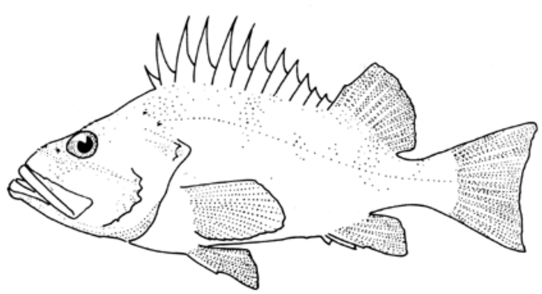
Status and Productivity of Cowcod, *Sebastes levis*, in the Southern California Bight, 2013

by

E.J. Dick and Alec D. MacCall



Fisheries Ecology Division
Southwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
110 Shaffer Road
Santa Cruz, California 95060

August 20, 2014

Table of Contents

Executive Summary

Stock

This is an assessment of *Sebastes levis* ("cowcod" rockfish) 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. Hess et al. (2014) recently 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 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. 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 a 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 1969. Commercial catches since 1969 and recreational catches since 1981 were updated with the latest available estimates, resulting in only minor changes since the last assessment. Estimates of annual removals for cowcod over the last ten years have not exceeded 1 mt (Table a).

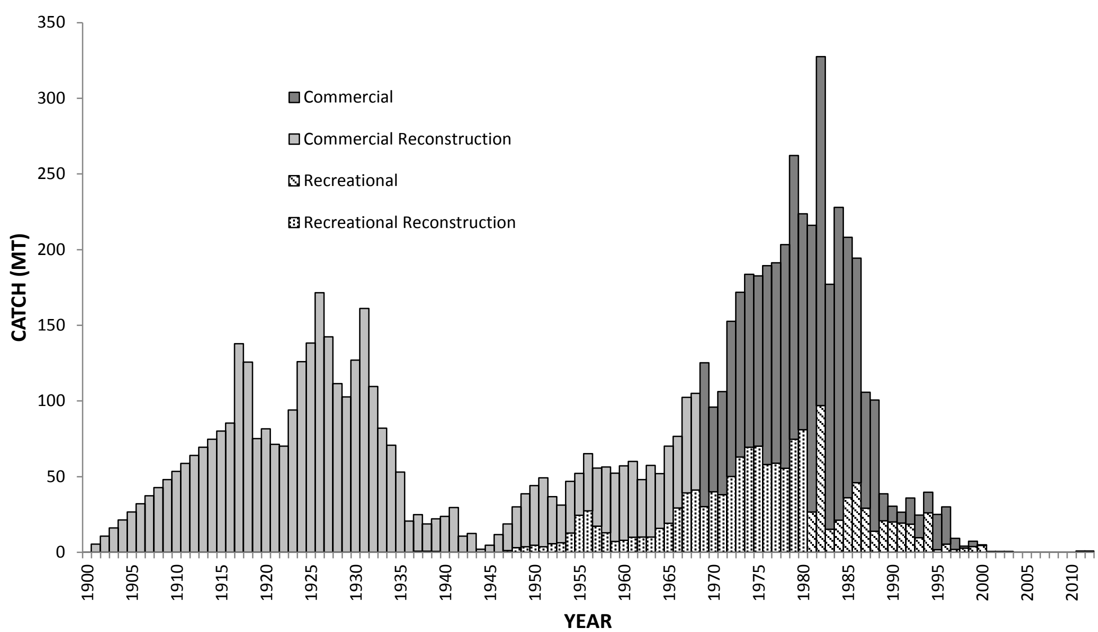


Figure a. Estimated commercial and recreational removals of cowcod in the Southern California Bight, 1900-2012.

Table a: Recent cowcod removals (mt).

Year	Recreational	Commercial	Total
2003	0.48	0.00	0.48
2004	0.45	0.41	0.86
2005	0.15	0.00	0.15
2006	0.07	0.00	0.07
2007	0.11	0.10	0.21
2008	0.25	0.00	0.25
2009	0.21	0.00	0.21
2010	0.17	0.00	0.17
2011	0.83	0.00	0.83
2012	0.82	0.00	0.82

Data and assessment

This assessment uses Extended Depletion-Based Stock Reduction Analysis (XDB-SRA) to estimate stock status, scale, and productivity. The population dynamics are approximated by a biomass dynamic equation with lagged recruitment. The model incorporates a flexible production function, and all model parameters are estimated in a fully Bayesian framework, unlike previous assessments, where important parameters were assigned fixed values. XDB-SRA input data are restricted to abundance indices. Length and age composition data are summarized in this document, but were not included in the assessment due to poor temporal coverage and small sample sizes.

The base model is fit to five fishery-independent data sources: four time series of relative abundance (CalCOFI larval abundance survey, Sanitation District trawl surveys, NWFSC trawl survey, and NWFSC hook-and-line survey), and a visual survey estimate of absolute abundance in 2002. A trip-based CPUE time series (1980-1999) derived from Commercial Passenger Fishing Vessel logbook records was considered at length, but ultimately excluded due to difficulties identifying effective effort for cowcod. Importantly, all four fishery-independent time series show increasing trends in recent years. These trends are consistent with the high-productivity alternative presented in the previous assessment and are in agreement with the 2002 visual survey estimate of absolute abundance. Very little recent information is available from fishery-dependent sources due to regulatory restrictions.

Stock biomass

The base case model suggests that median spawning biomass (defined as one half of vulnerable biomass) decreased until the early 1930s, then increased as effort targeting cowcod declined. The model indicates rapid decreases in spawning biomass from the 1970s to mid-1980s. Median spawning biomass fell below the Minimum Stock Size Threshold (MSST) from 1983 through 2004, with a low of 9% of unfished biomass in 1987. Since then, the base model suggests the stock has increased to 34% of unfished equilibrium biomass (SB_0) in 2013 (median estimate), with a 95% posterior credibility interval (hereafter "interval") of 15.0% to 65.6% (Table b, Figures b and c). Relative to the previous assessments, changes in the perception of stock status and productivity reflect increasing trends in the fishery-independent surveys as well as exclusion of a fishery-dependent index (CPFV logbook) with a strong pattern of hyperdepletion (showing an exaggerated decline). Median unfished female spawning biomass in the base model is 1549 mt (compared to 2183 mt in the previous assessment), with a 95% interval of 990 to 2683 mt. Median female spawning biomass in 2013 is estimated at 524 mt (95% interval of 273-924 mt). For purposes of calculating ABCs, the estimated standard deviation of the natural logarithm of spawning biomass in 2013 was 0.32.

Table b: Recent trend in beginning of the year median biomass and median depletion (percentage of unfished biomass)

Year	Spawning Biomass (mt)	~95% credibility interval	Estimated depletion	~95% credibility interval
2004	375	(204, 716)	24.4%	(11.4%, 45.6%)
2005	396	(216, 738)	25.6%	(11.9%, 47.9%)
2006	414	(228, 761)	26.9%	(12.4%, 50.5%)
2007	433	(236, 783)	28.1%	(12.8%, 52.8%)
2008	448	(243, 807)	29.1%	(13.2%, 54.8%)
2009	463	(250, 828)	30.1%	(13.6%, 56.4%)
2010	479	(256, 852)	31.0%	(14%, 58.6%)
2011	495	(261, 875)	32.0%	(14.3%, 61%)
2012	509	(267, 900)	32.9%	(14.6%, 63.3%)
2013	524	(273, 924)	33.9%	(15%, 65.6%)

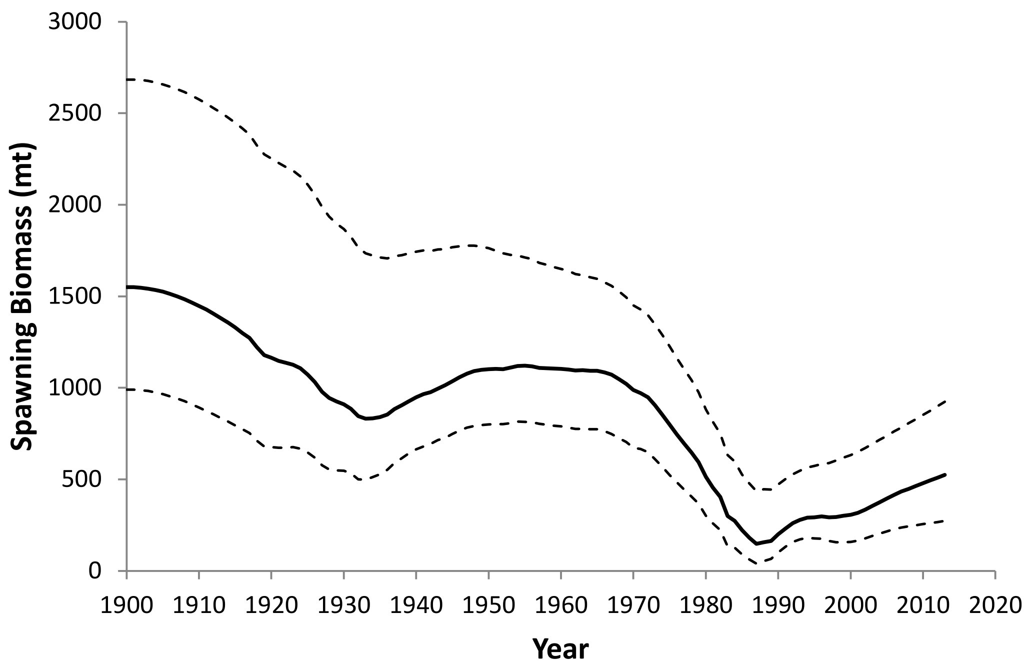


Figure b: Median biomass trajectory with 95% credibility intervals

Recruitment

As in the previous assessment, production in the population model is assumed to be a deterministic function of spawning biomass. Recruitment pulses may be evident in the abundance indices, but insufficient information is available to reliably estimate the relative strength of individual year classes.

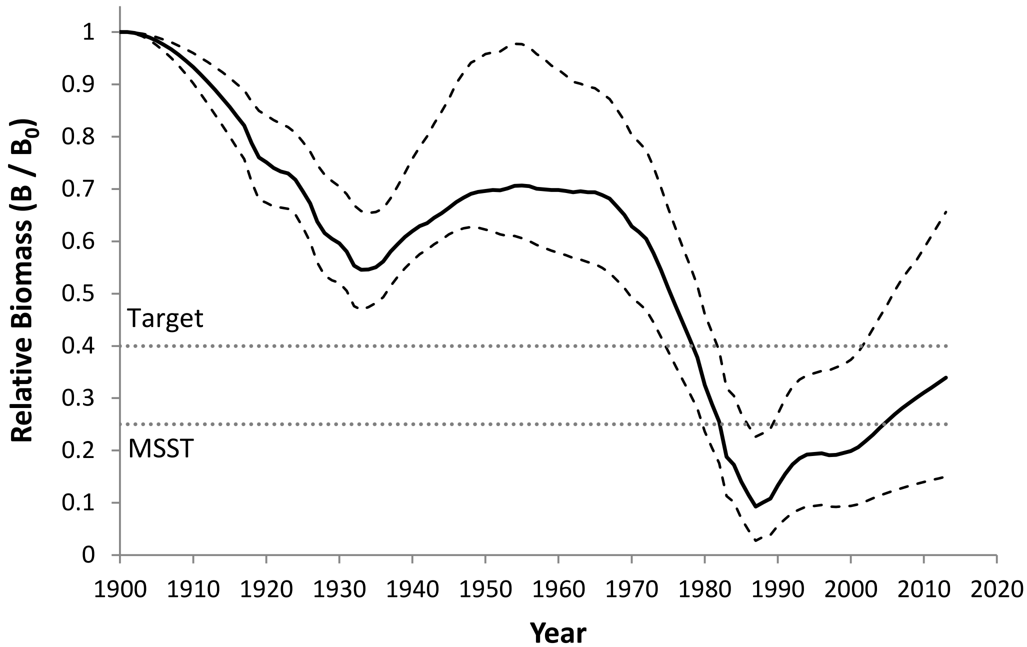


Figure c. Median biomass relative to unfished biomass ("depletion," solid line) with 95% posterior credibility intervals (dashed lines) for the base case assessment model.

Exploitation status

Estimated harvest rates for cowcod were highest during the mid-1980s (Figures d and e). Retention of cowcod was prohibited from January 2001 to January 2011. Even with limited allocations to the rationalized trawl fleet in 2011 and 2012, the base model suggests that removals of cowcod have been less than 0.2% of vulnerable biomass since 2003 (Table c). The model-estimated harvest rate (catch / vulnerable biomass) that produces long-term MSY (5.5%) is roughly twice the proxy (SPR 50%) harvest rate from the last assessment (2.7%). A proxy ($B_{40\%}$) MSY harvest rate (5.0%) was recommended by the SSC for use in management. Unlike previous assessments, the recent increasing trends in fishery-independent surveys allow the model to estimate the rate of increase in stock size. However, the 95% posterior interval for the proxy MSY harvest rate (1.2% - 11.3%) reflects considerable uncertainty in the data regarding stock productivity (Table d).

Table c. Recent harvest rates (catch as a percentage of biomass of age-11 and older fish)

Year	Median Harvest Rate
2003	<0.2%
2004	<0.2%
2005	<0.2%
2006	<0.2%
2007	<0.2%
2008	<0.2%
2009	<0.2%
2010	<0.2%
2011	<0.2%
2012	<0.2%

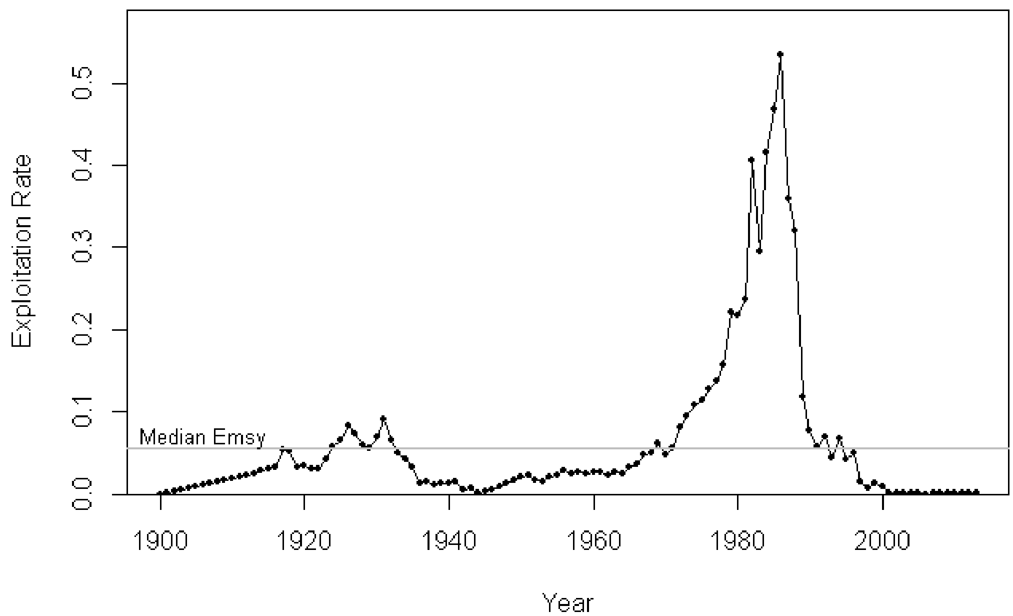


Figure d. Time-series of median harvest rates (total catch divided by age-11 and older biomass) for the base case model. The gray line is the estimated median harvest rate producing MSY.

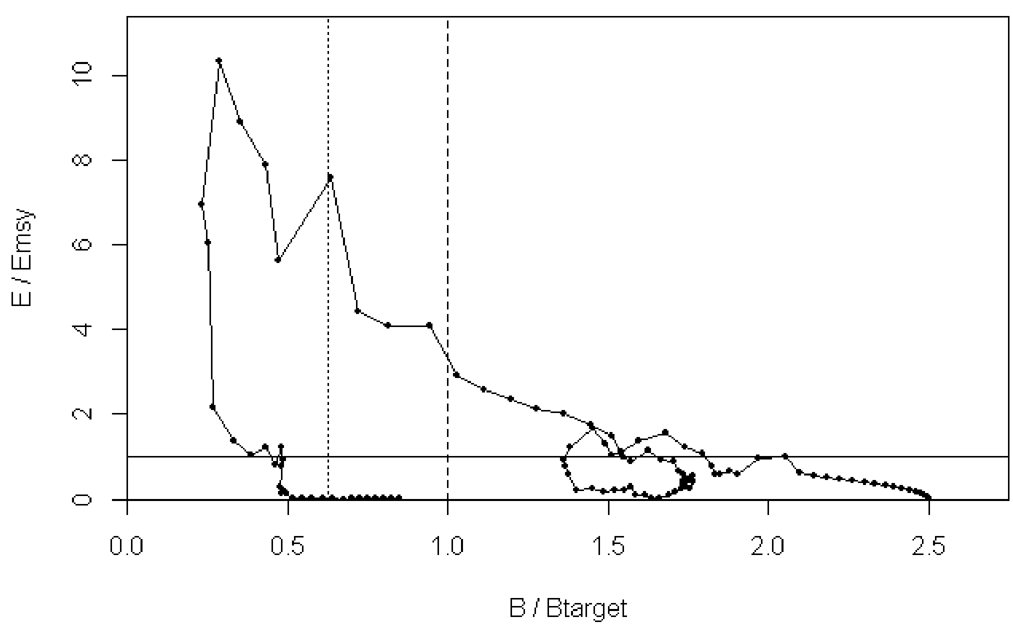


Figure e. Phase plot of median annual harvest rates divided by the median MSY harvest rate vs. median spawning biomass divided by the target spawning biomass (40% of unfished spawning biomass) for the base case model. Target and limit reference points are shown for Emsy (solid horizontal line), target biomass (dashed vertical line), and the minimum stock size threshold for biomass (dotted vertical line).

Ecosystem considerations

No environmental correlations or food web considerations were considered explicitly in the model. Possible "cultivation effect" predator-prey effects on recruitment dynamics were considered by means of the flexible production function used in the assessment.

Reference points

The results of this assessment suggest that cowcod in the Southern California Bight constitute a smaller, but more productive stock than was estimated from recent assessments. Reference points estimated from the data are consistent with the PFMC's proxy for B_{MSY} (40% of unfished biomass). Proxies for MSY harvest rates based on spawning potential ratios (e.g. SPR 50%) are not estimated, as these rely on an age-structured modeling framework. Although nominal SPR-based proxies can be calculated external to the model (e.g. a life table approach) their utility is limited for biomass dynamic models in which growth and recruitment are combined into the net production function.

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

Quantity	**2.5th percentile**	**Median**	**97.5th percentile**
Unfished Spawning Biomass (SB_0, mt)	990	1549	2684
Unfished age 11+ biomass (mt)	1981	3099	5368
Spawning Biomass in 2013	273	524	924
Depletion in 2013 (% of SB_0)	15.0%	33.9%	65.6%
Reference points based on estimated MSY			
Spawning biomass at *MSY* (SB_{MSY})	256	629	1162
SB_{MSY} / SB_0	0.121	0.422	0.745
Exploitation rate corresponding to *MSY*	2.2%	5.5%	12.6%
MSY (mt)	30	69	103
Reference points based on $SB_{40\%}$ proxy MSY harvest rate			
Proxy spawning biomass ($SB_{40\%}$)	396	620	1074
Exploitation rate resulting in $B_{40\%}$	1.2%	5.0%	11.3%
Yield from $B_{40\%}$ proxy harvest rate at $B_{40\%}$ (mt)	25	62	98

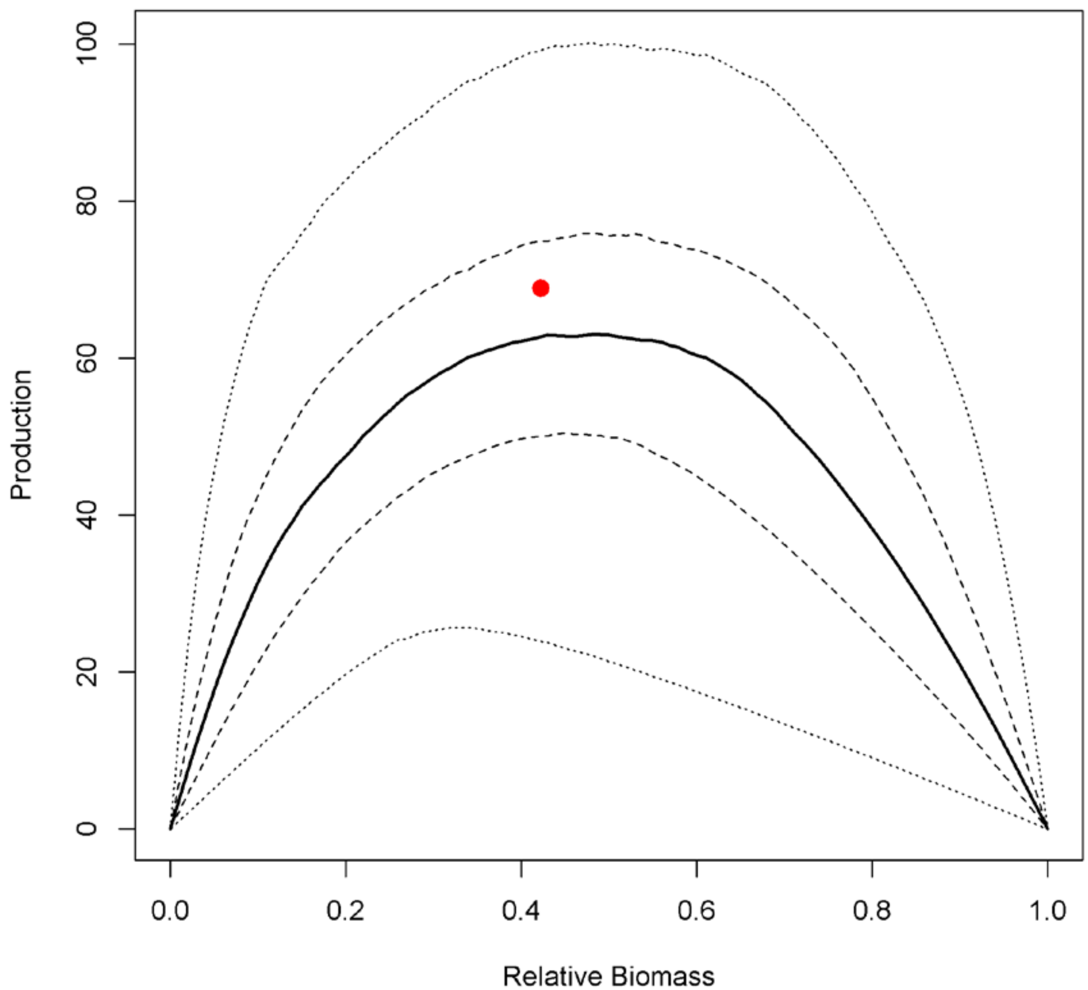


Figure f. Distribution of yield curves from the base model. The solid, dashed, and dotted lines are median, interquartile, and 95th percentiles of production, respectively, given relative biomass. The red circle represents the marginal medians of B_{MSY}/B_0 and MSY.

Management performance

From 2003-2012, total mortality of cowcod has remained below the target level (Table e). The majority of discard mortality during this time period comes from the limited-entry trawl fishery north of 34° 27′ N. latitude (NWFSC, 2013). The establishment of coast-wide Rockfish Conservation Areas and Cowcod Conservation Areas south of Point Conception (34° 27′ N. latitude) has been effective at minimizing cowcod bycatch.

The procedure for calculating the cowcod OFL was revised for the 2011-2012 management cycle. The Council’s Scientific and Statistical Committee classified the stock assessment for cowcod in the SCB as a Category 2 (data-moderate) assessment. Sustainable yield from Point Conception to Cape Mendocino was estimated using a new Category 3 (data-poor) method, Depletion-Based Stock Reduction Analysis or DB-SRA. The 2011-2012 OFLs for the combined stock south of 40° 10′ N. latitude were defined as the sum of the OFLs from these two regions. The Acceptable Biological Catch (ABCs) for each region was derived from the Council’s ABC control rule. The statewide ACL calculation for the 2011-12 and 2013-14 cycles followed the convention of previous management cycles, and was set equal to twice the ACL associated with the SCB (see Appendix C for revised calculations recommended for the 2015-16 cycle.)

Table e. Total mortality (mt) of cowcod by year and area. Commercial mortality estimates (retained + discarded catch) are from the West Coast Groundfish Observer Program and recreational estimates are from RecFIN (weight of catch types A and B1).

	COMMERCIAL		**RECREATIONAL**					
YEAR	**North of 34° 27′**	**South of 34° 27′**	**North of 34° 27′**	**South of 34° 27′**	**TOTAL**	**OFL**	**ABC**	**OY (ACL)**
2003	0.22	0.00	--	0.48	0.70	--	24	4.8
2004	0.54	0.41	--	0.45	1.40	--	24	4.8
2005	1.15	0.00	--	0.15	1.30	--	24	4.2
2006	2.20	0.00	--	0.07	2.27	--	24	4.2
2007	1.93	0.10	0.19	0.11	2.33	--	36	4
2008	0.48	0.00	--	0.25	0.73	--	36	4
2009	1.45	0.00	--	0.21	1.66	--	13	4
2010	1.00	0.00	0.02	0.17	1.20	--	14	4
2011	0.02	0.00	--	0.83	0.85	13.00	8	(3)
2012	0.00	0.00	0.02	0.82	0.84	13.00	8	(3)
Grand Total	**9.00**	**0.51**	**0.23**	**3.53**	**13.28**			

Unresolved problems and major uncertainties

Although every fishery-independent time series included in the base model suggests recent increases in cowcod biomass, the rate of increase is variable among data sources. Continued monitoring of each data source is essential to verify current estimates of stock productivity as the stock rebuilds.

The STAT questions whether catch rates from the CPFV logbook data can be standardized to accurately reflect changes in abundance of cowcod. Indices derived from the CPFV logbook time series are highly influential to the assessment, due to their length, but are not consistent with available fishery-independent surveys and cannot be updated to inform future productivity.

Uncertainty in this assessment is characterized in a fully Bayesian framework. However, posterior distributions from the base model do not account for other sources of uncertainty, including alternative model structures (e.g., process error) and the magnitude of historical catch (a problem shared with other methods used to assess West Coast groundfish stocks).

Research and data needs

Annual Catch Limits for the area south of Cape Mendocino are currently defined as twice the ACL set for the SCB. A reliable estimate of absolute abundance and/or a time series of relative abundance is needed to assess the status of cowcod in waters between Point Conception and Cape Mendocino.

Fishery-independent (extractive) surveys are not currently sampling inside the Cowcod Conservation Areas, which likely contain a large fraction of the population. To better understand rebuilding progress, this policy could be reconsidered given the more optimistic results of the assessment.

Additional information is needed on cowcod stock structure and life history traits, including but not limited to dispersal between U.S. and Mexican waters, and potential differences in life history characteristics (e.g. growth, maturity, fecundity, longevity) among the recently identified genetic lineages.

Consider regular, but not necessarily annual, visual surveys of absolute cowcod abundance in the SCB (inside & outside the CCAs) and central California.

Decision table

Projections of yield, biomass, and stock depletion presented in this assessment are preliminary, and will be replaced by results from a separate cowcod rebuilding analysis.

The STAT prepared a decision table using low, medium, and high states of nature defined as the 12.5%, 50%, and 87.5% percentiles of the posterior distributions. A range of fixed catch alternatives with sufficient contrast was selected to illustrate the implications of alternative management actions under the three states of nature (Table f).

Table f. Summary table of 12-year projections beginning in 2015 for alternate states of nature based on an axis uncertainty. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels.

			Model Results (Possible True State of Nature)					
			Low (12.5%)		Median		High (87.5%)	
	Year	Catch	spBio	depl	spBio	depl	spBio	depl
Reference	2015	0	386	0.223	559	0.360	787	0.554
	2016	0	399	0.229	577	0.372	816	0.575
	2017	0	413	0.235	598	0.384	841	0.596
	2018	0	426	0.242	619	0.396	865	0.615
	2019	0	441	0.248	638	0.408	888	0.638
	2020	0	454	0.255	658	0.420	913	0.659
	2021	0	468	0.262	679	0.432	938	0.679
	2022	0	482	0.268	700	0.445	960	0.699
	2023	0	494	0.275	721	0.457	983	0.720
	2024	0	507	0.281	741	0.469	1007	0.741
Current ACL	2015	1.5	386	0.223	559	0.360	787	0.554
	2016	1.5	398	0.228	577	0.372	815	0.575
	2017	1.5	412	0.234	597	0.383	839	0.594
	2018	1.5	424	0.240	617	0.395	863	0.614
	2019	1.5	438	0.246	636	0.407	886	0.636
	2020	1.5	451	0.253	655	0.418	909	0.656
	2021	1.5	464	0.259	675	0.430	934	0.676
	2022	1.5	477	0.266	696	0.442	956	0.696
	2023	1.5	489	0.272	716	0.454	978	0.716
	2024	1.5	502	0.278	736	0.466	1002	0.737
Possible ACL	2015	5	386	0.223	559	0.360	787	0.554
	2016	5	397	0.227	575	0.371	813	0.573
	2017	5	408	0.232	593	0.381	836	0.592
	2018	5	419	0.238	612	0.392	858	0.610
	2019	5	432	0.243	629	0.403	879	0.631
	2020	5	443	0.249	647	0.414	902	0.650
	2021	5	455	0.255	666	0.424	925	0.669
	2022	5	467	0.260	685	0.435	945	0.689
	2023	5	478	0.266	705	0.447	967	0.707
	2024	5	489	0.272	724	0.457	989	0.726
Possible ACL	2015	10	386	0.223	559	0.360	787	0.554
	2016	10	394	0.226	572	0.369	811	0.571
	2017	10	403	0.229	588	0.378	831	0.588
	2018	10	412	0.234	605	0.388	851	0.604
	2019	10	423	0.238	620	0.397	870	0.623
	2020	10	433	0.243	637	0.407	890	0.641
	2021	10	442	0.248	654	0.416	911	0.659
	2022	10	451	0.253	670	0.426	930	0.678
	2023	10	461	0.258	688	0.437	950	0.694
	2024	10	471	0.262	705	0.446	971	0.712
Possible ACL	2015	15	386	0.223	559	0.360	787	0.554
	2016	15	392	0.224	570	0.367	808	0.569
	2017	15	399	0.227	583	0.375	826	0.585
	2018	15	405	0.230	598	0.383	844	0.599
	2019	15	413	0.233	611	0.391	860	0.616
	2020	15	422	0.237	625	0.399	879	0.633
	2021	15	429	0.241	640	0.408	898	0.648
	2022	15	436	0.244	656	0.416	915	0.667
	2023	15	445	0.249	671	0.426	934	0.682
	2024	15	453	0.252	688	0.435	953	0.699

Rebuilding projections

Table g: Median depletion, female spawning biomass, probabilities of recovery, and catch for model runs 1-9 in the cowcod rebuilding analysis (Dick and MacCall, 2014). Bold values indicate Pr{recovery} ≥ 0.5.

	Run								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	T(F=0)	**current ACL**	**current rate**	**Ttarget**	**Tmax 2057**	**Tmax 2097**	**40-10**	**ABC**	**OFL**
Median depletion									
2013	33.9%	33.9%	33.9%	33.9%	33.9%	33.9%	33.9%	33.9%	33.9%
2014	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%
2015	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%
2016	37.2%	37.2%	37.0%	35.5%	35.5%	35.4%	35.9%	35.7%	35.4%
2017	38.4%	38.3%	38.0%	35.1%	35.2%	35.0%	36.0%	35.5%	35.0%
2018	39.6%	39.5%	38.9%	34.9%	35.0%	34.7%	36.1%	35.5%	34.7%
2019	**40.8%**	**40.7%**	39.9%	34.6%	34.8%	34.5%	36.2%	35.5%	34.5%
2020	**42.0%**	**41.8%**	**40.9%**	34.6%	34.9%	34.4%	36.4%	35.6%	34.4%
2021	**43.2%**	**42.9%**	**41.9%**	34.6%	34.9%	34.4%	36.6%	35.7%	34.4%
2022	**44.5%**	**44.2%**	**42.9%**	34.7%	35.0%	34.4%	36.9%	35.9%	34.4%
2023	**45.7%**	**45.3%**	**43.9%**	34.9%	35.2%	34.6%	37.2%	36.2%	34.6%
2024	**46.9%**	**46.5%**	**44.9%**	35.1%	35.4%	34.8%	37.6%	36.5%	34.8%
Median female SSB (mt)									
2013	524.5	524.5	524.5	524.5	524.5	524.5	524.5	524.5	524.5
2014	541.9	541.9	541.9	541.9	541.9	541.9	541.9	541.9	541.9
2015	559.4	559.4	559.4	559.4	559.4	559.4	559.4	559.4	559.4
2016	577.3	576.6	573.4	550.8	551.7	549.9	557.6	554.4	549.8
2017	598.0	596.5	590.3	548.0	549.6	546.3	560.6	554.6	546.2
2018	619.1	617.0	607.8	545.2	547.6	542.7	563.8	555.1	542.7
2019	638.3	635.4	623.5	543.7	546.5	540.5	567.0	555.9	540.5
2020	658.4	655.0	640.3	544.9	548.2	541.1	572.0	559.0	541.0
2021	679.0	674.7	657.4	545.9	549.9	541.6	577.2	562.6	541.5
2022	700.1	695.1	674.4	548.1	552.2	543.6	582.2	565.9	543.6
2023	721.3	715.8	692.7	551.7	556.3	546.9	589.2	571.9	546.8
2024	741.2	735.1	709.8	556.6	561.4	551.2	595.4	578.2	551.1
Probability of rebuilding									
2013	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336
2014	0.363	0.363	0.363	0.363	0.363	0.363	0.363	0.363	0.363
2015	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392
2016	0.424	0.423	0.418	0.383	0.385	0.383	0.393	0.388	0.383
2017	0.454	0.452	0.444	0.378	0.381	0.375	0.396	0.386	0.375
2018	0.490	0.486	0.469	0.374	0.378	0.371	0.400	0.390	0.371
2019	**0.522**	**0.518**	0.498	0.374	0.378	0.371	0.407	0.393	0.371
2020	**0.548**	**0.543**	**0.524**	0.375	0.381	0.371	0.414	0.396	0.371
2021	**0.575**	**0.566**	**0.542**	0.379	0.387	0.374	0.423	0.402	0.374
2022	**0.600**	**0.592**	**0.563**	0.387	0.391	0.377	0.429	0.410	0.377
2023	**0.629**	**0.621**	**0.583**	0.392	0.396	0.384	0.441	0.416	0.384
2024	**0.651**	**0.645**	**0.604**	0.396	0.402	0.392	0.454	0.424	0.392
Catch (fixed at median)									
2013	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2014	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2015	0	1.5	7.8	53.0	51.3	54.9	39.3	45.8	55.0
2016	0	1.5	8.0	52.3	50.6	54.0	39.1	45.4	54.1
2017	0	1.6	8.3	51.7	50.2	53.4	39.2	45.1	53.4
2018	0	1.6	8.5	51.4	50.0	53.0	39.6	45.1	53.0
2019	0	1.7	8.7	51.3	49.9	52.8	40.1	45.2	52.8
2020	0	1.7	9.0	51.3	49.9	52.7	40.6	45.3	52.8
2021	0	1.8	9.2	51.3	50.0	52.7	41.2	45.6	52.8
2022	0	1.8	9.4	51.5	50.2	52.9	42.1	45.9	52.9
2023	0	1.9	9.7	51.7	50.4	53.1	43.2	46.2	53.0
2024	0	1.9	9.9	52.0	50.8	53.3	44.4	46.6	53.3

Table h. Summary table of base model results. Reported OFLs and ACLs are for the combined Conception and Monterey INPFC areas. Catch is SCB only.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Estimated Total catch (mt)	0.48	0.86	0.15	0.07	0.21	0.25	0.21	0.17	0.83	0.82	NA
OFL (mt)	24	24	24	24	36	36	13	14	13	13	11
ACL (mt)	4.8	4.8	4.2	4.2	4	4	4	4	3	3	3
Exploitation rate (catch/ age 11+ biomass)	0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	NA
Age 11+ biomass (mt)	711	749	791	829	867	895	927	958	990	1018	1049
Spawning Biomass (mt)	355	375	396	415	433	448	463	479	495	509	525
2.5th percentile	191	204	216	228	236	243	250	256	261	267	273
97.5th percentile	694	716	738	761	783	807	828	852	875	900	924
Depletion (%)	23.0%	24.4%	25.6%	26.9%	28.1%	29.1%	30.1%	31.0%	32.0%	32.9%	33.9%
2.5th percentile	10.8%	11.4%	11.9%	12.4%	12.8%	13.2%	13.6%	14.0%	14.3%	14.6%	15.0%
97.5th percentile	43.2%	45.6%	47.9%	50.5%	52.8%	54.8%	56.4%	58.6%	61.0%	63.3%	65.6%

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) to northern Baja California, in depths from 50-300 m. Hess et al. (2014) recently 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. 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.

1.2 Map

Assumed stock boundaries for the 2013 cowcod assessment are shown in Figure 1.

1.3 Life History

Cowcod are a long-lived, slow-growing species that require a decade or more to reach sexual maturity. Fertilization is internal, with females giving birth to planktonic larvae mainly during winter months. Larvae develop into a pelagic juvenile stage, settling to benthic habitats after about 3 months. Adults are piscivorous, with a diet consisting mainly of fishes, squids, and octopi. Cowcod are easily identified at all life stages, including larvae.

Natural Mortality
Maximum observed age for cowcod is 55 years (Love et al. 2002). Dick et al. (2007) estimated the natural mortality rate using three methods, reporting a range of values from 0.027 to 0.064 based on Beverton's (1992) method, a range of total mortality (Z) estimates from 0.038 to 0.072 based on catch curve analysis and Hoenig's geometric mean regression. Additional details regarding treatment of natural mortality in this assessment are in section 2.3.4.

Maturation, spawning, and fecundity
Love et al. (1990) reported length at 50% maturity as 43 cm, or roughly 11 years old. They found no evidence of sexual dimorphism in size at maturity. Peak spawning occurs in January in Southern California and December in Northern California, with larval extrusion observed from November through May in Southern California. Love et al. also reported evidence of multiple broods in cowcod, particularly large individuals in Southern California. Cowcod are a highly fecund species, with large females producing 2 million eggs (Love et al. 1990). Dick (2009) found no evidence of increasing weight-specific fecundity (i.e. spawning output is roughly proportional to spawning biomass).

Growth
Cowcod are among the largest species in the genus *Sebastes* (94 cm max. length). The model used for this assessment does not explicitly account for growth, but von Bertalanffy growth parameters (L_∞ = 870 mm, k = 0.052 yr^{-1}, and t0 = -1.94 years) were estimated by Dick et al. in the 2007 cowcod assessment (Figure 2). Love et al. (1990) found a roughly cubic relationship

between cowcod weight (grams) and length (cm), with approximate parameter values a=0.01 and b=3.1 for the power function $W=aL^b$.

Habitat associations
Juvenile cowcod were once thought to associate primarily with soft sediments, but recent research (Love and Yoklavich, 2008) using visual surveys found juveniles mainly associate with low-relief, hard substrate. Young-of-the-year were observed over a wide depth range (52-277 m), with juveniles slightly deeper, and adults mainly deeper than 150 m. Larger juveniles increasingly associate with high-relief, complex rocky substrate, the primary habitat for adult cowcod.

1.4 Ecosystem Considerations

Cowcod are piscivores, sharing a trophic position with lingcod as the top-level groundfish predators in rocky habitat. No environmental correlations or food web considerations were considered explicitly in the model. However, a food web effect in which adults crop down forage species that are potential competitors/predators of their own juveniles is implicitly considered in the Pella-Tomlinson-Fletcher production function (and would have been excluded by a Beverton-Holt SRR). 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 $B_{MSY}/B_0 \approx 0.6$.

1.5 Fishery Information

Since retention of cowcod was prohibited in 2001, the vast majority of removals have been regulatory discards. Historically, cowcod was highly sought after as a "trophy" fish in the recreational fishery, due to their large size. Despite their appeal to anglers, cowcod have 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). The CPFV fleet began ca. 1919 in California, numbering about 200 vessels in 1939. After 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. Dick et al. (2007) evaluated historical (1970s) length composition data from the CPFV fleet, and found that length at 50% selectivity was around 34 cm. The current base model assumes knife-edge selectivity at age 11 (roughly 40cm).

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 common after 1943 in Santa Barbara county and northward. Prior to 1968, no trawl gear could be processed south of Ventura County. Set net gear was introduced in the 1970s, and became the primary source of cowcod landings in the mid-1980s. Net landings declined in the 1990s following passage of Proposition 132. Dick et al. (2007) evaluated length composition data for the three primary commercial gears (trawl, hook-and-line, and net fisheries) and found considerable variability in the size composition among years. Selectivity for the combined commercial fleet was set equal to the maturity curve (Dick et al. 2007), which is consistent with the assumptions in the XDB-SRA base model. Increases in commercial landings during the late 1970s and early 1980s were largely due to expansion of the set net fishery (Figure 4, Figure 5).

1.6 Summary of Management History

Commercial Fisheries
Prior to the first cowcod assessment in 1999, cowcod were managed as part of the PFMC's "remaining rockfish" complex. The ABC for remaining rockfish in the combined Conception, Monterey, and Eureka areas was initially 9,500 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, an ABC of 5 mt was adopted for the Conception INPFC, which was added to an ABC of 19 mt for the Monterey area (based on average landings from 1983-1997). ABCs and OYs after 2002 are shown in Table 1. Since 2011, a small allocation of cowcod has been retained by the rationalized trawl fishery.

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 fishermen.

Cowcod Conservation Areas (CCA)
In 2001, two depth-based area closures were implemented to reduce fishing mortality of cowcod, prohibiting bottom-fishing deeper than 20 fm (Figure 6). 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
Total removals of cowcod have been below the maximum catch limits (Table 1). Without an assessment for waters north of Point Conception, it is difficult to evaluate management performance for that area. However, total removals are so low it seems unlikely that overfishing is occurring. If removals in the northern portion of the stock increase, the STAT recommends prioritization of research to inform estimates of stock abundance and trends in that area.

2 Assessment

2.1 Data

2.1.1 Removals (Landings and Discard)

A complete summary of cowcod removals in the Southern California Bight, by year and data source, is provided in Table 2 and Table 3.

2.1.1.1 Commercial Landings Reconstruction, 1900-1968

Commercial landings of cowcod prior to 1969 (prior to landings data available in CALCOM) 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 reconstruction used in 2007 and that 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). Relevant text, tables, and figures from the 2007 and 2009 cowcod assessments are included here 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, we 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 4). These data combine the genus *Sebastolobus* (thornyheads) with *Sebastes*, and include rockfish caught in foreign waters 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 7). This result prompted us 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 live-access server (http://las.pfeg.noaa.gov/LAS/CA_market_catch.html) with commercial landings originally published in the CDF&G Fish Bulletin series. Similar to the data from Fish Bulletin No. 105, rockfish landings in this dataset include thornyheads (up to 1977); however, the ERD data exclude fish caught in foreign waters. We queried this database to obtain total rockfish landings by region for the period 1928-1968 (Table 4). The 6 geographic regions in the ERD database 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 the ERD database. The "Central" area is spatially equivalent to the ERD's Monterey and San Francisco areas, and the "Northern" area is equivalent to the ERD's Eureka region. When the ERD data from Southern California are spatially aggregated to mimic the Southern rockfish landings in Fish Bulletin No. 105, the ERD landings are consistently smaller than the Fish Bulletin landings. This is expected, because the ERD data only include fish caught in U.S. waters. To account for this difference, we calculated annual estimates of "foreign-caught rockfish" (Table 5) as the difference between the sum of the ERD 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, we 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 hence the ERD database) 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. We 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 8, Table 5). 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 9, Table 5). 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 5). 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 5).

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 9.

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 6). 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 10).

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 7), 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 rather than the area south of Point Conception (Figure 11). 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 “Uncertainty and Sensitivity Analyses” section for effects of alternative commercial catch reconstructions on model outputs.

2.1.1.2 Commercial Landings, 1969-2000

We queried the CALCOM database (CALCOM, 2013), the source of California’s commercial landings estimates, for cowcod landings from 1969-2012. Landings from 2002-2012 were replaced with total commercial mortality estimates from the West Coast Groundfish Observer Program (WCGOP, see section 2.1.1.3). Total commercial mortality in 2001 was assumed to be equal to the 2002 estimate from WCGOP.

A comparison of estimates from CALCOM and those available from PacFIN suggests that that species compositions in PacFIN have not been updated to reflect the most recent species composition data (i.e. have not used the most recent species composition data). Preliminary analysis suggests that over 90% of the observed differences in catch for cowcod are attributed to outdated species compositions (Table 8).

Under the current CALCOM data management policy, two annual expansions are done at the beginning of each year: the preliminary expansion for the most recent year, and the final expansion for the previous year. Occasionally there is a need to perform expansions that are not part of the regular schedule. This can happen when a significant amount of new data is added to CALCOM (e.g. historical port sample data are recovered) or when a major issue is detected (e.g. when it was determined that a market category definition changed over time). When new expansions are performed in CALCOM, PacFIN is notified and data feeds (percentages of each species for each landed strata) are made available upon request. Updates to the species composition data in PacFIN are underway.

2.1.1.3 Commercial mortality, 2002-2012

From January 2001 to January 2011 retention of cowcod was prohibited in all commercial sectors. Removals during this time period primarily consisted of regulatory discards. The STAT received estimates of total commercial mortality from the West Coast Groundfish Observer Program for the years 2002-2012 (Table 3, J. Jannot, pers. comm.). Since cowcod are generally not retained due to regulations, a discard ratio was developed using the ratio of observed discard to the sum of removals for species associated with cowcod (based on NWFSC trawl survey data). Specifically, the denominator of the discard ratio was the sum of removals for *Sebastes elongatus, S. paucispinis, S. entomelas, S. saxicola,* and *S. chlorostictus*. Total commercial mortality in 2001 (the first year retention was prohibited) was assumed to be equal to the 2002 estimate from WCGOP.

2.1.1.4 Reconstructed Recreational Removals, 1928-1980

The 2009 cowcod assessment (Dick et al., 2009) updated estimates of recreational removals prior to 1981, based on catch reconstructions by Ralston et al. (2010). Unlike the commercial landings estimates in that report, the recreational catch reconstruction included estimates of discard and was stratified at Point Conception. The recreational estimates from Ralston et al. were used in this assessment without modification. Dick et al. (2009, p. 21) compared the revised catch history for Southern California to that of Butler et al. (1999), which was derived from average expansions of CPFV logbook and L.A. Times catch reports to RecFIN cowcod catch during 1980-1997.

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. The composition data mainly reflects 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.

2.1.1.5 Recreational Removals, 1981-2012

Recreational removals (retained and discarded catch) were queried from the RecFIN database (www.recfin.org). If catch in numbers were reported for a stratum and no weight was reported, estimates of catch in weight were obtained by borrowing average weight information from adjacent years. Years with missing data were estimated using linear interpolation (e.g. interruptions of sampling due to lack of funding).

Specifically, recreational removals were taken to be the weight (mt) of catch types A + B1, with linear interpolation of years 1989-92 between 2-year averages for 1987-88 and 1993-94. 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. Estimated removals in 2009 (0.21 mt) were interpolated from adjacent years.

2.1.2 Length and age composition data

Historically, length and age composition data for cowcod have not provided reliable information about the relative strength of cohorts (Butler et al. 1999, Piner et al. 2005, Dick et al. 2007). The modeling framework chosen for this assessment is tuned to abundance indices, but we do not rule out the potential utility of composition data in future assessments. We briefly summarize composition information from previous assessments (although additional details are available in those documents) and describe data sources that have become available since the last assessment.

Length composition data from the recreational fishery
Length data from the recreational fishery are sparse, with only 262 lengths available from RecFIN for the period 1980-2000 in Southern California (114 lengths in Northern California). Reported lengths prior to 1993 appear to be estimates from weight measurements, further reducing the sample sizes. The best available length composition data for cowcod are from onboard CPFV observers in the mid-1970s (Table 9 and Figure 12; 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).

Length composition data from the commercial fishery
Length data from CALCOM are more abundant, particularly for the net fishery (Figure 13). However, even in the net fishery sample sizes and compositions differ greatly among years, with no evidence of modal progression or consistent information about size-dependent vulnerability to the gear (Figure 14).

Age composition data
Cowcod age data are limited in terms of both sample size and temporal coverage. We present sample sizes for the NWFSC trawl and hook-and-line surveys in their respective sections (below), and summarize the data available from other sources in Table 10.

2.1.3 Fishery-Independent Indices of Abundance

2.1.3.1 CalCOFI Ichthyoplankton

Raw CalCOFI Survey sample data for 1951-2011 were downloaded from the IchthyoDB website (https://oceaninformatics.ucsd.edu/ichthyoplankton/secure/login.php), producing data from 19,296 ichthyoplankton tows, of which 213 were positive for cowcod larvae. After re-coding years to begin in November (the traditional CalCOFI pattern), the monthly distribution of samples is shown in Table 11.

Cowcod were not identified in CalCOFI data prior to 1966 in central California (north of Avila, CalCOFI line 77). Since then, 21 positive cowcod observations have been recorded in central California, but only 3 positives have occurred since 1982 (2 of which were in 2011). For these reasons, a CalCOFI index for central California was not considered further.

The bulk of positive stations are in southern California waters. Cowcod larvae were regularly encountered before 1976 and after 1999, but were very rare from 1979 to 1998, during which there were only four positive samples of cowcod larvae (Figure 15). During the past decade there has been a clear increase in cowcod occurrences. A closer look at the within-year pattern is provided by assigning samples to ten-day period beginning on November 1. The distribution of southern California CalCOFI sampling dates is shown in Table 12, indicating that recent sampling done mainly in January and April misses much of February and March when fraction positive tends to be highest (Table 11).

The list of sampling stations was reduced to 24 regularly-sampled locations where cowcod larvae have been taken historically in southern California (CalCOFI lines 80 through 93). Frequency of occurrence at these stations was calculated for three roughly equivalent periods, 1951-60 (25 positive locations, Figure 16), 1961-75 (23 positive locations, Figure 17), and 1999-2011 (19 positive locations, Figure 18). The most notable change is a northward shift during the 1960s.

Seasonality was represented by three SEASONS (Table 13) that were chosen to divide the number of positives into approximately equal numbers (EARLY is 1 Nov to 5 Feb; MID is 6 Feb to 17 March; LATE is 18 March to May). In order to eliminate zeroes, YEARS consisted of 5-year time blocks, except that the low abundance period of 1976 to 1996 was a single block. Use of five-year time blocks addresses the difficulties with CalCOFI data that were described in previous assessments. An exploratory fixed-effect GLM of the proportion positive in southern California used 9 time-blocked YEAR strata, 25 LOCATION strata (Figure 19), and 3 SEASON strata (Figure 20). All interaction terms were rejected by BIC. The estimated YEAR effects are the abundance index; precision was estimated by jackknife (Table 14, Figure 21).

The long string of zero (16 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, 1976 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.

2.1.3.2 Sanitation District demersal trawl surveys

In the first cowcod assessment (Butler et al., 1999), an index was developed using data from the Orange County and Los Angeles County Sanitation Districts. This index was deleted from more recent attempts due to an apparent lack of new information. The Sanitation District trawl surveys are re-evaluated here in view of more recent data indicating an increase in cowcod abundance.

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 22). 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 quarters 2 and 4 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. 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 2012) were not included in the final analysis.

The final data set from the Orange County Sanitation District includes 819 hauls conducted at 8 stations over 42 years, with 58 cowcod observed in 35 positive hauls (4.3% positive; Table 15). Average size of cowcod caught in the OCSD trawls was 13 cm, consistent with an advanced stage young-of-the-year.

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 22). In 1991, a fourth station was added to each transect at 305m. Quarterly trawl data for 1972 to 2012 were obtained from Bill Furlong (LACSD, pers. comm.), consisting of 2179 samples of which 128 were positive for cowcod, most (65%) of which were young-of-the-year. Positive samples occurred mostly (75%) in the fourth quarter and before 1999 cowcod presence was restricted almost entirely to the fourth quarter. Consequently, only the fourth quarter trawl samples are used for the abundance index. Average size of cowcod in the selected hauls was 13 cm, which is consistent with advanced young-of-the-year. 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 325 hauls conducted at 9 stations during the fourth quarter (stations T0-61, T0-137, T1-61, T1-137, T1-305, T4-61, T4-137, T5-61, and T5-137). A total of 150 cowcod were observed in 60 positive hauls (18% positive, Table 16). All stations were sampled annually, excluding 1978 and 2003, except for station T1-305 which was occupied since 1991. A single 4th-quarter haul was completed at each station each year, except for station T5-61 which was sampled twice 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 23).

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, and 2006-2011.

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. 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 17), which accounts for differences among stations (Figure 24) and quarters, shows a slightly faster decline between the first two block-years, but is otherwise very similar to the raw proportion of positive tows across years (Figure 25).

2.1.3.3 NWFSC trawl survey

Raw data from the 2003-2012 NWFSC Trawl Surveys were provided in spreadsheet format by Beth Horness (NWFSC, Pers. Comm.). A total of 166 tows were positive for cowcod, 162 of which were south of Cape Mendocino (Figure 26, Figure 27). The fraction of positive tows was highest between 100-250 meters (Figure 28). An increasing trend in abundance of small (<1 kg) cowcod is apparent for Southern California, but no clear trend is evident north of Point Conception (Figure 29). Average weights for small cowcod (<1 kg) show no trend over time (Figure 30). The largest portion of the sampled population was in the northern portion of the southern California Bight, with local concentrations encountered off Monterey and Point Reyes (Table 18).

The distribution of cowcod mean weights indicates that trawl survey tows strongly favor small, young fish (Figure 31). A 1-kg fish tends to be about 10 years old. Mean age of cowcod caught by the survey south of Point Conception was 4 years (Table 19).

In southern California waters between 32.5 N Lat and 34.5 N Lat large cowcod (>1 kg) are not encountered frequently enough (average Npos is 1.5 per year) to support a direct index of large fish abundance. However, trawl catches of small cowcod (<1 kg, mean age 4 years) average 6.6 per year, and can support an index of recent production in southern California waters. We developed an index of small (<1 kg) cowcod abundance, modeling the proportion of positive hauls (N = 240 tows between 100 and 250m depth) using a binomial GLM with year and depth effects (Table 20, Figure 32). Given the average age of the small cowcod, we treat this as an index of adult abundance 4 years earlier (1999-2008).

2.1.3.4 NWFSC hook-and-line survey

Since 2004, the NWFSC has conducted a hook-and-line survey targeting shelf rockfish at fixed stations in the Southern California Bight. Given the rarity of cowcod encounters, the STAT developed an index using "drop" as an approximate unit of effort. The STAT was provided data on the number of cowcod encountered by year, site, vessel, and drop number (Jim Benante, PSMFC, and John Harms, NWFSC, pers. comm.). At each ‘drop,’ three deckhands simultaneously deploy five, 5-hook sampling rigs (75 hooks total per site) 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). See Harms et al. (2008) for a complete description of sampling methods. Sampling coverage (# of drops) over time for sites that have encountered cowcod at least once has varied in some cases, but is generally consistent (Table 21). The survey aims to complete five drops per site each year, but unavoidably sites are missed in some years, and only 2 drops were completed at site 414 in 2005 and site 6 in 2006. Available otoliths were aged (Table 24).

Catch (in weight; Table 22) per drop was modeled using a delta-GLM with year and site effects, with uncertainty estimates calculated from a jackknife algorithm (Table 23, Figure 33). Compared to raw CPUE (catch per drop), the standardized index suggests a slightly slower rate of increase due to differences in site occupancy over time and site-specific catch rates (Figure 34). Sites with fewer than 2 positive observations were excluded (sites 17, 21, 24, 29, 36, 43, 77, 137, 147, 149, 154, 168, 181, 186, 200, and 205), with the final data set consisting of 907 drops (136 positive) from 23 sites over the period 2004-2012. The year effects from the binomial model in the delta-GLM are largely responsible for the trend in the index (Figure 35). No trend is evident in the positive component (i.e. conditional mean) of the index.

2.1.3.5 Visual (Submersible) Survey of Cowcod in the CCAs, 2002

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, The survey estimated 524 mt of cowcod biomass (CV=0.26) within the CCAs. 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 adjustment was applied to the total biomass estimate to better reflect the selectivity assumptions in XDB-SRA.

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 used to derive the prior for q are in Appendix IV of Piner et al. (2005). In short, 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 approximately 1/3 of cowcod biomass in the SCB was outside the CCAs ($q \cong 0.75$). Following Piner et al. (2005), the prior for q in this assessment is specified as a normal prior on log(q), with mean -0.2863 and log-scale standard deviation of 0.5.

2.1.3.6 Southern California Bight Cowcod Assessment Survey (2012)

Between October and December 2012, the SWFSC used a remotely operated vehicle (ROV) to survey cowcod habitat (K. Steirhoff, pers. comm.). The survey encountered 189 cowcod during 167 transects, stratified by depth and substrate type, at 18 sites in the SCB. Sites were inside and outside the CCAs, between 67 and 268 m depth.(Figure 44). Survey results are pending.

2.1.3.7 SWFSC Rockfish Recruitment and Ecosystem Assessment Survey

In 2013 the NOAA Fisheries Santa Cruz Laboratory encountered the highest numbers of cowcod in the 30 year history of their annual rockfish recruitment and ecosystem assessment survey. Note that the survey was originally confined to central California (Monterey Bay to Point Reyes) from 1983-2003 and was expanded in 2004 to include almost the entire California coast (San Diego to Mendocino). While cowcod were more consistently collected from 2004 onward due to the expanded survey area, the catches in 2013 exceed all previous years combined (Table 25). Although the observed cowcod occurred primarily in the core survey area (Central California), lower numbers in Southern California are likely due to earlier settlement of pelagic juveniles prior to sampling (K. Sakuma, pers. comm.). If this turns out to be a strong year class, it would recruit to the reproductive population ca. 2024, but may be encountered as bycatch or in surveys (e.g. Sanitation Districts, NWFSC trawl and/or hook-and-line) before that time.

2.1.4 Fishery-Dependent Indices of Abundance

2.1.4.1 CPFV logbook CPUE index

The catch of cowcod has been reported in CPFV logbooks since 1963, but trip-specific data are available beginning only since 1980. The earlier logbook data exist as summarized aggregate monthly catch and effort by CDFW reporting block. The catch rate data cease being informative after 1999 when restrictive regulations were enacted for the purpose of rebuilding a depleted stock.

Logbook data for cowcod in the area north of Point Conception are highly variable, showing little trend, relative to catch in the SCB (Figure 36). Seventy-eight percent of cowcod recorded as kept north of Point Conception from 1964-1999 were caught in 4 years. For these reasons, no attempt was made to derive an index of cowcod abundance north of Point Conception.

Cowcod assessments and updates in 1999, 2005, 2007, and 2009 utilized CPFV-based abundance indexes based on the aggregate data from 1963 to 2000. Since 2005, various STAR Panels have recommended analysis of the individual CPFV trip records that are available since 1980. However, since the 2007 assessment was initially scheduled as an update (and later changed to a full) and the 2009 assessment was an update, the aggregated index was retained with minor changes. The present assessment (2013) is the first attempt to examine the trip-based data. As with all of the abundance indexes previously used in cowcod assessments, their utility for assessing cowcod has been debated. Although the aggregate CPFV index was only remaining time series of abundance in the 2005 and 2007 assessments, both STAR Panels questioned whether the CPFV index itself should be used.

Aggregated CPUE

The 2007 (and 2009 update) assessment used a spatial stratification that is based largely on the assumption that adjacent (or nearby) blocks are likely to have similar trends in CPUE (a recommendation of the 1999 STAR panel). These groups of blocks formed 10 REGIONs (Figure 37). Blocks below the first quartile of mean CPUE were excluded, as well as any data from the months of May-October due to seasonal changes in target species. The analysis also excluded blocks that represent data of uncertain location, and catch reported in blocks that don't exist. Blocks with very sparse time series (<3 years with positive catch of cowcod) were dropped from the analysis. The fishing season was defined to include the months of November through April the following year. The index was derived from the YEAR effect from a delta-lognormal GLM. YEAR-REGION strata were too sparse (excessive numbers of zeroes and unsampled strata) to allow rigorous evaluation of interaction terms, and a main effects model was adopted. As with previous treatments of the aggregated month-block data, the resulting index showed a pattern of “hyperdepletion,” especially at the beginning and end of the time series (Figure 38). The 1999 and 2000 index values were anomalously low, and could not be fit satisfactorily by the assessment models. The reason for the hyperdepletion is not known, but speculation includes possible shifts in targeting and reporting behavior, and possible localized depletion at favored fishing sites.

Trip-Based CPUE
From this data set we developed three versions of trip-based CPUE before and during the STAR Panel review. These are referred to as “Cowcod-Only CPUE”, “Rockfish Trip CPUE”, and “Filtered CPUE.”

Cowcod-Only CPUE
Anticipating difficulty in determining which trips were targeting cowcod (see following methods), we considered that the only reliable indicator that the fishing trip sampled cowcod habitat may be the presence of cowcod itself. Distributions of catch per angler hour appeared to be approximately exponential (as might be suspected for a rare, non-aggregating species), in which case it is justified to use the “first” cowcod to indicate a valid trip, and to calculate CPUE from the remainder of the catch, i.e., CPUE = (N-1)/angler-hour. Trips that only caught a single cowcod now form the “zero” observations contributing to the binomial portion of the delta-GLM. Further support for the exponential assumption was provided by the estimated gamma shape parameter (1.13) from the final delta-GLM. A value of 1 corresponds to an exponential distribution.

The full data set included 5482 trips in which cowcod were recorded, of which 1595 trips recorded a single cowcod. Months of October-December were assigned the YEAR value of the following January. Logs were filed by 896 unique vessels, of which 76 vessels recorded more than 15 positive trips. These vessels were assumed to consistently target cowcod, and the remaining logs were deleted from consideration, leaving 5265 trips. Of these, 5021 trips were in CDFW reporting blocks that could be assigned to one of 11 REGIONS based, with minor modifications, on the regions in the 2007 and 2009 assessments (Figure 39). After deleting trips from nominal YEAR 2000 (October to December of 1999), the final data consisted of 4898 trips (1336 with a single cowcod, and 3562 with multiple cowcod). Preliminary delta-gamma GLMs supported collapse of MONTH effects into two SEASONs: October-January plus September, and February-August. Vessel IDs were not used as explanatory variables, but merit possible consideration as random effects in a future mixed-model (GLMM) analysis. The final delta-gamma GLM used fixed effects of YEAR (20), REGION (11) and SEASON (2). The Gamma main effects model was favored over a model with a YEAR:REGION interaction term by an AIC difference of 62. Including a YEAR:REGION interaction term in the binomial model failed to converge, in part due to sparse data (strata containing all zero observations). Standard errors of YEAR effects in the delta-GLM index were estimated by jackknife (Table 26).

The Cowcod-Only CPUE index is fairly similar to the aggregated CPUE index for the period 1980 to 1994 (Figure 40). However, from 1995 to 1999 the trip-based index holds steady while the aggregated CPUE drops tenfold. While the new trip-based index clearly addresses the issue of hyperdepletion in the original, aggregated index, it is possible that the data selection criteria have introduced a property of hyperstability. We evaluate the property of hyperstability by examining properties of the binomial and lognormal components of a delta-GLM based on "Rockfish-Trip CPUE."

A final consideration is the best specification for the distribution of positives in the delta-GLM. We have adopted a delta-gamma specification with an estimated gamma shape parameter that supports the assumption of an exponential distribution. However when the alternative specification of a delta-lognormal GLM is considered, both AIC and other diagnostics very strongly favor a lognormal distribution for the positives. The trajectory of YEAR effects from the alternative delta-lognormal model appears roughly similar to that from the adopted delta-gamma GLM, and link-scale predictions from both models show no clear indication of bias (Figure 41). The STAT preferred the delta-gamma GLM as being formally justifiable (supporting the exponential assumption) despite the information criterion supporting a delta-lognormal GLM.

Rockfish-Trip CPUE

The Rockfish-Trip CPUE analysis was an intermediate work product developed 1) as a step toward the following Filtered CPUE, and 2) as a tool for understanding the properties of the Cowcod-Only CPUE. It was not used as an index of abundance in the assessment modeling. A total of 373975 CPFV trip logs cover the years 1980-1999; subsequent years are not considered due to regulatory changes. Unlike the Cowcod-Only CPUE, we did not use vessel information to filter the data. Of the documented trips, 69781 logs showed more rockfish taken than non-rockfish taxa (and catch rate was at least one fish per angler); further pre-filtering consisted of dropping any trip in which the following taxa were present: yellowfin, skipjack, bluefin, bigeye, albacore, dolphinfish, wahoo, salmon, scallop, lobster), leaving 69057 trips. Finally, trips were deleted if they did not occur within the 11 cowcod REGIONS in Figure 39, leaving 58900 trips of which 4961 were positive for cowcod; this subset is referred to as "rockfish trips."

We analyzed catch per trip (ignoring number of anglers or hours fished) by a main-effects delta-lognormal GLM, using YEAR, REGION and MONTH effects. The time series of estimated YEAR effects from the two components of the delta-GLM (Figure 42) reveal probable hyperstability in the cowcod-only model. The binomial portion shows that the fraction of trip catching cowcod declined during the 1980s, and stabilized at a lower level in the 1990s. There was an insignificant drop in the last two years, suggesting that the cowcod encounter rate was similar to previous years. The number of cowcod caught on positive trips shows a drop from 6.5 to 4.5 fish per trip during the early 1980s, a stable catch rate of 4 fish from the mid-1980s to the mid-1990s, and then a sharp drop in the late 1990s. Changes in the binomial probabilities appear to be more important than changes in catch rates for positive trips. This is consistent with a pattern of serial depletion, and may indicate that the Cowcod-Only CPUE is hyperstable, and should be considered to be unreliable.

Filtered CPUE

Presences and absences of non-rockfish species in the Rockfish-Trip subset of the logbooks were used to filter the logbook record down to those most likely to have fished in cowcod habitat (Stephens and MacCall 2004). The logistic regression coefficients (Figure 43) were unusual in that lingcod was the only positive indicator, while all of the other taxa were negative to strongly negative indicators (as expected from knowledge of their biology). The consequence for filtering is that the indicator species are unable to identify likely cowcod habitat, but are effective only in identifying unlikely habitat. The highest estimated probability that cowcod should be present was only 0.2, which indicates very poor reliability. The rate of false negatives is also unacceptable: 79% of the positive cowcod trips are discarded with estimated probabilities below the conventional threshold where false negatives equal false positives. Of the 5270 trips that were retained, only 1088 were positive for cowcod. The discarded trips included 3873 that were positive for cowcod. The filtered data set was used in a delta-lognormal GLM, giving YEAR effects that tend to resemble the aggregated CPUE series until the mid-1990s (Figure 40). The filtered data show a drop in 1998-99 CPUE, but not as severe as seen in the aggregate CPUE.

2.1.4.2 RecFIN dockside CPUE data

A query of RecFIN sample data showed 184 cowcod observations in about 200000 angler-hours of fishing. The data set is too thin to support Stephens-MacCall sorting for relevant trips, and three years reported zero cowcod. Therefore, a RecFIN-based CPUE index was not considered.

2.1.4.3 Onboard CPFV observer data

Monk et al. (in prep) recently created a relational database for onboard CDFW CPFV observer data collected from 1999-2011. This database was recently used to develop indices of abundance for assessments of three nearshore species (china rockfish, copper rockfish, and brown rockfish). We queried the database for the number of cowcod kept and returned by year and county (Table 27). Too few cowcod were observed to provide information on trends in abundance, probably due to depth restrictions designed to reduce the number of cowcod encounters. A larger number of cowcod were reported in 2011 than in previous years.

2.2 History of Modeling Approaches Used for this Stock

The first 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 larval 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 fit 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).

2.2.1 Response to STAR panel recommendations from the most recent previous assessment

STAR panel recommendations are provided below (italics), followed by STAT comments.

Present and consider all available data potentially relevant to abundance trends in recent and historical years (e.g., outfall surveys, CalCOFI data, NWFSC bottom trawl data, observer data, and hook and line survey data). Data for recent and current trends are important in tracking progress towards rebuilding. Historical data may be useful in corroborating trends in CPFV logbook data.

This is a primary goal of the new assessment. The STAT evaluated all of the requested data sources, and incorporated information from each in the new model.

Enhance modeling procedures for standardizing CPFV data, particularly in representing potential interactions between year and region.

The STAT developed a trip-based index from the CPFV data that lacks the hyperdepletion pattern evident in the previous assessments. The Gamma (exponential) model did not support interactions between year and region (ΔAIC=65). The proportion of positive observations was too small to evaluate the interaction term in the binomial model. The revised (trip-based) CPFV index was not included in the final base model due to evidence of hyperstable properties.

Provide reviewers with complete sets of model diagnostics for standardized abundance indices based on CPFV and other types of data.

The STAT provided descriptions of our model selection procedures.

Conduct additional video surveys to provide direct measures of current cowcod biomass and to facilitate interpretation of the existing video survey data. Ideally, video sampling should be carried out both inside and outside the Cowcod Conservation Areas so that extrapolation to the entire stock is not required.

The STAT agrees with this recommendation and suggests that the next assessment consider results from the recently-completed SWFSC Southern California Bight Cowcod Assessment Survey.

Reconstruct the cowcod rockfish catch history using all available data including catch by gear and by region. The reconstruction should include an envelope of high and low values to set bounds for exploration of alternative catch histories. As has been recommended previously by a variety of STAR Panels, the reconstruction of historical rockfish landings needs to be done comprehensively across all rockfish species to ensure efficiency and consistency.

The historical catch reconstruction in this assessment was developed using regional estimates of total rockfish catch and gear-specific species compositions (proportion cowcod). Sensitivity of the model to alternative reconstructions was tested. The STAT recommends additional research on methods to incorporate catch uncertainty in stock assessments.

A preliminary query of the RecFIN database showed a very small number of cowcod in the RecFIN sample data. The Panel recommended that a thorough investigation of these data be prepared for the next assessment of this stock.

The STAT did not have time to address this concern, and considered the weight of catch types A+B1 in RecFIN to be the best available record of recreational removals.

Re-examine the assumption that commercial selectivity at length is the same as maturity at length.

The current model assumes that age 11+ fish are mature and 100% selected by the fishery.

Conduct a full Bayesian assessment if possible. Cowcod are an ideal potential case because of the simple model structure and uncertainties about key model parameters and data.

The XDB-SRA base model is fully Bayesian.

General or long term
Develop surveys that track trends in abundance of cowcod. The NWFSC bottom trawl shelf and slope surveys should, in particular, be evaluated for cowcod.

The STAT developed and incorporated a NWFSC trawl survey index into the base model. Results from the Southern California Bight Cowcod Assessment Survey are pending.

For the historical and recent fisheries, evaluate the relative capacity of fishing fleets and markets for cowcod to determine how much catch might have reasonably been taken during historical periods and whether relatively high fishing mortality rates during the late 1980s are plausible.

Exploitation rates in the base model are much lower than the previous assessment.

Evaluate the hypothesis that CPFV indices are nonlinear measures of stock biomass.

The STAT chose to work with the trip level CPFV data instead of the month/block aggregate data to address this issue. A revised, trip-based CPFV index did not have the hyperdepletion pattern from the previous assessment, but appeared to have hyperstable properties.

2.2.2 Report of consultations with AP and MT representatives

During the pre-STAR panel data webinar, the STAT provided a description of historical catch estimates and abundance indices used in the draft assessment base model. The GMT representative requested clarification regarding the choice to use CALCOM landings estimates rather than PacFIN. Comparison of CALCOM and PacFIN estimates showed that PacFIN landings did not reflect the most recent species composition data in CALCOM (see section 2.1.1.2 for additional details). CDFW provided a list of comments and questions on an earlier draft of the assessment. The STAT has attempted to address each of these in the current version, and thanks CDFW staff for their input.

2.3 Model Description

2.3.1 Extended Depletion-Based Stock Reduction Analysis (XDB-SRA)

This assessment uses a Bayesian extension of Depletion-Based Stock Reduction Analysis (DB-SRA; Dick and MacCall 2011). Prior predictive distributions from DB-SRA are updated by specification of likelihood functions for a set of abundance indices, generating posterior distributions for model parameters and derived quantities such as stock status, biomass, and sustainable yield (OFL).The model is coded in the R language/environment, and the base model used version 24.

2.3.2 Population Dynamics Model

We revise the dynamics equation used by Dick and MacCall (2011) to better approximate a time lag in recruitment, rather than a lag in net production. Biomass in each year is defined as

$$B_t = B_{t-1} + P(B_{t-A}) - C_{t-1} + (1 - e^{-M})(B_{t-A} - B_{t-1}) \quad (1)$$

where B_t represents mature and vulnerable biomass at time *t* and C_t represents catch at time *t*. Biomass in the first year is assumed equal to unfished equilibrium biomass, and spawning biomass is nominally 50% of total mature biomass. All removals were combined into one fleet, with assumed 'knife-edge' selectivity set equal to age at maturity (A = 11 years). P is a latent production function based on biomass *A* years earlier. Following Dick and MacCall (2011), we use a hybrid production function based on the Pella-Tomlinson-Fletcher (PTF) and Graham-Schaefer models. The last term in equation (1) adjusts the natural mortality component of net production to reflect biomass at time B_{t-1} rather than B_{t-a} (Aalto et al., in prep.). If, for example, B_{t-A} is larger than B_{t-1}, a model without this correction factor would underestimate production, and vice versa. Note that the correction term disappears when lag times for recruitment and survival are the same.

2.3.3 Likelihood Components

For each abundance index, *I*, we assume a normal likelihood function for log-scale biomass and index values, scaled by a catchability coefficient, q.

$$l(B, q, a; I) = \prod_{i=1}^{n} N(log(I_i/q); log(B_i), v_i + a). \quad (2)$$

Where *n* is the number of years in the index. The variance of the normal likelihood is composed of an annual variance component, v_i (estimated external to the model and assumed known for the i^{th} year), and an additive variance term, *a*, that is common to all years and estimated in the model.

2.3.4 Prior Distributions

Prior probability distributions for parameters in the population dynamics model are shown in Figure 45, with details and derivations provided below.

Relative Depletion (Δ): Since Δ (= $1-B_t/B_0$) is constrained to be between 0 and 1, we use a truncated beta distribution as a prior. The distribution was truncated below 0.01 and above 0.99 to exclude improbable values of stock status.

Previous STAR Panels recommended using PSA vulnerability scores (Cope et al. 2011) to establish depletion priors for data-moderate assessments. We adopt the truncated beta prior used for the data-moderate stock assessments, with mean = 0.7 and standard deviation of 0.2.

Natural mortality rate (M): We specify a lognormal prior distribution for M with an arithmetic mean of 0.055 based on catch curve analysis (Butler et al., 1999) and log-scale standard deviation of 0.4 based on Hoenig's (1983) regression data. M was fixed at 0.055 in the previous assessment. Dick et al. (2007) compared alternative estimators of M for cowcod, reporting a range of 0.027 – 0.072. For comparison, the 2.5^{th} and 97.5^{th} percentiles of the lognormal prior used for the base model are 0.023 and 0.111, respectively.

$\underline{B_{MSY}/B_0}$: We assume a diffuse (nearly uniform) prior for the location of B_{MSY} relative to unfished biomass. Specifically, we use a truncated beta distribution for this parameter with bounds 0.05 and 0.95, chosen to exclude unrealistic parameter values. The prior mean was 0.5 with standard deviation 0.285.

$\underline{F_{MSY}/M}$: We assume a lognormal prior distribution, with arithmetic mean 0.97 and log-scale standard deviation 0.46. These parameter values are based on the work of Zhou et al. (2012) who conducted a meta-analysis of the ratio Fmsy/M for 245 stocks. Specifically, we used the prior for teleosts (n=88 species) and approximated the log-scale standard deviation of the prior by multiplying the reported standard error by the square root of the sample size.

Additive variance (a): Additive variance parameters were assigned a uniform prior in log space. A lower bound of 50 kg was chosen as a practical minimum estimate of variability in observed biomass, with an upper bound chosen through visual inspection of preliminary importance sampling results to confirm that posterior draws were not truncated.

Catchability (q): Catchability coefficients for most indices were not estimated. Their likelihood was derived by integrating over $log(q)$ with a diffuse, improper prior (uniform from $-\infty$ to $+\infty$). The exception is the catchability coefficient for the 2002 visual survey, which was assigned a normal prior on log(q) with mean -0.2863 and standard deviation 0.5.

2.3.5 Monte Carlo Simulation of Posterior Distributions

Sampling Importance Resampling (SIR; Rubin 1988) is implemented by calculating the total likelihood associated with each DB-SRA biomass trajectory (parameter vector) followed by resampling from the prior distributions using the likelihoods as weights. One performance measure is the size of the maximum resampling weight. All runs had acceptably small maximum weights (<0.01).

2.4 Model Selection and Evaluation

2.4.1 Transition from the 2009 Assessment

The 2009 cowcod assessment was an age-structured production model with deterministic recruitment, fit to the aggregated CPFV logbook index and the 2002 visual survey biomass estimate. Productivity parameters were fixed (steepness = 0.6, natural mortality = 0.055), leaving only virgin recruitment (R_0) to be estimated.

The XDB-SRA model, when fit to the data in the 2009 assessment, produces results that are consistent with the age-structured production model. The assumed level of productivity in the 2009 base model produces a lower estimate of unfished biomass than the XDB-SRA model with all parameters estimated (a smaller, more productive stock; Figure 46). When the steepness parameter is freely estimated in the 2009 base model, the decline in the aggregate CPFV logbook index pushes steepness to its lower bound of 0.2, with unfished biomass larger than the XDB-SRA model (a larger stock with no surplus production). Differences in the production functions for XDB-SRA and the age-structured model preclude an exact match, but the trends are qualitatively similar and the scale of the population is consistent with the range produced by the 2009 assessment under alternative productivity assumptions (Figure 46).

2.4.2 Alternative Treatments of the CPFV Logbook Data

Initial efforts to fit the model to CPFV logbook data resulted in population trends similar to those observed in the previous assessment. STAR panel reports from previous assessments recommended further examination of the CPFV logbook index, so we evaluated several treatments of the CPFV logbook data. First, we fit the model to the aggregated CPUE time series estimated by Dick et al. (2007), but dropped the year 2000 data point and included the 2002 visual survey as in the last assessment (run "agg_63-99" in Figure 47). We dropped the 2000 data point because the bag limit for cowcod was set at 1 fish per angler and it is likely that the results of the previous year's assessment affected angler behavior. Even without the 2000 data point, the time series was qualitatively similar to the previous assessment, showing a heavily depleted stock (7% of unfished; Figure 48) with an estimated MSY harvest rate of 1.3% and maximum harvest rates just under 0.4 (Figure 49). Interesting results from this run include a bimodal posterior distribution for B_{MSY}/B_0, with one mode centered above values greater than 0.5 (Figure 50, third row, far left). $B_{MSY}/B_0 > 0.5$ is a region of the generalized production function's parameter space that is unavailable under the assumption of a Beverton-Holt Stock Recruitment Relationship in the previous assessment (BH-SRR).

To show the effects of truncating the time series (from 1963-1999 to 1980-1999) and excluding trips not encountering cowcod (the "Cowcod Only" version of the index), we first truncated the time series of aggregated data (run "agg_80-99" in Figure 47 through Figure 50), which had little effect apart from the perception of a slightly less depleted stock with a greater fraction of the B_{MSY}/B_0 density above 0.5. However, a greater change was evident in both stock status and productivity when the more recent, trip-level index was appended to the earlier (1963-1979) time series based on aggregated data (Figure 47 through Figure 50). In fact, both runs containing trip-level data (runs "agg+trip" and "trip_80-99") produce similar results: a significantly less depleted stock with slight upward shifts in both M and Fmsy/M.

As a final "treatment" of the CPFV logbook data, we excluded the index but included all fishery-independent indices (run "noCPFV"). Whereas the bimodality in Bmsy/B0 was present to varying degrees in all models fit to the CPFV logbook data (regardless of treatment), excluding the CPFV data and fitting only the fishery-independent indices resulted in a unimodal posterior for Bmsy/B0 (Figure 50). This 'fishery-independent' model also suggested a more productive, but smaller stock, with higher estimates of M and Fmsy/M and a median unfished biomass almost half of the runs containing the CPFV data (Figure 47).

2.4.3 Influence of Individual Data Sources

We evaluated the sensitivity of model results to each data set by dropping one source at a time. Removing individual fishery-independent indices had little effect on the model results compared to the impact of removing the CPFV logbook index (Figure 51 through Figure 54). Dropping the CPFV index has the greatest effect on the model results (and suggests it is inconsistent with the other data sources). However, maximum harvest rates resulting from the "Fishery Independent" model (fit to all indices except the CPFV index) are 2-3 times as high as the models fit to the CPFV data (Figure 53). This is due to the reduction in scale of estimated biomass when the CPFV index is removed. The STAR panel for the last assessment suggested that the plausibility of high exploitation rates should be considered during selection of a final model for cowcod. We considered this criterion when selecting data to include in the base model, but ultimately chose to exclude the CPFV index after determining that 1) the index was extremely sensitive to alternative definitions of effective effort for cowcod, and 2) noting that peak harvest rates in the "fishery-independent" model, although still questionable, were much lower than estimates in the 2007 and 2009 assessments (Figure 55).

2.4.4 Convergence of Base Model

The base model was fit to the five fishery-independent indices with 500000 simulations. 20% of the trajectories were rejected due to negative biomass estimates. We resampled 15000 draws from the retained set of trajectories with weights proportional to the likelihoods, generating a maximum resampling weight less than 0.004.

2.5 Responses to STAR Panel Recommendations

The STAT presented the STAR panel with estimated medians and the percentage change relative to the pre-STAR panel base model for all requested runs.

Request 1: Investigate the influence of the delta model parameter prior on the model results by modeling a non-informative prior.
Rationale: To examine the influence of the delta model parameter prior.
Response: The STAT fit the data in the pre-STAR panel base model (including the CPFV logbook index) after changing the prior for relative stock biomass in 2000 (Delta) to a nearly uniform distribution over the interval 0.01 to 0.99 (Figure 56). The number of simulations was reduced to 100,000, resulting in less smooth posterior distributions, but provides adequate estimates of median values for purposes of this comparison. The diffuse prior had little effect on trajectories of annual median spawning biomass (Figure 57), relative biomass (Figure 58), or harvest rates (Figure 59).

Request 2: Investigate the Fmsy/M model parameter prior by 1) using a non-informative prior; and 2) using the prior based only on *Sebastes* data.
Rationale: To examine the influence of the Fmsy/M model parameter prior.
Response: The STAT compared model results based on alternative priors for Fmsy/M (Figure 60, Table 32). The prior in the base model ("Teleost" case) was compared to a prior with the same arithmetic-scale mean, but twice the log-scale standard deviation ("Twice Sigma" case). Results based on a uniform distribution with bounds (0,4) were also evaluated. Lastly, a prior derived from Zhou et al. (2012) for Scorpaenids was developed, as described below. All runs were based on 100,000 simulations.
Zhou et al. (2012) reports a median-unbiased estimate of Fmsy/M = 0.694 (SE = 0.095) for the order Scorpaeniformes. From these reported values, we construct a prior for Fmsy/M that approximates the posterior predictive distribution of Fmsy/M for Scorpaenids. If we assume the standard error of the mean-unbiased estimate is also 0.095, then the standard deviation, σ, of the data should be roughly 0.095*sqrt(35)=0.562, where 35 is the number of observed Scorpaenid species. Given this estimate of the standard deviation, the arithmetic-scale mean of the lognormal distribution is roughly $0.694*\exp(\sigma^2/2) = 0.813$. Since we want a log-scale standard deviation (the prior is lognormal), we approximated a CV of 0.562/0.813 = 0.691, which converts to a log-scale standard deviation of 0.625 using the relationship $CV=\mathrm{sqrt}(\exp(\sigma^2)-1)$. The "Zhou" prior for Scorpaenids is specified as a lognormal distribution with mean 0.813 (arithmetic scale) and log-scale standard deviation of 0.625. The alternative priors had little effect on median spawning biomass, depletion, and harvest rates (shown in Figure 61, Figure 62, and Figure 63, respectively).

Request 3: Investigate the use of a more informative prior for Bmsy/B0 based on the life history of cowcod by modeling the data-moderate prior.
Rationale: To examine the impact of a more informative Bmsy/B0 prior.
Response: The STAT compared model results based on alternative priors for Bmsy/B0 (Figure 64, Table 33). The prior in the base model was compared to a prior used in assessments of Data-Moderate (D-M) stocks completed earlier this year (PFMC, 2013). The alternative prior had little effect on spawning biomass, depletion, and harvest rates (shown in Figure 65, Figure 66, and Figure 67, respectively).

Request 4: Plot the proportion positive (in log and arithmetic space) in the regions in the CPFV index by year (with rockfish present) to see if there are spatial changes over time.
Rationale: To investigate possible hyperstability.
Response: The STAT team presented CPUE results that included only trips that caught more rockfish than all other taxa as a proxy for rocky habitat (~70,000 trips). Results of standardizing n-1 cowcod filtering and rockfish trips filtering were similar with a bit more hyperstability in the n-1cowcod data. STAT team also noted an unreliable drop in CPUE in 1998 and 1999, possibly due to changing fishery behaviors. (See request 9). STAR Panel agreed that dropping 1998 and 1999 may be reasonable pending new standardization.

Specifically, the STAT compared annual trip-based CPUEs without reference to season or location, for all of southern California combined. Two sorting approaches were compared. The first used cowcod to identify relevant trips (5287), and defined CPUE as (N-1)/ang-hr. In calculating the average CPUE, trips that caught 1 cowcod were treated as zeroes. The second sorting approach was to use rockfish as indicating relevant trips, so a trip was counted if the rockfish catch exceeded the catch of all other taxa, and the catch rate was at least 1 fish per angler (69781 trips). In this case CPUE was simply N/ang-hr (Figure 68).

Request 5: Plot the proportion (n-1) (in log and arithmetic space) of the cowcod-only trips in CPFV regions (using the dataset in the base model index).
Rationale: To investigate possible hyperstability.
Response: STAT team provided plots of CPUE by region. CPUE (N-1 per angler-hour) estimates show serial depletion based on distance from shore (Figure 69). The presence of serial depletion may be indicative of hyper-stability in the cowcod only trips.

Request 6: Plot the number of CalCOFI larvae by tow and number of tows by station (using the five-year block stratification).
Rationale: To better understand the quality of the data behind the binomial model and validate the binomial model used to represent abundance.
Response: STAT team presented the number of larvae captured and the proportion positive by station and year. 80% of positives stations are 1 larva and 13% are 2 larvae (Table 34). Proportion positive stations are also quite low (average 2.7% positive, Table 35).

Request 7: Profile on q (range from 0.375-1.5) for the visual survey.

Rationale: To determine the influence of the estimated q for the visual survey.
Response: STAT team provided results based on alternative priors for q (half and double in arithmetic space, same log-scale SD). If prior is large (1.5) data prefer a smaller q. At a q=.375 prior and posterior are similar. Prior affects scale (Figure 70) and only increasing the median of q will affect stock status (Figure 71). This request was a pure sensitivity analysis and did not provide a motivation to change from the historical base model prior.

Request 8: Provide sensitivity runs of historical catch uncertainty (recreational: pre 1981; commercial: pre 1969) by doubling and halving the catches in these years. Do these runs with and without the CPFV index included.
Rationale: To determine how historical catch uncertainty influences the production model.
Response: STAT team provided results of model runs that altered historical catch (Figure 72) and either used or dropped the CPFV index. Use of CPFV index in the model affected the scale of the population, increasing biomass and decreasing harvest rates (Figure 73, Figure 74). Higher historical catches leads to higher levels of B0 and higher depletion in 2013 (Figure 75). The converse is true for low historical catches. Changing historical catch did not greatly affect estimates of current biomass. Use of CPFV has influence on depletion for higher historical catch likely due to rejection of implausible runs at very low biomasses. The model was sensitive to assumptions about historical catch (and inclusion of CPFV index), which led to request 10.

Request 9: Based on the findings of request 4, continue filtering the data informing the CPFV index based on rockfish trips only(with further filtering criteria explored by the STAT) and including regions and seasons in the CPFV dataset to produce new delta GLM estimates of CPUE.
Rationale: To explore more representative CPUE data for cowcod.
Response: The STAT team filtered CPFV trip logs rockfish trips (>50% rockfish), the number of rockfish per angler, and no-groundfish catch to produce a dataset of rockfish trips. Data were further subdivided by non-rockfish species thought to co-occur with cowcod (~59,000 obs). Only trips with lingcod were consistently caught with cowcod, which further reduced the observations(5270 trips). This resulted in only 1088 positive cowcod trips, which was only a small fraction of the trips taking cowcod. The STAT team presented results from a delta-GLM using the reduced dataset. The binomial portion of the index indicated a decline in number of locations taking cowcod through time. CPUE of positives observations were relatively stable. STAT team concluded that using positive cowcod only trips likely produced a hyper-stable index. The STAT team recommends not using the CPFV index in the assessment model due to difficulty in getting a representative subset of CPFV observations to standardize. STAR Panel accepted this decision.

Specific steps taken to standardize the index were as follows:

- Consider years 1980 to 1999: total data set of 373975 trips
- Keep trips where rockfish were the majority of the catch (in numbers) and the number caught exceeded the number of anglers, leaving 69781 trips

- Delete trips that caught tuna, yellowfin, skipjack, Bluefin, bigeye, albacore, dolphinfish, wahoo, salmon, scallop, or lobster: 69057 trips
- Delete explanatory species if less than 1000 positive trips (deletes jack mackerel, mako shark, blue shark, white seabass, black croaker, yellow croaker, white croaker, opaleye, blacksmith, sargo) leaves 14 explanatory taxa (rockfish deleted because always present) plus cowcod.
- Remove halfmoon as an indicator—slightly positive for cowcod, but too rare to be meaningful.
- Assign blocks to regions as in previous CPFV. Trips outside assigned regions were dropped, leaving 58900 trips
- Species filtering (with region offsets) gives probability of encountering a cowcod on a trip, given the presence/absence of indicator species in catch. There are 4961 positives in the raw data, so retain the top 4961 trips (ranked in descending order by probabilities), giving a cutoff threshold of 0.205977. Take the rest of the trips at that probability level, giving 5270 retained trips. This retains 1088 positive cowcod trips and discards 3873 positive trips. This seemed questionable.

The species coefficients in the binomial model were negative for all species (counter-indicators of cowcod) except lingcod (Figure 76). The filtering was unable to recognize "cowcod effort" but it could determine if cowcod were unlikely to be encountered. Given the number of records to be retained, which is approximately equal to the original number of positives, the filter discarded the trip if anything other than lingcod was present. This resulted in 78% of the positive cowcod trips being discarded.

To complete the analysis, 5270 trips were put into a delta-GLM, and a lognormal error structure for the positive data was strongly favored by AIC. Month effects were collapsed into two "seasons": July & August, and all other months. Region effects (Figure 77) were only somewhat similar to expectations, but not satisfying (San Nicolas Island, SNI, is too low; San Pedro Channel, SPC, is too high, etc.). The index resembled the patterns previously shown for raw CPUE, with an initial decline, followed by a flat trend (Figure 78). The index was also noisy, with year-to-year variability exceeding estimated measurement error.

Examination of the two delta-GLM components is revealing (Figure 79).The main source of the declining trend is in the binomial portion, indicating that locations containing cowcod were becoming scarcer, with chances of encounter dropping by half. However the trend for the positives indicates that if cowcod were encountered, catch rates were fairly constant over much of the time period, with a slight decrease at the beginning. This combination of patterns suggests localized depletion. We can also look at the entire trip catch in the same way. The binomial portion is the same, but the positive portion shows how many fish were caught by all of the anglers on the trip (Figure 80).The trend is a gradual decline from about 6 fish to about 4 fish per trip, with some leveling toward the end. The last two points raise a suspicion that the number of cowcod may have been under-reported. Taken together, these patterns suggest that use of positive cowcod trips is likely to produce a hyperstable index.

Request 10: Provide a table of all likelihood components for alternative historical catch scenarios.
Rationale: To get a better understanding of model fits to these alternative catch scenarios.
Response: The STAT team presented the distribution of total and component likelihoods for models fit assuming the base level of historical catch and 0.5x and 2x levels of catch (Figure 81 to Figure 87). There were essentially no differences in the fit to the data for each of the catch series indicating the data cannot provide information of the magnitude of historical catches.

Request 11: Examine the sensitivity to the assumption of time-lagged (i.e., knife-edge) maturity and selectivity with 8-year and 14-year time lags.
Rationale: To explore the sensitivity to a reasonable range of time lag assumptions.
Response: STAT team presented SSB and depletion from models with alternative time-lagged maturity and found it did make a difference. A shorter time lag resulted in SSB that was smaller and less depleted and converse for longer time-lag (Figure 88). Depletion was 33%, 39% and 29% depletion for base, a_{mat} =8 yr and a_{mat} 14 yr (Figure 89). Harvest rates were only slightly affected, with higher rates for shorter time lags (Figure 90). The STAT team recognized that the model results are sensitive to this assumption but noted that the current assumption is consistent with available data. STAR panel is in agreement with keeping this assumption for the base model.

Based on discussion from preceding requests and original documentation, the STAT team and STAR panel agreed to a base model that was the same as the original model except for the removal of the CPFV index. The final base model includes the following likelihood components:

- Visual (submersible) Survey of CCA (biomass estimate with prior on q)
- CalCOFI larval abundance index (fraction positive)
- NWFSC Trawl fraction positive index
- NWFSC Hook and Line Survey catch-per-drop index
- Sanitation District Trawl fraction positive index

Request 12: Present base model with 10-year projection with 3mt future catch. Provide the full diagnostics, especially the fit to the indices. Present a series of runs with each index included as the only index in the model.
Response: The STAT presented results of the base model described above to the STAR Panel, with 20-year projections assuming 1.5 mt catch in the SCB (one half the combined ACL for the Conception and Monterey INPFC areas). Base model results are described in Section 2.6.

Models fit to single indices are generally consistent with the revised base model that is fit to all 5 fishery-independent indices, with respect to the scale of median spawning biomass (Figure 91). Median biomass in 2013, as a percentage of unfished biomass, is about 34% for the base model, bracketed by fitting only the Sanitation District index (22%) and only the CalCOFI index (48%) (Figure 92). Interestingly, the base model has the lowest estimate of median unfished biomass when compared to the 'individual' model fits, and accordingly the highest harvest rates (peaking over 50%; Figure 93).

2.6 Base-Model Results

Nine parameters are estimated in the XDB-SRA base model (Table 36). These include the four parameters in the population dynamics equation (natural mortality rate, M [yr^{-1}], the ratio of the MSY fishing mortality rate to natural mortality rate, F_{MSY}/M, relative biomass producing MSY, B_{MSY}/B_0, and "delta" (Δ) = $1-B_{2000}/B_0$), a catchability coefficient for the visual transect survey, and additive variance parameters for all indices except the visual transect survey. The marginal posterior density for the natural mortality rate, M, is similar to the prior, with a median of 0.054. The posterior for F_{MSY}/M shows a slight shift toward higher values, relative to the prior (median $F_{MSY}/M = 1.05$). The posterior distribution for the visual survey q has an (arithmetic scale) median of 0.746, very similar to the analysis presented in the 2005 assessment (Piner et al. 2005, Appendix IV), which found that approximately 75% of cowcod biomass was in the CCA. This result differs from previous assessments, in which the posterior for *q* suggested the survey over-counted cowcod biomass by 2-3 times (due to the influence of the aggregated CPFV logbook index). The STAT considers the current estimates of survey q to be more credible, particularly given the potential issues associated with aggregated CPFV logbook data (e.g. hyperdepletion and difficulty in defining effective effort for cowcod). The two long-term fishery-independent indices (CalCOFI and the Sanitation District) are more variable than the short-term indices (NWFSC trawl and hook-and-line), resulting in larger median estimates of additive variance.

Median 2013 spawning biomass in the base model is below target biomass, but above the minimum stock size threshold (Figure 94), with tails of the distribution extending below the MSST and above target biomass (Table 37). The data in the base model considerably reduce uncertainty in stock status, relative to the prior distributions (Figure 95). The median estimate of depletion in 2013 from the base model is 33.9% with 2.5th and 97.5th percentiles of 15% and 67%, respectively (Table 37, Figure 96).

The base model suggests that median harvest rates around 1930 were near the MSY rate, then declined due to shifts in fishing effort and WWII (Figure 97). Following the war, catch rates slowly increased until about 1970, then rose quickly to a maximum of approximately 54% of vulnerable biomass in the mid-1980s. The model-estimated MSY harvest rate is 5.5%, similar to the proxy ($B_{40\%}$) harvest rate of 5% (Table 37), but higher than the SPR harvest rate in the 2009 assessment (2.7%). Median harvest rates were roughly 8-10 times the median MSY harvest rate in the mid-1980s, then declined to near zero after 2000, followed by steady increases in stock biomass (Figure 98).

The bivariate posterior distribution for F_{MSY}/M and B_{MSY}/B_0 (Figure 99) shows a slight shift toward higher values of F_{MSY}/M, overall, with a slight negative correlation between F_{MSY}/M and B_{MSY}/B_0. One third of the posterior parameter vectors support B_{MSY} values greater than 50% of unfished biomass (the limit at which productivity goes to zero under the Beverton-Holt and Ricker stock-recruitment relationships). Trajectories generated from the prior predictive distributions were increasingly rejected as values of B_{MSY}/B_0 exceeded 0.7 (Figure 100, dotted and dashed lines in bottom left panel). However, the fishery-independent data sources in the base model clearly update B_{MSY}/B_0 relative to the "post-model, pre-data" distribution, and favor values of B_{MSY} near the proxy biomass target of $B_{40\%}$ (Figure 100, solid line in bottom left panel). Rejection regions for F_{MSY}/M and M were insignificant, as were rejection regions for Delta except for trajectories that were extremely depleted in 2000 (comparing dotted and dashed lines in Figure 100). The posterior distribution for stock depletion in the year 2000 (“Delta”) shows the greatest amount of updating relative to the prior, but the data contain little information about natural mortality, *M*, producing a posterior distribution similar to the prior (Figure 100).

No strong correlations are evident between parameters in the population model (Figure 101). The model predicts higher values of unfished biomass for lower values of B_{MSY}/B_0 (Figure 102) and greater maximum yields (as a fraction of B_0) for higher B_{MSY}/B_0 (Figure 103). This pattern is possible due to the generalized production curve, which decouples the location of maximum production (B_{MSY}/B_0) from its magnitude.

The Bayesian model does not identify a single, most likely trajectory, and therefore presentation of the distribution of yield curves is something the STAT continues to refine. We plotted percentiles (2.5%, 50%, and 97.5%) of production over a grid of values for B_{MSY}/B_0 (Figure 104). Medians of the marginal distributions for MSY and B_{MSY}/B_0 (red dot in Figure 104) do not correspond to the peak of any particular trajectory, but the data and model clearly support a range of possibilities, with peak production occurring over a wide range of biomass levels relative to unfished biomass.

The posterior distributions for the additive variance components provide some information about which indices are best fit by the biomass dynamics (Figure 105). The model fits the two NWFSC indices with little need for added variance, but adds considerable variance to the CalCOFI and Sanitation District indices. This is due, in part, to the fluctuations in the early part of the CalCOFI index and the first year of the Sanitation District index. Larger additive variance estimates reduce the influence of the two long-term indices in the model.

As mentioned before, the posterior distribution for catchability of the visual survey is very consistent with the prior, suggesting the survey observed roughly 75% of the SCB biomass (Figure 106). Catchability parameters for the other indices were integrated across a uniform prior for log(q), but distributions of calculated values are shown for reference. Apart from the expected relationship between catchability and stock status (Delta), no strong correlations were apparent between model parameters (Figure 107).

2.6.1 Fits to Indices of Abundance

We illustrate how the base model scales the various time series of relative abundance by plotting each index divided by its median *q* (i.e. rescaled to biomass units) over time (Figure 108). The relative precision of each index, specifically the effect of the larger additive variance estimates in the CalCOFI and Sanitation District indices, is evident through comparison of posterior predictive biomass intervals for all indices (Figure 109).

For each individual data source, we present two figures comparing predicted biomass to the index. We first compare log-scale biomass to the log-scale index with error bars, and then show the index observations relative to 90% posterior predictive intervals and the expected biomass.

The fit to the NWFSC trawl survey index does not show any obvious patterns in the residuals, and all observations are within the predictive intervals (Figure 110, Figure 111).

The model does not match the rate of decline suggested by the first time-blocked point in the Sanitation District (SCCWRP) trawl survey index (Figure 112, Figure 113). The last four observations are below the posterior median, but all observed points fall within the posterior predictive intervals.

The fit to the NWFSC hook and line index is quite good, with no strong trends in the residuals (Figure 114, Figure 115). The first observation (survey year 2004) is at the lower edge of the predictive interval.

The biomass dynamics in the model are unable to match the variability of the CalCOFI index, but the long-term trend is consistent with the other data sources (Figure 116, Figure 117). The model predictions pass between the lower observations in the 1950s and the higher estimates from the late 1960s and 1970s, and do not match the rate of increase suggested by the index in later years. The amount of added variance reduces the influence of this index, relative to other data sources.

The posterior median estimate for the visual survey almost exactly matches the observed biomass estimate (Figure 118, Figure 119).

2.6.2 Discard

Discard in years prior to 2001 is assumed to be zero in the commercial fleet, and is part of the A+B1 catch estimate obtained from RecFIN. Ally et al. (1991) report 100% retention of cowcod recorded by onboard observers in the Southern California CPFV fishery between 1985 and 1987. Beginning in 2001, WCGOP estimates of total commercial mortality are combined.

2.7 Uncertainty and Sensitivity Analyses

Uncertainty in the Bayesian Model is represented by the posterior distributions for the model parameters. These distributions reflect uncertainty in the generalized production function, but likely underestimate uncertainty due to assumption of deterministic population dynamics in each posterior trajectory.

2.7.1 Uncertainty in commercial catch reconstruction data

Dick et al. (2007) expressed concern that the proportion of cowcod estimated from port sample data in the 1980s might not be representative of species compositions in earlier years. In particular the 5-year average proportion of cowcod observed in the Los Angeles hook and line fishery (12.85%) seemed high, despite the relatively large number of samples supporting the estimate. A sensitivity analysis based on a 50% reduction in the assumed proportion of cowcod in this fishery was prepared for the draft assessment, but was extended as part of STAR Panel Request #8 to include a wider range of historical catch levels (see section 2.5).

2.7.2 Alternative Prior Distributions

Sensitivity of model results to alternative prior distributions are described in the Responses to STAR Panel Requests (see Requests 1, 2, and 3 in section 2.5).

2.7.3 Influence of Individual Indices on Model Results

To evaluate the influence of each index on the base model results, we removed one index at a time and re-ran the model. Removing the CalCOFI index has the greatest effect, increasing median unfished spawning biomass to about 1900 mt, and reducing median depletion (2013 biomass as a percentage of unfished) to 22% (Figure 120 and Figure 121). Removing the Sanitation District index has the next largest effect, this time reducing unfished stock biomass to just above 1400 mt, with 2013 stock status above target (41% of unfished). Peak median harvest rates are lower when the CalCOFI index is removed (45%) and highest when the NWFSC Trawl survey index was removed (59%) (Figure 122).

2.7.4 Retrospective Analysis

We evaluated the sensitivity of the model to recent data by truncating time series of relative abundance and refitting the model. We truncated data in two blocks (first including data through 1999, then through 2004) and compared results to the base model. Time series of catch through 2012 were retained in the model, effectively serving as forecasts in the runs with truncated data.

Truncating the time series had little effect on the scale of the population, even back to1999 (Figure 123). Median relative biomass in 2013 decreased from 34% in the base model to 28% and 26% when the data were truncated to 2004 and 1999, respectively (Figure 124). The change in depletion is caused by removing the increasing trends in recent years. Median harvest rates estimated using the truncated data sets were very similar to the base model (Figure 125).

3 Reference Points

3.1.1 Base Model Parameter Estimates

The data in the cowcod base model are most informative about stock status (relative biomass), as seen by the reduction in variance relative to the prior (Figure 100, lower right panel). The posterior distribution for Delta did not change when a less informative (nearly uniform) prior was used, demonstrating that estimates of stock status are driven by the data, not the priors. The location of B_{MSY} relative to unfished biomass (B_0) had a posterior median near the PFMC proxy for B_{MSY}, with considerable support for values greater than 0.5. The posterior distribution for Fmsy/M was only slightly shifted toward larger values (median of 1.05), and the posterior for natural mortality changed little from the prior. Additive variance parameters were larger for the longer time series, reducing the influence of these data sources. Finally, the posterior distribution of the catchability coefficient for the visual survey was centered almost exactly on the prior mean, with a slightly reduced variance relative to the prior. See Table 36 for summary statistics of the estimated model parameters.

3.1.2 Base Model Reference Points

Reference points for the base model describe a smaller, more productive stock than in past cowcod stock assessments (Table 37). Median unfished and current (2013) spawning biomasses are 1549 mt and 524 mt, respectively. Stock depletion is 33.9% of unfished biomass. Reference points based on model-estimated parameters are only slightly higher than the $B_{40\%}$ proxy values (Table 37).

3.1.3 Base Model Time Series

Time series of median age 11+ biomass, spawning stock biomass, depletion, exploitation rate, and relative exploitation rate, are provided in Table 38.

4 Harvest Projections and Decision Tables

Harvest projections presented in this assessment are preliminary and will be replaced by a separate rebuilding analysis.

The STAT prepared a decision table using low, medium, and high states of nature defined as the 12.5%, 50%, and 87.5% percentiles of the posterior distributions. A range of fixed catch alternatives with sufficient contrast was selected to illustrate the implications of alternative management actions under the three states of nature (see Table f in the Executive Summary).

5 Regional Management Considerations

Cowcod OFLs are estimated as the sum of the assessment for the Southern California Bight, and a DB-SRA yield estimate for the “northern” area, between Point Conception and Cape Mendocino. Details related to the calculation of the OFL for the northern area are provided as Appendix C.

6 Research Needs

1. Investigate stock structure of cowcod in adjacent areas, especially the population in waters off Mexico.
2. Reinvestigate the CPFV data to attempt to produce a CPUE time series to be used as an index of relative abundance. CPFV has a historical basis for inclusion and produces time-series that has a smaller interannual variability than other indices.
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.
4. Investigate methods to include uncertainty in historical catches in the modeling.
5. Evaluate methods used to reconstruct historical catches of cowcod and other rockfish.
6. The STAT team expressed the most confidence in the NWFSC Hook-and-Line and visual surveys. The STAT and STAR panel recommend continuing these indices into the future and extending the survey into the CCAs.
7. Consider using F_{MSY}/M priors based on rockfish rather than teleosts.

7 Acknowledgments

The STAT would like to thank Tom Jagielo, STAR panel chair, and other members of the panel (Kevin Piner, Beatriz Roel, and Yan Jiao), as well as Advisory Panel members Bob Leos (GMT), Gerry Richter (GAP), and John DeVore (PFMC) for their insightful comments and suggestions during the review process. We also thank Stacey Miller for her assistance with document distribution, communication with the panel, and other important preparatory steps prior to the meeting.

Special thanks to Shelly Walther and Bill Furlong from the Los Angeles County Sanitation District, Hai Nguyen and Jeff Armstrong from the Orange County Sanitation District, Curtis Cash and Craig Campbell from the City of Los Angeles Environmental Monitoring Division and Tim Stebbins from the City of San Diego Marine Biology Laboratory for their help in obtaining and interpreting data from the southern California Bight sanitation district surveys.

Other contributors of data essential to the assessment include John Harms and Jim Benante (Hook and Line survey data), Beth Horness (NWFSC trawl survey data), Jason Jannot (WCGOP mortality estimates), John Hess, Carlos Garza, and Libby Gilbert (genetic stock structure information), Mary Yoklavich (visual survey), Don Pearson (cowcod age estimates and commercial landings), Keith Sakuma (SWFSC juvenile rockfish survey), and Kevin Stierhoff (description of forthcoming cowcod ROV survey).

8 Literature Cited

Ally, J., D. Ono, R Read, and M. Wallace. 1991. Status of major Southern California marine sport fish species with management recommendations, based on analyses of catch and size composition data collected on board commercial passenger fishing vessels from 1985 through 1987. California Department of Fish and Game, Marine Resources Division, Administrative Report No. 90-2. May, 1991. 376 p.

Beverton, R. J. H. 1992. Patterns of reproductive strategy parameters in some marine teleost fishes. Journal of Fish Biology 42(Supplement B):137-160.

Butler, J. L., L. D. Jacobson and J.T. Barnes. 1999. Stock assessment of cowcod rockfish. In: Pacific Fishery Management Council. 1999. Appendix: Status of the Pacific Coast Groundfish Fishery through 1999 and recommended biological catches for 2000: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, Oregon, 97201.

CALCOM (California Cooperative Survey: CDFG, Belmont, CA; PSMFC, Belmont, CA; NMFS, Santa Cruz, CA)

California Department of Fish and Game, Fish Bulletins No. 1 – 178 are available online at http://ceo.ucsd.edu/fishbull/

Collins and Crooke (unpublished manuscript). An evaluation of the commercial passenger fishing vessel record system and the results of sampling the Southern California catch for species and size composition, 1975-1978.

Cope, J.M., J. DeVore, E.J. Dick, K. Ames, J. Budrick, D. Erickson, J. Grebel, G. Hanshew, R. Jones, L. Mattes, C. Niles, S. Williams. 2011. An approach to defining species complexes for U.S. west coast groundfishes using vulnerabilities and ecological distributions. North American Journal of Fisheries Management 31: 589-604.

Deriso, R. B. 1980. Harvesting strategies and parameter estimation for an age-structured model. Canadian Journal of Fisheries and Aquatic Sciences 37: 268-282.

Dick, E.J., S. Ralston, and D. Pearson. 2007. Status of cowcod, Sebastes levis, in the Southern California Bight. Pacific Fisheries Management Council, Portland, OR. December, 2007.

Dick, E. J. 2009. Modeling the Reproductive Potential of Rockfishes (Sebastes spp.) doctoral dissertation, University of California, Santa Cruz, 239 p.

Dick, E.J., S. Ralston, and D. Pearson. 2009. Updated status of cowcod, Sebastes levis, in the Southern California Bight. Pacific Fisheries Management Council, Portland, OR. June 2009.

Dick, E. J. and A. D. MacCall. 2011. Depletion-Based Stock Reduction Analysis: A catch-based method for determining sustainable yields for data-poor fish stocks. Fisheries Research 110: 331-341.

Frey, H. W., ed. 1971. California's living marine resources and their utilization. California Department of Fish and Game. 148 pp.

Hess, J., P. Chittaro, A. Elz, E. Gilbert-Horvath, V. Simon, and J. Garza. 2014. Cryptic population structure in the severely depleted cowcod, *Sebastes levis*. Canadian Journal of Fisheries and Aquatic Sciences 71(1): 81-92.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 81: 898-903.

Love, M., P. Morris, M. McCrae, and R. Collins. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the Southern California Bight. NOAA Technical Report NMFS 87, 38 p.

Love, M. S., M. Yoklavich, and L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley.

Piner, K., E. Dick, and J. Field. 2005 Stock Status of Cowcod in the Southern California Bight and Future Prospects. Pacific Fishery Management Council, Portland, Oregon. May 25, 2005. 107 p.

MacCall, A. D. 2002. Fishery-management and stock-rebuilding prospects under conditions of low frequency environmental variability and species interactions. Bull. Mar. Sci. 70:613-628.

Methot, R. and C. Wetzel. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management, Fisheries Research 142: 86-99.

Miller, D.J. and D. Gotshall. 1965. Ocean sportfish catch and effort from Oregon to Point Arguello, California: July 1, 1957-June 30, 1961. Calif. Dept. Fish and Game, Fish Bull. 130. 135 p.

Monk, M. E. Dick, E. Hibsch, D. Pearson. (in prep.) Documentation of a Relational Database for the California Recreational Fisheries Survey Onboard Sampling Program.

Ralston, S. D. Pearson, J. Field, and M. Key. 2010. Documentation of the California catch reconstruction project. NOAA Technical Memorandum NMFS 461, 80 p.

Rogers, J. B. M. Wilkins, D. Kamikawa, F. Wallace, T. L. Builder, M. Zimmerman, M. Kander, and B. Culver. 1996. Status of the remaining rockfish in the Sebastes complex in 1996 and recommendations for management in 1997. Appendix E In Pacific Fishery Management Council Status of the Pacific coast groundfish fishery through 1996 and Recommended Acceptable Biological Catches for 1997. Pacific Fishery Management Council, Portland, OR. 59 p

Rubin, D.B. 1988. Using the SIR algorithm to simulate posterior distributions. Bayesian Statistics 3: Proceedings of the Third Valencia International Meeting, June 1-5, 1987. Clarendon Press, Oxford.

Schnute, J. 1985. A general theory for analysis of catch and effort data. Can. J. Fish. Aquat. Sci. 42: 414-429.

Stephens, A. and A. MacCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. Fisheries Research 70: 299-310.

Walters, C., and J. F. Kitchell. 2001. Cultivation/depensation effects on juvenile survival and recruitment: implications for the theory of fishing. Can. J. Fish. Aquat. Sci. 58: 39–50

Yoklavich, M., M. Love, and K. Forney (2007). A fishery-independent assessment of an overfished rockfish stock, cowcod (Sebastes levis), using direct observations from an occupied submersible. Canadian Journal of Fisheries and Aquatic Sciences 64(12): 1795-1804

9 Tables

Table 1. Total mortality (mt) of cowcod by year and area. Commercial mortality estimates (retained + discarded catch) are from the West Coast Groundfish Observer Program and recreational estimates are from RecFIN (weight of catch types A and B1).

	COMMERCIAL		RECREATIONAL					
YEAR	North of 34° 27′	South of 34° 27′	North of 34° 27′	South of 34° 27′	TOTAL	OFL	ABC	OY (ACL)
2003	0.22	0.00	--	0.48	0.70	--	24	4.8
2004	0.54	0.41	--	0.45	1.40	--	24	4.8
2005	1.15	0.00	--	0.15	1.30	--	24	4.2
2006	2.20	0.00	--	0.07	2.27	--	24	4.2
2007	1.93	0.10	0.19	0.11	2.33	--	36	4
2008	0.48	0.00	--	0.25	0.73	--	36	4
2009	1.45	0.00	--	0.21	1.66	--	13	4
2010	1.00	0.00	0.02	0.17	1.20	--	14	4
2011	0.02	0.00	--	0.83	0.85	13.00	8	(3)
2012	0.00	0.00	0.02	0.82	0.84	13.00	8	(3)
Grand Total	**9.00**	**0.51**	**0.23**	**3.53**	**13.28**			

Table 2. Estimated cowcod removals (1900-1956) in the SCB, by year and data source.

Year	Dick et al. Comm. Recon.	CALCOM	WCGOP	Ralston et al. Rec. Recon.	RecFIN	TOTAL
1900	0.01					0.01
1901	5.34					5.34
1902	10.68					10.68
1903	16.01					16.01
1904	21.35					21.35
1905	26.68					26.68
1906	32.02					32.02
1907	37.35					37.35
1908	42.68					42.68
1909	48.02					48.02
1910	53.35					53.35
1911	58.69					58.69
1912	64.02					64.02
1913	69.35					69.35
1914	74.69					74.69
1915	80.02					80.02
1916	85.36					85.36
1917	137.73					137.73
1918	125.59					125.59
1919	75.1					75.10
1920	81.57					81.57
1921	71.26					71.26
1922	70.11					70.11
1923	93.94					93.94
1924	125.94					125.94
1925	138.15					138.15
1926	171.48					171.48
1927	142.3					142.30
1928	111.3			0.05		111.35
1929	102.48			0.11		102.59
1930	126.78			0.16		126.94
1931	160.8			0.22		161.02
1932	109.27			0.27		109.54
1933	81.64			0.33		81.97
1934	70.36			0.38		70.74
1935	52.56			0.44		53.00
1936	20.19			0.44		20.63
1937	24.22			0.66		24.88
1938	18.08			0.63		18.71
1939	21.5			0.51		22.01
1940	23.28			0.41		23.69
1941	29.1			0.38		29.48
1942	10.4			0.2		10.60
1943	12.18			0.19		12.37
1944	1.83			0.16		1.99
1945	4.38			0.21		4.59
1946	11.3			0.36		11.66
1947	17.58			1.18		18.76
1948	26.87			3.05		29.92
1949	35.05			3.63		38.68
1950	39.37			4.63		44.00
1951	45.57			3.62		49.19
1952	31.05			5.62		36.67
1953	24.88			6.33		31.21
1954	34.05			12.76		46.81
1955	27.62			24.43		52.05
1956	37.8			27.37		65.17

Table 3. Estimated cowcod removals (1957-2012) in the SCB, by year and data source.

Year	Dick et al. Comm. Recon.	CALCOM	WCGOP	Ralston et al. Rec. Recon.	RecFIN	TOTAL
1957	38.43			17.25		55.68
1958	43.54			12.82		56.36
1959	45.09			7.21		52.30
1960	49.18			7.87		57.05
1961	50.05			9.99		60.04
1962	37.92			10.11		48.03
1963	47.21			10.13		57.34
1964	36.07			15.82		51.89
1965	50.97			19.11		70.08
1966	47.41			29.22		76.63
1967	63.22			39.15		102.37
1968	63.87			41.15		105.02
1969		95.00		30.13		125.13
1970		55.93		39.92		95.85
1971		68.07		38.03		106.10
1972		102.52		50.1		152.62
1973		108.81		62.98		171.79
1974		114.28		69.38		183.66
1975		112.49		70.06		182.55
1976		131.38		57.97		189.35
1977		132.46		58.77		191.23
1978		147.77		55.41		203.18
1979		187.55		74.6		262.15
1980		142.65		80.98		223.63
1981		189.42			26.55	215.97
1982		230.52			96.99	327.51
1983		161.92			15.13	177.05
1984		206.66			21.22	227.88
1985		172.12			35.99	208.11
1986		148.37			45.99	194.36
1987		76.64			29.14	105.78
1988		86.62			13.91	100.53
1989		17.87			20.79	38.66
1990		10.41			20.06	30.46
1991		7.10			19.32	26.42
1992		17.22			18.58	35.80
1993		14.85			9.68	24.54
1994		13.63			26.01	39.65
1995		23.30			1.75	25.05
1996		24.58			5.36	29.93
1997		7.30			1.85	9.15
1998		1.21			2.81	4.03
1999		3.47			3.77	7.24
2000		0.45			4.49	4.94
2001			0.09		0.49	0.58
2002			0.09		0.49	0.58
2003			0.00		0.48	0.48
2004			0.41		0.45	0.86
2005			0.00		0.15	0.15
2006			0.00		0.07	0.07
2007			0.10		0.11	0.21
2008			0.00		0.25	0.25
2009			0.00		0.21	0.21
2010			0.00		0.17	0.17
2011			0.00		0.83	0.83
2012			0.00		0.82	0.82

Table 4. Regional rockfish landings (metric tons) from CDF&G Fish Bulletin No. 105 (1958) and the NMFS SWFSC ERD Live-Access Server (http://las.pfeg.noaa.gov/LAS/CA_market_catch.html).

	CDF&G Fish Bulletin No. 105			NMFS ERD Live Access 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 5. 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 NMFS SWFSC ERD Live Access 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 6. 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 7. 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	15	485	19	492
1985	19	514	6	196	38	1098	19	739
1986	43	1335	5	215	38	1262	64	2388
1987	3	99	7	315	37	1422	55	2007
1988	15	537	0	0	9	316	25	848

Table 8. List of differences in cowcod landings between CALCOM and PacFIN and probable cause (sorted by absolute differences in descending order). Error Type Codes: SP = species composition in PacFIN different than in CALCOM, CE=possible error in CALCOM from manual updating, UK=could not determine source of error.

YEAR	CALCOM	PACFIN	% DIFF	abs(P-C)	Error Type
1984	555163	531002	-4%	24161	SP
1982	568623	554153	-3%	14470	SP
1981	473878	486180	3%	12302	SP
1989	86888	96293	11%	9405	SP
1998	37927	43190	14%	5263	SP
1985	410038	404775	-1%	5263	SP
1997	118010	123169	4%	5159	SP
1999	22932	27275	19%	4343	SP
1988	217735	221431	2%	3696	CE
1995	146984	149661	2%	2677	SP
1986	357810	355186	-1%	2624	CE
1996	108060	110493	2%	2433	SP
1994	79237	77129	-3%	2108	SP
1983	401369	402476	0%	1107	SP
1991	58926	59530	1%	604	UK
2001	1767	2118	20%	351	UK
1990	76118	75926	0%	192	
2000	3069	3217	5%	148	UK
2002	217	356	64%	139	UK
1992	131644	131511	0%	133	
1987	191054	190969	0%	85	
1993	103657	103635	0%	22	
2003	112	113	1%	1	
2004	68	68	0%	0	
2005	85	85	0%	0	
2006	0	0		0	
2007	888	888	0%	0	
2008	0	0		0	
2009	135	135	0%	0	
2010	66	66	0%	0	
2011	32	32	0%	0	

Table 9. Length composition sample sizes (number of trips and number of cowcod) from a 1970s onboard CPFV sampling program in the Southern California Bight.

CPFV observer data, Nov-Apr only		
Shift year	**No. Trips**	**No. Cowcod**
1974	11	47
1975	105	318
1976	70	303
1977	62	276
1978	12	68

Table 10. Number of cowcod ages by region, source, and year (see separate tables for age data from NWFSC trawl and hook-and-line surveys).

South of Point Conception

Source	Region	Year	Number of ages
CALCOM	So. CA	1985	34
CALCOM	So. CA	1986	30
Butler "Sport"	So. CA	1975	17
Butler "Sport"	So. CA	1976	60
Butler "Sport"	So. CA	1977	29
Butler "Sport"	So. CA	1978	19
Butler "Sport"	So. CA	1979	1
Butler "Sport"	So. CA	1980	1
Butler "Sport"	So. CA	1981	2
Total			**193**

North of Point Conception

Source	Region	Year	Number of ages
CALCOM	No. CA	1982	4
CALCOM	No. CA	1983	3
CALCOM	No. CA	1984	25
CALCOM	No. CA	1985	11
CALCOM	No. CA	1986	1
SWFSC/FED GF Ecology	No. CA	2001	3
SWFSC/FED GF Ecology	No. CA	2002	56
SWFSC/FED GF Ecology	No. CA	2003	18
SWFSC/FED GF Ecology	No. CA	2004	31
SWFSC/FED GF Ecology	No. CA	2005	11
SWFSC/FED GF Ecology	No. CA	2006	1
Triennial Survey	No. CA	2004	14
Slope Survey	No. CA	2002	15
Total			**193**

Table 11. Monthly distribution of cowcod samples in CalCOFI surveys

	11	12	1	2	3	4	5	6	7	8	9	10	Total
Npos	4	5	66	49	27	31	16	10	4	0	0	1	213
Nsamp	1246	579	2618	1780	1368	2972	1591	1057	2420	1125	677	1863	19296
fracpos	0.3%	0.9%	2.5%	2.8%	2.0%	1.0%	1.0%	0.9%	0.2%	0.0%	0.0%	0.1%	

Table 12. Date distribution of CalCOFI samples in southern California waters. Horizontal lines indicate time blocks used for abundance index.

Year\Date	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	Total
1951							16	3		17	1	4	12		13	8		15	2	10		10		111
1952		13	4				11	10	5	16		20		8	16			28	3	7	38			179
1953						20	12	3	30			26	5		29	8	8	24	13	17	41			236
1954		12	16			35		6	29			34			13	26		5	35		12	24		247
1955		15	20			9	14		9	12		12	11		17	7			6	24	8	25		189
1956		14	10			23		6	18			24	1		4	23		33		18	14			188
1957			30						27			16	11		15	13		33			34			179
1958	28		3	10			5	16	25		10	22		6	23	7	7	27		3	24	7		223
1959	22	4	25				13	17	12	12	11	10	5	5	7	30		37			23	14		247
1960	26	2	16	13		27	6			17	13	8	22	16	21				18	7		29	7	248
1961						7	6	13	14						7	25	2						6	80
1962						6	1	27					7		26	1								68
1963						8	1	27							21	12	7							76
1964						15	9	2	30						8	30						26	2	122
1965							26	14						15	24							24		103
1966						1	7	12	8	37				31	4		6	37				29	8	180
1967		8	29																			13	15	65
1968						12	24														29	8		73
1969						15	21		7	28		2		1	35			36						145
1970		35	1																					36
1972						8	22		35			3	31		6	7								112
1975		54				24	19	8			8	53						8	43	2			16	235
1976			28																					28
1978			8	24		4	40			10	20	7		7	27	1			10	28		8	4	198
1979						1	29			19	13				17	14	13	12	7					125
1980										3	26									30				59
1981		21	12				31	2		2				13	40	12			20	12				165
1982													19	12										31
1983													20	12										32
1984					1	31				15	13	7			15	16				20		13		131
1985										5	26						6	20	6					63
1986						8	6	2	14	16								13	20					79
1987	16										7	24					7	26						80
1988	22	4					10	23									10	21						90
1989							7	26								21	12							66
1990											2	20	12			20	10							64
1991						14	20				15	16												65
1992								16	16						7	22	4							65
1993						7	27							9	25									68
1994							7	27					7	26	1									68
1995						21	12								22	9								64
1996								10	24							20	11							65
1997								14	20					7	15	8								64
1998			7				7	17	8			7	1	7	22	5			8			12		101
1999	11		8	2		10	23							7	26									87
2000						14	20								20	14							7	75
2001						15	16								22	12								65
2002							3	20	10					21	12									66
2003	13							9	23	1				2	21	11								80
2004						22	11						7	25	1									66
2005					2	19	10									22	14							67
2006	1							4	21	9				7	29									71
2007						7	20	9						7	22								7	72
2008						17	17							21	5									60
2009						19	17					18	18											72
2010	8					7	14	13							9		22	8	3					84
2011						7	21	8							7	35								78
Total	147	182	217	49	3	433	581	364	385	219	165	333	189	265	654	439	139	383	194	178	223	242	72	6056

Table 13. Sample sizes associated with intra-year SEASONS and LOCATIONS.

	Samples					Positives				
Location	EARLY	MID	LATE	Total		EARLY	MID	LATE	Total	fracpos
8050	97	40	97	234		5	3	4	12	5.1%
8055	69	35	83	187		6	2	0	8	4.3%
8060	76	36	82	194		0	1	1	2	1.0%
8144	45	14	40	99		2	0	1	3	3.0%
8342	182	103	216	501		7	9	6	22	4.4%
8351	66	34	78	178		4	4	5	13	7.3%
8355	59	32	79	170		5	3	1	9	5.3%
8360	66	39	82	187		1	3	1	5	2.7%
8733	109	56	133	298		3	2	1	6	2.0%
8740	63	35	81	179		2	4	1	7	3.9%
8745	59	30	77	166		3	1	2	6	3.6%
8750	60	33	84	177		6	4	8	18	10.2%
8755	60	29	77	166		0	0	3	3	1.8%
8760	114	65	183	362		1	1	0	2	0.6%
9028	83	41	92	216		0	1	2	3	1.4%
9030	82	43	96	221		0	3	0	3	1.4%
9037	107	49	119	275		2	1	1	4	1.5%
9045	72	39	88	199		1	1	0	2	1.0%
9050	86	41	108	235		1	1	0	2	0.9%
9060	75	40	88	203		0	1	2	3	1.5%
9330	144	69	178	391		2	1	4	7	1.8%
9335	55	24	79	158		0	1	2	3	1.9%
9340	68	37	87	192		0	1	3	4	2.1%
9350	68	36	87	191		0	3	3	6	3.1%
9355	113	58	166	337		1	0	1	2	0.6%
Total	2078	1058	2580	5716		52	51	52	155	2.7%
fracpos	2.5%	4.8%	2.0%	2.7%						

Table 14. Cowcod abundance indexes from CalCOFI surveys.

Year	Index	Std. Error	CV	log.sd
1953	0.0301	0.00619	0.211	0.209
1958	0.0231	0.00483	0.219	0.216
1963	0.0293	0.00868	0.310	0.303
1968	0.0811	0.01462	0.188	0.187
1974	0.0441	0.01157	0.265	0.261
1986	0.0028	0.00129	0.461	0.439
1999	0.0138	0.00493	0.457	0.435
2004	0.0201	0.00706	0.366	0.355
2009	0.0443	0.01164	0.276	0.270

Table 15. 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	2	2	2	2	2				10
1971	2	2	2	2	2				10
1972	2	2	2	2	2				10
1973	2	2	2	2	2				10
1974	2	2	2	2	2				10
1975	2	2	2	2	2				10
1976	2	2	2	2	2				10
1977	2	2	2	2	2				10
1978	2	2	2	2	2				10
1979	2	2	2	2	2	2			12
1980	2	2	2	2	2	2			12
1981	2	2	2	2	2	2			12
1982	2	2	2	2	2	2			12
1983	2	2	2	2	2	2			12
1984	2	2	2	2	2	2			12
1985	4	4	4	4		4			20
1986	4	4	4	4		4			20
1987	4	4	4	4		4			20
1988	4	4	4	4		4			20
1989	4	4	4	4		4			20
1990	4	4	4	4		4			20
1991	6	4	4	4		4			22
1992	6	4	4	4		4			22
1993	6	4	4	4		4			22
1994	4	4	2	4		2			16
1995	4	4	4	4		4			20
1996	4	4	4	4		4			20
1997	4	4	4	4		4		2	22
1998	5	4	4			4	5	4	26
1999	6	4	4	3		4	6	4	31
2000	6	4	4			4	6	4	28
2001	6	4	5			4	6	4	29
2002	6	4	6			4	6	4	30
2003	6	4	6			4	6	4	30
2004	6	4	6			4	6	4	30
2005	6	4	6			4	6	4	30
2006	6	4	6			4	6	4	30
2007	6	4	6			4	6	4	30
2008	6	3	6			3	6	3	27
2009	6	4	6			4	6	4	30
2010	6	4	6			4	6	4	30
2011	2	2	2			2	2	2	12
Total	167	135	153	85	30	115	79	55	819

b) Number of positive hauls

	Station									Percent
Shift-Year	T1	T2	T3	T4	T5	T10	T12	T14	Total	Positive
1970	0	0	1	1	0				2	20.0%
1971	0	1	1	1	1				4	40.0%
1972	0	0	0	1	1				2	20.0%
1973	1	0	1	0	1				3	30.0%
1974	0	0	0	0	0				0	0.0%
1975	0	0	0	0	0				0	0.0%
1976	0	0	0	0	0				0	0.0%
1977	0	0	1	0	0				1	10.0%
1978	0	0	0	0	0				0	0.0%
1979	0	0	0	0	0	0			0	0.0%
1980	0	0	0	0	0	0			0	0.0%
1981	0	0	0	0	0	0			0	0.0%
1982	0	0	0	0	0	0			0	0.0%
1983	0	0	0	0	0	0			0	0.0%
1984	0	0	0	0	0	1			1	8.3%
1985	0	0	0	0		0			0	0.0%
1986	0	0	0	0		0			0	0.0%
1987	0	0	0	0		0			0	0.0%
1988	0	0	0	0		1			1	5.0%
1989	0	0	0	0		0			0	0.0%
1990	0	0	0	0		1			1	5.0%
1991	0	0	0	0		0			0	0.0%
1992	0	0	0	0		0			0	0.0%
1993	0	0	0	0		0			0	0.0%
1994	0	0	0	0		0			0	0.0%
1995	0	0	0	0		0			0	0.0%
1996	0	0	0	0		0			0	0.0%
1997	0	0	0	0		0		0	0	0.0%
1998	0	0	0			0	0	0	0	0.0%
1999	0	0	0	0		1	0	2	3	9.7%
2000	0	0	0			0	1	2	3	10.7%
2001	0	0	0			1	0	0	1	3.4%
2002	0	0	0			2	0	1	3	10.0%
2003	0	0	0			0	0	0	0	0.0%
2004	0	0	0			1	0	0	1	3.3%
2005	0	0	0			0	0	1	1	3.3%
2006	0	0	0			0	0	0	0	0.0%
2007	0	0	0			0	0	0	0	0.0%
2008	0	0	0			0	0	0	0	0.0%
2009	0	0	0			1	0	1	2	6.7%
2010	0	0	3			1	0	1	5	16.7%
2011	0	0	1			0	0	0	1	8.3%
Total	1	1	8	3	3	10	1	8	35	4.3%

Table 16. Total hauls per year and number of positive cowcod hauls from the Los Angeles County Sanitation District survey. See text for a list of stations included in the index.

Year	Total hauls	Positive Hauls	Percent Positive
1972	8	3	38%
1973	8	7	88%
1974	8	3	38%
1975	9	8	89%
1976	8	2	25%
1977	8	3	38%
1979	8	2	25%
1980	8	3	38%
1981	8	1	13%
1982	8	1	13%
1983	8	1	13%
1984	8	1	13%
1985	8	0	0%
1986	8	3	38%
1987	8	1	13%
1988	8	2	25%
1989	8	0	0%
1990	8	0	0%
1991	9	0	0%
1992	9	0	0%
1993	9	1	11%
1994	9	2	22%
1995	9	0	0%
1996	9	1	11%
1997	9	0	0%
1998	9	0	0%
1999	9	1	11%
2000	9	2	22%
2001	9	0	0%
2002	9	1	11%
2004	9	0	0%
2005	9	0	0%
2006	9	0	0%
2007	9	0	0%
2008	9	1	11%
2009	9	3	33%
2010	9	6	67%
2011	9	1	11%
TOTAL	325	60	18%

Table 17. Index of cowcod abundance in L.A. and Orange County Sanitation District trawls. Year is central year in time block.

Year	GLM.index	binom.CV	log.SD
1973	0.536	0.143	0.142
1978	0.127	0.282	0.276
1983	0.031	0.437	0.418
1988	0.047	0.343	0.334
1993	0.015	0.571	0.532
1998	0.045	0.307	0.300
2003	0.031	0.371	0.359
2009	0.076	0.219	0.216

Table 18. Frequency of positive tows for cowcod in 2003-2012 NWFSC Trawl Survey by half-degree bins (bin name is southernmost latitude).

Latitude	Nsamp	Npos	FracPos	
32	29	0		
32.5	195	5	2.6%	
33	247	4	1.6%	
33.5	297	32	10.8%	
34	395	37	9.4%	Conception
34.5	224	7	3.1%	
35	262	5	1.9%	
35.5	178	3	1.7%	
36	109	4	3.7%	
36.5	84	11	13.1%	Monterey
37	211	16	7.6%	
37.5	109	6	5.5%	
38	182	19	10.4%	Pt. Reyes
38.5	105	7	6.7%	
39	128	3	2.3%	
39.5	112	3	2.7%	Mendocino

Table 19. Number of aged cowcod otoliths and average ages by year and region from the NWFSC combined trawl survey.

	North of Point Conception		South of Point Conception	
Year	**Number of ages**	**Average age**	**Number of ages**	**Average age**
2003	5	3.2	8	6.9
2004	21	3.7	4	3.5
2005	14	3.9	11	3.3
2006	6	6.2	20	4.4
2007	4	5.8	17	6.8
2008	5	4.6	12	2.6
2009	14	10.7	8	6.5
2010	17	6.5	41	3.0
2011	17	3.4	12	1.4
2012	33	4.5	40	3.8
Grand Total	**136**	**5.1**	**173**	**3.9**

Table 20. NWFSC trawl survey index of small (<1kg) cowcod abundance in southern California waters. Sampling years are 2003-2012. The index is shifted by 4 years (average age of catch) to represent spawning biomass four years earlier.

year	index	log.sigma
1999	0.207	0.531
2000	0.285	0.403
2001	0.310	0.369
2002	0.212	0.406
2003	0.230	0.357
2004	0.271	0.334
2005	0.166	0.370
2006	0.434	0.230
2007	0.219	0.359
2008	0.323	0.284

Table 21. Sampling coverage (number of drops) for the NWFSC hook-and-line survey sites that have encountered cowcod since 2004.

Site Number	2004	2005	2006	2007	Year 2008	2009	2010	2011	2012	Grand Total
2	5	5	5	5	5	5	5	5	5	45
6	5		5		5	5	5	5	5	35
15		5	5	5	5	5	5	5	5	40
17	5	5	5	5	5	5	5		5	40
18	5	5	5	5	5	5	5		5	40
21			5	5	5	5	5		5	30
24			5	5	5	5	5		5	30
29	5	5	5	5	5	5	5		5	40
31	5	5	5	5	5	5	5		5	40
33	5	5	5	5	5	5	5	5	5	45
36	5	5	5	5	5	5	5	5	5	45
43	5	5	5	5	5	5	5	5	5	45
52	5	5	5	5	5	5	5	5	5	45
77	5				5	5	5	5	5	30
79	5	5	5	5	5	5	5	5	5	45
137	5	5	5	5	5	5	5	5	5	45
139	5	5		5	5	5	5	5	5	40
147	5	5	5	5	5	5	5	5	5	45
149	5				5	5	5	5	5	30
151	5	5	5	5	5	5	5	5	5	45
154	5	5	5	5	5	5	5	5	5	45
168		5	5	5	5	5	5	5	5	40
181		5		5	5	5	5	5	5	35
182	5	5		5	5	5	5	5	5	40
186	5	5		5	5	5	5	5	5	40
200		5	5	5	5	5	5	5	5	40
205	5	5	5	5	5	5	5	5	5	45
209		5	5	5	5	5	5	5	5	40
231	5				5	5	5	5	5	30
232	5				5	5	5	5	5	30
243	5	5	5	5	5	5	5	5	5	45
342		5	5	5	5	5	5	5	5	40
346	5	5	5	5	5	5	5	5	5	45
350		5	5	5	5	5	5	5	5	40
352	5	5	5	5	5	5	5	5	5	45
377		5	5	5	5	5	5		5	35
385			5	5	5	5	5	5	5	35
414		2	5	5	5	5	5	5	5	37
418					5	5	5	5	5	25
Grand Total	130	147	150	165	195	195	195	160	195	1532

Table 22. Catch in weight (kg) for the NWFSC hook-and-line survey sites that have encountered cowcod since 2004.

Site Number	2004	2005	2006	2007	Year 2008	2009	2010	2011	2012	Grand Total
2	0	0	2.78	3.24	0	0	0	0	3.24	9.26
6	0		3.18		3.32	8.32	0	0	0	14.82
15		0	0	0	0	2.48	1.76	0	0	4.24
17	0	0	0	0	0	0	0		7.42	7.42
18	0	1.66	4.96	0	0	0	0		0	6.62
21			0	0	0	0	4.98		0	4.98
24			0	4.28	0	0	0		0	4.28
29	0	0	0	0	4.92	0	0		0	4.92
31	0	0	0	4.58	0	6.8	0		0	11.38
33	0	0	0	1.8	1.04	0	0	0	0.1	2.94
36	0	2.82	0	0	0	0	0	0	0	2.82
43	0	2.02	0	0	0	0	0	0	0	2.02
52	0	0	0	9.24	0	3.36	0	0	0	12.6
77	0				0	0	0	0	2.36	2.36
79	0	3.64	2.2	0	1.92	4.54	0	0	0	12.3
137	4.12	0	0	0	0	0	0	0	0	4.12
139	0	0		0	0	0	4.12	0	9.74	13.86
147	0	0	0	0	0	0	2.74	0	0	2.74
149	0				0	0	0	0	1.55	1.55
151	0	0	0	0	0	4.22	0	1.46	0	5.68
154	0	0	0	0	0	0	3.8	0	0	3.8
168		0	0	0	0	0	0	0	2.92	2.92
181		0		0	0	4.06	0	0	0	4.06
182	0	0		3.18	4.66	0	0	0	0	7.84
186	0	0		3.04	0	0	0	0	0	3.04
200		4.92	0	0	0	0	0	0	0	4.92
205	0	0	0	4.16	0	0	0	0	0	4.16
209		0	4.34	0	0	6.68	0	0	0	11.02
231	2.35				13.24	11.5	0	3.96	9.03	40.08
232	0				11.34	5	0	50.98	25.88	93.2
243	0	0	0	0	1.68	0	0	2.62	0	4.3
342		3.38	13.42	5.1	0	9.38	3.56	0	7.72	42.56
346	11.58	17.76	0	19.62	2.8	17.4	15.52	37.32	21.92	143.92
350		15.79	3.86	5.48	0	5.3	16.28	22.82	6.77	76.3
352	7.25	5.2	0	1.46	6.34	7.9	0	5.22	18.8	52.17
377		0	0	0	0	7.22	5.55		0	12.77
385			5.9	0	5.26	0	0	0	6.98	18.14
414		19.26	0	20.84	24.22	16.46	34.42	0	32.4	147.6
418					0	18.16	0	14.76	0	32.92
Grand Total	25.3	76.45	40.64	86.02	80.74	138.78	92.73	139.14	156.83	836.63

Table 23. NWFSC hook-and-line survey delta-GLM index

year	index	CV
2004	0.144	0.608
2005	0.486	0.327
2006	0.335	0.433
2007	0.550	0.335
2008	0.400	0.297
2009	0.798	0.282
2010	0.301	0.349
2011	0.603	0.310
2012	0.706	0.252

Table 24. Number of cowcod ages, by year, from the NWFSC hook-and-line survey. Age estimates for 2008 are pending.

Year	Number of ages
2003	1
2004	6
2005	17
2006	11
2007	23
2008	
2009	30
2010	21
2011	24
2012	36

Table 25. Cowcod observed in the SWFSC annual rockfish recruitment and ecosystem assessment survey.

		Core Area		Core + Expanded Area	
CRUISE	YEAR	SUM	MEAN COWCOD PER HAUL	SUM	MEAN COWCOD PER HAUL
8303	1983	0	0.000		
8406	1984	0	0.000		
8505	1985	2	0.031		
8608	1986	1	0.011		
8705	1987	17	0.160		
8806	1988	1	0.010		
8904	1989	1	0.010		
9005	1990	0	0.000		
9105	1991	0	0.000		
9206	1992	5	0.053		
9307	1993	5	0.050		
9406	1994	0	0.000		
9506	1995	0	0.000		
9606	1996	0	0.000		
9707	1997	0	0.000		
9807	1998	0	0.000		
9903	1999	0	0.000		
0002	2000	1	0.010		
0103	2001	3	0.033		
0205	2002	2	0.026		
0304	2003	1	0.010		
0403	2004	1	0.011	5	0.035
0504	2005	0	0.000	7	0.047
0603	2006	0	0.000	2	0.013
0703	2007	0	0.000	3	0.018
0803	2008	0	0.000	2	0.020
0902	2009	1	0.012	2	0.015
1002	2010	5	0.058	8	0.060
1101	2011	3	0.057	3	0.048
1203	2012	1	0.015	10	0.106
1305	2013	99	1.456	101	0.706

Table 26. Trip-based CPUE index from CPFV logbook records.

year	index	log.SD
1980	0.0523	0.1061
1981	0.0435	0.0906
1982	0.0469	0.1000
1983	0.0426	0.1684
1984	0.0326	0.1202
1985	0.0387	0.1196
1986	0.0309	0.1500
1987	0.0241	0.1347
1988	0.0315	0.3413
1989	0.0496	0.1878
1990	0.0229	0.2095
1991	0.0216	0.1230
1992	0.0361	0.1542
1993	0.0258	0.1517
1994	0.0378	0.2124
1995	0.0317	0.1433
1996	0.0298	0.1836
1997	0.0340	0.1636
1998	0.0290	0.2967
1999	0.0301	0.3255

Table 27. Number of cowcod (kept and returned) reported by onboard CPFV observers, 1999-2011.

Region / Year	**Kept**	**Returned**
Central_CA		
1999	2	0
2001	1	1
2002	4	1
2005	0	1
2007	0	2
2009	0	2
Southern_CA		
1999	10	0
2000	3	0
2002	5	3
2004	1	6
2005	0	6
2006	0	6
2007	0	1
2008	1	5
2009	4	4
2010	0	5
2011	0	20
Grand Total	**31**	**63**

Table 28. Estimated medians from the STAR Panel's requested runs 1 through 7 (not all requests required model runs). Pre-STAR panel base model medians are included for reference.

Quantity	Base Model	Request 1 Uniform_Delta	Request 2a Unif_Fmsy/M	Request 2b 2x Sigma Fmsy/M	Request 2c Scorp. Fmsy/M	Request 3 D-M Bmsy/B0	Request 7a Sub q = 1.5	Request 7b Visual q = 0.375
Imp.logQ, CPFV	-10.372	-10.421	-10.364	-10.430	-10.435	-10.413	-10.193	-10.550
Imp.logQ, NW Trawl	-8.385	-8.398	-8.369	-8.388	-8.376	-8.418	-8.174	-8.559
Imp.logQ, San. Dist.	-9.937	-9.970	-9.922	-9.977	-9.969	-9.953	-9.724	-10.087
Imp.logQ, NW Hook	-7.896	-7.903	-7.871	-7.873	-7.877	-7.934	-7.687	-8.045
Imp.logQ, CalCOFI	-11.261	-11.278	-11.235	-11.283	-11.277	-11.283	-11.096	-11.390
logQ, Visual Survey	-0.699	-0.656	-0.688	-0.676	-0.732	-0.731	-0.412	-1.020
Log(a), CPFV	-4.205	-4.109	-4.098	-4.233	-4.305	-4.197	-4.222	-4.226
Log(a), NW Trawl	-3.951	-3.890	-3.715	-3.760	-3.778	-3.803	-3.839	-3.784
Log(a), San. Dist.	-0.446	-0.590	-0.337	-0.409	-0.518	-0.639	-0.893	-0.515
Log(a), NW Hook	-3.437	-3.378	-3.573	-3.300	-3.426	-3.519	-3.587	-3.528
Log(a), CalCOFI	-0.917	-0.878	-0.932	-0.819	-0.736	-0.917	-0.615	-0.818
M	0.041	0.042	0.047	0.044	0.045	0.039	0.049	0.036
Fmsy/M	0.728	0.721	0.665	0.466	0.533	0.695	0.612	0.734
Delta	0.750	0.759	0.761	0.763	0.763	0.759	0.776	0.741
Bmsy/B0	0.456	0.417	0.452	0.512	0.483	0.384	0.640	0.412
Fmsy	0.031	0.029	0.027	0.021	0.025	0.028	0.029	0.026
Emsy	0.030	0.029	0.026	0.020	0.024	0.027	0.028	0.025
MSY	53.1	52.5	51.1	43.7	45.7	49.6	47.9	49.8
Bmsy	1933.5	1885.1	1994.8	2234.7	2139.3	1840.0	2123.5	2104.7
B1900	4567.4	4701.7	4662.9	4792.0	4760.2	4808.7	3845.9	5005.3
B2013	1450.3	1439.1	1406.2	1395.7	1409.9	1520.5	1176.6	1632.2
OFL2013	40.3	39.9	38.4	28.2	32.2	41.1	31.9	39.6
OFL2014	41.1	40.7	39.1	28.6	32.7	42.0	32.6	40.4
OFL2015	41.9	41.6	39.8	29.1	33.2	42.9	33.2	41.2
OFL2016	42.9	42.3	40.5	29.5	33.7	43.7	33.9	42.0
SB2013/SB0	0.326	0.322	0.309	0.289	0.293	0.315	0.280	0.335
F2012/Fmsy	0.052	0.055	0.059	0.077	0.065	0.056	0.060	0.059
B40%	1827.0	1880.7	1865.2	1916.8	1904.1	1923.5	1538.4	2002.1
Emsy(B40% proxy)	0.024	0.025	0.022	0.019	0.020	0.025	0.024	0.022
MSY(B40% proxy)	42.2	41.9	36.3	34.8	35.9	45.3	38.3	43.4

Table 29. Estimated medians from the STAR Panel's requested runs 1 through 7 (not all requests required model runs), expressed as a percentage change relative to the median, pre-STAR base model results (i.e. 100% x (sensitivity-base)/base). Blue and red horizontal bars indicate positive and negative differences, respectively.

Quantity	Base Model	Request 1 Uniform_Delta	Request 2a Unif_Fmsy/M	Request 2b 2x Sigma Fmsy/M	Request 2c Scorp. Fmsy/M	Request 3 D-M Bmsy/B0	Request 7a Sub q = 1.5	Request 7b Visual q = 0.375
Imp.logQ, CPFV	0%	0%	0%	1%	1%	0%	-2%	2%
Imp.logQ, NW Trawl	0%	0%	0%	0%	0%	0%	-3%	2%
Imp.logQ, San. Dist.	0%	0%	0%	0%	0%	0%	-2%	2%
Imp.logQ, NW Hook	0%	0%	0%	0%	0%	0%	-3%	2%
Imp.logQ, CalCOFI	0%	0%	0%	0%	0%	0%	-1%	1%
logQ, Visual Survey	0%	-6%	-2%	-3%	5%	5%	-41%	46%
Log(a), CPFV	0%	-2%	-3%	1%	2%	0%	0%	0%
Log(a), NW Trawl	0%	-2%	-6%	-5%	-4%	-4%	-3%	-4%
Log(a), San. Dist.	0%	33%	-24%	-8%	16%	43%	100%	16%
Log(a), NW Hook	0%	-2%	4%	-4%	0%	2%	4%	3%
Log(a), CalCOFI	0%	-4%	2%	-11%	-20%	0%	-33%	-11%
M	0%	1%	15%	6%	9%	-4%	20%	-11%
Fmsy/M	0%	-1%	-9%	-36%	-27%	-4%	-16%	1%
Delta	0%	1%	1%	2%	2%	1%	3%	-1%
Bmsy/B0	0%	-9%	-1%	12%	6%	-16%	40%	-10%
Fmsy	0%	-4%	-11%	-32%	-19%	-8%	-4%	-14%
Emsy	0%	-3%	-11%	-32%	-20%	-8%	-4%	-14%
MSY	0%	-1%	-4%	-18%	-14%	-7%	-10%	-6%
Bmsy	0%	-3%	3%	16%	11%	-5%	10%	9%
B1900	0%	3%	2%	5%	4%	5%	-16%	10%
B2013	0%	-1%	-3%	-4%	-3%	5%	-19%	13%
OFL2013	0%	-1%	-5%	-30%	-20%	2%	-21%	-2%
OFL2014	0%	-1%	-5%	-30%	-21%	2%	-21%	-2%
OFL2015	0%	-1%	-5%	-31%	-21%	2%	-21%	-2%
OFL2016	0%	-1%	-6%	-31%	-21%	2%	-21%	-2%
SB2013/SB0	0%	-1%	-5%	-11%	-10%	-3%	-14%	3%
F2012/Fmsy	0%	4%	13%	46%	24%	6%	15%	12%
B40%	0%	3%	2%	5%	4%	5%	-16%	10%
Emsy(B40% proxy)	0%	5%	-8%	-21%	-19%	3%	1%	-10%
MSY(B40% proxy)	0%	-1%	-14%	-18%	-15%	7%	-9%	3%

Table 30. Estimated medians from the STAR Panel's requested runs 8 through 11 (not all requests required model runs). Pre-STAR panel base model medians are included for reference.

Quantity	Base Model	Request 8a 1/2 catch	Request 8b 2x catch	*Base Model no CPFV*	Request 8c 1/2 catch, no CPFV	Request 8d 2x catch, no CPFV	Request 11a Amat = 8	Request 11b Amat = 14
Imp.logQ, CPFV	-10.372	-10.472	-10.315	--	--	--	-10.319	-10.518
Imp.logQ, NW Trawl	-8.385	-8.473	-8.277	-7.931	-7.886	-7.922	-8.377	-8.493
Imp.logQ, San. Dist.	-9.937	-10.005	-9.850	-9.358	-9.309	-9.295	-9.890	-10.067
Imp.logQ, NW Hook	-7.896	-7.980	-7.789	-7.542	-7.496	-7.540	-7.914	-7.970
Imp.logQ, CalCOFI	-11.261	-11.290	-11.291	-10.808	-10.780	-10.785	-11.224	-11.376
logQ, Visual Survey	-0.699	-0.803	-0.611	-0.293	-0.274	-0.301	-0.667	-0.796
Log(a), CPFV	-4.205	-4.117	-4.168	--	--	--	-4.196	-4.224
Log(a), NW Trawl	-3.951	-4.033	-4.000	-3.945	-3.881	-3.870	-3.704	-3.730
Log(a), San. Dist.	-0.446	-0.467	-0.527	-0.669	-0.601	-0.677	-0.520	-0.589
Log(a), NW Hook	-3.437	-3.423	-3.345	-3.569	-3.635	-3.505	-3.383	-3.606
Log(a), CalCOFI	-0.917	-0.668	-0.836	-1.132	-1.149	-1.139	-0.926	-0.799
M	0.041	0.046	0.037	0.056	0.059	0.057	0.049	0.033
Fmsy/M	0.728	0.766	0.714	1.060	1.135	1.086	0.777	0.701
Delta	0.750	0.677	0.846	0.802	0.765	0.860	0.732	0.748
Bmsy/B0	0.456	0.392	0.603	0.417	0.413	0.465	0.526	0.340
Fmsy	0.031	0.031	0.027	0.058	0.064	0.061	0.040	0.023
Emsy	0.030	0.030	0.026	0.055	0.060	0.058	0.038	0.022
MSY	53.1	45.3	88.0	69.0	61.0	108.7	64.7	38.3
Bmsy	1933.5	1567.5	3511.4	1259.4	1022.6	1795.9	1835.1	2054.4
B1900	4567.4	3681.4	6546.2	3110.5	2523.3	4327.8	3816.1	5176.8
B2013	1450.3	1546.9	1308.9	1074.7	1023.7	1122.5	1508.7	1512.1
OFL2013	40.3	46.4	35.5	57.4	62.8	63.8	52.8	34.0
OFL2014	41.1	47.4	36.1	59.0	64.9	65.9	54.4	34.5
OFL2015	41.9	48.3	36.8	61.2	67.0	68.4	55.7	34.9
OFL2016	42.9	49.3	37.5	63.2	68.9	71.0	57.3	35.4
SB2013/SB0	0.326	0.411	0.202	0.339	0.402	0.261	0.388	0.293
F2012/Fmsy	0.052	0.050	0.058	0.032	0.028	0.029	0.041	0.070
B40%	1827.0	1472.6	2618.5	1244.2	1009.3	1731.1	1526.5	2070.7
Emsy(B40% proxy)	0.024	0.025	0.025	0.051	0.056	0.055	0.037	0.015
MSY(B40% proxy)	42.2	37.8	62.0	63.2	55.9	95.7	56.0	32.0

Table 31. Estimated medians from the STAR Panel's requested runs 8 through 11 (not all requests required model runs), expressed as a percentage change relative to the median, pre-STAR base model results (i.e. 100% x (sensitivity-base)/base). Blue and red horizontal bars indicate positive and negative differences, respectively.

Quantity	Base Model	Request 8a 1/2 catch	Request 8b 2x catch	*Base Model no CPFV*	Request 8c 1/2 catch, no CPFV	Request 8d 2x catch, no CPFV	Request 11a Amat = 8	Request 11b Amat = 14
Imp.logQ, CPFV	0%	1%	-1%	--	--	--	-1%	1%
Imp.logQ, NW Trawl	0%	1%	-1%	-5%	-6%	-6%	0%	1%
Imp.logQ, San. Dist.	0%	1%	-1%	-6%	-6%	-6%	0%	1%
Imp.logQ, NW Hook	0%	1%	-1%	-4%	-5%	-5%	0%	1%
Imp.logQ, CalCOFI	0%	0%	0%	-4%	-4%	-4%	0%	1%
logQ, Visual Survey	0%	15%	-13%	-58%	-61%	-57%	-5%	14%
Log(a), CPFV	0%	-2%	-1%	--	--	--	0%	0%
Log(a), NW Trawl	0%	2%	1%	0%	-2%	-2%	-6%	-6%
Log(a), San. Dist.	0%	5%	18%	50%	35%	52%	17%	32%
Log(a), NW Hook	0%	0%	-3%	4%	6%	2%	-2%	5%
Log(a), CalCOFI	0%	-27%	-9%	23%	25%	24%	1%	-13%
M	0%	12%	-9%	36%	44%	38%	19%	-20%
Fmsy/M	0%	5%	-2%	46%	56%	49%	7%	-4%
Delta	0%	-10%	13%	7%	2%	15%	-2%	0%
Bmsy/B0	0%	-14%	32%	-9%	-9%	2%	15%	-25%
Fmsy	0%	2%	-11%	91%	108%	99%	30%	-26%
Emsy	0%	2%	-11%	86%	103%	95%	29%	-25%
MSY	0%	-15%	66%	30%	15%	105%	22%	-28%
Bmsy	0%	-19%	82%	-35%	-47%	-7%	-5%	6%
B1900	0%	-19%	43%	-32%	-45%	-5%	-16%	13%
B2013	0%	7%	-10%	-26%	-29%	-23%	4%	4%
OFL2013	0%	15%	-12%	42%	56%	58%	31%	-16%
OFL2014	0%	15%	-12%	43%	58%	60%	32%	-16%
OFL2015	0%	15%	-12%	46%	60%	63%	33%	-17%
OFL2016	0%	15%	-13%	47%	61%	66%	33%	-17%
SB2013/SB0	0%	26%	-38%	4%	23%	-20%	19%	-10%
F2012/Fmsy	0%	-5%	11%	-40%	-46%	-44%	-21%	33%
B40%	0%	-19%	43%	-32%	-45%	-5%	-16%	13%
Emsy(B40% proxy)	0%	4%	3%	111%	130%	126%	52%	-38%
MSY(B40% proxy)	0%	-10%	47%	50%	32%	127%	33%	-24%

Table 32. (Response to STAR Panel Request 2) Alternative prior distributions for Fmsy/M. Parameters of the lognormal distributions are the arithmetic mean and log-scale standard deviation.

Description	**Distribution**
Zhou Teleost (base model)	Lognormal(mean=0.97, logSD=0.46)
Twice Sigma	Lognormal(mean=0.97, logSD=0.92)
Uniform	Uniform(0,4)
Zhou Scorpaenid	Lognormal(mean=0.813, logSD=0.625)

Table 33. (Response to STAR Panel Request 3) Alternative prior distributions for Bmsy/B0. Parameters are the mean and standard deviation of the standard beta distribution.

Description	**Distribution**
Base	Bounded beta (mean=0.5, SD=0.285)
Data-Moderate	Bounded beta (mean=0.4, SD=0.15)

Table 34. (Response to STAR Panel Request 6) Frequency of Nlarvae in southern California CalCOFI samples. The underlying data set has not been reduced to the selected stations used in the cowcod index, and contains 165 positive tows as compared with the 155 positive tows in the index data set. The additional positives come from stations that were not sampled regularly.

		Number of larvae in tow								
Years	Nsamps	0	pos	1	2	3	4	5	9	13
1953	1324	1293	31	27	3	0	1	0	0	0
1958	1426	1401	25	22	3	0	0	0	0	0
1963	736	724	12	11	0	0	1	0	0	0
1968	672	634	38	28	5	2	1	0	1	1
1974	577	558	19	15	2	0	1	1	0	0
1986	2595	2589	6	3	3	0	0	0	0	0
1999	695	689	6	5	1	0	0	0	0	0
2004	705	695	10	8	0	1	1	0	0	0
2009	787	769	18	12	4	2	0	0	0	0
all years	9517	9352	165	131	21	5	5	1	1	1
fracpos				79.4%	12.7%	3.0%	3.0%	0.6%	0.6%	0.6%

Table 35. (Response to STAR Panel Request 6) Positive stations used in the CalCOFI index, summarized by location and time period.

Npositive											Nsamples											
Sta\Year	1953	1958	1963	1968	1974	1986	1999	2004	2009	Total	1953	1958	1963	1968	1974	1986	1999	2004	2009	Total		fracpos
8050	1	1	1	5	2	1	0	1	0	12	27	31	25	28	20	55	9	19	20	234		5.1%
8055	0	1	1	1	2	1	1	0	1	8	32	36	14	13	9	51	9	12	11	187		4.3%
8060	0	0	0	0	0	0	0	1	1	2	33	36	15	14	9	52	9	14	12	194		1.0%
8144	0		0		1	1	0	0	1	3	2		9		20	25	10	13	20	99		3.0%
8246	1	2	1	0	0	0				4	9	34	12	13	3	23				94		4.3%
8340	0	2	0	0	0	0	0	0	1	3	17	33	14	14	6	49	14	14	13	174		1.7%
8342	2	2	0	3	3	0	0	1	1	12	26	37	12	14	10	52	15	14	13	193		6.2%
8344	2	0	0		1	0				3	17	1	3		16	3				40		7.5%
8351	1	4	1	5	1	0	0	0	1	13	22	35	13	14	7	49	14	13	11	178		7.3%
8355	1	0	1	4	2	1	0	0	0	9	24	26	13	14	7	49	12	14	11	170		5.3%
8360	1	0	1	0	0	1	1	1	0	5	29	35	13	14	7	53	12	13	11	187		2.7%
8733	2	0	0	3	0	0	0	0	1	6	32	24	23	27	17	103	20	26	26	298		2.0%
8740	1	1	0	2	1	0	0	1	1	7	30	37	11	14	7	44	10	13	13	179		3.9%
8745	1	1	1	2	1	0	0	0	0	6	19	28	11	14	7	54	9	13	11	166		3.6%
8750	5	3	0	3	1	0	2	0	4	18	26	35	10	13	7	53	9	12	12	177		10.2%
8755	0	0	0	2	0	0	0	0	1	3	20	27	11	14	7	52	9	13	13	166		1.8%
8760	0	1	0	0	0	0	0	0	1	2	43	71	33	33	12	103	17	25	25	362		0.6%
9028	0	1	0	1	1	0	0	0	0	3	28	36	16	13	13	53	16	18	23	216		1.4%
9030	0	2	1	0	0	0	0	0	0	3	37	36	11	13	21	61	16	13	13	221		1.4%
9037	1	0	0	1	0	0	0	1	1	4	38	36	11	13	10	83	32	26	26	275		1.5%
9045	1	0	0	0	0	0	0	1	0	2	36	36	11	14	10	52	16	13	11	199		1.0%
9050	0	0	0	1	0	0	0	0	1	2	43	64	11	15	10	51	15	13	13	235		0.9%
9060	1	0	0	1	1	0	0	0	0	3	36	37	11	14	10	55	14	13	13	203		1.5%
9327	0	1	1	1	0	0	1	1	0	5	27	35	17	26	11	45	11	13	13	198		2.5%
9330	1	1	0	0	0	0	0	0	0	2	35	35	11	14	8	53	11	13	13	193		1.0%
9335	0	1	1	1	0	0	0	0	0	3	10	28	11	13	8	52	11	12	13	158		1.9%
9340	3	0	1	0	0	0	0	0	0	4	33	36	11	14	8	53	11	13	13	192		2.1%
9350	2	2	1	0	0	0	0	1	0	6	34	36	11	14	7	52	11	13	13	191		3.1%
9355	0	0	0	1	0	0	0	0	1	2	35	59	22	27	16	107	20	26	25	337		0.6%
Total	27	26	12	37	17	5	5	9	17	155	800	1000	396	443	303	1587	362	414	411	5716		2.7%

Table 36. Estimated parameters in the base model.

	Prior Distribution				Posterior Percentiles				
Parameter Description	**Density Function**	**mean**	**std. dev.**	**bounds**	**5%**	**25%**	**50%**	**75%**	**95%**
Natural mortality, M	lognormal	0.055	0.4	(0,Inf)	0.030	0.043	0.054	0.069	0.099
Fmsy / M	lognormal	0.97	0.46	(0,Inf)	0.522	0.803	1.051	1.372	2.029
Delta (Δ) in year 2000	beta	0.7	0.2	(0.01,0.99)	0.657	0.749	0.801	0.847	0.894
Bmsy / Bo	beta	0.5	0.285	(0.05,0.95)	0.156	0.303	0.422	0.545	0.708
log catchability for visual survey	normal	-0.2863	0.5	(-Inf, Inf)	-0.878	-0.523	-0.293	-0.058	0.284
Additive variance (log scale)									
NWFSC Trawl Survey	log-uniform			(-5.3, 0.18*)	-5.165	-4.566	-3.854	-3.059	-1.964
Sanitation District Trawl Survey	log-uniform			(-5.3, 1.39*)	-1.803	-1.138	-0.674	-0.169	0.546
NWFSC Hook-and-Line Survey	log-uniform			(-5.3, 0.18*)	-5.144	-4.465	-3.595	-2.681	-1.543
CalCOFI Ichthyoplankton Survey	log-uniform			(-5.3, 1.5*)	-2.324	-1.607	-1.126	-0.639	0.088

* upper bounds of log-uniform priors are chosen to avoid restricting the posterior distribution, based on trial runs

Table 37. Reference points from the base model for cowcod in the SCB. Estimates are posterior medians and do not represent a single population trajectory.

Quantity	**2.5^{th} percentile**	**Median**	**97.5^{th} percentile**
Unfished Spawning Biomass (SB_0, mt)	990	1549	2684
Unfished age 11+ biomass (mt)	1981	3099	5368
Spawning Biomass in 2013	273	524	924
Depletion in 2013 (% of SB_0)	15.0%	33.9%	65.6%
Reference points based on estimated MSY			
Spawning biomass at *MSY* (SB_{MSY})	256	629	1162
SB_{MSY} / SB_0	0.121	0.422	0.745
Exploitation rate corresponding to *MSY*	0.022	0.055	0.126
MSY (mt)	30.0	68.9	103.1
Reference points based on $SB_{40\%}$ proxy MSY harvest rate			
Proxy SB at MSY ($B_{40\%}$)	396	620	1074
Exploitation rate resulting in $B_{40\%}$	0.012	0.050	0.113
Yield from $B_{40\%}$ proxy harvest rate at $B_{40\%}$ (mt)	24.6	62.2	98.4

Table 38. Time series of catch, age 11+ biomass, spawning biomass, depletion, exploitation rate (catch / vulnerable biomass), and exploitation rate relative to the estimated MSY rate.

Year	Catch	Biomass, Age 11+	SSB	Depletion	Exp. Rate (C/B)	E/Emsy
1900	0	3098.8	1549.4	1	0	0
1901	5.3	3098.8	1549.4	1	0.002	0.032
1902	10.7	3093.4	1546.7	0.998	0.003	0.064
1903	16	3083.4	1541.7	0.995	0.005	0.097
1904	21.4	3068.9	1534.4	0.99	0.007	0.13
1905	26.7	3049.7	1524.8	0.984	0.009	0.163
1906	32	3025.9	1513	0.976	0.011	0.198
1907	37.4	2999.1	1499.6	0.967	0.012	0.233
1908	42.7	2967.5	1483.7	0.957	0.014	0.269
1909	48	2931.6	1465.8	0.946	0.016	0.306
1910	53.4	2895.5	1447.7	0.933	0.018	0.344
1911	58.7	2854.3	1427.1	0.92	0.021	0.385
1912	64	2810	1405	0.905	0.023	0.428
1913	69.3	2761.6	1380.8	0.89	0.025	0.471
1914	74.7	2712.8	1356.4	0.873	0.028	0.518
1915	80	2659	1329.5	0.857	0.03	0.565
1916	85.4	2599.5	1299.8	0.839	0.033	0.616
1917	137.7	2545.1	1272.5	0.822	0.054	1.018
1918	125.6	2443.5	1221.8	0.788	0.051	0.971
1919	75.1	2356.9	1178.4	0.761	0.032	0.603
1920	81.6	2327.8	1163.9	0.751	0.035	0.664
1921	71.3	2295	1147.5	0.74	0.031	0.588
1922	70.1	2272.2	1136.1	0.734	0.031	0.584
1923	93.9	2254.2	1127.1	0.73	0.042	0.787
1924	125.9	2215.8	1107.9	0.718	0.057	1.072
1925	138.2	2145.5	1072.7	0.696	0.064	1.214
1926	171.5	2064.3	1032.1	0.672	0.083	1.567
1927	142.3	1957.3	978.6	0.638	0.073	1.37
1928	111.3	1888.3	944.1	0.615	0.059	1.113
1929	102.6	1850.1	925	0.605	0.055	1.043
1930	126.9	1820.2	910.1	0.596	0.07	1.305
1931	161	1772	886	0.58	0.091	1.696
1932	109.5	1690.5	845.3	0.553	0.065	1.212
1933	82	1664.1	832.1	0.546	0.049	0.919
1934	70.7	1665.2	832.6	0.546	0.042	0.788
1935	53	1680.2	840.1	0.551	0.032	0.582
1936	20.6	1707.7	853.9	0.561	0.012	0.222
1937	24.9	1766.6	883.3	0.58	0.014	0.259
1938	18.7	1808.5	904.2	0.594	0.01	0.19
1939	22	1853.3	926.7	0.609	0.012	0.216
1940	23.7	1896.2	948.1	0.62	0.012	0.228
1941	29.5	1931.7	965.8	0.629	0.015	0.278
1942	10.6	1954.4	977.2	0.635	0.005	0.099
1943	12.4	1991.5	995.7	0.645	0.006	0.113
1944	2	2029.2	1014.6	0.653	0.001	0.018
1945	4.6	2071.9	1036	0.664	0.002	0.04
1946	11.7	2115.9	1058	0.675	0.006	0.1
1947	18.8	2155.7	1077.9	0.684	0.009	0.159
1948	29.9	2181.6	1090.8	0.691	0.014	0.251
1949	38.7	2197.3	1098.7	0.695	0.018	0.322
1950	44	2205	1102.5	0.696	0.02	0.365
1951	49.2	2207	1103.5	0.698	0.022	0.408
1952	36.7	2204.7	1102.4	0.698	0.017	0.304
1953	31.2	2219.8	1109.9	0.701	0.014	0.258
1954	46.8	2237.7	1118.9	0.706	0.021	0.383
1955	52	2240.8	1120.4	0.707	0.023	0.426
1956	65.2	2236.6	1118.3	0.706	0.029	0.535
1957	55.7	2219.2	1109.6	0.701	0.025	0.46

Table 38 (Continued).

Year	Catch	Biomass, Age 11+	SSB	Depletion	Exp. Rate (C/B)	E/Emsy
1958	56.4	2214.8	1107.4	0.699	0.025	0.467
1959	52.3	2209.5	1104.7	0.698	0.024	0.435
1960	57	2206.8	1103.4	0.698	0.026	0.475
1961	60	2200.1	1100	0.696	0.027	0.502
1962	48	2190.9	1095.4	0.694	0.022	0.404
1963	57.3	2194.2	1097.1	0.696	0.026	0.482
1964	51.9	2187.6	1093.8	0.694	0.024	0.438
1965	70.1	2187.7	1093.8	0.694	0.032	0.593
1966	76.6	2170	1085	0.689	0.035	0.656
1967	102.4	2145.5	1072.7	0.682	0.048	0.887
1968	105	2095.2	1047.6	0.666	0.05	0.934
1969	125.1	2044.4	1022.2	0.65	0.061	1.141
1970	95.8	1977.3	988.6	0.629	0.048	0.903
1971	106.1	1942.1	971	0.618	0.055	1.018
1972	152.6	1898.6	949.3	0.605	0.08	1.498
1973	171.8	1811.2	905.6	0.578	0.095	1.766
1974	183.7	1706.6	853.3	0.545	0.108	2.003
1975	182.6	1597.2	798.6	0.51	0.114	2.133
1976	189.3	1493.8	746.9	0.478	0.127	2.363
1977	191.2	1392.2	696.1	0.445	0.137	2.564
1978	203.2	1292.4	646.2	0.412	0.157	2.932
1979	262.1	1188.3	594.1	0.378	0.221	4.107
1980	223.6	1026.9	513.4	0.325	0.218	4.076
1981	216	910.7	455.3	0.288	0.237	4.437
1982	327.5	808.6	404.3	0.255	0.405	7.574
1983	177.1	600.3	300.1	0.188	0.295	5.638
1984	227.9	547.5	273.8	0.173	0.416	7.881
1985	208.1	444.4	222.2	0.14	0.468	8.923
1986	194.4	363.5	181.8	0.115	0.535	10.351
1987	105.8	294.8	147.4	0.093	0.359	6.947
1988	100.5	313.4	156.7	0.1	0.321	6.052
1989	38.7	329.2	164.6	0.108	0.117	2.178
1990	30.5	400.1	200	0.133	0.076	1.391
1991	26.4	463.6	231.8	0.155	0.057	1.031
1992	35.8	522.1	261	0.173	0.069	1.239
1993	24.5	557.2	278.6	0.185	0.044	0.795
1994	39.6	583	291.5	0.192	0.068	1.233
1995	25.1	586.9	293.5	0.193	0.043	0.778
1996	29.9	596	298	0.195	0.05	0.923
1997	9.2	585.7	292.9	0.191	0.016	0.288
1998	4	589.2	294.6	0.192	0.007	0.127
1999	7.2	601.5	300.7	0.195	0.012	0.224
2000	4.9	612.9	306.5	0.199	0.008	0.15
2001	0.6	636.1	318	0.206	0.001	0.017
2002	0.6	670.1	335.1	0.218	0.001	0.016
2003	0.5	710.6	355.3	0.23	0.001	0.013
2004	0.9	749.4	374.7	0.244	0.001	0.021
2005	0.2	791.1	395.6	0.256	0	0.004
2006	0.1	829	414.5	0.269	0	0.002
2007	0.2	866.5	433.2	0.281	0	0.004
2008	0.2	895.3	447.6	0.291	0	0.005
2009	0.2	926.5	463.2	0.301	0	0.004
2010	0.2	958.1	479.1	0.31	0	0.003
2011	0.8	989.7	494.9	0.32	0.001	0.015
2012	0.8	1018	509	0.329	0.001	0.015
2013	1.5	1049	524.5	0.339	0.001	0.026
2014	1.5	1083.7	541.9	0.35	0.001	0.025
2015	1.5	1118.8	559.4	0.36	0.001	0.025

10 Figures

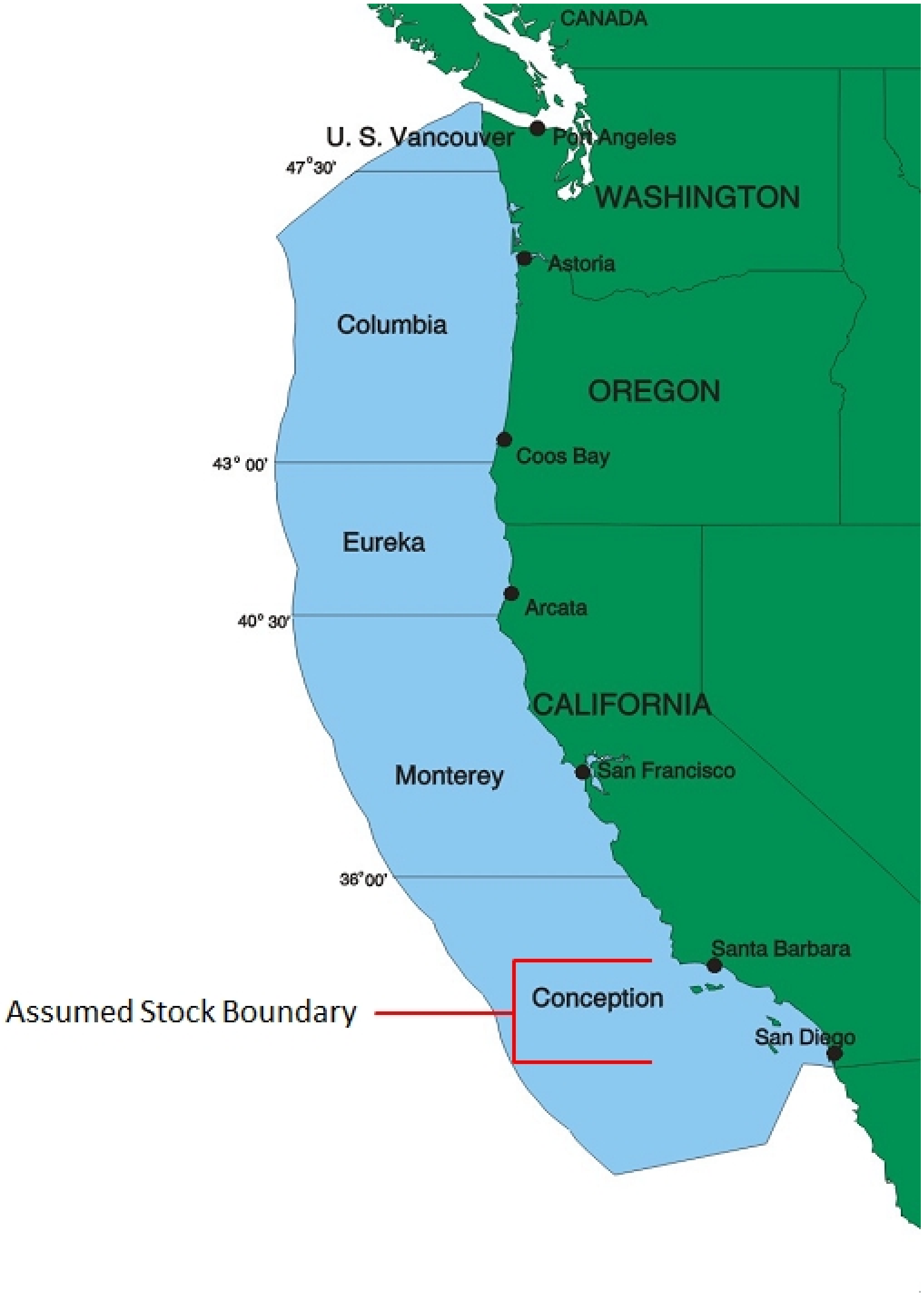


Figure 1. Assumed stock boundary (U.S. waters off California, south of 34° 27′ N. latitude) for the cowcod base model, showing INPFC areas.

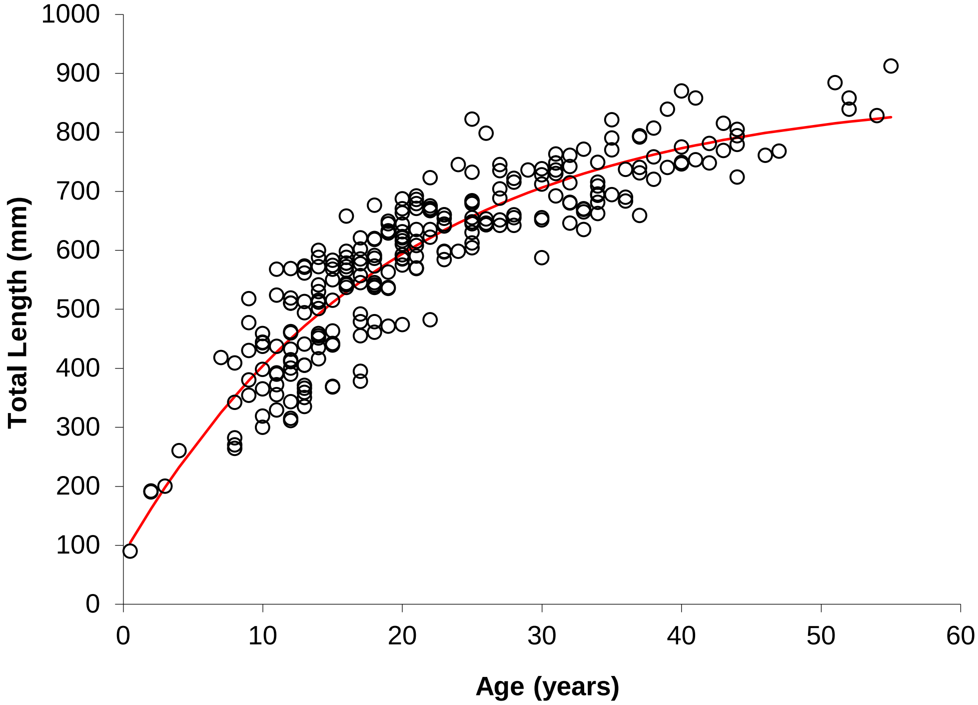


Figure 2. Fit of von Bertalanffy growth curve to length-at-age data, sexes combined (Dick et al. 2007).

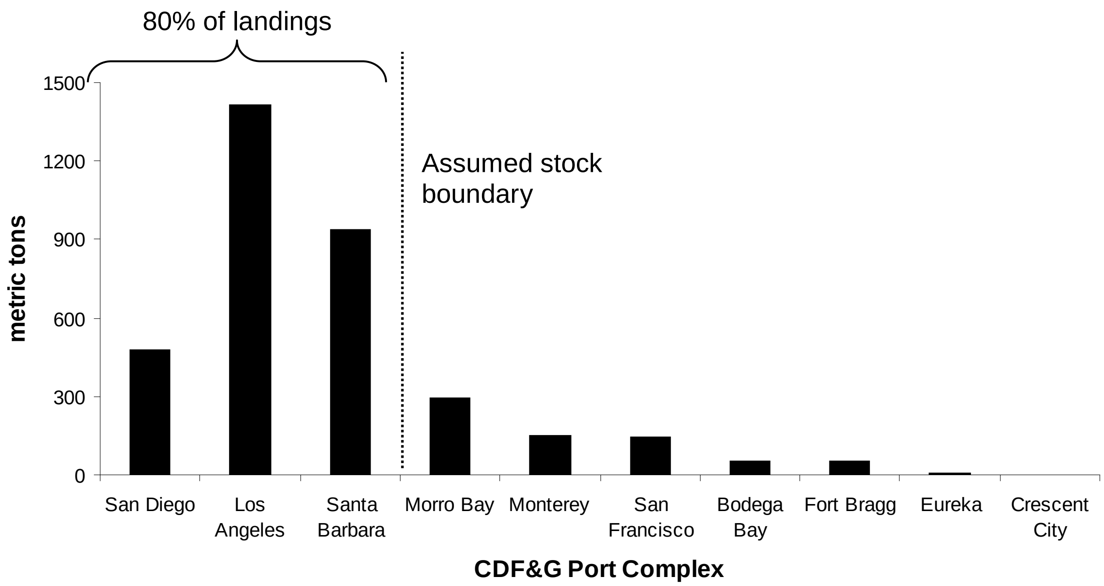


Figure 3. Cowcod landings by port complex, 1969-2005. Source: CALCOM.

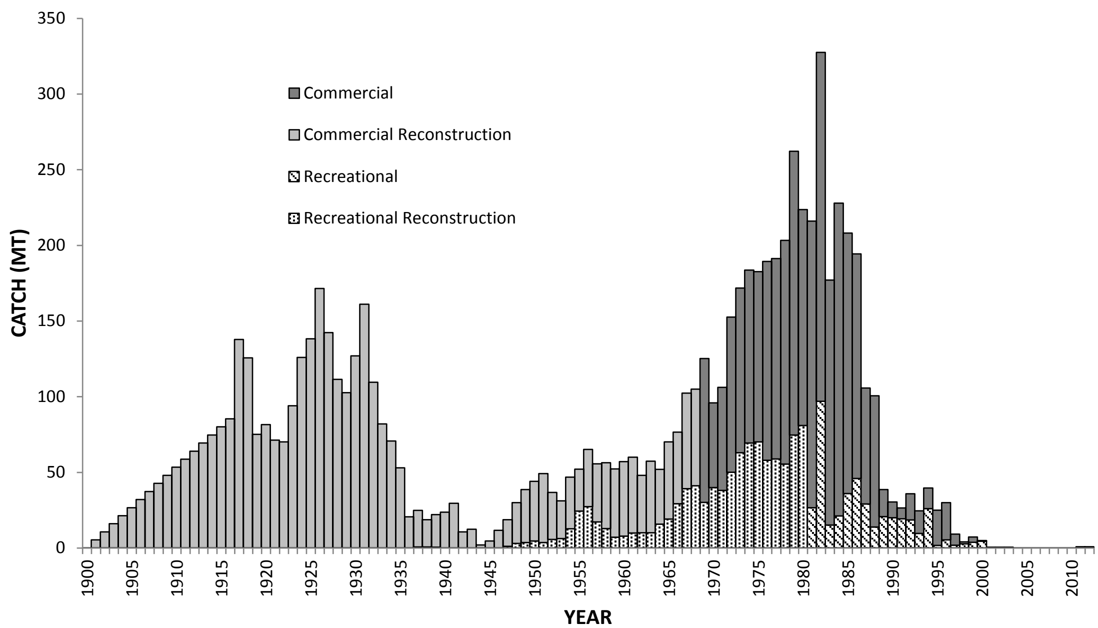


Figure 4. Estimated commercial and recreational removals of cowcod in the Southern California Bight, 1900-2012.

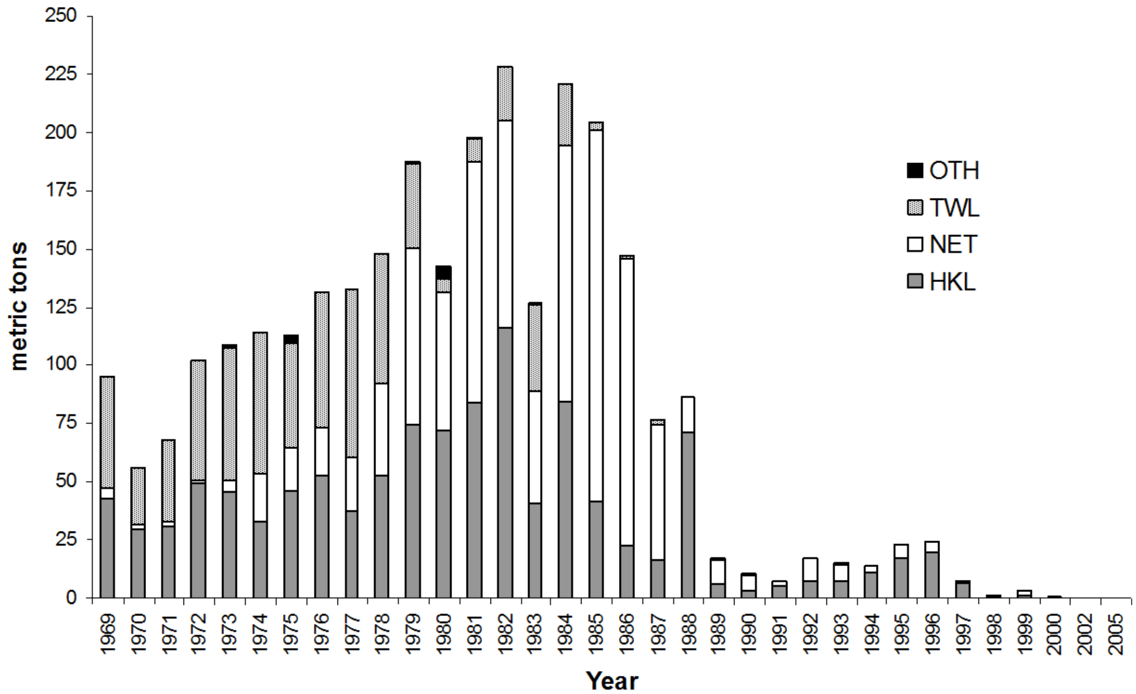


Figure 5. Commercial catches of cowcod by gear type (CALCOM, 2007). Gear groups are hook & line (HKL), trawl (TWL), net (NET), and other (OTH).

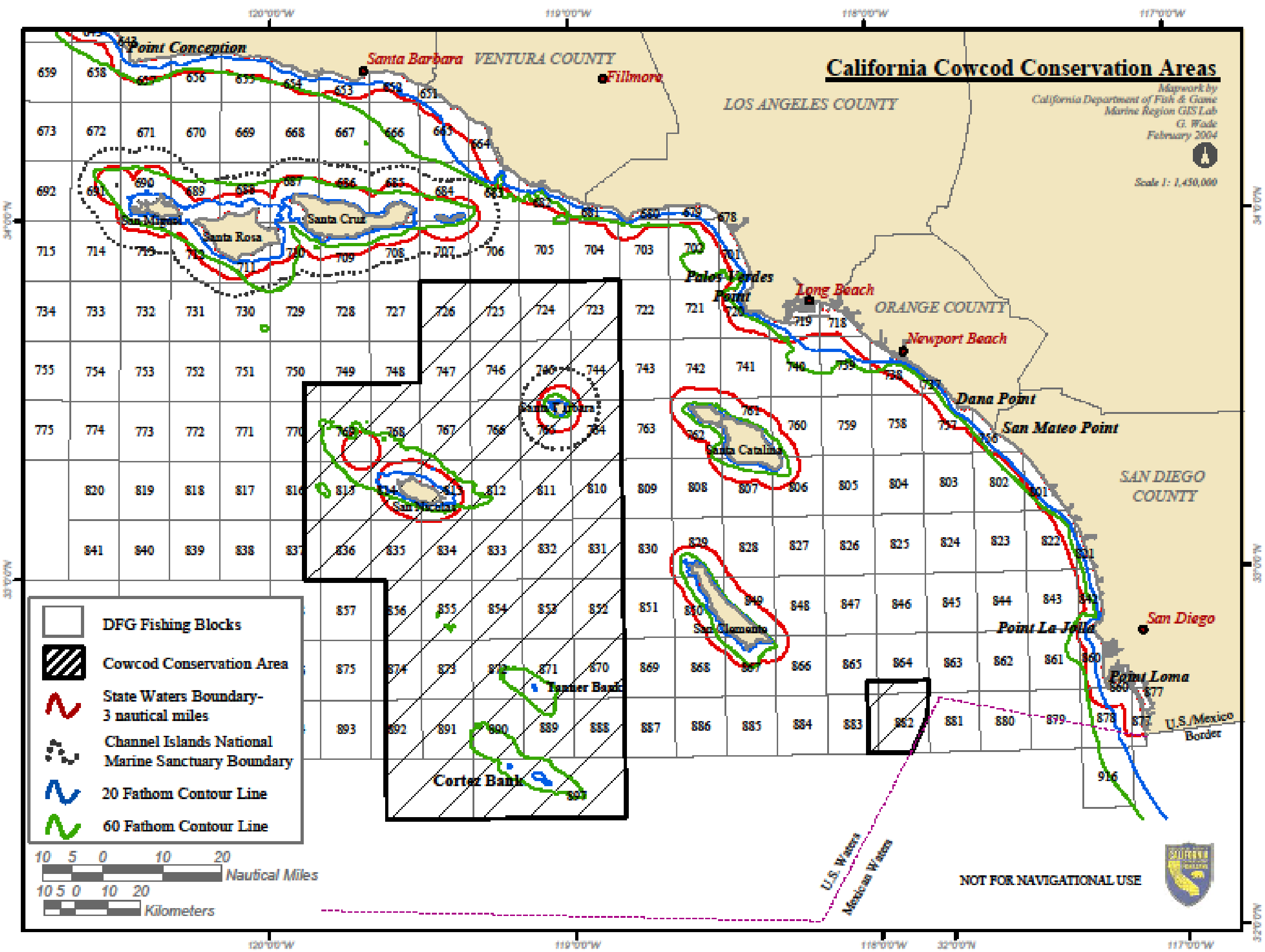


Figure 6. Cowcod Conservation Areas in the Southern California Bight. Source: CDFW (http://www.dfg.ca.gov/marine/cowcod.asp)

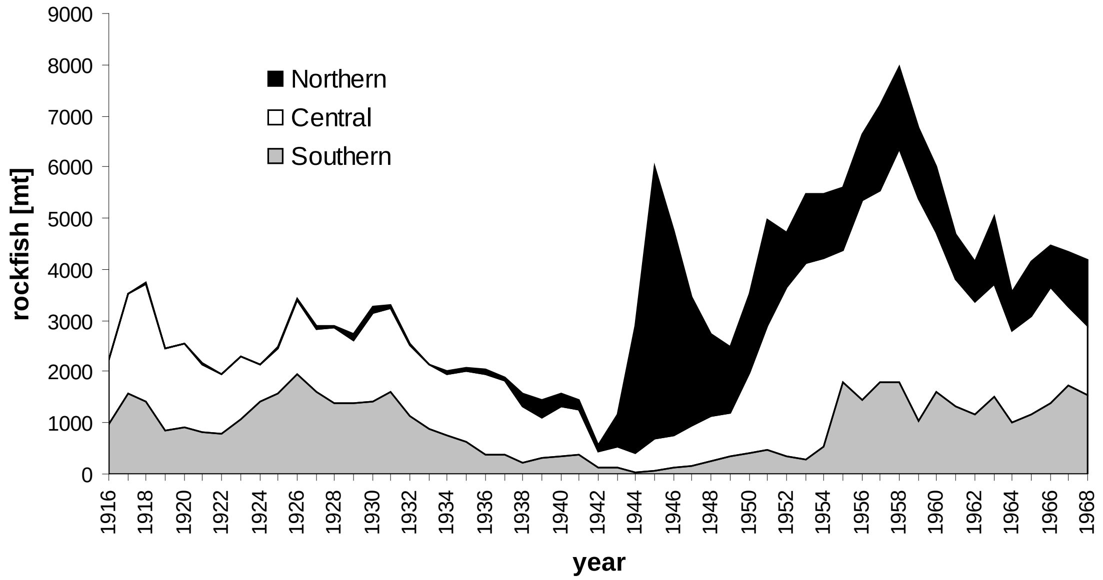


Figure 7: Total commercial rockfish landings by area in California, 1916-1968. See text for definition of regions. Data from 1916-1927 are from CDF&G Fish Bulletin No. 105 (1958), and data after 1927 are from the NMFS SWFSC ERD Live-Access Server.

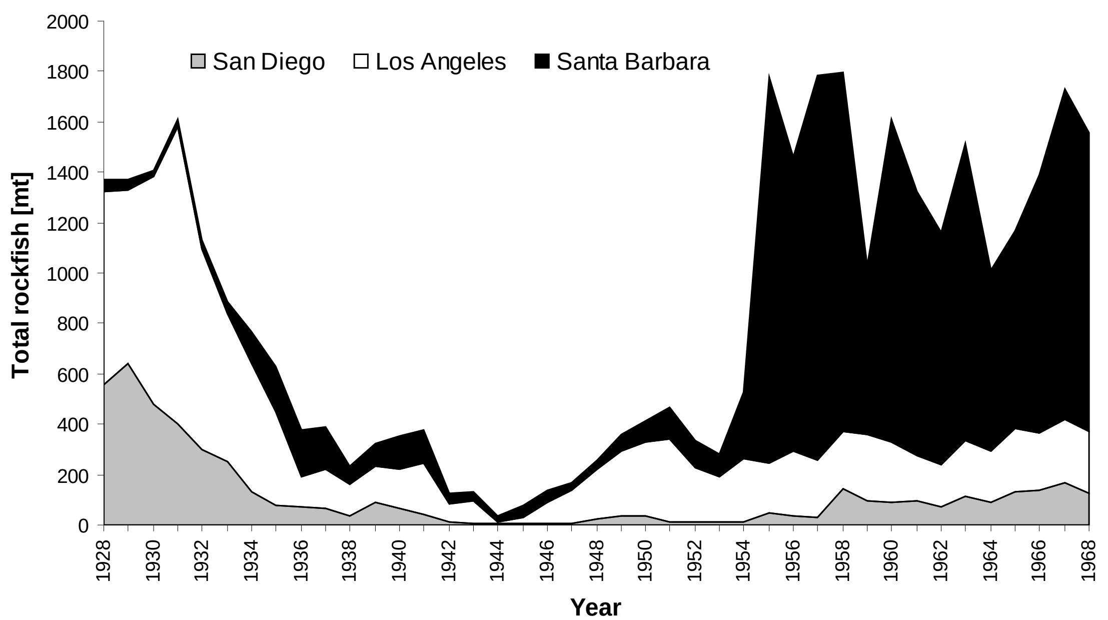


Figure 8. Total commercial rockfish landings in Southern California, 1928-1968, from the ERD database. Landings include thornyheads (genus *Sebastolobus*) and exclude foreign catch. Increased catch in the Santa Barbara region (1954+) is largely due to landings at Morro Bay and Avila.

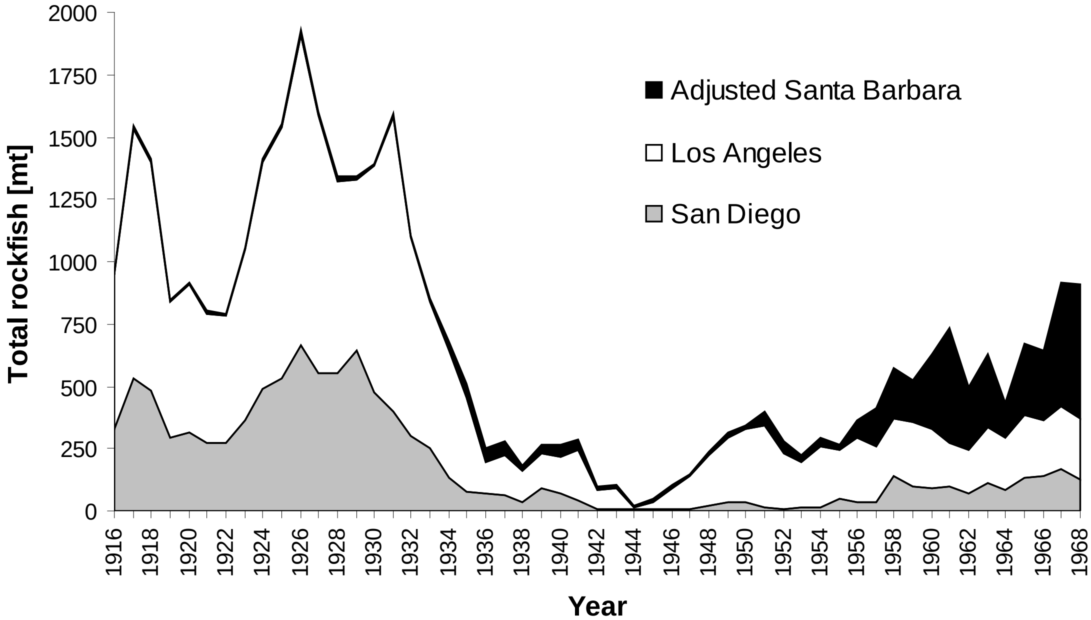


Figure 9. Total commercial rockfish landings in Southern California by region, 1916-1968. Catch in the Santa Barbara region has been adjusted to exclude landings at Morro Bay and Avila

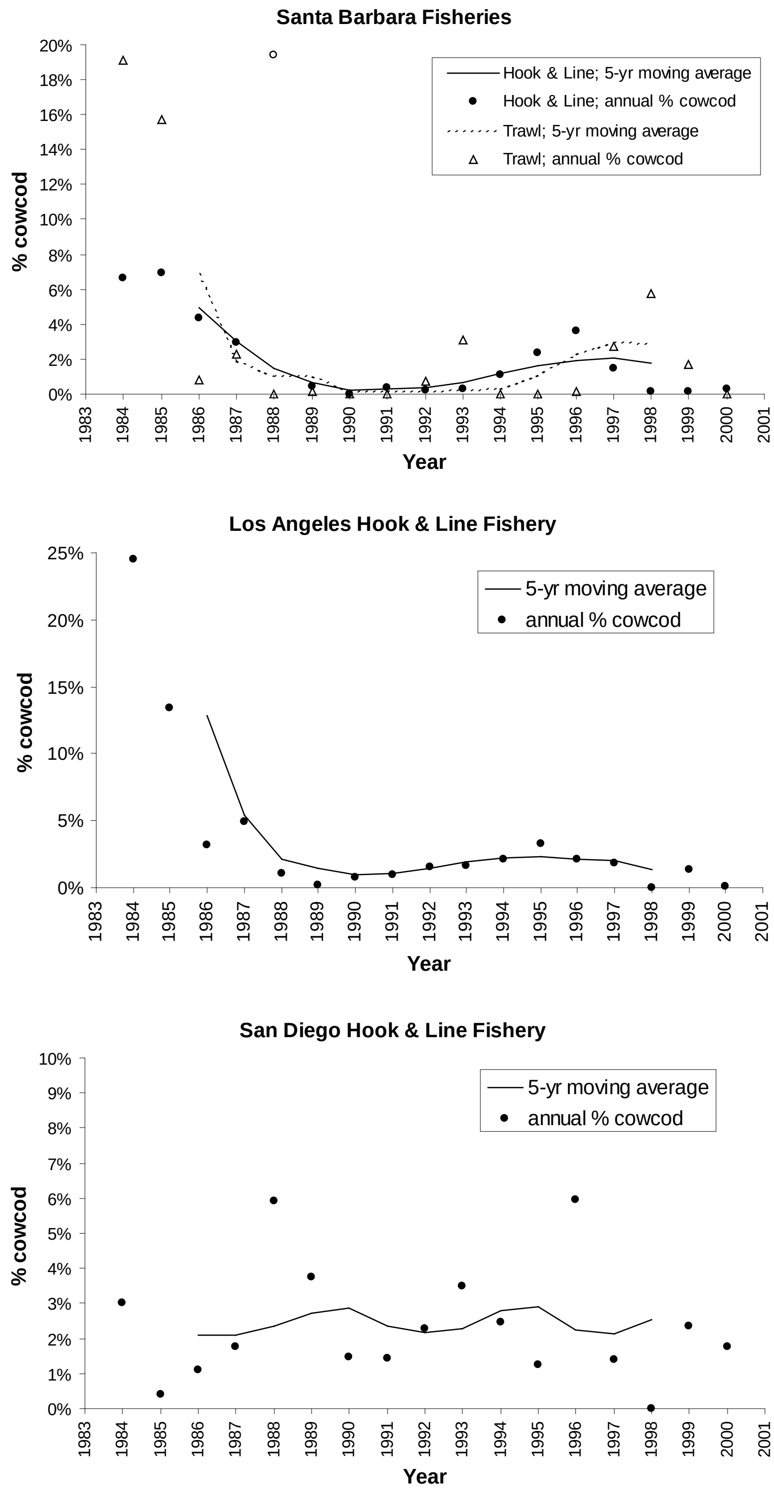


Figure 10. Percent cowcod in rockfish landings, 1984-2000, by year, port, and gear. Moving averages for the Santa Barbara hook & line fishery do not include data from 1988 (open circle).

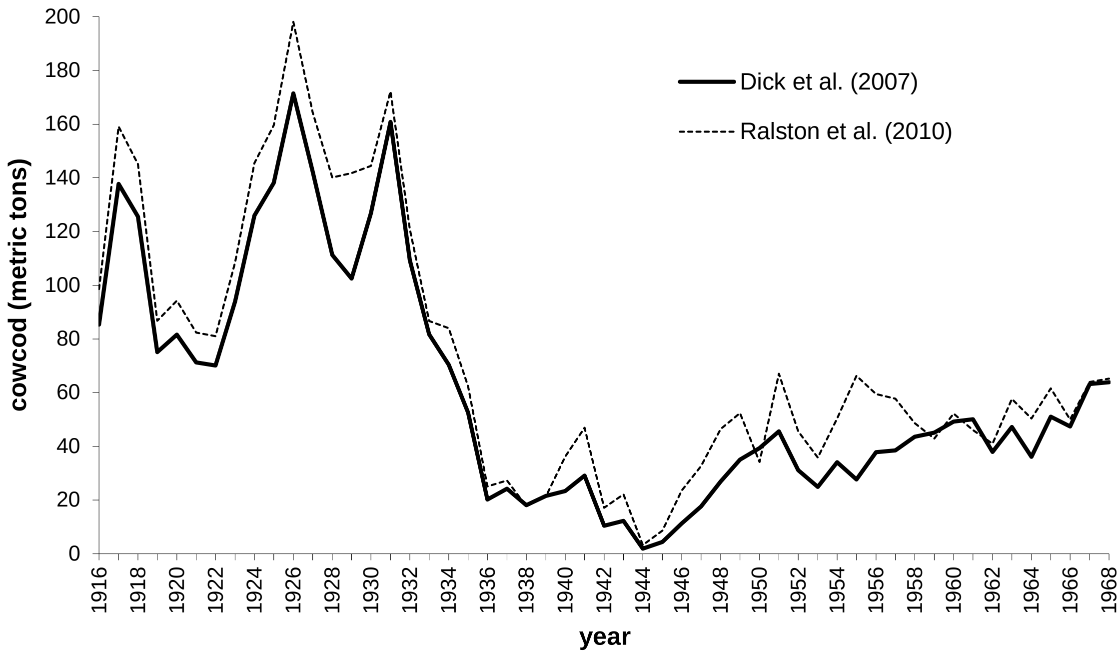


Figure 11. Comparison of historical commercial catch reconstructions for cowcod. Estimates by Ralston et al. (2010) represent catch in the Conception INPFC area. Dick et al. (2007) estimated cowcod catches for U.S. waters south of Point Conception.

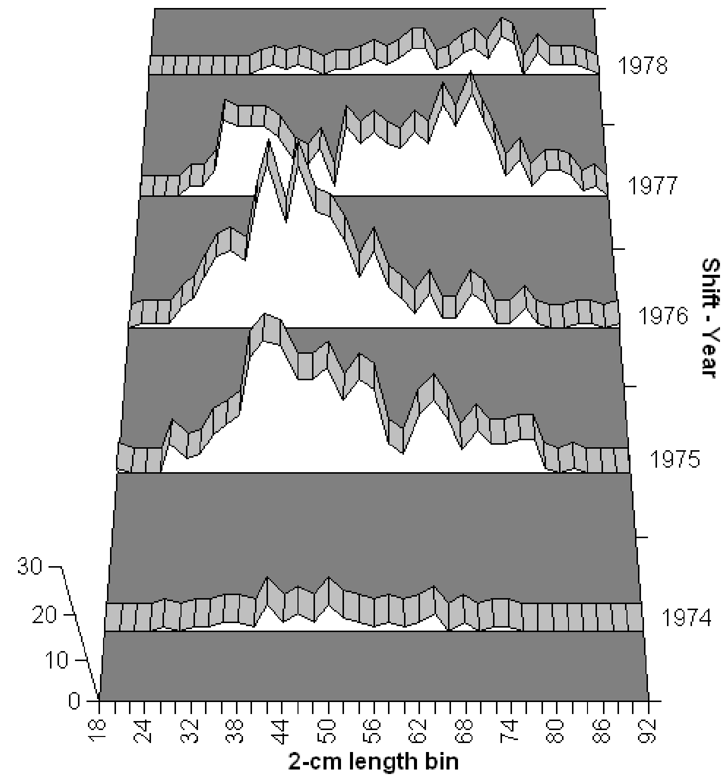


Figure 12. Cowcod length compositions from onboard CPFV sampling in Southern California, 1974-1978.

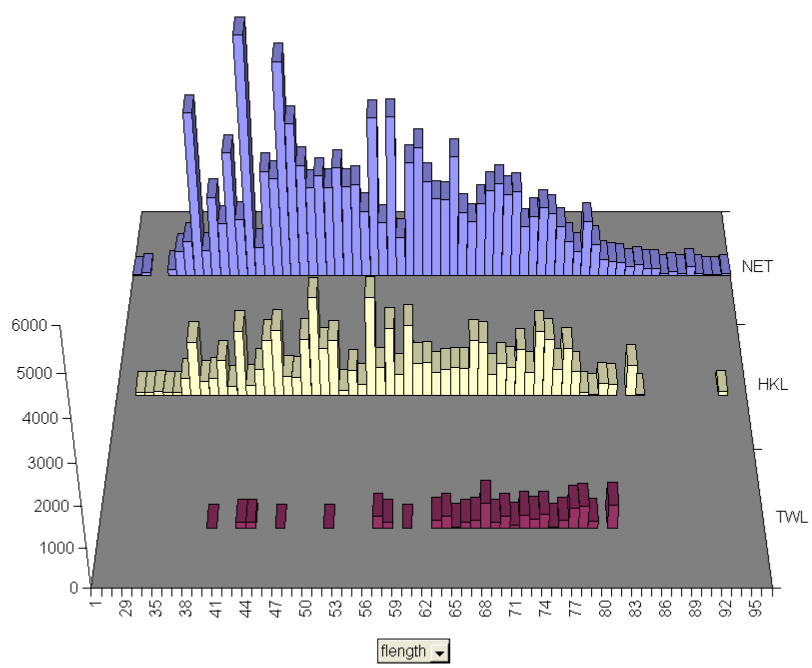


Figure 13. Frequency distributions of cowcod lengths from the commercial fishery, by gear group (all years combined).

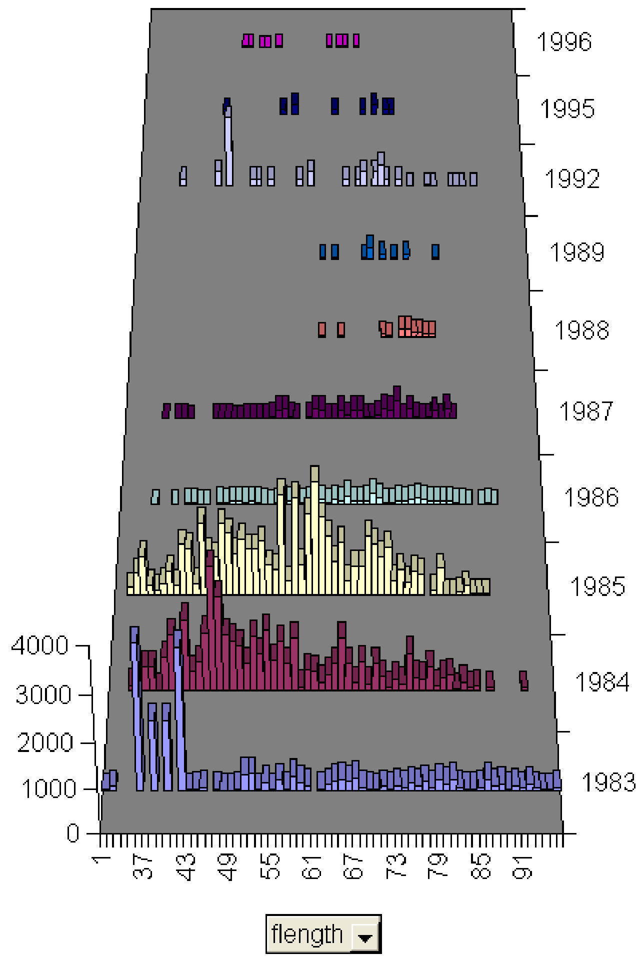


Figure 14. Frequency distributions of cowcod lengths, by year, for the net fishery in Southern California.

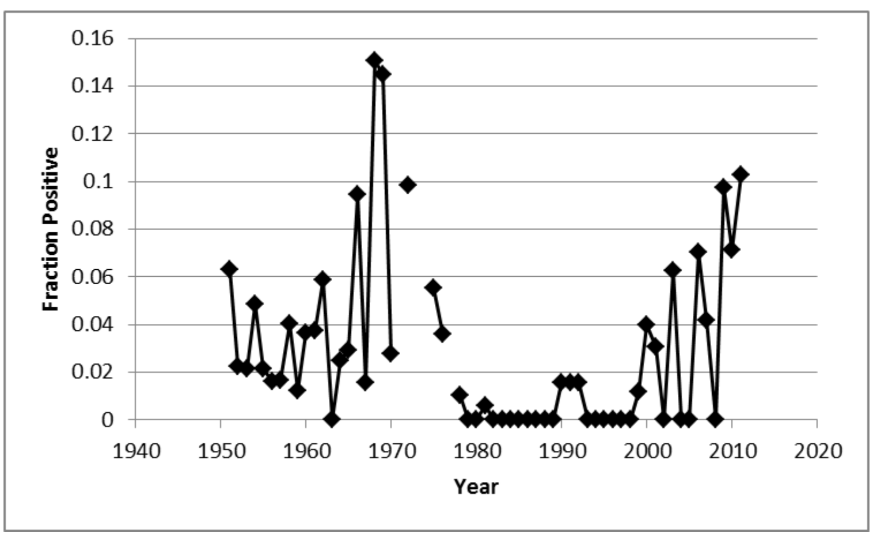


Figure 15. Fraction of southern California CalCOFI samples positive for cowcod.

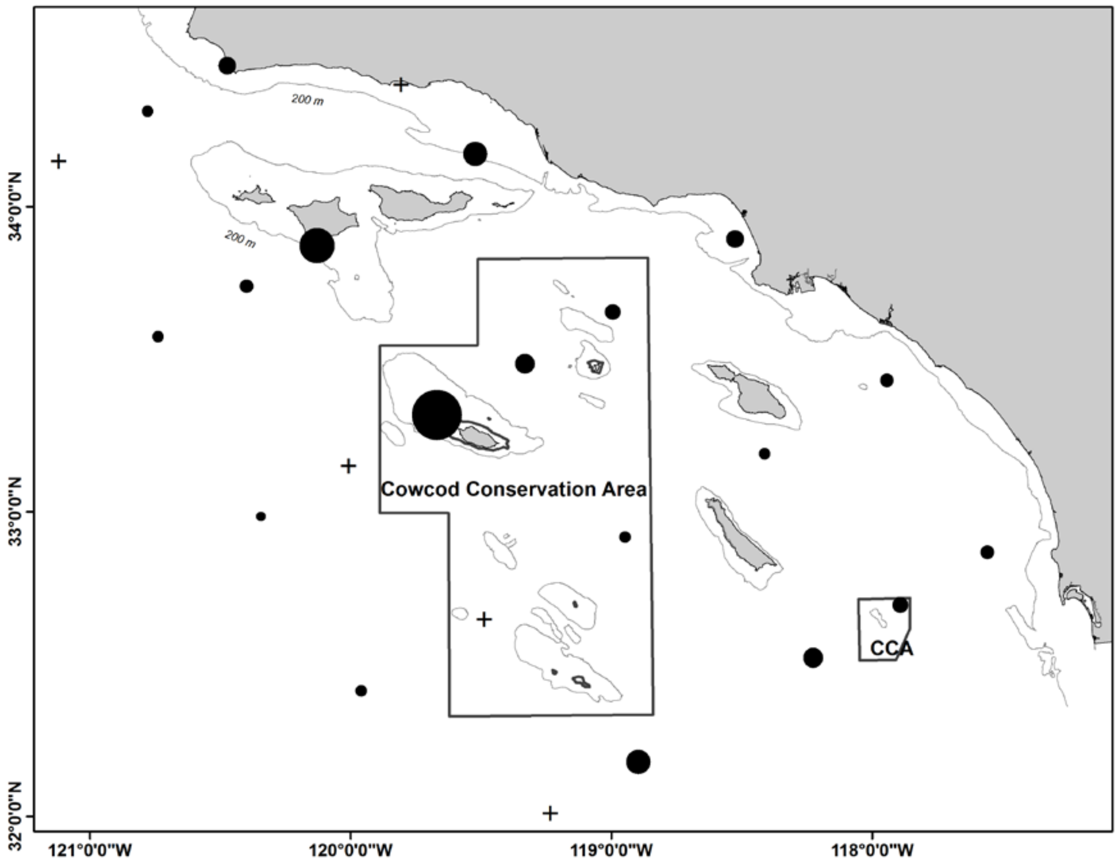


Figure 16. Fraction of tows positive for cowcod (1951-60) at CalCOFI stations. Circle size is proportional to the fraction of positive tows (maximum size = 0.131). Plus signs indicate stations that did not observe cowcod.

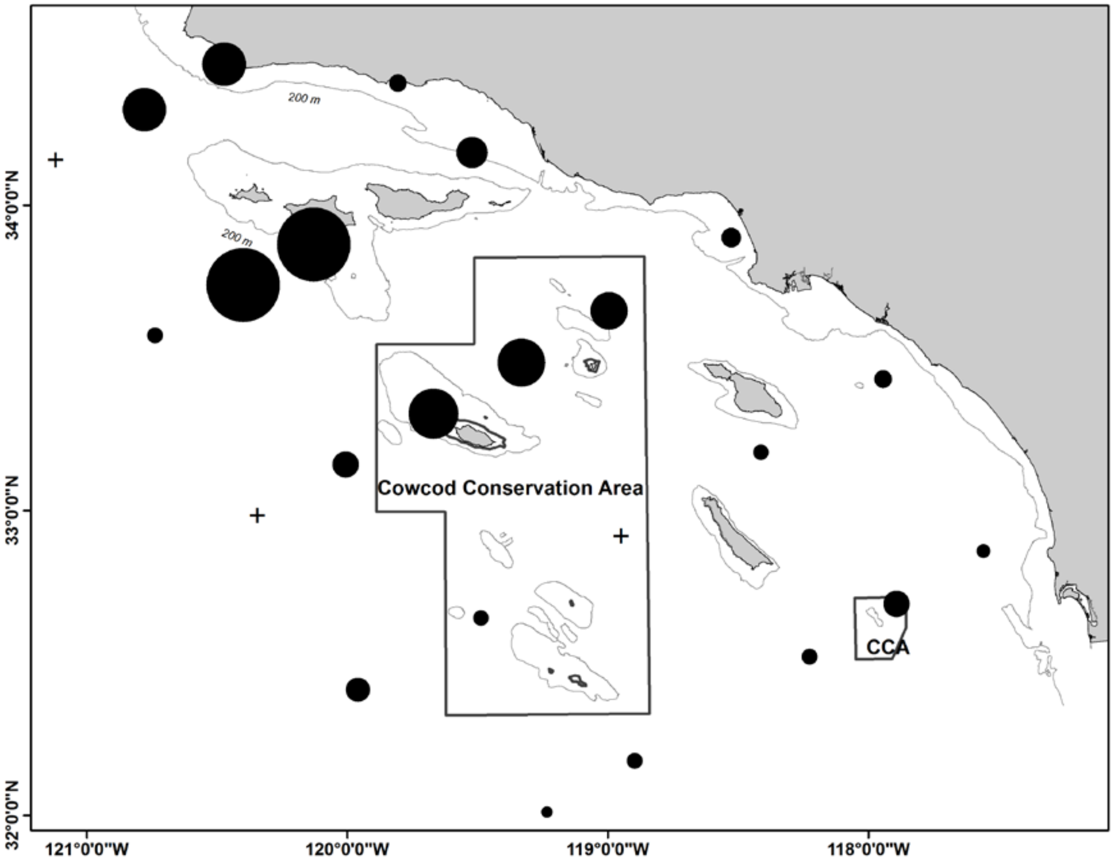


Figure 17. Fraction of tows positive for cowcod (1961-75) at CalCOFI stations. Circle size is proportional to the fraction of positive tows (maximum size = 0.206). Plus signs indicate stations that did not observe cowcod.

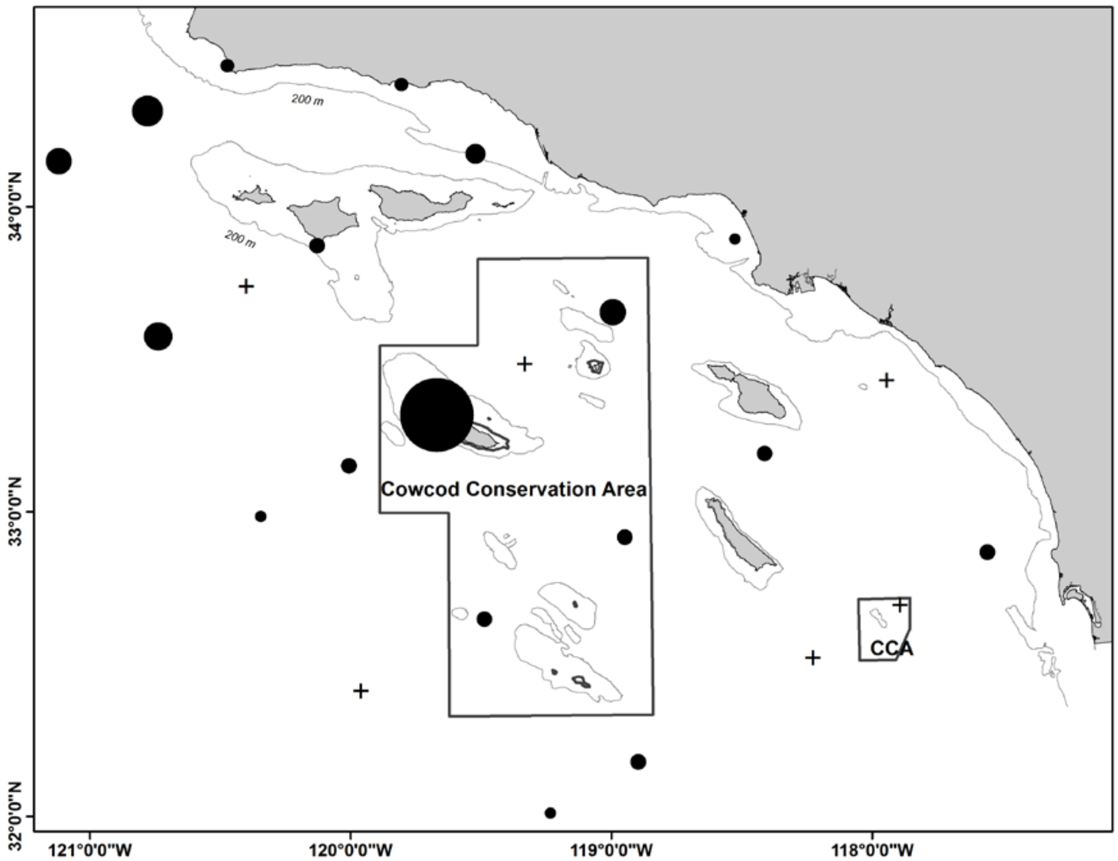


Figure 18. Fraction of tows positive for cowcod (1999-2011) at CalCOFI stations. Circle size is proportional to the fraction of positive tows (maximum size = 0.2). Plus signs indicate stations that did not observe cowcod.

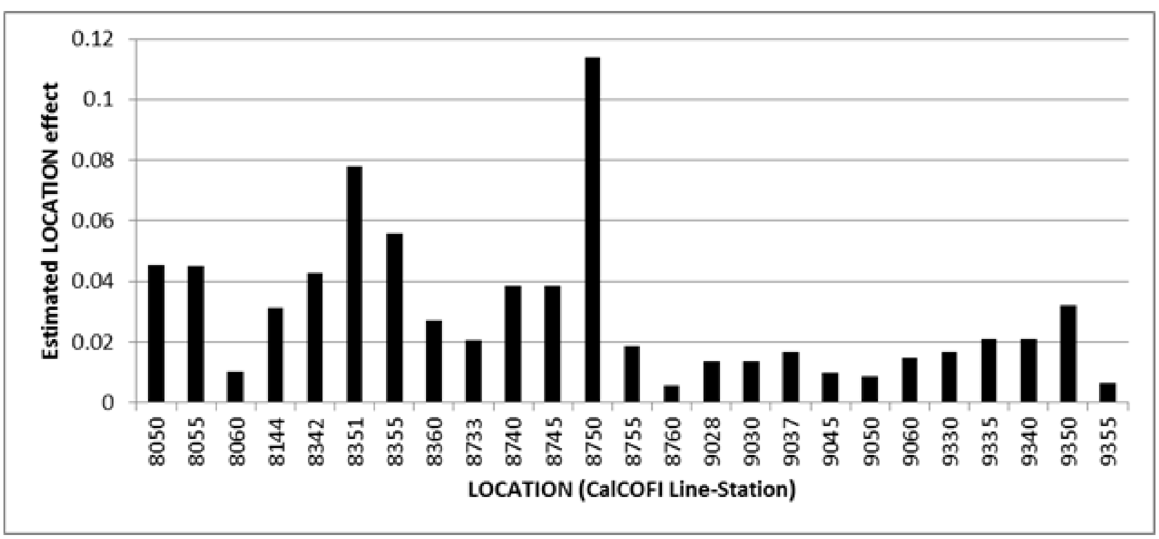


Figure 19. Estimated LOCATION effects from binomial GLM.

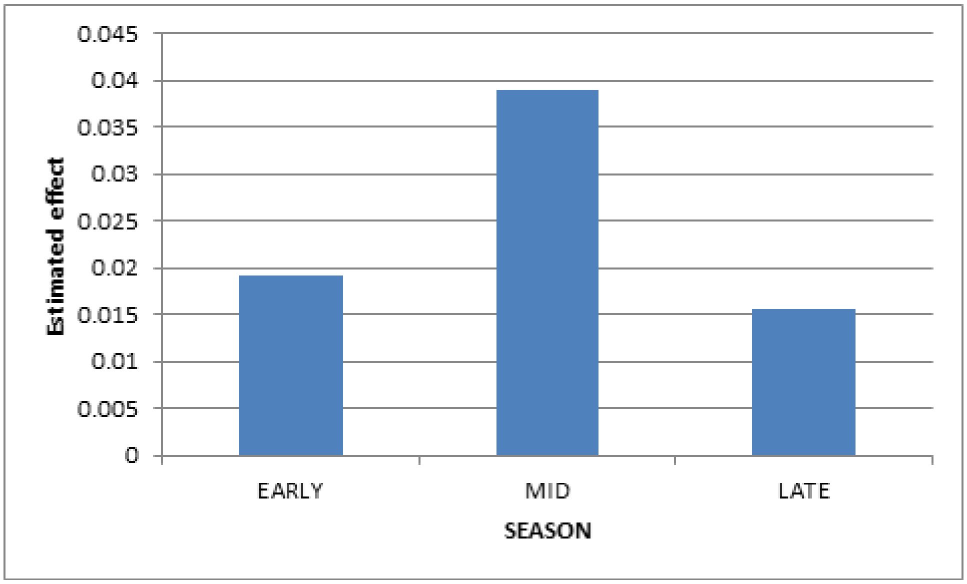


Figure 20. Estimated SEASON effects from binomial GLM. EARLY is 1 Nov to 5 Feb; MID is 6 Feb to 17 March; LATE is 18 March to May.

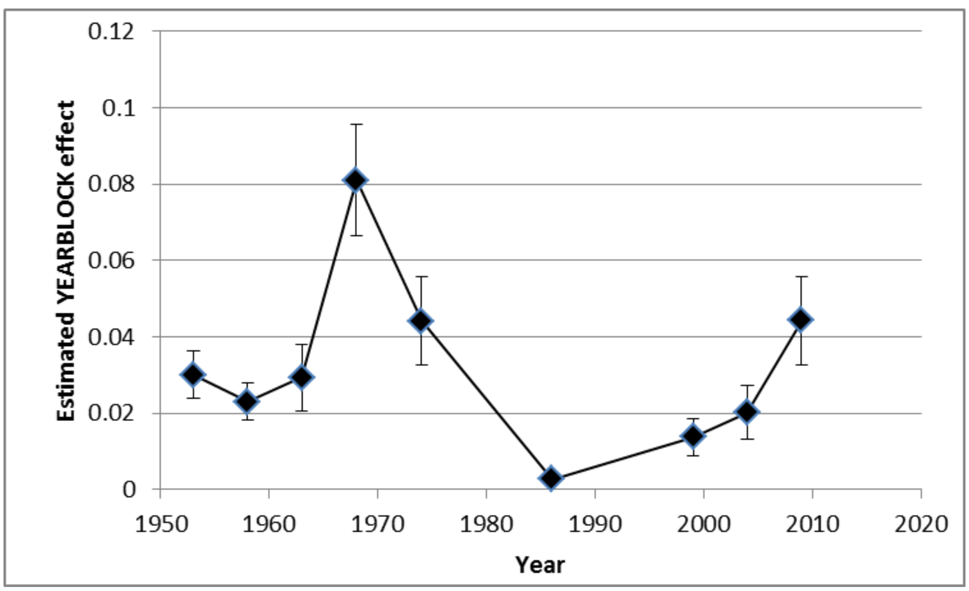


Figure 21. CalCOFI index of larval abundance , using time blocks. Error bars are 1 standard error.

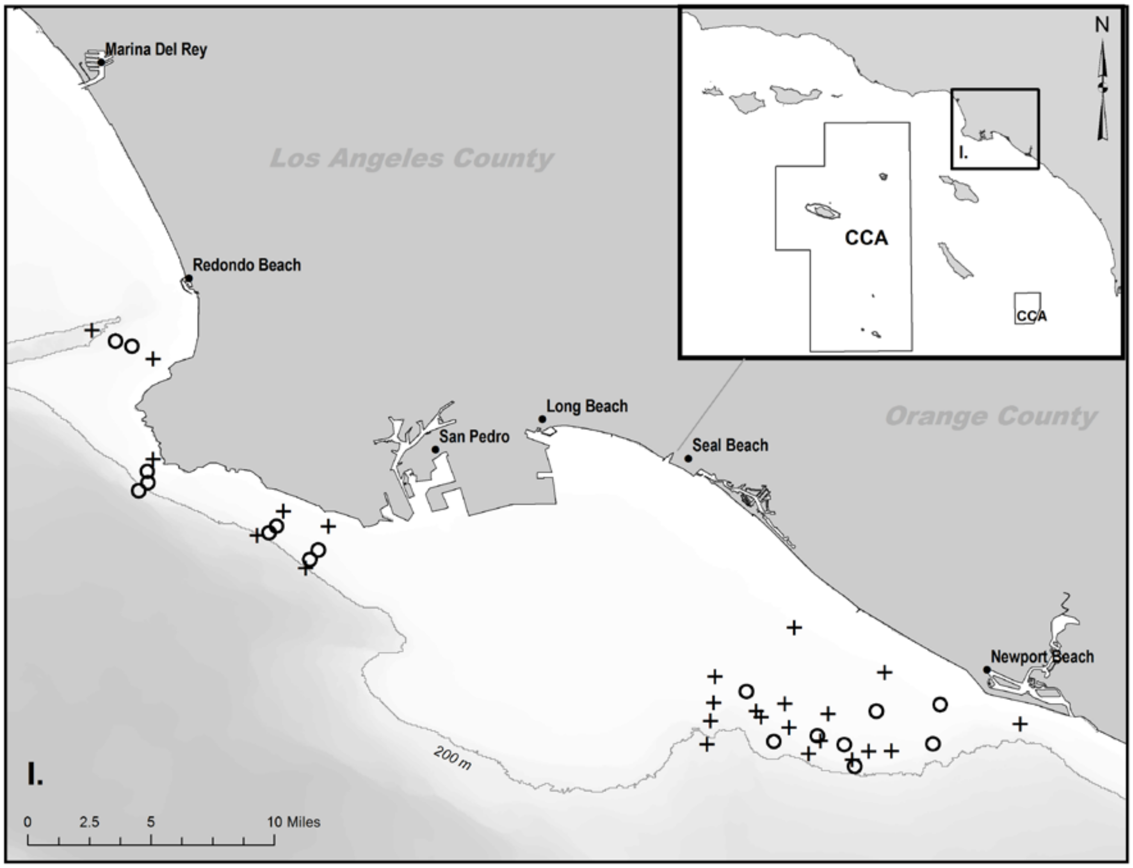


Figure 22. Location of trawls conducted by the Los Angeles and Orange County Sanitation Districts. Circles indicate stations where cowcod have been taken, plus signs indicate stations where cowcod have not been taken.

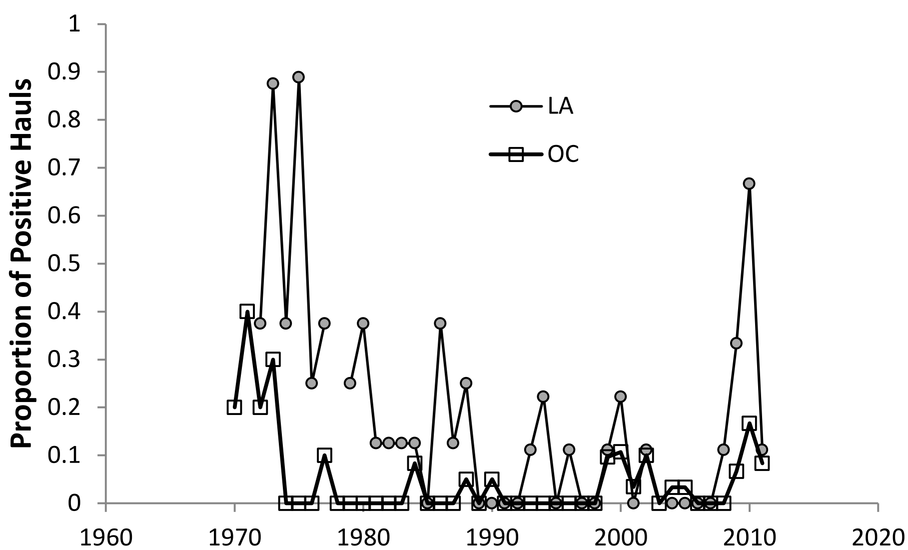


Figure 23. Proportion of hauls positive for cowcod by year and survey in the Los Angeles County (LA) and Orange County (OC) Sanitation District surveys.

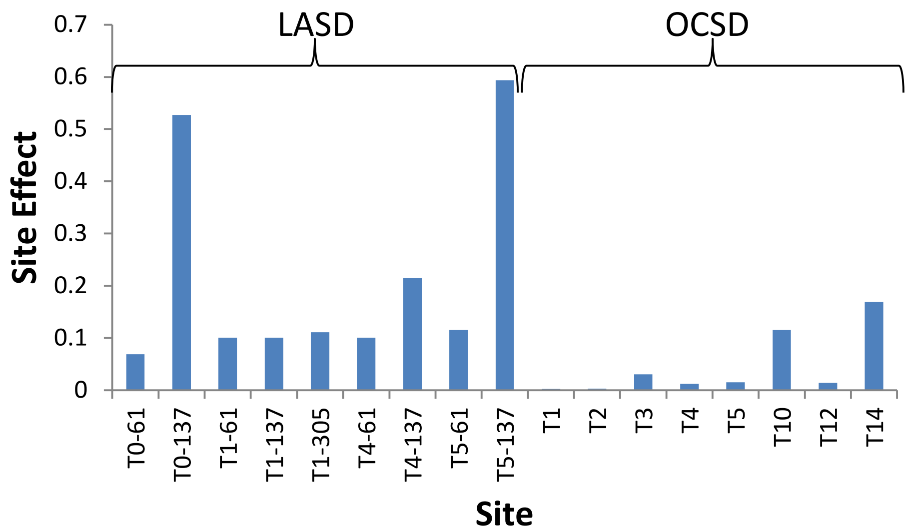


Figure 24. Site effects from the combined Sanitation District index.

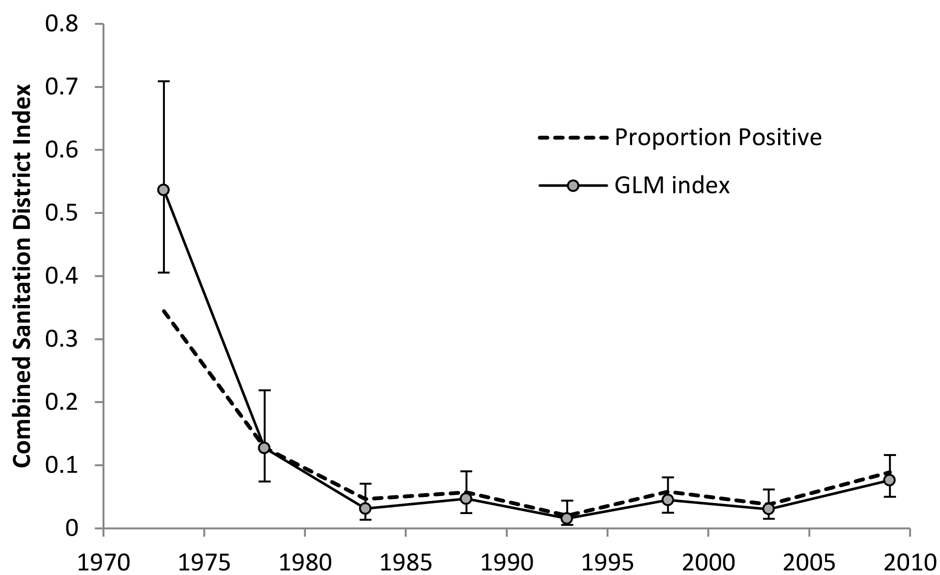


Figure 25. Comparison of the combined LA/OC Sanitation District GLM index (with station and quarter effects) to the proportion of positive hauls in a given year (not accounting for station or quarter effects). Error bars are 95% lognormal confidence intervals.

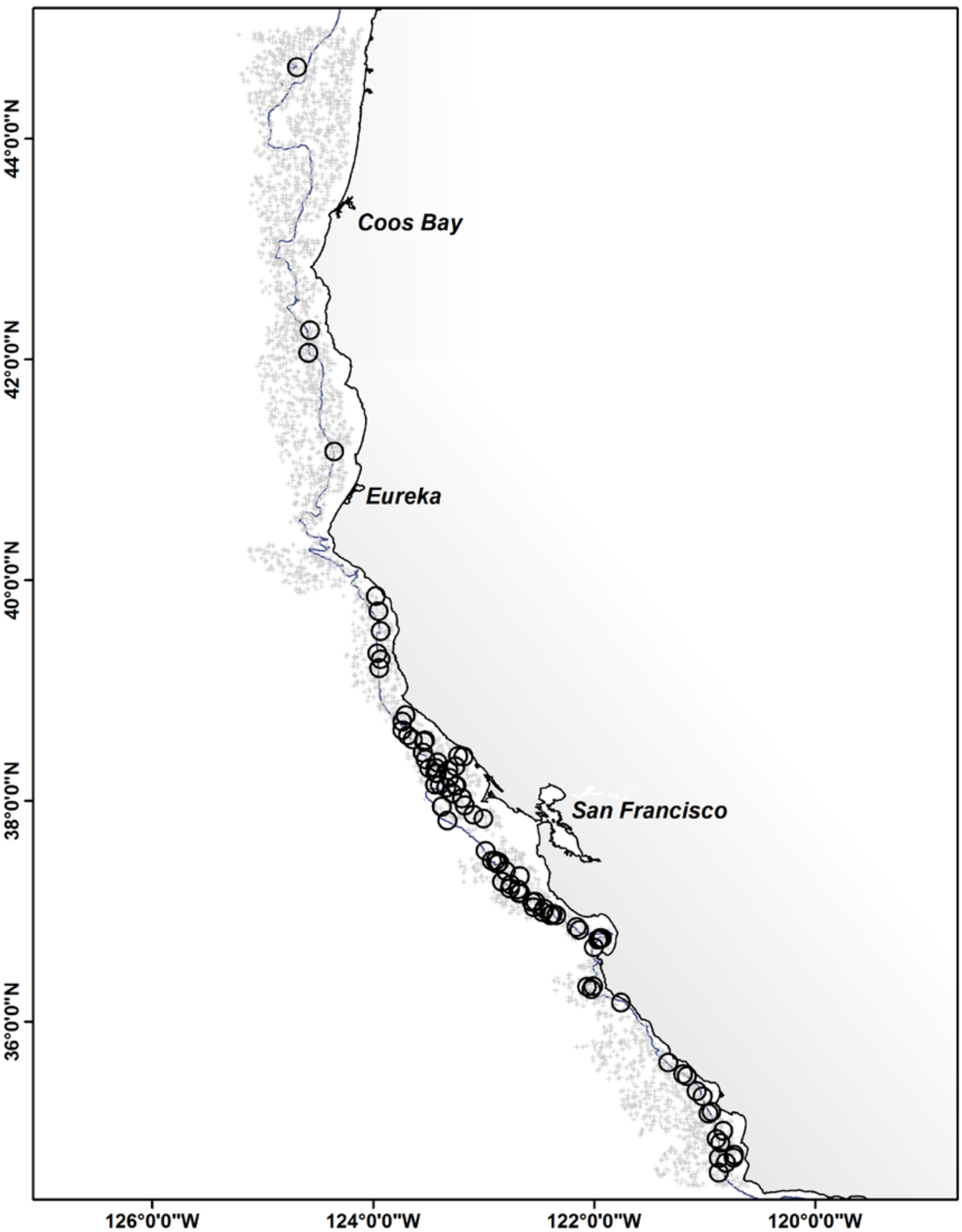


Figure 26. NWFSC combined trawl survey effort (plus signs) and positive hauls for cowcod (circles), north of Point Conception.

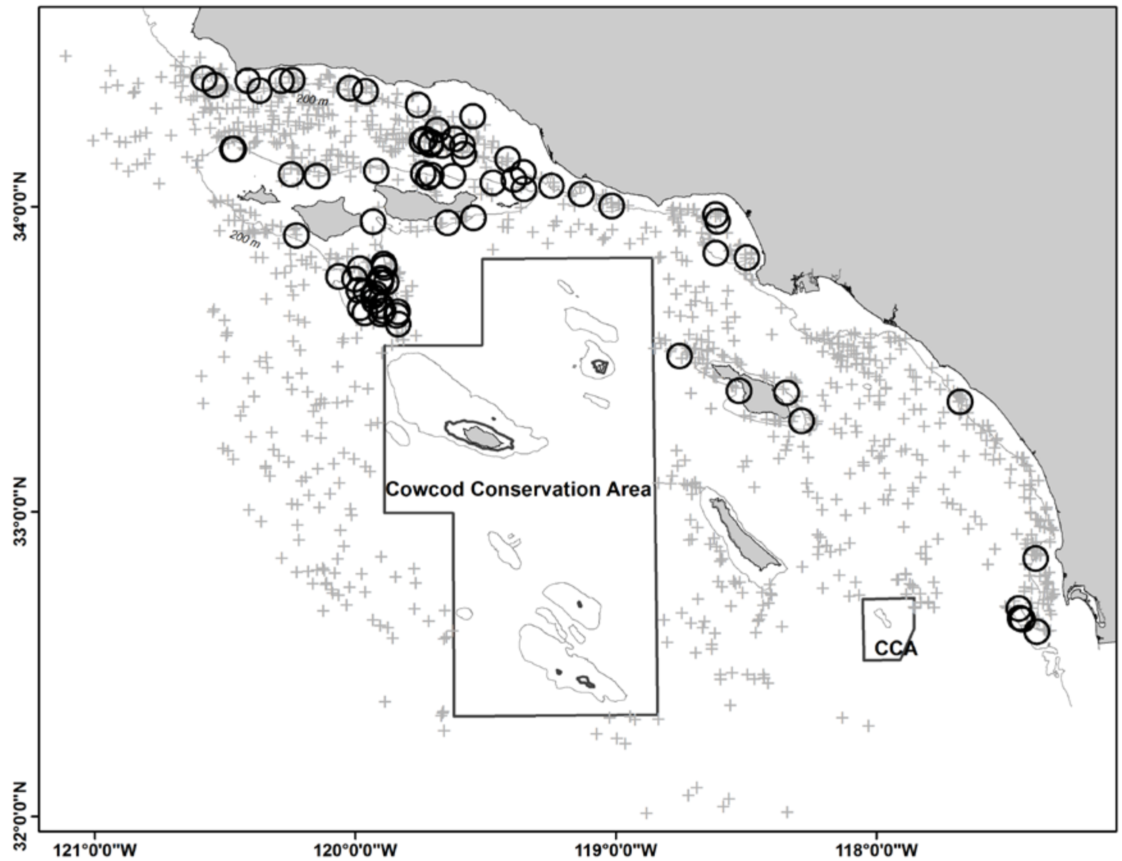


Figure 27. NWFSC combined trawl survey effort (plus signs) and positive hauls for cowcod (circles), south of Point Conception.

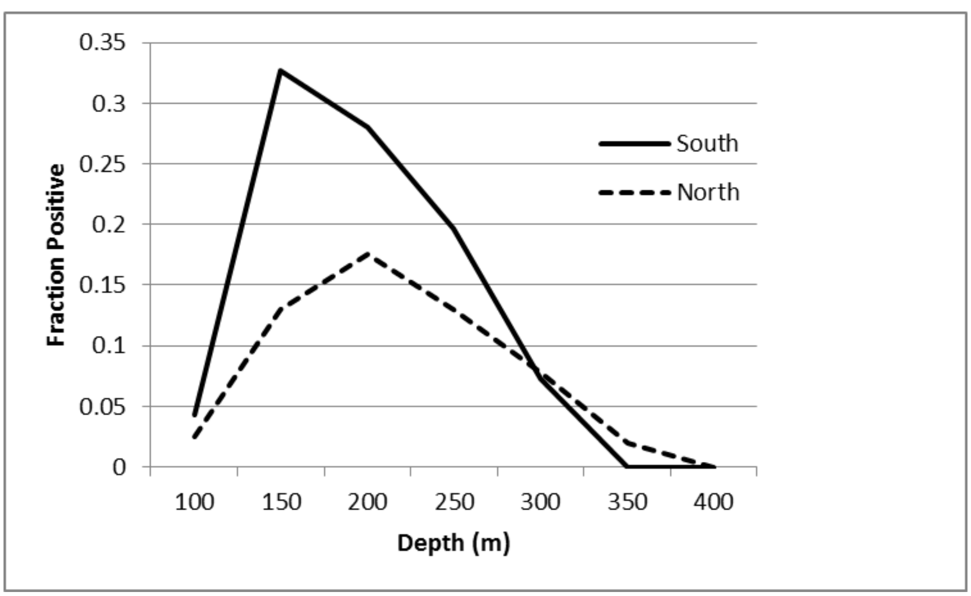


Figure 28. Fraction of hauls positive for cowcod by 50-meter depth bin in the NWFSC combined trawl survey, north and south of Point Conception.

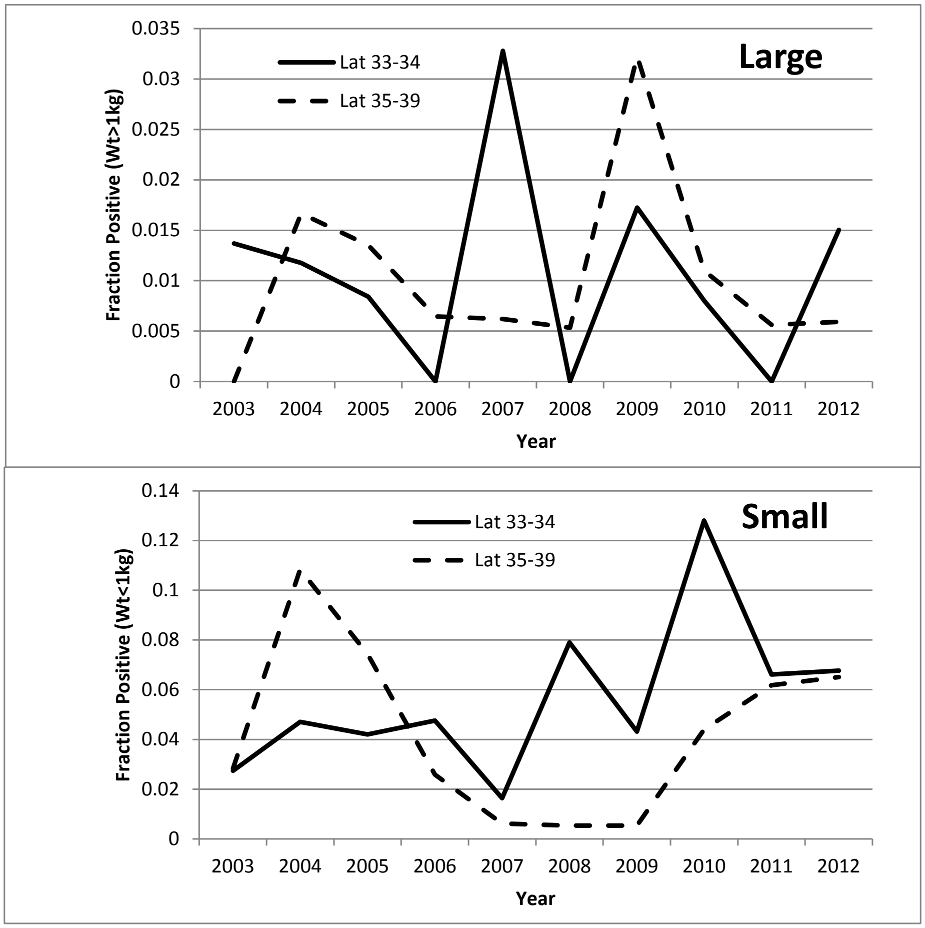


Figure 29. Comparison of trends in large (>1 kg) and small (<1 kg) cowcod from the NWFSC trawl survey, north and south of Point Conception.

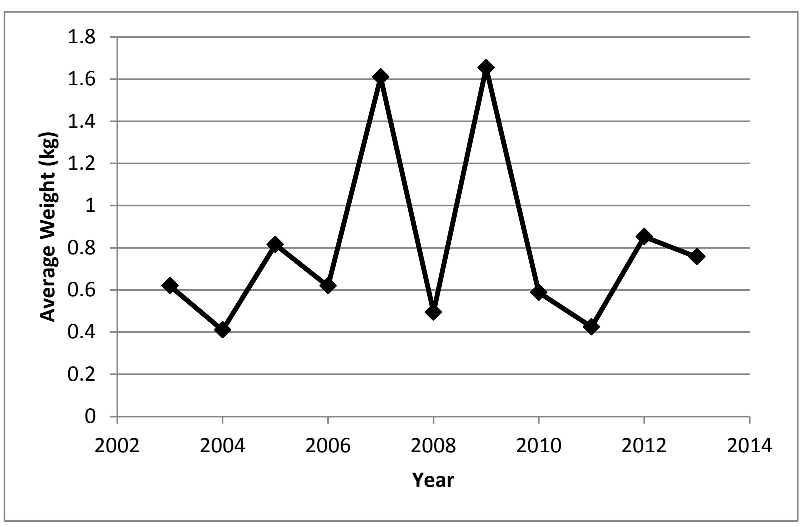


Figure 30. Average weight by year of cowcod in the NWFSC trawl survey.

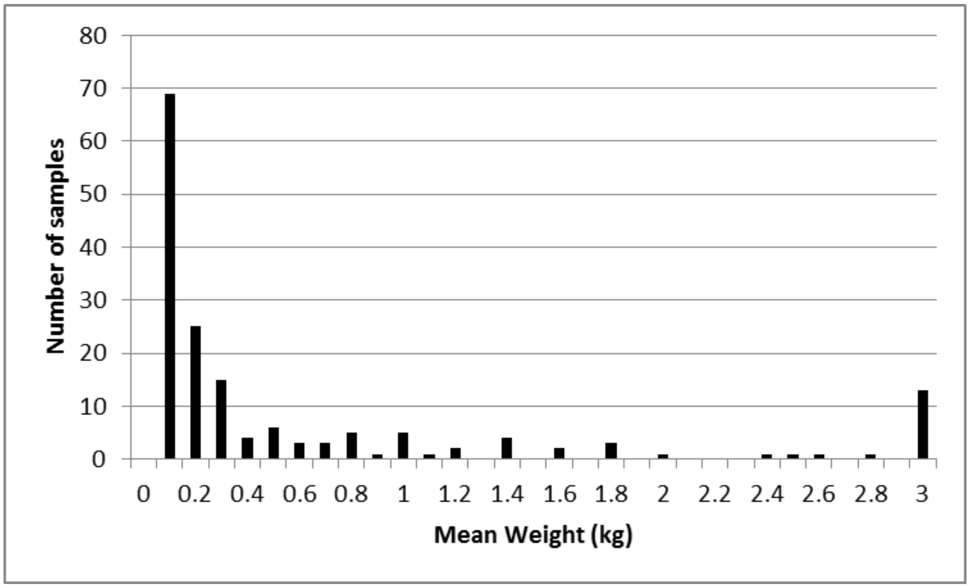


Figure 31. Frequency distribution of mean weight of cowcod caught in trawl surveys. The 3-kilogram size includes all larger values.

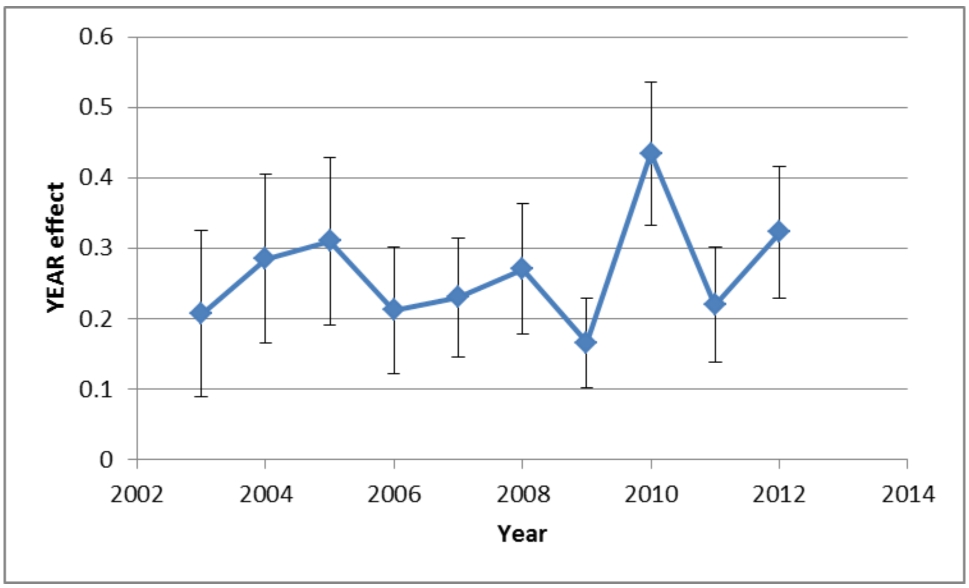


Figure 32. NWFSC trawl survey index of small (<1kg) cowcod abundance in southern California waters. Error bars are 1 SE.

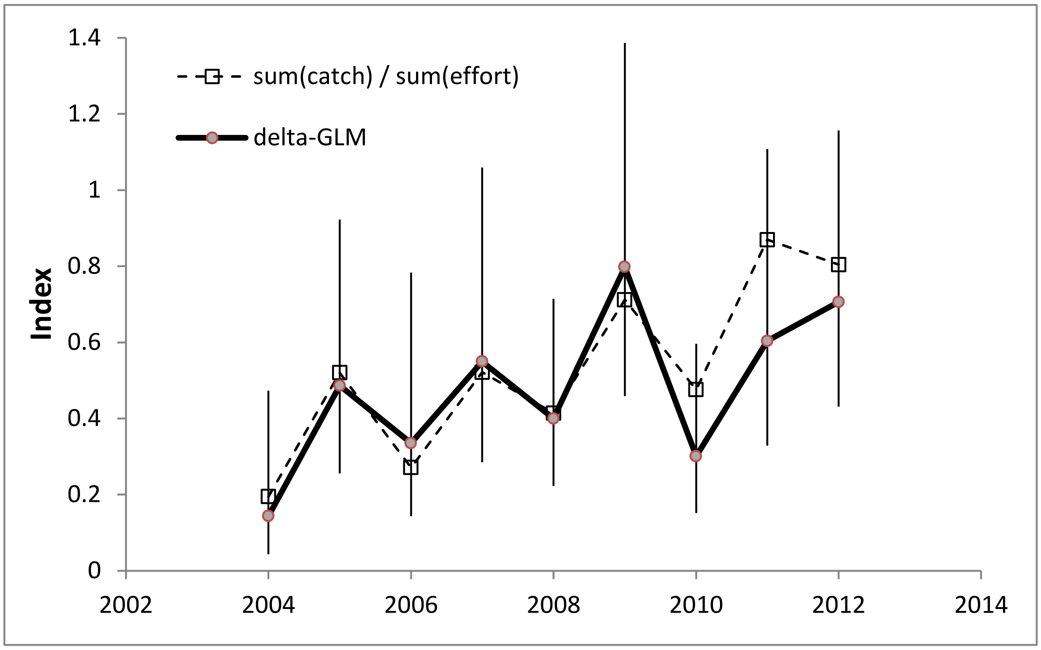


Figure 33. Raw CPUE (catch per drop) and delta-GLM index for the NWFSC hook-and-line survey. Bars are 95% jackknifed confidence intervals assuming a lognormal error structure.

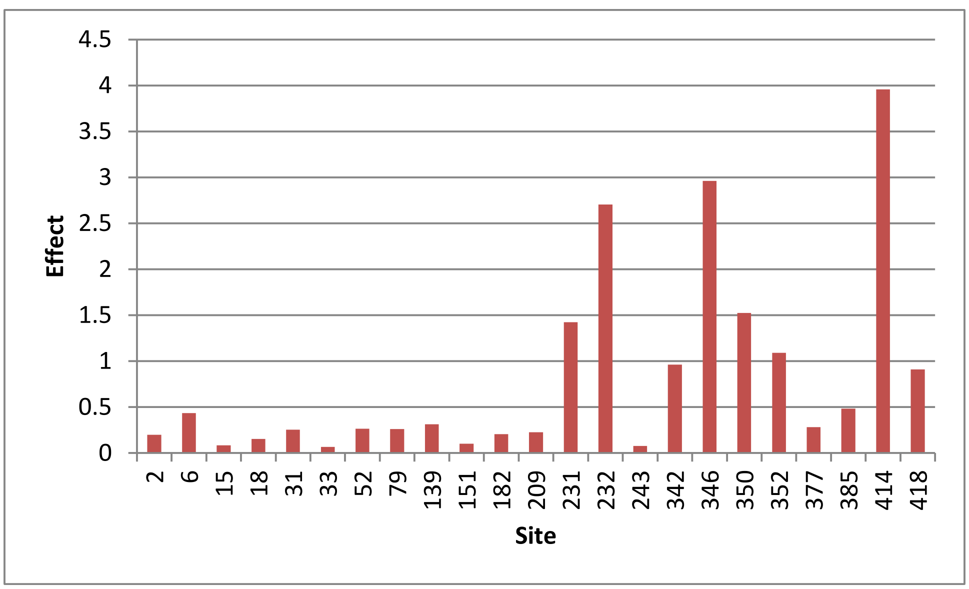


Figure 34. Site effects for NWFSC delta-GLM index for cowcod.

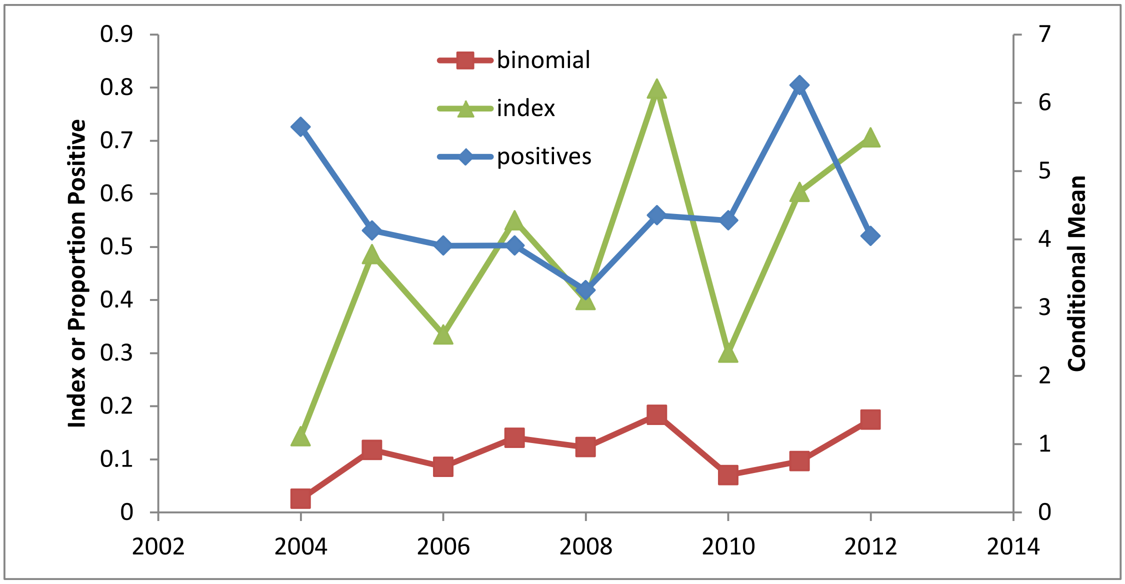


Figure 35. Binomial and positive (conditional mean) components of the NWFSC hook-and-line index for cowcod, compared to the final index (product of the two components).

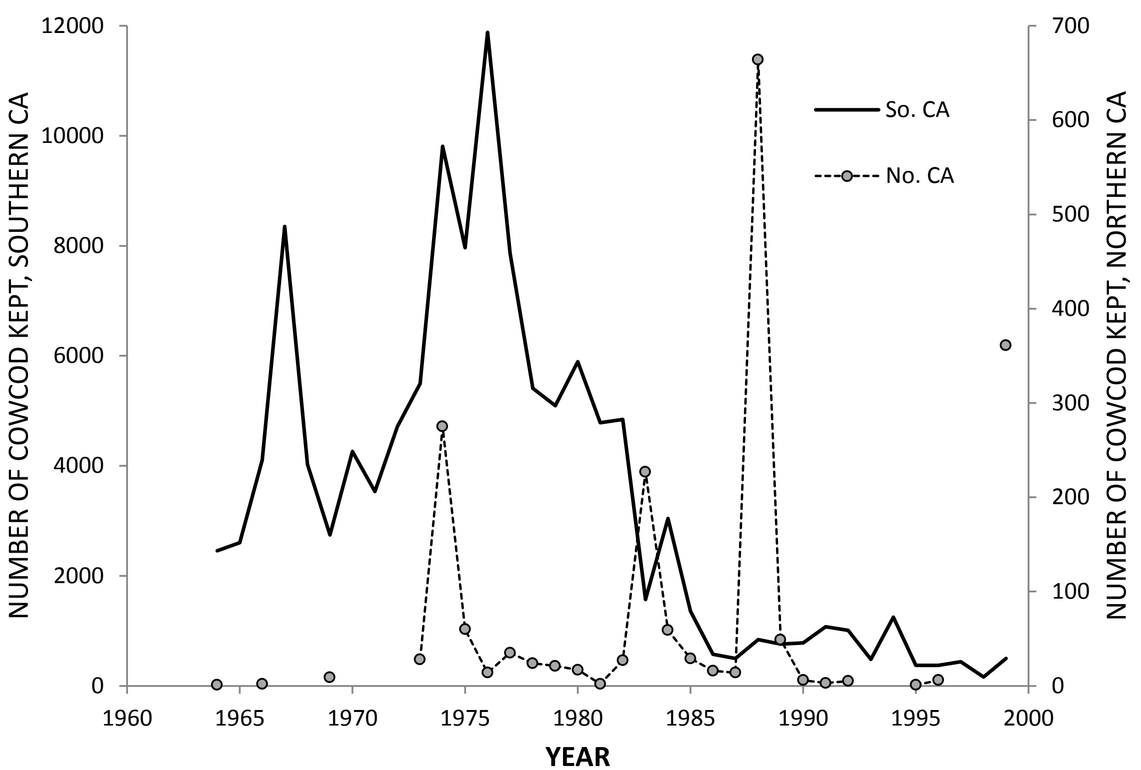


Figure 36. Number of cowcod recorded as kept in the California CPFV logbook database, by region. “Southern CA” = CDFW statistical blocks 651 and greater, “Northern CA” = block numbers less than 651.

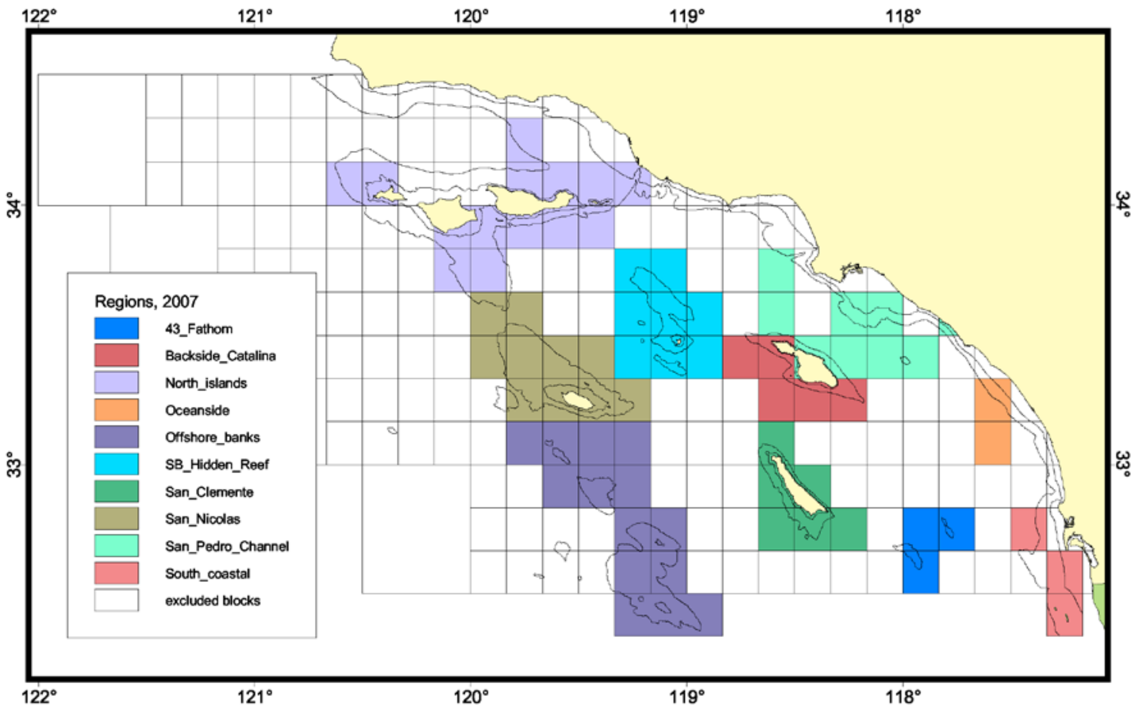


Figure 37. Spatial stratification of CDFW fishing blocks for the monthly aggregated CPFV logbook index, as used in the 2007 and 2009 cowcod assessments (Dick et al. 2007).

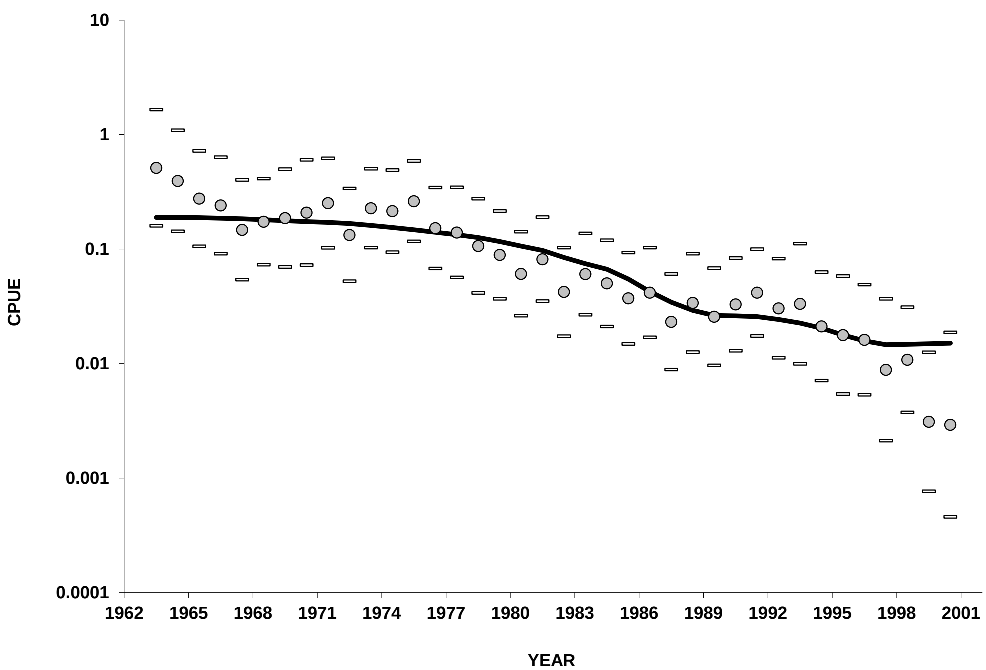


Figure 38. Base model fit to the (log-scale) CPFV logbook index in the 2009 cowcod assessment (Dick et al. 2009), showing hyperdepletion pattern.

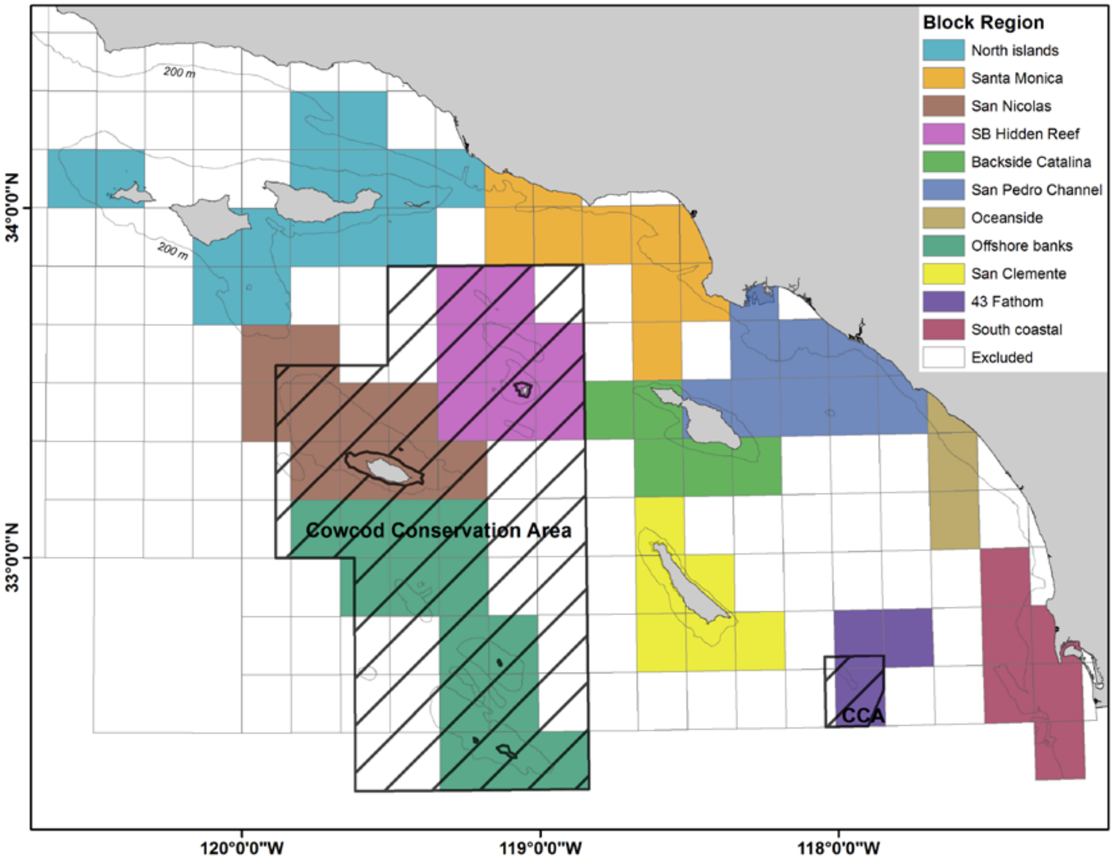


Figure 39. Spatial stratification of CDFW fishing blocks for the trip-based CPFV logbook index.

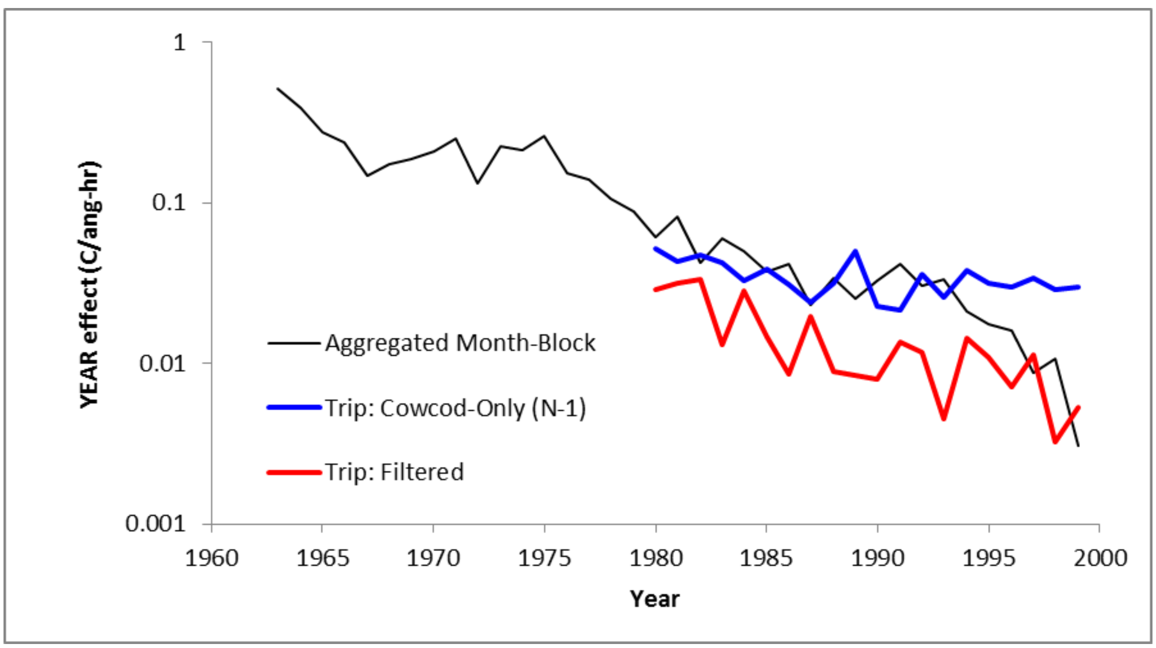


Figure 40. Comparison of three cowcod CPUE indices derived from CPFV logbook data.

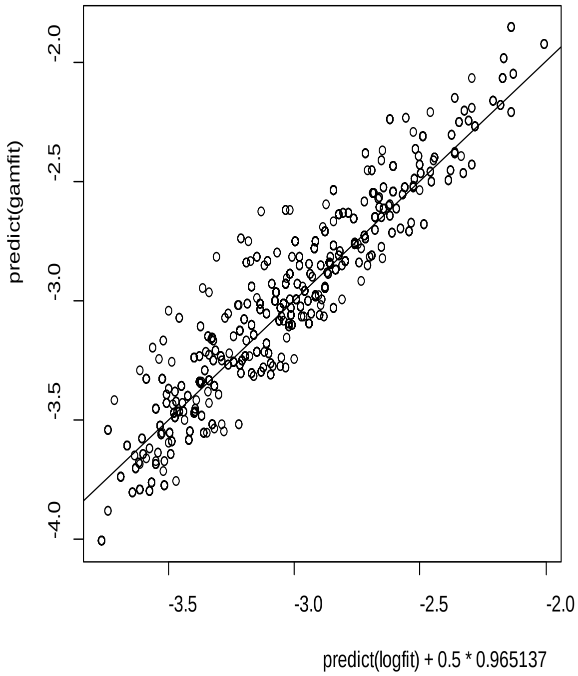


Figure 41. Comparison of predicted values for positive CPFV logbook data, based on a (bias-adjusted) Gaussian model for log(CPUE) and a Gamma model with a log link function.

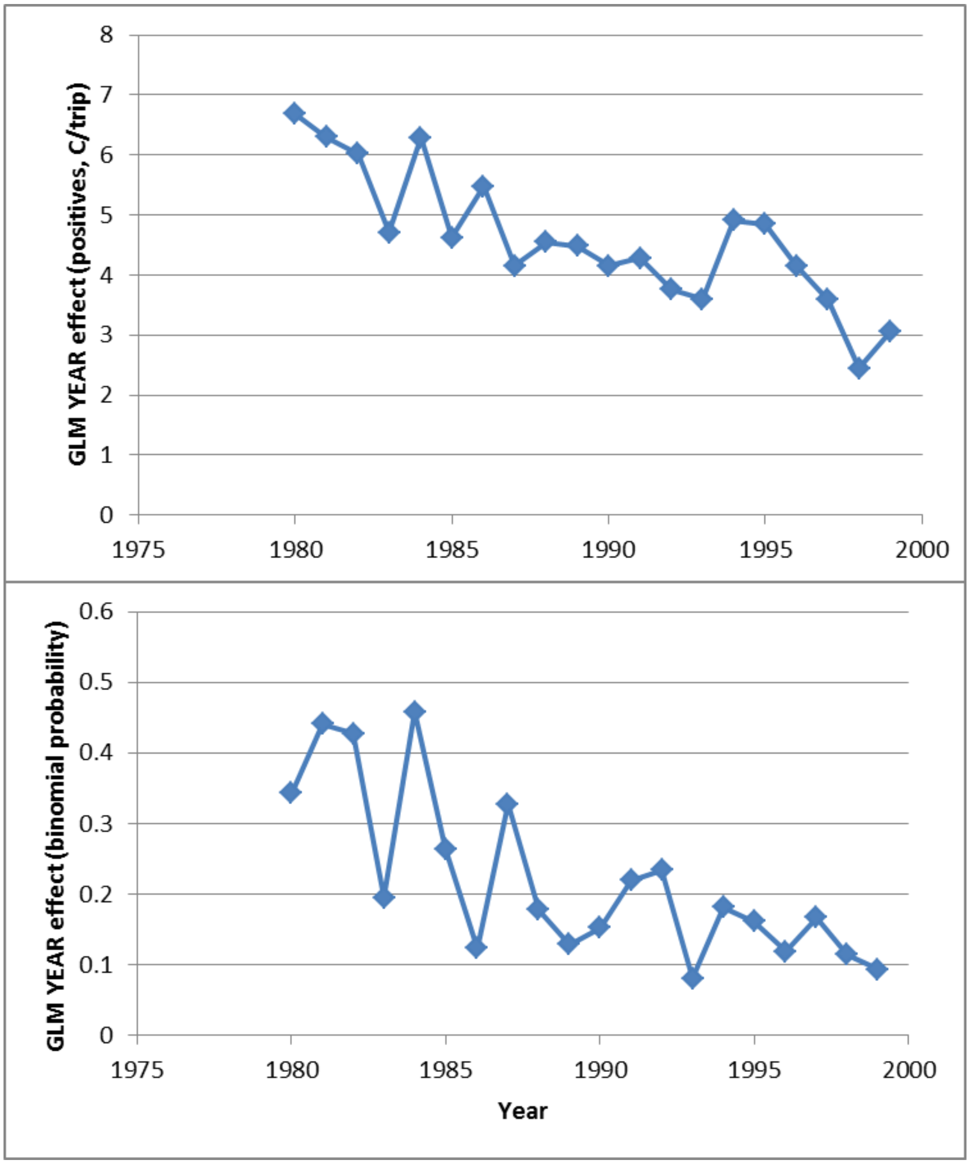


Figure 42. Time series of YEAR effects from the two portions of a delta-lognormal model of cowcod catch per trip using Rockfish-Trips Only logs.

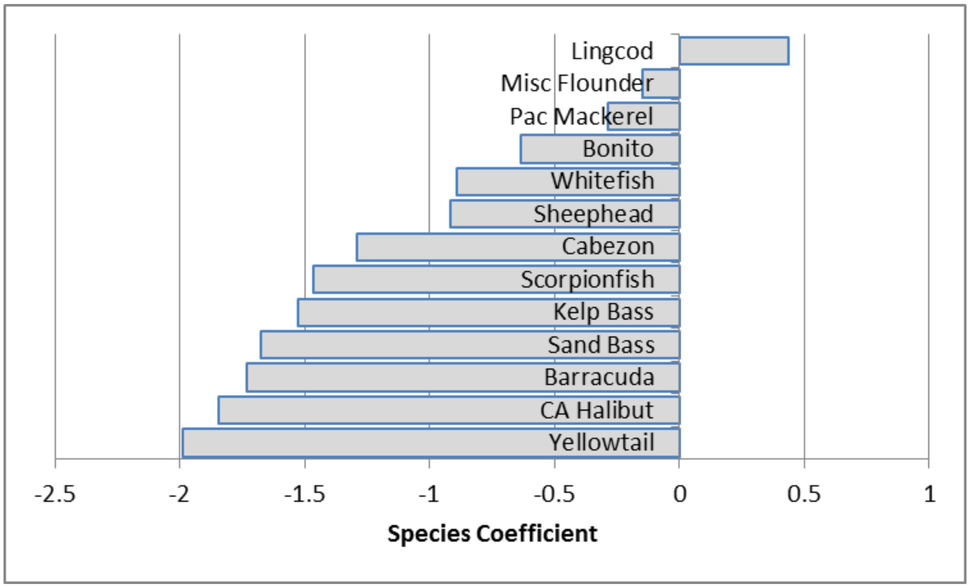


Figure 43. Logistic regression coefficients of species presence used to filter the CPFV logbook data ("Rockfish-Trip" subset).

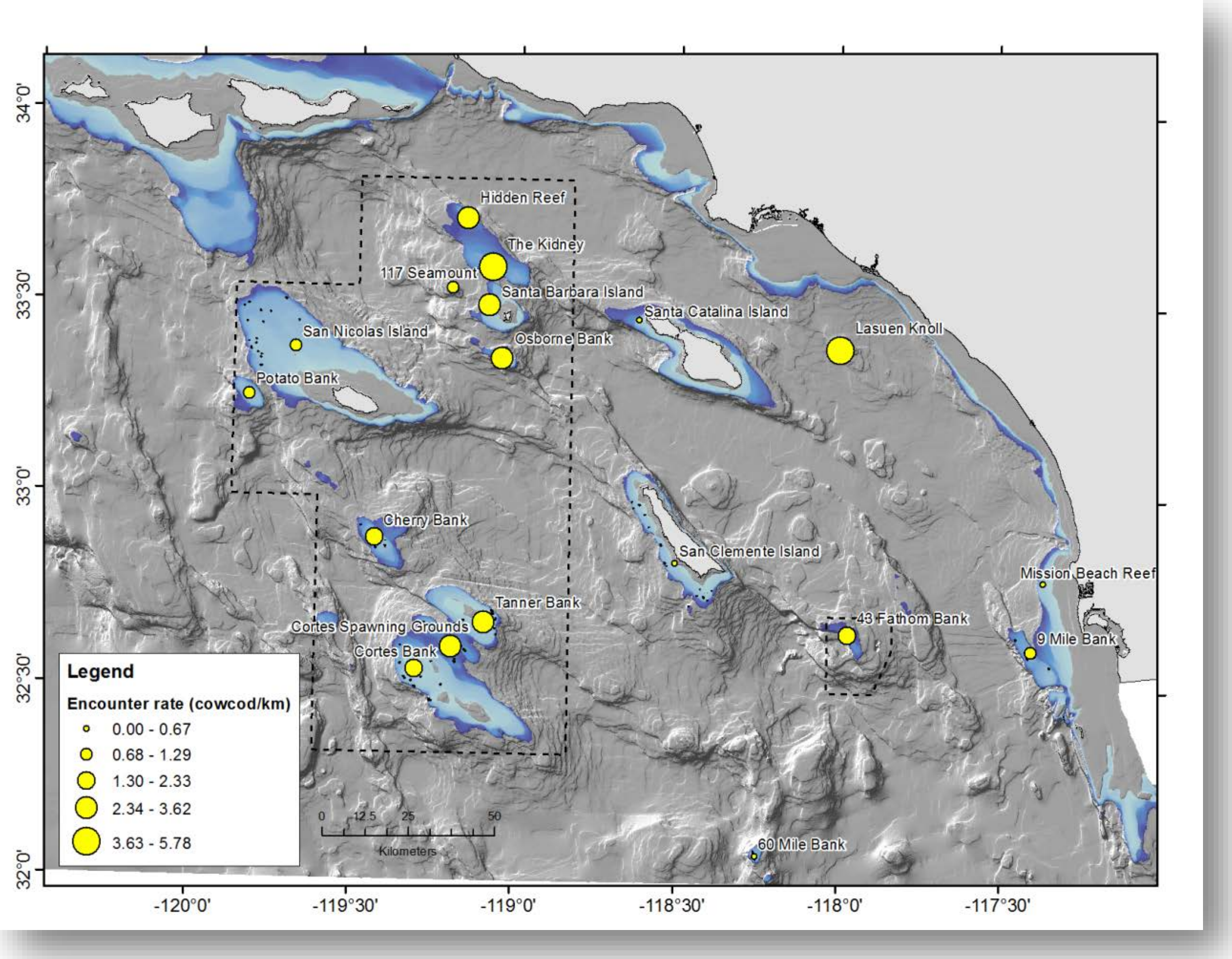


Figure 44. Encounter rates of cowcod from the 2012 Southern California Bight Cowcod Assessment Survey. 167 transects were surveyed by remotely operated vehicle at 18 sites. Estimates of cowcod abundance and biomass from the survey are pending. Figure courtesy of K. Steirhoff, NMFS SWFSC.

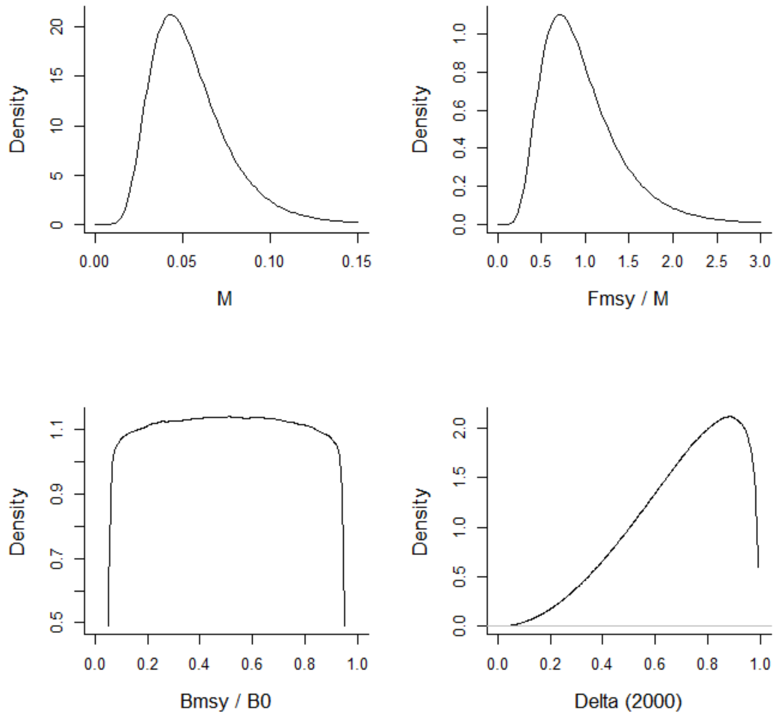


Figure 45. Prior distributions for population dynamics parameters in the cowcod base model.

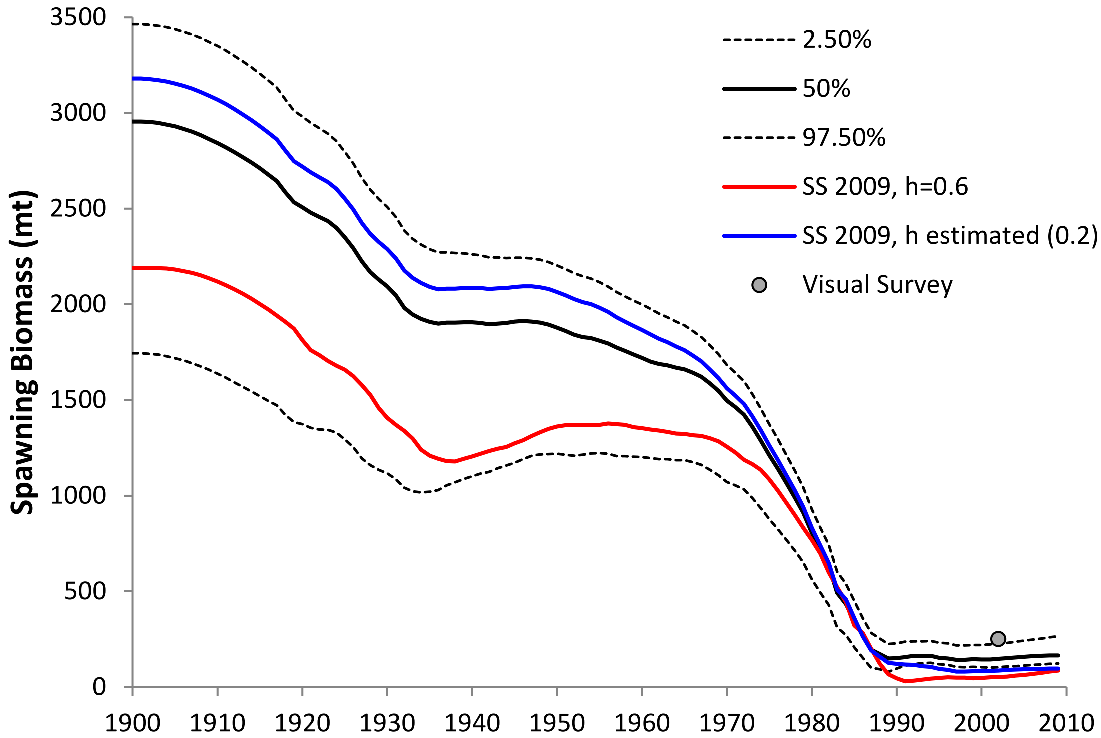


Figure 46. Spawning biomass estimates from three models fit to the data from the 2009 cowcod assessment. The red solid line is the 2009 base case model, with steepness (h) fixed at 0.6. The blue solid line is the same model with steepness estimated (h=0.2). The black solid line is median biomass from the XDB-SRA model, all parameters estimated, with 2.5% and 97.5% quantiles (black dashed lines).

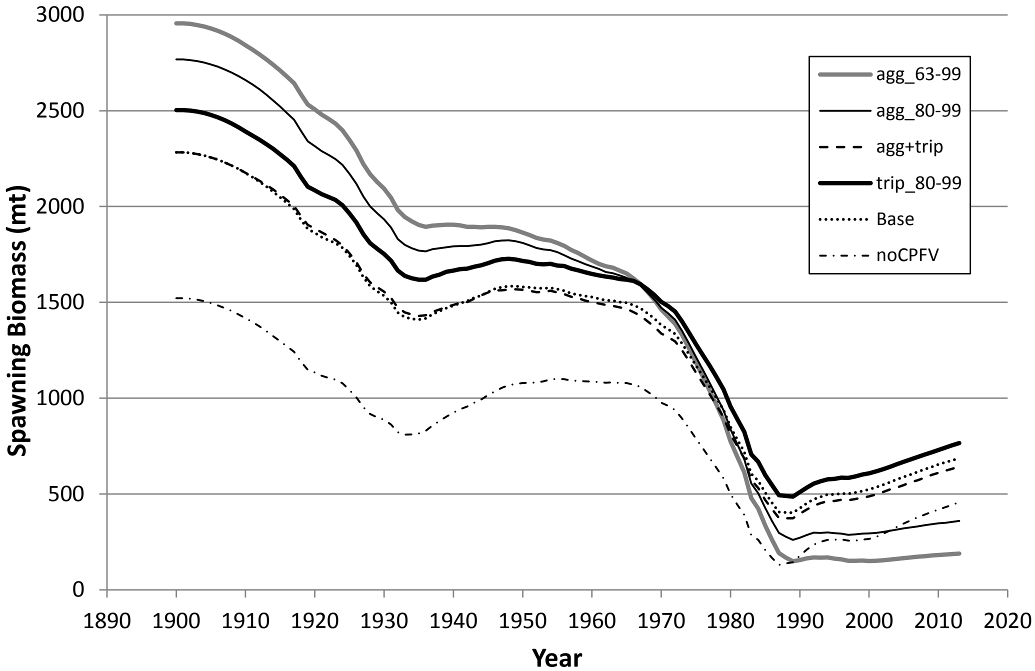


Figure 47. Effect of alternative CPFV logbook treatments on median spawning biomass trajectories. Base model included for reference.

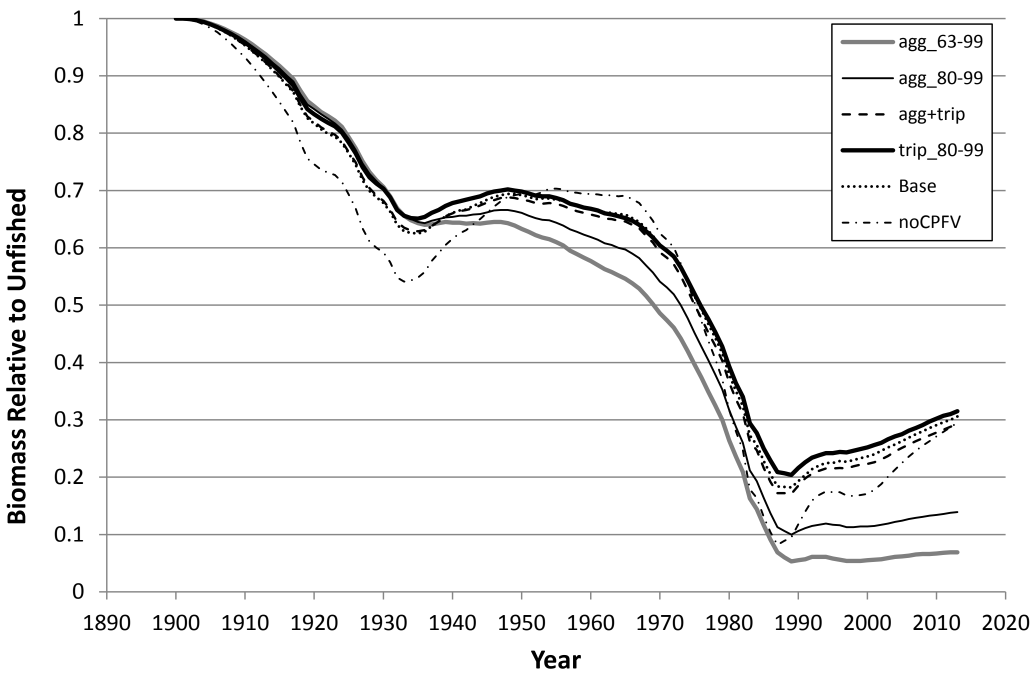


Figure 48. Effect of alternative CPFV logbook treatments on relative spawning biomass trajectories. Base model included for reference.

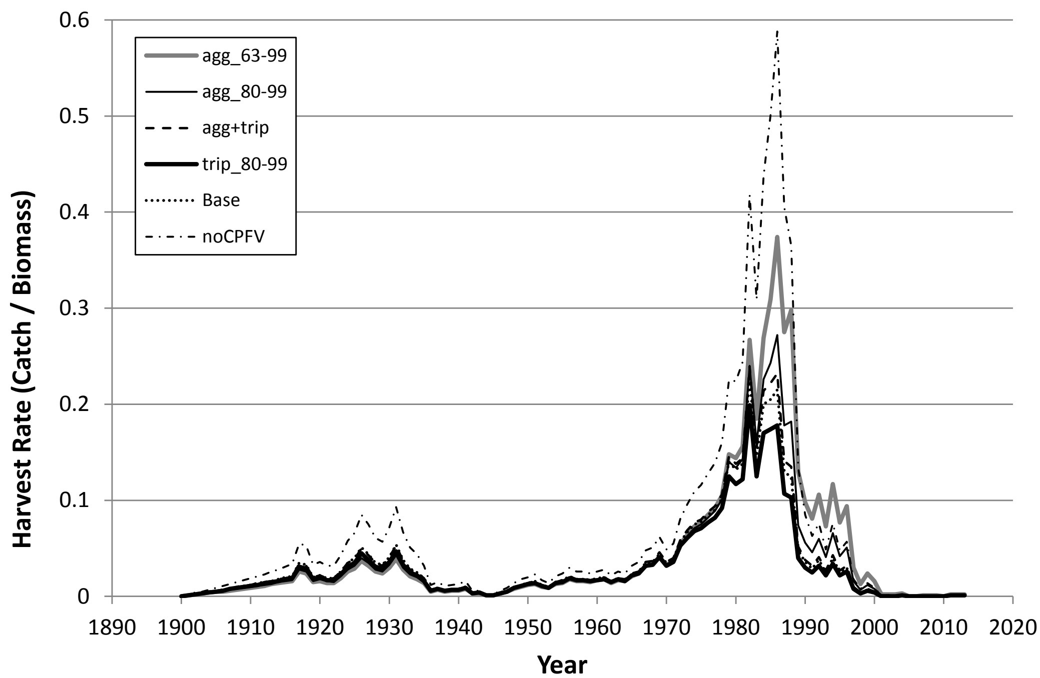


Figure 49. Effect of alternative CPFV logbook treatments on annual harvest rates. Base model included for reference.

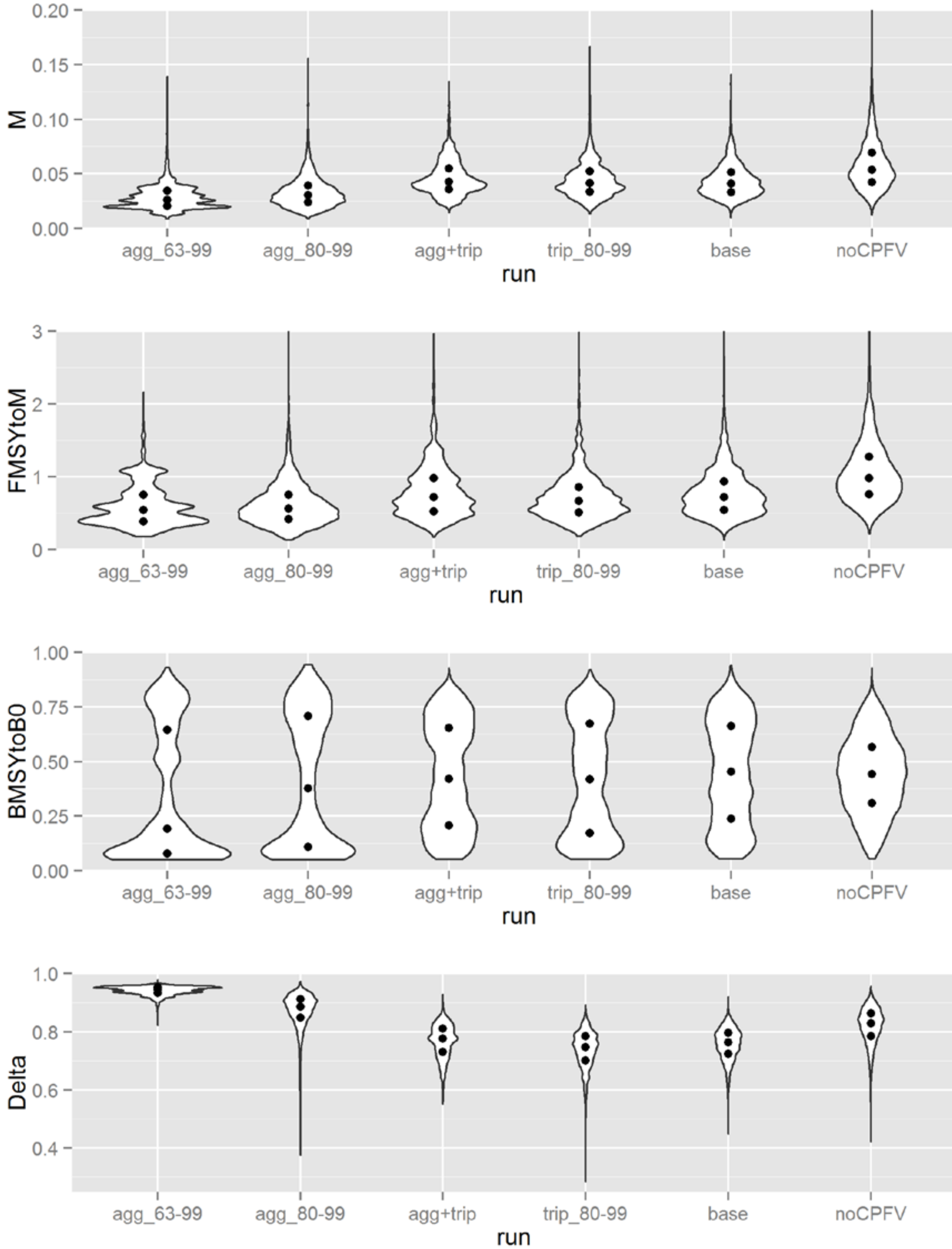


Figure 50. Comparison of posterior parameter distributions for models fit to alternative treatments of CPFV logbook data. Points inside 'violin' plots represent the median and interquartile range, and violins for each parameter are scaled to have equal areas. Base model included for reference.

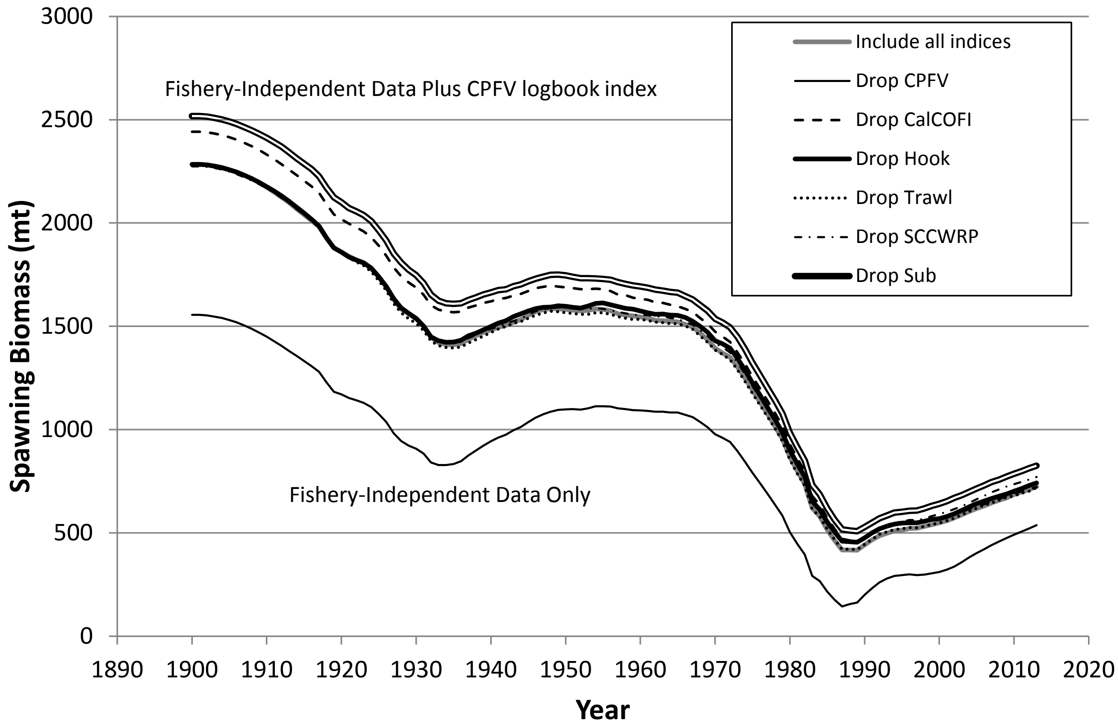


Figure 51. Effect of removing individual indices on median spawning biomass trajectories. A model fit to all six indices (including CPFV logbook) is included for reference. All models fit to the CPFV logbook index estimate a larger stock, relative to the model fit only to fishery-independent data sets.

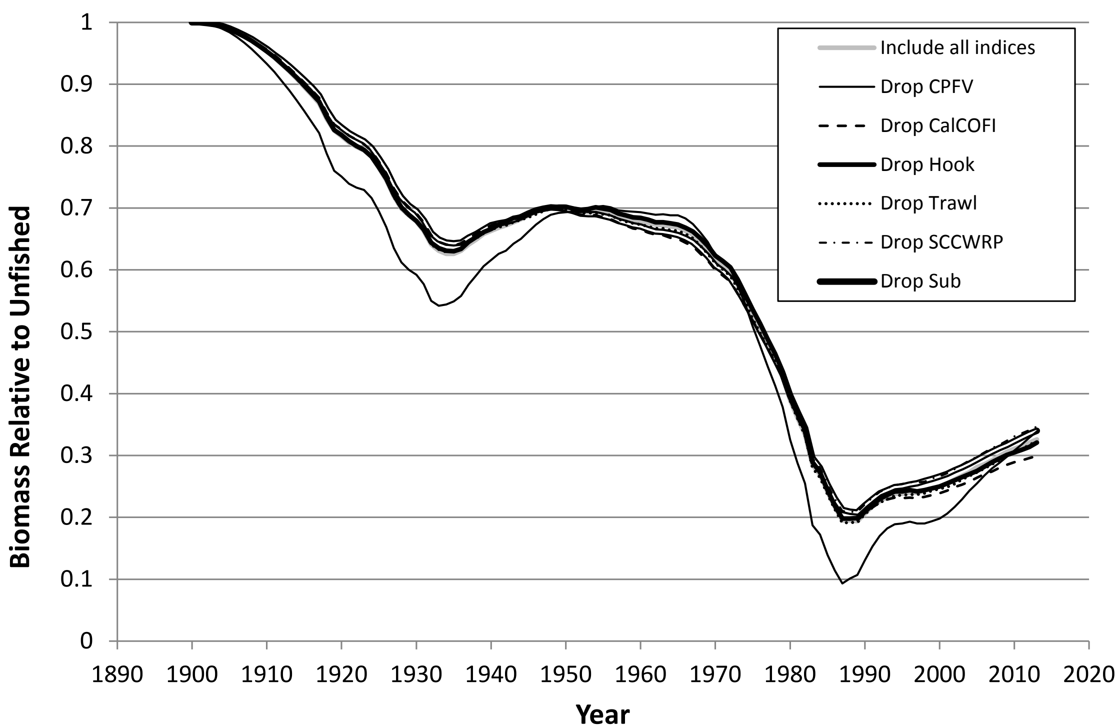


Figure 52. Effect of removing individual indices on median "depletion" (relative spawning biomass).

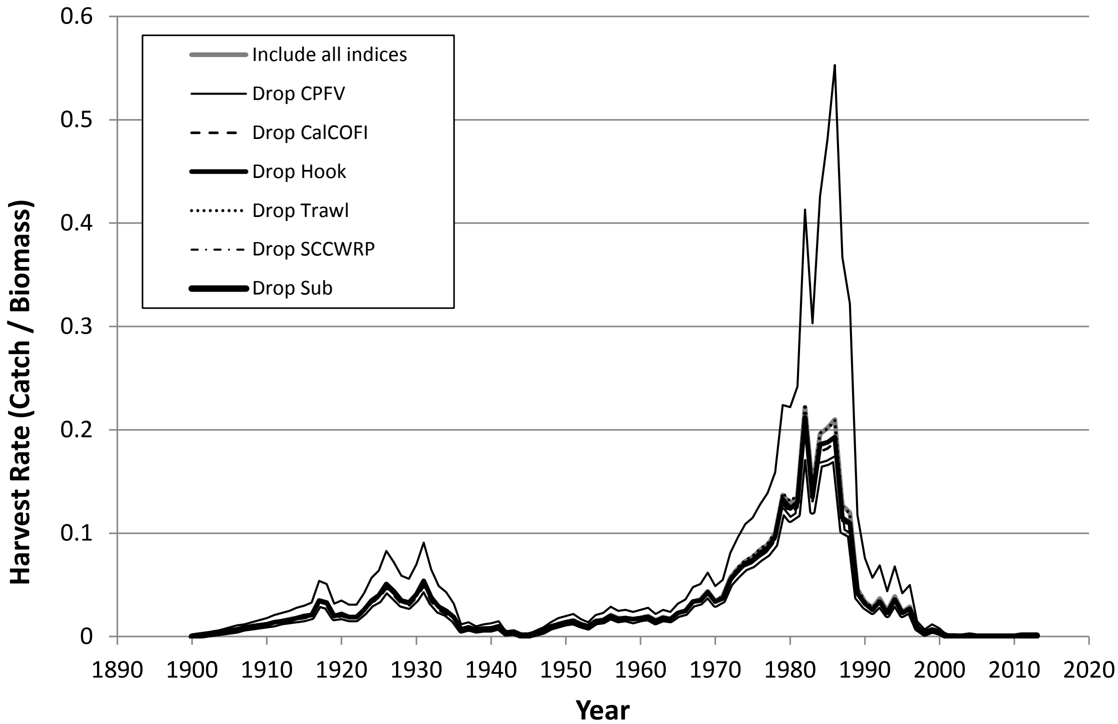


Figure 53. Effect of removing individual indices on estimates of annual harvest rates (catch divided by age 11+ biomass).

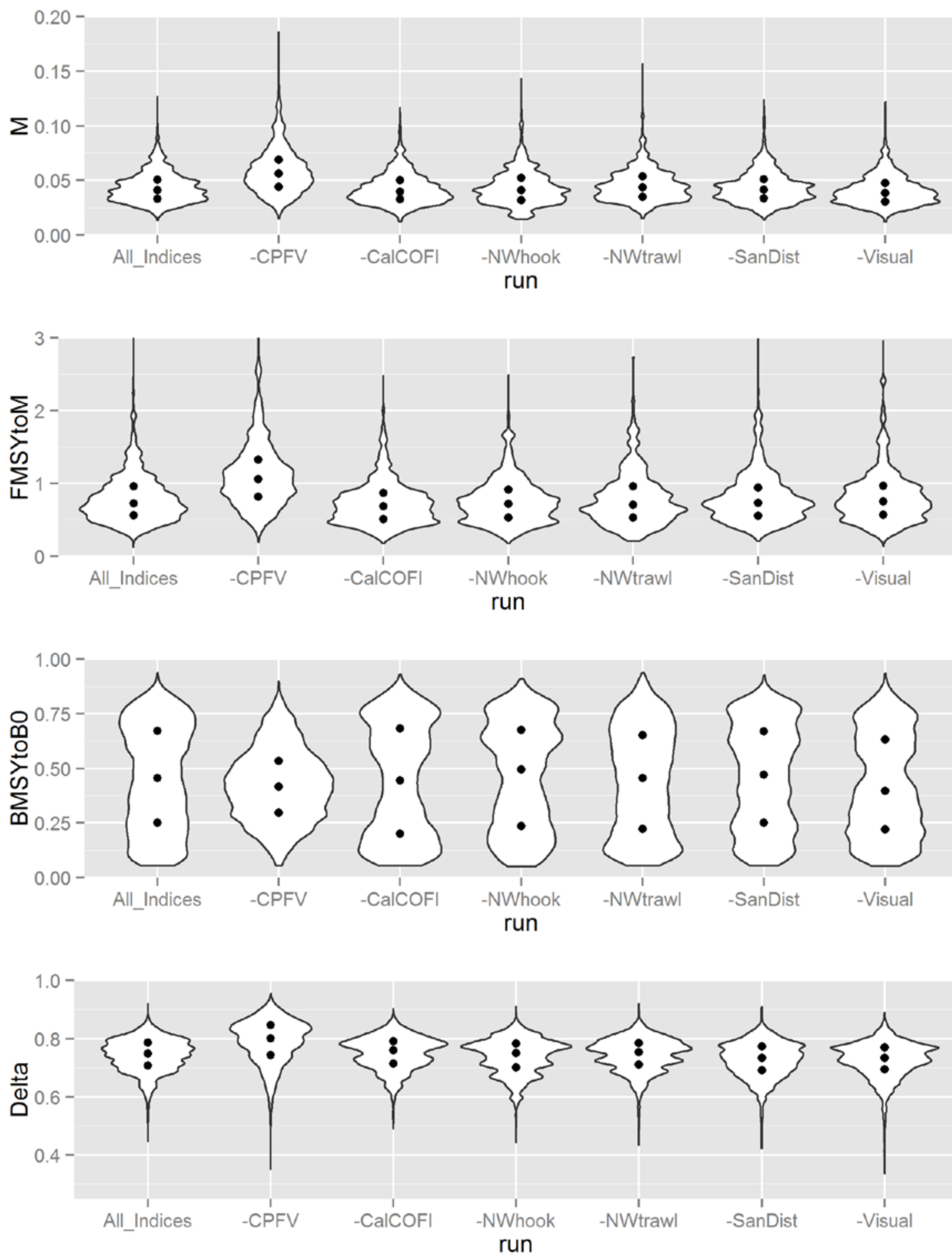


Figure 54. Comparison of posterior parameter distributions for models with individual indices removed "-[index name]." Model fit to all indices included for reference. Points inside 'violin' plots represent the median and interquartile range, and violins for each parameter are scaled to have equal areas.

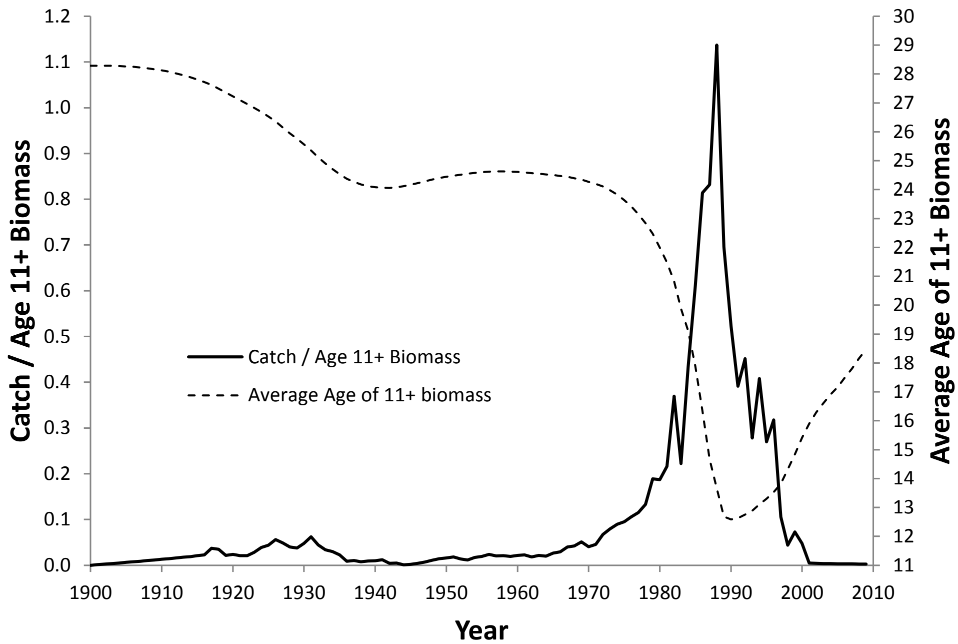


Figure 55. Harvest rates (catch divided by age 11+ biomass) from the 2009 cowcod assessment. The 2007 cowcod assessment had similar harvest rates (see Dick et al. 2007; their Figure 28).

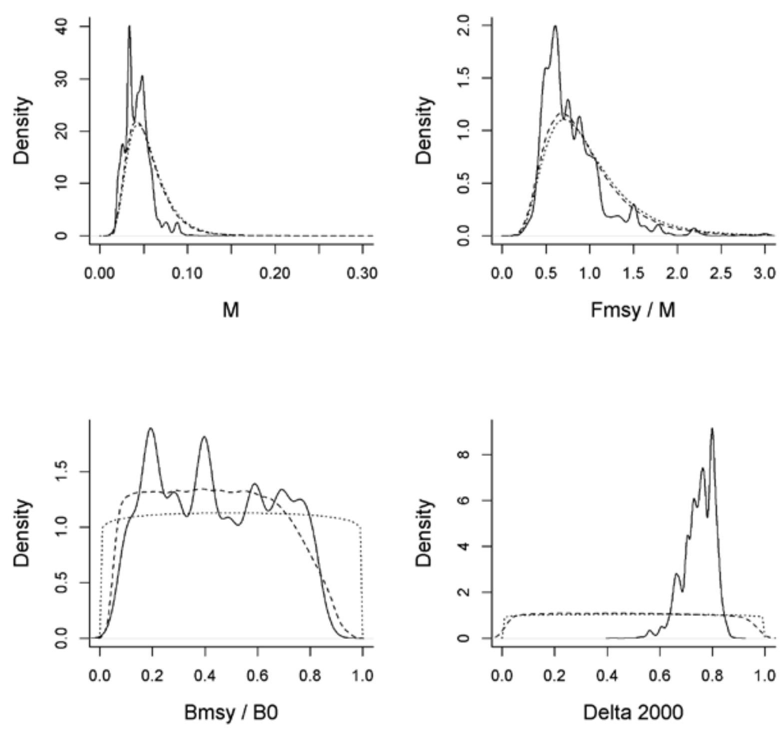


Figure 56. (Response to STAR Panel Request 1) Prior (dotted lines), post-model pre-data (dashed lines), and posterior (solid lines) distributions of population parameters for the model with a diffuse prior on relative biomass reduction (delta) in the year 2000.

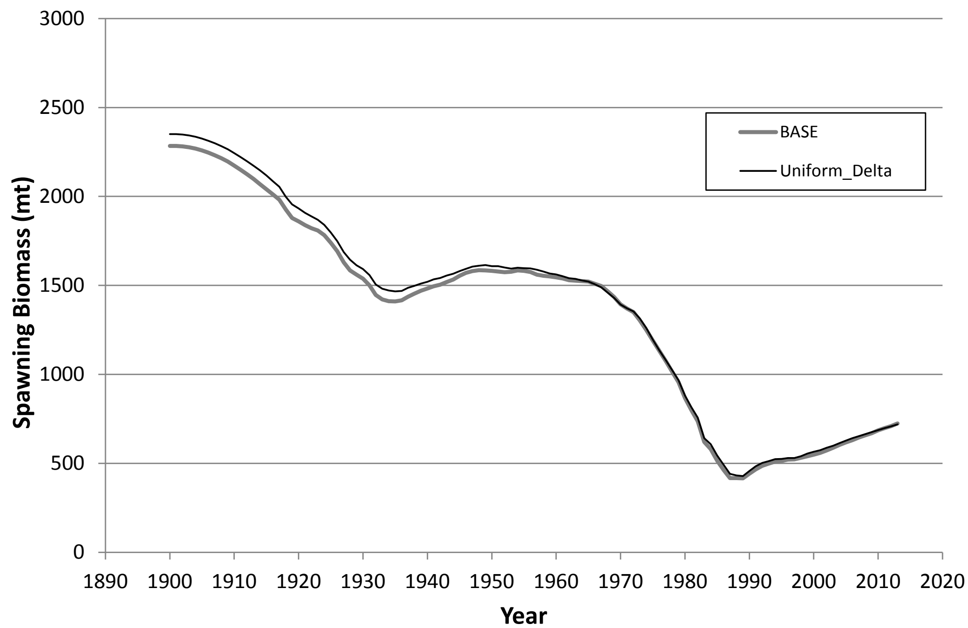


Figure 57. (Response to STAR Panel Request 1) Median spawning biomass estimates by year, comparing results from the delta prior used in the pre-STAR panel base model ("Base," including CPFV logbook data) to a nearly uniform prior distribution over the interval 0.01 to 0.99.

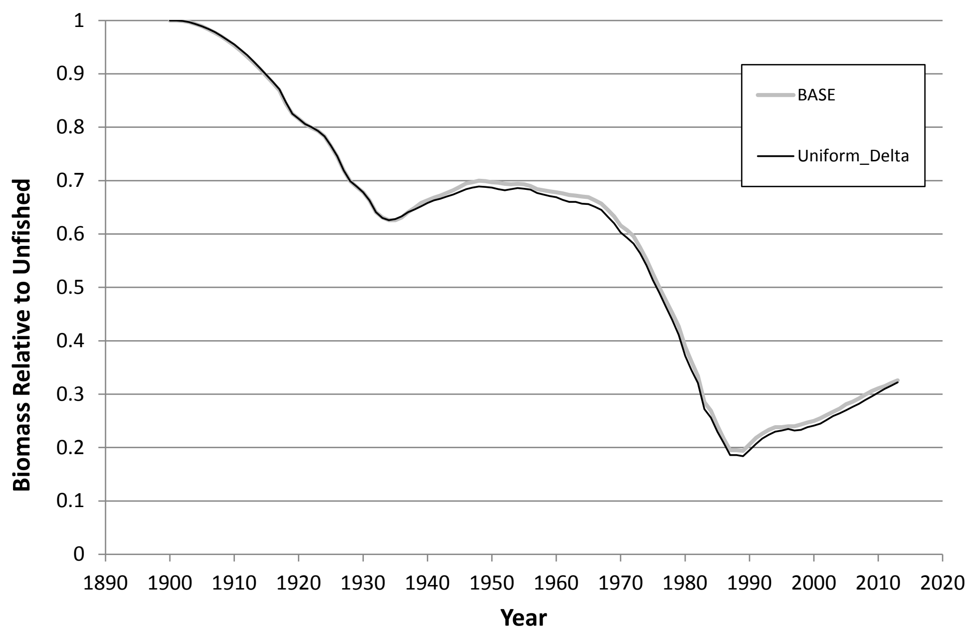


Figure 58. (Response to STAR Panel Request 1) Median relative biomass (B/B0) estimates by year, comparing results from the delta prior used in the pre-STAR panel base model ("Base," including CPFV logbook data) to a nearly uniform prior distribution over the interval 0.01 to 0.99.

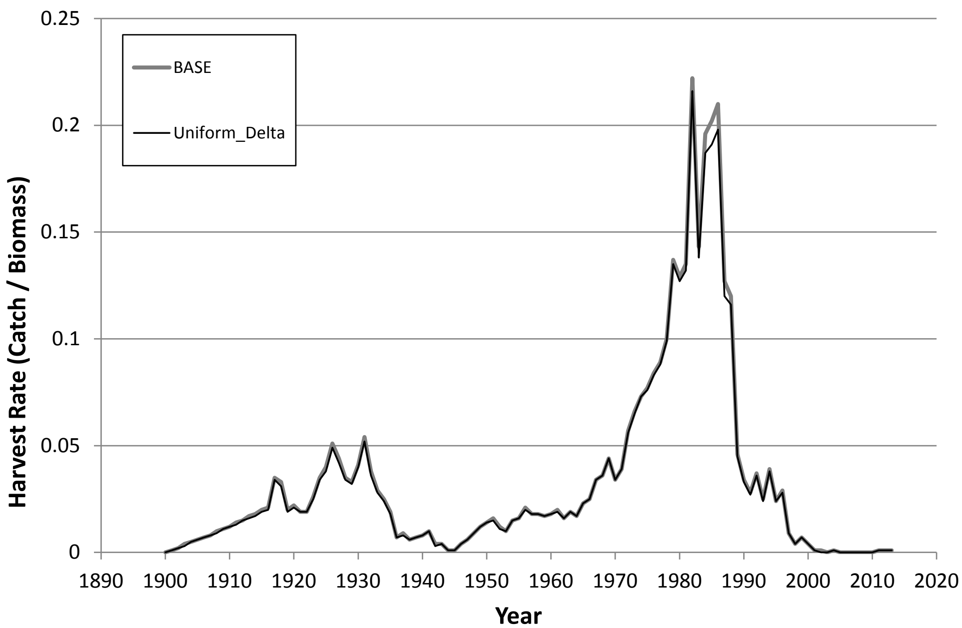


Figure 59. (Response to STAR Panel Request 1) Median harvest rate (catch/biomass) estimates by year, comparing results from the delta prior used in the pre-STAR panel base model ("Base," including CPFV logbook data) to a nearly uniform prior distribution over the interval 0.01 to 0.99.

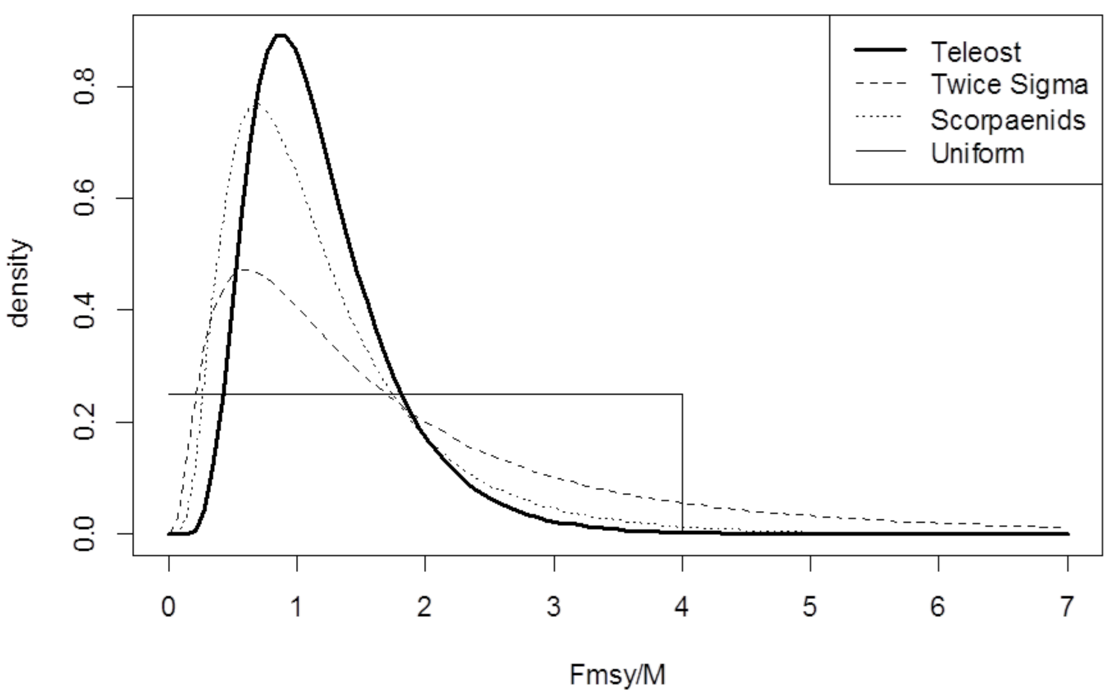


Figure 60. (Response to STAR Panel Request 2) Alternative prior distributions for Fmsy/M.

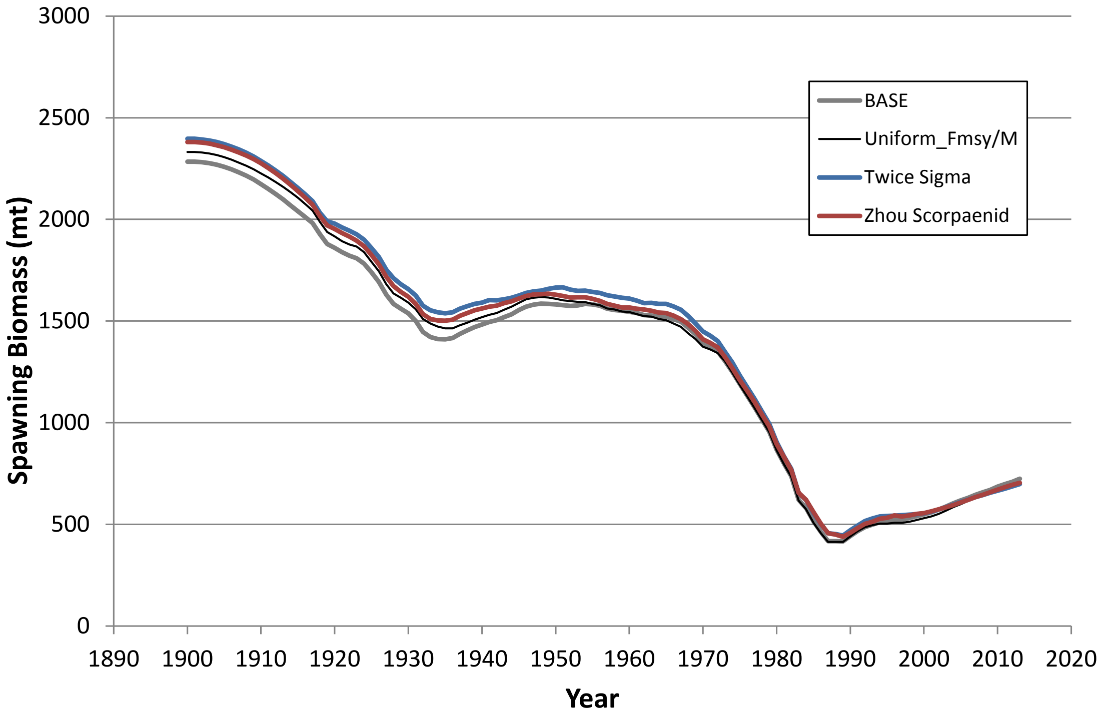


Figure 61. (Response to STAR Panel Request 2) Median spawning biomass trajectories under alternative priors for Fmsy/M. “Base” refers to the pre-STAR panel base model (including CPFV index).

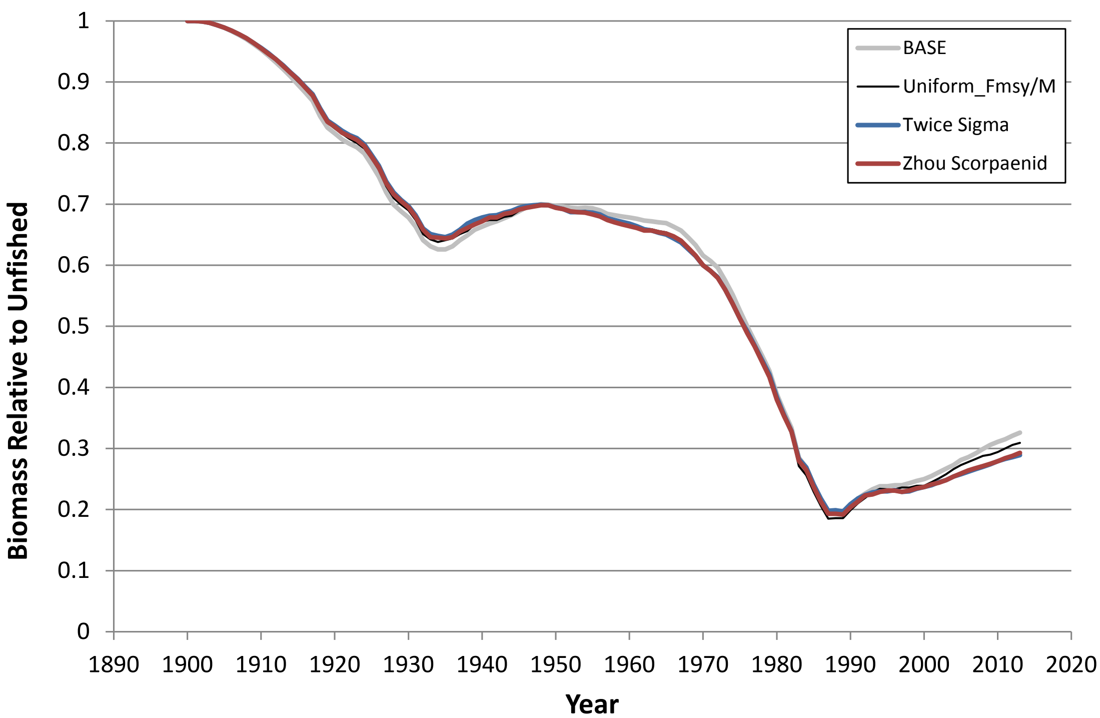


Figure 62. (Response to STAR Panel Request 2) Median depletion (relative biomass) trajectories under alternative priors for Fmsy/M. “Base” refers to the pre-STAR panel base model (including CPFV index).

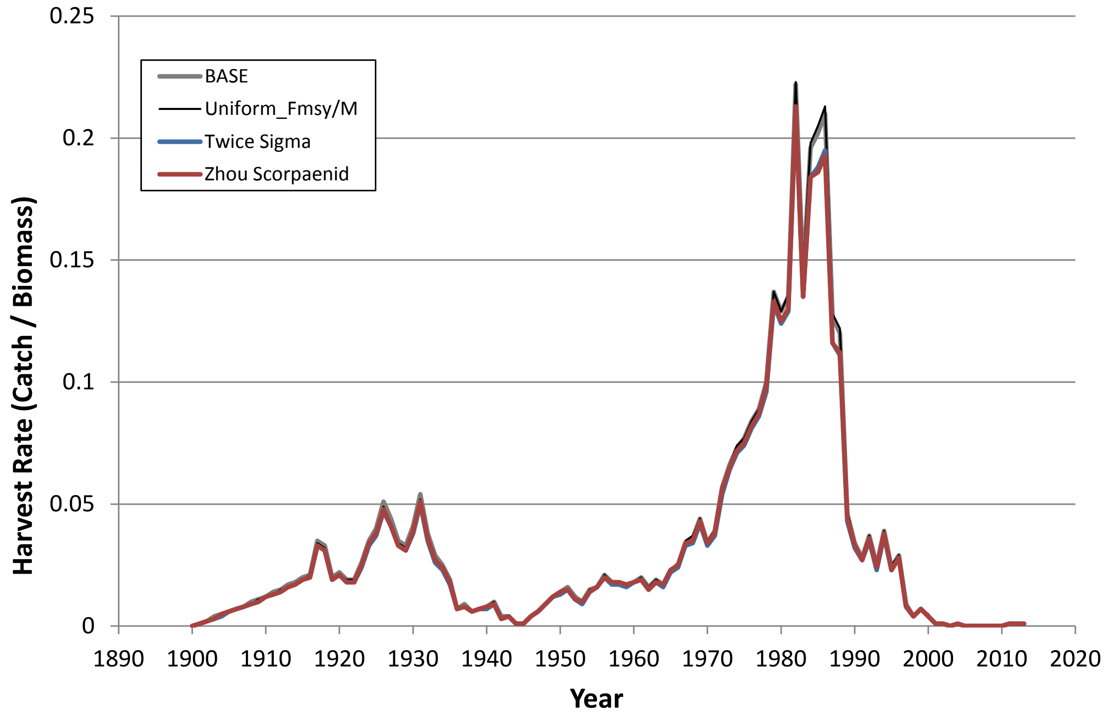


Figure 63. (Response to STAR Panel Request 2) Median harvest rates (catch / age 11+ biomass) under alternative priors for Fmsy/M. "Base" refers to the pre-STAR panel base model (including CPFV index).

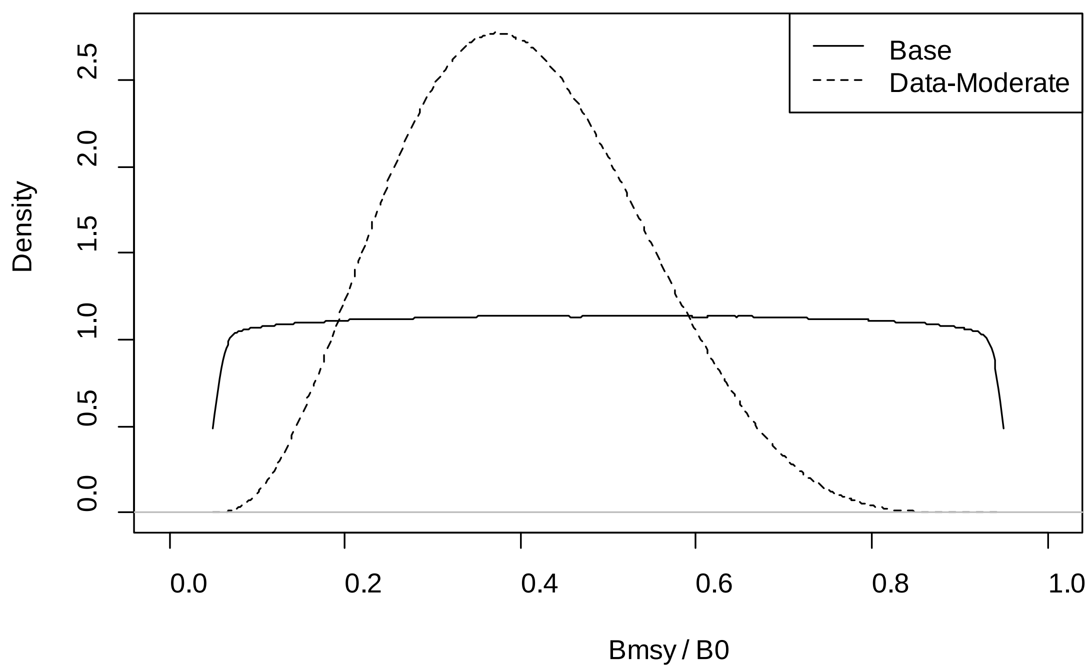


Figure 64. (Response to STAR Panel Request 3) Alternative prior distributions for Bmsy/B0.

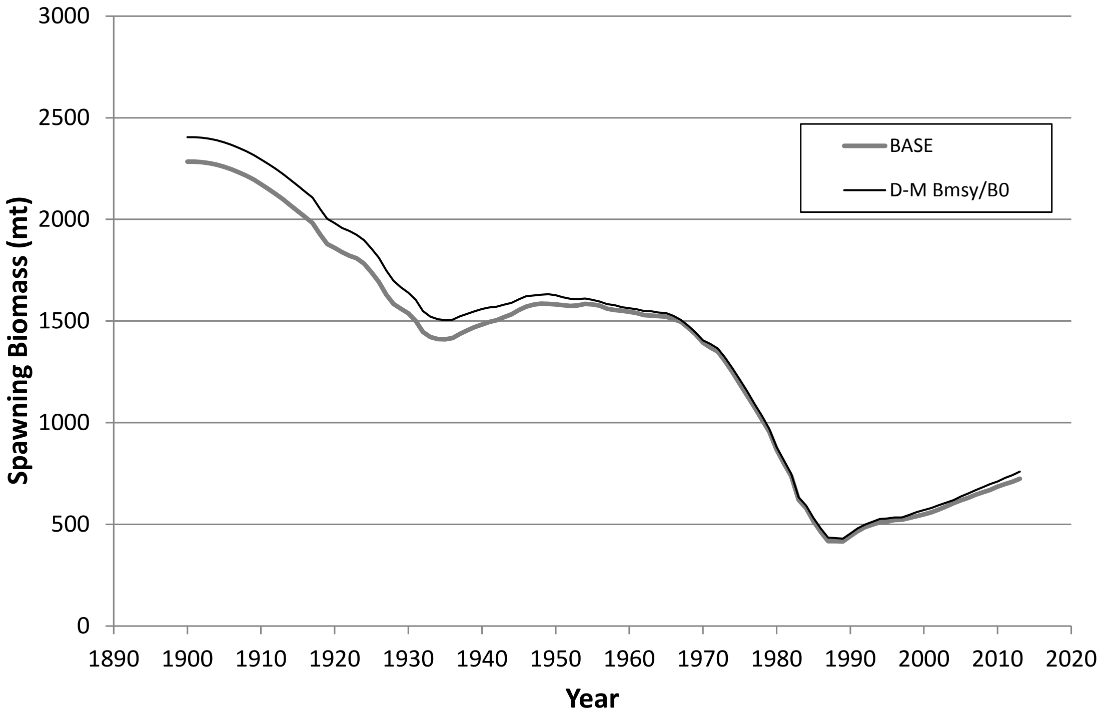


Figure 65. (Response to STAR Panel Request 3) Median spawning biomass trajectories under alternative priors for Bmsy/B0. “Base” refers to the pre-STAR panel base model (including CPFV index).

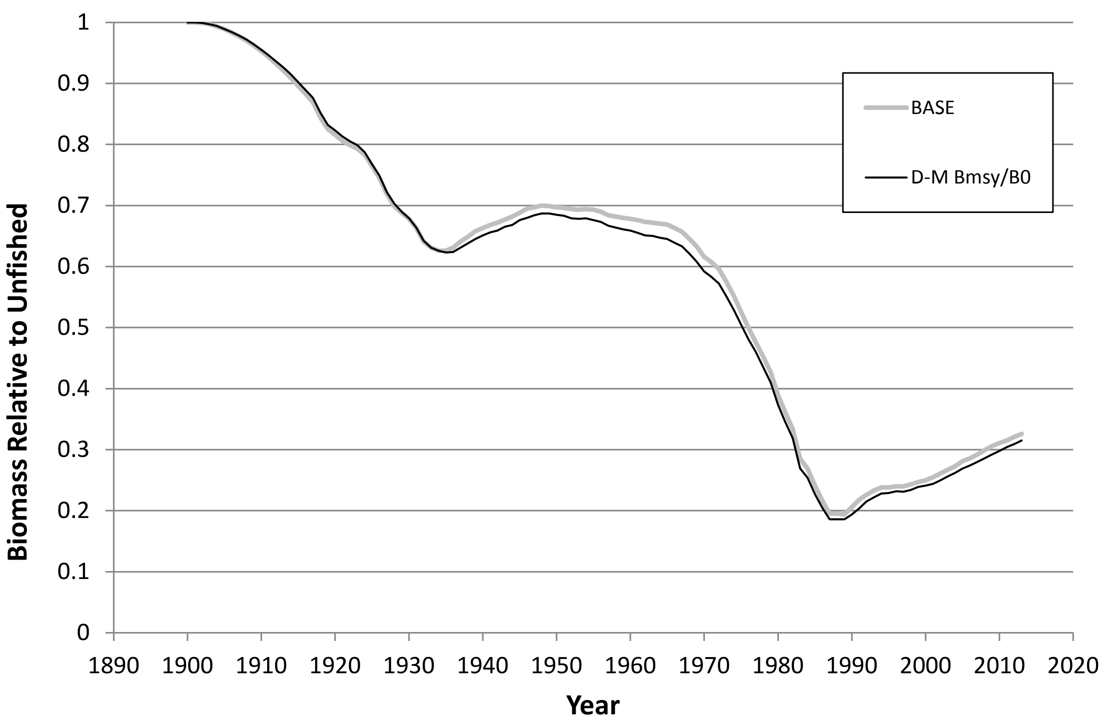


Figure 66. (Response to STAR Panel Request 3) Median relative biomass trajectories under alternative priors for Bmsy/B0. “Base” refers to the pre-STAR panel base model (including CPFV index).

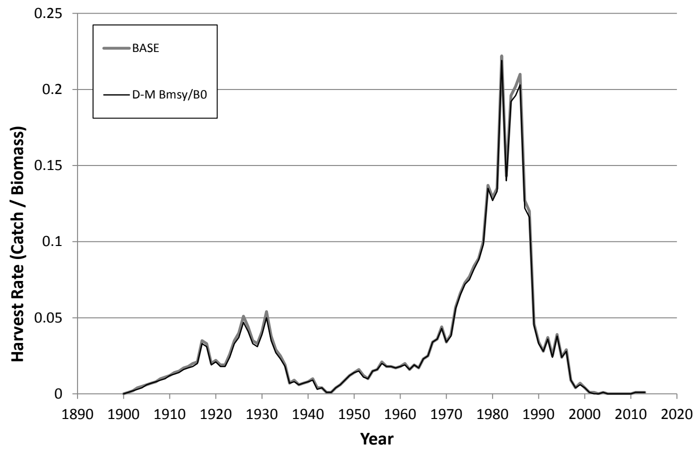


Figure 67. (Response to STAR Panel Request 3) Median harvest rates under alternative priors for Bmsy/B0. “Base” refers to the pre-STAR panel base model (including CPFV index).

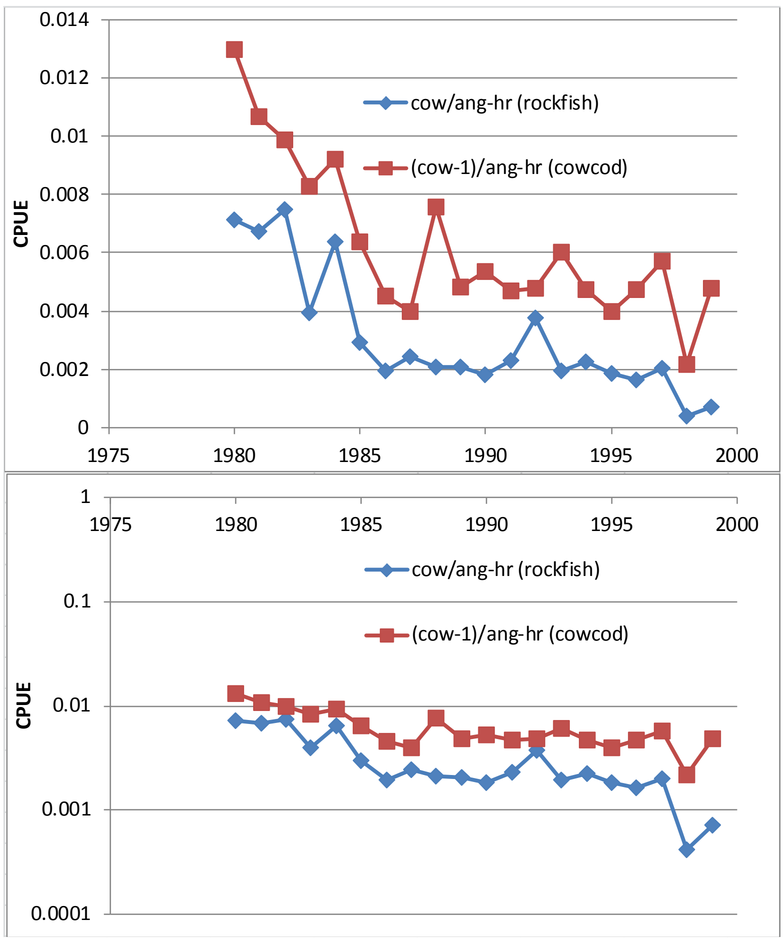


Figure 68. (Response to STAR Panel Request 4) CPUE time series derived from trip-based CPFV logbook data using alternative methods for identifying relevant trips (effective effort for cowcod).

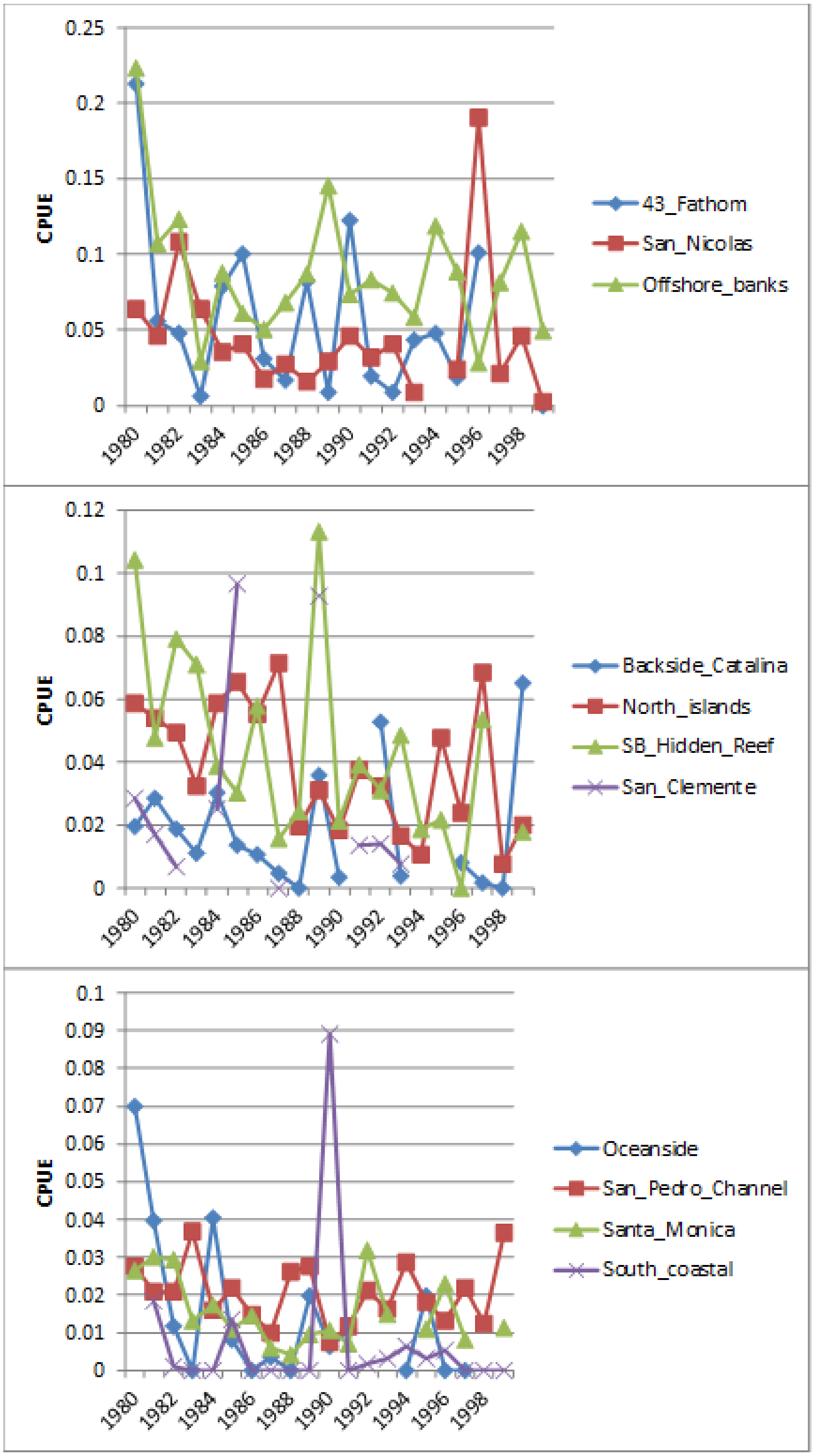


Figure 69. (Response to STAR Panel Request 5) Average CPUE (N-1 per ang-hr) from the trip-based CPFV logbook database, by year and region.

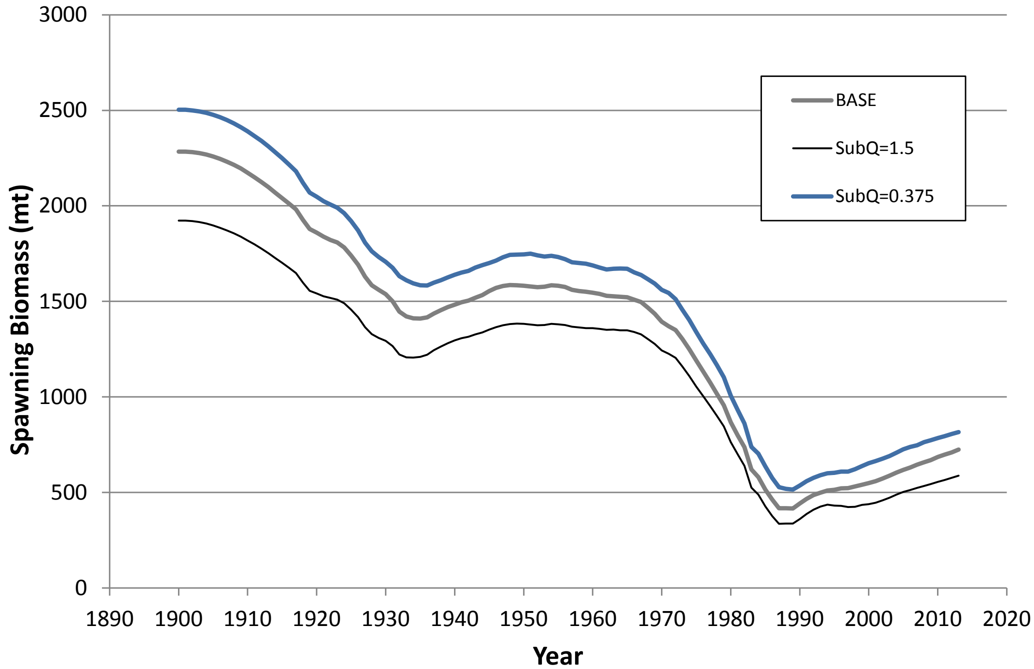


Figure 70. (Response to STAR Panel Request 7) Median spawning biomass trajectories under alternative priors for catchability of the visual survey. “Base” refers to the pre-STAR panel base model (including CPFV index).

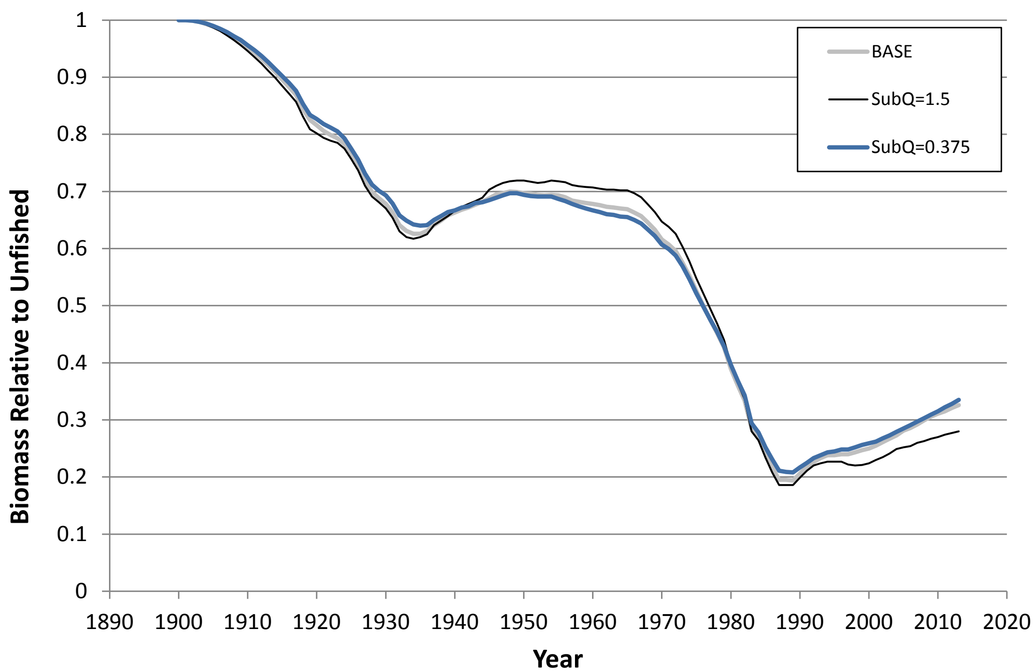


Figure 71. (Response to STAR Panel Request 7) Median relative biomass trajectories under alternative priors for catchability of the visual survey. “Base” refers to the pre-STAR panel base model (including CPFV index).

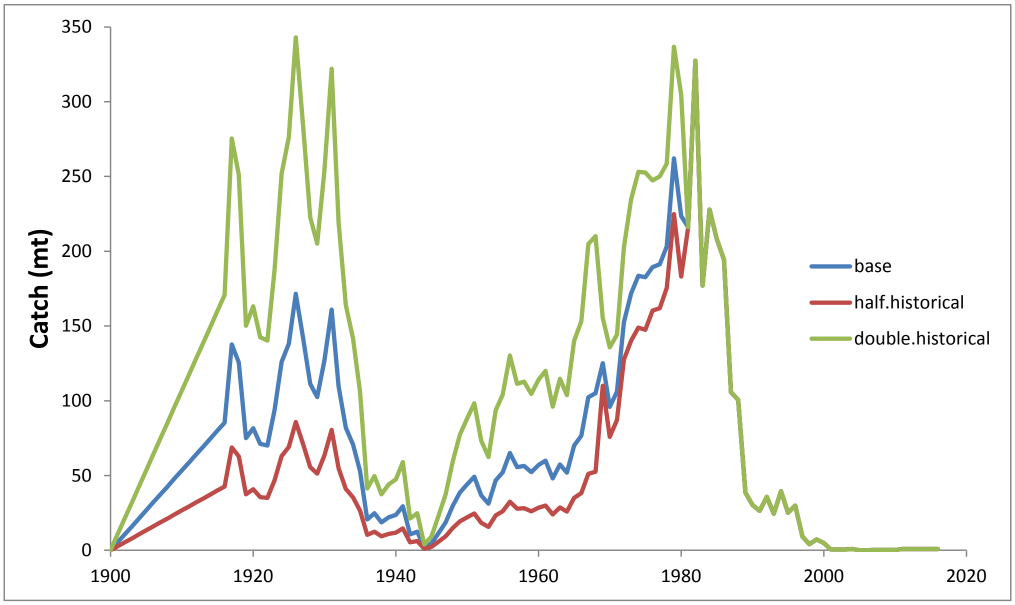


Figure 72. (Response to STAR Panel Request 8) Alternative historical catch time series (half/double base catches).

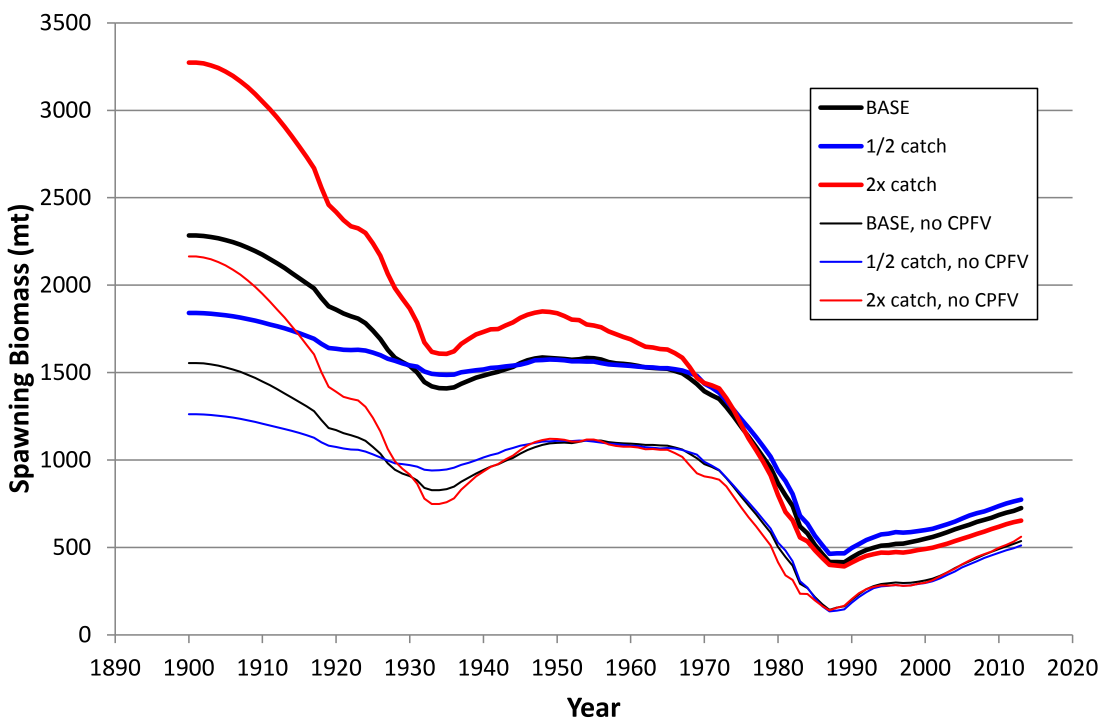


Figure 73. (Response to STAR Panel Request 8) Median spawning biomass trajectories under alternative historical catch levels, with and without the CPFV logbook index. "Base" refers to the pre-STAR panel base model (including CPFV index).

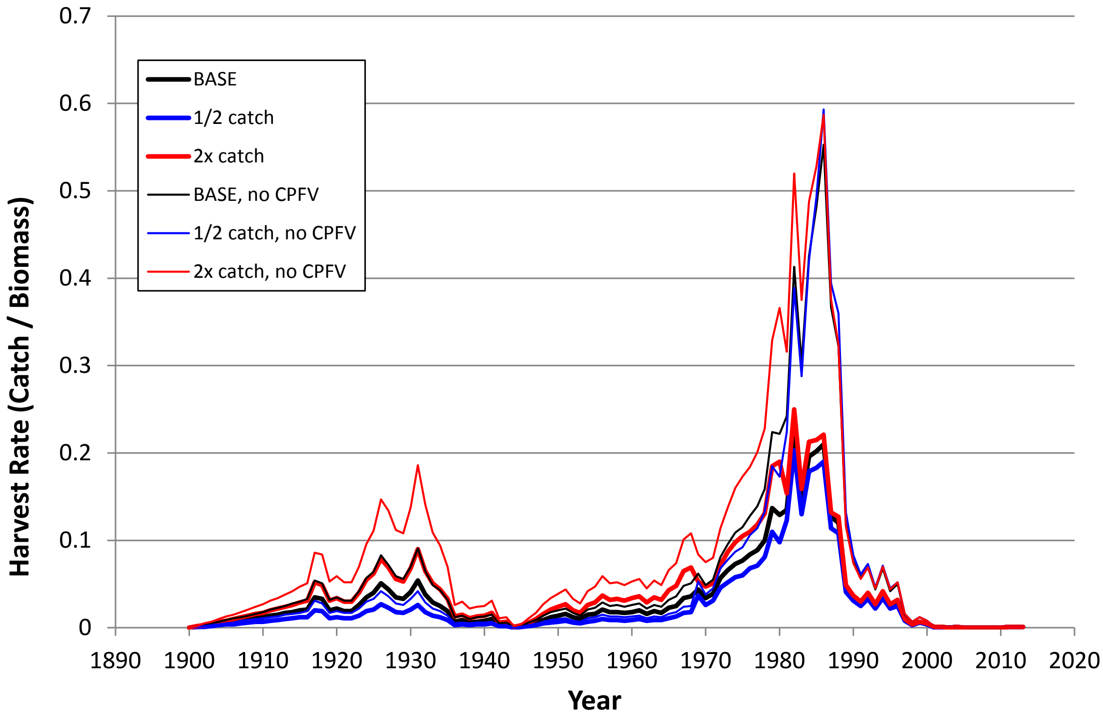


Figure 74. (Response to STAR Panel Request 8) Median harvest rates under alternative historical catch levels, with and without the CPFV logbook index. “Base” refers to the pre-STAR panel base model (including CPFV index).

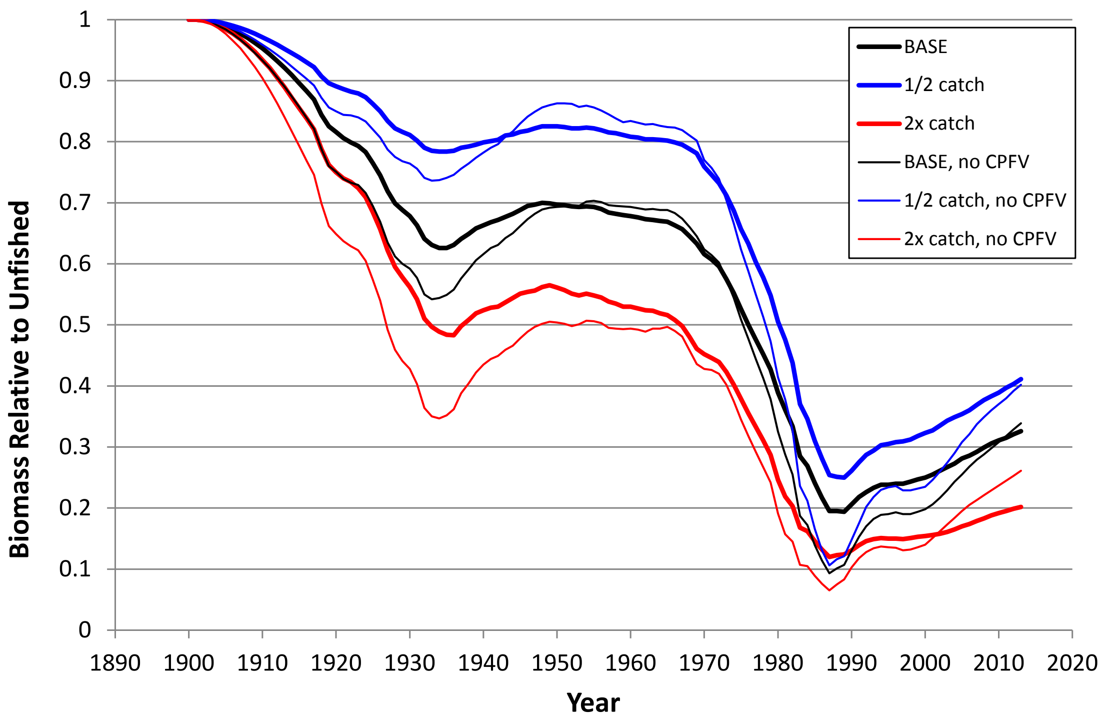


Figure 75. (Response to STAR Panel Request 8) Median relative biomass trajectories under alternative historical catch levels, with and without the CPFV logbook index. “Base” refers to the pre-STAR panel base model (including CPFV index).

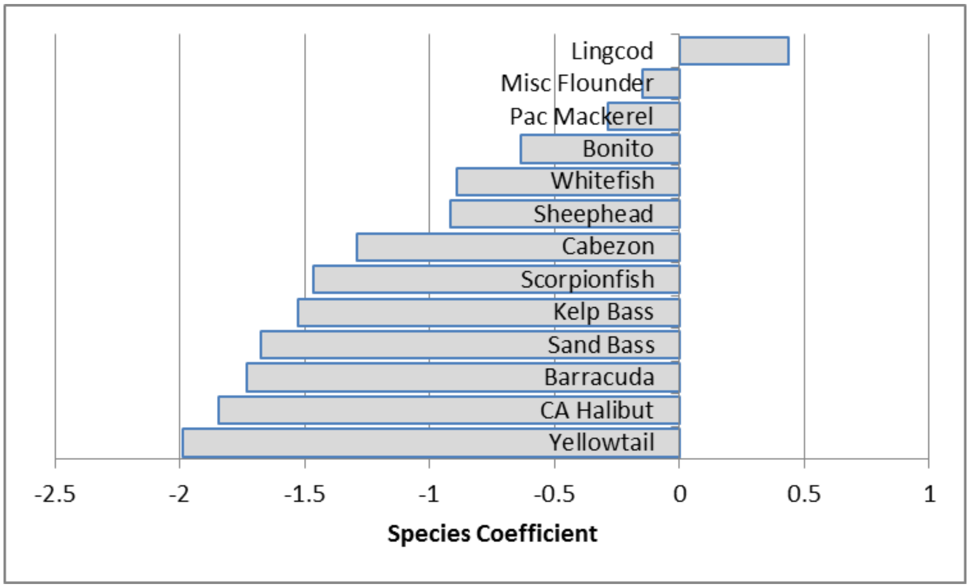


Figure 76. (Response to STAR Panel Request 9) Coefficients from the Stephens-MacCall species filter (binomial GLM). All indicator species were counter-indicators for cowcod except lingcod.

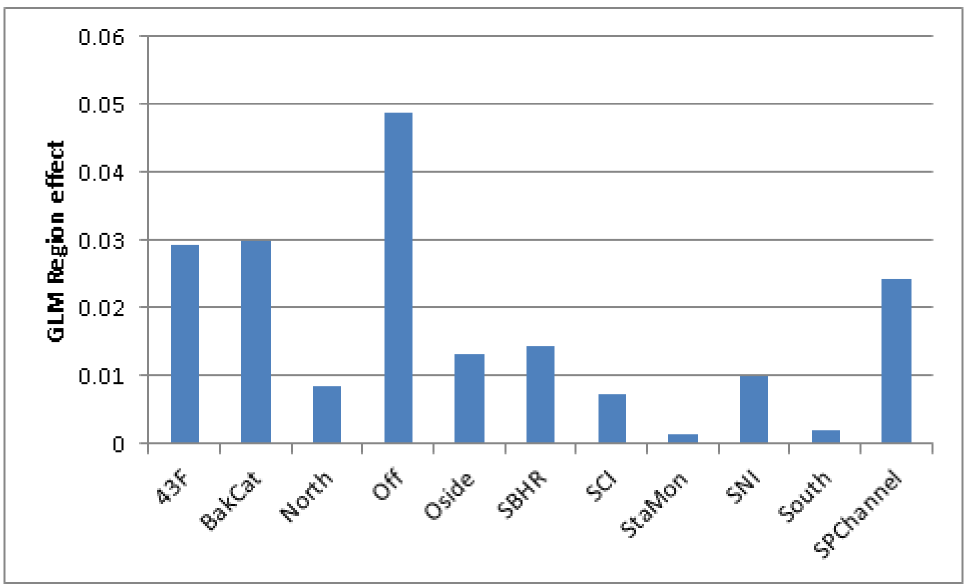


Figure 77. (Response to STAR Panel Request 9) Region effects from the delta-GLM model for CPFV logbook CPUE data, after Stephens-MacCall filter was applied.

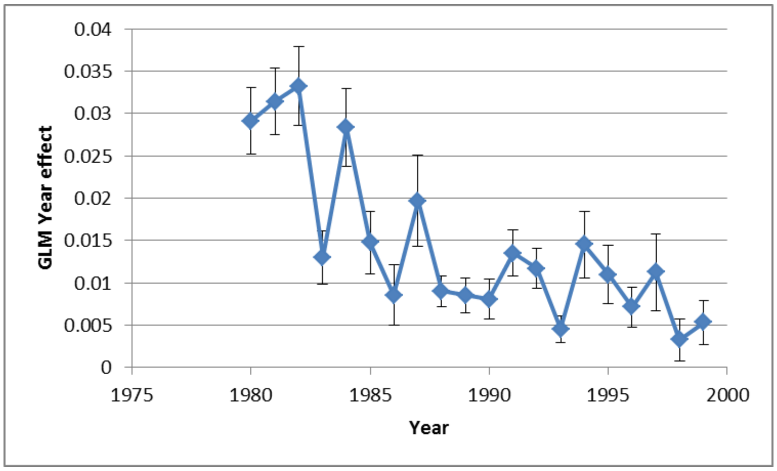


Figure 78. (Response to STAR Panel Request 9) Year effects from the delta-GLM model for CPFV logbook CPUE data, after Stephens-MacCall filter was applied.

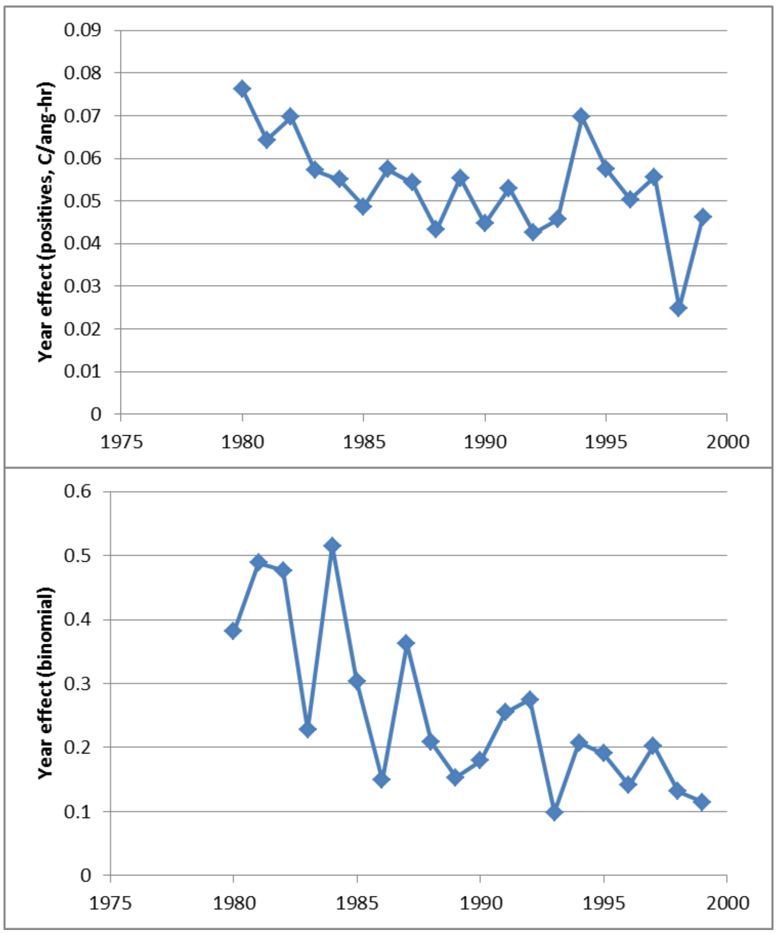


Figure 79. (Response to STAR Panel Request 9) Year effects from the two components (binomial and conditional mean) of the delta-GLM model for CPFV logbook CPUE data, after Stephens-MacCall filter was applied.

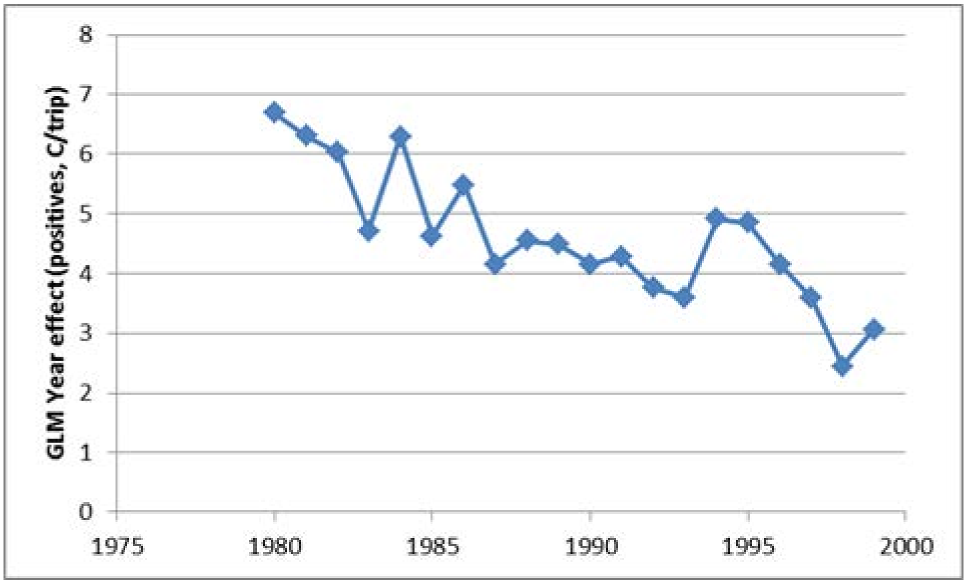


Figure 80. (Response to STAR Panel Request 9) Number of cowcod caught per trip (positive trips only).

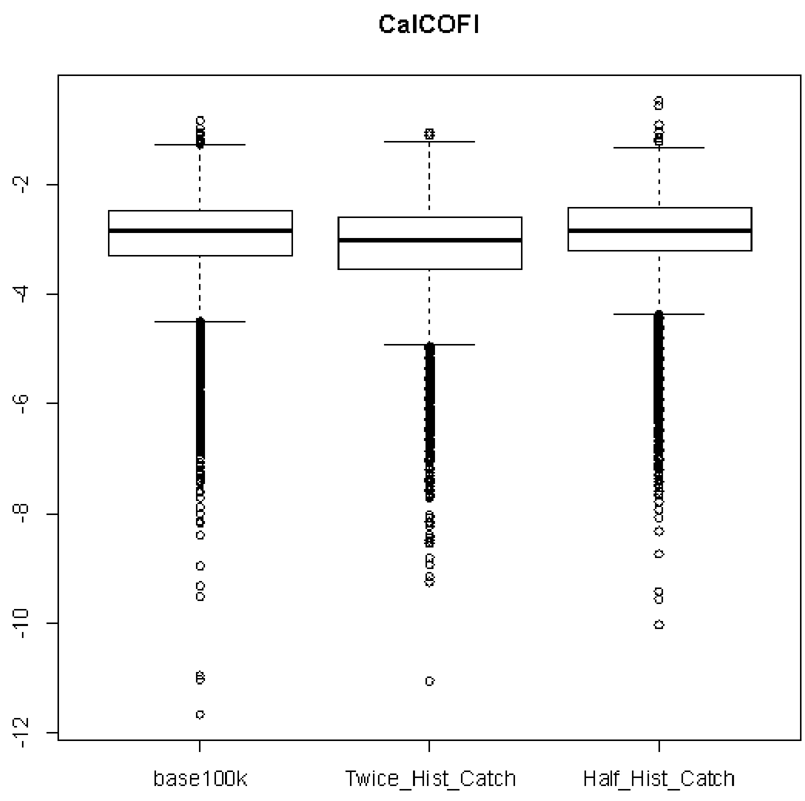


Figure 81. (Response to STAR Panel Request 10) Log-likelihood distributions for the CalCOFI index under alternative catch histories.

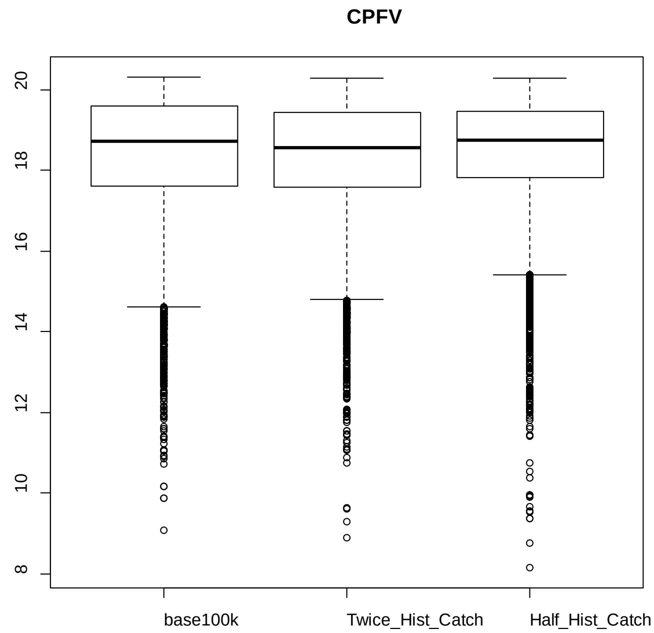


Figure 82. (Response to STAR Panel Request 10) Log-likelihood distributions for the CPFV logbook index under alternative catch histories.

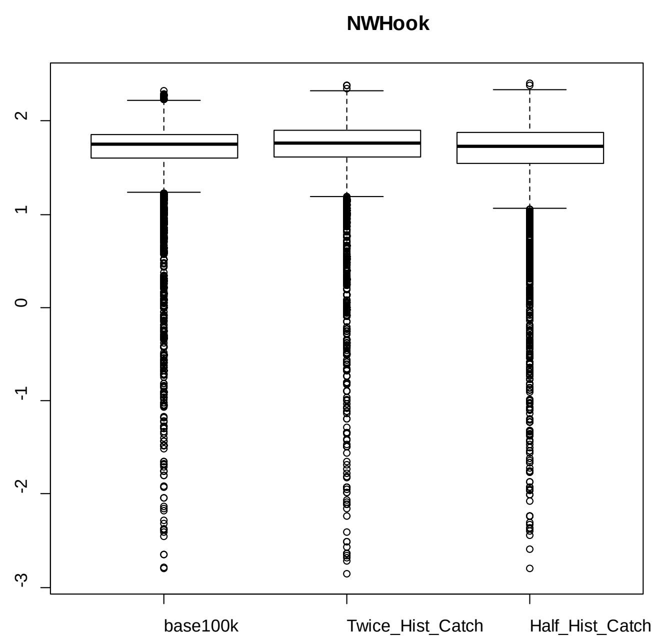


Figure 83. (Response to STAR Panel Request 10) Log-likelihood distributions for the NWFSC Hook-and-Line Survey index under alternative catch histories.

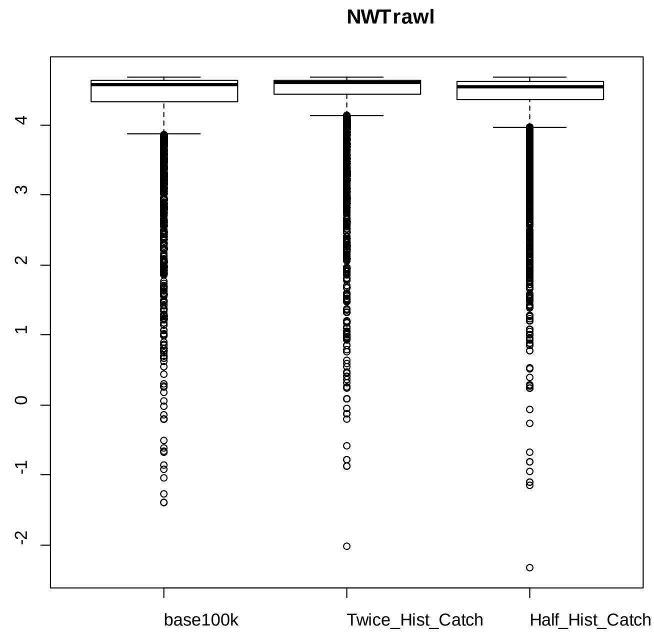


Figure 84. (Response to STAR Panel Request 10) Log-likelihood distributions for the NWFSC Trawl Survey index under alternative catch histories.

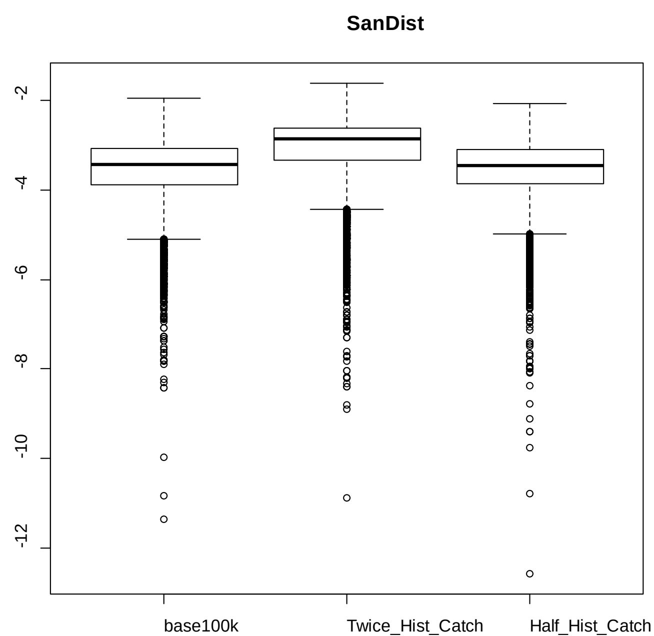


Figure 85. (Response to STAR Panel Request 10) Log-likelihood distributions for the Sanitation District index under alternative catch histories.

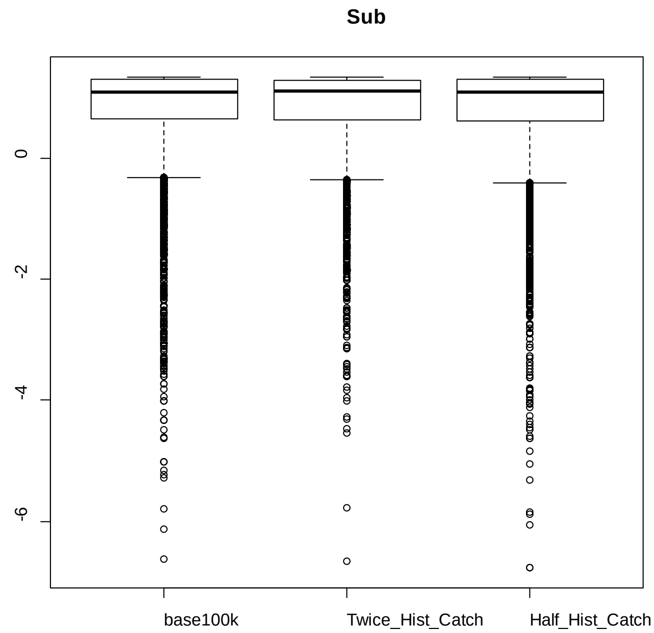


Figure 86. (Response to STAR Panel Request 10) Log-likelihood distributions for the Visual (Sub) Survey index under alternative catch histories.

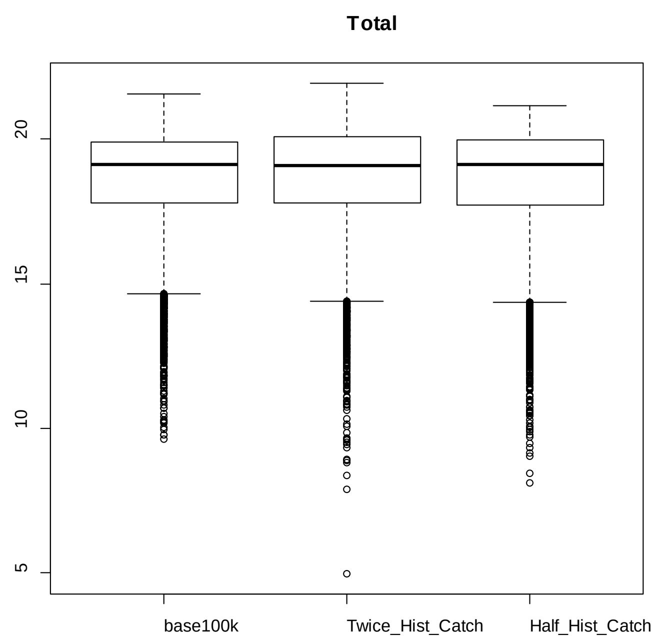


Figure 87. (Response to STAR Panel Request 10) Total Log-likelihood distributions under alternative catch histories.

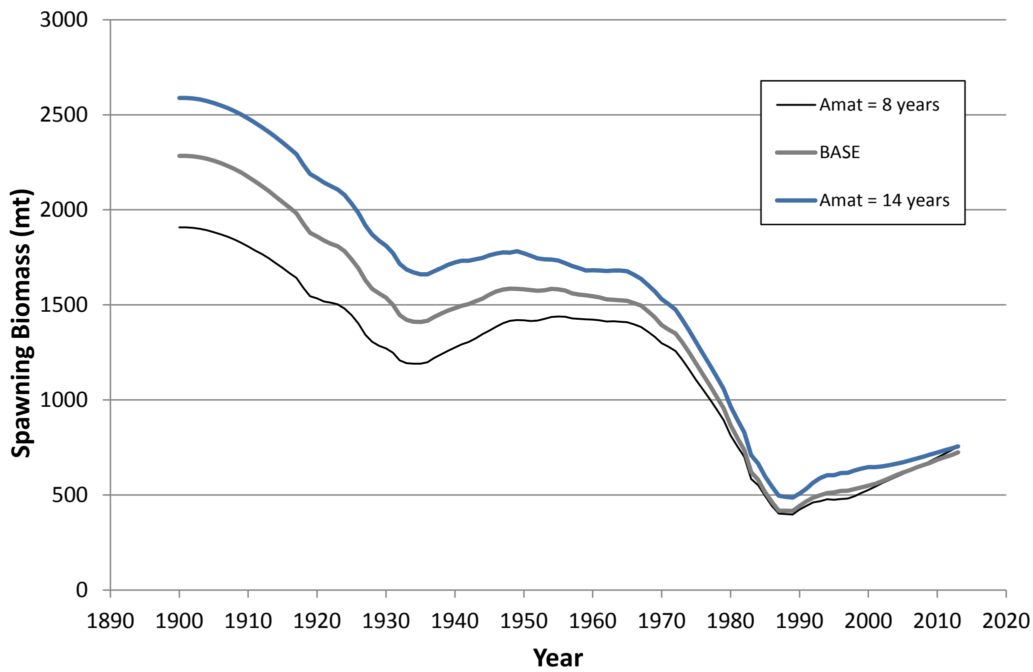


Figure 88. (Response to STAR Panel Request 11) Median spawning biomass trajectories under alternative time lag assumptions (+/- 3 years from age 11 assumption in base case). "Base" refers to the pre-STAR panel base model (including CPFV index).

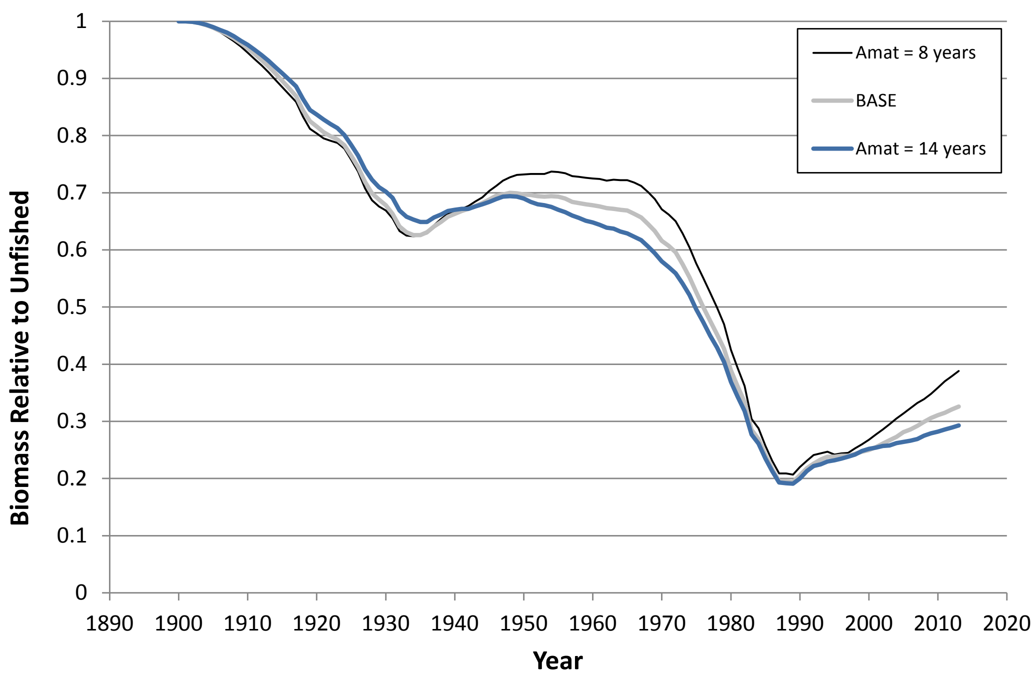


Figure 89. (Response to STAR Panel Request 11) Median relative biomass ("depletion) trajectories under alternative time lag assumptions (+/- 3 years from age 11 assumption in base case). "Base" refers to the pre-STAR panel base model (including CPFV index).

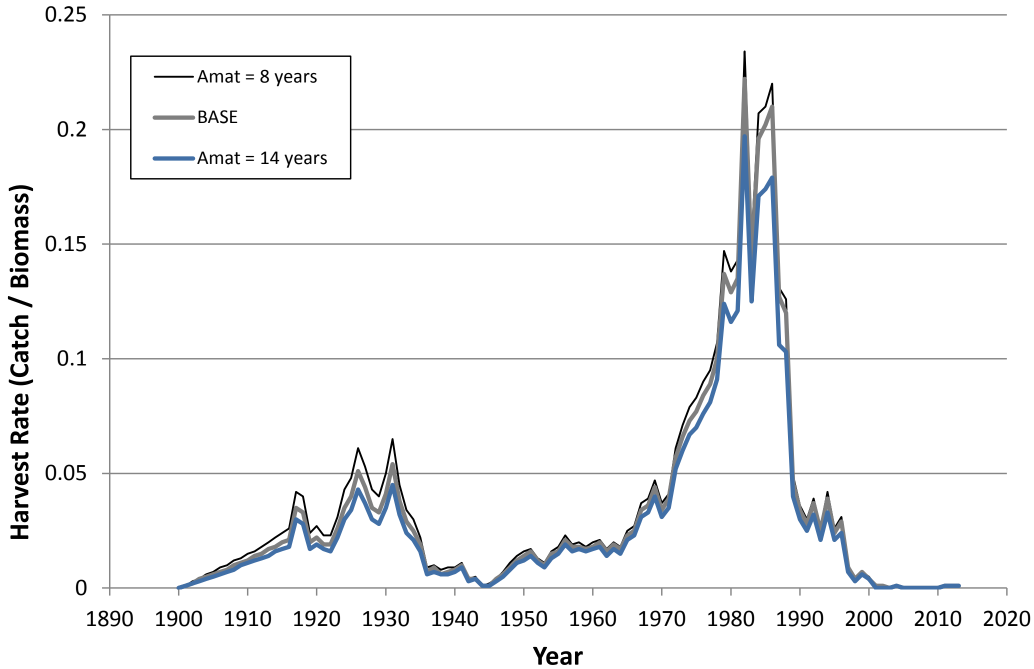


Figure 90. (Response to STAR Panel Request 11) Median harvest rates under alternative time lag assumptions (+/- 3 years from age 11 assumption in base case). “Base” refers to the pre-STAR panel base model (including CPFV index).

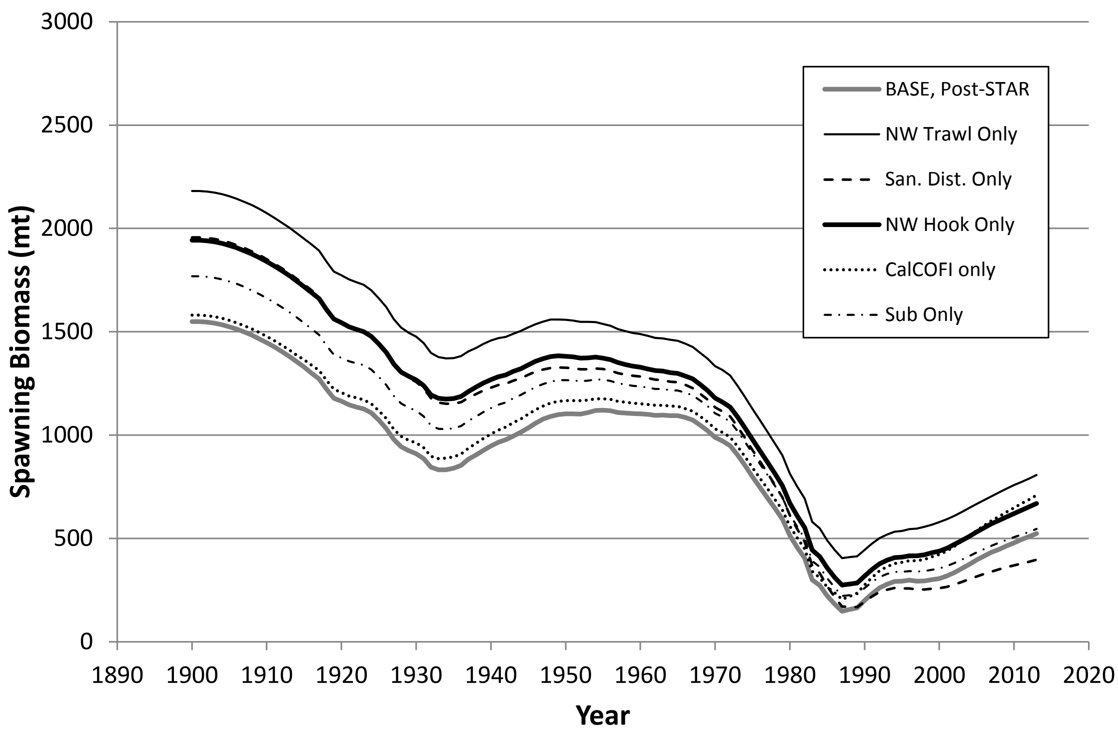


Figure 91. (Response to STAR Panel Request 12) Median spawning biomass trajectories from the Post-STAR Panel base model, compared to fits to single indices.

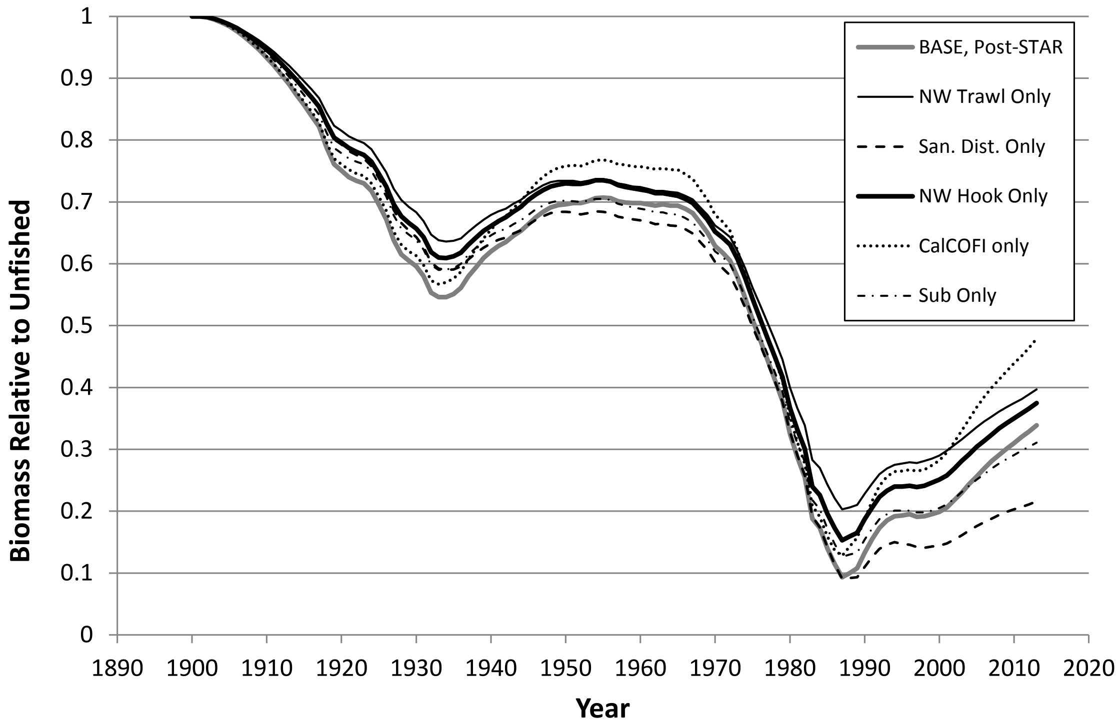


Figure 92. (Response to STAR Panel Request 12) Median relative biomass trajectories from the Post-STAR Panel base model, compared to fits to single indices.

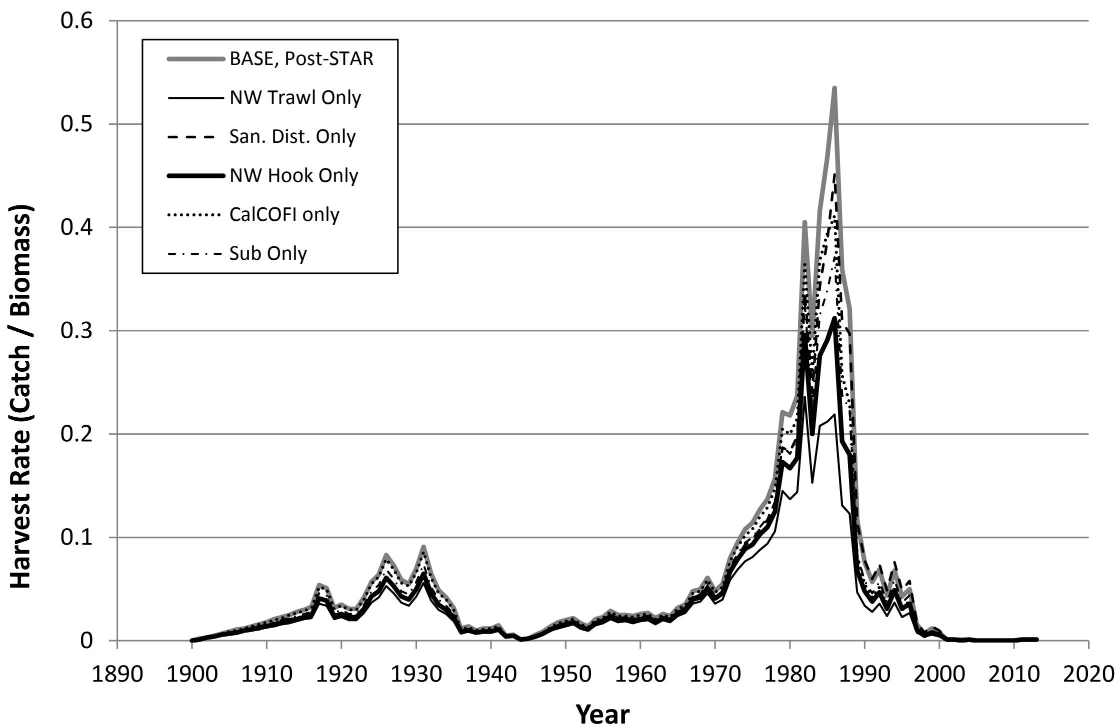


Figure 93. (Response to STAR Panel Request 12) Median harvest rates from the Post-STAR Panel base model, compared to fits to single indices.

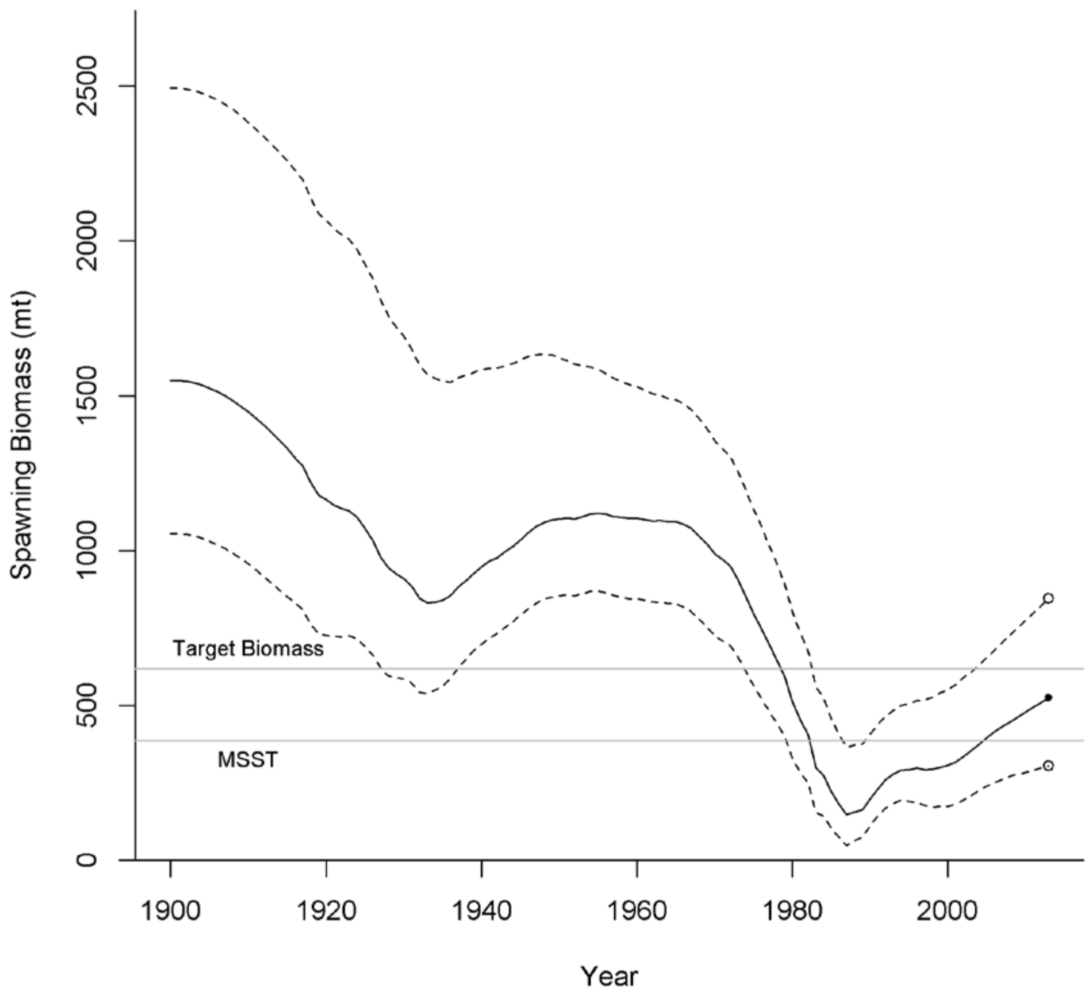


Figure 94. Distribution of spawning biomass trajectories from the base model (median = solid line, 5th and 95th percentile = dashed lines), relative to Target Biomass (40% of unfished biomass) and the Minimum Stock Size Threshold (MSST, 25% of unfished biomass). Circles indicate values in 2013.

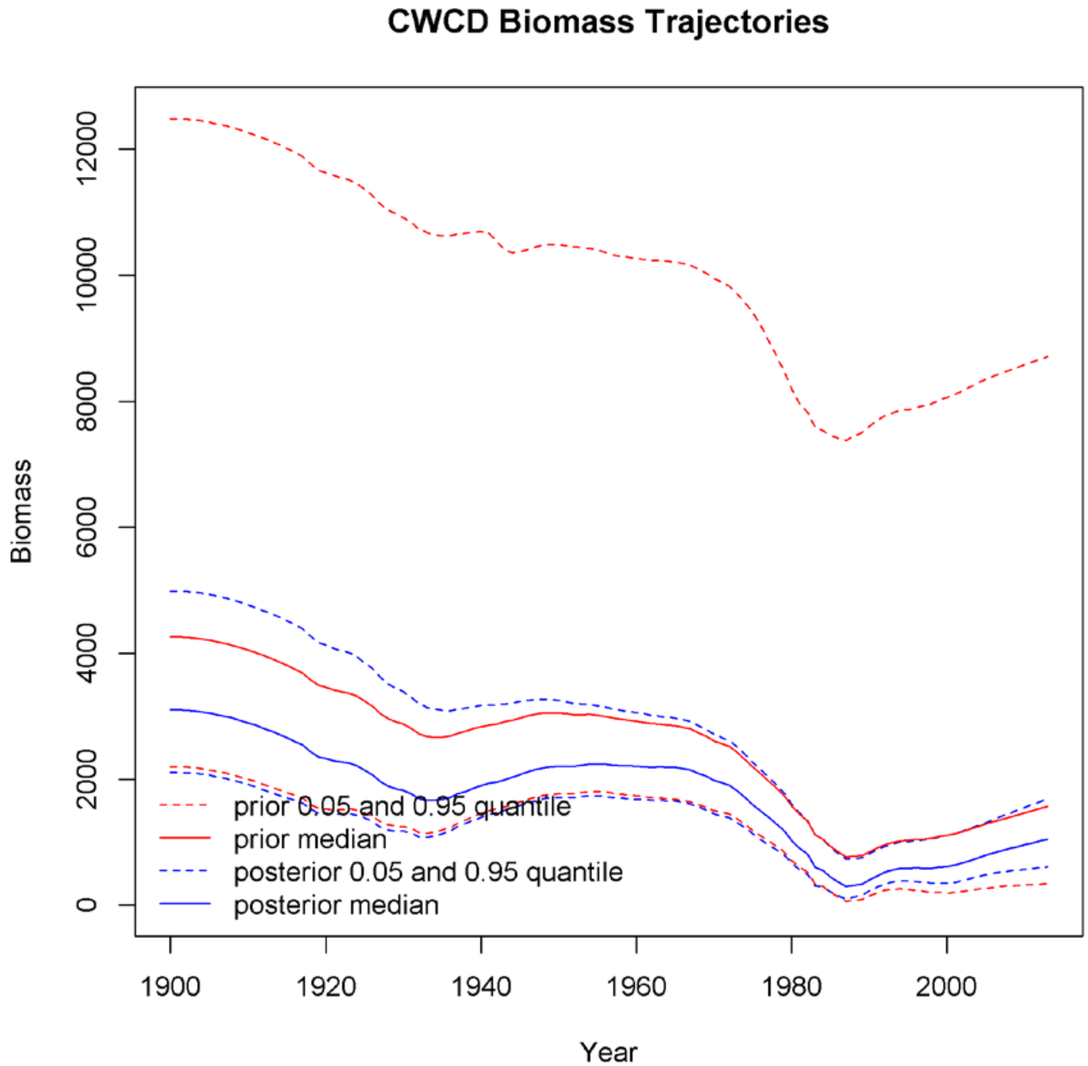


Figure 95. Total mature biomass from the prior predictive distribution (DB-SRA, in red) and the posterior distribution (XDB-SRA, in blue). Median = (solid lines) and 5th and 95th quantiles = (dashed lines).

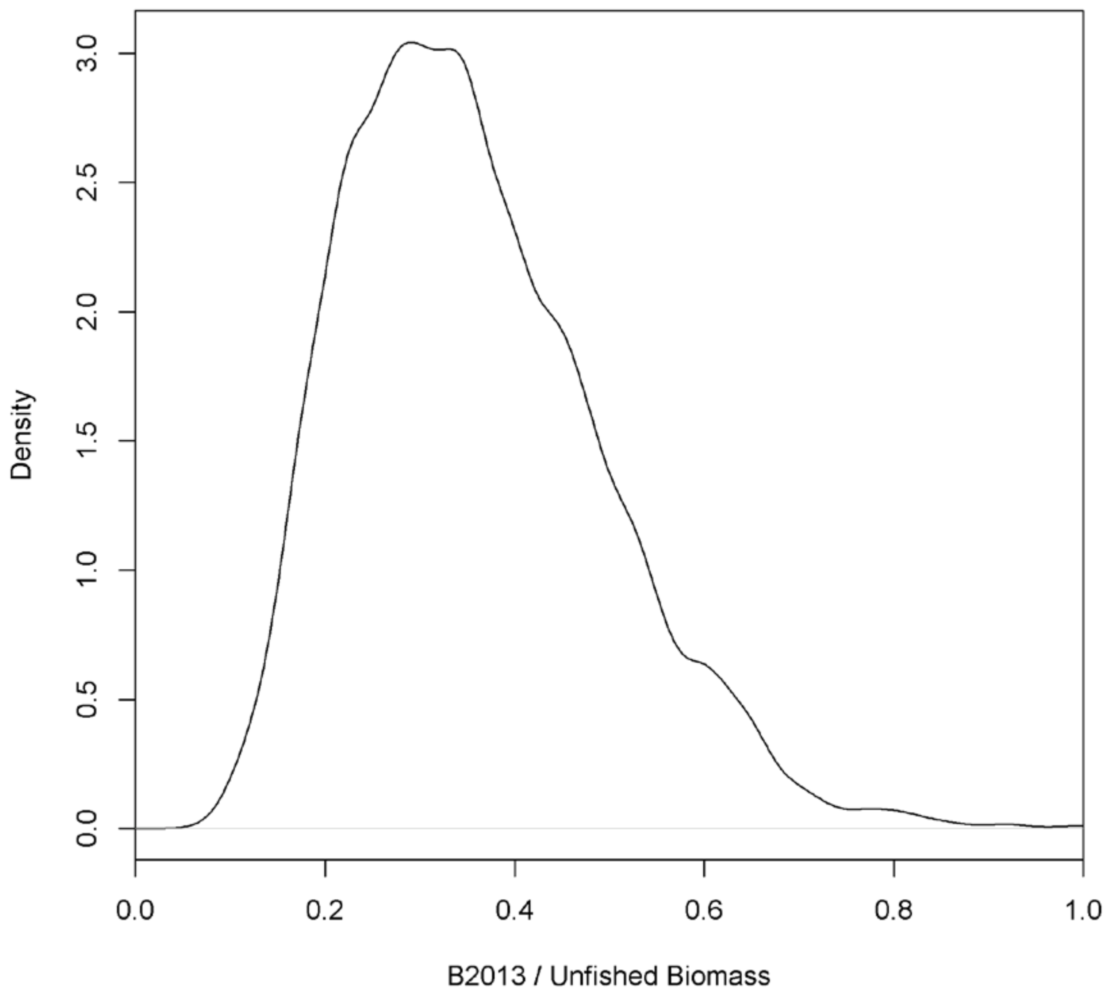


Figure 96. Posterior density of “depletion” (biomass in 2013 relative to unfished biomass) for the cowcod base model.

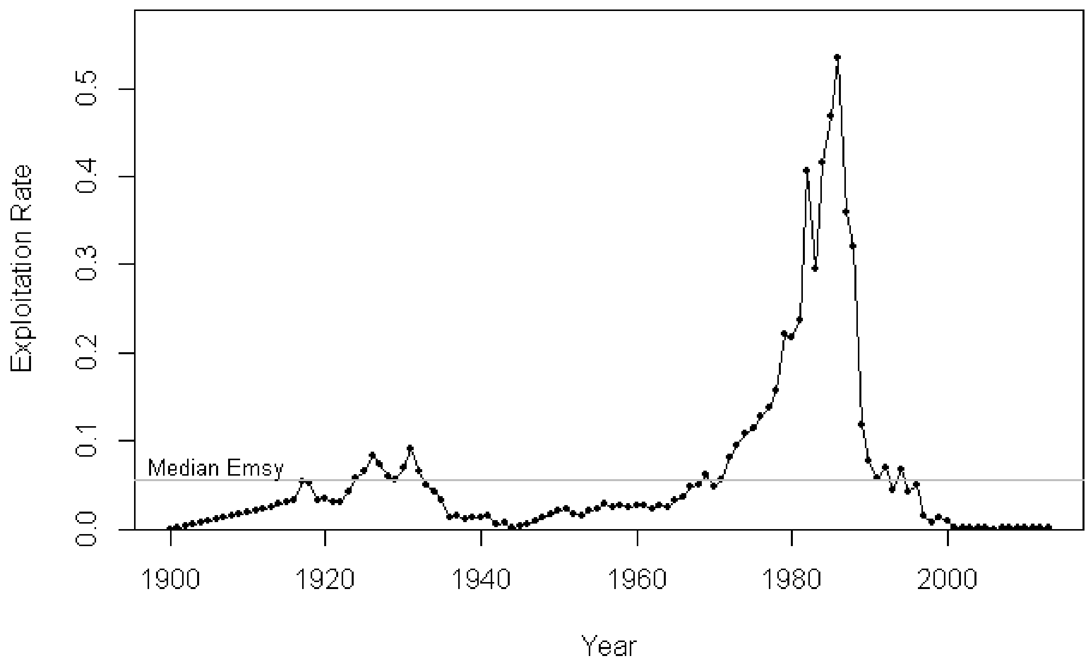


Figure 97. Median exploitation rate (exploitation rate = catch / vulnerable biomass) time series for the cowcod base model. Median exploitation rate producing long-term MSY (E_{MSY}) shown for reference.

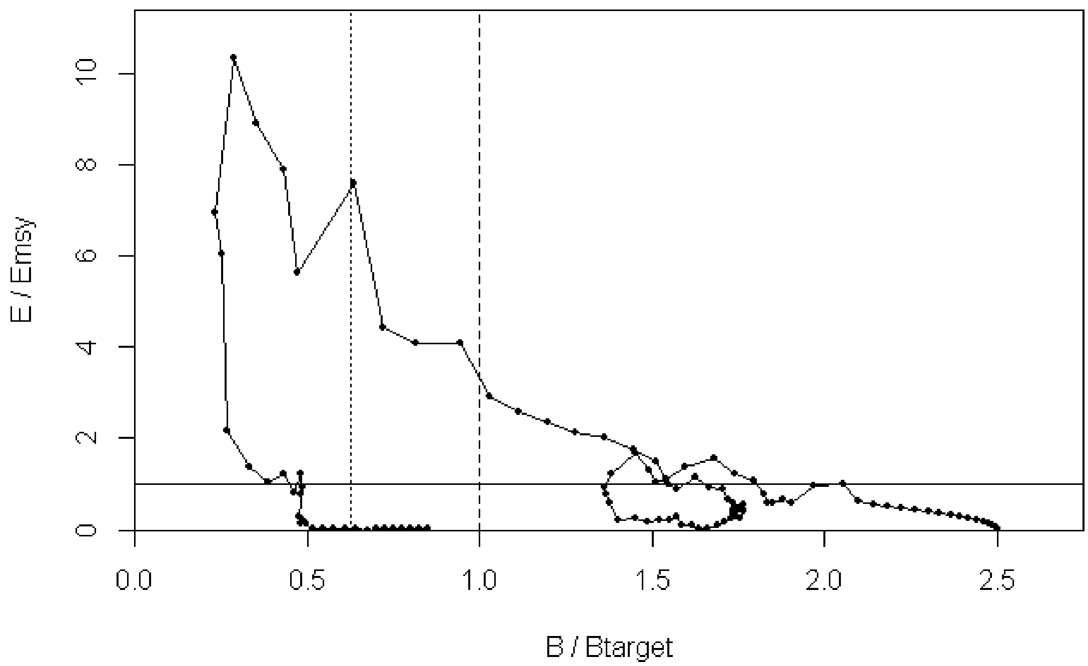


Figure 98. Phase plot of median annual harvest rates divided by the median MSY harvest rate vs. median spawning biomass divided by the target spawning biomass (40% of unfished spawning biomass) for the base case model. Target and limit reference points are shown for Emsy (solid horizontal line), target biomass (dashed vertical line), and the minimum stock size threshold for biomass (dotted vertical line).

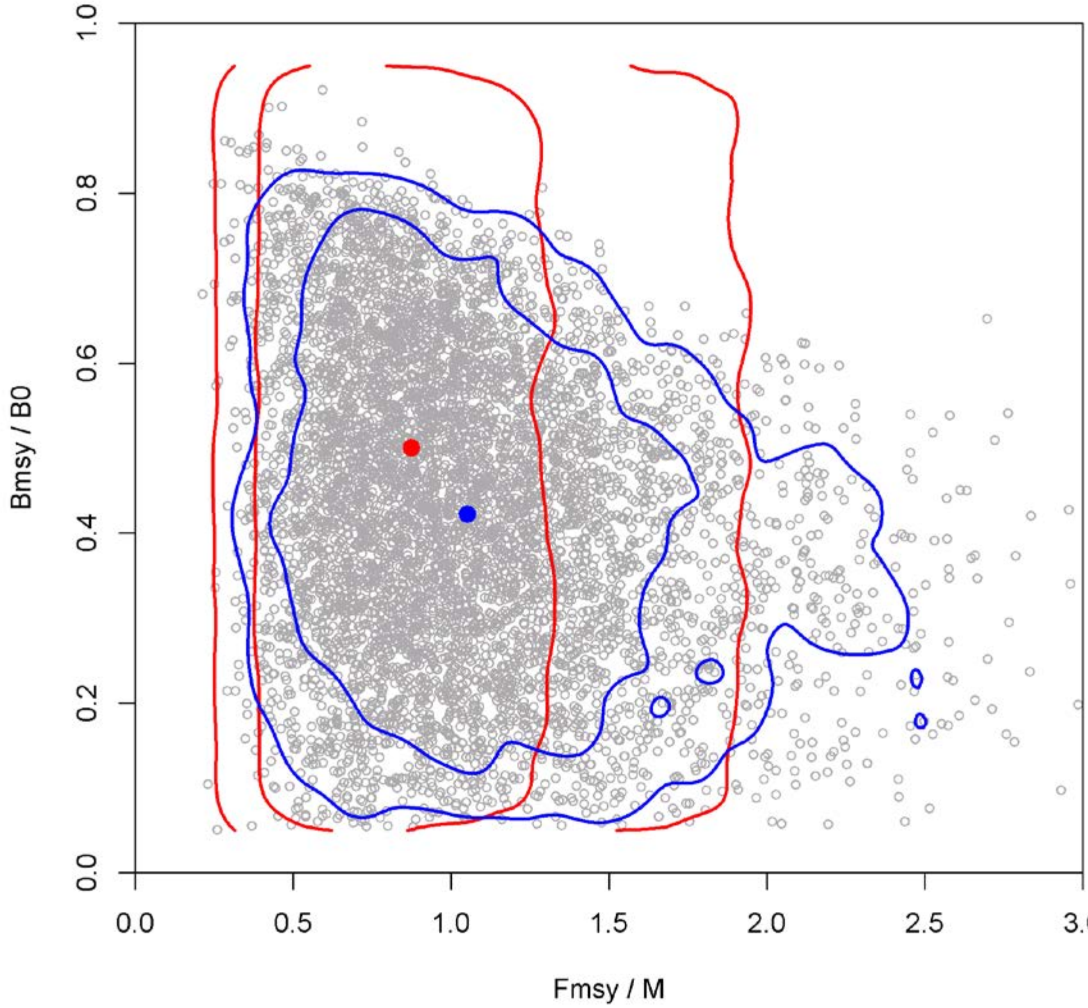


Figure 99. Bivariate prior and posterior distributions for Fmsy/M and Bmsy/B0 from the base model. Red lines are 75% and 95% contours of the prior, blue lines are updated posterior contours. Grey circles are posterior draws, large solid circles are centroids (medians) of the prior and posterior (red and blue, respectively).

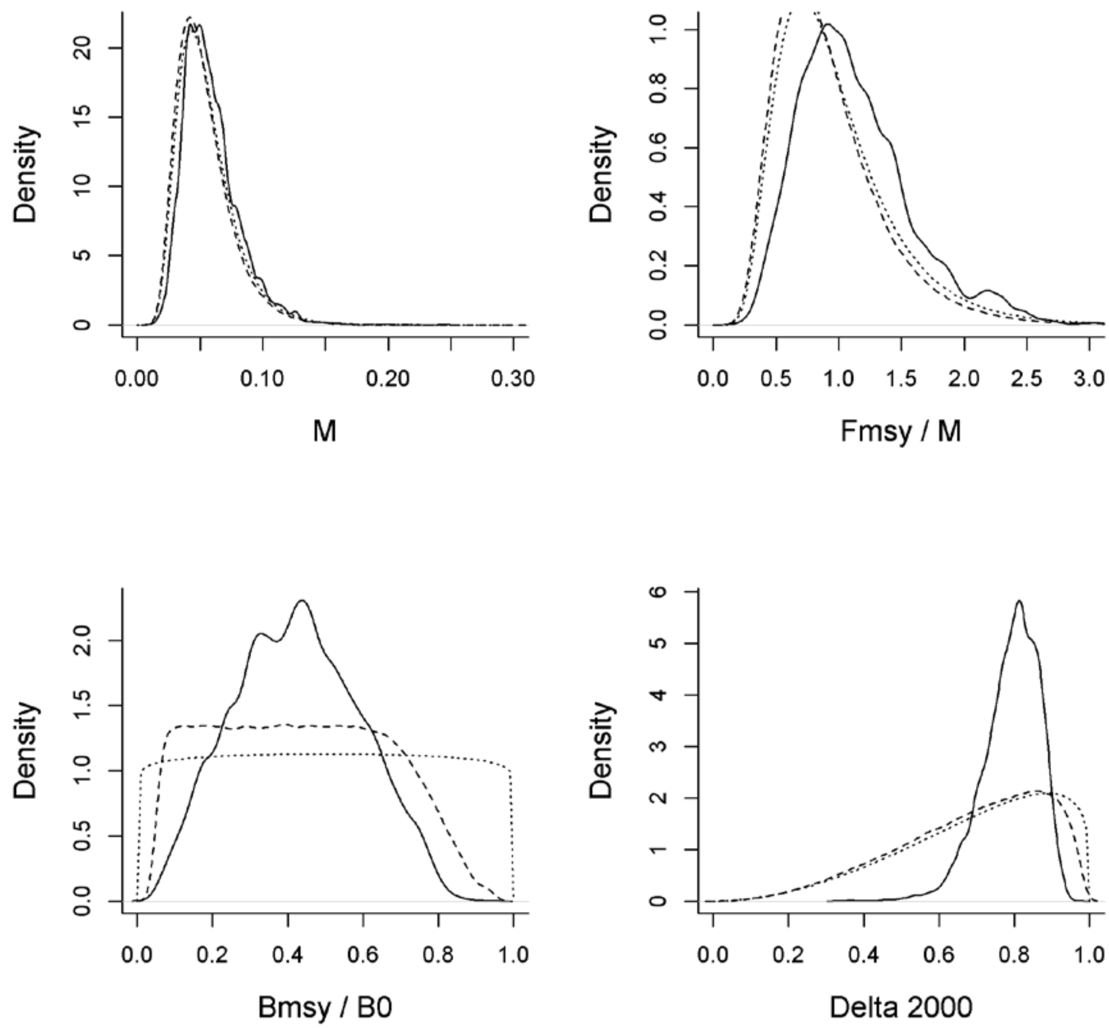


Figure 100. Distributions for XDB-SRA population dynamics parameters. Prior (dotted), post-model pre-data (dashed), and posterior (solid) distributions.

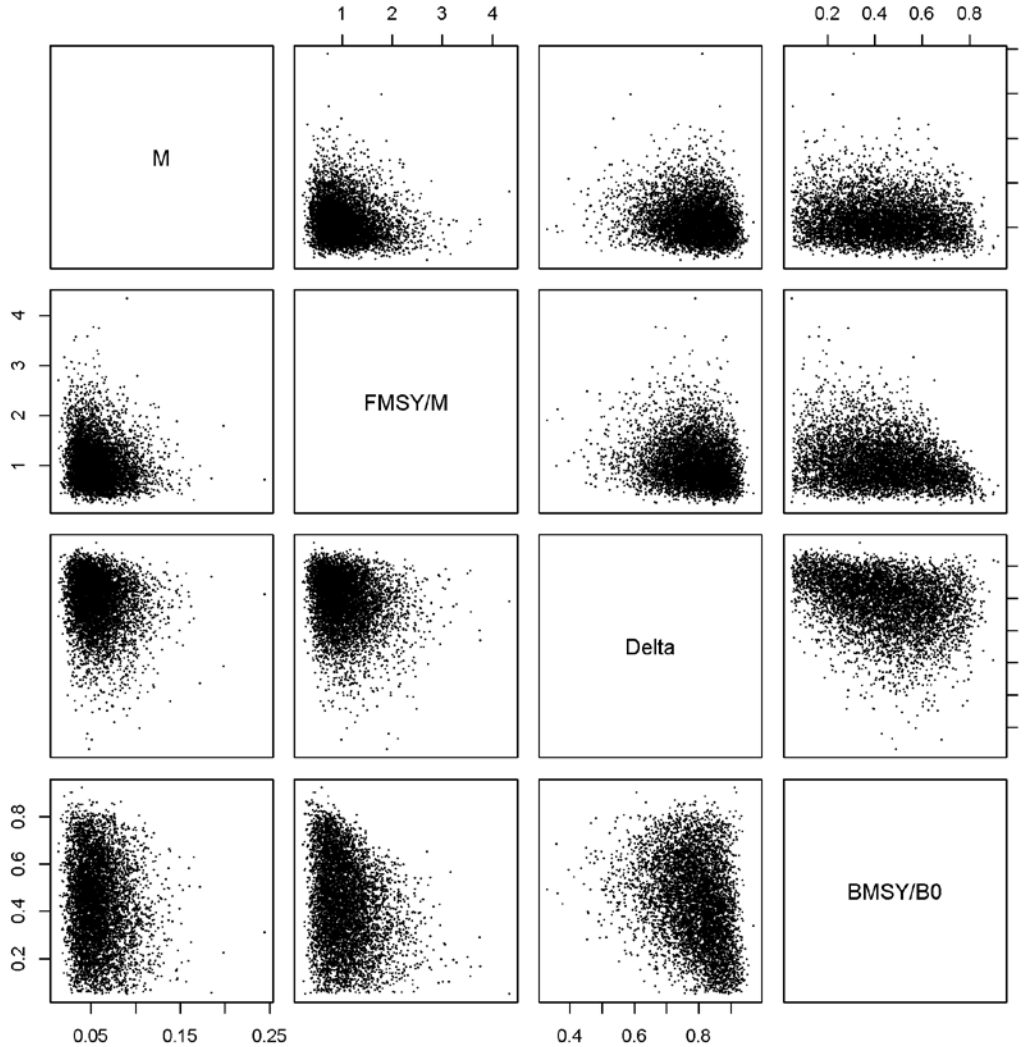


Figure 101. Pairwise scatterplots of population dynamics parameters in base model.

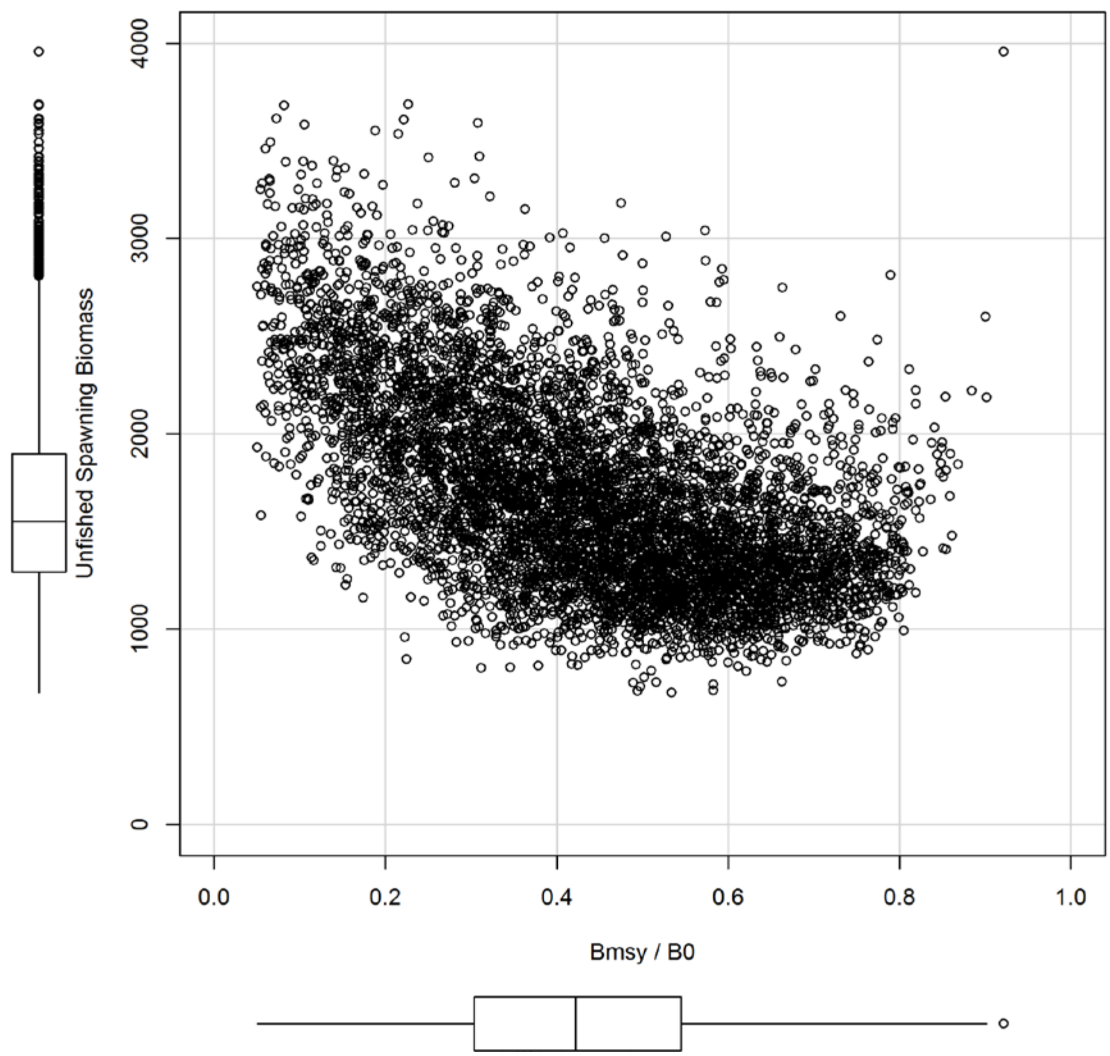


Figure 102. Relationship between unfished spawning biomass and B_{MSY}/B_0 in base model.

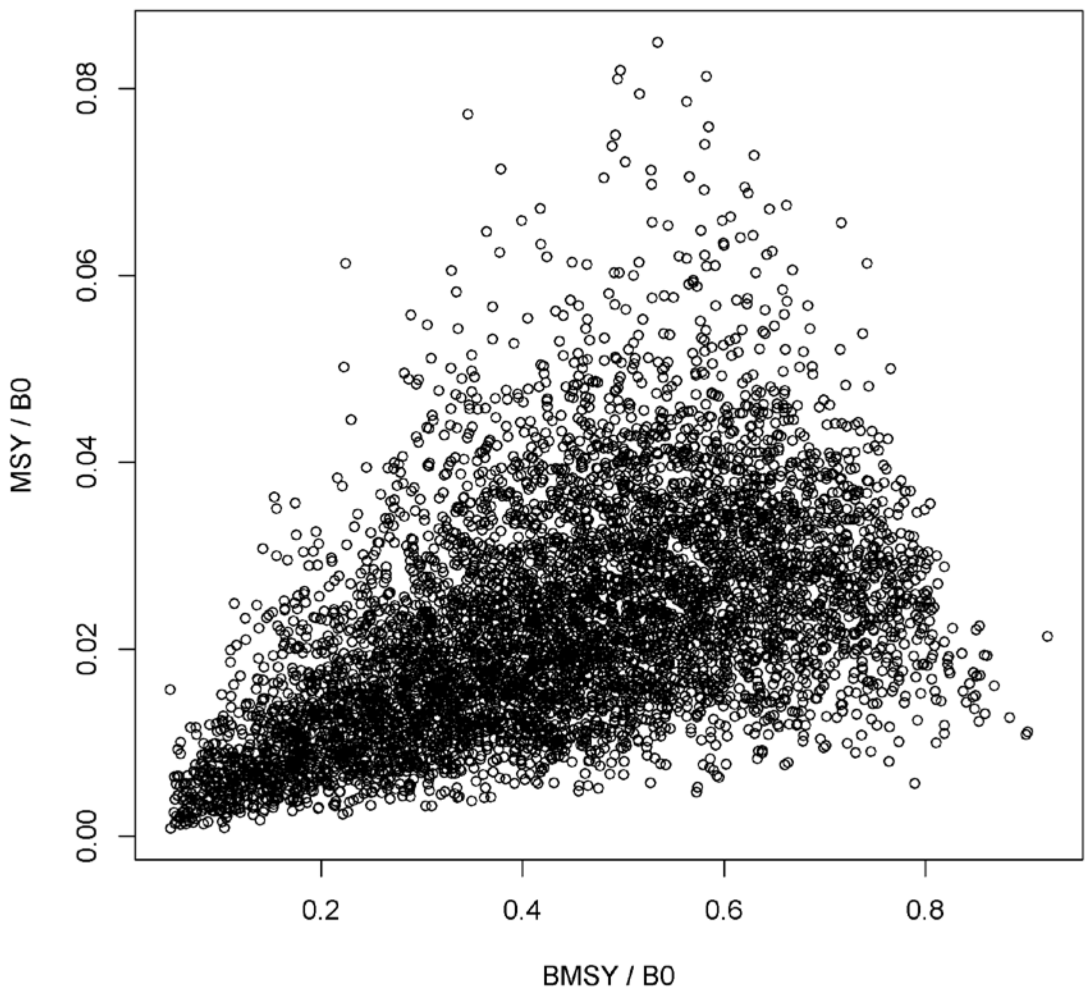


Figure 103. Relationship between MSY and B_{MSY}, relative to B_0. Each point represents the peak of a yield curve, in units of B_0.

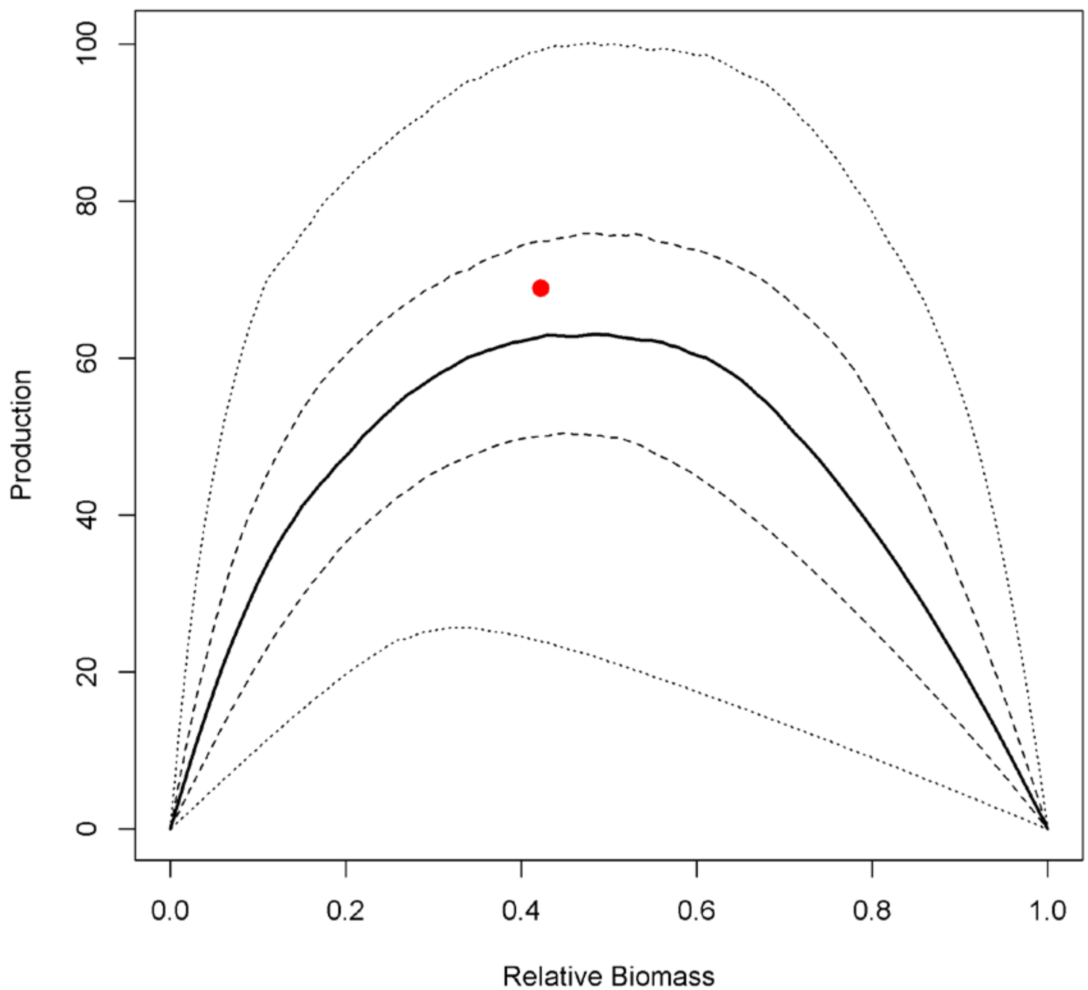


Figure 104. Distribution of yield curves from the base model. The solid, dashed, and dotted lines are median, interquartile, and 95th percentiles of production, respectively, given relative biomass. The red circle represents the marginal medians of B_{MSY}/B_0 and MSY.

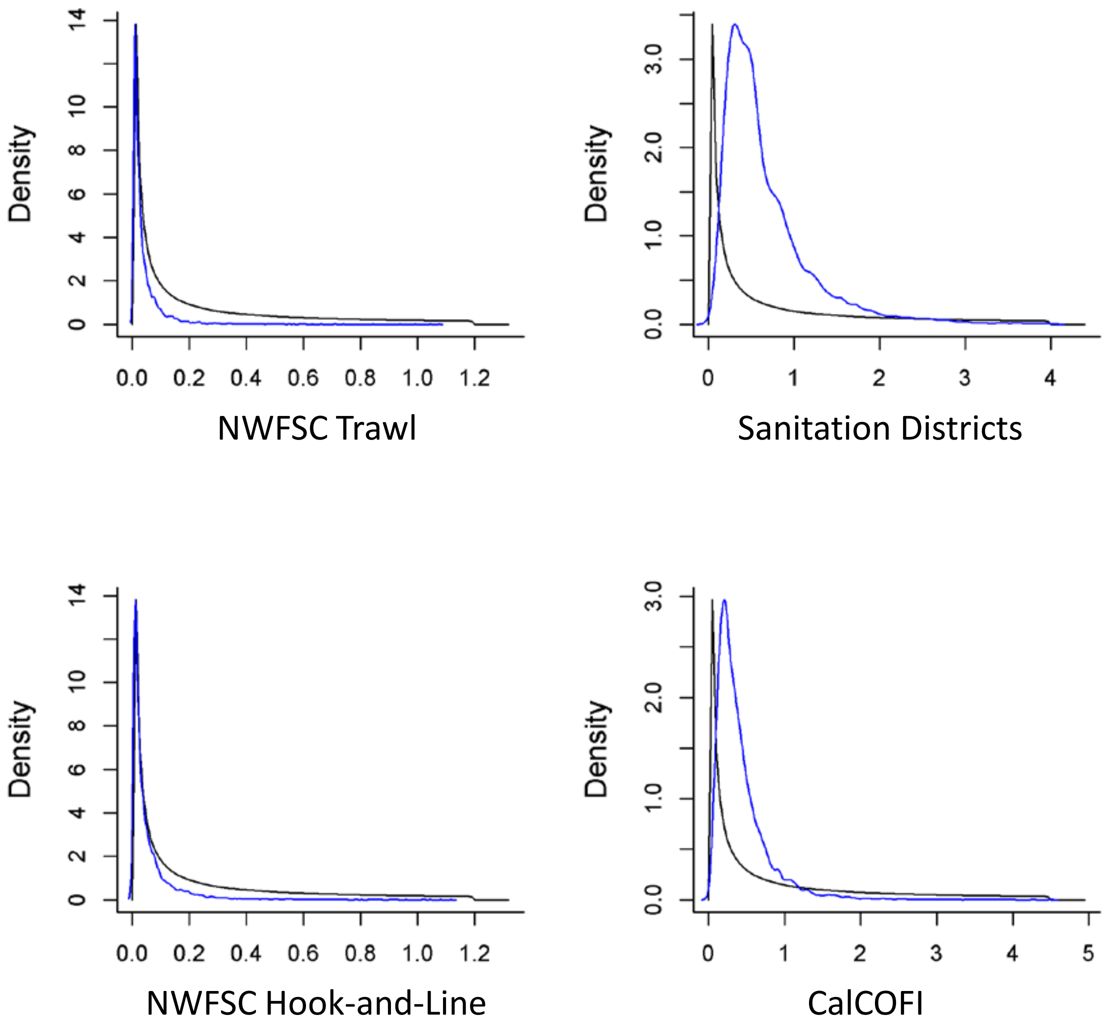


Figure 105. Additive variance parameters for the 4 time series in the base model. Solid black line is the log-uniform prior, blue line is the posterior distribution.

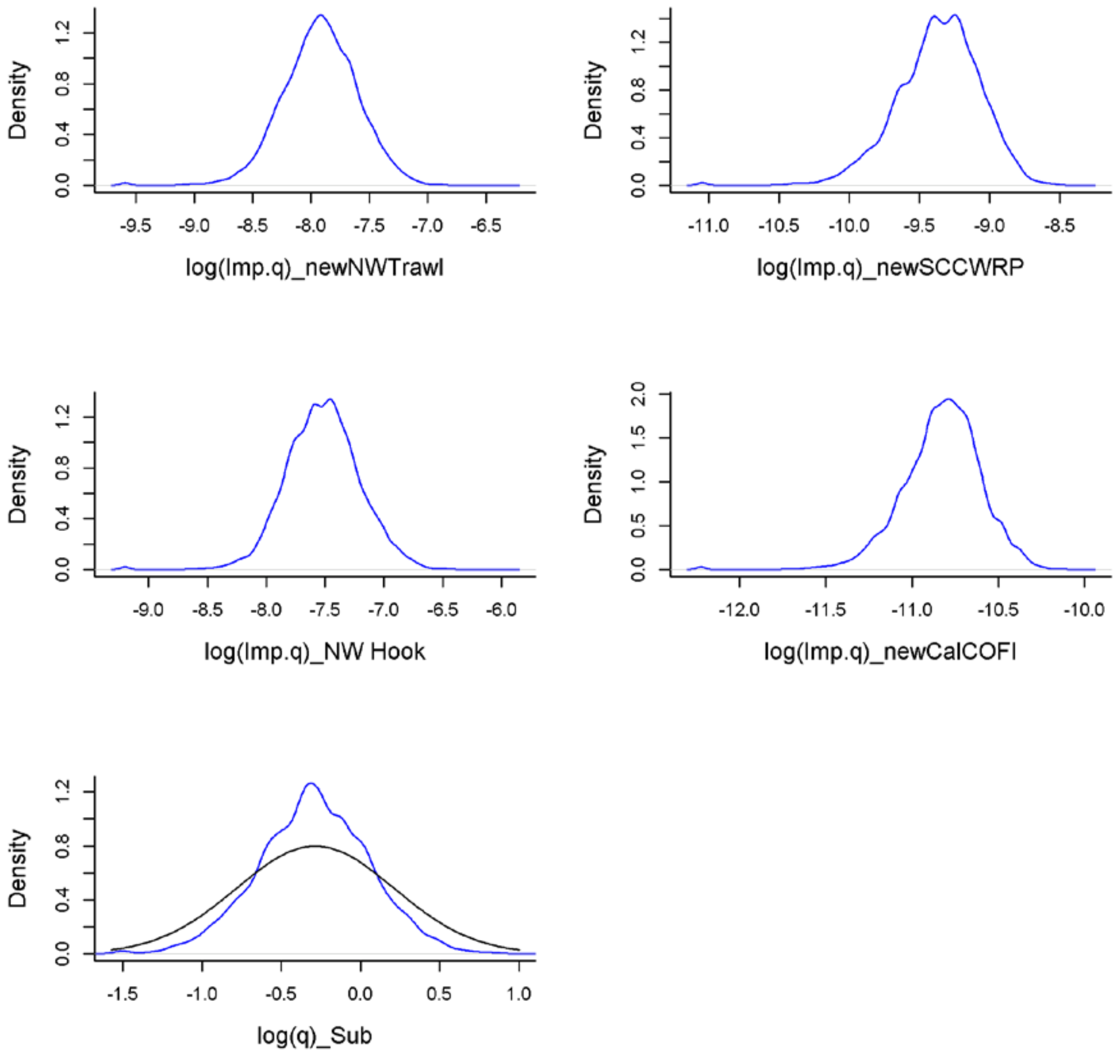


Figure 106. Catchability coefficients (q) in the base model (log scale). The posterior visual survey q (blue density, bottom left) is shown relative to the prior distribution (black).

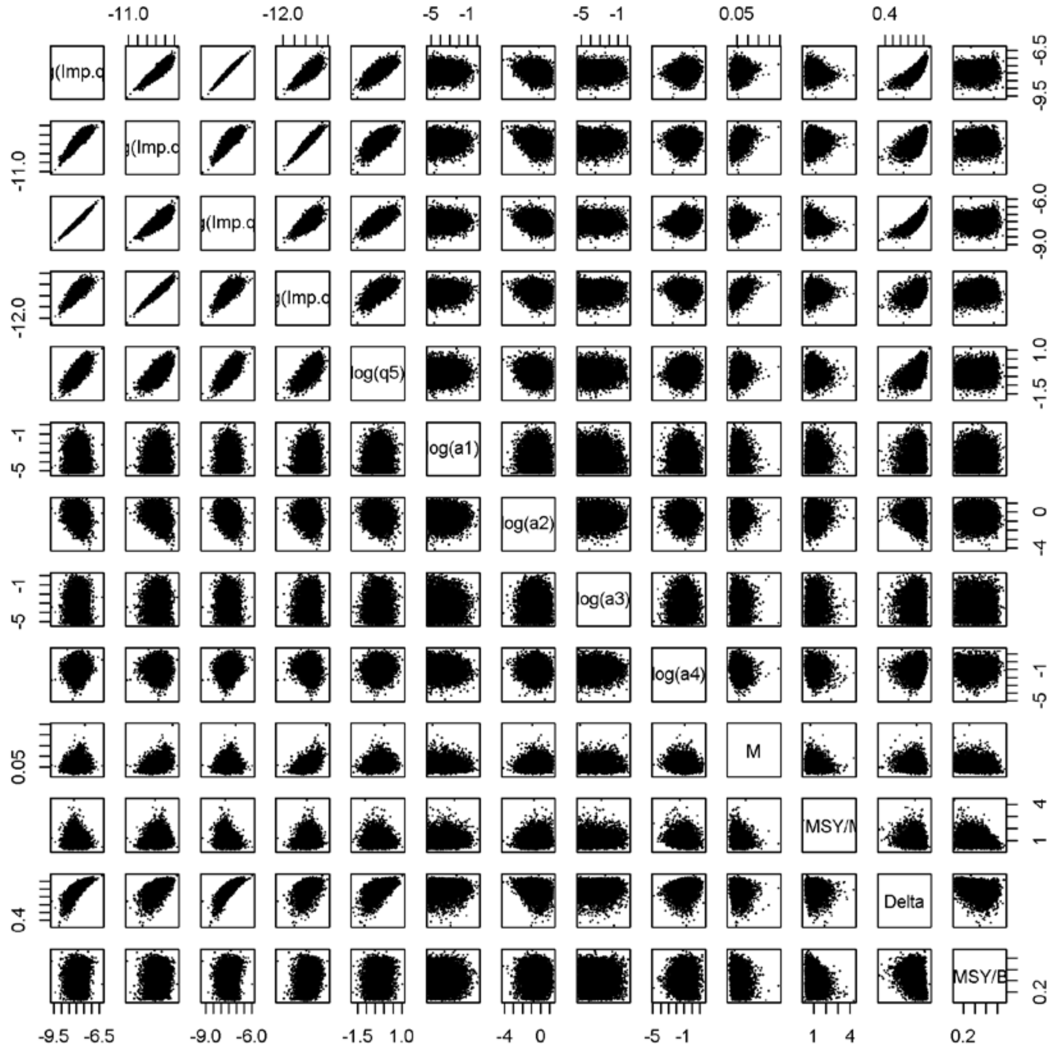


Figure 107. Pairwise scatterplot of all estimated model parameters in the base model (plus 5 calculated q's for survey time series, in the upper left 5x5 matrix).

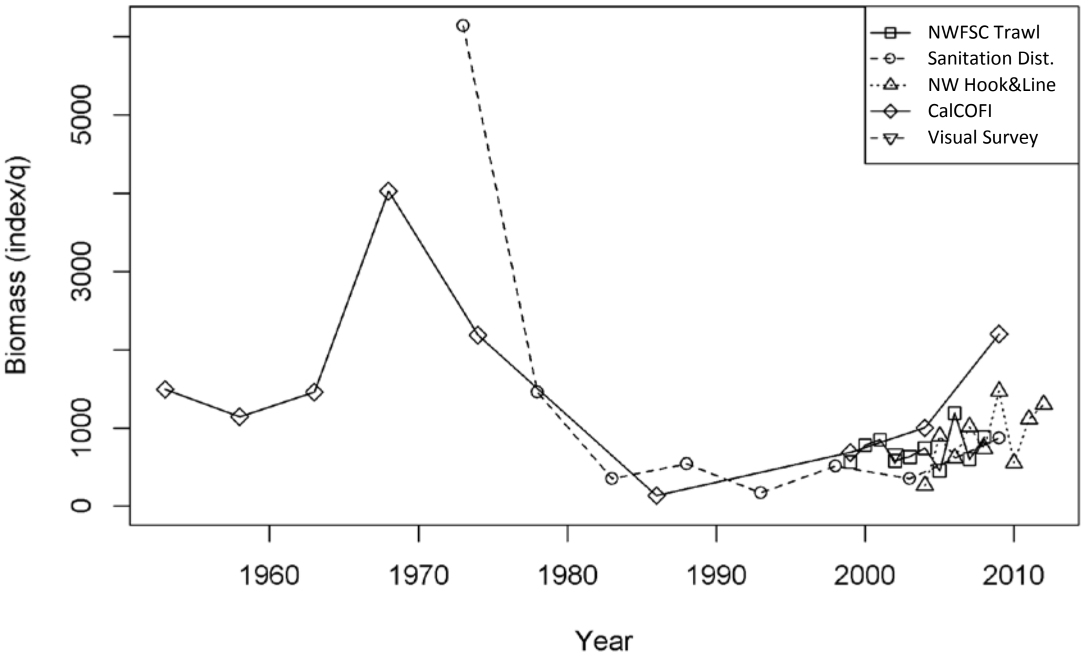


Figure 108. Indices of abundance, rescaled to units of biomass (dividing each index by its median q).

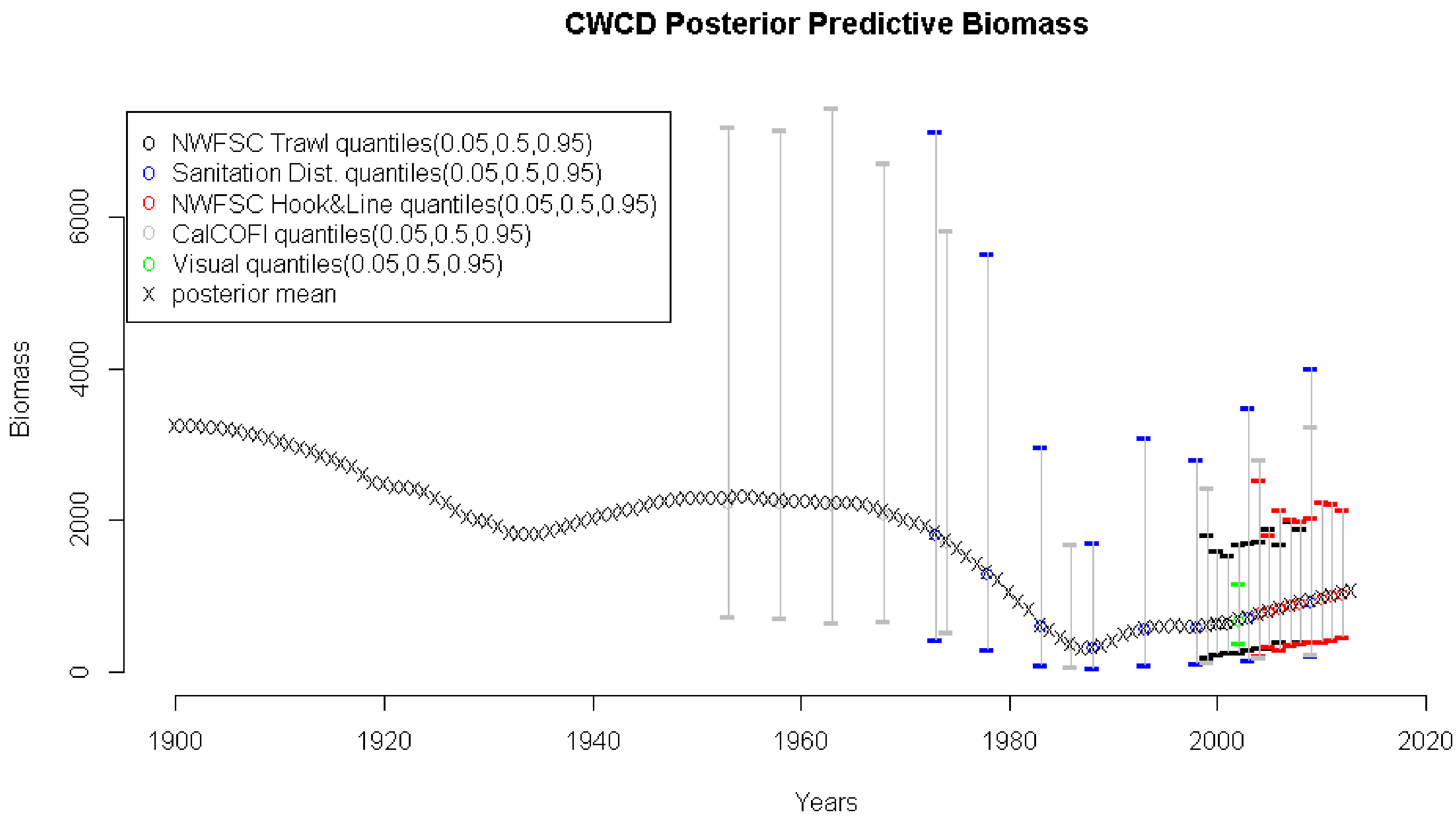


Figure 109. Posterior predictive intervals (5th and 95th percentiles) of vulnerable biomass for all indices in the base model, and the posterior mean of vulnerable biomass (X's).

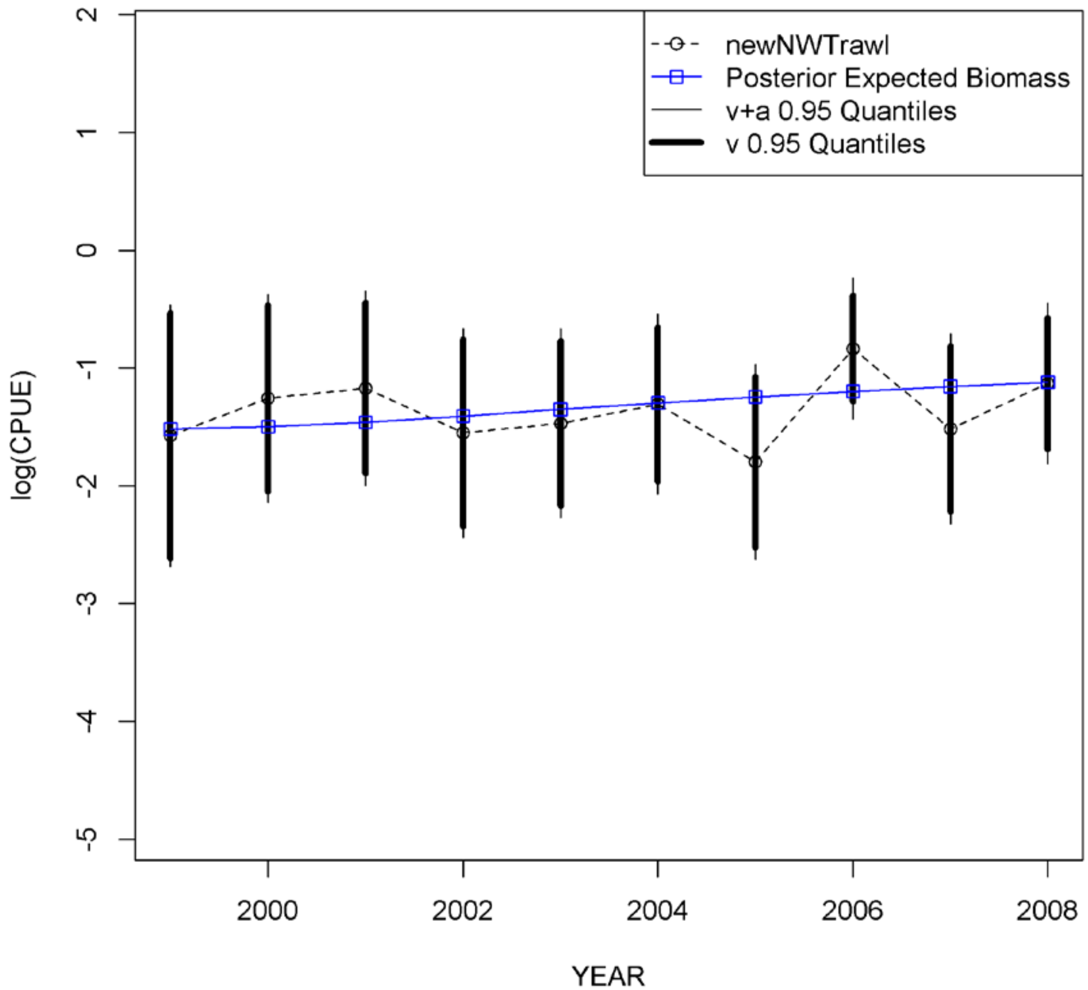


Figure 110. Log-scale fit of the NWFSC Trawl Survey index (2003-2012, with 4-year lag) to vulnerable biomass (1999-2008). Dashed line with circles is the index, blue line with squares is the posterior expected biomass, thick vertical lines are the 95% intervals from the input (fixed) variances, and the thin vertical lines are the 95% intervals with estimated added variance.

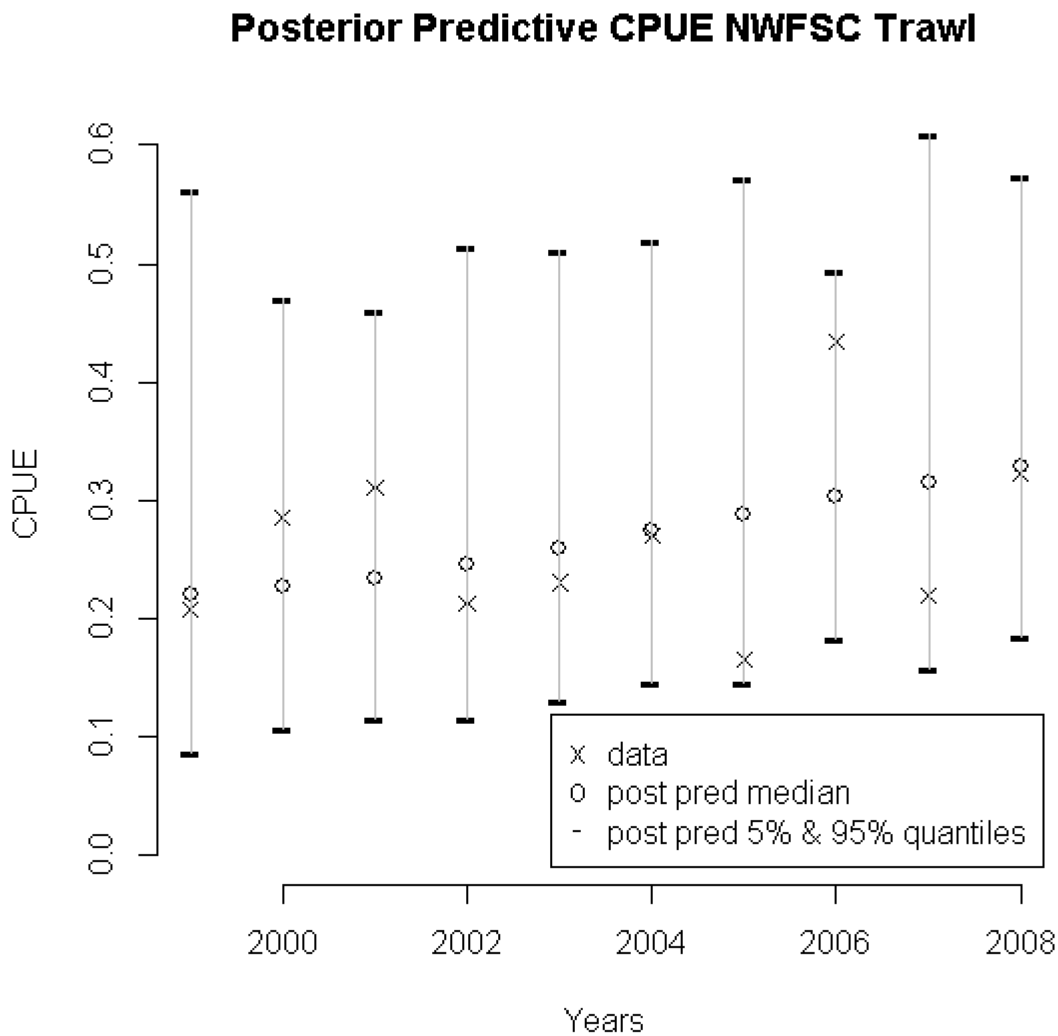


Figure 111. Posterior predictive intervals (5th and 95th quantiles) and median values, relative to observed data (X's) from the NWFSC Trawl Survey index (2003-2012, with 4-year lag).

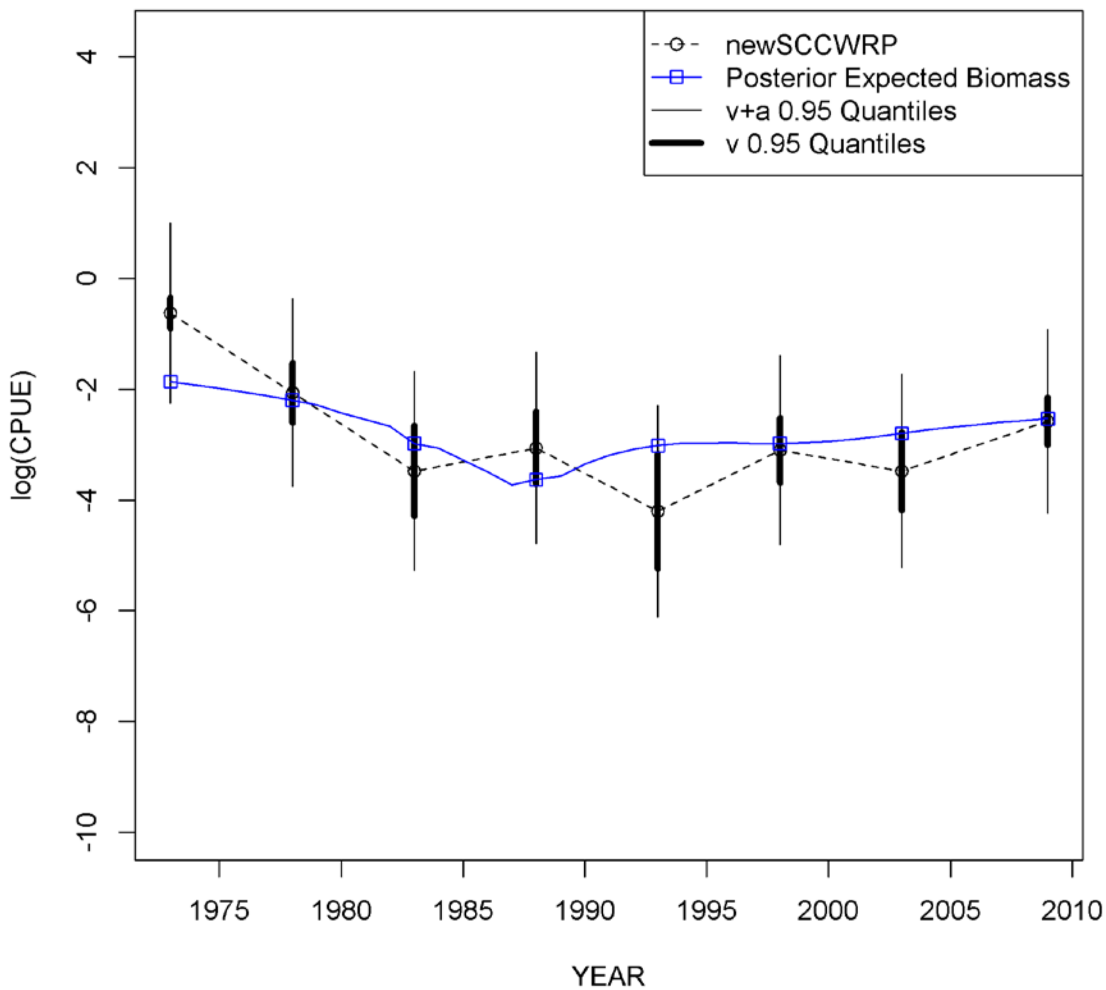


Figure 112. Log-scale fit of the Sanitation District Trawl Survey index. Dashed line with circles is the index, blue line with squares is the posterior expected biomass, thick vertical lines are the 95% intervals from the input (fixed) variances, and the thin vertical lines are the 95% intervals with estimated added variance

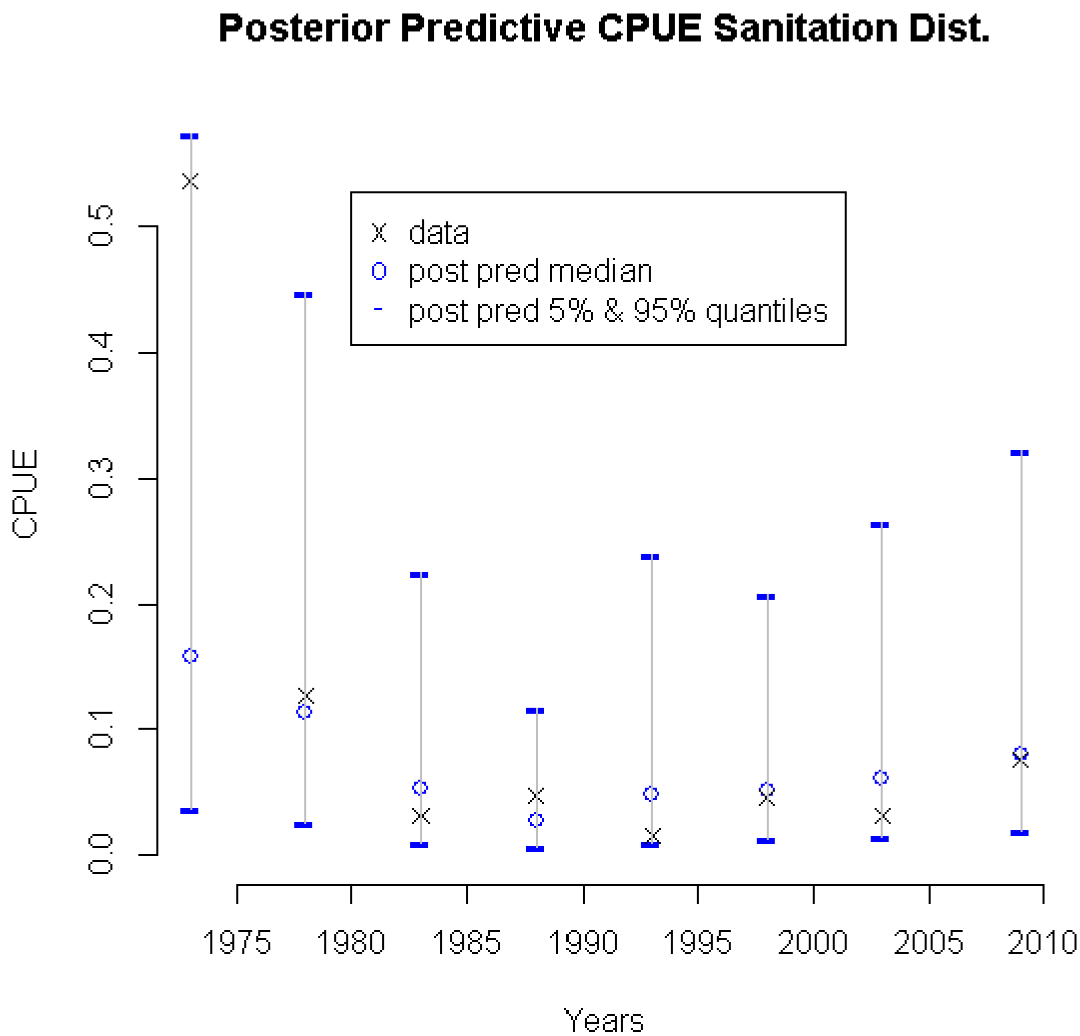


Figure 113. Posterior predictive intervals (5^{th} and 95^{th} quantiles) and median values (circles), relative to observed data (X's) from the Sanitation District Trawl Survey index.

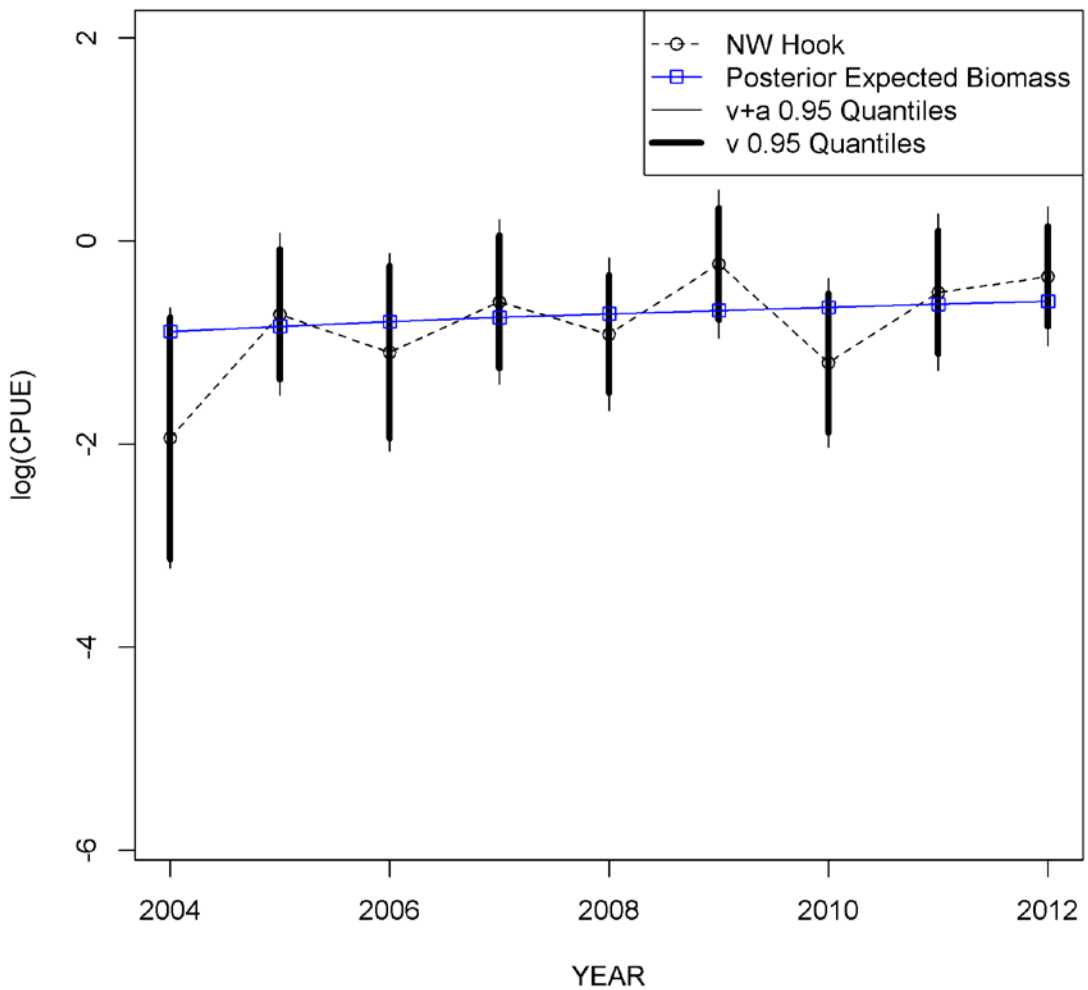


Figure 114. Log-scale fit of the NWFSC Hook-and-Line Survey index (2004-2012) to vulnerable biomass. Dashed line with circles is the index, blue line with squares is the posterior expected biomass, thick vertical lines are the 95% intervals from the input (fixed) variances, and the thin vertical lines are the 95% intervals with estimated added variance.

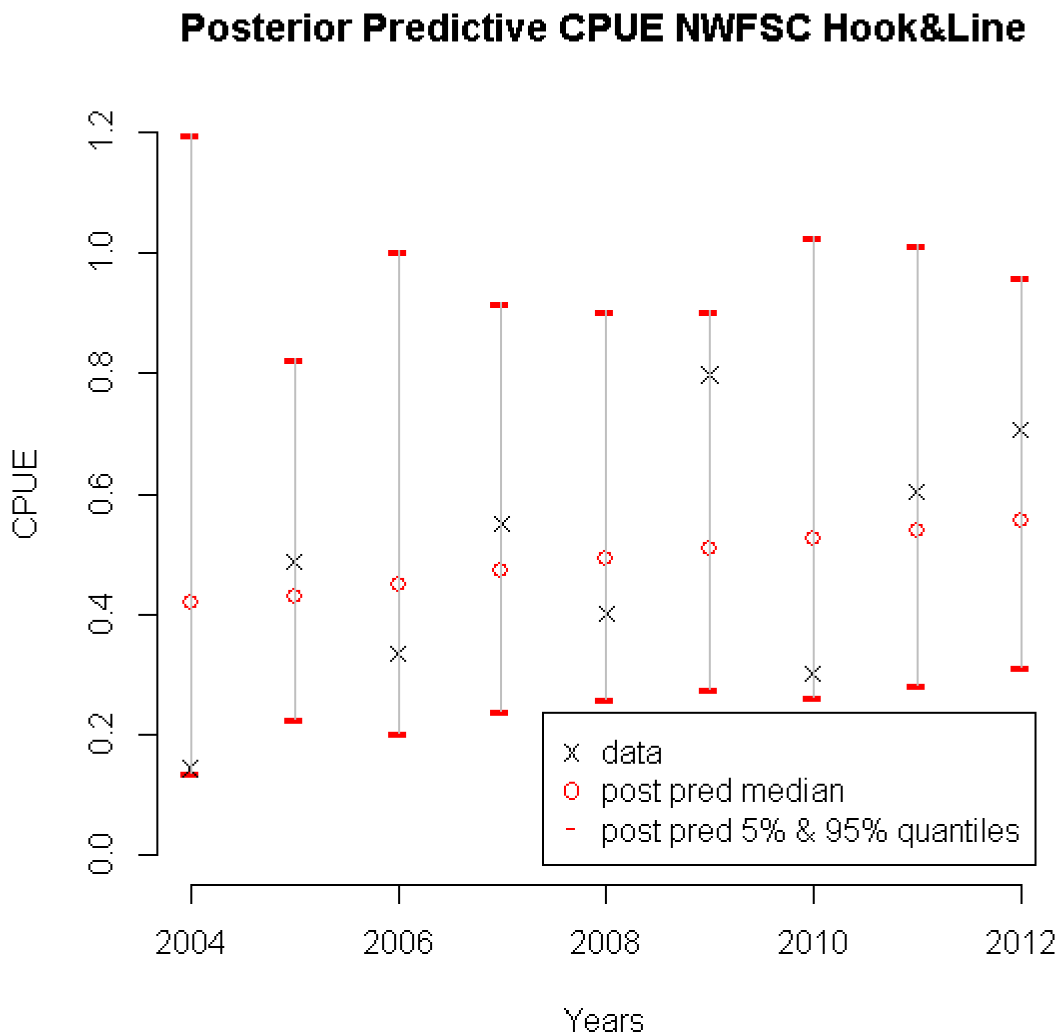


Figure 115. Posterior predictive intervals (5th and 95th quantiles) and median values, relative to observed data (X's) from the NWFSC Hook-and-Line Survey index.

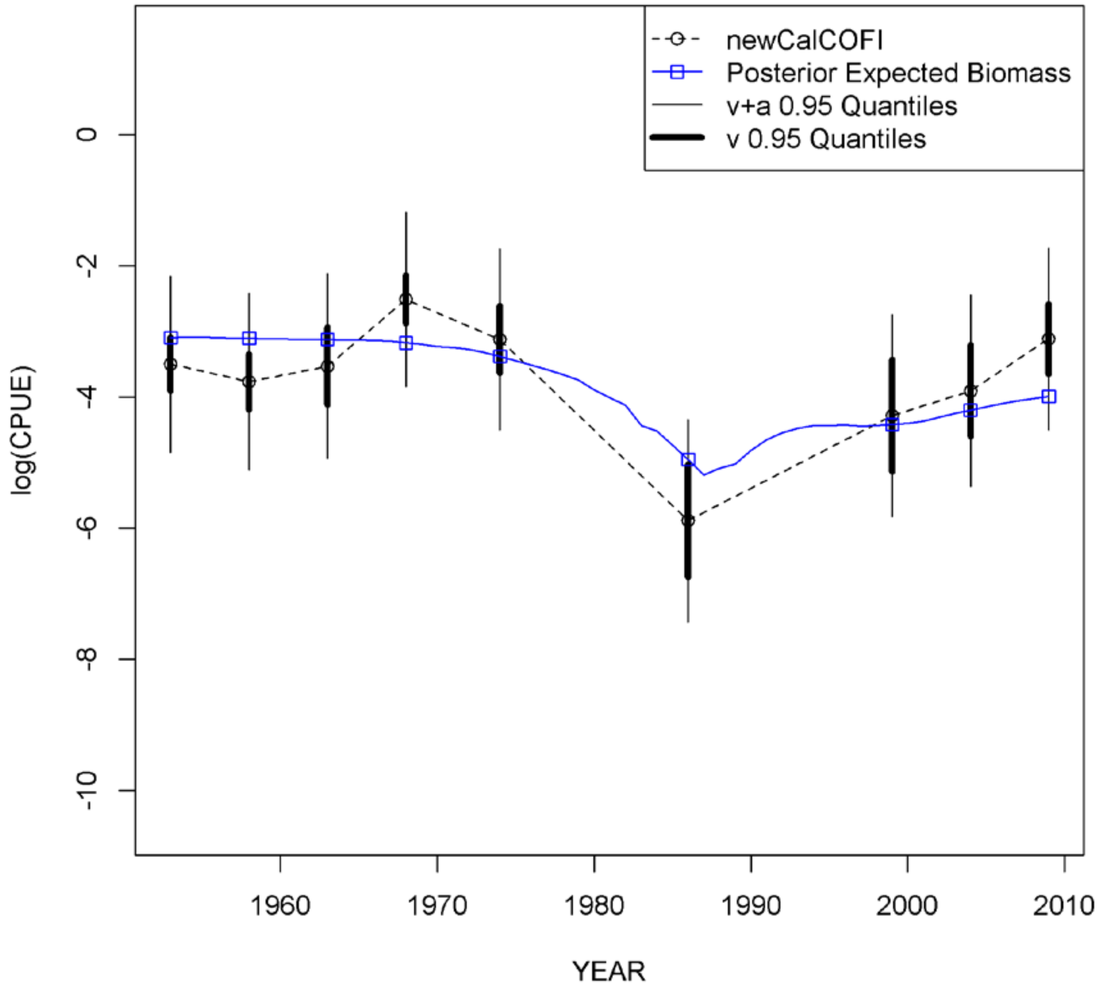


Figure 116. Log-scale fit of the CalCOFI Ichthyoplankton Survey index. Dashed line with circles is the index, blue line with squares is the posterior expected biomass, thick vertical lines are the 95% intervals from the input (fixed) variances, and the thin vertical lines are the 95% intervals with estimated added variance.

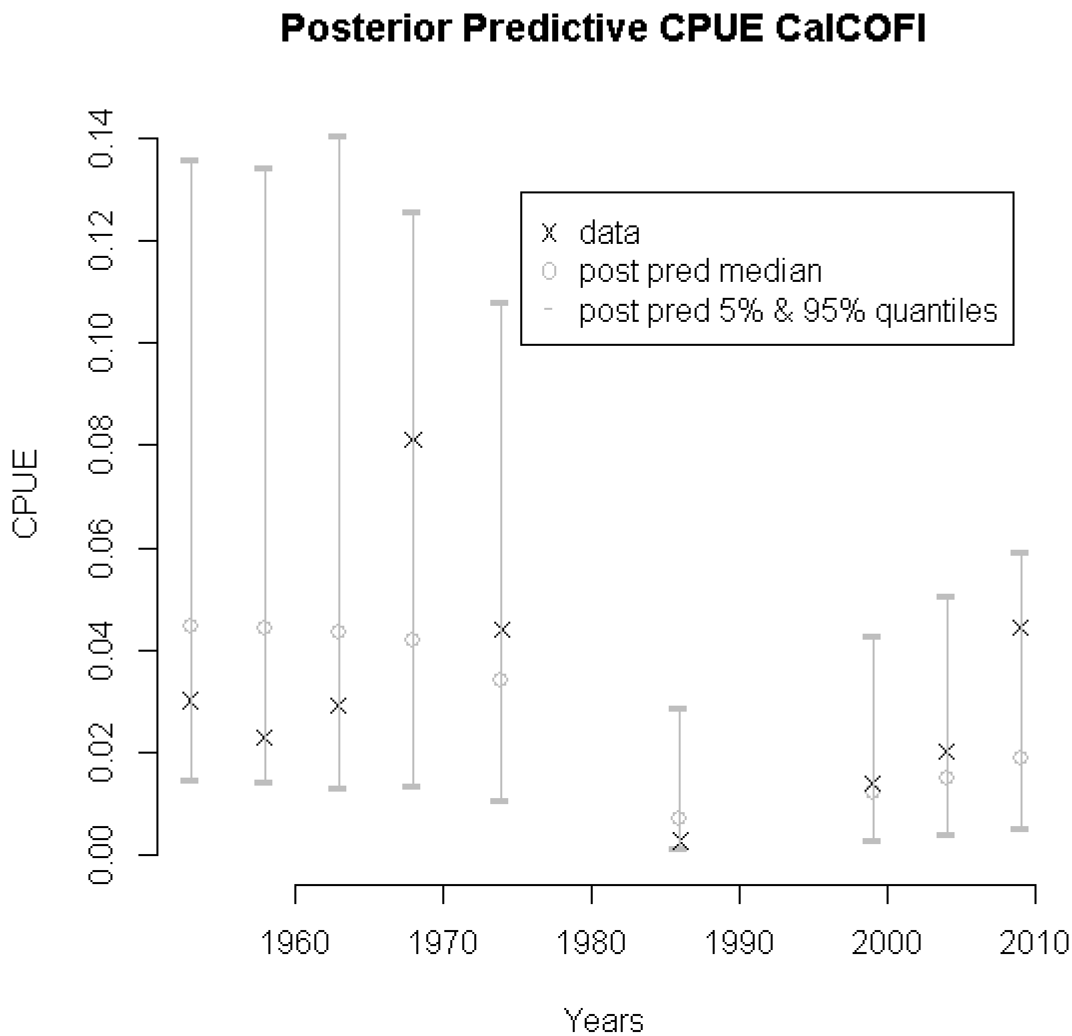


Figure 117. Posterior predictive intervals (5th and 95th quantiles) and median values (circles), relative to observed data (X's) from the CalCOFI Ichthyoplankton Survey index.

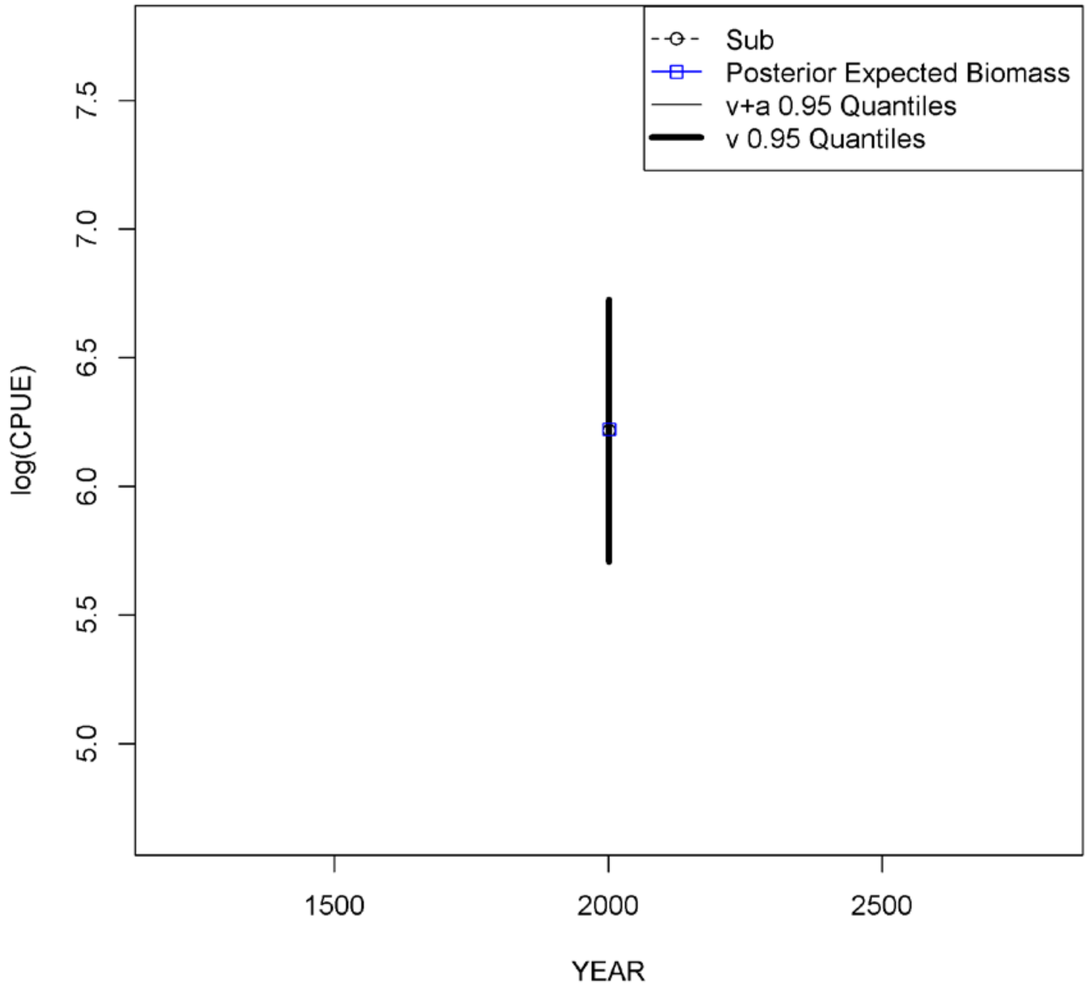


Figure 118. Log-scale fit of the 2002 Visual (Submersible) Transect Survey index. Dashed line with circles is the index, blue line with squares is the posterior expected biomass, thick vertical lines are the 95% intervals from the input (fixed) variances, and the thin vertical lines are the 95% intervals with estimated added variance.

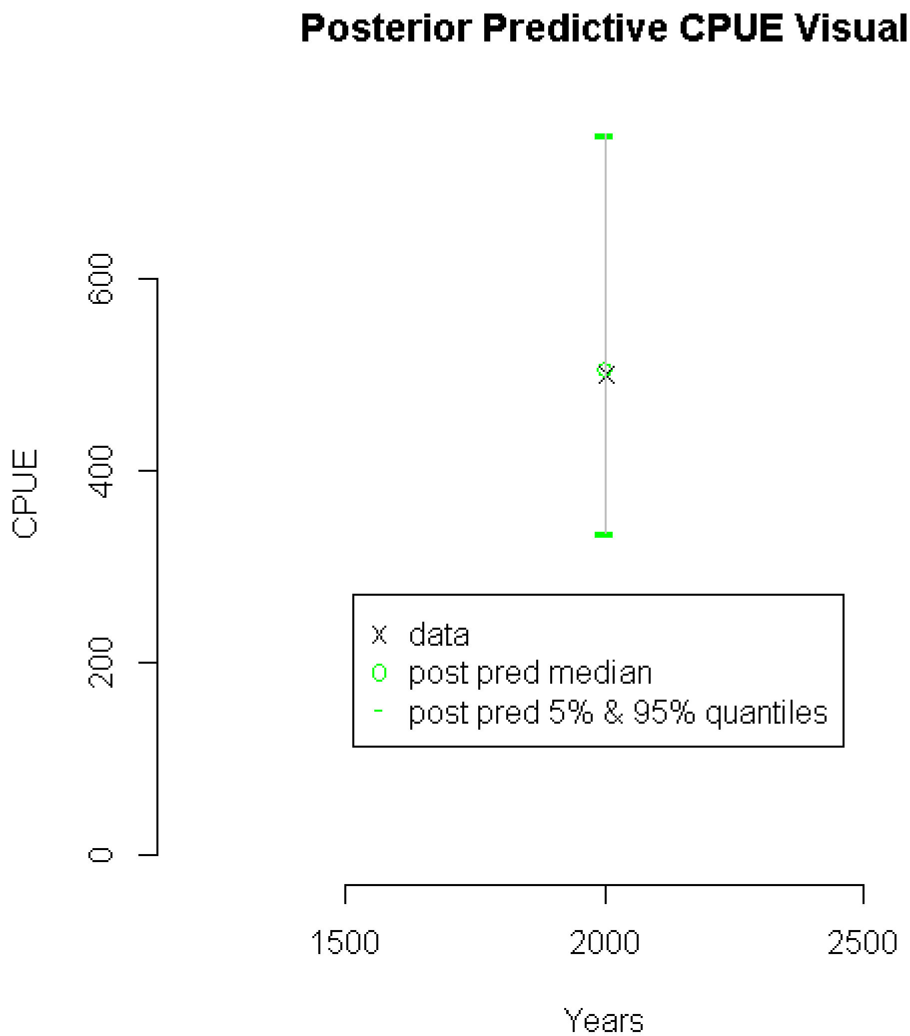


Figure 119. Posterior predictive intervals (5th and 95th quantiles) and median value (circle), relative to observed datum (X) from the 2002 Visual (Submersible) Transect Survey.

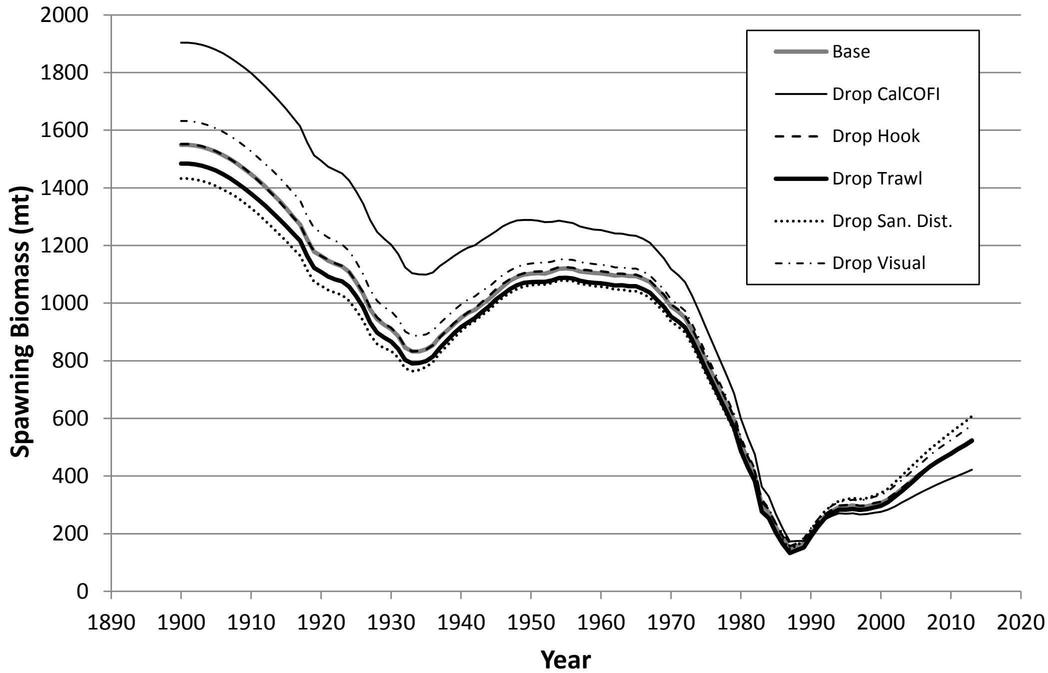


Figure 120. Median spawning biomass trajectories from the Post-STAR Panel base model, compared to models with individual indices removed.

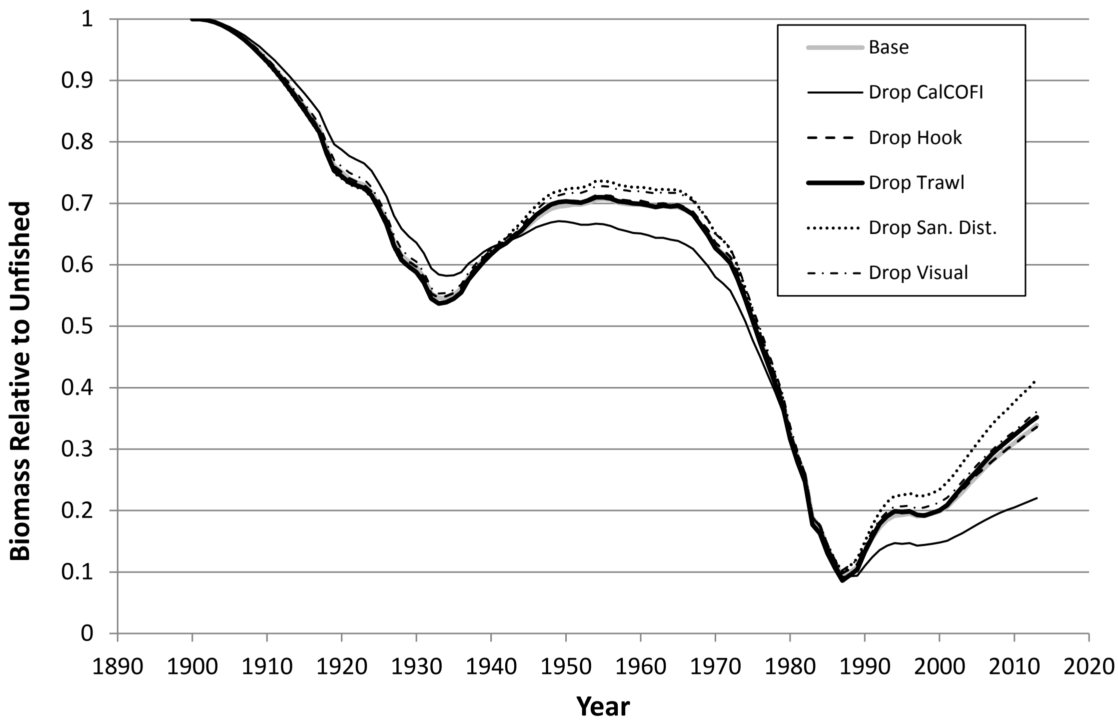


Figure 121. Median relative biomass trajectories from the Post-STAR Panel base model, compared to models with individual indices removed

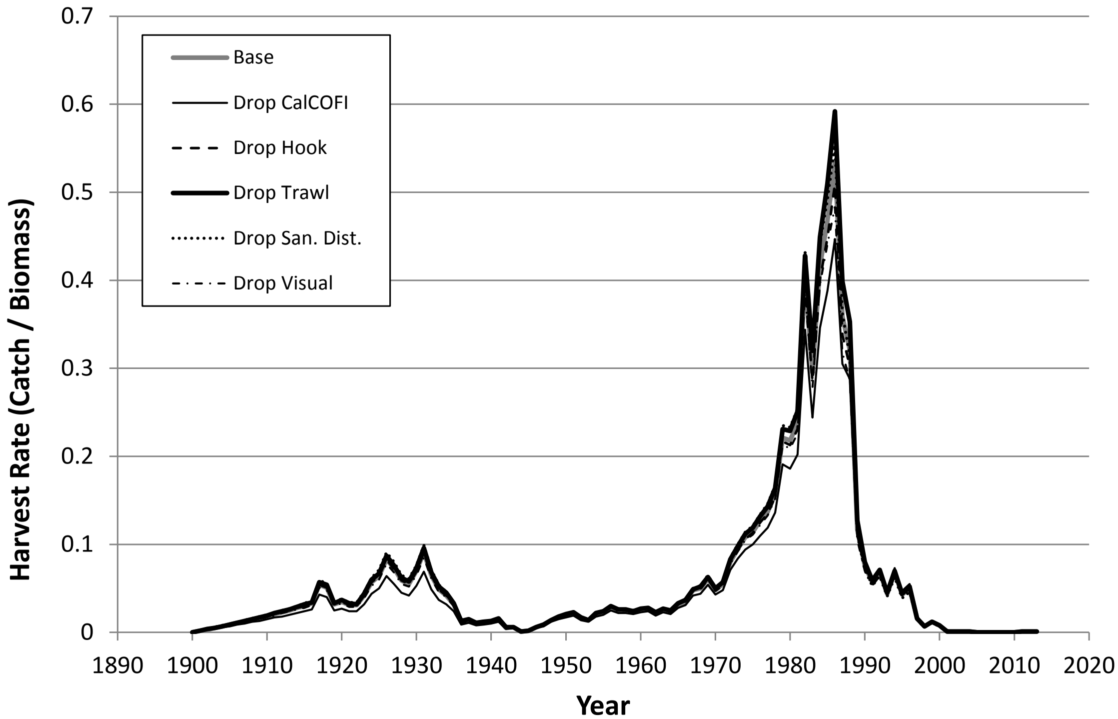


Figure 122. Median harvest rates from the Post-STAR Panel base model, compared to models with individual indices removed

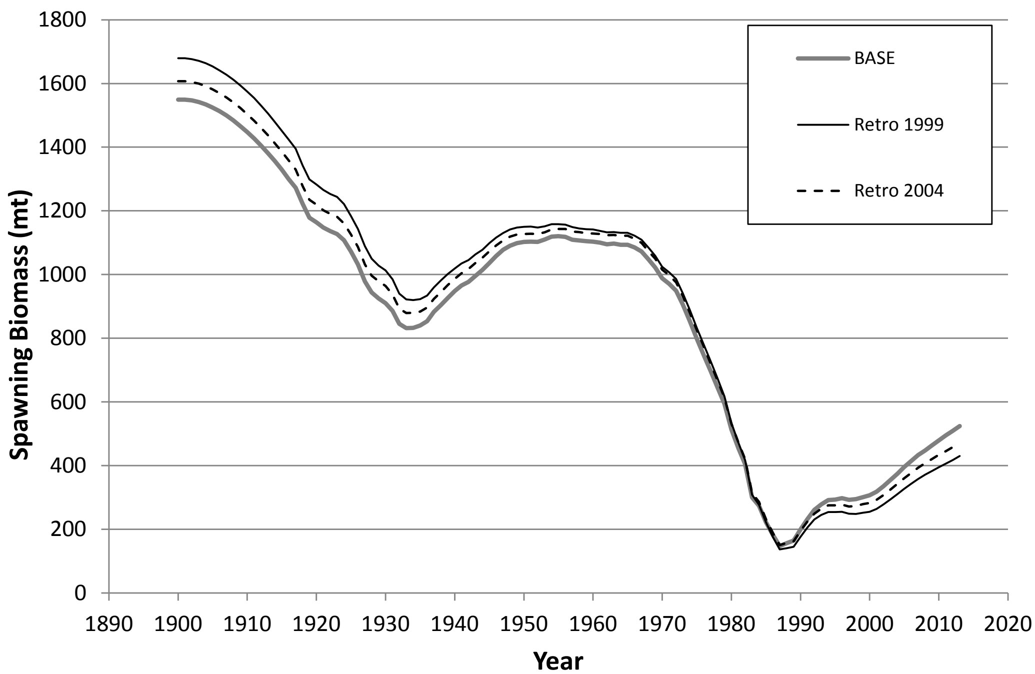


Figure 123. Median spawning biomass trajectories from retrospective analyses, truncating abundance indices to 2007, 2002, and 1998. Base model included for reference.

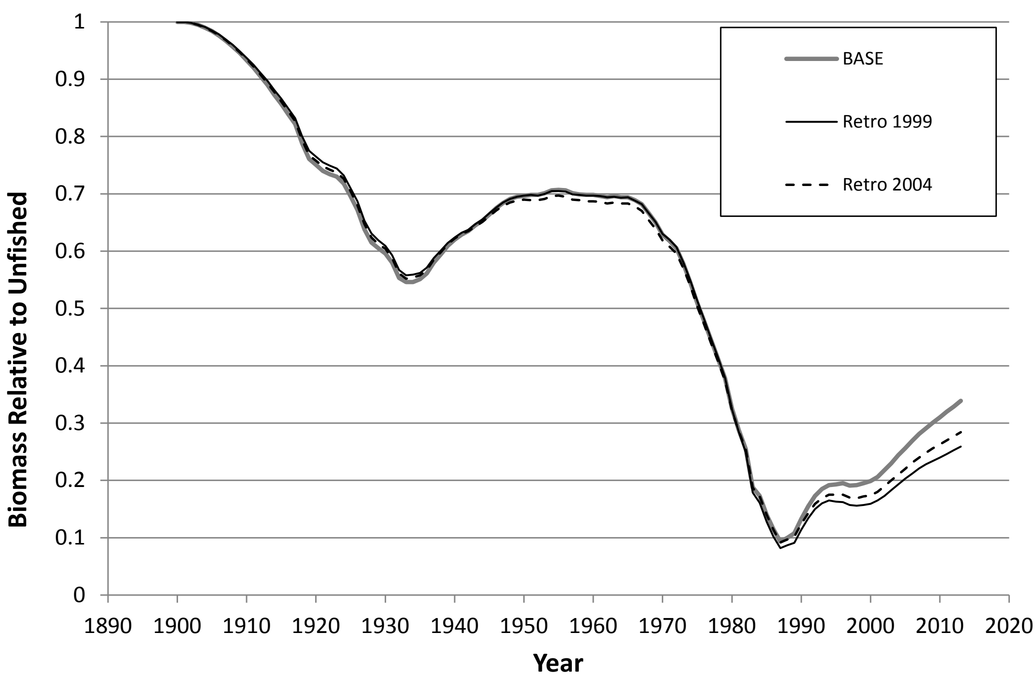


Figure 124. Median relative spawning biomass trajectories from retrospective analyses, truncating abundance indices to 2007, 2002, and 1998. Base model included for reference.

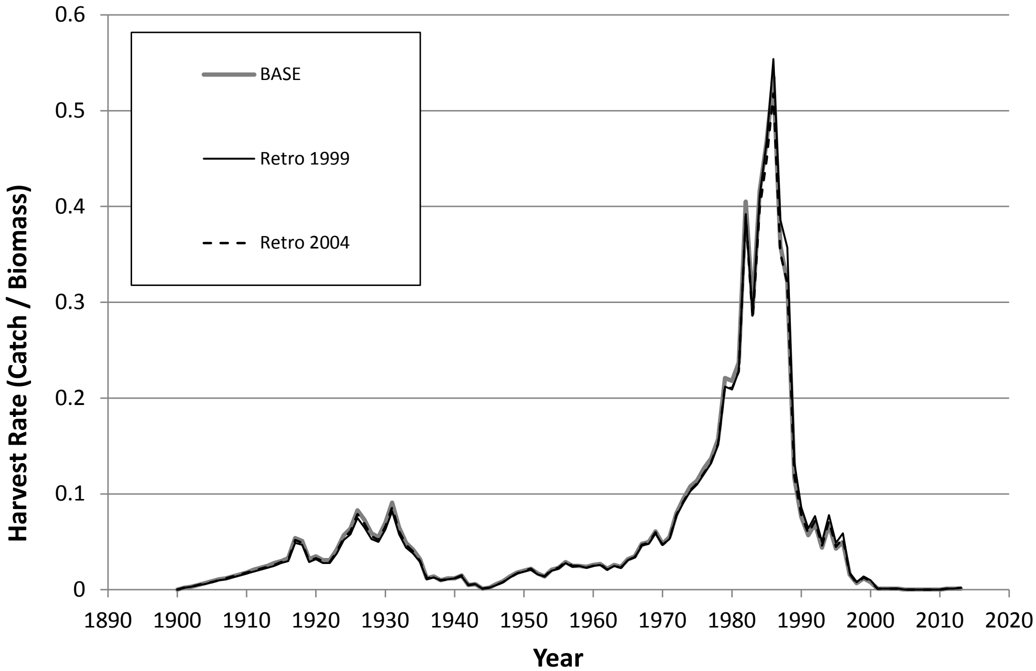


Figure 125. Median annual harvest rates from retrospective analyses, truncating abundance indices to 2007, 2002, and 1998. Base model included for reference.

Appendix A. XDB-SRA data files

Appendix A.1. Catch

catch.mt	year
0.01	1900
5.34	1901
10.68	1902
16.01	1903
21.35	1904
26.68	1905
32.02	1906
37.35	1907
42.68	1908
48.02	1909
53.35	1910
58.69	1911
64.02	1912
69.35	1913
74.69	1914
80.02	1915
85.36	1916
137.73	1917
125.59	1918
75.1	1919
81.57	1920
71.26	1921
70.11	1922
93.94	1923
125.94	1924
138.15	1925
171.48	1926
142.3	1927
111.35	1928
102.59	1929
126.94	1930
161.02	1931
109.54	1932
81.97	1933
70.74	1934
53	1935
20.63	1936
24.88	1937
18.71	1938
22.01	1939
23.69	1940
29.48	1941
10.6	1942
12.37	1943
1.99	1944

4.59	1945
11.66	1946
18.76	1947
29.92	1948
38.68	1949
44	1950
49.19	1951
36.67	1952
31.21	1953
46.81	1954
52.05	1955
65.17	1956
55.68	1957
56.36	1958
52.3	1959
57.05	1960
60.04	1961
48.03	1962
57.34	1963
51.89	1964
70.08	1965
76.63	1966
102.37	1967
105.02	1968
125.13	1969
95.85	1970
106.1	1971
152.62	1972
171.79	1973
183.66	1974
182.55	1975
189.35	1976
191.23	1977
203.18	1978
262.15	1979
223.63	1980
215.97	1981
327.51	1982
177.05	1983
227.88	1984
208.11	1985
194.36	1986
105.78	1987
100.53	1988
38.66	1989
30.46	1990
26.42	1991
35.8	1992
24.54	1993
39.65	1994
25.05	1995

29.93	1996
9.15	1997
4.03	1998
7.24	1999
4.94	2000
0.58	2001
0.58	2002
0.48	2003
0.86	2004
0.15	2005
0.07	2006
0.21	2007
0.25	2008
0.21	2009
0.17	2010
0.83	2011
0.82	2012
0.83	2013 # avg. of 2011-12
0.83	2014 # avg. of 2011-12
0.83	2015 # avg. of 2011-12
0.83	2016 # avg. of 2011-12

Appendix A.2. NWFSC trawl survey index (4-year offset)

year	index	sigma.lnX.
1999	0.2071543	0.530952416
2000	0.2849131	0.403054854
2001	0.3102929	0.369174727
2002	0.2122672	0.405874285
2003	0.2302692	0.356999726
2004	0.2706166	0.333752622
2005	0.1656464	0.369851176
2006	0.4342021	0.229552796
2007	0.2194043	0.358962276
2008	0.3225766	0.284433887

Appendix A.3. Sanitation District trawl survey index (5-year time blocks)

year	index	sigma.lnX.
1973	0.536	0.142
1978	0.127	0.276
1983	0.031	0.418
1988	0.047	0.334
1993	0.015	0.532
1998	0.045	0.3
2003	0.031	0.359
2009	0.076	0.216

Appendix A.4. NWFSC hook-and-line survey index

year	index	sigma.lnX.
2004	0.1436499	0.608389277
2005	0.4860135	0.326935435
2006	0.3349771	0.433438755
2007	0.5496947	0.334772558
2008	0.3995499	0.29677224
2009	0.7977309	0.281920339
2010	0.3008201	0.34878955
2011	0.6034886	0.310088658
2012	0.7059486	0.251883863

Appendix A.5. CalCOFI Ichthyoplankton (5-year time blocks)

year	index	sigma.lnX.
1953	0.030125162	0.208548835
1958	0.023079926	0.215986688
1963	0.029334458	0.302708783
1968	0.081053264	0.186543613
1974	0.044052331	0.260923856
1986	0.002778817	0.438692569
1999	0.013798416	0.435306873
2004	0.020138975	0.354579933
2009	0.044280336	0.270490437

Appendix A.6. Visual survey of CCAs

year	index	sigma.lnX.
2002	500.7	0.26

Appendix B. XDB-SRA control file

sci.name	Sebastes levis
common.name	Cowcod
species.code	CWCD
age.mat	11
delta.yr	2000
DBSRA.OFL.yr	2016
M.est	0.055
SD.lnM	0.4
FMSYtoMratio	0.97
SD.FMSYtoMratio	0.46
Delta	0.7
SD.Delta	0.2
DeltaLowerBound	0.01
DeltaUpperBound	0.99
BMSYtoB0ratio	0.5
SD.BMSYtoB0ratio	0.285
BMSYtoB0LowerBound	0.05
BMSYtoB0UpperBound	0.95
random.seed	4989

Appendix C.

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 2013 benchmark or "full" assessment of the substock in the Southern California Bight (SCB) indicated that median spawning biomass of cowcod in the SCB was 34% of its unfished level in 2013, with a 95% posterior interval ranging from 15% to 66%.

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). 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 the 2011-12 and 2013-14 management cycles, a DB-SRA model was used to estimate the 2015-16 OFL contribution 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 2013 cowcod assessment used a Bayesian extension of DB-SRA (XDB-SRA), providing posterior distributions for the DB-SRA model parameters. This assumes that parameters describing productivity and status of the SCB substock are representative of the substock north of Point Conception. No other information regarding stock status or trends in biomass is currently available for the northern substock.

Catch estimates for U.S. waters north of Point Conception (Table C1 and Figure C1) 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). California recreational landings (MRFSS) from 1987 and 1990-1992 were estimated using linear interpolation due to missing values or database errors. Since cowcod is managed as part of the shelf rockfish complex, 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 total removals north of Point Conception are typically less than removals in the SCB, the DB-SRA model produces biomass estimates for the northern substock that are considerably lower than the assessed region (Figure C2). 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 less depleted northern stock in 2013 (Figure C3). This is due to differences in the catch time series between regions. The DB-SRA estimate of median OFL for 2015 is very similar to the median DCAC estimate (Table C2), although the distributions of yield differ in variability and skewness (Figure C4).

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 C3).

Following review of the DB-SRA model for the area north of Point Conception the SSC recommended that the ACL contribution for cowcod north of Point Conception be computed by applying the fishing mortality rate for the southern area to the biomass from the DB-SRA model (http://www.pcouncil.org/wp-content/uploads/D5b_SUP_SSC_RPT_MAR2014BB.pdf). ACL estimates using this approach are provided for each rebuilding analysis run requested by the Council (Table C4). Coastwide estimates were calculated as the sum of the ACL components for areas north and south of Point Conception. ACLs for the management areas north and south of 40 10 N. latitude were based on the proportion of catch in each area (Table C3), i.e. 3% of the coastwide ACL was assigned to the Council’s northern shelf rockfish complex.

Literature Cited

Butler, J. L., L. D. Jacobson and J.T. Barnes. 1999. Stock assessment of cowcod rockfish. In: Pacific Fishery Management Council. 1999. Appendix: Status of the Pacific Coast Groundfish Fishery through 1999 and recommended biological catches for 2000: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, Oregon, 97201.

Dick, E.J. and Alec D. MacCall. 2013. Status and Productivity of Cowcod, *Sebastes levis*, in the Southern California Bight, 2013. Report submitted to the Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, Oregon, 97201.

Dick, E.J. and Alec D. MacCall. 2014.Cowcod rebuilding analysis. Report submitted to the Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, Oregon, 97201. May 23, 2014.

MacCall, A.D. 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. ICES J. Mar. Sci. 66:2267-2271.

Ralston, S. D. Pearson, J. Field, and M. Key. 2010. Documentation of the California catch reconstruction project. NOAA Technical Memorandum NMFS 461, 80 p.

Rogers, J. B. M. Wilkins, D. Kamikawa, F. Wallace, T. L. Builder, M. Zimmerman, M. Kander, and B. Culver. 1996. Status of the remaining rockfish in the Sebastes complex in 1996 and recommendations for management in 1997. Appendix E In Pacific Fishery Management Council Status of the Pacific coast groundfish fishery through 1996 and Recommended Acceptable Biological Catches for 1997. Pacific Fishery Management Council, Portland, OR. 59 p.

TABLES AND FIGURES

Table C1. Reconstructed catches of cowcod north of Point Conception, 1916-2012, 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 C1. (Continued) Reconstructed catches of cowcod north of Point Conception, 1916-2012.

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	0.07			0.06		0.09			0.22
2003					0.22				0.22
2004					0.54				0.54
2005					1.15				1.15
2006					2.20				2.20
2007					1.93		0.09		2.02
2008					0.48				0.48
2009					1.45				1.45
2010					1.00		0.02		1.02
2011					0.02				0.02
2012					0.00		0.02		0.02

Table C2. Percentiles of DCAC and DB-SRA yield estimates for cowcod north of Point Conception.

		DB-SRA	
Percentile	DCAC	OFL 2015	OFL 2016
2.5%	5.6	3.7	3.8
25%	10.5	8.7	8.9
50% (median)	**12.9**	**13.3**	**13.7**
75%	14.7	19.9	20.6
97.5%	16.9	40.3	41.4

Table C3. 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%

Table C4. Regional components of cowcod Annual Catch Limits (ACLs) based on the assessment (Southern CA) and DB-SRA model (Northern CA and OR), for each exploitation rate reported in the cowcod rebuilding analysis (Dick and MacCall, 2014). Coastwide totals for each run are apportioned to management areas north and south of 40° 10′ N. latitude using the proportion of historical catch in each area (3% in the northern region). See Dick and MacCall (2014) for descriptions of individual runs.

			Median So. CA ACL		Median NoCA-OR ACL		Coastwide ACL		South of 40-10		North of 40-10	
Run	Description	Exploitation Rate	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
1	T(F=0)	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	current ACL	0.0013	1.5	1.5	0.3	0.3	1.8	1.9	1.8	1.9	0.0	0.0
3	current rate	0.0070	7.8	8.0	1.7	1.8	9.5	9.8	9.5	9.7	0.1	0.1
4	Ttarget	0.0474	53.0	52.3	11.6	11.9	64.5	64.2	64.2	63.8	0.3	0.4
5	Tmax 2057	0.0458	51.3	50.6	11.2	11.6	62.5	62.2	62.1	61.9	0.3	0.3
6	Tmax 2097	0.0490	54.9	54.0	12.0	12.4	66.8	66.4	66.5	66.0	0.4	0.4
7	40-10	0.0352	39.3	39.1	8.6	8.9	47.9	47.9	47.7	47.7	0.3	0.3
8	ABC	0.0409	45.8	45.4	10.0	10.3	55.8	55.8	55.5	55.4	0.3	0.3
9	OFL	0.0491	55.0	54.1	12.0	12.4	67.0	66.5	66.6	66.1	0.4	0.4
10	So. CA ACL=1.5	0.0013	1.5	1.5	0.3	0.3	1.8	1.9	1.8	1.9	0.0	0.0
11	So. CA ACL=2.0	0.0018	2.0	2.1	0.4	0.5	2.4	2.5	2.4	2.5	0.0	0.0
12	So. CA ACL=2.5	0.0022	2.5	2.6	0.5	0.6	3.0	3.1	3.0	3.1	0.0	0.0
13	So. CA ACL=3.0	0.0027	3.0	3.1	0.7	0.7	3.7	3.8	3.6	3.7	0.0	0.0
14	So. CA ACL=3.5	0.0031	3.5	3.6	0.8	0.8	4.3	4.4	4.2	4.4	0.0	0.0
15	So. CA ACL=4.0	0.0036	4.0	4.1	0.9	0.9	4.9	5.0	4.8	5.0	0.0	0.0
16	So. CA ACL=4.5	0.0040	4.5	4.6	1.0	1.0	5.5	5.6	5.5	5.6	0.0	0.0
17	So. CA ACL=5.0	0.0045	5.0	5.1	1.1	1.1	6.1	6.3	6.1	6.2	0.0	0.0
18	So. CA ACL=5.5	0.0049	5.5	5.7	1.2	1.2	6.7	6.9	6.7	6.9	0.0	0.0
19	So. CA ACL=6.0	0.0054	6.0	6.2	1.3	1.4	7.3	7.5	7.3	7.5	0.0	0.0
20	So. CA ACL=6.5	0.0058	6.5	6.7	1.4	1.5	7.9	8.1	7.9	8.1	0.0	0.0
21	So. CA ACL=7.0	0.0063	7.0	7.2	1.5	1.6	8.5	8.8	8.5	8.7	0.0	0.0
22	So. CA ACL=7.5	0.0067	7.5	7.7	1.6	1.7	9.1	9.4	9.1	9.3	0.0	0.1
23	So. CA ACL=8.0	0.0072	8.0	8.2	1.7	1.8	9.7	10.0	9.7	10.0	0.1	0.1
24	Pr{rebuild by 2022} = 0.5	0.0203	22.7	23.0	5.0	5.1	27.7	28.1	27.5	28.0	0.1	0.2
25	Pr{rebuild by 2025} = 0.5	0.0281	31.4	31.6	6.9	7.1	38.3	38.7	38.1	38.4	0.2	0.2
26	Pr{rebuild by 2030} = 0.5	0.0356	39.9	39.8	8.7	9.0	48.6	48.8	48.3	48.5	0.3	0.3
27	Pr{rebuild by 2035} = 0.5	0.0391	43.7	43.5	9.5	9.9	53.3	53.3	53.0	53.0	0.3	0.3

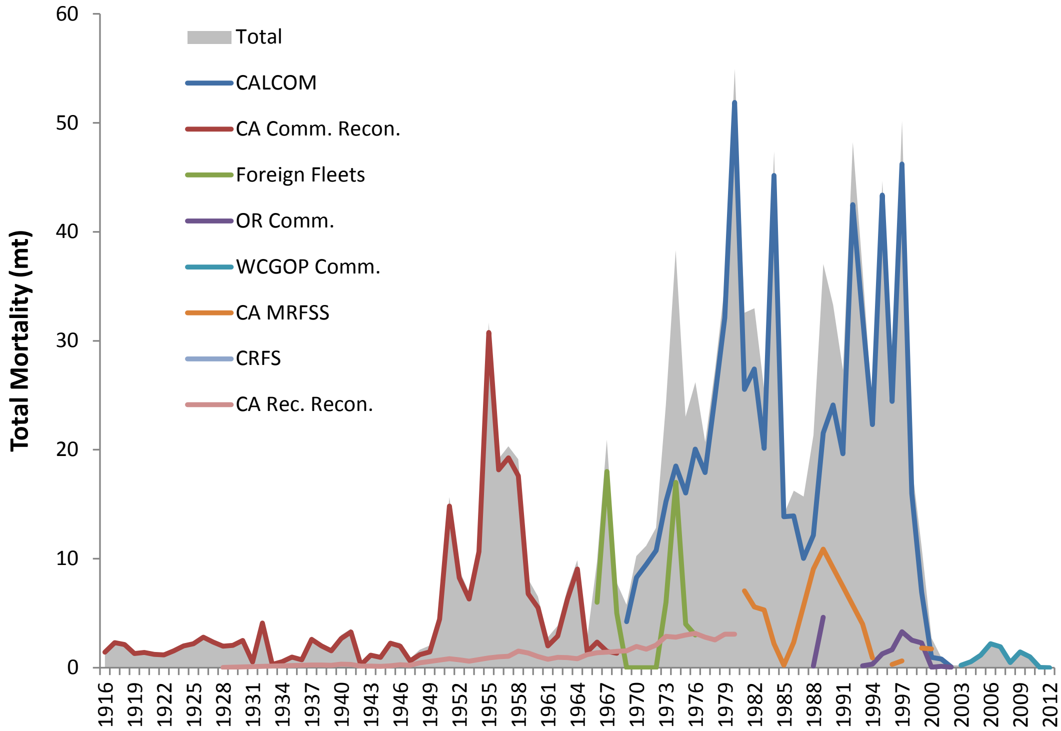


Figure C1. Reconstructed catches of cowcod north of Point Conception, 1916-2012, by year and source.

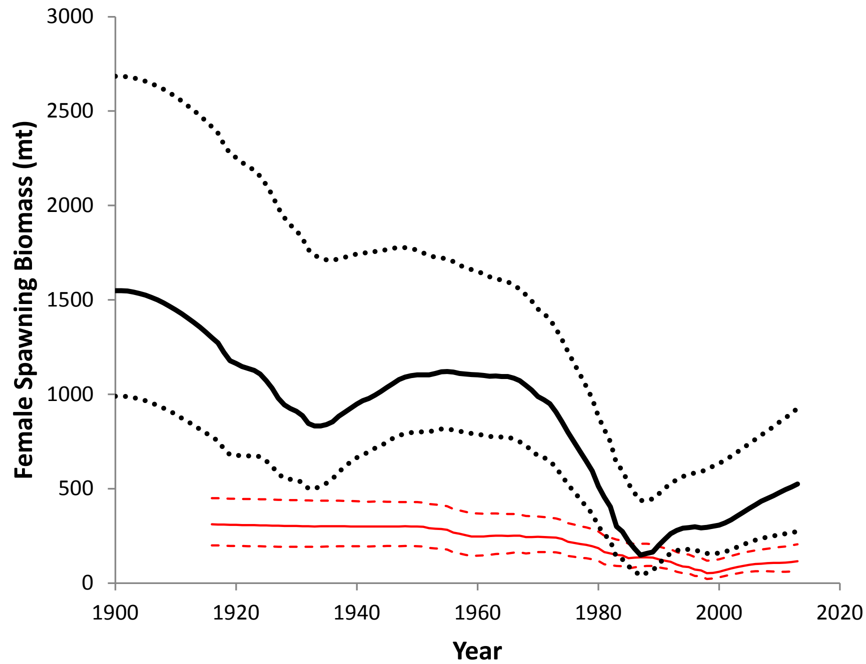


Figure C2. Cowcod female spawning biomass percentiles from the XDB-SRA model for the SCB (black) and the northern DB-SRA model (red). Solid lines are median biomass, with 2.5 and 97.5 percentiles shown by dotted/dashed lines.

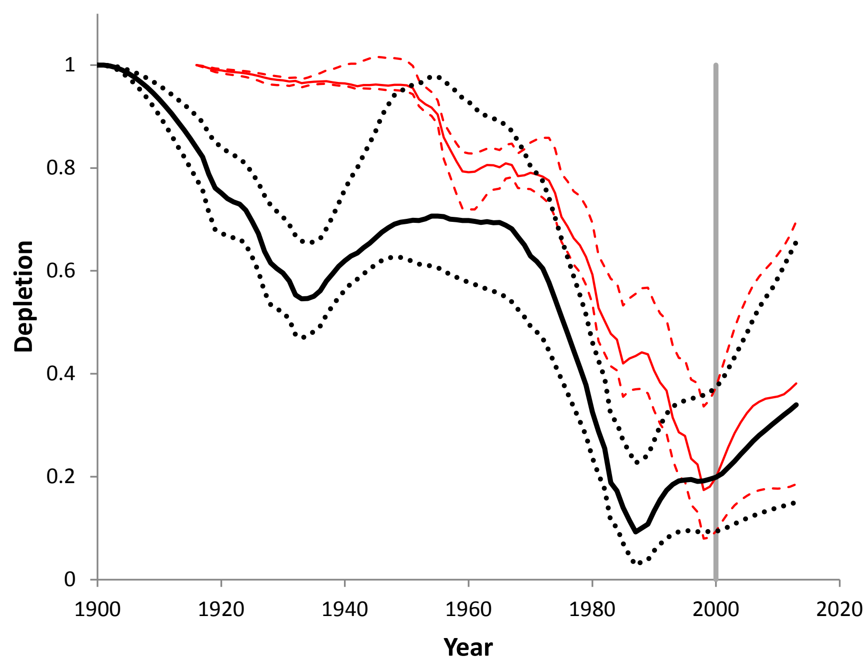


Figure C3. Comparison of depletion percentiles from the southern XDB-SRA (black) and northern DB-SRA (red) cowcod models. Solid lines are median trajectories, with 2.5 and 97.5 percentiles (dotted/dashed lines). Distributions of depletion in 2000 are assumed equal for the two areas (vertical line).

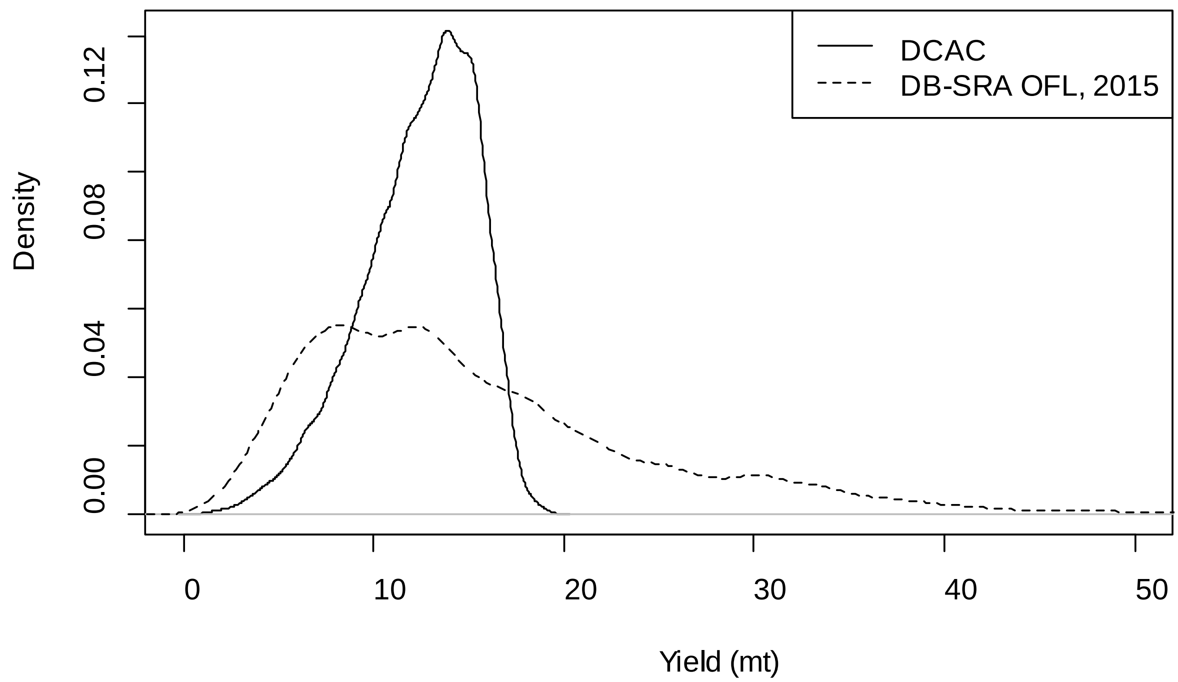


Figure C4. Estimated yield distributions (mt) for cowcod north of Point Conception, derived from posterior draws from the Southern California cowcod assessment. The DCAC estimate is based on removals from 1950-1999. The 2015 OFL estimate from DB-SRA assumes removals of 1.5 mt per year from 2013-2014.