The Status of California Halibut (*Paralichthys californicus*) in U.S. Waters off Southern California in 2023

January 16, 2025

Prepared by

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This report may be cited as:
Coates, J.H., Hicks, A., Valero, J., Meyer, K. 2025. The Status of California Halibut in U.S. Waters off Southern California in 2023. California Department of Fish & Wildlife. Available from: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=229693

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Acronym Definitions:
ABC: Acceptable Biological Catch
ACL: Annual Catch Limit
CAAL: Conditional age-at-length
CalCOFI: California Cooperative Oceanic Fisheries Investigations
CALCOM: California Cooperative Groundfish Survey Database
CCFRP: California Collaborative Fisheries Research Program
CDFW (formerly CDFG): California Department of Fish and Wildlife (formerly Fish and Game)
ComHL: Commercial hook and line fleet
CPAH: Catch-per-angler-hour
CPFV: Commercial Passenger Fishing Vessel (aka “party” or “charter” boats, or “PC mode”)
CPUE: Catch-per-unit-effort
CRFS: California Recreational Fisheries Survey
GMT: Groundfish Management Team of the PFMC
MRFSS: Marine Recreational Fisheries Statistics Survey
MSY: Maximum Sustainable Yield
NMFS: National Marine Fisheries Service
NWFSC: Northwest Fisheries Science Center
ODFW: Oregon Department of Fish and Wildlife
OFL: Overfishing Limit
OtherRec: Private recreational fishing fleet combining private and rental vessels and shore-based effort
PacFIN: Pacific Fisheries Information Network
PFMC: Pacific Fishery Management Council
PISCO: Partnership for the Interdisciplinary Study of Coastal Oceans
PSMFC: Pacific States Marine Fisheries Commission
RecFIN: Recreational Fisheries Information Network
RREAS: The NMFS SWFSC’s Rockfish Recruitment and Ecosystem Assessment Survey
SPR: Spawning Potential Ratio
SSC: Scientific and Statistical Committee of the PFMC
STAR: Stock Assessment Review (Panel)
STAT: Stock Assessment Team
SWFSC: Southwest Fisheries Science Center
WCGOP: West Coast Groundfish Observer Program
WDFW: Washington Department of Fish and Wildlife
YOY: Young-of-the-year

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Executive Summary

Stock

This assessment reports the status of California halibut (*Paralichthys californicus*) (halibut) off the southern California coast between Point Arguello and the U.S.-Mexico border through 2023. It assumes that stocks above and below those boundaries do not contribute nor take from the population being assessed here.

Catches

The earliest commercial catch records of halibut were reported statewide in 1916 and peaked in 1917 at approximately 3.5 million pounds. The majority of these early catches occurred in southern California using entangling net gear. The first records of recreational catch come from CPFV logbooks in 1936 and surveys estimating catch and effort for all recreational modes do not become available until 1980. We developed a historical catch reconstruction based on these records and historical descriptions, ramping up catches from zero in 1880 (Figure i). Together, these sources of information indicate high exploitation rates commercially in the 1910s and recreationally in the 1950s and 60s.

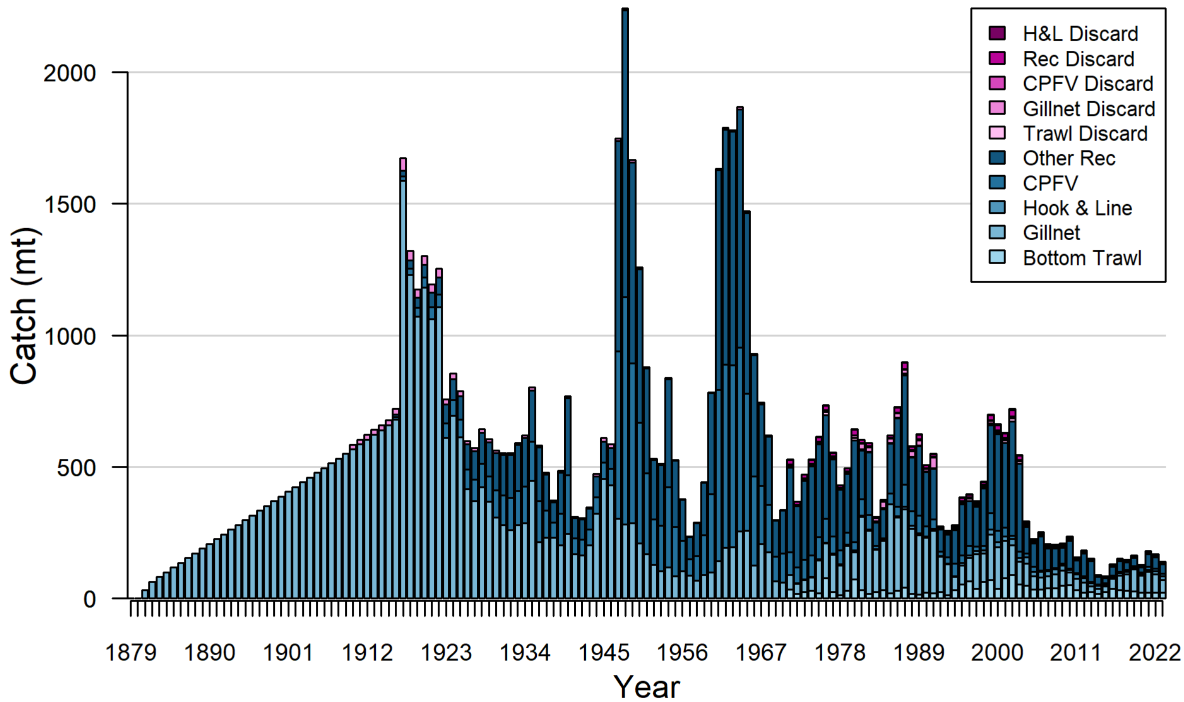


Figure i. Historic retained landings (blue colors) and discarded mortality (pink colors) by fleet used for sensitivity testing. Commercial landings prior to 1971 were attributed to the gillnet fleet. A constant ramp up was assumed between 1880 and the earliest landings records in 1916. Estimates of recreational landings are not available prior to 1971 are based off of CPFV logbook records.

Detailed commercial catch records with improved spatial and gear information begin in 1971. Since that time, gillnet has been the dominant commercial gear type over trawl and hook and line during most years, particularly during the 1980s. Recreationally, catches from private or rental vessels and shore-based methods (OtherRec) have been substantially larger than from commercial passenger fishing vessels (CPFVs). Discard fleets associated with each retention fleet are provided with catches based on discard rate information gathered by observers and expert judgement estimates of mortality experienced by those discarded fish. Catch among these fleets is estimated to be a small fraction of the overall catch in each year. The base model begins in 1971 and the historical reconstruction was used in sensitivity testing.

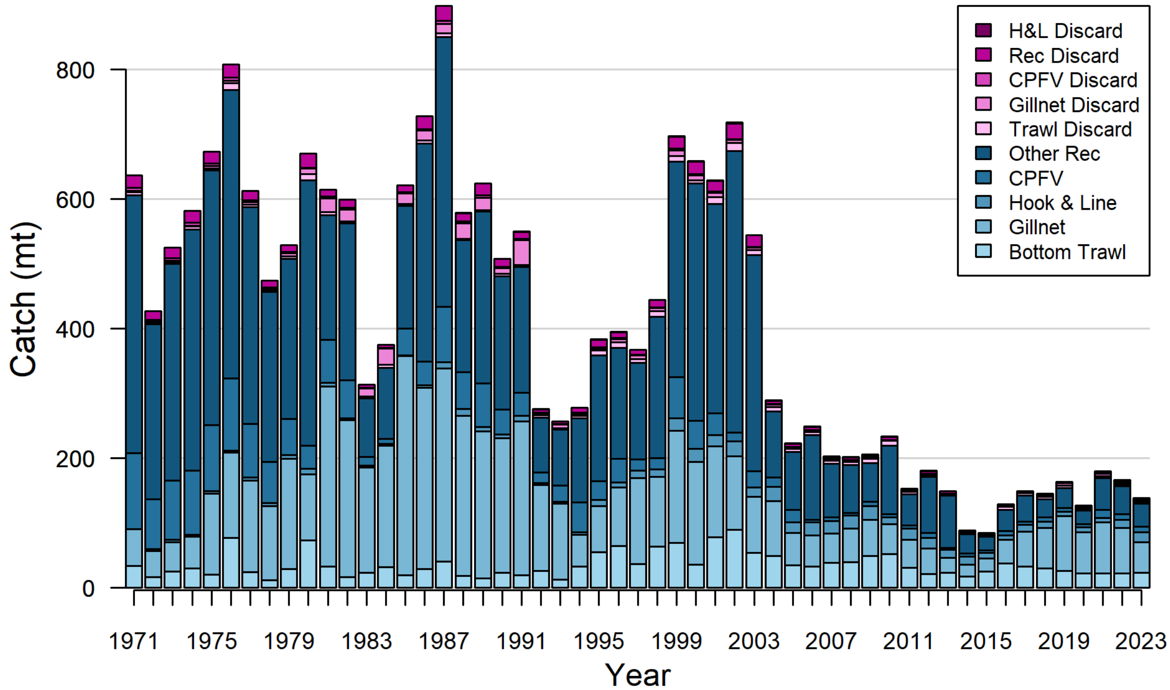


Figure ii. Retained landings (blue colors) and discarded mortality (pink colors) by fleet.

Table i. Recent catches (mt) by fleet and total catch summed across fleets.

Year	Trawl	Gillnet	ComHL	CPFV	OtherRec	Trawl Discard	Gillnet Discard	CPFV Discard	OtherRec Discard	ComHL Discard	Total Catch
2014	17.75	18.10	13.02	4.62	29.91	2.43	0.85	0.15	1.34	0.71	88.88
2015	25.62	20.25	8.51	3.51	20.98	3.51	0.95	0.09	0.91	0.46	84.79
2016	37.72	36.51	7.01	6.29	32.78	5.17	1.71	0.24	1.16	0.38	128.97
2017	33.09	53.82	10.58	4.47	40.41	4.53	0.50	0.14	1.49	0.57	149.60
2018	30.20	62.71	9.23	6.87	27.97	4.14	2.94	0.26	1.19	0.50	145.98
2019	26.44	84.10	7.27	5.50	30.81	3.62	3.94	0.31	1.60	0.39	163.99
2020	22.56	63.70	7.24	5.24	20.81	3.09	2.99	0.21	0.95	0.39	127.17
2021	22.07	79.18	6.90	12.05	49.58	3.02	3.71	0.53	2.48	0.37	179.89
2022	23.01	69.77	12.36	8.38	43.36	3.15	3.27	0.40	2.32	0.67	166.69
2023	23.07	47.45	15.45	8.85	35.57	3.16	2.22	0.40	1.80	0.84	138.81

Data and Assessment

This assessment uses Stock Synthesis (ver. 3.30.19.01) for a sex-specific, age- and length-structured statistical catch-at-age model with different natural mortality rates, growth, and selectivity parameters for males and females. The model is fit to two fishery-dependent indices of relative abundance calculated from standardized CPFV logbook and trawl logbook data, a fishery-independent index of recruitment calculated from standardized CalCOFI larval data, as well as length composition data from both recreational and commercial fisheries and age composition data from the commercial fisheries. There are five separate retention fleets in the model with corresponding discard fleets; CPFV, OtherRec, bottom trawl, gillnet, and commercial hook-and-line (ComHL). Selectivity is estimated separately for males and females for the retention fleets for trawl, gillnet, and OtherRec. Selectivity is not sex-specific for the other retention fleets due to a lack of male length samples. Selectivity is estimated for the discard fleets for trawl, gillnet and CPFV with OtherRec and ComHL being mirrored to CPFV. Female growth parameters are estimated with the exception of L at Amax which is fixed at an externally estimated value. Male growth parameters are fixed at external estimates with the exception of K, which is allowed to be estimated. R0 is estimated within the model but natural mortality (M) is fixed based on reported maximum longevity and steepness (h) is fixed at 0.9. The modeling period begins in 1971, which is substantially later than the onset of the fishery in the late 1800s. Initial conditions were based on historical landings data that were also used in a test of sensitivity of model results to an initial condition of no catch in 1880 and historical catch reconstruction for landings between 1881-1970 (Figure i). Within model uncertainty is explicitly included in this assessment by parameter estimation uncertainty, while among model uncertainty is explored through sensitivity analyses addressing alternative input assumptions such as data treatment, and model specification sensitivity to the treatment of life history parameters, selectivity, and recruitment.

Timeseries

The spawning output was estimated to be nearly 13 billion eggs in 2024 and an unfished spawning output of 96 billion eggs (Figure iii). Relative spawning biomass in 2024 is estimated to be 14%, just above the overfished reference point of 12.5% (Figure iv). The highest total catch since 1971 occurred in 1987 at 899 MT and catches have been under 200 MT for the last decade (Figure ii). A period of high fishing intensity in the late 1980s and early 1990s resulted in a decline in spawning output to very low levels (Figure vi). A period of high recruitment during this time may have prevented stock collapse and allowed for modest increase in spawning output around 2000 (Figure v). Recruitment deviations are estimated to have been below the Beverton-Holt prediction for most years since 2000. However, with low catches, spawning output has been increasing since 2005.

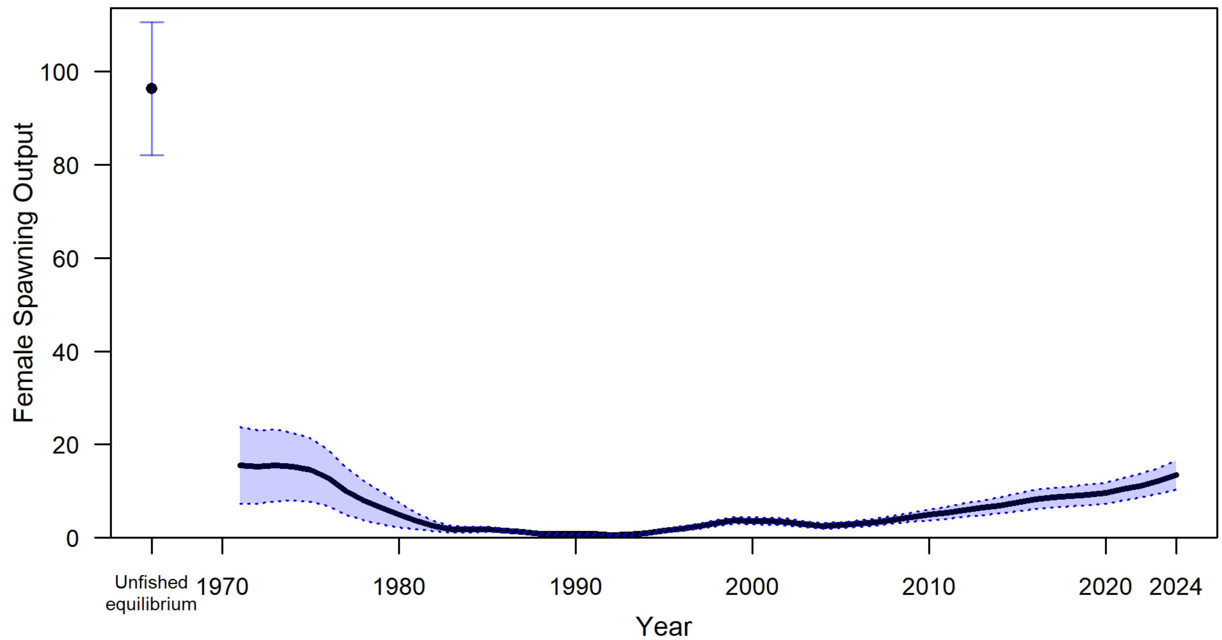


Figure iii. Estimated female spawning output with a 95% asymptotic confidence interval.

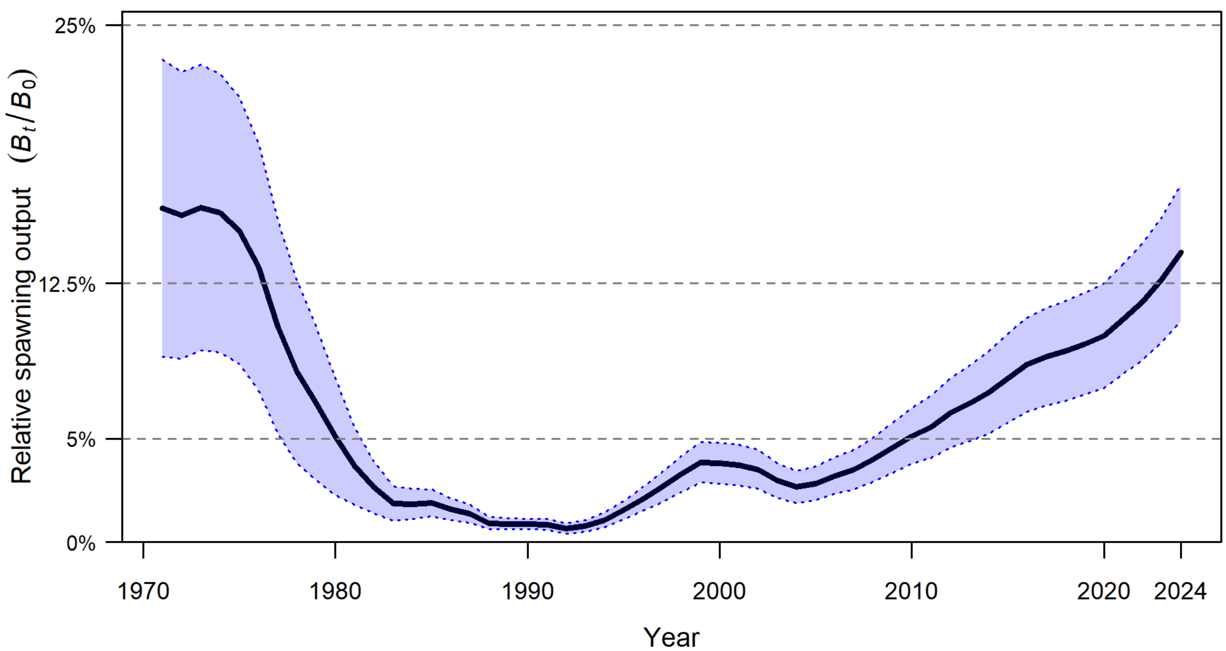


Figure iv. Estimated relative female spawning output with a 95% asymptotic confidence interval. Horizontal lines show PFMC proxy reference points for flatfish.

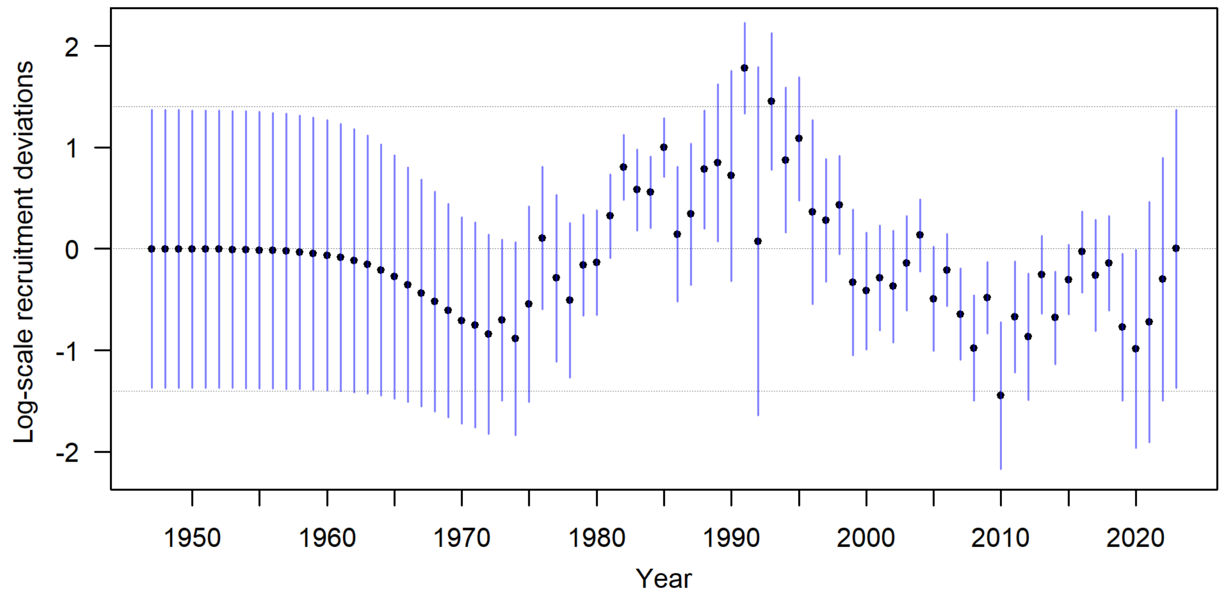


Figure v. Estimated recruitment deviates with 95% confidence intervals. Horizontal lines show zero and 2 times sigmaR of 0.7.

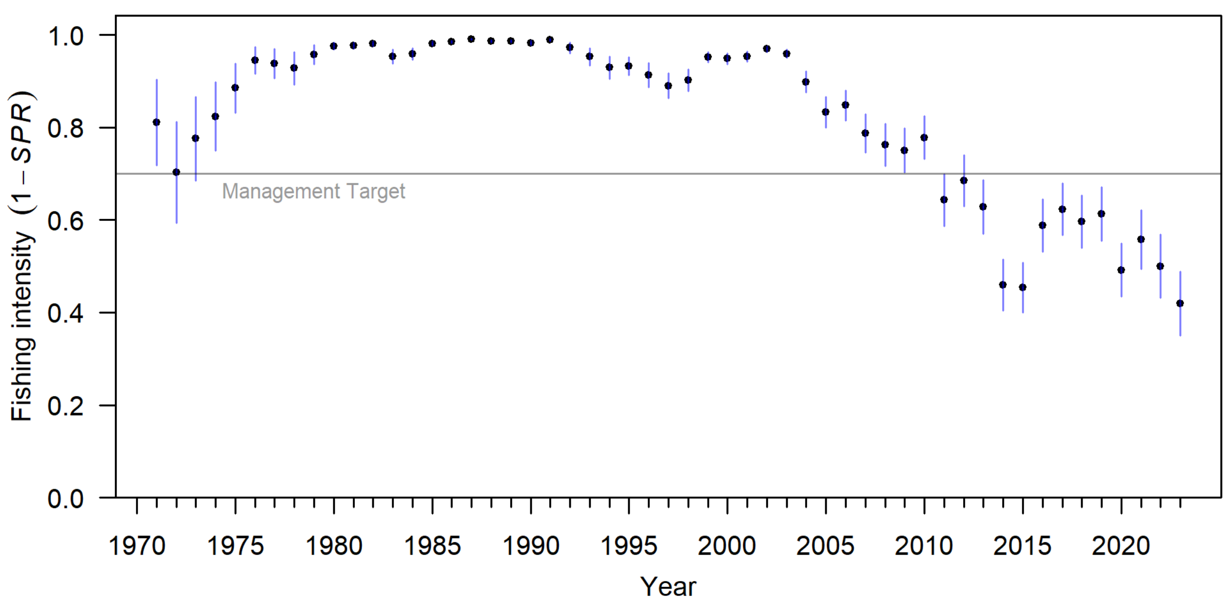


Figure vi. Estimated fishing intensity measured as 1 minus the spawning potential ratio (SPR) with 95% confidence intervals. The horizontal line is the PFMC target SPR rate of 30%.

Ecosystem Considerations

This stock assessment does not explicitly incorporate environmental factors into the assessment model. However, the model is fit to an index of recruitment based on standardized captures of halibut larvae from the California Cooperative Oceanic Fisheries Investigation (CalCOFI) survey. Good correspondence between the index, estimated recruitment deviations, and El Nino Southern Index (ENSO) values, corroborates findings in the literature that halibut recruitment is positively associated with warm water periods. This information, length composition data, and the CPFV index used within the model, all support that recruitment was high in the early 1990s.

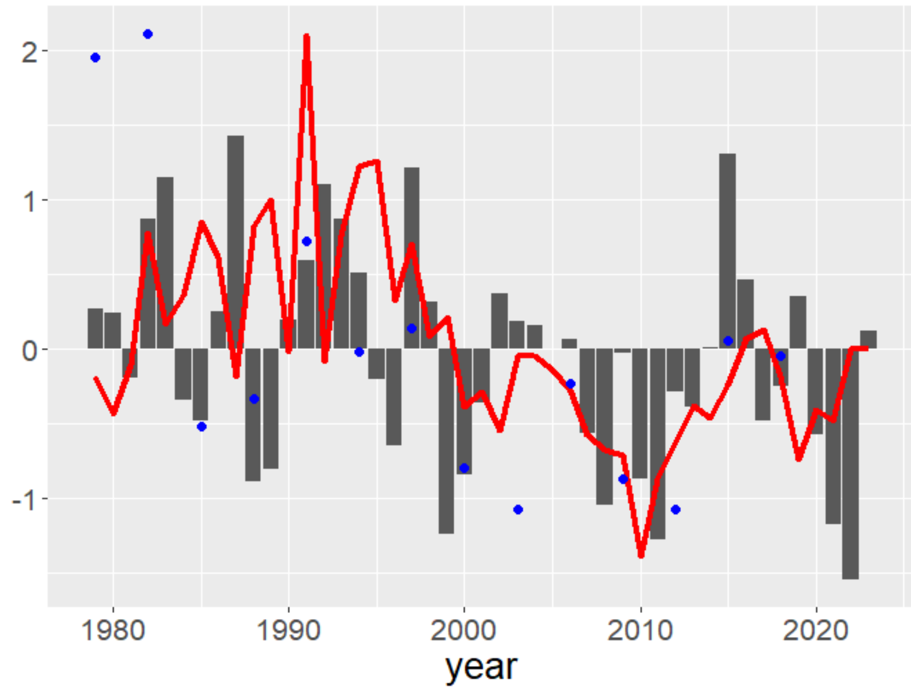


Figure vii. CalCOFI index values standardized to their mean (blue circles) compared to annual mean ENSO index (grey bars) and log recruitment deviations (red line).

Reference Points

We present the results of this assessment relative to the Pacific Fishery Management Council (PFMC) reference points for flatfish which define overfished and target status at 12.5 and 25% of the unfished spawning biomass, respectively. This assessment estimates the relative spawning biomass in 2024 to have been just above the overfished reference point at 14.0%. The equilibrium yield curve illustrated in Figure viii shows that current equilibrium yield corresponds to a slightly lower SPR value than MSY. Rather than being a normal shaped curve, the curve is skewed such that yield quickly declines to zero at low SPR values suggesting high management risk to SPR values to the left of MSY.

Estimated reference points and management quantities are shown in Table ii. The PFMC uses a proxy SPR for MSY of 30% for flatfish with a 25:5 control rule linearly reducing catches to determine future OFLs. The long-term equilibrium yield when using $F_{SPR=30\%}$ is estimated to be 611 mt. The yield when using an F that would lead to a long-term equilibrium spawning output of 25% of unfished spawning output would be 628 mt, which equates to an SPR of 27.1%. MSY is estimated to be 662 mt associated with an SPR of 17.4%.

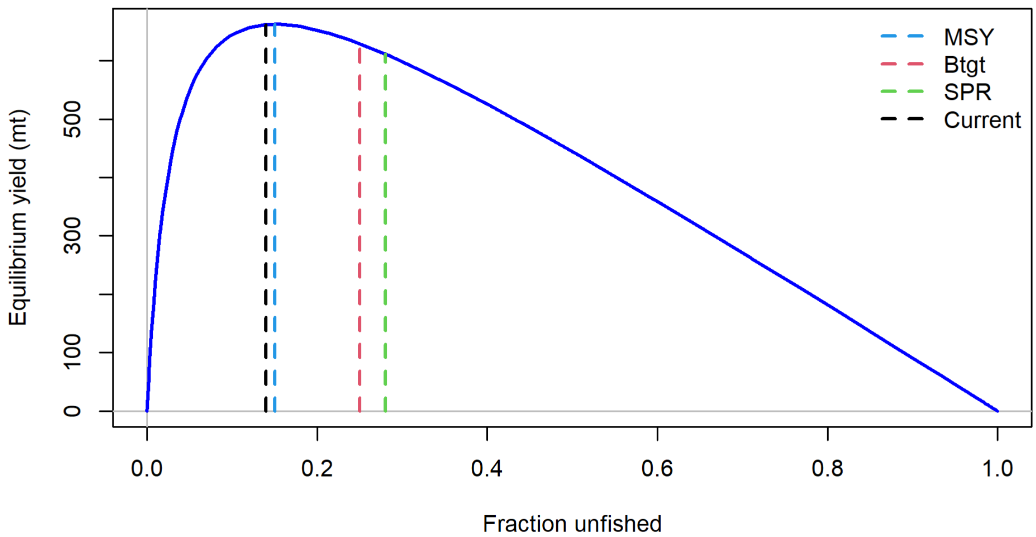


Figure viii. Equilibrium yield curve for the base model and reference points.

Table ii. Reference points and management quantities for the base model with 95% confidence intervals.

Reference Points	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output (millions of eggs)	96337.8	83906.6	108769.0
Unfished Age 3+ Biomass (mt)	16280.3	14175.87	18384.7
Unfished Recruitment (R0)	1129.42	983.6816	1275.2
2024 Spawning Output (millions of eggs)	13475.5	10355.73	16595.3
2024 Fraction Unfished	0.140	0.107	0.173
Reference Points Based SO25%			
Proxy Spawning Output (millions of eggs) SO25%	24084.4	20976.6	27192.2
SPR Resulting in SO25%	0.271	0.271	0.271
Exploitation Rate Resulting in SO25%	0.091	0.087	0.095
Yield with SPR Based on SO25% (mt)	628.8	545.8	711.8
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output (millions of eggs) (SPR30)	26974.6	23493.86	30455.34
SPR30	0.3		
Exploitation Rate Corresponding to SPR30	0.083	0.080	0.087
Yield with SPR30 at SO SPR (mt)	611.1	530.6	691.6
Reference Points Based on Estimated MSY Values			
Spawning Output (millions of eggs) at MSY (SO MSY)	14444.8	12644.0	16245.6
SPR MSY	0.174	0.169	0.178
Exploitation Rate Corresponding to SPR MSY	0.129	0.124	0.134
MSY (mt)	662.3	574.0	750.7

Harvest Projections and Decision Tables

Forecasted fishing mortality (mortality from landings and discards) using an SPR equal to 30% and a 25:5 control rule to linearly reduce the fishing mortality is greater than recent fishing mortality and results in an increasing stock status. The predicted fishing mortality is less than the equilibrium fishing mortality at SPR=30% because recent recruitment has been below average and the spawning output is estimated less than 25%, thus the control rule also reduces fishing mortality. At these predicted fishing mortality levels, the stock is projected to be at 16% of unfished spawning output in 2028.

The decision tables provide information about the projected stock status over the next five years under different scenarios for catch and across the two major axes of uncertainty in halibut life history. We chose natural mortality and fecundity as these axes. Base model natural morality is based on a reported maximum longevity of 30 and 23-years for females and males, respectively. However, the oldest observed female in CDFW samples is 24, corresponding to a higher natural mortality. Base model fecundity increases with female length, as reported in the literature for central California halibut. However, the range of lengths studied was limited and therefore the alternative fecundity uses a common assumption of proportionality to spawning biomass. The decision tables provide two five-year catch projections that would maintain the stock on average, in the long-term, at an SPR of 30%. One uses a 25-5 harvest control rule and the other does not. The third catch projection fixes catch at the average observed between 2019-2023. Given that halibut is not managed using a quota system, these catch projections are highly uncertain. Regulations do not directly limit catch or effort for either the commercial or recreational sectors targeting halibut and catch has the potential to grow substantially.

Table iii provides values associated with the base model assumption of fecundity increasing with female length and

Table iv provides values associated with the assumption that fecundity is proportional to spawning biomass. Both tables compare the natural mortality values that were fixed in the base model with a higher alternative setting female mortality equal to males at 0.235. All of the scenarios presented with fecundity proportional to female size indicate an increase in stock status over the next five years. In this scenario, high natural mortality lowers the scale of spawning output and increases stock status. When fecundity is modeled as proportional to spawning biomass, the scale of spawning output is greatly reduced and the fraction unfished is increased. Importantly, under this fecundity assumption and with high natural mortality, the higher catches associated with maintaining the stock above SPR 30% produce decreasing stock status over the next five years. All scenarios assume average recruitment for recent year classes, which begin to influence spawning output at the end of the five-year projection. If recent uninformed recruitment is lower than average, as it has been for most years since 2000, these projections may be overoptimistic.

Table iii. Decision table with the base model assumption for fecundity (fecundity related to female size). Catch projection alternatives include maintaining the stock above SPR 40% using a 25-5 harvest control rule, maintaining the stock above 30% without a harvest control rule, and fixed catch at the average from 2019-2023. Fixed 5-year average catches are a mixture of biomass and number of fish.

			Base		High Natural Mortality	
	Year	Catch	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
SPR 30%, 25-5 Harvest Control Rule Applied	2024	196.83	13,476	0.140	12,337	0.244
	2025	196.17	14,076	0.146	12,633	0.250
	2026	201.29	14,536	0.151	12,762	0.252
	2027	218.31	14,958	0.155	12,832	0.254
	2028	245.37	15,439	0.160	12,926	0.255
SPR 30%, No Harvest Control Rule	2024	242.45	13,476	0.140	12,337	0.244
	2025	231.54	13,762	0.143	12,357	0.244
	2026	230.77	13,928	0.145	12,243	0.242
	2027	245.23	14,084	0.146	12,109	0.239
	2028	270.81	14,333	0.149	12,039	0.238
5-Year Average Catch Fixed	2024	120.19	13,476	0.140	12,337	0.244
	2025	120.19	14,596	0.152	13,091	0.259
	2026	120.19	15,648	0.162	13,715	0.271
	2027	120.19	16,733	0.174	14,311	0.283
	2028	120.19	17,999	0.187	15,010	0.297

Table iv. Decision table assuming that fecundity is proportional to spawning biomass. Catch projection alternatives include maintaining the stock above SPR 30% using a 25-5 harvest control rule, maintaining the stock above 30% without a harvest control rule, and fixed catch at the average from 2019-2023. Fixed 5-yr average catches are a mixture of biomass and number of fish.

			Base		High Natural Mortality	
	Year	Catch	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
SPR 30%, 25-5 Harvest Control Rule Applied	2024	196.83	2,151	0.267	2,236	0.413
	2025	196.17	2,165	0.269	2,189	0.404
	2026	201.29	2,185	0.271	2,151	0.397
	2027	218.31	2,230	0.277	2,145	0.396
	2028	245.37	2,292	0.284	2,160	0.399
SPR 30%, No Harvest Control Rule	2024	242.45	2,151	0.267	2,236	0.413
	2025	231.54	2,111	0.262	2,138	0.395
	2026	230.77	2,087	0.259	2,064	0.381
	2027	245.23	2,097	0.260	2,030	0.375
	2028	270.81	2,129	0.264	2,024	0.374
5-Year Average Catch Fixed	2024	120.19	2,151	0.267	2,236	0.413
	2025	120.19	2,255	0.28	2,272	0.419
	2026	120.19	2,365	0.293	2,312	0.427
	2027	120.19	2,505	0.311	2,383	0.440
	2028	120.19	2,682	0.333	2,489	0.460

Major Uncertainties and Research Needs

This assessment models the southern California halibut stock as separate from stocks in Mexico as well as central and northern California. There is likely both larval dispersal as well as some adult movement across these boundaries. Improved understanding of halibut movement across the U.S.-Mexico border is badly needed as well as across Point Conception. Growth estimates were highly variable in this assessment. Continued sampling and processing of age structures should be prioritized to allow for internal estimation of growth parameters and continued assessment of recruitment. This assessment suggests that southern California halibut have experienced recruitment regimes. More research is needed to understand the drivers of these regimes and potential impacts resulting from climate change as well as temperature dependent sex determination. This assessment used a fecundity relationship increasing with female size based on Barnes and Starr (2018) which had a large impact on overall results. This relationship was derived from a relatively narrow range of female sizes and further research on a wider range is needed to confirm results. This fecundity estimate was based on multiplying batch fecundity by an average number of spawning events per year. There is a high degree of uncertainty in female halibut spawning frequency and its relationship to female size or age and environmental conditions. No information on discards from the ComHL fleet has been collected. Observer data for this and all fleets will be important for improved estimates of discard amounts and selectivities.

1 Introduction

1.1 Basic Information

California halibut (*Paralichthys californicus*) (halibut) is a flatfish that is most abundant between central California and northern Baja California and is the subject of robust recreational and commercial fisheries employing several gear types. The species biology and fisheries throughout California are described in detail within the California Halibut Enhanced Status Report (CDFW 2022a; https://marinespecies.wildlife.ca.gov/california-halibut/true/). Here we present brief summaries of the biology and fisheries of halibut statewide to aid in interpretation of the assessment but refer readers to the Enhanced Status Report for further detail. This assessment pertains to the southern California halibut stock that ranges from the U.S.-Mexico border to Point Arguello. The full range of halibut extends approximately from Cabo Falsa, Baja California (Love and Passarelli 2020) to the Quillayute River in Washington (Pattie and Baker 1969). Halibut are generally distributed across benthic habitat with soft bottom substrate such as sand or mud, and further concentrated both near and within bays, estuaries, and other coastal areas shallower than 197 ft (60 m) (Love 2011), although adult halibut can be found across their entire known depth range from the surf to 1,040 ft (317 m) (Love and Passarelli 2020). Juveniles settle into bays and estuaries, or in shallow water on the open coast, and use these areas until they grow larger and mature (Kramer 1990). In some areas along the coast of California, significant bays or estuaries are not available, such as from Point Conception to Morro Bay and from Morro Bay to Elkhorn Slough (Monterey County). Settled juveniles must select a nursery habitat alternative, such as shallow waters on the open coast, and this may affect the demography of adult populations (Fodrie and Levin 2008). As sexually mature adults, halibut generally begin seasonal offshore and onshore directional movement. Adult females generally use bays and estuaries as a resting area following spawning events in nearby coastal waters, while adult males generally remain in coastal waters following maturation and are rarely documented in a resting spawning condition (CDFW unpublished data). Adult males and females generally exhibit directional movement to deeper coastal waters during the winter (CDFW unpublished data).

Relatively little is known about halibut movement along the coast and its relationship to stock structure. Consistent but sparse patterns emerged from tagging studies showing that sub-legal sized fish do not move significant distances alongshore in either central (Tupen 1990, Domeier and Chun 1995), or southern California (Haaker 1975, Young 1962, Posner and Lavenberg 1999, Domeier and Chun 1995). Of the few larger fish that were tagged, a small percentage were observed to travel relatively large distances and six fish crossed the oceanographic break of Point Conception (Domeier and Chun 1995). Inconsistent tag recovery efforts prevent conclusions about the dominant direction of travel, particularly towards Mexico where tag recovery efforts were absent. The most recently available genetic study indicated a well-mixed population (Craig et al 2011), however it is difficult to interpret these results at the time scales needed to inform management.

Latitudinal differences in halibut life history characteristics do suggest some population structure. Halibut grow slightly more quickly and attain a lower maximum size in central California than the southern California Bight (Barnes et al 2015). Female halibut reach maturity at a smaller size and slightly younger age in southern California, while there is no apparent difference in male maturity patterns between the regions (Lesyna and Barnes 2016, Love and Brooks 1990). Barnes et al (2015) observed a gradient in peak spawning output, with peak reproductive output occurring the earliest in Mexico and progressing northward with the season. Differences in sex ratio between central and southern California were observed by MacNair et al. (2001), who noted that males comprised 69% of those fish sampled in southern California, while the central California sex ratio (of sub-legal sized fish) was approximately equal. Differences in age structure were also found between regions and at finer scales within the southern California bight (MacNair et al 2001, Sunada et al 1990).

Sex ratio has been observed to differ depending on the gear and sampling methods. Commercial catch is generally skewed towards females. Reed and MacCall (1988) report the commercial fishery landings are from 60% to 80% females. Similarly, Pattison and McAllister (1990) found 75% of the sampled fish to be females in combined data from a variety of gears. Sunada et al. (1990) analyzed sampled data from southern California ports using gill and trawl nets, and they found that females out-numbered males by 4.3:1 overall. In contrast, studies targeting smaller fish with research trawls found that males comprised a slight majority (MacNair et al. 2001). Haaker (1975) also found the sex ratio is highly skewed to newly recruited males (<100 mm) in nearshore samples taken from Anaheim Bay. Males are assumed to have a higher natural mortality rate than females based on the ages of sampled fish. More importantly, while both sexes undergo ontogenetic migration offshore, females have been found to more frequently migrate on and offshore (CDFW unpublished data), likely due to higher metabolic needs associated with egg production. Adult females generally re-utilize bays and estuaries as a resting area following spawning events in nearby coastal waters, while adult males generally remain in coastal waters following maturation and are rarely documented in a resting spawning condition (CDFW unpublished data). Adult males and females generally exhibit directional movement to deeper coastal waters during the winter (CDFW unpublished data). These differences in behavior likely make females more vulnerable to fishing.

1.2 Map

A map displaying the stock boundaries is provided in Figure 1. The southern stock, assessed here, is defined as the region between Point Arguello and the U.S.-Mexico border along the California Coast. We refer to the stock and fishery north of Point Arguello as the northern halibut stock. The southern stock assessment assumes independence between these regions.

1.3 Life History Characteristics

Early Life History

Larval density patterns observed in CalCOFI surveys suggest halibut spawn between Rosario Bay, northern Baja California, to Point Conception year-round with a major peak in February and minor secondary peaks in July and October (Moser and Watson 1990). They have been observed to spawn in water less than 20 meters deep (Frey 1971). Their eggs remain planktonic in the upper portion of the water column and hatch after about 30 days (Lavenberg et al. 1986). Larvae are planktonic for about 20 days and eventually settle along the calmer portions of the open coast and in embayments, where they live for a year or more (Kramer 1990, 1991).

Stock-Recruit Relationship

Flatfish are generally considered prolific spawners, as a number of heavily exploited stocks were observed to produce large quantities of recruits (Rice et al. 2005). Halibut may be similarly capable since a 22-inch female was observed to produce 300,000 eggs per week in the laboratory (Berkson 1990). Estimates of the steepness of the Beverton-Holt stock recruitment relationship for 14 stocks from the family Pleuronectidae were provided in Myers et al. (1999) and ranged from 0.80 to 0.84. Although these values appear highly productive, Maunder et al. (2010) considered them to be negatively biased estimates.

Environmental Influence on Recruitment

Recruitment and catch have shown large fluctuations over time, suggesting that inter-annual recruitment strength for halibut is environmentally driven. There is a clear environment-recruit relationship in the San Francisco Bay area that links positive ENSO events to periods of high recruitment in many years. Also, Berkson (1990) estimated statewide recruitment to the fishery in 1985-87 that was increased following the El Nino event in 1982-83. The mechanisms linking oceanographic variability to recruitment strength for halibut could be related to the optimal water temperature for halibut to develop physiologically, in which the colder northern waters become more favorable for growth while those in southern California become too warm. It is also possible that there are changes in circulation patterns during certain climatic regimes that either advect larvae offshore, transport them to areas of the coast with less favorable nearshore habitat, or transport them south of the U.S.-Mexico border. An additional possible mechanism linking oceanographic variability to halibut recruitment could be changes in forage assemblages such that the amount and/or quality of food for young halibut mediates their recruitment success.

Growth

Female halibut grow faster than males and attain a larger terminal size in both the central and southern regions (Barnes et al 2015, MacNair et al. 2001, Pattison and McAlister 1990, Sunada et al. 1990, CDFW unpublished data). Females and males grow more slowly and attain a larger overall size in southern California when compared to data from northern California (Barnes et al 2015, CDFW unpublished data). Varying von Bertalanffy parameter estimates have been reported by studies employing different sampling and estimation methods accessing more sub-legal or legal sized fish (Sunada et al 1990, Barnes et al 2015, MacNair et al 2001, Tupen 1990). CDFW began aging otoliths taken from portside samples in southern California in 2007 and has continued through the present. This assessment examines the sensitivity of results to internal and external estimation of growth parameters based on these samples. Figure 61 illustrates the final growth curve implementing a mixture of fixed and estimated parameters and Figure 62 illustrates the external estimates. This assessment also uses parameters of an externally estimated allometric length-weight model based on CDFW port sampling data (Figure 63 and Figure 64).

Natural Mortality

A wide range of natural mortality rates have been estimated for halibut based on empirical relationships, ranging from 0.1 – 0.6. Reed and MacCall (1988) estimated M as 0.3 for both sexes based on Pauly (1979) and 0.15 on a maximum age of 30 years (also both sexes) using Hoenig's method. Pattison and McAllister (1990) found maximum ages of 30 and 23 for females and males, respectively, although the maximum age reported through sampling the fishery is 24 in the past decade (CDFW unpublished data). Using an approach recommended in the 'Accepted Practices and Guidelines for Groundfish Stock Assessments' (PFMC 2023), produces an estimate of 0.18 for females and 0.235 for males based on the maximum ages of 30 and 23, respectively (Then et al 2015, Hamel 2015, Hamel & Cope 2022, http://barefootecologist.com.au/shiny_m).

Maturity and Fecundity

California halibut maturity was studied in southern California by Love and Brooks (1990) who visually examined gonad samples during peak reproductive season in the southern California Bight. They found that 50% of females were mature at 4 years, and 100% at 7 years. In northern California, Lesyna and Barnes (2016) found that females matured at younger ages. Specifically, 50% of females were mature at 2.6 years old, and 100% were mature by 4 years using visual techniques. Lesyna and Barnes (2016) reported maturity using both visual and histological techniques, which are considered more accurate. Despite the potential inaccuracy of visual techniques, we used information from Love and Brooks to model the logistic female maturity curve in this assessment (Figure 10) because this is the only study reporting maturity for fish in southern California. Only female maturity is parameterized in the model.

Halibut are batch spawners with a protracted spawning season that varies by region. The spawning season peaks earlier in the south than in the north (Barnes et al 2015). They are also prolific spawners with batch fecundity estimated to be 455,000 – 589,000 eggs per female (Caddell et al 1990). Determining the spawning frequency in wild populations has proven difficult, as halibut are asynchronous spawners and spawning patterns vary with latitude and likely between years due to environmental variability. Barnes and Starr (2018) estimated that average batch fecundity was 597,445 +/-318,419 eggs per female, which resulted in an annual fecundity estimate of 5,200,000 – 81,000,000 eggs per fish based on an inter-spawning interval estimated to be between 1.3 and 2.7 days. Barnes and Starr (2018) report batch fecundity with female length for fish between 747 and 914 mm allowing for estimation of a log linear relationship. While this is a narrow range of sizes, we consider this to be the best available information for halibut fecundity and model fecundity as a function of length in this assessment (Figure 10). Fecundity is predicted to be much greater for larger female halibut and a 125 cm female that is approximately ten times heavier than a 59 cm female has a fecundity that is 69 times that of a 59 cm female halibut.

1.4 Ecosystem considerations

Ecological information was not explicitly represented in the stock assessment model. This is due to a complicated mechanistic relationship between halibut population dynamics and the California Current ecosystem. As mentioned above, successful recruitment may be related to a temperature optimum rather than simply warming trends. The loss of coastal wetlands as settlement habitat may have been detrimental to halibut recruitment and productivity (Fodrie and Levin 2008) but it is unclear to what extent this has impacted the stock overall and over what timeframe. The Southern California Wetlands Recovery Project estimated that greater than 95% of coastal wetlands were lost in Los Angeles and San Diego counties and a recent analysis that reconstructed historic wetland extent estimated that 85% of tidal wetlands have been lost along the entire west coast (Brophy et al 2019). The halibut population may be impacted by the fluctuation of coastal pelagic forage species as smaller halibut have been found to primarily feed on northern anchovy (Roberts et al. 1982; Plummer et al. 1983), while larger halibut were observed to feed on Pacific Sardine (Wertz and Domeier 1997). However, the presence of a variety of other species in their guts suggests they may also be sufficiently general in their diet to prevent observation of strong trophic linkages.

1.5 Fishery Information

Halibut have a long history of commercial exploitation along the coast of California, with the first landings observed in the 1870’s. Although there was no catch record until 1916, the all-time peak in catch occurred in 1917 with 3.5 million pounds of halibut landed, most of which originated in southern California (Figure 11). The next major peak occurred in 1946 at over 1.2 million pounds, then in 1965 at over 0.8 million pounds. The majority of the catch originated in southern California until the late 1960’s, when northern California landings began contributing equally to the statewide catch. Since 1960, landings have fluctuated between 0.3 and 1.3 million pounds although they have been on the lower side of that range in the past decade. Landings in northern California have consistently exceeded southern California landings since 2009. A variety of gears have been used to target halibut that generally fall into three categories: trawl, entangling nets, and hook and line.

The trawl fishery for flatfish began in California when the paranzella net was introduced in San Francisco Bay in 1876 (Bureau of Commercial Fisheries 1936). The fleet soon expanded into southern California but by the early 1900's, legislation prohibited the use of trawl nets off Los Angeles and San Diego Counties, limiting landings by trawl relative to other gears. Trawling was more comprehensively banned in state waters in 1915 with some exceptions. One of those exceptions in Santa Barbara County became known as the California halibut trawl grounds (CHTG) in 1971. Light touch trawls were defined by legislation in 2004 and were required in certain parts of southern California but only a slightly less vague gear code was used to describe this gear type ("trawl with footrope less than 8") and encompassed both mandatory light touch trawl gear along with other trawl gears. Fishermen have refined trawl gear to meet their objectives over the years, but for the purposes of this model it was not possible to separate them into meaningful categories. This is in part due to the record-keeping limitations on landings, but also due to a lack of compositional data from the trawl fleets that prevent estimation of key selectivity parameters. All trawl gears targeting halibut were consequently combined into one fleet.

The gillnet fleet is comprised of two slightly different types of entangling gear; trammel and set gillnets. Trammel nets were introduced to southern California in the 1880's and were used to target halibut along with several other species. This was the dominant gear type used in Baja, San Diego and Los Angeles Counties when these areas represented the majority of the catch during the fishery's peak (Barsky 1990). Gillnet gear was prohibited in state waters south of Point Arguello in 1994 but substantial fishing grounds suitable for the gear type remained in federal waters. In 1989, the minimum mesh size permitted for targeting halibut increased from 8 to 8.5 inches. Similar to trawl landings, gillnet gear types are not recorded in sufficient detail to allow the separation into different categories that may have unique selectivity patterns. The gillnet logbook data also lack detailed information on gear specifications. Based on observer data, however, we do know that a variety of mesh sizes were and are still used and that trammel nets make up a portion of the fleet. We explore selectivity time blocks relative to this mesh size change.

The commercial hook-and-line fishery has historically contributed less to the overall catch than other fisheries but has increased significantly over the past decade. The fleet consists of smaller boats using rods and reels to drift fish or use salmon trolling gear. These fish are often sold live, which earns a higher ex-vessel price. It is also less expensive to equip a boat for hook-and-line fishing than for other gears and it is a completely open access fishery, so participants are able to join more freely and at significantly less cost than in the other commercial fleets.

Participation in the trawl and gillnet fisheries has been relatively low since the early 2000s while vessels using hook and line gear increased in that same period. Figure 12 shows the statewide number of unique vessels making halibut landings since 1969. Permits to target halibut in the CHTG have been required since 2006 when 61 permits were issued. In 2023, 40 halibut trawl permits were issued. A gillnet gear permit was initially required in 1980 when 231 general gill net permits were issued. This permit is not specific to halibut as a target but rather to the gear type. In 2023, 93 of these permits were issued.

Recreational fishery information is more limited than commercial. Directed surveys estimating recreational catch and effort did not begin until 1980. Statewide CPFV catch was reported in Fishery Bulletins beginning in 1936. Based on records from CPFV logbooks (which date back to 1946), the majority of recreational catch came from southern California until roughly the 1960s when effort began to increase to the north. Reed and MacCall (1988) reported that CPFV caught halibut represented about 40% of the total recreational catch in the mid-1960s. Recreational take of halibut is almost exclusively hook-and-line and for the purposes of this model is divided into a commercial passenger fishing vessel (CPFV) fleet, and a fleet that encompasses anglers from shore or on their own boats (Recreational – Other). They are separated due to the likely different dynamics (e.g. vessel size, angler skill, angler behavior, etc.) between charter operations and independent anglers.

1.6 Summary of Management History and Performance

Halibut are managed by the California Department of Fish and Wildlife (CDFW) using provisions established under the Fish and Game Code, and with regulations established under Title 14 of the California Code of Regulations. Although halibut inhabit waters well beyond 3 nautical miles from shore, which are under the state's authority, halibut captured within federal waters (3-200 nm) but landed in the state must still adhere to California's established rules and regulations. A detailed timeline of state management actions is provided in Appendix A.1; a high-level summary is provided below. There are several federal rulemakings that indirectly impact halibut fishing which are briefly discussed but not included in the appendix.

The first management action pertaining to the halibut fishery was adopted in 1911, which prohibited the use of trammel nets (a type of entangling net) within state waters. Trawling was also prohibited in state waters in 1915, and a prohibition on the sale of any commercially caught halibut less than 4 lbs (~1.8 kg) was established. A minimum legal size of 22 inches was not established in the commercial fishery until 1979, but the 4 lb minimum weight roughly corresponded to a 22-inch fish (the approximate size at maturity for females). Both the trawl and gillnet fisheries experienced various regional openings and closures along the California coast for almost the next century.

The use of gill and trammel nets became fully prohibited within state waters south of Point Arguello (southern California) as a provision of the Marine Resources Protection Act of 1994. In 2000, gill and trammel nets were prohibited between Point Reyes and Point Arguello (central California) in waters less than 60 fathoms. The central California set gillnet fishery was greatly reduced by this restriction, as waters greater than 60 fathoms are not ideal for setting gillnet gear on the seafloor. In southern California, however, the gillnet fleet was only slightly impacted and remained operational since no depth restriction was established south of Point Arguello, gillnet grounds were still available outside of the three-mile limit. In 1989, the minimum mesh size for gillnets targeting halibut was increased statewide from 8" to 8.5", although a portion of the fleet was already using this mesh size.

Trawling has generally been prohibited in state waters, except for a small area between 1 and 3 nautical miles offshore of Santa Barbara and Ventura counties, but has experienced various regional openings and closures over many years. In 1971 the area offshore of Santa Barbara became officially known as the California halibut trawl grounds in regulation, and a four-month seasonal closure was adopted to protect spawning adults. A minimum cod-end mesh size of 7.5 inches was also adopted, in contrast to the 4.5-inch minimum mesh size required in the federal trawl fleet. The boundaries of the trawl grounds were slightly adjusted in 2006 to avoid damaging an area of sensitive biogenic habitat on the seafloor.

Trawling for halibut still occurs in federal waters, although the available area for trawling is reduced by federal depth restrictions intended to protect certain species of groundfish as well as seasonal gear conflicts (e.g. commercial crab pots). The Eastern and Western Cowcod Conservation areas were established in 2001, which prohibit the use of trawl gear over several hundred square miles. Several areas were additionally closed to trawling in 2006 in an effort to protect habitat essential to rockfish, as identified by the Pacific Fishery Management Council. The impacts of these federal closures on trawlers targeting halibut have not been evaluated.

A recreational minimum legal size of 22 inches was established in 1971. It is expected that this regulation significantly increased the amount of discarding that occurred in the recreational fisheries, although no length composition data are available prior to this time. Daily bag limits were adopted at the same time with three and five fish north and south of Point Sur, respectively. This bag limit was unchanged until 2023 when the northern limit was reduced to two fish under an emergency, temporary rule change. The change was initially prompted by a salmon fishery closure and other restrictions to groundfish leading to concern that anglers might shift an unsustainable amount of effort to California halibut, which might also experience lower recruitment during a cold-water period. This new limit is anticipated to become permanent in 2024. A network of Marine Protected Areas (MPAs) was established within state waters in a multi-year process concluding in 2012. The MPAs do span soft bottom habitat, but halibut were not identified as a species likely to benefit from this scale of spatial management by CDFW during the regional MPA planning processes.

1.7 Fisheries off Mexico

There is undoubtedly some degree of population connectivity between halibut in California waters and the stock(s) located along the western coast of Baja California and Baja California Sur, Mexico. Halibut occur south of the U.S-Mexico border to Magdalena Bay, with a few isolated reports of halibut as far south as Todos Santos. The National Commission of Aquaculture and Fisheries (CONAPESCA) manages the Mexican halibut fishery, which includes a set gillnet fleet, an ‘artisanal’ hook and line fleet, as well as recreational and subsistence fisheries. Unfortunately, what little landings data are available are recorded as ‘flatfish’ in aggregate. According to a recent evaluation of several commercial halibut fleets in Mexico by the Monterey Bay Seafood Watch program, no flatfish species have been formally assessed (Crespo and Tovar 2018).

2 Data

The data that were available and used in this assessment are summarized in Figure 13. Figure 14 illustrates estimates of landings and corresponding discard mortality for each of the five fleets over the modeling period for each region. Detailed descriptions of all available data sources are provided in the following sections.

2.1 Commercial Data

2.1.1 Commercial Fishery Landings

1880 – 1915
Entangling nets are reported to have been used since the 1880s to catch halibut and shark (Ueber 1988) and were the only gear used by the San Diego and San Pedro halibut fleet until

the early 1900s (Clark 1931). Catch data are not available over this timeframe. We therefore used a ramp up from no catch in 1880 to the first reported catch in 1916 and attributed the full amount to the gillnet fleet (Figure 15). This was used only in sensitivity testing.

1916 – 1929

Statewide halibut catches are reported in Fish Bulletin 149 (Heimann and Carlisle 1970) and are not available by port complex or gear type. It is likely that these numbers also include imported halibut that originated in Mexican waters so the total reported catch was reduced by 35% to reflect catch only from California waters (Barsky 1990). We then assumed the total amount originated in southern California given that the fishery is reported to have been centered off southern and Baja California in the early years (Clark 1921) and the percentage of catch in California waters that was taken in waters north of Santa Barbara in the first year of regionally reported data (1930) was less than 8%. Again, this information was used only in sensitivity testing.

1930-1970

Catch data are available by port complex beginning in 1930 but are not reported by gear type (Barsky 1990). Catch recorded under the San Diego, Los Angeles, and Santa Barbara port complexes are included in this assessment of the southern stock. The values reported by Barksy (1990) were reduced by 35% to remove fish from Mexican waters.

1971 – 2023

Data from 1971 to present are available from the Department's Marine Landings Data System (MLDS), which includes more detailed information on gear type, fish condition, port of landing, and commercial block number, among other fields. Catch was allocated to each region based on port of landing rather than block number since port was more reliably and consistently reported. Catch landed in ports south of Point Arguello was allocated to the southern stock assessed here.

Multiple condition codes were used to describe the state of a fish at the time of landing, which relate to the weight recorded on the landing receipt. Most fish were landed in whole condition, but a significant (~14%) of fish landed over the entire timeseries were landed in 'dressed' condition. Based on a comparative analysis of whole fish weights vs gilled/gutted weights, the following correction factor was applied to fish weight in dressed condition: $W_{whole =} -0.0529 + W_{dressed} \times 1.096$.

The three predominant methods of commercial fishing have been trawling, gill/trammel nets, and hook and line. There were also many miscellaneous gear types recorded, some of which are legacy and some could have been in error. They were assigned to the fishing method most closely resembling one of the major gear types. For example, 'entangling net' was included in the gillnet catch, and 'trolling' was included in the hook and line fishery. The catch data without an assigned gear type was assigned to the three main gears according to the ratio of landings by gear type for a given region and year.

Several different codes have been used to describe trawl gear since 1969. Over the entire timeseries, the majority of trawl landings were recorded either 'bottom trawl', 'single-rigged trawl', or 'trawl with footrope < 8 inches' as the method of take, in descending order of frequency. Differences in trawl gear used within the fleet certainly exist, as well as differences related to state and federal regulatory changes over the years. The ambiguity in the definitions of these codes, as well as a lack of gear-specific length composition data in many years led to a decision to combine all trawl gears in the model. There is inadequate length data from the three main trawl gear codes with which to compare differences in selectivity outside of the model. Similarly, several codes used to describe different configurations of entangling nets including trammel nets, gillnets, and different mesh sizes are seen in halibut landings records and were combined here into a single gillnet fleet.

2.1.2 Commercial Discards

Trawl

The West Coast Groundfish Observer Program (WCGOP) provided observer data for the halibut trawl fishery for the years 2003 – 2020. The number of observed tows ranged from 1 to 71. We excluded years with five or less tows. The resulting mean discard rate based on the weight of fish (discard/retained) was 27%. We applied that rate to all years with trawl landings to generate an estimated annual discard amount. We then assumed a mortality rate of 0.5 and attributed the resulting discard mortality to a separate trawl discard fleet.

Gillnet

The Southwest Fisheries Science Center's Gillnet Observer Program (SWFSC_GOP) provided observer data from southern California for the years 1990-1992, 2006-2007, 2009-2013, and 2017. Annual discard rates for these years were calculated by dividing the total number of halibut recorded as discarded by the total retained for all observed sets combined. This observer program collected catch and discards only in units of numbers and did not sample fish weights. However, it did sample fish lengths and these could be used in future assessments to modify the discard ratio in numbers to one based on weight using these lengths and the average length to weight relationship. Calculated rates for 2006, and 2009 were excluded as a result of either very low sample size and/or highly unrealistic estimates of discard rate. Coverage rates for those years were not explicitly calculated by the SWFSC_GOP for the halibut fleet, but the number of observed sets in a given year ranged from 14 to 435. CDFW directed an observer program (CDFW_GOP) in southern California from 1983-1989, and annual discard rates were calculated using the methods described above. The number of sets observed in a given year ranged from 27 to 397. We excluded the discard estimate from 1983 due to being unrealistically high. The CDFW_GOP program was intended to document the impact of an increase in the minimum mesh size for gillnets targeting Halibut from 8 in. to 8.5 in. that was implemented in 1989. The mean discard rate for this earlier period (1984-1988) was 25% and for the later period (1989-2017) was 15%. For both data sets, all net sets were included in discard calculations regardless of mesh size. Despite the prohibition on targeting halibut with small mesh in 1989, observer data indicates substantial catch of halibut associated with nets with mesh <8 inches and we know that some nets are outfitted with both small and large mesh panels.

An annual discard amount, assuming 30% mortality, was calculated by applying annual discard rates to annual landings amounts for years where data is available. For years without observation, the early period mean was applied during the period 1980-1983, and the later period mean was applied after that. The commercial size limit of 22 inches was established in 1979. Thus, we assumed a lower discard rate of 10% for years prior to 1980. There likely were discarded fish early in the gillnet fleet history due both to discarding damaged fish and also the presence of a 4-lb minimum weight limit since 1915 that later became a 22-in size limit. However, we expect there would have been more retention for personal use and less enforcement. While the observer data does not indicate the reason for discards, it does show that approximately 17% of fish caught are damaged.

Commercial Hook and Line

No discard information has been collected on the commercial hook and line fleet. Because the fishing gear is similar to that used by the CPFV fleets, the mean of the annual discard ratios observed from the CPFV fleet (described below) was used. This discard ratio was modified by the ratio of average weight of discarded to retained fish using CRFS onboard CPFV observer data to convert this discard ratio in numbers of fish to one reflecting weight. This ratio was then applied to the commercial hook and line landings to generate annual discard amounts.

2.1.3 Commercial Length and Age Composition Data

Length

Commercial length and age composition data of the retained catch are available from several sources. The Department's State Finfish Management Project has collected port samples since 2007. Prior to 2007, commercial lengths are available from the Department's historic market sampling database which spans the years 1983 – 2006. Both databases contain information on gear, block number, and port of landing, but the associated sex was not consistently recorded in the earlier (pre-2007) data, or when samples are collected from the live fish fishery. The amount of sampling for the commercial fleets was variable with some years with few to none. Years with fewer than 20 fish sampled were excluded from the compositions.

Length composition data on retained and discarded halibut from the gillnet fleet are available from the CDFW_GOP (1983-1989) and from the SWFSC_GOP (1990-1994, 1999, 2007, and 2010-2017). Length composition data from discarded fish from the trawl fleet are available from the WCGOP for the years 2002-2018. Lengths for discarded fish are also available for the recreational CPFV fleet from 2005 to 2010 collected by the California Recreational Fishing Survey (CRFS).

Age

CDFW began collecting age composition data in 2007 from the three commercial gear types. However, sample sizes, geographic coverage, and representation from the different gear types varied greatly by region and year, primarily due to staffing constraints. Age compositions were included as conditional age-at-length data in the model.

2.2 Recreational Data

2.2.1 Recreational Fishery Landings

The earliest recreational catch data began with the Fishery Bulletins publishing of statewide CPFV catches from logbooks in numbers of fish in 1936. Data on other modes of fishing does not become available until 1971. However, Reed and MacCall (1988) report that CPFV caught fish represented about 40% of total recreational catch in the 1960s. Recreational catch estimates by mode were available from three sources: 1971-1979 were reconstructed from the CPFV logbook data (Maunder et al 2010), 1980-2003 were obtained from the Marine Recreational Fisheries Statistical Survey (MRFSS), and data from 2004-2023 were taken from the CRFS (www.recfin.org). It should be noted that recreational catch data was estimated using a different sampling design prior to 2004, which may explain the abrupt decline in recreational catch estimates between 2003 and 2004. Both MRFSS and CRFS provide total mortality estimates for numbers of fish taken recreationally that are calculated by multiplying catch rate estimates (estimated from field survey data) by total effort estimation. The MRFSS data user manual indicates that MRFSS effort estimation had relied exclusively on an offsite survey called the Coastal Household Telephone Survey (CHTS). In comparison, the source of data for private and rental boat fishing mode (PR) effort estimation became a combination of field intercept data and an offsite survey called the Angler License Directory Telephone Survey (ALDTS) (CDFW 2022b). From 2004 to present, field intercept data is used to generate CRFS estimates of effort for PR trips that return to public access sites during the day (PR-PAD). ALDTS data is used to generate CRFS effort estimates for the smaller portion of PR trips that return to private access sites or at night (PR-PAN).

ALDTS data enables effort estimation for all modes, not just the modes for which effort estimation is needed for CRFS (i.e., PR-PAN). In particular, as ALDTS collects data on the hour and site (public vs. private) of PR trip return, effort estimates can be made for PR-PAD and PR-PAN. For PR-PAN, the effort estimates from ALDTS can be compared with those from the PR intercept survey.

This comparison showed that ALDTS estimates for PR-PAD effort typically far exceeded corresponding more credible estimates from the far more intensive PR-PAD intercept survey. Accordingly, beginning in 2008 CRFS ceased using unamended ALDTS estimate for PR-PAN effort and instead initially used a complex method that eventually was replaced by a more systematic and direct method whereby the PR-PAN effort estimate is found by multiplying the ALDTS estimate by a CRFS district-specific scaling factor ('F-factor') based on recent past data from both ALDTS and the PR field surveys. F-factor is the long-term average ratio of field survey PR-PAD effort to ADLTS PR-PAD effort (CDFW 2022b). F-Factor is approximately 0.4 for southern California.

A comparison of CHTS and ALDTS questionnaires and CHTS and ALDTS effort estimation methods revealed that despite some differences (e.g., longer recall period for CHTS, different sample frames, etc.) the two surveys had a lot in common (e.g., similar approaches to sample draw and interview quota, similar questions that were used for effort estimation, and similar estimation methods). Because of their similarities we hypothesize that CHTS was subject to similar sources of error and bias as ALDTS and that it would be worthwhile to run a sensitivity analysis where all years of MRFSS PR total catch are multiplied by 0.4 in an attempt to calibrate MRFSS PR total catch estimates to CRFS. Note that this calibration does not account for potential differences in the MRFSS and CRFS catch rate surveys.

For additional confirmation that effort estimates were inflated by the MRFSS survey, we plotted the effort estimates across the time series for the southern California region, ocean waters <= 3 miles from the mainland, and PR mode (Figure 16). This shows a long-term average ratio between the MRFSS and CRFS years of about 0.2. We explore sensitivity of the assessment model to MRFSS catch estimates by 0.4 (see section 3.4.2).

2.2.2 Recreational Discards

Commercial Passenger Fishing Vessels

Estimates of total discard from the CPFV fleet were much higher proportionally than those documented for the trawl or gillnet fisheries. This is likely a function of differences in the selectivity of hook and line gear (as opposed to gillnet and/or trawl gear which have minimum mesh and cod-end sizes that allow a higher proportion of sub-legal sized fish to evade capture). CPFV logbooks began recording both the number of fish kept per trip since 1980 and the number of fish released in 1995. The mean discard ratio between 1995 and 2020 was 1.9. This was multiplied by the catch estimates for this fleet annually from 1971 to 2020 and a mortality rate of 10% to generate an annual estimate of discard mortality.

Private Boat and Shore (Rec-Other)
While estimates of discard ratios from angler interviews are available since 2004, we chose to apply the mean CPFV discard ratio to this fleet. Reporting compliance is relatively high among CPFVs and self-reported catch from angler interviews that is unobserved by CDFW staff may be less reliable. Additionally, selectivity parameters for the rec-other fleet were mirrored to those estimated for the CPFV fleet due to the unavailability of discard length composition data from the private boat and shore-based anglers.

2.2.3 Recreational Length and Age Composition Data

Length
Recreational length composition data was obtained from several sources. RecFIN provides retained length data obtained from recreational surveys (MRFSS/CRFS) from 1980-2023. Those data were collected from all recreational fishing modes but were not sex specific until 2013. Lengths representing the whole catch (retained plus discarded) are available for the CPFV fleet from 2005-2010. No discard lengths are available for the Rec-Other fleet.

Age
CDFW staff collected a small number of age samples from fish retained by the recreational fleets. A total of 19 ages were collected from the CPFV fleet between 2012 and 2019. A total of 117 ages were collected from other recreational fleets between 2009 and 2021. Sampling was conducted randomly during opportunistic sampling events.

2.2.4 CPFV Logbook Index of Abundance

Logbook data from the California CPFV fleet is stored in the Department's Marine Log System (MLS) database. Data through 2022 contained 4,269,922 species records and 687,209 trips statewide. This dataset contains individual trip records with information reported by the vessel captain, including: the number of unique species caught, the port of landing, the 10x10 nautical mile fishing block where the majority of fishing occurred, the number of contributing anglers, and the number of hours spent actively fishing, among other fields.

Sub-setting Procedure
Data filtering procedures and the resulting reduction in sample size and change in the proportion of trips catching halibut are described in Table 5. Fishing trips in blocks that were greater than 650 were assigned to southern California. Catch records lacking species information or flagged as having uncertain species identifications were removed. Ports that were infrequently sampled and offshore fishing blocks were removed.

An important step in using catch and effort data is determining an appropriate measure of effort and sub-setting the database to include information only from those trips on which anglers could have potentially caught a halibut. In the 2010 stock assessment, this was achieved by relying on expert judgement about species associated with halibut in the catch. The CPFV logbook data were subset to only include trips that contained one or more of those associated species although a list of species identified as commonly associated with halibut was not provided in the 2010 assessment.

Per the recommendations of the 2010 STAR panel, a less subjective approach to sub-setting the CPFV logbook data was taken in this analysis by applying the trip filtering method described in Stephens and MacCall (2004). This approach applies a logistic regression to species-specific presence/absence data per fishing trip to predict the probability of catching a halibut given the species composition of the catch.

Stephens-MacCall filter
The filtered southern California CPFV dataset contained 624,001 individual trips recorded between 1980 and 2022. Species which comprised 0.1% or less of the total number of records were removed from the data based on the logic that rarely encountered species are not very informative about the likelihood of catching halibut.

A logistic regression was fit to the remaining 58 ‘indicator’ species. White seabass, yellowfin croaker, barred sand bass, spotted sand bass, and unspecified flounder emerged as the five species most likely to co-occur with halibut (Figure 17). The area under the characteristic curve (AUC) for this binomial model is 0.702, a moderate improvement over a random classifier (Figure 18).

The method for excluding trips from the dataset involved first identifying a threshold which minimizes the absolute difference between observed and predicted halibut catch from the logistic model (per Stephens and MacCall 2004). Based on the identified threshold, 52,324 trips (~8.4% of the data) were flagged as ‘False Positives’, or trips where the model predicted a halibut in the catch but zero halibut were observed. The majority of the trips did not catch halibut and were predicted by the model to not catch halibut. Only these 502,531 trips were removed from the dataset. Thus, all trips predicted to catch a halibut including false positives, and all trips that did catch a halibut were retained, leaving 121,775 trips remaining for the development of a regional CPUE index (Table 5). ‘False Negatives’, or trips where one or more halibut were observed but the model did not predict a halibut in the catch, were not omitted from the data based on the logic that halibut presence is inherently an indicator of relevant fishing effort.

Southern California CPFV Index: Standardization Approach
A range of alternative model structures were explored including probability distributions (delta-lognormal and negative binomial) and covariates (year, month, block, and region). Region indicated three geographic sub-regions to capture different spatial dynamics and trends in catch rates exhibited by the CPFV fleet across the southern California bight. Data was assigned to either the Santa Barbara area, the LA/San Diego area, or the Channel Islands area according to the block number where the majority of the fishing took place (Figure 19). Models were run using the R package sdmTMB with spatial and spatiotemporal fields turned off. The number of halibut caught on a trip was predicted by fixed factors with the log of angler hours as an effort offset. We used AIC to determine the best model within each probability distribution then selected the final model based on Q-Q plots and residuals. The delta-lognormal distribution was selected for the final model with covariates for year, month, and block (Figure 20 and Table 6).

The final index has large standard errors, particularly in the last decade (Figure 21), but shows a similar trend over time to an empirical index calculated with the same data (Figure 22).

2.2.5 Trawl Logbook Index of Abundance

Trawl logbook records are stored in the CDFW Marine Log System (MLS) back to 1980, as well as the PacFIN database back to 2004. Procedures for data entry, storage, and sharing between these systems have varied over time with some periods of duplicated effort and others with PFMC staff entering logs with federally managed groundfish and CDFW staff entering logs with only state managed species. Currently both systems are maintained and data are merged regularly so that PacFIN contains complete records for all trawl types. For this analysis, PacFIN records from 2005-2022 were appended to MLS records from 1997-2004. Records with an average set latitude equal to or less than 34.5772°N were assigned to the southern California region. In the few cases where no set coordinates were available, records were assigned based on port of landing. Logbook data are available from the trawl fishery beginning in 1980, but compliance rates were variable across years and regions. Compliance rates are defined as the percentage of individual landings that have a corresponding logbook record. In southern California, the index is calculated from data beginning in 1997 when compliance rates first rose above 30%. Between 1997 and 2018, between 33-95% of actively fishing vessels submitted trawl logs. We removed trips from rarely or inconsistently used ports as well as records recording tows with a duration greater than 10 hours. Despite filtering tow locations to GPS positions within southern California, some fishing blocks north of Point Arguello remained in the data and these trips were removed.

The combined databases from 1997-2022 contained 70,939 trips in southern California (Table 7). The data were then subset to include only records of trips that identified halibut as the target species, when that information was available, and those trips with an average depth of 50 meters or less. This decision was motivated by examining the average trip depth reported on trawl logbooks that landed halibut. Those data show that the majority of halibut are captured in depths shallower than 50 meters.

Similar to the CPFV logbook index, we used sdmTMB with spatial and spatiotemporal fields off to explore models with different probability distributions and covariates. Covariates included year, port, month, and depth centered and scaled by its mean then squared. We also examined models predicting the number of halibut caught at the level of individual trips as well as summarized up to the trip level with tow hours as an effort offset. Based on Q-Q plots, residuals, and AIC, the delta-lognormal distribution was selected for the final model with covariates for year, month, port, and scaled depth predicting halibut caught at the level of individual sets (Table 8 and Figure 23).

Both raw CPUE, calculated as the annual average of set level CPUE, and the modeled index show high levels in 2021 and 2022 (Figure 24 and Figure 25). Total pounds landed by the commercial trawl fleet have been relatively low (Figure 26), indicating that effort has also been low.

2.3 Fishery Independent Data

The California Cooperative Oceanic Fisheries Investigation (CalCOFI) provides an extended time series of data on ichthyoplankton collected by bongo nets at fixed stations throughout the California current with core stations occurring in southern California. Raw CalCOFI sample data for 1951-2021 were provided by A. Thompson (NMFS, SWFSC) who filtered the data for consistency in sampling methods across the time series. Surveys during the early years of the program were conducted monthly and also were not always located at what later became fixed sampling stations. During these years, only one monthly survey was selected per season at a time closely matched to the currently quarterly sampling. Sampling locations outside of the current fixed station pattern were removed. Additional nearshore (SCCOOS) stations were added to the program in 2004 but these were not included for this analysis. Offshore stations (station numbers <=60) were also excluded.

These filters produced a data set with 6,498 ichthyoplankton tows, of which 232 were positive for halibut larvae. The data were further filtered to include only survey stations that had seen halibut larvae at least once during the time series and tows that occurred at a latitude less than 34.5°N. Halibut larvae were observed in all seasons (
Table 9). The resulting frequency of samples and positive halibut observations by line and station are reported in Table 10 and illustrated in Figure 27. The final index was based on a total of 4,249 tows and 224 positive halibut observations. Due to high interannual variability in the proportion of positive tows (Table 11), data were binned into three-year 'super years'. The model selection using AIC best supported a binomial GLM with super-year, season, and line-station effects. Season was retained in the model despite inconsistency in sampling in recent years with no winter samples from 2014-2019, no sampling in 2018, and only spring samples in 2017 and 2019. The final model was run in the R package rstanarm with the index and uncertainty being the mean and standard error of posterior predictions.

The final index (Figure 29) showed a similar trend to the empirical index based on the proportion of positive tows for halibut by super year (Figure 28) with peak abundance occurring in the late 1980s to early 1990s.

2.4 Biological Data

All biological parameters for each sex are provided in Table 12 and Table 13, which also specifies which are fixed and which are estimated internally. The rationale for each parameter choice is provided below.

Natural Mortality
The 2010 halibut assessment fixed natural mortality (M) at 0.2 for females and 0.3 for males based on M estimates for summer flounder, another species in the genus Paralichthys (Maunder et al 2010). Lower observed maximum age in the population for males and different growth patterns between the sexes support the assumption that males experience different, likely higher M. Estimating M directly is extraordinarily difficult and estimation of M within the model is confounded with other uncertain parameters such as growth and steepness, as well as uncertainty in the aging process. We therefore fixed M at values calculated using the approach developed by Then et al. (2015) and updated by Hamel & Cope (2022) using the equation $M = 5.4/A_{max}$. We used the maximum reported ages of 30 and 23 for females and males to produce point estimates of 0.18 and 0.2347826.

Growth
Growth parameters were updated from the 2020 assessment which fixed all parameters based on external estimates from a von Bertalanffy growth function (VBGF). Our approach was to first, externally estimate VBGF parameters using all available age and length data and the Schnute parameterization with L1 representing length at age 2 and L2 representing length at age 14 for both sexes. Second, these parameters for L at Amax, L at Amin, and K were entered as priors for both sexes. Third, we explored the model's ability to estimate growth parameters that are biologically realistic and allowed CVs to be estimated. Ultimately, female L at Amax was fixed at the external estimate while all other parameters were allowed to be estimated. Male L at Amax and L at Amin were fixed at the external estimates while K, and the CV of young and old fish were estimated. Male CVs were later fixed at their estimated values to improve stability.

Weight -length relationships were modeled using CDFW unpublished data sampled from a combination of fisheries in southern California, fit to the allometric growth equation, $Weight =$

$\alpha \times Length^{\beta}$. Growth in terms of body size is almost perfectly isometric with length, and the relationship is very similar between male and female fish though there are less observations for large males. The two sexes are parameterized separately in the model.

Reproduction
The maturity-at-length ogive was estimated for southern California halibut by Love and Brooks (1990), and in central California by Lesyna and Barnes (2016). Parameters presented in Love and Brooks are used to model logistic maturity in the assessment and are not estimated. We modeled fecundity proportional to female length based on estimates of batch fecundity with length and average number of spawning events per year reported by Barnes and Starr (2018). This is a departure from the 2020 assessment which set fecundity proportional to spawning biomass.

Stock-Recruit Relationship
Little information is available to inform the parameter choice for the stock-recruit relationship other than meta-analyses of other flatfish with similar life histories (Myers et al. 1999). The steepness parameter (h) defines the proportion of unfished recruitment that would occur if the population was reduced to 20% of its unfished biomass. The 2010 assessment used a steepness value of 1 based on values used in an assessment of Summer Flounder, a flatfish of the same genus with a similar life history that inhabits the northwestern Atlantic. The steepness value was reduced to 0.9 in the 2020 assessment to reflect their high fecundity, but also represent a more biologically reasonable relationship between stock size and recruitment capacity and we maintained this assumption. A range of steepness values was tested in the sensitivity analyses.

2.5 Datasets Considered, but not Used

Conditional Age at Length Growth Fleet
The CDFW age at length database includes samples of halibut from several fishery-independent research surveys that could be included in a "growth fleet" in the model conditional age at length data. These samples were derived from various surveys using hook and line and trawl gear by CDFW staff and other researchers. Research trawls typically used otter trawls with smaller dimensions and mesh sizes (1-1.5 inch) than are used by the commercial trawl fishing fleet (7.5 inch). CDFW has conducted surveys since 2018 in shallow water (10-25 ft). The Orange and Los Angeles County sanitation districts conduct surveys within a wider depth range but focused near sewage outfalls. The Southern California Coastal Water Research Project (SCCWRP) conducts surveys every 5 years at a range of depths and random locations throughout the southern California Bight. Because these surveys are limited in their temporal scales and spatial representativeness, they were not considered for indices of abundance. Also, because the survey trawl gear is very different from commercial trawl gear, they could not be associated with the fishing fleet. Determining an appropriate selectivity for these samples aggregating multiple survey types was challenging and estimates of growth parameters within the model were sensitive to fleet selectivities. Therefore, the growth fleet was removed from the base model.

Private, Rental Boat, and Shore-Based Recreational Catch per Unit Effort
The CRFS program conducts interviews of anglers returning to launch ramps and fishing from shore. We constructed a standardized abundance index based on the number of sampler observed halibut and the number of angler trips between 2004-2022. The data was filtered to

include only CRFS districts 1 and 2 for southern California as well as only the nearshore, bay, Santa Rosa Island, Santa Cruz Island, and Santa Catalina Island water areas where halibut catches were highest. Other data filtering procedures were to include only surveys conducted during February to November, trips reporting hook and line gear as the primary gear type, and trips with halibut as the reported primary or secondary target species. The index was modeled with a negative binomial probability distribution with an effort offset and covariates included district, wave, primary target species, and year with interaction terms for district x primary target, district x wave, district x year, and primary target x year. The final model was run in the R package rstanarm with the index and uncertainty being the mean and standard error of posterior predictions. The index was ultimately not included in the assessment model for several reasons. The data included only 2,071 retained halibut which is a much smaller sample size than the other fishery-dependent indices included in this assessment. The q-q plot showed substantial deviation from a straight line (Figure 32), and the model poorly predicted the number of observations with zero halibut (Figure 33). Finally, the index showed anomalously low values between 2012-2014 that we could not explain (Figure 34).

Swept-Area Estimate of Abundance

Domeier (1994) conducted a trawl survey which specifically targeted halibut in the southern region, generating an estimate of abundance using the ‘swept-area’ approach. They estimated number of fish in the southern area, including islands, was 3,862,104 with 90% confidence intervals (CI) ± 712,740. However, this estimate likely has significant bias for several reasons. First, few large individuals were caught, suggesting that the gear type was only selecting smaller individuals. The sex ratio also captured a higher percentage of male halibut, further suggesting gear selection toward smaller individuals. In addition, it was implicitly assumed that fish were evenly distributed across space and time and that catchability = 1. Both of these assumptions are very unlikely to have been met in this survey and consequently, this abundance estimate was not used in the model.

Ocean Resources Enhancement Hatchery Program (OREHP) Gillnet Survey

The OREHP gillnet survey was designed to monitor the effects of releasing hatchery-raised White Seabass in southern California. Halibut were incidentally caught in some of the gillnetting efforts. Two separate surveys were conducted; the first by The California State University of Northridge (CSUN) survey, which covered the northern two-thirds of the Southern California Bight and the second by Hubbs-Sea World Research Institute (HSWRI) which covered the lower third of the bight ending at the US-Mexico border. The two surveys used different gillnet specifications (e.g. mesh size, panel height) that would have impacted their selectivity curves. In addition, both surveys switched mesh sizes over the course of the survey, although CSUN standardized their gear in 1992. Length data (not sex specific) were available with which to estimate selectivity for each of the two surveys. However, they must be considered separately, they each only cover a small portion of the coast, and there was variation in the gear used by HSWRI. In addition, the gillnets were set approximately 1 meter off the bottom with the intent of targeting white seabass. Likely for this reason, sample sizes were low and previously standardized indices (Maunder 2010) had very high CV’s. Therefore, the two OREHP surveys were deemed unreliable indices of abundance and were not included in the model.

Southern California Edison Impingement and Trawl Surveys

The Southern California Edison company has been conducting several types of impingement surveys as well as a trawl survey in the southern California bight beginning in 1972. The impingement surveys provide data on the number of fish captured per volume of water, and while the surveys are of a fine temporal scale, they only provide data for very specific locations (power generating stations). Consequently, the impingement data were not used in the assessment. The trawl survey was also conducted over a very small spatial area nearshore to several electricity generating facilities. For this reason, the trawl survey data were not considered representative and were not used to construct an index of abundance. A standardized index resulting from these data was found to have moderately high CV's and was excluded from the previous assessment with similar justification (Maunder 2010). However, samples from this survey were used to inform growth in the current model by including them in the conditional age at length data within a growth fleet.

Los Angeles County Sanitation Districts (LACSD) Trawl Survey

Halibut catch and length composition data have been collected semi-annually since 1973 by trawl surveys conducted by the three sanitation districts in LA county (LACSD 2018). However, the data are only collected across a very small geographic area spanning the Palos Verdes Peninsula and are likely unrepresentative of population trends which occur across the southern California bight. Additionally, only positive catch data are available for Halibut, which precludes creating a standardized index of abundance and sex was not identified for measured halibut. For these reasons, the LACSD data were only used to inform growth in the current model by including them in the conditional age at length data within a growth fleet.

3 Model

3.1 Previous Assessments

3.1.1 History of Modeling Approaches

The first statistical catch-at-age model for halibut using the integrated analysis program Stock Synthesis (SS2; Method and Wetzel 2013) was conducted in 2010 (Maunder et al 2010). Two stocks divided at Point Conception were modelled separately with different growth, natural mortality, and selectivity parameters for males and females. Due to limited size composition and discard data for the central stock, selectivity parameters were mirrored to the southern stock. The model was fit to length composition data and indices of abundance from CPFV and trawl logbook data. The southern model was initiated in 1971 at an estimated depletion of 16% and by 2010 the stock was estimated to be depleted to 14% of unfished levels.

A similar configuration was used for an assessment update in 2021 conducted by CDFW staff member Kathryn Meyer. A peer review was conducted and found that neither the central or southern California models were adequate for use in management. The report stemming from that review is provided as an appendix to the Terms of Reference for this assessment review. The post-review base model estimated stock depletion in the final year (2020) at approximately 20%. Final assessment reports for those regional models were not produced, in part because the models would not be used for management and additionally because of a lack of staff capacity. The present assessment represents an effort to meet the primary research recommendations of the peer review for the southern model only. Below we list the 2020 peer review recommendations for future research and data collection pertaining to the southern stock, along with actions taken for the present assessment to meet those recommendations.

3.1.2 2020 Assessment Recommendations

The following are responses to recommendations for future research and data collection identified by the 2020 peer review panel. Additionally, we address responses to other technical deficiencies of the 2020 model in section 3.3.1.

1)

a) Recommendation: Reconstruct historical commercial and recreational landings using all available data (e.g., Fish Bulletins 32, 49, and 174) and reasonable assumptions about early, undocumented time periods. A time series of historical catches extending back to (or nearly to) the start of the fishery would eliminate the need to estimate initial fishing mortality rates. This is the most common approach to modeling groundfish populations off the U.S. West Coast. Estimates of initial Fs were sensitive to assumptions about initial equilibrium catch in the southern model and were not estimable in the northern model.

b) Response: We constructed a time series of historical commercial and recreational catches back to 1916 and assumed a linear ramp up from 0 to the 1916 catch value. California's statistical records on fish landings began in 1916 and summaries of that data were reported in Fish Bulletins. Historic landings of California halibut as well as other historical information about the fishery were compiled by Barsky (1990). Statewide catches of California halibut were available from 1916 to 1929 with corrections made to exclude fish caught in Mexico but landed in California. I assumed all the landings during this period could be attributed to southern California based on the following statement: "The geographic center of the halibut fishery has changed. Historically the fishery was centered off southern and Baja California. When collection of fish statistics began (1916), large catches of halibut were made by the San Pedro fleet in local waters from January to June. From June to December the fleet fished Mexican waters and made large catches, most of which were landed in San Diego (Clark 1931). North of Ventura County, the fishery was much smaller." Landings by port region were reported from 1930 to 1970. I summed the reported landings for southern ports and applied a reduction of 35% across all years to exclude Mexican fish. All of the catch prior to 1971 was attributed to the gillnet fleet and a ramp from 1880 to 1916 was used to estimate catches back to a year when catch would have been close to zero based on historical descriptions from Ueber (1988) indicating "entangling nets" dominated the fishery and have been used continuously since the 1880s. For recreational fleets, statewide CPFV catch reported on logbooks in numbers of fish is published in Fishery Bulletins beginning in 1936. Based on logbooks collected since 1980, CPFV catches in central CA were historically very small, especially prior to 2000. Therefore, I assumed the historical statewide CPFV landings reports could be attributed to southern CA. A linear ramp up in catch from 0 in 1916 was used. Reed and MacCall (1988) report that CPFV caught fish represented about 40% of total recreational catch in the 1960s. I assumed this proportion was consistent for all years prior to 1971 and used it to attribute catches to the OtherRec fleet. Recreational bag and size limits were not in place until 1971 so no historical recreational discard catches were used. Sensitivity of the assessment model to these historical catches was explored.

2)

a) Recommendation: The CalCOFI ichthyoplankton time series extends back to 1951 in Southern California. Extending the modeled time period (at least back to 1951) would allow for the entire CalCOFI ichthyoplankton time series to be included in the southern model. Investigate why estimates of uncertainty (i.e., the annual log-scale standard errors) for this index were so large in the revised binomial index.

b) Response: The CalCOFI index was fully revised as described in section 2.1.9. Index values back to 1951 were used for model runs extended back to 1880.

3)

a) Recommendation: Increase sampling of the full population's age structures to allow for internal estimation of all growth parameters in the models. This will also allow for comparison of regional growth patterns. The Panel recommends that CDFW increase efforts to collect age structures (otoliths) on an annual basis to assist with estimation of growth and recruitment parameters in the model. Sampling should account for both sexes in a way that is representative of the largest fisheries (e.g., bottom trawl and non-CPFV recreational boats). Roughly 50-100 otoliths per sex and major fishery (200-400 otoliths total, per year in each region) is a recommended minimum, with a target sampling rate of twice that amount.

b) Response: CDFW staff are making efforts to continue otolith sampling but currently don't have capacity to increase beyond historical sample sizes.

4)
  a) Recommendation: Collect information on discard rates and the size distribution of discarded fish in major commercial and recreational fleets in both the Northern and Southern areas.
  b) Response: Improved discard monitoring is a long-term goal for CDFW. Recent studies of the trawl fleet designed to quantify catch and bycatch relative to the California Halibut Trawl Grounds can be used to improve our understanding of discard sizes and reasons.

5)
  a) Recommendation: The southern model is sensitive to assumptions about the fecundity-size relationship (see Request #6). Develop size-dependent brood (batch) fecundity relationships (e.g., fecundity-length) that reflect increases in weight-specific fecundity (eggs/gram) with female size or age. Also investigate whether the number of broods produced in a year varies as a function of female size or age.
  b) Response: We used estimates of batch fecundity with female size reported by Barnes and Starr (2018) to model fecundity as described in section 2.1.10 and present sensitivity to alternative assumptions. Fecundity proportional to spawning biomass and to female length were used as an axis of uncertainty in the decision tables (tables 17 and 18).

6)
  a) Recommendation: Collect additional gonads for maturity studies, being sure to adequately sample the 50-70 cm size range to better estimate the slope of the maturity ogive; do this for both the northern and southern areas.
  b) Response: This remains a goal for CDFW.

7)
  a) Recommendation: Information on the densities and size/age compositions of California halibut, in particular in areas directly south of the U.S. California-Mexico border, would improve our understanding of ranges, dynamics and status of stocks which extend into Mexico.
  b) Response: This remains a goal for CDFW.

8)
  a) Recommendation: Investigate the influence of ocean warming on the distribution and life history characteristics of the two stocks.
  b) Response: This remains a goal for CDFW.

9)
  a) Recommendation: Likelihood profiles indicated that recruitment deviations were a large component of the total likelihood. The specified level of recruitment variability (sigma-R of 0.6) was less than the standard deviation of the estimated recruitments (0.887) in the southern model. The influence of sigma-R on estimates of recruitment and other model outputs should be examined further.

b) Response: We fixed sigma-R at 0.7 for this assessment, providing a value that is slightly larger than the standard deviation of recruitment deviations in the main estimation period, which is 0.67. We performed a sensitivity fixing sigma-R to a value of 0.9 and this is described in section 3.4.2.

10)

a) Recommendation: Given the size that halibut can attain, it may be beneficial to format the composition data using 2-cm length bins, rather than 1-cm bins as in the base models. This reduces model dimension, speeds estimation, effectively doubles the number of samples per data bin in conditional age-at-length data, and has been shown to produce unbiased results (Monnahan et al. 2016). The 2-cm bin width should apply only to data bins. Population length bins should remain 1-cm.

b) Response: Data bins were revised to 2-cm for the present assessment.

11)

a) Recommendation: Long-term declines in the amount of estuarine habitat in California may have affected the productivity, status, and/or scale of the California halibut population relative to historical periods. This environmental factor is not explicitly accounted for in the current assessment, but may be a topic worth exploring as part of a Management Strategy Evaluation (MSE).

b) Response: CDFW has been developing tools for MSE and has worked with the creators of the MSEtool R package to increase the platform's capacity to model multiple stocks and fleets as well as recreational bag limits. We plan to construct an operating model based on the present assessment results and perform an MSE.

3.2 Model Description

The southern U.S. population of California halibut (*Paralichthys californicus*) is assessed in Stock Synthesis (ver. 3.30.19.01) using a sex-specific, age- and length-structured statistical catch-at-age model with different natural mortality rates, growth, and selectivity parameters for males and females. The model is fit to two fishery-dependent indices of relative abundance calculated from standardized CPFV logbook and trawl logbook data, a fishery-independent index of recruitment calculated from standardized CalCOFI larval data, as well as length composition data from both recreational and commercial fisheries and age composition data from the commercial fisheries (Figure 13). There are five separate retention fleets in the model with corresponding discard fleets; Commercial Passenger Fishing Vessel (CPFV), recreational hook-and-line (OtherRec), bottom trawl, gillnet, and commercial hook-and-line (ComHL). Selectivity is estimated separately for males and females for the retention fleets for trawl, gillnet, and OtherRec. Selectivity is not sex-specific for the other retention fleets due to a lack of male length samples. Selectivity is estimated for the discard fleets for trawl, gillnet and CPFV with OtherRec and ComHL being mirrored to CPFV. We assume asymptotic selectivity for the ComHL and CPFV fleets due to their ability to fish farther from shore where larger halibut are located and the presence of larger halibut in the length samples from those fleets. Other fleet selectivities are assumed to be dome shaped. Female growth parameters are estimated with the exception of L at Amax which is fixed at an externally estimated value. Male growth parameters are fixed at external estimates with the exception of K, which is allowed to be estimated. R0 is estimated within the model but natural mortality (M) and steepness (h) are fixed. The modeling period begins in 1971, which is substantially later than the onset of the fishery in the late 1800s. This decision was based on very limited data prior to 1971 and an exploration of the sensitivity of model results to extension of the model to an assumed initial condition of no catch in 1880 and historical catch reconstruction for landings between 1881-1970.

3.3 Model Structure and Assumptions

3.3.1 Transition to the Current Stock Assessment

Model files from the 2020 update were available for this assessment. The goal of this assessment was to respond to the peer review recommendations from the 2020 update that could be immediately implemented, with the hope of achieving a model useful for management decision making. In addition to the recommendations addressed in the section above, we addressed additional concerns of peer reviewers highlighted in other sections of their report and made other adjustments we deemed appropriate.

The main additional efforts undertaken since the 2020 update and changes to the model are listed here and described more fully in sections below.

- All abundance indices were re-analyzed.
- Francis weights were applied to tune the sample sizes of length and age by fleet. Three iterations of adjustments were made until the tuning factors were close to one, except that input sample sizes were not upweighted. Previously, tuning was done only until the uncertainty value around the Francis factors overlapped one. Years for recruitment bias were also adjusted.
- All landings data were updated adding additional years to extend the time series through 2023. Previously overlooked gear codes associated with the gillnet fleet were added, increasing recent gillnet landings.
- All age data and estimates of uncertainty were updated and extended to 2022.
- All length composition data were updated and extended to 2023.
- Discard rates were used to estimate annual amounts of discard and provided to the model as discard fleets associated with each landings fleet. Originally, discard rates were input to the model and it was unclear if the equilibrium catch from each fleet represented landings only or landings plus discards.
- Historic landings data and an assumed ramp up from zero landings were used to examine the sensitivity of model results to initial conditions.
- The CalCOFI larval index of abundance was reanalyzed, including new coefficients of variation. The time series was extended to 1950 for model versions including historical data previous to 1971. The index was revised in the assessment to be indicative of recruitment, rather than spawning stock abundance. CalCOFI bongo net tows sample halibut larvae that have already experienced post-egg survival which may make them more indicative of recruitment than spawning biomass. Additionally, the index was not fitting spawning biomass well and showed a similar trend to the recruitment deviations.
- Some previously fixed growth parameters were allowed to be estimated within the model (see section 3.3.6).
- We used Point Arguello as the boundary differentiating the southern stock from the central California stock, rather than Point Conception which had been used previously. This was done to better align with regulations which differentiate areas where gillnet gear is permitted and the boundary of the California Halibut Trawl Grounds. Point Arguello lies approximately 12 miles north-west of Point Conception.

3.3.2 Summary of the Fleets

Eleven fleets are included in the base model:

Commercial: Six commercial fleets were specified which include landings fleets for gillnet, trawl, and hook and line gears as well as corresponding discard fleets for each. These fleets were specified in weight. We are aware of no estimates of discard mortality specifically for California halibut. We assumed discard mortality rates of 50, 30, and 10% for the trawl, gillnet, and recreational fleets, respectively.

Recreational: Four recreational fleets were specified in numbers of fish including retained catch for the Commercial Passenger Fishing Vessel (CPFV) fleet, retained catch for all other forms of recreational take (but is primarily hook-and-line from personal vessels) (OtherRec), as well as discard fleets for each.

Survey: CalCOFI survey data were used to develop a triennial index of recruitment.

3.3.3 Other Specifications

Length compositions were available by year and gear type with a wide range of sample sizes. Those year/fleet/sex combinations which contained less than 20 length samples were omitted from the analysis.

Southern California has a long history of halibut fishing prior to the beginning of the modeling period. The average landings for the 20 years prior to 1971 (1951-1970) was attributed to each of the commercial fleets as an initial equilibrium catch in the proportion those fleets represented during the first five years of the modeling period (1971-1975). The average CPFV catch reported on logbooks between 1951 and 1970 was provided to the CPFV fleet. An initial catch was provided to the OtherRec fleet based on a report from Reed and MacCall (1988) that CPFV catch represented approximately 40% of the total recreational catch in the 1960s. Discard fleets were provided with catches based on multiplication of the corresponding retention fleet catch with discard rates and mortalities as described in sections 2.1.2 and 2.2.2. We found that initial fishing mortality rates estimated for the commercial hook and line and discard fleets were so small that they hit their lower bounds of 0. We then combined the discard fleets together and grouped commercial hook and line fleet catch with trawl.

The model includes population age bins ranging from 0 to 30 years, after which point any older predicted ages are lumped into the 30-year-old bin as a ‘plus group’. There were no age observations greater than 30. The population and data length bins range from 10 to 140 cm in 2 cm increments, again with the max end of that range acting as a ‘plus group’. The following likelihood components are included: catch, indices, discards, length compositions, age compositions, and recruitment.

3.3.4 Modeling Software

Stock Synthesis (Methot and Wetzl 2013), version 3.30.19.01 was the selected modeling framework for this assessment. Post-processing of the assessment output was done in R using the r4SS package (v1.49.1).

3.3.5 Data Weighting Approach

The length and age compositional data were iteratively reweighted using the method of (Francis et al 2011). Models were reweighted as follows:

- With input sample size multipliers for age-at-length compositions fixed at 1.0, input sample sizes for length compositions were multiplied by a factor less than 1 so that the Franics data weighting method multipliers were close to one.
- Input sample sizes for age-at-length compositions were then multiplied by a factor less than 1 so that the Francis data weighting method multipliers were close to one. Suggestions for a multiplier greater than one were left at one to not upweight more than the input sample size (i.e., the number of samples which is larger than commonly used as an input sample size).
- Input sample sizes for length compositions were multiplied by a newly suggested factor less than 1 so that the Franics data weighting method multipliers were close to one. This was a minor adjustment.

Additional down-weighting of some discard fleet length compositions was done to reduce the size of residuals. Most length compositions were down-weighted from the input sample sizes. Data source weights (or emphasis factors) can also be specified in Stock Synthesis (i.e., "lambdas"). In this assessment, there was no clear reason to down-weight (or up-weight) particular data sources relative to each other (apart from the application of Francis weights to the composition data and additive variances to some indices), so all likelihood components were assumed to have equal emphasis (l=1) in the base case model.

3.3.6 Key Assumptions and Structural Choices

As many parameters as possible were estimated to propagate uncertainty into derived quantities such as estimated spawning output. However, many parameters were fixed (Table 12) because there was very little information informing them or estimating them resulting in an unstable model (e.g. lack of consistent convergence).

Selectivity: The peak, and ascending and descending limb parameters for double normal selectivity curves were estimated for the trawl, gillnet, and OtherRec retention fleets. Peak and ascending limb parameters were estimated for the ComHL and CPFV fleets, allowing their selectivities to be asymptotic. Males and females were modeled separately for those fleets with male length samples including trawl, gillnet, and OtherRec. Discard fleet double normal selectivity parameters were estimated for sexes combined with OtherRec and ComHL discard selectivities mirrored to CPFV due to larger sample sizes for that fleet.

Stock-recruitment: R_0 was estimated but all other stock-recruit parameters were fixed (steepness (h) = 0.9, SigmaR (σ_R) = 0.7).

Natural Mortality: Natural mortality (*M*) rates for females and males were fixed at 0.18 and 0.235, respectively, determined using maximum ages of 30 and 23 (see above).

Catchability: Catchability (*Q*) parameters were estimated for the two fishery-dependent CPUE indices (trawl and CPFV) and one fishery-independent index of recruitment (CalCOFI).

Initial F: Initial fishing mortality rates were estimated for the trawl, gillnet and OtherRec fleets and assumed to be zero for the other fleets.

Recruitment deviations: Recruitment deviations were estimated for all years from 1947 to 2023 with 1977 to 2021 representing the main period that was forced to sum to zero.

Growth: All female growth parameters were estimated with the exception of L at Amax, representing length at age 14, which was fixed at an externally estimated value. Only von Bertalanffy K was estimated for males and other parameters were fixed at externally estimated values. The male and female coefficients of variation-at-age (CVs-at-age) were modelled as a linear relationship with length-at-age. Female CVs were estimated and male CVs were fixed at values estimated when fixing all growth parameters except the CVs in an early run.

Many of the key assumptions and structural choices made in this assessment were evaluated through sensitivity analysis (section 3.4.2). A major assumption within this assessment was the decision to separate the stocks at Point Arguello and the U.S.-Mexico border, and to model southern California as a distinct population. There is certainly some degree of adult movement and/or larval dispersal across both of those borders, which is not captured within this modeling framework. In addition, the decision to initiate the model in 1971 when data became more available but well after development of the fishery, likely introduced uncertainty in the estimation of initial stock status. This assumption was explored in sensitivity analysis. Combining different trawl and gillnet gear configurations into general gear categories ignores potential variability in the selectivity of those gear configurations. Unreliability in reporting of gear codes on landing receipts and the lack of specificity in gear configurations in observer data required this assumption. We allowed selectivity to be sex-specific for those fleets having length samples with sex recorded. We also assumed that those fleets tending to operate closer to shore, including trawl, gillnet, and OtherRec, have dome-shaped selectivity. Adult females migrate on and offshore due to energy requirements associated with egg production while adult males mostly remain offshore. Males may therefore be less available to the trawl, gillnet, and OtherRec fleets and the largest individuals residing in deeper waters may also be less available. We included a time block on gillnet selectivity due to a regulatory change in the minimum allowed mesh size from 8 to 8.5-inches when targeting halibut. The rule change occurred in 1989 but we assume full adoption of the rule by the fleet did not occur until 1996.

3.3.7 Evaluation of Parameters

Model parameters were evaluated for stability and precision along likelihood profile gradients, and against the main assumptions in the base case model (section 3.4.2). Stability was examined by ensuring that model parameters were not up against a lower or upper bound and had sufficiently low gradients (Table 13 and Table 14). Parameter precision was also monitored by looking at estimated standard deviations to assess the variability associated with point estimates.

3.4 Base Model Results

3.4.1 Parameter Estimates

A total of 141 parameters were estimated, including 5 growth parameters (Table 13), 1 stock-recruit parameter (Table 13), 77 recruitment deviations (Appendix B), 3 initial *F*s (Table 13), 3 extra standard deviations on the index data (Table 13), and 52 selectivity parameters (Table 14).

Growth parameter estimates were highly variable among alternative model structures and were closely linked to selectivity. At times, estimated growth curves produced maximum sizes for females greatly in excess of the largest ever recorded females and CVs for both female and male curves could be large. We attempted to compromise between allowing internal estimation of parameters and controlling for biologically realistic results. We did this by fixing female L at Amax at an externally estimated value based on all available age-length data at 104.04. Female L at Amin was then estimated to be 26.67, whereas the external estimate was 35.74, and the estimated K was 0.121 which was slightly lower than the external estimate of 0.129. Male parameters were fixed, with the exception of *k*, which was estimated to be 0.070, less than the external estimate of 0.174. Ultimately, the base model shows females and males growing similarly until age 4 when females begin to achieve larger sizes and on average can reach sizes about 10cm larger than males with wide variability (Figure 62).

Dome-shaped selectivities with a steep ascending limb near the minimum legal size were estimated for trawl and gillnet fleets and allowed to be sex-specific (Figure 36). Fewer males are selected by the trawl fleet with the maximum selectivity being less than one (relative to female selectivity) and also showing a descending limb at smaller sizes than females. Many fewer males are selected by the gillnet fleet (maximum selectivity at 0.153). We consider these results to be biologically realistic given the regulations and behaviors structuring fishing operations in these fleets. While some halibut are caught by state halibut permitted vessels and vessels targeting federally managed groundfish outside of state waters (3 miles from shore), much halibut trawl effort occurs within the California Halibut Trawl Grounds which provide exceptions to the state's more general prohibition on trawling within state waters, and allow for trawling for halibut between 1 and 3 miles from shore between Point Arguello and Point Mugu (Figure 35). This focuses halibut trawling effort in waters relatively close to shore where males are less frequently encountered. Set gillnet fishing is similarly restricted to outside state waters with the exception that fishing can occur up to 1 mile from shore or 70 fathoms (whichever is less) around the Channel Islands. This allowance around the Channel Islands and difficulty in operating set gillnets in waters greater than 60 fathoms, also concentrates effort for this fleet in relatively nearshore waters. Parameters estimated separately for the two time blocks for the gillnet fleet suggest slightly greater retention of small fish prior to 1996.

Asymptotic selectivities ramping up quickly after the minimum legal size were not sex-specific for the ComHL and CPFV fleets (Figure 36), in part due to a lack of male length samples, and additionally because these fleets have a greater capability to fish offshore waters. Sex specific selectivities with dome shape and a flat peak were estimated for the OtherRec fleet. Length samples for this fleet show that while some large fish are caught, they are a smaller proportion of samples than the ComHL and CPFV fleets likely due to limited ability for recreational vessels to reach offshore waters.

Dome-shaped selectivities for the discard fleets were estimated and showed peaks at lower lengths, as anticipated (Figure 37). The trawl discard fleet selectivity is nearly knife-edged at the minimum legal size while the gillnet discard fleet shows a more curved shape allowing for some larger fish to be discarded. This may relate to discards of legal-sized fish due to damage in the nets. Comparison of the selectivity curves between the time blocks for the gillnet discard fleet indicates fewer large fish were discarded in the early period when net mesh size was smaller while the selectivity of small fish was similar between the two periods. Selectivity estimated for the CPFV discard fleet suggests that fleet selects smaller fish than the trawl and gillnet fleets but then shows a near knife-edge decline in selectivity near the minimum legal size. The CalCOFI index selectivity was fixed to 1 for age-0 fish and 0 for all other ages (i.e. a recruitment index).

The time series of estimated recruitments and annual recruitment deviations are shown in Figure 38 and Figure 39 . The deviations suggest halibut are subject to recruitment regimes with a period of high recruitment happening in the 1980s and 90s and low recruitment since 2000. Uncertainty in recruitment is highest for three years in the early 1990s and has been low from 2000-2020. The recruitment bias adjustment applied across years is shown in Figure 40.

3.4.2 Fits to the Data

Fits to the three abundance indices generally follow the patterns of the observations, but don't match some extreme observations thus the standard error is inflated. The trawl index indicates peaks in abundance in 2009, 2021, and 2022 with 2009 being the only year model predictions are outside of inflated 95% uncertainty intervals for this index (Figure 41). The fit to the CPFV index is remarkably good and generally follows the pattern over the entire time-series including a large increase in the index in 1995 and a further increase in 2000 (Figure 41). Similar to the trawl index, the CPFV index shows an increasing trend in recent years (Figure 31). The fit to the CalCOFI recruitment index is also good as recruitment indices are expected to have a lot of extra variability and process error (Figure 41). It indicates the highest recruitments in the 1980s and 90s and low recruitments since 2000 which aligns with the estimated recruitment deviations, suggesting that it is not in conflict with other data sources (Figure 38 and Figure 39). Figure 30 illustrates the relationship between the CalCOFI index values standardized to their mean and log recruitment deviations as well as annual monthly mean ENSO index (https://psl.noaa.gov/enso/mei/). The CalCOFI index and recruitment deviations tend to be high during positive ENSO periods suggesting an influence of environmental regimes in halibut recruitment which is reflected in the index.

Fits to length composition data follow the general patterns of the data when aggregated over all years (Figure 42). The fits to male observations, which are few, for the bottom trawl fleet show a slightly higher peak than observed. Fits to the discard length compositions also follow the observed data with a steep right hand limb at the size limit. Occasionally, there are observations below the size limit in the landings or above the size limit in the discards which resulted in large residuals.

Pearson residuals for the length compositions for each year, sex, and fleet are shown in Figure 43 to Figure 48. The fits to bottom trawl landed length compositions show some patterns in the earliest years, but good fits and small residuals in more recent years. The fits to males show a bias in the early years and a large residual for a large fish in the one year observed with males since the late 1980s. Fits to the gillnet landed length compositions are similar with a slight pattern in the earliest years, generally good in later years, and some clear misfits to the earliest male observations. In the early years, fewer medium sized fish are observed than expected and greater numbers of small and large fish are observed than expected. We explored a variety of alternative selectivity parameterizations to improve these fits but could not explain the pattern (see Appendix C). Very few males are selected in the gillnet fishery (Figure 36). Occasional observations of halibut below the legal size limit occurred in gillnet landings in the 1980s and 1990s, which is why a time block on selectivity was included. The selectivity curve has a value slightly greater than zero at lengths below the size limit, but the double normal functional form and the inter-year variability in observations below the size limit make it difficult to fit these observations of small halibut. Hook and line observations of landings did not identify any males thus male-specific selectivity was not estimated. Pearson residuals for the hook and line fishery show no concerns other than a few rare large residuals of undersized halibut. The CPFV fleet contains many years of unsexed data and few years of female observations. Pearson residuals show a good fit to recent years, a slight pattern in the 1980s, and occasional large residuals for

undersized halibut. The largest residual occurs in the 134 cm length bin in 1998 and it was very rare for a large residual for these large lengths. The Pearson residuals show the most deviations from expected length compositions below the legal size limit, especially in the 1980s. Pearson residuals are generally small without patterns since 1990. Length observations for discards from the Bottom Trawl, Gillnet, and CPFV fleets show occasional large residuals for halibut larger than the legal size limit. The CPFV observed some very small fish in the mid-2000s that show a high positive residual (higher observed value than expected).
Observed and expected mean lengths for each fleet and sex are shown in in Figure 49 to Figure 54. Observed mean lengths were variable across years, but expected mean lengths followed the general trends. Observed and expected mean lengths of landings have declined in recent years. The largest mean length was observed in the Hook and Line landings in 2012 and subsequently declined; the expected mean length did not follow these observations (Figure 51). Discard mean length was smaller than landings and consistent across years, although the later gillnet discard observations are quite variable given small sample sizes.

Fits to age-at-length comps (Figure 55 to Figure 60) showed good fits to mean observed age-at-length. However, fits to the standard deviation of age-at-length were often greater than observed. Observations of length-at-age are mostly within the 95% interval of the fitted growth curve determined from the CVs of length-at-age. Observations tended to be farther from the estimated mean length-at-age when above the estimated mean length-at-age, but assuming a lognormal distribution for length-at-age did not improve the fits.

3.4.3 Population Trajectory

The female spawning output, in numbers of eggs, is used to measure the population status, and because a fecundity relationship is used, larger fish contribute more to the spawning output. This also means that the spawning output may be more sensitive to fishing and reach low values even when there is a larger amount of total biomass present.

The female spawning output was estimated at about 15 billion eggs in 1971, declined to very low values in the 1990’s (less than 1 billion eggs), and has increased since then to nearly 13 billion eggs in 2024 (Figure 65). Unfished equilibrium spawning output was estimated at approximately 96 billion eggs. Relative spawning output (spawning output relative to unfished equilibrium spawning output) was estimated at about 16% in 1971, declined rapidly to near 1% in the 1990’s, and then increased to near 14% in 2024 (Figure 66). The 95% confidence interval for the estimated 2024 relative spawning output ranges from 10.7% to 17.3%.

The estimated age 3+ biomass follows a similar pattern as spawning output, but shows some wider changes in the 1980s and 1990s, and a smaller increase in the 2000s (Figure 67). The age 3+ biomass was at a low value of slightly greater than 1,000 mt in 1992 (approximately 6.4% of unfished equilibrium age 3+ biomass) when total catch was 256 mt. Larger than average recruitment throughout the 1980s and 1990s resulted in an increasing biomass when total catch was less than 400 mt.

The fishing intensity, measured using spawning potential ratio (1 - SPR), increased to values near 0.99 in the 1980s and 1990s indicating unsustainable catches during this time (Figure 68). In recent years the fishing intensity has been reduced and has been less than the PFMC target 1-SPR target of 70% (estimated at 0.42 in 2023). Exploitation rate, reported as a proxy by dividing the total catch by age 3+ biomass, increased quickly throughout the 1970s, peaked in the late 1980s, then subsequently decreased to levels near the exploitation rate expected when fishing at the SPR target (Figure 69). Different fleets select different size ranges of the population, thus exploitation rate is a general indicator of fishing pressure.

3.5 Model Diagnostics

3.5.1 Convergence

Model convergence was checked during development of a base model by ensuring that

- The final gradient of the likelihood surface was less than 0.0001
- Parameters were checked to ensure that they were not hitting a minimum or maximum bound
- A search for a better minimum was conducted using jittered starting values ("jitter fraction" in r4ss function "jitter" set = 0.05). A total of 100 jittered runs were performed for the base model.

No parameters were at the bounds (min or max), and the gradient of the base model was 5.83516e-05. Across all 100 jittered runs, the model found no minima lower than the base case log likelihood (1774.94) and very few jittered runs returned to the exact minimum suggesting that the amount of jitter was adequate to explore the likelihood space, but the model had difficulty finding the minimum again given the amount of jitter (Figure 70). Care was taken throughout the sensitivities to ensure the model was converging.

3.5.2 Sensitivity Analyses

We evaluated sensitivity of the southern halibut stock model using a variety of sensitivity tests with alternative model configurations. These included:

- Extending the catch time series to an assumed year with zero catch and using available historical landings data.
- Investigation of Sigma-R.
- Various combinations of fixed and estimated growth parameters.
- Inclusion of a growth fleet including age samples that can't be associated with fishing fleets.
- Removal of the selectivity time block for the gillnet fleet.
- Various selectivity configurations including changing selectivities from dome shaped to asymptotic as well as removing sex-specific selectivity.
- Excluding indices one at a time.
- Including a fishery-dependent index for the OtherRec fleet.
- Reducing catches from the early period of the OtherRec by 0.4.
- Adding a time block for the OtherRec fleet based on observations of size composition deviates.
- McAllister-Ianelli weighting.
- Fecundity proportional to spawning biomass rather than length.
- Removing the minimum sample size threshold for inclusion of length samples.
- Estimating male and female natural mortality with lognormal priors following Hamel & Cope (2022).
- Estimating steepness with and without a prior.

Assumptions about fleet selectivity can have large repercussions on estimated stock status. Hump-shaped selectivity assumes large fish are less selected by a fleet and therefore their absence from length sample data need not imply that large fish are absent or have been removed by the fishery. They may still exist in the population and contribute to production. We assumed that the trawl, gillnet, and OtherRec fleets have hump-shaped selectivity and therefore don't fully select for large halibut given their concentration of effort in nearshore waters. We also assumed that the ComHL and CPFV fleets have asymptotic selectivity and therefore do fully select for large halibut given their ability to access offshore waters. We examined the impact of these assumptions by estimating asymptotic selectivities for all fleets and therefore the possibility that all fleets fully select for large halibut. We also examined a scenario with hump-shaped selectivity for all fleets. As expected, hump-shaped selectivity for all fleets results in a higher total spawning biomass and relative spawning biomass in comparison to the base model, and asymptotic selectivity for all fleets shows the lowest spawning biomass (Figure 71 and Figure 72). Given the low proportion of males in the samples, we also assumed sex-specific selectivity for all fleets with sex-specific data. This resulted in slightly higher relative spawning biomass than the base model at the end of the time series. Removing the time block on gillnet selectivity that accounts for a change in the minimum allowable net mesh size has almost no impact on spawning biomass (Figure 71).

Estimates of growth parameters could vary widely in this assessment. We examined the impact of this uncertainty by comparing a model that allowed for all growth parameters to be estimated and a model fixing all growth parameters at external estimates with the base model. Fixed parameters resulted in the highest spawning biomass and relative spawning biomass (Figure 74). Estimated parameters resulted in the lowest spawning biomass and intermediate relative spawning biomass. Estimating all growth parameters resulted in a low female maximum length, even lower than males after the age of 20. Male CV around growth length at age was very high. In comparison, fixed parameters at external estimates allow females to reach a larger maximum size that is consistently larger than males. The base model growth curves are more similar to the fixed estimates but allow slightly larger maximum sizes for both sexes. Including a growth fleet in the age composition data results in almost no change to spawning biomass (Figure 73).

We constructed a standardized abundance index based on survey data for the private recreational anglers representing the OtherRec fleet but ultimately did not include this index in the assessment (see section 2.5). This decision was in part due to unexplained patterns in the index resulting in three years of anomalously low values. Inclusion of this index, as well as inclusion of the index while removing the three anomalously low values, had little impact on spawning biomass or relative spawning biomass (Figure 75 and Figure 76). We also explored the impact of putting a time block on OtherRec selectivity at 1988 due to relatively larger residuals in the length composition data showing more small fish between 20-50 cm than expected in the early years of the dataset. This had little impact on model results.

We compared models that excluded each abundance index individually relative to the base model. Exclusion of the CPFV logbook index had the greatest impact resulting in higher spawning biomass and relative spawning biomass than the base model (Figure 77 and Figure 78). Removal of the CalCOFI and trawl logbook indices had relatively little impact.

We explored a group of sensitivities related to population productivity. First we allowed steepness (h) to be estimated with a prior based on the base model's fixed value, and without a prior. We also allowed female natural mortality to be estimated with male natural mortality fixed as an offset, but do not show these results because of the complications with growth parameters. Finally, we allowed fecundity to be proportional to spawning stock biomass rather than to female length. Each of these scenarios resulted in lower initial total spawning output than the base model (Figure 79), and thus higher relative spawning output in the final model year than the base model (Figure 80). Estimation of h with a prior resulted in a value of 0.99 and without a prior a value of 1. Natural mortality for females and males was estimated to be 0.24 and 0.42, respectively.

Other sensitivities included the use of McCalister-Ianelli weighting procedures rather than using the Francis method and increasing sigmaR from 0.7 to 0.9. McCalister-Ianelli weighting resulted in higher spawning biomass (Figure 81) and relative spawning biomass in recent years (Figure 82). Increasing sigmaR resulted in increased initial spawning biomass but little impact later in the time series and therefore lower relative spawning biomass in recent years relative to the base model. The base model length composition data includes samples only in year, fleet, sex combinations with greater than or equal to 20 fish. We removed this restriction allowing for all length samples to be included and this had almost no impact on results.

We explored alternative scenarios for historical catches. We used historical commercial and recreational landings data to extend the catch time series back to an assumed beginning of the fishery in 1880 (see sections 2.1.1 and 2.2.1 for details on data sources and 3.1.2 for a full explanation of assumptions) (Figure 11). This produced lower spawning biomass and relative spawning biomass until about 1980 when the time series converge and there is almost no difference in the estimates in recent years (Figure 83 and Figure 84). We reduced the estimated catches in the early part of the OtherRec fleet time series from 1971 to 2004 by a factor of 0.4. These estimates were based on the MRFSS survey which may have inflated effort estimates (see section 2.2.1). This resulted in slightly lower spawning biomass and relative spawning biomass when compared to the base model (Figure 83 and Figure 84).

Among the sensitivity tests exploring alternative data inputs, removal of the CPFV index had the greatest impact on relative spawning output (Figure 85). This resulted from a large impact on spawning output in the final year. Among the structural sensitivity tests, changing fecundity from being proportional to female length to proportional to spawning stock biomass had the greatest impact on relative spawning output (Figure 86). Fecundity that is proportional to female length produces a lower stock status resulting from both an impact to virgin and final year spawning output. However, yield is not as greatly impacted. Relative spawning output is increased by estimating natural mortality, which resulted in a higher M. Comparisons of likelihood and derived and estimated parameters among sensitivity tests are shown in Table 18 through Table 20.

3.5.3 Retrospective Analysis

We conducted a ten-year retrospective analysis by removing years of data ranging from 2014-2023. Relative spawning biomass is consistently, slightly reduced across the full time series with each successive removal of a year of data (Figure 87). This appears to be because total spawning output is estimated to be slightly lower with successive removals early in the time series (Figure 88). Comparison of recruitment deviations with successive removals shows that peak recruitment is estimated to be lower with the inclusion of more years of data and higher with fewer years of data (Figure 89).

3.5.4 Likelihood Profiles

Fixed parameters in this model include female and male natural mortality (M) and steepness (h). These are commonly fixed parameters that are difficult to estimate. We also fixed the female growth parameter for length at age 14 due to instability in the model when estimating this parameter. We examined the likelihood of a range of values for these fixed parameters looking at evidence for our assumption from different data sources. We also included the parameters R_0

and the female CV at age 14, which were estimated. For each likelihood profile, we provide the relative likelihood for the survey index, length composition, age composition, and recruitment data types as well as their component data sources. We also provide the impacts of varying parameter values on the recruitment deviation, relative spawning biomass, and spawning output time series.

The lowest total relative likelihood for female natural mortality was found to be lower than the fixed value in this assessment at 0.18 (Figure 90). Relative likelihood was minimized at a higher natural mortality data for the survey data and was lowest for the length data. Age data indicated relative likelihood being minimized lower than the fixed value. Recruitment is consistently reduced across the time series at lower values for female M (Figure 91) but the impact of female M on recruitment devaitions varies across the time series with lower M producing lower devations in recent years (Figure 92). Lower female M results in higher relative spawning biomass in the early portion of the time series and later switches to resulting in lower relative spawning biomass later in the series (Figure 93). Total spawning output is consistently higher with lower female M (Figure 94). All data sources pointed to higher natural mortality for males than the fixed value at 0.23 with length data being much more informative than all other data sources (Figure 95). Patterns in recruitment, recruitment devation, relative spawning biomass, and spawning output across a range of male natural mortality values had less influence on these derived outputs when compared to those for female natural mortality (Figure 96 to Figure 98). Higher values of male natural mortality also showed very little influence on spawning output (Figure 99).

This assessment fixes h at 0.9. Survey and age data suggest the relative likelihood is minimized at h values between 0.9 and 1 (Figure 100). The total likelihood of length data is minimized close to 1 with this pattern being dominated by RecOther fleet samples (Figure 100). Steepness values closer to 1 would result in lower recruitment (Figure 101) and higher recruitment deviation (Figure 102) in recent years, with higher relative spawning biomass (Figure 103) and slightly lower total spawning output (Figure 104) at the end of the time series.

The base model for this assessment estimates virgin recruitment (R_0) at 7.03. Likelihood profiles show that recruitment estimates (i.e. the deviation from mean recruitment) drive the overall likelihood with the length, survey and age data types being less informative and length and age suggesting higher values (Figure 105). Higher values of R_0 result in higher recruitment (Figure 106) and higher recruitment deviations (Figure 107) in recent years of the time series. This results in lower relative spawning biomass (Figure 108) but little change to total spawning output (Figure 109) in recent years because equilibrium unfished spawning biomass changes with R_0.

Estimates of female growth parameters were varied with different model scenarios, particularly for selectivity, and at times suggested females reach sizes larger than those observed. For this reason, female length at age 14 (L at Amax) was fixed at an externally estimated value of 104.04. Likelihood profiles show that relative likelihood is minimized at a lower value for the length data and higher for the age data (Figure 110). Conflicts among the data sources show that there is a high degree of uncertainty in this parameter and that further research is needed to better understand female growth and biases among the data sources. Recruitment and recruitment deviations are not greatly impacted by change in this parameter (Figure 111 and Figure 112). However, reducing females maximum size increases relative spawning biomass (Figure 113) and decreases total spawning output (Figure 114) at the end of the time series. Similar to estimates of female L at Amax, estimates of female CV at Amax could be large and resulted in females much larger than those observed. However, when fixing the maximum length at age 14, the CV parameter was estimated at a reasonable value 0.196. However, there is conflict among the data sources related to this parameter (Figure 115). Similar to L at Amax, the CV of this parameter has little impact on estimates of recruitment or recruitment deviations. The CV also has little impact on relative spawning biomass (Figure 116).

4 Management

4.1 Reference Points

We present the results of this assessment relative to the PFMC reference points for flatfish which define overfished and target status at 12.5 and 25% of the unfished spawning biomass, respectively. . This assessment estimates the relative spawning biomass in 2024 to have been just above the overfished reference point at 14.0%. These reference points were established by the PFMC Scientific and Statistical Committee in response to the 2009 petrale sole assessment (see first paragraph of Executive Summary in Haltuch et al. 2009). It was determined that the higher groundfish reference points may not be appropriate for flatfish that can be more productive than other groundfish and persist sustainably at lower relative biomass levels. The flatfish reference points were based on evaluation of information on flatfish productivity (steepness) for assessed west coast flatfish, published meta-analyses of other flatfish stocks, and recommendations on appropriate proxies for BMSY and FMSY in the literature. The California halibut assessments in 2010 and 2020 also used these reference points. The equilibrium yield curve illustrated in Figure 117 shows that current equilibrium yield corresponds to a slightly lower SPR value than MSY. Rather than being a normal shaped curve, the curve is skewed such that yield quickly declines to zero at low SPR values suggesting high management risk to yields to the left of MSY.

Estimated reference points and management quantities are shown in Table 15. The PFMC uses a proxy SPR for MSY of 30% for flatfish with a 25:5 control rule linearly reducing catches to determine future OFLs. The long-term equilibrium yield when using $F_{SPR=30\%}$ is estimated to be 611 mt. The yield when using an F that would lead to a long-term equilibrium spawning output of 25% of unfished spawning output would be 628 mt, which equates to an SPR of 27.1%. MSY is estimated to be 662 mt associated with an SPR of 17.4%.

4.2 Evaluation of Uncertainty

The CV for estimated spawning biomass in 2024 is 11.8% but there is considerable additional structural uncertainty as identified in the sensitivities and likelihood profiles. The fecundity relationship has a large effect on spawning output and stock status. The base model uses a fecundity curve related to female size based on Barnes and Starr (2018) while the 2020 assessment used a fecundity relationship with spawning stock biomass. Natural mortality was fixed in the base model and also had a large effect on spawning output and stock status. The decision tables present structural uncertainty related to these two assumptions.

4.3 Harvest Projections and Decision Tables

Forecasted fishing mortality (mortality from landings and discards) using an SPR equal to 30% and a 25:5 control rule to linearly reduce the fishing mortality is greater than recent fishing mortality and results in an increasing stock status (Table 16). The predicted fishing mortality is less than the equilibrium fishing mortality at SPR=30% (Table 15) because recent recruitment has been below average. At the predicted fishing mortality levels using an SPR value of 30% and a 25:5 control rule, the stock is projected to be at 16% of unfished spawning output in 2028 (Table 16).

Decision tables are provided by Table 21 and Table 22. Two five-year catch projections are provided that would maintain the stock on average, in the long-term, at an SPR of 30%. One uses a 25-5 harvest control rule and the other does not. The third catch projection fixes catch at the average observed between 2019-2023. Given that halibut is not managed using a quota system, these catch projections are highly uncertain. Regulations do not directly limit catch or effort for either the commercial or recreational sectors targeting halibut. However, the trawl and gillnet fleets are subject to restricted access permits that limit the number of vessels making landings. This is likely to keep catch within these fleets similar to their recent levels (see section 1.5). The commercial hook and line fleet is open access so catch within this fleet may grow. The recreational fleets are limited primarily by size and bag limits. Catch by these fleets has historically been much higher than recent years and has the potential to grow substantially. Table 21 provides values associated with the base model assumption of fecundity increasing with female length and Table 22 provides values associated with the assumption that fecundity is proportional to spawning biomass. Both tables compare the natural mortality values that were fixed in the base model with a higher alternative setting female mortality equal to males at 0.235. All of the scenarios presented with fecundity proportion al to female size indicate an increase in stock status over the next five years (Table 21). In this scenario, high natural mortality lowers the scale of spawning output and increases stock status. When fecundity is modeled as proportional to spawning biomass, the scale of spawning output is greatly reduced and the fraction unfished in increased (Table 22). Importantly, under this fecundity assumption and with high natural mortality, the higher catches associated with maintaining the stock above SPR 30% produce decreasing stock status over the next five years. All scenarios assume average recruitment. If recruitment is low over this time period, as it has been for most years since 2000, these projections are over-optimistic.

4.4 Regional and Spatial Management Considerations

A variety of spatial restrictions on fishing impact the fleets targeting halibut. Commercial trawl vessels with state permits to target halibut may only operate outside of state waters unless they are within the CHTG. Vessels with federal permits to target groundfish may take up to 150 lbs of halibut per trip without a California halibut trawl permit. Both these federal vessels and state permitted vessels are subject to spatial restrictions designed for groundfish such as the rockfish conservation areas and the cowcod conservation area. Set gillnet fishing is similarly restricted to outside state waters south of Point Arguello, with the exception that fishing can occur up to 1 mile from shore or 70 fathoms (whichever is less) around the Channel Islands. All commercial and recreational fleets must abide by the restrictions of California’s marine protected area network. While the network was not designed specifically to protect halibut, some MPAs include a significant amount of soft bottom habitat in depths less than 300 ft which likely provides conservation benefit to halibut. The Vandenberg State Marine Reserve is the largest MPA containing halibut habitat in shallow waters and includes 19.6 square nautical miles of soft bottom habitat in less than 98 ft depth. Surveys comparing relative halibut abundance or length distributions across protected and unprotected areas have not been done.

Spatial closures are expected to increase spatial heterogeneity in abundance and size structure of stocks and this can complicate the assumptions made in stock assessment models. Both the commercial trawl and CPFV indices of abundance used in this assessment can reflect only fish caught outside spatial closures and therefore may not reflect potentially higher abundances or larger sizes within them.

Another likely source of structural uncertainty is the assumption that this is a closed stock within the boundaries of Southern California. There may be influence from the northern stock and California halibut in waters off Mexico. This could be one reason that the stock status was estimated very low in the 1990s but recovered quickly.

4.5 Unresolved Problems and Major Uncertainties

This assessment models the southern California halibut stock as separate from stocks in Mexico as well as central and northern California. There is likely both larval dispersal as well as some adult movement across these boundaries. Improved understanding of halibut movement across the U.S.-Mexico border is badly needed as well as across Point Conception.

Growth estimates were highly variable in this assessment. Age data are limited and the capacity for CDFW to increase age sample collection and processing is unlikely to increase. Partnering with stakeholders and possibly restructuring age sample collection procedures may be helpful. This assessment suggests that southern California halibut have experienced recruitment regimes. More research is needed to understand the drivers of these regimes and potential impacts resulting from climate change. Temperature has also been found to influence sex determination with more juveniles developing as males with higher temperatures (MacNamara et al. 2024). There is also a need to understand the impacts of coastal development on juvenile halibut nursery areas.

This assessment used a fecundity relationship increasing with female size based on Barnes and Starr (2018) which had a large impact on overall results. This relationship was derived from a relatively narrow range of female sizes and further research on a wider range is needed to confirm results. This fecundity estimate was based on multiplying batch fecundity by an average number of spawning events per year. There is a high degree of uncertainty in female halibut spawning frequency and its relationship to female size or age and environmental conditions.

4.6 Research and Data Needs

1. Growth parameters were unstable in this assessment and required a combined approach of using some fixed and some estimated parameters. Increased sampling of the population's age structures should be prioritized to allow for internal estimation of all growth parameters in the model. Sampling should be structured to account for both sexes and be representative of the largest fleets.
2. The choice of fecundity relationship has a large impact on model results. Further research is needed to expand estimates of batch fecundity across a larger range of female sizes and to better understand the frequency of spawning and its relationship to female size and ocean conditions.
3. Continue researching MRFSS sampling methods and differences from CRFS methods to better understand whether a correction factor should be applied to early private and rental boat recreational catch estimates.
4. Further refine indices of abundance, exploring spatial and spatiotemporal fields in sdmTMB.
5. The STAT for the next assessment will determine appropriate methods to stratify and expand the length samples across samples and areas to calculate a length composition representative of the total catch for a specific fleet.
6. Observation of commercial hook and line fishing at sea would help to determine if retained fish are appropriately parameterized with asymptotic selectivity. Also, there are currently no size data for discarded fish from this fleet.

7. Investigate the influence of ocean warming on recruitment and sex determination.

5 Acknowledgements

We thank CDFW staff Kirsten Ramey, Kristine Lesyna, Travis Tanaka, Paul Reilly, and Miranda Haggerty for their dedication to halibut research and management and for their patience with answering assessor questions. We also thank CDFW staff member Allison Dedrick for help with the figures in this report. We thank E.J. Dick for sharing his general stock synthesis expertise, methodology for CalCOFI data analysis, and understanding of MRFSS data. Thanks to Chanel Wetzel and Melissa Monk for sharing their expertise in development of abundance indices using sdmTMB.

6 References

Barnes, C.L., Starr, R.M., and P.N. Reilly. 2015. Growth, mortality, and reproductive seasonality of California halibut (*Paralichthys californicus*): a biogeographic approach. California Cooperative Oceanic Fisheries Investigation Reports. 56: 110-118.

Barnes, C.L. and R.M. Starr. 2018. Reproductive tactics of California Halibut (P*aralichthys californicus*): Combining spawning season, interspawning interval, and batch fecundity to estimate annual reproductive output for a multiple-batch spawning fish. CalCOFI Rep., Vol 59, pp 102 – 114.

Barsky, K. 1990. History of the Commercial California Halibut Fishery. Fish Bulletin. State of California, The Resources Agency, Department of Fish and Game. 174:217.

Berkson, J. M. 1990. Fish Bulletin. State of California, The Resources Agency, Department of Fish and Game. 174:399.

Brophy, L.S., Greene, C.M., Hare, V.C., Holycross, B., Lanier, A., Heady, W.N., O'Connor, K., Imaki, H., Haddad, T., and R. Dana. 2019. Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. PLoS ONE 14(8): e0218558.

Caddell, S.M., Gadomski, D.M., and L.R. Abbott. 1990. Induced spawning of the California halibut under artificial and natural conditions. pp. 175-198 In: C.W. Haugen (ed.)., The California halibut, *Paralichthys californicus*, resource and fisheries. Calif. Dept. Fish Game, Fish Bull. 174.

CDFW. 2022a. California Department of Fish and Wildlife. California halibut, *Paralichthys californicus*, Enhanced Status Report. Contributors: Lesyna, K., Reilly, P. https://marinespecies.wildlife.ca.gov/california-halibut/true/

CDFW (California Department of Fish and Wildlife). 2022b. California Recreational Fisheries Survey Methods

Clark, G.H. 1930. California halibut. California Fish and Game. 16: 315-317.

Clark, G.H. 1931. The California halibut (Paralichthys californicus) and an analysis of the boat catches. California Division of Fish and Game, Fish Bulletin. 32: pg. 52.

Craig, M.T., Fodrie, F.J., Allen, L.G., Chartier, L.A., and R.J. Toonen. 2011. Discordant Phylogeographic and Biogeographic Breaks in California Halibut. Bulletin of the Southern California Academy of Sciences. 110 (3): 141-151.

Domeier, M.L. and C.S.Y. Chun. 1995. A tagging study of the California halibut, *Paralichthys californicus*. California Cooperative Oceanic Fisheries Investigations Reports 36:204-207.

Fodrie FJ, Levin LA. 2008. Linking juvenile habitat utilization to population dynamics of California Halibut. Limnol. Oceanogr 53:799–812.

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

Gilbert, C.H., and N.B. Scofield. 1898. Notes on a collection of fishes from the Colorado Basin in Arizona. U.S. Nat. Mus Proc. 20 (1131): 487-499.

Haaker, P.L. 1975. The biology of the California halibut, *Paralichthys californicus* (Ayres), in Anaheim Bay, California. In The marine resources of Anaheim Bay (E. D. Lane and C. W. Hill, eds), p. 137–151. Calif. Dep. Fish Game, Fish Bull. 165.

Haltuch, M.A., Hicks, A. 2009. Status of the U.S. petrale sole resource in 2008. https://www.pcouncil.org/documents/2009/11/status-of-the-u-s-petrale-sole-resource-in-2008-november-17-2009.pdf/

Hamel, O.S. 2015. A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES J. Mar. Sci.

Hamel, O.S., Cope, J.M. 2022. Development and considerations for application of a longevity-based prior for the natural mortality rate. Fisheries Research. 256.

Heimann, R. F, & Carlisle, J. G. 1970. Fish Bulletin 149. The California Marine Fish Catch For 1968 and Historical Review 1916-68. *UC San Diego: Library – Scripps Collection*. Retrieved from https://escholarship.org/uc/item/7g5908xw.

Kramer, S.H. 1990. Distribution and abundance of juvenile California halibut, *Paralichthys californicus*, in shallow waters of San Diego County. In C.W. Haugen (ed.), The California halibut, *Paralichthys californicus*, resource and fisheries, p. 99-126. Calif. Fish Game, Fish Bull. 174.

Kramer, S.H., 1991. Growth, Mortality, and Movements of Juvenile California Halibut *Paralichthys californicus* in Shallow Coastal and Bay Habitats of San Diego County, California. Fishery Bulletin. 89:195-207

Lavenherg, R.J., G.E. McGowan, A.E. Jahn, J.H. Peterson, and T.C. Sciarrota. 1986. Abundance of southern California nearshore ichthyoplankton: 1979-1984. Calif. Coop. Oceanic Fish. Invest. Rep. 27:53-64.

Lesyna, K.M., and C.L. Barnes. 2016. Assessment of length and age at maturity for California halibut (*Paralichthys californicus*), including a histologically-based description of the reproductive cycle. California Fish and Game. 102(3):79-99.

Love, M.S., and A. Brooks. 1990. Size and age at first maturity of the California halibut, *Paralichthys californicus*, in the Southern California Bight. Fish Bulletin. 174: 167-174.

Love M. 2011. Certainly more than you want to know about the fishes of the Pacific Coast: a postmodern experience. Really Big Press.

Love MS, Passarelli JK. Editors. 2020. Miller and Lea's Guide to the Coastal Marine Fishes of California, 2nd ed. Davis: UC Agriculture and Natural Resources Publication 3556.
MacNair, L.S., Domeier, M.L., and C.S.Y. Chun. 2001. Age, growth, and mortality of California halibut, *Paralichthys californicus*, along southern and central California. Fishery Bulletin. 99: 588-600.

MacNamara, R., Mankiewicz, J.L., Salger, S.A., Stuart, K., Borski, R.J., Godwin, J., Drawbridge, M. 2024. Temperature regulates sex determination and growth in the paralichthid flatfish California halibut. Journal of Experimental Zoology Part A. 341(7): 811-821.

Maunder, M., Reilly, P., Tanaka, T., Schmidt, G., and K. Pentilla. 2010. California halibut stock assessment. California Department of Fish and Game, Marine Region.

Moser, H.G., and W. Watson. 1990. Distribution and abundance of early life history stages of the California halibut, *Paralichthys californicus*, and comparisons with fantail sole, *Xysteurys liolepis*. In C.W. Haugen (ed.), The California halibut, *Paralichthys californicus*, resource and fisheries, p. 31-84. Calif. Fish Game, Fish Bull. 174.

Myers, R.A., Bowen, K.G., and Barrowman, N.J. 1999. Maximum reproductive rate of fish at low population sizes. Canadian Journal of Fisheries and Aquatic Sciences 56: 2404-2419. Needle, C.L. 2002. Recruitment models: diagnosis and prognosis. Reviews in Fish Biology and Fisheries 11: 95-111.

Pattie, B.H., and C.S. Baker. 1969. Extensions of the known northern range limits of ocean whitefish, *Caulolatilus princeps*, and California halibut, *Paralichthys californicus*. J. Fish. Res. Board Can. 26 (5): 1371-1372.

Pattison, C., and R.D. McAllister. 1990. Age determination of California halibut, *Paralichthys californicus*. Fish Bulletin. 174: 207-216.

Pauly. D. 1979. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Explor. Mer 39(2):175-192.

Plummer, K.M., Demartini, E.E., and Roberts, D.A. 1983. The feeding habits and distribution of juvenile-small adult California halibut (*Paralichthys californicus*) in coastal waters off northern San Diego county. CalCOFI rep. Vol. XXIV. 1983.

Posner, M., and R.J. Lavenberg. 1999. Movement of California halibut along the coast of California. California Fish and Game. 85: 45-55.

Reed, R.R. and A.D. MacCall. 1988. Changing the size limit: How it could affect California halibut fisheries. Calif. Coop. Oceanic Fish. Invest. Rep. 29:158-166.

Rice, J. Cadrin, S.X., and W.G. Clark. 2005. Assessment and management of flatfish stocks. In Flatfishes. pp. 461-490.

Roberts, D., E. DeMartini, C. Engel, and K. Plummer. 1982. A preliminary evaluation of prey selection by juvenile-small adult California halibut (*Paralichthys culifornicus*) in nearshore coastal waters off southern California. In G.M. Cailliet and C.A. Simenstad (eds.), Gutshop ’81, Fish Food Habits Studies, Proceedings Third Pac. Workshop: Asilomar Conf. Center, Pacific Grove, Calif.; December 6-9, 1981, p. 214-223.

Sunada, J.S. 1985. Prawn resource assessment cruise. Cruise Report 85-X-10. Calif. Dept. Fish and Game. Unpublished. Available from CDFG, Long Beach.

Sunada, J.S., Velez, P.V., and C.A. Pattison. 1990. Age, size, and sex composition of California halibut from southern California commercial fishery landings, 1983-1988. In The California halibut, *Paralichthys californicus*, resources and fisheries [C.W. Haugen, ed.], pp.303-319. California Department of Fish and Game, Fish Bulletin 174.

Then, A. Y., J. M. Hoenig, N. G. Hall, D. A. Hewitt. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES J. Mar. Sci. 72: 82-92.

Tupen, J.W. 1990. Movement and growth of tagged California halibut, *Paralichthys californicus*, off the central coast of California. In C.W. Haugen (ed.), The California halibut, *Paralichthys californicus*, resource and fisheries, p. 199-206. Calif. Fish Game, Fish Bull. 174.

Ueber, E. 1988. The traditional central California setnet fishery. Marine Fisheries Review, 50(2): 40–48.

Wallace, M. 1990. Catch estimates, size composition, and distribution of California Halibut caught by southern California commercial passenger fishing vessel anglers. In The California halibut, *Paralichthys californicus*, resources and fisheries [C.W. Haugen, ed.], pp.383-397. California Department of Fish and Game, Fish Bulletin 174.

Wertz S.P. and M.L. Domeier. 1997. Relative importance of prey items to California halibut. California Fish and Game 83(1):21-29.

Young, P.H. 1962. California halibut investigation. Proc. First Nat. Coastal Shallow Water Res. Conf., Tallahassee, Fla. Pp. 623-625.

7 Tables

Table 5. Data filtering procedures for the CPFV logbook abundance index.

Description	Samples	Percent_Positive
California data south of Point Arguello	687209	0.122
Remove uncertain species data and records with no or unreasonable effort	672816	0.124
Remove infrequently sampled ports	672776	0.107
Limit to Coastal Blocks	624001	0.111
Stephens-MacCall, Remove predicted false negatives	121775	0.568
Remove extreme catch rates	121518	0.567

Table 6. CPFV logbook GLM probability distributions, factors, AIC, and negative log likelihood.

Probability Distribution	Covariates	AIC	NLL
Delta Lognormal	Year, Month, Block	440172	-219847
Delta Lognormal	Year, Month, Region	445641	-222712
Delta Lognormal	Year, Month, Region, Region x Year	442282	-220872
Negative Binomial	Year, Month, Block	424740	-212250
Negative Binomial	Year, Month, Region	428284	-214087

Table 7. Trawl logbook data filtering procedure and resulting change in trip number and percent of trips with halibut.

Description	Samples	Percent Positive
Trawl logbook data south of Point Arguello	70939	0.606577482
Targeting CA halibut, <50 m depth	78682	0.830393228
Remove rarely or inconsistently used ports	56005	0.778966164
Remove sets with no effort info or extreme long tows	55865	0.779146156
Remove blocks <643	48202	0.778971827

Table 8. Trawl logbook GLM probability distributions, factors, AIC, and negative log likelihood.

Set or Trip Level	Probability Distribution	Covariates	AIC	NLL
Set	Delta Lognormal	Year, Port, Month, Depth Scaled	359023	179424
Set	Negative Binomal	Year, Port, Month, Depth Scaled	387239	-193576
Trip	Delta Lognormal	Year, Port, Month, Depth Scaled	153986	-76906

Trip	Negative Binomal	Year, Port, Month, Depth Scaled	163552	-81732
Trip	Negative Binomal	Year, Port, Month	165179	-82521
Trip	Tweedie	Year, Port, Month, Depth Scaled	156995	-78452

Table 9. Data used for the CalCOFI abundance index. Number of plankton tows, tows with larval CA halibut, and the proportion of positive tows by season.

Season	Tows	Positive Tows	Proportion Positive
fall	910	30	0.033
spring	1156	71	0.061
summer	1157	58	0.050
winter	1026	65	0.063

Table 10. Data used for the CalCOFI abundance index. Number of plankton tows, tows with larval CA halibut, and the proportion of positive tows by line and station location.

Line_Station	Tows	Positive Tows	Proportion Positive
80 51	184	19	0.103
80 55	200	1	0.005
80 60	206	1	0.005
81.8 46.9	127	6	0.047
83.3 40.6	150	27	0.180
83.3 42	149	12	0.081
83.3 51	196	6	0.031
86.7 33	174	36	0.207
86.7 35	206	14	0.068
86.7 40	195	6	0.031
86.7 45	198	2	0.010
86.7 50	200	1	0.005
90 28	203	36	0.177
90 30	173	13	0.075
90 35	141	1	0.007
90 37	208	1	0.005
90 53	187	1	0.005
93.3 26.7	146	21	0.144
93.3 28	178	11	0.062
93.3 30	210	6	0.029
93.3 35	201	1	0.005
93.3 40	208	1	0.005
93.3 50	209	1	0.005

Table 11. Data used for the CalCOFI abundance index. Number of plankton tows, tows with larval CA halibut, and the proportion of positive tows by year.

Year	Tows	Positive Tows	Proportion Positive		Year	Tows	Positive Tows	Proportion Positive
1951	32	1	0.031		1998	90	9	0.100
1952	29	0	0.000		1999	89	0	0.000
1953	29	0	0.000		2000	91	3	0.033
1954	29	0	0.000		2001	92	5	0.054
1955	27	2	0.074		2002	90	0	0.000
1956	26	1	0.038		2003	91	0	0.000
1957	41	1	0.024		2004	91	4	0.044
1958	45	2	0.044		2005	89	6	0.067
1959	55	3	0.055		2006	90	7	0.078
1960	56	0	0.000		2007	88	2	0.023
1961	60	2	0.033		2008	90	2	0.022
1962	57	3	0.053		2009	87	3	0.034
1963	66	5	0.076		2010	88	2	0.023
1964	68	2	0.029		2011	92	0	0.000
1965	68	8	0.118		2012	91	3	0.033
1966	64	2	0.031		2013	90	1	0.011
1967	17	1	0.059		2014	87	4	0.046
1968	33	4	0.121		2015	92	8	0.087
1969	68	3	0.044		2016	66	6	0.091
1972	33	2	0.061		2017	69	5	0.072
1975	82	3	0.037		2018	63	4	0.063
1978	63	10	0.159		2019	38	3	0.079
1981	63	12	0.190		2020	23	2	0.087
1983	19	1	0.053		2021	23	2	0.087
1984	83	3	0.036					
1985	82	4	0.049					
1986	84	4	0.048					
1987	88	4	0.045					
1988	88	4	0.045					
1989	90	6	0.067					
1990	69	6	0.087					
1991	89	9	0.101					
1992	90	8	0.089					
1993	92	7	0.076					
1994	92	4	0.043					
1995	91	5	0.055					
1996	91	9	0.099					
1997	90	2	0.022					

Table 12. Values of parameters that were fixed in the base model.

Parameter	Value
Female Natural Mortality	0.180
Male Natural Mortality	0.235
Female length at age 14	104.04
Female weight-length (intercept)	0.00000621
Female weight-length (exponent)	3.14
Female length at 50% mature	47.1
Female mautiry curve slope	-0.15
Female fecundity at length (intercept)	1.1061e-10
Female fecundity at length (slope)	5.91
Male natural mortality	0.235
Male length at age 2	31.17
Male length at age 14	86.81
Male CV of length at age 2	0.089
Male CV of length at age 14	0.212
Male weight-at-length (intercept)	0.00000607
Male weight-at-length (exponent)	3.14
Steepness	0.9
SigmaR	0.7

Table 13. Key non-selectivity parameters estimated in the base model with the estimated value, standard deviation, lower and upper bounds, and final gradient.

Parameter	Value	SD	Lower	Upper	Gradient
Female Length at age 2	26.67	0.96	1.00	45.00	2.01E-06
Female *k*	0.12	0.01	0.01	1.00	8.08E-06
Female CV of length at age 2	0.07	0.01	0.01	0.50	1.22E-06
Female CV of length at age 14	0.22	0.02	0.01	0.50	1.99E-06
Male *k*	0.07	0.01	0.01	1.00	2.56E-06
$\ln(R_0)$	7.03	0.07	3.00	15.00	9.01E-05
Initial *F* Bottom Trawl	0.021	0.004	0	1	-1.49E-06
Initial *F* Gillnet	0.037	0.008	0	2	-2.64E-06
Initial *F* CPFV	0.062	0.009	0	1	-3.68E-06
Initial *F* Other Rec	0.119	0.017	0	1	-4.24E-06
Initial *F* Discard	0.007	0.001	0	1	-9.60E-07
Extra SD Bottom Trawl Index	0.148	0.032	0	0.5	1.87E-07
Extra SD CPFV Index	0.121	0.023	0	0.5	4.17E-08
Extra SD CalCOFI Index	0.163	0.111	0	0.9	-2.99E-08

Table 14. Estimated selectivity parameters for each fleet in the base model with the estimated value, standard deviation, lower and upper bounds, and final gradient.

Parameter	**Value**	**SD**	**Lower**	**Upper**	**Gradient**

Size_DblN_peak_Bottom.Trawl(1)	57.432	0.604	30	80	6.48E-07
Size_DblN_ascend_se_Bottom.Trawl(1)	2.322	0.393	-5	10	-3.81E-07
Size_DblN_descend_se_Bottom.Trawl(1)	7.456	0.217	-5	20	8.26E-07
SzSel_Male_Peak_Bottom.Trawl(1)	1.322	2.352	-10	10	-2.19E-07
SzSel_Male_Ascend_Bottom.Trawl(1)	0.900	0.774	-5	5	2.37E-08
SzSel_Male_Descend_Bottom.Trawl(1)	-3.232	0.718	-10	9	-3.10E-07
SzSel_Male_Scale_Bottom.Trawl(1)	0.252	0.071	0.01	1	1.24E-07
Size_DblN_peak_Gillnet(2)	68.441	1.458	30	100	3.31E-08
Size_DblN_ascend_se_Gillnet(2)	4.289	0.262	-5	10	-9.30E-08
Size_DblN_descend_se_Gillnet(2)	7.489	0.289	-5	20	9.20E-08
Size_DblN_start_logit_Gillnet(2)	-10.174	11.787	-15	9	3.26E-08
SzSel_Male_Peak_Gillnet(2)	-4.515	1.403	-10	10	-1.13E-08
SzSel_Male_Ascend_Gillnet(2)	-0.530	0.405	-5	5	-6.81E-08
SzSel_Male_Descend_Gillnet(2)	-0.617	1.015	-10	9	9.46E-07
SzSel_Male_Scale_Gillnet(2)	0.154	0.025	0.01	1	8.33E-07
Size_DblN_peak_Comm.HL(3)	55.865	0.153	30	90	8.40E-08
Size_DblN_start_logit_Comm.HL(3)	-6.853	2.016	-15	9	-1.26E-07
Size_DblN_peak_CPFV(4)	56.691	0.545	30	80	2.15E-07
Size_DblN_ascend_se_CPFV(4)	2.019	0.333	-5	15	-1.82E-07
Size_DblN_start_logit_CPFV(4)	-5.656	0.421	-15	9	8.29E-08
Size_DblN_peak_Other.Rec(5)	57.123	0.317	30	80	-1.73E-06
Size_DblN_top_logit_Other.Rec(5)	-0.157	0.283	-15	15	-8.92E-06
Size_DblN_ascend_se_Other.Rec(5)	1.483	0.319	-5	10	1.36E-06
Size_DblN_descend_se_Other.Rec(5)	5.940	0.627	-5	20	-2.26E-06
Size_DblN_start_logit_Other.Rec(5)	-4.708	0.136	-15	9	1.84E-06
SzSel_Male_Peak_Other.Rec(5)	2.060	0.929	-10	10	-7.65E-07
SzSel_Male_Ascend_Other.Rec(5)	1.793	0.452	-5	5	9.08E-07
SzSel_Male_Descend_Other.Rec(5)	0.659	1.269	-10	9	3.63E-07
SzSel_Male_Scale_Other.Rec(5)	0.542	0.083	0.01	1	1.04E-06

Table 14. Estimated selectivity parameters for each fleet in the base model with the estimated value, standard deviation, lower and upper bounds, and final gradient.

Parameter	Value	SD	Lower	Upper	Gradient
Size_DblN_peak_Bottom.Trawl.Discard(6)	40.725	0.387	30	80	1.96E-07
Size_DblN_top_logit_Bottom.Trawl.Discard(6)	-1.974	0.065	-15	15	8.56E-08
Size_DblN_descend_se_Bottom.Trawl.Discard(6)	0.738	0.574	-15	20	9.54E-08
Size_DblN_peak_Gillnet.Discard(7)	53.109	6.410	30	80	2.73E-08
Size_DblN_top_logit_Gillnet.Discard(7)	-11.090	59.292	-15	15	-3.12E-07
Size_DblN_ascend_se_Gillnet.Discard(7)	4.806	1.002	-5	10	-1.57E-07
Size_DblN_descend_se_Gillnet.Discard(7)	5.306	1.306	-15	20	-5.32E-07
Size_DblN_peak_CPFV.Discard(8)	39.890	1.151	30	80	-1.56E-07
Size_DblN_top_logit_CPFV.Discard(8)	-1.969	0.217	-15	15	-1.20E-06
Size_DblN_descend_se_CPFV.Discard(8)	2.305	1.277	-15	20	-6.49E-09
Size_DblN_end_logit_CPFV.Discard(8)	-2.517	0.638	-15	9	-4.80E-07
Size_DblN_peak_Gillnet(2)_BLK1repl_1971	64.831	0.623	30	90	2.49E-06
Size_DblN_ascend_se_Gillnet(2)_BLK1repl_1971	3.742	0.130	-5	10	-1.82E-06
Size_DblN_descend_se_Gillnet(2)_BLK1repl_1971	7.848	0.467	-5	20	2.22E-06
Size_DblN_start_logit_Gillnet(2)_BLK1repl_1971	-8.528	0.746	-15	9	-2.09E-07
Size_DblN_peak_Gillnet.Discard(7)_BLK1repl_1971	51.911	0.893	30	90	3.68E-07
Size_DblN_ascend_se_Gillnet.Discard(7)_BLK1repl_1971	5.030	0.144	-5	10	-2.22E-07
Size_DblN_descend_se_Gillnet.Discard(7)_BLK1repl_1971	1.907	0.727	-5	20	-6.48E-08

Table 15. Reference points and management quantities for the base model with 95% confidence intervals.

Reference Points	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output (millions of eggs)	96337.8	83906.57	108769
Unfished Age 3+ Biomass (mt)	16280.3	14175.87	18384.73
Unfished Recruitment (R0)	1129.42	983.6816	1275.158
2024 Spawning Output (millions of eggs)	13475.5	10355.73	16595.27
2024 Fraction Unfished	0.139878	0.106877	0.172879
Reference Points Based SO25\%			
Proxy Spawning Output (millions of eggs) SO25\%	24084.4	20976.6	27192.2
SPR Resulting in SO25\%	0.270833	0.270833	0.270833
Exploitation Rate Resulting in SO25\%	0.091103	0.087454	0.094752
Yield with SPR Based On SO25\% (mt)	628.795	545.8272	711.7628
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output (millions of eggs) (SPR30)	26974.6	23493.86	30455.34
SPR30	0.3		
Exploitation Rate Corresponding to SPR30	0.0828872	0.079603	0.086172
Yield with SPR30 at SO SPR (mt)	611.086	530.6091	691.5629
Reference Points Based on Estimated MSY Values			
Spawning Output (millions of eggs) at MSY (SO MSY)	14444.8	12644.01	16245.59
SPR MSY	0.173552	0.168804	0.1783
Exploitation Rate Corresponding to SPR MSY	0.128864	0.123992	0.133736
MSY (mt)	662.333	574.0068	750.6592

Table 16. Estimated quantities given fishing mortality since 2014 and projected quantities (italics) through 2033 assuming fishing mortality determined from SPR=30% and a 25:5 control rule. Refer to decision tables for predicted fishing mortality using SPR=30% without a control rule.

Year	Assumed Fishing Mortality (mt)	Predicted Fishing Mortality with a 25:5 control rule (mt)	Age 3+ Biomass (mt)	Spawning Output (millions of eggs)	Fraction Unfished
2014	89		2,116	6,948	0.072
2015	85		2,186	7,625	0.079
2016	129		2,327	8,258	0.086
2017	150		2,404	8,629	0.090
2018	146		2,518	8,892	0.092
2019	164		2,721	9,237	0.096
2020	127		2,920	9,620	0.100
2021	180		3,208	10,399	0.108
2022	167		3,385	11,191	0.116
2023	139		3,528	12,225	0.127
2024		*267*	*3,688*	*13,476*	*0.140*
2025		*272*	*3,766*	*14,076*	*0.146*
2026		*292*	*3,943*	*14,536*	*0.151*
2027		*326*	*4,191*	*14,958*	*0.155*
2028		*365*	*4,491*	*15,439*	*0.160*
2029		*405*	*4,815*	*16,042*	*0.167*
2030		*441*	*5,139*	*16,778*	*0.174*
2031		*472*	*5,444*	*17,632*	*0.183*
2032		*499*	*5,721*	*18,578*	*0.193*
2033		*329*	*5,965*	*19,566*	*0.203*

Table 17. Time series of population estimates from the base model

Year	Total Biomass (mt)	Spawning Output	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1971	4932.61	15536.00	0.16	415.42	637.04	0.81	0.13
1972	4691.66	15217.00	0.16	374.36	427.58	0.70	0.09
1973	4607.21	15573.90	0.16	428.03	525.45	0.78	0.12
1974	4366.60	15319.20	0.16	353.02	581.93	0.82	0.14
1975	4017.21	14509.50	0.15	487.73	673.86	0.88	0.17
1976	3541.31	12823.60	0.13	907.91	807.90	0.95	0.23
1977	2918.65	10063.80	0.10	577.90	613.23	0.94	0.22
1978	2546.63	7948.71	0.08	436.73	474.59	0.93	0.20
1979	2379.22	6476.99	0.07	578.56	529.46	0.96	0.23
1980	2209.12	4934.76	0.05	537.42	670.61	0.98	0.32
1981	1942.42	3547.44	0.04	737.56	615.06	0.98	0.34
1982	1755.18	2558.57	0.03	1014.50	599.48	0.98	0.37
1983	1611.26	1797.19	0.02	665.38	313.65	0.95	0.22
1984	1786.98	1780.24	0.02	645.03	375.72	0.96	0.24
1985	1961.65	1825.26	0.02	1020.48	621.52	0.98	0.34
1986	1955.50	1530.38	0.02	388.53	728.43	0.98	0.41
1987	1860.86	1318.11	0.01	428.75	898.80	0.99	0.54
1988	1572.70	884.16	0.01	500.97	578.75	0.99	0.39
1989	1513.34	847.81	0.01	518.01	624.49	0.99	0.44
1990	1381.52	846.73	0.01	454.86	508.46	0.98	0.40
1991	1310.86	827.10	0.01	1291.17	550.29	0.99	0.46
1992	1193.10	627.14	0.01	188.19	275.97	0.97	0.26
1993	1364.06	757.60	0.01	868.72	257.50	0.95	0.23
1994	1603.16	1030.79	0.01	614.64	278.53	0.93	0.18
1995	1869.16	1493.63	0.02	979.57	383.84	0.93	0.23
1996	2075.33	2017.47	0.02	572.35	395.21	0.91	0.21
1997	2275.21	2560.46	0.03	599.79	368.08	0.89	0.18
1998	2510.78	3174.91	0.03	774.77	444.88	0.90	0.19
1999	2669.10	3720.31	0.04	388.57	697.47	0.95	0.28
2000	2562.19	3672.47	0.04	354.99	658.90	0.95	0.27
2001	2433.52	3581.72	0.04	399.53	629.13	0.95	0.27
2002	2264.71	3388.22	0.04	358.81	718.19	0.97	0.33
2003	1949.01	2865.74	0.03	415.46	544.96	0.96	0.29
2004	1744.76	2576.11	0.03	520.36	290.19	0.90	0.18
2005	1760.83	2734.77	0.03	286.41	223.01	0.83	0.13
2006	1844.32	3084.81	0.03	403.35	249.79	0.85	0.14
2007	1902.36	3385.44	0.04	272.65	203.49	0.79	0.11
2008	1998.44	3852.54	0.04	206.06	202.20	0.76	0.11
2009	2080.27	4390.10	0.05	356.45	206.12	0.75	0.10
2010	2130.60	4935.56	0.05	142.33	233.95	0.78	0.11

Year	Total Biomass (mt)	Spawning Output	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
2011	2121.63	5353.99	0.06	317.11	153.59	0.64	0.07
2012	2166.77	5989.72	0.06	271.10	181.21	0.68	0.09
2013	2166.99	6453.96	0.07	510.75	149.89	0.63	0.07
2014	2193.12	6947.65	0.07	341.38	88.88	0.46	0.04
2015	2293.80	7624.89	0.08	509.96	84.79	0.45	0.04
2016	2419.73	8258.07	0.09	684.14	128.97	0.59	0.06
2017	2531.74	8628.98	0.09	548.12	149.60	0.62	0.06
2018	2667.16	8891.95	0.09	622.51	145.98	0.60	0.06
2019	2849.81	9236.63	0.10	353.82	163.99	0.61	0.06
2020	3044.81	9620.34	0.10	303.76	127.17	0.49	0.04
2021	3287.43	10398.90	0.11	424.47	179.89	0.56	0.06
2022	3466.31	11191.10	0.12	689.84	166.69	0.50	0.05
2023	3646.72	12225.00	0.13	948.20	138.81	0.42	0.04
2024	3864.99	13475.50	0.14	964.65	267.43	0.63	0.00
2025	3985.31	14076.00	0.15	971.68	266.58	0.64	0.00
2026	4165.69	14536.20	0.15	976.74	271.86	0.64	0.00
2027	4415.04	14958.00	0.16	981.15	292.03	0.65	0.00
2028	4716.25	15438.70	0.16	985.92	325.72	0.65	0.00
2029	5041.71	16042.00	0.17	991.56	365.21	0.66	0.00
2030	5366.42	16777.80	0.17	997.97	404.67	0.66	0.00
2031	5672.95	17631.80	0.18	1004.83	440.82	0.67	0.00
2032	5951.47	18578.00	0.19	1011.79	472.26	0.68	0.00
2033	6197.19	19566.40	0.20	1018.43	498.60	0.68	0.00

Table 18. Likelihoods, derived parameters, and estimated parameters for data sensitivities.

Label	Base	Other Rec Index	No Trawl Index	No CPFV Index	No CalCOFI Index	Historical Catches (1880)	Growth Fleet	All Length Samples	Adjusted rec catch (MRFSS)
TOTAL likelihood	1774.94	1773.44	1802.60	1822.35	1775.39	1768.27	2038.95	1910.27	1775.49
Survey likelihood	-88.36	-89.61	-61.19	-40.91	-87.21	-93.57	-87.67	-88.12	-88.16
Length Comp likelihood	1300.42	1299.84	1300.93	1297.64	1298.89	1299.66	1478.37	1440.62	1300.48
Age Comp likelihood	552.15	552.48	550.70	555.85	552.45	552.08	639.27	548.21	552.32
Recruitment likelihood	10.60	10.58	12.02	9.63	11.11	9.96	8.83	9.51	10.70
ln(R0)	7.03	7.03	7.02	7.09	7.01	7.14	7.00	6.94	7.03
SSB Unfished	96337.80	96500.40	94307.50	103930.00	94418.20	108037.00	92235.70	86085.10	96176.60
Fraction Unfished 2024	0.14	0.14	0.13	0.17	0.14	0.13	0.14	0.14	0.14
Steepness	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
M Female	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
M Male	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Length Amin Female	26.67	26.64	26.42	26.74	26.73	26.57	27.27	25.33	26.69
Length Amin Male	31.17	31.17	31.17	31.17	31.17	31.17	31.17	31.17	31.17
Length Amax Female	104.04	104.04	104.04	104.04	104.04	104.04	104.04	104.04	104.04
Length Amax Male	86.81	86.81	86.81	86.81	86.81	86.81	86.81	86.81	86.81
K Female	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.12
K Male	0.07	0.07	0.06	0.07	0.07	0.07	0.08	0.08	0.07
CV young Female	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07
CV young Male	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
CV old Female	0.22	0.22	0.21	0.23	0.22	0.22	0.21	0.21	0.22
CV old Male	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21

Table 19. Likelihoods, derived parameters, and estimated parameters for structural sensitivities.

Label	Base	SigmaR=0.9	MI Weighting	Growth Fixed	Fecundity Proportional to SB	Growth Estimated	M estimated	Estimate h No Prior	Estimate h
TOTAL likelihood	1774.94	1779.05	2132.57	1867.32	1750.16	1754.17	1713.02	1747.31	1781.55
Survey likelihood	-88.36	-88.83	-85.49	-91.16	-88.79	-90.51	-84.51	-87.25	-89.02
Length Comp likelihood	1300.42	1299.37	1630.78	1335.64	1292.74	1278.98	1253.96	1291.87	1294.37
Age Comp likelihood	552.15	551.09	576.15	613.04	549.60	561.74	541.24	549.65	550.59
Recruitment likelihood	10.60	17.24	10.94	9.64	-3.50	3.83	1.08	-7.17	4.04
ln(R0)	7.03	7.23	7.04	6.77	6.63	6.86	7.29	6.40	6.78
SSB Unfished	96337.80	118640.00	96625.30	77586.30	8061.09	45110.70	53156.30	53784.60	76037.80
Fraction Unfished 2024	0.14	0.11	0.14	0.19	0.27	0.19	0.22	0.25	0.16
Steepness	0.90	0.90	0.90	0.90	0.90	0.90	0.90	1.00	0.94
M Female	0.18	0.18	0.18	0.18	0.18	0.18	0.24	0.18	0.18
M Male	0.23	0.23	0.23	0.23	0.23	0.23	0.42	0.23	0.23
Length Amin Female	26.67	26.60	27.43	35.74	26.33	25.44	26.40	26.40	26.35
Length Amin Male	31.17	31.17	31.17	31.17	31.17	32.45	31.17	31.17	31.17
Length Amax Female	104.04	104.04	104.04	104.04	104.04	91.20	104.04	104.04	104.04
Length Amax Male	86.81	86.81	86.81	86.81	86.81	62.53	86.81	86.81	86.81
K Female	0.12	0.12	0.12	0.13	0.12	0.20	0.12	0.12	0.12
K Male	0.07	0.07	0.05	0.17	0.08	0.13	0.09	0.08	0.07
CV young Female	0.07	0.07	0.07	0.18	0.06	0.03	0.07	0.06	0.07
CV young Male	0.09	0.09	0.09	0.09	0.09	0.04	0.09	0.09	0.09
CV old Female	0.22	0.22	0.21	0.20	0.24	0.23	0.22	0.24	0.22
CV old Male	0.21	0.21	0.21	0.21	0.21	0.50	0.21	0.21	0.21

Table 20. Likelihoods, derived parameters, and estimated parameters for other sensitivities.

Label	Base	Hump-Shaped Selectivity	Asymptotic Selectivity	No Sex Select	Other Rec Index Added	Other Rec, no low points	Other Rec Block	No Gillnet Block
TOTAL likelihood	1774.94	1768.72	1823.15	1860.86	1773.44	1765.04	1736.63	1783.56
Survey likelihood	-88.3648	-89.0542	-86.3264	-86.3425	-89.6054	-97.0352	-89.7344	-88.6729
Length Comp likelihood	1300.42	1295.44	1338.83	1364.23	1299.84	1299.49	1275.82	1308.08
Age Comp likelihood	552.147	552.741	554.315	575.298	552.479	552.505	549.435	552.763
Recruitment likelihood	10.595	9.46174	16.1685	7.54305	10.5843	9.95125	1.01267	11.2529
ln(R0)	7.02946	7.02508	7.04479	6.88439	7.03247	7.04535	6.88224	7.03118
SSB Unfished	96337.8	98348.6	88984.3	80184.6	96500.4	97440.4	80644.4	95480.1
Fraction Unfished 2024	0.139878	0.150729	0.101068	0.157942	0.14083	0.146894	0.155567	0.138714
Steepness	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
M Female	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
M Male	0.234783	0.234783	0.234783	0.234783	0.234783	0.234783	0.234783	0.234783
Length Amin Female	26.6683	26.8686	26.4404	26.0181	26.6359	26.6182	26.4782	26.4952
Length Amin Male	31.17	31.17	31.17	31.17	31.17	31.17	31.17	31.17
Length Amax Female	104.04	104.04	104.04	104.04	104.04	104.04	104.04	104.04
Length Amax Male	86.81	86.81	86.81	86.81	86.81	86.81	86.81	86.81
K Female	0.121238	0.118315	0.123381	0.140678	0.121428	0.121237	0.12084	0.123643
K Male	0.070208	0.0681335	0.0643726	0.01	0.069873	0.0694484	0.090425	0.069748
CV young Female	0.065849	0.0611397	0.0937574	0.071646	0.066115	0.066677	0.07277	0.066094
CV young Male	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089
CV old Female	0.217839	0.232585	0.165707	0.196613	0.217123	0.215341	0.200639	0.21222
CV old Male	0.212	0.212	0.212	0.212	0.212	0.212	0.212	0.212

Table 21. Decision table with the base model assumption for fecundity (fecundity related to female size). Catch projection alternatives include maintaining the stock above SPR 30% using a 25-5 harvest control rule, maintaining the stock above 30% without a harvest control rule, and fixed catch at the average from 2019-2023. Fixed 5-yr average catches are a mixture of biomass and number of fish.

			Base		High Natural Mortality	
	Year	Catch	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
SPR 30%, 25-5 Harvest Control Rule Applied	2024	196.83	13,476	0.140	12,337	0.244
	2025	196.17	14,076	0.146	12,633	0.250
	2026	201.29	14,536	0.151	12,762	0.252
	2027	218.31	14,958	0.155	12,832	0.254
	2028	245.37	15,439	0.160	12,926	0.255
SPR 30%, No Harvest Control Rule	2024	242.45	13,476	0.140	12,337	0.244
	2025	231.54	13,762	0.143	12,357	0.244
	2026	230.77	13,928	0.145	12,243	0.242
	2027	245.23	14,084	0.146	12,109	0.239
	2028	270.81	14,333	0.149	12,039	0.238
5-Year Average Catch Fixed	2024	120.19	13,476	0.140	12,337	0.244
	2025	120.19	14,596	0.152	13,091	0.259
	2026	120.19	15,648	0.162	13,715	0.271
	2027	120.19	16,733	0.174	14,311	0.283
	2028	120.19	17,999	0.187	15,010	0.297

Table 22. Decision table assuming that fecundity is proportional to spawning biomass. Catch projection alternatives include maintaining the stock above SPR 30% using a 25-5 harvest control rule, maintaining the stock above 30% without a harvest control rule, and fixed catch at the average from 2019-2023. Fixed 5-yr average catches are a mixture of biomass and number of fish.

			Base		High Natural Mortality	
	Year	Catch	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
SPR 30%, 25-5 Harvest Control Rule Applied	2024	196.83	2,151	0.267	2,236	0.413
	2025	196.17	2,165	0.269	2,189	0.404
	2026	201.29	2,185	0.271	2,151	0.397
	2027	218.31	2,230	0.277	2,145	0.396
	2028	245.37	2,292	0.284	2,160	0.399
SPR 30%, No Harvest Control Rule	2024	242.45	2,151	0.267	2,236	0.413
	2025	231.54	2,111	0.262	2,138	0.395
	2026	230.77	2,087	0.259	2,064	0.381
	2027	245.23	2,097	0.260	2,030	0.375
	2028	270.81	2,129	0.264	2,024	0.374
5-Year Average Catch Fixed	2024	120.19	2,151	0.267	2,236	0.413
	2025	120.19	2,255	0.28	2,272	0.419
	2026	120.19	2,365	0.293	2,312	0.427
	2027	120.19	2,505	0.311	2,383	0.440
	2028	120.19	2,682	0.333	2,489	0.460

8 Figures

Figure 9. Map showing the delineation of the two California Halibut stocks at Point Arguello. The southern stock extends south to the U.S. – Mexico border, while the central stock extends north to Point Arena.

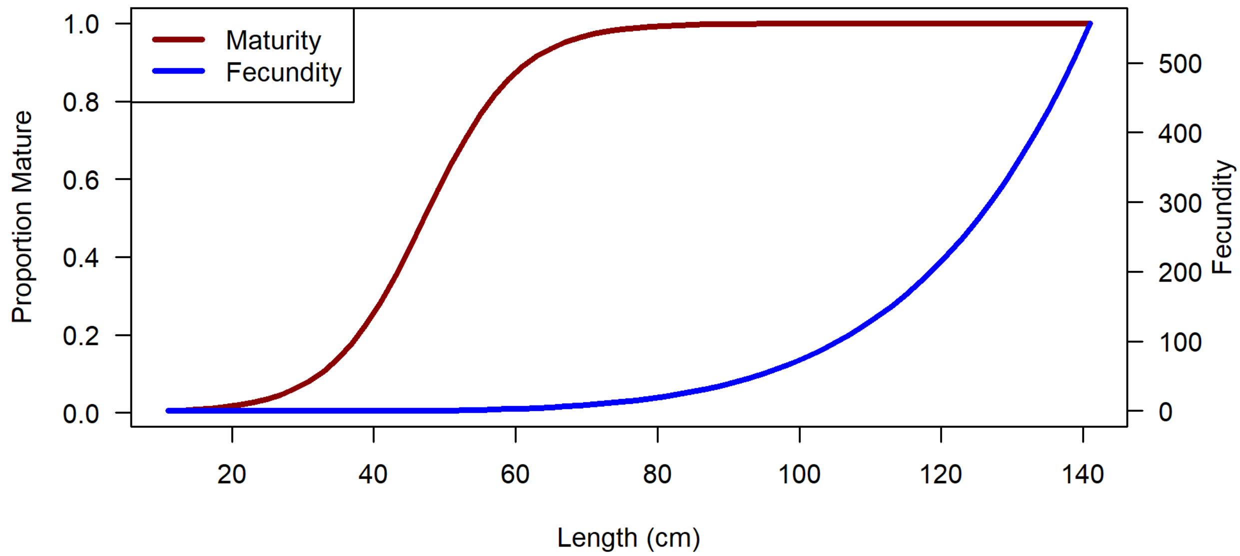


Figure 10. Proportion of females that are mature (red) and fecundity (blue) as a function of length.

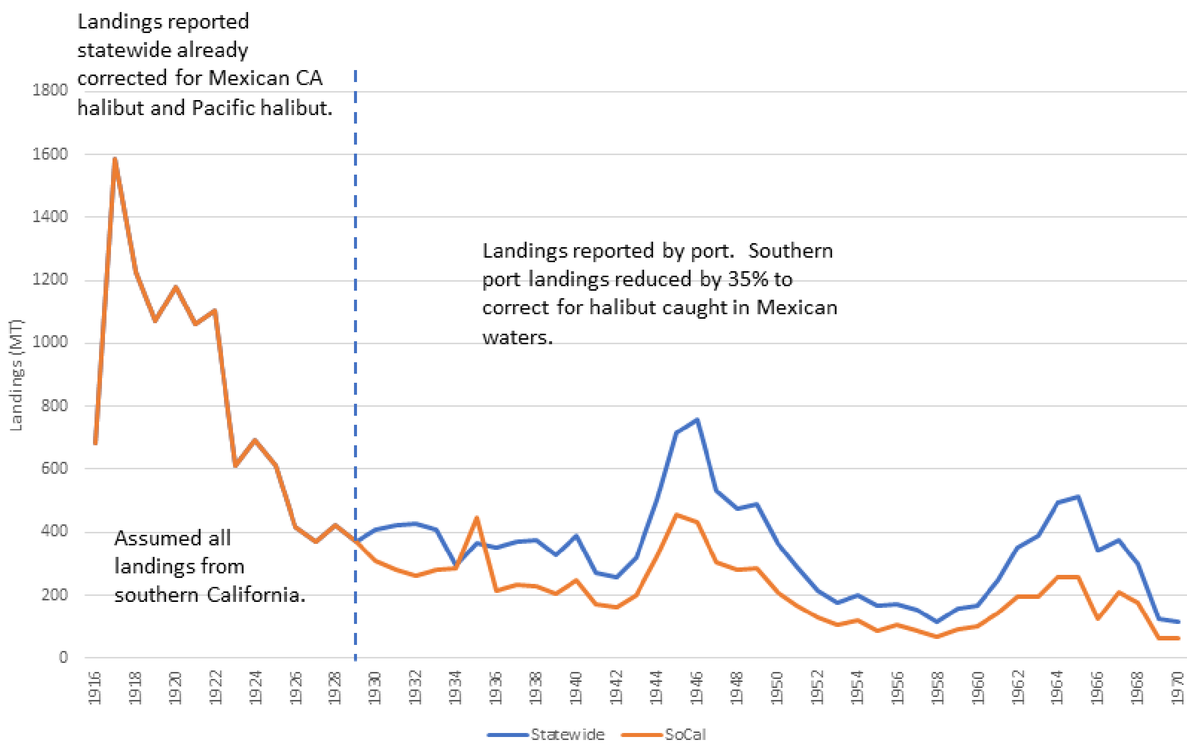


Figure 11. Historic commercial landings. Only statewide landings are available prior to 1930. These were reported by Barsky (1990) corrected for fish landed in Mexican waters and mixed landings of California and Pacific halibut (orange pre-1930). The fishery was centered in southern California in these early years. Landings by port region become available in 1930 and are reported by Barsky (1990) uncorrected. The southern port regions were summed and

corrected for Mexican fish (orange post-1930). The sum of all statewide port regions landings are shown in blue.

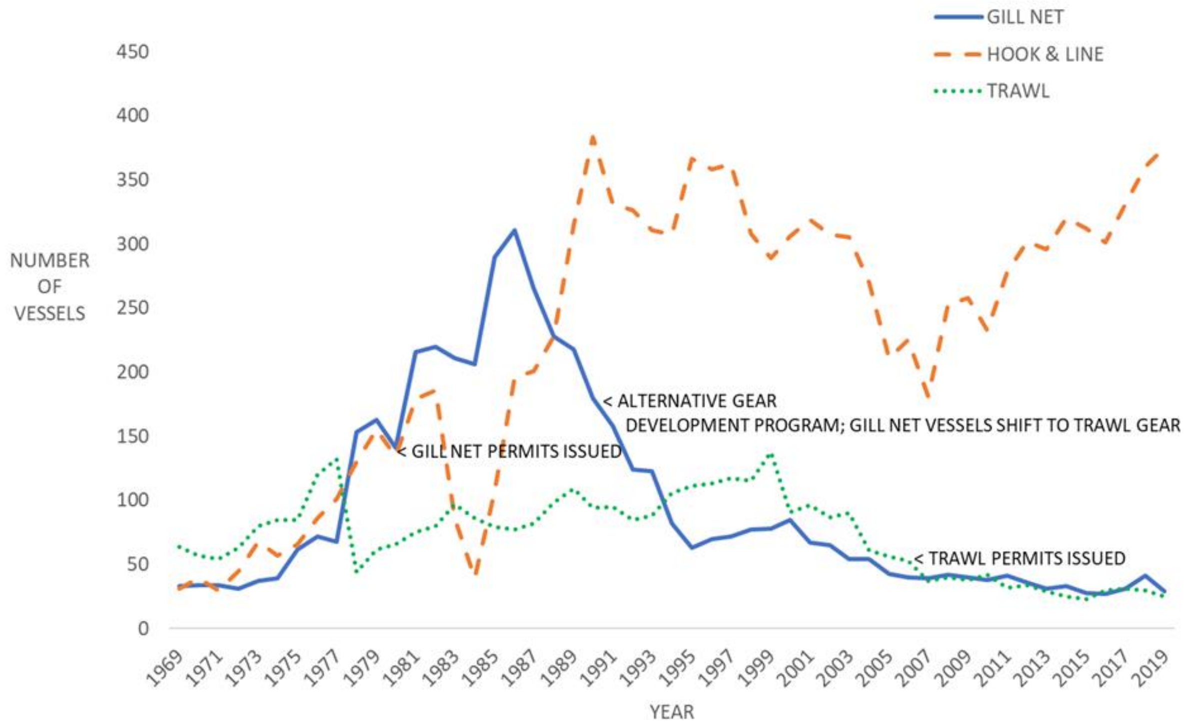


Figure 12. Number of commercial fishing vessels that reported halibut landings (MLDS, December 2020). Vessels were separated by gear type and summed by year.

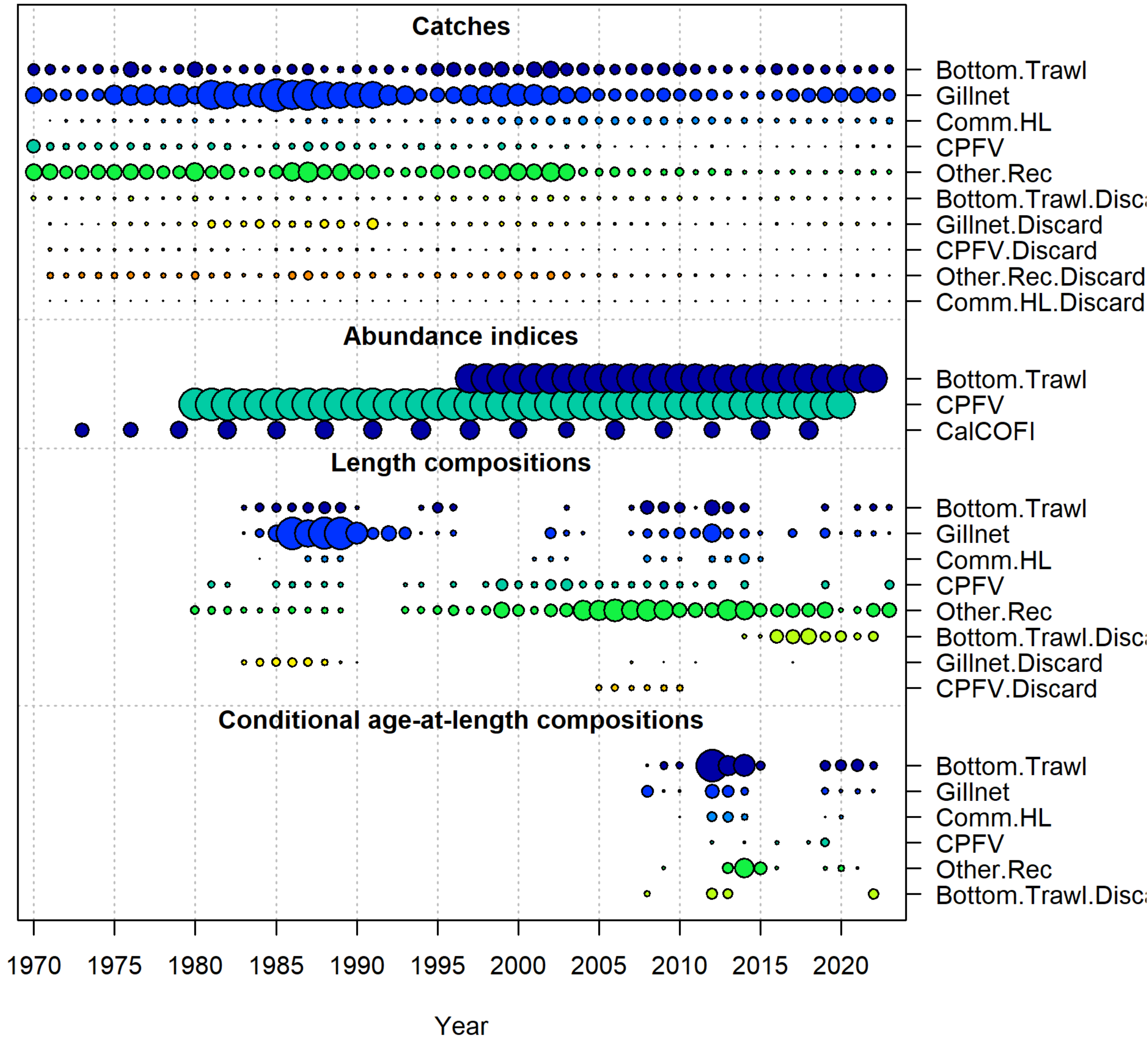


Figure 13. Data presence by year for each fleet, where circle area is relative within a data type. Circles are proportional to total catch for catches; to precision for indices, discards, and mean body weight observations; and to total sample size for compositions and mean weight- or length-at-age observations. Observations excluded from the likelihood have equal size for all years. Note that since the circles are scaled relative to maximum within each type, the scaling within separate plots should not be compared.

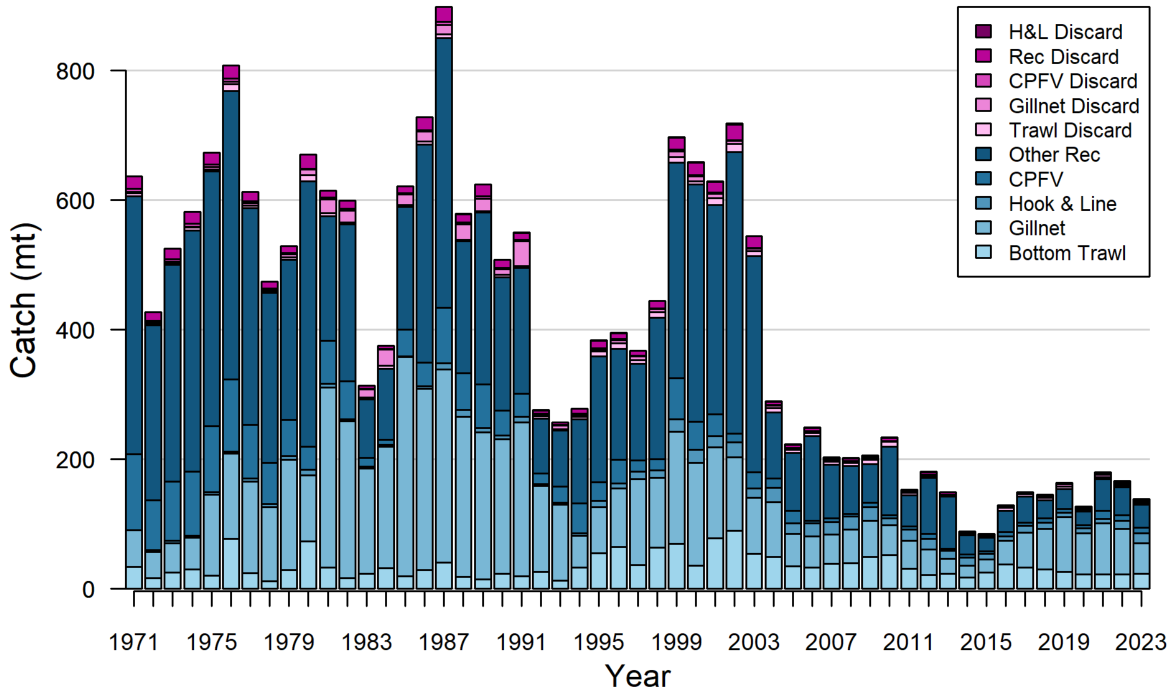


Figure 14. Retained landings (blue colors) and discarded mortality (pink colors) by fleet.

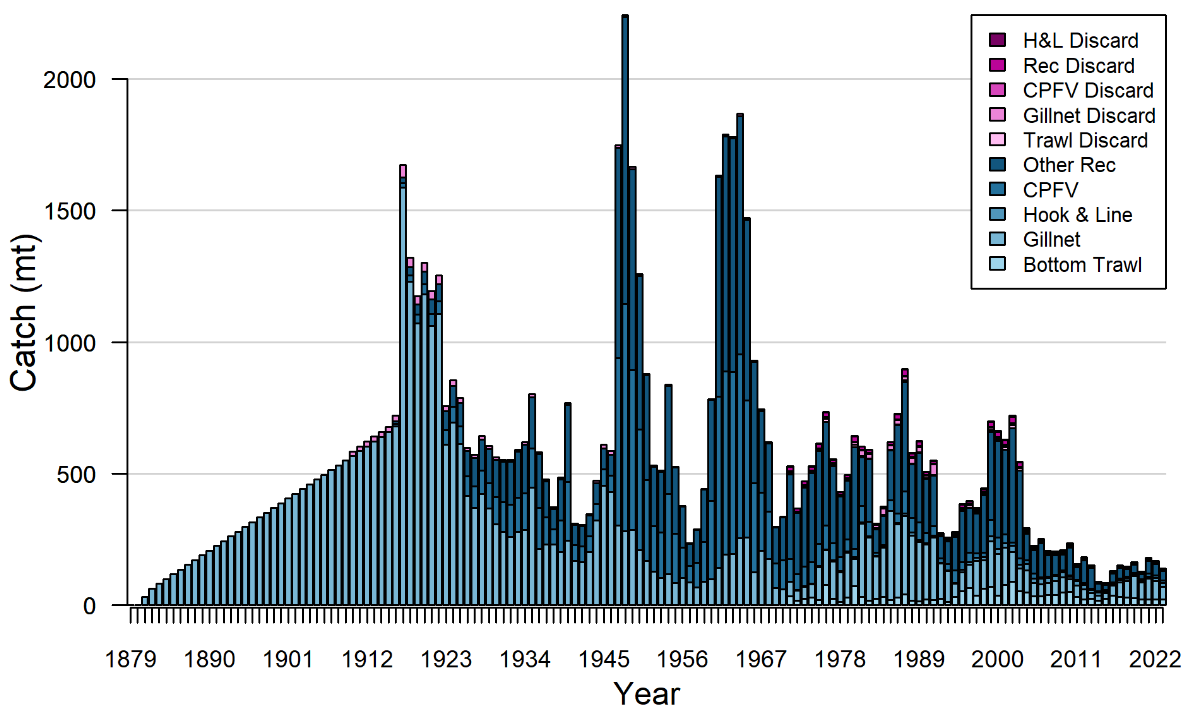


Figure 15. Historic retained landings (blue colors) and discarded mortality (pink colors) by fleet used for sensitivity testing. Commercial landings prior to 1971 were attributed to the gillnet fleet. A constant ramp up was assumed between 1880 and the earliest landings records in 1916. Estimates of recreational landings are not available prior to 1971 and none were assumed.

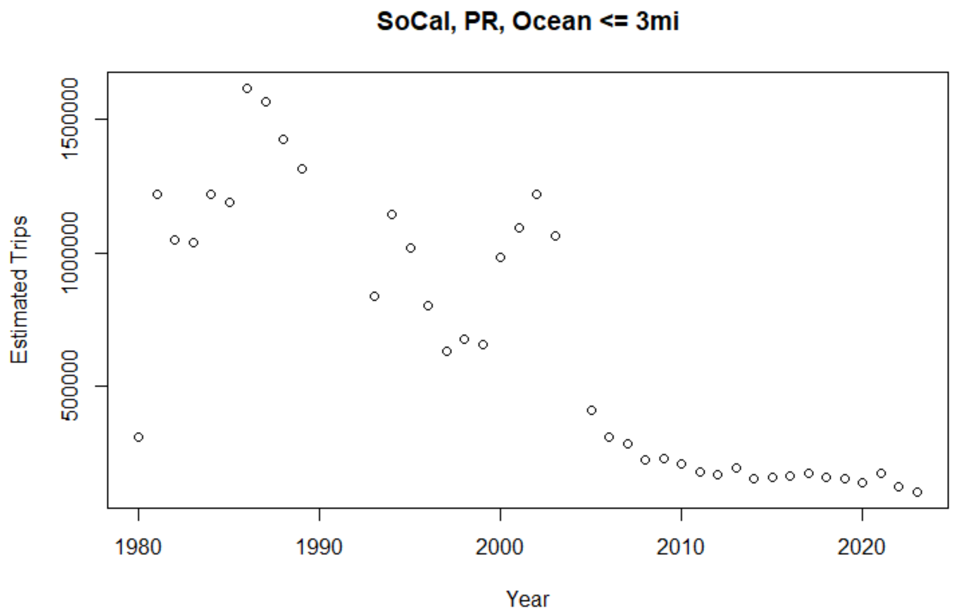


Figure 16. Effort estimates in numbers of angler trips for southern California, private and rental recreational vessels, fishing within ocean waters <= 3 miles from shore.

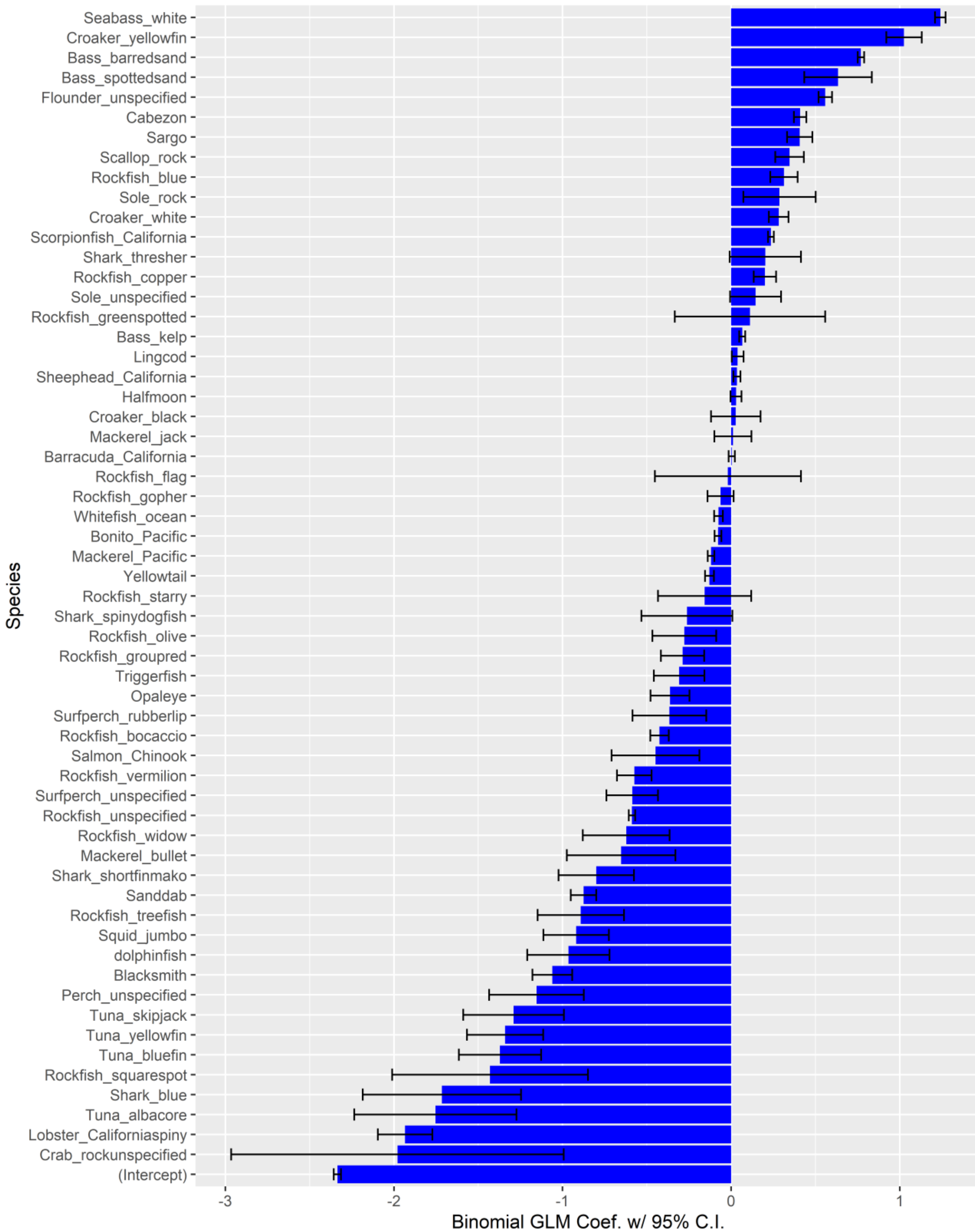


Figure 17. Species coefficients (blue bars) from the binomial GLM for presence/absence of California halibut in the CPFV logbook data for southern California. Horizontal black bars are 95% confidence intervals.

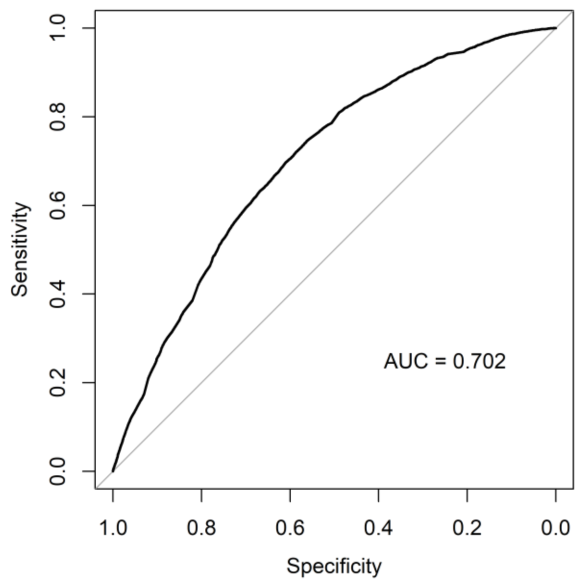


Figure 18. CPFV logbook Receiver Operating Characteristic (ROC) curve for Stephens-MacCall logistic regression model. AUC is the probability that a randomly chosen observation of presence would be assigned a higher ranked prediction than a randomly chosen observation of absence.

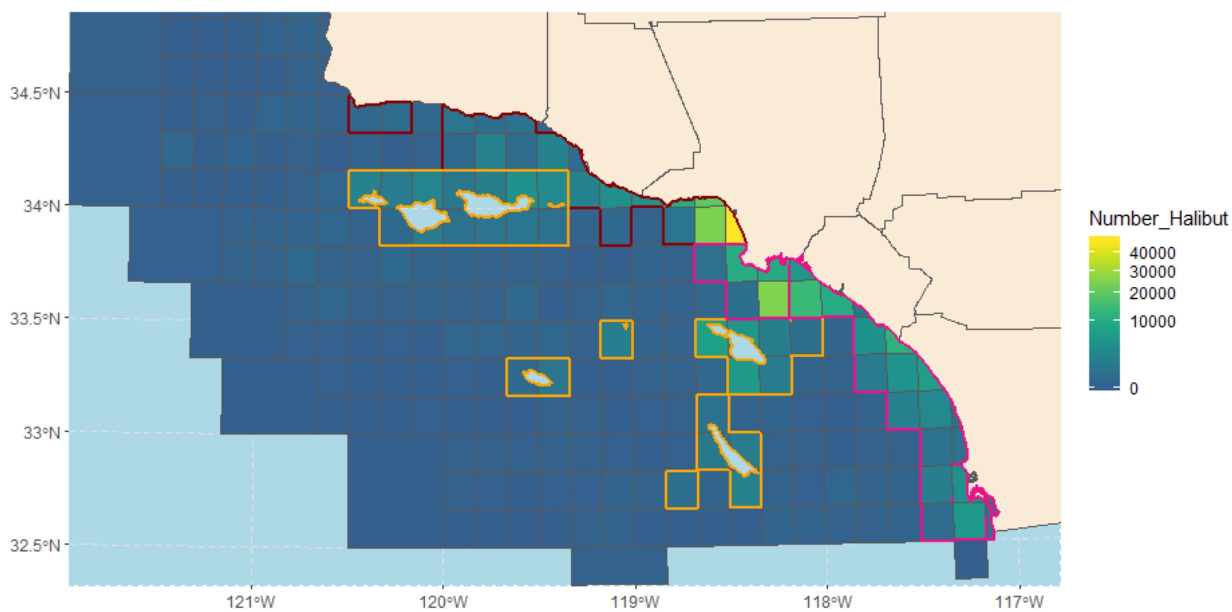


Figure 19. Map of the three sub-regions used to develop the southern California CPFV index. The background color represents the square root of the total number of Halibut caught by CPFV vessels over the entire timeseries (1980-2019), with the relative value indicated by the color legend. The 10x10 nautical blocks which are outlined were included in the CPFV index. Those surrounded in dark red were included in the Santa Barbara area sub-region, those surrounded by the orange line were included in the Channel Islands sub-region, and those surrounded by pink were included in the Los Angeles/San Diego area sub-region.

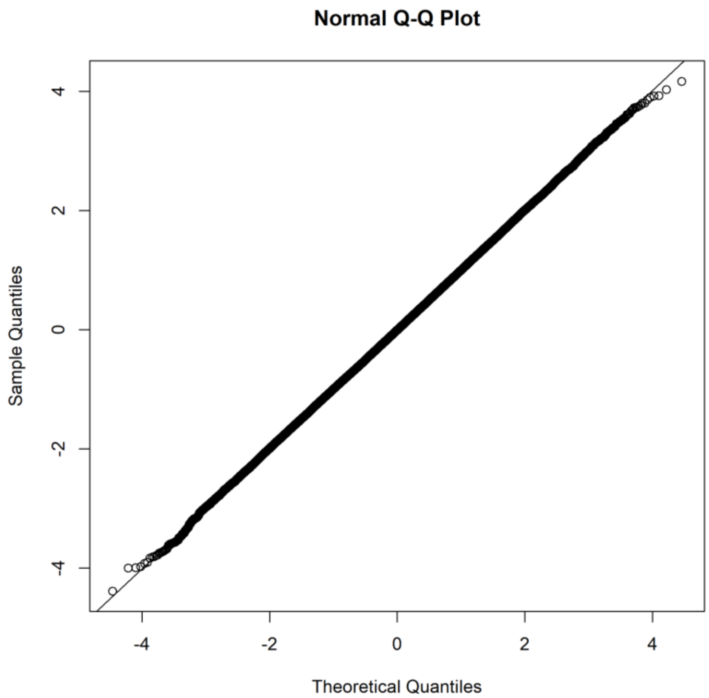


Figure 20. Q-Q plot for the delta-lognormal model for the CPFV logbook index using year, month, and block covariates.

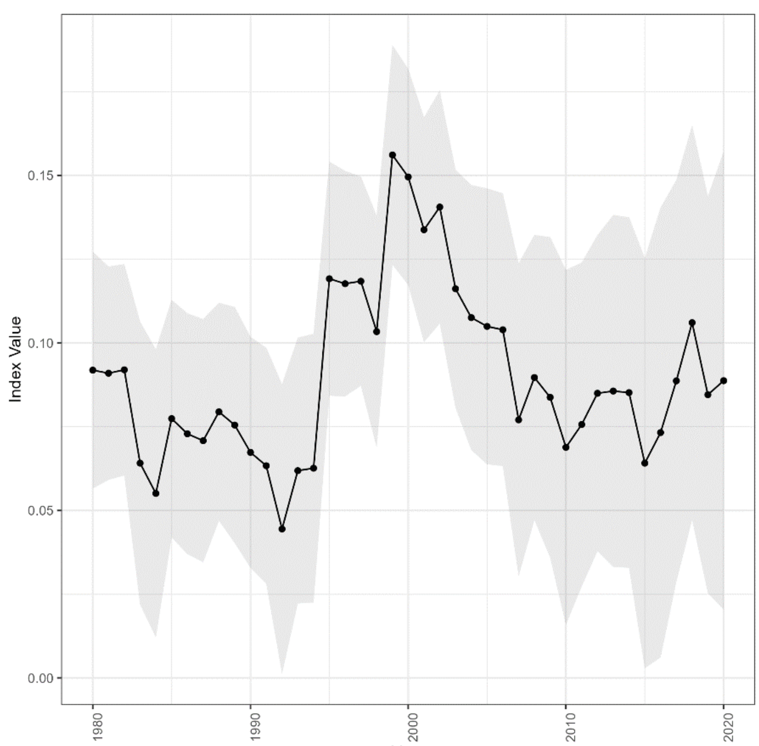


Figure 21. CPFV logbook index and standard error.

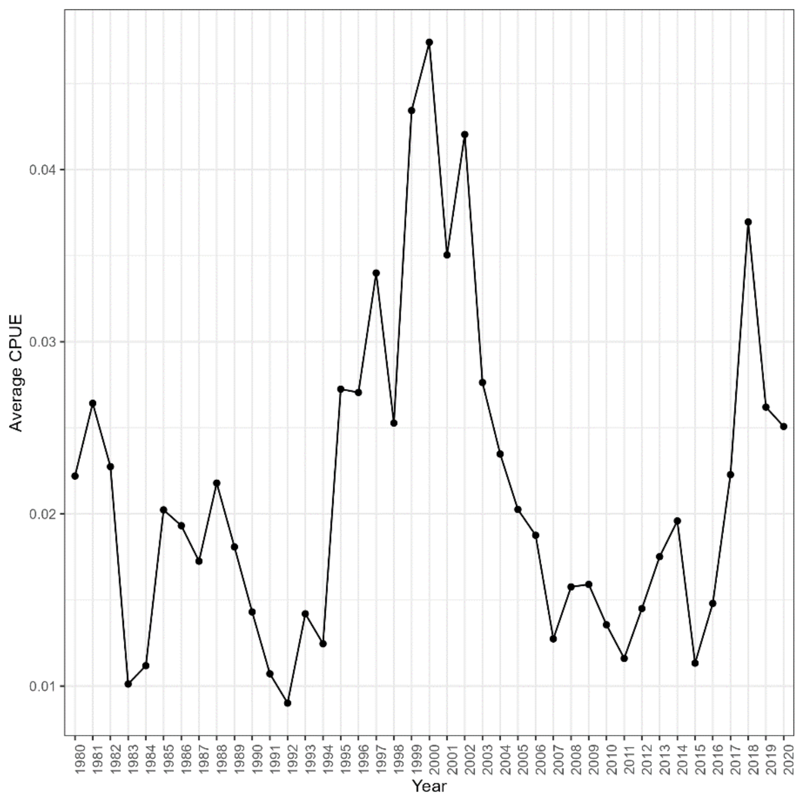


Figure 22. CPFV logbook empirical (raw) catch per unit effort using filtered data.

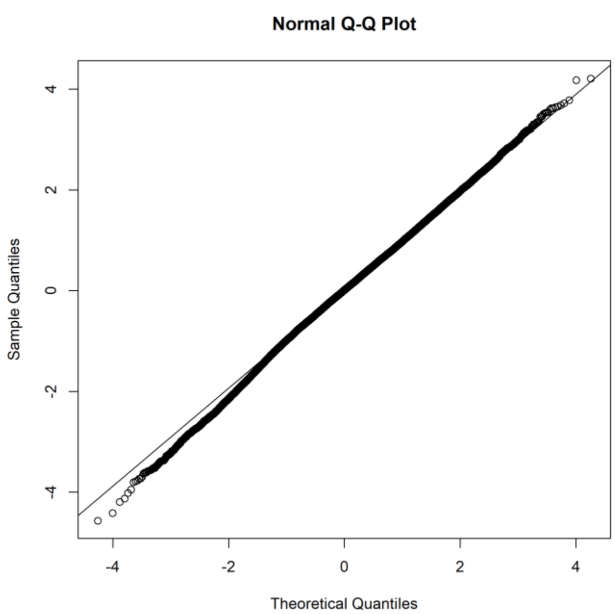


Figure 23. Q-Q plot for the trawl logbook delta lognormal model with year, port, month, and depth covariates.

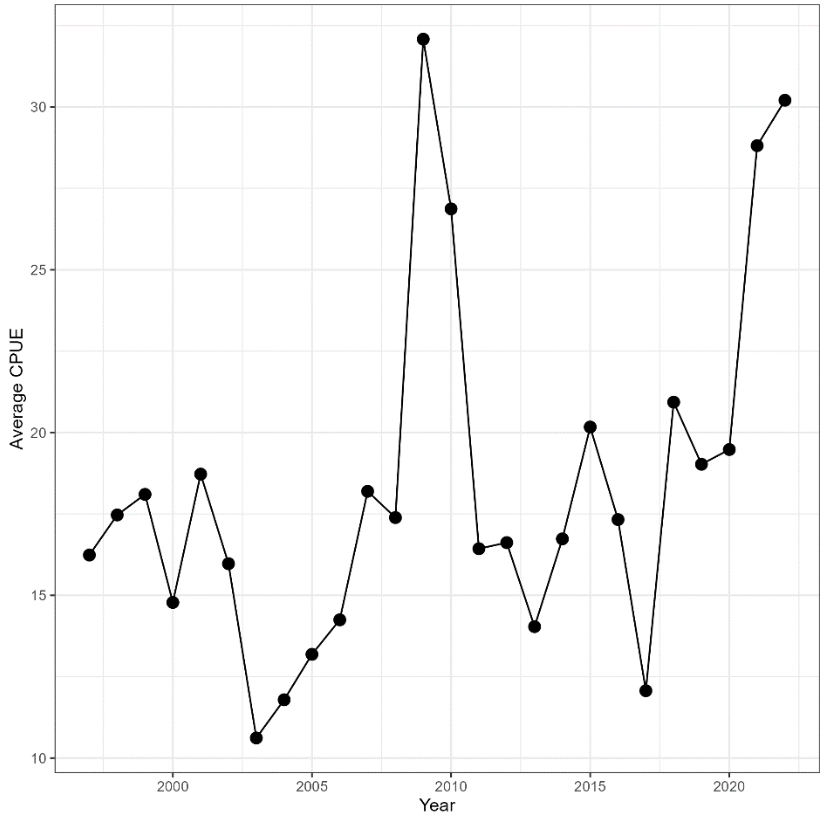


Figure 24. Trawl logbook CPUE using average set-level catch and effort

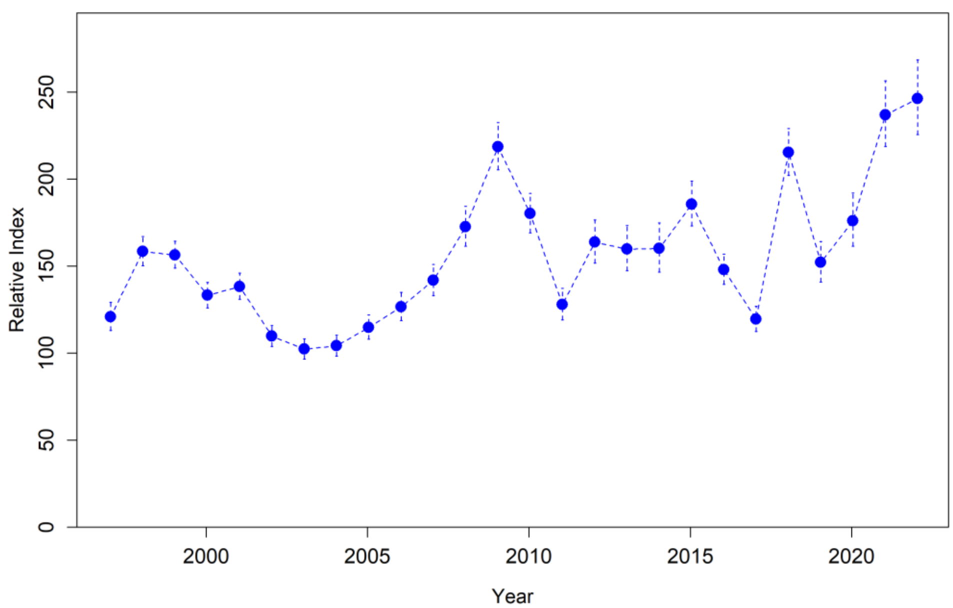


Figure 25. Trawl logbook index and standard error.

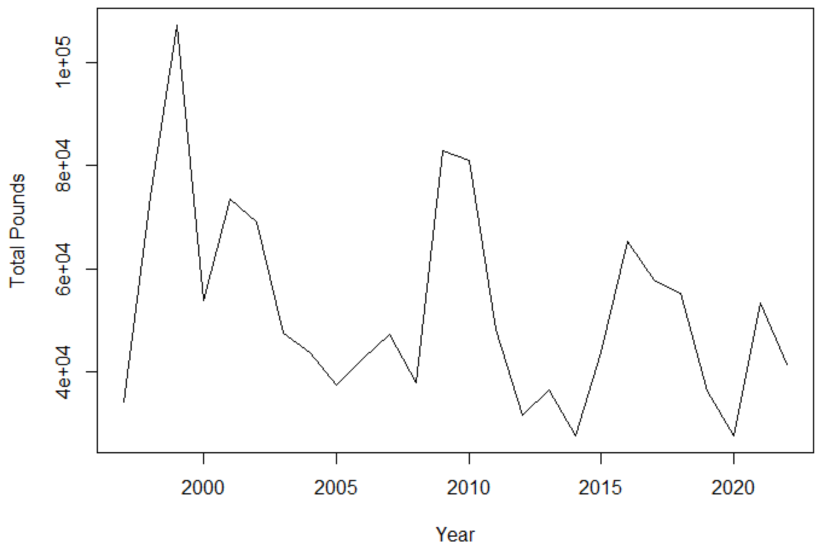


Figure 26. Trawl logbook total pounds landed by year.

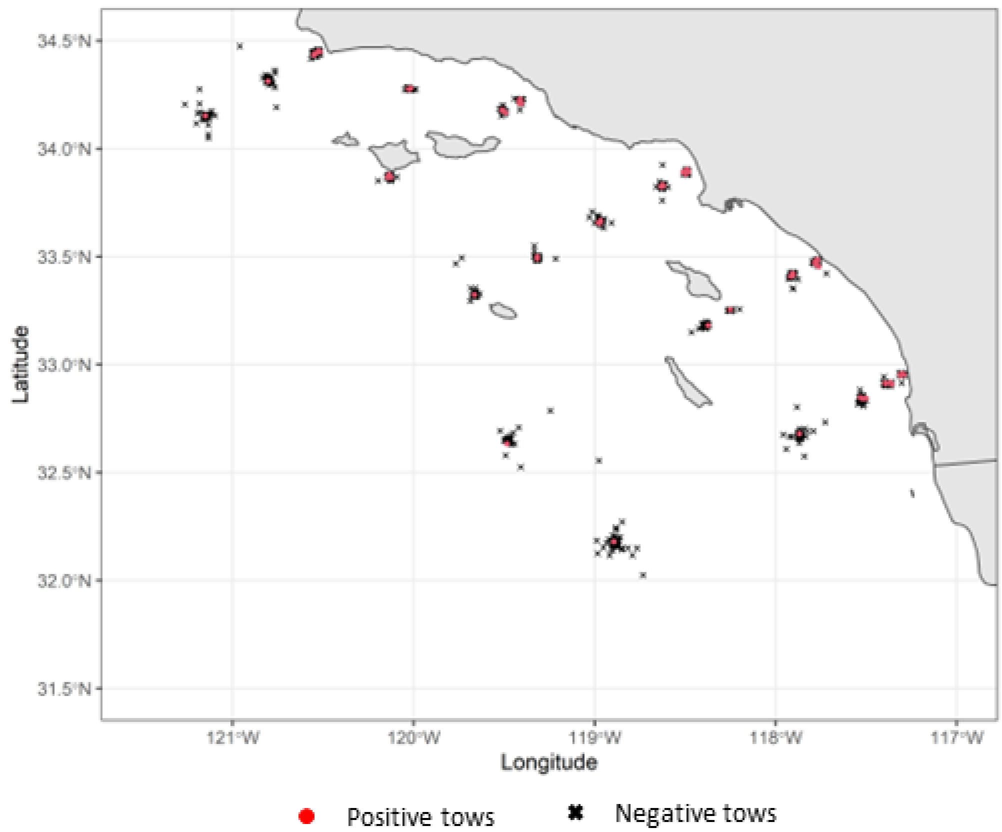


Figure 27. Data used for the CalCOFI abundance index showing the location of survey lines and stations included with positive tows containing CA halibut (red circle) and negative tows without CA halibut (black x).

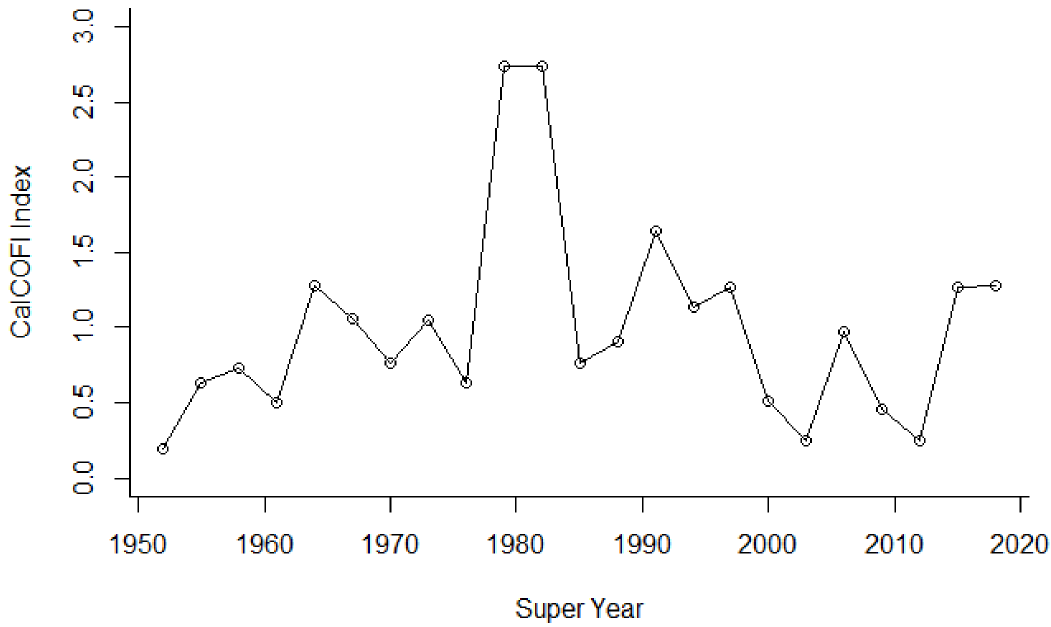


Figure 28. Empirical CalCOFI larval index based on the proportion of positive plankton tows for CA halibut.

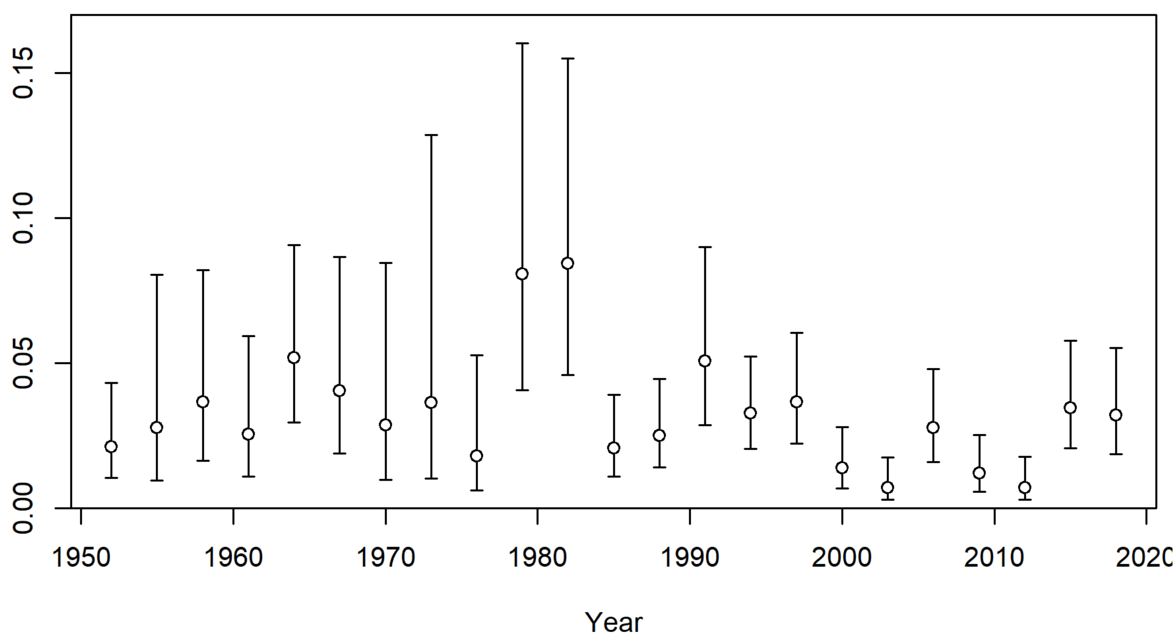


Figure 29. CalCOFI model index of recruitment.

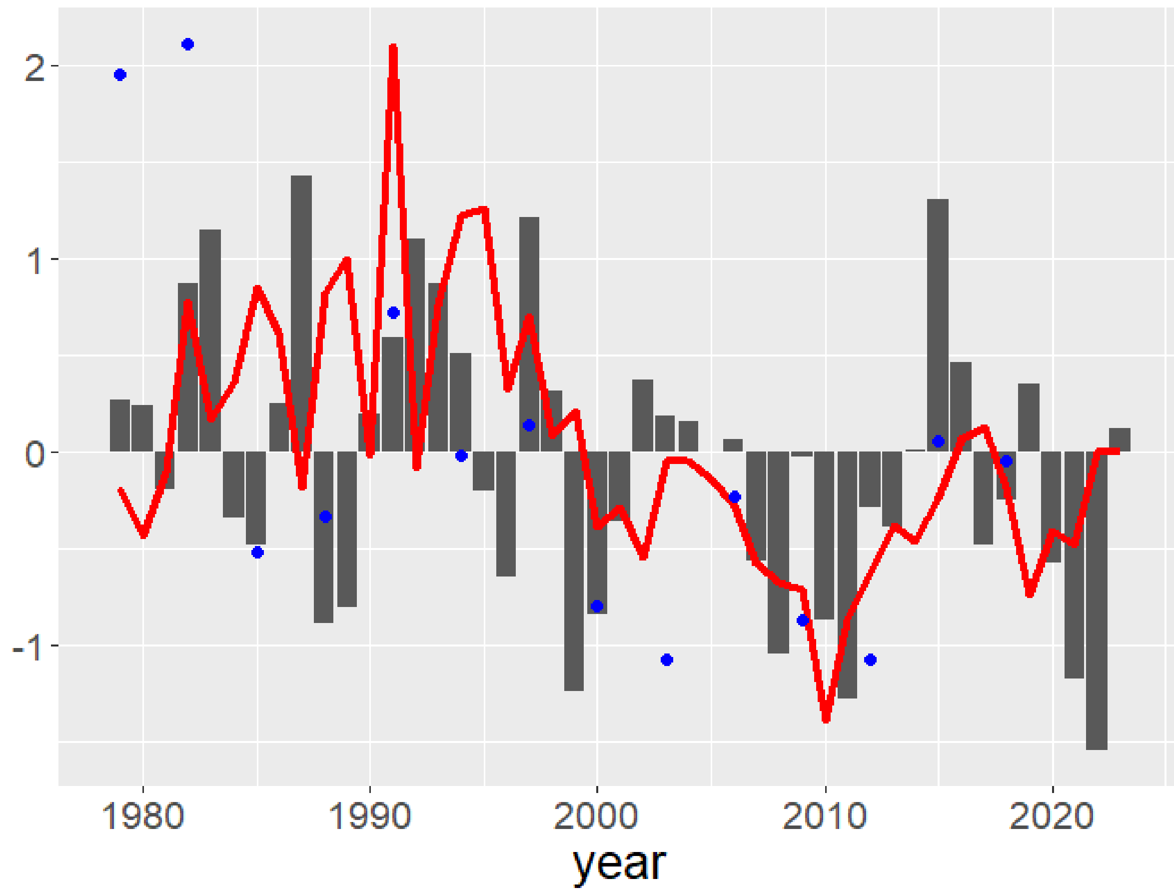


Figure 30. CalCOFI index values standardized to their mean (blue circles) compared to annual mean ENSO index (grey bars) and log recruitment deviations (red line).

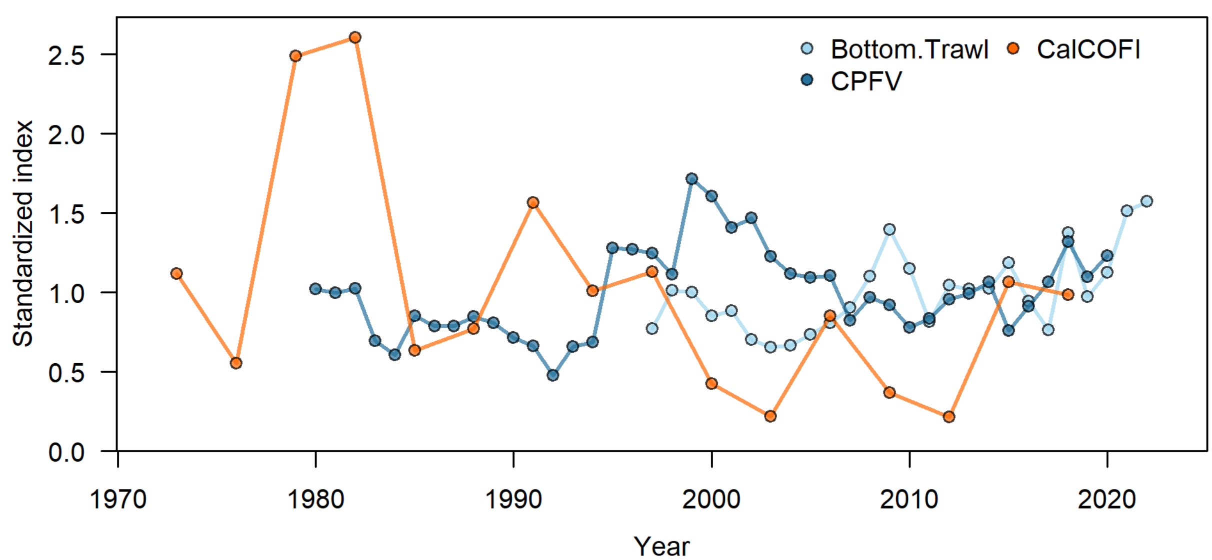


Figure 31. Indices of abundance standardized to their mean.

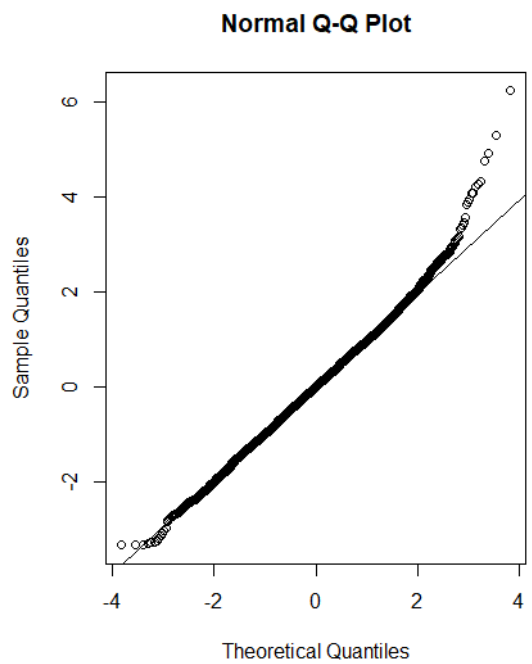


Figure 32. Q-Q plot for the OtherRecl fleet abundance index.

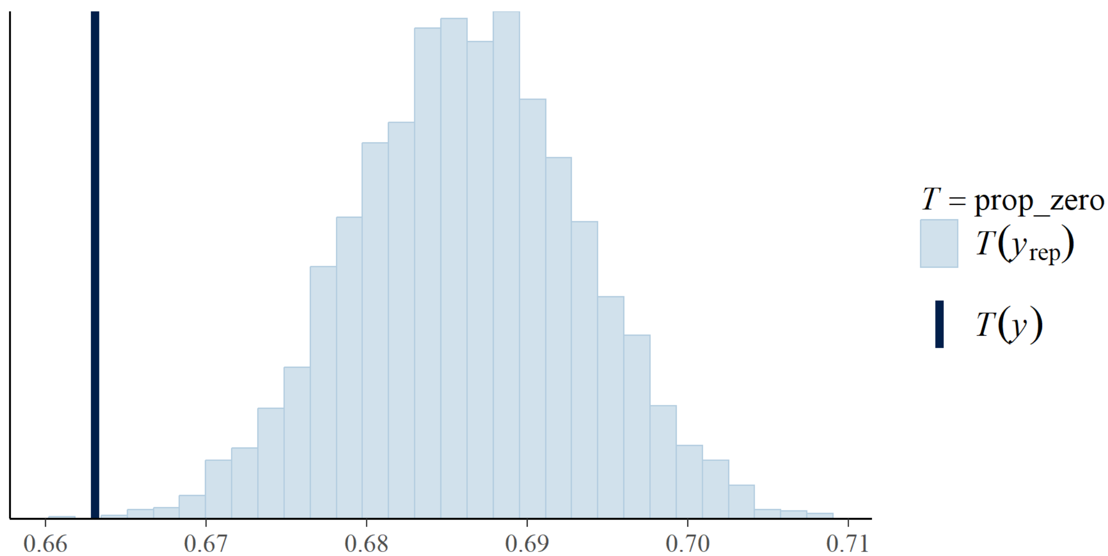


Figure 33. Posterior predictive distribution of the proportion of zero observations in the OtherRec fleet index.

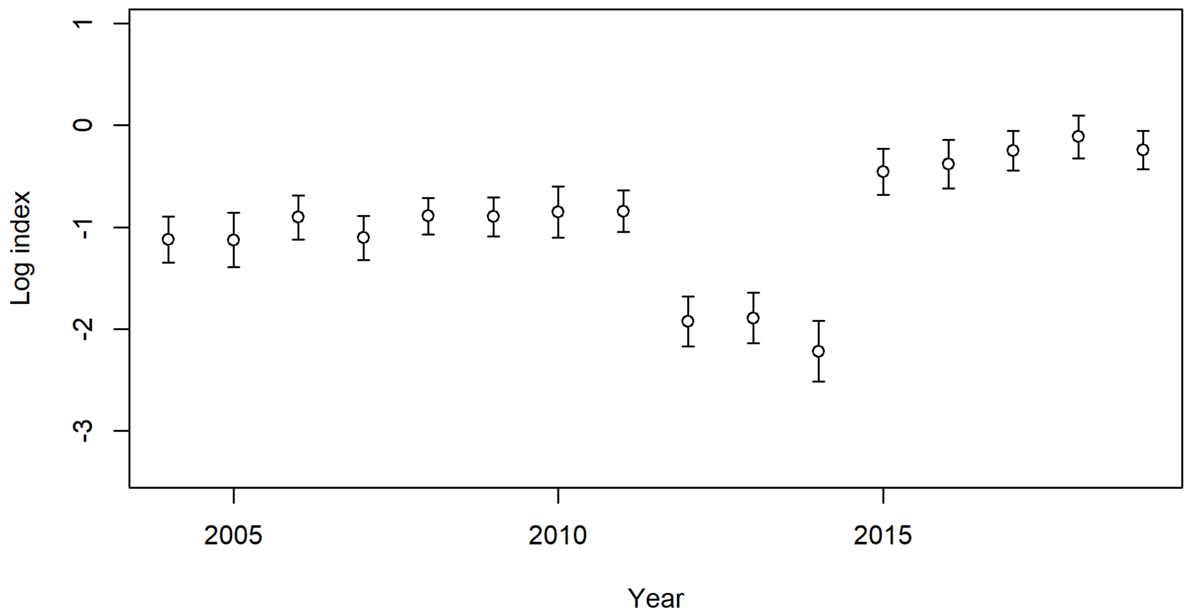


Figure 34. OtherRec fleet index and standard error.

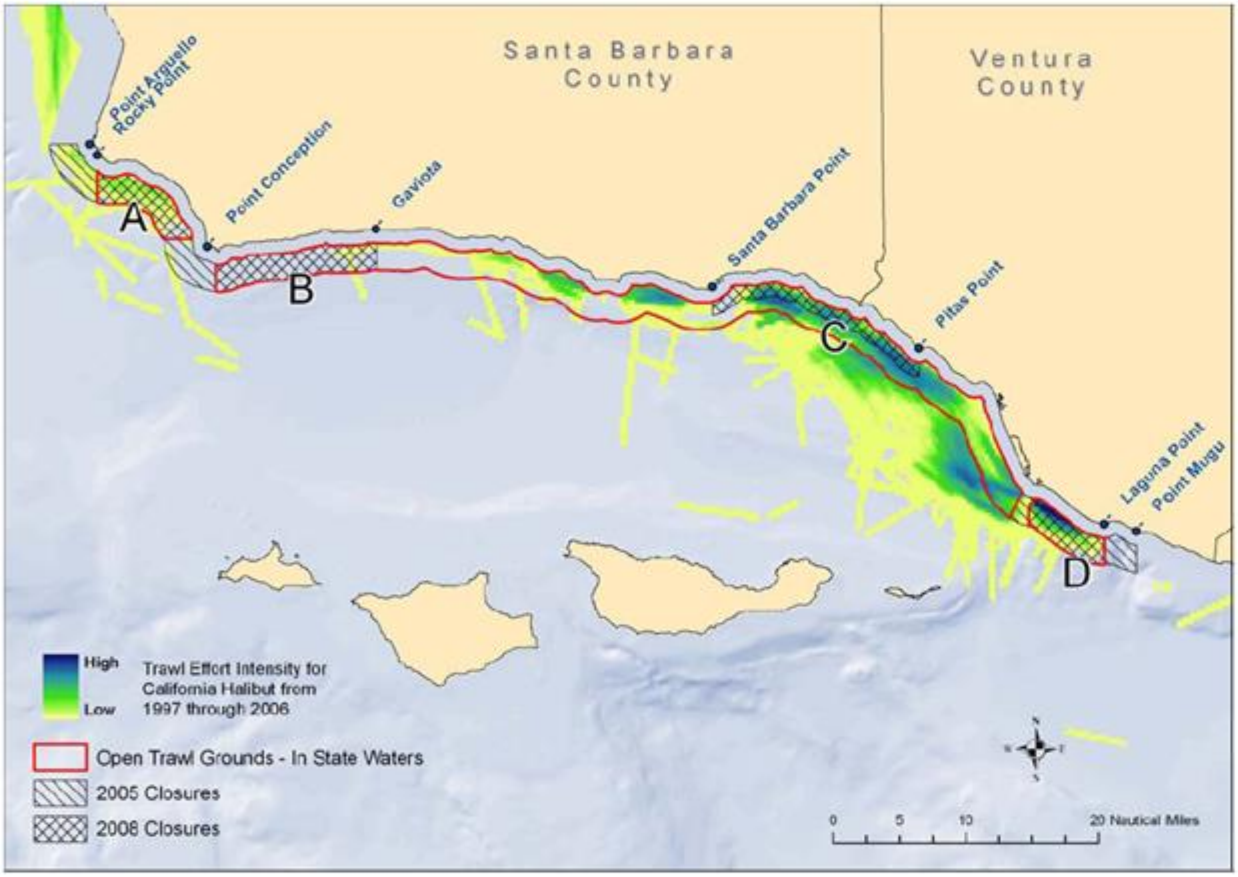


Figure 35. Map of the California Halibut Trawl Grounds (CHTG), including the areas that were closed to trawling in 2005, and the areas proposed for closure in 2008 (only area B was closed). The CHTG are located in the Southern California Bight and primarily consist of soft bottom habitat with an average depth of 174 ft (53 m). Trawl effort intensity from 1997 to 2006 is also mapped. Figure sourced from Frimodig and others 2008. (CDFW 2022a)

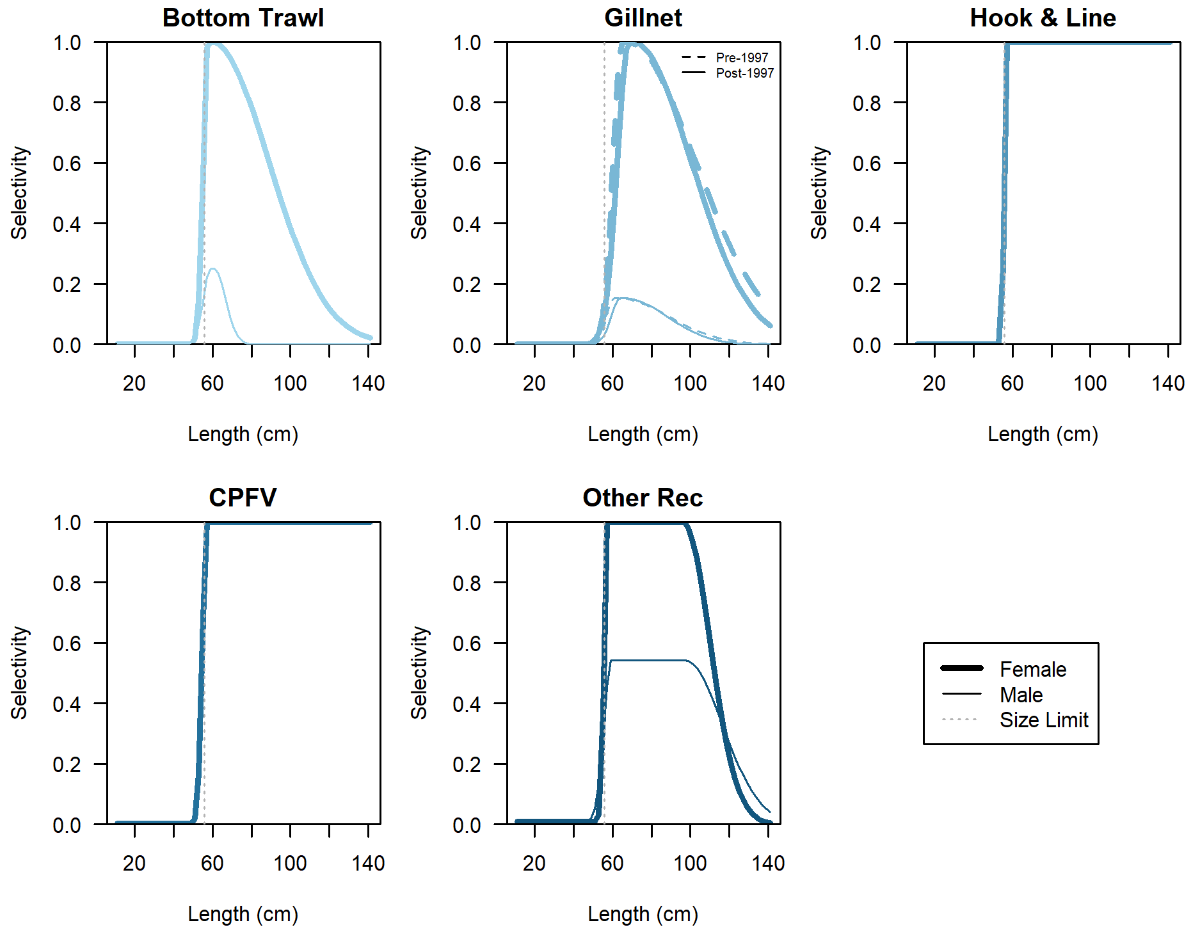


Figure 36. Estimated female and male selectivity curves for the retention fleets. The 22-inch (55.9 cm) size limit is shown as a vertical dotted line.

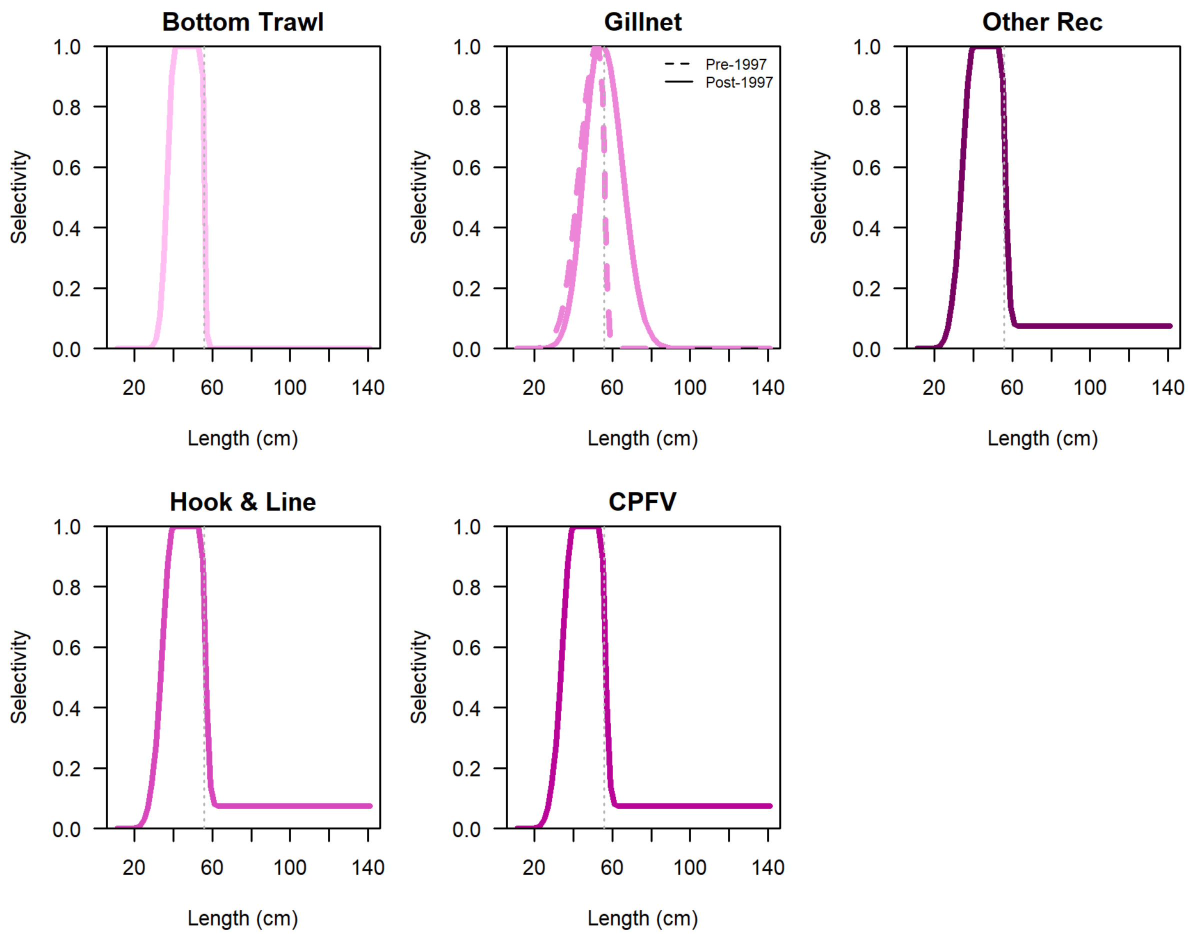


Figure 37. Estimated selectivity curves for the discard fleets (male and female are assumed equal). The 22-inch (55.9 cm) size limit is shown as a vertical dotted line.

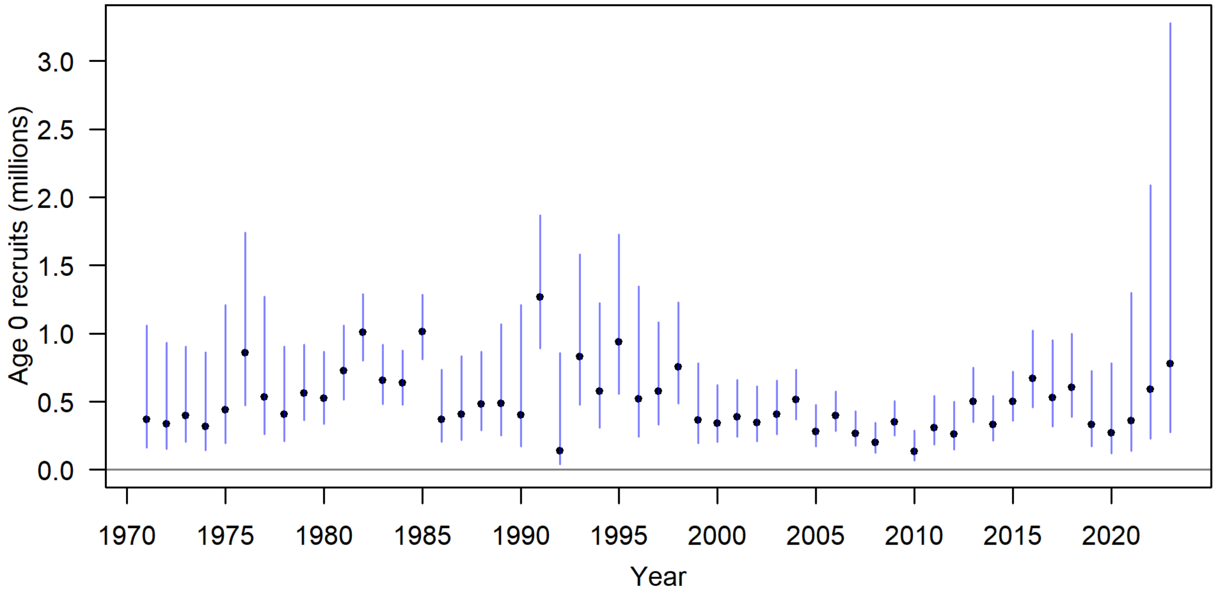


Figure 38. Estimated recruitment time-series with 95% confidence intervals.

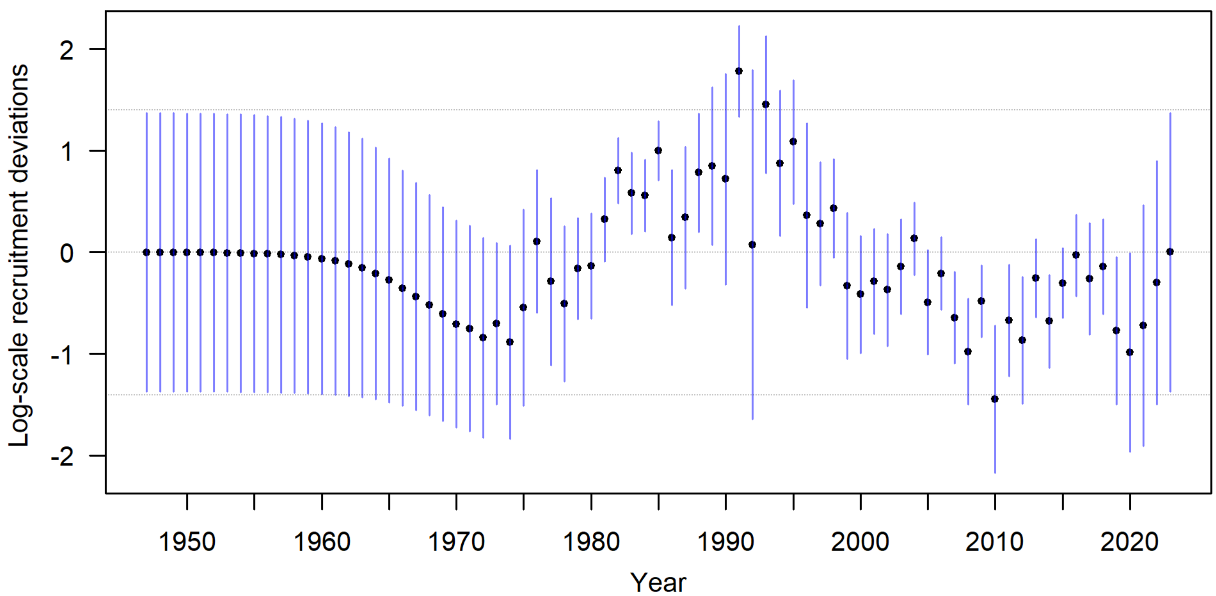


Figure 39. Estimated recruitment deviates with 95% confidence intervals. Horizontal lines show zero and ±2 times sigmaR of 0.7.

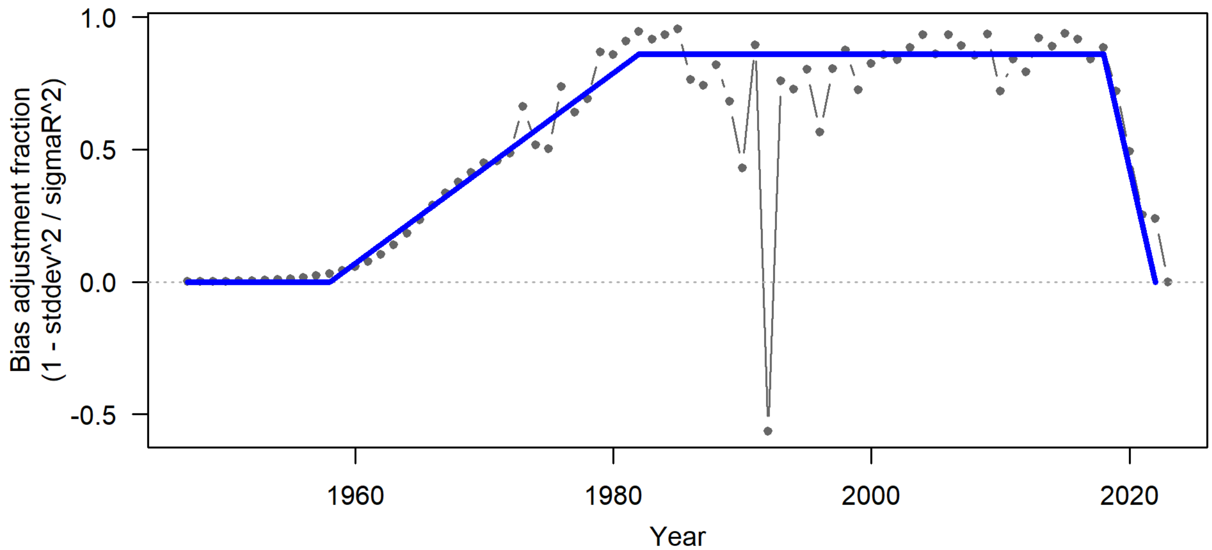


Figure 40. Comparison of estimated asymptotic variance in recruitment deviations to sigmaR and the bias adjustment ramp used in the base model.

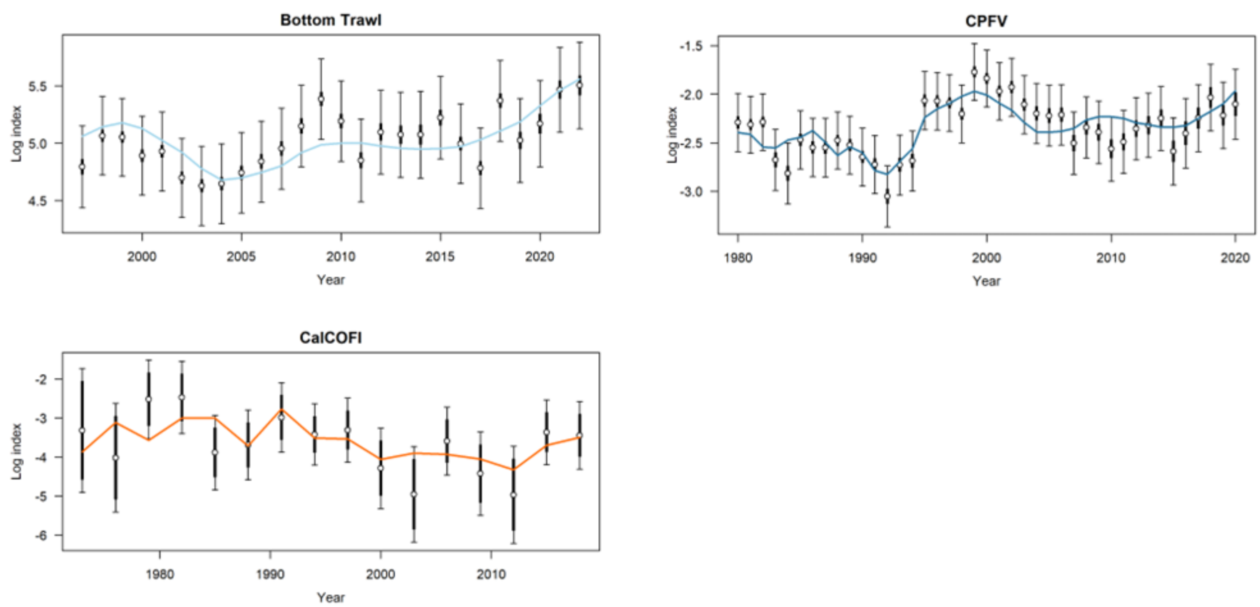


Figure 41. Fits (colored line) to bottom trawl, CPFV, and CalCOFI indices of abundance in natural log-scale. Observations are shown as open circles with the thick vertical line representing the 95% confidence interval based on the input standard error and the thin vertical lines representing the 95% confidence interval based on the input standard error plus the estimated extra standard error.

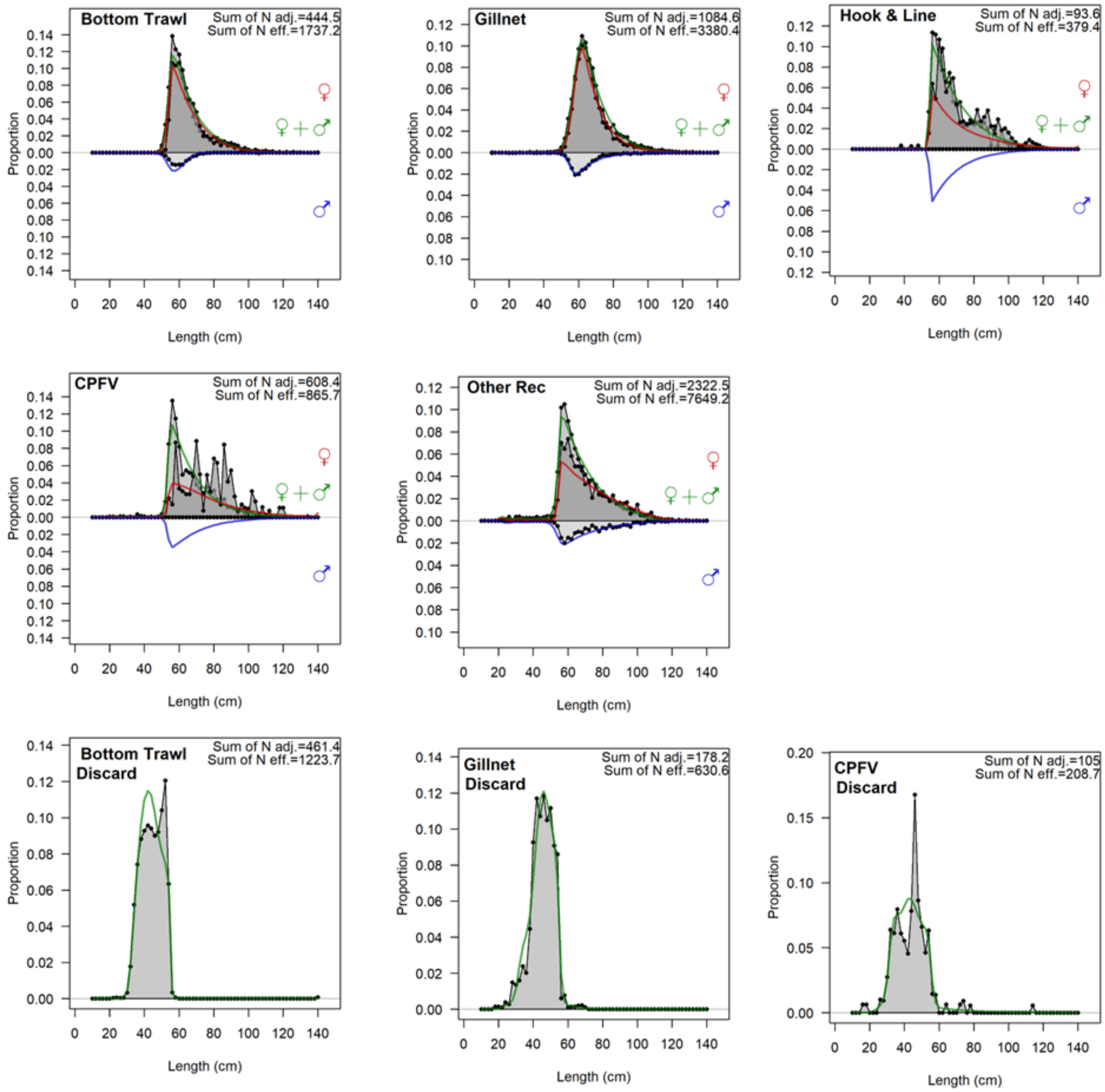


Figure 42. Fits to length compositions for each fleet aggregated over all years.

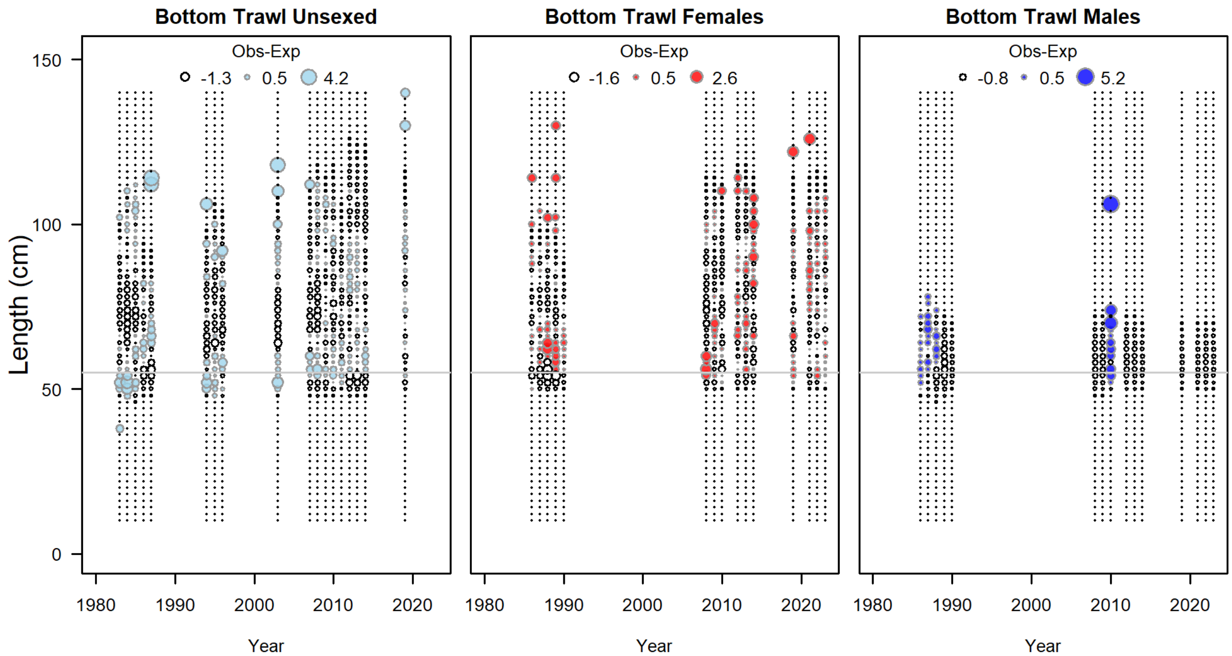


Figure 43. Pearson residuals for sex-specific fits to Bottom Trawl length compositions sampled from landings. The horizontal gray line shows the approximate legal size limit.

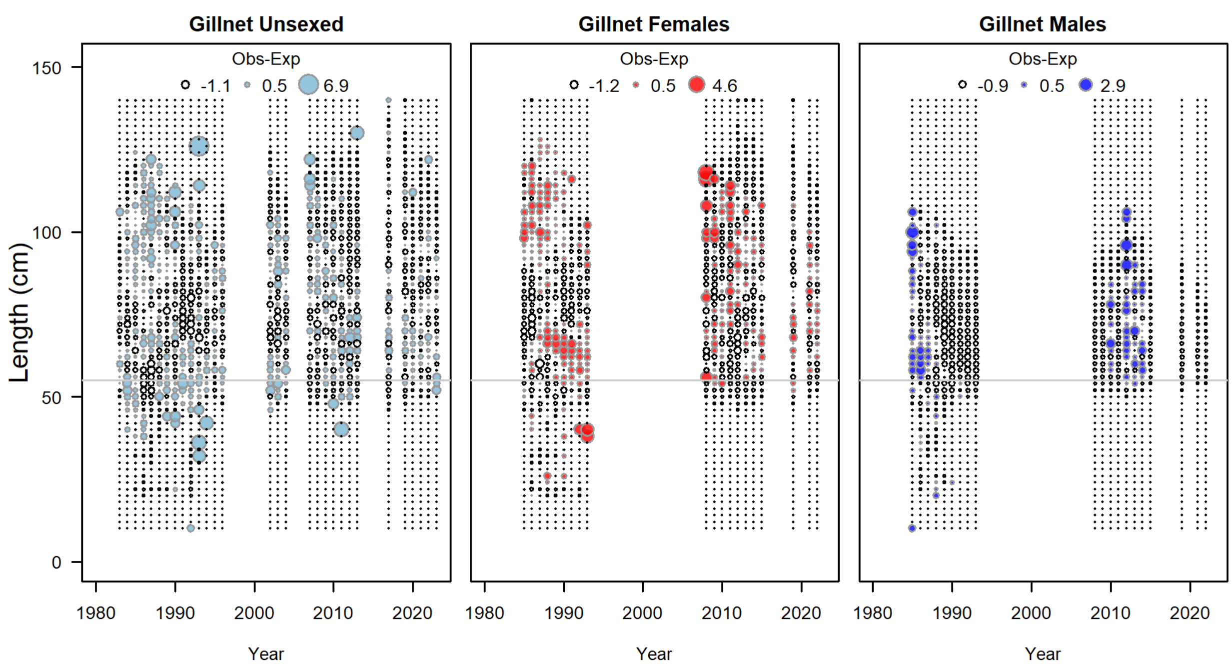


Figure 44. Pearson residuals for sex-specific fits to Gillnet length compositions sampled from landings. The horizontal gray line shows the approximate legal size limit.

Figure 45. Pearson residuals for sex-specific fits to Commercial Hook & Line length compositions sampled from landings. The horizontal gray line shows the approximate legal size limit.

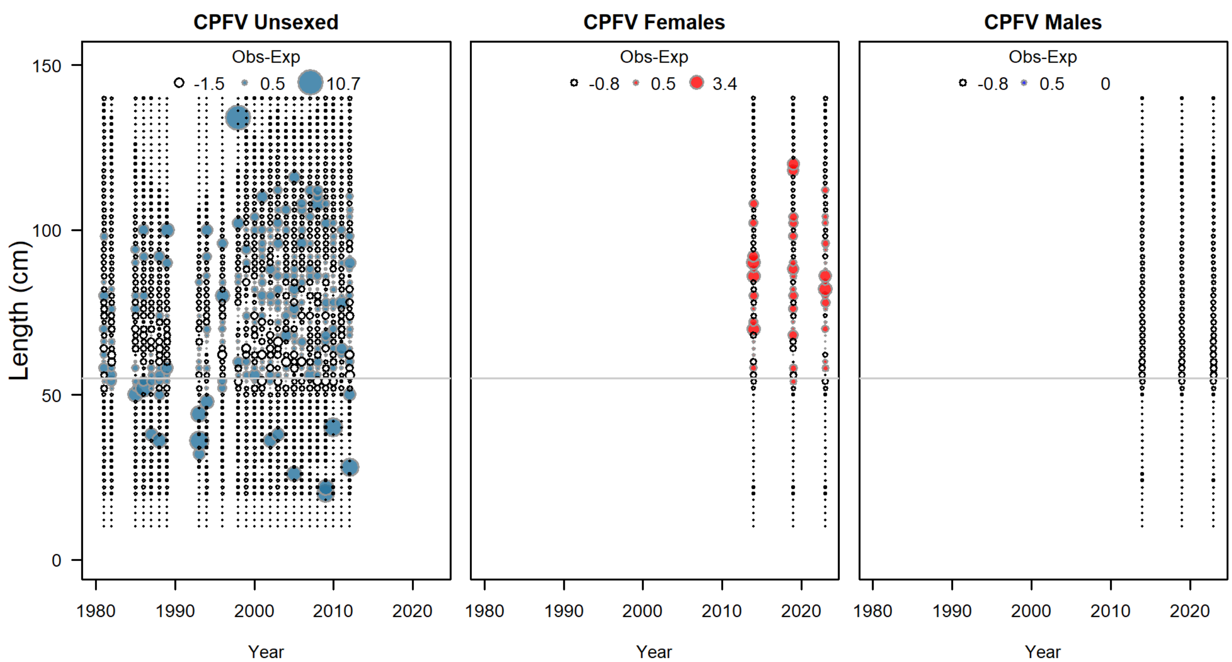


Figure 46. Pearson residuals for sex-specific fits to CPFV length compositions sampled from landings. No males were specifically identified in these samples. The horizontal gray line shows the approximate legal size limit.

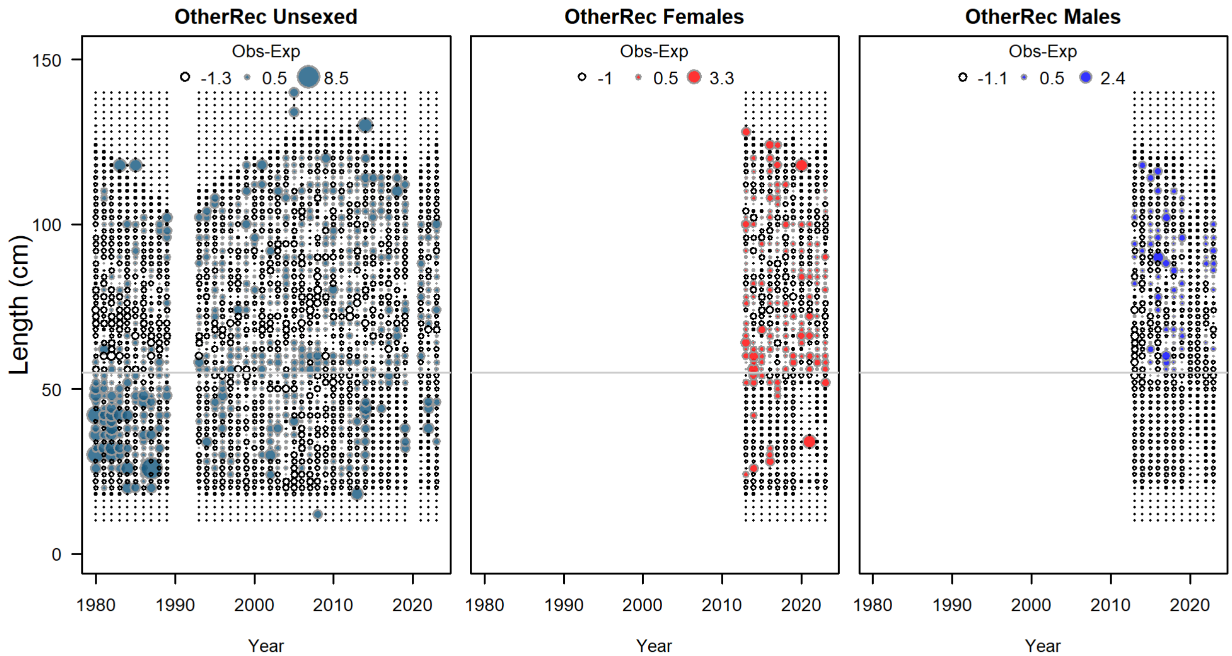


Figure 47. Pearson residuals for sex-specific fits to Other Recreational length compositions sampled from landings. The horizontal gray line shows the approximate legal size limit.

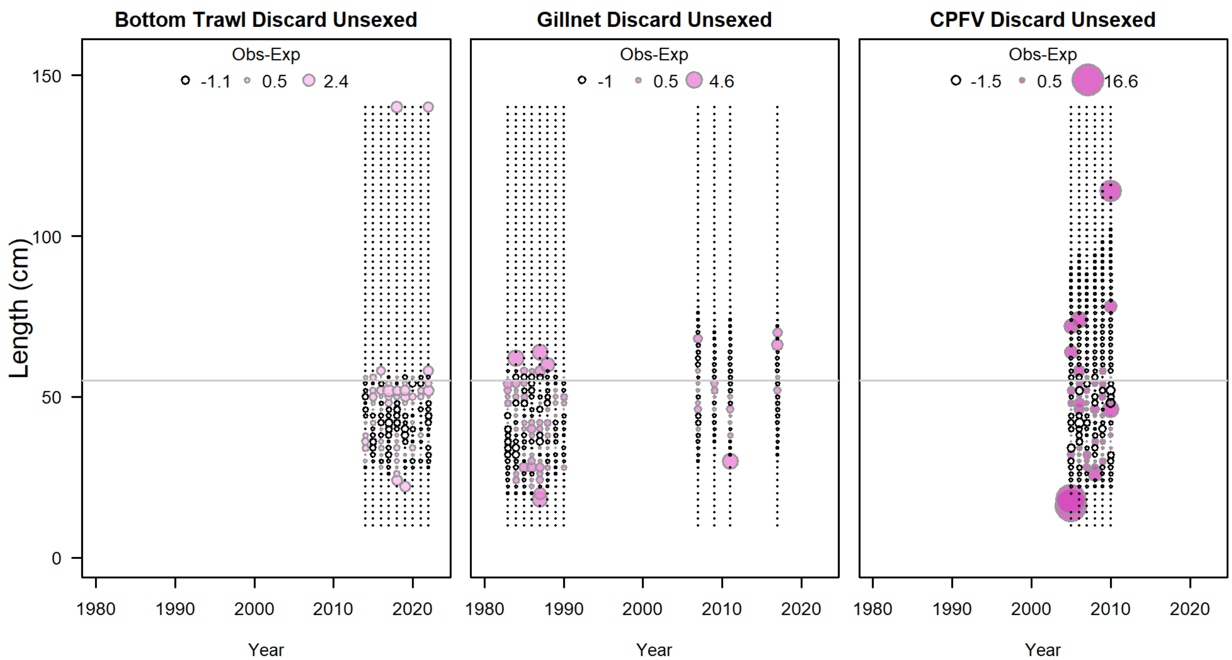


Figure 48. Pearson residuals for sex-specific fits to length compositions sampled from discards of Bottom Trawl, Gillnet, and CPFV fleets. The horizontal gray line shows the approximate legal size limit.

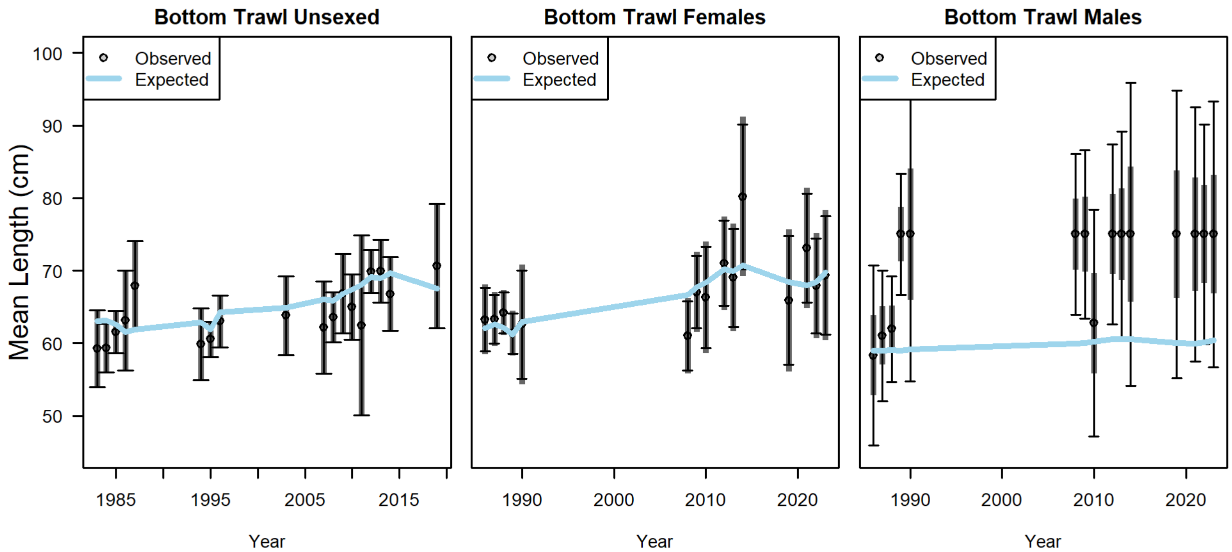


Figure 49. Expected and observed mean lengths for bottom trawl landings. Thick lines represent 95% confidence intervals calculated from the input adjusted sample sizes and thin lines with a horizontal mark show the 95% confidence intervals calculated using further adjustment to sample sizes based on the Francis method.

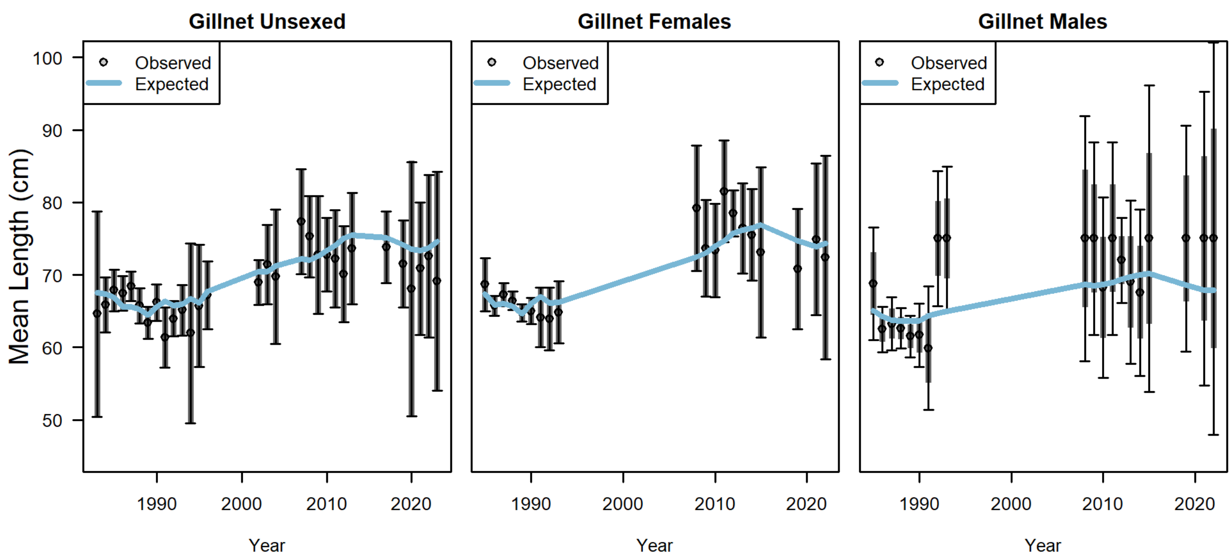


Figure 50. Expected and observed mean lengths for gillnet landings. Thick lines represent 95% confidence intervals calculated from the input adjusted sample sizes and thin lines with a horizontal mark show the 95% confidence intervals calculated using further adjustment to sample sizes based on the Francis method.

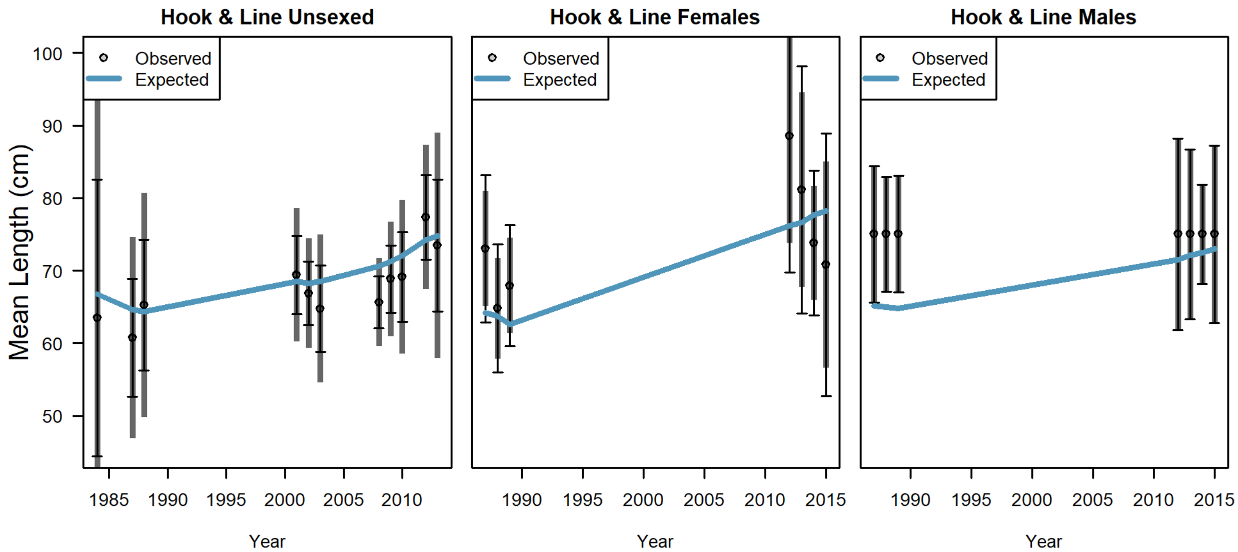


Figure 51. Expected and observed mean lengths for Hook & Line landings. Thick lines represent 95% confidence intervals calculated from the input adjusted sample sizes and thin lines with a horizontal mark show the 95% confidence intervals calculated using further adjustment to sample sizes based on the Francis method.

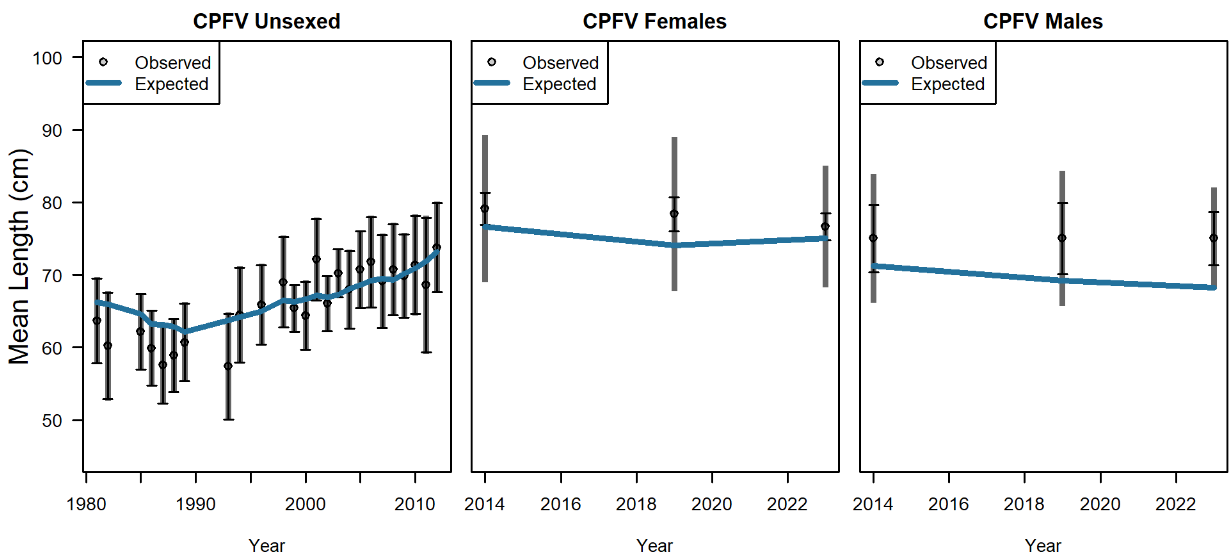


Figure 52. Expected and observed mean lengths for CPFV landings. Thick lines represent 95% confidence intervals calculated from the input adjusted sample sizes and thin lines with a horizontal mark show the 95% confidence intervals calculated using further adjustment to sample sizes based on the Francis method.

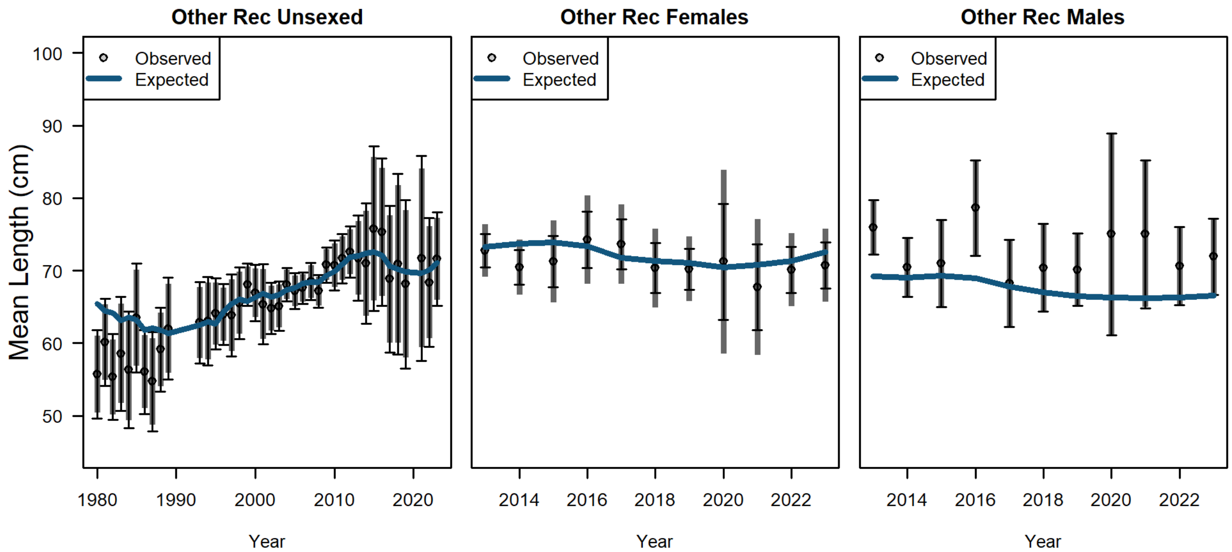


Figure 53. Expected and observed mean lengths for Other Recreational landings. Thick lines represent 95% confidence intervals calculated from the input adjusted sample sizes and thin lines with a horizontal mark show the 95% confidence intervals calculated using further adjustment to sample sizes based on the Francis method.

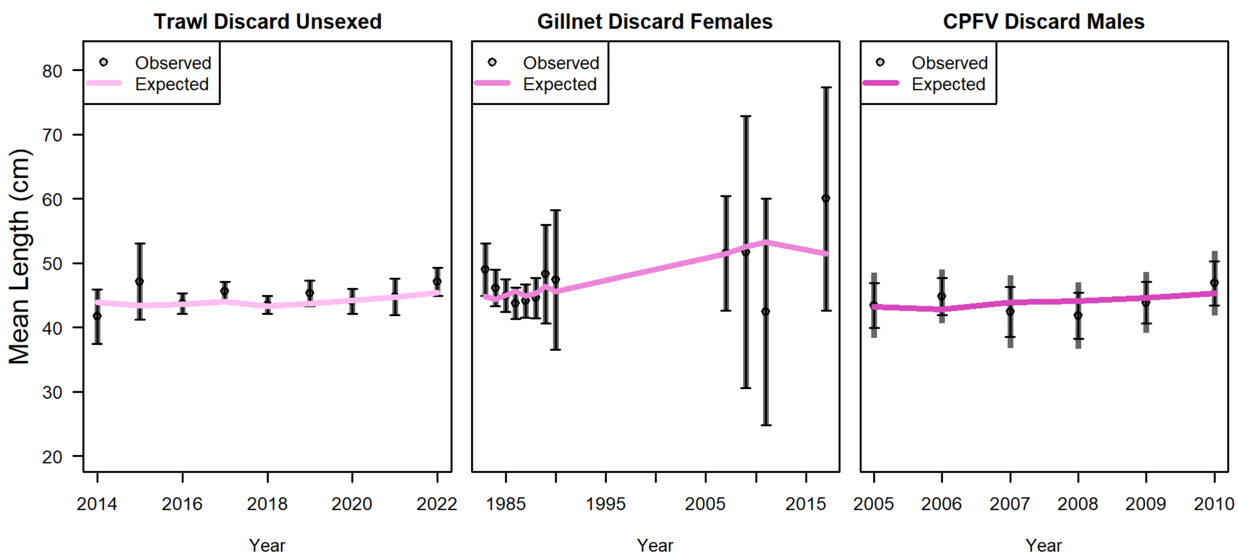


Figure 54. Expected and observed mean lengths for bottom trawl, gillnet, and CPFV discards. Thick lines represent 95% confidence intervals calculated from the input adjusted sample sizes and thin lines with a horizontal mark show the 95% confidence intervals calculated using further adjustment to sample sizes based on the Francis method.

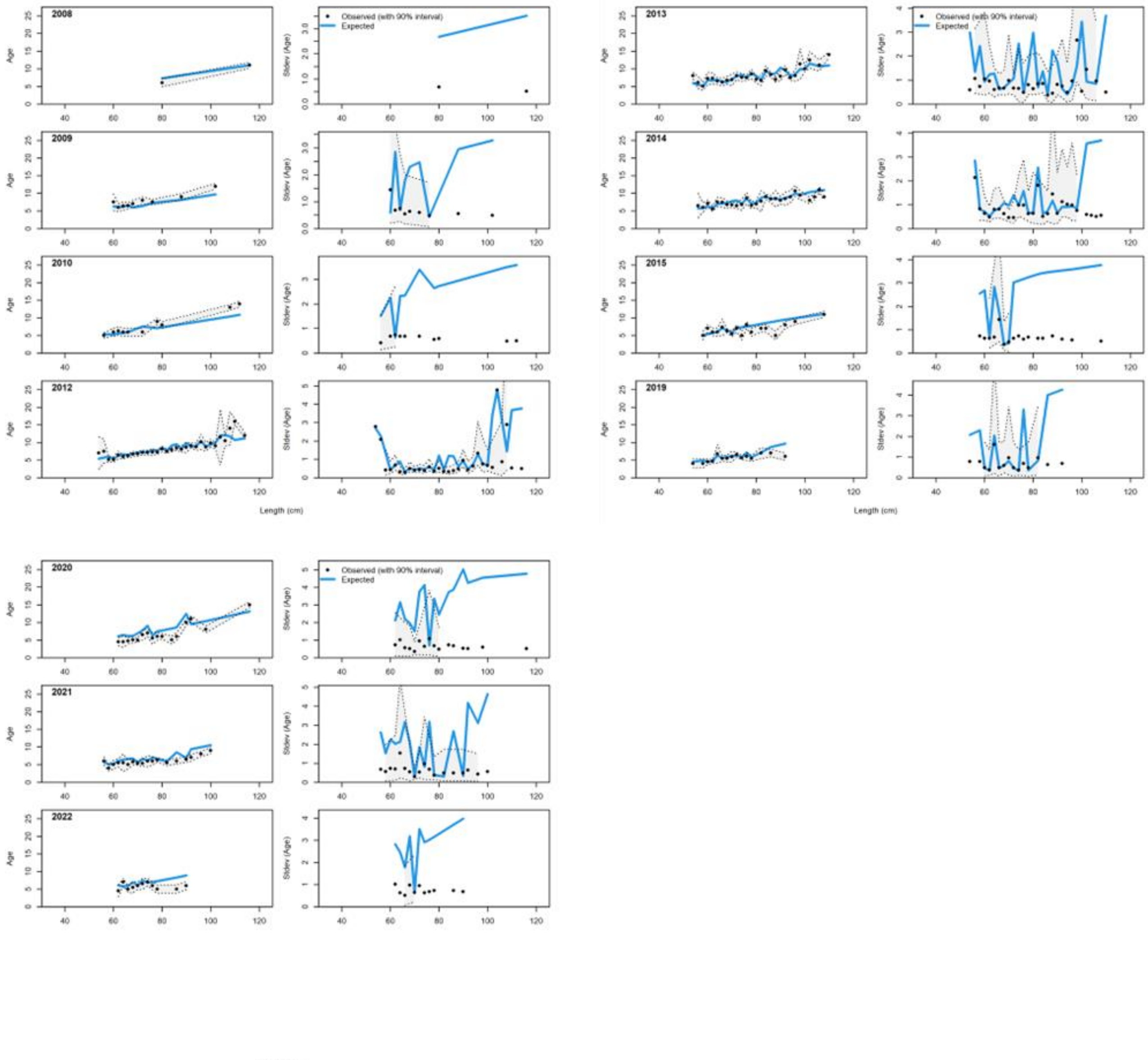


Figure 55. Fits to conditional age-at-length data for Bottom Trawl landings.

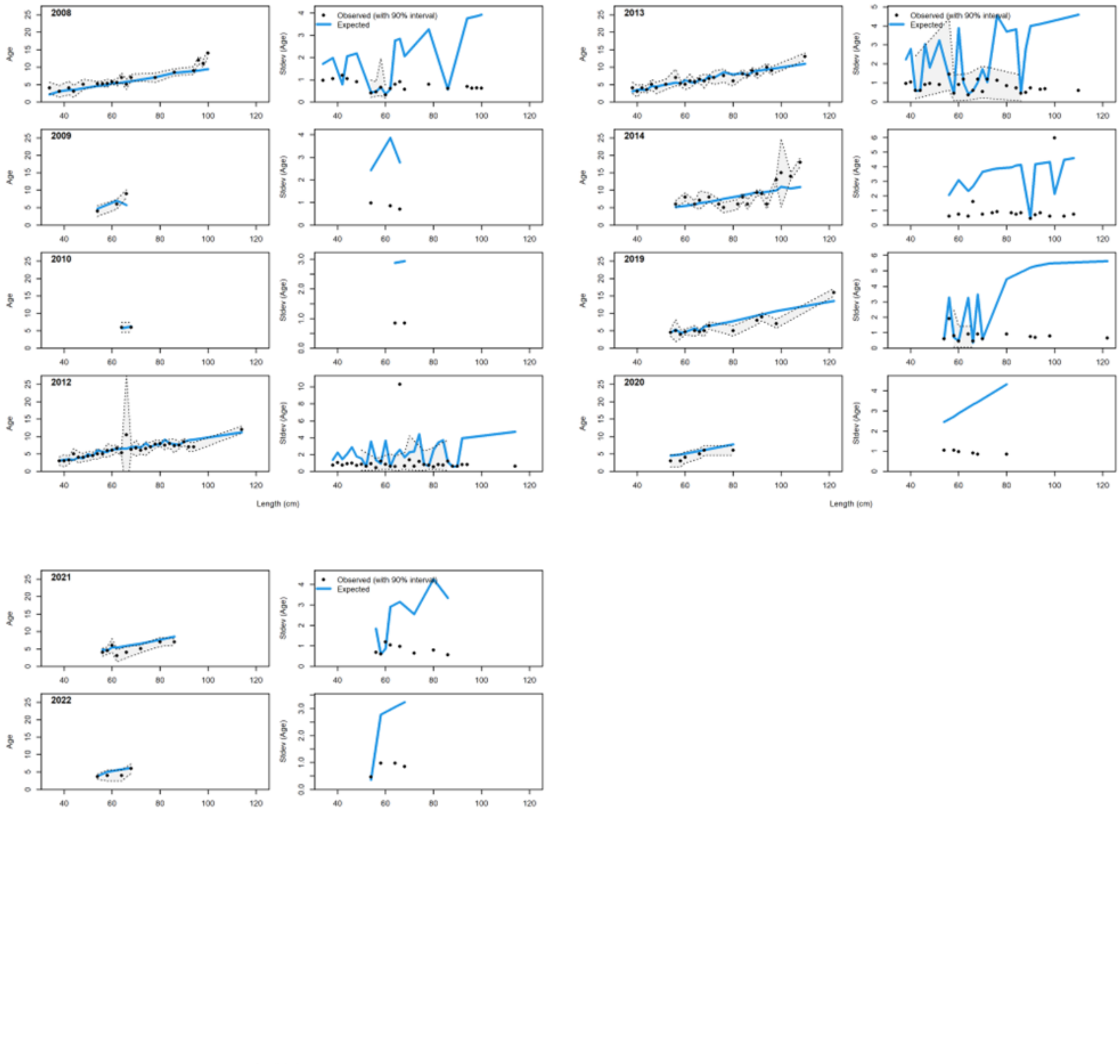


Figure 56. Fits to conditional age-at-length for Gillnet landings.

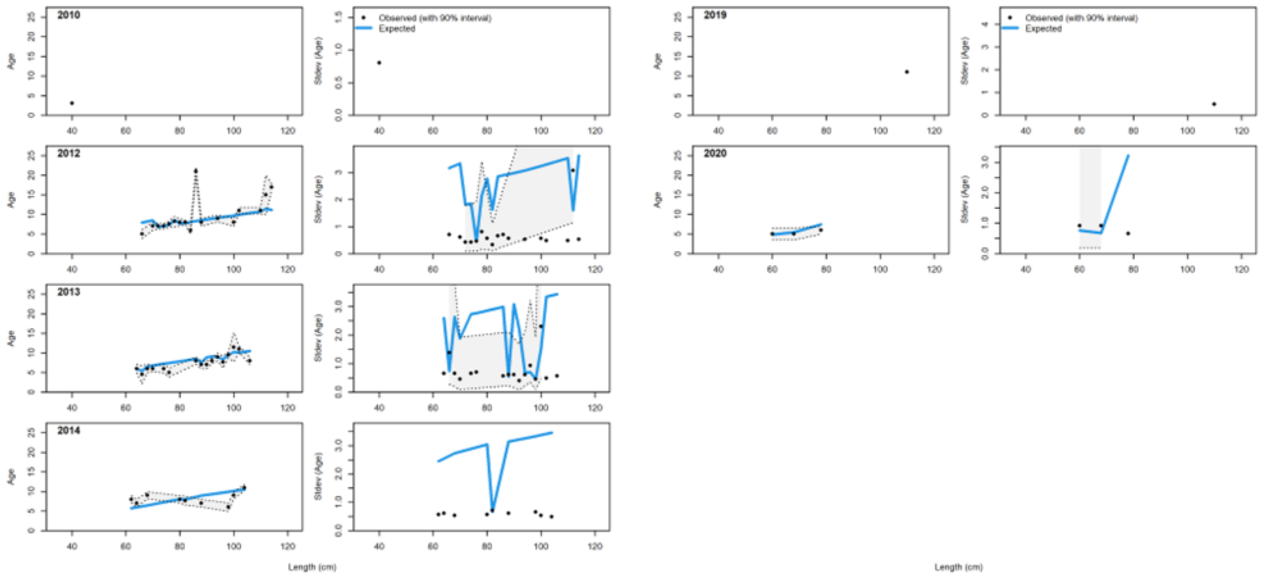


Figure 57. Fits to conditional age-at-length for Hook & Line landings.

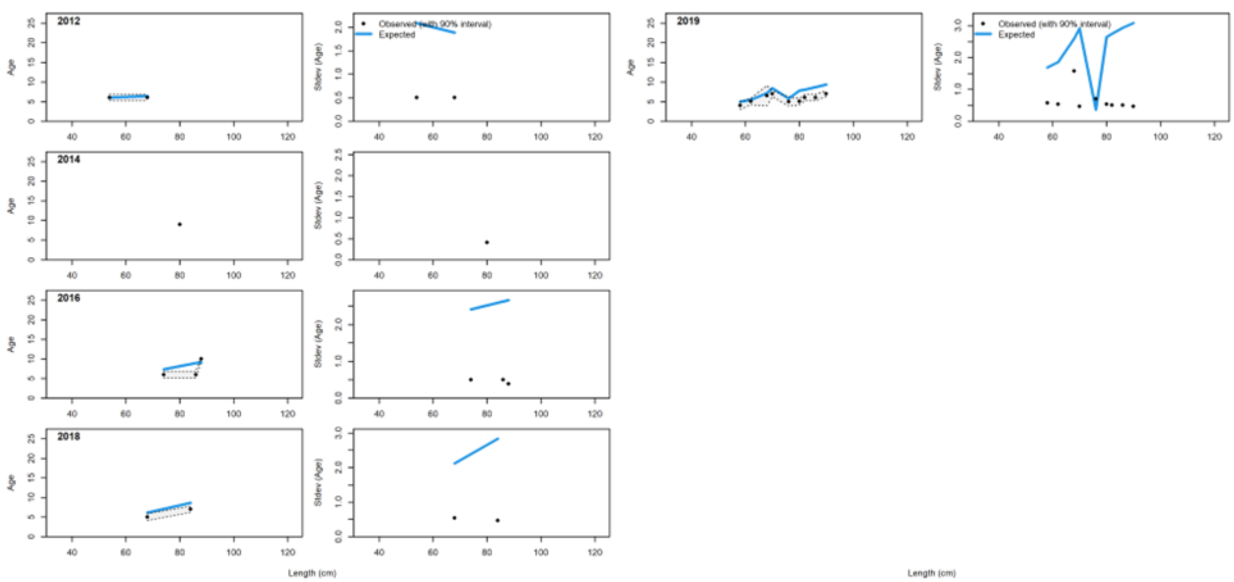


Figure 58. Fits to conditional age-at-length for CPFV landings.

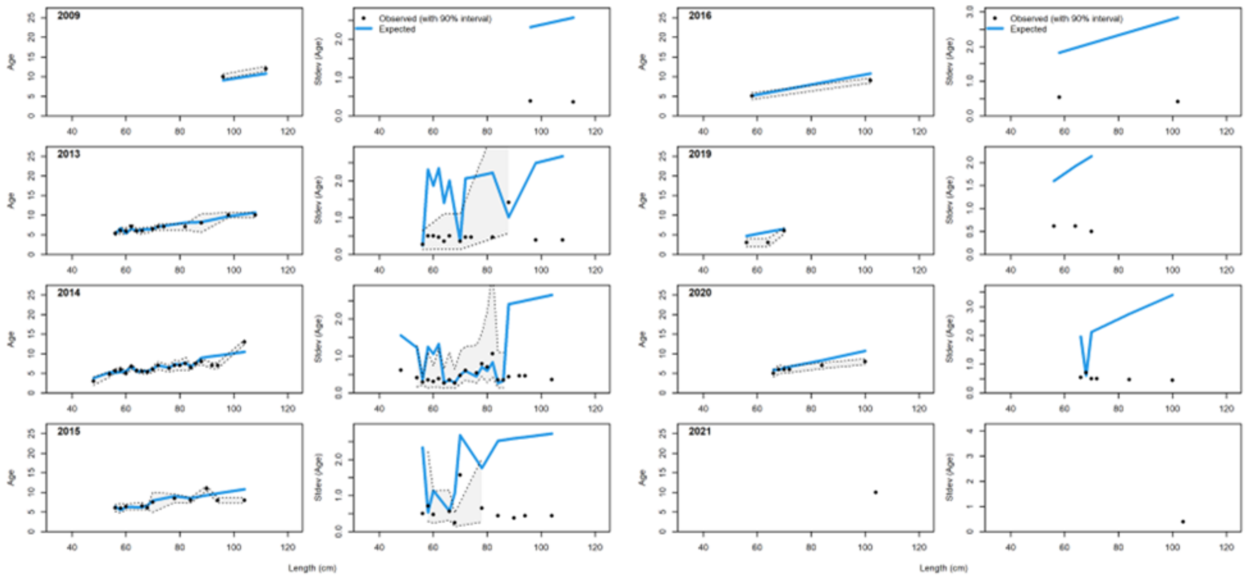


Figure 59. Fits to conditional age-at-length for Other Recreational landings.

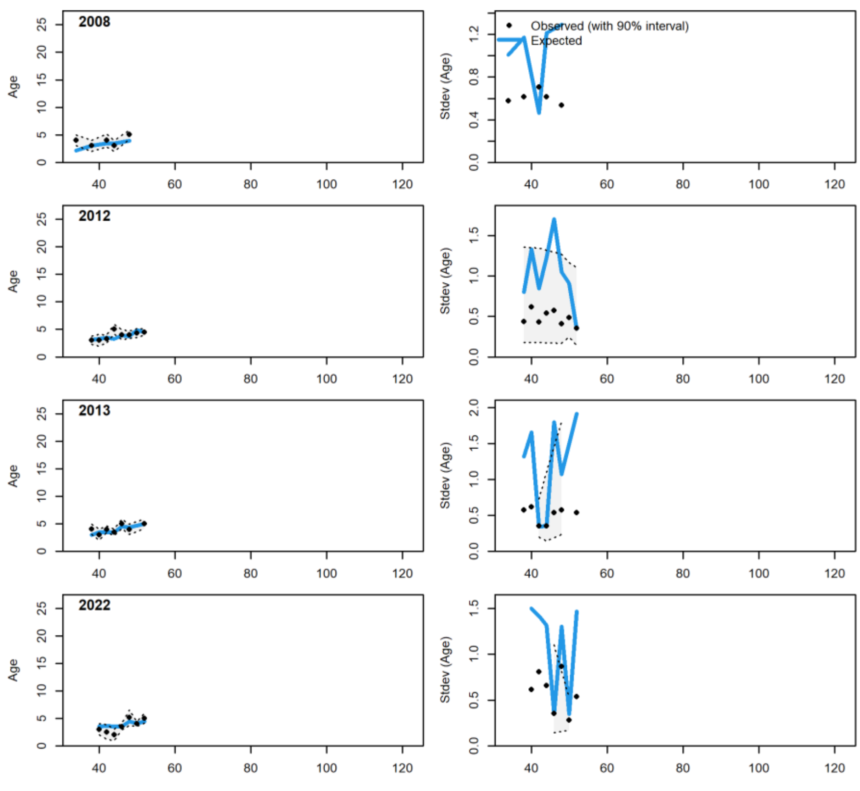


Figure 60. Fits to conditional age-at-length for Bottom Trawl discards.

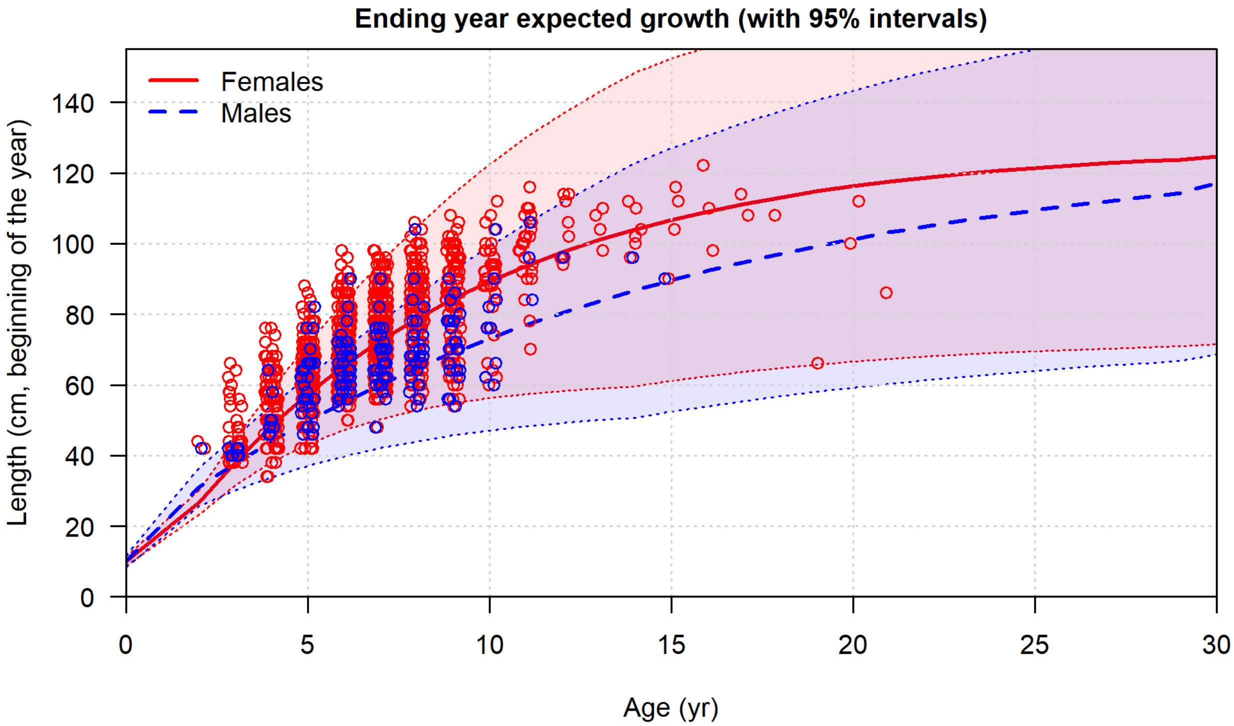


Figure 61. Fitted growth curve and 95% interval with length-at-age observations from all fleets shown.

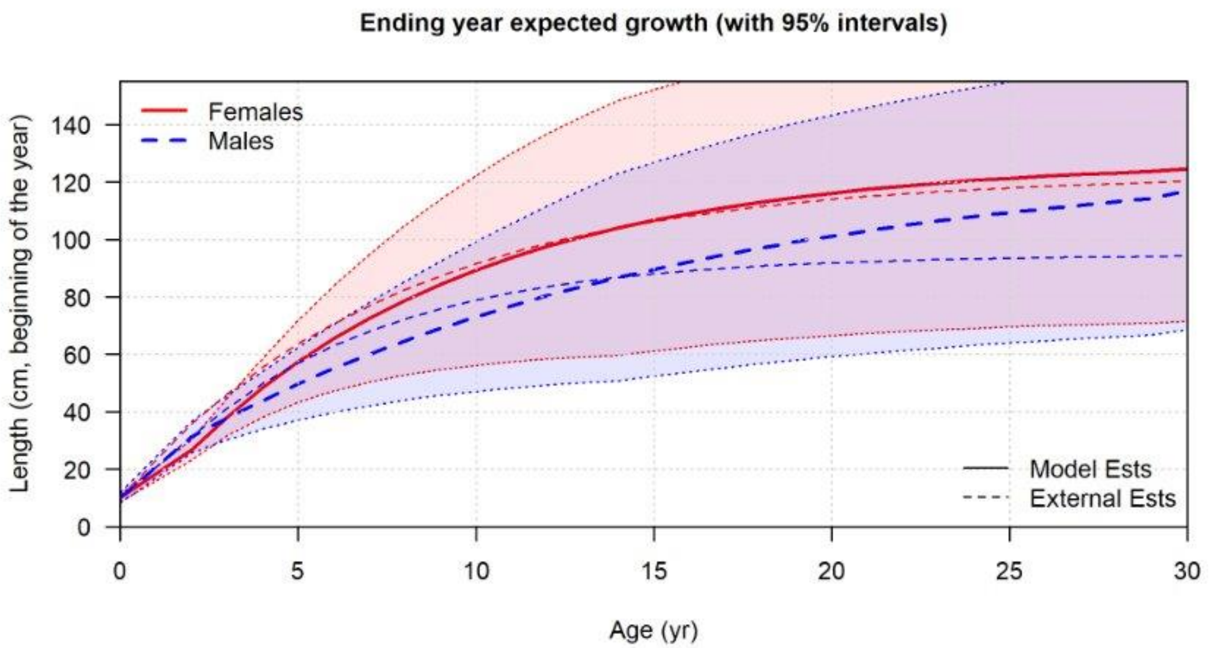


Figure 62. Comparison of fitted growth curve and 95% interval with externally estimated growth curves.

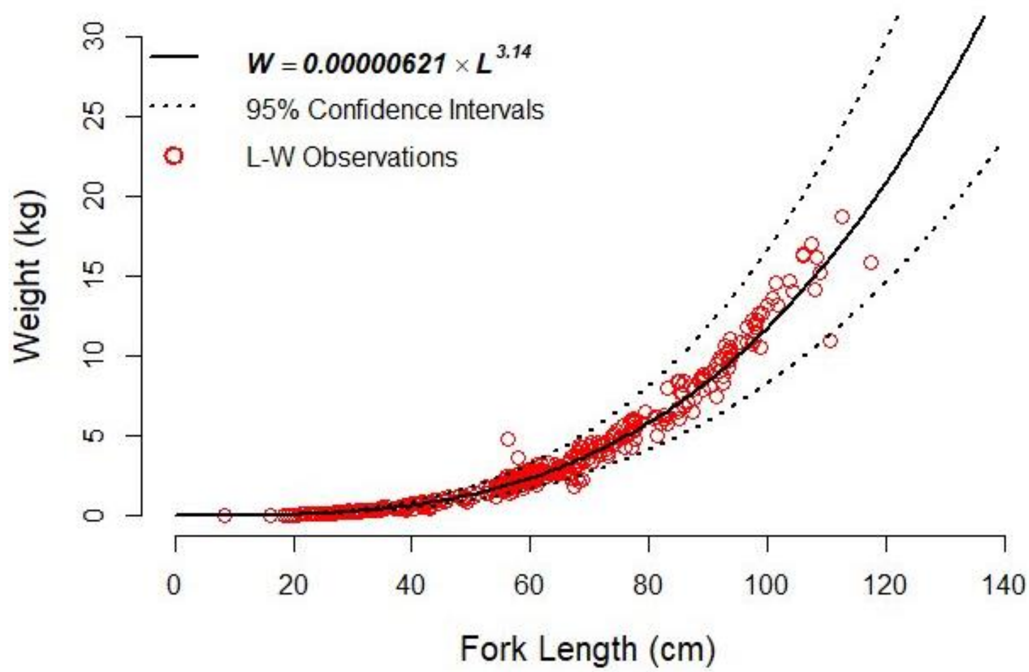


Figure 63. Length-weight relationship for female halibut from southern California.

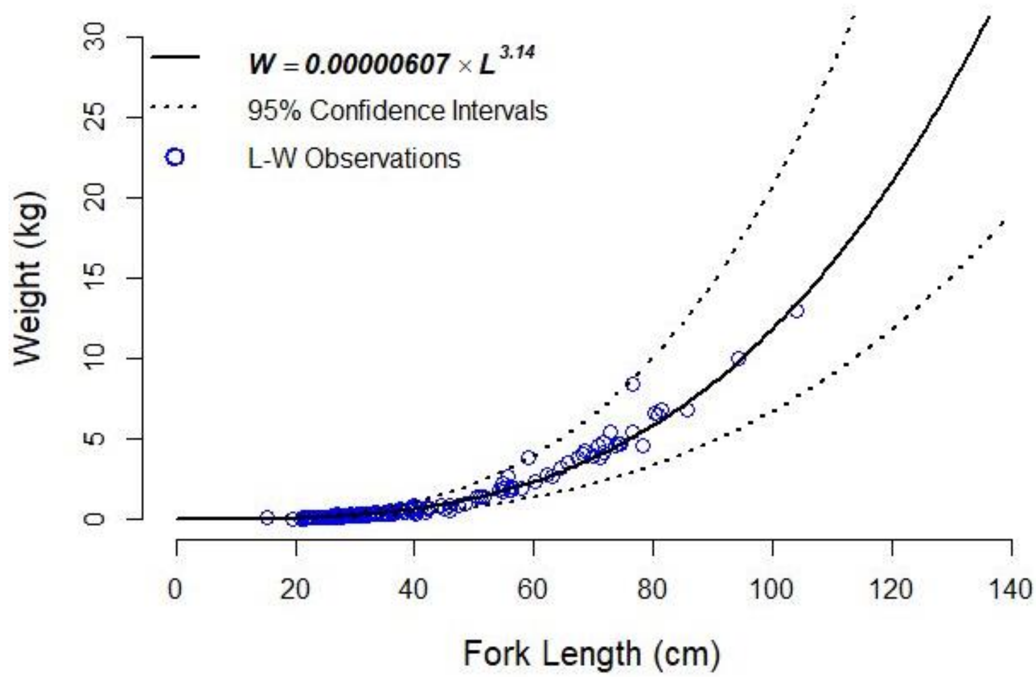


Figure 64. Length-weight relationship for male halibut from southern California.

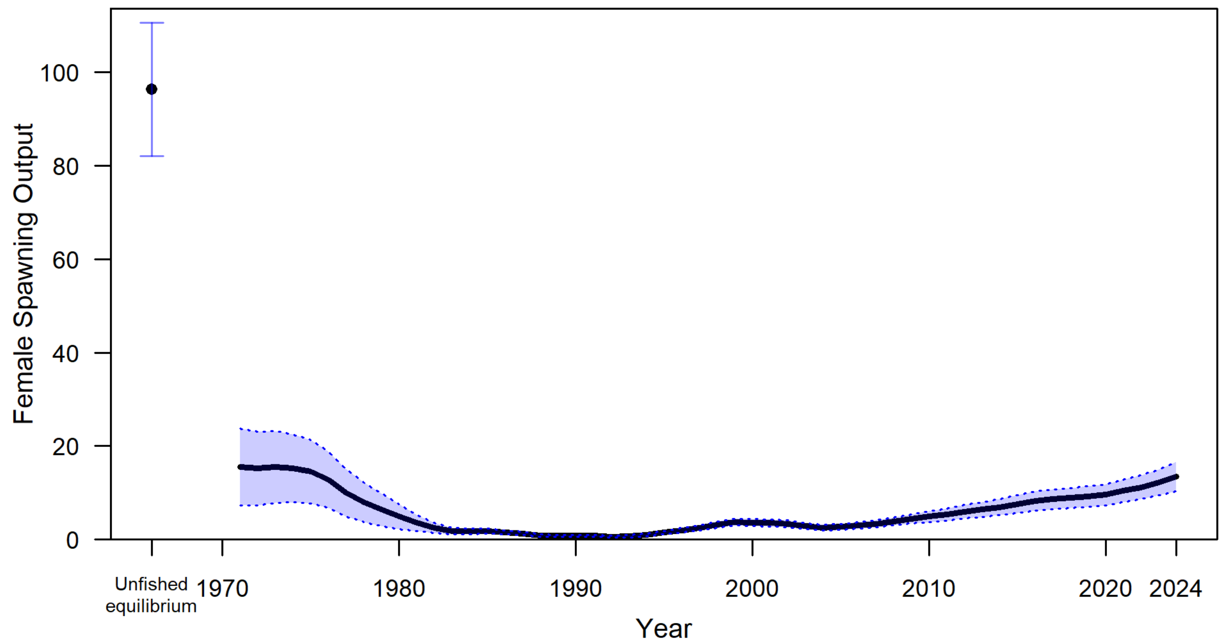


Figure 65. Estimated female spawning output with a 95% asymptotic confidence interval.

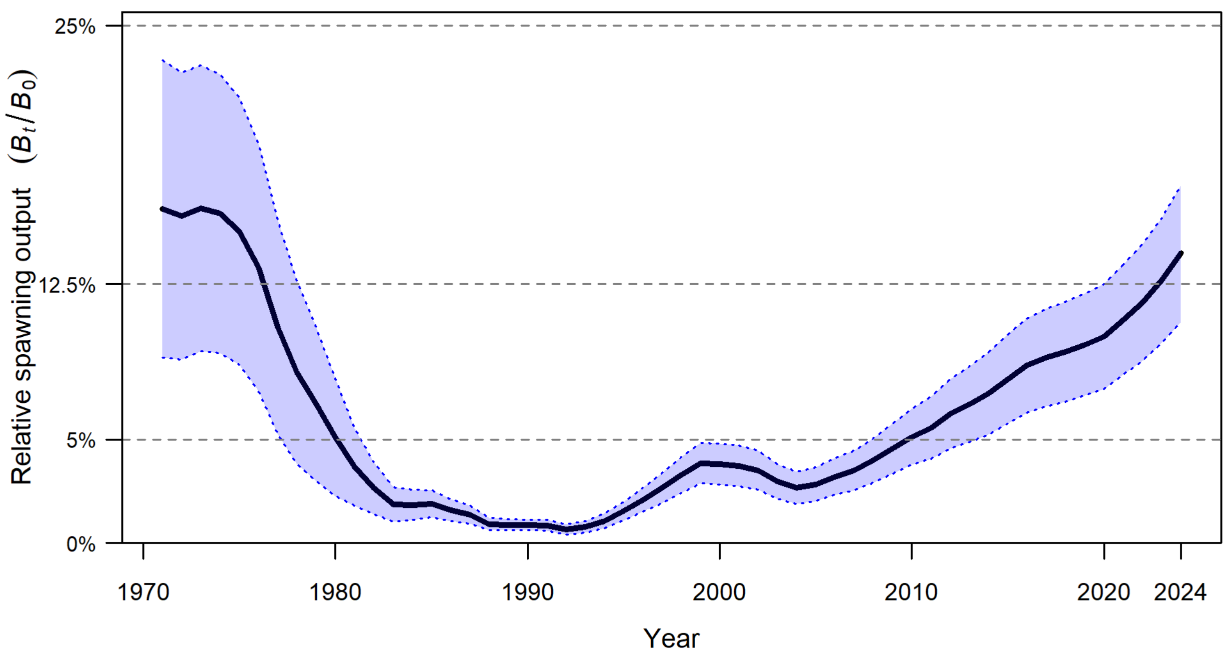


Figure 66. Estimated relative female spawning output with a 95% asymptotic confidence interval. Horizontal lines show PFMC proxy reference points for flatfish.

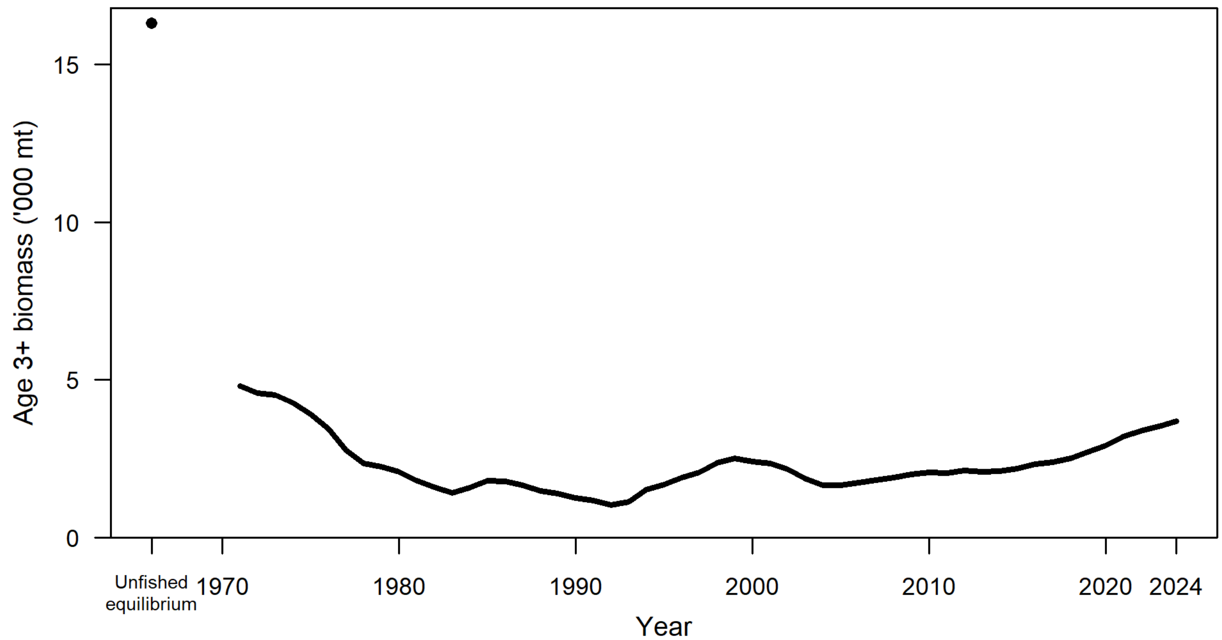


Figure 67. Estimated age 3+ biomass from 1971 to 2024.

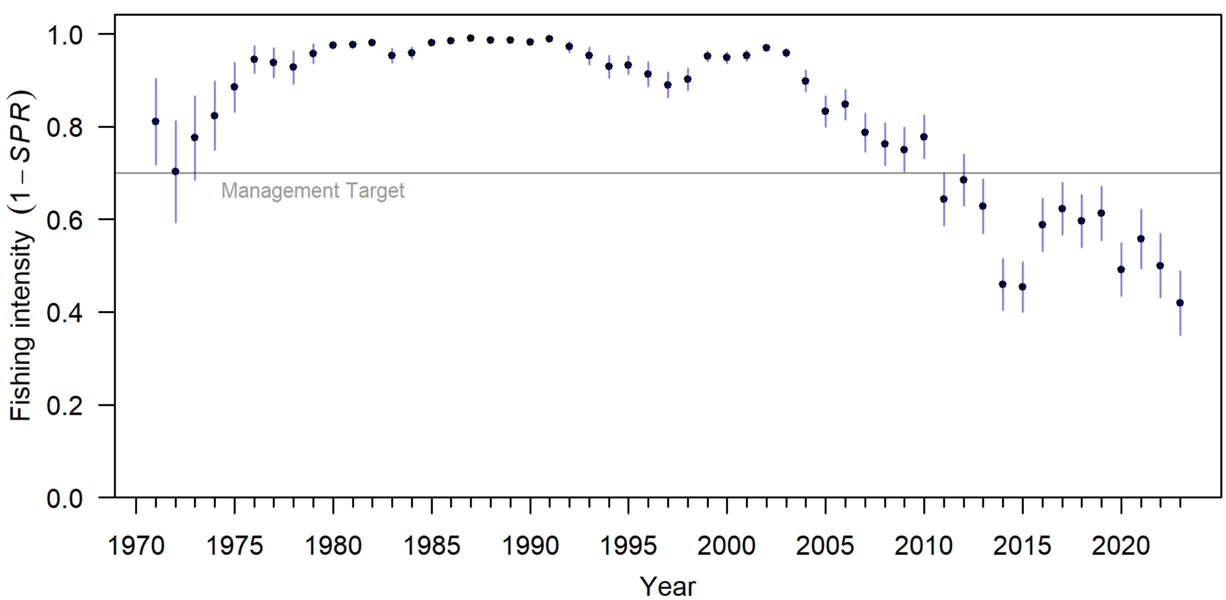


Figure 68. Estimated fishing intensity measured as 1 minus the spawning potential ratio (SPR) with 95% confidence intervals. The horizontal line is the target SPR rate of 30%.

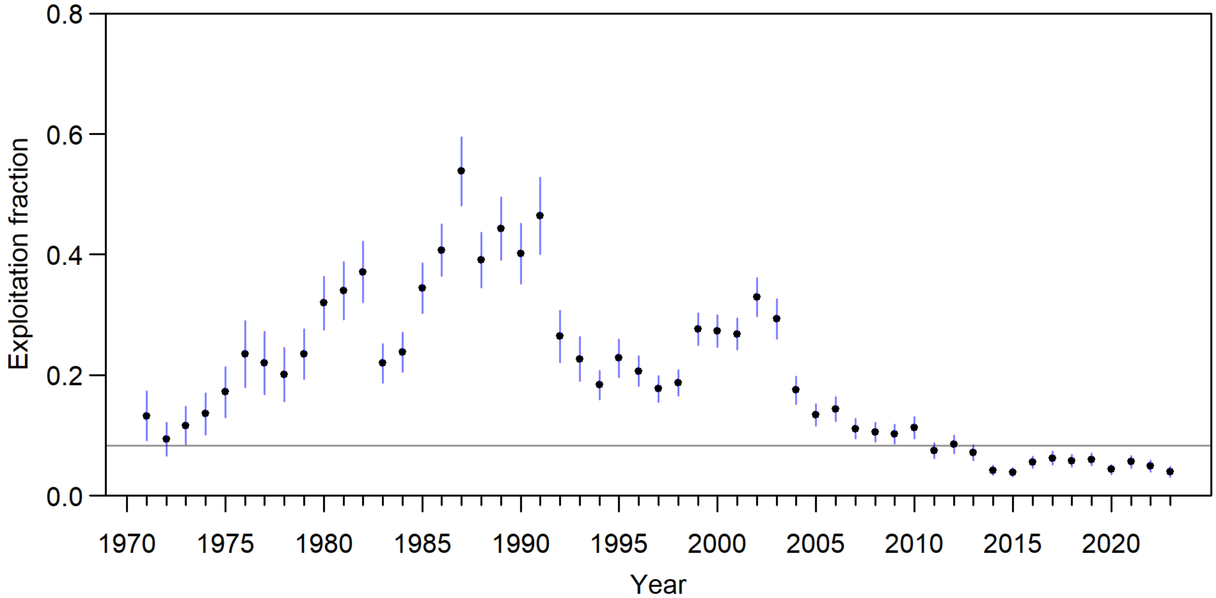


Figure 69. Estimated proxy exploitation rate (total catch divided by age 3+ biomass) with 95% confidence intervals. The horizontal line is the exploitation rate associated with the target SPR of 30%.

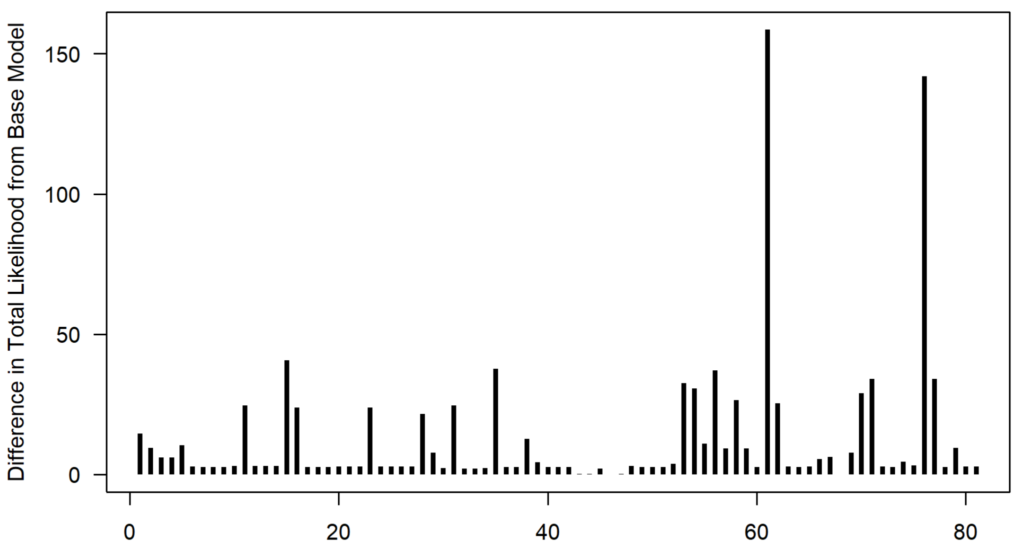


Figure 70. Difference in log likelihood compared to the base model log likelihood when starting optimization from randomly jittered parameters.

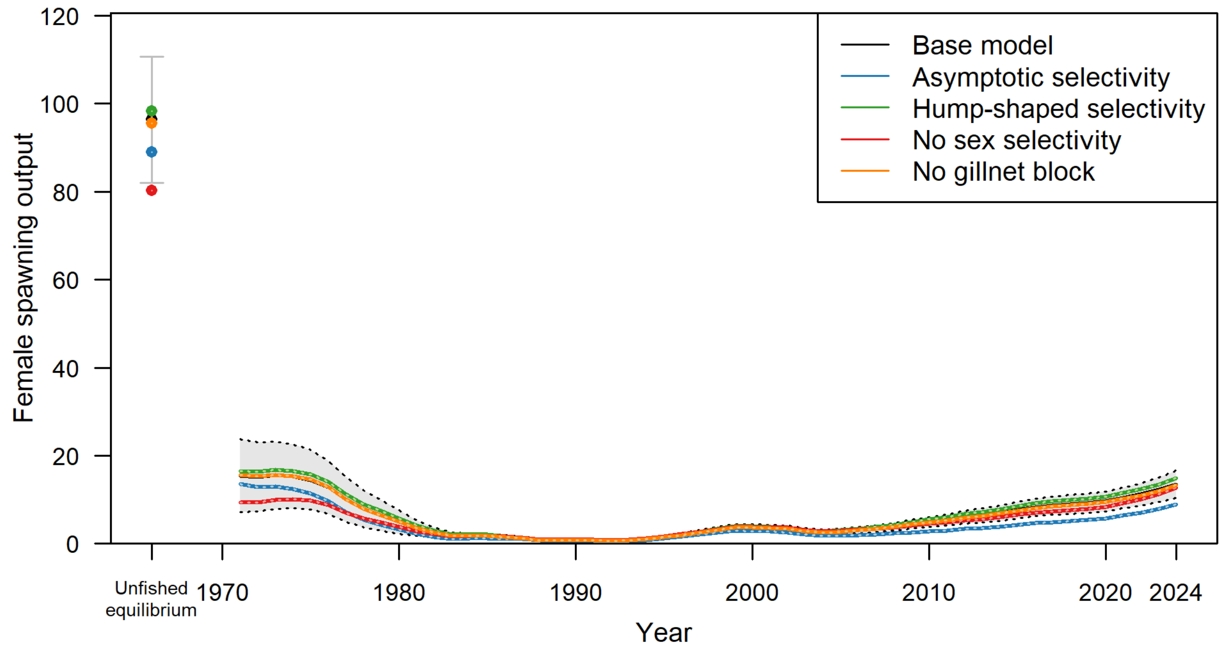


Figure 71. Sensitivity of spawning output to asymptotic selectivity curves in all retention fleets (not discard) (blue), hump-shaped selectivity for commercial hook & line and CPFV fleets (green), no sex selectivity (red) and no selectivity block for the gillnet retention and discard fleets (orange) compared to the base model (black). Models are shown with 95% confidence intervals.

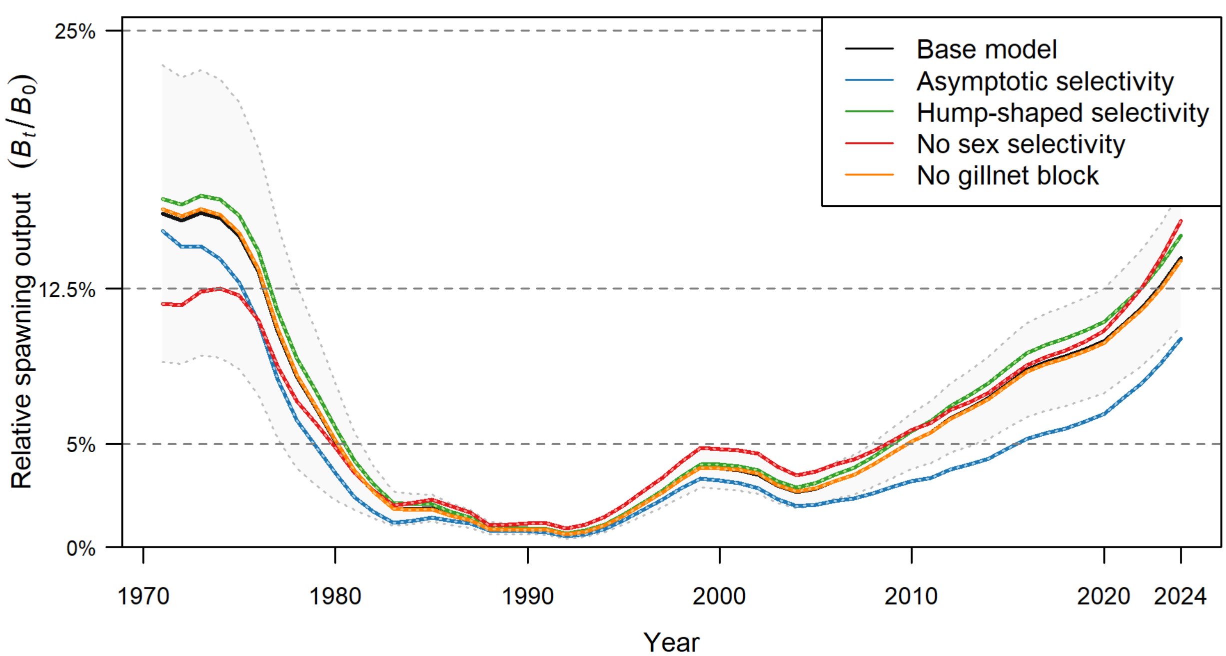


Figure 72. Sensitivity of relative spawning output to asymptotic selectivity curves in all retention fleets (not discard) (blue), hump-shaped selectivity for commercial hook & line and CPFV fleets (green), no sex selectivity (red) and no selectivity block for the gillnet retention and discard fleets (orange) compared to the base model (black). Models are shown with 95% confidence intervals.

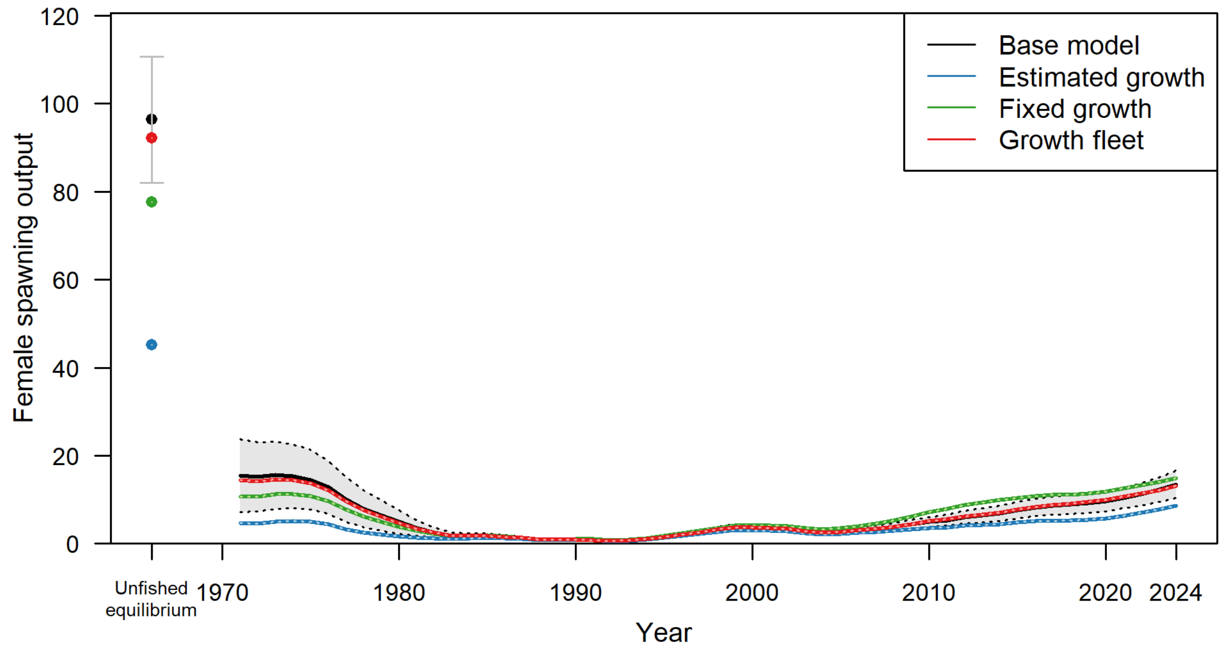


Figure 73. Sensitivity of spawning output to estimating all growth parameters (blue), fixing all growth parameters to values of an externally-fit growth model (green), and including a growth fleet with samples outside the other eleven fleets (red) compared to the base model (black). Models are shown with 95% confidence intervals.

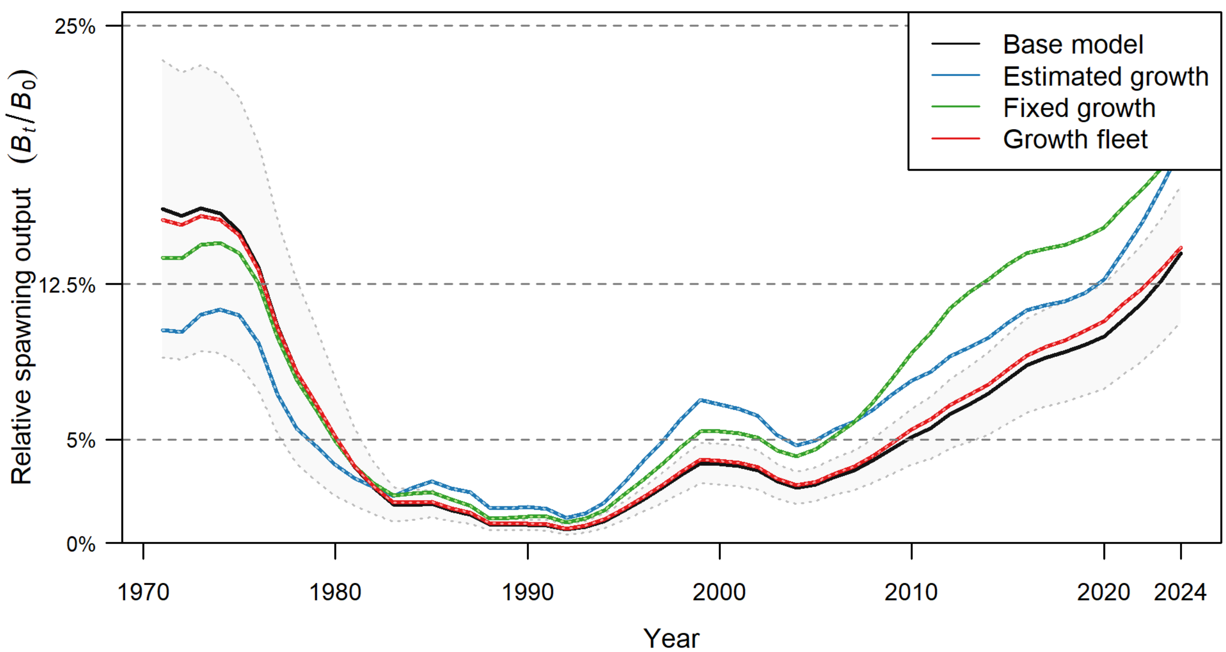


Figure 74. Sensitivity of relative spawning output to estimating all growth parameters (blue), fixing all growth parameters to values of an externally-fit growth model (green), and including a growth fleet with samples outside the other eleven fleets (red) compared to the base model (black). Models are shown with 95% confidence intervals.

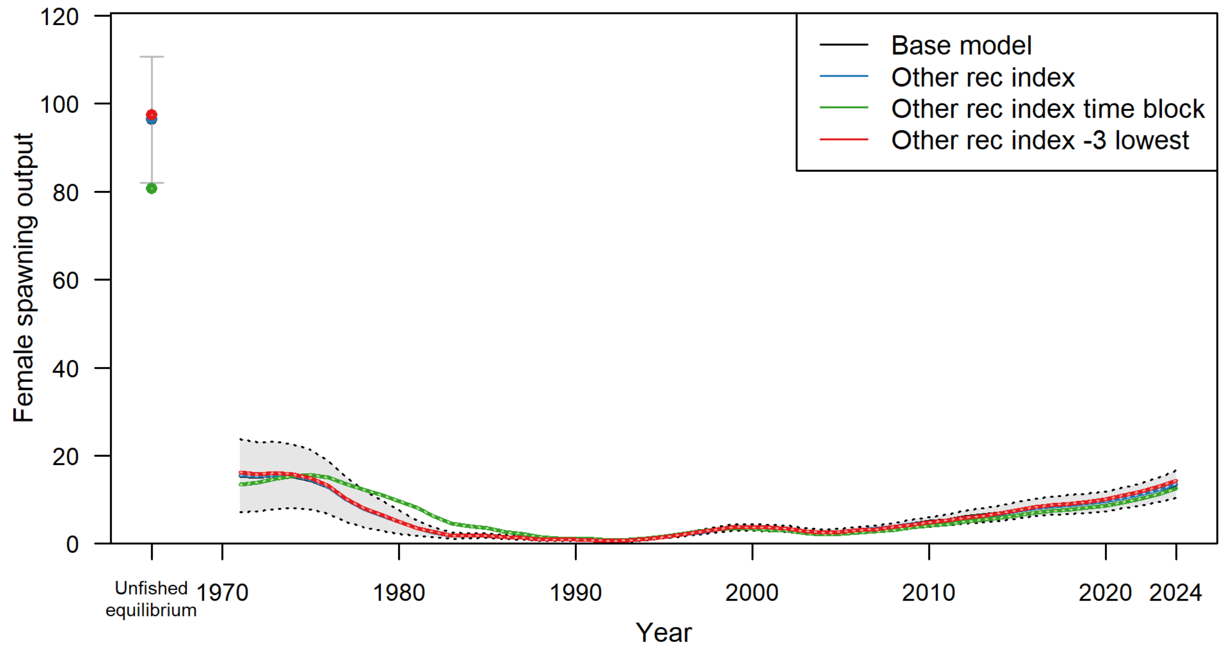


Figure 75. Sensitivity of spawning output to including an index for other recreational catches (blue), including the index with a time block (green), and including the index with the three lowest values omitted (red) compared to the base (black). Models are shown with 95% confidence intervals.

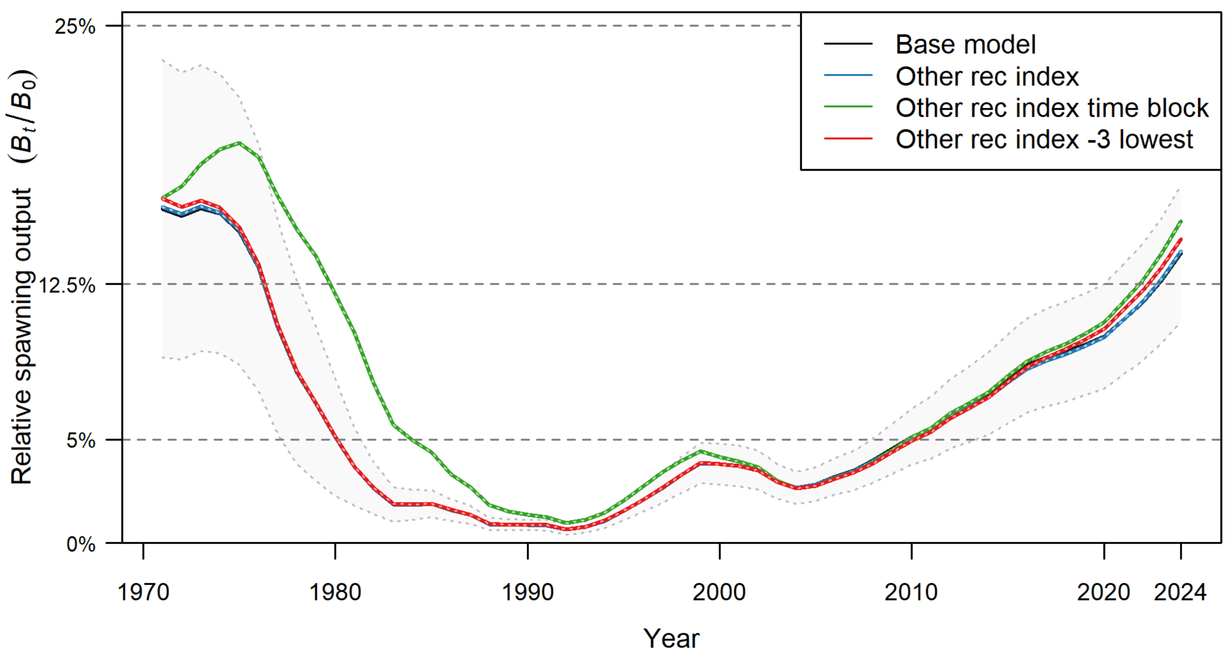


Figure 76. Sensitivity of spawning output to including an index for other recreational catches (blue), including the index with a time block (green), and including the index with the three lowest values omitted (red) compared to the base (black). Models are shown with 95% confidence intervals.

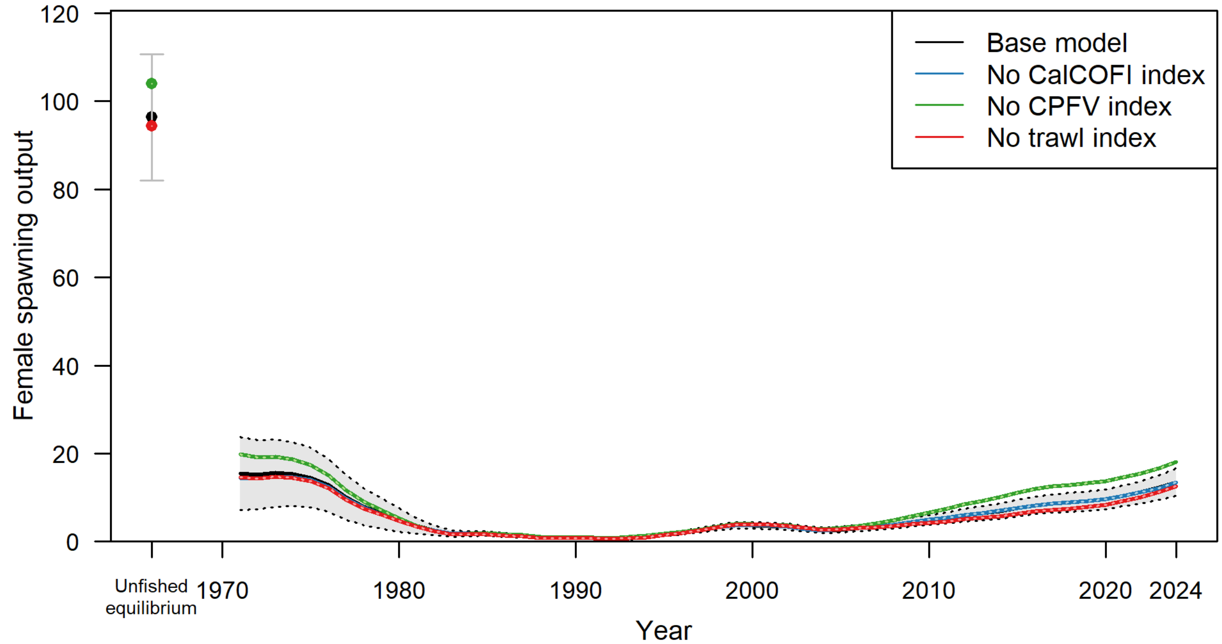


Figure 77. Sensitivity of spawning output to removing the CalCOFI index (blue), removing the CPFV index (green) and removing the trawl index (red) compared to the base model (black). Models are shown with 95% confidence intervals.

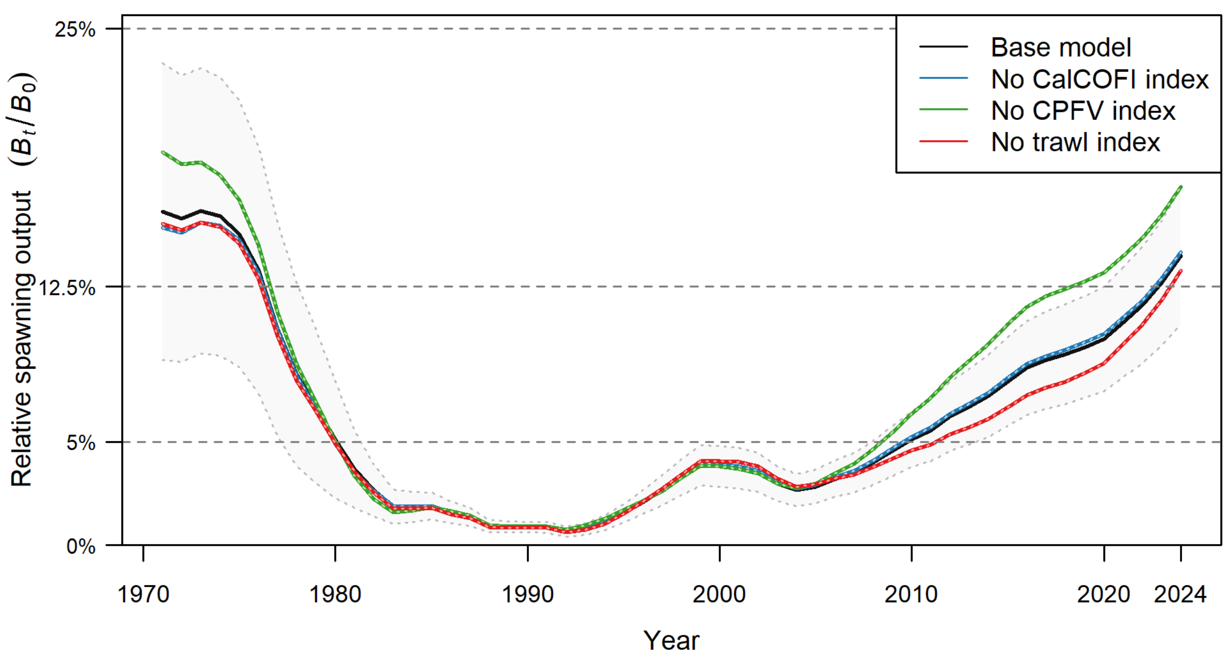


Figure 78. Sensitivity of relative spawning output to removing the CalCOFI index (blue), removing the CPFV index (green) and removing the trawl index (red) compared to the base model (black). Models are shown with 95% confidence intervals.

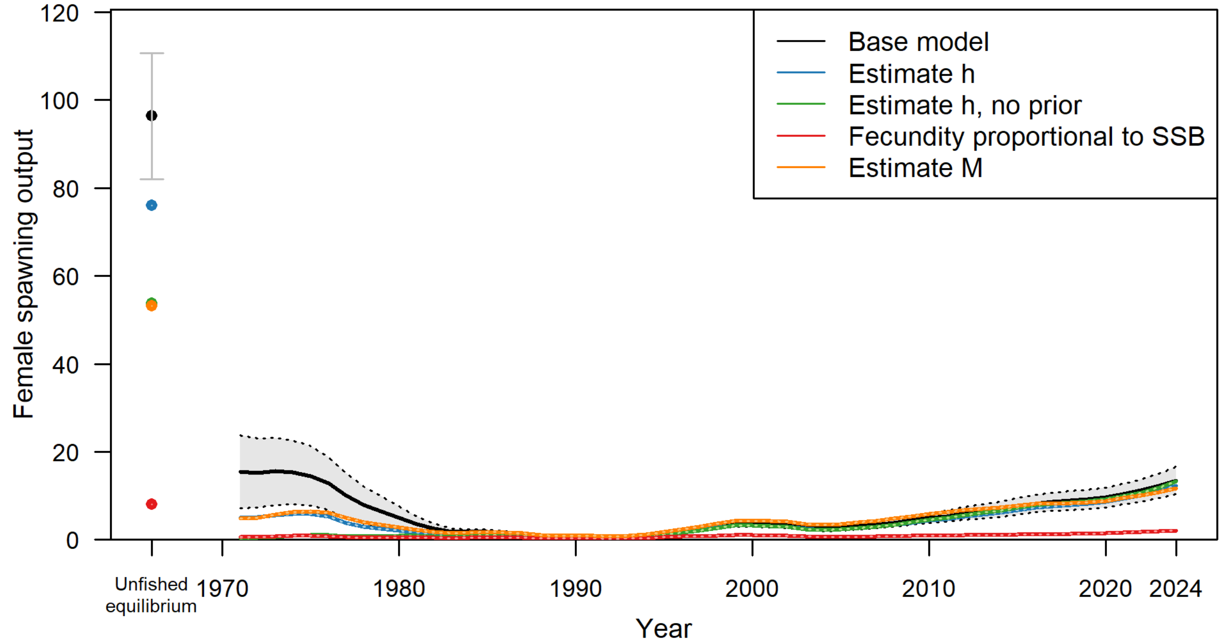


Figure 79. Sensitivity of spawning output to estimating steepness using the fixed value from the 2020 assessment (0.9) as a prior (blue) and estimating steepness with no prior (green) compared to the base model (black). Other sensitivities with base h shown are setting fecundity proportional to spawning stock output (red) and estimating natural mortality (orange). Models are shown with 95% confidence intervals.

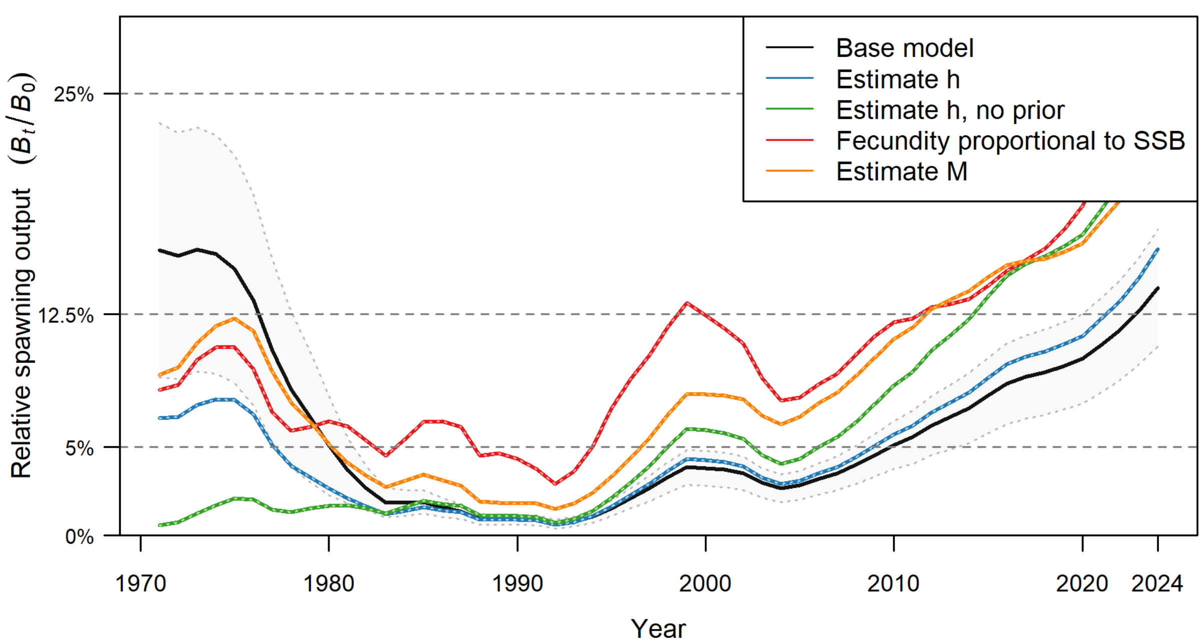


Figure 80. Sensitivity of relative spawning output to estimating steepness using the fixed value from the 2020 assessment (0.9) as a prior (blue) and estimating steepness with no prior (green) compared to the base model (black). Other sensitivities with base h shown are setting fecundity proportional to spawning stock output (red) and estimating natural mortality (orange). Models are shown with 95% confidence intervals.

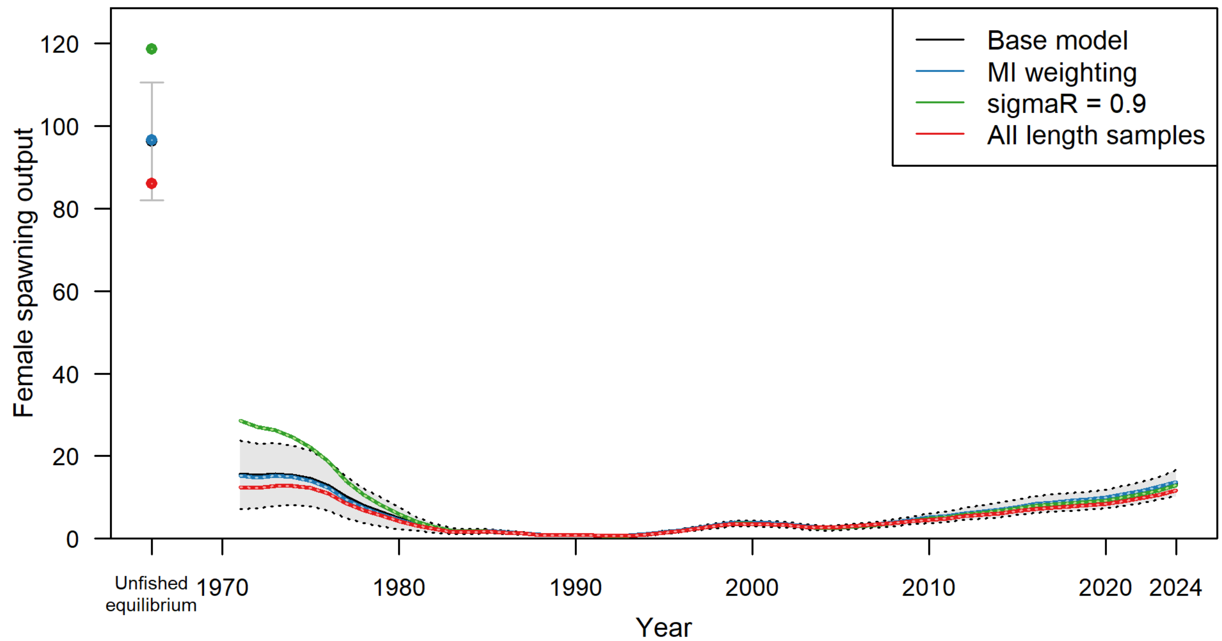


Figure 81. Sensitivity of spawning output to McAllister-Ianelli data weighting (blue), increasing sigmaR to 0.9 (green), and including all length samples regardless of low sample sizes (red), compared to the base model (black). Models are shown with 95% confidence intervals.

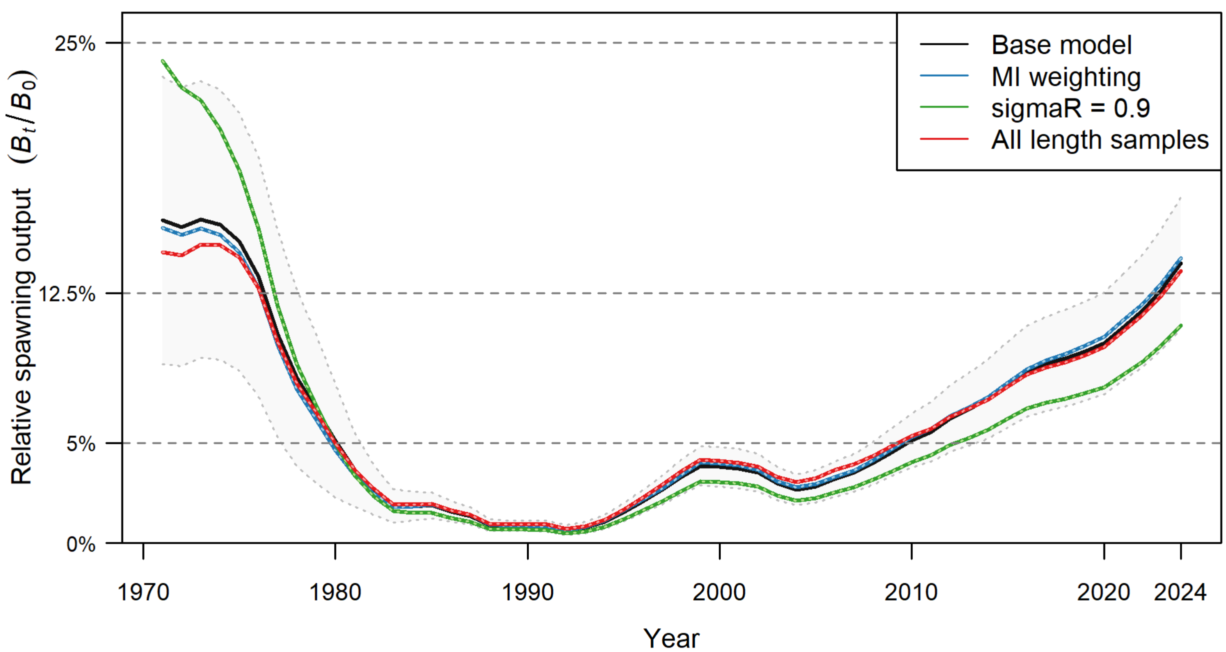


Figure 82. Sensitivity of relative spawning output to McAllister-Ianelli data weighting (blue), increasing sigmaR to 0.9 (green), and including all length samples regardless of low sample sizes (red), compared to the base model (black). Models are shown with 95% confidence intervals.

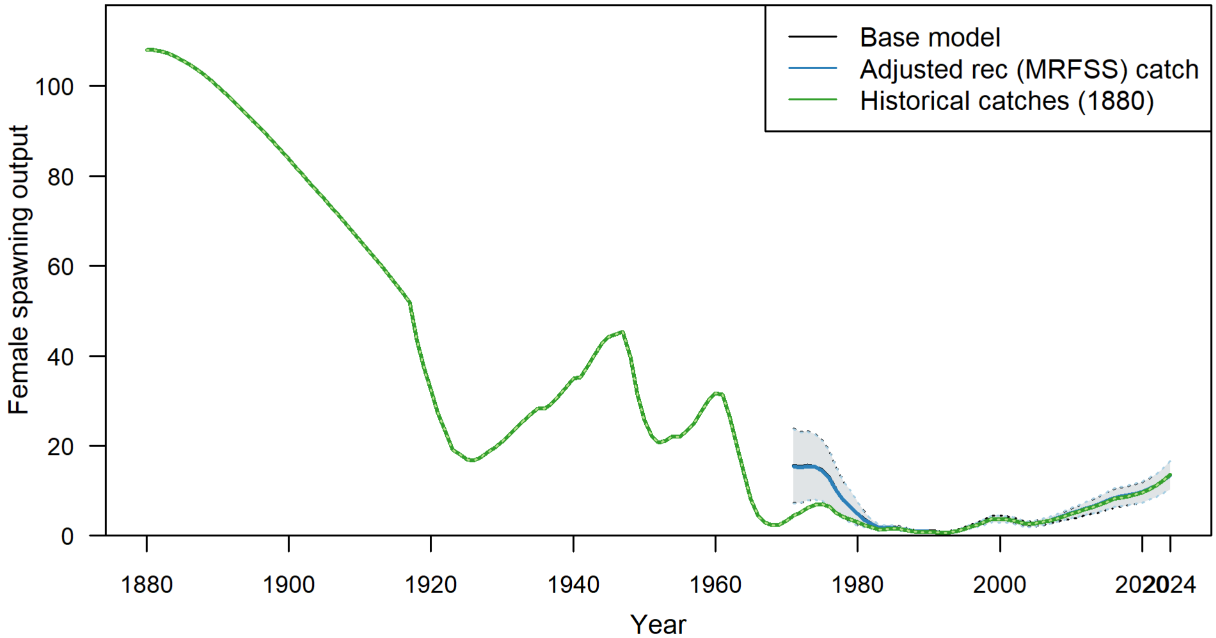


Figure 83. Sensitivity of spawning output to extension of the catch series to 1880 (green) and reduction of OtherRec fleet catches from 1971-2004 to account for possible bias in MRFSS survey effort estimates (blue).

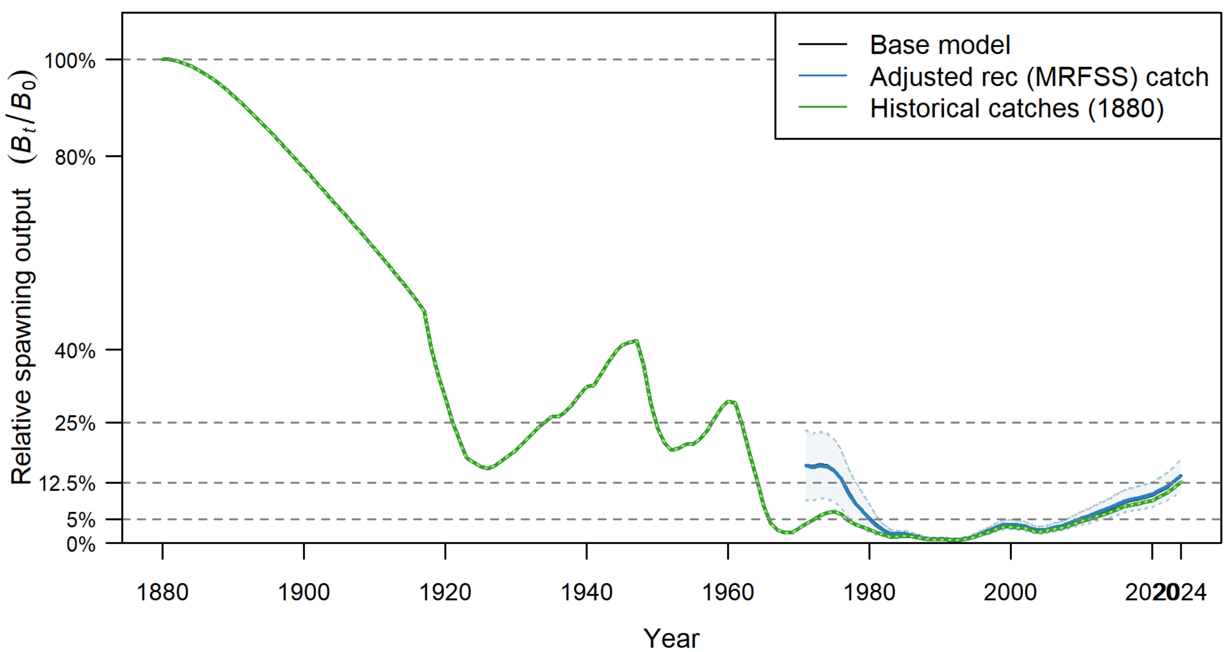


Figure 84. Sensitivity of relative spawning output to extension of the catch series to 1880 (green) and reduction of OtherRec fleet catches from 1971-2004 to account for possible bias in MRFSS survey effort estimates (blue).

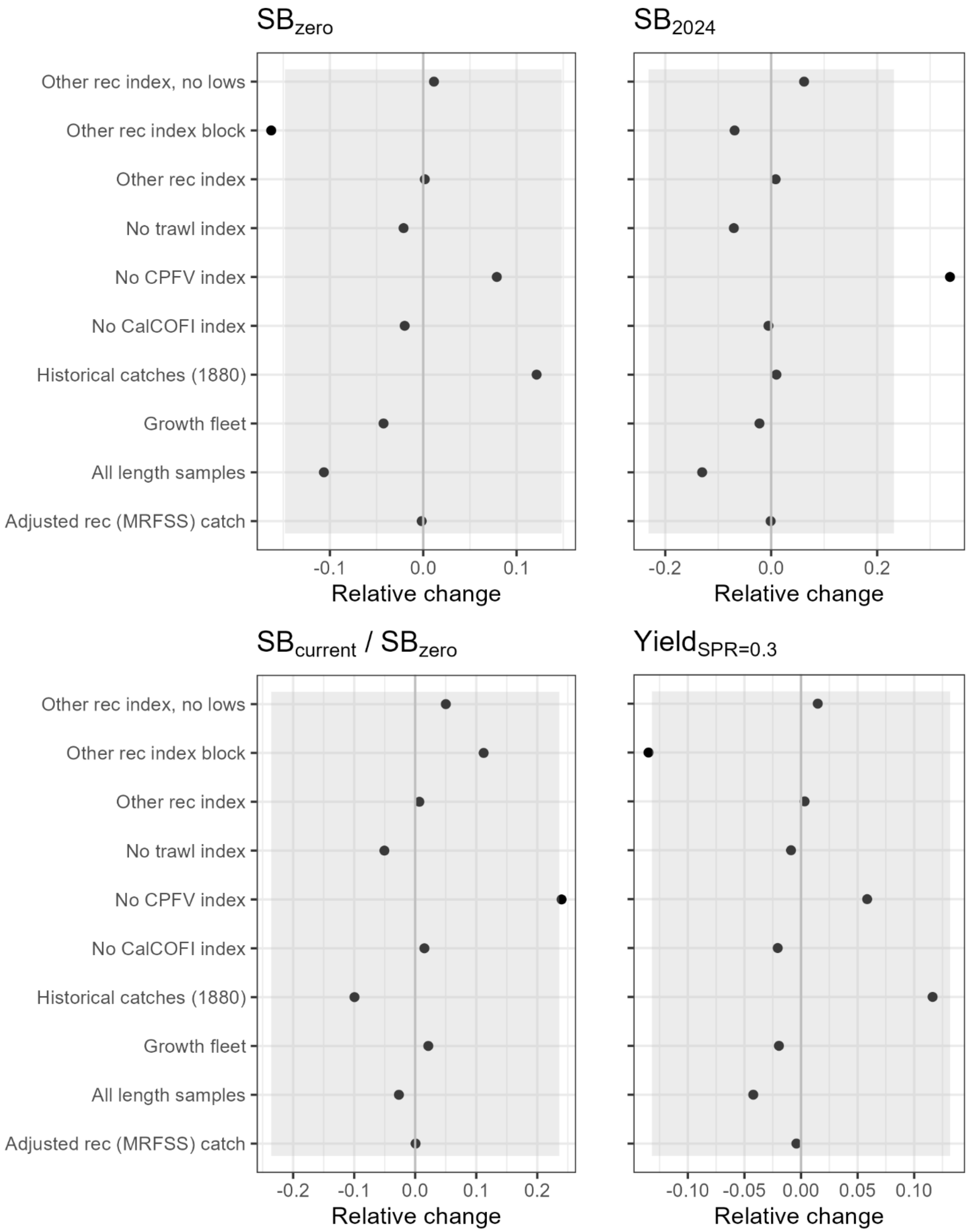


Figure 85. Comparison of the sensitivity of virgin spawning output, spawning output in 2024, relative spawning output, and yield to alternative data inputs.

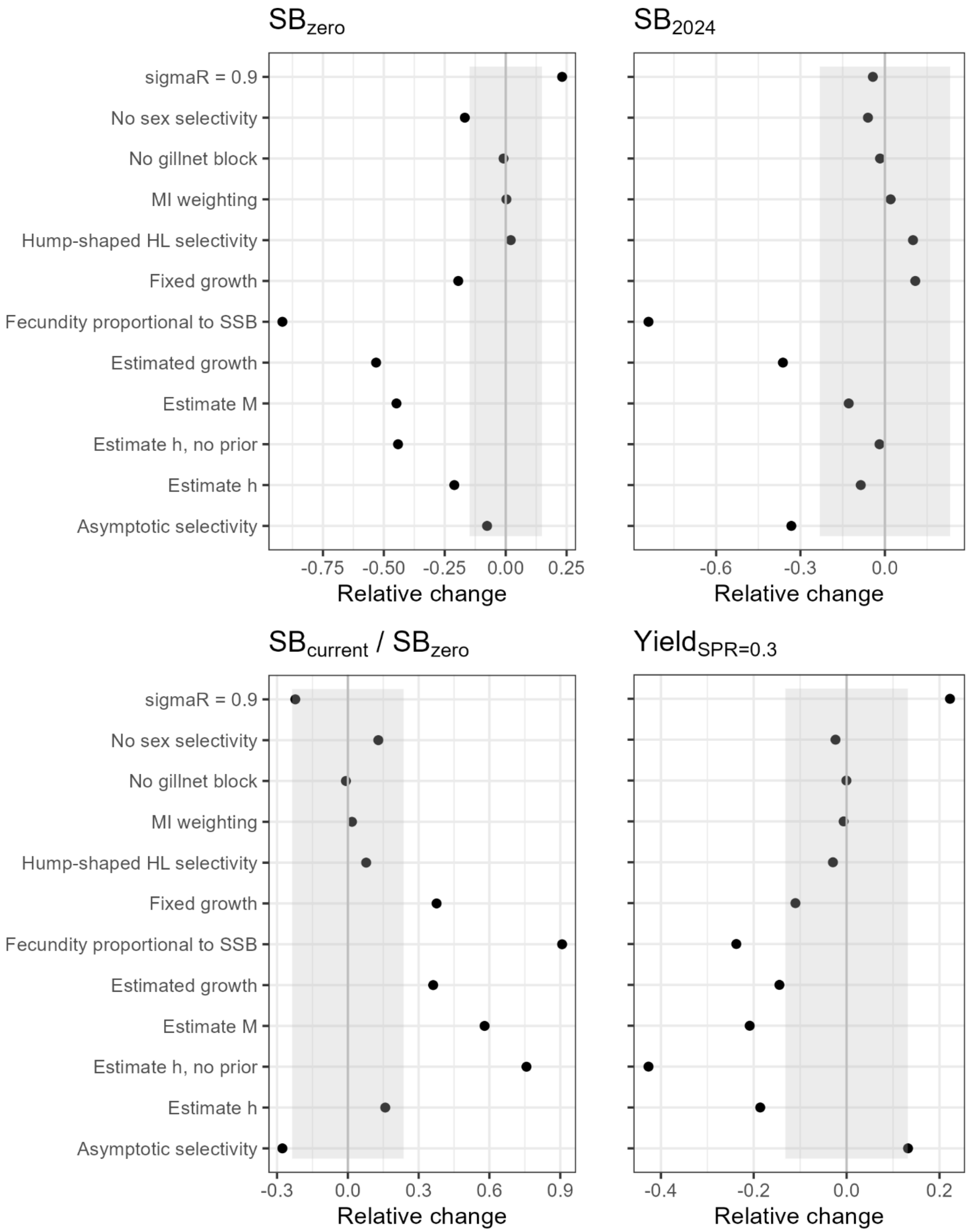


Figure 86. Comparison of the sensitivity of virgin spawning output, spawning output in 2024, relative spawning output, and yield to alternative model structures.

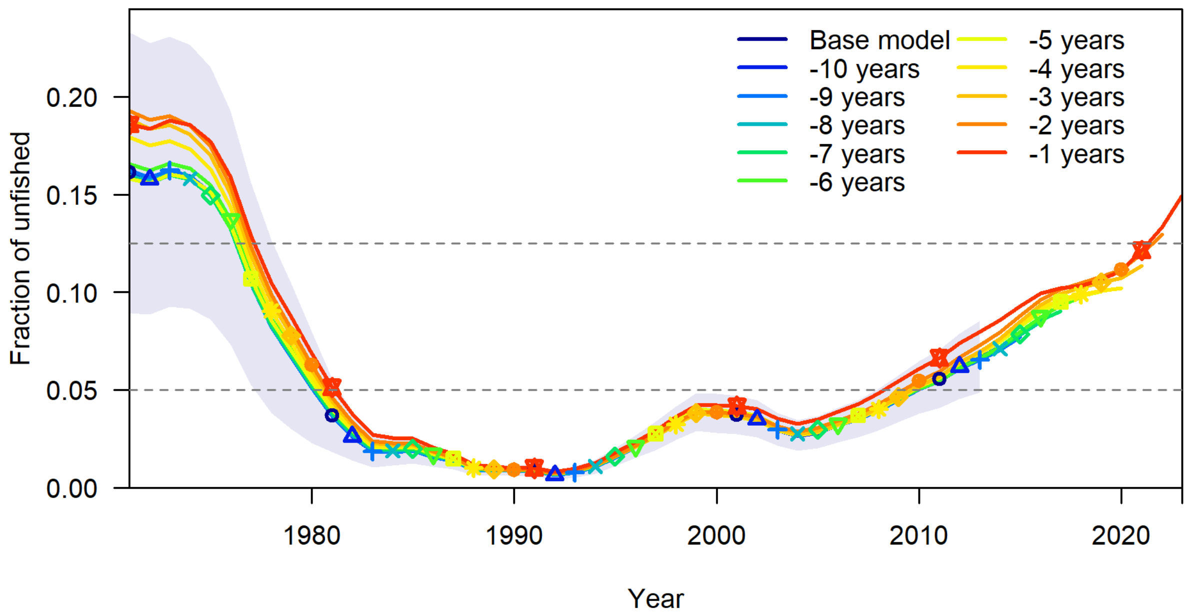


Figure 87. Relative spawning output for a ten-year retrospective analysis.

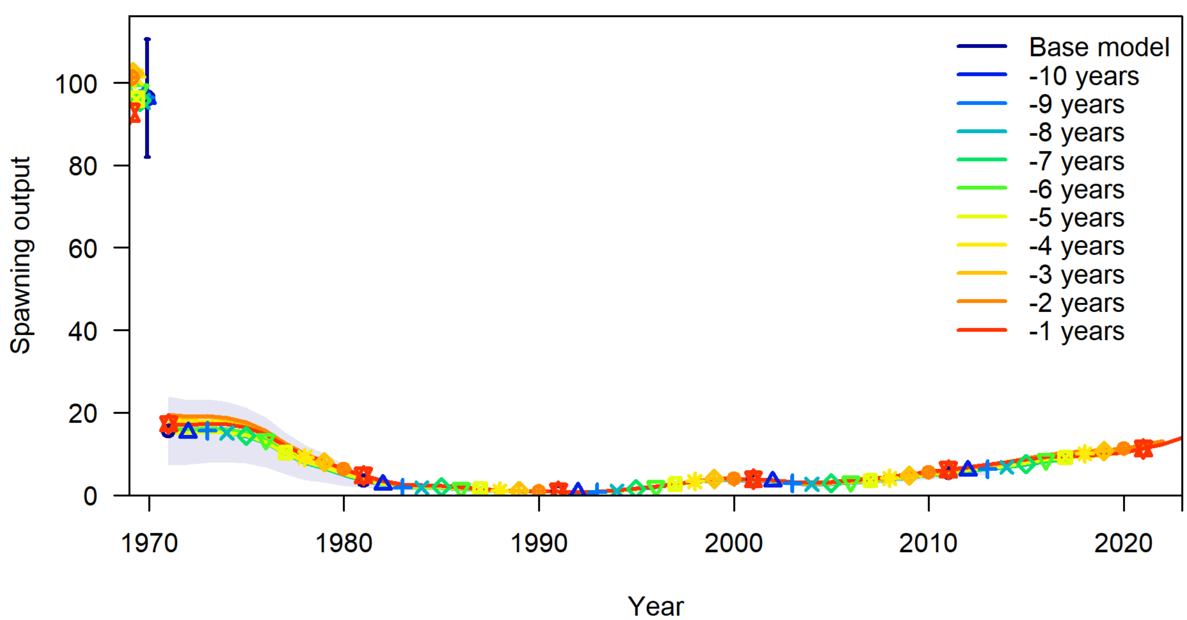


Figure 88. Total spawning output for a ten-year retrospective analysis.

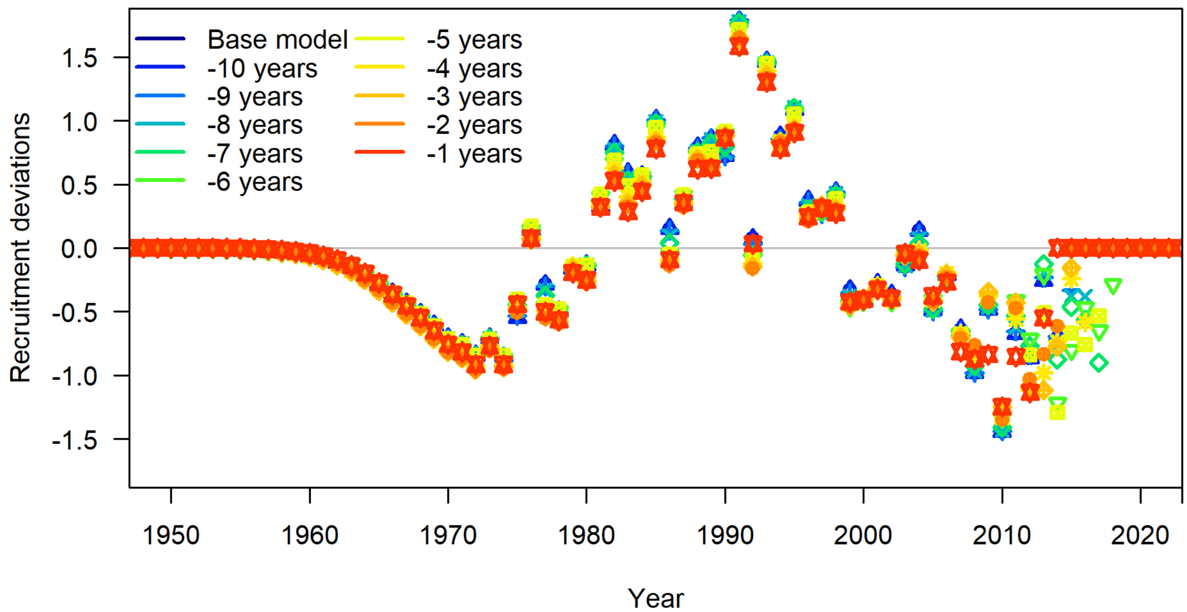


Figure 89. Estimated recruitment from a ten-year retrospective analysis.

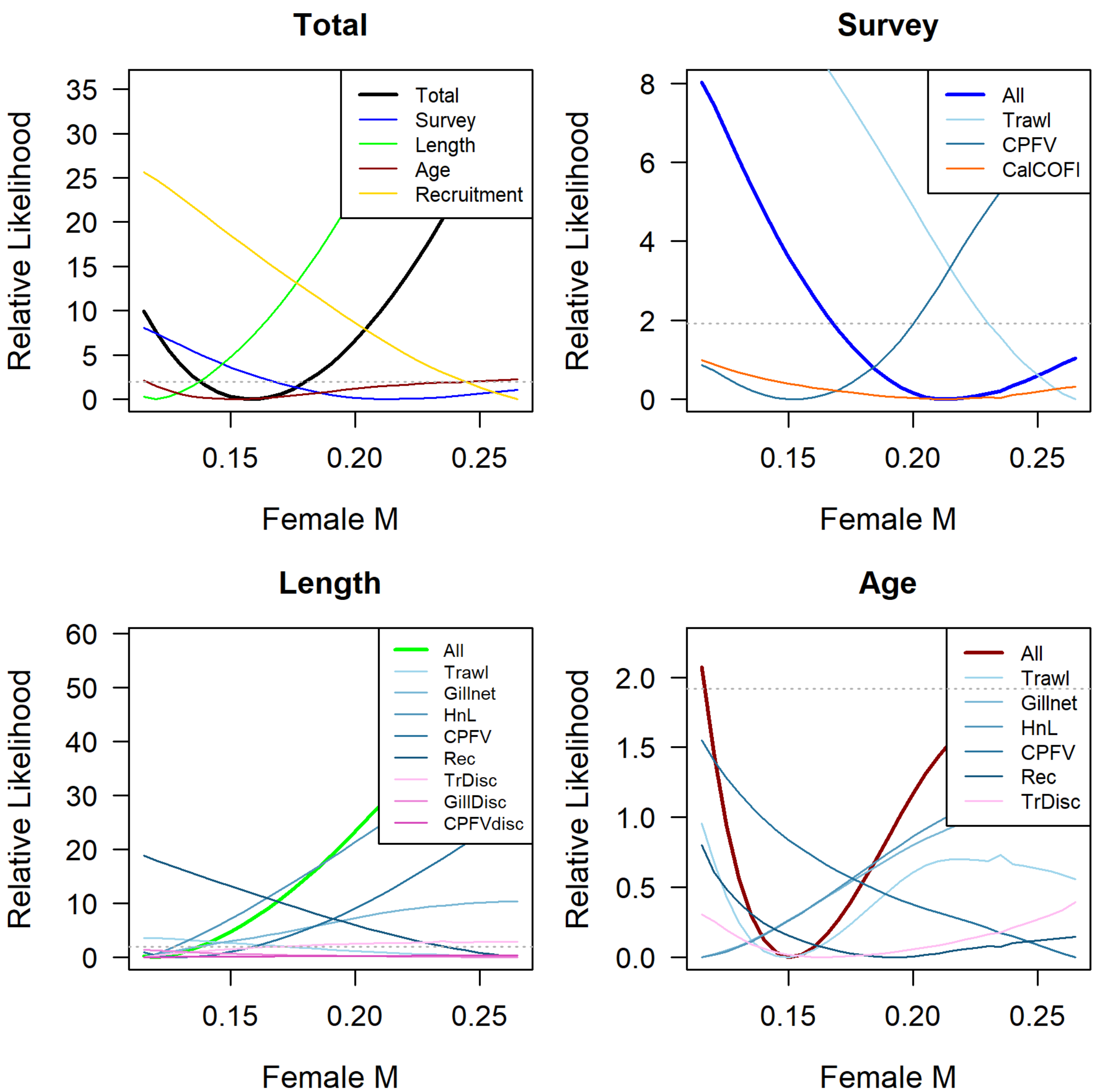


Figure 90. Likelihood profiles for female natural mortality.

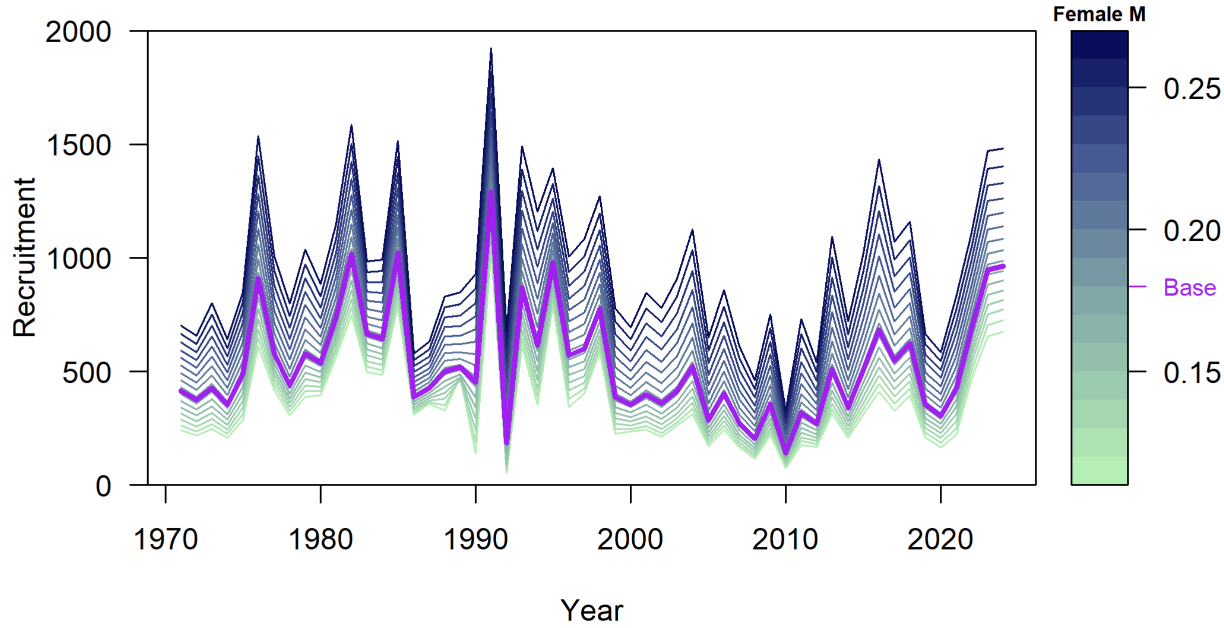


Figure 91. Estimated recruitment across a range of values for female natural mortality.

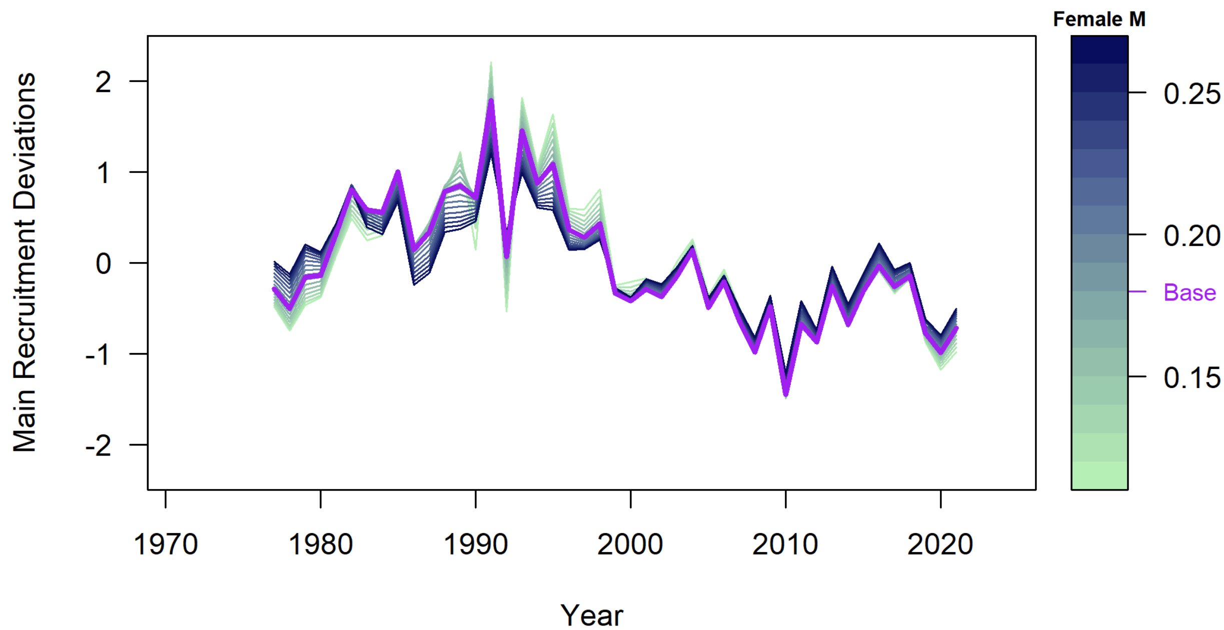


Figure 92. Recruitment deviations during the main period of recruitment estimation across a range of values for female natural mortality.

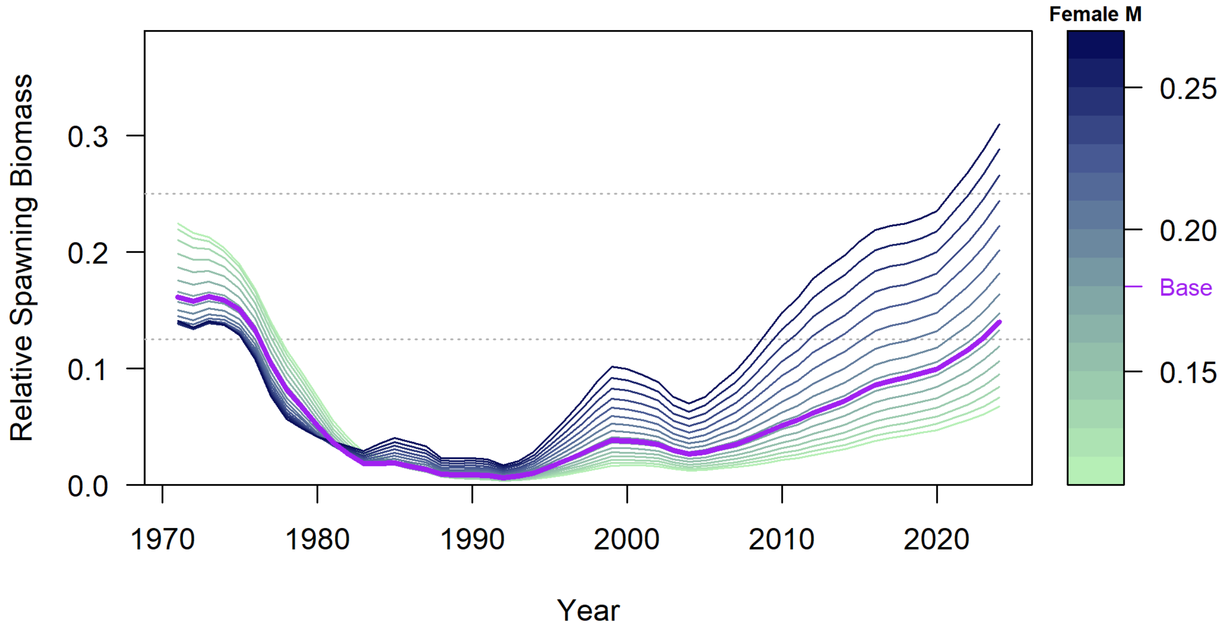


Figure 93. Relative spawning output across a range of values for female natural mortality.

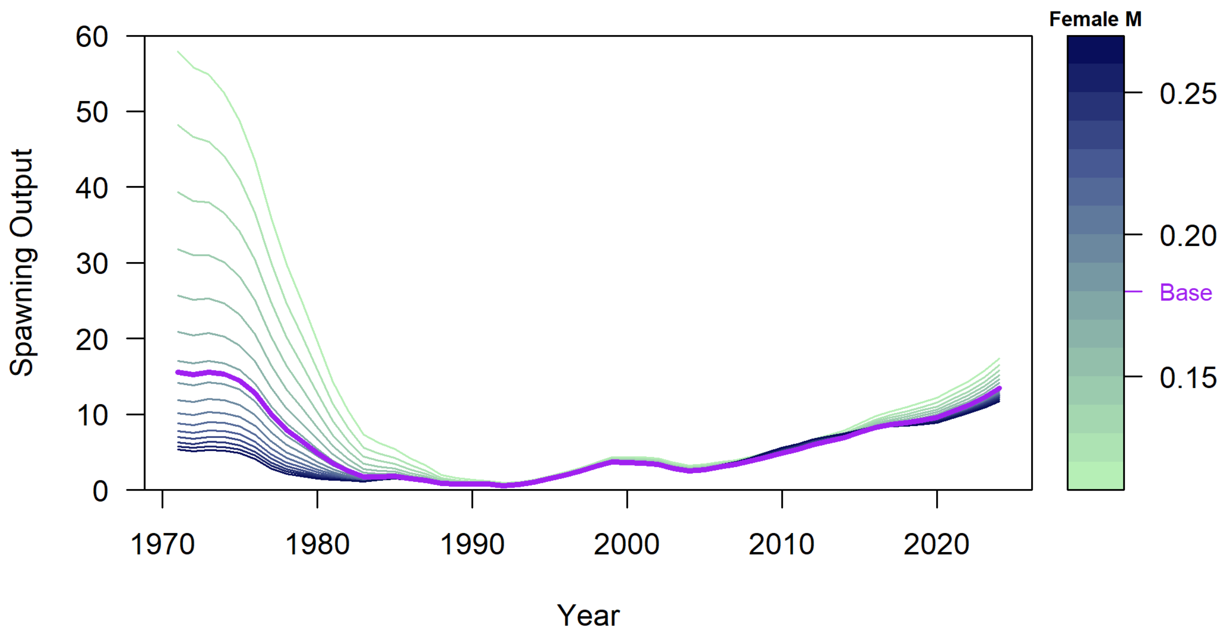


Figure 94. Spawning output across a range of values for female natural mortality.

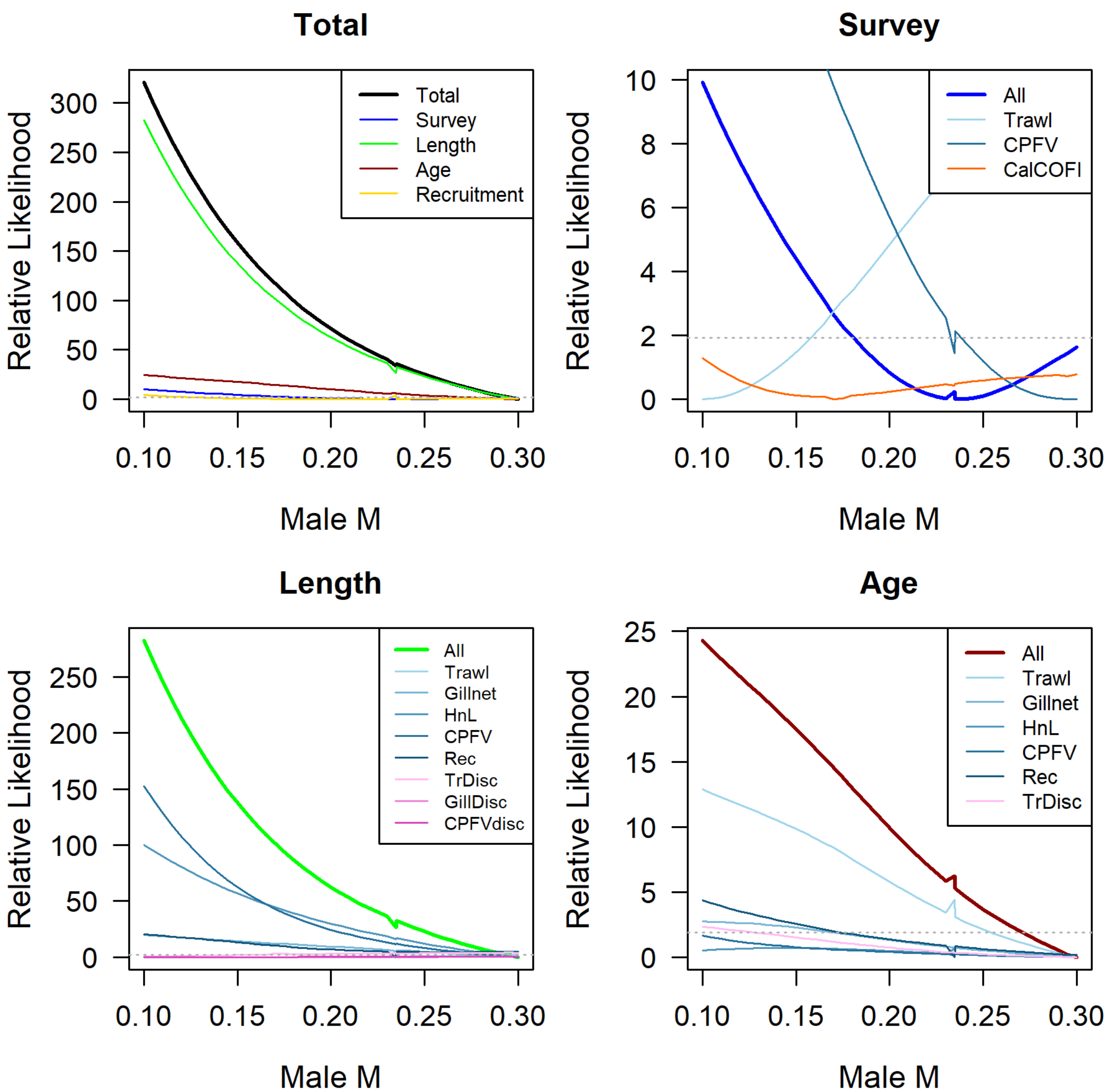


Figure 95. Likelihood profiles for male natural mortality.

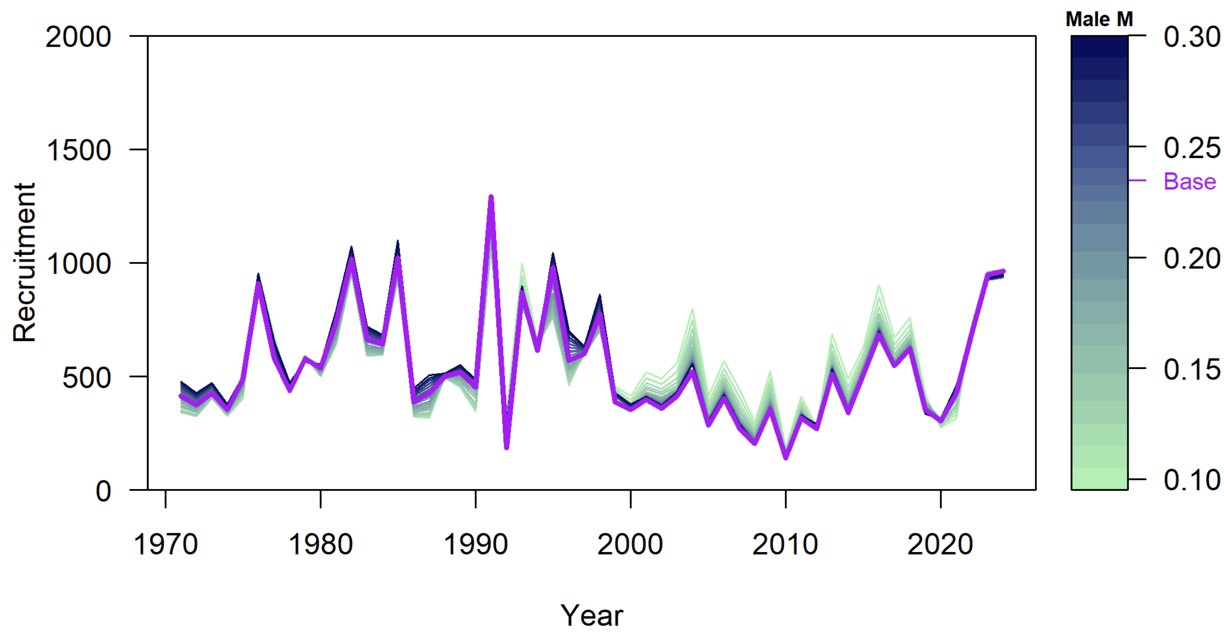


Figure 96. Estimated recruitment across a range of values for male natural mortality.

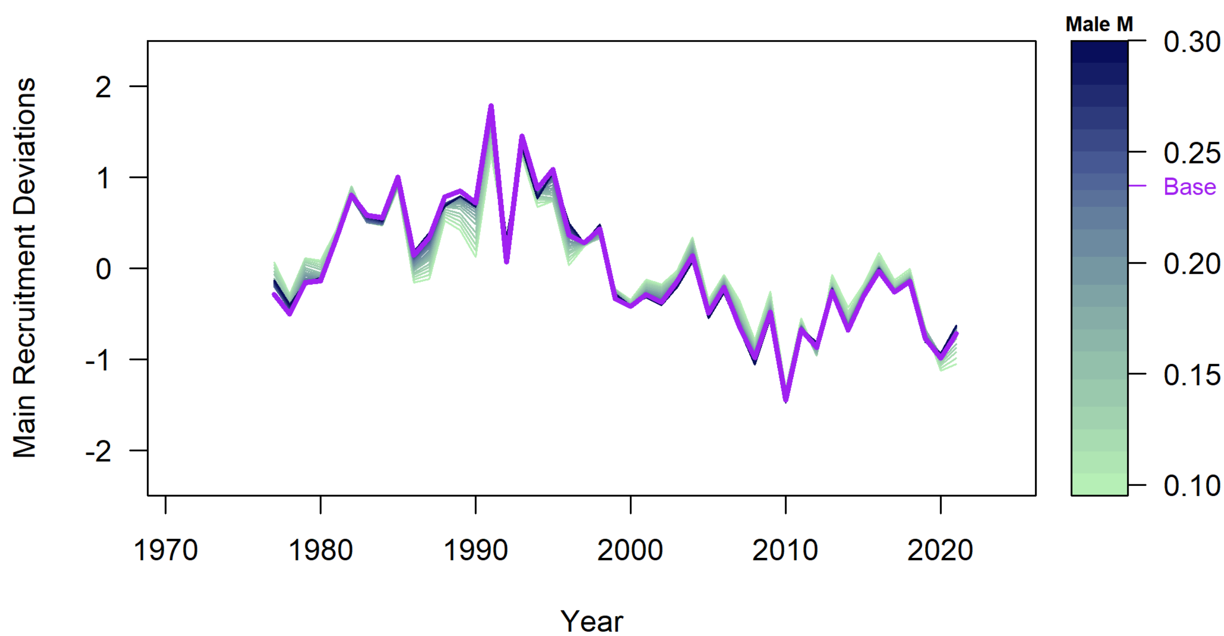


Figure 97. Recruitment deviations during the main period of recruitment estimation across a range of values for male natural mortality

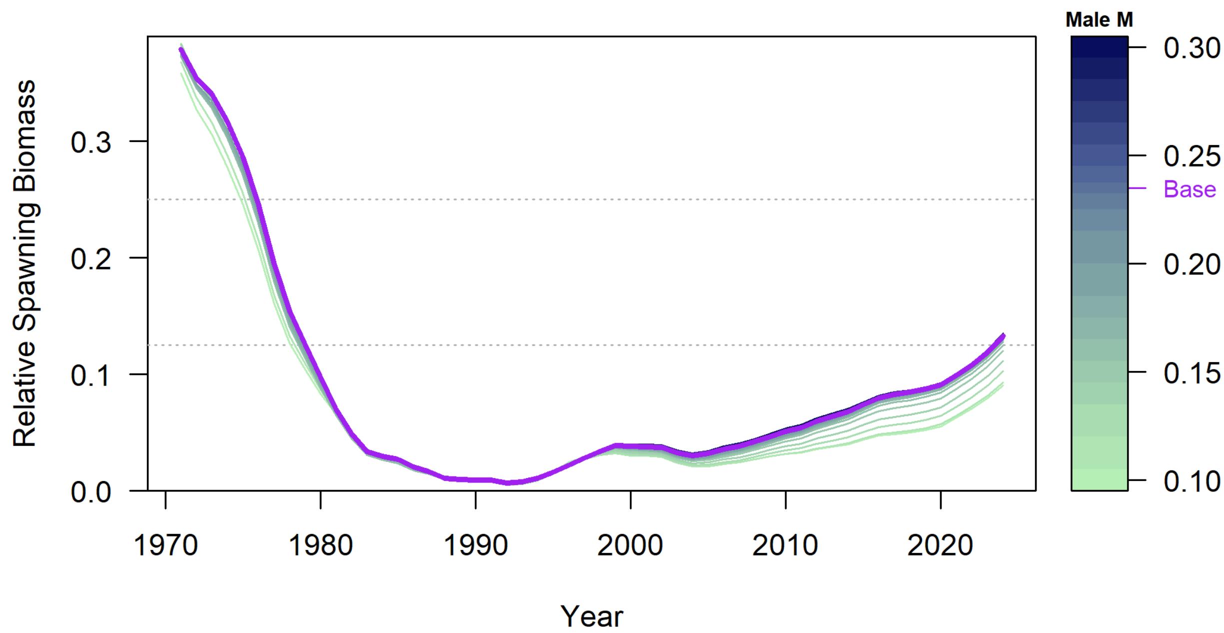


Figure 98. Relative spawning output across a range of values for female natural mortality.

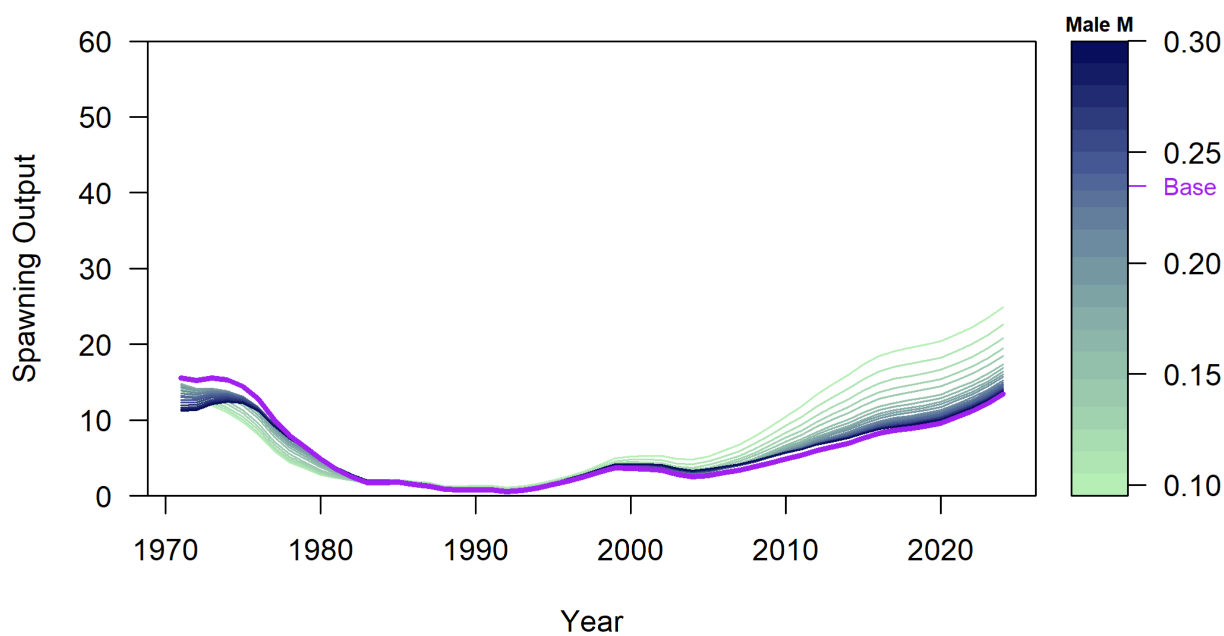


Figure 99. Spawning output across a range of values for male natural mortality.

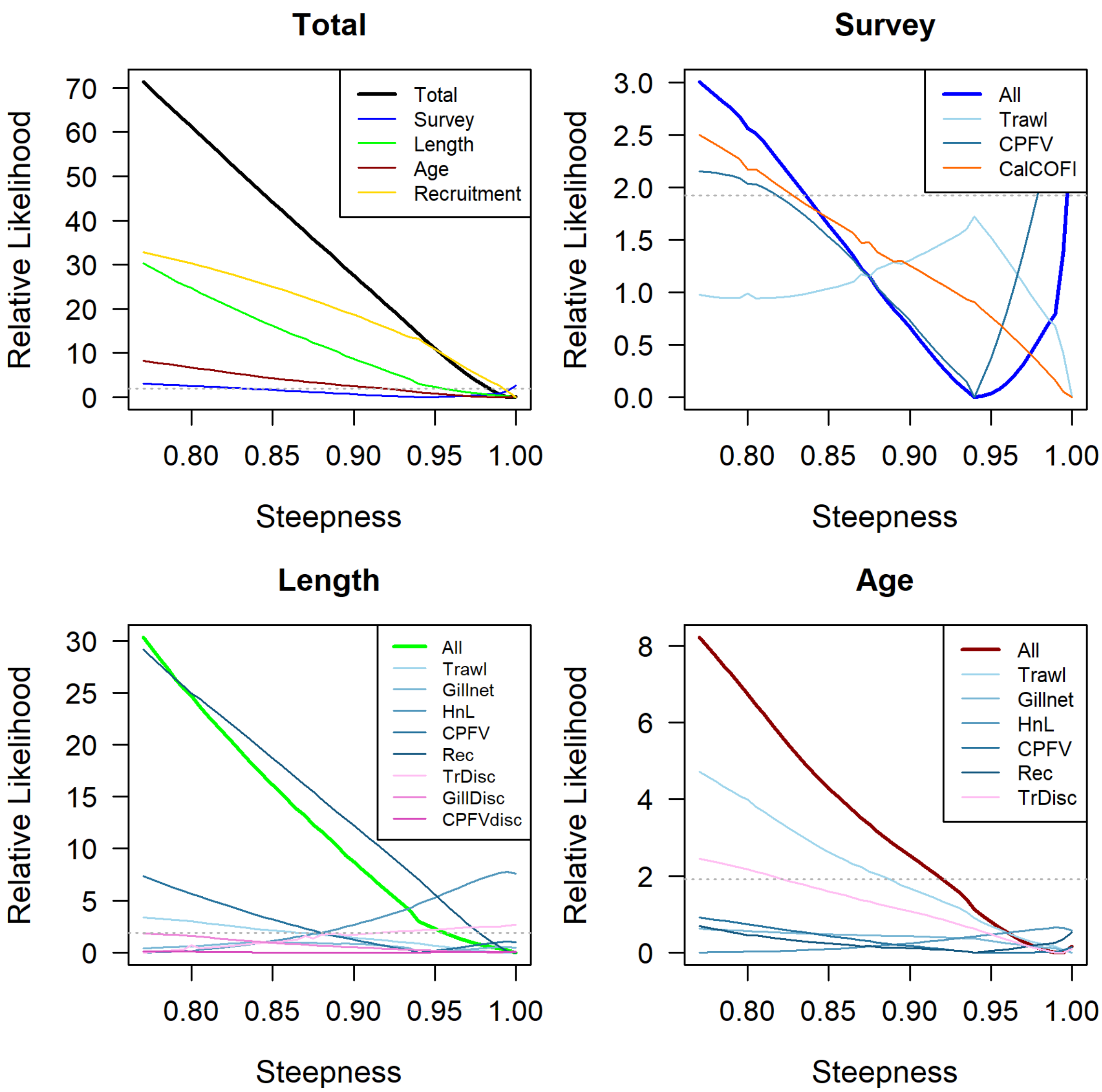


Figure 100. Likelihood profile for steepness (h).

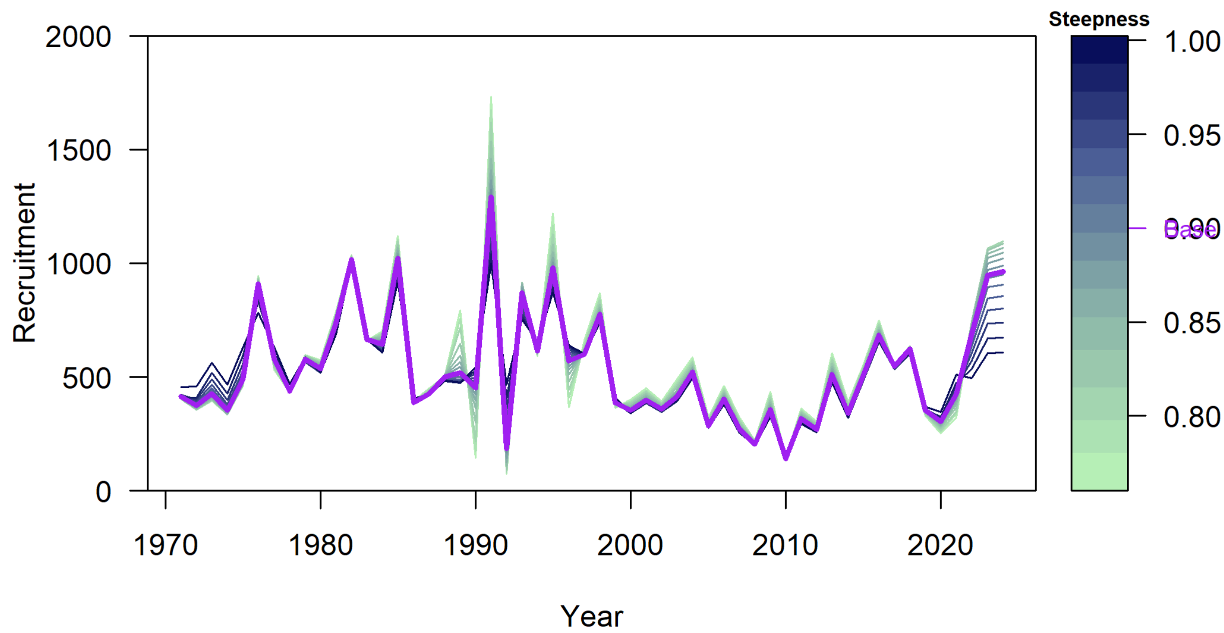


Figure 101. Estimated recruitment across a range of values for steepness (h).

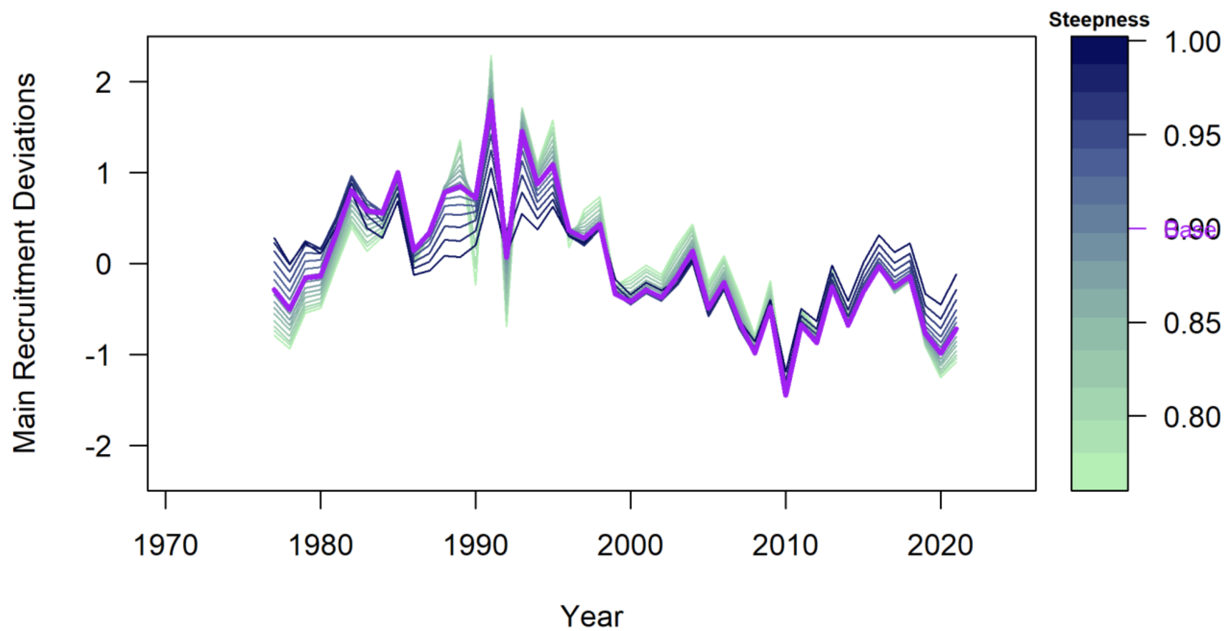


Figure 102. Recruitment deviations during the main period of recruitment estimation across a range of values for steepness (h).

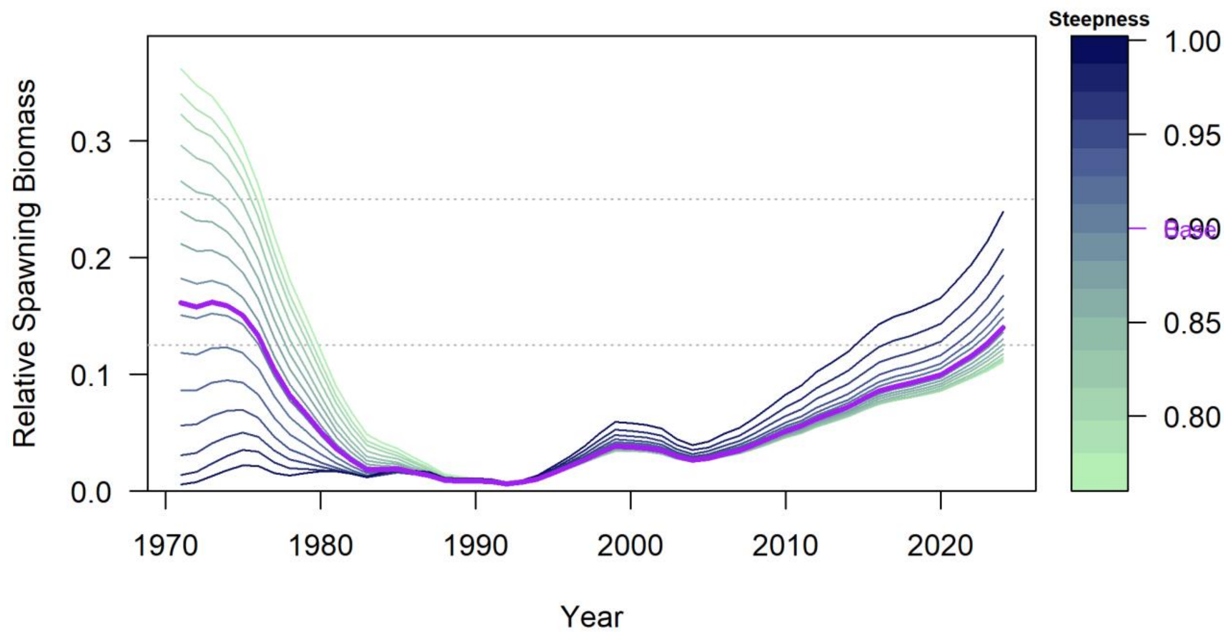


Figure 103. Relative spawning output across a range of steepness values.

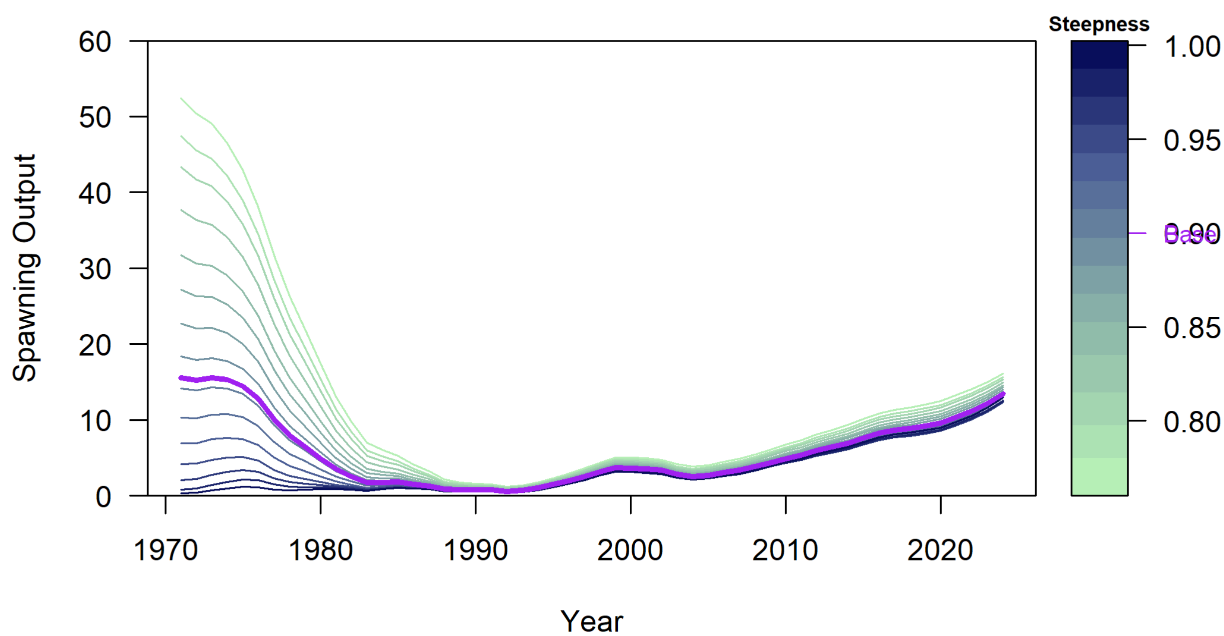


Figure 104. Total spawning output across a range of steepness values.

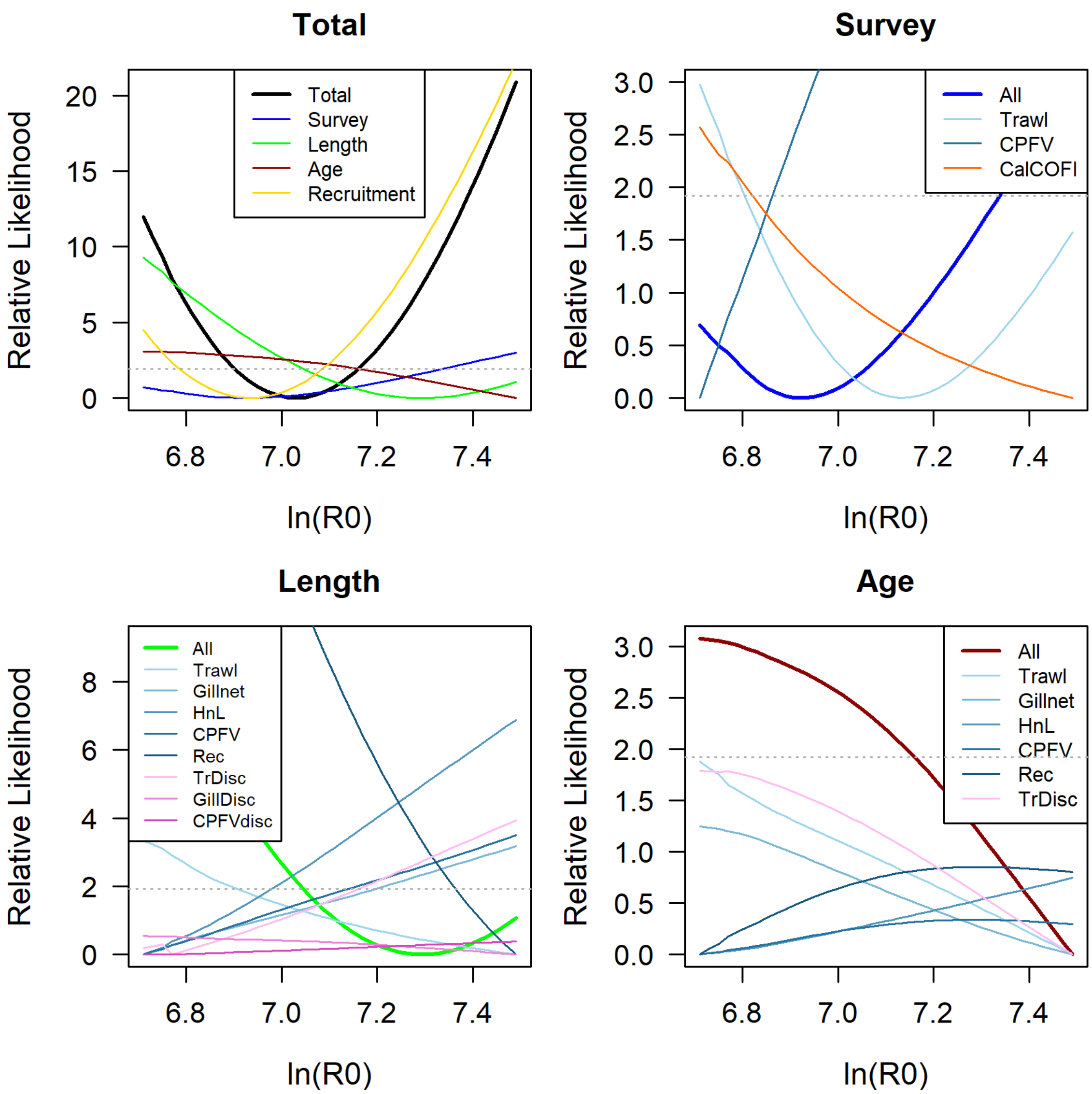


Figure 105. Likelihood profiles for virgin recruitment (R0).

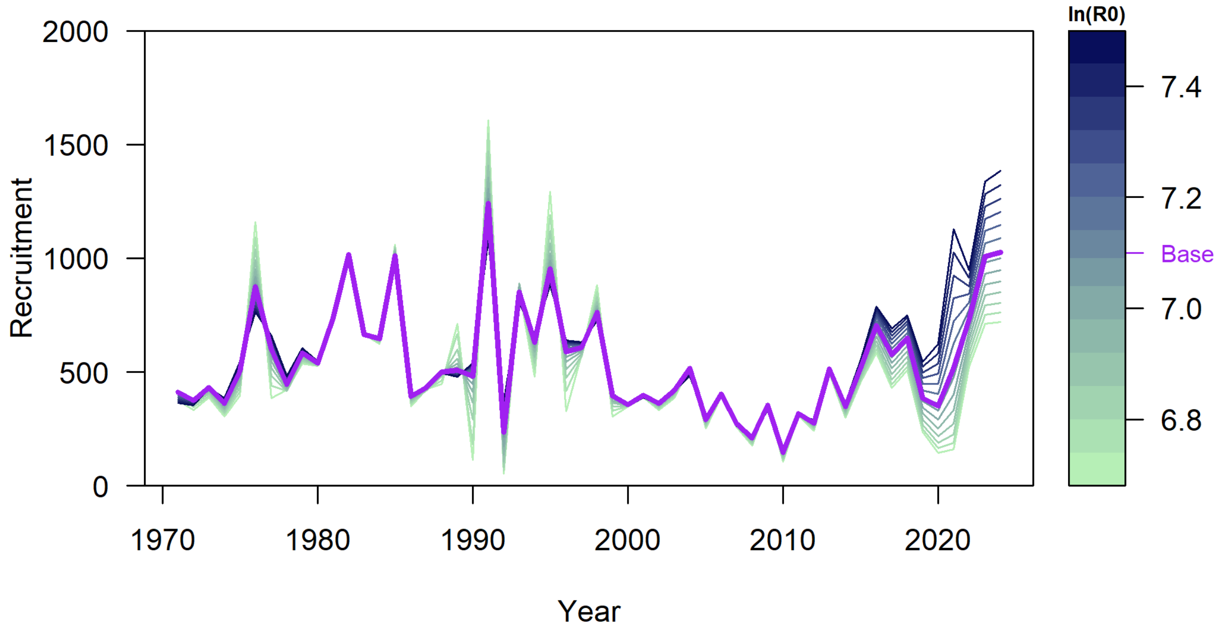


Figure 106. Estimated recruitment across a range of values for virgin recruitment (R0).

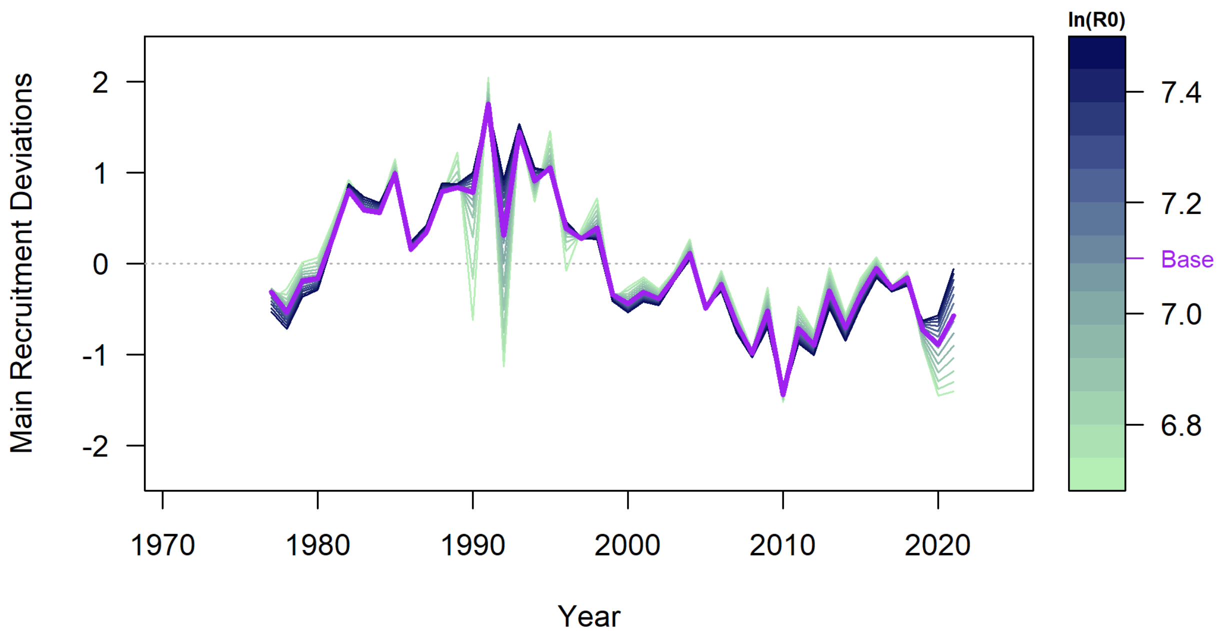


Figure 107. Estimated recruitment deviation across a range of values for virgin recruitment (R0).

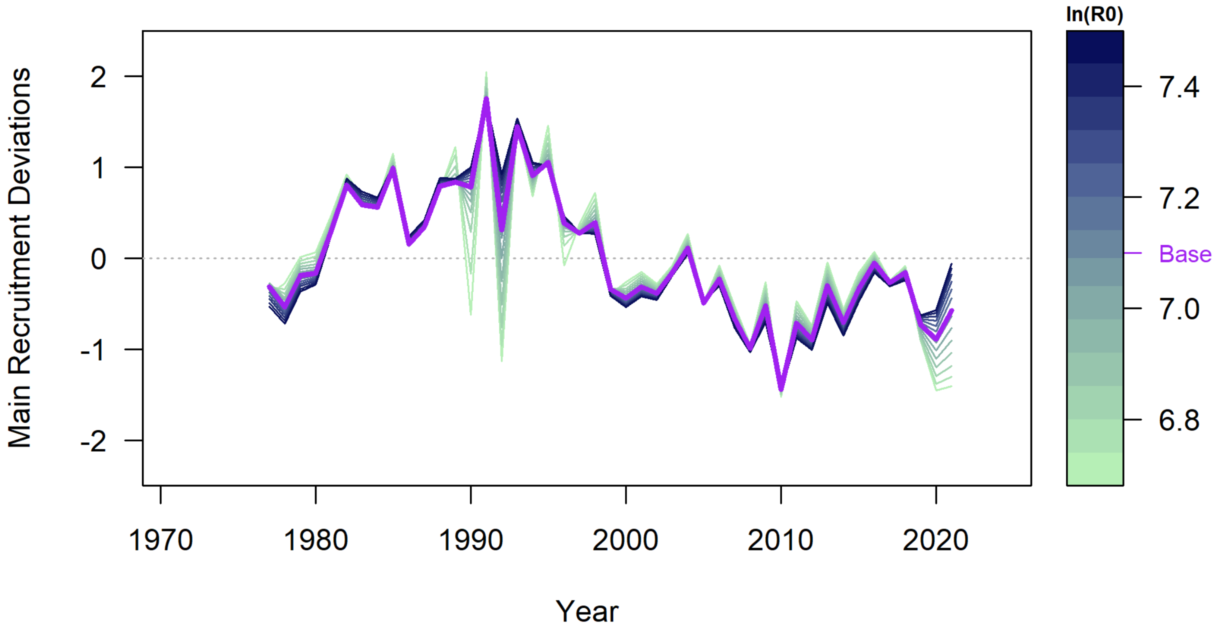


Figure 108. Relative spawning output across a range of values for virgin recruitment (R0).

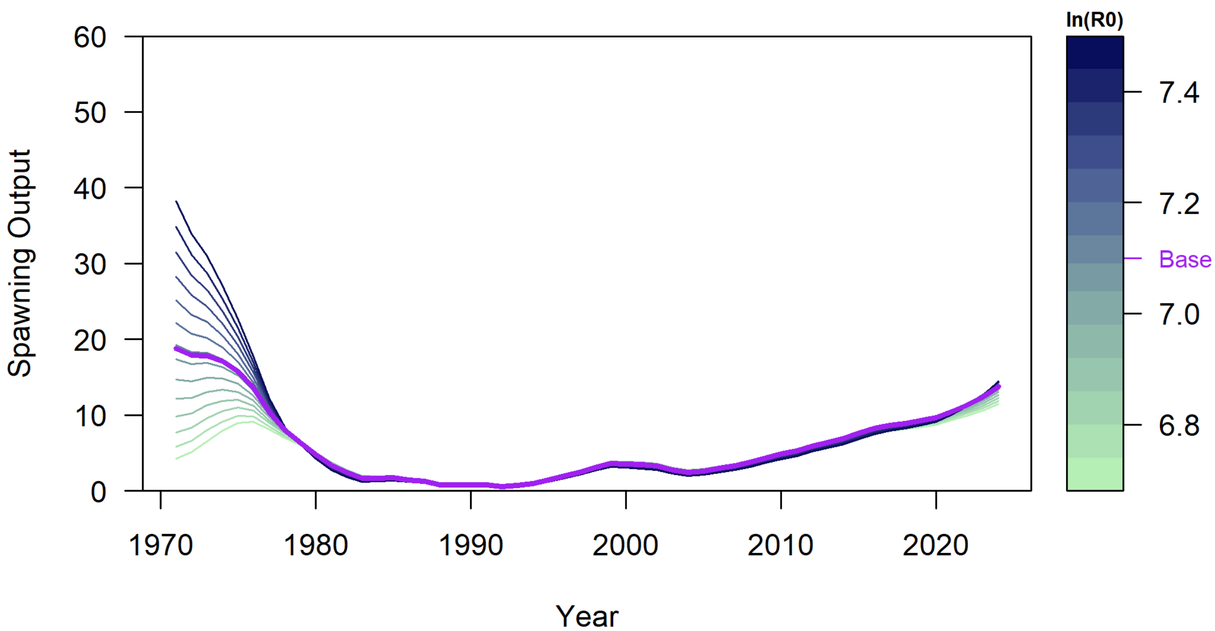


Figure 109. Total spawning output across a range of values for virgin recruitment (R0).

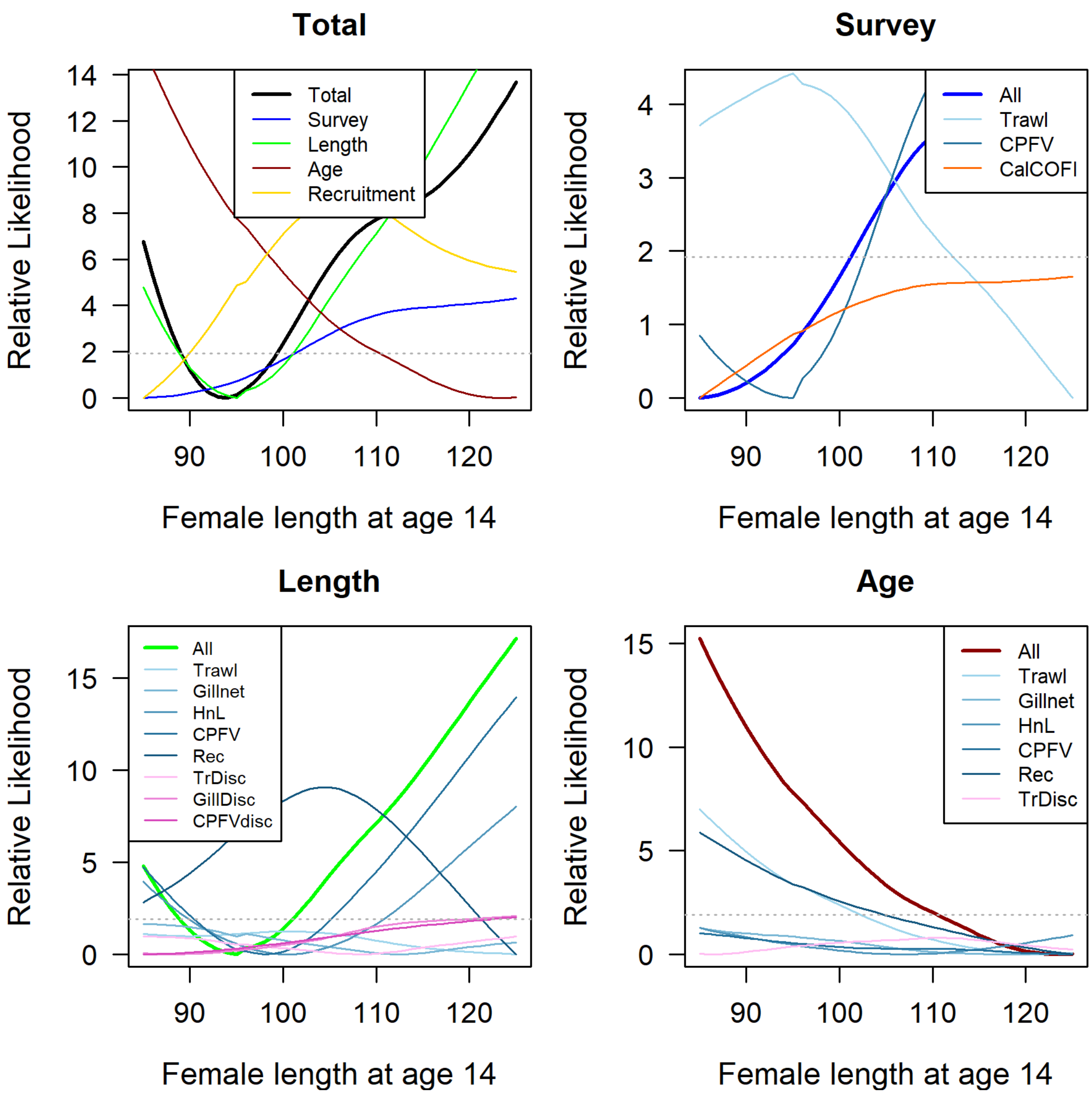


Figure 110. Likelihood profiles for female length at age 14 (L at Amax).

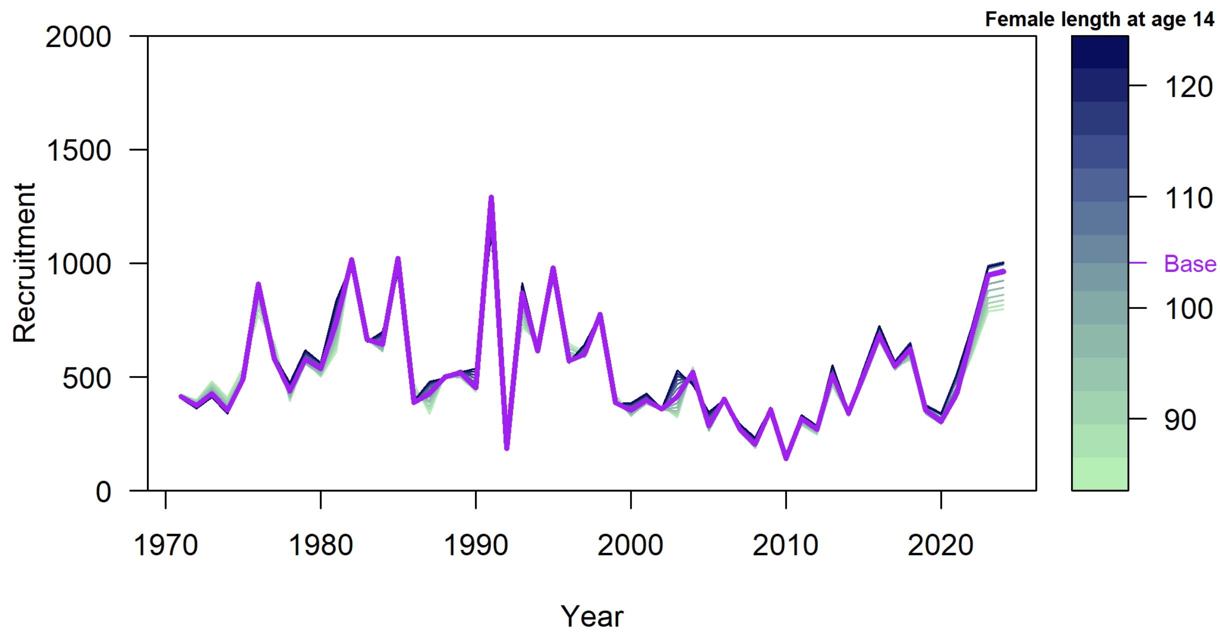


Figure 111. Estimated recruitment across a range of values for female length at age 14 (L at Amax).

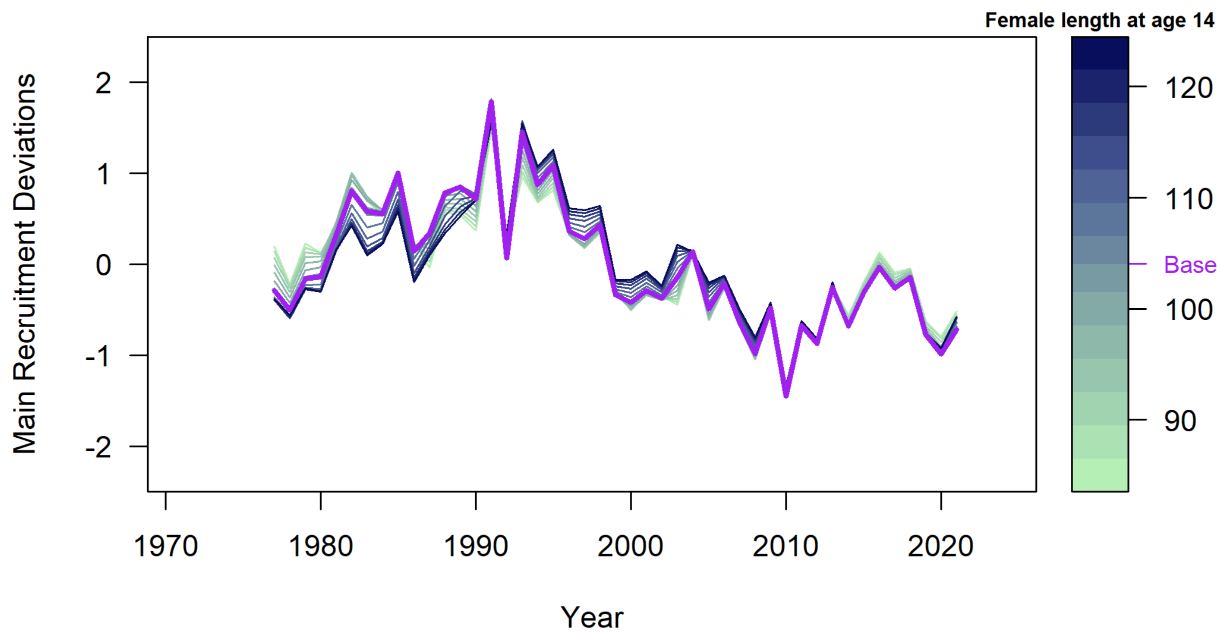


Figure 112. Recruitment deviations during the main period of recruitment estimation across a range of values for female length at age 14 (L at Amax).

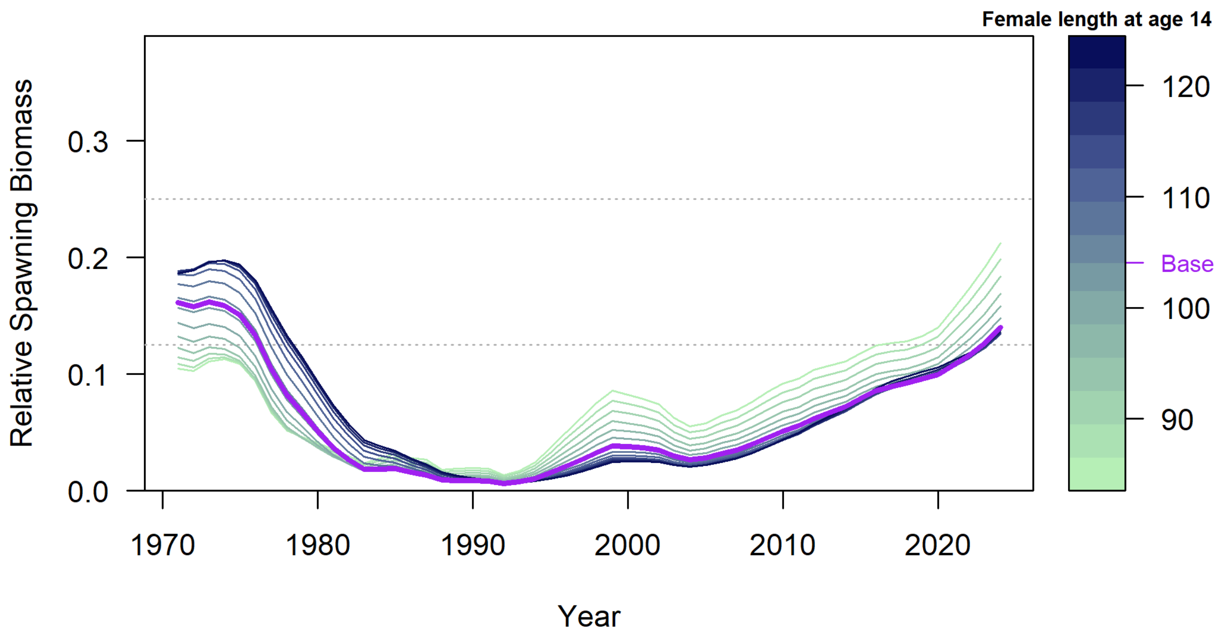


Figure 113. Relative spawning biomass across a range of values for female length at age 14 (L at Amax).

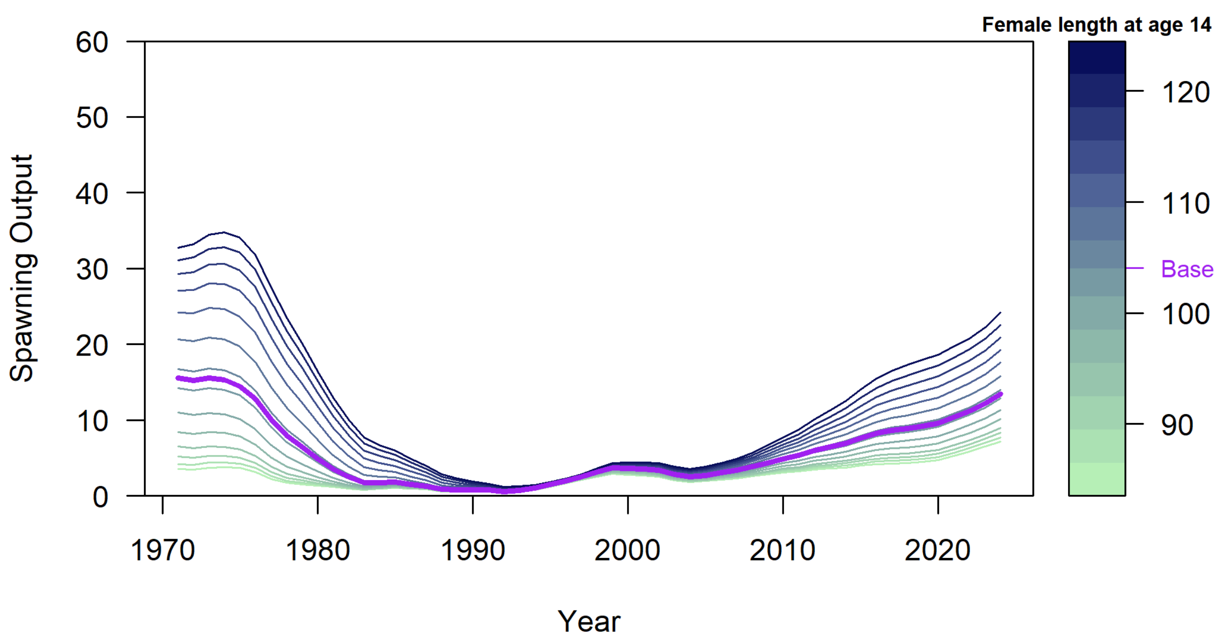


Figure 114. Total spawning output across a range of values for female length at age 14 (L at Amax).

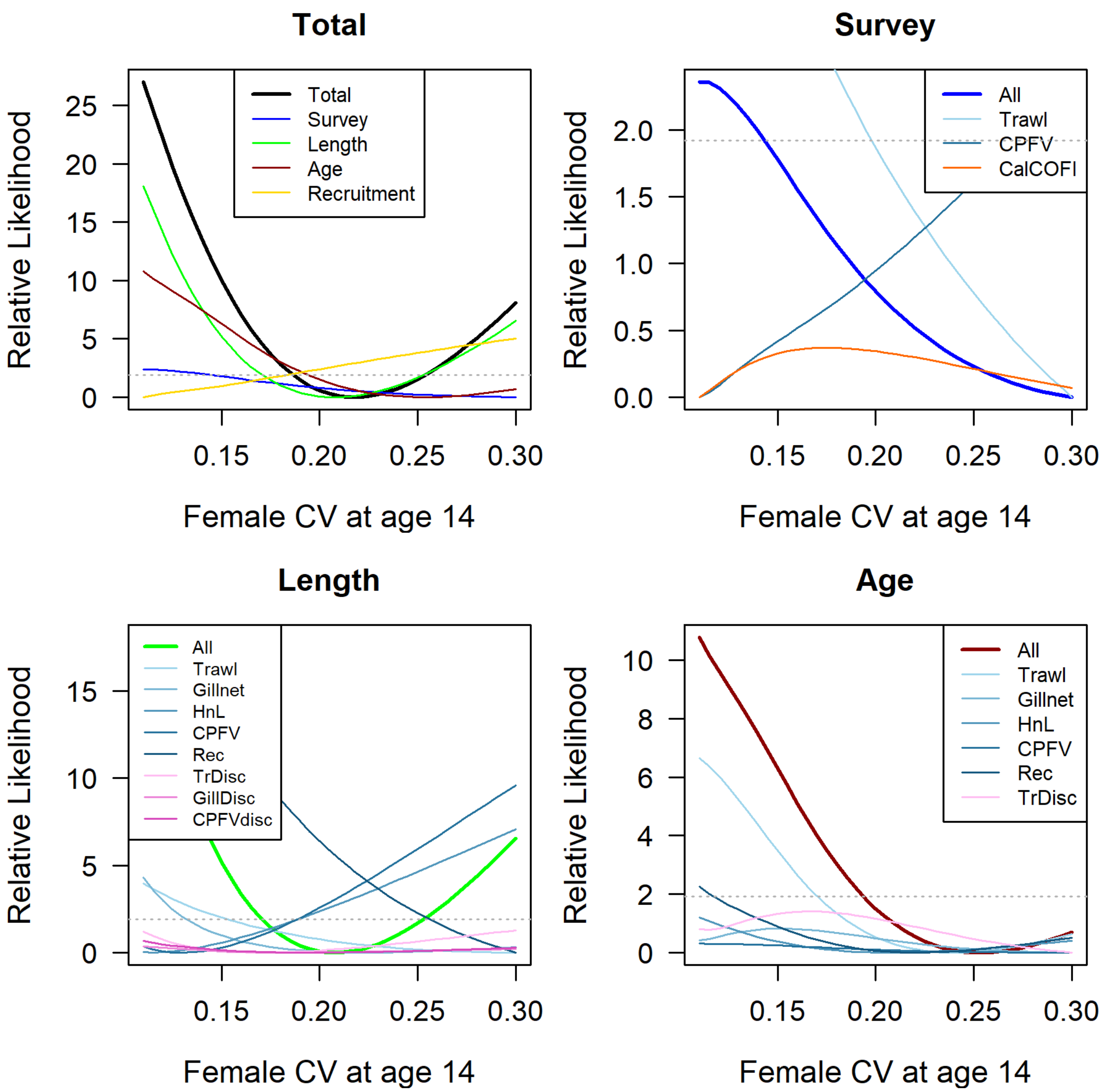


Figure 115. Likelihood profiles for the coefficient of variation in female length at age 14.

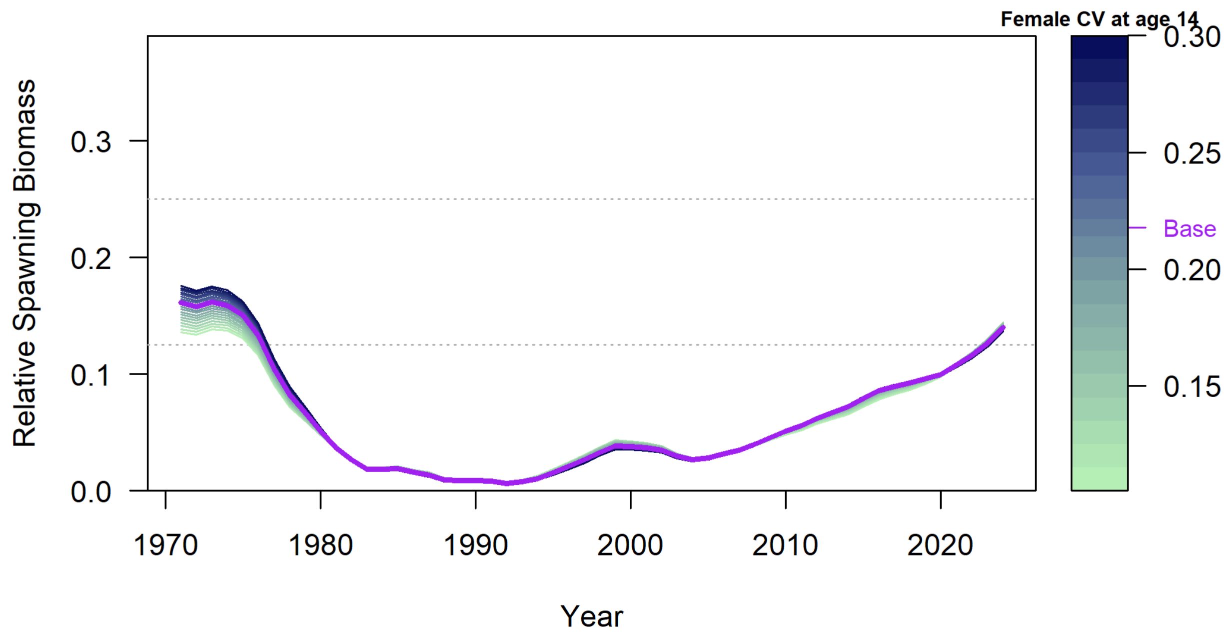


Figure 116. Relative spawning biomass across a range of values for the coefficient of variation in female length at age 14.

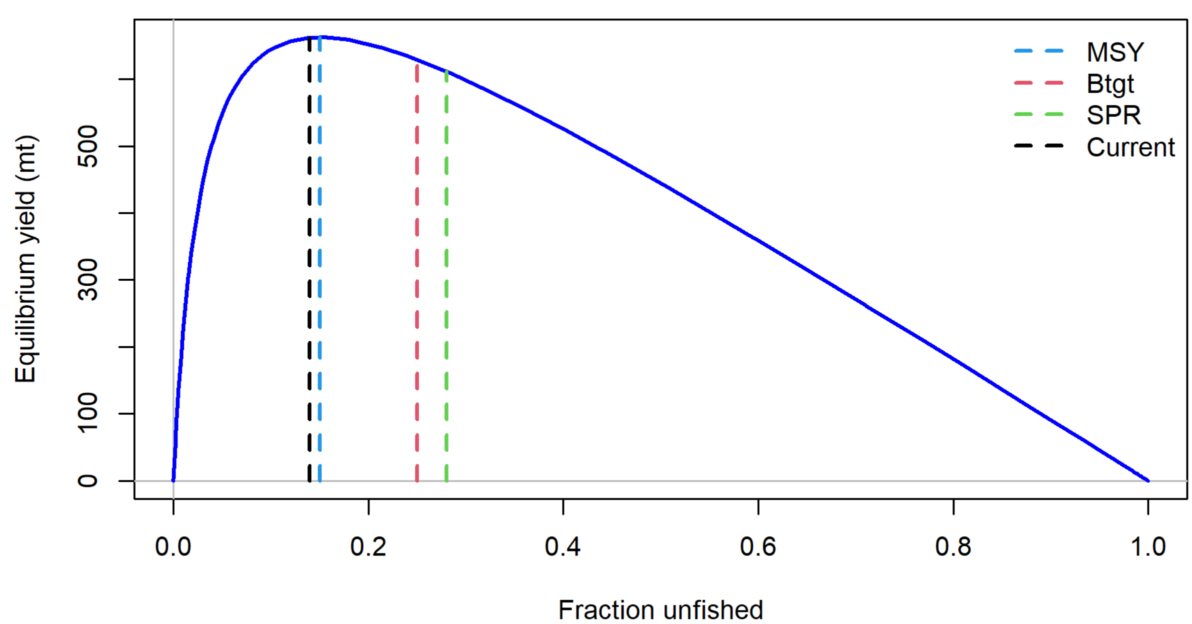


Figure 117. Equilibrium yield curve for the base model and reference points.

Appendix A History of Fishery Regulations

Commercial

1911- Trammel nets are prohibited in state waters.
1913- Trammel nets are permitted but required to be pulled within 6 hours.
1913- Trawl nets are prohibited in state waters off the coast of Los Angeles, Ventura, Orange, and San Diego counties. Trawl nets are prohibited within Monterey Bay.
1915- Trawling is prohibited in all state waters.
1915- California halibut less than 4 lbs (1.8 kg) in the round cannot be bought or sold.
1925- Legislation is changed to allow trawling off the coast of Santa Barbara within state waters.
1931- Commercially-caught California halibut less than 3.5 lbs (1.6 kg) dressed with the head on or 3 lbs (1.4 kg) dressed with the head off cannot be bought or sold (Recreationally-caught halibut may never be bought or sold). Up to 30 lbs (13.5 kg) of underweight California halibut can be retained by a commercial fisherman for personal use only.
1936- Market category for California halibut is established on landing receipts to distinguish from Pacific halibut.
1953- Waters off the Santa Barbara coast are closed to trawling again and trawling is prohibited in all state waters.
1968- Trawl nets are authorized between Point Sur and Cape San Martin in waters not less than 1 nm from the mainland shore. Trawl nets are also permitted between Point Arguello and El Capitan Point in Santa Barbara County in waters not less than 25 fathoms (fm) or 1 nm from shore.
1971- The California Halibut Trawl Grounds (CHTG) are established in southern California (Fish and Game Code sec. 8495).
1971- A 4-month trawl closure within the CHTG is implemented from February through May to protect spawning adults.
1972- A minimum mesh size of 7.5 inches is established for the cod end of trawl nets used within the CHTG.
1973- The 4-month trawl closure within the CHTG is changed to 15 March to 15 June. 1975- A minimum mesh size of 4.5 inches for the mesh of any part of a groundfish trawl net is established. This still applies to federal waters where halibut fishing occurs.
1979- A minimum size limit of 22 inches TL for all commercially-landed California halibut is established. For any licensed commercial fisherman, up to 30 pounds of halibut per day below minimum legal size may be possessed for personal use if taken incidentally in commercial fishing.
1985- Minimum mesh size for gill and trammel nets used to take halibut is increased to 8.5 inches (216 mm) between Point Dume (Los Angeles County) and Ragged Point (San Luis Obispo County).
1985- The number of halibut less than 22 inches total length that may be possessed by commercial fishermen for personal use is reduced to four fish.
1989- An 8.5-inch (216 mm) minimum mesh size for gill and trammel nets used to take halibut is adopted statewide. Gill and trammel nets are prohibited in Santa Monica Bay.
1989- The definition of the CHTG is amended and the 25-fm clause is removed.
1993- 3 nm seaward boundary of the CHTG established.
1994- The Marine Resources Protection Zone is established by legislation: it prohibits the use of gill nets within 3 nm of shore south of Point Arguello and within 1 nm from shore or 70 fm (whichever is less) around the Channel Islands.
2000- An emergency closure is established in waters less than 60 fm from Point Reyes to Point Arguello for the use of gill nets to take halibut.

2002- A permanent closure is established in waters less than 60 fm from Point Reyes to Point Arguello for the use of gill nets to take halibut.
2004- Senate Bill 1459 gives the Fish and Game Commission (Commission) authority over the management of the California halibut bottom trawl fishery.
2004- No halibut less than 22 inches total length may be taken, possessed or sold. 2004- SB 1459 closes all state waters to bottom trawling, with the exception of the CHTG. This includes historic trawl grounds for halibut within state waters of Monterey Bay which are greater than 3 nm from shore. However, the Monterey Bay trawl closure is not enforced until 2006.
2005- Due to SB 1459, 13 percent of the CHTG are closed to bottom trawling. These are the only state waters to date in which bottom trawling is allowed.
2006 A California halibut bottom trawl vessel permit is required for any commercial trawl vessel to land halibut taken in state waters, and in federal waters for landings exceeding 150 pounds
2008- Due to SB 1459, an additional section of the CHTG is closed to bottom trawling.
2009- Commission establishes regulations defining “light touch” trawl gear as the only trawl gear allowed within the CHTG.

Recreational

1971- A minimum size limit of 22 inches total length (TL) for all recreationally landed California halibut is established.
1971- A recreational bag limit of three fish north of Point Sur and five fish south of Point Sur is established.
2024-The bag limit north of Point Sur was reduced to two fish.

Appendix B All Estimated Parameters

Parameter	Value	SE	Min	Max	Gradient
L_at_Amin_Fem_GP_1	28.4572	2.5250	1	45	3.60E-07
VonBert_K_Fem_GP_1	0.0915	0.0168	0.01	1	6.50E-07
CV_young_Fem_GP_1	0.1775	0.0238	0.01	0.5	4.59E-07
CV_old_Fem_GP_1	0.1956	0.0252	0.01	0.5	1.87E-07
VonBert_K_Mal_GP_1	0.1019	0.0114	0.01	1	5.86E-07
SR_LN(R0)	6.8829	0.0756	3	15	1.15E-05
Early_InitAge_24	0.0052	0.7018	-15	15	-1.09E-05
Early_InitAge_23	0.0062	0.7022	-15	15	3.02E-05
Early_InitAge_22	0.0073	0.7026	-15	15	-2.63E-05
Early_InitAge_21	0.0085	0.7030	-15	15	3.19E-05
Early_InitAge_20	0.0094	0.7033	-15	15	-2.28E-05
Early_InitAge_19	0.0102	0.7036	-15	15	-2.71E-05
Early_InitAge_18	0.0100	0.7035	-15	15	7.19E-06
Early_InitAge_17	0.0092	0.7032	-15	15	1.19E-06
Early_InitAge_16	0.0068	0.7024	-15	15	9.41E-06
Early_InitAge_15	0.0024	0.7008	-15	15	-1.68E-06
Early_InitAge_14	-0.0044	0.6984	-15	15	6.57E-07
Early_InitAge_13	-0.0144	0.6949	-15	15	3.69E-07
Early_InitAge_12	-0.0297	0.6896	-15	15	3.06E-07
Early_InitAge_11	-0.0512	0.6823	-15	15	2.09E-07
Early_InitAge_10	-0.0802	0.6727	-15	15	6.21E-07
Early_InitAge_9	-0.1183	0.6605	-15	15	1.03E-06
Early_InitAge_8	-0.1664	0.6455	-15	15	6.97E-07
Early_InitAge_7	-0.2247	0.6281	-15	15	1.71E-07
Early_InitAge_6	-0.2927	0.6090	-15	15	1.16E-06
Early_InitAge_5	-0.3678	0.5894	-15	15	1.42E-06
Early_InitAge_4	-0.4466	0.5711	-15	15	1.47E-06
Early_InitAge_3	-0.5265	0.5543	-15	15	1.13E-06
Early_InitAge_2	-0.6100	0.5384	-15	15	1.43E-06
Early_InitAge_1	-0.6985	0.5232	-15	15	1.39E-06
Early_RecrDev_1971	-0.7696	0.5130	-15	15	1.25E-06
Early_RecrDev_1972	-0.8511	0.5008	-15	15	1.40E-06
Early_RecrDev_1973	-0.6853	0.4075	-15	15	1.34E-06
Early_RecrDev_1974	-0.8561	0.4904	-15	15	1.39E-06
Early_RecrDev_1975	-0.5593	0.4901	-15	15	1.47E-06
Early_RecrDev_1976	-0.1627	0.4442	-15	15	2.47E-06
Main_RecrDev_1977	-0.0785	0.3869	-15	15	1.92E-06
Main_RecrDev_1978	-0.8061	0.4967	-15	15	4.05E-07
Main_RecrDev_1979	-0.1885	0.3015	-15	15	9.15E-07
Main_RecrDev_1980	-0.4387	0.4065	-15	15	8.57E-07
Main_RecrDev_1981	-0.1000	0.3717	-15	15	3.78E-07
Main_RecrDev_1982	0.7717	0.1997	-15	15	1.63E-06
Main_RecrDev_1983	0.1614	0.3708	-15	15	2.19E-07
Main_RecrDev_1984	0.3577	0.3105	-15	15	8.30E-07
Main_RecrDev_1985	0.8514	0.2494	-15	15	7.34E-07
Main_RecrDev_1986	0.6080	0.3806	-15	15	1.60E-07
Main_RecrDev_1987	-0.1912	0.6487	-15	15	-1.98E-07
Main_RecrDev_1988	0.8243	0.3618	-15	15	5.61E-07
Main_RecrDev_1989	0.9965	0.4012	-15	15	-4.35E-07
Main_RecrDev_1990	-0.0170	0.8295	-15	15	-5.77E-07
Main_RecrDev_1991	2.0986	0.2131	-15	15	3.08E-07
Main_RecrDev_1992	-0.0849	0.8323	-15	15	1.84E-07
Main_RecrDev_1993	0.7598	0.9894	-15	15	1.51E-07
Main_RecrDev_1994	1.2237	0.5132	-15	15	-1.74E-07
Main_RecrDev_1995	1.2576	0.3782	-15	15	-2.19E-07

Parameter	Value	SE	Min	Max	Gradient
Main_RecrDev_1996	0.3244	0.5429	-15	15	-1.03E-07
Main_RecrDev_1997	0.6999	0.2860	-15	15	-2.77E-07
Main_RecrDev_1998	0.0836	0.5021	-15	15	6.35E-08
Main_RecrDev_1999	0.2072	0.3439	-15	15	-5.61E-07
Main_RecrDev_2000	-0.3866	0.3182	-15	15	-3.79E-07
Main_RecrDev_2001	-0.2862	0.2703	-15	15	1.17E-08
Main_RecrDev_2002	-0.5524	0.2691	-15	15	-3.96E-07
Main_RecrDev_2003	-0.0470	0.1657	-15	15	-1.60E-07
Main_RecrDev_2004	-0.0486	0.1448	-15	15	-1.30E-07
Main_RecrDev_2005	-0.1405	0.1345	-15	15	-3.71E-07
Main_RecrDev_2006	-0.2789	0.1255	-15	15	-4.00E-07
Main_RecrDev_2007	-0.5724	0.1397	-15	15	-4.83E-07
Main_RecrDev_2008	-0.6815	0.1472	-15	15	-2.16E-07
Main_RecrDev_2009	-0.7184	0.1535	-15	15	-3.38E-07
Main_RecrDev_2010	-1.3910	0.2642	-15	15	-2.98E-07
Main_RecrDev_2011	-0.8717	0.2917	-15	15	-4.31E-07
Main_RecrDev_2012	-0.6297	0.2758	-15	15	2.13E-07
Main_RecrDev_2013	-0.3798	0.2322	-15	15	-3.87E-07
Main_RecrDev_2014	-0.4636	0.2128	-15	15	-2.08E-07
Main_RecrDev_2015	-0.2454	0.1794	-15	15	-1.33E-07
Main_RecrDev_2016	0.0628	0.2036	-15	15	-4.15E-07
Main_RecrDev_2017	0.1317	0.2552	-15	15	-2.76E-07
Main_RecrDev_2018	-0.1864	0.2749	-15	15	-2.98E-07
Main_RecrDev_2019	-0.7398	0.4167	-15	15	-3.50E-07
Main_RecrDev_2020	-0.4083	0.4790	-15	15	-4.41E-07
Main_RecrDev_2021	-0.4871	0.6655	-15	15	-8.69E-07
InitF_seas_1_flt_1Bottom.Trawl	0.0137	0.0023	0	1	-3.10E-07
InitF_seas_1_flt_2Gillnet	0.0334	0.0061	0	2	-4.26E-07
InitF_seas_1_flt_5Other.Rec	0.0779	0.0097	0	1	-5.33E-07
Q_extraSD_Bottom.Trawl(1)	0.1712	0.0371	0	0.5	4.38E-08
Q_extraSD_CPFV(4)	0.1031	0.0210	0	0.5	3.02E-08
Q_extraSD_CalCOFI(11)	0.1618	0.1179	0	0.9	3.86E-08
Size_DblN_peak_Bottom.Trawl(1)	57.3273	0.7266	30	80	1.17E-07
Size_DblN_top_logit_Bottom.Trawl(1)	-10.7188	63.1306	-15	15	9.77E-10
Size_DblN_ascend_se_Bottom.Trawl(1)	1.8102	0.5770	-5	10	-8.04E-07
Size_DblN_descend_se_Bottom.Trawl(1)	7.7093	0.2816	-5	20	1.67E-07
SzSel_Male_Peak_Bottom.Trawl(1)	0.2420	1.7509	-10	10	1.19E-07
SzSel_Male_Ascend_Bottom.Trawl(1)	1.0666	0.7082	-5	5	-3.90E-07
SzSel_Male_Descend_Bottom.Trawl(1)	-3.3077	0.5990	-10	9	-2.47E-07
SzSel_Male_Scale_Bottom.Trawl(1)	0.7523	0.2102	0.01	1	-2.79E-08
Size_DblN_peak_Gillnet(2)	68.0905	1.4669	30	100	4.25E-07
Size_DblN_top_logit_Gillnet(2)	-11.6766	53.0483	-15	15	-5.54E-09
Size_DblN_ascend_se_Gillnet(2)	4.2399	0.2584	-5	10	1.38E-07
Size_DblN_descend_se_Gillnet(2)	7.4813	0.2722	-5	20	4.16E-08
Size_DblN_start_logit_Gillnet(2)	-9.7706	8.2097	-15	9	-9.94E-09
SzSel_Male_Peak_Gillnet(2)	-3.1987	1.4493	-10	10	2.60E-09
SzSel_Male_Ascend_Gillnet(2)	-0.2942	0.3852	-5	5	-9.27E-08
SzSel_Male_Descend_Gillnet(2)	-0.0935	1.3627	-10	9	1.23E-07
SzSel_Male_Scale_Gillnet(2)	0.1818	0.0329	0.01	1	7.21E-08
Size_DblN_peak_Comm.HL(3)	55.4638	85.3116	30	90	3.30E-08
Size_DblN_ascend_se_Comm.HL(3)	-1.8480	370.9010	-15	10	-5.10E-08
Size_DblN_start_logit_Comm.HL(3)	-6.7231	1.7374	-15	9	1.72E-09
Size_DblN_peak_CPFV(4)	56.5790	0.5285	30	80	-1.18E-07
Size_DblN_ascend_se_CPFV(4)	1.9733	0.3282	-5	15	6.23E-08
Size_DblN_start_logit_CPFV(4)	-5.6897	0.4246	-15	9	-7.15E-09
Size_DblN_peak_Other.Rec(5)	57.0580	0.4919	30	80	-2.28E-07
Size_DblN_top_logit_Other.Rec(5)	-0.0393	0.4343	-15	15	-1.53E-06
Size_DblN_ascend_se_Other.Rec(5)	1.3080	0.5457	-5	10	-6.65E-08

Parameter	Value	SE	Min	Max	Gradient
Size_DblN_descend_se_Other.Rec(5)	5.6704	1.0116	-5	20	-4.03E-07
Size_DblN_start_logit_Other.Rec(5)	-4.4481	0.1958	-15	9	1.94E-07
SzSel_Male_Peak_Other.Rec(5)	1.7689	1.7564	-10	10	-1.74E-07
SzSel_Male_Ascend_Other.Rec(5)	1.8308	0.7471	-5	5	5.04E-08
SzSel_Male_Descend_Other.Rec(5)	1.5697	3.2369	-10	9	5.93E-08
SzSel_Male_Scale_Other.Rec(5)	0.7794	0.1781	0.01	1	8.74E-08
Size_DblN_peak_Bottom.Trawl.Discard(6)	43.5744	2.0257	30	80	5.42E-08
Size_DblN_top_logit_Bottom.Trawl.Discard(6)	-2.2624	0.2554	-15	15	9.09E-08
Size_DblN_ascend_se_Bottom.Trawl.Discard (6)	3.9508	0.3823	-5	10	-1.03E-07
Size_DblN_descend_se_Bottom.Trawl.Discar d(6)	0.8127	0.6493	-15	20	1.10E-07
Size_DblN_peak_Gillnet.Discard(7)	53.0535	7.6799	30	80	-5.25E-08
Size_DblN_top_logit_Gillnet.Discard(7)	-10.9351	60.8987	-15	15	6.84E-09
Size_DblN_ascend_se_Gillnet.Discard(7)	4.7399	1.2238	-5	10	5.19E-08
Size_DblN_descend_se_Gillnet.Discard(7)	5.3714	1.5990	-15	20	7.69E-08
Size_DblN_peak_CPFV.Discard(8)	48.9094	3.9699	30	80	-5.00E-08
Size_DblN_top_logit_CPFV.Discard(8)	-3.5521	1.9685	-15	15	1.55E-07
Size_DblN_ascend_se_CPFV.Discard(8)	5.3954	0.4249	-5	10	3.57E-07
Size_DblN_descend_se_CPFV.Discard(8)	2.4390	1.3006	-15	20	1.73E-07
Size_DblN_end_logit_CPFV.Discard(8)	-2.6723	0.6732	-15	9	-3.06E-07
Size_DblN_peak_Gillnet(2)_BLK1repl_1971	64.1244	0.5811	30	90	3.73E-07
Size_DblN_ascend_se_Gillnet(2)_BLK1repl_ 1971	3.6265	0.1287	-5	10	-1.55E-07
Size_DblN_descend_se_Gillnet(2)_BLK1repl _1971	7.6003	0.3345	-5	20	8.07E-08
Size_DblN_start_logit_Gillnet(2)_BLK1repl_1 971	-8.4338	0.6553	-15	9	1.89E-07
Size_DblN_peak_Gillnet.Discard(7)_BLK1repl _1971	51.9258	1.0455	30	90	3.06E-07
Size_DblN_ascend_se_Gillnet.Discard(7)_BL K1repl_1971	4.9895	0.1696	-5	10	3.34E-07
Size_DblN_descend_se_Gillnet.Discard(7)_B LK1repl_1971	1.9071	0.8560	-5	20	1.68E-07

Appendix C Responses to Requests from the 2024 Peer Review

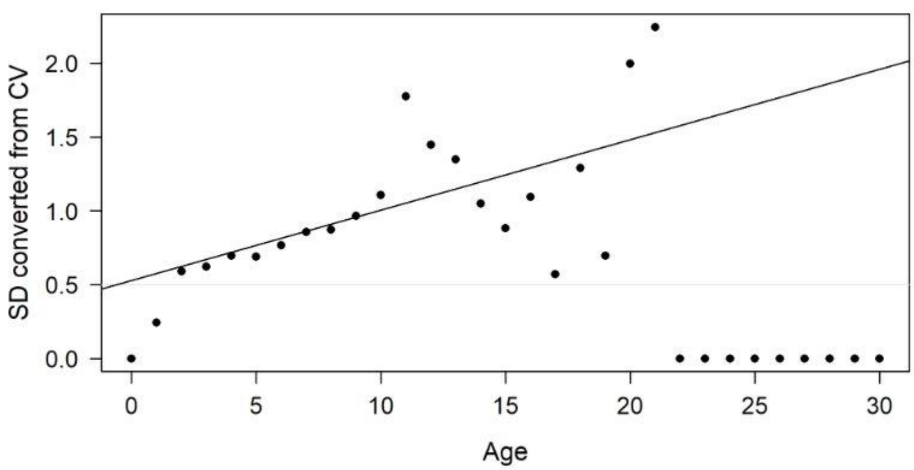
Day 1

Data Requests

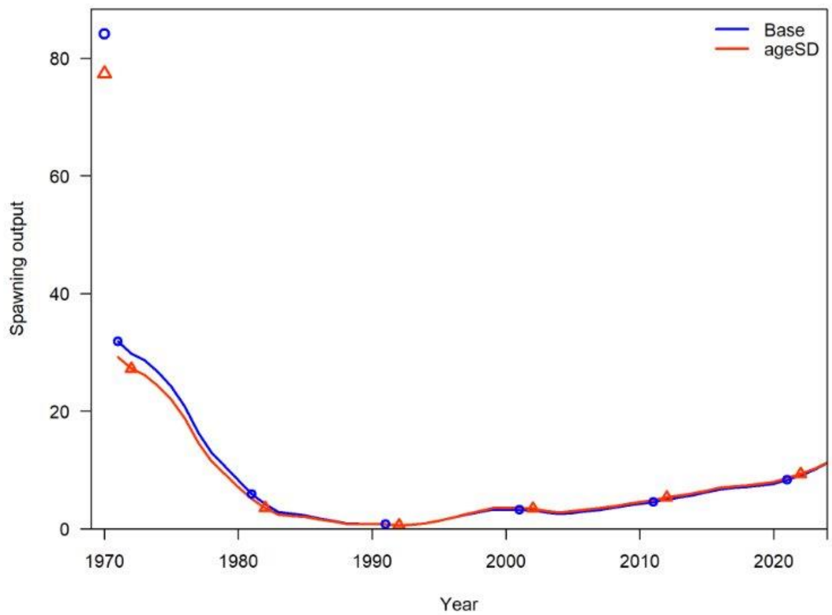
1. **Request**: Re-evaluate how ageing error was input into the model - should be SD rather than CV. Apply a smoother to predicted SDs if necessary.

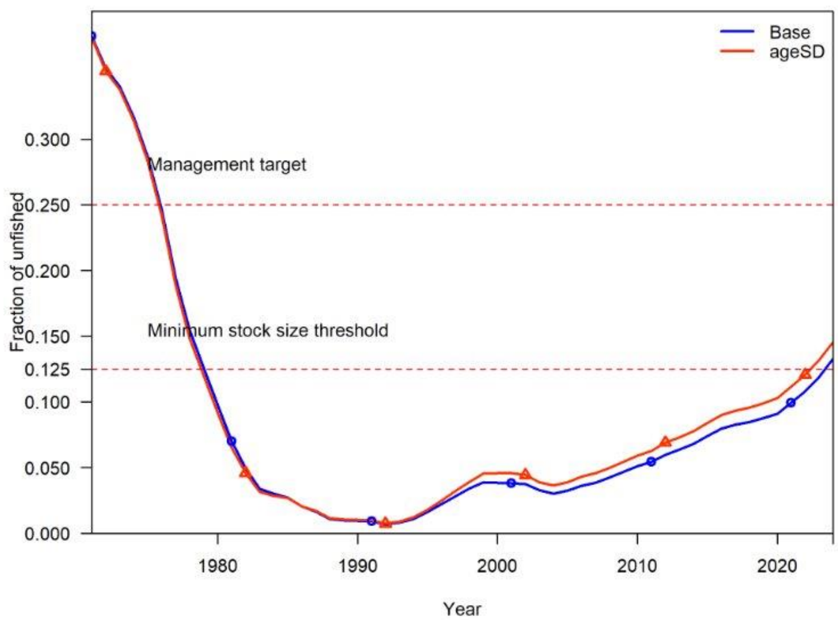
a. Rationale: Stock synthesis assumes ageing error is input as an SD.

b. STAT Response: Stock synthesis uses standard deviation for ageing error inputs and we erroneously used coefficients of variation. CVs are so small that this is effectively no error. We converted CVs to SDs by multiplying each CV by the age then fit a linear regression to the SDs from ages 2 through 21.

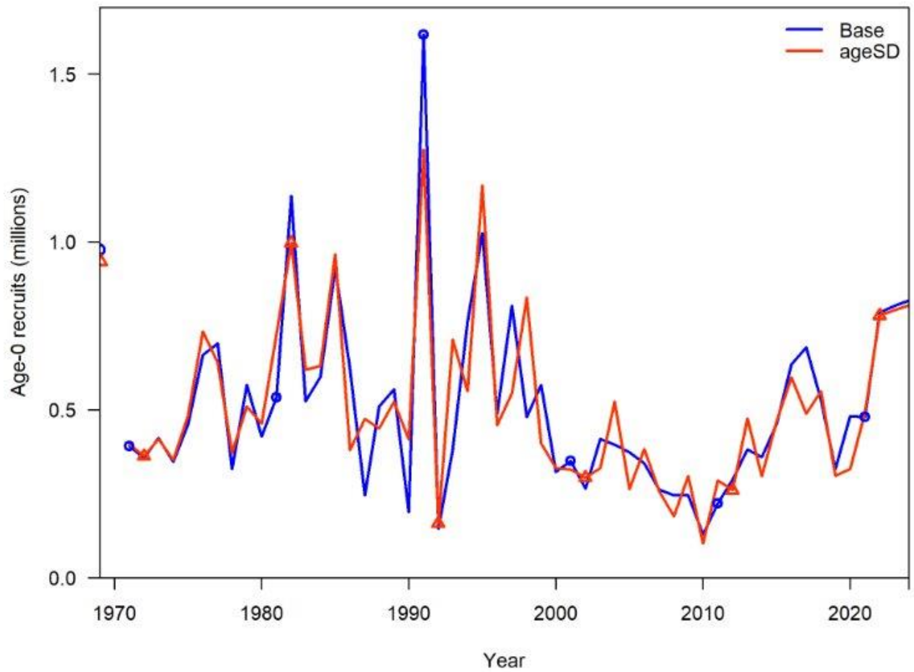


This resulted in a slightly lower initial spawning output and consequently a slightly higher relative biomass in 2023.





This also had several effects on recruitment including decreasing the extremely high recruitment estimate in 1991 and producing a more jagged recruitment pattern between 2000 and 2020.



Ageing error using SDs was implemented in all further modeling.

2. Request: Check what units the Bottom Trawl log book index should be input into the model in.

a. Rationale: The base model has the bottom trawl index specified as biomass, but the STAT believes that the logbook index could be based on numbers.

b. STAT Response: The data modeled by the trawl logbook index was “pounds hailed.” The index was appropriately input with units of weight and no change was necessary in response to this request.

3. Request: Check if the discard ratio from WCGOP (commercial bottom trawl) is estimated using numbers or weights of fish. If numbers, repopulate using weight. There is a column in the WCGOP data called “DIS_MT” that is the estimated discard in metric tons.

a. Rationale: Discard mortality is measured as numbers of individuals, but weight is typically the default method for assessors to process these data.

b. STAT Response: The discard ratio was calculated appropriately using the weight of retained and discarded fish. No change was necessary in response to this request.

4. Request: Describe the justifications for using discard fleets in the base model and the pros and cons relative to using retention curves.

a. Rationale: This is a change from the 2020 model and would be useful to justify the change. There was also a thought that discards may be better predicted over time with retention curves.

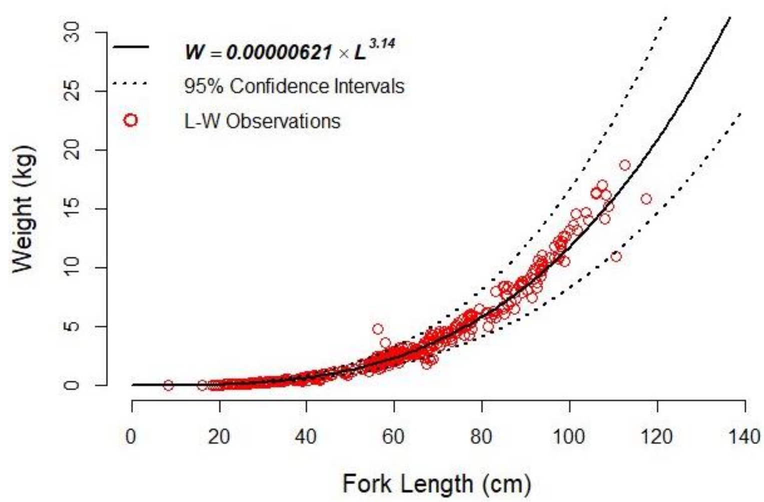
b. STAT Response: We attempted to use retention curves in early iterations of this assessment by providing annual total discards as data accompanied by a 0.6 standard error. In many cases, this resulted in problematic selectivity and retention curves that indicated retention of fish at smaller sizes than selection. This had ramifications on growth parameter estimation and lead to unrealistic growth curves. We found that separating the issues of estimated selectivity and retention by modeling separate discard fleets with their own selectivity curves allowed for more explicit understanding of each fleet's dynamics. Both methods make similar use of the available discard data and associated assumptions. Modeling discards or discard rate as data (i.e. retention fleets) allows for incorporation of uncertainty in discards, which is a benefit. However, it's unclear how to determine the uncertainty of this data source.

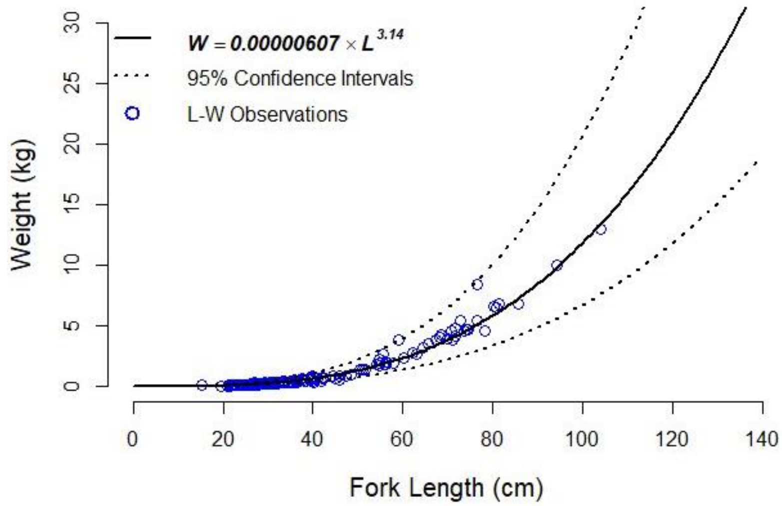
Biology Requests

5. B1.Request: Plot the weight-length curve with the data.

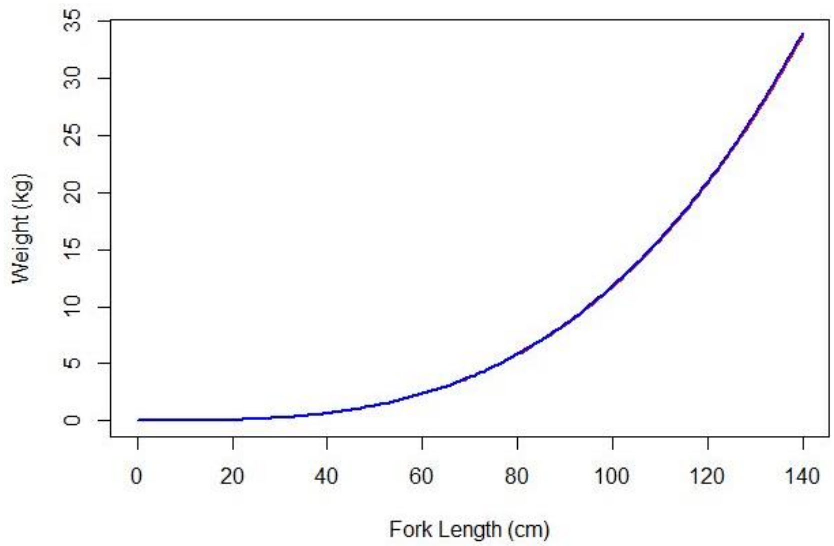
a. Rationale: It is helpful to see the data and the fits.

b. STAT Response: We calculated female and male length-weight relationships using all available weights of fish from southern California in the CDFW halibut project sample database and plotted them with the data.





Female and male weights were almost exactly the same.

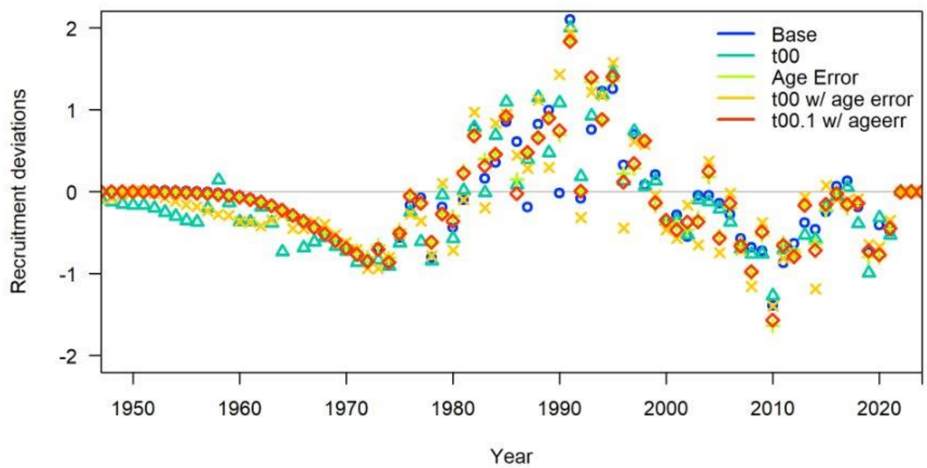


The pre-review base model used length-weight parameters from the 2020 assessment. We recommend updating to the values calculated in response to this request given we have increased certainty in the source of the data and can confirm that it uses only southern California fish.

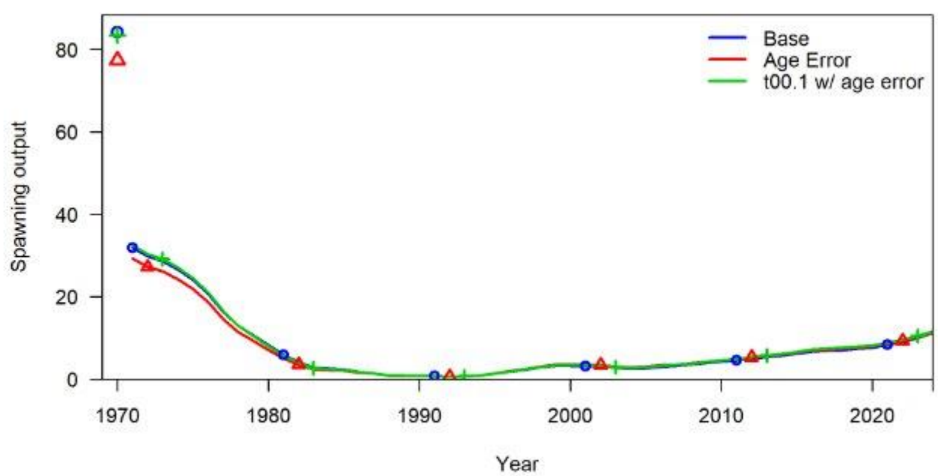
6. B2.Request: Explore fixing $t_0 = 0$ for sex-specific growth curves.

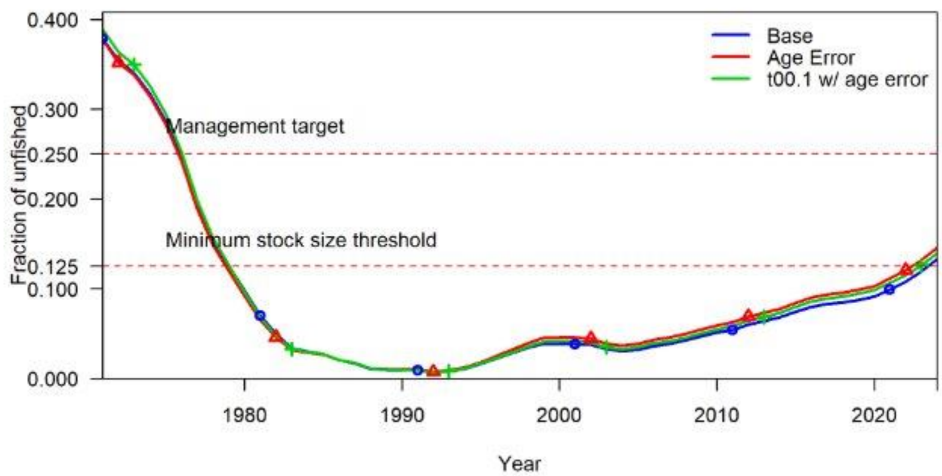
a. Rationale: Given limited sampling of smaller/younger fish, fixing t_0 would increase estimates of k and decrease estimates of L_{max}, likely improving fits to the data.

b. STAT Response: Stock synthesis uses von Bertalanffy growth curves only above the specified Amin value. Length declines linearly between the length at Amin and the length of the first size bin for length composition data (here 10 cm) at Age 0. To approximate a curve closer to the von Bertalanffy parameterization with t_0=0 we set the LatMinAge parameter 0 and fixed the L_at_Amin parameter to 0. Fixing this parameter to 0 resulted in some changes to estimated recruitments that we could not explain, particularly in the years leading up the main recruitment estimation period.

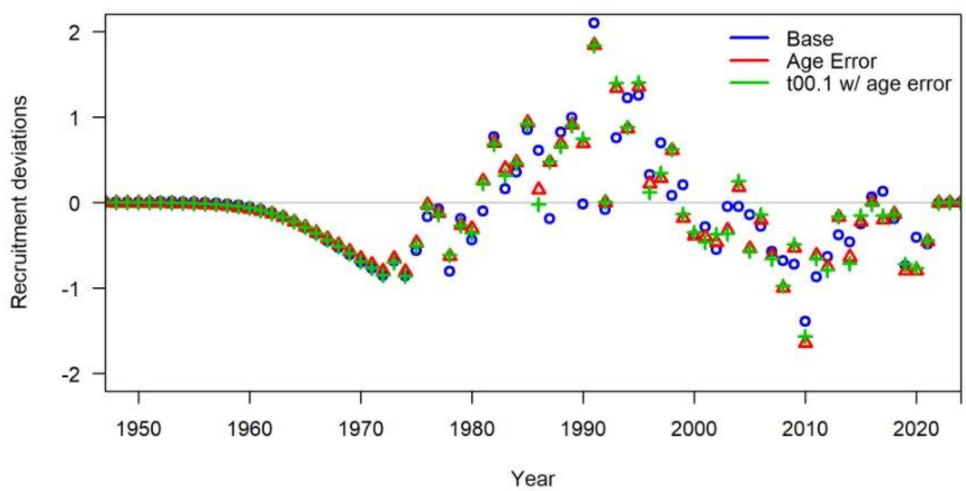


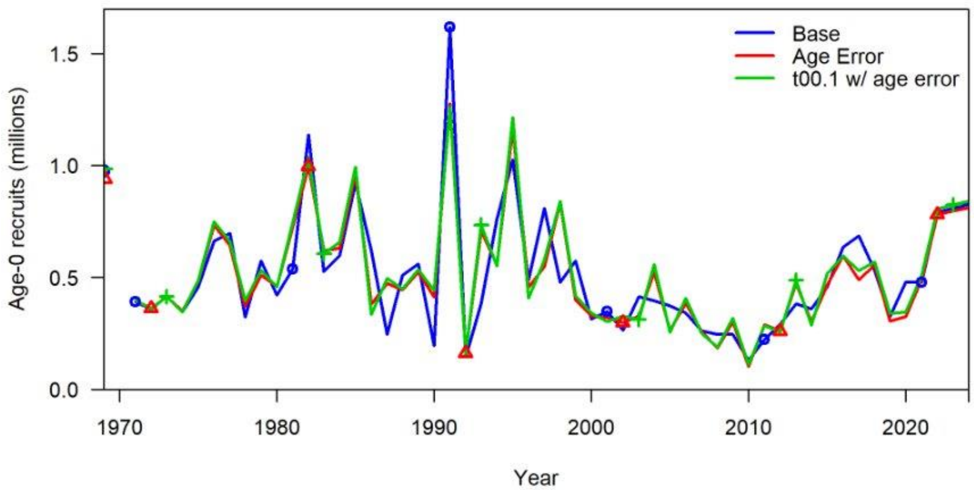
We then fixed L_at_Amin to a very small value (0.1) and compared results between the base model, adding the corrected ageing error from request #1, and correcting age error and setting L_at_Amin to 0.1.



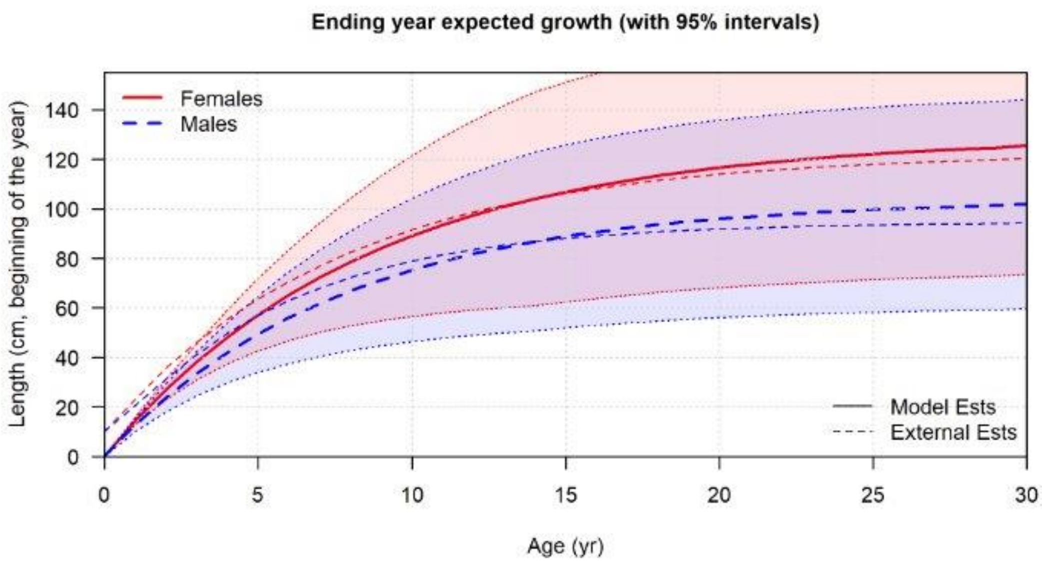


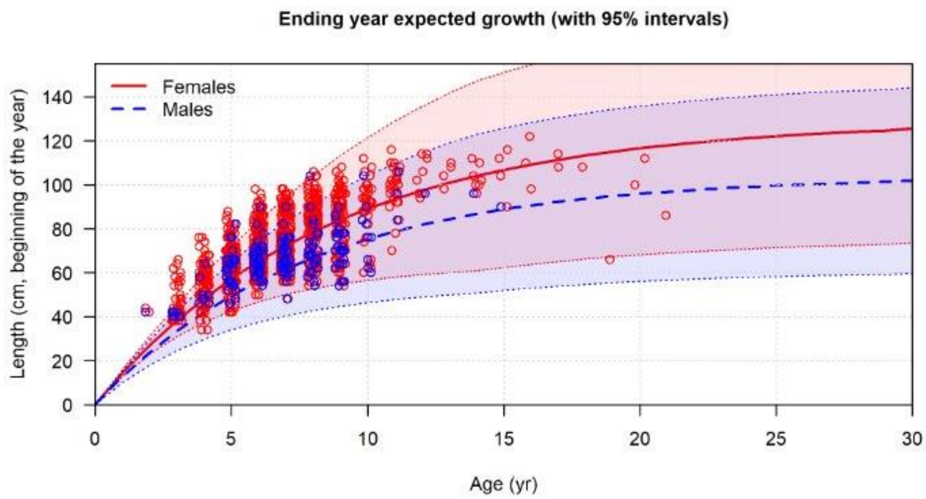
There are subtle differences in the biomass timeseries. Correcting the aging error decreased initial spawning output but layering t_0=0.1 onto this correction brought the initial spawning output back up to the base model value.





Recruitment patterns are almost identical between the original growth parameterization and t_0=0.1 when ageing error is corrected.





Setting t_0=0.1 may slightly worsen the fit to the length at age of young fish. Using the von Bertalanffy parameterization, t0 is theoretically the mean size of fish at birth, which may be 0 or some small positive value. However, this parameter also effects the shape of the curve at low ages and forcing a t0=1 may worsen the fit for other young ages that are nearing the first age of maturity or vulnerability to the fishery. We recommend returning to the base model parameterization but are open to discussion.

7. B3.Request: Explore mirroring appropriate male parameters (e.g., L_{min}, CVs) to the female parameters (no offset). Stock Synthesis allows mirroring of male natural mortality to females by setting the starting value to 0 but the reviewers are unsure if the other biological parameters have the same functionality.

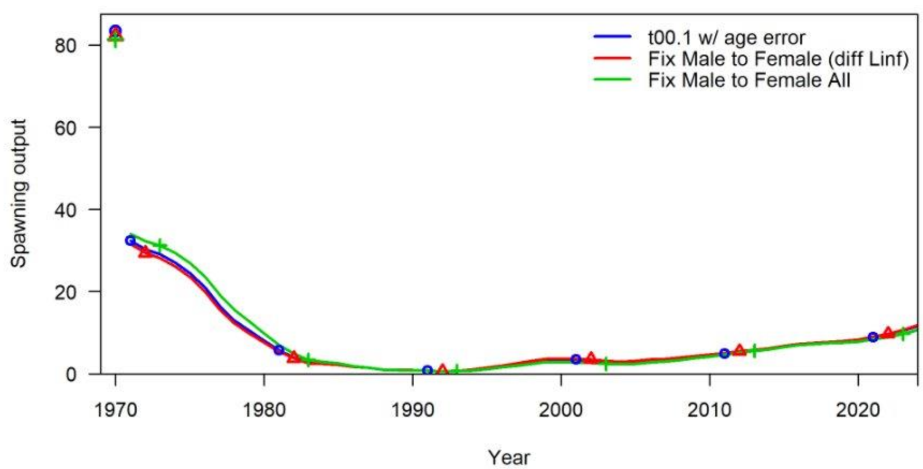
a. Rationale: The internally and externally estimated growth curves are quite different. This would allow more male parameters to be informed by internal estimation procedures.

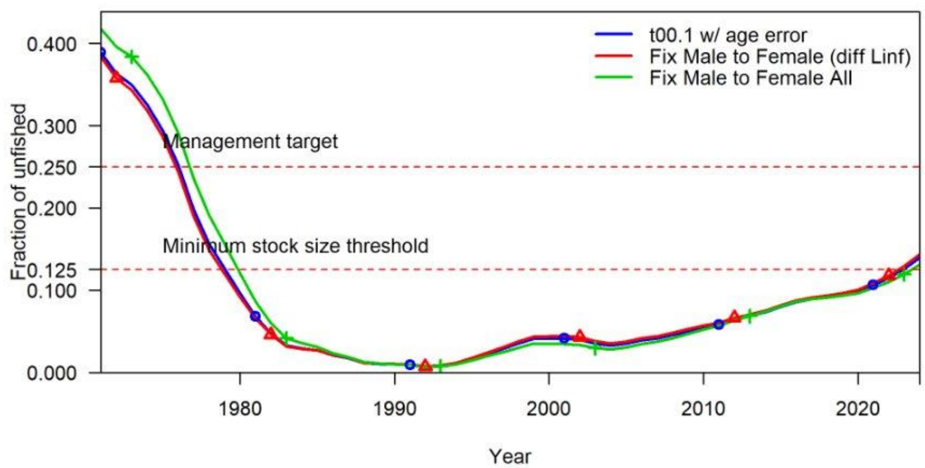
b. STAT Response: Setting male growth parameters to 0 does produce the desired result of Stock Synthesis mirroring them to female values. The table below shows parameter values for four scenarios that were compared in response to this request. Values in gray are fixed. Values in italics are the implied length at age 2, given other parameters and assumptions. We compared the base model, to a model setting the lower age parameter to 0 and length at that age to 0.1 (t0=0.1). This t0=0.1 setting was carried through the next scenario fixing male k and CVs to the female values (fix) and setting male k, CVs, and L-at-age-14 to the female values (fix all).

c.

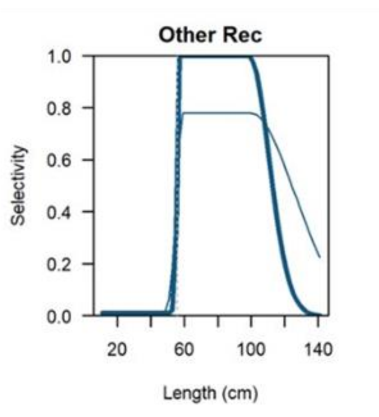
	Base		t0.1		Fix		Fix all
	Fem	Male	Fem	Male	Fem	Male	Fem/Male
L-at-age 2	28.5	31.2	*27.04*	*23.73*	*27.47*	*22.93*	*26.11*
L-at-age 14	104	86.8	104	86.8	104	86.8	104
k	0.092	0.102	0.117	0.129	0.121		0.109
CV young	*0.18 (age 2)*	0.09	0.03 *(age 0)*	0.09	0.01 (*age 0*)		0.07 (*age 0*)
CV old	0.20	0.21	0.21	0.21	0.22		0.19

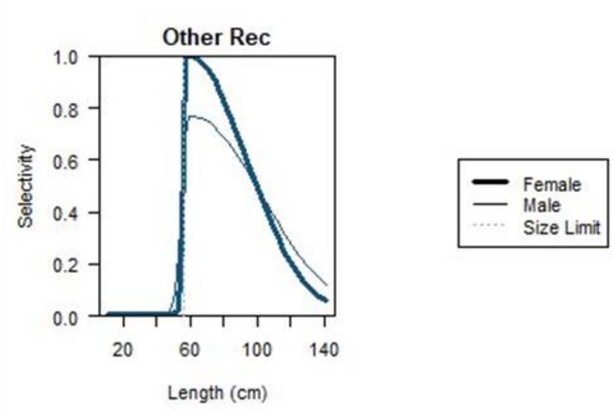
Fixing male growth to female parameter values has surprisingly little impact on the biomass timeseries. This is likely due to the relatively rare capture of males and therefore their reduced importance to this fishery.





However, we did see an impact to the estimation of selectivity for the OtherRec fleet. The plot on the right shows selectivity when male growth parameters are fixed to female values.



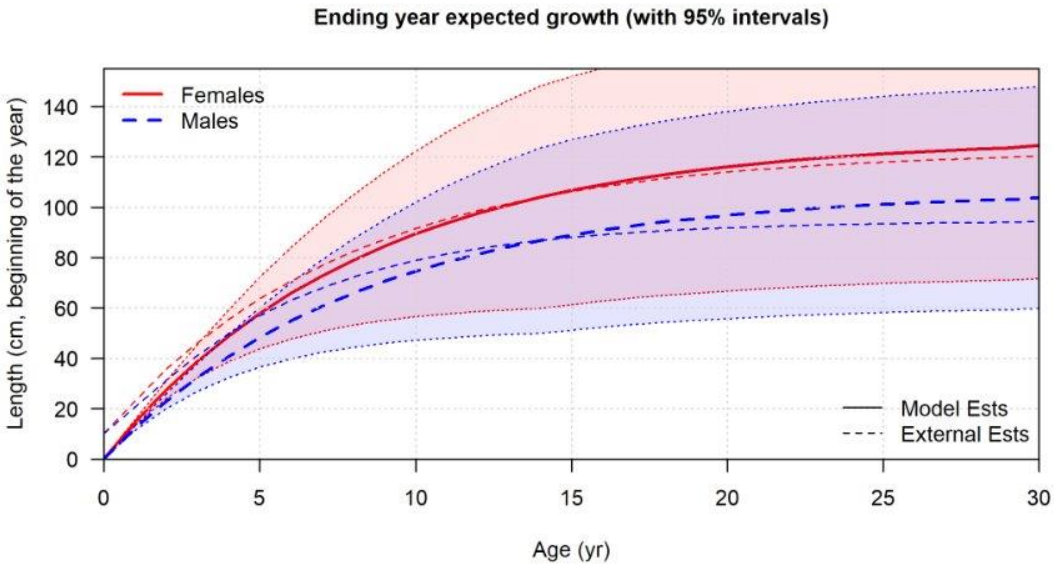


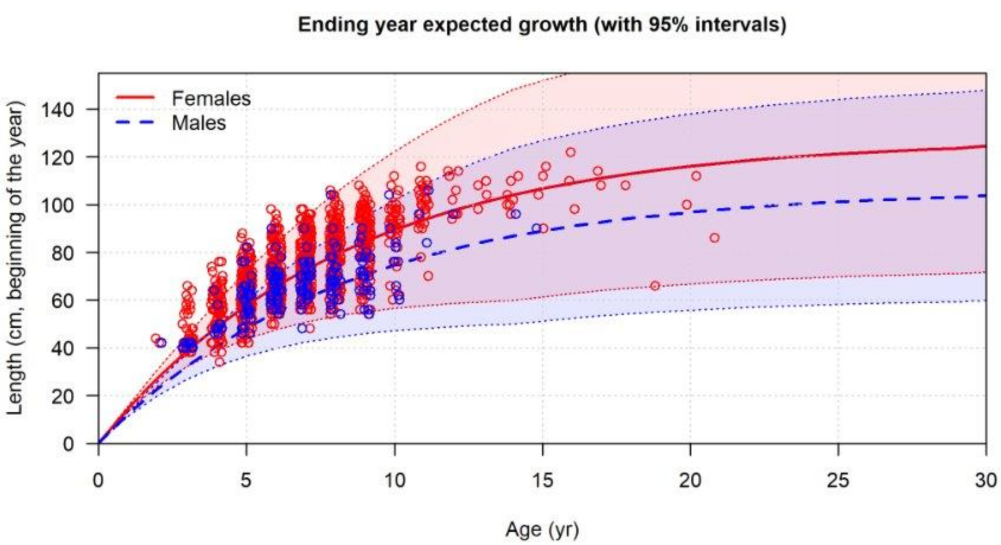
Dimorphic growth is a well known feature of California halibut and is likely important to capture in this assessment, though it may only be important at older ages. We recommend maintaining the base model parameterization.

8. B4.Request: Once request 2 and 3 are done in the biology section, plot the model estimated growth by sex, the external growth estimates, and the data.

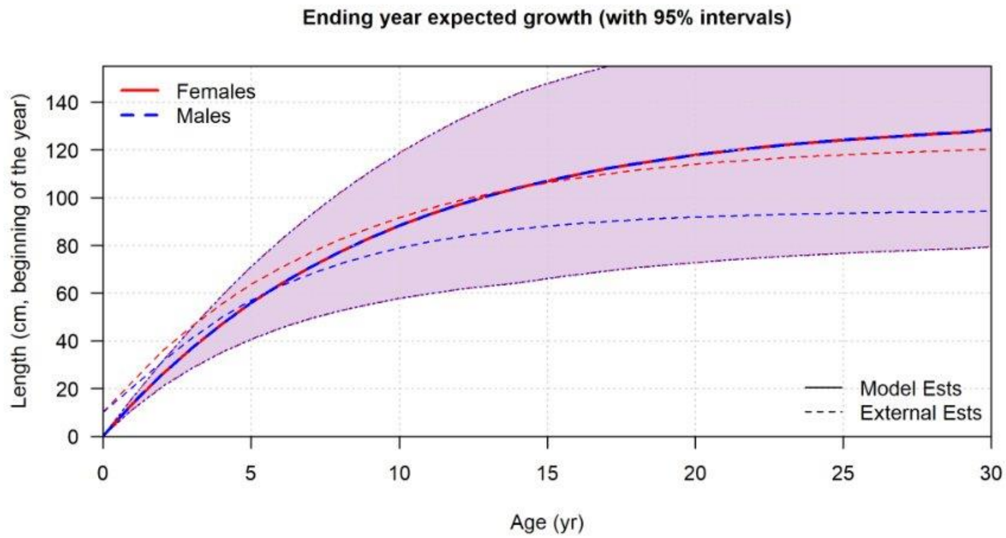
a. Rationale: Visualizing the model estimated growth and the external growth curves with the data can allow us to determine if the growth is fitting the data.

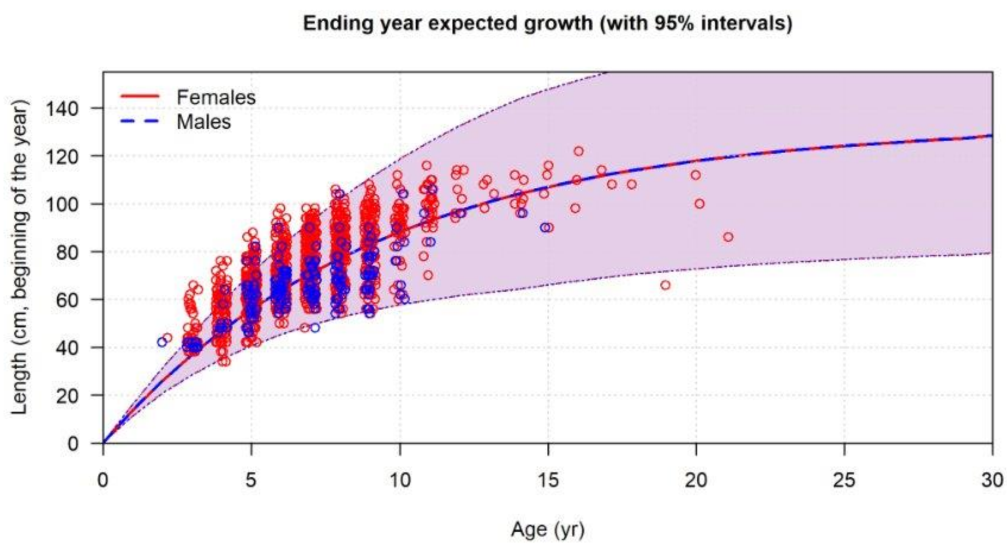
b. STAT Response: We first show the comparison between the externally estimated growth parameters and the new model estimates of growth while setting t0=0. Next, we show the new model estimates with the data.





Then we show the growth curve with male parameters fixed to female in comparison with the external estimates. Finally, we show the fixed female and male curves with the data.



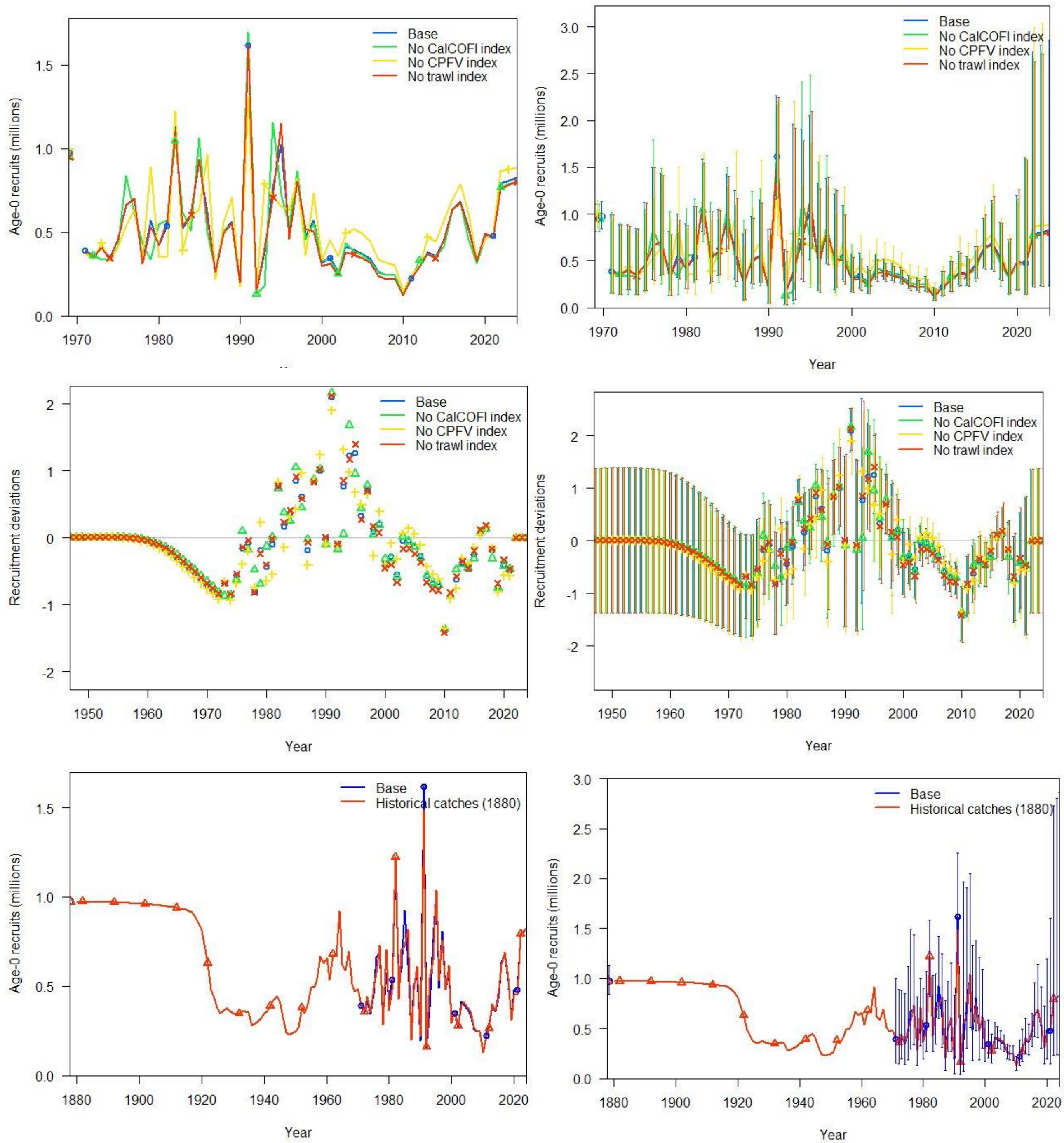


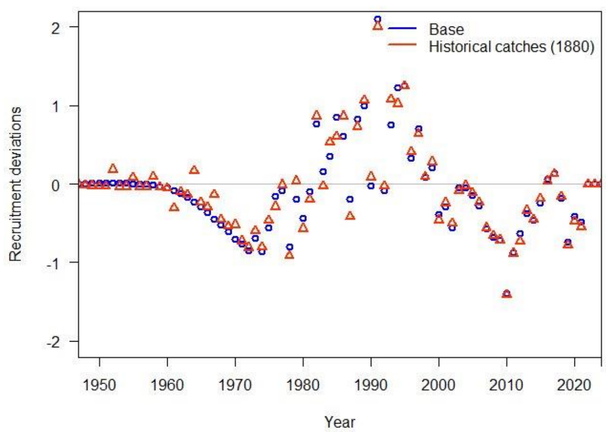
Modeling Requests

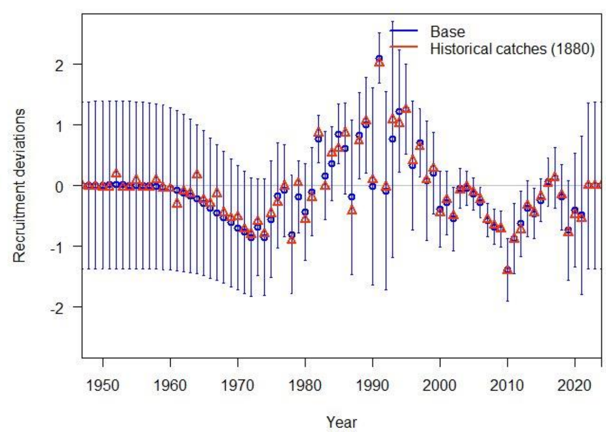
9. M2.Request: Look through the recruitment deviation figures from the already run sensitivities (including removing the CPFV, CalCOFI indices, and the full time-series model) and any new potential base model from the above requests to better understand how recruitment deviation estimates are changing.

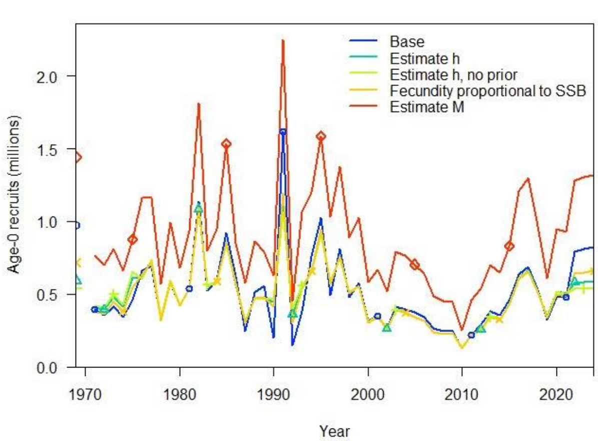
a. Rationale: We would like to explore what factors drive the estimates of large recruitment deviations with high uncertainty during the 1990s.

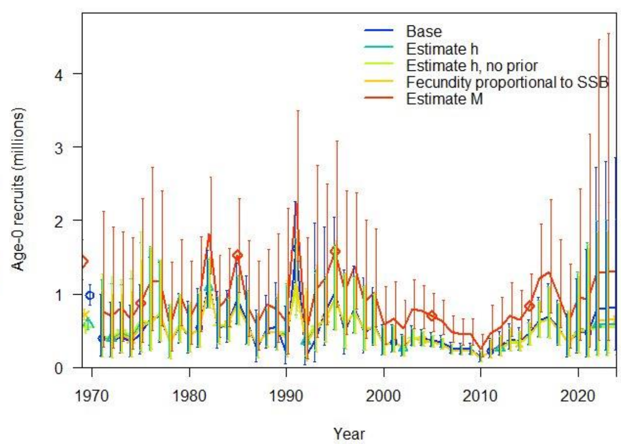
b. STAT Response: We plotted the timeseries for Age-0 recruits with and without uncertainty, and recruitment deviations with and without uncertainty, for all sensitivity scenarios reported in the pre-review assessment report.

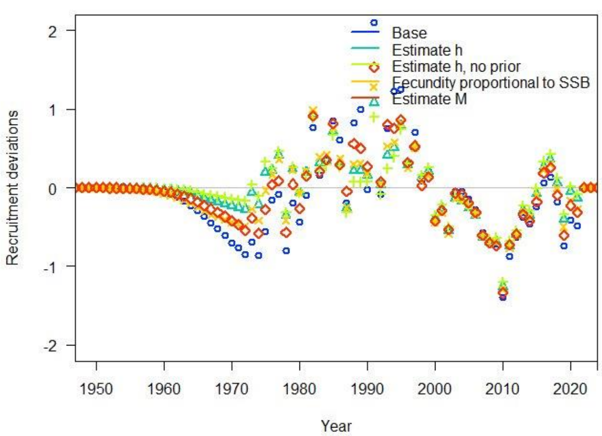

Base
No CalCOFI index
No CPFV index
No trawl index
Age-0 recruits (millions)
Recruitment deviations
Historical catches (1880)
Year

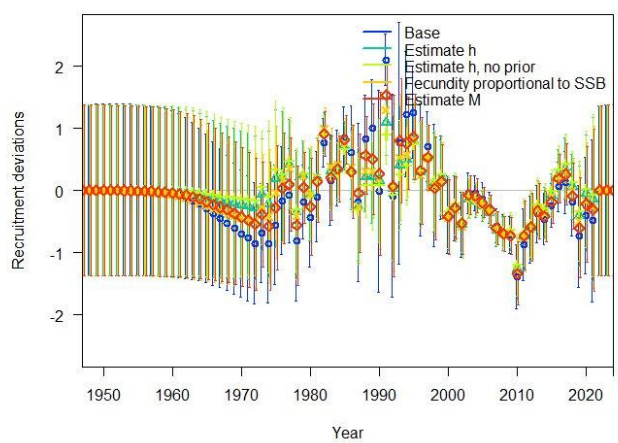

Base
Historical catches (1880)
Recruitment deviations
Year

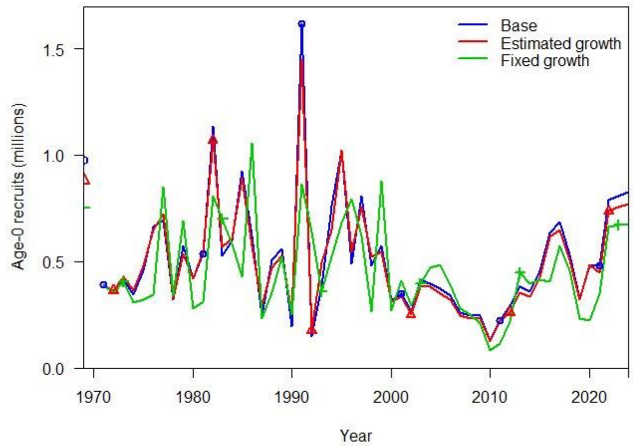

Base
Historical catches (1880)
Recruitment deviations
Year

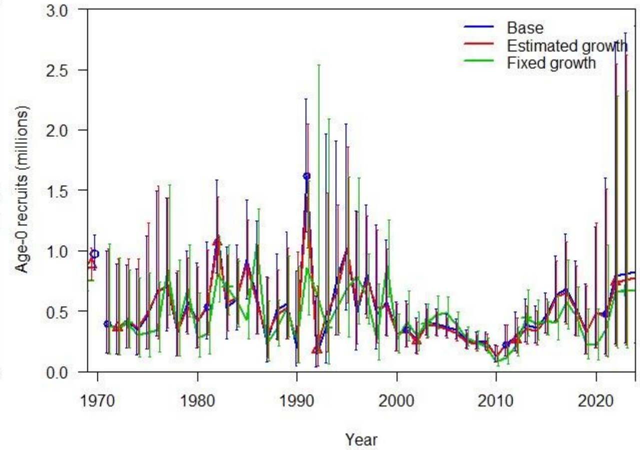

Base
Estimate h
Estimate h, no prior
Fecundity proportional to SSB
Estimate M
Age-0 recruits (millions)
Year

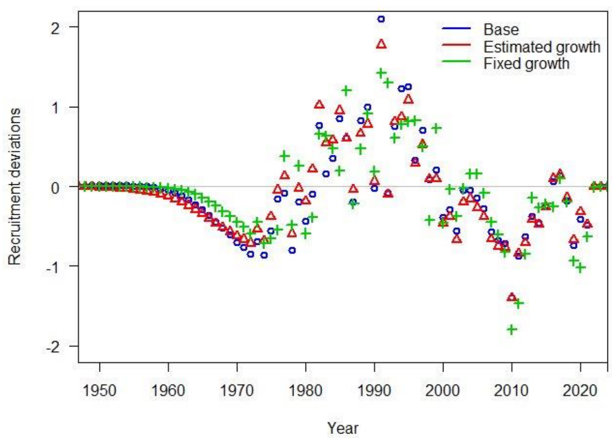

Base
Estimate h
Estimate h, no prior
Fecundity proportional to SSB
Estimate M
Age-0 recruits (millions)
Year

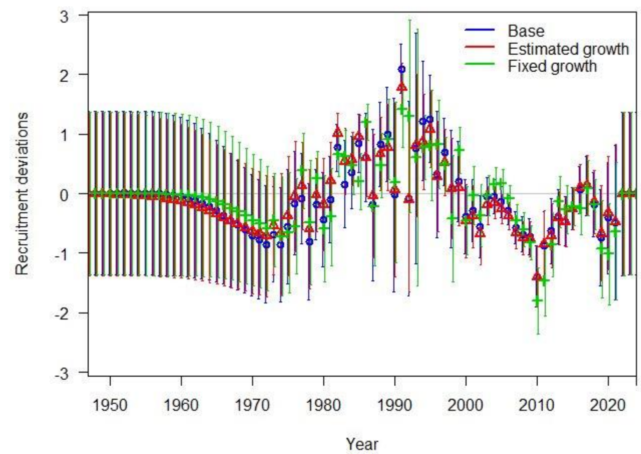

Base
Estimate h
Estimate h, no prior
Fecundity proportional to SSB
Estimate M
Recruitment deviations
Year

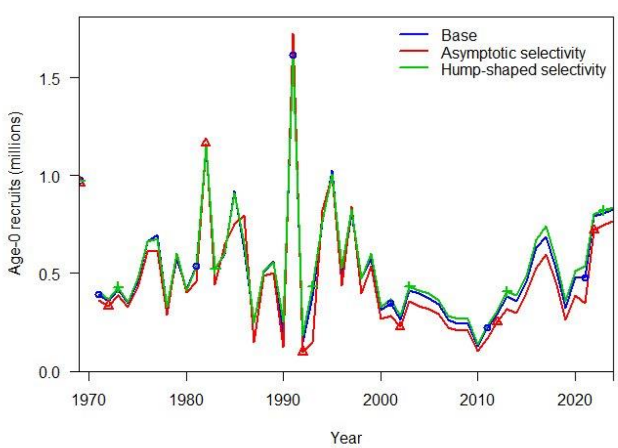

Base
Estimate h
Estimate h, no prior
Fecundity proportional to SSB
Estimate M
Recruitment deviations
Year

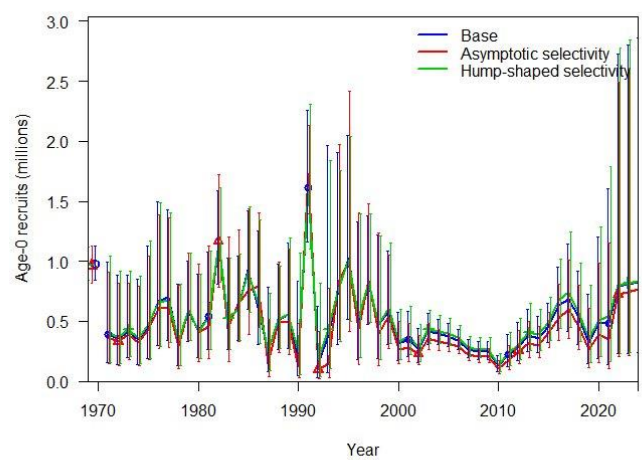

Base
Estimated growth
Fixed growth
Age-0 recruits (millions)
Year

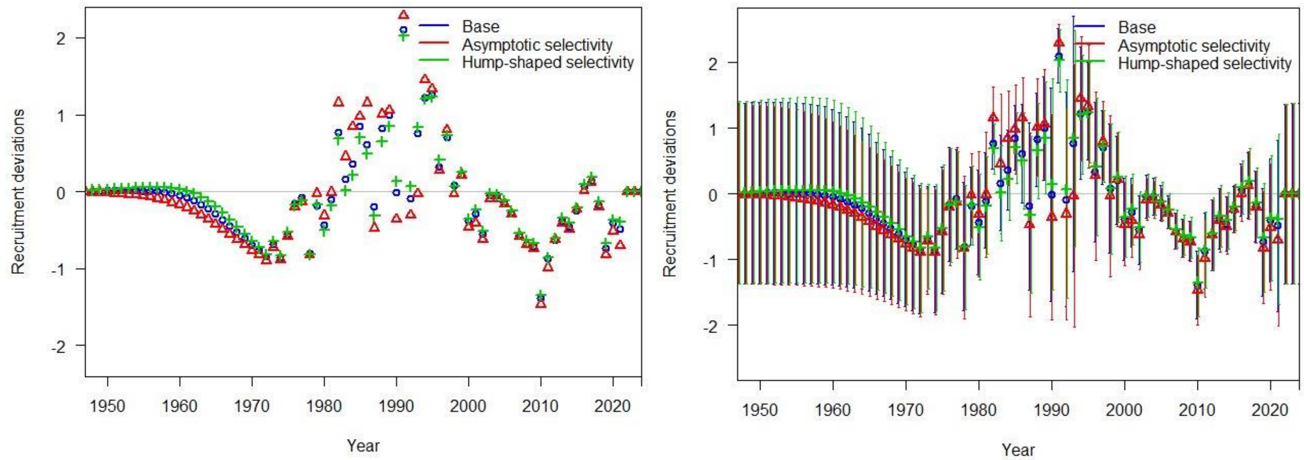

Base
Estimated growth
Fixed growth
Age-0 recruits (millions)
Year


Base
Estimated growth
Fixed growth
Recruitment deviations
Year


Base
Estimated growth
Fixed growth
Recruitment deviations
Year


Base
Asymptotic selectivity
Hump-shaped selectivity
Age-0 recruits (millions)
Year


Base
Asymptotic selectivity
Hump-shaped selectivity
Age-0 recruits (millions)
Year



The high recruitment estimate remains consistent with the removal of each index. Removal of the CalCOFI index brings down the 1991 only slightly and also shifts a secondary peak by one year. This may be the result of that index using a 3-year superyear. Removal of the CPFV index produces higher peaks before 1990 and reduces a large peak in the mid 1990s but trends are largely similar. Removal of the CalCOFI index increases uncertainty in several years. Inclusion of historical data on landings back to 1880 slightly dampens the 1991 recruitment estimate. Allowing steepness to be estimated (which goes to a higher value) and fixing growth dampens the 1991 recruitment.

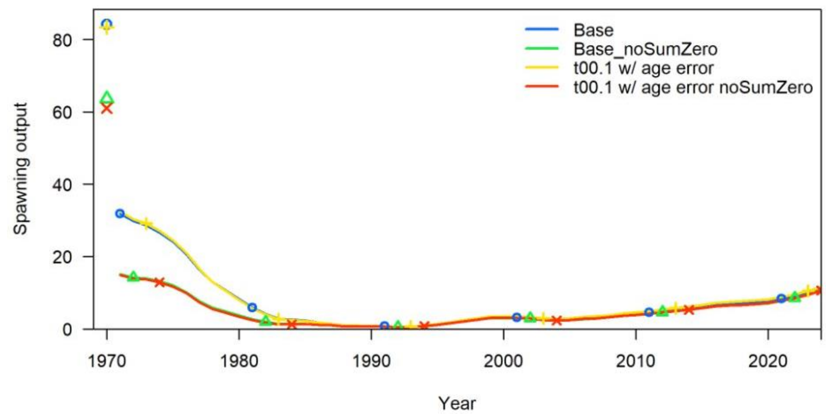
10. M4.Request: Remove the constraint that the main period for recruitment sums to zero. Report the sum of the unconstrained recruitment deviations.

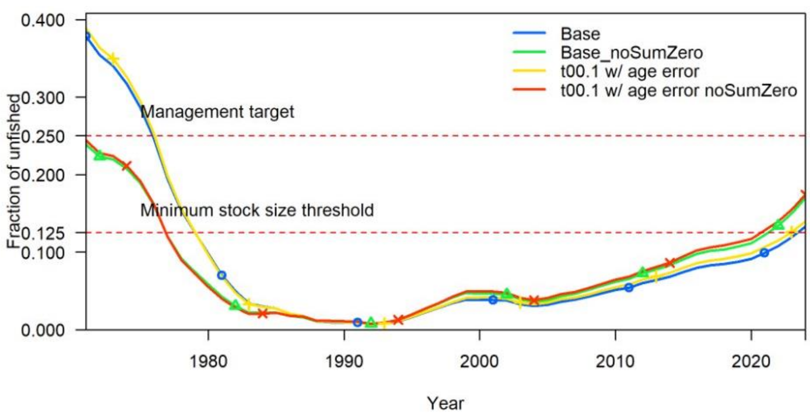
a. Rationale: Explore the patterns in recruitment and the unexpectedly large uncertainty to ensure that the sum to zero constraint is not impacting the estimated annual deviations.

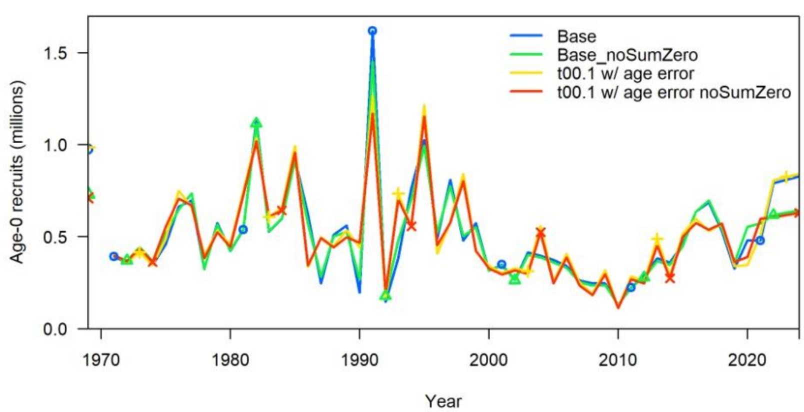
b. STAT Response: We compared four model runs including the base model, base not summing to 0, setting t0=0.1 with deviates summing to zero, and t0=0.1 with deviates not summing to 0. The table below provides the sum of deviates and R0 for each of these scenarios. The ratio of R0 between summing and not summing to 0 for comparable models are both approximately 1.3. The exponentiated value of the sum of deviates when not forcing to zero for both models is also approximately 1.3. This indicates that recruitment deviates shifted up and R0 shifted down almost equally.

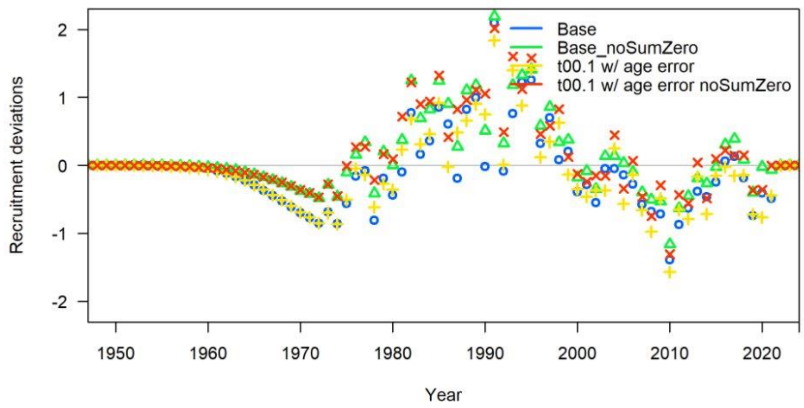
Run	Mean (main recr devs)	R0
Base	0	975
Base not sum to zero	0.29	729
t0.1 ageing error	0	984
t0.1 ageing error not sum to zero	0.30	710

The plots below compare these four scenarios impacts on spawning output, relative spawning output and recruitment.









Estimated recruitment deviations are far from zero-centered when not forced to be but actual recruitment estimates are almost the same, as is biomass since about 1990. When the main recruitment deviates do not sum to zero, R_0 no longer represents average recruitment and reference points lose meaning. Therefore, we recommend summing to zero.

Follow up request during the break: show metrics of how these changes in request 6 affects goodness of fit (negLL), look at likelihood components to see what is driving changes; Pre-review base; Ageing error + t0

a. Rationale: It is useful to compare total likelihoods and likelihood components when deciding which model to move forward with.

b. STAT Response: The table below provides total likelihood and likelihood components of the four main model revisions presented on day 1. The lowest total likelihood is seen for the model correcting the ageing error method while maintaining the growth parameterization from the base model due to a lower likelihood in length compositions.

	Total	Recr	Surv	Length	Age
Base (no ageing error)	1422.21	9.88	-90.26	995.55	506.99
Base (with ageing error)	1413.98	10.76	-90.66	983.36	510.47
t0 (uses age error)	1425.22	11.17	-90.93	992.68	512.25
Male2Fem (uses age error), (t0 =0.1)	1424.61	11.29	-91.03	988.40	515.88

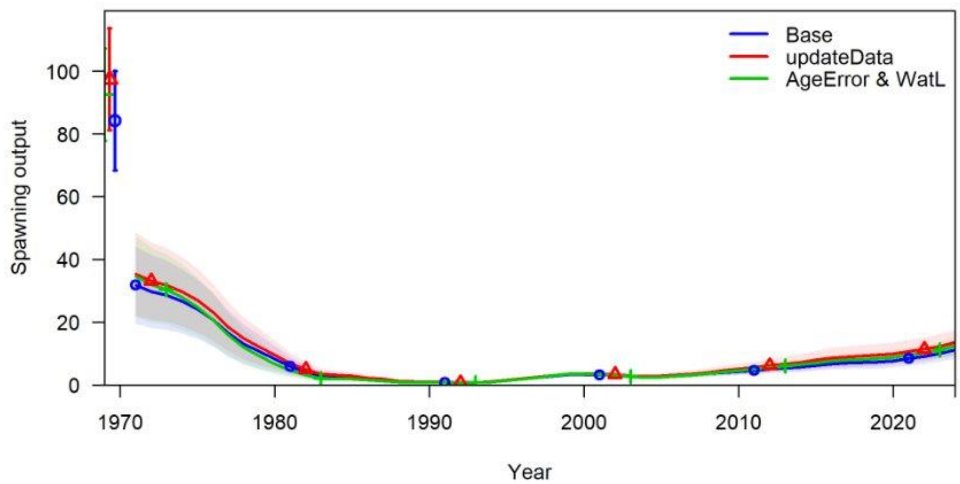
Day 2

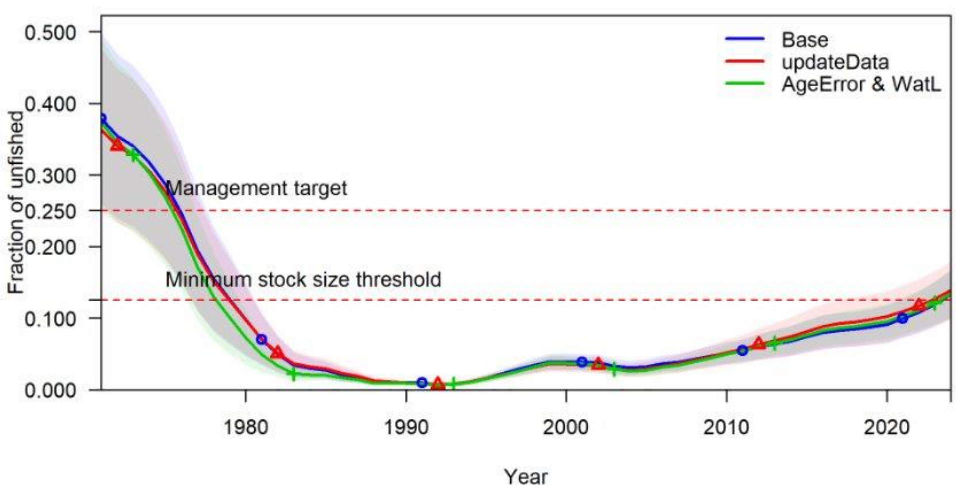
Base all runs off of the pre-review base model with the following adjustments:

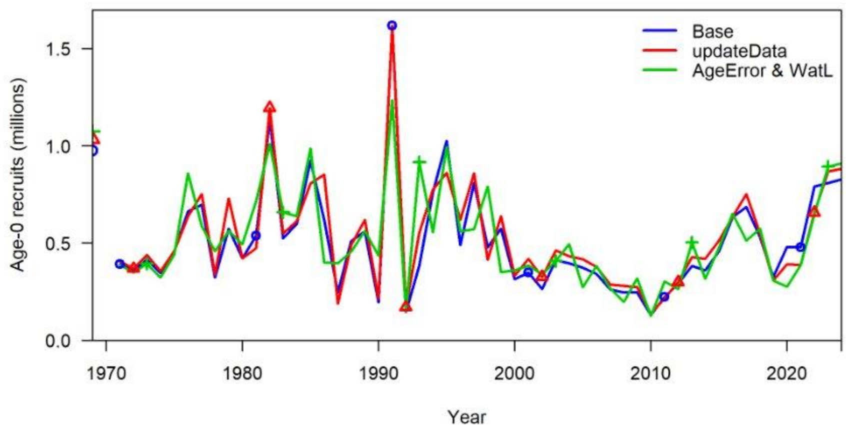
- Fixed ageing error (request 1)
- Updated length-weight relationship (request 5)
- Data problems the STAT has identified are fixed
- Retune composition data weights if needed.

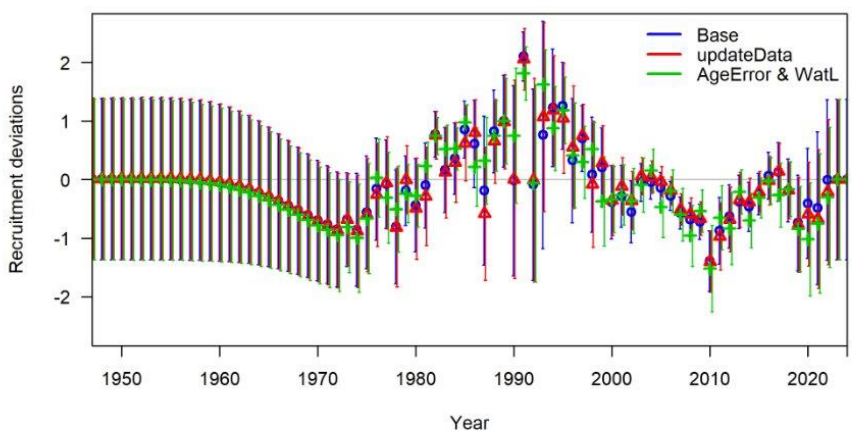
- Please add r4ss plots and model files to the google drive folder.
- Please report changes in likelihood for comparable data groups as appropriate along with model comparison figures (spawning output, spawning depletion, recruitment, recruitment deviations), in addition to any other outputs the STAT finds interesting.

The bulleted requests above were met and day 2 began with a presentation of bridging from the original base model to models meeting these requests. Likelihoods are not comparable among these models.







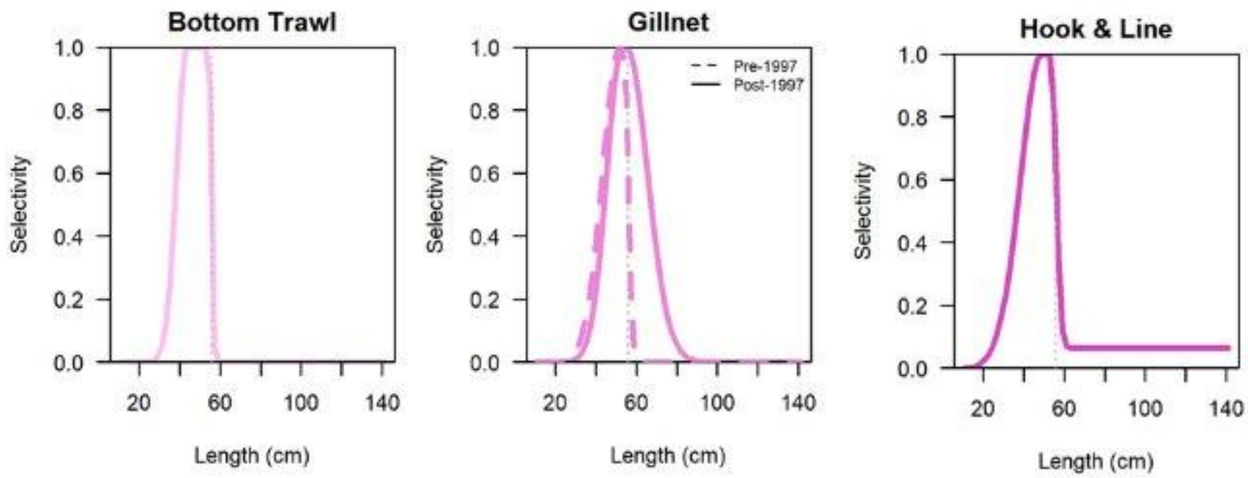


11. **Request:** Separate out removals during initial model conditions into retention and discards for all fleets.

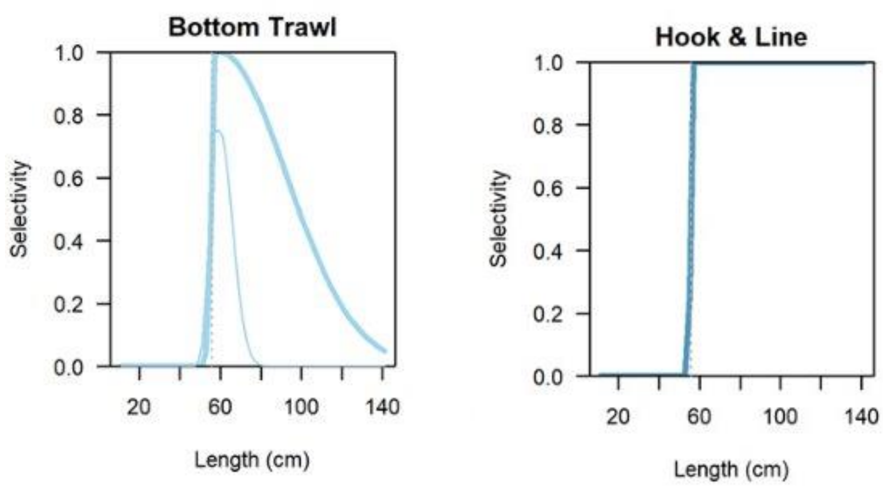
a. Rationale: The commercial hook-and-line, CPFV, and each of the discard fleets do not have an assumed equilibrium catch in the base model. For consistency, assume a reasonable level of equilibrium catch for each fleet in the model. This will also ensure that the appropriate removals by size from either retained or discarded fish are removed appropriately from the initial population structure.

b. STAT Response: For our first attempt to meet this request, we attributed initial equilibrium catch to all ten fleets. Recreational CPFV average catch from logbooks during the ten years prior to the start of the model (1951 to 1970) was attributed to the CPFV fleet. Reed and MacCall (1988) reported that CPFV catch represented approximately 40% of total recreational catch in the 1960s. We used this to calculate an equilibrium catch amount for the OtherRec fleet based on the CPFV fleet. Recreational discard fleets were provided with no catch since the minimum size and bag limits were not established until 1971. We used the commercial catch (not differentiated by gear type) reported on Fishery Bulletins and used for our historical time series extending back to 1880 to determine commercial initial equilibrium catches. The average for the period between 1951 and 1970 was 136.7 MT. We attributed this to the three commercial fleets based on their relative proportion in the catch during the first five years of the modeling period (1951-1975). Commercial discard fleets were attributed catch by multiplying the retention fleet catch by a discard ratio and discard mortality rates appropriate for each fleet. Using this procedure, all discard fleets and the commercial hook and line retention fleet estimates of initial fishing mortality it the lower parameter bound of zero.

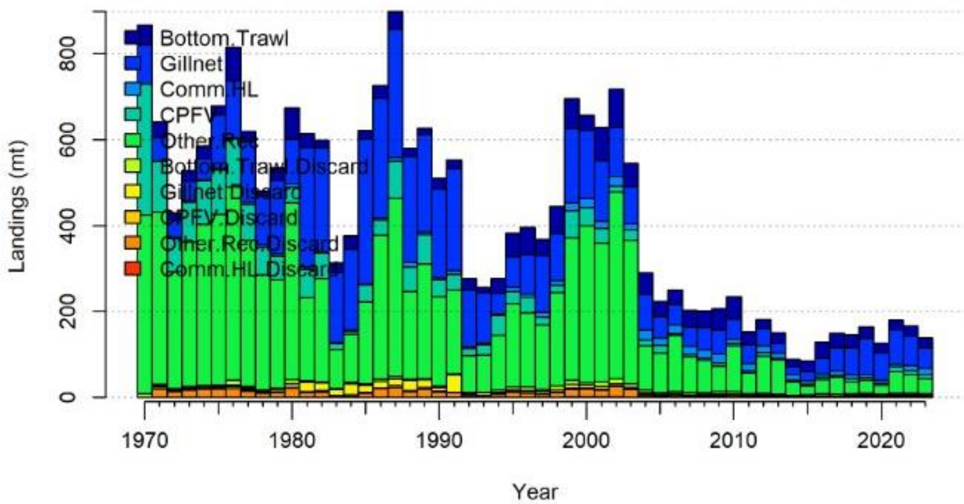
In order to prevent parameter estimates from hitting their bounds, we combined all commercial discard catches and attributed them to the trawl discard fleet. We felt this was appropriate given that the trawl and commercial hook and line discard selectivity patterns are very similar with nearly knife edge right hand limbs at the minimum size limit. The early block of the gillnet discard fleet selectivity also shows this pattern. Below we show the trawl, gillnet, and commercial hook and line discard fleet selectivities to illustrate these patterns. OtherRec is shown because the commercial hook and line fleet is mirrored to OtherRec.



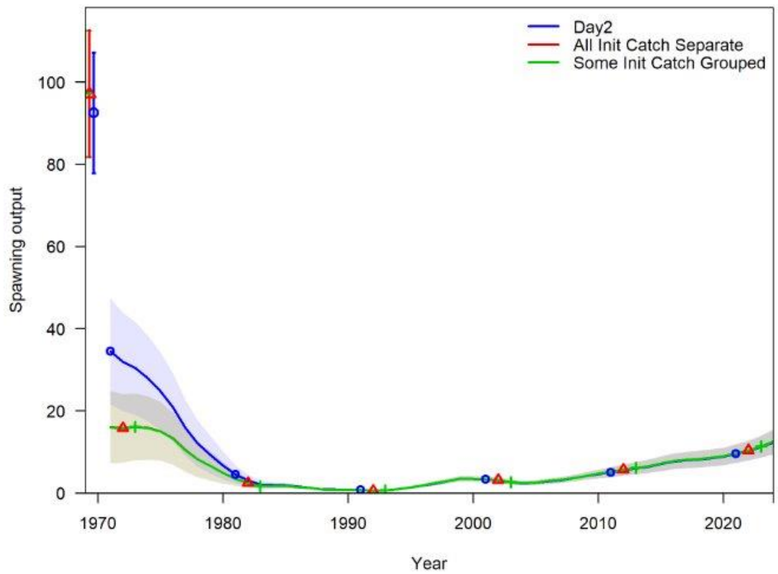
We also combined the commercial hook and line retention fleet initial catch with the trawl retention fleet since the hook and line catch was very small. Those fleet's selectivities are shown below to illustrate that they both show nearly knife edge retention at the size limit.



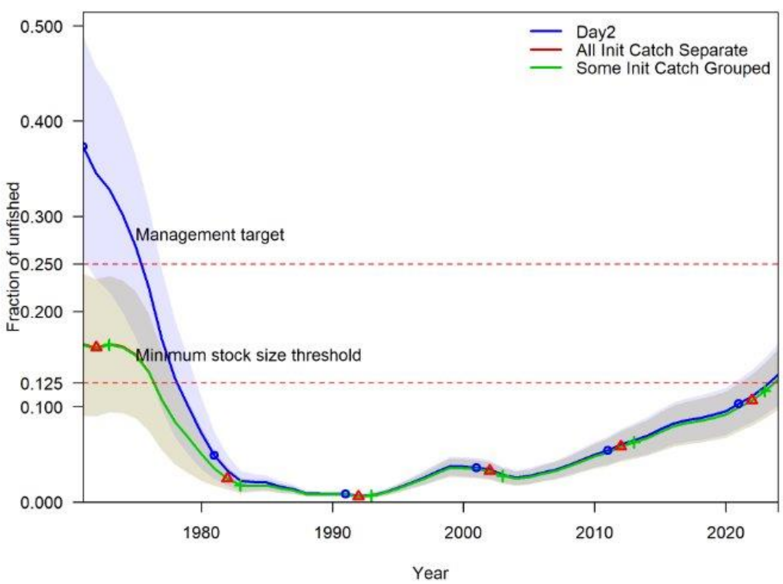
Following this modification, the combined discard fleet estimate of initial F continues to hit the lower bound, but we recommend continuing with this structure. Revised initial catches are shown below in the first bar of the catch time series. We also show comparisons of spawning output, relative spawning output, recruitment, and likelihoods. The change in initial conditions impacts the initial spawning biomass but has little impact on relative spawning biomass in recent years or on recruitment. Total likelihood is slightly reduced but the final model (Some Init Catch Grouped) was tuned and therefore is not comparable.



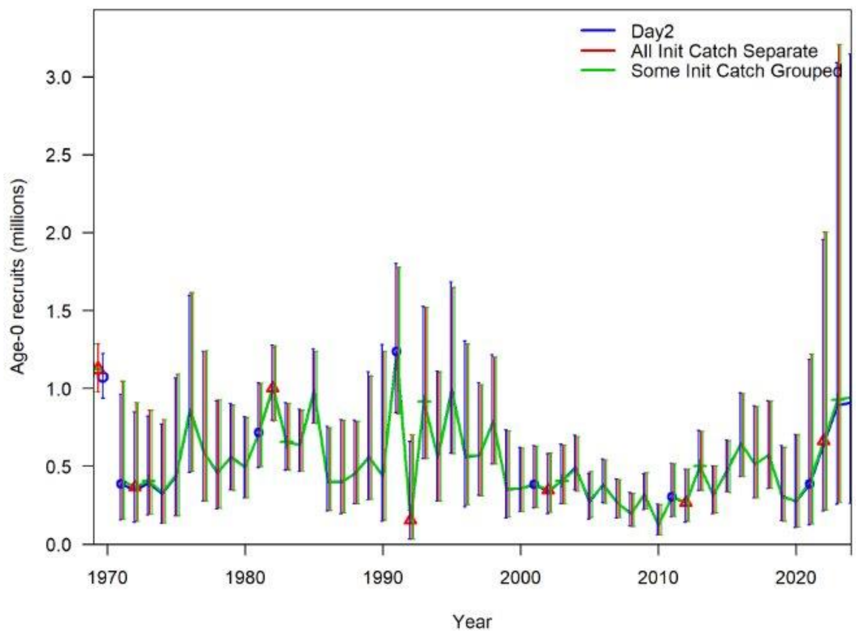
Label	Day 2	All Init Catch Separate	Some Init Catch Grouped
TOTAL_like	1706.32	1705.07	1702.53
Survey_like	-88.26	-88.28	-88.32
Length_comp_like	1233.24	1232.17	1229.61
Age_comp_like	547.75	547.96	548.04
Recruitment_like	13.45	13.07	13.05
Forecast_Recruitment_like	0.09	0.1	0.1

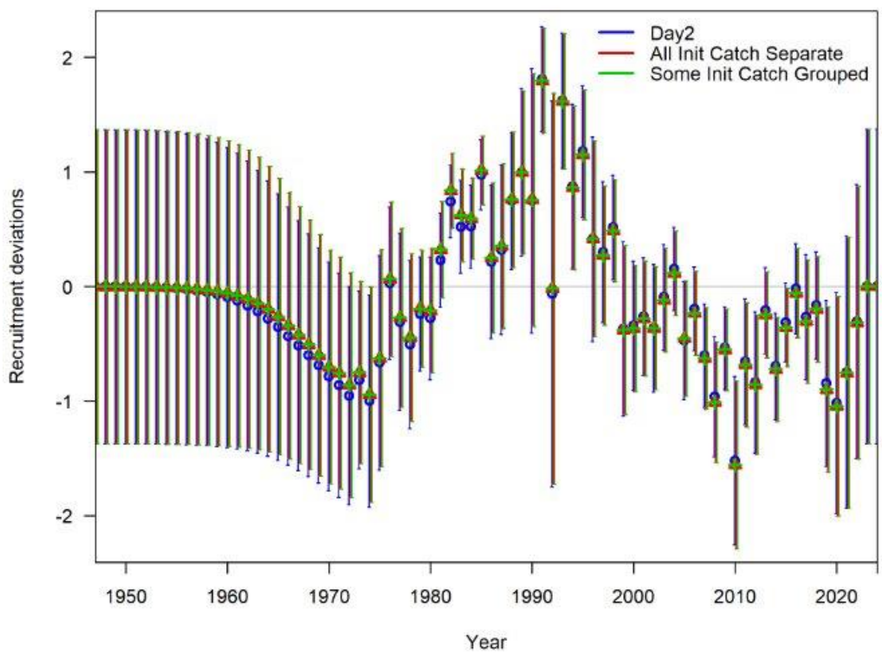


Day2
All Init Catch Separate
Some Init Catch Grouped
Spawning output
Year



Day2
All Init Catch Separate
Some Init Catch Grouped
Fraction of unfished
Management target
Minimum stock size threshold
Year

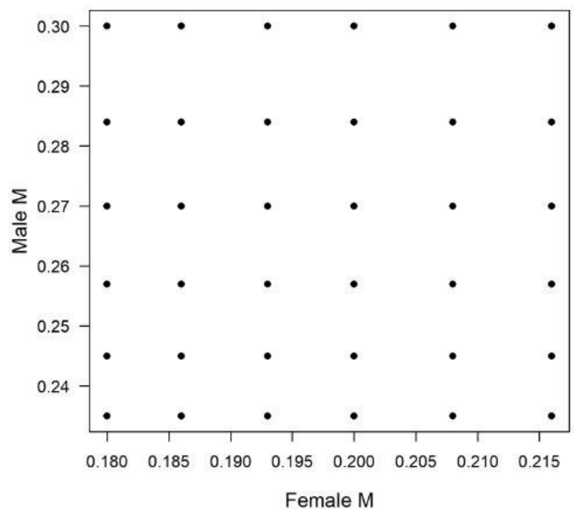


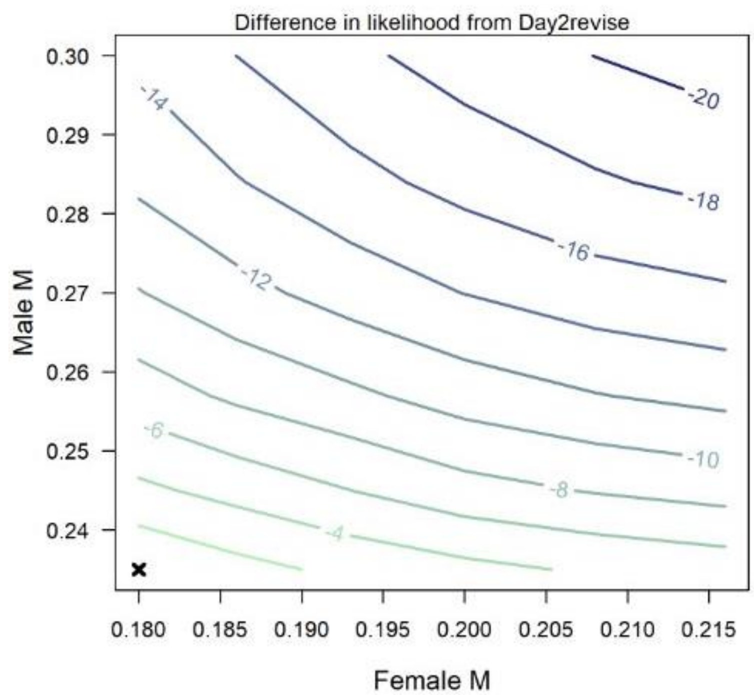


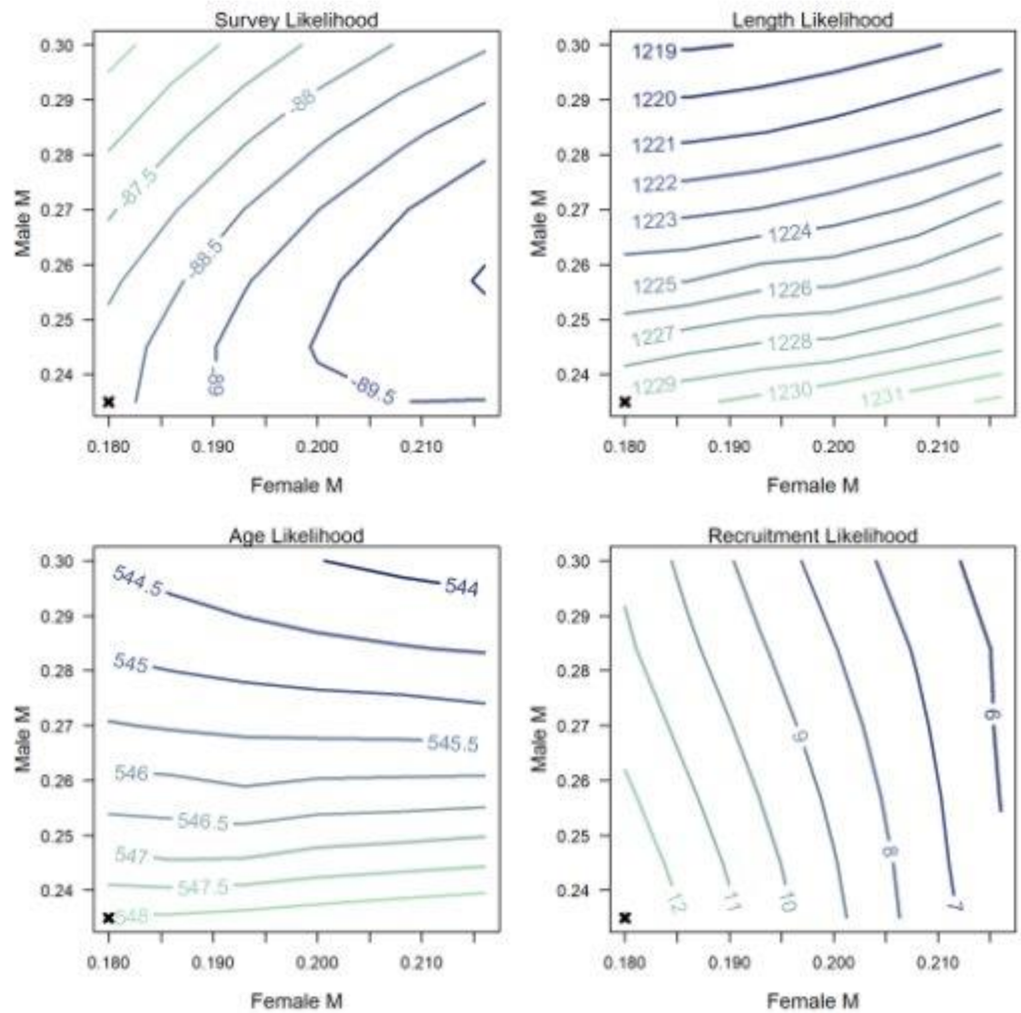
12. Request: Use the STAT's preferred model from previous requests to run a profile over natural mortality. Change the fixed value for both females and males together using a maximum age ranging between 25-30 yr (M = 0.216, 0.208, 0.20, 0.193, 0.186, 0.18) for females and 18-23 yr (M = 0.30, 0.284, 0.270, 0.257, 0.245, 0.235) for males and the Hamel and Cope (2022) prior.

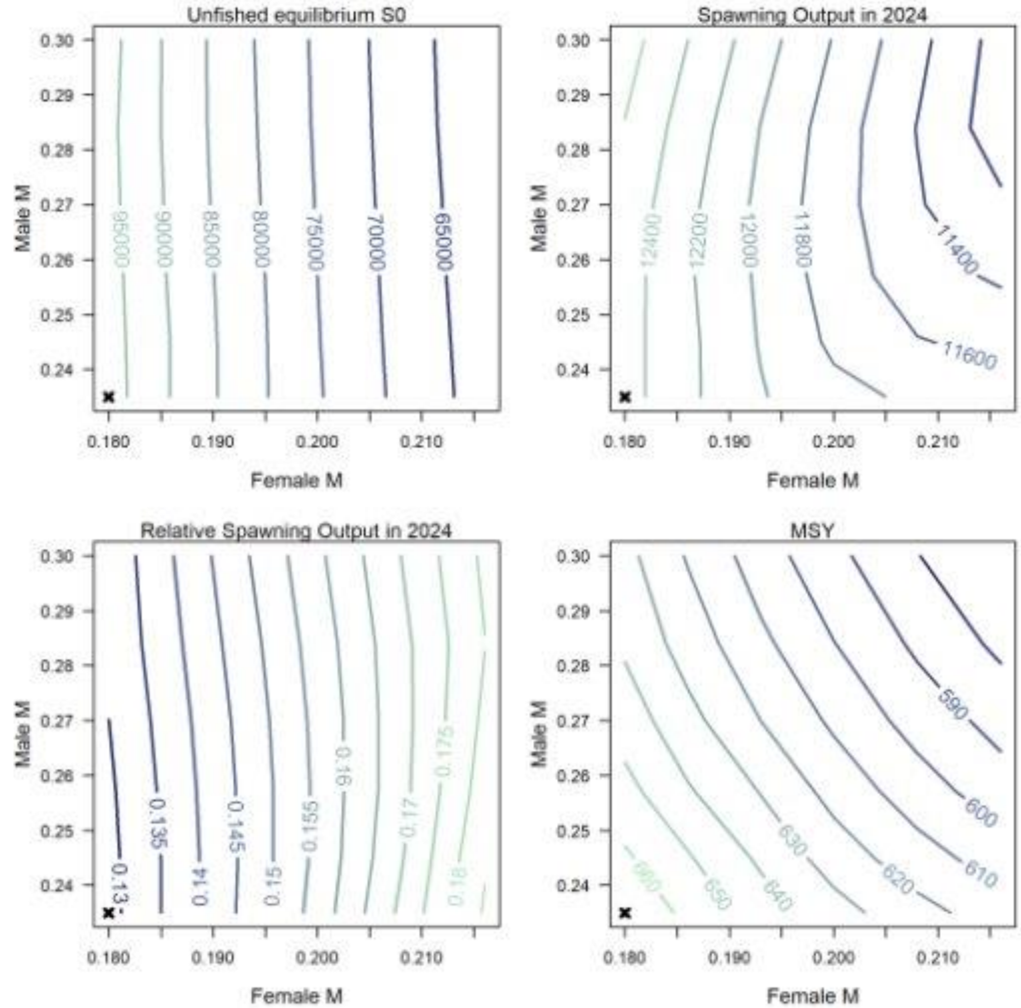
a. Rationale: Recent CDFW ages show maxima of 15 yr for males and 21 yr for females off southern California. A longevity of 30 yr came from a fish with unknown location or time (Pattison and McAllister 1990). There are also assumptions from using a maximum age based on a heavily depleted population without extensive age collections, which would better estimate tails of a distribution.

b. STAT Response: We created a grid of female and male natural mortality values and ran Stock Synthesis to determine likelihoods at these fixed values.






Survey Likelihood
Length Likelihood
Age Likelihood
Recruitment Likelihood
Male M
Female M
-87.5
-88
-88.5
-89
-89.5
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
544
544.5
545
545.5
546
546.5
547
547.5
548
6
7
8
9
10
11
12
0.180
0.190
0.200
0.210
0.24
0.25
0.26
0.27
0.28
0.29
0.30



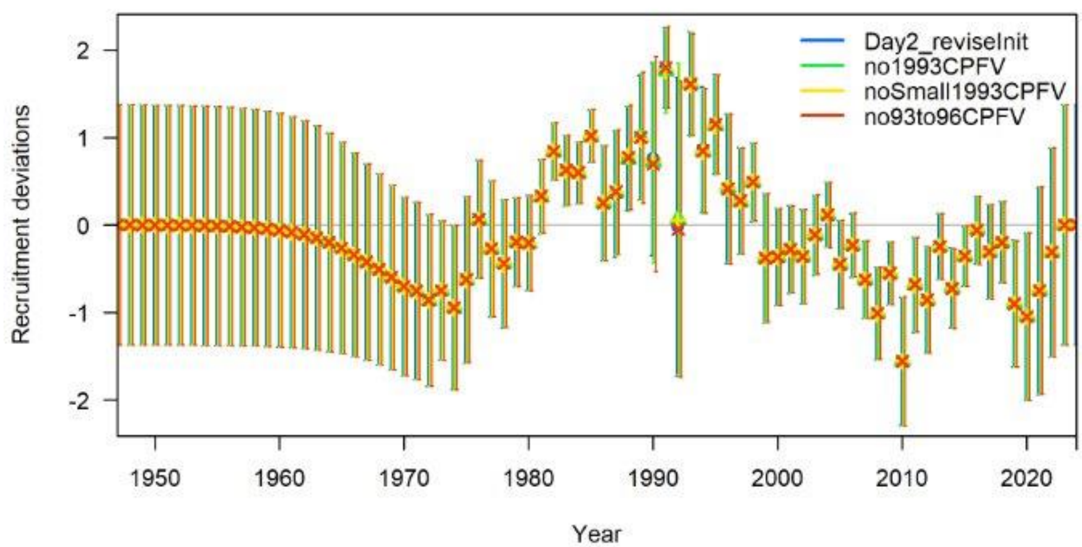
We tested natural mortality values that ranged higher than those in our base model (not symmetrical around the base values). Base values were based on a maximum observed age reported in the literature that is older than any fish that have been observed by our research. Additionally, when M is allowed to be estimated, it estimates high. Likelihood changes are steeper with changes in male M values, probably as the model is seeking to explain the lack of males in the observed composition data. Spawning output variation is almost completely dependent on female M and yield is similarly affected by both parameters.

There are three reasons why we are not observing fish that are as old as the maximum age reported. Those are 1) that M is higher than our base model values and CA halibut do not get as old as the maximum reported age, 2) fishing mortality is high and fish are unable to achieve old ages due to fishing pressure, and 3) the selectivity is dome-shaped and old fish are invulnerable to the fleets. We are unable to distinguish among these reasons but suggest that this stock has a long history of exploitation that likely has compressed the age composition.

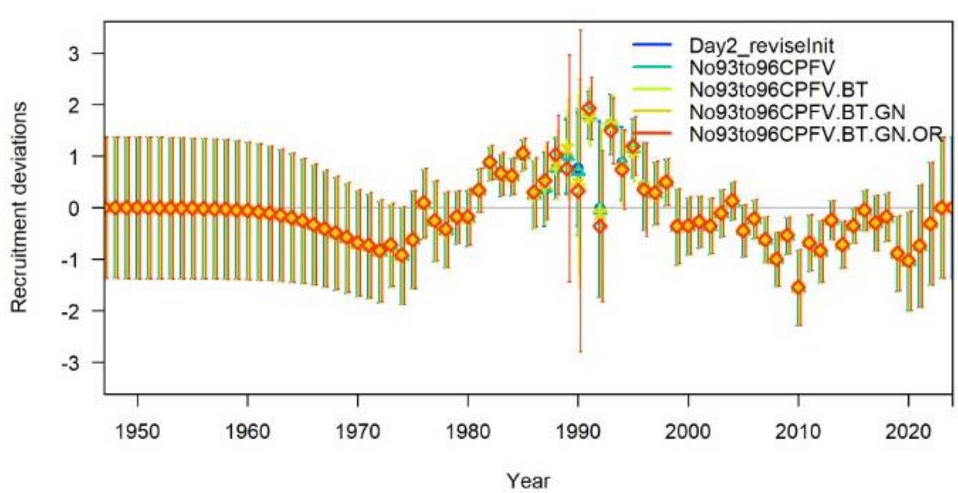
13. Request: Follow up to Request 9: Remove the length composition of retained fish from the CPFV fleet in 1993 to see if that reduces the estimated peak in recruitment in 1991. If dropping these data does not change the estimated 1991 recruitment deviation, please look across other years and fleets to identify the data source this signal is coming from.

a. Rationale: The recruitment deviation being estimated in 1991 is the highest of the time series. The STAT showed the estimated recruitment deviations across various sensitivities in Day 1 Request 9 and the deviation in this year appeared consistent across the initial sensitivities indicating the composition data may be informing this estimate. The length composition data in 1993 from the CPFV fleet appeared to have some small fish observed in the retained fish and combined with the limited selectivity for small fish, these data could be informing the estimated recruitment deviation in 1991.

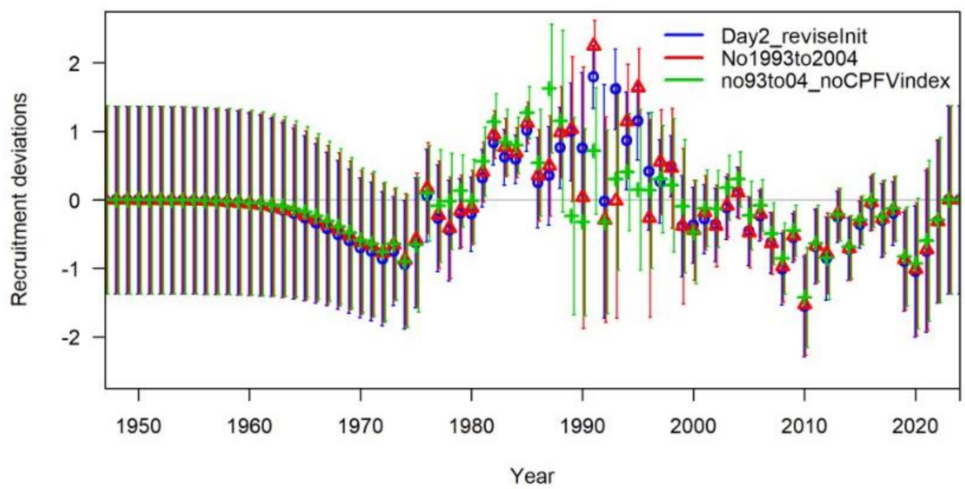
b. STAT Response: In an effort to identify data influencing the peak in estimated recruitment in 1991 we took three approaches focusing on the CPFV fleet. First, we removed all of the lengths 1993. Second, we removed only fish less than 43 cm in 1993. Third, we removed all lengths from 1993, 1994, and 1996.



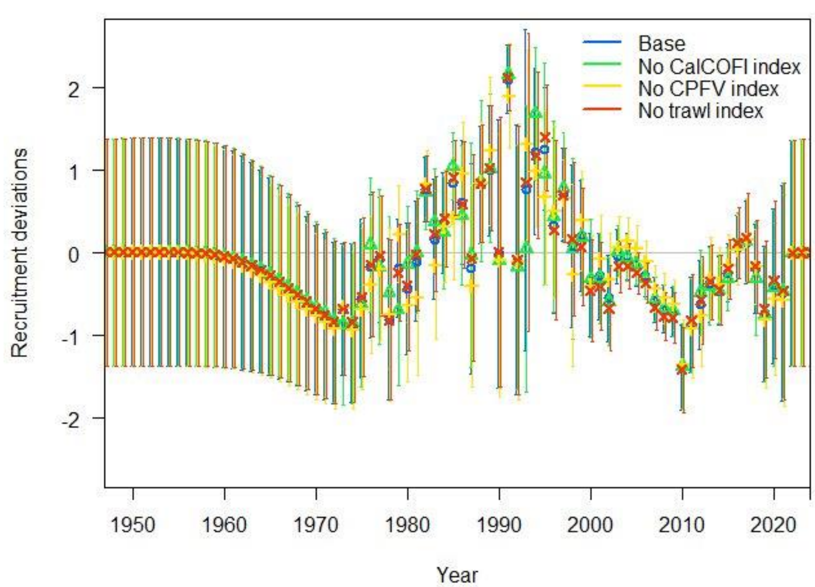
These changes had little impact on recruitment deviations. We then removed all length data from 1993-1996 for all fleets sequentially.



Finally, we removed all lengths from all fleets between 1993 and 2004, as well as combining that removal with the removal of the CPFV index.



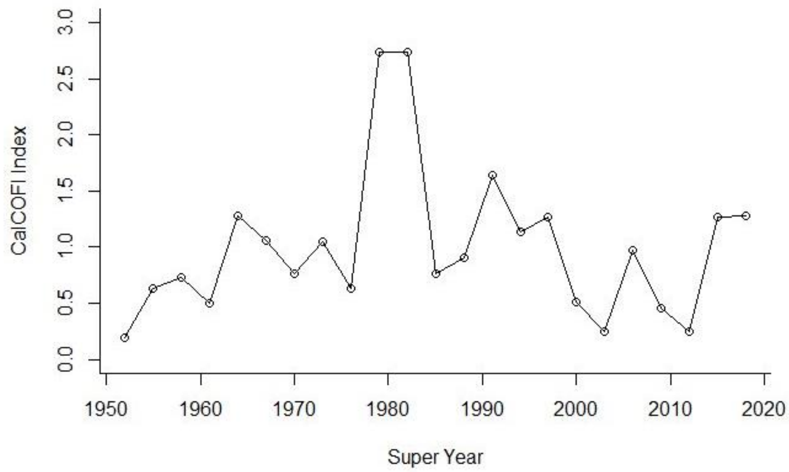
Removing lengths from fleets sequentially did not reduce the 1991 recruitment and removing and even increased it in the case of data from all fleets being removed. Removal of the CPFV index while retaining all length data also did not reduce the 1991 recruitment estimate. The 1991 recruitment was only reduced when data from all fleets between 1993 and 2004 was removed as well as the CPFV index. We find that multiple data sources are influencing the 1991 recruitment estimate. The CPFV index is a major influence on the recruitment estimate in that year, as well as the uncertainty around adjacent years. It is likely that the model is forced to estimate high recruitment in that period in order to support a concurrent increase in the CPFV index. While this might otherwise be a cause for concern, multiple sources of data support the hypothesis that recruitment was high in that period.



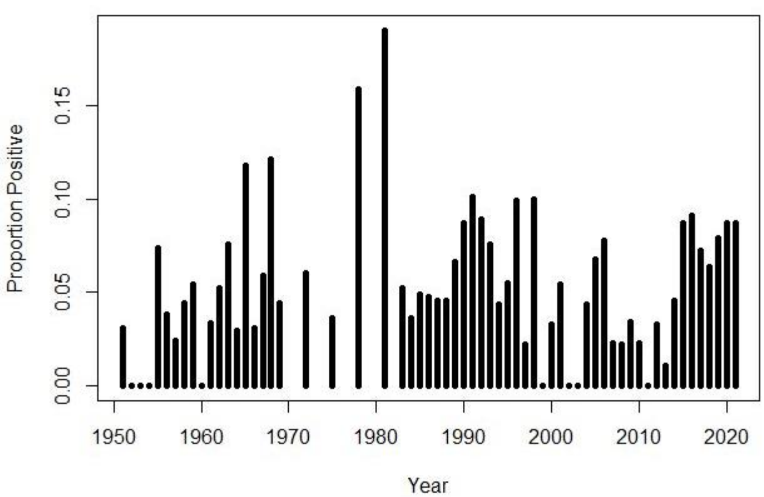
14. Request: Report the percent positive tows from the CalCOFI survey by year.

a. Rationale: The CalCOFI survey is binned into three-year increments (i.e., "super" years). These calculations will help identify whether there was a large recruitment event in the early 1990s or the model is "making fish". It would be useful to see if there was a particular year with an abnormally high number of positive tows.

STAT Response: CalCOFI indicates potential high recruitment in the 1990s. Ranked by the proportion of plankton tows that collected CA halibut, 1991 saw the fifth highest proportion since 1951. Other years in the 1990s also had a high proportion of positive tows. Interestingly, the proportion of positive tows has also been relatively high in recent years, but the samples sizes have been lwo.



Year	Tows	Positive Tows	Proportion Positive
1981	63	12	0.19
1978	63	10	0.159
1968	33	4	0.121
1965	68	8	0.118
1991	89	9	0.101



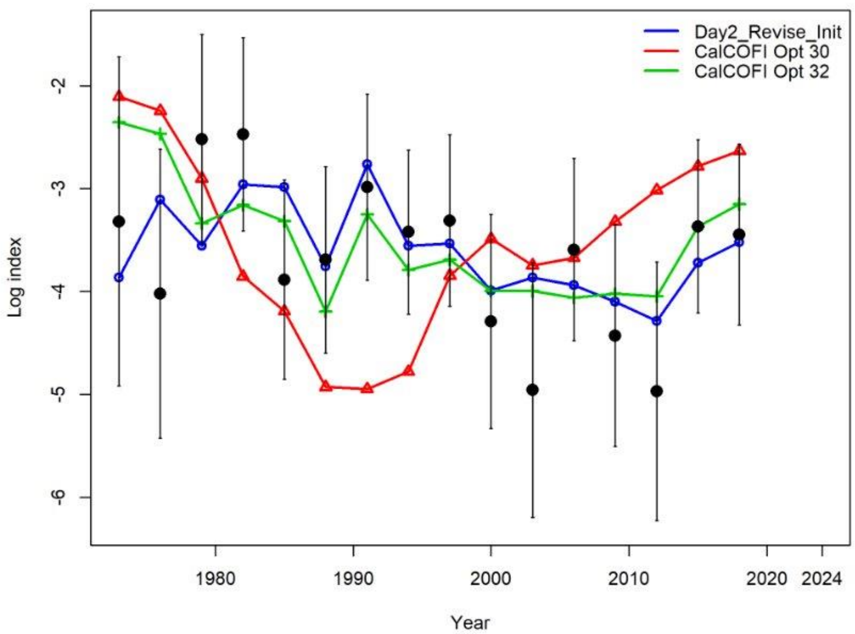
1998	90	9	0.1
1996	91	9	0.099
2016	66	6	0.091
1992	90	8	0.089
1990	69	6	0.087
2015	92	8	0.087
2020	23	2	0.087
2021	23	2	0.087
2019	38	3	0.079

15. Request: Run two sensitivities with the CalCOFI index: 1) input as a spawning biomass index (option 30) and 2) input as spawning biomass*exp(recruitment dev) (option 32) rather than a recruitment index.

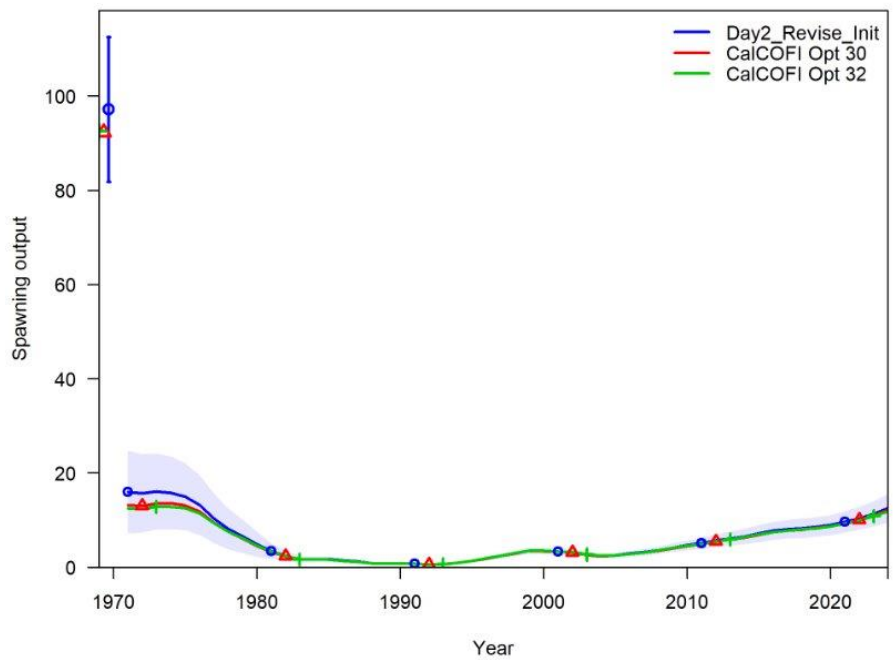
a. Rationale: Other assessments have input the CalCOFI index as a spawning output survey. If the observations occur following stochastic processes that are related to recruitment but prior to density-dependence, then option 32 may be appropriate. These runs will be useful to understand impacts on model estimates based on how the source data are input to the model.

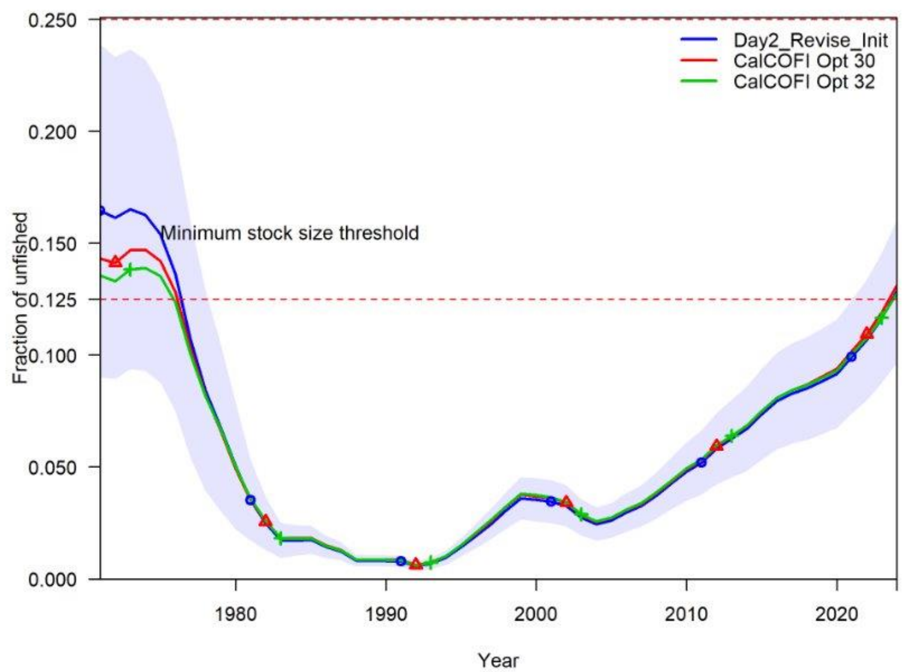
b. STAT Response: Each option produces a different trend in the CalCOFI index. Option 30, which designates an index of spawning biomass, is most different from the other options which use CalCOFI as an index of recruitment. The lowest total likelihood is observed using the base model assumption of a recruitment index. Larvae may help to indicate future recruitment or past spawner abundance given that they occupy an intermediate position in ontogenetic processes between egg and adult. It is commonly thought that larvae are better indicators of past spawner abundance but this may not be the case for CA halibut.

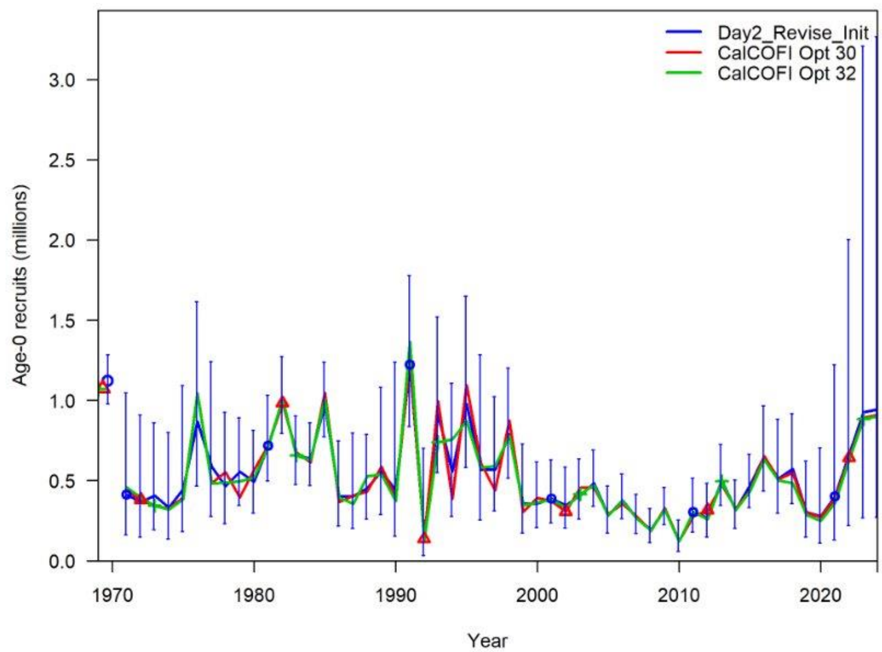
Label	Day2 Revise Init	CalCOFI Opt 30	CalCOFI Opt 32
TOTAL_like	1702.53	1713.49	1704.94
Survey_like	-88.32	-76.65	-86.97
Length_comp_like	1229.61	1229.2	1230.42
Age_comp_like	548.04	548.36	548.38
Recruitment_like	13.05	12.43	12.93
Forecast_Recruitment_like	0.1	0.1	0.11

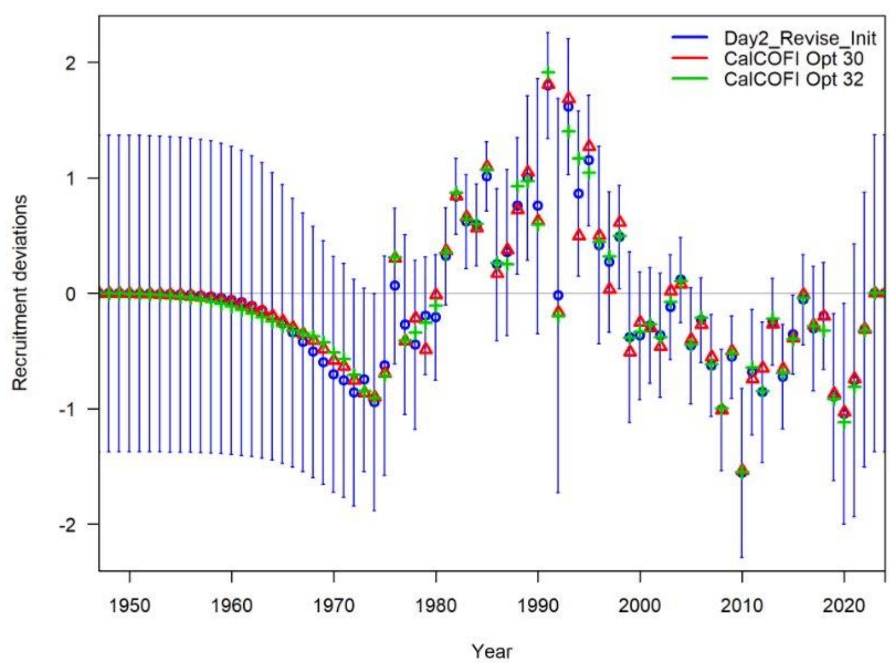


Day2_Revise_Init
CalCOFI Opt 30
CalCOFI Opt 32
Log index
Year
-2
-3
-4
-5
-6
1980
1990
2000
2010
2020
2024


Day2_Revise_Init
CalCOFI Opt 30
CalCOFI Opt 32
Spawning output
Year
0
20
40
60
80
100
1970
1980
1990
2000
2010
2020


Day2_Revise_Init
CalCOFI Opt 30
CalCOFI Opt 32
Minimum stock size threshold
Fraction of unfished
Year
0.000
0.050
0.100
0.125
0.150
0.200
0.250
1980
1990
2000
2010
2020

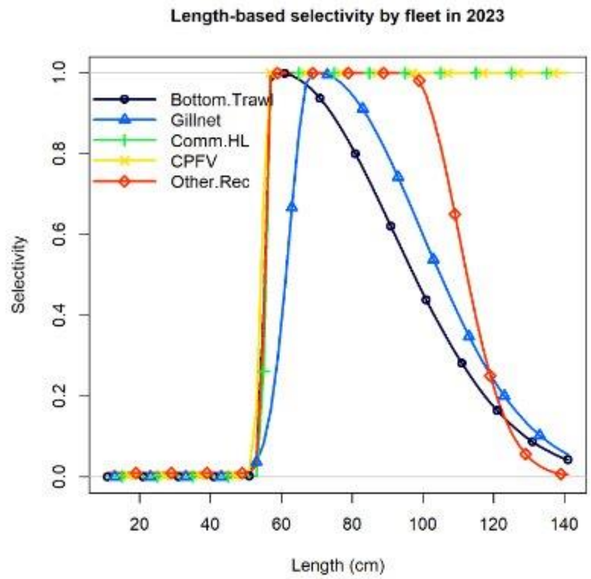


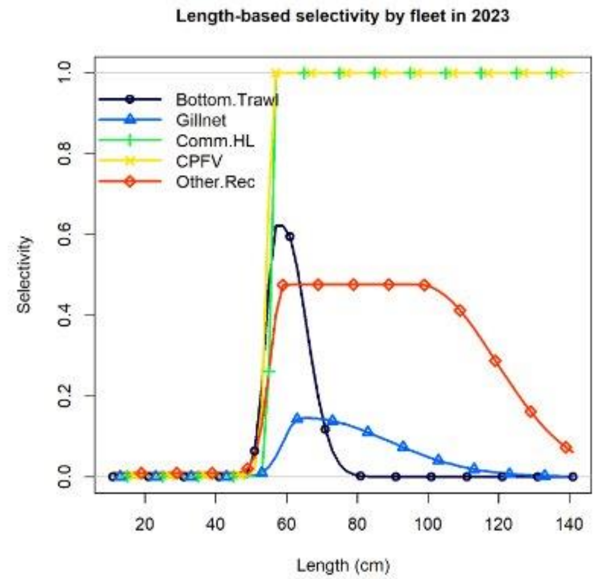


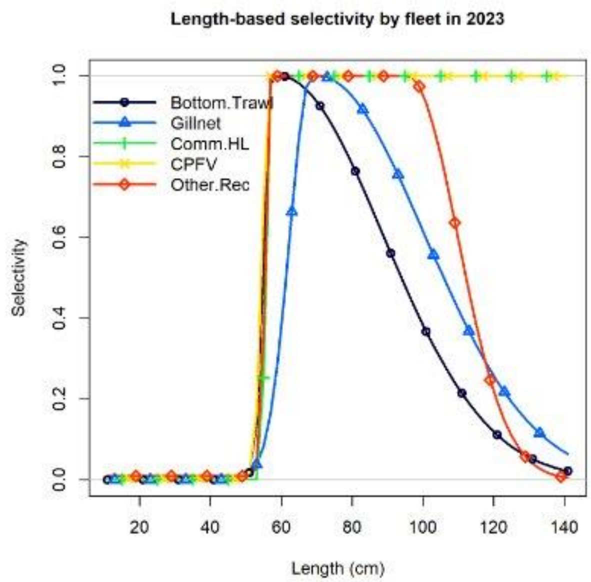
16. Request: Enter length composition data as unsexed or females/males (type 3) combined. Any samples that contained only females would indicate zero males.

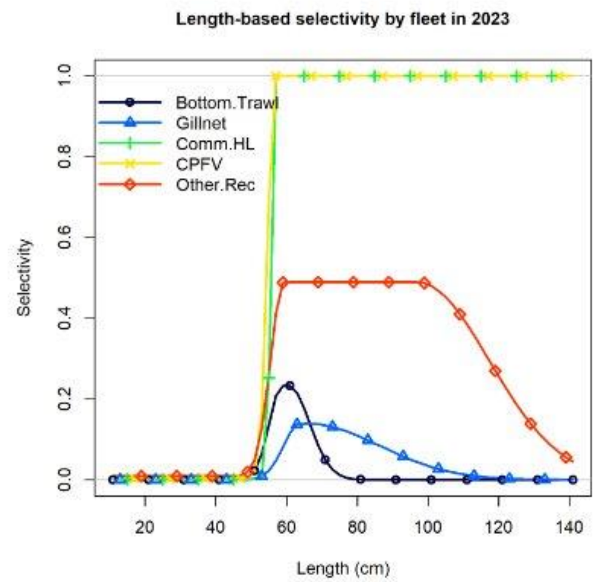
a. Rationale: The samplers would record a male if present, zero males is a valid observation.

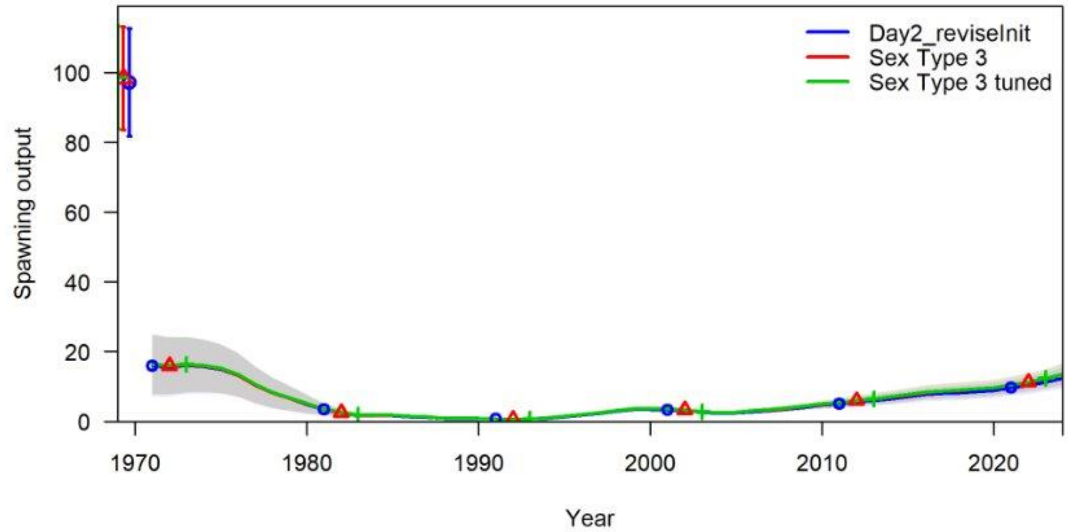
b. STAT Response: All composition data input with sex=1 was changed to sex=3 with no male observations. No sex=2 data were present. Sex-specific selectivity curves for gillnet and OtherRec showed only slight differences but selectivity of males in trawl gear was substantially reduced. The model had some difficulty with convergence so length compositions were tuned, making likelihoods not comparable. Relative spawning output in the final year was slightly higher with this sex type conversion.

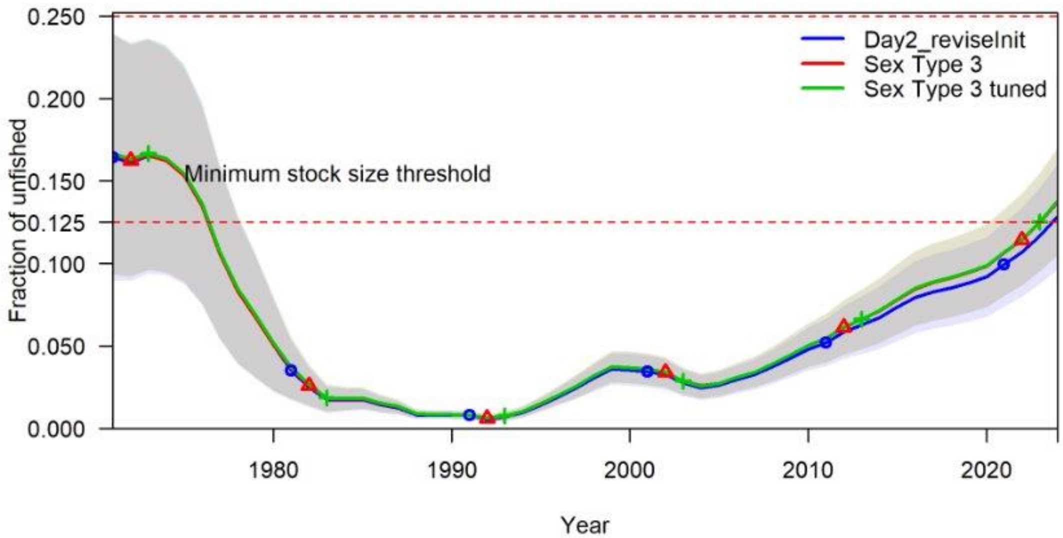










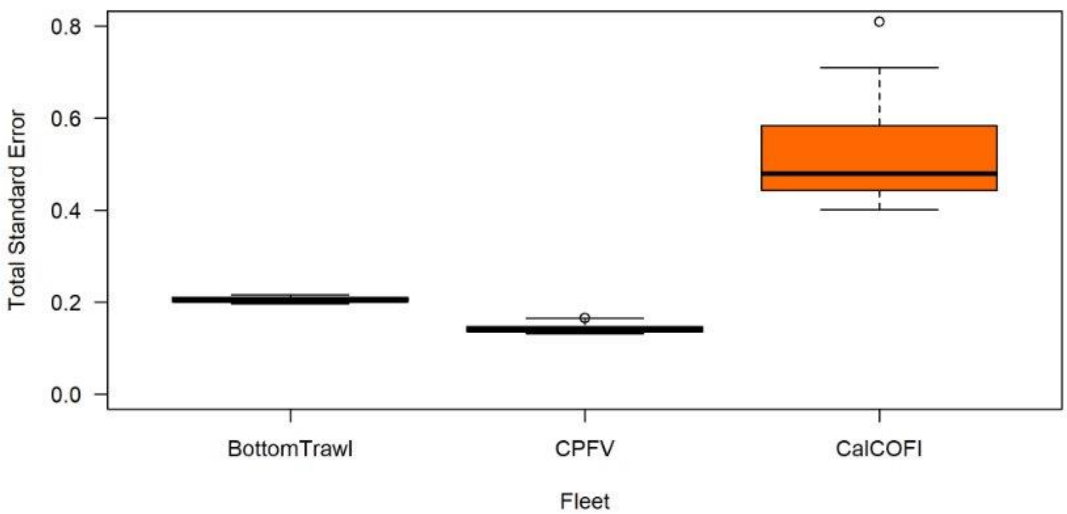


Label	Day2 revised	Sex=3
TOTAL_like	1702.53	1789.86
Survey_like	-88.32	-88.68
Length_comp_like	1229.61	1314.64
Age_comp_like	548.04	552.14
Recruitment_like	13.05	11.61
Forecast_Recruitment_like	0.1	0.1

17. Request: Present a metric that helps understand the weighting and relative importance of indices. For example, this could be an average of the standard deviations of the fleet-specific indices after adding the estimated extra standard deviation.

a. Rationale:

b.	STAT Response: We calculated the average standard error among years in the time series for each index. These standard errors were the combination of the original index error and additional error calculated by Stock Synthesis to improve index fit. The box plot below shows that the CalCOFI index has the highest error and highest variability in error from year to year. It is a shorter time series and has the least amount of weight in the model.



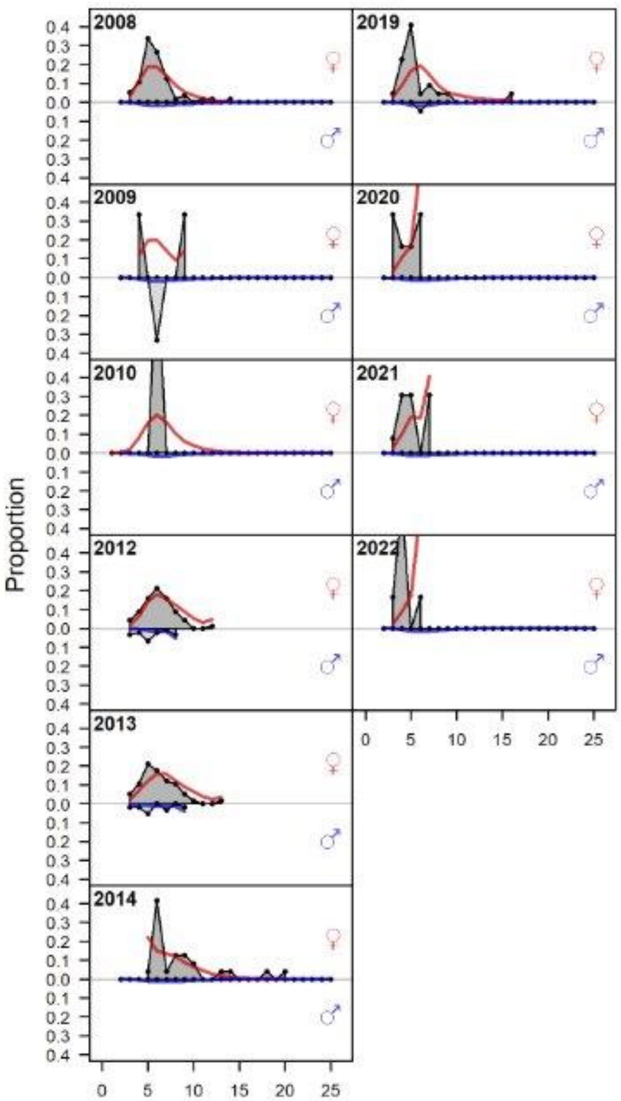
Bottom Trawl	CPFV	CalCOFI
0.205	0.142	0.534

18.	Request: In the pre-review base model, the age data are all entered as conditioned on length, i.e., as conditional-age-at-length (CAAL). For each year-fleet combination with CAAL data, add rows with the corresponding marginal age compositions, summed across all lengths and marked as marginal age-composition data by setting the Lbin_Lo and Lbin_Hi fields to -1. Set the FLEET field value to its negative value to indicate to Synthesis to exclude the log-likelihood for this row of data, but include fits in the report file.

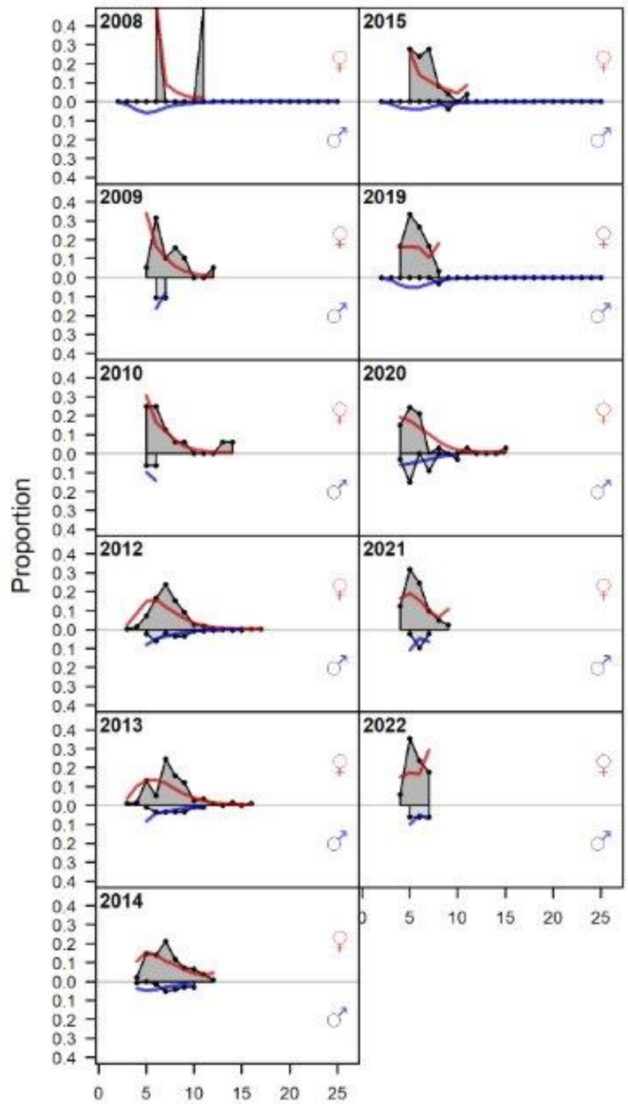
a.	Rationale: It is difficult to interpret CAAL data because the signal from a cohort is scattered across multiple length rows. The occurrence of strong and weak cohorts are easier to identify in the marginal age-compositions.

b.	STAT Response: We summed age observations over lengths for each year/fleet/sex combination and input these age compositions with a negative fleet number. We then plot the fits to these marginal age compositions. We found that small sample sizes for marginal age compositions made assessing fits difficult and cohorts were not visible but fits generally appeared to be acceptable.

Trawl



Gillnet



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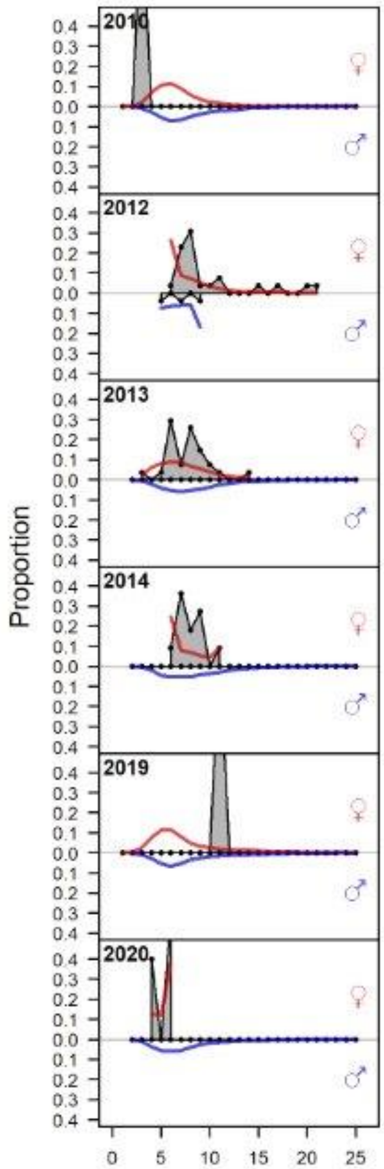
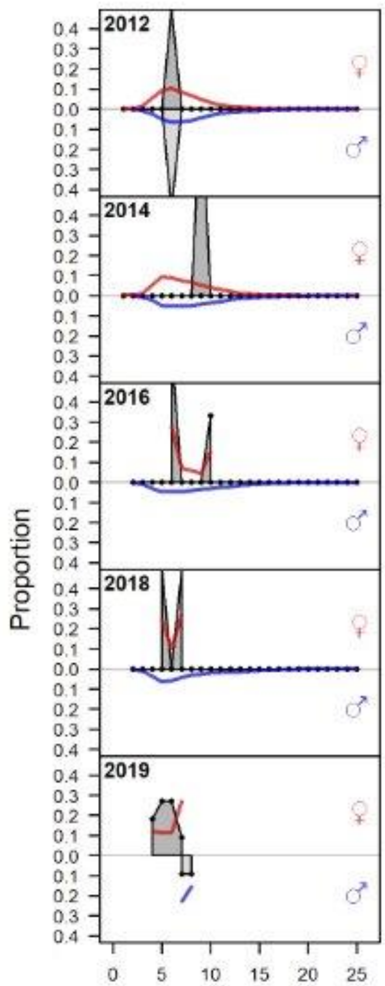
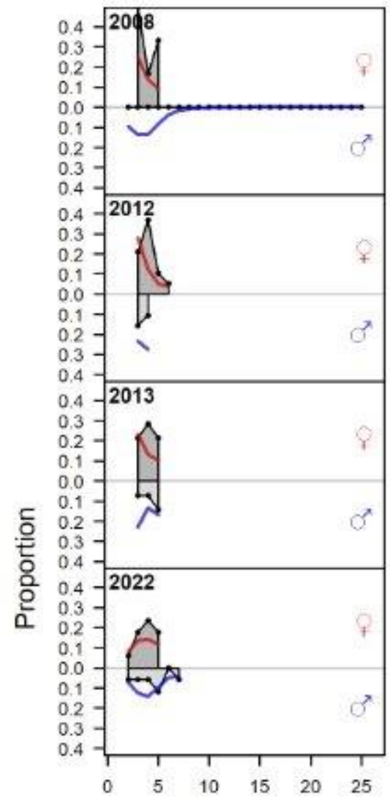
Commercial Hook & Line



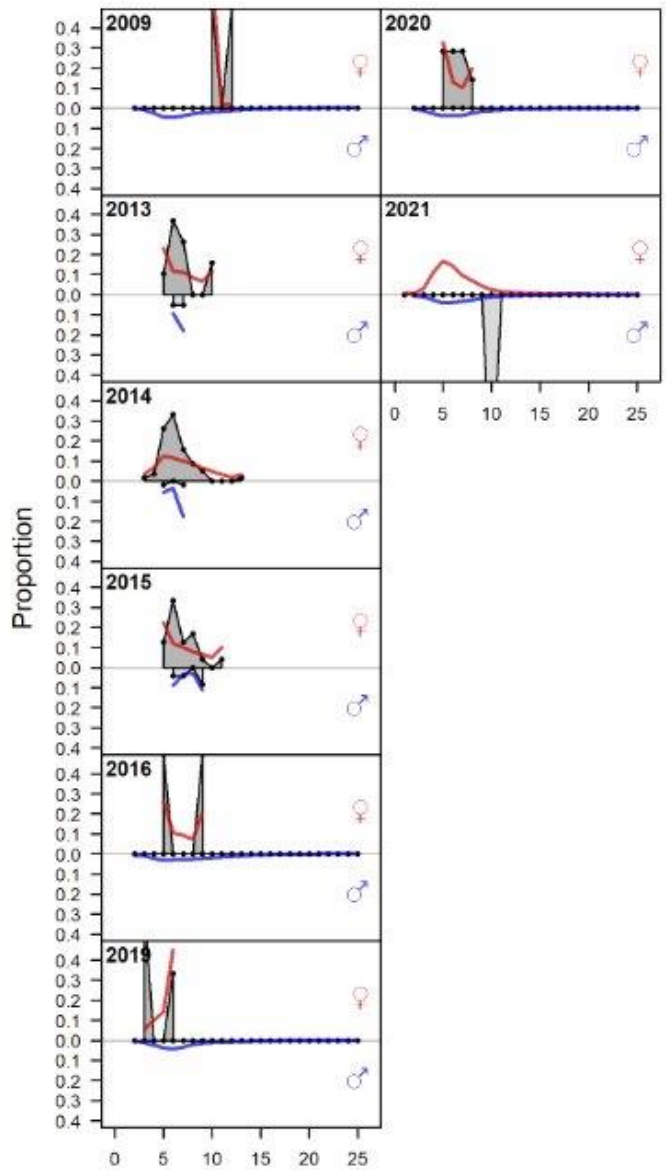
CPFV



Trawl Discard



OtherRec



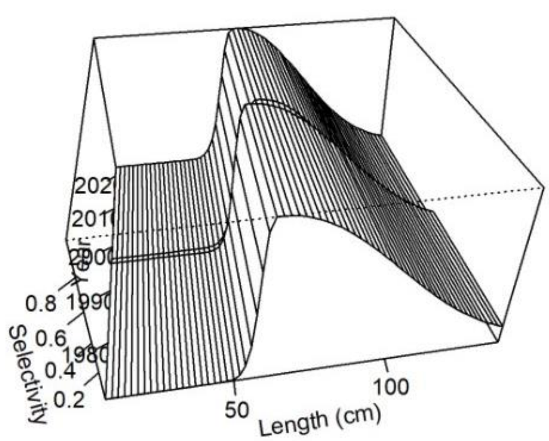
2009
2020
2013
2021
2014
2015
2016
2019
Proportion
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
♀
♂

19. Request: Explore which parameters are being estimated in the early selectivity block for the gillnet fishery to see if adjusting these parameters can improve the fit to the length composition data.

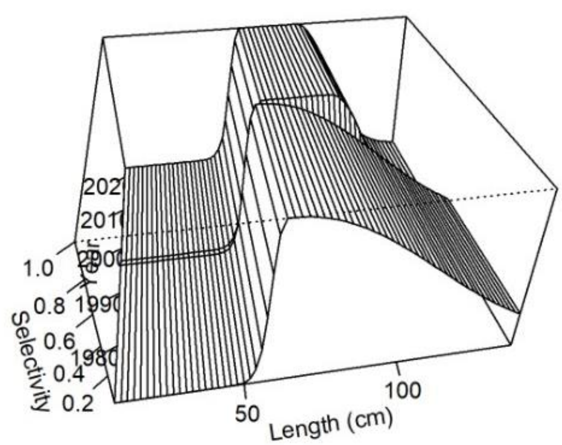
a. Rational: The draft model the Pearson residuals for the early selectivity block for the gillnet fleet (retained) had a pattern of overfitting smaller and larger fish while underfitting the intermediate sizes.

b. STAT Response: We first estimated a top parameter in the early block which was not previously estimated. We then estimated a top and final-at-last-bin for both block periods. We show these compared to the reference model for the second day of peer review which incorporates revised initial conditions (Day 2 Revise Init). The time block was used to account for a change in the minimum mesh size for gillnets from 8 to 8.5 inches that occurred in 1989. However, the composition data suggested placement of the block in 1996. It is possible that full adoption and/or enforcement of the mesh size change did not take place until several years after implementation of the rule. There was also a change in rules affecting the spatial distribution of the fishery in 1994 that could have impacted size selectivity. While there is a slightly lower likelihood with the addition of three new parameters, we are unable to explain the resulting selectivity pattern and recommend retaining the base model parameterization.

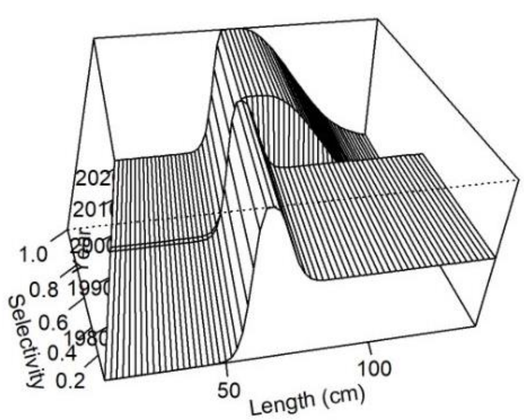
Day 2 Revise Init



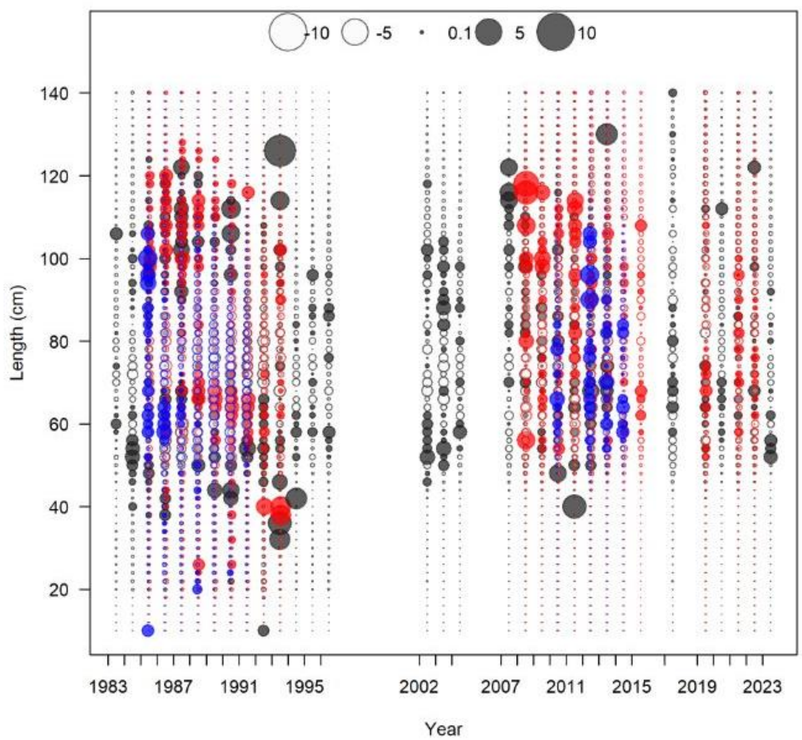
Estimate Top



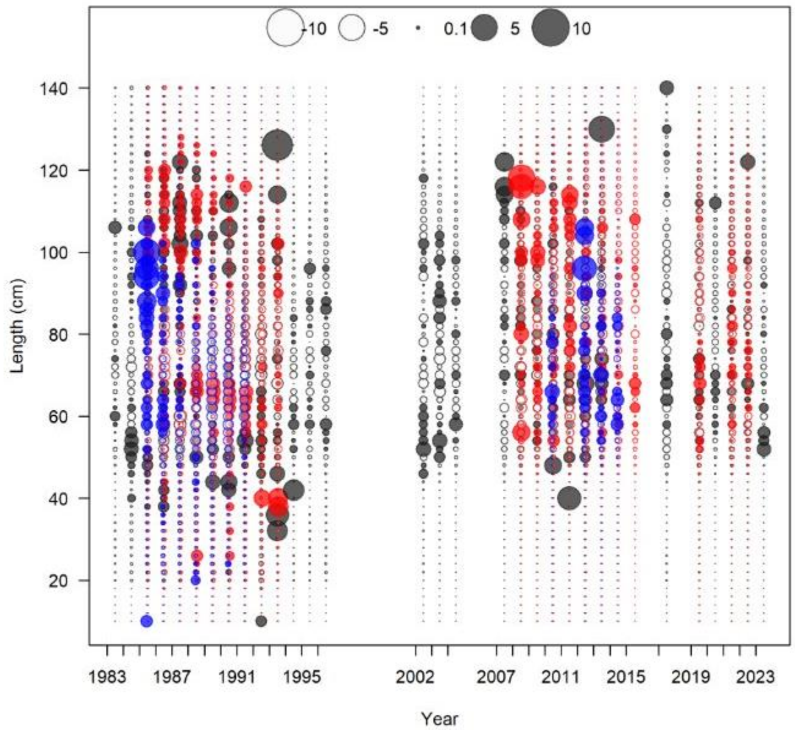
Estimate Top & Last



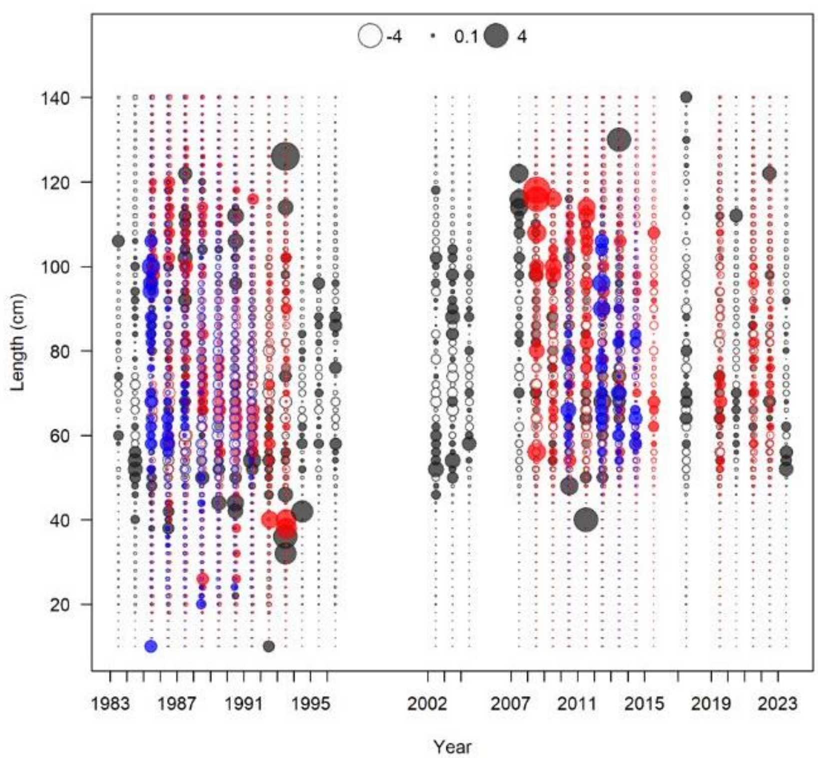
Day 2 Revise Init



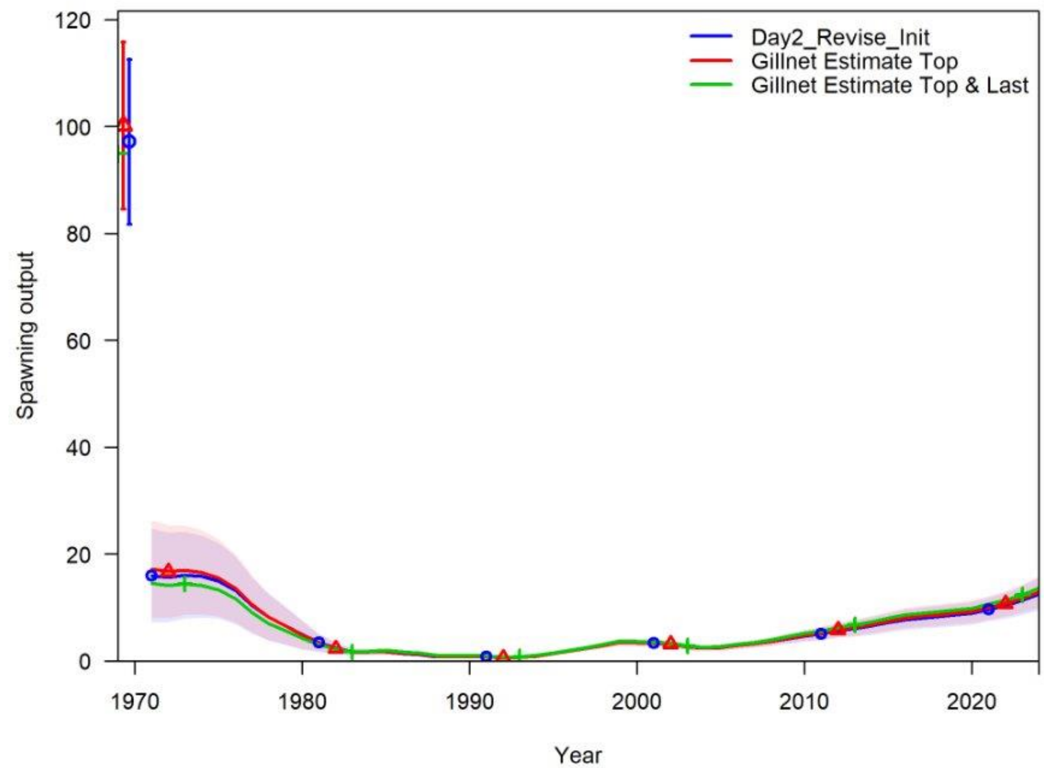
Estimate Top



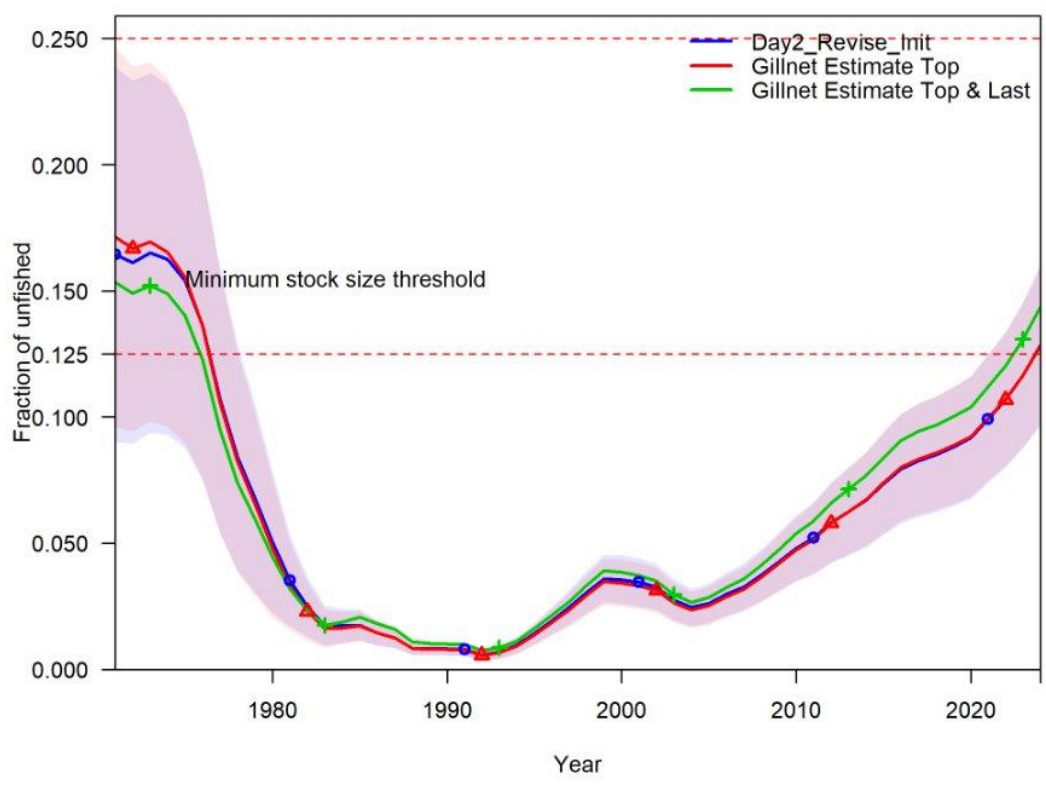
Estimate Top & Last



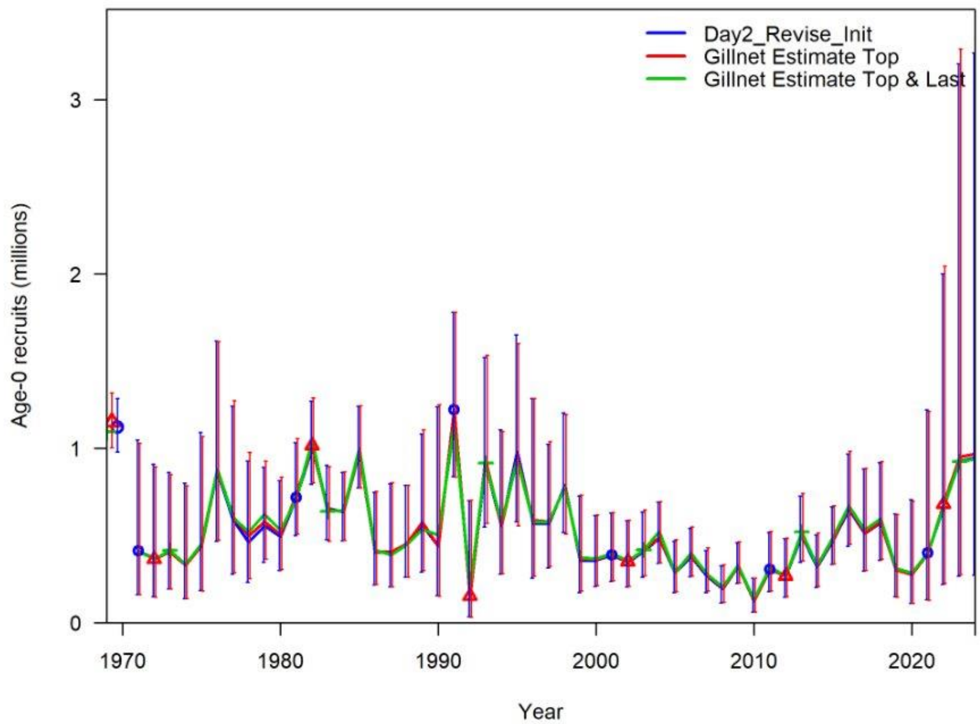
Label	Day 2 Revise Init	GN Estimate Top	GN Estimate Top & Last
TOTAL_like	1702.53	1700.64	1688.8
Survey_like	-88.32	-87.19	-85.3
Length_comp_like	1229.61	1225.9	1216.24
Age_comp_like	548.04	547.97	547.88
Recruitment_like	13.05	13.81	9.83
Forecast_Recruitment_like	0.1	0.1	0.1

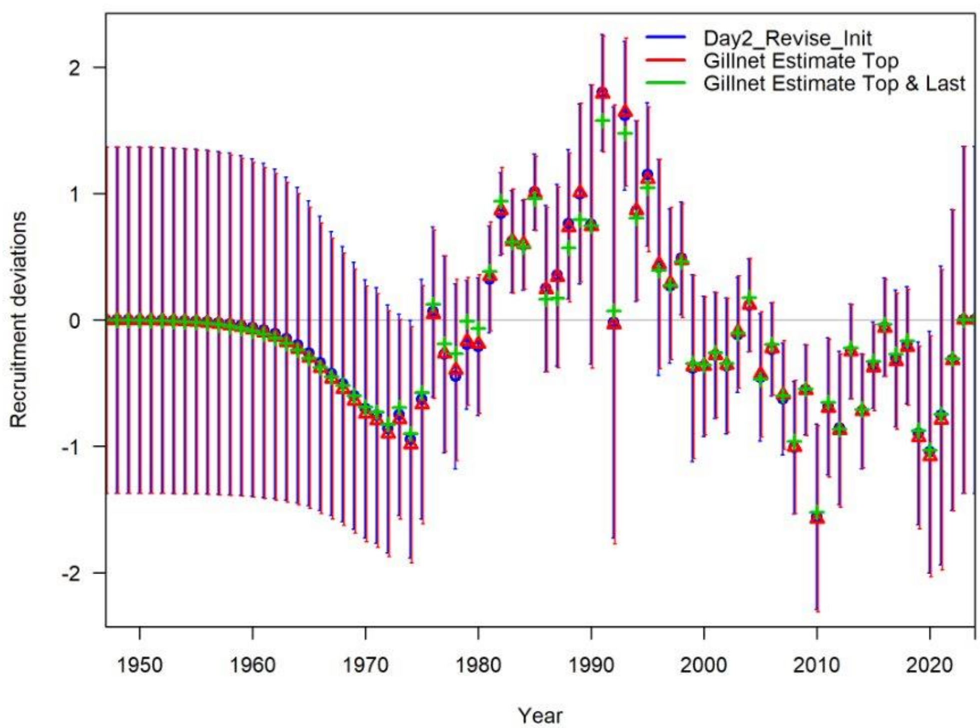


Day2_Revise_Init
Gillnet Estimate Top
Gillnet Estimate Top & Last
Spawning output
Year



Day2_Revise_Init
Gillnet Estimate Top
Gillnet Estimate Top & Last
Minimum stock size threshold
Fraction of unfished
Year


Day2_Revise_Init
Gillnet Estimate Top
Gillnet Estimate Top & Last
Age-0 recruits (millions)
Year
0
1
2
3
1970
1980
1990
2000
2010
2020

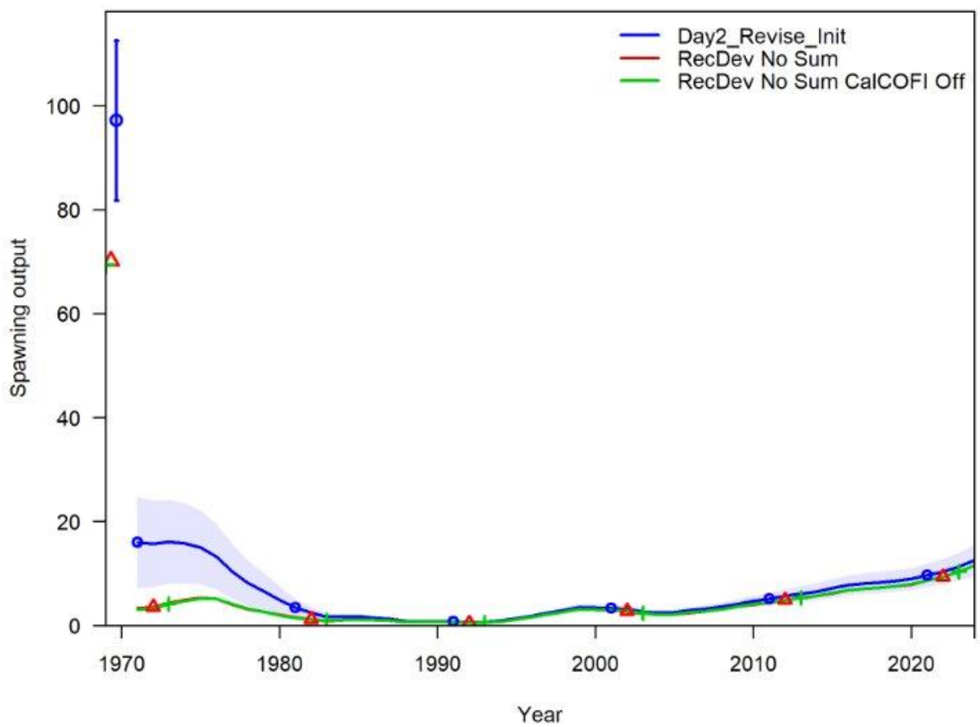

Day2_Revise_Init
Gillnet Estimate Top
Gillnet Estimate Top & Last
Recruitment deviations
Year
-2
-1
0
1
2
1950
1960
1970
1980
1990
2000
2010
2020

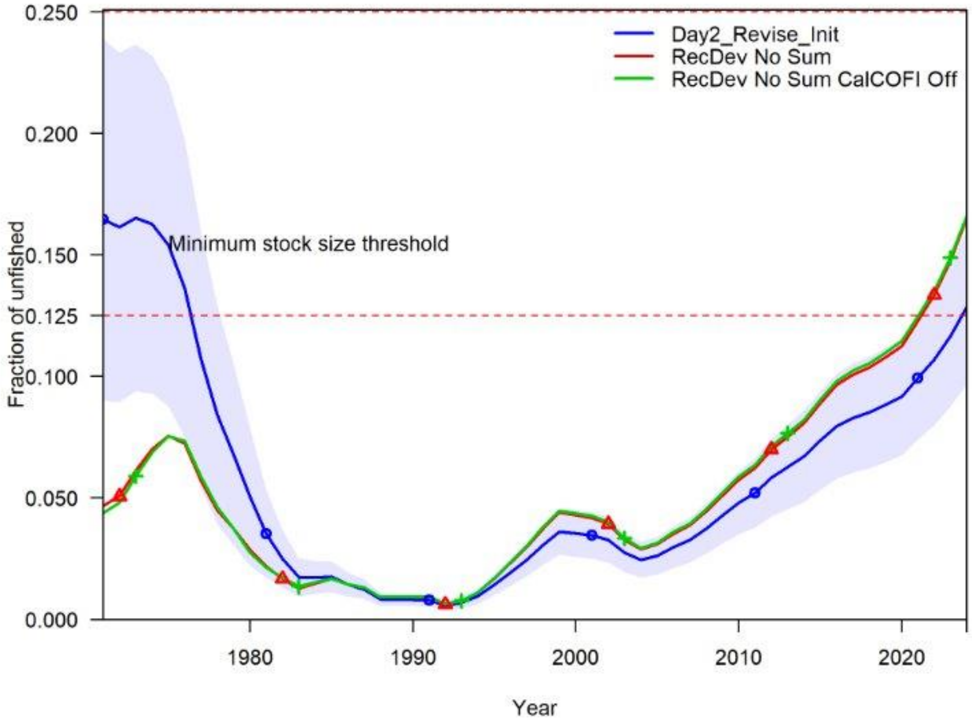
20. Request: Follow up to Day 1, Modeling Request 4: Remove constraint that rec devs sum to 0. Remove the CalCOFI index and remove the constraint that rec devs sum to 0.

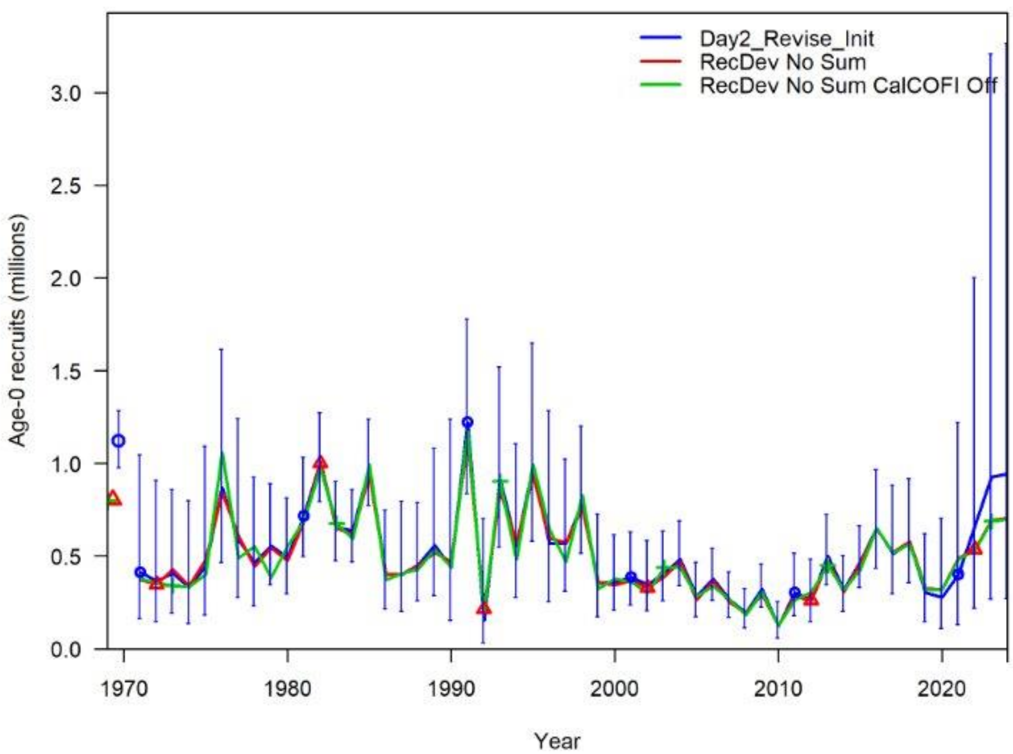
a. Rationale: Understanding the influence of this recruitment survey may be influencing the model behavior (relatively large departure from summing to zero) when recruitment deviations are not forced to sum to 0.

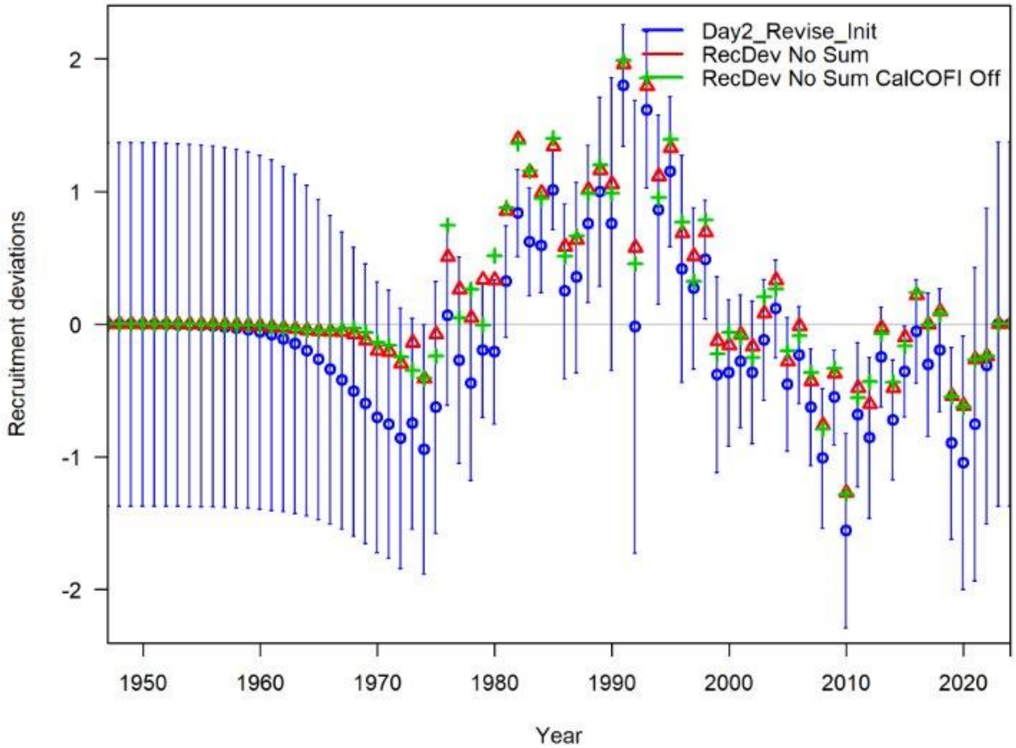
b. STAT Response: The total likelihood is lower when not forcing recruitment deviations to sum to one. However, we do not recommend this approach because it makes reference points difficult to define.

Label	Day 2	RecDev No Sum	RecDev No Sum CalCOFI Off
TOTAL_like	1702.53	1694.54	1695.17
Survey_like	-88.32	-88.95	-87.95
Length_comp_like	1229.61	1223.38	1222.24
Age_comp_like	548.04	546.74	547.14
Recruitment_like	13.05	13.27	13.64
Forecast_Recruitment_like	0.1	0.06	0.06




Day2_Revise_Init
RecDev No Sum
RecDev No Sum CalCOFI Off
Minimum stock size threshold
Fraction of unfished
0.250
0.200
0.150
0.125
0.100
0.050
0.000
1980
1990
2000
2010
2020
Year


Day2_Revise_Init
RecDev No Sum
RecDev No Sum CalCOFI Off
Age-0 recruits (millions)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1970
1980
1990
2000
2010
2020
Year



21. Request: Evaluate all selectivity parameters to determine if parameters are being estimated on the bounds. have high standard deviations (poorly informed by the data), or have high correlations and fix parameters if necessary.

a. Rationale: The pre-review panel base model had a number of selectivity parameters with high standard deviations and/or were correlated which can impact model performance when estimating a hessian.

b. STAT Response: We used the new, tuned model using sex type 3 from request 16 and examined parameters for bounds, standard error, and correlations. We disregarded recruitment parameters that were uninformed. The table below highlights parameters either hitting their bounds or with high CVs.

Parameter	**Value**	**Min**	**Max**	**Status**	**Parm_StDev**	**CV**
InitF_seas_1_flt_6Bottom.Trawl.Discard	0.0067774	0.00	1.0	LO	0.0006699	9.9%
Size_DblN_**top**_logit_Bottom.Trawl(1)	-11.51	-15	15	OK	54.89	-477.0%
SzSel_Male_Peak_Bottom.Trawl(1)	1.224	-10	10	OK	2.405	196.5%
Size_DblN_**top**_logit_Gillnet(2)	-11.63	-15	15	OK	53.52	-460.0%
Size_DblN_start_logit_Gillnet(2)	-10.2	-15	9	OK	11.79	-115.5%
Size_DblN_ascend_se_Comm.HL(3)	-0.611	-15	10	OK	70.64	-11557.3%
Size_DblN_**top**_logit_Other.Rec(5)	-0.176	-15	15	OK	0.265	-150.6%
SzSel_Male_Descend_Other.Rec(5)	0.748	-10	9	OK	1.29	172.3%
Size_DblN_**top**_logit_Gillnet.Discard(7)	-11.02	-15	15	OK	60.02	-544.7%

The two tables below highlight parameters that have very high or very low correlations.

Parameter.i	Parameter.j	Correlation
Size_DblN_**ascend**_se_Comm.HL(3)	Size_DblN_**peak**_Comm.HL(3)	0.999987
Size_DblN_**ascend**_se_Bottom.Trawl.Discard(6)	Size_DblN_**peak**_Bottom.Trawl.Discard(6)	0.960326
Size_DblN_**ascend**_se_CPFV.Discard(8)	Size_DblN_**peak**_CPFV.Discard(8)	0.958474
Size_DblN_**ascend**_se_Gillnet(2)	Size_DblN_**peak**_Gillnet(2)	0.926335
Size_DblN_top_logit_Bottom.Trawl.Discard(6)	Size_DblN_peak_Bottom.Trawl.Discard(6)	-0.917977
Size_DblN_**ascend**_se_CPFV(4)	Size_DblN_**peak**_CPFV(4)	0.916338
Size_DblN_**ascend**_se_Gillnet(2)_BLK1repl_1971	Size_DblN_**peak**_Gillnet(2)_BLK1repl_1971	0.906923
SzSel_Male_**Ascend**_Gillnet(2)	SzSel_Male_**Peak**_Gillnet(2)	0.892738

Parameter	max_correlation
Size_DblN_top_logit_Gillnet(2)	0.00587091
Size_DblN_top_logit_Bottom.Trawl(1)	0.00694342

We fixed ascending limb parameters for the commercial hook & line, trawl discard, and CPFV discard fleets. We also fixed the trawl and gillnet "top" parameters at their estimated values to improve model behavior. However, we recommend that these parameters be explored if new data becomes available to allow for estimation of a wider top if necessary.

Day 3

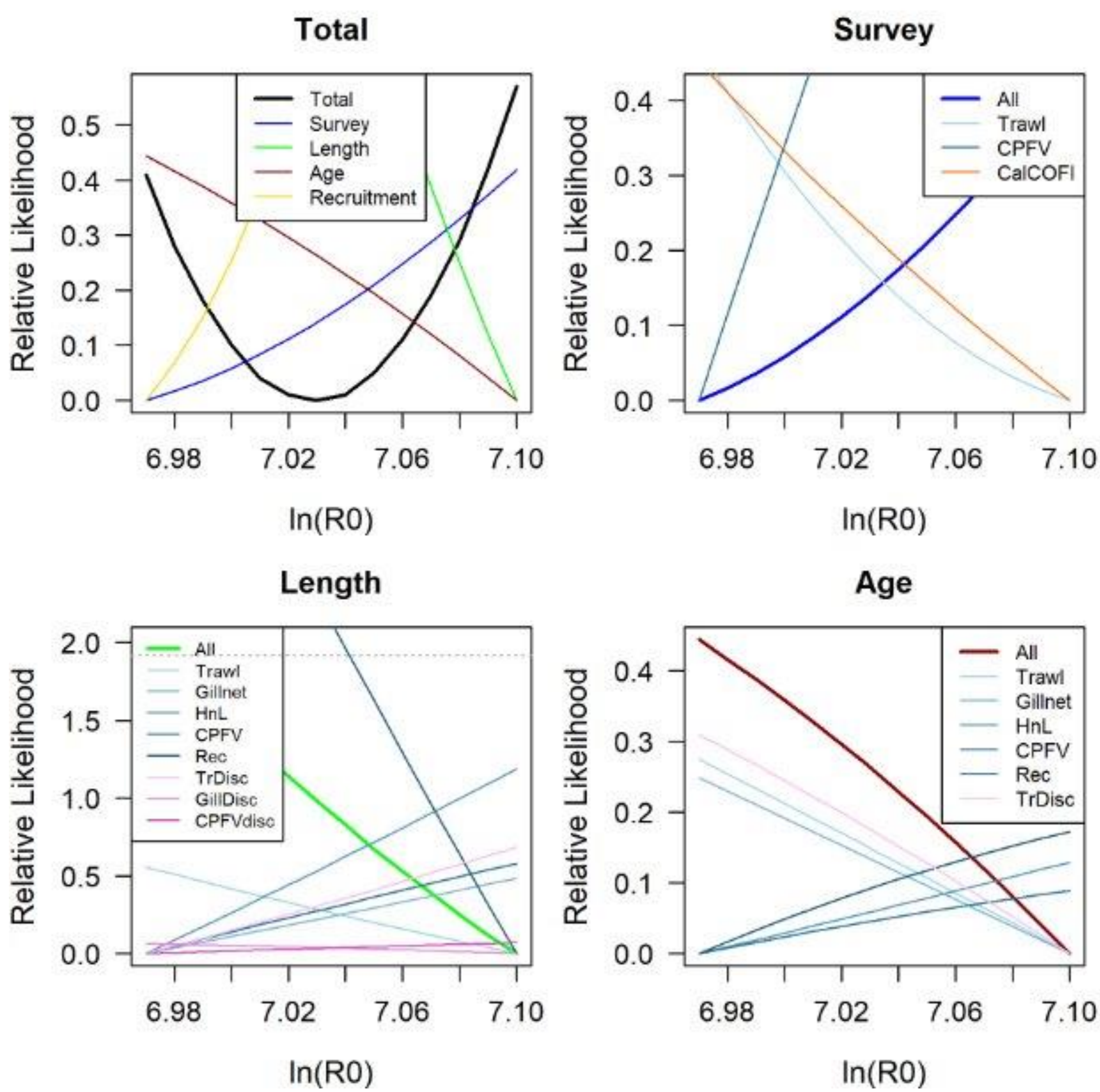
New Base Model

- Fixed ageing error (request 1)
- Updated length-weight relationship (request 5)
- Data problems the STAT has identified are fixed
- Initial F approach from request #11 with the initial commercial discards combined
- All sex-specific length composition data are input as sex = 3.
- Fix select ascending selectivity parameters that were highly uncertain and/or were highly correlated.
- Retuned

22.	Request: Run a likelihood profile over R0 and produce the 4-panel profile plots (total, survey, length, and age).

a.	Rational: The initial model R0 estimate was most informed by recruitment.

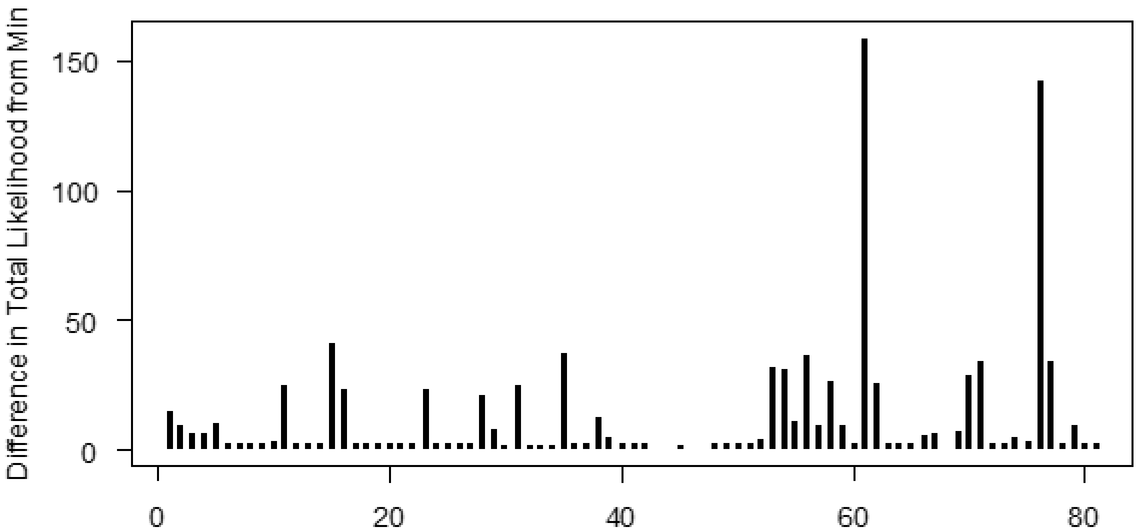
b.	STAT response: There is conflict among the data types with regard to estimation of R0. The length and age composition data point to higher values while survey and recruitment data point to lower values. The CPFV survey is opposite to the other surveys but dominates the total survey data type likelihood, likely because the CPFV survey is a longer time series and well fit. There is also conflict among the specific length and age data sources.



23. Request: Run jitters in parallel for the proposed base model.

a. Rational: This will ensure that the base model is the best fit to the data.

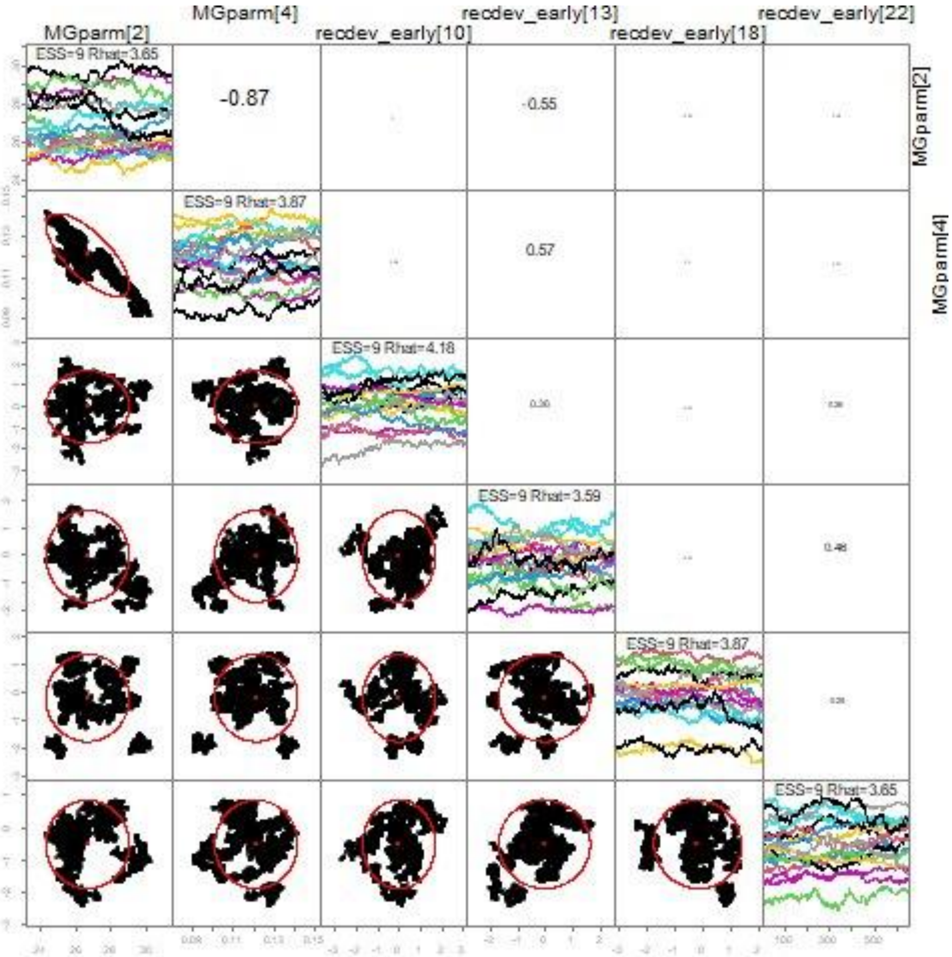
b. STAT Response: We jittered the model and found a model with a slightly lower likelihood. We adjusted some parameter starting values and phasing until we found that we were consistently achieving that lower total likelihood value. We then jittered again to ensure that now lower likelihood model was found. The histogram below illustrates that no lower likelihoods were identified.



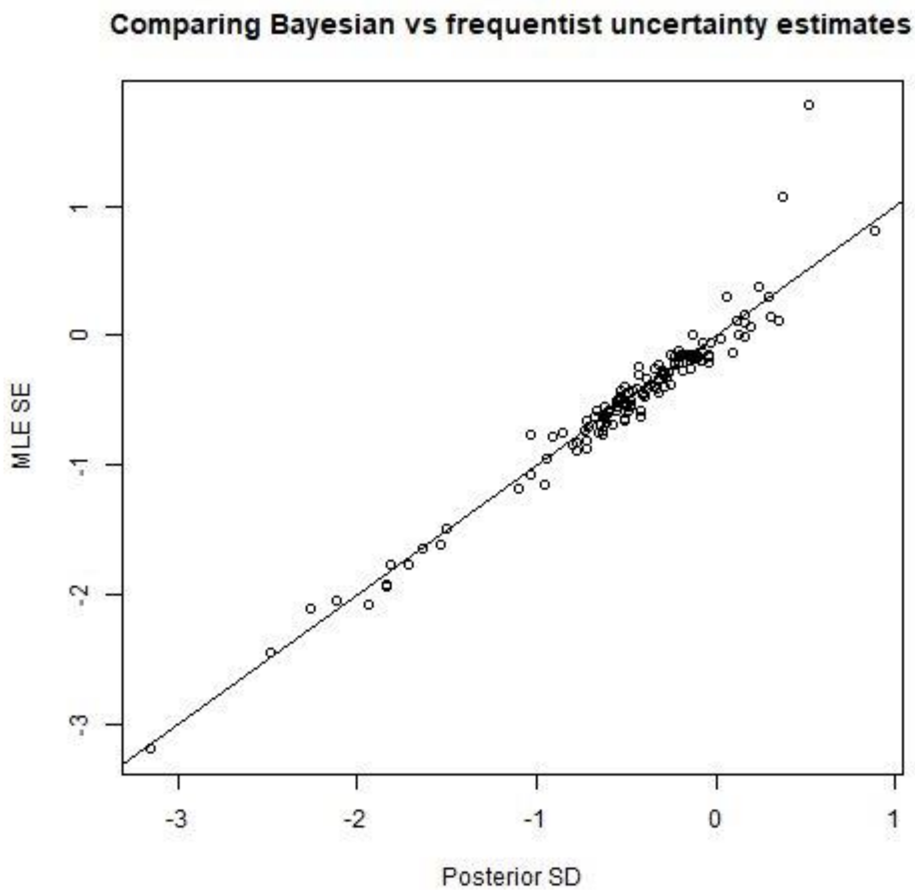
24. Request: Run a limited MCMC run using adnuts via this script: https://github.com/pfmc-assessments/PEPtools/blob/main/R/run_regularization.r

a. Rational: This brief MCMC run can help identify if any of the parameters are either not moving from the initial starting parameter or appear to be uninformed.

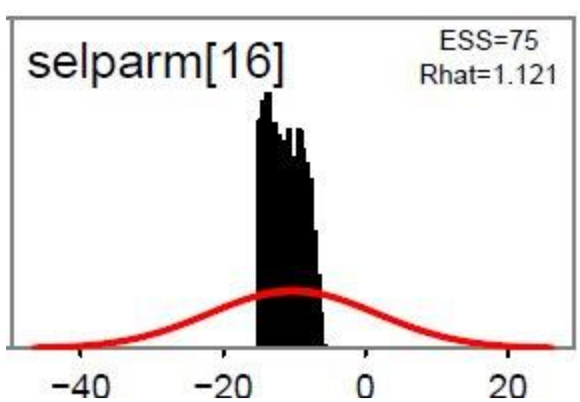
b. STAT Response: We ran the function run regularization from PEPtools. Output from that function is shown below. A correlation between growth parameters was highlighted (and expected). Some uninformed recruitment deviations had poor convergence, which is also expected. Overall, the uncertainty from the MLE and the short Bayesian run were similar.



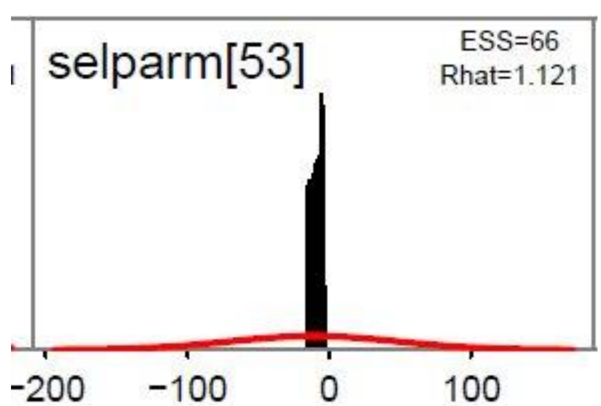
MGparm[2]
MGparm[4]
recdev_early[10]
recdev_early[13]
recdev_early[18]
recdev_early[22]
ESS=9 Rhat=3.65
-0.87
-0.55
ESS=9 Rhat=3.87
0.57
ESS=9 Rhat=4.18
ESS=9 Rhat=3.59
0.46
ESS=9 Rhat=3.87
ESS=9 Rhat=3.65



Start_logit_Gillnet



Top_logit_Gillnet_Discard



Supplementary Materials Provided for Review

Base Model Files

- control.ss
- data.ss
- forecast.ss
- starter.ss
- ss.par
- Report.sso

Terms of Reference