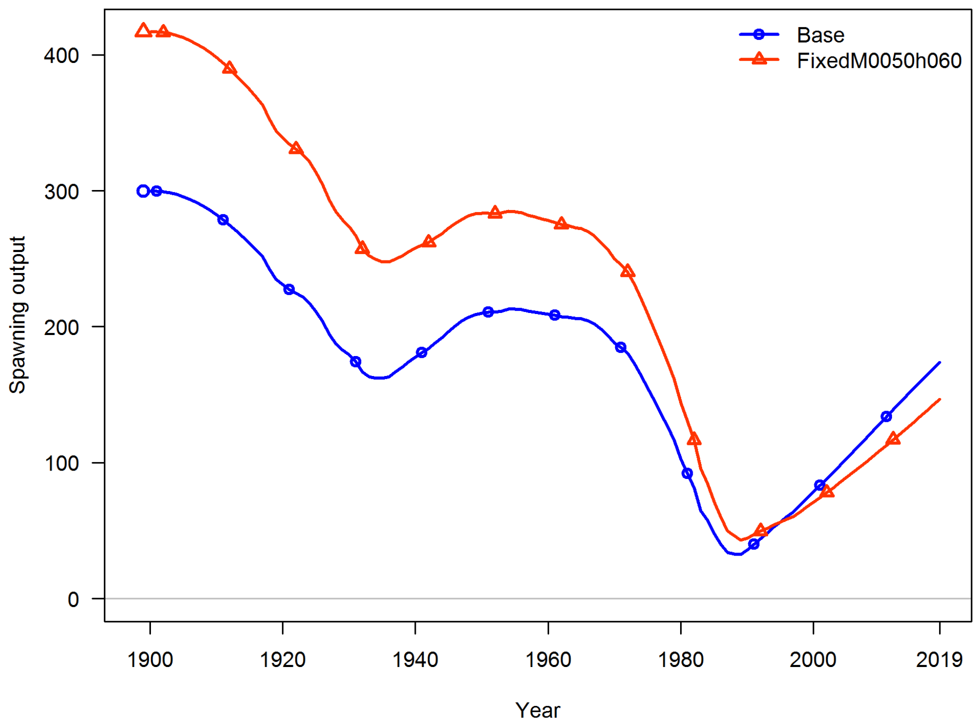


Figure 112: Comparison of spawning output from the pre-STAR base model, and the same model with steepness fixed at 0.6 and M fixed at 0.055 (estimates from the 2007 and 2009 cowcod assessments).

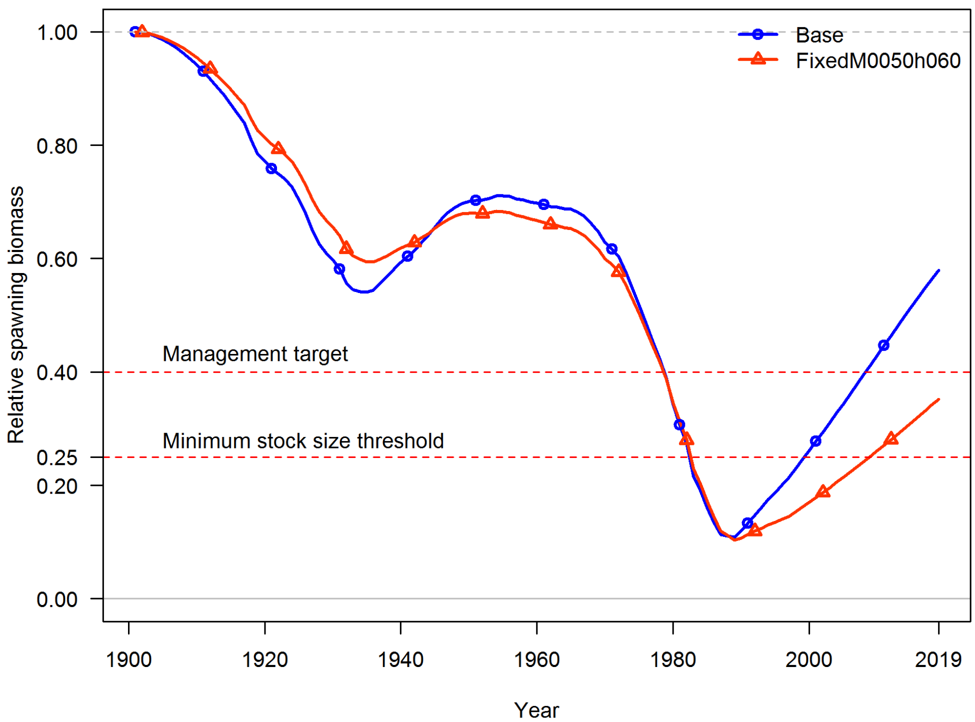


Figure 113: Comparison of spawning depletion from the pre-STAR base model, and the same model with steepness fixed at 0.6 and M fixed at 0.055 (estimates from the 2007 and 2009 cowcod assessments).

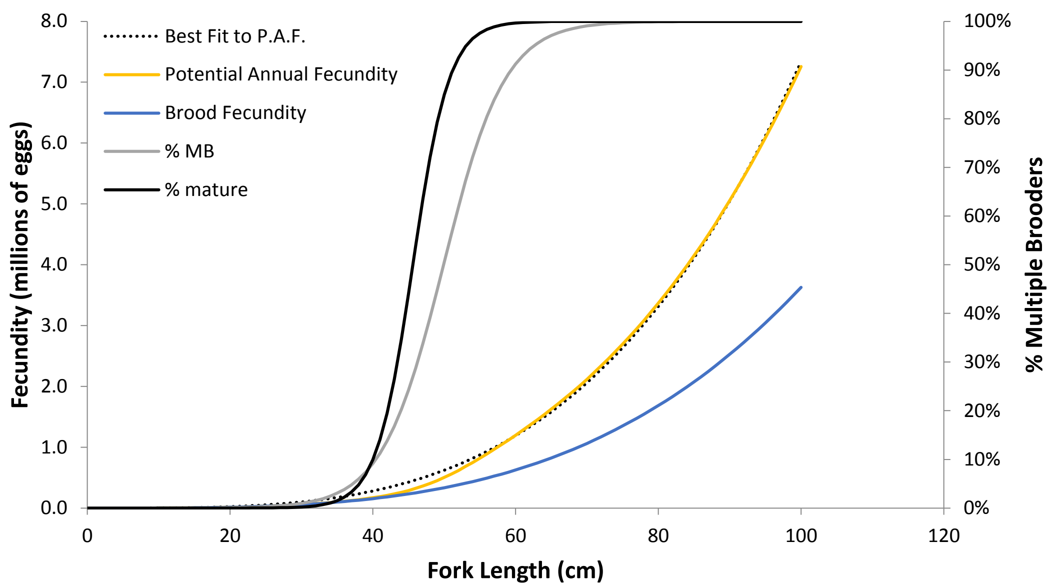


Figure 114:Estimate of Potential Annual Fecundity assuming a size-dependent frequency of multiple broods (grey line, up to 2 broods maximum) that is similar to the maturity ogive (black solid line). "Brood fecundity" is the base model fecundity relationship, "Potential Annual Fecundity"(PAF) equals brood fecundity multiplied by the expected number of broods at length (1 + % MB). An allometric fecundity-length relationship was fit to approximate PAF (black dashed line).

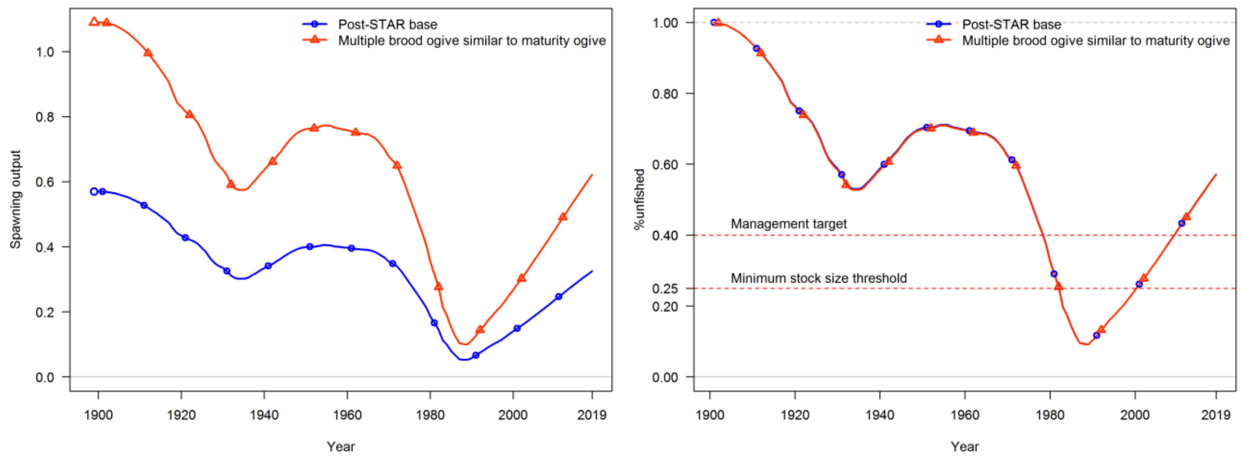


Figure 115: Changes in spawning output (left panel) and stock depletion (right panel) associated with the first multiple brooding sensitivity. The percentage of females producing multiple broods (the "MB ogive") as a function of length is similar to the percentage of mature females at length in this example.

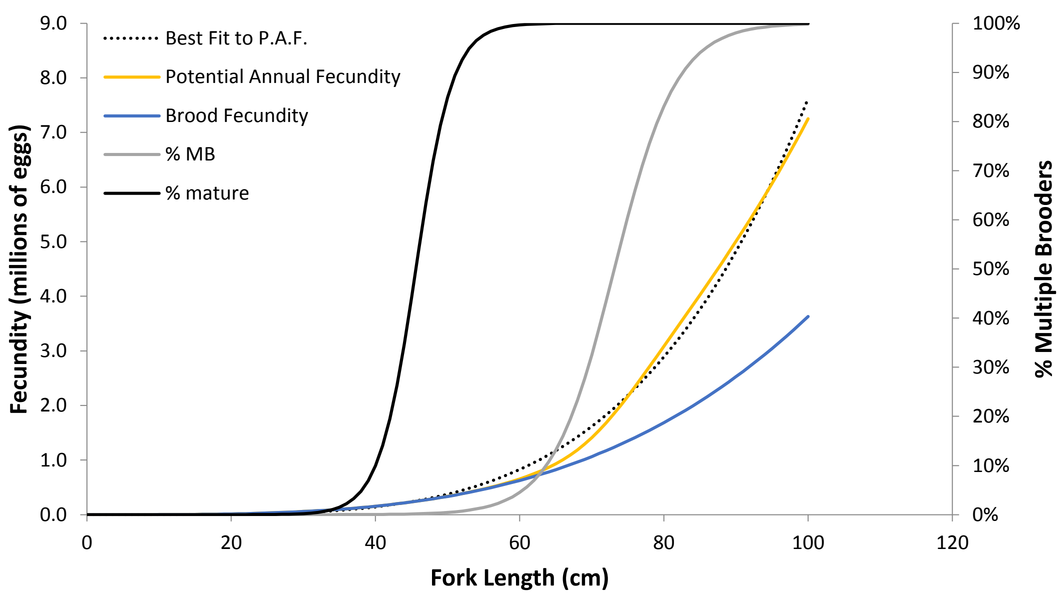


Figure 116: Estimate of Potential Annual Fecundity assuming that size-dependent frequency of multiple broods (grey line, up to 2 broods maximum) increases at larger sizes than the percentage of mature females (black solid line). "Brood fecundity" is the base model fecundity relationship, "Potential Annual Fecundity"(PAF) equals brood fecundity multiplied by the expected number of broods at length (1 + % MB). An allometric fecundity-length relationship was fit to approximate PAF (black dashed line).

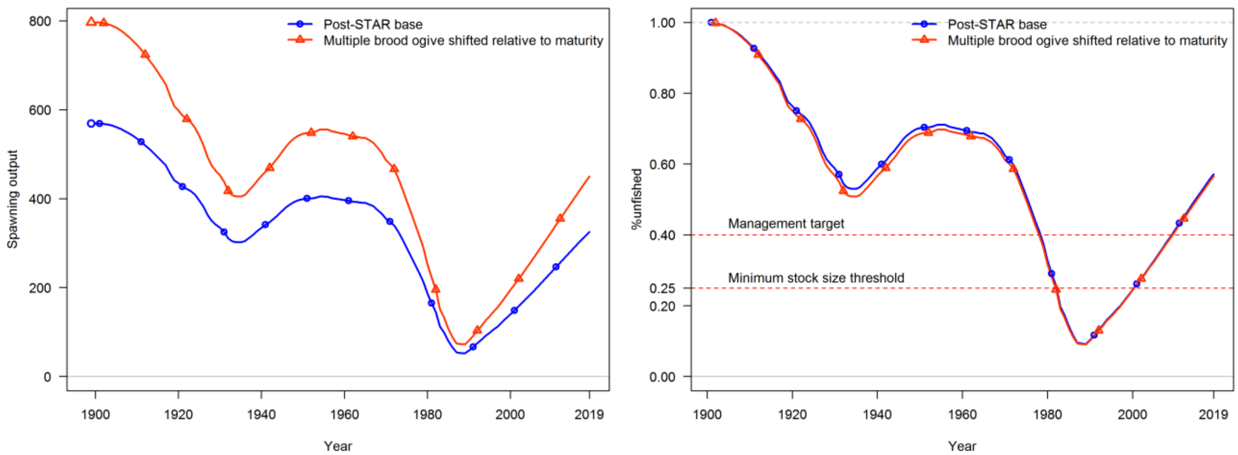


Figure 117: Changes in spawning output (left panel) and stock depletion (right panel) associated with the second multiple brooding sensitivity. In this example, the percentage of females producing multiple broods (the “MB ogive”) increases at larger sizes than the percentage of mature females.

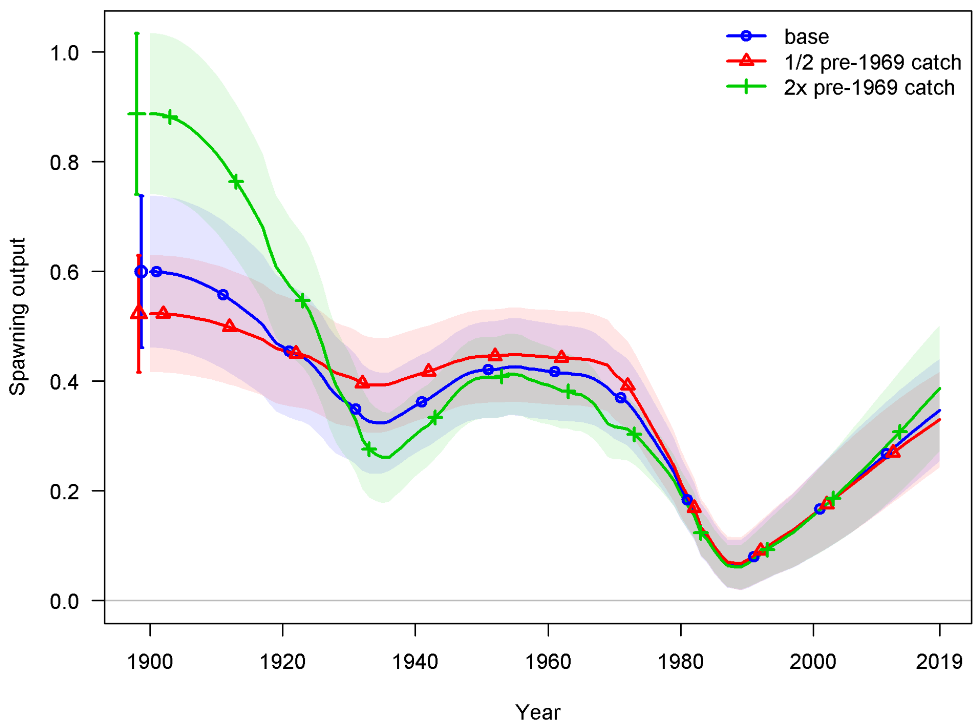


Figure 118: Changes in spawning output trajectories under alternative assumptions about the magnitude of historical (pre-1969) catch.

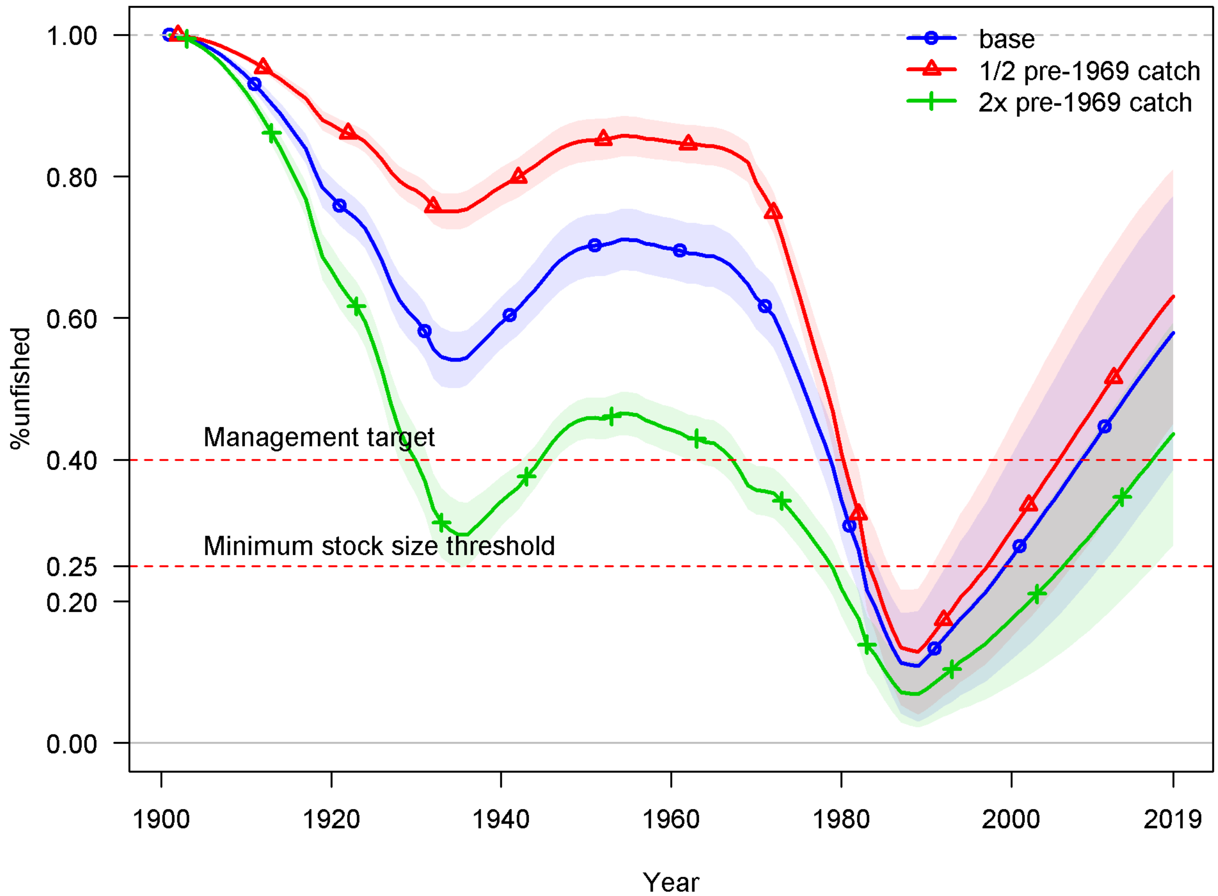


Figure 119: Changes in stock depletion under alternative assumptions about the magnitude of historical (pre-1969) catch.

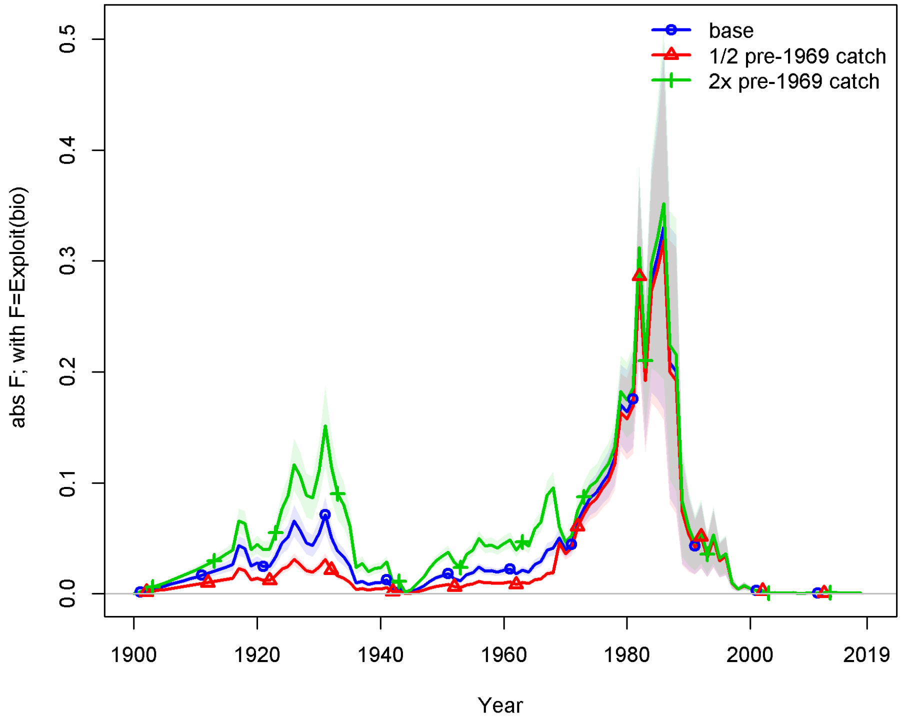


Figure 120: Changes in estimated harvest rates under alternative assumptions about the magnitude of historical (pre-1969) catch.

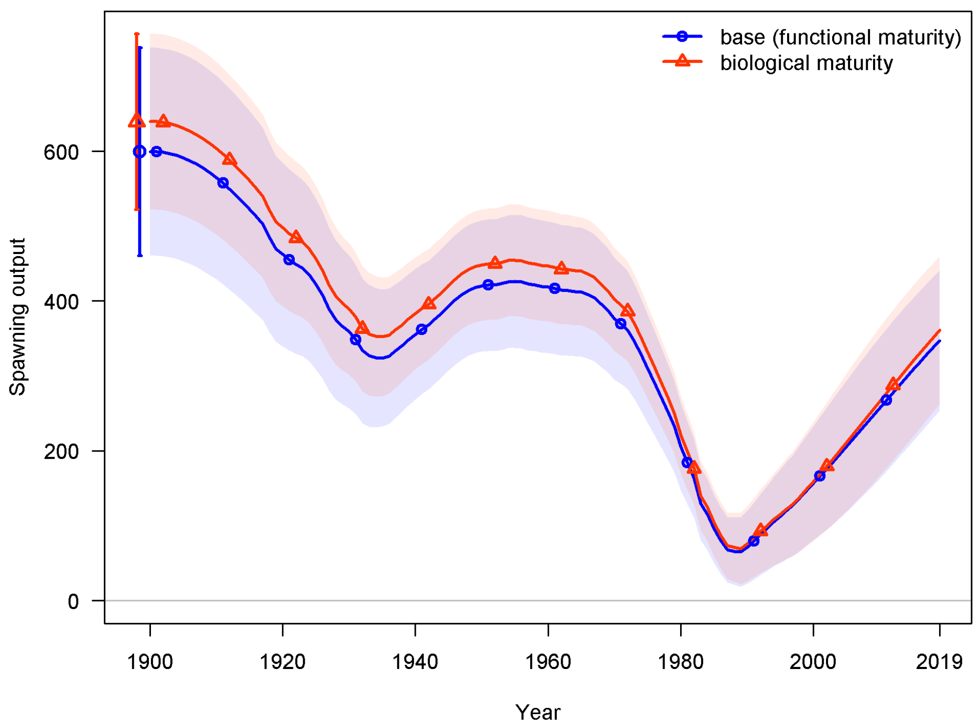


Figure 121: Spawning output trajectories for the base model (functional maturity ogive) and a model using the biological maturity ogive.

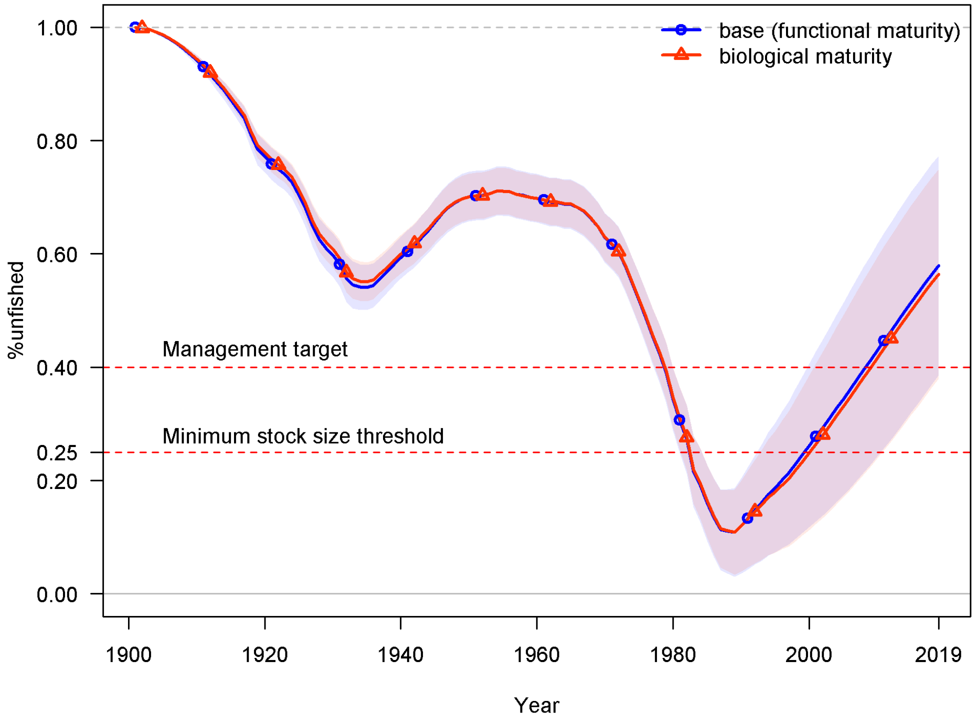


Figure 122: Spawning output relative to unfished spawning output, for the base model (functional maturity ogive) and a model using the biological maturity ogive.

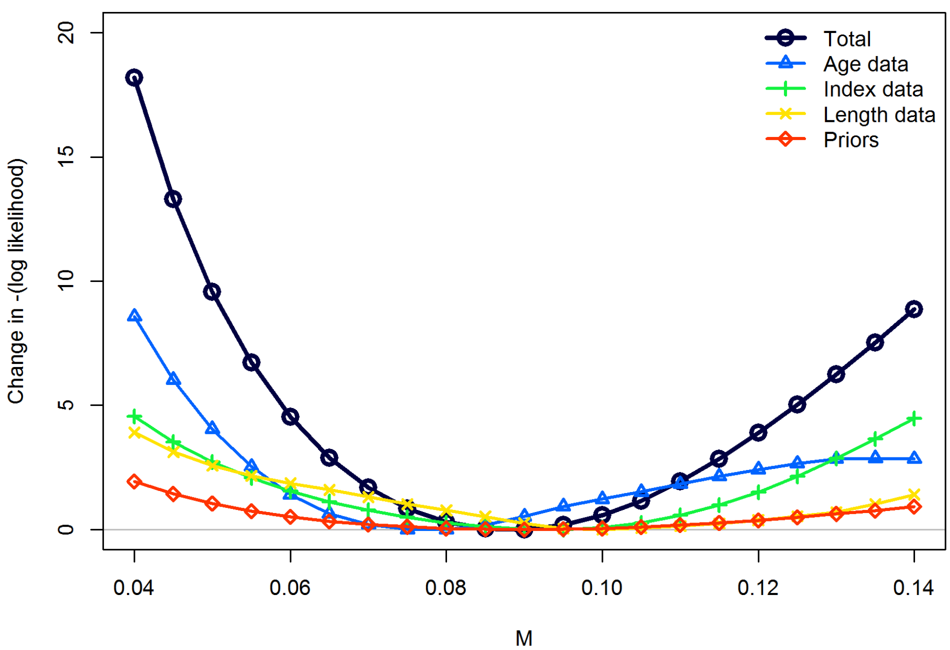


Figure 123: Likelihood profile for natural mortality (M) in the base model.

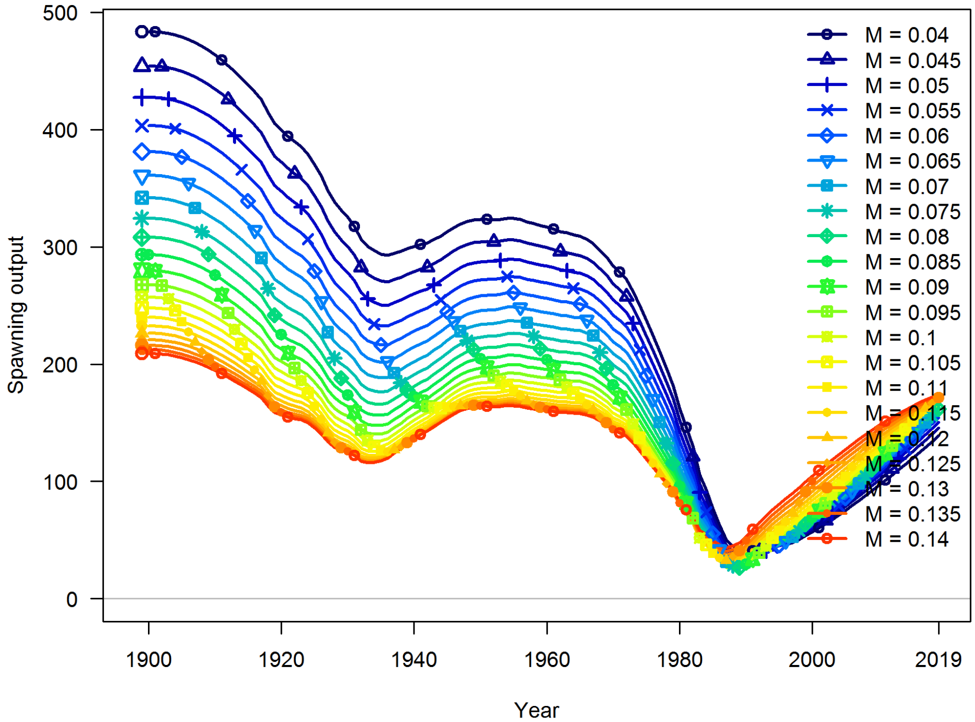


Figure 124: Spawning output trajectories associated with alternative M values.

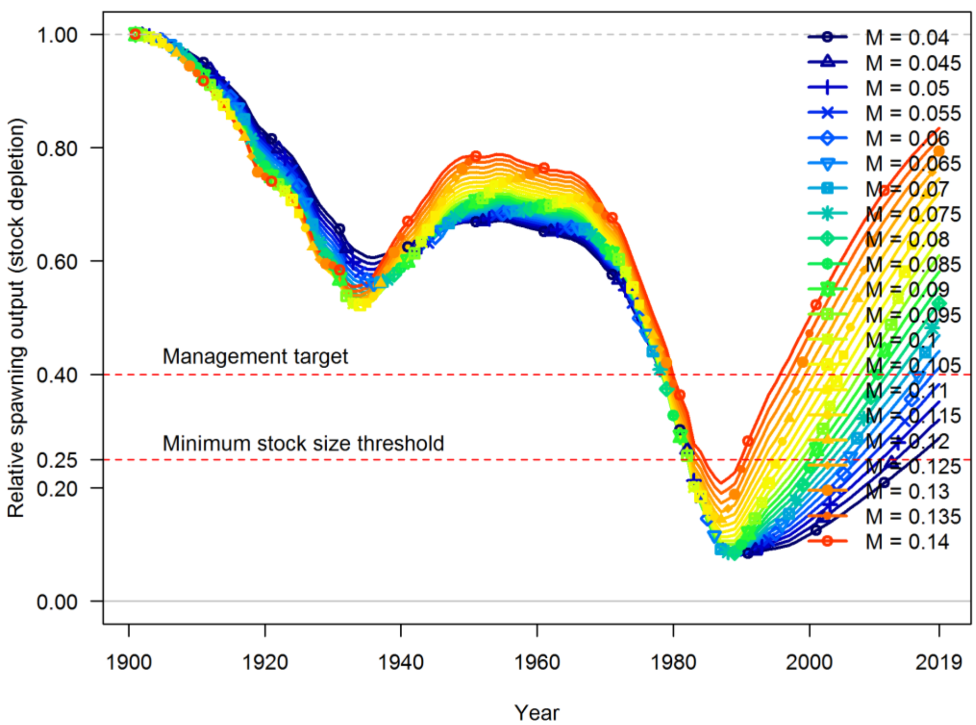


Figure 125: Spawning output relative to unfished spawning output (depletion) as a function of M.

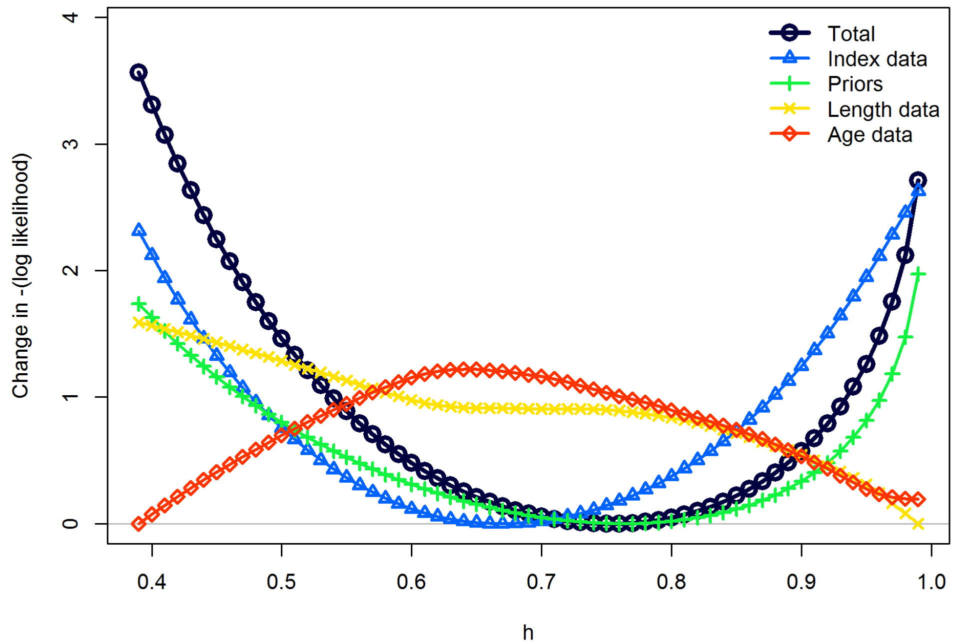


Figure 126: Likelihood profile for Beverton-Holt steepness (h).

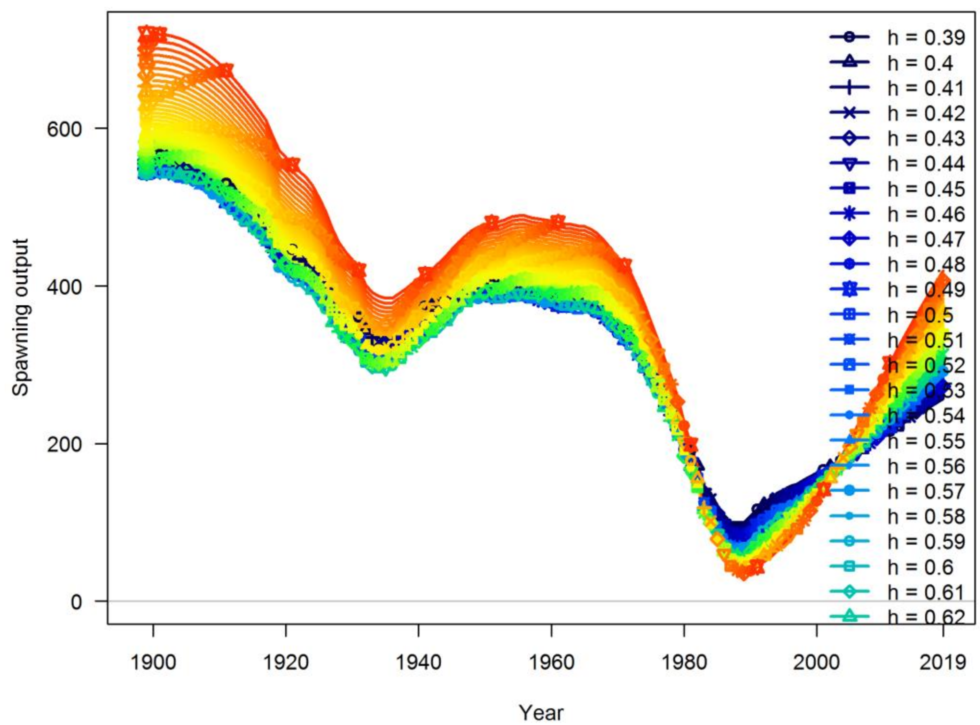


Figure 127: Spawning output trajectories associated with alternative steepness values. Values in the plot are double the true estimates due to the use of a single-sex model.

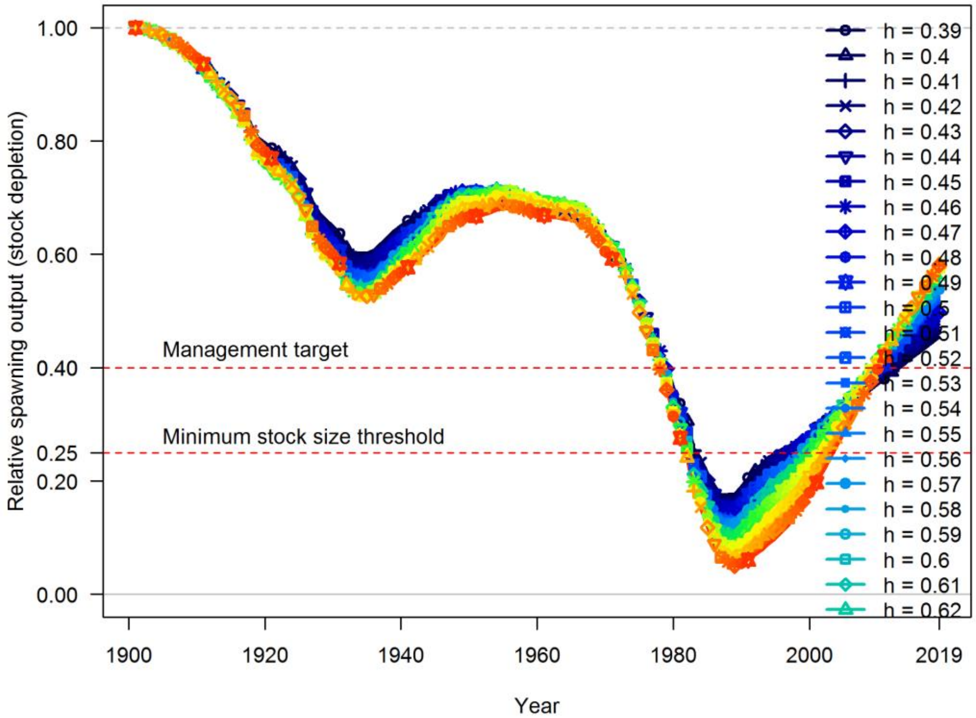


Figure 128: Spawning output relative to unfished spawning output (depletion) as a function of steepness.

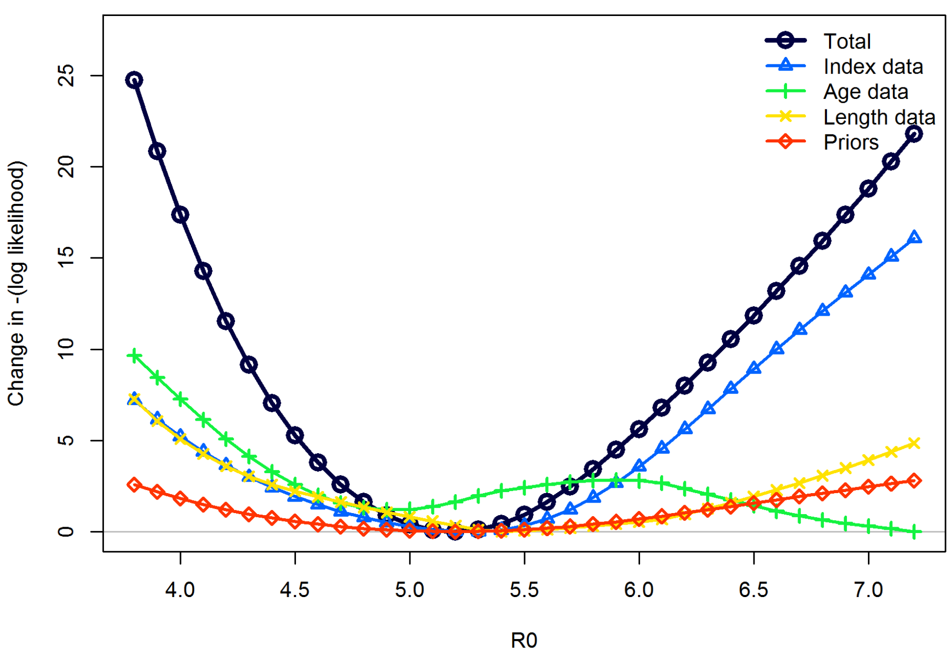


Figure 129: Likelihood profile for the logarithm of equilibrium recruitment (R_0)

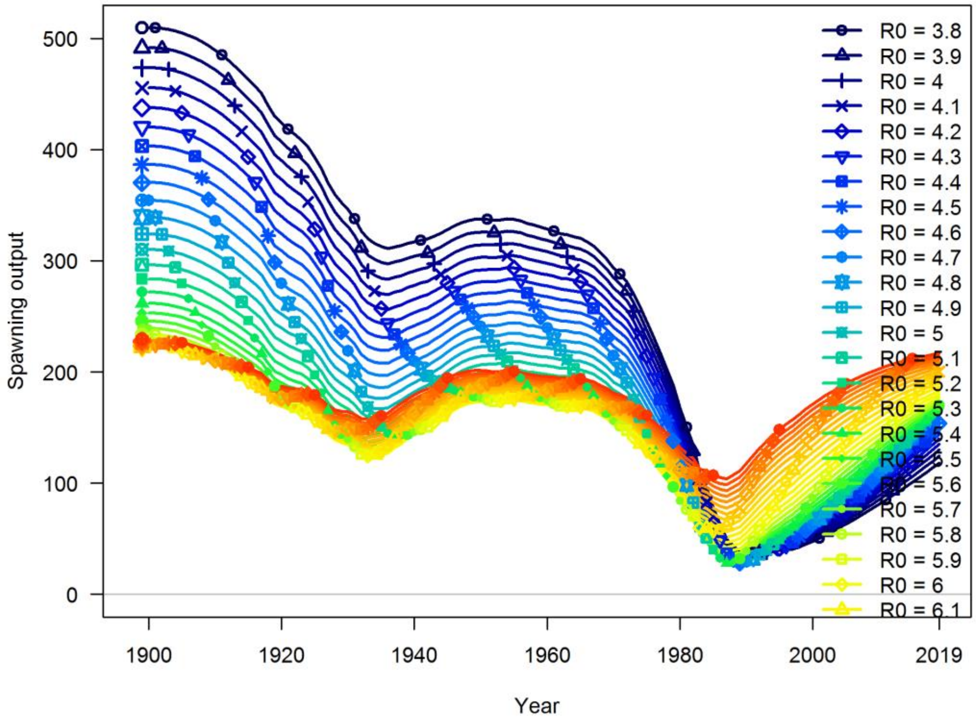


Figure 130: Spawning output trajectories associated with alternative values of equilibrium recruitment (R_0).

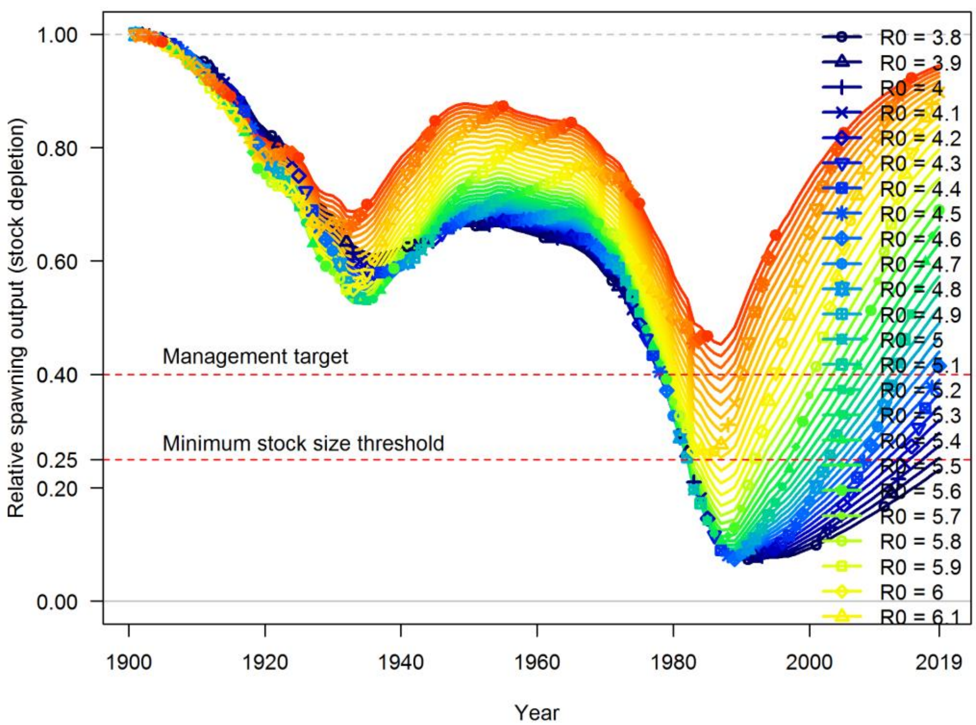


Figure 131: Spawning output relative to unfished spawning output (depletion) as a function of equilibrium recruitment (R_0).

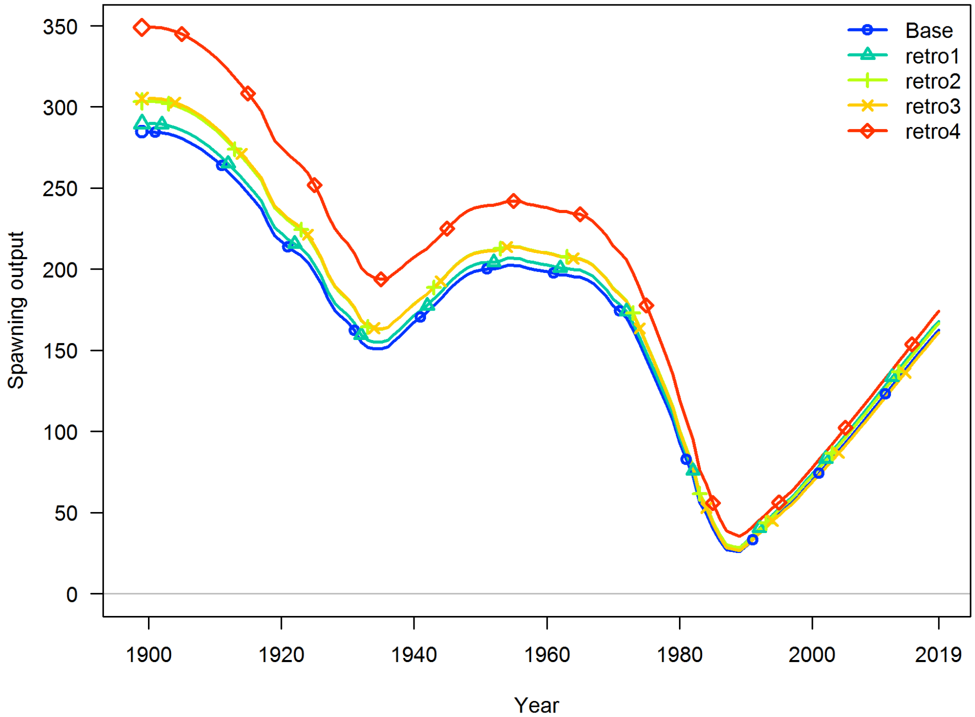


Figure 132: Retrospective plot for the cowcod base model.

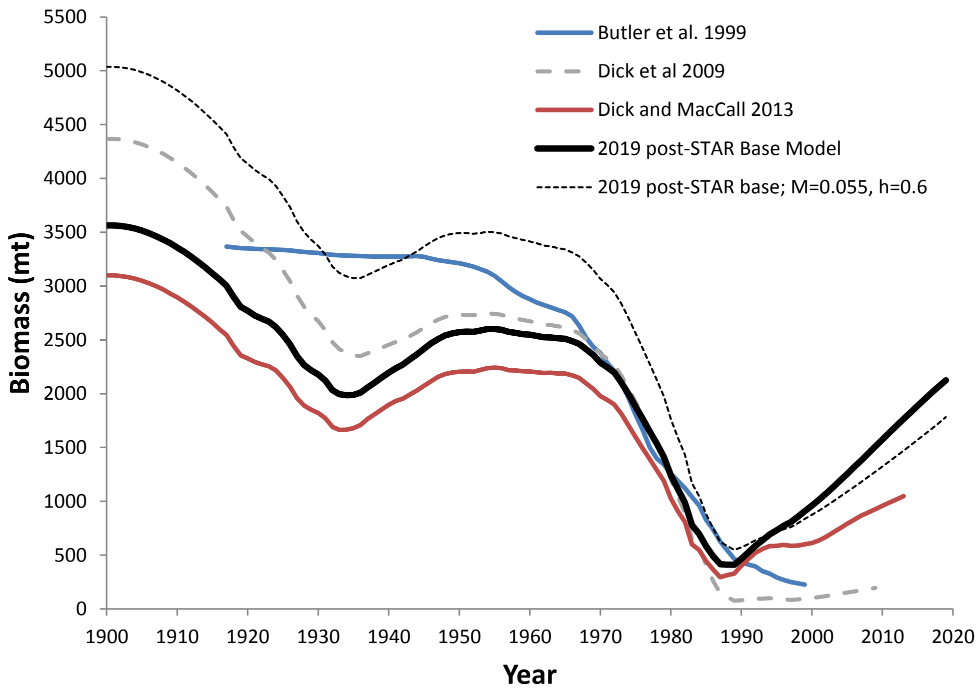


Figure 133: Comparison of biomass trajectories from the 2019 post-STAR base model and previous assessments of cowcod. See text for details.

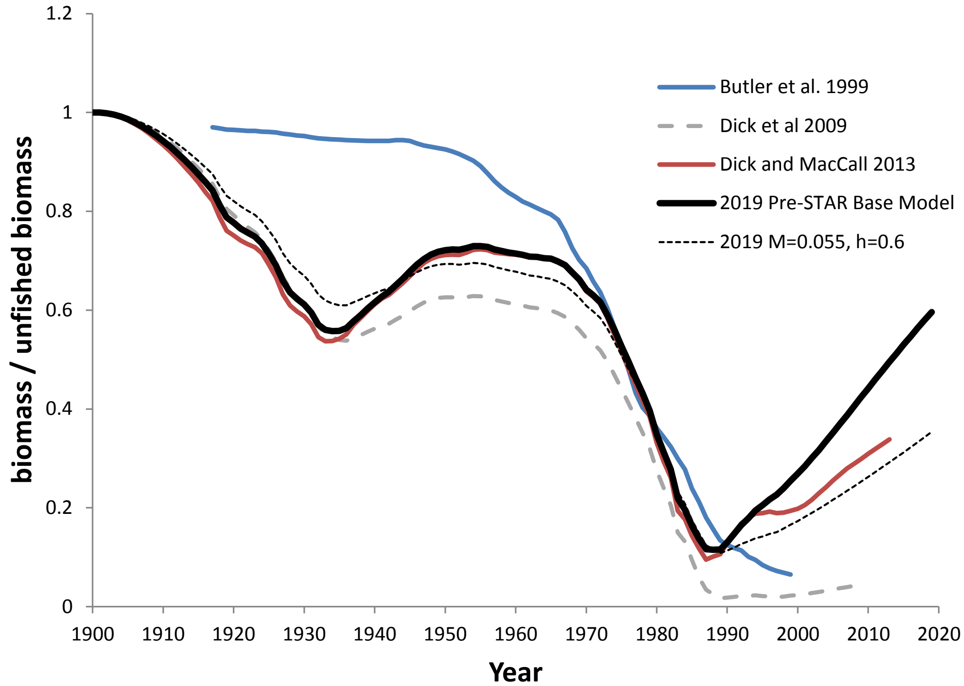


Figure 134: Comparison of relative biomass (B / B_0) trajectories from the 2019 post-STAR base model and previous assessments of cowcod. See text for details.

Appendix A. Federal Commercial Fishery Regulations Related to Cowcod

Regulation date	Area description	Regulation
1/1/2000	3600 4010	Cowcod, limited entry fixed gear, 1 fish per landing
1/1/2000	3600 South	Cowcod,Open Access gear except exempted trawl, closed
1/1/2000	3600 South	Cowcod,limited entry fixed gear, closed
1/1/2000	3600 4010	Cowcod, Open Access gear except exempted trawl, 1 fish per landing
1/1/2000	4010 South	Limited entry trawl, small footrope or midwater trawl only, cowcod, 1 fish per landing
3/1/2000	3600 4010	Cowcod, Open Access gear except exempted trawl, closed
3/1/2000	3600 South	Cowcod,limited entry fixed gear, 1 fish per landing
3/1/2000	3600 South	Cowcod,Open Access gear except exempted trawl, 1 fish per landing
3/1/2000	3600 4010	Cowcod, limited entry fixed gear, closed
5/1/2000	3600 4010	Cowcod, limited entry fixed gear, 1 fish per landing
5/1/2000	3600 South	Cowcod, limited entry fixed gear, 1 fish per landing
5/1/2000	3600 4010	Cowcod rockfish, Open Access gear except exempted trawl, 1 fish per landing
1/1/2001	ALL	cowcod, open access, closed
1/1/2001	ALL	Cowcod, limited entry fixed gear, closed
1/1/2001	ALL	Cowcod, limited entry trawl, small footrope or midwater trawl only, no retention
1/1/2002	ALL	cowcod, open access, closed
1/1/2002	ALL	Cowcod, limited entry fixed gear, closed
1/1/2002	ALL	cowcod, limited entry trawl, midwater or small footrope only, closed
1/1/2003	4010 North	cowcod, open access gears, closed
1/1/2003	4010 North	cowcod, limited entry fixed gear, closed
1/1/2003	4010 South	cowcod, open access gear, closed
1/1/2003	4010 South	cowcod, limited entry fixed gear, closed
1/1/2003	4010 South	cowcod, limited entry trawl, small footrope or midwater trawl only, closed
1/1/2004	4010 South	cowcod, open access gear, closed
1/1/2004	4010 South	cowcod rockfish, limited entry fixed gear, closed
1/1/2004	4010 South	cowcod, limited entry trawl, closed
1/1/2005	4010 South	cowcod, open access gear, closed
1/1/2005	4010 South	cowcod, limited entry trawl, closed
1/1/2005	4010 South	cowcod, limited entry fixed gear, closed
1/1/2005	4010 North	minor shelf rockfish north including shortbelly, widow, yellowtail, chilipepper, bocaccio, and cowcod, limited entry fixed gear, 200 lbs per month
1/1/2005	4010 North	minor shelf rockfish north including shortbelly, widow, yellowtail, bocaccio, chilipepper and cowcod, open access gears, 200 lbs per month
1/1/2005	4010 North	minor shelf rockfish north including shortbelly, widow, bocaccio, chilipepper, cowcod, and yelloweye rockfish, limited entry trawl gear, midwater trawl for widow rockfish, before the primary whiting season - closed; during the primary whiting season , in trips with at least 10000 lbs of whiting - combined widow rockfish and yellowtail rockfish 500 lbs per trip with a cumulative limit of 1500 lbs of widow rockfish per month. Midwater trawl permitted in the RCA. After the primary whiting season - closed
1/1/2005	4010 North	minor shel rockfish north including shortbelly, widow, bocaccio, chilipepper, cowcod, and yelloweye rockfish, limited entry trawl gear, large and small footrope, 300 lbs per 2 months
1/1/2005	4010 North	minor shelf rockfish north including shortbelly, widow, bocaccio, chilipepper, cowcod, and yelloweye rockfish, limited entry trawl gear, selective flatfish gear, 300 lbs per month
1/1/2005	4010 North	minor shelf rockfish north including shortbelly, widow, bocaccio, chilipepper, cowcod, and yelloweye rockfish, limited entry trawl gear, multiple bottom trawl gear, 300 lbs per month
5/1/2005	4010 North	minor shelf rockfish north including shortbelly, widow, bocaccio, chilipepper, cowcod, and yelloweye rockfish, limited entry trawl gear, multiple bottom trawl gear, 300 lbs per 2 months of which no more than 200 lbs per month may be yelloweye rockfish
5/1/2005	4010 North	minor shelf rockfish north including shortbelly, widow, bocaccio, chilipepper, cowcod, and yelloweye rockfish, limited entry trawl gear, selective flatfish gear, 1000 lbs per month no more than 200 lbs per month of which may be yelloweye rockfish
11/1/2005	4010 North	minor shelf rockfish north including shortbelly, widow, bocaccio, chilipepper, cowcod, and yelloweye rockfish, limited entry trawl gear, selective flatfish gear, 300 lbs per month
11/1/2005	4010 North	minor shelf rockfish north including shortbelly, widow, bocaccio, chilipepper, cowcod, and yelloweye rockfish, limited entry trawl gear, multiple bottom trawl gear, 300 lbs per month
1/1/2006	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yellowtail rockfish, open access gear, 200 lbs per month
1/1/2006	4010 North	minor shelf rockfish north including shortbelly, widow, yellowtail, bocaccio, chilipepper, and cowcod, limited entry fixed gear, 200 lbs per month
1/1/2006	4010 North	minor shelf rockfish north including shortbelly, widow rockfish, yelloweye, bocaccio, chilipepper, and cowcod, limited entry trawl, large and small footrope gear, 150 lbs per month
1/1/2006	4010 North	minor shelf rockfish north including shortbelly, widow rockfish, yelloweye, bocaccio, chilipepper, and cowcod, limited entry trawl, selective flatfish trawl gear, 300 lbs per month

1/1/2006	4010 North	minor shelf rockfish north including shortbelly, widow rockfish, yelloweye, bocaccio, chilipepper, and cowcod,limited entry trawl, multiple bottom trawl gear, 300 lbs per month
1/1/2006	4010 South	cowcod, open access gear, closed
1/1/2006	4010 South	cowcod, limited entry fixed gear, closed
1/1/2006	4010 South	cowcod, limited entry trawl, closed
3/1/2006	4010 North	minor shelf rockfish north including shortbelly, widow rockfish, yelloweye, bocaccio, chilipepper, and cowcod, limited entry trawl, large and small footrope gear, 300 lbs per 2 months
5/1/2006	4010 North	minor shelf rockfish north including shortbelly, widow rockfish, yelloweye, bocaccio, chilipepper, and cowcod,limited entry trawl, multiple bottom trawl gear, 300 lbs per 2 months, no more than 200 lbs per 2 months of which may be yelloweye rockfish
5/1/2006	4010 North	minor shelf rockfish north including shortbelly, widow rockfish, yelloweye, bocaccio, chilipepper, and cowcod, limited entry trawl, selective flatfish trawl gear, 1000 lbs per month, no more than 200 lbs per month of which may be yelloweye rockfish
11/1/2006	4010 North	minor shelf rockfish north including shortbelly, widow rockfish, yelloweye, bocaccio, chilipepper, and cowcod, limited entry trawl, selective flatfish trawl gear, 300 lbs per month
11/1/2006	4010 North	minor shelf rockfish north including shortbelly, widow rockfish, yelloweye, bocaccio, chilipepper, and cowcod,limited entry trawl, multiple bottom trawl gear, 300 lbs per month
1/1/2007	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yellowtail, limited entry fixed gear, 200 lbs per month
1/1/2007	4010 South	cowcod, limited entry fixed gear, closed
1/1/2007	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow and yellowtail, open access gears, 200 lbs per month
1/1/2007	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, large and small footrope gear, 300 lbs per 2 months
1/1/2007	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 300 lbs per month
1/1/2007	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month
1/1/2007	4010 South	cowcod, open access gear, closed
1/1/2007	4010 South	cowcod, limited entry trawl, closed
5/1/2007	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month, no more than 200 lbs per month of which may be yelloweye rockfish
5/1/2007	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 1000 lbs per month, no more than 200 lbs per month of which may be yelloweye rockfish
11/1/2007	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 300 lbs per month
11/1/2007	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month
1/1/2008	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, large and small footrope gear, 300 lbs per 2 months
1/1/2008	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 300 lbs per month
1/1/2008	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month
1/1/2008	4010 South	cowcod, open access gear, closed
1/1/2008	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow and yellowtail, open access gears, 200 lbs per month
1/1/2008	4010 South	cowcod, limited entry fixed gear, closed
1/1/2008	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yellowtail, limited entry fixed gear, 200 lbs per month
1/1/2008	4010 South	cowcod, limited entry trawl, closed
5/1/2008	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month, no more than 200 lbs per month of which may be yelloweye rockfish
5/1/2008	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 1000 lbs per month, no more than 200 lbs per month of which may be yelloweye rockfish
11/1/2008	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 300 lbs per month
11/1/2008	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month
1/1/2009	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, large and small footrope gear, 300 lbs per 2 months
1/1/2009	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 300 lbs per month
1/1/2009	4010 South	cowcod, open access gear, closed

1/1/2009	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yellowtail, limited entry fixed gear, 200 lbs per month
1/1/2009	4010 South	cowcod, limited entry fixed gear, closed
1/1/2009	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow and yellowtail, open access gears, 200 lbs per month
1/1/2009	4010 South	cowcod, limited entry trawl, closed
1/1/2009	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month
5/1/2009	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month, no more than 200 lbs per month of which may be yelloweye rockfish
5/1/2009	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod,shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 1000 lbs per month, no more than 200 lbs per month of which may be yelloweye rockfish
11/1/2009	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 300 lbs per month
11/1/2009	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month
1/1/2010	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, large and small footrope gear, 300 lbs per 2 months
1/1/2010	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 300 lbs per month
1/1/2010	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month
1/1/2010	4010 South	cowcod, limited entry trawl, closed
1/1/2010	4010 South	cowcod, open access gear, closed
1/1/2010	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow and yellowtail, open access gears, 200 lbs per month
1/1/2010	4010 South	cowcod, limited entry fixed gear, closed
1/1/2010	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yellowtail, limited entry fixed gear, 200 lbs per month
5/1/2010	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month, no more than 200 lbs per month of which may be yelloweye rockfish
5/1/2010	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod,shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 1000 lbs per month, no more than 200 lbs per month of which may be yelloweye rockfish
11/1/2010	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, selective flatfish trawl, 300 lbs per month
11/1/2010	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yelloweye, limited entry trawl, multiple bottom trawl gear, 300 lbs per month
1/1/2011	ALL	cowcod managed in part by IFQ
1/1/2011	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yellowtail, limited entry fixed gear, 200 lbs per month
1/1/2011	4010 South	cowcod, limited entry fixed gear, closed
1/1/2011	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow and yellowtail, open access gears, 200 lbs per month
1/1/2011	4010 South	cowcod, open access gear, closed
1/1/2012	4010 South	cowcod, open access gear, closed
1/1/2012	4010 South	cowcod, limited entry fixed gear, closed
1/1/2012	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yellowtail, limited entry fixed gear, 200 lbs per month
1/1/2012	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow and yellowtail, open access gears, 200 lbs per month
1/1/2013	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow and yellowtail, open access gears, 200 lbs per month
1/1/2013	4010 North	minor shelf rockfish north including bocaccio, chilipepper, cowcod, shortbelly, widow, and yellowtail, limited entry fixed gear, 200 lbs per month
1/1/2013	4010 South	cowcod, limited entry fixed gear, closed
1/1/2013	4010 South	cowcod, open access gear, closed
1/1/2014	4010 North	non-trawl, limited entry, minor shelf rockfish including shortbelly, widow, and yellowtail rockfish, bocaccio, chilipepper, and cowcod, 200 lbs per month
1/1/2014	4010 South	non-trawl, limited entry, cowcod, Closed
1/1/2014	4010 North	non-trawl, open access, minor shelf rockfish including shortbelly, widow, yellowtail, bocaccio, chilipepper rockfish, and cowcod, 200 lbs per month
1/1/2014	4010 South	non-trawl, open access, cowcod, closed
1/1/2015	4010 North	non-trawl, limited entry, minor shelf rockfish including shortbelly, widow, and yellowtail rockfish, bocaccio, chilipepper, and cowcod, 200 lbs per month

1/1/2015	4010 South	non-trawl, limited entry, cowcod, Closed
1/1/2015	4010 North	non-trawl, open access, minor shelf rockfish including shortbelly, widow, yellowtail, bocaccio, chilipepper rockfish, and cowcod, 200 lbs per month
1/1/2015	4010 South	non-trawl, open access, cowcod, closed
1/1/2016	4010 North	non-trawl, limited entry, minor shelf rockfish including shortbelly, widow, and yellowtail rockfish, bocaccio, chilipepper, and cowcod, 200 lbs per month
1/1/2016	4010 South	non-trawl, limited entry, cowcod, Closed
1/1/2016	4010 North	non-trawl, open access, minor shelf rockfish including shortbelly, widow, yellowtail, bocaccio, chilipepper rockfish, and cowcod, 200 lbs per month
1/1/2016	4010 South	non-trawl, open access, cowcod, closed
1/1/2017	4010 North	non-trawl, limited entry, minor shelf rockfish including shortbelly, widow, and yellowtail rockfish, bocaccio, chilipepper, and cowcod, 200 lbs per month
1/1/2017	4010 South	non-trawl, limited entry, cowcod, Closed
1/1/2017	4010 North	non-trawl, open access, minor shelf rockfish including shortbelly, widow, yellowtail, bocaccio, chilipepper rockfish, and cowcod, 200 lbs per month
1/1/2017	4010 South	non-trawl, open access, cowcod, closed
1/1/2018	4010 North	non-trawl, limited entry, minor shelf rockfish including shortbelly, widow, and yellowtail rockfish, bocaccio, chilipepper, and cowcod, 200 lbs per month
1/1/2018	4010 South	non-trawl, limited entry, cowcod, Closed
1/1/2018	4010 North	non-trawl, open access, minor shelf rockfish including shortbelly, widow, yellowtail, bocaccio, chilipepper rockfish, and cowcod, 200 lbs per month
1/1/2018	4010 South	non-trawl, open access, cowcod, closed
1/1/2019	4010 North	non-trawl, limited entry, minor shelf rockfish including shortbelly, widow, and yellowtail rockfish, bocaccio, chilipepper, and cowcod, 200 lbs per month
1/1/2019	4010 South	non-trawl, limited entry, cowcod, Closed
1/1/2019	4010 North	non-trawl, open access, minor shelf rockfish including shortbelly, widow, yellowtail, bocaccio, chilipepper rockfish, and cowcod, 200 lbs per month
1/1/2019	4010 South	non-trawl, open access, cowcod, closed

Appendix B. Catch-based estimates of sustainable yield for cowcod (*Sebastes levis*) in U.S. waters north of 34° 27′ N. latitude (Point Conception).

Background

Cowcod (*Sebastes levis*) is managed as a single stock in U.S. waters extending from the U.S.-Mexico border to just north of Cape Mendocino (40° 10′ N. latitude). It was declared overfished in 2000 following the first assessment of the stock in U.S. waters south of Point Conception, roughly 34° 27′ N. latitude (Butler et al. 1999). The most recent benchmark or "full" assessment (Dick and He, 2019) of the substock in the Southern California Bight (SCB) indicated that spawning output of cowcod in the SCB was 57% of its unfished level in 2019 (36% - 76% based on low and high states of nature in the decision table).

The procedure for calculating the cowcod overfishing limit (OFL) was revised for the 2011-2012 management cycle. The Council's Scientific and Statistical Committee (SSC) classified the stock assessment for cowcod in the SCB as a Category 2 (data-moderate) assessment. The OFL contribution from the substock between Point Conception to Cape Mendocino was estimated using a Category 3 (data-poor) method, Depletion-Based Stock Reduction Analysis (DB-SRA, Dick and MacCall, 2011). The OFL for the combined stock south of 40° 10′ N. latitude is currently the sum of the OFLs from these two models. To account for scientific uncertainty, the Acceptable Biological Catch (ABC) in each region was derived from the Council's ABC control rule. The annual catch limit (ACL) calculation followed the convention from previous management cycles, and was set equal to twice the ACL associated with the SCB substock.

Updated DB-SRA model for cowcod north of Point Conception

Following the procedure used in previous management cycles, a DB-SRA model was used to estimate the 2021-2022 OFL contributions for the cowcod substock north of Point Conception. An estimate of sustainable yield based on Depletion-Corrected Average Catch (DCAC; MacCall, 2009) is provided for comparison. The DCAC estimate is based on landings from 1950-1999, the period of significant removals, and assumes that the change is stock status over this period equals depletion of the SCB substock as of 2000, as estimated by the XDB-SRA model.

The 2019 cowcod assessment used Stock Synthesis, which is not parameterized in the same way as DB-SRA. Spawning output relative to unfished in 2000 was 24.5%, which was used to define the mean of the 'delta' prior in DB-SRA (1-0.245 = 0.755). Other parameters in DB-SRA were set equal to values used for data-poor (tier 3) stocks and described in Dick and MacCall (2010). No other information regarding stock status or trends in biomass is currently available for the northern cowcod substock.

Catch estimates for U.S. waters north of Point Conception (Table F1 and Figure F1) were compiled from California's commercial landings database (CALCOM), a reconstruction of commercial and recreational landings in California (Ralston et al., 2010), a database of removals by foreign fleets (Rogers et al., 1996), a reconstruction of commercial landings in Oregon (Gertseva et al., pers. comm.), and the RecFIN website (www.recfin.org). Since recent trawl mortality is almost exclusively north of Point Conception, total mortality from the GEMM Report trawl sector used as a proxy for commercial mortality since 2002. California recreational landings (MRFSS) from 1987 and 1990-1992 were estimated using linear interpolation due to missing values or database errors. Recreational catch is assumed equal 0.6 mt in 2019 and after, and assumed commercial catch increases from 1.2 mt in 2019 to 1.9 mt in subsequent years.

Since cowcod is managed as part of the shelf rockfish complex north of Cape Mendocino, an estimate of cumulative landings from sources north and south of Cape Mendocino was calculated for purposes of allocating the northern substock OFL to management areas north/south of Cape Mendocino.

Results and Discussion

Since historical removals north of Point Conception were less than removals in the SCB, the DB-SRA model produces biomass estimates for the northern substock that are lower than the assessed region (Figure F2). This suggests that the convention of doubling the ACL from the SCB assessment may result in harvest rates for the coastwide stock that exceed the target rate, particularly in the northern region. The current harvest levels are conducive to rapid stock recovery, but this analysis shows that region-specific harvest levels should be considered for a rebuilt stock.

The DB-SRA model assumes that status (depletion) of the northern substock in 2000 is identical for both regions, but results in a slightly more depleted northern stock in 2019 (Figure F3). This is due to differences in the catch time series between regions. The DB-SRA estimate of median OFL for 2021 is very similar to the median DCAC estimate (Table F2), although the distributions of yield differ in variability and skewness (Figure F4).

Cowcod are more abundant in the south, with a significant (but unknown) portion of the stock extending into Mexico. Cumulative landings suggest that only 3% of cowcod removals north of Point Conception occur north of Cape Mendocino (Table F3).

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TABLES AND FIGURES

Table F1. Reconstructed catches of cowcod north of Point Conception, 1916-2018, by year and source.

Year	CALCOM	CA Comm. Recon.	Foreign Fleets	OR Comm.	WCGOP Comm.	CA MRFSS	CRFS	CA Rec. Recon.	Total
1916		1.43							1.43
1917		2.30							2.30
1918		2.14							2.14
1919		1.30							1.30
1920		1.40							1.40
1921		1.22							1.22
1922		1.18							1.18
1923		1.56							1.56
1924		2.02							2.02
1925		2.21							2.21
1926		2.80							2.80
1927		2.35							2.35
1928		1.98						0.03	2.02
1929		2.05						0.06	2.11
1930		2.49						0.07	2.57
1931		0.52						0.10	0.62
1932		4.09						0.12	4.22
1933		0.29						0.15	0.44
1934		0.56						0.17	0.73
1935		0.98						0.19	1.17
1936		0.72						0.22	0.94
1937		2.60						0.26	2.86
1938		1.99						0.26	2.25
1939		1.55						0.22	1.77
1940		2.67						0.32	3.00
1941		3.27						0.30	3.57
1942		0.24						0.16	0.40
1943		1.15						0.15	1.30
1944		0.95						0.12	1.08
1945		2.26						0.17	2.42
1946		1.99						0.28	2.27
1947		0.62						0.23	0.84
1948		1.21						0.45	1.66
1949		1.46						0.58	2.04
1950		4.45						0.71	5.16
1951		14.83						0.82	15.65
1952		8.26						0.72	8.98
1953		6.32						0.61	6.93
1954		10.67						0.76	11.43
1955		30.76						0.90	31.67
1956		18.16						1.01	19.17
1957		19.26						1.06	20.32
1958		17.60						1.53	19.13
1959		6.78						1.36	8.15
1960		5.50						1.03	6.54
1961		2.02						0.77	2.78
1962		2.91						0.94	3.85
1963		6.32						0.92	7.24

Table F1. (Continued) Reconstructed catches of cowcod north of Point Conception, 1916-2018.

Year	CALCOM	CA Comm. Recon.	Foreign Fleets	OR Comm.	WCGOP Comm.	CA MRFSS	CRFS	CA Rec. Recon.	Total
1964		9.05						0.82	9.87
1965		1.45						1.20	2.66
1966		2.34	6.00					1.37	9.71
1967		1.50	18.00					1.42	20.92
1968		1.33	5.00					1.49	7.82
1969	4.23		0.00					1.55	5.78
1970	8.28		0.00					1.96	10.25
1971	9.49		0.00					1.70	11.19
1972	10.76		0.00					2.08	12.84
1973	15.25		6.00					2.87	24.12
1974	18.51		17.00					2.80	38.31
1975	16.03		4.00					3.00	23.03
1976	20.06		3.00					3.14	26.20
1977	17.90							2.80	20.70
1978	24.83							2.55	27.38
1979	32.12							3.08	35.20
1980	51.86							3.08	54.95
1981	25.53					7.05			32.58
1982	27.40					5.58			32.99
1983	20.13					5.30			25.43
1984	45.16					2.21			47.37
1985	13.87					0.22			14.09
1986	13.93					2.32			16.25
1987	10.03					5.68			15.71
1988	12.14			0.15		9.05			21.34
1989	21.54			4.63		10.87			37.04
1990	24.12					9.16			33.28
1991	19.63			0.23		7.44			27.30
1992	42.50					5.73			48.22
1993	32.16			0.17		4.02			36.35
1994	22.31			0.34		0.89			23.54
1995	43.37			1.29					44.66
1996	24.44			1.66		0.29			26.39
1997	46.23			3.30		0.63			50.17
1998	15.99			2.54					18.53
1999	6.93			2.27		1.80			11.00
2000	0.94			0.04		1.73			2.71
2001	0.80			0.13					0.93
2002				0.06	2.66	0.09			2.81
2003					0.18				0.18
2004					0.74				0.74
2005					0.57		0.05		0.62
2006					0.86		0.12		0.98
2007					1.03		0.31		1.33
2008					0.17		0.2		0.39
2009					0.42		0.12		0.54
2010					0.26		0.03		0.29
2011					0.02		0.07		0.09
2012					0.10		0.01		0.12

Table F1. (Continued) Reconstructed catches of cowcod north of Point Conception, 1916-2018.

Year	**CALCOM**	**CA Comm. Recon.**	**Foreign Fleets**	**OR Comm.**	**WCGOP Comm.**	**CA MRFSS**	**CRFS**	**CA Rec. Recon.**	**Total**
2013					0.20		0.01		0.22
2014					0.19		0.03		0.22
2015					0.43		0.02		0.45
2016					0.30		0.02		0.32
2017					0.58		0.30		0.88
2018					0.60		0.43		1.03

Table F2. Percentiles of DCAC and DB-SRA yield estimates for cowcod north of Point Conception.

		DB-SRA	
Percentile	DCAC	OFL 2021	OFL 2022
2.5%	8.8	7.2	7.4
25%	11.9	13.9	14.2
50% (median)	**13.5**	**18.9**	**19.2**
75%	15.0	24.8	25.2
97.5%	17.3	39.0	39.4

Table F3. Cumulative and percent cowcod catch by source and management area (Point Conception to Cape Mendocino (40-10) and north of Cape Mendocino.

Source	Pt. Conc. to 40-10	North of 40-10
CALCOM	688.83	9.74
CA Comm. Recon.	215.85	11.22
Foreign Fleets	59.00	
OR Comm.		16.80
CA Rec (combined)	134.86	
WCGOP	8.99	
TOTAL (mt)	1107.53	37.76
TOTAL (%)	97%	3%

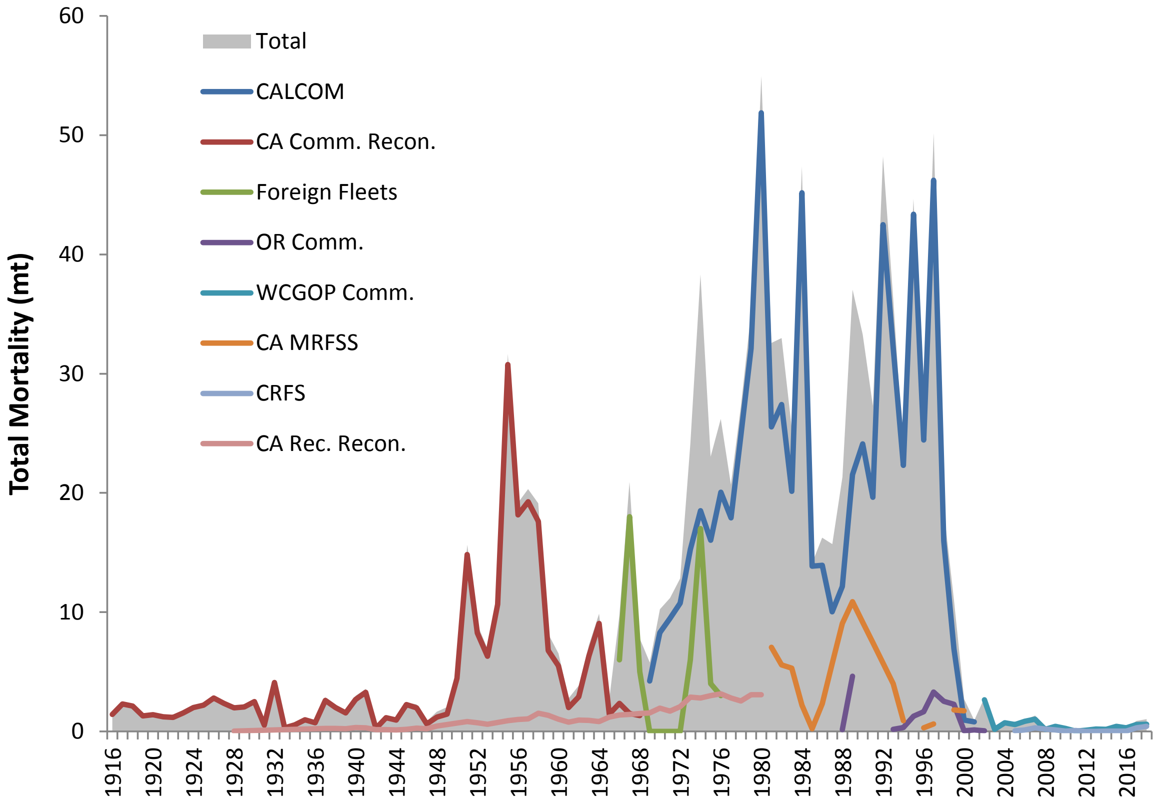

Figure F1. Reconstructed catches of cowcod north of Point Conception, 1916-2018, by year and source.

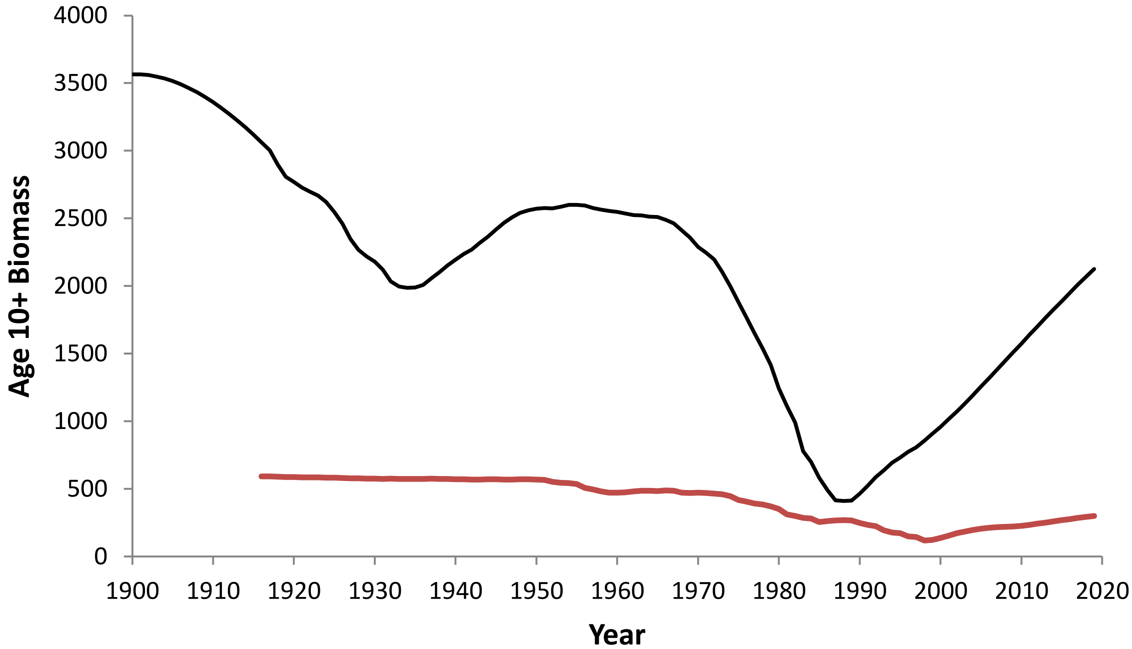

Figure F2. Cowcod age 10+ biomass from the 2019 Stock Synthesis base model for the SCB (black) and the northern DB-SRA model (red).

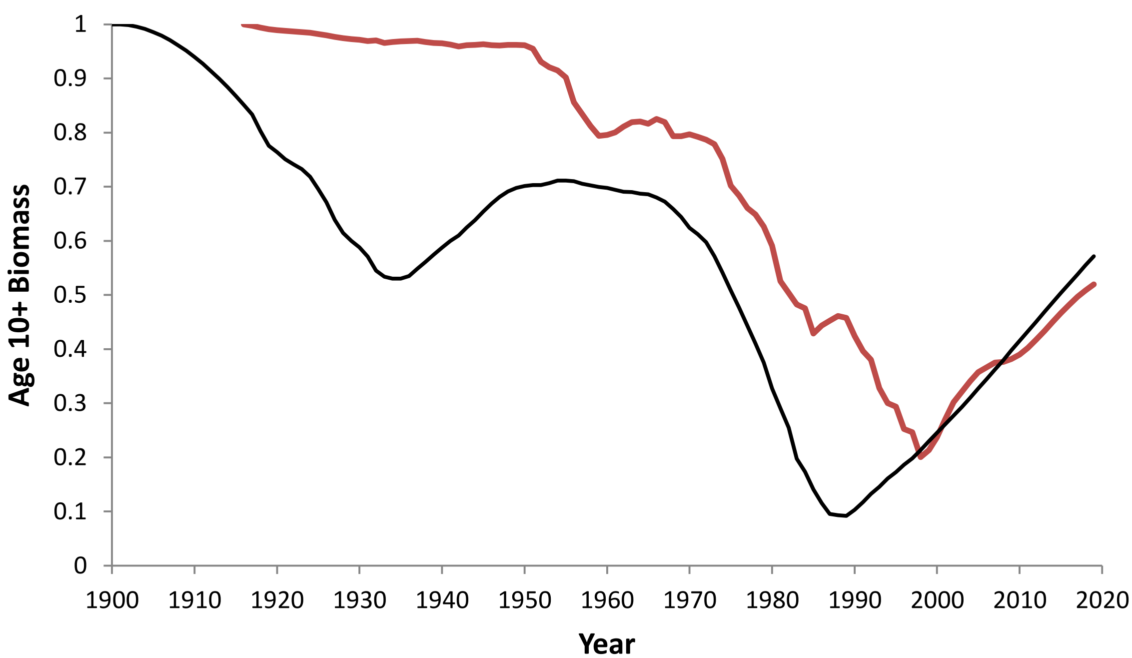

Figure F3. Comparison of depletion percentiles from the southern California assessment (black) and northern DB-SRA (red) cowcod models. Depletion in 2000 is assumed to be equal (24.5% of unfished) for the two areas.

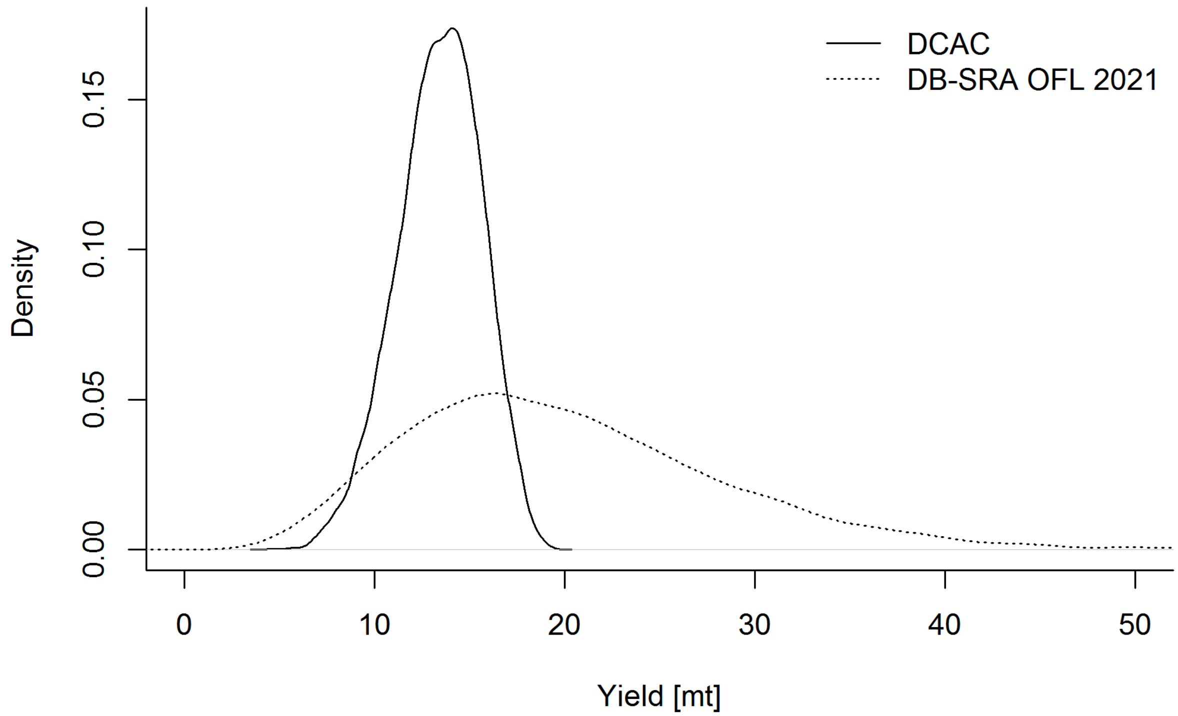

Figure F4. Estimated yield distributions (mt) for cowcod north of Point Conception. The DCAC estimate is based on removals from 1950-1999. The 2021 OFL estimate from DB-SRA assumes the stock was depleted to 24.5% of unfished biomass in 2000, recreational removals of 0.6 mt per year from 2019-2020, and commercial removals of 1.2 mt in 2019 and 1.9 mt in 2020.

Appendix C. Decision Tables with P* = 0.4 and P* = 0.3.

Table C1: Decision table summarizing 12-year projections (2019 – 2030) for cowcod according to three alternative states of nature varying natural mortality and commercial fishery selectivity (length at 50% selectivity). Columns range over low, medium, and high state of nature, and rows range over different assumptions of total catch levels corresponding to the default harvest control rule catches from each state of nature **with P*=0.4**. Catches in 2019 and 2020 were proposed by the GMT representative. Catch is in mt, spawning output is in billions of eggs, and depletion is the percentage of spawning output relative to unfished spawning output. Outcomes below target spawning output (40% of unfished spawning output) are shaded in gray.

			State of nature					
			Low		Base case		High	
			M=0.055, $L_{50\%}$=35 cm		M=0.088, $L_{50\%}$=45.6 cm		M=0.098, $L_{50\%}$=55cm	
Management decision	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	39.8	330	38.1%	343	60.3%	434	77.8%
	2022	39.6	336	38.7%	346	60.9%	435	78.0%
Low	2023	39.5	341	39.3%	350	61.4%	435	78.0%
Catch	2024	39.3	346	39.9%	352	61.9%	436	78.1%
	2025	38.9	351	40.5%	355	62.4%	436	78.1%
	2026	38.6	356	41.1%	357	62.8%	435	78.0%
	2027	38.2	361	41.6%	359	63.2%	435	78.0%
	2028	37.8	366	42.1%	361	63.5%	435	77.9%
	2029	37.4	370	42.7%	363	63.9%	434	77.9%
	2030	37.1	375	43.2%	365	64.2%	434	77.8%
	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	72.4	330	38.1%	343	60.3%	434	77.8%
	2022	70.5	331	38.2%	342	60.0%	430	77.1%
Base	2023	68.7	331	38.2%	340	59.8%	426	76.4%
Catch	2024	67.1	331	38.2%	339	59.5%	422	75.7%
	2025	65.5	331	38.2%	337	59.3%	418	75.0%
	2026	64.0	330	38.1%	336	59.0%	414	74.3%
	2027	62.6	330	38.0%	335	58.9%	411	73.6%
	2028	61.3	329	37.9%	334	58.7%	407	73.0%
	2029	60.0	328	37.8%	333	58.6%	404	72.3%
	2030	58.8	327	37.7%	333	58.5%	400	71.8%
	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	111.6	330	38.1%	343	60.3%	434	77.8%
	2022	106.9	325	37.5%	336	59.1%	424	76.0%
High	2023	102.6	319	36.8%	330	57.9%	415	74.4%
Catch	2024	98.6	314	36.2%	323	56.8%	406	72.8%
	2025	95.0	308	35.5%	317	55.7%	399	71.4%
	2026	91.6	301	34.8%	311	54.6%	392	70.2%
	2027	88.5	295	34.1%	305	53.6%	385	69.0%
	2028	85.6	289	33.4%	300	52.6%	379	68.0%
	2029	82.8	283	32.7%	295	51.8%	374	67.1%
	2030	80.4	278	32.0%	290	51.0%	370	66.4%

Table C2: Decision table summarizing 12-year projections (2019 – 2030) for cowcod according to three alternative states of nature varying natural mortality and commercial fishery selectivity (length at 50% selectivity). Columns range over low, medium, and high state of nature, and rows range over different assumptions of total catch levels corresponding to the default harvest control rule catches from each state of nature **with P*=0.3**. Catches in 2019 and 2020 were proposed by the GMT representative. Catch is in mt, spawning output is in billions of eggs, and depletion is the percentage of spawning output relative to unfished spawning output. Outcomes below target spawning output (40% of unfished spawning output) are shaded in gray.

			State of nature					
			Low		Base case		High	
			M=0.055, $L_{50\%}$=35 cm		M=0.088, $L_{50\%}$=45.6 cm		M=0.098, $L_{50\%}$=55cm	
Management decision	Year	Catch	Spawning Output	Depletion	Spawning Output	Depletion	Spawning Output	Depletion
Low Catch	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	29.7	330	38.1%	343	60.3%	434	77.8%
	2022	29.2	337	38.9%	348	61.1%	436	78.2%
	2023	28.7	344	39.7%	353	61.9%	438	78.6%
	2024	28.1	351	40.5%	357	62.7%	440	78.9%
	2025	27.3	358	41.3%	361	63.5%	442	79.2%
	2026	26.6	365	42.1%	365	64.2%	443	79.4%
	2027	26.0	372	42.9%	369	64.9%	444	79.7%
	2028	25.3	379	43.7%	373	65.5%	446	79.9%
	2029	24.7	386	44.5%	377	66.2%	447	80.1%
	2030	24.1	392	45.3%	381	66.9%	448	80.4%
Base Catch	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	54.0	330	38.1%	343	60.3%	434	77.8%
	2022	52.0	334	38.5%	344	60.5%	433	77.6%
	2023	50.1	337	38.9%	345	60.7%	432	77.4%
	2024	48.3	340	39.2%	347	60.9%	430	77.1%
	2025	46.5	343	39.6%	348	61.2%	429	76.9%
	2026	44.8	346	39.9%	350	61.4%	428	76.7%
	2027	43.2	349	40.2%	351	61.7%	427	76.5%
	2028	41.7	352	40.6%	353	62.0%	426	76.3%
	2029	40.3	355	40.9%	355	62.4%	425	76.1%
	2030	38.9	358	41.3%	357	62.8%	424	76.0%
High Catch	2019	3.1	308	35.5%	325	57.1%	422	75.6%
	2020	3.1	319	36.8%	334	58.7%	428	76.7%
	2021	83.3	330	38.1%	343	60.3%	434	77.8%
	2022	79.0	329	38.0%	340	59.8%	428	76.8%
	2023	75.1	328	37.8%	338	59.3%	423	75.8%
	2024	71.4	327	37.7%	335	58.9%	418	75.0%
	2025	67.9	326	37.6%	333	58.5%	414	74.3%
	2026	64.7	325	37.4%	331	58.1%	411	73.6%
	2027	61.8	324	37.3%	329	57.8%	408	73.1%
	2028	59.1	323	37.2%	328	57.6%	405	72.7%
	2029	56.5	322	37.1%	327	57.4%	403	72.3%
	2030	54.1	322	37.1%	326	57.3%	402	72.1%