

Status of Black Rockfish (*Sebastes melanops*) off Washington and  
federal waters in 2023



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Correct citation for this publication:

Cope, J.M. , L.K. Hillier, C.B. Niles , T.-. Tsou, K.E. Hinton, F.P. Caltabellotta. 2023.  
Status of Black Rockfish (*Sebastodes melanops*) off Washington and federal waters in 2023.  
Pacific Fishery Management Council, Portland, Oregon. 211 p.

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## **Executive summary**

### **Stock**

This assessment reports the status of Black Rockfish (*Sebastes melanops*) off Washington state using data through 2022. Black Rockfish are also found in California and Oregon waters of the U.S. West Coast, and those are treated in separate area-based stock assessments given different management considerations and exploitation histories as discussed at the pre-stock assessment workshop in February 2023 (Council 2023). The biogeographic separation and differing exploitation histories in the populations off Oregon and Washington is believed substantial enough to justify separating those populations into different management units and stock assessments. Black Rockfish are also caught from the waters off British Columbia and Alaska. The state of Alaska is currently conducting assessments of stock status in Alaskan waters. Genetic studies of stock structure indicate fish in Alaska are more differentiated than those along the contiguous west coast of the United States, and that genetic diversity varies in a non-systematic way from California to Oregon (Hess, Hyde, and Moran 2023).

### **Removals**

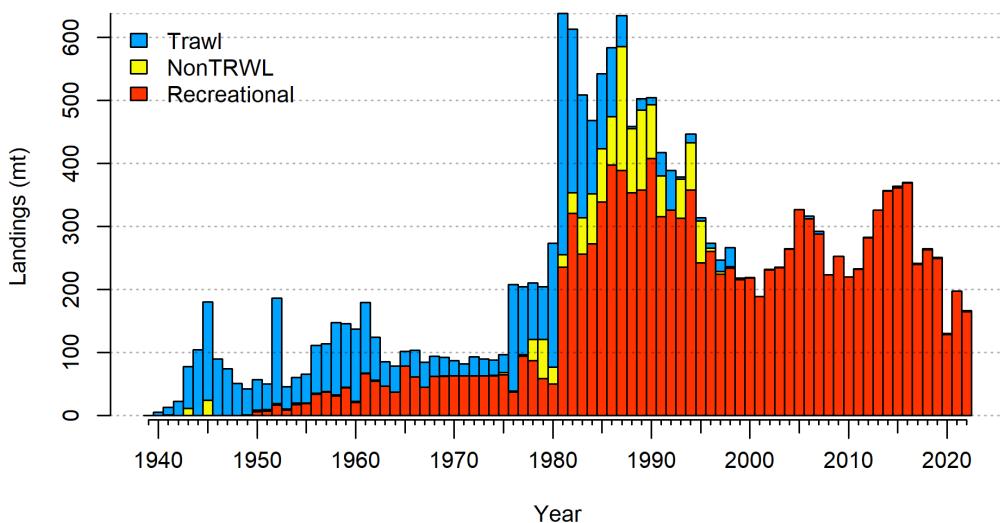
Black Rockfish have been caught by a wide variety of gear types in Washington and since the late 1990s are almost exclusively caught recreationally and is an important target species for recreational charter-boats and private sport anglers (Figure i). There has been almost no trawl or non-trawl landings of Black Rockfish in recent years (Table i), but trawl landings in the 1940s to 1970s and the commercial jig fishery in the 1980s were more prominent (Figure i).

Commercial landings of Black Rockfish are generally considered negligible prior to 1940. The catch series prior to 1981 for these assessments were derived by applying available estimates or assumed values for the proportion of Black Rockfish landings in reported landings of rockfish. Observer data, which are available since the early 2000s, indicate low levels of discarding of Black Rockfish, generally less than 2% of total catch. While Black Rockfish are unlikely to have ever comprised a large percentage of overall rockfish landings due to their low abundance compared to other rockfish species, it seems plausible that they have been more than a trivial component due to their nearshore distribution for many years.

Overall, removals of Black Rockfish remained relatively low (less than 100 mt) until the mid to late 1970s when landings quickly quadrupled with the expansion of the recreational fishery. Since the 1980s, removals have consistently fluctuated between 300 and 600 mt (no major trend), comprising mostly of removals from the ocean boat recreational fleet and the non-trawl commercial fleet (Figure i).

**Table i:** Recent landings by fleet and total landings summed across fleets.

Year	Trawl	NonTRWL	Recreational	Total Landings
2013	0.08	0.00	325.94	326.02
2014	0.99	0.01	355.96	356.96
2015	0.95	1.38	361.11	363.44
2016	0.50	0.23	368.66	369.39
2017	0.24	1.19	239.59	241.02
2018	0.03	1.85	262.91	264.79
2019	0.01	1.88	249.20	251.09
2020	0.05	1.92	128.39	130.36
2021	0.01	0.64	197.04	197.68
2022	0.00	1.12	164.93	166.05



**Figure i:** Landings by fleet used in the reference model where catches in metric tons by fleet are stacked.

## **Data and assessment**

The first Black Rockfish stock assessment along the west coast of the United States that included the majority of Oregon waters was completed in 1994, covering the area south of Cape Falcon, Oregon to north of Point Piedros Blancos, California (Sampson 2007). The first assessment for waters off Washington was done in 1994, with additional stock assessments in 1999 and 2007. In 2015, a subsequent assessment was completed that included Washington waters only as one of three (also Oregon and California) separate assessment areas delineated by state lines (J. M. Cope et al. 2016). Similarly, this assessment treats Washington waters as a single assessment area. The previous two assessments used Stock Synthesis software, as does this one (version 3.30.21.00).

This assessment integrates data and information from multiple sources into one modeling framework. The stock assessment model for Black Rockfish is informed by catch data from two commercial fleets and one recreational fleet, six abundance indices, six sets of length composition data, and three sets of conditional age-at-length compositions. It also uses two ageing error matrices to incorporate ageing imprecision and applies fixed parameterizations of weight-at-length, maturity-at-length, fecundity-at-length, the Beverton-Holt stock-recruitment steepness value, and recruitment variability. Life history parameters were sex-specific (i.e., a two-sex model) with natural mortality fixed at estimates from the previous assessment (but rationalized through life history theory) and most growth and recruitment parameters estimated. Additional parameters that were estimated include initial population scale ( $\ln R_0$ ), selectivity for each fishery and survey, and extra survey variance. The base model was tuned to account for the weighting of the length and age data and index variances (which were estimated), as well as the specification of the recruitment bias adjustments. Derived quantities include, among other things, the time series of spawning biomass, age and size structure, and current and projected future stock status. The model covers the years 1940 to 2022, with a 12 year forecast beginning in 2023.

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 weighting, and model specification sensitivity to the treatment of life history parameters, selectivity, recruitment, and survey catchability. A reference model was selected that best fit the observed data while concomitantly balancing the desire to capture the central tendency across those sources of uncertainty, ensure model realism and tractability, and promote robustness to potential model misspecification.

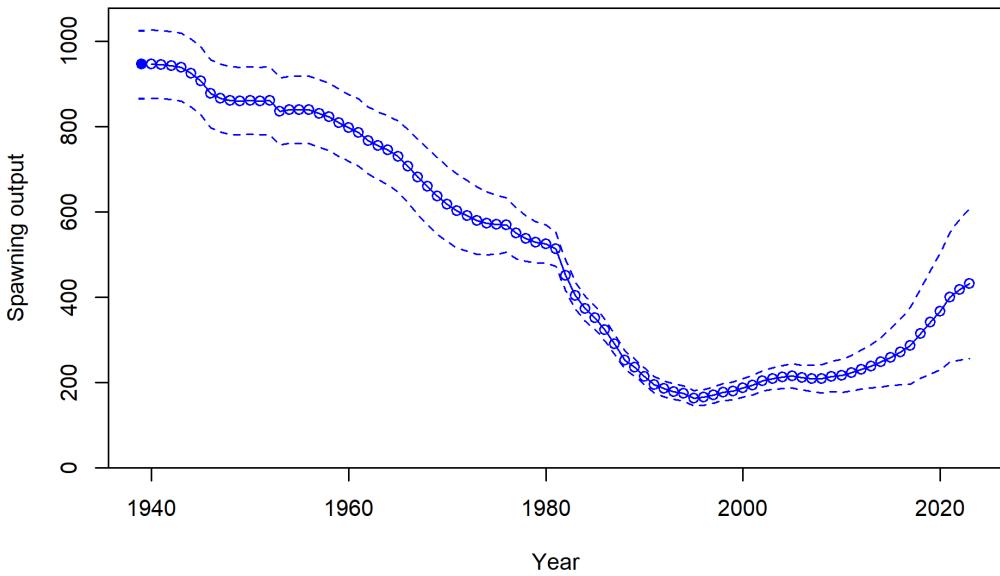
## **Stock biomass and dynamics**

Spawning output (in millions of eggs; meggs) instead of spawning biomass is used to report the functionally mature population scale because fecundity is nonlinearly related to body female weight. The estimated spawning output at the beginning of 2023 was 431 meggs (~95 percent asymptotic intervals: 255 to 606 meggs, Table ii and Figure ii), which when compared to unfished spawning output (946) meggs gives a relative stock status level of 46 percent (~95 percent asymptotic intervals: 30 to 61 percent, Figure iii). Overall, spawning

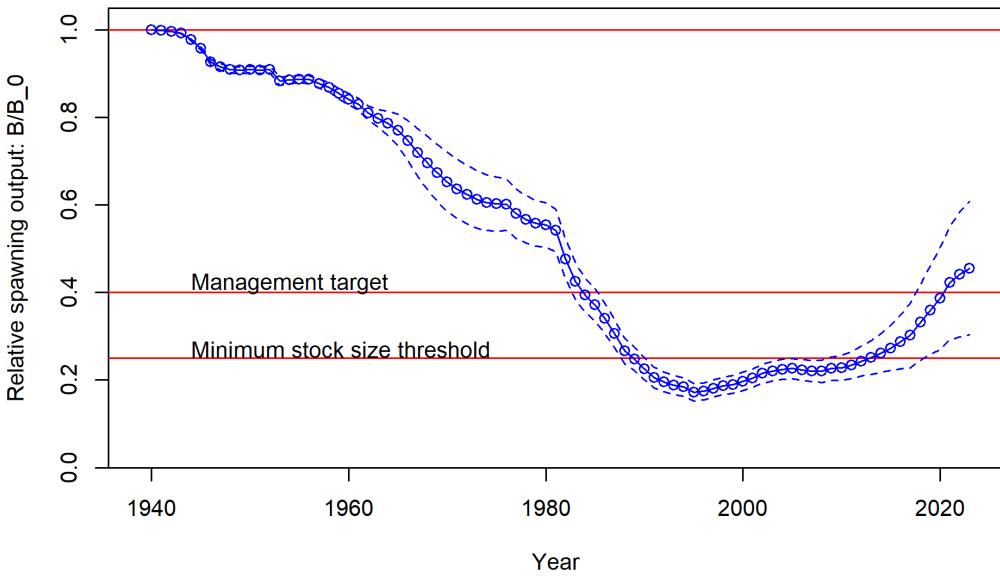
output declined with the onset of commercial fishing, further decreasing with the increasing recreational removals in the 1980s and continued to decline until the commercial fisheries were shutdown in the late 1990s. Notable recent estimated recruitment pulses occurred in 2000, 2008, and 2011. A decade of positive recruitments of varying strengths support a increase in the time series despite recent lower recruitment deviations. The minimum relative stock size of 17 percent of unfished levels is estimated to have occurred in 1995. The stock may have been below the overfished threshold in the 1980s. Currently the stock is estimated to be above the management target of  $SO_{40\%}$  in 2023 and is estimated to have surpassed the target only recently (Table ii and Figure iii).

**Table ii:** Estimated recent trend in spawning output and the fraction unfished and the 95 percent intervals.

Year	Spawning Output	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2013	238.06	187.13	288.99	0.25	0.21	0.29
2014	247.47	189.54	305.39	0.26	0.22	0.31
2015	258.38	191.58	325.17	0.27	0.22	0.33
2016	271.40	193.85	348.95	0.29	0.22	0.35
2017	285.61	195.45	375.77	0.30	0.23	0.38
2018	314.18	209.42	418.95	0.33	0.25	0.42
2019	340.69	220.12	461.25	0.36	0.26	0.46
2020	365.97	229.31	502.63	0.39	0.27	0.50
2021	399.51	247.45	551.58	0.42	0.29	0.55
2022	417.51	252.29	582.73	0.44	0.30	0.58
2023	430.90	255.42	606.37	0.46	0.30	0.61



**Figure ii:** Estimated time series of spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.



**Figure iii:** Estimated time series of fraction of unfished spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.

## Recruitment

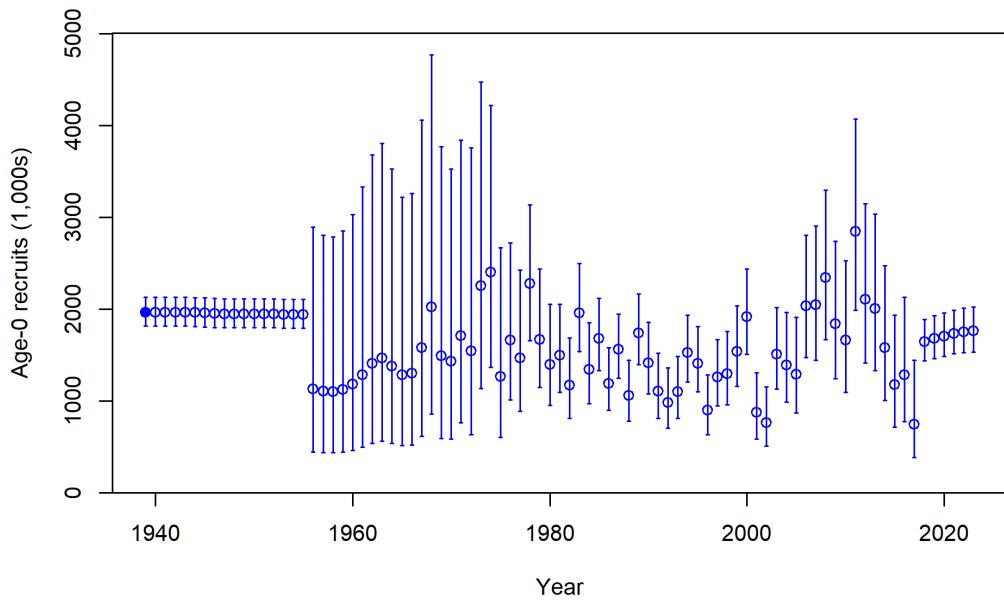
Recruitment is informed by the data and estimated from 1970s to 2017, before and after which it is assumed taken from the stock-recruit relationship (Table iii and Figure iv). The highest recruitment years occurred in 2000, 2008, and 2011. The large 2008 and 2011 year classes, as well as several above average year classes in the mid 2000s to early 2010s, contributed to the recent increase in Black Rockfish biomass. Recruitment is informed mostly by the composition data. While the Black Rockfish stock has been reduced to levels that theoretically would provide some information on how recruitment compensation changes across spawning biomass levels (i.e., inform the steepness parameter), the assessment model could not adequately estimate a reasonable steepness parameter given that most of the data was collected after the major decline and/or did not show much contrast. Thus, recruitment is based on a fixed assumption about steepness ( $h = 0.72$ ) and recruitment variability ( $\sigma_R = 0.6$ ).

**Table iii:** Estimated recent trend in recruitment and recruitment deviations and the 95 percent intervals.

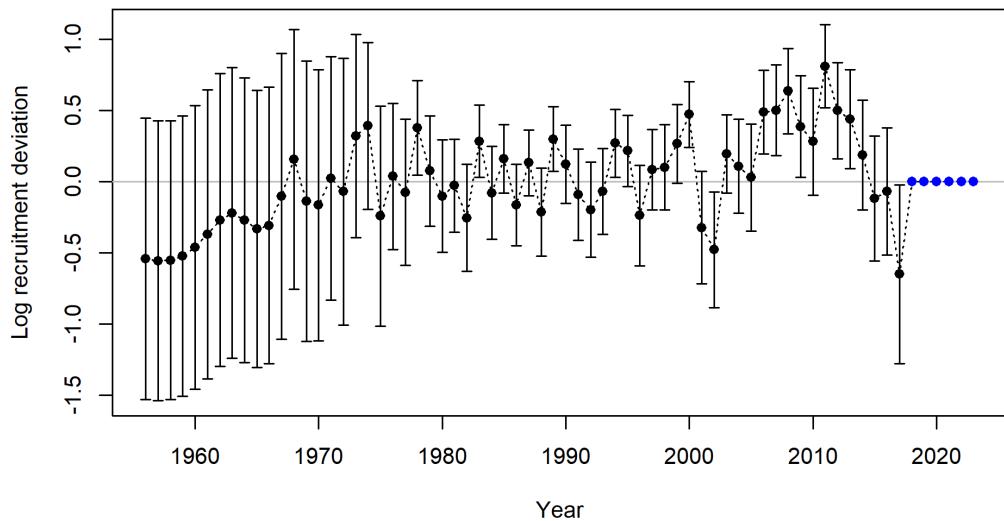
Year	Recruit- ment	Lower Interval	Upper Interval	Recruit- ment Deviations	Lower Interval	Upper Interval
2013	2007.07	1327.90	3033.61	0.44	0.09	0.78
2014	1577.24	1005.94	2472.99	0.19	-0.20	0.57
2015	1175.06	714.83	1931.59	-0.12	-0.56	0.32
2016	1283.13	772.89	2130.21	-0.07	-0.52	0.38
2017	744.19	383.43	1444.37	-0.65	-1.28	-0.02
2018	1644.88	1433.91	1886.88	0.00	0.00	0.00
2019	1676.81	1459.95	1925.89	0.00	0.00	0.00
2020	1703.90	1481.98	1959.05	0.00	0.00	0.00
2021	1735.61	1513.40	1990.45	0.00	0.00	0.00
2022	1750.94	1525.23	2010.05	0.00	0.00	0.00
2023	1761.68	1533.36	2024.00	0.00	0.00	0.00

## Exploitation status

Fishing intensity, as measured by the SPR rate ( $1 - \text{SPR}$ ), has remained high and above the target of 50% since the 1980s and only recently dropped below the target ( $1 - \text{SPR}_{50\%}$ ). Highest fishing rates were in the 1980s to mid 1990s after which it started to drop (Table iv and Figures vi and vii). The steepness value of 0.72 indicates that a lower value of SPR (or equivalently a higher fishing intensity than  $\text{SPR}_{50\%}$ ) would be consistent with the biomass-based target of ( $\text{SO}_{40\%}$ ) for sustainable removals. Trends in fishing intensity largely mirrored that of landings until the 1990s, after which recruitment pulses countered



**Figure iv:** Estimated time series of age-0 recruits (1000s) for the base model with 95 percent intervals.

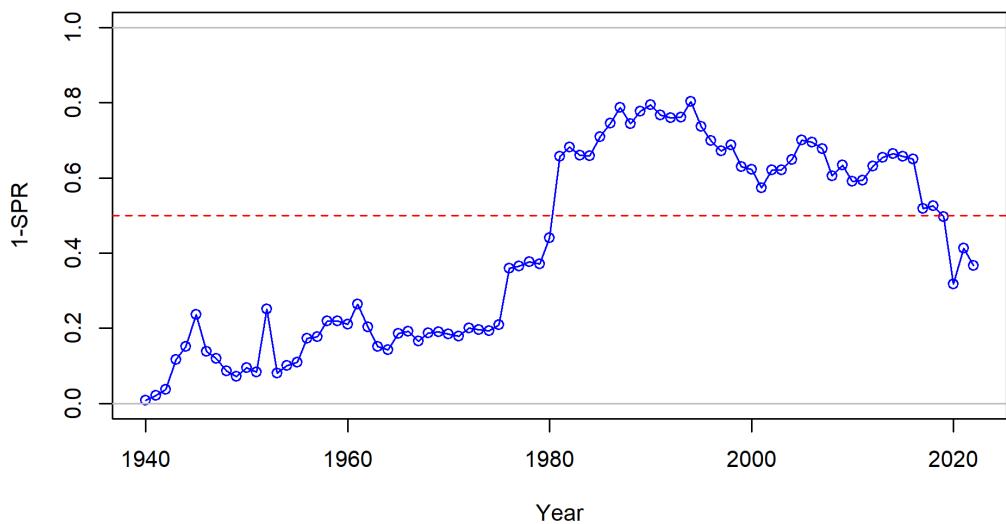


**Figure v:** Estimated time series of recruitment deviations.

the catches somewhat to lower overall fishing intensity (Figure vi). The maximum fishing intensity was 0.8 in 1994, which is well above the target SPR-based harvest rate of 0.50. The current level of 0.41 for 2022 is below that target. Fishing intensity over the past decade has ranged between 0.32 and 0.67 and the exploitation rate (range of 0.03 - 0.07, Table iv) has come down since the mid-1990s. Current estimates indicate that Black Rockfish spawning output is greater than the target biomass level ( $SO_{40\%}$ ), though fishing intensity remains near the target  $F_{MSY}$  proxy harvest rate of 1 -  $SPR_{50\%}$  (Figure vii).

**Table iv:** Estimated recent trend in the 1-SPR where SPR is the spawning potential ratio the exploitation rate, and the 95 percent intervals.

Year	1-SPR	Lower Interval	Upper Interval	Exploitation Rate	Lower Interval	Upper Interval
2013	0.65	0.60	0.71	0.06	0.05	0.08
2014	0.67	0.60	0.73	0.07	0.05	0.08
2015	0.66	0.59	0.73	0.07	0.05	0.09
2016	0.65	0.57	0.73	0.07	0.05	0.09
2017	0.52	0.43	0.61	0.05	0.03	0.06
2018	0.53	0.43	0.62	0.05	0.03	0.07
2019	0.50	0.40	0.59	0.05	0.03	0.07
2020	0.32	0.23	0.40	0.03	0.02	0.03
2021	0.41	0.31	0.51	0.04	0.03	0.05
2022	0.37	0.27	0.46	0.03	0.02	0.04



**Figure vi:** Estimated 1 - relative spawning ratio (SPR) by year for the base model. The management target is plotted as a red horizontal line and values above this reflect harvest in excess of the proxy harvest rate.

## Ecosystem considerations

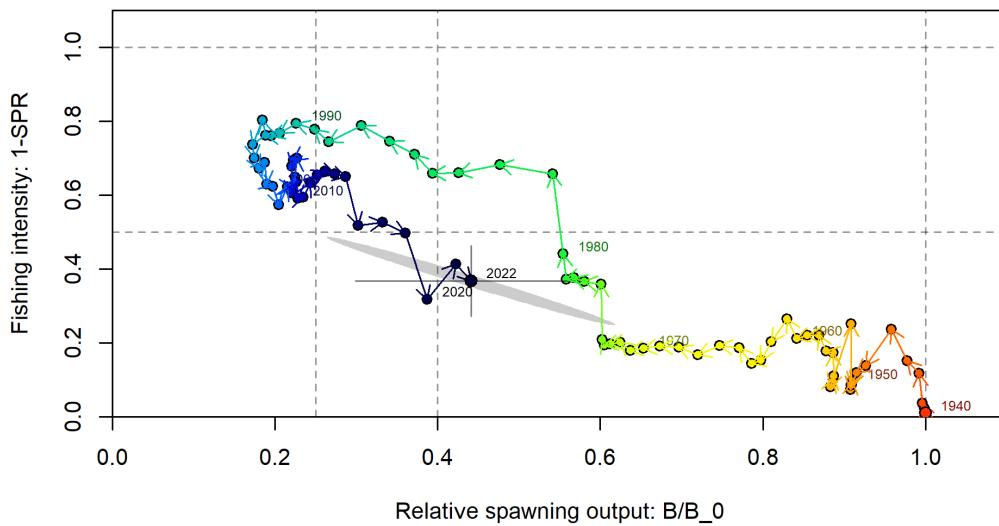
This stock assessment does not explicitly incorporate trophic interactions, habitat factors, or environmental factors into the assessment model. More predation, diet and habitat work, and mechanistic linkages to environmental conditions would be needed to incorporate these elements into the stock assessment and should remain a priority. McClure et al. (2023) report the climate vulnerability for several west coast groundfishes, including Black Rockfish. Black Rockfish demonstrated both high biological sensitivity and high climate exposure risk, to give it an overall high vulnerability score to climate change. This result should also be considered with the fact that, like many rockfishes, periods of low productivity is not unusual to Black Rockfish and their extended longevity (though admittedly this seems shorter than previously believed and should be reconsidered) has historically allowed them to wait for advantageous productivity periods. Additional stressors such as fishing and climate change that possibly truncate longevity could bring significant challenges to population sustainability.

## Reference points

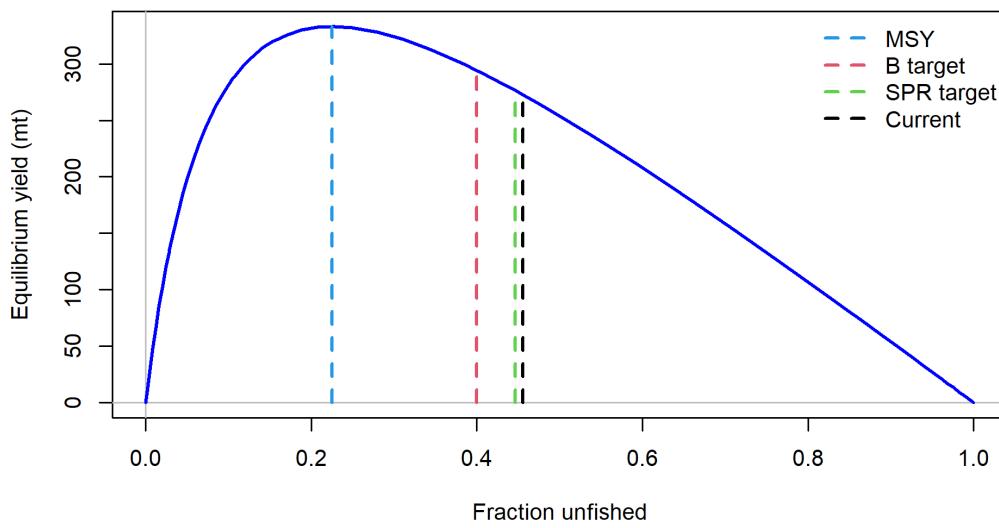
Reference points were based on the rockfish FMSY proxy ( $SPR_{50\%}$ ), target relative biomass (40%), and estimated selectivity and catch for each fleet (Table 5). The Black Rockfish population in Washington at the start of 2023 is estimated to be just above the target biomass, and fishing intensity during 2022 is estimated to be just below the fishing intensity target (Figure vii). The yield values are lower than the previous assessment for similar reference points due to updated life history estimates and estimates of the total scale of the population, despite the overall stock status being a bit higher. The proxy MSY values of management quantities are by definition more conservative compared to the estimated MSY and MSY relative to 40% biomass because of the assumed steepness value. Sustainable total yield, removals, using the proxy  $SPR_{50\%}$  is 277 mt. The spawning output equivalent to 40 percent of the unfished spawning output ( $SO_{40\%}$ ) calculated using the SPR target ( $SPR_{50\%}$ ) was 422.1 meggs.

Recent removals have been well below the point estimate of potential long-term yields calculated using an  $SPR_{50\%}$  reference point, leading to a population that has continued to increase over recent years despite a string of lower average recruitments. The equilibrium estimates of yield relative to biomass based on a steepness value fixed at 0.72 are provided in Figure viii, where vertical dashed lines indicate the estimate of fraction unfished at the start of 2023 (current) and the estimated management targets calculated based on the relative target biomass (B target), the SPR target, and the maximum sustainable yield (MSY).

The 2023 spawning biomass relative to unfished equilibrium spawning biomass, based on the 2022 fishing year, is above (0.46) the management target of 0.4 of unfished spawning output. The relative biomass and the ratio of the estimated SPR to the management target ( $SPR_{50\%}$ ) across all model years are shown in Figure vii where warmer colors (red) represent early years and colder colors (blue) represent recent years. There have been periods where the stock status has decreased below the target and limit relative biomass, and fishing intensity has been higher than the target fishing intensity based on  $SPR_{50\%}$ .



**Figure vii:** Phase plot of estimated 1-SPR versus fraction unfished for the base model.



**Figure viii:** Equilibrium yield curve for the base case model. Values are based on (the time invariant) fishery selectivities and with steepness fixed at 0.72.

**Table v:** Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	946.03	870.06	1022.00
Unfished Age 0+ Biomass (mt)	8729.15	8025.72	9432.58
Unfished Recruitment (R0)	1966.34	1808.44	2124.24
Spawning Output (2023)	430.90	255.42	606.37
Fraction Unfished (2023)	0.46	0.30	0.61
Reference Points Based SB40\%	NA	NA	NA
Proxy Spawning Output SB40\%	378.41	348.03	408.80
SPR Resulting in SB40\%	0.46	0.46	0.46
Exploitation Rate Resulting in SB40\%	0.05	0.05	0.05
Yield with SPR Based On SB40\% (mt)	294.29	270.66	317.93
Reference Points Based on SPR Proxy for MSY	NA	NA	NA
Proxy Spawning Output (SPR50)	422.08	388.18	455.97
SPR50	0.50	NA	NA
Exploitation Rate Corresponding to SPR50	0.05	0.05	0.05
Yield with SPR50 at SB SPR (mt)	276.60	254.38	298.82
Reference Points Based on Estimated MSY Values	NA	NA	NA
Spawning Output at MSY (SB MSY)	212.94	195.82	230.06
SPR MSY	0.30	0.30	0.30
Exploitation Rate Corresponding to SPR MSY	0.08	0.08	0.08
MSY (mt)	333.10	306.37	359.82

## Management performance

Black Rockfish removals have been below the equivalent ABC-ACL over the recent decade (Table ??). Exploitation on Black Rockfish increased starting around 1940 and reached a high in the late 1970s. Since that time, catch has mostly fluctuated between 300 and 500 mt per year, with some years exceeding 600 mt. Removals have averaged 483 mt over the past decade. The last ten years of Black Rockfish acceptable biological catch (ABC) and annual catch limit (ACL) (which are equivalent) has been set, by definition, below the overfishing limit (OFL) (Table ??).

**Table vi:** Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	946.03	870.06	1022.00
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SPR MSY	0.30	0.30	0.30
Exploitation Rate Corresponding to SPR MSY	0.08	0.08	0.08
MSY (mt)	333.10	306.37	359.82

## Unresolved problems and major uncertainties

The biggest uncertainty is in the life history values, especially longevity and natural mortality. Lack of contrast in the biological data, despite generous sample sizes, can also make interpreting the population dynamics difficult, though current stock status does seem to be robust to this data.

## Scientific uncertainty

The model-estimated uncertainty around the 2023 spawning biomass was  $\sigma = 0.21$  and the uncertainty around the OFL was  $\sigma = 0.19$ . This is likely underestimate of overall uncertainty because of the necessity to fix some life history parameters such as natural mortality and steepness, as well as a lack of explicit incorporation of model structural uncertainty. The alternative states of nature used to bracket uncertainty in the decision table assist with encapsulating model structure uncertainty.

## Harvest Projections and Decision Table

The following text will be modified, as appropriate, after the STAR panel and SSC meeting. The Black Rockfish assessment is being considered as a category 2 assessment with a  $P^* = 0.45$ , sigma = 0.72, and a time-varying buffer applied to the OFL. These multipliers are also combined with the rockfish MSY proxy of FSPR=50% MSY and the 40-10 harvest control rule to calculate OFLs, ABCs and ACLs. A twelve year (2023-2034) projection of the reference model using these specifications along with input removals for 2023 and 2024 provided by the Groundfish Management Team is provided in Table vii.

**Table vii:** Projections of potential OFLs (mt), ABCs (mt), the buffer (ABC = buffer x OFL), estimated spawning biomass, and fraction unfished for Oregon portion of the vermillion stock. The North of 40°10'N OFL and ABC for 2021 and 2022 are included for comparison.

Year	OFL 40°10'N	ACL 40°10'N	Predicted OFL	ABC Catch	Buffer	Spawning Output	Fraction Unfished
2021	9.70	8.10	13.01	12.96	1.00	21.37	0.73
2022	9.70	8.10	13.35	12.96	1.00	21.53	0.73
2023	-	-	13.41	12.54	0.94	21.75	0.74
2024	-	-	13.29	12.36	0.93	21.85	0.75
2025	-	-	13.03	12.06	0.93	21.74	0.74
2026	-	-	12.72	11.73	0.92	21.46	0.73
2027	-	-	12.41	11.38	0.92	21.08	0.72
2028	-	-	12.10	11.05	0.91	20.65	0.71
2029	-	-	11.82	10.74	0.91	20.20	0.69
2030	-	-	11.56	10.45	0.90	19.75	0.68
2031	-	-	11.31	10.18	0.90	19.33	0.66
2032	-	-	11.08	9.94	0.90	18.92	0.65

Uncertainty in management quantities for the reference model was characterized by exploring various model specifications in a decision table. Initial explorations are considering alternative specifications of natural mortality and population scale. The resultant decision table will be provided in Table viii.

Further details about selecting the decision table states of nature will be added here after the STAR panel.

Further details summarizing the results presented in the decision table will be added here after the STAR panel.

**Table viii:** Decision table summary of 10 year projections beginning in 2023 for alternative states of nature based on an axis of uncertainty related to model structure relative to the reference model (i.e., estimate catchability, Q, associated with the acoustic-visual survey and no estimation of recruitment deviations) . Columns range over low (12.5 quantile), mid (reference model), and high states (87.5 quantile) of nature and rows range over different catch level assumptions. Values in italics indicate years where the stock size prevented the full catch removals.

Year	Catch	Estimate Q		Reference Model		No Rec Devs	
		Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
2023	-	-	-	-	-	-	-
2024	-	-	-	-	-	-	-
2025	-	-	-	-	-	-	-
2026	-	-	-	-	-	-	-
2027	-	-	-	-	-	-	-
P*=0.45	2028	-	-	-	-	-	-
sigma=0.5	2029	-	-	-	-	-	-
	2030	-	-	-	-	-	-
	2031	-	-	-	-	-	-
	2032	-	-	-	-	-	-
	2033	-	-	-	-	-	-
	2034	-	-	-	-	-	-
	2023	-	-	-	-	-	-
	2024	-	-	-	-	-	-
	2025	-	-	-	-	-	-
	2026	-	-	-	-	-	-
	2027	-	-	-	-	-	-
P*=0.4	2028	-	-	-	-	-	-
sigma=0.5	2029	-	-	-	-	-	-
	2030	-	-	-	-	-	-
	2031	-	-	-	-	-	-
	2032	-	-	-	-	-	-
	2033	-	-	-	-	-	-
	2034	-	-	-	-	-	-
	2023	-	-	-	-	-	-
	2024	-	-	-	-	-	-
	2025	-	-	-	-	-	-
	2026	-	-	-	-	-	-
Equilibrium yield from FMSY proxy of SPR=0.5	2027	-	-	-	-	-	-
	2028	-	-	-	-	-	-
	2029	-	-	-	-	-	-
	2030	-	-	-	-	-	-
	2031	-	-	-	-	-	-
	2032	-	-	-	-	-	-
	2033	-	-	-	-	-	-
	2034	-	-	-	-	-	-

## **Research and data needs**

Recommended avenues for research to help improve future Black Rockfish stock assessments:

1. Continue to develop the nearshore fishery-independent survey, as the other available surveys provide weak information for the trend in the population.
2. Improve understanding of broader ecosystem considerations within the context of Black Rockfish (and other nearshore species) management. Evaluate and develop linkages between Black Rockfish population dynamics and environmental, oceanographic, and climate variables. In particular, develop multi-scale models (e.g., species distribution models) that can evaluate spatial patterns (e.g., multi-use areas or closures to fishing) and climate impacts (e.g., growth or distribution shifts) for vulnerable nearshore species. Utilize the growing body of ecosystem information available for the California Current Large Marine Ecosystem, as exemplified in the PFMC IEA report.
3. Continue work on the investigation into the movement, behavior or mortality of older (> age 10) females to further reconcile their absence in fisheries data. In particular, conduct genetics studies on fish observed off of the continental shelf (middle of the gyre and at sea mounts) to determine their association with the nearshore stocks.
4. Continue to build evidence for appropriate natural mortality values for females and males. This will help resolve the extent to which dome-shaped age-based selectivity may be occurring for each.
5. Design and conduct research studies to better understand the trade-offs revealed in this assessment between Black Rockfish biology and population scale that seem be at odds. If discrepancies can not be uncovered, evaluate management procedures that are as robust as can be to this trade-off.
6. Conduct early life history studies that provide a better understanding of the ecology and habitats of Black Rockfish from settlement to age-1.

# 1 Introduction

This assessment report describes the stock of Black Rockfish (*Sebastodes melanops*) off the Washington coast in U.S. waters, using data through 2022. The stocks of Black Rockfish in Washington, Oregon, and California waters are each modeled as separate stocks with the population estimates reported in stock-specific assessment reports (Figure 1). This assessment does not account for populations located in Canadian waters or other areas off the U.S. West Coast and assumes that these southern and northern populations do not contribute to nor take from the population being assessed here.

## 1.1 Basic Information

Black Rockfish (*Sebastodes melanops*) are an important component of the recreational fisheries in the nearshore waters off central and northern California, Oregon, and Washington, as well as the non-trawl commercial fisheries in California and Oregon. They range as far north as Amchitka and Kodiak islands in Alaska and are considered uncommon south of central California (Milton S. Love, Yoklavich, and Thorsteinson 2002).

A first assessment of Black Rockfish off considered the population off Oregon and California (S. Ralston and Dick 2003) and reviewed the evidence supporting genetic stock structure for Black Rockfish and other rockfish off the U.S. West Coast and concluded that the Oregon and California populations of Black Rockfish are probably not genetically heterogeneous. That assessment treated the Black Rockfish off California and Oregon as a unit stock. Previous assessments of Black Rockfish off Washington (F. R. Wallace, Hoffman, and Tagart 1999; Y. W. Wallace F. R. aand Cheng and Tsou 2007) describe a study of coastal Black Rockfish genetic structure using 10 sampled sites collected from northern California to southern British Columbia t 1995-97. Results of that study support the notion of separate genetic stocks north and south of Cape Falcon. However, a later study (Baker 1999) of Black Rockfish collected from eight sites along the northern Oregon coast concluded that Black Rockfish from north and south of Cape Falcon were genetically very similar.

Although a stock boundary line at the Columbia River seems reasonable for Black Rockfish, both because it is a state fishery management boundary and because the Columbia River plume is likely to be a natural barrier to the north-south exchange of Black Rockfish adults and larvae, the 2007 assessment of Black Rockfish off Oregon and California (Sampson 2007) differed slightly from Ralston and Dick (2003) in placing the northern boundary at Cape Falcon rather than at the Columbia River. The boundary was changed to avoid overlap with the separate northern assessment (Y. W. Wallace F. R. aand Cheng and Tsou 2007) and to simplify the process of assembling historical commercial landings data, which are largely available in terms of Pacific Marine Fisheries Commission (PMFC) statistical areas. The northern boundary of PMFC Area 2C is at Cape Falcon (Figure 1). Given the spatial resolution of the historical commercial fishery data, it is very problematic to estimate the catch of Black Rockfish taken north of Cape Falcon but south of the Columbia River.

During a preliminary workshop in April 2015 (Council 2015), to discuss approaches for assessing Black Rockfish, China rockfish (*S. nebulosus*), and kelp greenling (*Hexagrammos decagrammus*), it was agreed that the assessments for these nearshore species should at a minimum be spatially stratified with boundaries at the CA/OR border (42°00' N latitude) and the OR/WA border (46°16' N latitude). Such a spatial stratification would be consistent with two ideas: (a) these nearshore species do not exhibit much adult movement and (b) exploitation and management histories have varied significantly among the three states. Together these features would likely create appreciable state-to-state differences in age composition for each of the three species. Stock assessment teams were advised that they could use geographic strata that were finer than the state level if there were data to support such an approach (Figure 1).

At the same nearshore stock assessment workshop, it was agreed that recreational catch histories for the stocks of Black Rockfish should be assembled on the basis of port of landing rather than location of fish capture, even though fishing vessels landing their catches into a port in one state might have captured fish in waters off a neighboring state.

Accounting for location of capture is very problematic for recreationally caught fish and for commercial catches taken with non-trawl types of gear (e.g., hook-and-line), for which there are no or very limited logbooks that report fishing location. For these regional assessments the commercially caught Black Rockfish were apportioned to assessment region based on the port of landing, with the exception of trawl caught fish landed into Astoria, OR. Most of these fish were assumed to have been caught off Washington and most of the trawl landings into Astoria were therefore included with the catch history for the Washington assessment region. Details are provided below in Section 2.1.1.1 The PacFIN Era (1981 to 2014).

## 1.2 Life History

Adults tend to occur in schools over rocky structure at depths less than 40 fathoms, and sometimes feed actively on or near the surface. They feed on a wide variety of prey including zooplankton, krill, mysids, sand lance, and juvenile rockfish, and are subject to predation by lingcod and marine mammals (Milton S. Love, Yoklavich, and Thorsteinson 2002).

Although tagging studies have documented some individuals moving long distances (several hundreds of miles), the vast majority of recaptured individuals were found close to the areas of initial capture and tagging (Culver 1987; Ayres 1988; Wallace F. et al. 2010; Starr and Green 2007). Results from a 2004-05 study off Newport, OR of 42 Black Rockfish implanted with acoustic tags indicated that all but seven fish remained within range of a 3 x 5 km array of acoustic receivers during one full year of monitoring and had relatively small home ranges that did not vary seasonally (S. J. Parker et al. 1995). Green and Starr (2011) report similar findings from a study in Carmel Bay, CA of 23 acoustically tagged Black Rockfish. The extensive Washington state tagging study also supported low movements for most individuals, with some exceptional movements recorded (Wallace F. et al. 2010).

Like all members of the genus *Sebastodes*, Black Rockfish have internal fertilization and bear live young approximately two months after insemination. Black Rockfish are quite fecund, with a six-year-old female annually producing about 300,000 embryos and a 16-year-old producing about 950,000 embryos (S. J. Bobko and Berkeley 2004). Recent studies have demonstrated that the relative number and quality of larvae increase with age in female Black Rockfish (S. A. Berkeley, Chaoman, and Sogard 2004; Hixon, Johnson, and Sogard 2014a). Parturition of larvae occurs during winter (Echeverria 1987) and larvae and small juveniles are pelagic for several months to a year (Boehlert and Yoklavich 1983). Settlement occurs in estuaries, tide-pools, and in the nearshore at depths less than 20 m (Stein and Hassler 1989).

Black Rockfish begin recruiting to nearshore fisheries at 3-4 years of age, corresponding to a fork length of about 25-30 cm, and 50% of females attain maturity at about 6-8 years, corresponding to a fork length of about 38-42 cm. Adult female Black Rockfish grow 3-5 cm larger than males, with a few females attaining fork lengths greater than 55 cm.

### **1.3 Ecosystem Considerations**

No formal ecosystem considerations have been made given the lack of data for such an undertaking. Differences in growth though time have been considered in the model specification in the Washington model. Though the mechanism is not specified, this could certainly be due to process error driven by environmental conditions.

### **1.4 Historical and Current Fishery Information**

Black Rockfish are harvested by a wide variety of fishing methods including trawling, trolling, and hook-and-line fishing with jigs and long-lines. Although Black Rockfish have never been a dominant component of any commercial fisheries, they are important as incidental catch in the troll fishery for salmon and the troll and jig fisheries for groundfish. With the decline of salmon fishing opportunities in the late 1970s and early 1980s Black Rockfish became a vital target of marine recreational fisheries in Oregon and Washington, especially during periods of restricted or slack fishing for salmon, halibut, and tuna.

Black Rockfish are also an important component of the recreational fisheries in northern California but are of less significance south of Cape Mendocino due to their reduced prevalence compared to other species. Since 1990 annual recreational harvests of Black Rockfish have averaged 229.6 tons off California, 304.4 tons off Oregon, and 272.5 tons off Washington. Commercial annual harvests by non-trawl gear types during the same period averaged 44.6 tons in California, 62.0 tons in Oregon, and 14.7 tons in Washington. Harvests by trawl on average during this period have been less than 19.3 tons annually for all three states combined.

Removal histories have been a significant axis of uncertainty in the past assessments of Black Rockfish. Because of concerns about the effects of initial equilibrium assumptions on the level of depletion estimated in the preliminary base model, the 2003 Stock Assessment Review (STAR) panel worked with the Stock Assessment Team (STAT) to develop a catch history that avoided the need to assume historical catch and equilibrium conditions in the first year of the assessment. The assumed catch reconstruction began in 1946, ramping up from zero in 1945 and all prior years. In hindsight, this may not have been a good assumption, as indicated by the following text from (Cleaver 1965) that describes catches of rockfish from 1941 to 1949 in Oregon.

“The rockfish are caught by otter trawl and long-line gear. The principal species caught by the otter trawl are the Black Rockfish (*Sebastodes melanops*); green or yellowtail rockfish (*S. flavidus*); red or orange rockfish (*S. pinniger*); and rosefish (*S. alutus*). The landings of rockfish (all species) rose rapidly during the war from 1,301,400 pounds in 1941 to a peak of over 17,000,000 in 1945. Subsequently the landings fell rapidly because of decreased demand and leveled off at about 4,000,000 per year in 1949.

Cleaver (1965) also states, in an introductory section on Bottom Fisheries, that the “otter trawl fishery accounts for at least 95 percent by weight of the bottom fish landings.”

That Black Rockfish is one of only four species that Cleaver (1965) identifies as composing the large landings of rockfish in Oregon (most of which was actually taken off of Washington waters) during WWII suggests that Black Rockfish were not a trivial fraction of the large catches taken during the 1940s. One might also suppose that the otter trawl fishery took a large portion of the landings of Black Rockfish. Cleaver’s statements are certainly at odds with the catch reconstruction developed in the previous assessments.

It seems that Black Rockfish were also landed in appreciable quantities in California during the 1940s. Black Rockfish was identified by scientific name as one of the “half-dozen of the larger and more abundant species [that] make up over half of the annual California commercial poundage landed” (Anon. 1949).

A major task for the 2007 assessments of Black Rockfish in was developing a plausible reconstruction of historical landings of Black Rockfish and exploring the consequences of those landings. For the current set of assessments catch histories from the past assessments have been reconsidered. Formal catch reconstructions have been conducted in California (Stephen Ralston et al. 2010) and Oregon (Karnowski, Gertseva, and Stephens 2014), but even those relatively newer attempts were reconsidered in light of contributions from state agencies. For this assessment, Washington provided a first step in an approach to provide a reconstructed historical catch time series for a stock, something needed for all species in the state’s waters.

## **1.5 Summary of Management History and Performance**

Prior to 2000 the Pacific Fishery Management Council (PFMC or Council) managed the fishery for Black Rockfish as part of the *Sebastodes* complex, with no separate Acceptable Biological Catch (ABC) or Optimum Yield (OY) for Black Rockfish. In 2000 the Council established an ABC of 1,200 mt for Black Rockfish caught north of Cape Mendocino (in the Eureka, Columbia, and Vancouver INPFC statistical areas), but left Black Rockfish south of Cape Mendocino as part of the “other rockfish” category. For 2001 through 2003 the ABC for Black Rockfish caught north of Cape Mendocino was 1,115 mt annually, and Black Rockfish south of Cape Mendocino remained part of the “other rockfish” category and without a separate ABC or OY.

Regulation of the Black Rockfish fisheries by the PFMC prior to 2004 was accomplished primarily by trip limits for commercial fisheries and bag limit restrictions for recreational fisheries, with different limits applying in different geographic regions (see Table 1 in S. Ralston and Dick (2003)). Some other important regulations include the following.

- 1953: California prohibited trawling within three miles of shore.
- 1995: The commercial hook-and-line fishing in Washington state waters (0-3 miles) was closed to preserve recreational fishing opportunities and avoid localized depletion; the closure was extended to trawlers in 1999. Oregon established Black Rockfish management areas with reduced daily commercial fishery trip limits in area near ports with large recreational fisheries.
- 2000: Black Rockfish began to be managed by the Council as a minor nearshore species. Commercial trip limits were significantly reduced, with specific restrictions applying to Black Rockfish. California instituted seasonal closures for commercial and recreational fisheries inside 20 fathoms, reduced the bag limit for rockfish from 15 to 10 fish, and limited recreational gear to one line with three hooks.
- 2002: California adopted a Nearshore Fishery Management Plan and began more active management of nearshore fisheries including the use of seasonal, regional, and depth-specific closures. Oregon adopted an Interim Nearshore Fishery Management Plan in anticipation of increased pressure on nearshore stocks due to reduced fishing opportunities for groundfish in federal waters. Regulations included fishing-sector specific caps on retained harvests, set approximately at the levels attained in 2000.
- 2003: The Council established Rockfish Conservation Areas (RCAs) to control catches of overfished rockfish species, and large portions of the shelf were closed to fishing. Differential trip limits were applied north and south of a management boundary at 40°10' N. latitude for nearshore *Sebastodes* species. Nearshore permittees in California became subject to depth restrictions consistent with the shoreward non-trawl RCA boundary. In California the commercial and recreational fisheries for rockfish were closed early.
- In 2004 and 2005: the sport fishery in Oregon closed in September 2004 due to early attainment of the state’s limit for sport-caught Black Rockfish. This was the first time

that the sport rockfish fishery in Oregon had not been open all year. In 2005 it closed early again.

- In 2008 the groundfish trawl fishery was closed in Washington from the seaward RCA boundary to the shore north of  $48^{\circ}10' N$ . latitude to address increased encounters with yelloweye rockfish and canary rockfish.

In recent years California, Oregon and Washington regulations for the marine sport fisheries, which has been the major source of mortality on Black Rockfish, have become quite complicated and variable through time. Tools for regulating the sport fishery include closed areas, depth restrictions, seasonal closures, and bag limits.

California had no recreational bag limit for rockfish until 1990 when a 15 fish per day per angler limit was implemented. In 2000 the limit was reduced to 10 fish per day for each angler's combined bag of rockfish, cabezon and greenling. The fishing season was year-round prior to 2000 and since then has been variable by state management area. There were no gear restrictions prior to 2000. In 2000 anglers were limited to fishing one line with three hooks. Since 2001 they have been restricted to one line with two hooks. There is no minimum size limit for Black Rockfish.

Oregon had no recreational bag limits for marine fishes until 1976 when the state established a 25-fish limit. In 1978 the state established a daily limit of 15 fish for each angler's combined bag of rockfish, cabezon and greenling, which stayed in effect until 1994 when the state established a 10-fish-per-angler daily bag limit specifically for Black Rockfish. Following the early closure of the fishing season for Black Rockfish in 2004, the daily bag limit for Black Rockfish was dropped to 5 fish at the start of 2005 but was increased in-season to 6 fish. The per-angler daily bag limit was 6 fish during 2006 and 2007, 5 fish at the start of 2008 and increased in-season to 6 fish, 6 fish at the start of 2009 and increased in-season to 7 fish where it has remained since.

The goal of Oregon's sport fishery management is to maintain year-round fishing opportunities. In-season adjustments to regulations can be made more restrictive or less restrictive, depending on circumstances and the prospects for early attainment of harvest caps. Seasonal depth restrictions (e.g., inside 30 fathoms April 1 to September 30) are one tool used regularly in recent years to control the fishery, driven largely by the need to avoid bycatch of the primary rebuilding species, canary rockfish and yelloweye rockfish.

Washington had a recreational daily bag limit for rockfish (all species) of 15 fish per day from 1961 to 1991, 12 fish per day from 1992 to 1994, and 10 fish per day from 1995 to 2015. The bag limit for blue rockfish plus Black Rockfish in Marine Area 4B (Neah Bay) has been 6 fish per day since 2010. Fishing seasons for groundfish species are structured to provide year-round fishing opportunities, if possible. Depth restrictions vary by state management area, being more restrictive in the north compared to the south due to higher encounter rates with overfished yelloweye rockfish and canary rockfish. There is no minimum size limit for Black Rockfish.

In 2004 the coastwide ABC established for Black Rockfish was based on the projected yields derived from separate northern [wallace\_status\_1999] and southern [ralston\_status\_2003] stock assessments (Table 1). The northern assessment covered the Washington coast and the northernmost portion of Oregon, from Cape Falcon to the WA/OR border at the Columbia River. The southern assessment covered the entire Oregon coast and the California coastline north of Point Arena.

To account for the spatial overlap of the two assessment areas, 12% of the projected yield from the northern assessment was transferred to the southern region when deriving the coastwide ABC and OY values of 1,315 mt for 2004. State-by-state harvest guidelines were established: 326 mt for California, 450 mt for Oregon, and 540 mt for Washington. A similar approach was taken in 2005 and 2006 and the OY for the area south of the Columbia River was apportioned to harvest guidelines for California and Oregon based on a 42:58 split. The basis for this apportionment is unclear was to support separate harvest guidelines for each state. The catches were apportioned by the average catch share by state in the 1985-2002 period (Council 2004).

In all years when there has been an OY specified for Black Rockfish the estimated catch has been less than the OY, except for 2003 when the estimated coastwide catch exceeded the ABC for north of Cape Mendocino. In 2003 the estimated coastwide catch exceeded the OY by 183 mt for the region north of Cape Mendocino, but 290 mt of this coastwide catch was recreational harvest taken south of Cape Mendocino.

## 1.6 Canadian and Alaska fisheries

Black Rockfish is a “Non-Quota” species in the Department of Fisheries and Oceans Management Plan, and is not formally assessed in nearshore Canada waters (Fisheries and Canada 2014).

Add Alaska assessment text here.

## 2 Data and Model Inputs

A description of each data source is provided below (Figure 2).

## 2.1 Fishery-Dependent Data

### 2.1.1 Commercial

**2.1.1.1 Landings** The systems along the U.S. West Coast for monitoring commercial fishery landings in the past did not keep track of the landings of individual rockfish species, largely because many rockfish species have similar market characteristics and therefore were landed as an unsorted mix of species. Black rockfish in particular, which are a nearshore species and much less abundant than many of the offshore rockfish species, were generally landed in mixed-species categories and not required to sort into its own market category until 2006. As a consequence, the historical records do not provide a detailed accounting of the landings of black rockfish. The basic approach taken to develop the landings series in this assessment (as in past assessments) was to apply values for the proportion of black rockfish sampled in mixed-rockfish landings. Data on the proportions of black rockfish are sparse, with the consequence that the landings reconstructions are highly uncertain.

Commercial fishery landings of black rockfish in Washington are compiled from a variety of sources including PacFIN, agency reports, historical fish ticket information and communication with agency personnel (Table 48). Since 1935, commercial fishing vessels have been required to submit a fish receiving ticket (“fish ticket”) for each landing. Rockfish landings from domestic fishers are usually reported in mixed-species market categories, and are routinely sampled for species composition by port samplers. The information required on the ticket and sampling methods have changed through time. Due to these changes, we separated the data into three time periods 1935-1969, 1970-1980, and 1981-present based on the level of detail available in the data for compiling landing history in Washington for this assessment. Comparisons of the commercial catch in each fishery for the current and previous assessments (Figure X).

**2.1.1.1.1 Years 1935 to 1969** Although the original paper fish tickets are no longer available for this period, WDFW recently digitized the daily aggregated data from printed reports, to assist in reconstructing the commercial groundfish fishery landings history for Washington. These daily aggregated data reports contain summaries of daily catches for port-groups by gear and area fished. The data are available for 1935 and for 1949-1969, and were used as the basis for the black rockfish catch reconstruction for this time period.

During this period, mixed-species, nominal market categories were typically used for reporting of the aggregated data. Market categories such as “red rockfish”, “black rockfish” (BLK1), and “unidentified rockfish” (URCK) are typical on fish tickets during this time, lumping all red colored fish and black colored fish into these categories for reporting. For bottom trawl gears, the BLK1 market category consisted of mostly yellowtail rockfish and silvargrey rockfish (Greg Lippert, pers. comm.). To split the black rockfish landings out of the BLK1 market category, we assumed 10% of the BLK1 landings were *S. melanops* (BLCK). We

further assumed that no other nominal market categories in the trawl fishery contained *S. melanops* (see table below).

For the commercial jig and troll fisheries, rockfish were landed in the unidentified rockfish (URCK) market category. No species composition samples are available during this time, so we assumed 85% of URCK landings were *S. melanops*, which matches the species composition data from the 1985-1989 commercial jig fishery. These estimates were also supported by interviews with port samplers active during portions of this period. The rockfish caught by troll gears composed of mostly yellowtail and black rockfishes. Wright (1967) reported rockfish species composition of the troll landings by port. We assumed 80% of URCK caught off central Washington were BLCK and 20% for northern Washington landings.

**2.1.1.1.2 Years 1970 to 1980** Original fish ticket data were used for commercial catch estimate during this period. Fishing areas were better defined and reported during this period; there were no longer interstate areas due to the introduction of current management areas, with a boundary line at the OR/WA state border. However, issues with URCK market category remained. Species composition sampling of URCK were conducted for trawl and jig fisheries but not for salmon troll and the “other gears” gear types.

To estimate the trawl landings of black rockfish in the category URCK, we applied the current WDFW species composition algorithm by gear, port, and quarter. If no species composition samples were taken during a quarter, we first borrowed annual composition data for the gear/port group. If those data were not available, a coastwide annual composition for the particular gear type was applied. There was no borrowing of composition information across gear groups or years.

The commercial jig fleet operates in nearshore waters and black rockfish is the dominant component of the URCK landing for this gear type. Species composition sampling was not conducted during the 1970-1980 time period. Based on the samples collected in the 1980s, we assumed that black rockfish made up 80% of the total rockfish landed by the jig fleet. For the troll fishery, the same proportions as for the pre-1970 time period were applied.

Rockfish (URCK) were also landed in small amounts by other commercial fleets, such as fixed gears and salmon troll. The fleets in the 70s and 80s predominantly targeted sablefish and halibut in waters too deep for black rockfish. Port samplers did not recall observing any black rockfish in the fixed gear landings (James Beam and Greg Lippert, pers. comm.). Therefore, we assumed fixed gear landings were negligible. For URCK landed by the salmon troll fleet, the majority of troll landings was yellowtail rockfish with smaller numbers of widow, canary, and black rockfish (Wendy Beeghley and James Beam, pers. comm.). We assumed that 10% of the troll rockfish landings were black rockfish for 1970-1980.

**2.1.1.1.3 Years 1981 to the Present (the PacFIN era)** Commercial landings data for the modern era (1981 to present) are taken from the Pacific Fishery Information

system (PacFIN), which is a central repository for U.S. West Coast groundfish landings and auxiliary information collected by the three state fishery agencies and other agencies. A description of basic state data collection systems and overview of PacFIN is provided in Sampson and Crone (1997). Updated dockside sampling protocols and data processing procedures for Washington are described in Tsou et al. (2015) and Tsou and Weyland (2015). Rockfish landings from this period are pulled from the PacFIN comprehensive catch table. Landings in this table are the products of nominal landings, as well as area and species compositions. For the remaining URCK in this table, we applied a coastwide annual composition for each gear, as described above. After this step, there are still small amounts of URCK for trawl and setline gears. These landings are not included in this assessment.

For the jig-gear fishery, dockside sampling was conducted by the WDFW Ocean Sampling Program (OSP) during 1985-1991. These species composition data are not available in PacFIN. For landings during 1985-1991 the URCK species compositions were stratified by year and port. For other years, species compositions were stratified by port only. For jig-caught fish landed into Seattle annual species compositions from Neah Bay were applied (Table 49) because there was no port sampling in Seattle. The URCK market category was used until 2000, after which it was replaced by the Slope, Shelf, and Nearshore rockfish market categories. The commercial nearshore fishery was closed in 1999, so starting in 2000 there are negligible black rockfish landings in any market categories. In 2005 mandatory sorting was established for black rockfish, so all black rockfish landed should be recorded on fish tickets in the BLK1 category.

To assign URCK commercial salmon troll landings, we used the same reasoning assumption as applied to earlier periods (see 1970-1980) to assign 10% of the URCK landed in the salmon troll fishery to black rockfish. After a complete nearshore closure in 1999, black rockfish landings have been negligible.

It has been and continues to be a common practice for Oregon fleets to fish off Washington coast and land the catches at Oregon ports. Although the separate geographic assessments by state region would ideally have strict geographic separation of landed catch to the location of capture, this is not possible to accomplish because information on the fishing location is generally unavailable. Until recently logbooks that report area of capture were only available for landings by the groundfish trawl fleet. Oregon has required a logbook for commercial vessels participating in its nearshore fishery since 2004.

Staff from the Oregon Department of Fish and Wildlife (ODFW) used species composition samples collected during 1976 to 1993 to conduct an analysis of the spatial distribution of black rockfish landed at Astoria, OR. Astoria is the northernmost port in Oregon and is located near the mouth of the Columbia River, which forms the boundary between Oregon and Washington. The portion of aggregated rockfish landed pounds that were taken north of the Columbia River (i.e., from waters off Washington) was 98.6%. This percentage was applied to all historical trawl landings of rockfish at Oregon's Columbia River District ports prior to 1976. It was assumed 14.1% of the aggregated rockfish being Black in the 2015 assessment (Cope et al. 2016). This percentage is much higher than the values used for

Washington catch reconstruction. Therefore, we recalculated the portion by using Washington historical species composition data not available in PacFIN for pre-1981 and data available in PacFIN for 1981 to 1986. The revised proportions of black rockfish in the aggregated rockfish landings are 3% and 4% for pre-1981 and 1981-1986, respectively. Non-trawl landings into Astoria were assumed to have been caught from Oregon waters, same assumption as used in 2015 assessment.

Starting in 1994 black rockfish landed into Oregon were legally required to be sorted and sold in a separate black rockfish market category and were also reported as separate retained catches in the mandatory trawl logbooks. Based on the retained catches reported in the logbooks, the estimated proportion of the trawl-caught black rockfish that were caught from off Washington and landed into Astoria ranged from 65 to 100 percent. These black rockfish are accounted for in the Washington regional assessment (Table X).

The Washington Department of Fish and Wildlife (WDFW) provided commercial fishery landings based on fish ticket records of black rockfish harvested off Oregon by vessels landing at ports in Washington. Landings were less than 1 mt per year for the period 1971 to 2014; therefore, all landings to Washington ports were assumed to occur in waters off Washington in this assessment.

**2.1.1.2 Foreign Fishery Catches of Black Rockfish** Rogers (2003) developed catch reconstructions for removals by foreign trawlers operating off the U.S. West Coast during the late 1960s to mid-1970s. Although this study reports that Japanese vessels operating in the Columbia and Eureka statistical areas (Oregon and northern California) caught substantial amounts of black rockfish, with cumulative catches of more than 500 mt over 10 years, it seems very unlikely that foreign vessels could have operated sufficiently close to shore to catch appreciable amounts of black rockfish. This assessment does not include Rogers' estimates of foreign fleet removals of black rockfish.

## 2.1.2 Recreational Removals

Comparisons of the catch in each recreational fishery for the current and previous assessments are in Figure X.

The Washington recreational catch history of black rockfish was reconstructed using several direct and indirect records of black rockfish catch (Table X). All primary sources report catch in numbers of fish. As sources have been modified and re-evaluated, a completely new catch reconstruction for Washington was developed for 2015 assessment. This catch history was updated to include 2015-2022 estimates in this assessment.

### **2.1.3 Estimated Discards**

In the previous assessment, commercial discards were not accounted for due to the information provided by the West Coast Groundfish Observer Program (WCGOP) at that time, showing about a 1% discard rate in their survey. We evaluated the WCGOP estimates of black rockfish discards from 2002-2013, which showed a total of 32.2 mt in estimated discards and total landings of 2042.5 mt coastwide, resulting in a rough discard rate estimate of 1.58%. This amount of discards was included in the CA HKL non-live fishery landings, going back to 1916, and in the OR HKL non-live fishery landings to 1892. Given the minimal amount of discards, no further depth-dependent mortality estimates were evaluated for Oregon and California and this discard rate was added to the total commercial removals. Parker et al (2006) concluded that semi-pelagic, vertically mobile species, such as black rockfish, show less barotrauma; hence these estimates could be slightly overestimated.

Washington recreational discard estimates were not available until 2002. Numbers of discarded-by-depth black rockfish were estimated using the same catch expansion algorithm for landed catch. Surface release mortalities adopted by the Groundfish Management Team (GMT) in their death-by-depth matrix (11%, 20%, 29%, and 63%) were then applied to the number of release black rockfish for each of 4 release depth bins (0-10 fm, 11-20 fm, 21-30 fm, and >30fm), respectively. Total dead released black rockfish were then summed across each depth bin. The average weights of discards were assumed to be the same as the average weights of landed and multiplied by the number of released dead to get total dead in metric tons. For pre-2002 release, proportions of releases based on a ratio estimator using 2003-2007 data were applied. For the split between charter and private vessels, the same algorithm used for splitting retained catch was applied. The overall average discard rate in the recreational fisheries was 1.37%. There was no information on Washington commercial discards, so the rate of 1.37% (same as the historical recreational discards) was also applied to the entire commercial time series. This low rate was similar to discard rates estimated in the other states.

## **2.2 Size and Age Composition Data**

Fish length measurements, primarily from the recreational fishery, are one of the major sources of data for this assessment.

### **2.2.1 Length and Age Sample Sizes**

The level of commercial fishery sampling for black rockfish has been erratic, with almost no samples taken in Washington until the early 1990s (Figure X).

**2.2.1.1 Multinomial Sample Sizes** Initial input values for the multinomial samples sizes determine the relative weights applied in fitting the annual composition data within the set of observations for each fishery. The initial input values in this assessment were based on the following equation developed by I. Stewart and S. Miller (NWFSC), and presented at the 2006 Stock Assessment Data and Modeling workshop.  $\text{Neff} = \text{Ntrips} + 0.138 * \text{Nfish}$  if  $\text{Nfish}/\text{Ntrips} < 44$   $\text{Neff} = 7.06 * \text{Ntrips}$  if  $\text{Nfish}/\text{Ntrips} \geq 44$

Tuning of the assessment model involved multiplying the input sample sizes for each fishery by an adjustment factor to achieve a better balance between how well the model fit the set of composition data and how well it should have fit the data given the sample sizes underlying the data.

**2.2.1.2 Length Compositions** The length data for the assessment model were tabulated into 2-cm length bins ranging from 10 cm to 64 cm, with accumulator bins at each end.

The length composition data indicate some general differences between the three fishery types, with the trawl fisheries producing the largest fish, the recreational fisheries producing the smallest fish, and the non-trawl fisheries producing fish of intermediate length. There is little evidence in any of the length composition data of distinct modes or successions of modes from one year to the next that might represent strong year-classes.

#### **2.2.1.2.1 Washington Length Compositions Commercial**

The biological data for the commercial fishery were extracted from PacFIN on April 24th, 2015. These data are from trawl and non-trawl (hook-and-line) fisheries; there is no live-fish fishery off Washington. Of 9009 records (each representing a single specimen), 4989 were from the trawl fishery (Table X).

Length composition data are reported either in fork length or total length. Fork lengths are preferred; where they are missing the total length is used. These data are expanded to reduce the effect of non-uniform sampling effort (Table X). The expansions are by weight, catch/sampled catch; first on a per-trip level, and then on a per-year, per-fishery level. Expansion factors have a minimum value of 1, and are capped at their 90th percentile value. The final sample size is the product of the two expansion factors, which is then capped at its 90th percentile value. The final sample sizes for the WA biological data ranged from 1 to 389.7, with a median value of 10.4.

The data were stratified by gender and fishery. The final sample sizes were stratified and summed by length bin (10 cm to 64 cm bins, 2 cm in width), and an effective sample size is computed from the number of trips and number of fish each stratum represents, according to the Stewart and Miller method for multinomial fishery data. Unsexed fish were treated as above, but entered as a separate dataset.

## Recreational

The Washington Department of Fish and Wildlife biological database provided sampled length data from the recreational fishery for sexed and unsexed samples for years 1979-2014. Sexed samples were the largest sample sizes and covered most years (Table 53). Composition data were used as collected (i.e., not expanded). Effective sample sizes were based on unique “sequence” sizes, which is roughly equivalent to a trip.

**2.2.1.2.2 Tagging data** The Washington Department of Fish and Wildlife provided sampled length data from the tagging survey for sexed and unsexed samples for years 1981-2014 (Table 54). Unsexed and sexed data were generally available in different years. Like the recreational data, composition data were used as collected (i.e., not expanded) and effective sample sizes were based on unique “sequence” sizes, which is roughly equivalent to a trip.

**2.2.1.3 Age Compositions** Commercial age composition data were a subset of the length data, 7984 records in total, and were expanded in the same manner as the lengths (Table 55). Ages were stratified by fishery and gender, and binned in 1-year bins from 0 to 45, with additional bins 50 and 55. As for the length compositions, the unsexed fish (29 samples) were treated as a separate dataset. Samples were also available by sex for several years in the recreational data (Table 56).

Age-at-length compositions were not expanded; the final sample sizes were the sum of all individual age samples per length bin. For all three models, the ages were modeled as conditional age-at-length.

## 2.2.2 Abundance Indices

Age and length composition data by themselves do not provide sufficient information to reliably determine trends in stock abundance and biomass. Most assessments of U.S. West Coast groundfish stocks rely on estimates of stock biomass from research trawl surveys to provide information on biomass trends, but black rockfish are very infrequently caught in any of the bottom trawl surveys, which have a limited coverage of shallow nearshore waters (none of the surveys have ever been conducted in waters shallower than 55 m).

**2.2.2.1 Dockside catch-per-unit-effort for Washington** The WDFW provided recreational dockside fisheries data from 1981 through 2022 for consideration in this assessment. Data were collected at the trip level, with the number of landed fish and the number of anglers on each vessel being recorded. The amount of time fished by each angler was not recorded. This data had also been provided for the 2015 Black Rockfish Assessment where

authors used the Stephens-MacCall method (Stephens and MacCall 2004) as an objective approach for identifying trip records of catch/effort data, and several covariates including year, month, boat type, area, daily bag limits and depth restrictions. For the 2015 Assessment data were modeled using a delta-GLM approach, where the catch occurrence (binomial) component was modeled using a logit link function and the positive catch component was modeled using either lognormal or gamma distributions.

The recreational dockside data was considered for use in this assessment, however, management measures implemented over the past several decades impeded extracting a reliable signal for use as abundance indices. In 2003, management restricted summer fishing depths to shallower than 20-fathoms in WDFW marine areas 3 and 4, and in 2006 modified this depth restriction to 30-fathoms in marine areas 2, 3, and 4. Additionally, daily rockfish limits were 15 fish from 1981-1991, 12 fish from 1992-1994 (except in area 1 where it remained at 15), 10 fish from 1995-2016, and a reduction to 7 fish from 2017-2022. The effects of these management changes to CPUE of black rockfish could not be reconciled with changes in the abundance indices and therefore this dataset was not used in this assessment.

## 2.3 Fishery-Independent Data

### 2.3.1 Abundance Indices

**2.3.1.1 Nearshore Survey CPUE for Washington** Fishery-independent data available for this assessment came from two distinct WDFW research projects. The first was the Black Rockfish Tagging Program that was initiated in the early 1980s and provided CPUE of black rockfish captured for tag releases primarily off the central coast of Washington. The second data set was from the standardized Coastwide Rod-and-Reel Survey that began in 2019. While technically independent from one another, these two fishery-independent data sources had comparable components allowing the data to be considered in two different ways.

The Washington Black Rockfish Tagging Program was initiated in 1981 with the primary objective of collecting biological information such as growth and movement. The program continued through the 1980's with modifications to protocols including scope, primary objectives, and tagging methods. Details of this extensive program can be found in Wallace et al. (2010). Beginning in 1998, the geographic range of sampling was constrained, and effort was primarily focused on rocky habitats during spring months off the central coast of Washington in Marine Catch Area 2 (MCA 2). Sampling crews consisted of 8-15 anglers using rod-and-reel rigged with one to three single hook jigs per line. During the sampling process, catches of black rockfish per angler minute were recorded, as were covariates month and MCA. Black rockfish were targeted during each trip. In 2010, the WDFW expanded the tagging program to include additional nearshore bottomfish species and increased the geographic disbursement of tags to the entire 180-mile-long Washington coastline. The program retained a primary objective of targeting black rockfish during the spring tagging efforts.

Tag release data collected from the Tagging Program were used for constructing abundance indices in all previous assessments for Black Rockfish off Washington coast. The 2009 stock assessment review panel considered tagging q as one of the major uncertainties due to the spatial coverage of the tag-release sites focusing mainly on central Washington coastal waters. The 2015 Stock Assessment Review panel recommended future research to include definition and measurement of black rockfish habitat, the development of a coastwide fishery-independent survey for nearshore stocks, and improving CPUE standardization protocols [panel 2015].

Beginning in 2010, the WDFW started to address STAR panel comments and recommendations. In 2011, geographic coverage of the Tagging Program was expanded by adding more stations to the northern and southern coastal waters, while black rockfish remained the targeted species. In 2014, the WDFW decided to terminate the historical Black Rockfish Tagging Program and started to plan for a survey to include other nearshore groundfish species besides black rockfish, such as China, quillback, copper, lingcod, cabezon, and kelp greenling. A series of pilot studies were initiated for site selection, gear testing, and survey timing. The culmination of these efforts from 2014-2018 was the standardized nearshore Coastwide Rod-and-Reel Survey which was initiated in 2019. Since 2019, the WDFW has conducted an annual spring rod-and-reel survey targeting semi-pelagic bottomfish at 125 fixed stations (e.g., index stations) off the Washington coast. At each station, 5 anglers deploy standardized fishing rigs consisting of 2 shrimp flies and drift over the rocky habitat 3 times. Each drift is approximately 8 minutes long. Details regarding sample frame, site selection, and survey methodology for this survey can be found in the Groundfish Subcommittee of the Science and Statistical Committee Visual-Hydroacoustic Survey Methodology Review and Hook-and-Line Survey Workshop details from September 2022 (Reference document??).

For this assessment abundance indices using data from the two sampling programs described above were evaluated in two ways. First, data from the two projects were evaluated independently. The Black Rockfish Tagging Program tag release data were filtered for sampling events from 1998-2018 in MCA 2 during the spring months (March-July). This time series had the most consistent survey objectives and sampling protocols during the Program. Because black rockfish were explicitly targeted during these trips, no other filters were applied. Catch of black rockfish per angler hour was the response variable, which was an improvement from the past assessment, with covariates year and MCA. CPUE data analysis was done using a hurdle negative binomial regression model. Figure XX. shows the abundance estimates and 95% confidence intervals for each year. The standardized nearshore Coastwide Rod-and-Reel Survey data were also analyzed using a hurdle negative binomial regression model for data from years 2019, 2021, and 2022. Data from 2020 were excluded because only index stations in MCA2 were sampled prior to the survey being cancelled due to the Covid-19 pandemic. Covariates for these analyses included year, MCA, and depth. Figure XX. shows the abundance estimates and 95% confidence intervals for each year.

Secondly, data from the two projects were evaluated concurrently. Because sampling for both projects targeted black rockfish using rod-and-reel methods on rocky habitats, CPUE data for black rockfish was combined. Data were filtered for sampling only in MCA 2 during

spring months. Additionally, because of changes in survey designs from 2014-2018, only sets that were within 1km of any 1998-2013 central coast Tagging Program set in MCA 2 were included. The 1km buffer eliminated most sets done on sand or areas that would not have been fished in a tagging objective set. The index calculation did not include a depth covariate as depth was not recorded during the Tagging Program sampling. Data were analyzed using a hurdle negative binomial regression model for years 1998-2022 (no sampling occurred in MCA 2 in 2008 or 2017). Figure XX. Shows the abundance estimates and 95% confidence intervals for each year.

Model runs investigating the sensitivity to independent and combined indices for the fishery-independent research sampling projects were considered. Results of the sensitivity runs found no difference in using one time series or keeping them separate. We choose to keep them separate in the base model as there was a noticeable drop in the transition between the two surveys, thus allowing for a different catchability coefficient to be applied to each time period. It also supports the use of the nearshore survey and its wider coverage to be applied in future assessments.

**2.3.1.2 Olympic Coast National Marine Sanctuary adult and young of the year (YOY) surveys** Two surveys conducted between 2015 and 2022 from waters within the Olympic Coast National Marine Sanctuary (OCNMS) were provided for the first time. The adult survey uses SCUBA and belt transects to estimate black rockfish abundance, with fish <10cm considered. Detailed description of survey methods and aims are found in Tolimieri et al. (2023) and in a short description (contained in the supplemental materials on this assessment) provided by Ole Shelton (NWFSC), who kindly provided this data for consideration. The adult survey also supplies coarsely binned () length compositions that are used to estimate survey selectivity. The YOY survey is interpreted as an index of recruitment, though admittedly a rough one as it combines yellowtail and black rockfishes because they are indistinguishable visually at that size and age. For the purposes of this assessment, these data are included but not expected to provide strong signals. It is more to see if the trends in these data are consistent with the trends in the overall assessment.

## 2.4 Biological Data and Parameters

The major biological inputs to the models are natural mortality, age and growth parameters, weight-length, maturity and stock-recruitment parameters. The following sections outline the treatment of each section.

### 2.4.1 Natural Mortality

Natural mortality is a critical parameter that drives much of the outcome of stock assessments. This value is not directly measured for black rockfish, so it either needs to be estimated

or fixed in the model. Prior treatments have either used fixed ramps from lower to higher female natural mortality values (0.16 to 0.24 for females (2007 assessment); 0.17 to 0.2 (2015 assessment)) to constant male natural mortality value (0.16 in 2007; 0.17 in 2015). Females rapidly disappear from the population after 20 years of age, whereas males can still be found in their 30 and 40s, with the oldest individuals along the coast aged at 56 years (M. S. Love 1957). Females are rarely found in their 30s and males in their 40s in Oregon.

The reason for the lack of females has been debated for many years. The “hide them” (using age-based selectivity curves to hide older females) or “kill them” (using the above mentioned ramps of death to account for no older females in samples) was specifically considered since the last assessment among researchers from California to Alaska, and it was agreed that the “hide them” hypothesis is the least feasible situation (see Rasmussen et al. (2023) for a specific study that went looking for old females). It was also agreed a constant natural mortality rate should be used for this assessment.

Determining reasonable natural mortality values is also challenging as the quick disappearance of females from the population after 20 years old challenges typical biological assumptions, especially since black rockfishes have been the focus species when developing the theory of big old fat fecund female contributions to spawning output (Stephen J. Bobko and Berkeley 2004; Hixon, Johnson, and Sogard 2014b). In a study confirming the advanced capacity for output of older females (S. A. Berkeley, Chapman, and Sogard 2008) the oldest aged females in the study were under 20 years, so the enhanced reproductive capacity, despite the loss of females after 20 years of age, is still intact.

Using the Hamel and Cope (2022) longevity-based estimator of natural mortality as implemented in the natural mortality tool (2022), the following M values correspond to the longevity estimates:

- 0.108 at 50 years
- 0.135 at 40 years
- 0.180 at 30 years
- 0.216 at 25 years
- 0.270 at 20 years

These provide reasonable bookends for likely natural mortality values for black rockfish. For females, estimates based on the von Bertalanffy growth function range from 0.27-0.32 and for males, 0.34 to 0.38. Those estimates are on the very high side, and thus are not considered further.

Exploratory runs first attempted to estimate natural mortality with not unrealistic, but slightly low, estimates. The base model instead fixes natural mortality to the values from the last assessment (0.17 for females and 0.152 for males), while providing a sensitivity to the estimated M values. A likelihood profile across the above mentioned range of natural

mortality values, but maintaining the above ratio of female to male natural mortality, is also included to explore model sensitivity, as this parameter may be a useful parameter to establish different states of nature for uncertainty analysis.

**2.4.1.1 Age and growth relationship** The length-at-age was estimated for female and male Black Rockfish using data from collections sampling the commercial and recreational fisheries off the coast of Washington (Figure ?? and Figure ??), with all lengths in fork length and all ages in years. Figure 5 shows the predicted von Bertalanffy growth function (VBGF) fits to the data. Females grow larger than males and sex-specific growth parameters were estimated at the following values:

$$\text{Females } L_{\infty} = 51.19 \text{ cm; } k = 0.15; t_0 = -2.50$$

$$\text{Males } L_{\infty} = 47.26 \text{ cm; } k = 0.17; t_0 = -2.99$$

The coefficient of variation of length by age fluctuated around 0.07 to 0.1 for the most well sampled ages and was similar for each sex (Figure ??). When estimated in the models, these same values would often be produced, but it was ultimately determined it is more parsimonious to fix to 0.1 for both sexes. The value for  $t_0$  is also fixed in the base model, as estimation of that parameter lead to extremely high current biomass values.

The estimated VBGF parameters provided initial values for the estimation of growth in the model, as all age and length data are included in the model and parameters  $L_{\infty}$  and  $k$  are estimated. The resultant growth curves estimated by the model are presented in Figure 39. Sensitivity to fixing the growth parameters to the external values, fixing  $t_0$  to 0, and estimating  $t_0$  are explored through sensitivity analyses.

## 2.4.2 Ageing Bias and Precision

Counting ages from ageing structures in long-lived, temperate fishes is challenging. Ages derived from these structures can be hard to reproduce within and between readers (i.e., imprecision), and may not contain the true age (i.e., bias). Stock assessment outputs can be affected by bias and imprecision in ageing, thus it is important to quantify and integrate this source of variability when fitting age data in assessments. In Stock Synthesis, this is done by including ageing error matrices that include the mean age (row 1) and standard deviation in age (row 2). Ageing bias is implemented when the inputted mean age deviates from the expected middle age for any given age bin (e.g., 1.75 inputted versus 1.5 being the true age); ageing imprecision is given as the standard deviation for each age bin (row 2).

Washington Department of Fish and Wildlife has two main readers to assign to the available ages. Reader 1 read samples from the earliest period through 2018 and Reader 2 read samples

from 2019 to 2022. Age bias plots show little bias within and between the readers (Figure ??).

Estimation of ageing error matrices used the approach of Punt et al. (2008) and release 1.1.0 of the R package nwfscAgeingError (J. T. Thorson, Stewart, and Punt 2012). The ageing error matrix offers a way to calculate both bias and imprecision in age reads. Reader 1 is always considered unbiased, but may be imprecise. Bias relative to the primary reader is given for the second or additional readers. Several model configurations are available for exploration based on either the functional form (e.g., constant CV, curvilinear standard deviation, or curvilinear CV) of the bias in the second read or reader or in the precision of the readers. Model selection uses AIC corrected for small sample size (AICc), which converges to AIC when sample sizes are large. Bayesian Information Criterion (BIC) was also considered when selecting a final model. Table 1 provides model selection results of intra reader comparisons for the two readers.

The calculated bias relationships from the best fit model are shown in Figure 9 and confirm small to little bias between readers. Figure 10 shows the imprecision estimates of the best fit models. Each ageing error matrix was then applied to the appropriate time and fleet combination.

#### 2.4.3 Length-Weight Relationship

The length(cm)-weight(kg) relationship for Black Rockfish was estimated outside the model using biological data available from the Oregon commercial and recreational fisheries (Figure 15). The resultant relationship is very similar for both males and females, and is very close also to what is seen in the state of Washington (Figure 16). The estimated length-weight relationship for female fish was  $W=5.24556e-05L^{2.72}$  and males at  $W=2.47904e-05L^{2.91}$ .

#### 2.4.4 Maturation and Fecundity

Black Rockfish maturity was assumed to be based on length, as in past assessments. This assessment used functional maturity instead of biological maturity to describe the maturity schedule. Functional maturity was classified by a more stringent definition of maturity that considered abortive maturation (delayed participation in reproductive event), skipped spawning (mature individuals forgo spawning), and level of follicular atresia as opposed to biological maturity that only considers physiological development. Functional maturity included the biologically mature individuals that were actually expected to contribute to spawning in a given year.

Claire Rosemond (Oregon State University) and Melissa Head (Northwest Fisheries Science Center) provided estimates of both biological and functional maturity for Black Rockfish

sampled in 2014 to 2021 from September through April (the time period that includes yolk development and spawning). Samples were collected for fish caught in Oregon and Washington waters by biologists at Oregon State University, Oregon Department of Fish and Wildlife, and Washington Department of Fish and Wildlife. Biological maturity and functional maturity observations were fitted in separate models. Biological maturity and functional maturity status observations (0 = immature and 1 = mature, n = 644) were fitted in a logistic regression model (`glm` function, family = binomial, link = “logit”) and flexible spline model (Head et al. 2020). The estimated model parameters were used to calculate length at 50% maturity (L50%; Table 2) and maturity ogives (Figure 11). The delta method was used to calculate 95% confidence intervals for estimated L50% in the logistic regression and a bootstrapping method was used to calculate 95% confidence intervals for L50% in the flexible spline model.

A flexible spline model can capture skipped spawning in the maturity ogive by allowing a decreased asymptote from 1.0. There was evidence of skipped spawning in larger size classes and so the flexible spline model was determined to be the best representation of the reproductive biology of Black Rockfish for the sampled time period (Figure 12). The maturity vector input into the model as a fixed relationship is shown in Figure 13. Sensitivity of model output to the use of the biological and functional logistic relationships are explored.

The Black Rockfish fecundity-at-length relationship was provided by E.J. Dick (SWFSC) and based on the work from Dick (2009). The fecundity relationship was estimated equal to  $Fec=1.41e-08L^{4.68}$  in millions of eggs where  $L$  is length in cm. Fecundity-at-length is shown in Figure 14.

#### 2.4.5 Stock-recruitment function and compensation

The Beverton-Holt stock-recruit model (Beverton and Holt 1957) has been the traditional recruitment function for rockfishes and is assumed for black rockfish. Specifically, the re-parameterized Beverton-Holt that uses a steepness parameter defined as the proportion of average recruitment for an unfished population expected for a population at 20% of unfished spawning output (Mace and Doonan) was used in these assessments. This is a notoriously difficult parameter to estimate, thus several attempts to derive a prior of steepness have been attempted (Myers, Bridson, and Barrowman 1995; Dorn 2002). The Thorson-Dorn rockfish prior (developed for use West Coast rockfish assessments) was reviewed and endorsed by the Scientific and Statistical Committee (SSC) in 2017, and is the primary source of information on steepness for west coast rockfishes. The prior ( $h$ ; beta distribution with  $\mu=0.72$  and  $\sigma=0.15$ ) is used in this assessment, but attempts to estimate steepness were not successful, so it is fixed and its influence is explored via a likelihood profile.

#### **2.4.6 Sex Ratio**

No information on the sex ratio at birth was available so it was assumed to be 50:50.

### **2.5 Environmental and Ecosystem Data**

## **3 Assessment Model**

### **3.1 Summary of Previous Assessments and Reviews**

#### **3.1.1 History of Modeling Approaches Used for this Stock**

**3.1.1.1 Black Rockfish South of Cape Falcon** The first stock assessment of black rockfish off Oregon (Stewart 1993), which was limited in geographic scope to the northern portion of Oregon, was a Cohort Analysis based on age composition data collected from fish landed at Garibaldi. The first comprehensive analysis of the black rockfish stock off Oregon and California was by Ralston and Dick (2003), who developed a statistical catch-at-age model using Stock Synthesis. Sampson (2007) used a similar model configuration and approach.

In the 2007 assessment model the data were organized into three basic gear-types (Hook-and-Line, Trawl, and Recreational), the data from Oregon and California were kept separate, and the tuning indices were recreational angler CPUE series based on the same or similar data sources (MRFSS for both states, ORBS for Oregon, and CPFV surveys for California). Fishing effort was measured in terms of angler-days rather than the angler-hours metric used in the current California and Oregon regional assessment models. The 2007 assessment used the ODFW tagging study estimates of black rockfish abundance off Newport as a relative abundance index. Those data were unavailable for the 2003 assessment. The 2007 assessment also used a juvenile rockfish pre-recruit index, which was unavailable for the previous assessment.

The landings data series in the 2007 assessment differed quite substantially from the series developed by Ralston and Dick for the 2003 assessment. Neither of those assessments attempted to account for discards, instead assuming that discards were negligible.

**3.1.1.2 Black Rockfish North of Cape Falcon** Three full assessments for black rockfish, conducted in 1994, 1999, and 2007, modeled the black rockfish population found in coastal waters between Cape Falcon, Oregon and north to the U.S./Canadian border (F. R.

Wallace and Tagart 1994; F. R. Wallace, Hoffman, and Tagart 1999, 1999; Y. W. Wallace F. R. aand Cheng and Tsou 2007). There have been no update assessments for black rockfish resources.

The 1994 assessment utilized a Stock Synthesis model configuration, with two auxiliary data sets as black rockfish abundance indicators, one based on tagging CPUE and one on based coastal recreational bottomfish directed effort (F. R. Wallace and Tagart 1994).

Wallace et al (1999) constructed an assessment model by using the AD Model Builder software (ADMB; (Fournier 1997)) to assess black rockfish abundance. Three key features of the 1999 model were (1) the parameterization of the expected catches at age, (2) the definitions of the sampling units for the different types of data inputs, and (3) the integration of tagging data explicitly. The parameterization chosen mostly affected parameter bias whereas the sampling unit designation mostly affected estimator variance. Both bias and variance were components of overall parameter uncertainty. The parameterization and the sampling unit definitions were both designed to conform to the actual sampling protocol used, thereby propagating sampling uncertainty through to the final biomass estimates.

The 2007 assessment (Y. W. Wallace F. R. aand Cheng and Tsou 2007) employed Stock Synthesis 2. Unlike the 1999 assessment, CPUE from the tag release trips and Petersen tagging study abundance estimates were included as relative abundance indices.

**3.1.1.3 California, Oregon, and Washington Assessments** The 2015 assessment defined three distinct stocks for assessment. Each stock matched the state boundaries of California, Oregon and Washington. All assessments used the Stock Synthesis 3 version 3.24V. The Washington model had three fisheries (two commercial and one recreational) and considered two surveys. There were three primary data likelihood components for survey indices, lengths and ages. Fits to catches also contribute to the total likelihood, but is typically very small. The models was tuned using the Francis (2011) method for biological compositions and added variance for survey indices. Recruitment deviations were estimated. Natural mortality was treated as constant and sex-specific, with females having a higher natural mortality than males.

Results for the Washington assessment of black rockfish in 2015 estimated stock status in that year was 43%, and never showed a decline below the target biomass.

### **3.1.2 Most Recent STAR Panel and SSC Recommendations**

The STAR panel identified the following issues as sources of major uncertainty:

- Natural mortality, especially in females. There is no data to differentiate whether the missing older females are dying or are avoiding capture. The choice between using

a constant (as used in the California and Washington assessments) or step function (used in Oregon) is also an point of uncertainty.

- The level of cryptic biomass. This is a result of using dome-shaped selectivity to explain the absence of old females.
- Uncertainty in historical catch, especially in the historical trawl fishery.
- Acknowledging that there remains uncertainty in the stock-recruit relationship parameters (particularly the Beverton-Holt steepness parameter).

Most of the above recommendations were included in the 2015 assessment research recommendations. Additionally, stock structure for black rockfish was highlighted as a topic for further consideration, as was the development of a nearshore fishery-independent survey.

## 4 Model description

### 4.1 Modelling Platform

Stock Synthesis version 3.30.21 was used as the statistical catch-at-age modelling framework. This framework allows the integration of a variety of data types and model specifications. The SS-DL tool (<https://github.com/shcaba/SS-DL-tool>) was used for model exploration, likelihood profiling, and sensitivity analyses. The companion R package r4ss (version 1.38.0) along with R version 4.2.2 were used to investigate and plot model fits.

### 4.2 Bridging the assessment model from Stock Synthesis 3.24 to 3.30

Since several years have passed from the last assessment model, the Stock Synthesis (SS) modelling framework has undergone many changes. While the specific changes in the model can be found in the model change log, here we simply update the model from the older 3.24V version to the newer 3.30.20 version. The point here is to present any differences in the model outputs when using the same information. This was first done by migrating the data and parameter specifications from the former files to the newer files. This migration was assisted using the SS-DL tool. Once the old data was transferred to the SS 3.30.20 file, two versions of the model were ran.

- 1) Fixing all parameter values to the values found in the 2015 model.
- 2) Allowing the same parameters estimation specification as in the 2015 model.

Results are similar between models when all parameters are fixed from the 2015 model in the updated SS files, although there are scale differences (Figure 17) and small relative stock status differences (Figure 18) when the new SS version is allowed to estimate the same parameters as estimated in the 2015 version. These model comparisons are adequate to move ahead using the newest version of SS 3.30.20 without expecting large differences in reference models being due to versions of SS.

### 4.3 Model Structure and Assumptions

### 4.4 Model Structure, Evaluation, and Specification

#### 4.4.1 Fleet and survey designations

The Washington model is structured to track several fleets and include data from several surveys:

- Fleet 1: Commerical trawlfishery
- Fleet 2: Commercial non-trawl (mostly jig) fishery
- Fleet 3: Recreational boat fishery
- Survey 1: Private Boat
  
- Survey 2: Charter
- Survey 3: Tagging
- Survey 4: Nearshore
- Survey 5: OCNMS subadult-adult survey
- Survey 6: OCNMS young-of-the-year survey

### 4.5 Model likelihood components

There are five primary likelihood components for each assessment model:

1. Fit to survey indices of abundance.
2. Fit to length composition samples.
3. Fit to age composition samples (all fit as conditional age-at-length).
  
4. Penalties on recruitment deviations (specified differently for each model).
5. Prior distribution penalties

## 4.6 Reference model exploration, key assumptions and specification

The base assessment model for Washington Black Rockfish was developed to balance parsimony and realism, and the goal was to estimate a spawning output trajectory and relative stock status for the population of Black Rockfish in state and federal waters off Oregon. The model contains many assumptions to achieve parsimony and uses different data types and sources to estimate reality. A series of investigative model runs were done to achieve the final base model. Constructing integrated models (i.e., those fitting many data types) takes considerable model exploration using different configurations of the following treatments:

- Data types
- Parameter treatments: which parameter can, cannot and do not need to be estimated
- Phasing of parameter estimation
- Data weighting
- Exploration of local vs global minima (see model convergence section below)

The different biological data with and without the catch time series were first included to obtain an understanding of the signal of stock status coming from the data (Figure ??). Both the lengths and ages, with and without the removal time series, demonstrated a signal for a highly depleted stock. Stock scale was comparable once removal history was included, and showed lower estimates of scale. This departure from the ultimate reference model highlights the major uncertainty in the treatment of the biological data in when characterizing model uncertainty. Further sensitivities to the inclusion or exclusion of different indices of abundance are provided in the model sensitivity section.

Numerous exploratory models that included all data types and a variety of model specifications were subsequently explored and too numerous to fully report. In summary, the estimation of which life history parameters to estimate and fix was liberally explored. The following is a list of things that were explored, typically in combination with one another

- Estimate or fix  $M$
- Estimate or fix any of the three growth parameter for each sex
- Estimate or fix the stock-recruit relationship
- Estimate or assume constant recruitment. If estimating recruitment, for what years?
- Estimate or fix survey catchability for each survey
- Estimate additional survey variance for which survey
- Estimate or fix selectivity parameters
- Logistic or dome-shaped selectivity

After much consideration, it was determined that some parameters were inestimable ( $M, L_{min}$  for both sexes), some did not move much for initial values and could be fixed (e.g., CV

at length values, some selectivity parameters), and others could be estimated (e.g.,  $L_\infty$ ,  $k$ ,  $\ln R_0$ ). Estimation of  $L_m$  in or fixing it to the externally estimated values consistently gave very high estimates of  $L_\infty$  for both sexes, thus the  $L_m$  in value for both females and males was fixed so  $t_0 = 0$ , as this gave the most realistic  $L_\infty$  values. No priors were used on any of the estimated parameters except female  $L_\infty$  which used a normal prior and a standard deviation taken from the external fit to the growth curve (0.17). Length at maturity, fecundity-weight, and length-weight relationship, steepness ( $h$ ) and recruitment variance were all fixed.

Examination of the catches in the trawl fishery indicated much larger fish being caught versus those caught in the commercial non-trawl and recreational ocean boat fisheries (both of which have very similar mean lengths and aggregate catch compositions) in the same years. Dome-shaped selectivity was therefore allowed in those fisheries as well as the shore-based fleet (which catches much smaller individuals) and the MPA survey. The ORBS and MRFSS surveys were assumed to have the same selectivity as the recreational boat fishery fleet. While constant selectivity was assumed across all fleets, it was also noted that the earlier time series (prior to 2003) of the recreational boat fleet, as sampled by the MRFSS program, had consistently smaller mean lengths than the ORBS sampled years. The MRFSS years also had smaller samples with more uncertainty. Time varying selectivity was explored in the two periods to see if this improved the fit to the data, but no perceivable improvement was made and the resultant difference was very small in the derived model outputs, so a constant selectivity was assumed for the whole time period.

The full list of estimate and fixed parameters are found in Table 3.

The biggest uncertainty revealed in the model exploration was conflict in the signal of the biological data and that in the acoustic visual survey catchability. If the inherent uncertainty in the survey ( $CV = 0.45$ ) was used, additional variance estimated on a lower  $CV$ , or the catchability was estimated, the acoustic visual survey was essentially ignored (catchability was between 3 and 4, saying the survey overestimates abundance by 3 to 4 times), the scale and stock status dropped significantly. If the acoustic survey catchability, reviewed and deemed informative of overall black rockfish biomass in Oregon (Rasmussen et al. 2022), was assumed to be equal to 1, the biomass and stock status was much higher. Given there are serious issues with assuming either of the previous hypotheses are acceptable, the STAT determined a realistic upper bound (based on a calculated catchability from the uncertainty in the acoustic visual survey) for catchability of 1.822 (or  $\ln(q)$  of 0.6). This served as fixed value of catchability (which also required a small  $CV$  of 0.0001 on that index) to build the final reference model around.

General attributes of the reference model are that indices of abundance are assumed to have lognormal measurement errors. Length compositions and conditional age at length samples are all assumed to follow a multinomial sampling distribution, where the sample size is fixed at the input sample size calculated during compositional example, and where this input sample size is subsequently reweighted to account for additional sources of overdispersion (see below). Recruitment deviations were also estimated and assumed to follow a lognormal distribution, where the standard deviation of this distribution is tuned as explained below.

Sensitivity scenarios and likelihood profiles (on the catchability of the acoustic visual survey, steepness, and natural mortality) were used to explore uncertainty in the above model specifications and are reported below.

#### **4.6.1 Data Weighting**

The reference model allowed for the estimation of additional variance on all surveys except the acoustic visual survey. This additional variance allows the model to balance model fit to that data while acknowledging that variances may be underestimated in the index standardization. A sensitivity was run with no extra variance estimated, as well as removal of the index data were explored.

Initial sample sizes for the commercial and recreational length and conditional age-at-length compositions were based on the number of input effective samples sizes. The method of Francis (2011, equation TA1.8) was then used to balance the length and conditional age-at-length composition data among other inputs and likelihood components. The Francis method treats mean length and age as indices, with effective sample size defining the variance around the mean. If the variability around the mean does not encompass model predictions, the data should be down-weighted until predictions fit within the intervals. This method accounts for correlation in the data (i.e., the multinomial distribution), but can be sensitive to years that are outliers, as the amount of down-weighting is applied to all years within a data source, and are not year-specific. Sensitivities were performed examining different data-weighting treatments: 1) the Dirichlet-Multinomial approach (James T. Thorson et al. 2017), 2) the McAllister-Ianelli Harmonic Mean approach (McAllister and Ianelli 1997), or 3) no data-weighting of lengths.

#### **4.6.2 Model Changes from the Last Assessment**

Besides the addition of eight years of data and some changes in the estimation of some parameters, the biggest changes to the past assessment are:

- Additional of and fixing to the acoustic visual survey. This is different than the last model that fixed the stock scale to the tag survey catchability
- Estimation of recruitment
- Female natural mortality is no longer a step, but a constant value
- Length-based selectivity only (i.e., no age-based selectivity for females), and dome-shaped selectivity for the ocean boat fisheries (assumed logistic last time)
- Change in the removal history

## 4.7 Reference Model Diagnostics and Results

### 4.7.1 Model Convergence and Acceptability

While there is no definitive measure of model convergence, several measures are routinely applied. These criteria include a low maximum gradient ( $4.2729 \times 10^{-5}$ ), inversion of the Hessian (passed), acceptable fits to data (passed), and reasonable parameter values (passed).

Model efficiency was explored by doing a short run Bayesian analysis using the Random Walk Metropolis with 2000 draws, keeping all the draws and examining the fast mixing parameters. Those estimated parameters that do not move much from the initial values slow the model down and are recommended to be fixed at the starting value (Monnahan et al. 2019). This resulted in the fixing of five selectivity parameters (Figure 21).

An extra effort was given to ensure the model did not rest on a local likelihood minimum. This was done by starting the minimization process from dispersed parameter values away from the maximum likelihood estimates to determine if the approach found a better model fit (i.e., minimum negative log-likelihood value). Starting parameters used a jitter shift value of 0.005. This was repeated 100 times with 5 out of 100 runs returned to the reference model likelihood (Figure 19). A second jitter of 100 runs used a jitter shift value of 0.0005 and 11 out of 100 runs returned the reference model (Figure 20). This jitter showed a more commonly obtained secondary model near the reference model that gave very similar results, but was not a better overall fit. Out of the 200 jitter runs, a better fit, lower negative log-likelihood model was not found in any of the remaining runs. The model did not experience convergence issues when provided reasonable starting values. Through the jittering and likelihood profiles, the present reference model represents the best fit to the data given the assumptions made.

## 4.8 Base Model Results

### 4.8.0.1 Fits to the Data

**4.8.0.1.1 Lengths** Fits to the length data are examined based on the Pearson residuals-at-length, the annual mean lengths, and aggregated length composition data for the commercial and recreational fleets. Fits to the annual length composition are shown in Appendix A.

Pearson residuals of fits to the fishery and survey length data are reasonably small with no distinct patterns (Figure 22).

Model fits to the mean lengths, assuming Francis data-weighting, do not closely follow the dynamics in means lengths in the relatively small trawl fishery (Figure 23). The mean lengths

generally follow the trend seen in the non-trawl fishery (Figure 24) and recreational (Figure 25) fisheries, but still miss the detailed dynamics. The tagging survey fits are one of the better in the model (Figure 26). Fits to the mean length in the Nearshore survey, only three points at this point, are not particularly good (Figure 27). The fits to the mean length data from the dive survey does follow the general trend in the data (Figure 28). All length weighting are near the value of 1 as is expected when using the Francis weighting method. One thing to note is the general weak contrast in the data over the past two decades.

Aggregate fits over year by fleet are shown in Figure 29. The aggregates are fairly good, though there does seem to be a slight underfitting of the bigger individuals seen in the fishery-based samples.

**4.8.0.1.2 Conditional Age at Length** Fits to the mostly sex-specific conditional age at length data are examined based on the age-at-length Pearson residuals, the annual mean ages, and mean age at length by year for the trawl, non-trawl and ocean boat fishery samples. The maximum size of the Pearson residuals for each fleets was fairly small (maximum = 8.71, 18.54, and 25.87 for the trawl, non-trawl and recreational samples, respectively; Appendix B). The biggest residual was an extreme outlier, as most of the residuals were small and unnoteworthy and demonstrate the expected shape of the growth curve. There is more contrast in the age data versus the length data, as the mean age by year followed the population dynamics in the model (Figures 30, 31, and 32). The mean age for the trawl fishery was consistently around 10 years, whereas the mean ages for the non-trawl fishery started higher (13 years) and declined to around 8 years. The recreational fishery, the longest time series, started around 13, dropped to the lowest value of close to 8, levels off between 9 and 10 years, then increases to just under 12 years in 2022. Fits to the mean ages by length bins show acceptable fits consistent with model expectations Appendix C.

**4.8.0.1.3 Marginal Age compositions** Marginal age compositions are not fit in the model, but they are included in order to see how well they fit the reference model without influencing the likelihood Appendix D. Marginal length and age composition cannot be used in the same model given the overlap of the same fish in both samples. This is why ages conditioned on lengths are often used with the length compositions. But it still stands that age compositions, instead of lengths, could be used. So adding the marginal age compositions passively (i.e., not contributing to the overall likelihood of the model) can offer insight into how consistent they are with the current model fit. Overall the fits are very good, and in an exploratory model run the length compositions were replaced with the age compositions and a very similar model result was obtained. Thus the conditional age at length compositions coupled with either length or age compositions provide similar results. This is likely due to the fact that the conditional ages capture the underlying age structure sufficiently to following the age structure over time.

**4.8.0.1.4 Fits to Indices of Abundance** The fits to the six available indices of abundance are generally weak (Figures 33 to 38). The best fit index is found for the one with the longest time series, the private boat recreational fishery index (Figure 34). It demonstrates an initial poor fit in the period of large catches, but then captures a generally increasing trend. In contrast is the fit to the charter fishery that covers the same years and shows a very similar selectivity, but shows an opposing downward trend (Figure 33). The tagging (Figure 35) and nearshore (Figure 36) fisheries also overlap in the population being sampled by the recreational fishery indices, and both show general trends captured, but poor overall fits.

The two fishery independent surveys, the OCNMS dive (Figure 37) and the tagging survey (Figure 35) and the young of the year (YOY) survey (Figure 38) show mixed results in regard to fit. While the dive survey is not particularly well fit, the YOY survey does show some concurrence with the reference model.

#### 4.8.1 Reference Model Outputs

**4.8.1.1 Parameter Estimates** A total of five population parameters, four survey variances and eighteen selectivity parameters were estimated, along with sixty-two recruitment deviations. The reference model parameter estimates along with asymptotic standard errors are shown in Table 3 and the likelihood components are shown in Table 4. Estimates of derived outputs and reference points and approximate 95 percent asymptotic confidence intervals are provided in Table 5.

The estimates of sex-specific growth parameters showed some differences from the externally estimated starting values (Table 3 and Figure 39). The estimated  $L_{\infty}$  and  $k$  for females and males were slightly greater and lower than the values estimated externally, respectively. The majority of female and male Black Rockfish growth occurs at younger ages, reaching near maximum length by age 20-25, depending upon sex, with female Black Rockfish reaching larger maximum lengths (Figure 39).

The time series of estimated recruitment deviations and annual recruitment deviations are shown in Figures 40 and 41. Years with major recruitment deviations were estimated to have occurred around 1999, 2007, and 2010. These years are very similar to recruitment deviations seen in other rockfishes. One curious signal is the string of positive deviations from 2005-2013, though this is consistently apparent in most model runs. The variance check on the recruitment deviations indicates well informed recruitments from the early 1960s to 2017, providing justification for the estimation of recruitment (Figure 45). Recruitment deviations after 2017 are relatively uninformed and are not estimated, as is not unexpected from the lag in selectivity with the biological compositions. The recruitment bias adjustment applied within the model across years is shown in Figure 44. The Beverton-Holt stock-recruitment relationship compared to the recruitment deviations are given in Figure 43.

Estimated selectivity curves for each fleet and survey (Figure 46) are all logistic (even though dome-shaped parameters were estimated) and look plausible given the biology (i.e., as a model convergence check for realism, the selectivity curves must look plausible). The commercial fisheries are more right shifted than the other the recreational fishery. The estimate of the peak size of selectivity for the fisheries biggest removal sources (trawl: = cm; non-trawl = cm; recreational ocean boat = cm) are above the size of 50% functional maturity (40 cm).

**4.8.1.2 Population Trajectory** The predicted spawning output (in millions of eggs) is provided in Table 6 and plotted in Figure 47. Estimated spawning output shows a decline from the start of the time series, but a distinct drop in biomass starting in the early 1980s when the recreational fishery begins in earnest and there is a peak in the trawl fishery. This decline is consistent until the late 1990s when it then rebounds due to the cessation of the commercial fishery and several strong recruitments. The estimate of total biomass over time, which tracks that of spawning output, is shown in Figure 48.

Relative spawning output declined below the management target ( $SB_{40\%}$ ) in the 1980s when all three fisheries were active, but rebounded to above the target in the last couple of years (Figure 49). The relative stock status at the start of 2023 (0.42) is estimated to be above the rockfish relative biomass target of 0.4. Uncertainty intervals give a range of possible current stock status solidly in the precautionary zone or well above it, but still underestimate the total uncertainty across model specifications. This emphasizes the need for alternative model specifications (mainly in the treatment of natural mortality- see likelihood profile below) to capture a broader range of uncertainty. The strong recruitment events, as well as declining catches, seem responsible for the dramatic increase and elevated stock status. Numbers of age-0 individuals indicate those years of particularly strong recruitment (Figure 40).

This current estimate shows a lower overall biomass (Figure 50), but similar relative stock status, as the 2015 stock assessment (Figure 51). This lower biomass is largely due to the change in the catch history, removing 100 of metric tons of historical trawl catch, thus causing the assessment biomass to rescale downward.

## 4.9 Characterizing uncertainty

### 4.9.1 Sensitivity Analyses

Sensitivity analyses were conducted to evaluate model sensitivity to alternative data treatment and model specifications.

**4.9.1.1 Data treatment sensitivities** Data treatments explored were as follows:

- Treatment of abundance indices
  1. 2015 dockside survey
  2. 2015 dockside survey, no extra variance estimated
  3. No extra variance on private boat index
  4. No private boat index
  5. No charter index
  6. No private or dockside indices
  7. No tagging survey index
  8. No neashore survey
  9. No OCNMS survey
  10. No OCNMS YOY index
- Data weighting
  11. No data-weighting
  12. Dirichlet data-weighting
  13. McAllister-Ianelli data weighting

Likelihood values and estimates of key parameters and derived quantities from each sensitivity are available in Table 7. Derived quantities relative to the reference model are provided in Figure 52. Time series of spawning output and relative spawning output are shown in Figures 53 and 54.

The treatment of the index data did not have major effects on either the scale or relative status of the black rockfish stock. More weight on the dockside data, either the combined version from 2015, or the current version of the private boat index, led to more optimistic stock status due to a change in current stock size. These indices generally bring up the stock status even when downweighted with additional variance estimation on the index. This result is seen clearly when the private boat data is removed from the model, as the current stock size decreases, as does the current stock status. No other indices had much effect on the results.

Using other data weighting options caused the biggest change among the data treatment sensitivity runs, leading to changes in both initial and current stock status, as well as more optimistic current stock status, but the intensity of the increasing stock trajectory test our expectations of a rockfish population.

**4.9.1.2 Model specification sensitivities** Model specifications looked at the estimation of individual and combinations of life history parameters, the estimation of recruitment, and the treatment of fecundity and selectivity. All scenarios match the reference model specifications in all other aspects unless otherwise stated.

- Life history estimation

- Natural mortality ( $M$ )
  1. Estimate  $M$
  2. Lorenzen age varying  $M$
- Growth parameters
  3. Fix all growth parameters to external values, estimate  $M$
  4. Fix all growth parameters to external values
  5. Estimate  $L_m$  in
  6. Fix  $t_0 = 0$
  7. Estimate  $CV_{young}$  and  $CV_{old}$
- Reproductive Biology
  8. Use biological maturity ogive
  9. Use functional maturity ogive
  10. Fecundity proportional to weight
- Recruitment estimation
  11. No recruitment estimation
  12. Estimate recruitment for all years in the model

#### Miscellaneous 13. Estimate dome-shaped selectivity for all fleets

Likelihood values and estimates of key parameters and derived quantities from each sensitivity are available in Tables 8 and ???. Derived quantities relative to the reference model are provided in Figure 55. Time series of spawning output and relative spawning output are shown in Figures 56 and 57. None of the sensitivities indicated an overfished stock.

Estimating  $M$  either as a constant value or in an age-specific manner using the Lorenzen approach both result in lower  $M$  values, and thus lower stock scale, especially in current stock size, with a significantly different stock status when estimating age-specific  $M$ .

Fixing growth to the externally estimated values raised the initial stock status, but still lowered current stock status when  $M$  was estimated. Changes in the values of the smallest individuals, either in estimating the smallest size at age or fixing  $t_0$  to 0 resulted in higher current stock size, and thus significantly higher current stock status. Estimating the coefficient of variation had no effect on the model (one of the reasons it was fixed).

Treatment of the assumed maturity relationship had little affect on model results, though using the biological maturity did significantly change the scale of the current stock size. Assuming fecundity was proportional to weight did not effect relative stock status, but did raise the initial and current stock scale significantly to compensate for the reduced productivity.

Forging the estimation of recruitment did cause one of the bigger changes in current stock size, and thus one of the lower estimates of stock status. Estimating recruitment for the whole time series made little difference to results. Lastly, allowing for dome-shaped selectivity resulted in mostly logistic selectivity and no significant changes to model output.

#### 4.9.2 Likelihood Profiles

Likelihood profiles were conducted for the log of initial recruitment ( $\ln(R_0)$ ), steepness ( $h$ ), and female and male natural mortality ( $M$ ) varying together with a constant ratio matching the reference model (0.17/0.152, female and male values respectively). Likelihood profiles were conducted by fixing the featured parameter(s) at specific values across a range of values and estimating all remaining parameters. A likelihood profile offers insight into model sensitivity to changing model parameter values, while providing an additional way to describe uncertainty in the parameter by indentifying the range of parameters within 1.96 likelihood units of the reference model.

The profile on the assumption of  $\ln R_0$ , which sets the initial scale of the population demonstrates the expected scaling up and down of the population with increasing and decreasing initial recruitment, respectively (Figure 58). The likelihood profile is highly informed to the ultimate maximum likelihood estimate. The change in the current spawning output is steeper than the initial spawning output, leading to a u-shaped relationship in relative biomass. Once the  $\ln R_0$  approaches 7, the population approaches an overfished state. The age (all sources) and recruitment data are most supportive of a well-informed initial scale, whereas lengths (mainly the recreational data) tend to push the population very low and the index data quite high (Figure 59).

The steepness profile showed little information content for this parameter (Figure 60) as the best fit value went towards the bound of 1. Changing steepness mostly changed the estimate of current stock size, especially when steepness drops below 0.7. The lower steepness values rapidly decrease the relative stock size. The likelihood components except lengths pushed the steepness to the highest value; length cause the value to race to a minimum value. (Figure 61). There seems to be no real information on the value of this parameter in this model.

The combined profile that varies female and male  $M$  while maintaining the reference model offset demonstrates the model wants natural mortality values to be near the low end of reasonable natural mortality values (Figure 62). This lowering of the stock productivity results in stock status near the overfished limit. This type of sensitivity to stock productivity (similar to what we see with the steepness profile) makes natural mortality a strong candidate for exploring model specification uncertainty in order to build alternative states of nature for decision tables.

#### 4.9.3 Retrospective Analysis

A ten-year retrospective analysis was conducted by running the model and sequentially removing one year of data up through minus 10 years. Retrospective spawning output (Figure 63) and relatives stock status (Figure 64) estimates show a generally consistent pattern in population scale and trend. All models show the population increasing, with the

models removing the most data showing the increasing starting sooner and trending stronger upward. This results in a stock status firmly in the precautionary zone, whereas the models with more data put those same years closer to the overfished level. Some of this is due to the change in stock scale, though overall scale estimates are not strikingly different. Overall, the variation in scale and status are within the uncertainty bounds of the reference model, except the model that removes 9 and 10 years of data, which is slightly higher in both scale and stock status. The Mohn's rho evaluation of the degree of retrospective pattern is given in Table 9.

#### 4.9.4 Unresolved Problems and Major Uncertainties

## 5 Management

### 5.1 Reference Points

OREGON: Spawning output declined as it tracks quickly rising recreational catches in the late 1970s, then stabilizes (Figure 151) Stock status is above the target reference point (SB40%) at 60% (59%-62% 95% asymptotic intervals; Table 45). Unfished spawning output was measured at 1385 (1212-1557 95% asymptotic intervals; Table 45) and spawning output at the beginning of 2015 was estimated to be 838 (740-936 95% asymptotic intervals). According to this model specification, there is no time in which the stock was below the target or limit reference point, but is currently pointed downward. Fishing intensity has been less than the SPR50% rate the whole time series (Figure 173). The phase plot shows the interaction of fishing intensity and biomass targets (Figure 174). The equilibrium curve is shifted left, as expected from the high fixed steepness, showing a more productive stock than SPR50% would suggest (Figure 175). The target stock size based on the biomass target (SB40%) is 554 (millions of eggs), which gives a catch of 556 mt. Equilibrium yield at the proxy FMSY harvest rate corresponding to SPR50% is 518 mt (Table 45).

WA: Spawning output declined over a large extent of the time series, with an increasing and or more stable population prevailing since the late 1980s (Figure 221) Stock status is above the target reference point (40%) at 43% (36%-50% 95% asymptotic intervals; Figure 222). Unfished spawning output was measured at 1356 (1228-1483 95% asymptotic intervals; Table 67) and spawning output at the beginning of 2015 was estimated to be 582 (467-698 95% asymptotic intervals) There seems to be no time in which the stock was below the limit reference point and has only fluctuated above the target reference point. Recruitment has fluctuated regularly over the last 25 years (Figure 223 and Figure 224). Despite being above the target biomass, fishing intensity has been above the SPR50% rate in the last couple of years (Figure 237). The phase plot shows the interaction of fishing intensity and biomass targets (Figure 238). The equilibrium curve is shifted left, as expected from the high fixed steepness, showing a more productive stock than SPR50% would suggest (Figure 239). The

target stock size based on the biomass target (SB40%) is 542 (millions of eggs), which gives a catch of 337 mt. Equilibrium yield at the proxy FMSY harvest rate corresponding to SPR50% is 311 mt (Table 67).

From Vermilion: Reference points were calculated using the estimated fishery selectivity and removals in the most recent year of the model (2022, Table 5). Sustainable total yields were 276.6 mt when using an  $SPR_{50\%}$  reference harvest rate. The spawning output equivalent to 40 percent of the unfished spawning output ( $SB_{40\%}$ ) was 422.08 meggs.

The 2023 spawning output relative to unfished equilibrium spawning output is above the Black Rockfish relative biomass target of 40 percent (Figure 49). The fishing intensity,  $1 - SPR$ , of recent years was near or above the harvest rate limit ( $SPR_{50\%}$ ) for most of the 1980s and 1990s. Recent years also show near target fishing levels (Table 6 and Figure ??), highlighting how the sustainability of current fishing levels are very sensitive to incoming recruitment. Table 5 shows the full suite of estimated reference points for the base model and Figure ?? shows the equilibrium curve based on a steepness value fixed at 0.72.

## 5.2 Unresolved Problems and Major Uncertainties

## 5.3 Harvest Projections and Decision Tables

A ten year (2023-2032) projection of the reference model with removals in 2021 and 2022 provided by the Groundfish Management Team for each fleet under the category 1 ( $\sigma=0.5$ ) time-varying buffer using  $P^* = 0.45$  and 40-10 ABC control rule is provided in Table 10.

## 5.4 Evaluation of Scientific Uncertainty

The estimated uncertainty in the base model around the 2023 spawning output is  $\sigma = 0.21$  and the uncertainty in the base model around the 2023 OFL is  $\sigma = 0.19$ . The estimated model uncertainty was less than the category 1 groundfish data moderate assessment default value of  $\sigma = 0.5$ .

## 5.5 Research and Data Needs

# 6 Acknowledgments

Here are all the mad props!

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## **8 Tables**

**Table 1:** Ageing error models and resultant model selection (AICc) values for 9 models of bias and precision explored for each intra age reader comparison used in the black rockfish assessment. Bolded text indicates indicate the chosen model. Model codes: 0= unbiased; 1 = Constant CV; 2 = Curvilinear (SD for precision); 3= Curvilinear CV

		Reader 1		Second Reader		Model selection		
<b>Reader 1a vs Reader 1b</b>								
Model		Bias	Precision	Bias	Precision	AICc	$\Delta$ AICc	BIC
1		0	1	0	1	22980	99	23115
2		0	2	0	2	22959	78	23100
3		0	3	0	3	22948	67	23089
4		0	1	1	1	22915	34	23059
5		0	2	1	2	22912	31	23062
<b>6</b>		<b>0</b>	<b>3</b>	<b>1</b>	<b>3</b>	<b>22881</b>	<b>0</b>	<b>23031</b>
7		0	1	2	1	22911	30	23061
8		0	2	2	2	22882	1	23038
9		0	3	2	3	22907	26	23063
<b>Reader 2a vs Reader 2b</b>								
Model		Bias	Precision	Bias	Precision	AICc	$\Delta$ AICc	BIC
1		0	1	0	1	18918	62	19044
2		0	2	0	2	18915	59	19047
3		0	3	0	3	18915	59	19047
<b>4</b>		<b>0</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>18856</b>	<b>0</b>	<b>18991</b>
5		0	2	1	2	18884	28	19024
6		0	3	1	3	18859	3	18999
7		0	1	2	1	18858	2	18998
8		0	2	2	2	18862	6	19007
9		0	3	2	3	18862	6	19006

**Table 2:** Estimated biological and functional length at 50% maturity and slope values with logistic regression and flexible spline models

Model	Length at 50% maturity (95%)	slope
Biological logistic	34.38 (33.90-34.86)	-0.31
Functionl logistic	40.36 (39.89-40.83)	-0.38
Biological splie	34.01 (32.10-35.41)	NA
Functional spline	40.29 (39.88-40.77)	NA

**Table 3:** List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD).

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
NatM uniform Fem GP 1	0.170	-2	-	-	Log Norm (-1.89, 0.2)
L at Amin Fem GP 1	0.000	-3	-	-	None
L at Amax Fem GP 1	52.724	3	OK	0.177513	Normal (51.19, 0.2)
VonBert K Fem GP 1	0.118	3	OK	0.000866921	Normal (0.1513, 0.01)
CV young Fem GP 1	0.100	-1	-	-	None
CV old Fem GP 1	0.100	-4	-	-	None
Wtlen 1 Fem GP 1	0.000	-99	-	-	None
Wtlen 2 Fem GP 1	2.721	-99	-	-	None
Mat50% Fem GP 1	40.360	-99	-	-	None
Mat slope Fem GP 1	-0.380	-99	-	-	None
Eggs scalar Fem GP 1	0.000	-3	-	-	None
Eggs exp len Fem GP 1	4.685	-3	-	-	None
NatM uniform Mal GP 1	0.152	-2	-	-	Log Norm (-1.89712, 0.2)
L at Amin Mal GP 1	3.662	-3	-	-	None
L at Amax Mal GP 1	47.644	3	OK	0.17011	Normal (47.26, 0.2)
VonBert K Mal GP 1	0.140	3	OK	0.00127598	Normal (0.1656, 0.01)
CV young Mal GP 1	0.100	-4	-	-	None
CV old Mal GP 1	0.100	-4	-	-	None
Wtlen 1 Mal GP 1	0.000	-99	-	-	None
Wtlen 2 Mal GP 1	2.911	-99	-	-	None
CohortGrowDev	1.000	-1	-	-	None
FracFemale GP 1	0.500	-99	-	-	None
SR LN(R0)	7.584	1	OK	0.0409701	None
SR BH steep	0.720	-1	-	-	None
SR sigmaR	0.600	-6	-	-	None
SR regime	0.000	-99	-	-	None
SR autocorr	0.000	-99	-	-	None
Main RecrDev 1956	-0.542	2	act	0.504646	dev (NA, NA)

**Table 3:** List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD). (*continued*)

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
Main RecrDev 1957	-0.557	2	act	0.501107	dev (NA, NA)
Main RecrDev 1958	-0.553	2	act	0.500135	dev (NA, NA)
Main RecrDev 1959	-0.523	2	act	0.502584	dev (NA, NA)
Main RecrDev 1960	-0.462	2	act	0.508523	dev (NA, NA)
Main RecrDev 1961	-0.371	2	act	0.517537	dev (NA, NA)
Main RecrDev 1962	-0.271	2	act	0.524653	dev (NA, NA)
Main RecrDev 1963	-0.221	2	act	0.520706	dev (NA, NA)
Main RecrDev 1964	-0.273	2	act	0.510623	dev (NA, NA)
Main RecrDev 1965	-0.334	2	act	0.496888	dev (NA, NA)
Main RecrDev 1966	-0.309	2	act	0.496178	dev (NA, NA)
Main RecrDev 1967	-0.103	2	act	0.512087	dev (NA, NA)
Main RecrDev 1968	0.156	2	act	0.465572	dev (NA, NA)
Main RecrDev 1969	-0.138	2	act	0.502059	dev (NA, NA)
Main RecrDev 1970	-0.167	2	act	0.486724	dev (NA, NA)
Main RecrDev 1971	0.021	2	act	0.436301	dev (NA, NA)
Main RecrDev 1972	-0.072	2	act	0.478677	dev (NA, NA)
Main RecrDev 1973	0.318	2	act	0.363871	dev (NA, NA)
Main RecrDev 1974	0.390	2	act	0.298539	dev (NA, NA)
Main RecrDev 1975	-0.244	2	act	0.394486	dev (NA, NA)
Main RecrDev 1976	0.036	2	act	0.262285	dev (NA, NA)
Main RecrDev 1977	-0.076	2	act	0.262621	dev (NA, NA)
Main RecrDev 1978	0.376	2	act	0.169949	dev (NA, NA)
Main RecrDev 1979	0.074	2	act	0.197728	dev (NA, NA)
Main RecrDev 1980	-0.103	2	act	0.200962	dev (NA, NA)
Main RecrDev 1981	-0.029	2	act	0.16638	dev (NA, NA)
Main RecrDev 1982	-0.256	2	act	0.19119	dev (NA, NA)
Main RecrDev 1983	0.283	2	act	0.129618	dev (NA, NA)
Main RecrDev 1984	-0.080	2	act	0.167281	dev (NA, NA)
Main RecrDev 1985	0.159	2	act	0.123045	dev (NA, NA)

**Table 3:** List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD). (*continued*)

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
Main RecrDev 1986	-0.166	2	act	0.146325	dev (NA, NA)
Main RecrDev 1987	0.130	2	act	0.117056	dev (NA, NA)
Main RecrDev 1988	-0.216	2	act	0.158126	dev (NA, NA)
Main RecrDev 1989	0.298	2	act	0.115491	dev (NA, NA)
Main RecrDev 1990	0.122	2	act	0.140171	dev (NA, NA)
Main RecrDev 1991	-0.092	2	act	0.163661	dev (NA, NA)
Main RecrDev 1992	-0.198	2	act	0.17024	dev (NA, NA)
Main RecrDev 1993	-0.070	2	act	0.15452	dev (NA, NA)
Main RecrDev 1994	0.268	2	act	0.121279	dev (NA, NA)
Main RecrDev 1995	0.214	2	act	0.127919	dev (NA, NA)
Main RecrDev 1996	-0.239	2	act	0.180078	dev (NA, NA)
Main RecrDev 1997	0.083	2	act	0.144256	dev (NA, NA)
Main RecrDev 1998	0.099	2	act	0.153225	dev (NA, NA)
Main RecrDev 1999	0.264	2	act	0.140638	dev (NA, NA)
Main RecrDev 2000	0.471	2	act	0.118008	dev (NA, NA)
Main RecrDev 2001	-0.325	2	act	0.201609	dev (NA, NA)
Main RecrDev 2002	-0.479	2	act	0.207466	dev (NA, NA)
Main RecrDev 2003	0.194	2	act	0.14057	dev (NA, NA)
Main RecrDev 2004	0.107	2	act	0.168413	dev (NA, NA)
Main RecrDev 2005	0.027	2	act	0.19251	dev (NA, NA)
Main RecrDev 2006	0.489	2	act	0.150089	dev (NA, NA)
Main RecrDev 2007	0.500	2	act	0.162365	dev (NA, NA)
Main RecrDev 2008	0.634	2	act	0.153711	dev (NA, NA)
Main RecrDev 2009	0.386	2	act	0.181671	dev (NA, NA)
Main RecrDev 2010	0.281	2	act	0.19161	dev (NA, NA)
Main RecrDev 2011	0.809	2	act	0.149486	dev (NA, NA)
Main RecrDev 2012	0.498	2	act	0.172686	dev (NA, NA)
Main RecrDev 2013	0.438	2	act	0.176528	dev (NA, NA)
Main RecrDev 2014	0.186	2	act	0.196466	dev (NA, NA)

**Table 3:** List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD). (*continued*)

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
Main RecrDev 2015	-0.121	2	act	0.224077	dev (NA, NA)
Main RecrDev 2016	-0.070	2	act	0.228156	dev (NA, NA)
Main RecrDev 2017	-0.652	2	act	0.320455	dev (NA, NA)
Late RecrDev 2018	0.000	-	-	-	dev (NA, NA)
Late RecrDev 2019	0.000	-	-	-	dev (NA, NA)
Late RecrDev 2020	0.000	-	-	-	dev (NA, NA)
Late RecrDev 2021	0.000	-	-	-	dev (NA, NA)
Late RecrDev 2022	0.000	-	-	-	dev (NA, NA)
ForeRecr 2023	0.000	-	-	-	dev (NA, NA)
InitF seas 1 ft 1Trawl	0.000	-1	-	-	None
InitF seas 1 ft 2NonTRWL	0.000	-1	-	-	None
InitF seas 1 ft 3Recreational	0.000	-1	-	-	None
LnQ base Tagging(4)	-5.571	-1	-	-	None
LnQ base Nearshore survey(5)	-7.127	-1	-	-	None
Q extraSD Nearshore survey(5)	0.118	3	OK	0.118648	None
LnQ base OCNMS(6)	-7.398	-1	-	-	None
LnQ base OCNMS YOY(7)	-6.575	-1	-	-	None
Q extraSD OCNMS YOY(7)	1.796	3	OK	0.545567	None
LnQ base Private Boat(8)	-6.238	-1	-	-	None
Q extraSD Private Boat(8)	0.378	3	OK	0.0594576	None
LnQ base Charter(9)	-5.728	-1	-	-	None
Q extraSD Charter(9)	0.140	3	OK	0.055222	None
Size DblN peak Trawl(1)	50.023	5	OK	0.608916	None
Size DblN top logit Trawl(1)	0.811	5	OK	26.383	None
Size DblN ascend se Trawl(1)	3.462	5	OK	0.131308	None
Size DblN descend se Trawl(1)	2.200	-1	-	-	None
Size DblN start logit Trawl(1)	-5.000	-2	-	-	None
Size DblN end logit Trawl(1)	5.000	-1	-	-	None
Size DblN peak NonTRWL(2)	48.827	5	OK	1.42586	None

**Table 3:** List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD). (*continued*)

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
Size DblN top logit NonTRWL(2)	-0.795	5	OK	43.1572	None
Size DblN ascend se NonTRWL(2)	4.302	5	OK	0.196343	None
Size DblN descend se NonTRWL(2)	3.000	-1	-	-	None
Size DblN start logit NonTRWL(2)	-4.000	-2	-	-	None
Size DblN end logit NonTRWL(2)	5.000	-1	-	-	None
Size DblN peak Recreational(3)	43.518	5	OK	0.292059	None
Size DblN top logit Recreational(3)	2.497	5	OK	47.6645	None
Size DblN ascend se Recreational(3)	3.653	5	OK	0.0646033	None
Size DblN descend se Recreational(3)	3.000	-1	-	-	None
Size DblN start logit Recreational(3)	-4.000	-2	-	-	None
Size DblN end logit Recreational(3)	5.000	-1	-	-	None
Size DblN peak Tagging(4)	41.717	5	OK	0.856535	None
Size DblN top logit Tagging(4)	-3.708	5	OK	22.608	None
Size DblN ascend se Tagging(4)	3.354	5	OK	0.239297	None
Size DblN descend se Tagging(4)	2.200	-1	-	-	None
Size DblN start logit Tagging(4)	-4.000	-2	-	-	None
Size DblN end logit Tagging(4)	5.000	-1	-	-	None
Size DblN peak Nearshore survey(5)	32.245	2	OK	3.00104	None
Size DblN top logit Nearshore survey(5)	-2.601	1	OK	7.10136	None
Size DblN ascend se Nearshore survey(5)	3.750	2	OK	0.772931	None
Size DblN descend se Nearshore survey(5)	2.200	-1	-	-	None
Size DblN start logit Nearshore survey(5)	-4.000	-2	-	-	None
Size DblN end logit Nearshore survey(5)	5.000	-1	-	-	None
Size DblN peak OCNMS(6)	26.674	2	OK	1.26215	None
Size DblN top logit OCNMS(6)	3.505	1	OK	45.9922	None
Size DblN ascend se OCNMS(6)	3.585	-2	-	-	None
Size DblN descend se OCNMS(6)	-4.500	1	OK	235.007	None
Size DblN start logit OCNMS(6)	-15.000	-2	-	-	None
Size DblN end logit OCNMS(6)	-15.000	-1	-	-	None

**Table 3:** List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD). (*continued*)

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
SizeSel P1 Private Boat(8)	-1.000	-99	-	-	None
SizeSel P2 Private Boat(8)	-1.000	-99	-	-	None
SizeSel P1 Charter(9)	-1.000	-99	-	-	None
SizeSel P2 Charter(9)	-1.000	-99	-	-	None

**Table 4:** Likelihood components by source.

Label	Total
TOTAL	3761.06
Catch	0.00
Equil catch	0.00
Survey	-13.62
Length comp	656.84
Age comp	3091.76
Recruitment	-14.03
InitEQ Regime	0.00
Forecast Recruitment	0.00
Parm priors	40.12
Parm softbounds	0.00
Parm devs	0.00
Crash Pen	0.00

**Table 5:** Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	946.03	870.06	1022.00
Unfished Age 0+ Biomass (mt)	8729.15	8025.72	9432.58
Unfished Recruitment (R0)	1966.34	1808.44	2124.24
Spawning Output (2023)	430.90	255.42	606.37
Fraction Unfished (2023)	0.46	0.30	0.61
Reference Points Based SB40\%	NA	NA	NA
Proxy Spawning Output SB40\%	378.41	348.03	408.80
SPR Resulting in SB40\%	0.46	0.46	0.46
Exploitation Rate Resulting in SB40\%	0.05	0.05	0.05
Yield with SPR Based On SB40\% (mt)	294.29	270.66	317.93
Reference Points Based on SPR Proxy for MSY	NA	NA	NA
Proxy Spawning Output (SPR50)	422.08	388.18	455.97
SPR50	0.50	NA	NA
Exploitation Rate Corresponding to SPR50	0.05	0.05	0.05
Yield with SPR50 at SB SPR (mt)	276.60	254.38	298.82
Reference Points Based on Estimated MSY Values	NA	NA	NA
Spawning Output at MSY (SB MSY)	212.94	195.82	230.06
SPR MSY	0.30	0.30	0.30
Exploitation Rate Corresponding to SPR MSY	0.08	0.08	0.08
MSY (mt)	333.10	306.37	359.82

**Table 6:** Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawning Output	Total Biomass 0+ (mt)	Frac-tion Un-fished	Age-0 Recruits	Total Mortal-ity (mt)	1-SPR	Ex-ploita-tion Rate
1940	8729.15	946.03	8729.15	1.00	1966.36	5.35	0.01	0.00
1941	8724.89	945.00	8724.89	1.00	1966.15	12.80	0.02	0.00
1942	8715.12	942.65	8715.12	1.00	1965.68	22.45	0.04	0.00
1943	8698.83	938.64	8698.83	0.99	1964.86	78.04	0.12	0.01
1944	8639.57	924.58	8639.57	0.98	1961.94	104.72	0.15	0.01
1945	8566.29	906.51	8566.29	0.96	1958.07	180.49	0.24	0.02
1946	8439.69	876.53	8439.69	0.93	1951.33	89.39	0.14	0.01
1947	8400.48	866.22	8400.48	0.92	1948.91	74.43	0.12	0.01
1948	8377.28	860.10	8377.28	0.91	1947.45	51.33	0.09	0.01
1949	8374.62	859.26	8374.62	0.91	1947.25	42.19	0.07	0.01
1950	8379.02	860.58	8379.02	0.91	1947.57	56.88	0.09	0.01
1951	8370.27	859.51	8370.27	0.91	1947.31	49.99	0.08	0.01
1952	8367.41	859.90	8367.41	0.91	1947.40	186.30	0.25	0.02
1953	8255.81	835.30	8255.81	0.88	1941.35	46.16	0.08	0.01
1954	8267.53	838.44	8267.53	0.89	1942.14	60.17	0.10	0.01
1955	8265.79	839.12	8265.79	0.89	1942.31	65.37	0.11	0.01
1956	8196.51	838.77	8196.51	0.89	1129.55	111.58	0.17	0.01
1957	8043.89	830.36	8043.89	0.88	1103.77	113.91	0.18	0.01
1958	7849.86	822.20	7849.86	0.87	1098.75	147.85	0.22	0.02
1959	7599.34	808.24	7599.34	0.85	1122.16	145.35	0.22	0.02
1960	7336.07	796.21	7336.07	0.84	1182.38	136.80	0.21	0.02
1961	7083.49	785.22	7083.49	0.83	1283.23	179.06	0.26	0.03
1962	6810.57	766.54	6810.57	0.81	1405.10	123.87	0.20	0.02
1963	6610.43	754.42	6610.43	0.80	1463.88	85.27	0.15	0.01
1964	6460.06	743.99	6460.06	0.79	1377.03	78.29	0.14	0.01
1965	6326.84	729.12	6326.84	0.77	1283.60	101.78	0.19	0.02
1966	6184.28	706.64	6184.28	0.75	1301.77	103.57	0.19	0.02
1967	6077.11	681.12	6077.11	0.72	1581.21	84.64	0.17	0.01
1968	6048.74	658.82	6048.74	0.70	2023.78	93.81	0.19	0.02
1969	6018.67	636.93	6018.67	0.67	1490.53	92.71	0.19	0.02
1970	6001.26	617.82	6001.26	0.65	1431.76	87.27	0.18	0.01
1971	6016.11	602.48	6016.11	0.64	1709.51	82.38	0.18	0.01
1972	6038.27	590.62	6038.27	0.62	1543.19	93.47	0.20	0.02
1973	6110.88	579.49	6110.88	0.61	2256.07	90.15	0.20	0.01
1974	6237.94	572.65	6237.94	0.61	2402.48	88.25	0.19	0.01
1975	6322.54	569.95	6322.54	0.60	1265.09	96.96	0.21	0.02
1976	6405.70	568.84	6405.70	0.60	1660.18	207.52	0.36	0.03
1977	6379.02	549.14	6379.02	0.58	1466.17	204.23	0.37	0.03

**Table 6:** Time series of population estimates from the base model. (*continued*)

Year	Total Biomass (mt)	Spawning Output	Total Biomass 0+ (mt)	Frac-tion Un-fished	Age-0 Re-cruits	Total Mortal-ity (mt)	1-SPR	Ex-ploita-tion Rate
1978	6401.17	536.71	6401.17	0.57	2279.68	210.28	0.38	0.03
1979	6400.66	528.00	6400.66	0.56	1669.58	204.40	0.37	0.03
1980	6382.63	524.58	6382.63	0.55	1397.43	272.95	0.44	0.04
1981	6302.67	512.18	6302.67	0.54	1498.84	637.54	0.66	0.10
1982	5891.52	450.66	5891.52	0.48	1167.83	612.54	0.68	0.10
1983	5558.46	402.67	5558.46	0.43	1957.77	508.45	0.66	0.09
1984	5308.37	372.45	5308.37	0.39	1340.74	467.61	0.66	0.09
1985	5119.97	351.46	5119.97	0.37	1680.43	542.49	0.71	0.11
1986	4851.64	322.61	4851.64	0.34	1190.48	583.75	0.75	0.12
1987	4576.91	289.67	4576.91	0.31	1558.71	634.51	0.79	0.14
1988	4241.92	251.68	4241.92	0.27	1060.68	458.74	0.74	0.11
1989	4104.33	234.94	4104.33	0.25	1737.33	502.26	0.78	0.12
1990	3933.88	213.69	3933.88	0.23	1414.61	504.18	0.79	0.13
1991	3750.87	194.58	3750.87	0.21	1107.54	416.96	0.77	0.11
1992	3629.98	184.89	3629.98	0.20	977.89	388.38	0.76	0.11
1993	3527.24	178.42	3527.24	0.19	1097.39	378.11	0.76	0.11
1994	3452.66	174.28	3452.66	0.18	1525.58	446.28	0.80	0.13
1995	3329.74	162.89	3329.74	0.17	1409.91	313.83	0.74	0.09
1996	3295.32	164.67	3295.32	0.17	900.06	272.89	0.70	0.08
1997	3303.52	170.41	3303.52	0.18	1257.44	246.57	0.67	0.07
1998	3335.96	176.97	3335.96	0.19	1295.45	266.42	0.69	0.08
1999	3371.93	179.41	3371.93	0.19	1536.41	217.87	0.63	0.06
2000	3491.28	186.60	3491.28	0.20	1915.76	218.77	0.62	0.06
2001	3561.35	193.50	3561.35	0.20	875.14	188.85	0.57	0.05
2002	3620.65	203.53	3620.65	0.22	763.53	232.03	0.62	0.06
2003	3661.15	208.40	3661.15	0.22	1508.35	235.36	0.62	0.06
2004	3694.38	212.56	3694.38	0.22	1390.64	264.93	0.65	0.07
2005	3697.10	214.17	3697.10	0.23	1288.06	326.83	0.70	0.09
2006	3704.71	210.59	3704.71	0.22	2032.14	316.19	0.69	0.09
2007	3766.65	208.70	3766.65	0.22	2048.93	292.16	0.68	0.08
2008	3913.73	208.32	3913.73	0.22	2342.26	223.32	0.61	0.06
2009	4130.03	213.87	4130.03	0.23	1842.17	252.75	0.63	0.06
2010	4316.18	215.49	4316.18	0.23	1662.47	219.99	0.59	0.05
2011	4612.82	221.85	4612.82	0.23	2846.41	232.64	0.59	0.05
2012	4886.82	230.06	4886.82	0.24	2108.38	283.07	0.63	0.06
2013	5110.34	238.06	5110.34	0.25	2007.07	326.02	0.65	0.06
2014	5252.46	247.47	5252.46	0.26	1577.24	356.96	0.67	0.07
2015	5298.73	258.38	5298.73	0.27	1175.06	363.44	0.66	0.07
2016	5287.82	271.40	5287.82	0.29	1283.13	369.39	0.65	0.07

**Table 6:** Time series of population estimates from the base model. (*continued*)

Year	Total Biomass (mt)	Spawning Output	Total Biomass (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
2017	5180.63	285.61	5180.63	0.30	744.19	241.02	0.52	0.05
2018	5183.21	314.18	5183.21	0.33	1644.88	264.79	0.53	0.05
2019	5151.79	340.69	5151.79	0.36	1676.81	251.09	0.50	0.05
2020	5133.32	365.97	5133.32	0.39	1703.90	130.36	0.32	0.03
2021	5227.77	399.51	5227.77	0.42	1735.61	197.68	0.41	0.04
2022	5269.45	417.51	5269.45	0.44	1750.94	166.05	0.37	0.03
2023	5348.99	430.90	5348.99	0.46	1761.68	247.42	0.48	0.05

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities.

X	La-	Type	X0..Ref	X01..old	X02..old	X03..clpri	X04..no	X05..no	X06..no	X07..kno	X08..in	X09..rsho	X10..M	X11..N	X12..Y	X13..D	X14..B..McAll	
	bel		er-	side	side.no	xatc	boat	water	side.in-	dex							let	
		ence.	Model							dices								
1	AIC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
2	NA	AIC	7700.127670.847989.627700.127719.547720.407739.207693.907703.527700.907683.1438057.678862.478862.40															
3	NA	deltaAIC	0.00	-	289.50	0.00	19.42	20.28	39.08	-	3.40	0.78	-	30357.481162.281162.28				
					29.28					6.22			16.98					
4	Sur-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	vey_	li-																
	hood																	
5	NA	ALL	-	-	34.68	-	2.41	-	12.25	-	-	-	-	-	-	-	-	
					13.62	26.98		13.62		2.89		12.87	11.89	12.37	21.82	21.07	27.00	27.00
6	NA	Trawl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
7	NA	Non-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
		TRWL																
8	NA	Recre-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
		ational																
9	NA	Tag-	2.55	3.80	6.20	2.55	5.57	2.53	5.41	6.75	2.57	2.91	2.65	2.69	0.17	0.17		
		ging																
10	NA	Nearshore_	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
		sur-	1.69	1.69	1.72	1.69	1.68	1.69	1.68	1.69	1.69	1.69	1.69	1.71	1.70	1.70		
11	NA	OC-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
		NMS	0.43	0.34	0.42	0.43	0.05	0.42	0.05	0.10	0.43	0.34	0.40	0.72	0.97	0.97		
12	NA	OC-	8.46	8.49	8.43	8.46	8.56	8.47	8.56	8.60	8.46	8.50	8.52	8.41	8.37	8.37		
		NMS_YOY																
13	NA	Pri-	-	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	
		vate_Bd2t20																
14	NA	Char-	-	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	
		ter	10.31			10.31	10.00	9.95	9.62	10.42	10.31	10.30	10.30	12.83	12.85	12.85		

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

X	La-	Type	X0..Ref	X01..old	X02..old	X03..clpri	X04..no	X05..no	X06..no	X07..kno	X08..in	X09..rsno	X10..MNS	X10..Yno	X11..D	X12..McAll
	bel		er-	side	side.no	xate	boat	water		side.in-	dex					let
			ence.	Model						dices						
15	NA	Dock-side	NA	-	22.18	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
					37.23											
16	Surv_lan	Nada	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
17	NA	ALL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
18	NA	Trawl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	NA	Non-TRWL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	NA	Recreational	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	NA	Tag-ging	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
22	NA	Nearshore	00sur-vey	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
23	NA	OC-NMS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
24	NA	OC-NMS_YOY	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
25	NA	Pri-va-te_Boat	1.00	NA	NA	1.00	0.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
26	NA	Char-ter	1.00	NA	NA	1.00	1.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
27	NA	Dock-side	NA	1.00	1.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
28	Length	like-li-hood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
29	NA	ALL	656.84	655.73	664.85	656.84	653.33	657.05	653.61	655.10	656.82	656.13	656.67	2087.233902.083902.08		
30	NA	Trawl	134.96	135.70	139.87	134.96	133.32	135.10	133.46	134.50	134.96	134.92	134.94	195.00	579.71	579.71

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

X	La-	Type	X0..Ref	X01..old	X02..old	X03..clpri	X04..no	X05..no	X06..no	X07..kno	X08..in	X09..sho	X10..M	X11..N	X12..Y	X13..D	X14..B..McAll	
	bel	er-	side	side.no	xat	boat	water	side.in-	dex	dices	side	in-	sho	M	N	Y	D	let
62	NA	Char-	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
63	NA	Dock-	NA	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
64	Age_lan	Nla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
65	NA	ALL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
66	NA	Trawl	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
67	NA	Non-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
68	NA	TRWL	Recre-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
69	NA	Tag-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
70	NA	Nearsho	0.00	sur-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
71	NA	OC-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
72	NA	NMS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
73	NA	OC-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
74	NA	NMS	YOY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
75	NA	Pri-	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
76	NA	va-	Boat	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	NA	Char-	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	NA	Dock-	NA	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	NA	Param-	eters	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

X	Label	Type	X0..RefX01..oldX02cloldX03clpriX04..noX05..noX06r.noX07knoX08.inoX09shoX10CMNXX10YnoX112a.WndX12b.McAll			
		er- side	side.no.xno.theboatno.theboat	side.in- dex	dices	let
		ence.Model				
113	NA	Main_Re- crDev_1983	- 0.33 0.33 0.52	- 0.33 0.26 0.32	- 0.25 0.25 0.28	- 0.33 0.32 0.33
114	NA	Main_Re- crDev_1986	- - 0.30 0.50	- - 0.31 0.24	- - 0.30 0.23	- - 0.26 0.31
115	NA	Main_Re- crDev_1967	- - 0.10 0.30	- - 0.10 0.03	- - 0.09 0.02	- - 0.05 0.10
116	NA	Main_Re46 crDev_1968	0.16 - 0.16 0.07	0.24 0.17	0.25 0.23	0.16 0.17
117	NA	Main_Re- crDev_1969	- - 0.13 0.31	- - 0.14 0.07	- - 0.13 0.07	- - 0.09 0.14
118	NA	Main_Re- crDev_1970	- - 0.16 0.34	- - 0.17 0.10	- - 0.16 0.09	- - 0.17 0.13
119	NA	Main_Re02 crDev_1971	0.03 - 0.02 0.15	0.10 0.03	0.10 0.08	0.02 0.02
120	NA	Main_Re- crDev_1972	- - 0.06 0.19	- - 0.07 0.01	- - 0.07 0.01	- - 0.03 0.07
121	NA	Main_Re32 crDev_1973	0.33 0.16 0.32 0.39	0.32 0.39	0.39 0.37	0.32 0.33
122	NA	Main_Re39 crDev_1974	0.40 0.41 0.39 0.45	0.39 0.39	0.44 0.45	0.40 0.39
123	NA	Main_Re- crDev_1975	- - 0.23 0.21	- - 0.24 0.19	- - 0.25 0.25	- - 0.20 0.20
124	NA	Main_Re04 crDev_1976	0.05 0.20 0.04 0.09	0.04 0.02	0.08 0.09	0.04 0.05
125	NA	Main_Re- crDev_1977	- 0.14 0.06 0.08	- - 0.03 0.09	- - 0.04 0.04	- - 0.03 0.08
126	NA	Main_Re38 crDev_1978	0.39 0.72 0.38 0.42	0.38 0.42	0.36 0.41	0.38 0.43

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

X	Label	Type	X0..RefX01..oldX02cloldX03clpriX04..noX05..noX06r.noX07knoX08.inoX09shoX10CMNXX10YnoX11a.DInd8..McAll												
		er- side	side.no.xno.theboattheboat	side.in- dex	dices	let									
		ence.Model													
127	NA	Main_Re07 crDev_1979	0.09	0.45	0.07	0.12	0.06	0.10	0.12	0.07	0.08	0.08	0.25	0.21	0.21
128	NA	Main_Re- crDev_1980	- 0.08	0.25 0.10	- 0.06	- 0.12	- 0.08	- 0.06	- 0.10	- 0.09	- 0.10	- 0.06	- 0.10	- 0.10	
129	NA	Main_Re- crDev_1983	0.00 0.03	0.27 -	- 0.00	- -	- 0.04	- 0.01	- -	0.02 0.03	- 0.02	- 0.03	- 0.16	- 0.12	- 0.12
130	NA	Main_Re- crDev_1980	- 0.23	- 0.03	- 0.26	- 0.23	- 0.27	- 0.24	- 0.21	- 0.26	- 0.25	- 0.25	- 0.10	- 0.06	- 0.06
131	NA	Main_Re28 crDev_1983	0.31	0.46	0.28	0.31	0.27	0.29	0.33	0.28	0.29	0.28	0.37	0.34	0.34
132	NA	Main_Re- crDev_1988	- 0.05	0.03 0.08	- 0.06	- 0.09	- 0.07	- 0.04	- 0.08	- 0.07	- 0.08	- 0.14	- 0.10	- 0.10	
133	NA	Main_Re16 crDev_1985	0.19	0.29	0.16	0.17	0.15	0.17	0.20	0.16	0.17	0.16	0.22	0.18	0.18
134	NA	Main_Re- crDev_1986	- 0.14	- 0.02	- 0.17	- 0.15	- 0.17	- 0.16	- 0.12	- 0.17	- 0.16	- 0.16	- 0.00	- 0.03	- 0.03
135	NA	Main_Re13 crDev_1987	0.16	0.32	0.13	0.14	0.13	0.13	0.18	0.13	0.14	0.13	0.16	0.14	0.14
136	NA	Main_Re- crDev_1988	- 0.19	- 0.01	- 0.22	- 0.21	- 0.22	- 0.21	- 0.17	- 0.22	- 0.21	- 0.21	- 0.03	- 0.01	- 0.01
137	NA	Main_Re30 crDev_1989	0.33	0.49	0.30	0.30	0.30	0.30	0.34	0.30	0.30	0.30	0.34	0.32	0.32
138	NA	Main_Re12 crDev_1990	0.15	0.25	0.12	0.12	0.13	0.12	0.16	0.12	0.13	0.12	0.19	0.17	0.17
139	NA	Main_Re- crDev_1999	- 0.07	- 0.02	- 0.09	- 0.10	- 0.09	- 0.09	- 0.06	- 0.09	- 0.09	- 0.09	- 0.03	- 0.04	- 0.04
140	NA	Main_Re- crDev_1990	- 0.18	- 0.14	- 0.20	- 0.21	- 0.19	- 0.20	- 0.18	- 0.20	- 0.20	- 0.20	- 0.23	- 0.24	- 0.24

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

X	Label	Type	X0..RefX01..oldX02.oldX03.oldX04..noX05..noX06..noX07.knoX08..inX09..shoX10..OMX11..YnoX12..a.WndX13..McAll												
		er- ence. Model	side - no. x.no. the boat the boat	side.in- dex - dices	let										
141	NA	Main_Re- crDev_1993	- 0.05	- 0.01	- 0.07	- 0.08	- 0.07	- 0.07	- 0.06	- 0.07	- 0.07	- 0.07	- 0.12	- 0.12	- 0.12
142	NA	Main_Re- crDev_1994	0.28	0.33	0.27	0.26	0.27	0.26	0.26	0.27	0.27	0.27	0.20	0.20	0.20
143	NA	Main_Re- crDev_1995	0.22	0.29	0.21	0.21	0.22	0.21	0.19	0.21	0.22	0.22	0.16	0.16	0.16
144	NA	Main_Re- crDev_1996	- 0.24	- 0.15	- 0.24	- 0.24	- 0.23	- 0.24	- 0.27	- 0.24	- 0.24	- 0.24	- 0.30	- 0.30	- 0.30
145	NA	Main_Re- crDev_1997	0.08	0.18	0.08	0.07	0.09	0.08	0.05	0.08	0.08	0.08	0.07	0.08	0.08
146	NA	Main_Re- crDev_1998	0.09	0.13	0.10	0.09	0.10	0.09	0.06	0.10	0.10	0.10	0.11	0.12	0.12
147	NA	Main_Re- crDev_1999	0.25	0.25	0.26	0.25	0.27	0.25	0.22	0.26	0.26	0.26	0.29	0.31	0.31
148	NA	Main_Re- crDev_2000	0.46	0.41	0.47	0.45	0.47	0.45	0.42	0.47	0.47	0.47	0.53	0.56	0.56
149	NA	Main_Re- crDev_2003	- 0.34	- 0.39	- 0.33	- 0.35	- 0.33	- 0.35	- 0.37	- 0.33	- 0.33	- 0.33	- 0.27	- 0.23	- 0.23
150	NA	Main_Re- crDev_2008	- 0.50	- 0.55	- 0.48	- 0.51	- 0.48	- 0.51	- 0.53	- 0.48	- 0.48	- 0.48	- 0.42	- 0.38	- 0.38
151	NA	Main_Re- crDev_2003	0.17	0.08	0.19	0.16	0.19	0.16	0.14	0.19	0.19	0.19	0.32	0.38	0.38
152	NA	Main_Re- crDev_2004	0.08 0.07	- 0.11	0.06	0.10	0.06	0.05	0.11	0.10	0.11	0.23	0.29	0.29	
153	NA	Main_Re- crDev_2005	0.00 0.15	- 0.03	- 0.02	0.02 0.02	- 0.02	- 0.03	0.03	0.02	0.03	0.19	0.27	0.27	
154	NA	Main_Re- crDev_2006	0.46 0.49	0.39	0.49	0.43	0.48	0.42	0.43	0.49	0.48	0.49	0.68	0.77	0.77

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

X	La-	Type	X0..Ref	X01..old	X02..old	X03..clpri	X04..no	X05..no	X06..no	X07..kno	X08..in	X09..rsho	X10..M	X10..N	X11..Y	X12..D	X13..McAll
	bel		er-	side	side.no	xat	boat	water	side.in-	dex							let
			ence.	Model					dices								
169	NA	Late_R0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		crDev_2021															
170	NA	Late_R0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		crDev_2022															
171	NA	For-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		eReCr_2023															
172	NA	InitF_s@001_@t001	Tr@000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		TRWL															
173	NA	InitF_s@001_@t002	No@000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		ational															
174	NA	InitF_s@001_@t003	Re@000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		ating(4)	5.57	5.59	5.96	5.57	5.47	5.56	5.46	5.53	5.57	5.56	5.57	5.60	5.66	5.66	
175	NA	LnQ_base_Tag-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Survey(5)	7.13	7.06	7.29	7.13	6.83	7.11	6.82	6.88	7.13	7.08	7.11	7.48	3.79	3.79	
176	NA	LnQ_base_Nearshore	sur-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		traSD_Nearshore	sur-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
177	NA	Q_ex-0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
		traSD_Nearshore	sur-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
178	NA	LnQ_base_OC-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		NMS(6)	7.40	7.34	7.55	7.40	7.14	7.38	7.13	7.22	7.40	7.36	7.39	7.64	7.91	7.91	
179	NA	LnQ_base_OC-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		NMS_YOY(7)	6.53	6.64	6.58	6.40	6.57	6.40	6.41	6.58	6.54	6.56	6.64	6.79	6.79	6.79	
180	NA	Q_ex-1.80	1.80	1.79	1.80	1.83	1.80	1.83	1.84	1.80	1.81	1.80	1.78	1.76	1.76	1.76	
		traSD_OC-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
		NMS_YOY(7)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
181	NA	LnQ_base_Pri-NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		vate_B@28)		6.24	6.16	6.23	6.15	6.20	6.24	6.23	6.24	6.33	6.38	6.38			

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

X	La-	Type	X0..Ref	X01..old	X02..old	X03..clpri	X04..no	X05..no	X06..no	X07..no	X08..no	X09..no	X10..M	X10..N	X10..Y	X11..a	X11..D	X11..B..McAll
	bel		er-	side	side.no	xat	boat	water	side.in-	dex								let
			ence.	Model					dices									
182	NA	Q_ex- traSD_Pri- vate_Boat(8)	0.38	NA	NA	0.38	0.38	0.38	0.38	0.42	0.38	0.38	0.38	0.33	0.29	0.29	0.29	
183	NA	LnQ_base_Cha- ter(9)	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	
184	NA	Q_ex- traSD_Char- ter(9)	0.14	NA	NA	0.14	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.09	0.09	0.09	0.09	
185	NA	Size_DblN2pe50.0Trawl(1)	50.02	50.06	50.01	50.04	50.04	50.02	50.03	50.02	49.72	49.70	49.70					
186	NA	Size_DblN1_top0.83git_0196wl(1)	0.81	0.80	0.79	0.83	0.81	0.82	0.81	0.82	2.11	2.11	2.11					
187	NA	Size_DblN6_as-3.46_cend_se_Trawl(1)	3.46	3.46	3.47	3.46	3.47	3.47	3.46	3.46	3.45	3.45	3.45					
188	NA	Size_DblN0_de-2.20_scend_se_Trawl(1)	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20					
189	NA	Size_DblN_start_logit_Trawl(1)	-	-	-	-	-	-	-	-	-	-	-					
190	NA	Size_DblN0_end5.06git_5100wl(5)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00					
191	NA	Size_DblN83pe48.8Non48.70_TRWL(2)	48.83	48.87	48.82	48.86	48.84	48.83	48.83	48.83	47.82	47.77	47.77					
192	NA	Size_DblN_top1.95git_Non-TRWL(2)	0.91	0.80	0.83	0.63	0.82	0.81	0.80	0.80	0.80	0.81	0.81					
193	NA	Size_DblN0_as-4.30_cend_se_Non-TRWL(2)	4.34	4.30	4.31	4.30	4.31	4.30	4.30	4.30	4.30	4.22	4.22					
194	NA	Size_DblN0_de-3.00_scend_se_Non-TRWL(2)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00					
195	NA	Size_DblN_start_logit_Non-TRWL(2)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00					

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

X	La- bel	Type	X0..Ref	X01..old	X02..old	X03..clpri	X04..no	X05..no	X06..no	X07..no	X08..no	X09..no	X10..M	X10..N	X10..Y	X11..a	X11..D	X11..B..McAll
		er- ence. Model	side	side.no	xat	boat	water	side.in-	dex	side.in-	dex	side.in-	dex	side.in-	dex	side.in-	dex	let
220	NA	Size_DblN_end_logit_OC- NMS(6)15.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
221	NA	Size- Sel_P1_100- vate_Boat(8)	-	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	
222	NA	Size- Sel_P2_100- vate_Boat(8)	-	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	
223	NA	Size- Sel_P1_100har- ter(9)	-	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	
224	NA	Size- Sel_P2_100har- ter(9)	-	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	
225	NA	LnQ_base Dock- side(8)	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
226	NA	Q_ex- traSD_Dock- side(8)	NA	0.17	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
227	NA	Size- Sel_P1_Dock- side(8)	NA	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
228	NA	Size- Sel_P2_Dock- side(8)	NA	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
229	NA	ln(DM_Nata)_Nata_P1NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	5.28	5.28		
230	NA	ln(DM_Nata)_Nata_P2NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.39	4.39		
231	NA	ln(DM_Nata)_Nata_P3NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.23	6.23		
232	NA	ln(DM_Nata)_Nata_P4NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.70	4.70		

**Table 7:** Likelihood, parameter and derived quantities from data treatment sensitivities. (*continued*)

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities.

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

X	La-	Type	X0..Ref	X01..Es	KM	X02..Lo	X03..fix	X04..fix	X05..Est	X06..M	X07..Es	X08..Vbi	X09..at	X10..Fe	X11..tw	X12..dev	X13..Dens	ed.sel.est
	bel	er-	zen.M															
16	NA	ALL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
17	NA	Trawl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	NA	Non-TRWL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	NA	Recreational	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	NA	Tag-ging	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
21	NA	Nearshore	1.00	sur-1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
22	NA	OC-NMS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
23	NA	OC-NMS_YOY	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
24	NA	Pri- vate_Boat	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
25	NA	Char- ter	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
26	Length	NA	lik- hood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
27	NA	ALL	656.84	643.43	717.88	650.83	645.76	652.72	662.42	643.38	658.34	656.84	657.72	673.35	657.92	646.44		
28	NA	Trawl	134.96	134.35	143.51	95.55	94.52	116.11	109.81	134.12	135.18	134.96	135.08	141.81	134.98	133.72		
29	NA	Non-TRWL	56.22	54.81	61.45	49.80	49.92	54.04	51.26	56.66	56.32	56.22	56.28	57.91	56.37	56.09		
30	NA	Recreational	330.64	321.50	374.06	339.13	335.30	339.44	353.06	320.63	331.65	330.64	331.24	338.60	331.32	329.17		
31	NA	Tag-ging	18.87	17.02	21.91	27.93	28.33	24.33	26.98	15.75	19.02	18.87	18.96	17.51	19.02	14.68		

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

X	Label	Type	X0..RefX01..EsKM2..LoX03..fixX04..fixX05wEsKM6..MxX07..EsKM8..VisX09..atlogX10..FeX11..NwX12..DevX13..Densd.sel.est												
		er- e- re- cen- ce. Model	zen.M												
64	NA	Tag- ging	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	NA	Nearshore vey	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	NA	OC- NMS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
67	NA	OC- NMS_YOY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
68	NA	Private_Boat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
69	NA	Char- ter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	Param- eters	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
71	NA	NatM_0n17 form_Fem_GP_1	0.16	NA	0.17	0.10	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
72	NA	L_at_A0n0_Fem00GP0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
						26.30									
73	NA	L_at_A0n0_Fem68GP52J3	51.19	51.19	51.81	51.99	52.50	52.73	52.72	52.73	52.75	52.73	52.77		
74	NA	Von-Bert_K_Fem_GP_1	0.12	0.12	0.12	0.15	0.15	0.16	0.16	0.12	0.12	0.12	0.12	0.12	0.12
75	NA	CV_youngFem0.1GP_0.10	0.10	0.10	0.10	0.10	0.01	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
76	NA	CV_oldFem_GP_0.1	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10
77	NA	Wtlen_0.0Fem_0GP_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78	NA	Wtlen_2.7Fem_2GP_1	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72
79	NA	Mat50%0B6m_40B61	40.36	40.36	40.36	40.36	40.36	40.36	34.38	40.36	40.36	40.36	40.36	40.36	40.36

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

X	La-	Type	X0..Ref	X01..Es	X02..Lo	X03..fix	X04..wfix	X05..Est	X06..Mx	X07..Es	X08..Vbi	X09..at	X010..Fe	X11..tw	X12..dev	X13..Dens	sel.est
	bel	er-	zen.M														
		ence.	Model														
98	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-
		crDev_1956	0.79	0.63	0.71	1.20	0.55	0.57	0.59	0.50	0.54	0.52	0.34	0.38	0.57		
99	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1957	0.79	0.63	0.72	1.18	0.59	0.58	0.60	0.52	0.56	0.54	0.38	0.40	0.59		
100	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1958	0.76	0.61	0.71	1.13	0.57	0.59	0.60	0.52	0.55	0.53	0.40	0.42	0.58		
101	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1959	0.71	0.57	0.67	1.05	0.54	0.56	0.56	0.49	0.52	0.50	0.38	0.40	0.55		
102	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1960	0.63	0.49	0.61	0.93	0.50	0.51	0.50	0.43	0.46	0.44	0.34	0.36	0.49		
103	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1961	0.52	0.39	0.52	0.78	0.42	0.43	0.40	0.34	0.37	0.35	0.27	0.29	0.40		
104	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1962	0.40	0.27	0.43	0.61	0.31	0.35	0.30	0.24	0.27	0.25	0.18	0.20	0.30		
105	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1963	0.32	0.20	0.37	0.47	0.26	0.30	0.25	0.19	0.22	0.20	0.14	0.16	0.25		
106	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1964	0.36	0.25	0.39	0.44	0.31	0.33	0.31	0.24	0.27	0.25	0.19	0.21	0.30		
107	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1965	0.40	0.30	0.43	0.47	0.36	0.38	0.36	0.30	0.33	0.32	0.25	0.27	0.36		
108	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1966	0.37	0.28	0.40	0.43	0.32	0.36	0.33	0.27	0.31	0.29	0.23	0.25	0.33		
109	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1967	0.14	0.06	0.22	0.30	0.12	0.16	0.11	0.07	0.10	0.08	0.03	0.05	0.13		
110	NA	Main_Re16	0.17	0.25	0.16	0.49	0.15	0.10	0.12	0.19	0.16	0.18	NA	0.21	0.13		
111	NA	Main_Re-	-	-	-	-	-	-	-	-	-	-	-	NA	-	-	
		crDev_1968	0.15	0.09	0.17	0.20	0.15	0.17	0.15	0.11	0.14	0.12	0.07	0.09	0.16		
		crDev_1969	0.15	0.09	0.17	0.20	0.15	0.17	0.15	0.11	0.14	0.12	0.07	0.09	0.16		

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. *(continued)*

X	Label	Type	X0..RefX01..EsK02..LoX03..fixX04wfixX05wEsK06MxX07..EsK08VbiX09atExX10..FeX11twNoX12.devX13c.Dens	er-zen.M	nal.mat.ogive	sel.est
		er- ence.Model				
112	NA	Main_Re- crDev_1970	-	-	-	-
			0.17	0.11	0.23	0.24
					0.20	0.22
					0.19	0.14
					0.17	0.15
					NA	-
						0.10
						0.19
113	NA	Main_Re-02 crDev_1971	0.07	0.12	0.05	0.46
					0.00	-
						0.00
						0.05
						NA
						0.07
						0.00
114	NA	Main_Re- crDev_1972	-	-	-	0.02
			0.05	0.01	0.04	
					0.10	0.13
					0.05	0.04
					0.07	0.06
					NA	-
						0.02
						0.09
115	NA	Main_Re-32 crDev_1973	0.38	0.40	0.29	0.52
					0.28	0.23
					0.32	0.34
					0.32	0.33
					NA	0.36
						0.30
116	NA	Main_Re-39 crDev_1974	0.47	0.49	0.54	0.93
					0.37	0.33
					0.36	0.41
					0.39	0.40
					NA	0.42
						0.38
117	NA	Main_Re- crDev_1975	-	-	-	-
			0.21	0.21	0.28	0.27
					0.25	0.26
					0.18	0.22
					0.24	0.23
					NA	-
						0.19
						0.26
118	NA	Main_Re-04 crDev_1976	0.13	0.14	0.16	0.55
					-	-
					0.00	0.06
					0.04	0.05
					NA	0.07
						0.02
119	NA	Main_Re- crDev_1977	-	-	-	0.22
			0.01	0.01	0.01	
					0.18	0.21
					0.06	0.06
					0.08	0.06
					NA	-
						0.04
						0.09
120	NA	Main_Re-38 crDev_1978	0.48	0.46	0.41	0.75
					0.28	0.24
					0.39	0.39
					0.38	0.39
					NA	0.41
						0.37
121	NA	Main_Re-07 crDev_1979	0.17	0.15	0.15	0.44
					0.00	-
						0.04
						NA
						0.11
						0.06
122	NA	Main_Re- crDev_1980	-	-	-	0.17
			0.01	0.04	0.12	
					0.21	0.22
					0.09	0.09
					0.10	0.09
					NA	-
						0.07
						0.11
123	NA	Main_Re- crDev_1983	0.07	0.04	-	0.28
					-	-
					0.00	-
					-	-
					NA	0.00
						-
						0.04
124	NA	Main_Re- crDev_1988	-	-	-	-
			0.16	0.20	0.27	0.02
					0.44	0.42
					0.20	0.25
					0.26	0.25
					NA	-
						0.22
						0.26
125	NA	Main_Re-28 crDev_1983	0.39	0.35	0.34	0.61
					0.24	0.23
					0.29	0.28
					0.28	0.28
					NA	0.31
						0.28

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

X	Label	Type	X0..RefX01..EsX02..LoX03..fixX04..fixX05..fixX06..fixX07..EsX08..fixX09..fixX10..FeX11..twX12..DevX13..Densd..sel.est												
er-zen.M															
ence.Model															
126	NA	Main_Re- crDev_1984	0.01	-	0.03	0.24	-	-	-	-	-	-	NA	-	-
							0.19	0.19	0.02	0.08	0.08	0.08	0.05	0.08	
127	NA	Main_Re-16 crDev_1985	0.26	0.21	0.31	0.51	0.06	0.05	0.18	0.15	0.16	0.15	NA	0.18	0.16
128	NA	Main_Re- crDev_1986	-	-	-	0.10	-	-	-	-	-	-	NA	-	-
							0.29	0.35	0.12	0.18	0.17	0.17	0.14	0.17	
129	NA	Main_Re-13 crDev_1987	0.22	0.18	0.22	0.36	0.11	0.11	0.13	0.11	0.13	0.12	NA	0.16	0.13
130	NA	Main_Re- crDev_1988	-	-	-	-	-	-	-	-	-	-	NA	-	-
							0.14	0.18	0.18	0.07	0.24	0.22	0.23	0.19	0.22
131	NA	Main_Re-30 crDev_1989	0.37	0.34	0.32	0.43	0.29	0.31	0.31	0.26	0.30	0.28	NA	0.32	0.30
132	NA	Main_Re-12 crDev_1990	0.19	0.16	0.33	0.40	0.10	0.14	0.14	0.08	0.12	0.10	NA	0.15	0.12
133	NA	Main_Re- crDev_1999	-	-	0.07	0.13	-	-	-	-	-	-	NA	-	-
								0.12	0.11	0.10	0.14	0.09	0.12	0.06	0.09
134	NA	Main_Re- crDev_1990	-	-	0.00	0.04	-	-	-	-	-	-	NA	-	-
								0.27	0.23	0.20	0.26	0.20	0.23	0.17	0.20
135	NA	Main_Re- crDev_1993	-	-	0.08	0.11	-	-	-	-	-	-	NA	-	-
								0.11	0.15	0.08	0.13	0.07	0.10	0.04	0.07
136	NA	Main_Re-27 crDev_1994	0.33	0.30	0.38	0.42	0.21	0.24	0.25	0.20	0.27	0.23	NA	0.29	0.27
137	NA	Main_Re-21 crDev_1995	0.29	0.25	0.27	0.31	0.19	0.17	0.19	0.14	0.21	0.17	NA	0.24	0.21
138	NA	Main_Re- crDev_1996	-	-	-	-	-	-	-	-	-	-	NA	-	-
								0.26	0.28	0.25	0.31	0.24	0.28	0.21	0.24
139	NA	Main_Re-08 crDev_1997	0.16	0.11	0.04	0.10	0.05	0.10	0.06	0.02	0.08	0.05	NA	0.11	0.08

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

X	La-	Type	X0..Ref	X01..Es	KM	X02..Lo	X03..fix	X04..wfix	X05w	Est	M	X07..Es	K08V	bis	X09at	Ex	X10..Fe	X11w	No	Xt2..Dev	Xt3c..Dens	sel.est
	bel		er-	zen.M																		
140	NA	Main_Re40	crDev_1998	0.16	0.13	0.12	0.15	0.08	0.03	0.09	0.05	0.10	0.07	NA	0.13	0.10						
141	NA	Main_Re26	crDev_1999	0.32	0.29	0.30	0.32	0.22	0.32	0.25	0.22	0.26	0.24	NA	0.30	0.27						
142	NA	Main_Re47	crDev_2000	0.53	0.49	0.57	0.58	0.43	0.39	0.45	0.43	0.47	0.45	NA	0.50	0.48						
143	NA	Main_Re-	crDev_2003	-	-	-	-	-	-	-	-	-	-	NA	-	-						
				0.29	0.32	0.17	0.20	0.35	0.32	0.33	0.36	0.33	0.34		0.29	0.31						
144	NA	Main_Re-	crDev_2008	-	-	-	-	-	-	-	-	-	-	NA	-	-						
				0.45	0.48	0.48	0.53	0.46	0.45	0.48	0.50	0.48	0.49		0.44	0.47						
145	NA	Main_Re19	crDev_2003	0.22	0.19	0.20	0.15	0.22	0.27	0.20	0.17	0.19	0.18	NA	0.23	0.21						
146	NA	Main_Re41	crDev_2004	0.12	0.09	0.29	0.21	0.13	0.16	0.09	0.09	0.11	0.10	NA	0.15	0.13						
147	NA	Main_Re03	crDev_2005	0.04	-	0.12	0.02	0.15	0.18	0.08	0.01	0.03	0.02	NA	0.08	0.05						
				0.01																		
148	NA	Main_Re49	crDev_2006	0.49	0.45	0.70	0.60	0.50	0.58	0.49	0.48	0.49	0.48	NA	0.54	0.52						
149	NA	Main_Re50	crDev_2007	0.49	0.45	0.72	0.61	0.58	0.59	0.52	0.49	0.50	0.49	NA	0.55	0.54						
150	NA	Main_Re63	crDev_2008	0.61	0.56	0.85	0.73	0.68	0.78	0.65	0.63	0.63	0.63	NA	0.69	0.68						
151	NA	Main_Re39	crDev_2009	0.34	0.30	0.63	0.49	0.46	0.47	0.41	0.39	0.39	0.39	NA	0.45	0.44						
152	NA	Main_Re28	crDev_2010	0.22	0.18	0.37	0.21	0.36	0.43	0.30	0.29	0.28	0.29	NA	0.35	0.33						
153	NA	Main_Re81	crDev_2011	0.74	0.69	0.89	0.71	0.90	0.92	0.84	0.82	0.81	0.82	NA	0.88	0.87						

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

X	La-	Type	X0..Ref	X01..Es	X02..Lo	X03..fix	X04..wfix	X05..Est	X06..Mx	X07..Es	X08..Vbi	X09..at	X010..Fe	X11..tw	X12..dev	X13..Dens	ed.sel.est
	bel	er-	zen.M														nal.mat.ogive
		ence.Model															
169	NA	LnQ_base_Tag- ging(4)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			5.57	5.39	5.58	7.32	6.08	5.76	6.01	5.69	5.59	5.57	5.58	5.52	5.59	5.50	
170	NA	LnQ_base_Nearshore_ survey(5)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			7.13	6.76	6.90	8.28	6.79	7.44	7.59	7.25	7.20	7.13	7.17	6.69	7.20	6.97	
171	NA	Q_ex- traSD_Nearshore_ survey(5)	0.12	0.12	0.12	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.12	0.10	
172	NA	LnQ_base_OC- NMS(6)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			7.40	7.03	7.24	8.56	7.06	7.61	7.74	7.51	7.46	7.40	7.44	6.94	7.46	7.54	
173	NA	LnQ_base_OC- NMS_YOY(7)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			6.13	7.09	7.01	5.37	6.85	6.96	6.60	6.62	6.58	6.60	6.51	6.60	6.62		
174	NA	Q_ex- traSD_OC- NMS_YOY(7)	1.80	1.81	1.85	1.91	1.96	1.70	1.63	1.79	1.79	1.80	1.79	1.72	1.78	1.81	
175	NA	LnQ_base_Pri- vate_Boat(8)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			6.09	6.25	7.87	6.74	6.46	6.68	6.33	6.25	6.24	6.25	6.16	6.25	6.28		
176	NA	Q_ex- traSD_Pri- vate_Boat(8)	0.38	0.43	0.40	0.17	0.39	0.37	0.29	0.35	0.37	0.38	0.37	0.42	0.37	0.35	
177	NA	LnQ_base_Char- ter(9)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			5.73	5.64	5.76	7.12	6.25	5.91	6.06	5.79	5.73	5.73	5.73	5.68	5.73	5.74	
178	NA	Q_ex- traSD_Char- ter(9)	0.14	0.15	0.13	0.08	0.08	0.16	0.13	0.13	0.14	0.14	0.14	0.15	0.14	0.13	
179	NA	Size_D5IN2pe50_1Trawl(6)	49.80	50.07	49.96	49.56	50.88	50.03	50.02	50.02	49.95	50.05	50.00				
180	NA	Size_D6IN81_top0_06git_0T2wl(1)- 0.52	-	0.81	-	-	0.82	0.41	0.17	0.82	0.81	0.82	0.86	0.86	0.79		
181	NA	Size_D6IN6_as-3.48 cend_se_Trawl(1)	3.41	3.63	3.68	3.50	3.59	3.55	3.46	3.46	3.46	3.44	3.46	3.46	3.46	3.46	

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (continued)

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

X	Label	Type	X0..RefX01..EsX02..LoX03..fixX04..fixX05wX06MxX07..EsX08..biX09atX10..FeX11twX12..DevX13c..Dorned..sel.est
		er-zen.M	nal.mat.ogive
		ence.Model	
207	NA	Size_DblN_start_logit_Nearshore_surve(5) 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00 4.00	- - - - - - - - - - - - - - -
208	NA	Size_DblN_end_logit_Nearshore_surve(5) 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 -	- - - - - - - - - - - - - - - 3.28
209	NA	Size_DblN67pe26_43C-28.53 NMS(6)	15.00 10.85 26.40 25.07 26.23 26.61 26.67 26.64 28.89 26.55 13.04
210	NA	Size_DblN_top3_49git_1Q18- NMS(6)	1.66 3.68 3.53 1.37 3.55 3.51 3.50 3.51 3.16 3.51 2.62
211	NA	Size_DblN9_as-3.59 NMS(6)	3.59 3.59 3.59 3.59 3.59 3.59 3.59 3.59 3.59 3.59 3.59 3.59 3.59 3.59
212	NA	Size_DblN_descend_s4_50C- NMS(6)	4.50 9.47 4.51 4.86 4.50 4.51 4.50 4.50 4.50 4.50 4.49 4.50 4.50
213	NA	Size_DblN_start_logit_OC- NMS(6)15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00	- - - - - - - - - - - - - - -
214	NA	Size_DblN_end_logit_OC- NMS(6)15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 3.90	- - - - - - - - - - - - - - -
215	NA	Size-Sel_P1_1P01- NMS(6)15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00	- - - - - - - - - - - - - - -
216	NA	Size-Sel_P2_1P01- NMS(6)15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00	- - - - - - - - - - - - - - -
217	NA	Size-Sel_P1_1OBar- NMS(6)15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00 15.00	- - - - - - - - - - - - - - -

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

X	Label	Type	X0..RefX01..EsKM2..LoX03..fixX04..fixX05wEsKM6..MixX07..EsKM8..fixX09atlogX10..FeX11..NwX12..devX13..Densd..sel.est	
		er- e- re- nce. Model	zen.M	nal.mat.ogive
218	NA	Size- Sel_P2_10Bar- ter(9)	- - - - - 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00	- - - - - 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
219	NA	NatM_InZen- zen_Fem_GP_1	NA 0.17 NA	NA
220	NA	NatM_InZen- zen_Mal_GP_1	NA 0.15 NA	NA
221	NA	Main_RNA_crDev_1940	NA	- 0.18 NA
222	NA	Main_RNA_crDev_1941	NA	- 0.19 NA
223	NA	Main_RNA_crDev_1942	NA	- 0.20 NA
224	NA	Main_RNA_crDev_1943	NA	- 0.20 NA
225	NA	Main_RNA_crDev_1944	NA	- 0.21 NA
226	NA	Main_RNA_crDev_1945	NA	- 0.22 NA
227	NA	Main_RNA_crDev_1946	NA	- 0.22 NA
228	NA	Main_RNA_crDev_1947	NA	- 0.23 NA
229	NA	Main_RNA_crDev_1948	NA	- 0.23 NA
230	NA	Main_RNA_crDev_1949	NA	- 0.23 NA
231	NA	Main_RNA_crDev_1950	NA	- 0.23 NA

**Table 8:** Likelihood, parameter and derived quantities from model specification sensitivities. (*continued*)

X	La-	Type	X0..Ref	X01..Es	KM2..Lo	X03..fix	X04..fix	X05w	Es	KM4	Mx	X07..Es	K08V	bio	X09at	logX10..Fe	X11w	NoX12..Dev	X13c	Bmed	sel.est
	bel	er-	zen.M																		
232	NA	Main_RNA crDev_1951	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	0.23	NA		
233	NA	Main_RNA crDev_1952	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	0.23	NA		
234	NA	Main_RNA crDev_1953	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	0.24	NA		
235	NA	Main_RNA crDev_1954	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	0.27	NA		
236	NA	Main_RNA crDev_1955	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	0.30	NA		
237	De-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
	qui-																				
238	NA	SB0	946.03	856.71	785.70	2060.67	1621.55	1166.98	1239.57	978.61	1242.62	946.03	1746.17	801.54	918.46	971.29					
239	NA	SSB_2023	30.90	269.38	275.40	1941.15	495.23	735.97	891.42	494.02	690.68	430.90	920.83	232.60	468.77	497.00					
240	NA	Bra- tio_2023	0.46	0.31	0.35	0.94	0.31	0.63	0.72	0.50	0.56	0.46	0.53	0.29	0.51	0.51					
241	NA	MSY_SPR	60	245.89	251.07	565.39	212.44	313.71	334.09	285.48	310.15	276.60	295.11	234.94	268.40	283.03					
242	NA	F_SPR	0.05	0.05	0.04	0.06	0.04	0.06	0.06	0.05	0.06	0.05	0.05	0.05	0.05	0.05					

**Table 9:** The magnitude of retrospective pattern (Mohn's rho; Mohn, 1999) given the removal of ten years of data for fishing intensity ( $F$ ), fraction unfished (Figure 64), recruitment, and spawning stock biomass ( $SSB$ ; Figure 63). Columns are a derivation of Mohn's rho (Hurtado-Ferro et al. 2015) used by the Alaska Fisheries Science Center (AFSC), as originally described in Mohn (1999), and a derivation of Mohn's rho (Woods Hole Mohn's rho; Legault 2009) used by the Northeast Fisheries Science Center (NEFSC).

Quantity	AFSC	Mohn	NEFSC
$F$	0.2166536	2.166536	0.2127838
Fraction unfished	0.1070602	1.070602	0.4418694
Recruitment	-0.0734311	-0.734311	-0.3380007
$SSB$	0.05057448	0.5057448	-0.1174192

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**Table 10:** Projections of potential OFLs (mt), ABCs (mt), the buffer (ABC = buffer x OFL), estimated spawning biomass, and fraction unfished for Oregon portion of the vermillion stock. The North of 40°10'N OFL and ABC for 2021 and 2022 are included for comparison.

Year	OFL 40°10'N	ACL 40°10'N	Predicted OFL	ABC Catch	Buffer	Spawning Output	Fraction Unfished
2021	9.70	8.10	13.01	12.96	1.00	21.37	0.73
2022	9.70	8.10	13.35	12.96	1.00	21.53	0.73
2023	-	-	13.41	12.54	0.94	21.75	0.74
2024	-	-	13.29	12.36	0.93	21.85	0.75
2025	-	-	13.03	12.06	0.93	21.74	0.74
2026	-	-	12.72	11.73	0.92	21.46	0.73
2027	-	-	12.41	11.38	0.92	21.08	0.72
2028	-	-	12.10	11.05	0.91	20.65	0.71
2029	-	-	11.82	10.74	0.91	20.20	0.69
2030	-	-	11.56	10.45	0.90	19.75	0.68
2031	-	-	11.31	10.18	0.90	19.33	0.66
2032	-	-	11.08	9.94	0.90	18.92	0.65

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**Table 11:** Decision table summary of 10 year projections beginning in 2023 for alternative states of nature based on an axis of uncertainty about female and male natural mortality in the reference model. Columns range over low (12.5 quantile), mid (reference model), and high states (87.5 quantile) of nature and rows range over different catch level assumptions. Values in italics indicate years where the stock size prevented the full catch removals.

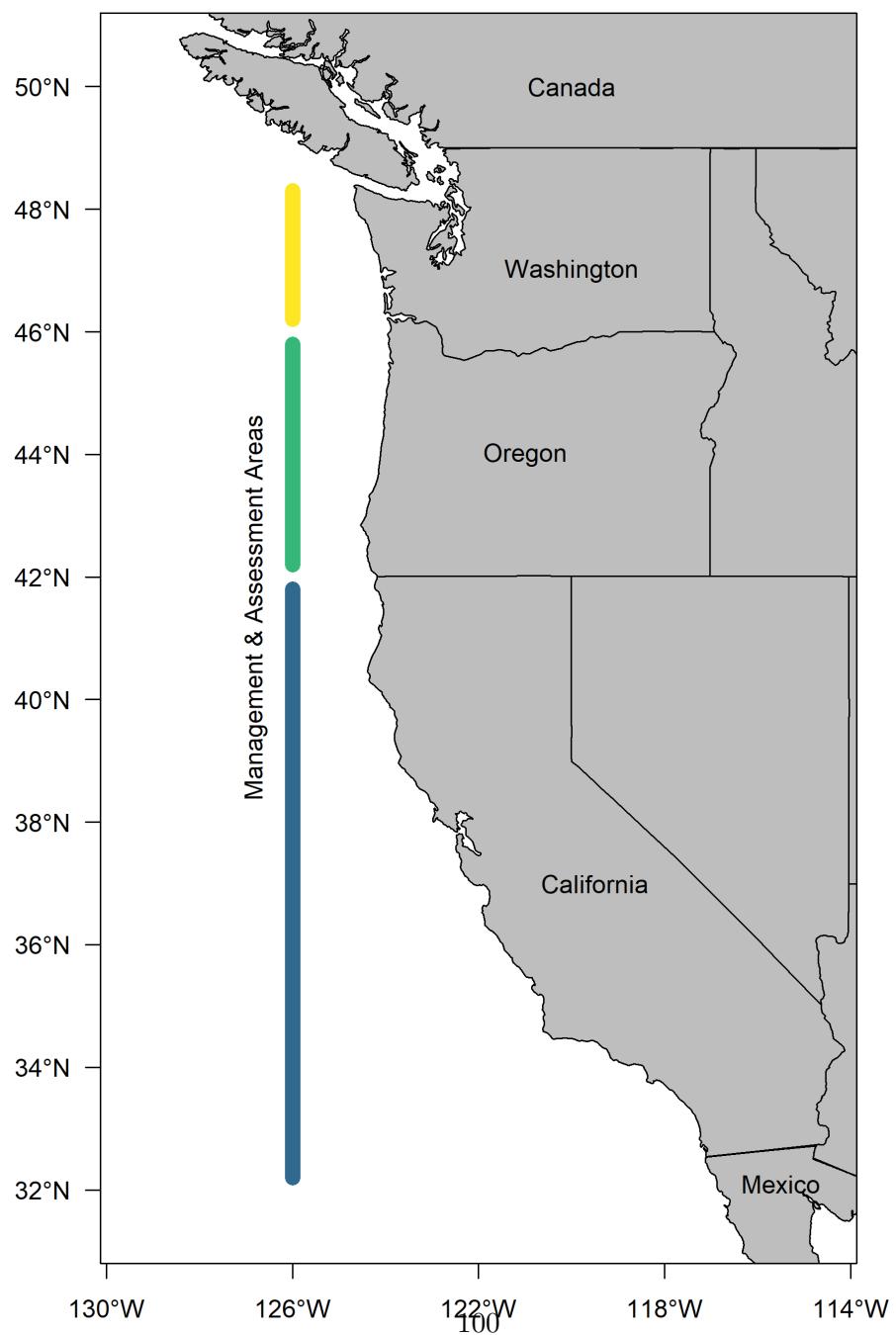
Year	Catch	3cm Female M = 0.071; Male = 0.065		3cm Female M = 0.079; Male = 0.073		Spawning Output	
		Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished		
$P^*=0.45$ $\sigma=0.5$	2021	12.96	17.70	0.62	21.37	0.73	24.46
	2022	12.96	17.76	0.62	21.53	0.73	24.68
	2023	12.60	17.89	0.63	21.79	0.74	25.01
	2024	12.45	17.93	0.63	21.92	0.75	25.20
	2025	12.19	17.81	0.63	21.85	0.74	25.16
	2026	11.89	17.56	0.62	21.63	0.74	24.93
	2027	11.56	17.23	0.60	21.29	0.72	24.58
	2028	11.24	16.86	0.59	20.90	0.71	24.16
	2029	10.93	16.46	0.58	20.48	0.70	23.70
	2030	10.63	16.06	0.56	20.04	0.68	23.23
$P^*=0.4$ $\sigma=0.5$	2031	10.36	15.67	0.55	19.62	0.67	22.76
	2032	10.10	15.29	0.54	19.21	0.65	22.31
	2021	12.96	17.70	0.62	21.37	0.73	24.46
	2022	12.96	17.76	0.62	21.53	0.73	24.68
	2023	11.77	17.89	0.63	21.79	0.74	25.01
	2024	11.60	18.00	0.63	21.99	0.75	25.27
	2025	11.34	17.96	0.63	21.99	0.75	25.30
	2026	11.04	17.78	0.62	21.84	0.74	25.14
	2027	10.72	17.53	0.62	21.58	0.73	24.87
	2028	10.41	17.22	0.60	21.25	0.72	24.51
$\text{Equilibrium}$ $\text{yield from}$ $\text{FMSY proxy}$ $\text{of SPR}=0.5$	2029	10.10	16.89	0.59	20.89	0.71	24.11
	2030	9.82	16.56	0.58	20.52	0.70	23.70
	2031	9.55	16.23	0.57	20.15	0.69	23.29
	2032	9.29	15.91	0.56	19.80	0.67	22.89
	2021	12.96	17.70	0.62	21.37	0.73	24.46
	2022	12.96	17.76	0.62	21.53	0.73	24.68
	2023	7.95	17.89	0.63	21.79	0.74	25.01
	2024	7.95	18.32	0.64	22.30	0.76	25.58
	2025	7.95	18.59	0.65	22.62	0.77	25.92
	2026	7.95	18.72	0.66	22.75	0.77	26.05
	2027	7.95	18.73	0.66	22.75	0.77	26.03
	2028	7.95	18.66	0.66	22.65	0.77	25.89
	2029	7.95	18.53	0.65	22.47	0.76	25.67
	2030	7.95	18.36	0.64	22.25	0.76	25.39
	2031	7.95	18.16	0.64	21.99	0.75	25.09
	2032	7.95	17.94	0.63	21.71	0.74	24.76

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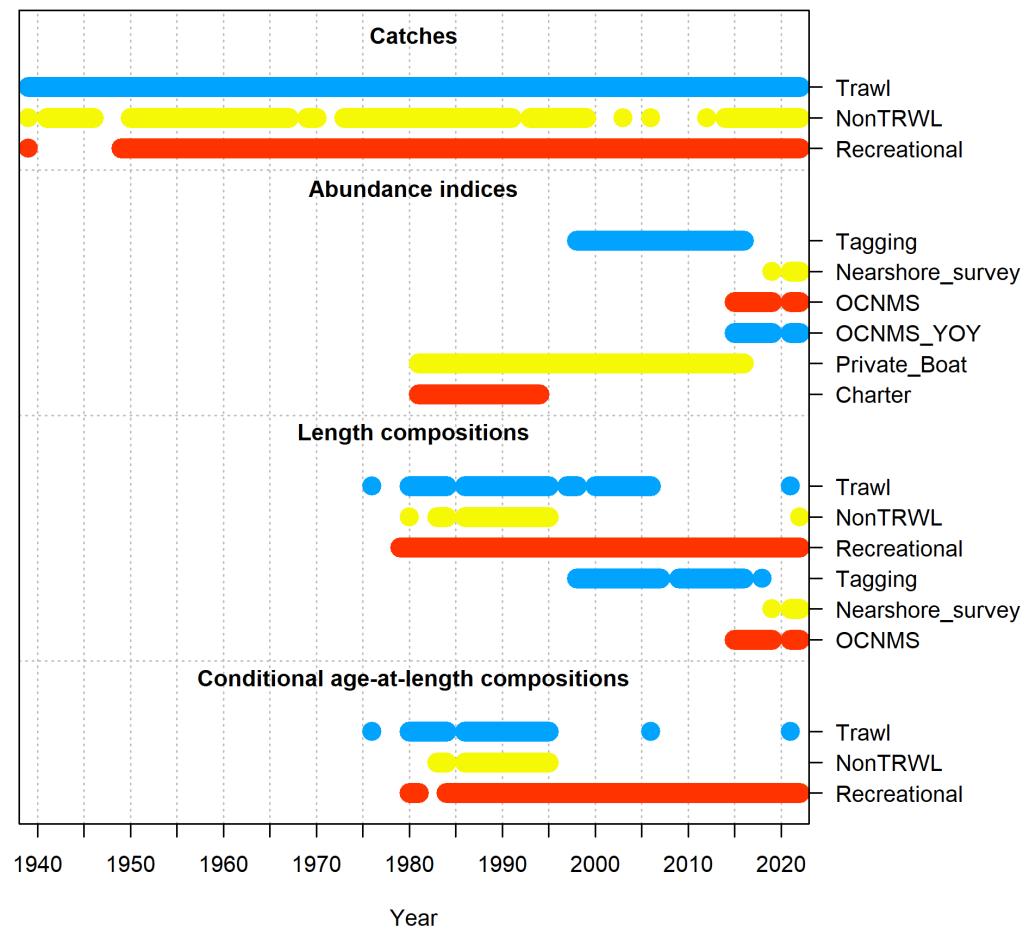


## 9 Figures

### 9.1 Data

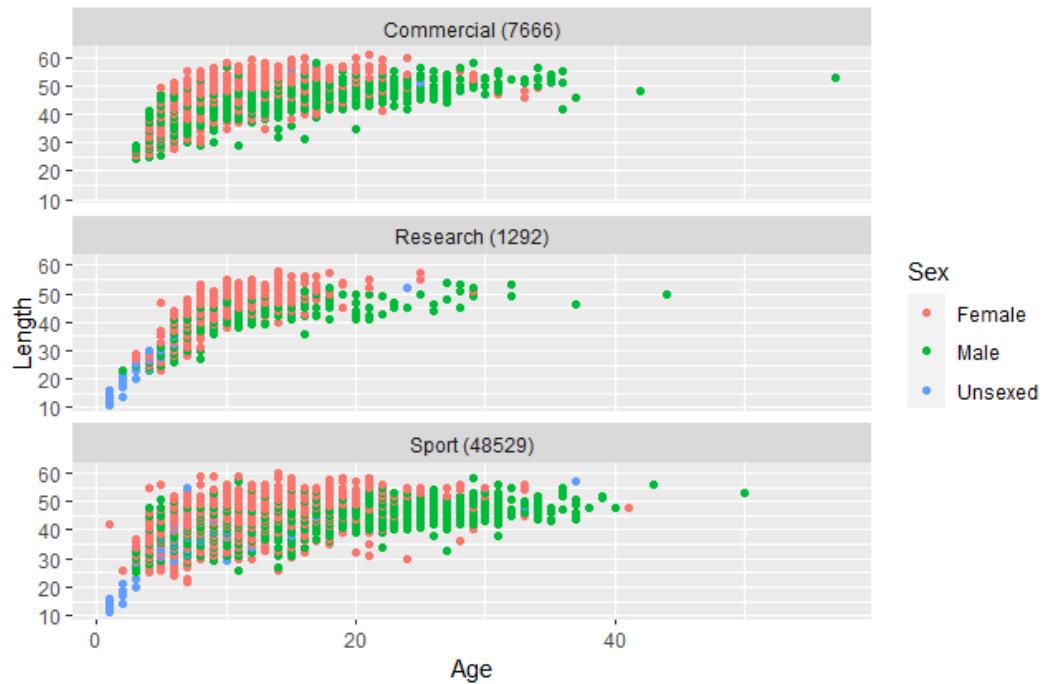


**Figure 1:** Map of the management and assessment areas for black rockfish.

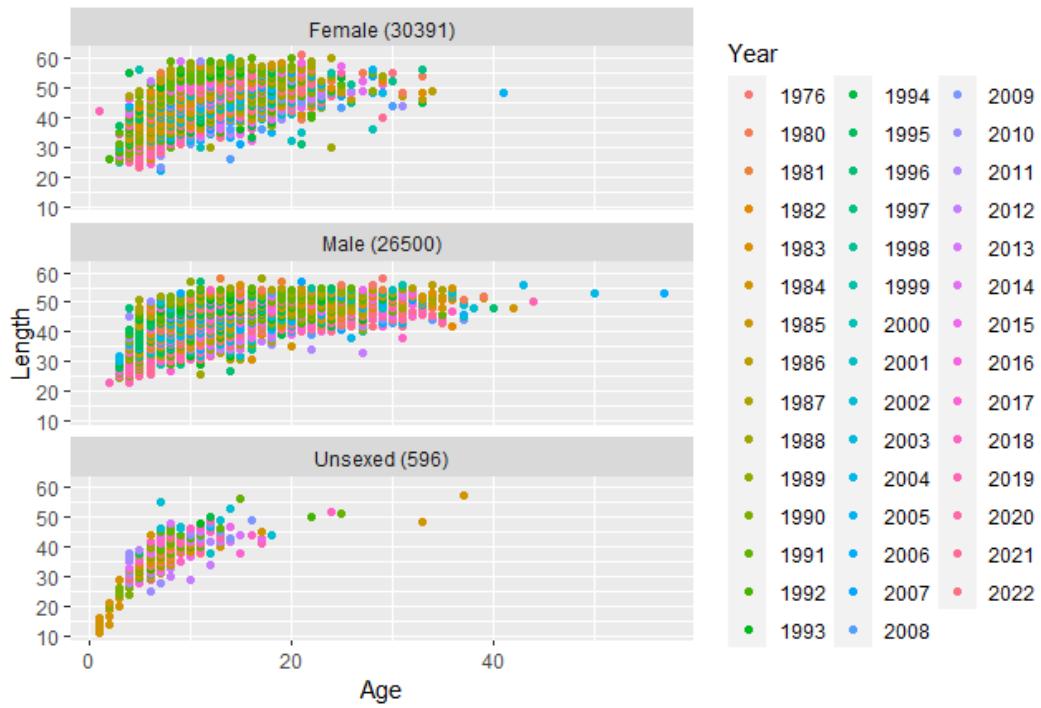


**Figure 2:** Summary of data sources used in the reference model.

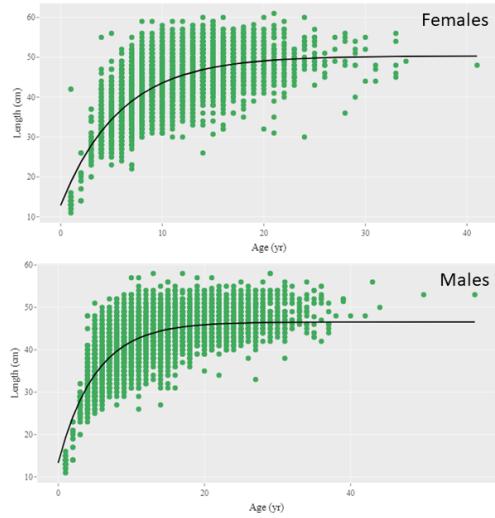
## 9.2 Biology



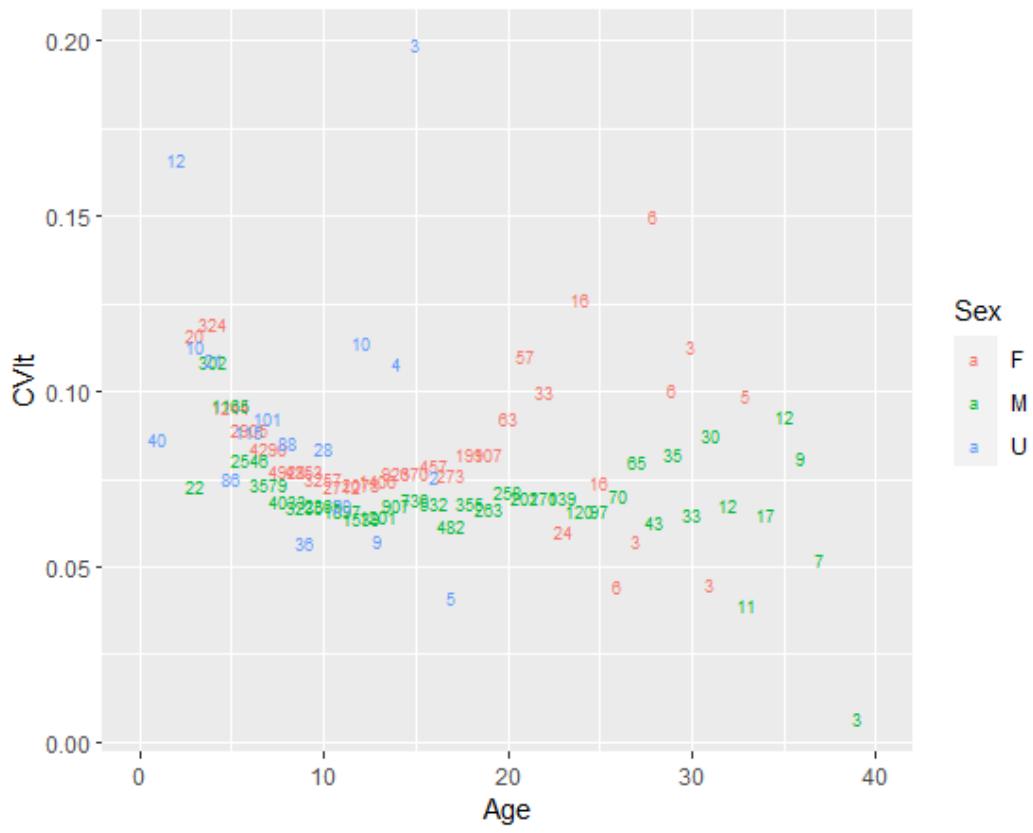
**Figure 3:** Observed length-at-age by data source and sex.



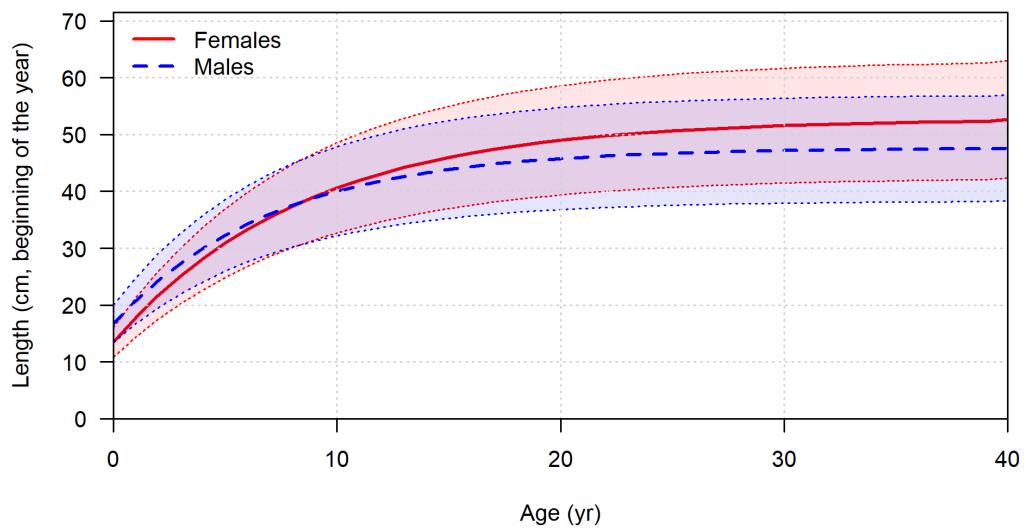
**Figure 4:** Observed length-at-age by sex and year. Total samples are indicated in parentheses.



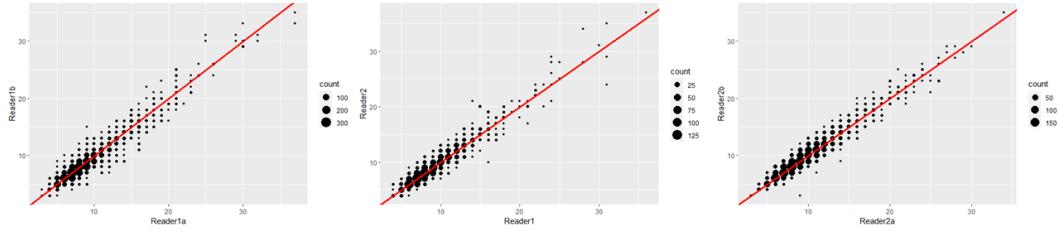
**Figure 5:** External fits to the observed length-at-age by sex.



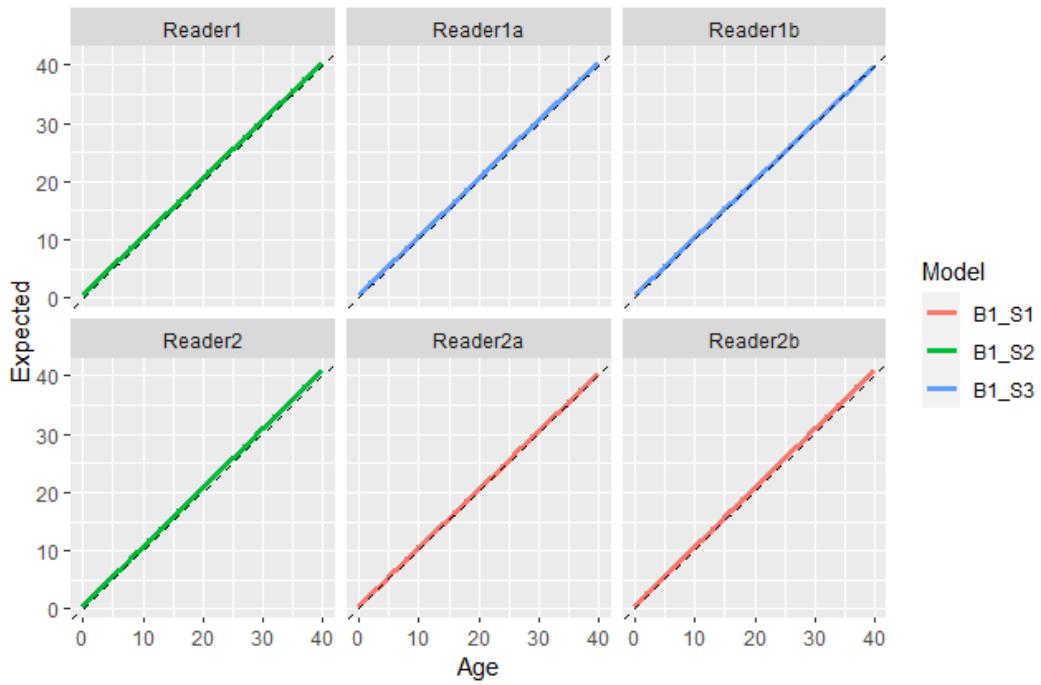
**Figure 6:** Coefficient of variation of length by age by sex. Numbers indicate samples by age and colors indicate sex.



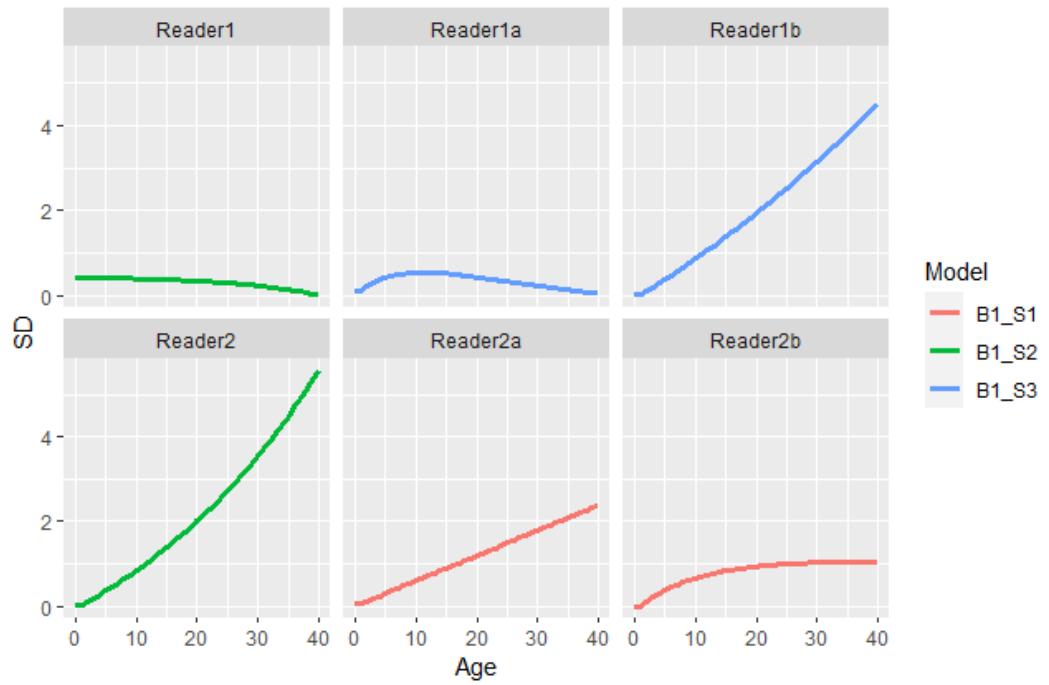
**Figure 7:** Model estimated length-at-age. Shaded area indicates 95 percent distribution of length-at-age around the estimated growth curve.



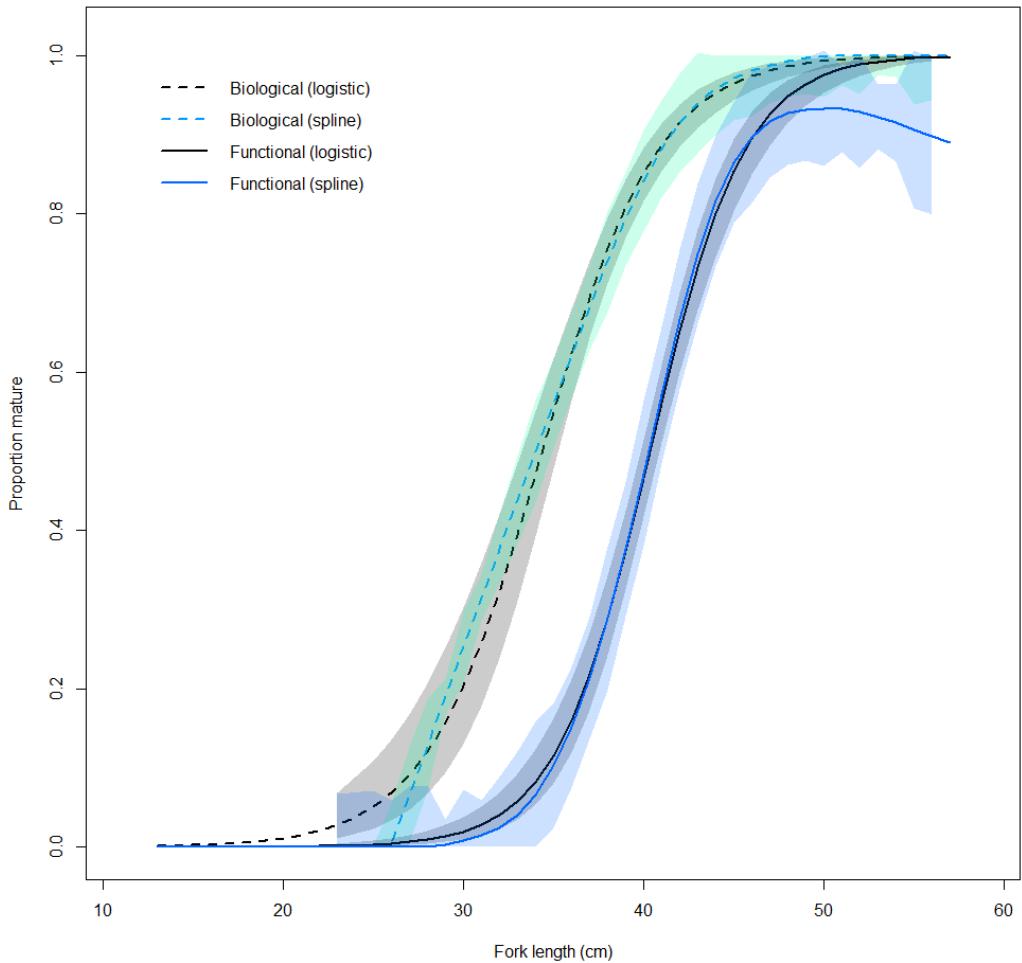
**Figure 8:** Ageing bias plots by reader comparisons.



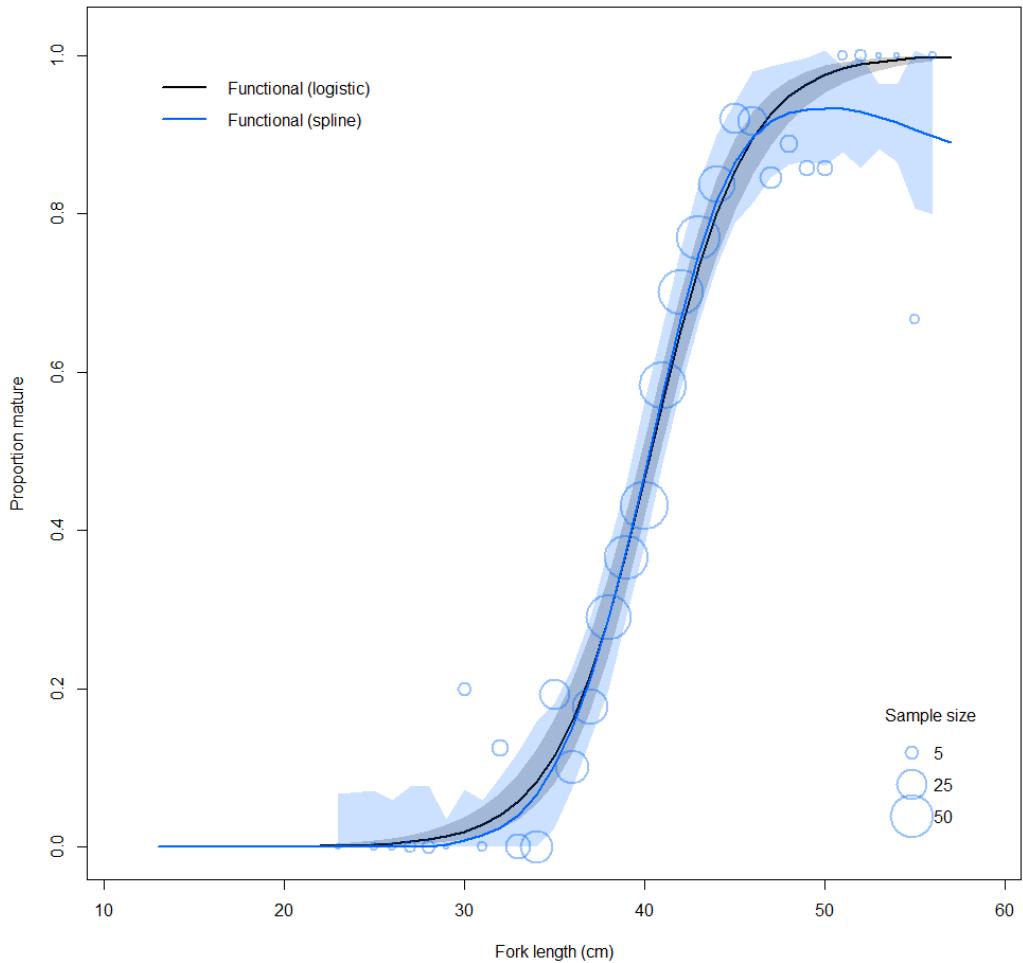
**Figure 9:** Estimated bias relationships for each considered matrix. Reader 1 is always considered unbiased. Reader 1a and 1b is an intra-reader comparison. B refers to the bias type and S refers to the imprecision type in the model selection for the ageing error matrix.



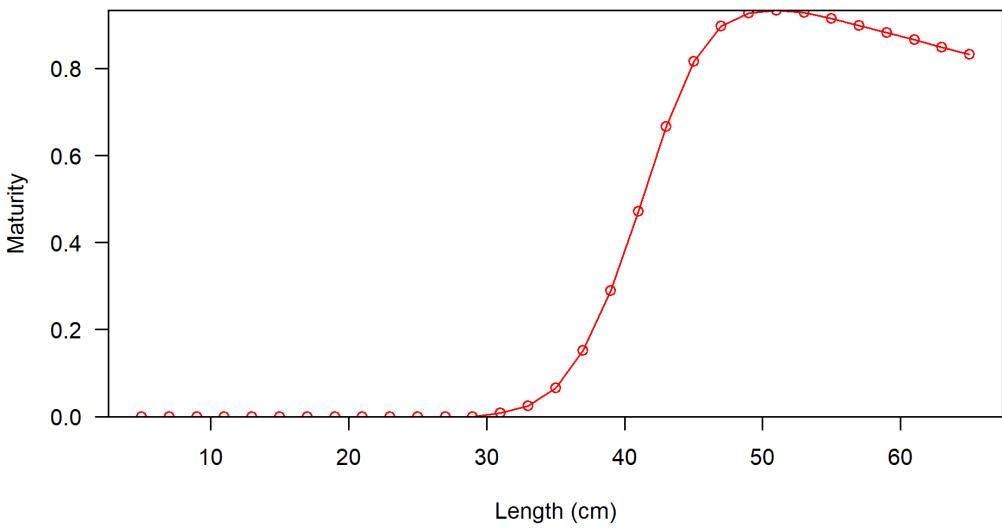
**Figure 10:** Ageing error matrix standard deviation (SD) values by comparison. B refers to the bias type and S refers to the imprecision type in the model selection for the ageing error matrix.



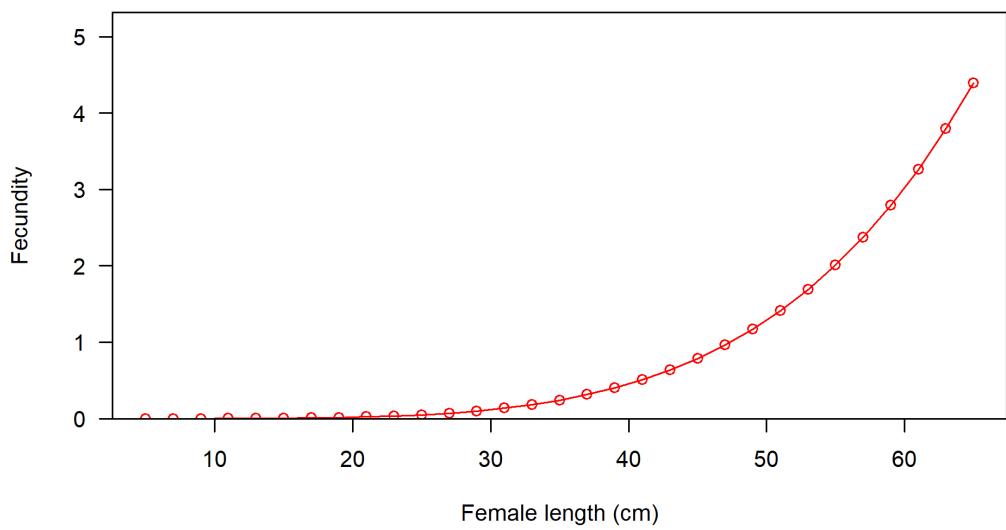
**Figure 11:** Biological and functional maturity ogives. Biological maturity ogives are represented by the dashed lines (logistic regression and 95% CI is grey, flexible spline and 95% CI is light green). Functional maturity ogives are represented by the solid lines (logistic regression and 95% CI is grey, flexible spline and 95% CI is light blue).



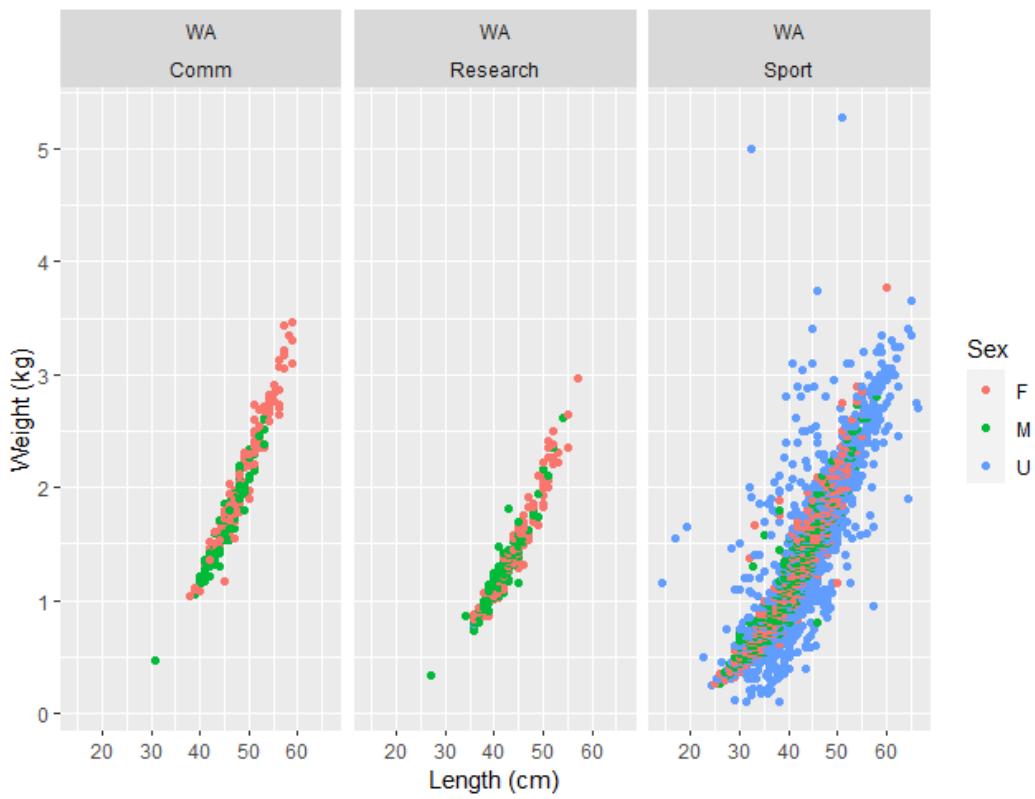
**Figure 12:** Functional maturity ogives and sample size. Functional maturity ogives are represented by the solid lines (logistic regression and 95% CI is grey, flexible spline and 95% CI is light blue) and sample size is denoted by the size of the bubbles).



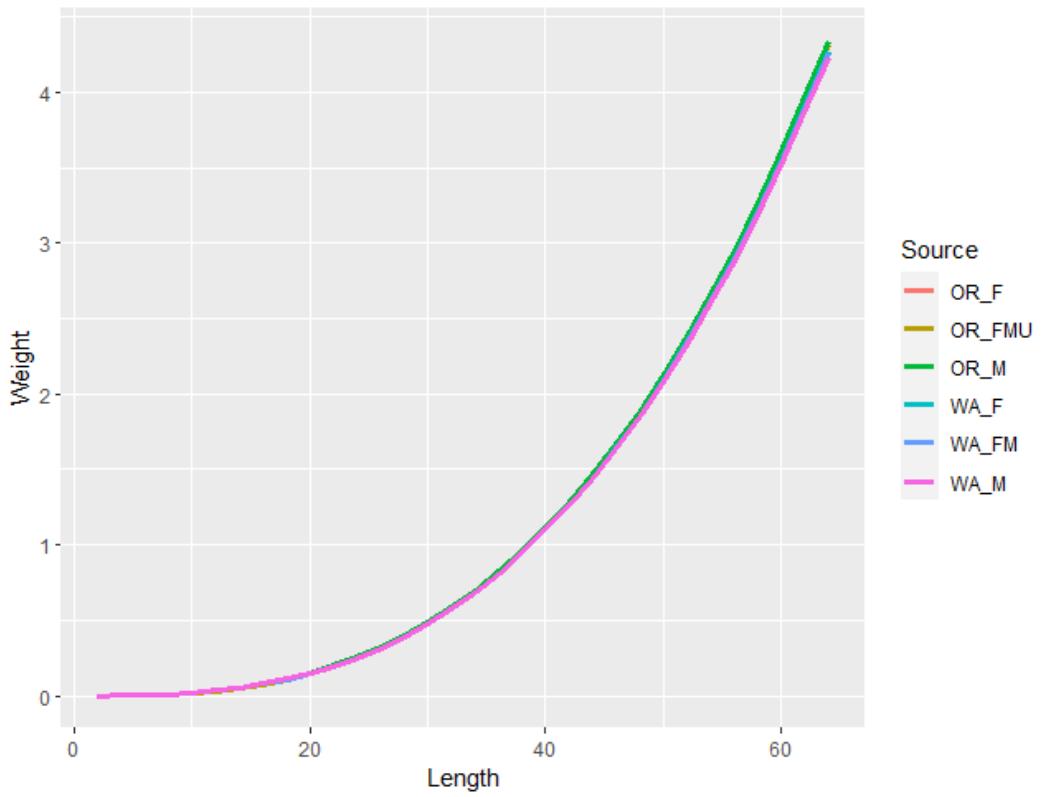
**Figure 13:** Maturity as a function of length (cm).



**Figure 14:** Fecundity (kg) as a function of length (cm).



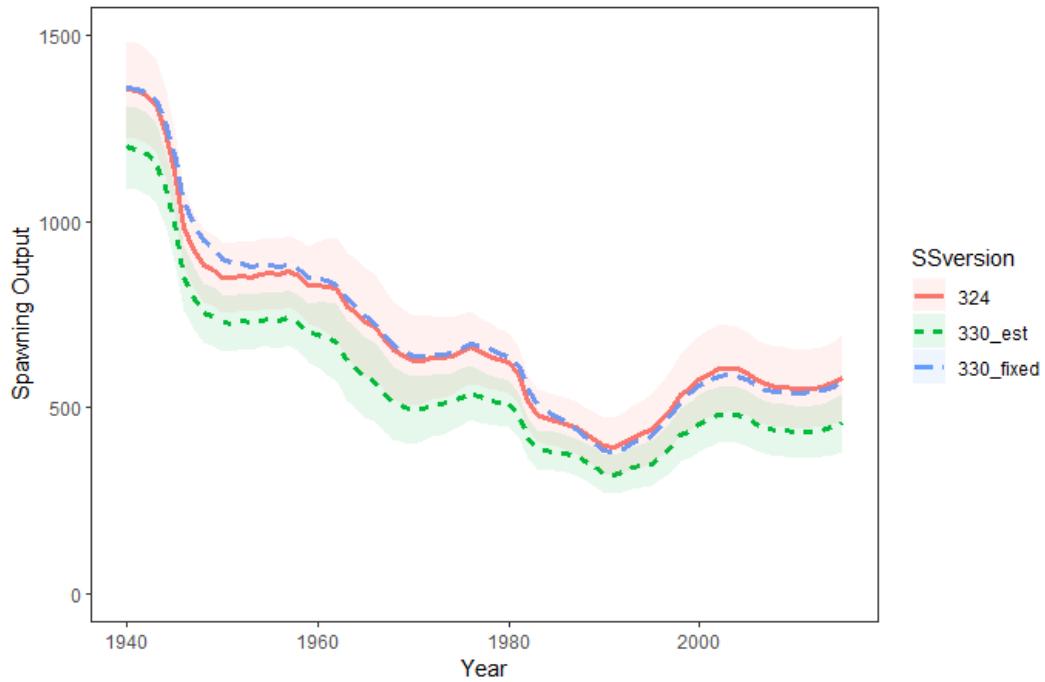
**Figure 15:** Sex-specific length (cm)-weight (kg) data for black rockfish samples by source.



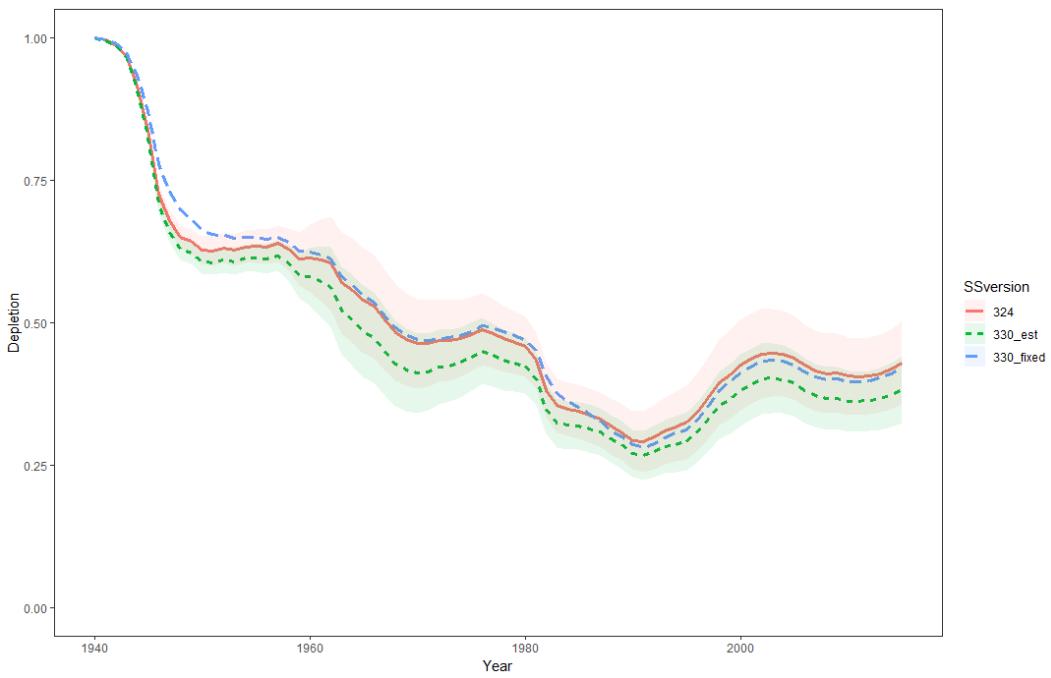
**Figure 16:** Sex-specific length (cm)-weight (kg) estimated power function relationships. Washington state estimate relationships are also provided for comparison.

## 9.3 Modeling

### 9.3.1 Bridging

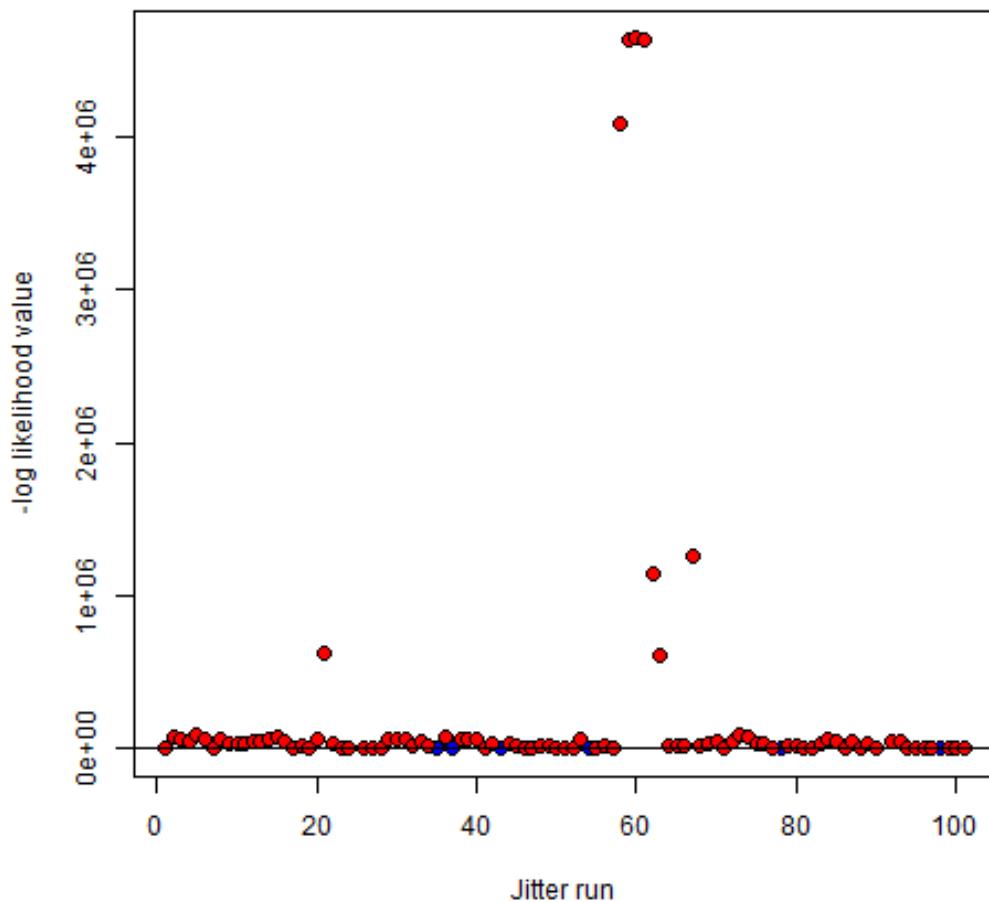


**Figure 17:** Comparison of spawning output for black rockfish in waters off of Washington between Stock Synthesis versions 3.24 and 3.30. Uncertainty envelops are 95% confidence intervals.

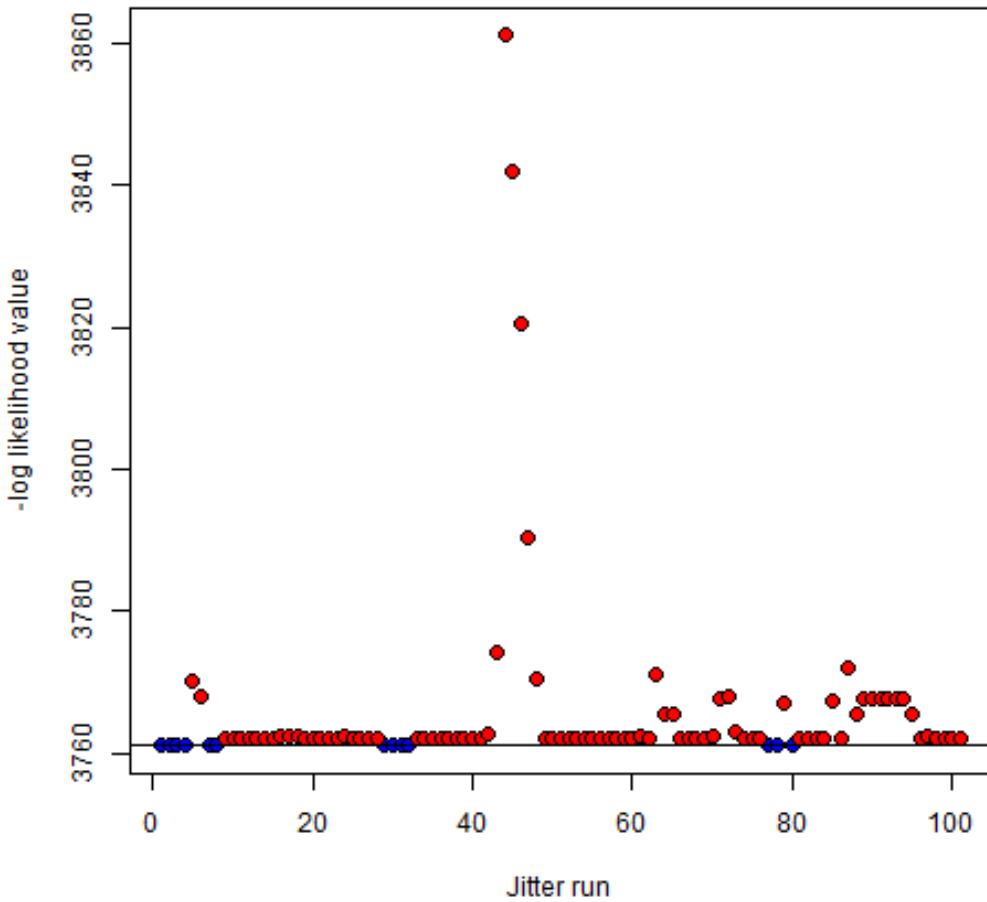


**Figure 18:** Comparison of spawning output for black rockfish in waters off of Washington between Stock Synthesis versions 3.24 and 3.30. Uncertainty envelops are 95% confidence intervals.

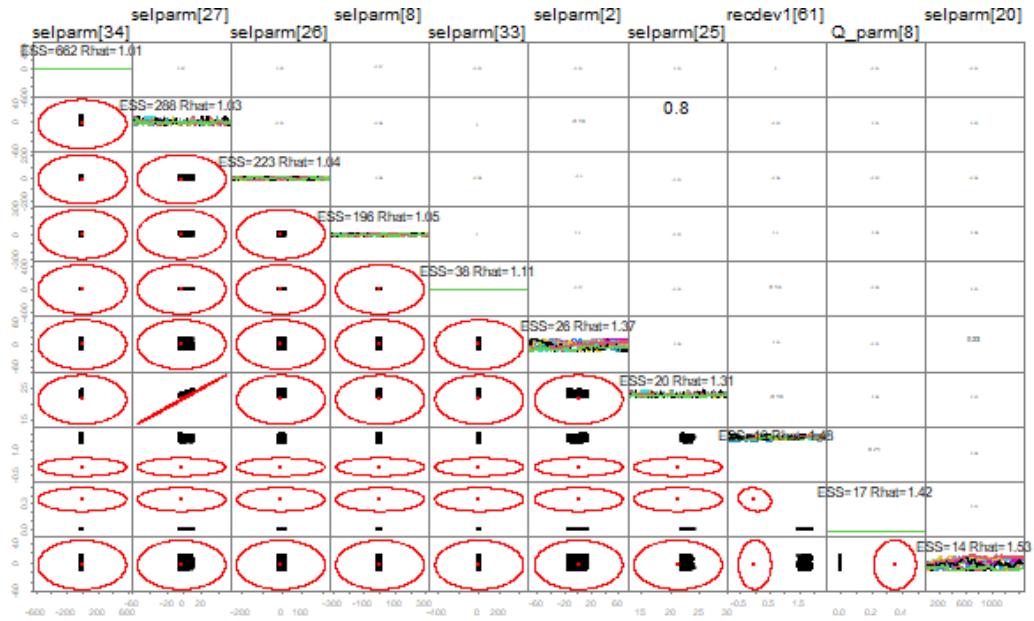
### 9.3.2 Jittering



**Figure 19:** Jitter runs (using a value of 0.01) for the black rockfish reference model, with jitter run number on the x-axis and -log likelihood value on the y-axis. Blue dot are models that match the likelihood value of the reference model, while red dots deviate from the reference model. All red dots are above the blue dots, indicating no better fit to the reference model was found.

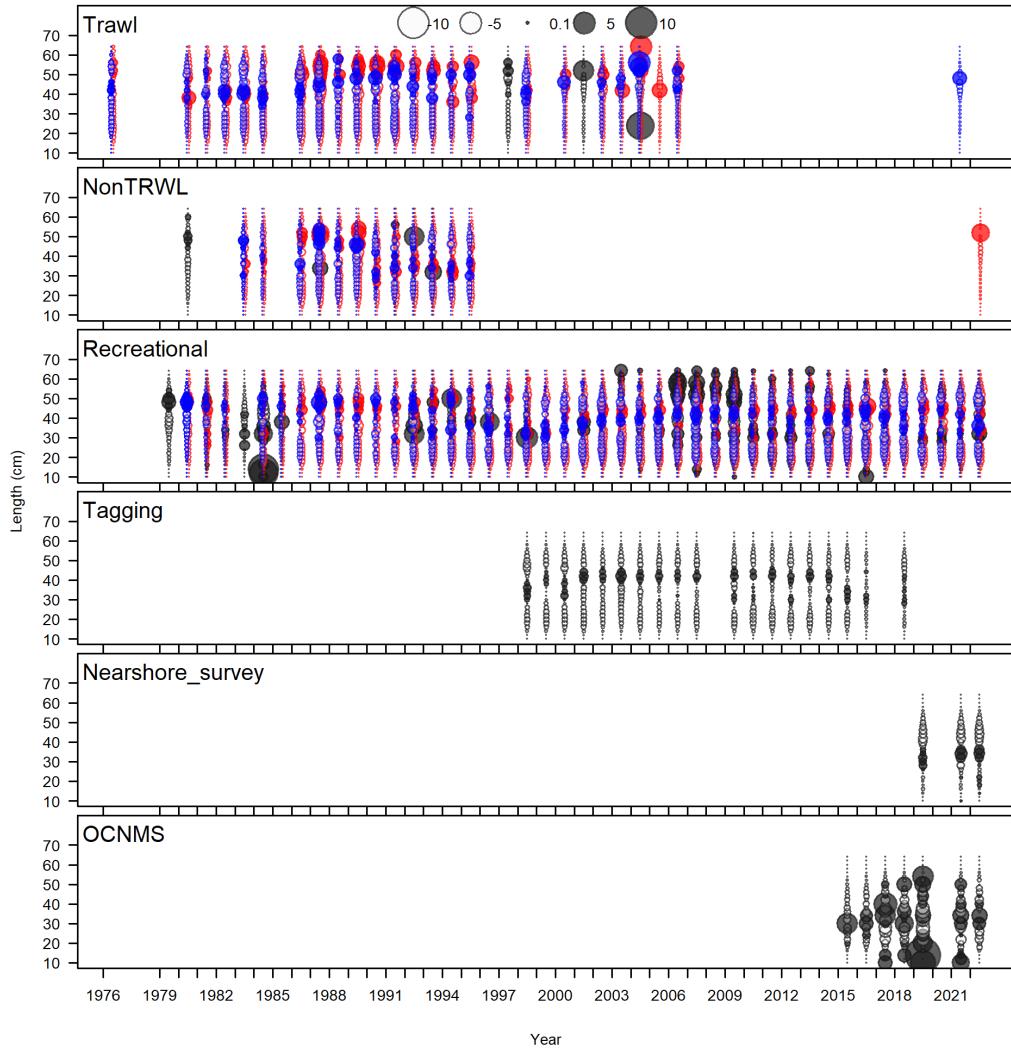


**Figure 20:** Jitter runs (using a value of 0.0005) for the black rockfish reference model, with jitter run number on the x-axis and -log likelihood value on the y-axis. Blue dots are models that match the likelihood value of the reference model, while red dots deviate from the reference model. All red dots are above the blue dots, indicating no better fit to the reference model was found.

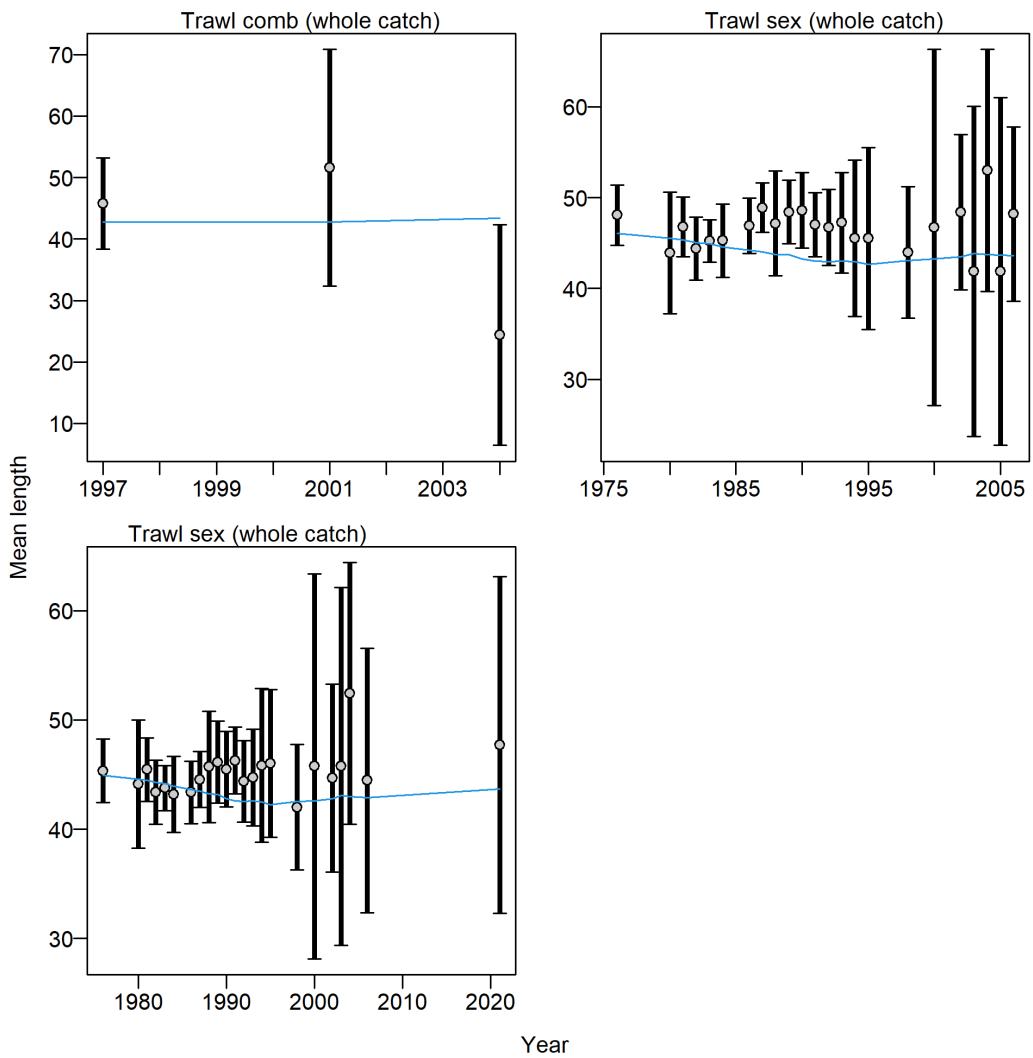


**Figure 21:** Pairs plots of the fastest mixing parameters from running 2000 posterior draws (and keep every draw) using the random walk Metropolis algorithm. Parameters that show little to no movement are recommended to be fixed to improve model speed and efficiency.

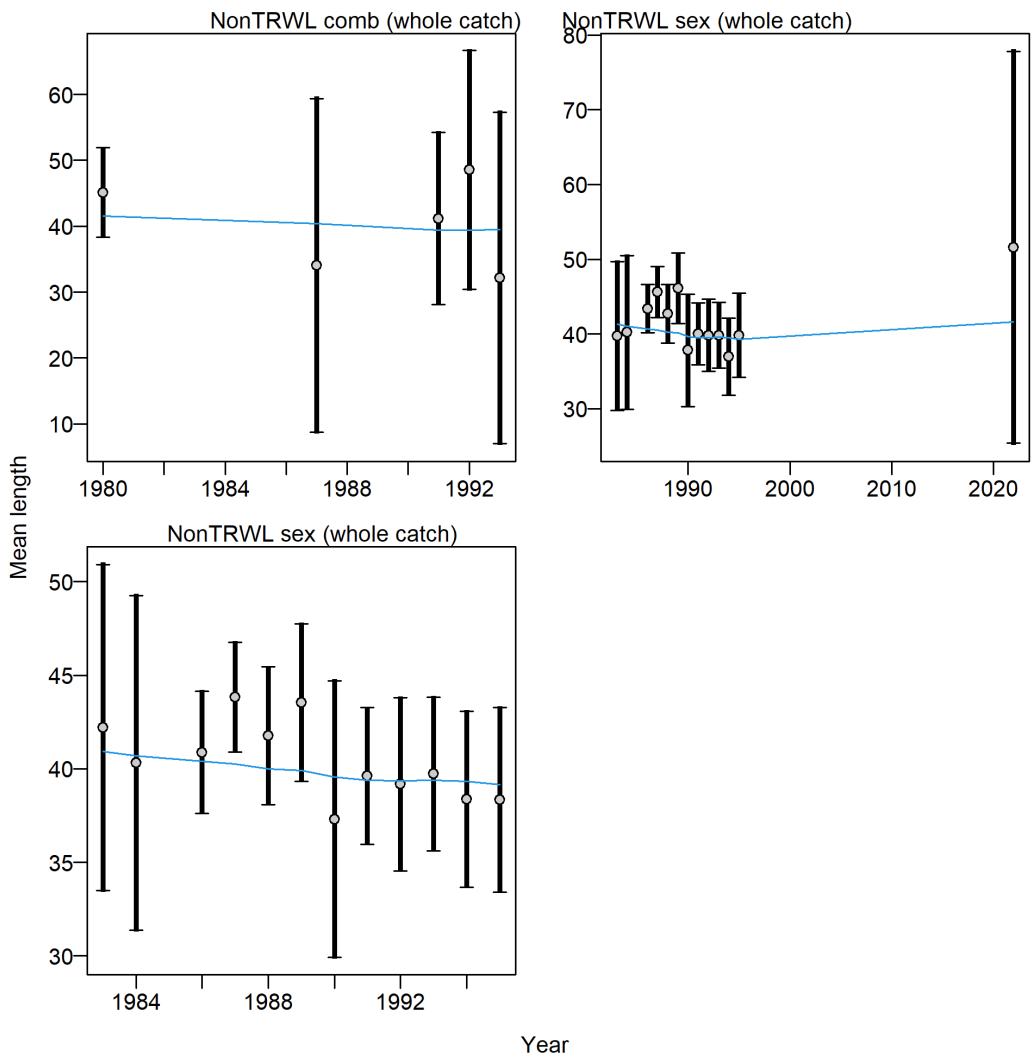
### 9.3.3 Fits to Data



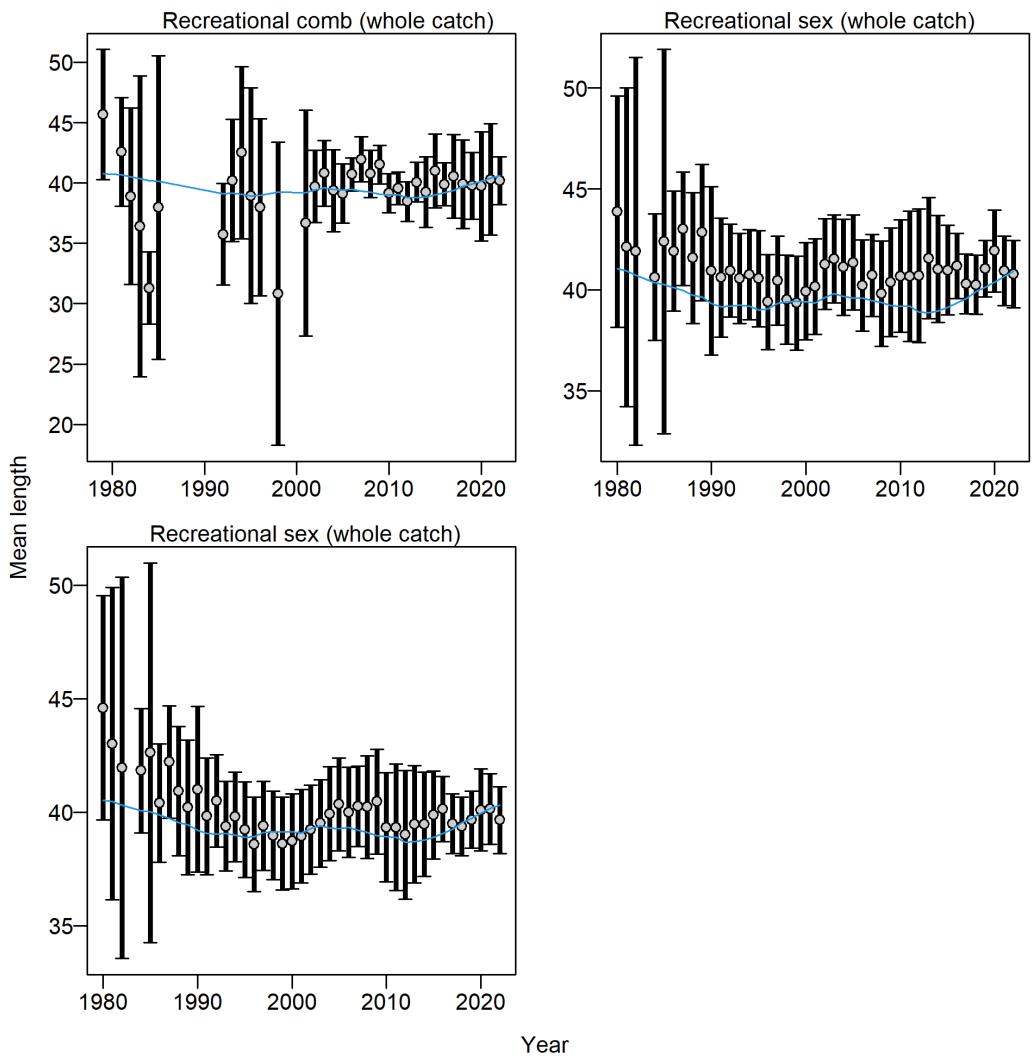
**Figure 22:** Pearson residuals for each fishing fleet and the MPA survey. Closed bubble are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).



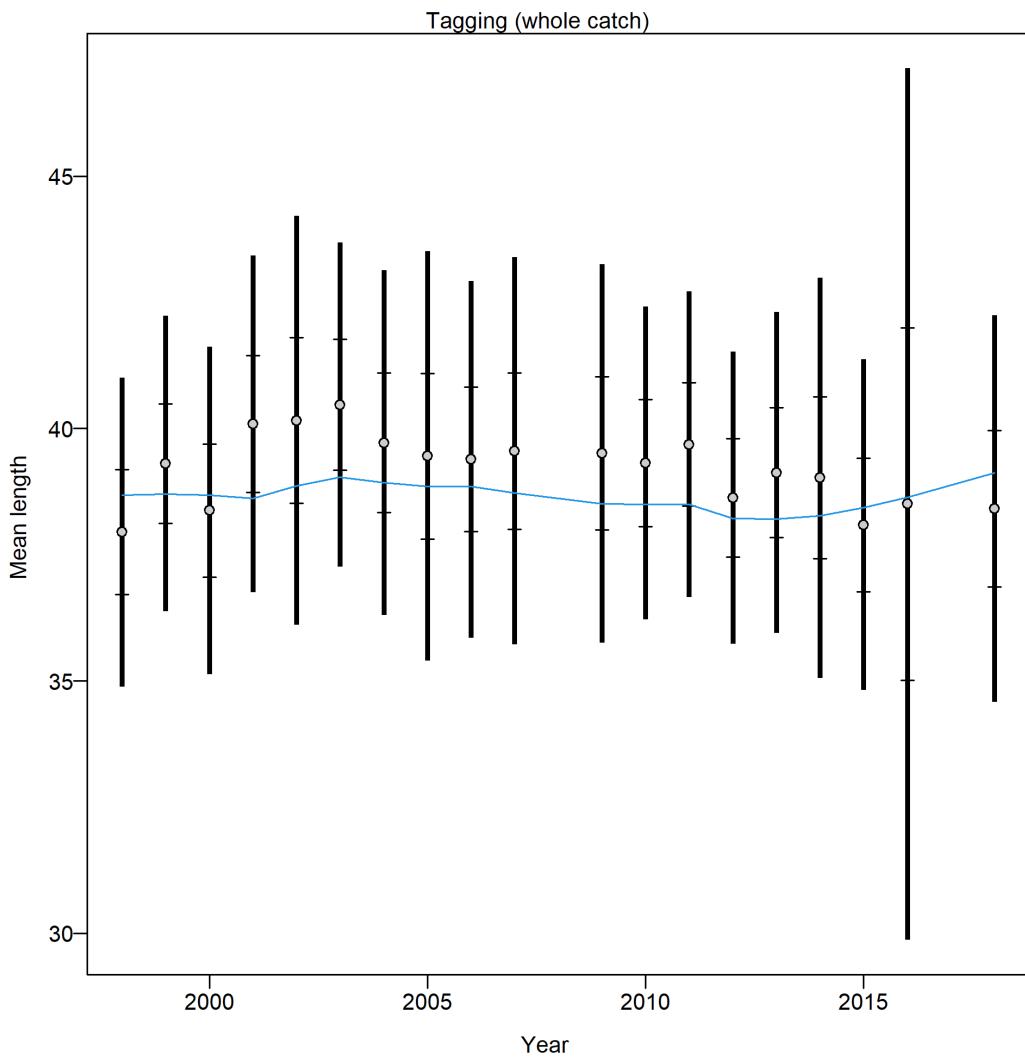
**Figure 23:** Mean length (cm) index from the commercial trawl fishery with 95 percent confidence intervals based on sample sizes and data weighting.



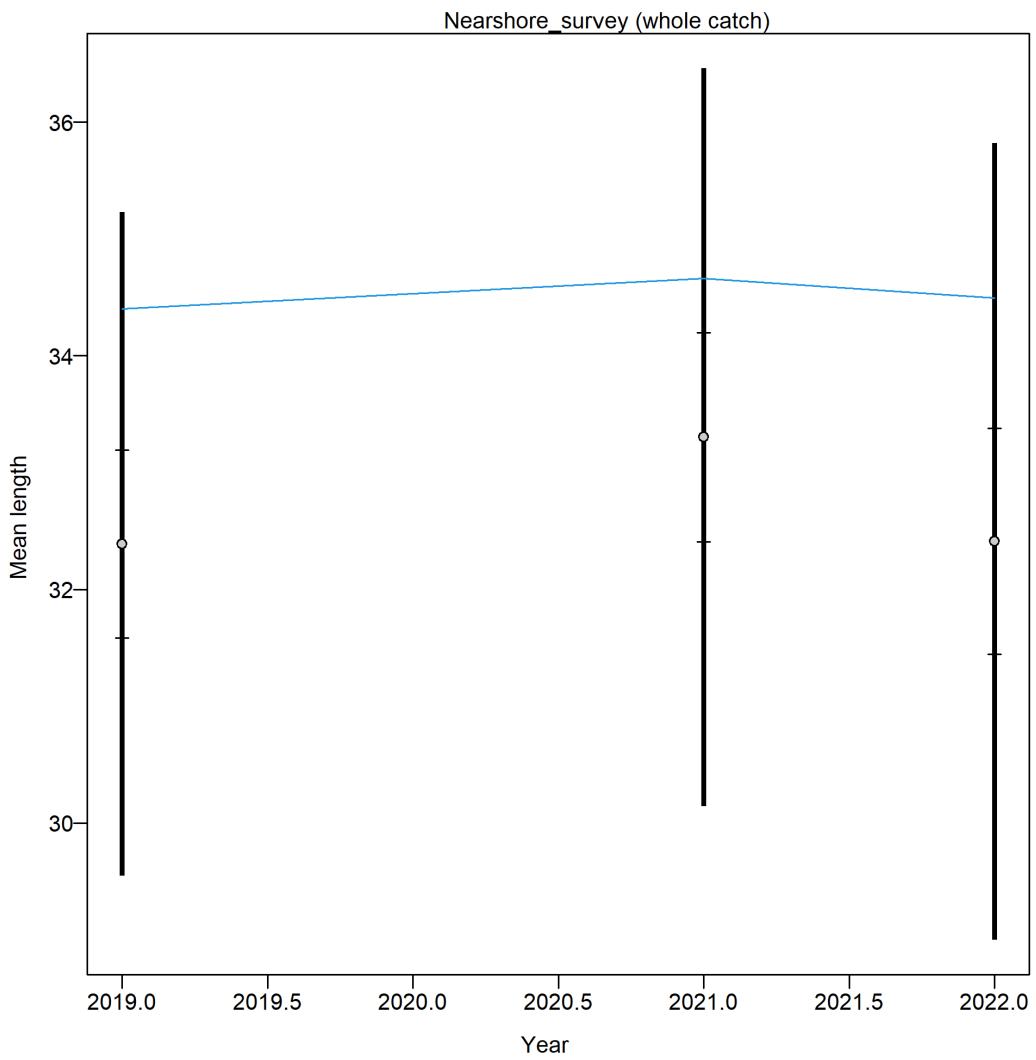
**Figure 24:** Mean length (cm) index from the commercial non-trawl fishery with 95 percent confidence intervals based on sample sizes and data weighting.



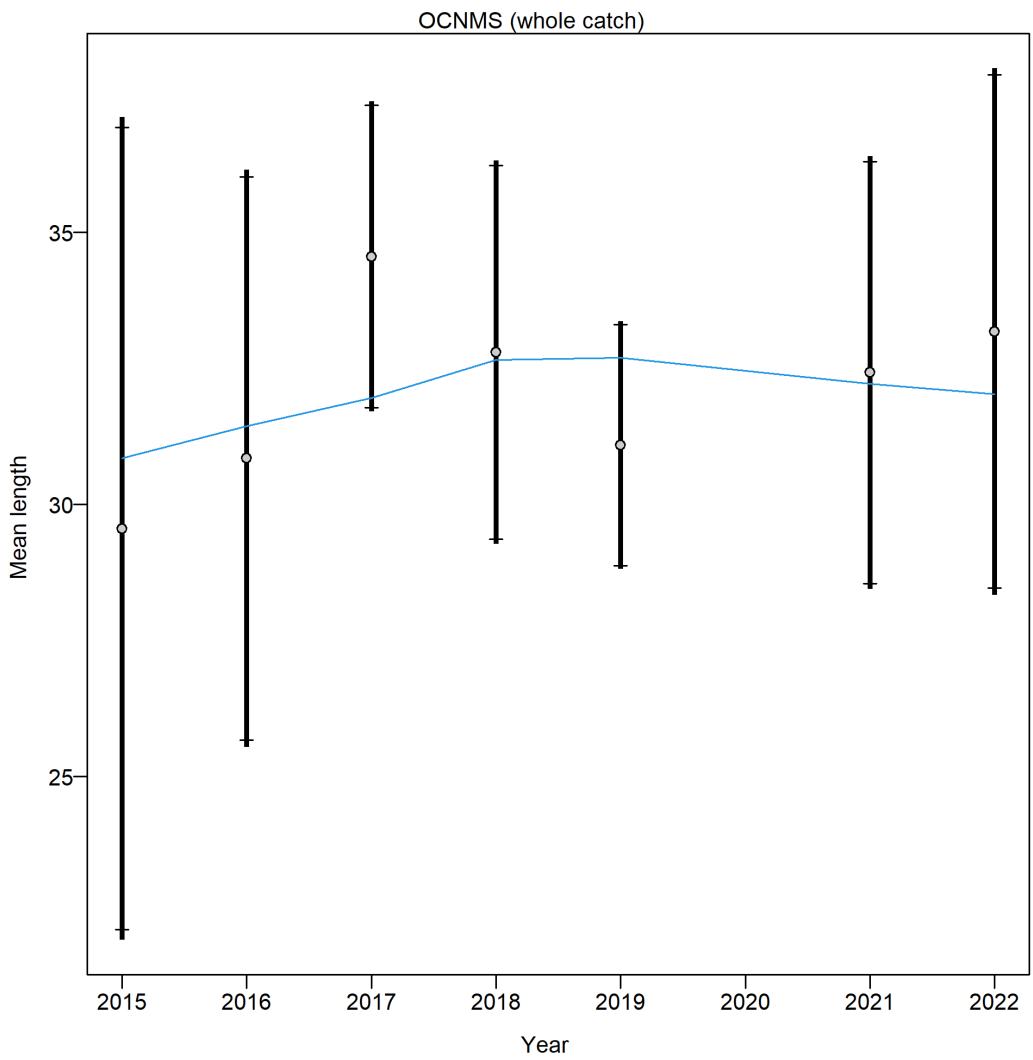
**Figure 25:** Mean length (cm) index from the recreational fishery with 95 percent confidence intervals based on sample sizes and data weighting.



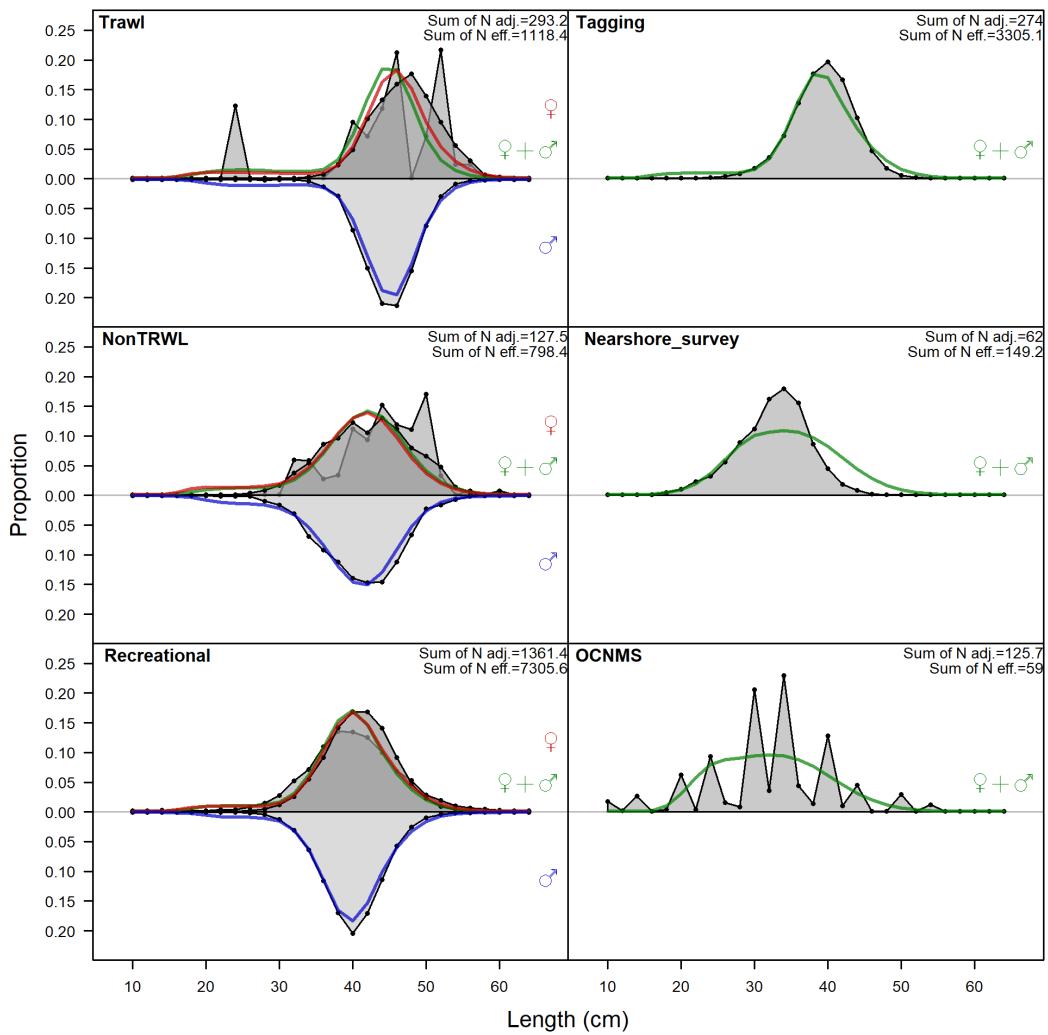
**Figure 26:** Mean length (cm) index from tagging survey with 95 percent confidence intervals based on sample sizes and data weighting.



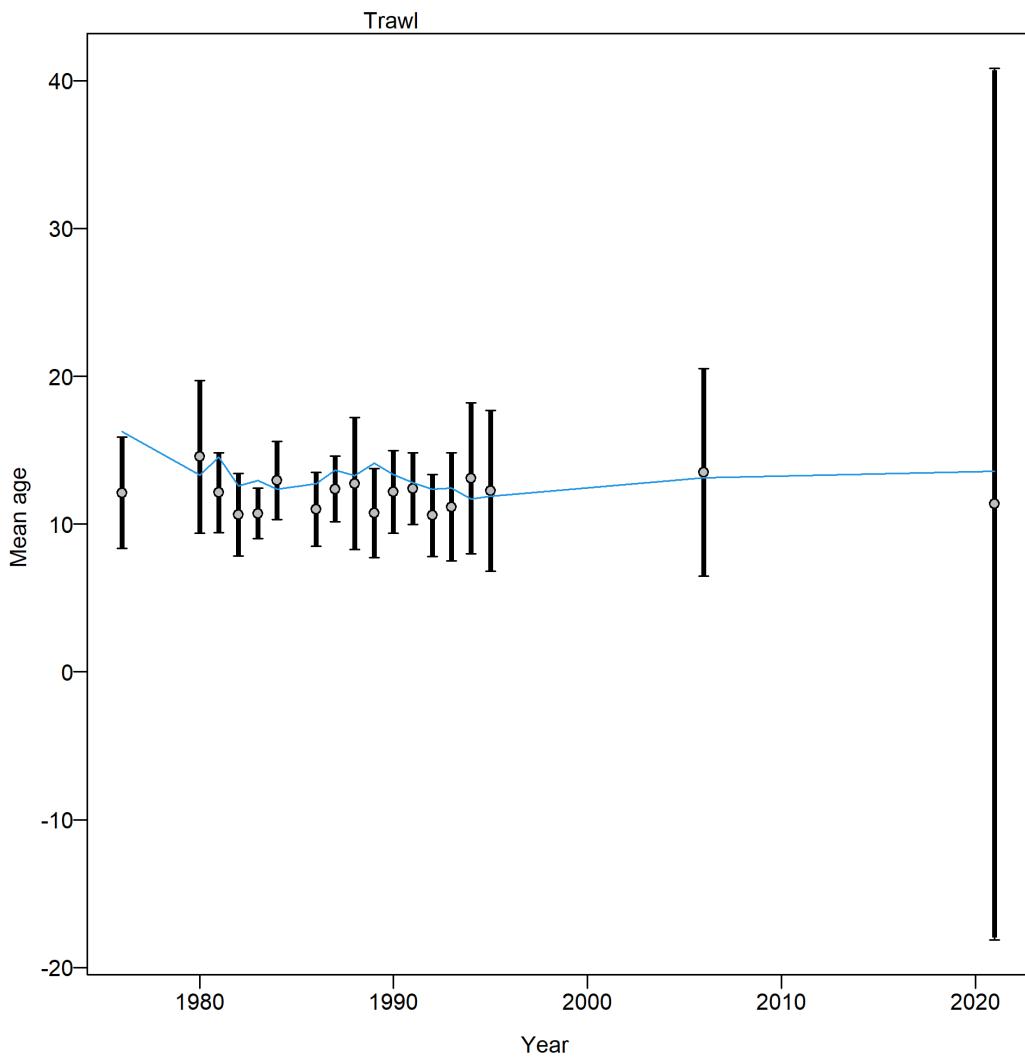
**Figure 27:** Mean length (cm) index from the Nearshore survey with 95 percent confidence intervals based on sample sizes and data weighting.



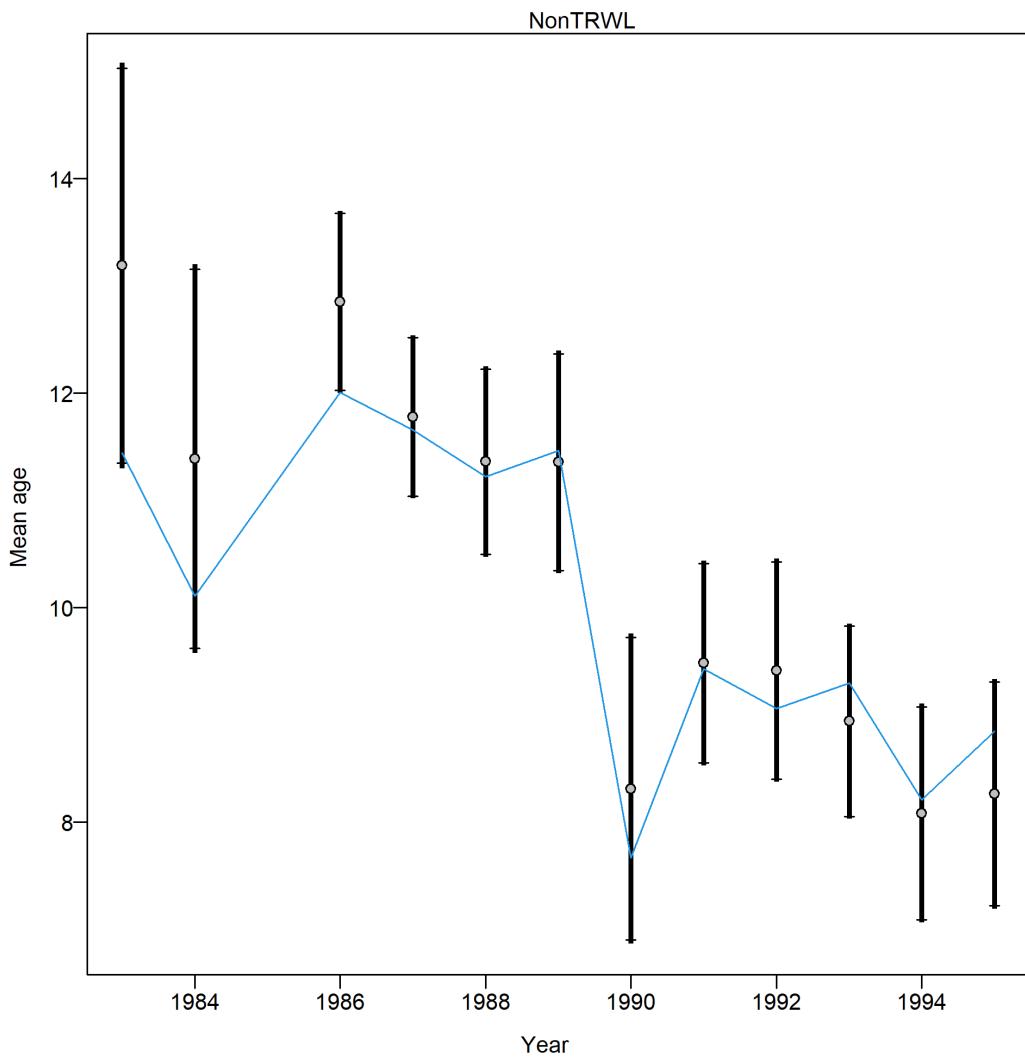
**Figure 28:** Mean length (cm) index from the OCNMS adult dive survey with 95 percent confidence intervals based on sample sizes and data weighting.



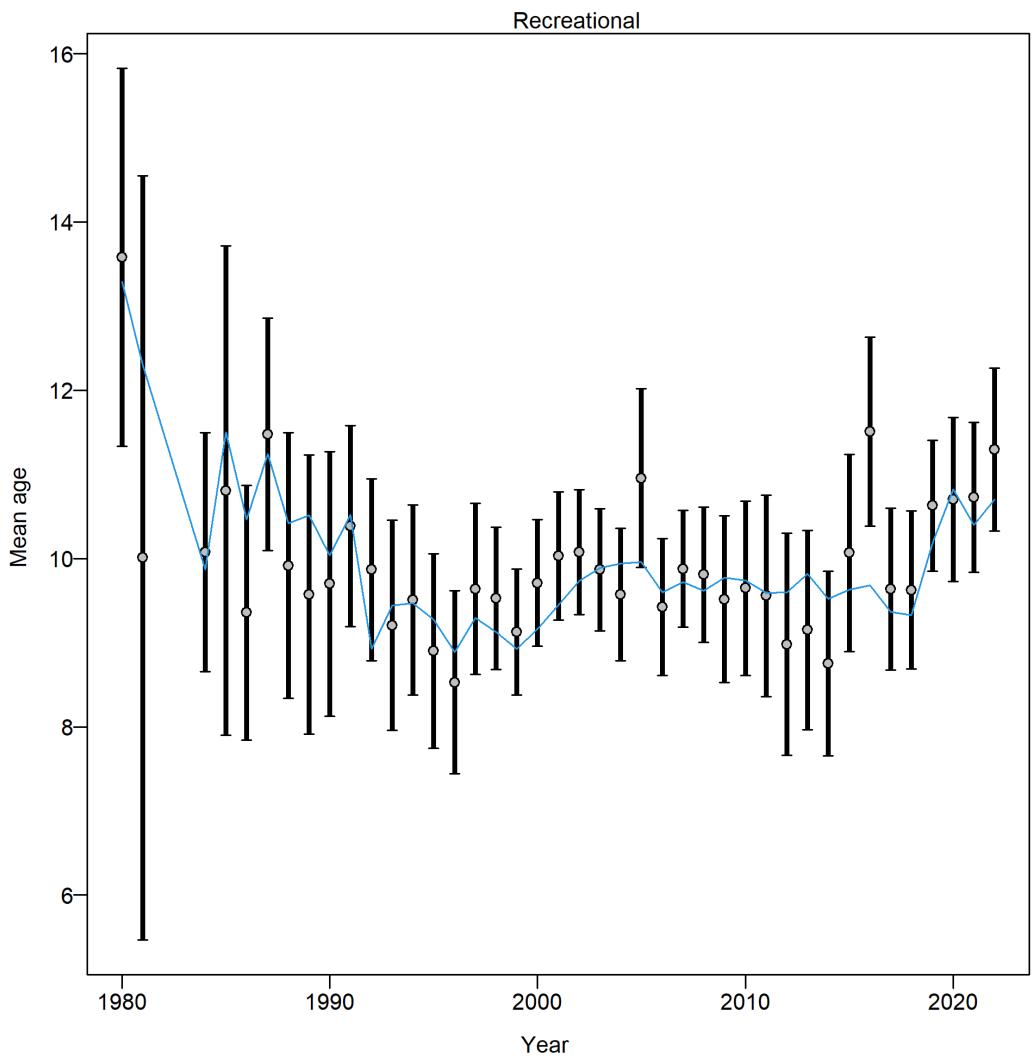
**Figure 29:** Aggregated length (cm) compositions over all years.



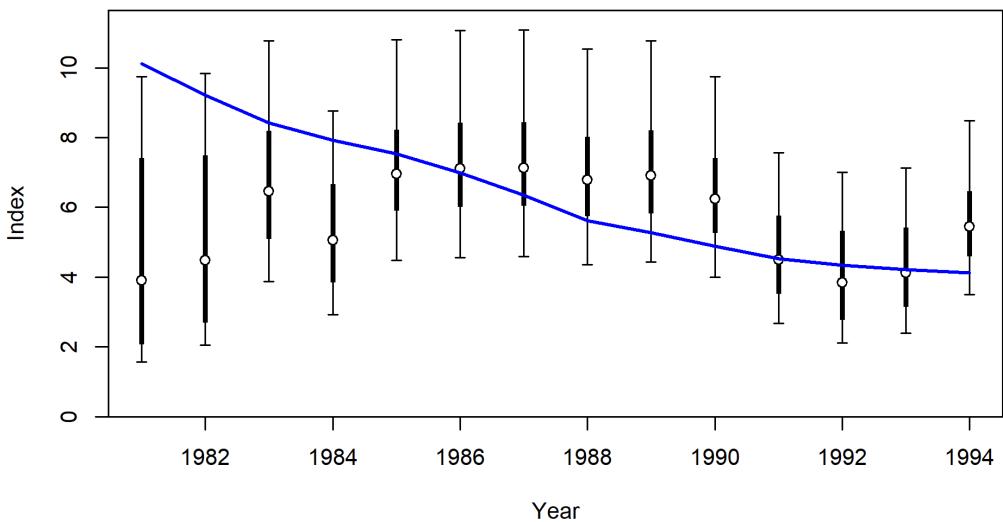
**Figure 30:** Mean age from conditional age-at-length data for the commercial trawl fishery.



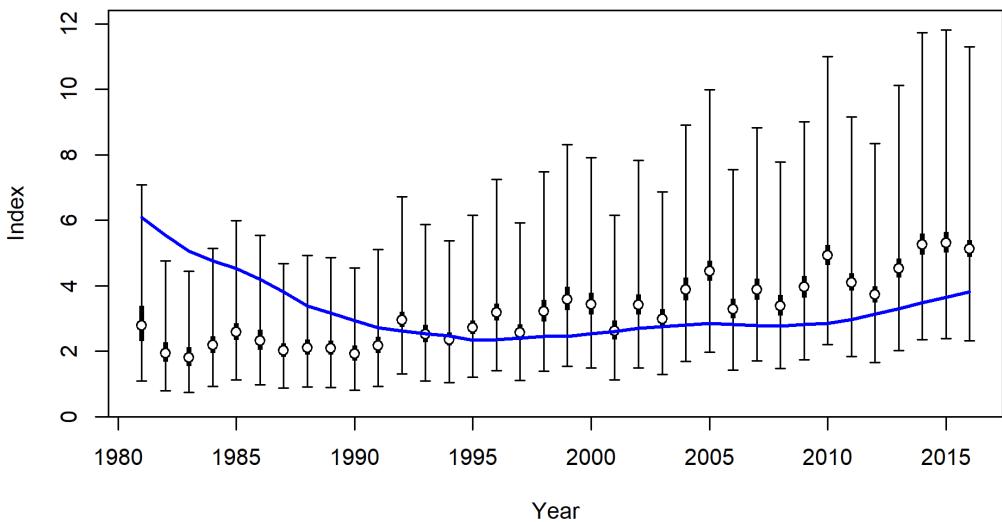
**Figure 31:** Mean age observations from the conditional age-at-length data from the commercial non-trawl fishery.



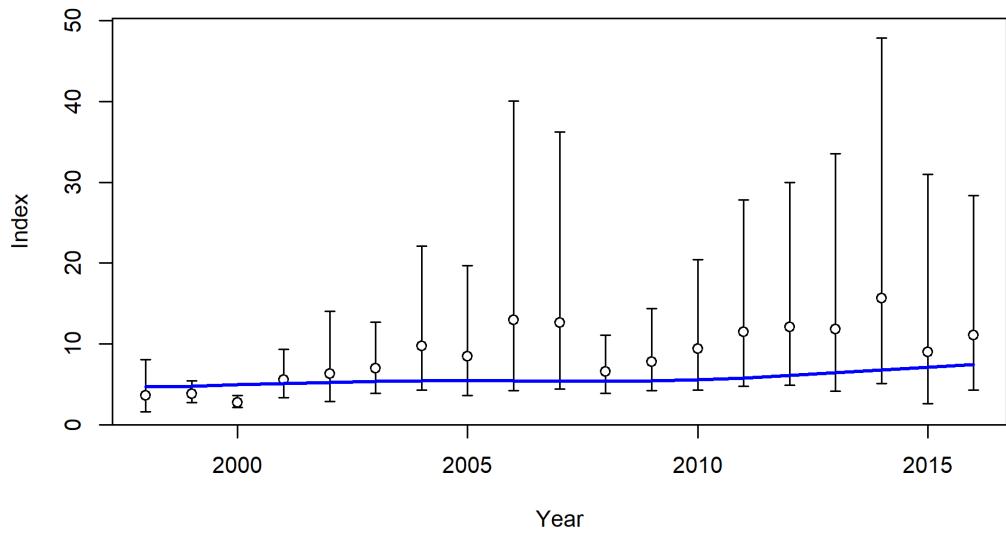
**Figure 32:** Mean age observations from the conditional age-at-length data from the recreational fishery.



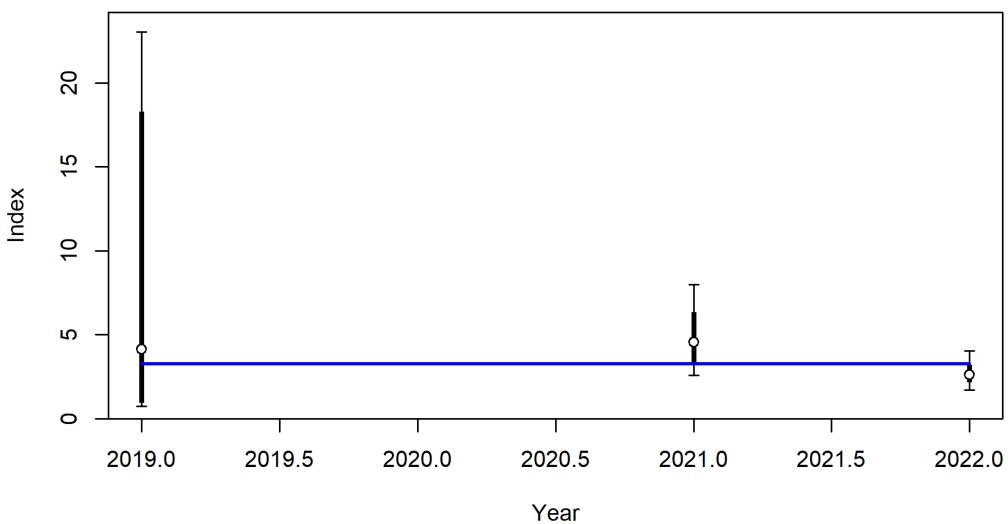
**Figure 33:** Fit to the charter fishery index of abundance.



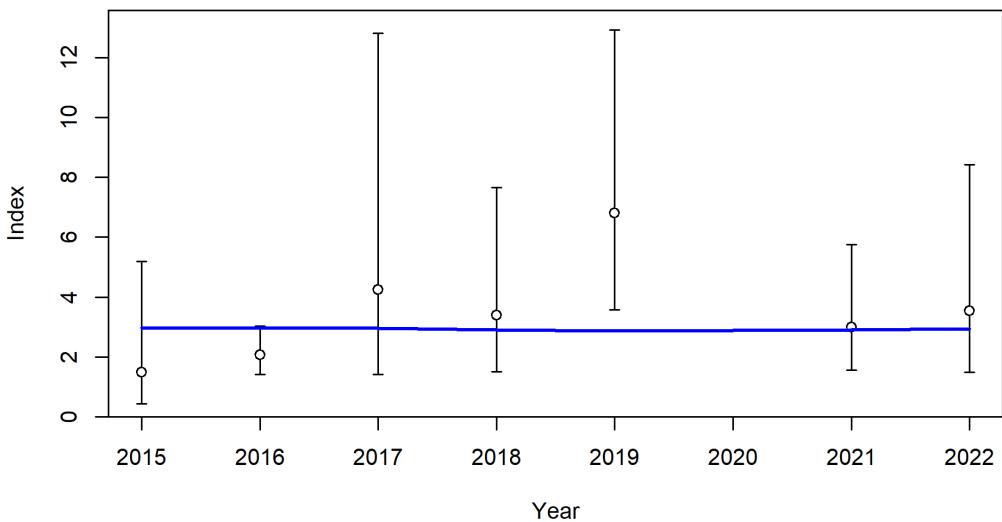
**Figure 34:** Fit to the private fishery index of abundance.



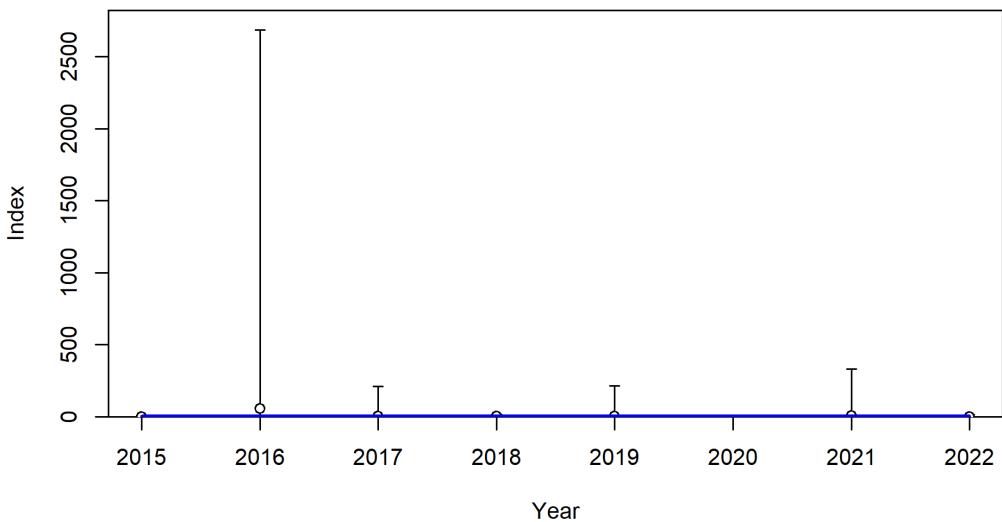
**Figure 35:** Fit to the tagging survey index of abundance.



**Figure 36:** Fit to the nearshore survey index of abundance.

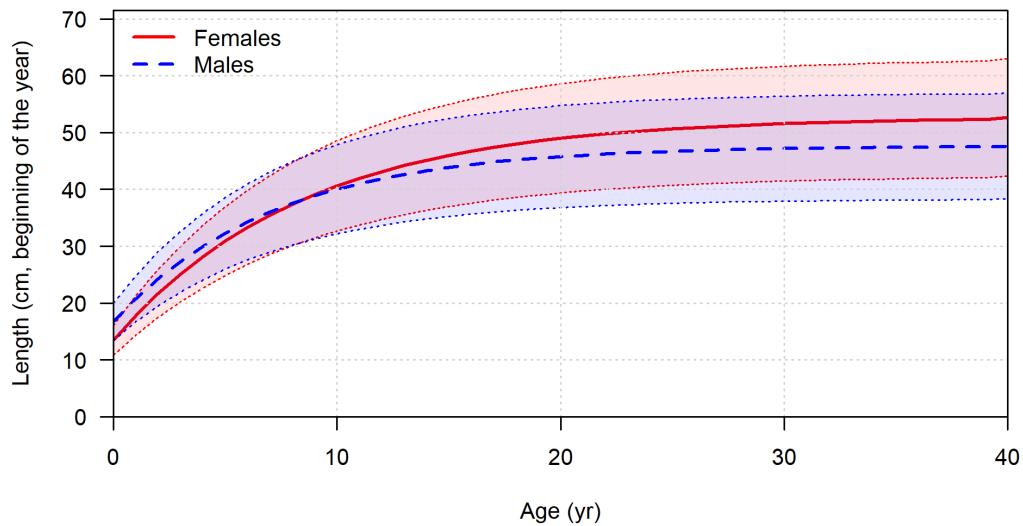


**Figure 37:** Fit to the OCNMS dive survey index of abundance.



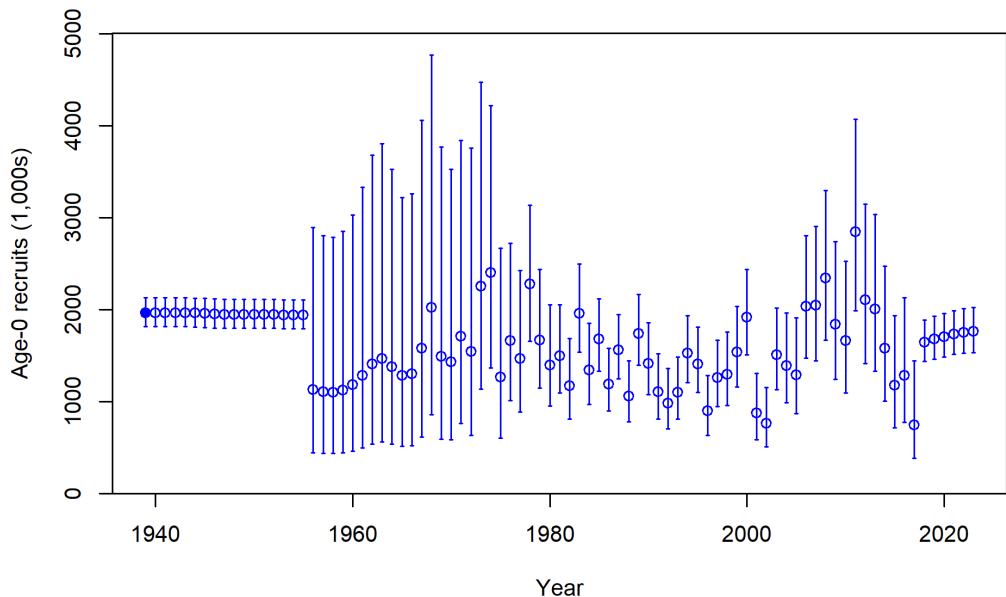
**Figure 38:** Fit to the OCNMS dive survey index of abundance.

### 9.3.4 Estimated Biology

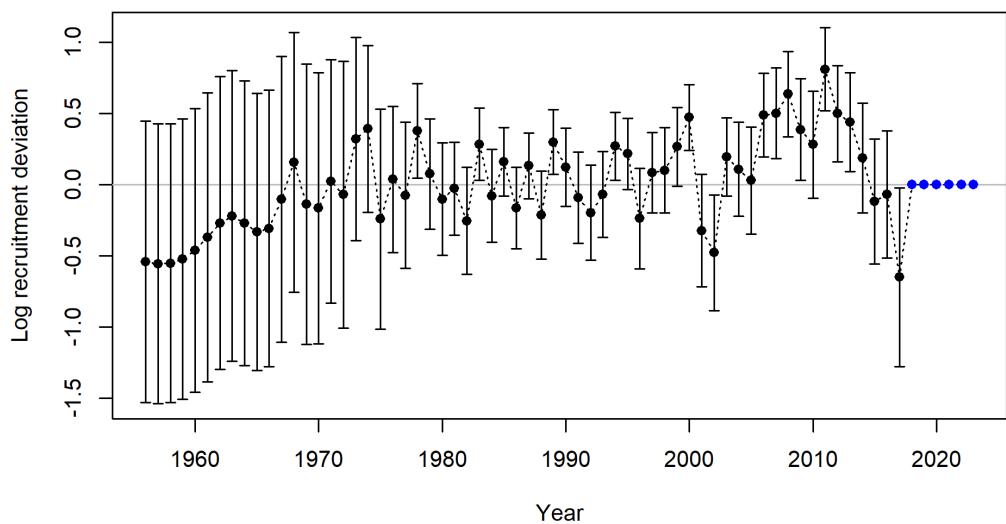


**Figure 39:** Model estimated length-at-age in the beginning of the year. Shaded area indicates 95 percent distribution of length-at-age around the estimated growth curve.

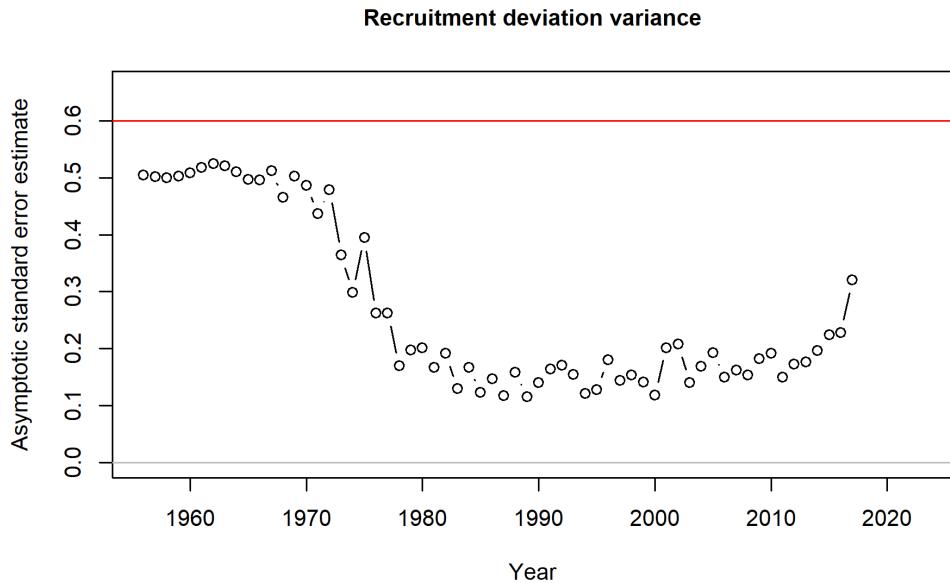
### 9.3.5 Recruitment



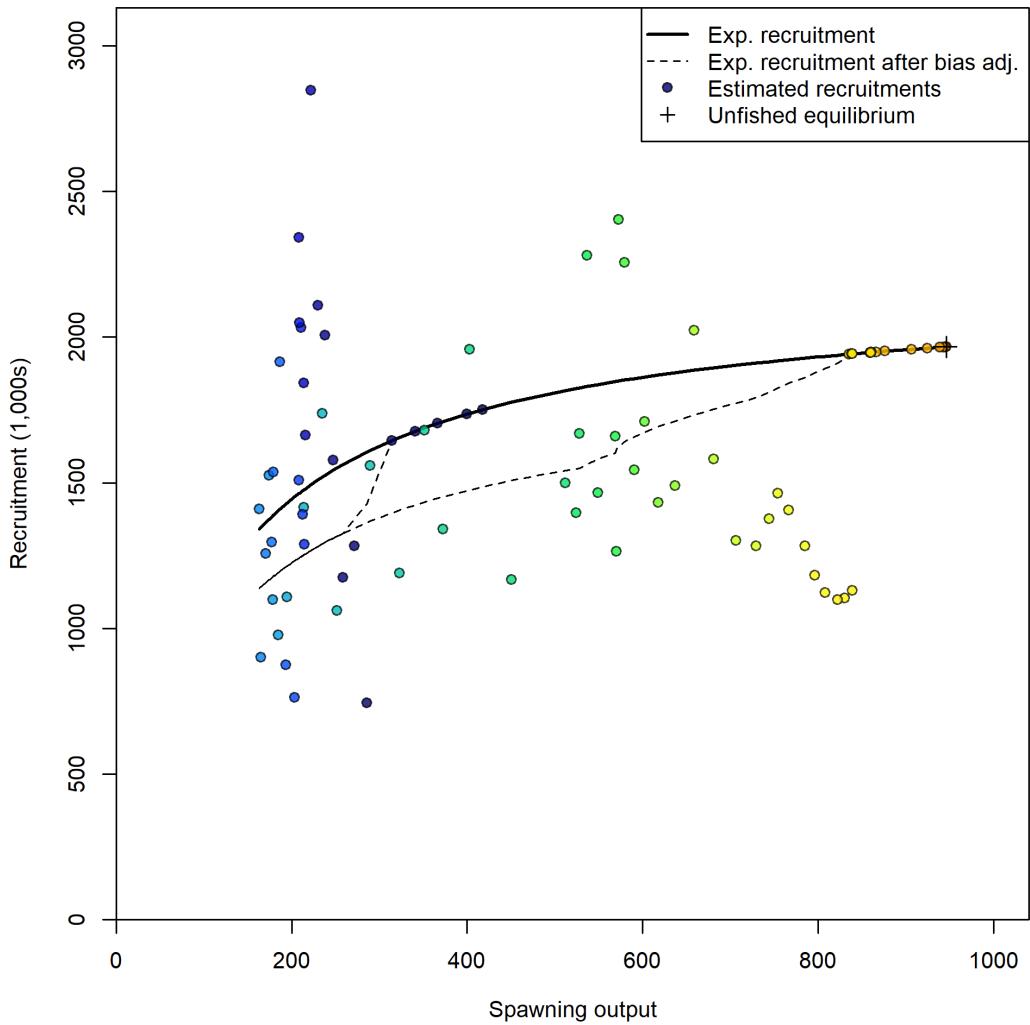
**Figure 40:** Estimated time series of age-0 recruits (1000s).



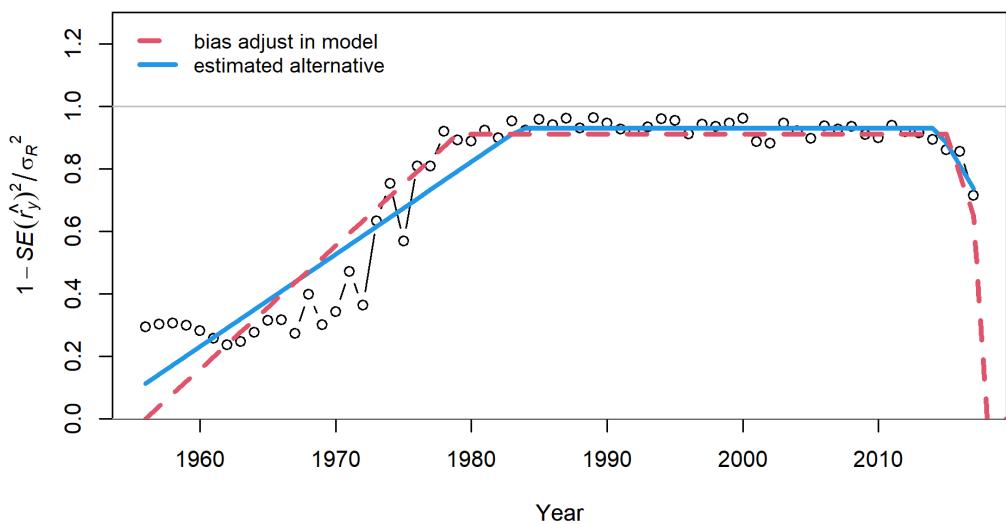
**Figure 41:** Estimated time series of recruitment deviations.



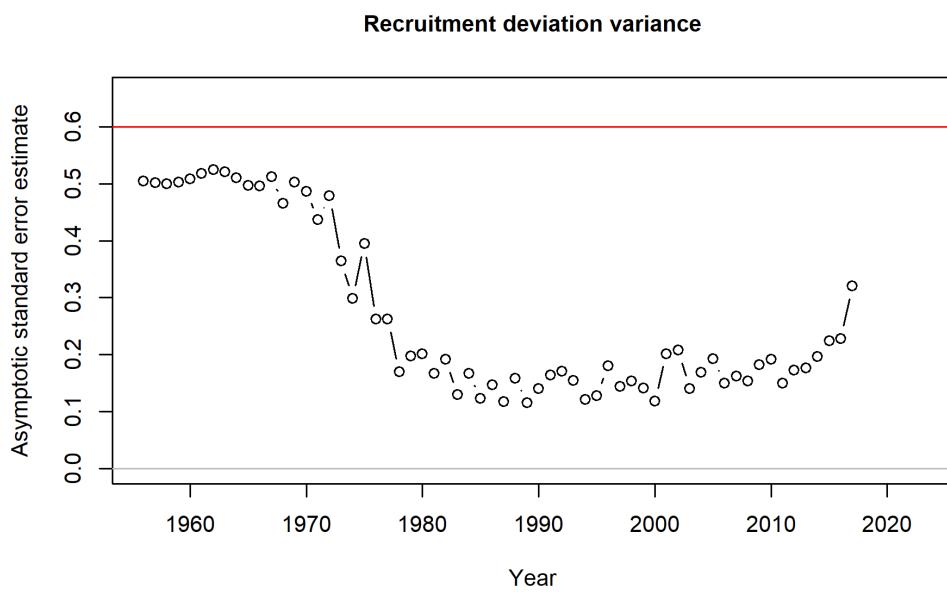
**Figure 42:** Recruitment deviations variance by year. This plot tracks the information content contained in each recruitment deviation. Values below the red line (assumed recruitment variability) indicates years with more informed recruitment deviations.



**Figure 43:** Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

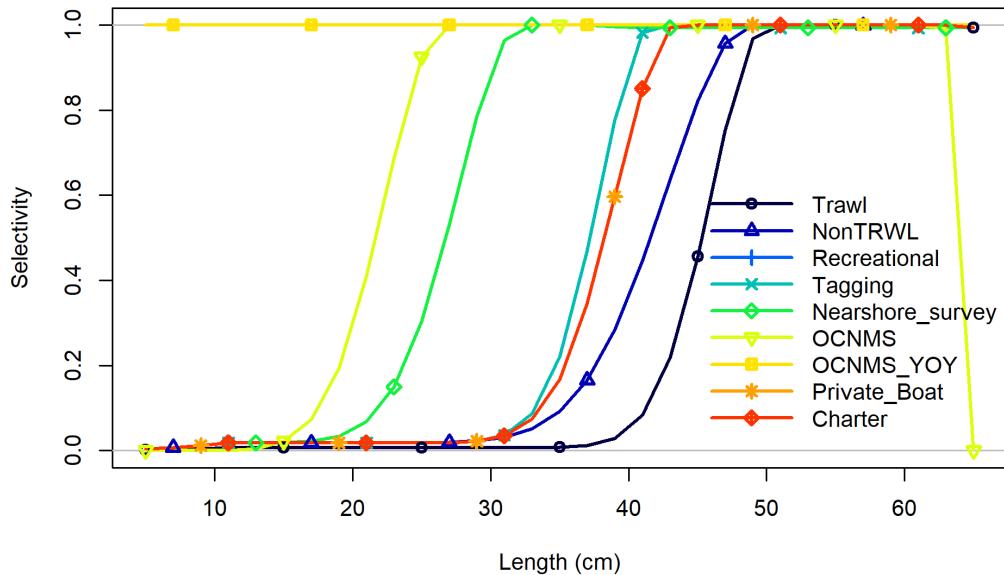


**Figure 44:** Recruitment bias adjustment applied in the reference model.



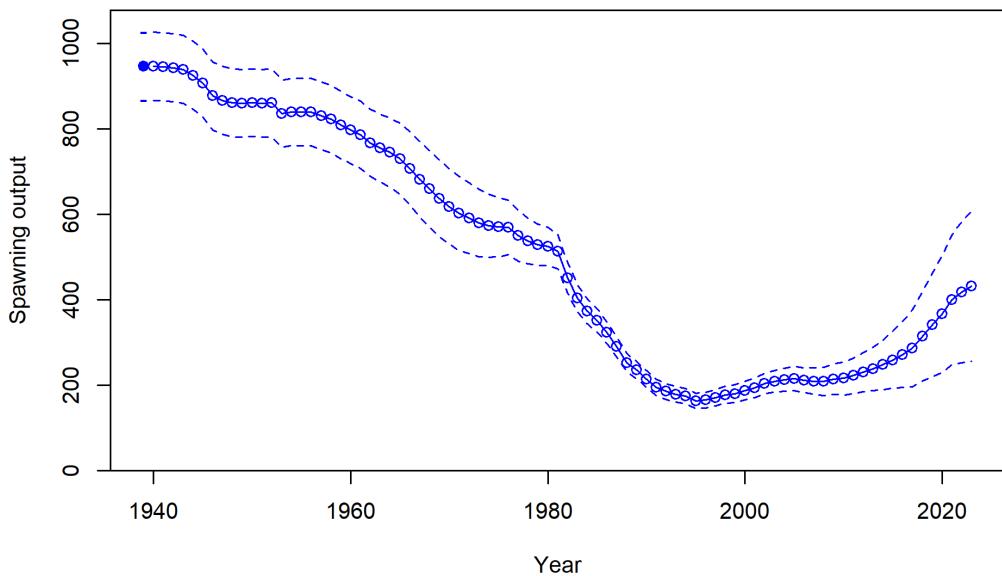
**Figure 45:** Recruitment deviations variance check. Low standard deviations indicate years with informative deviations .

### 9.3.6 Selectivity

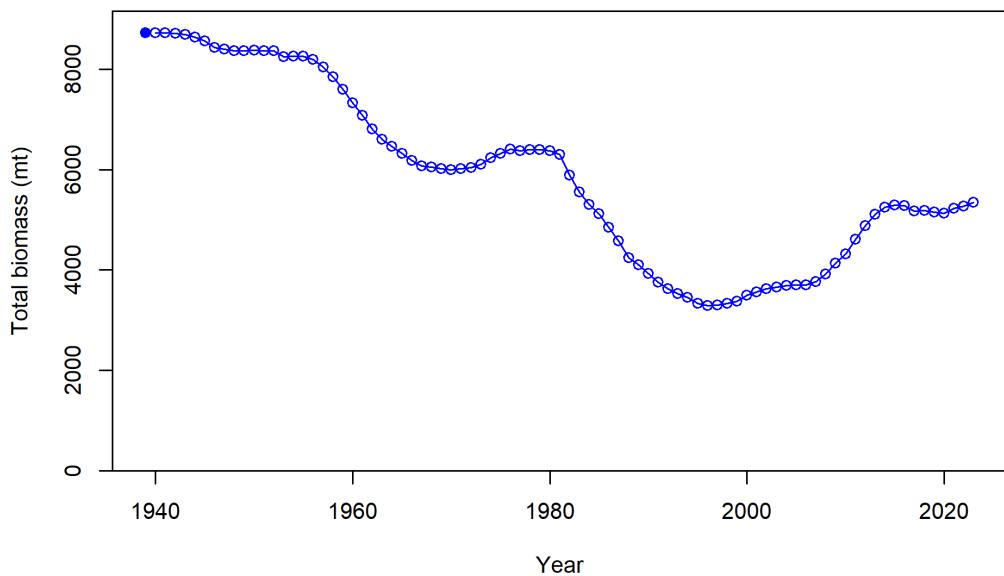


**Figure 46:** Length-based selectivity curves for each fleet and survey.

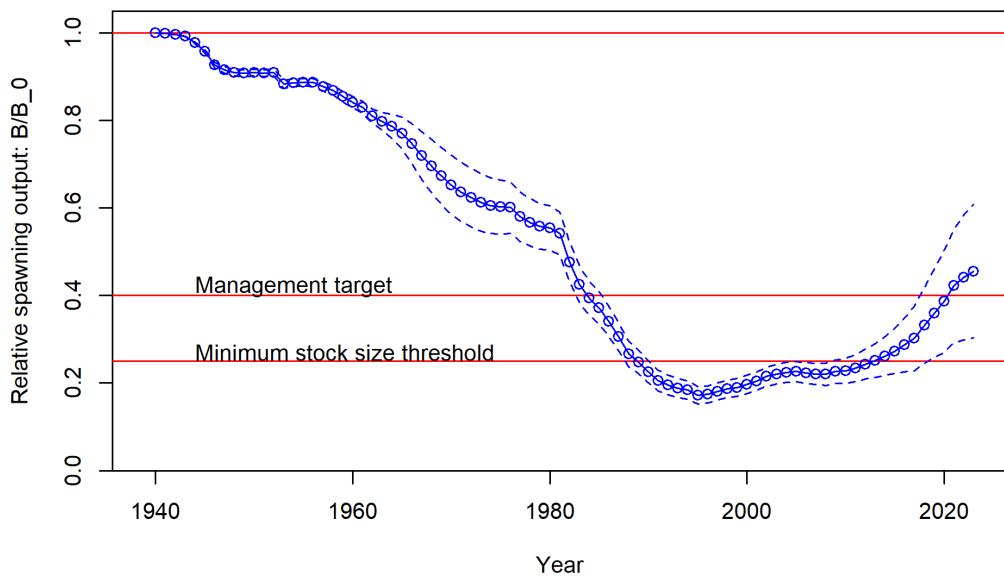
### 9.3.7 Time series



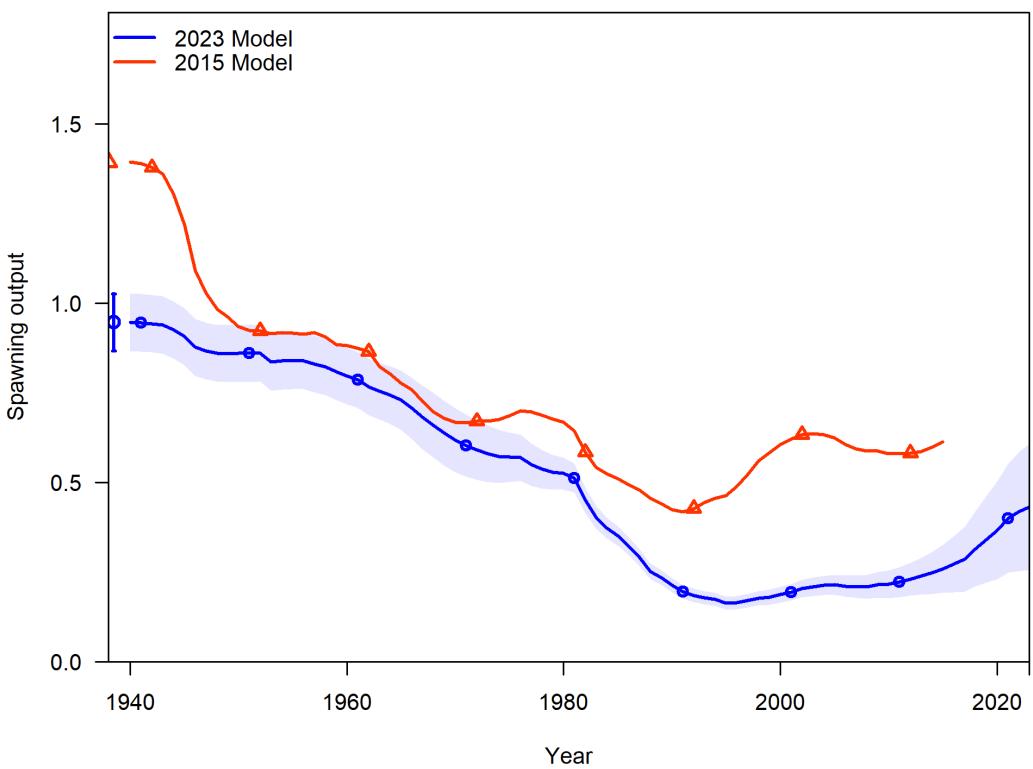
**Figure 47:** Estimated time series of spawning output (in millions of eggs).



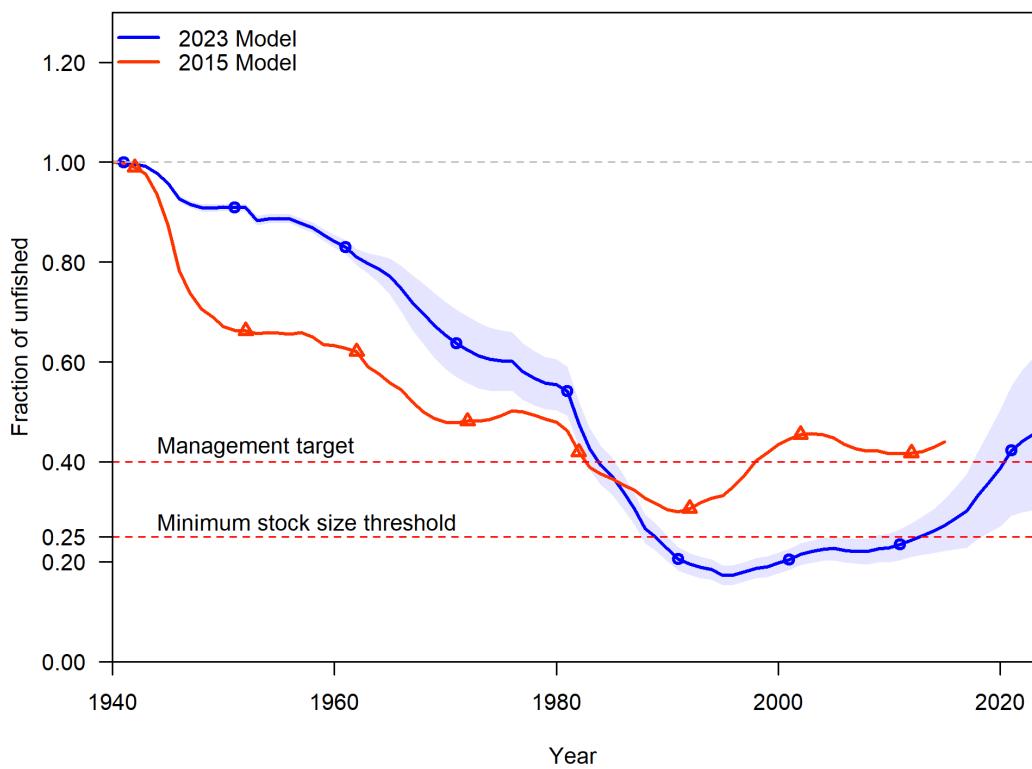
**Figure 48:** Estimated time series of total biomass (mt).



**Figure 49:** Estimated time series of fraction of unfished spawning output.

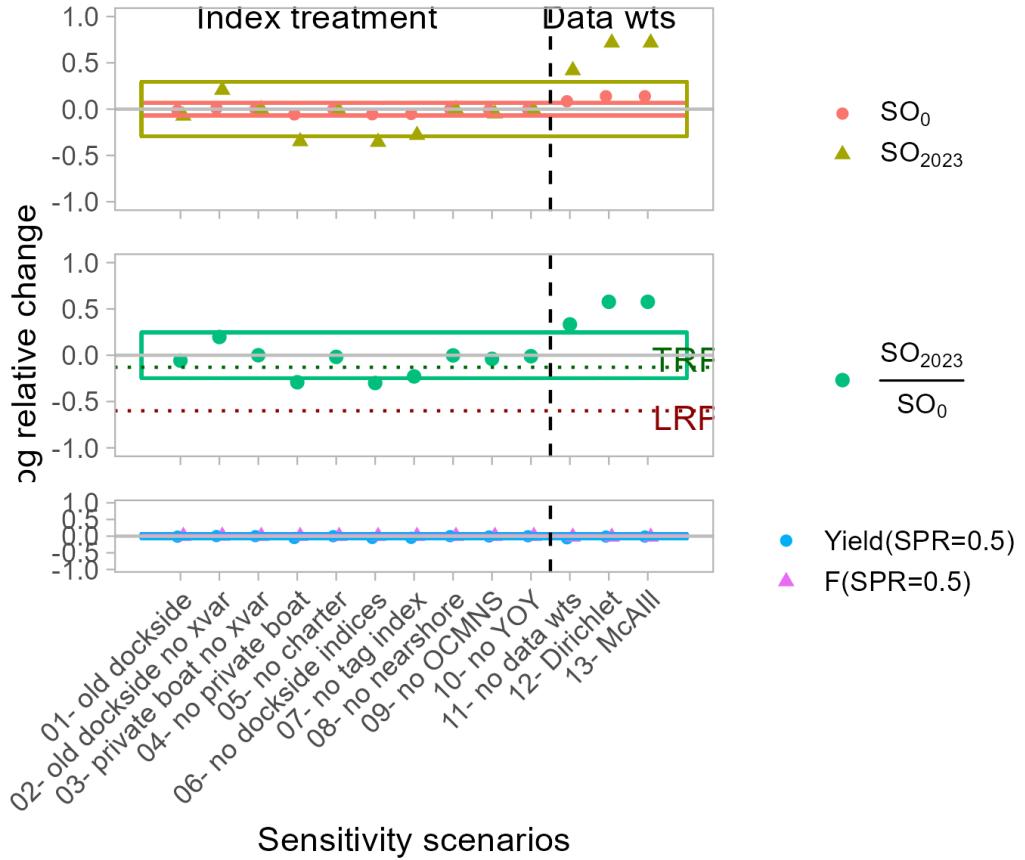


**Figure 50:** Comparison of the time series of spawning output between the 2015 and 2023 assessment results.

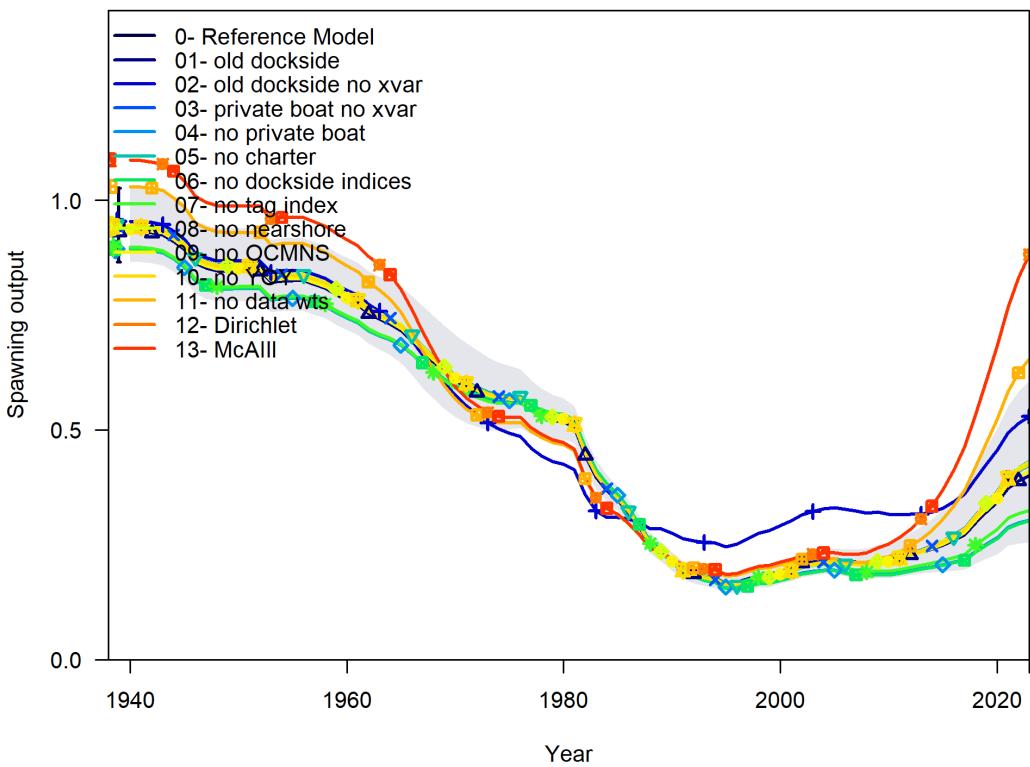


**Figure 51:** Comparison of the time series of relative spawning output between the 2015 and 2023 assessment results.

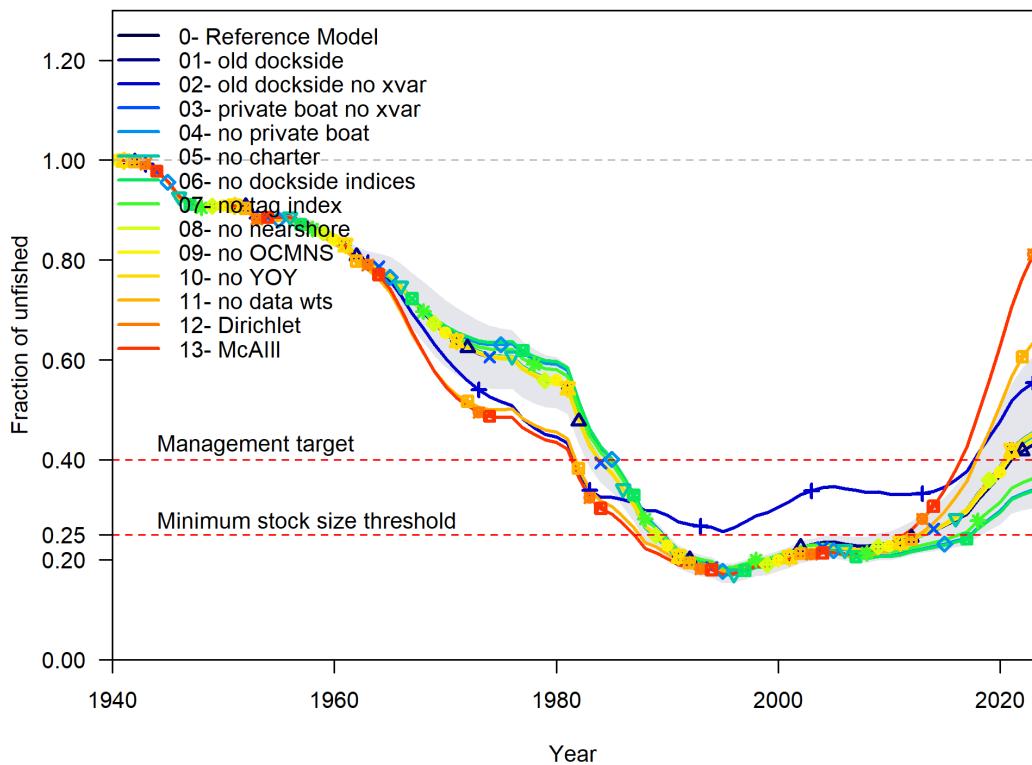
### 9.3.8 Sensitivities



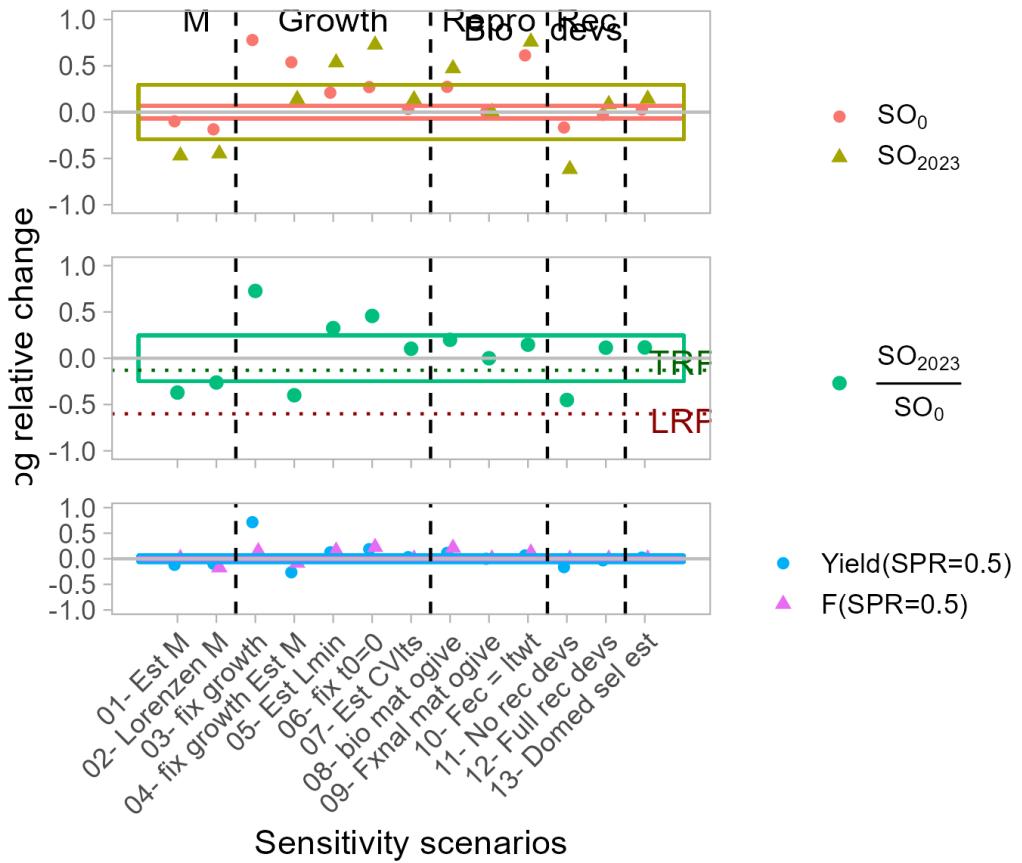
**Figure 52:** Log relative change ( $\log((\text{Model\_sensi}-\text{Model\_ref})/\text{Model\_ref})$ ) in data treatment for 5 derived quantities. Colored boxes indicate 95 percent confidence interval of the reference model.



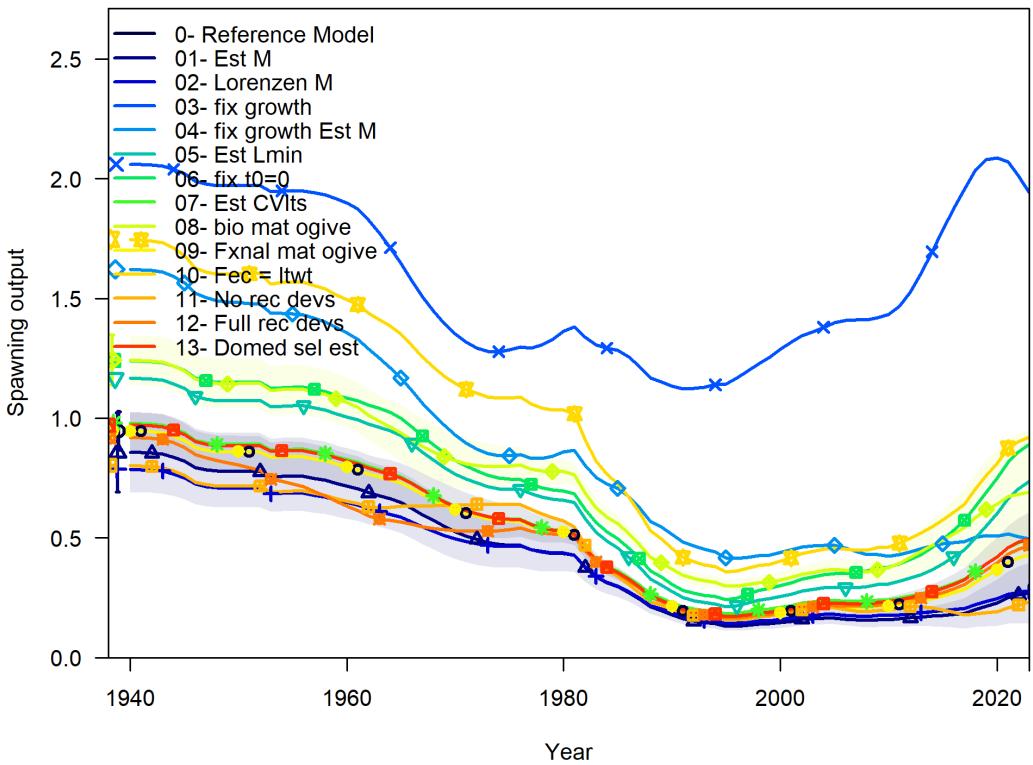
**Figure 53:** Spawning output (in millions of eggs) time series by data treatment compared to the reference model.



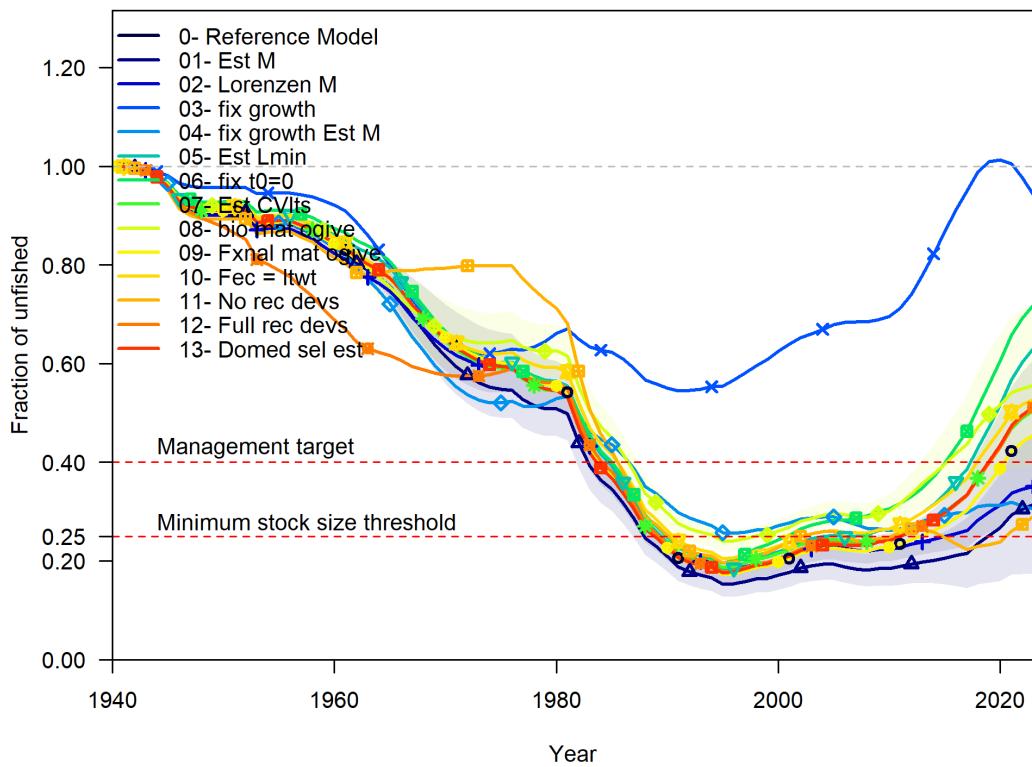
**Figure 54:** Relative spawning output time series by data treatment compared to the reference model. Missing scenarios mean the spawning output was too large to show.



**Figure 55:** Log relative change ( $\log((\text{Model\_sensi}-\text{Model\_ref})/\text{Model\_ref}))$ ) in model specification scenario for 5 derived quantities. Colored boxes indicate 95 percent confidence interval of the reference model.

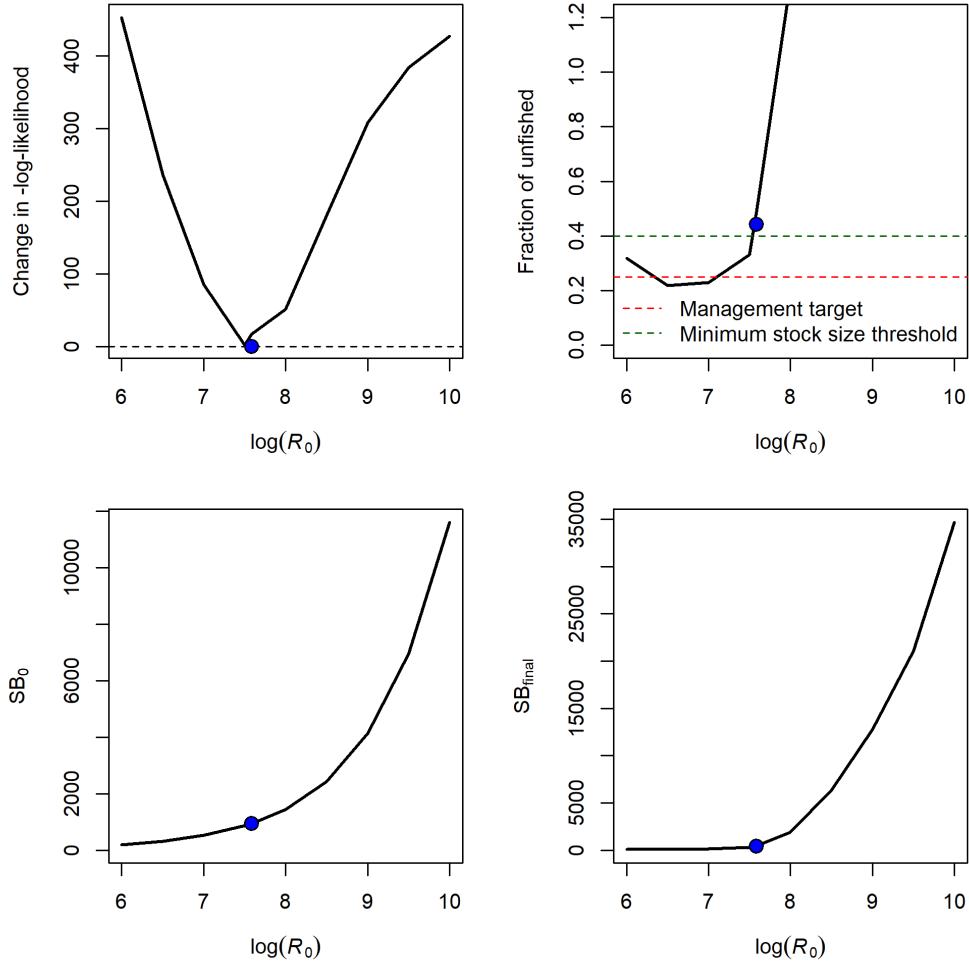


**Figure 56:** Spawning output (in millions of eggs) time series by model specification scenario compared to the reference model. Missing scenarios mean the spawning output was too large to show.

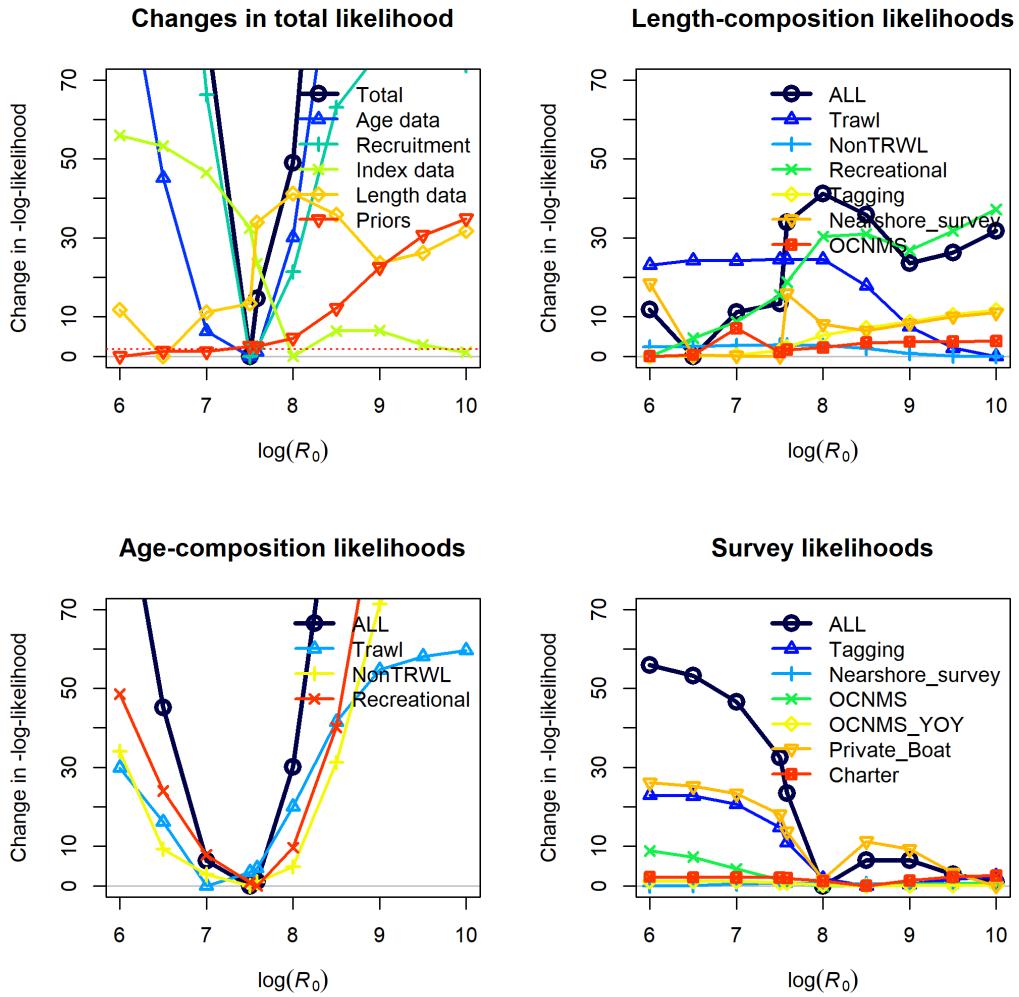


**Figure 57:** Relative spawning output time series by model specification scenario compared to the reference model.

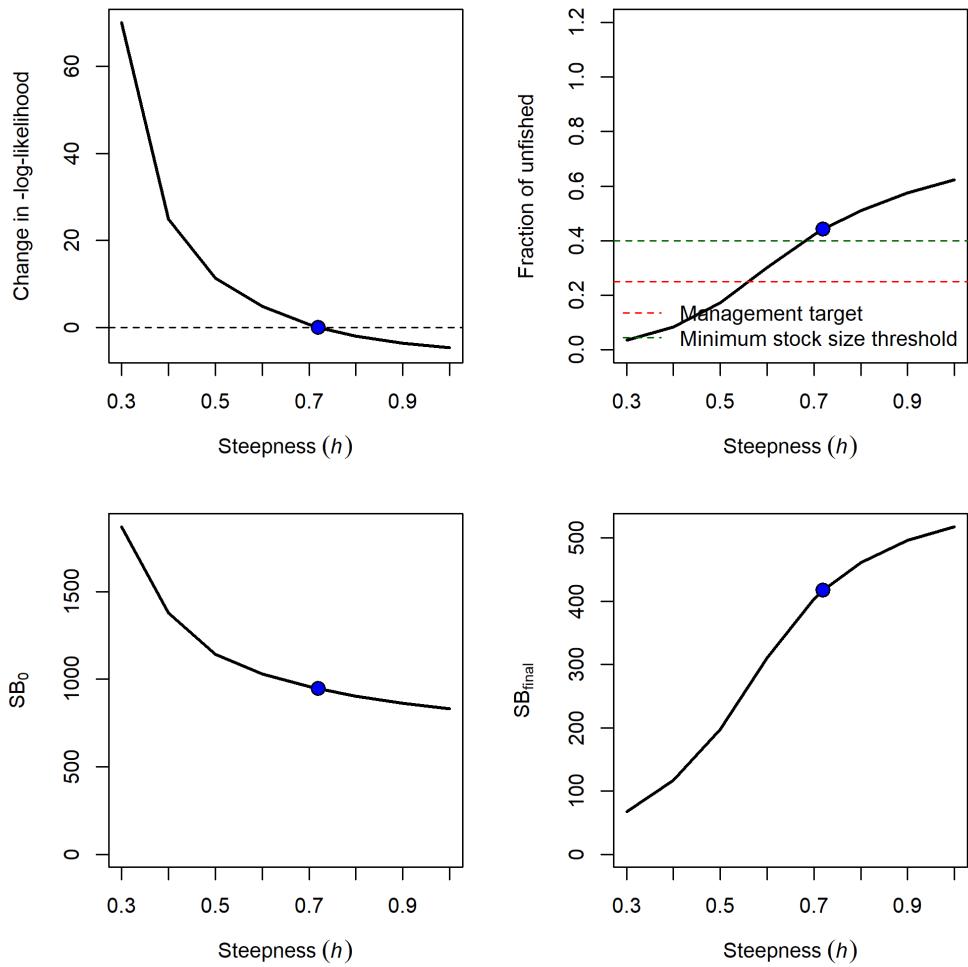
### 9.3.9 Likelihood Profiles



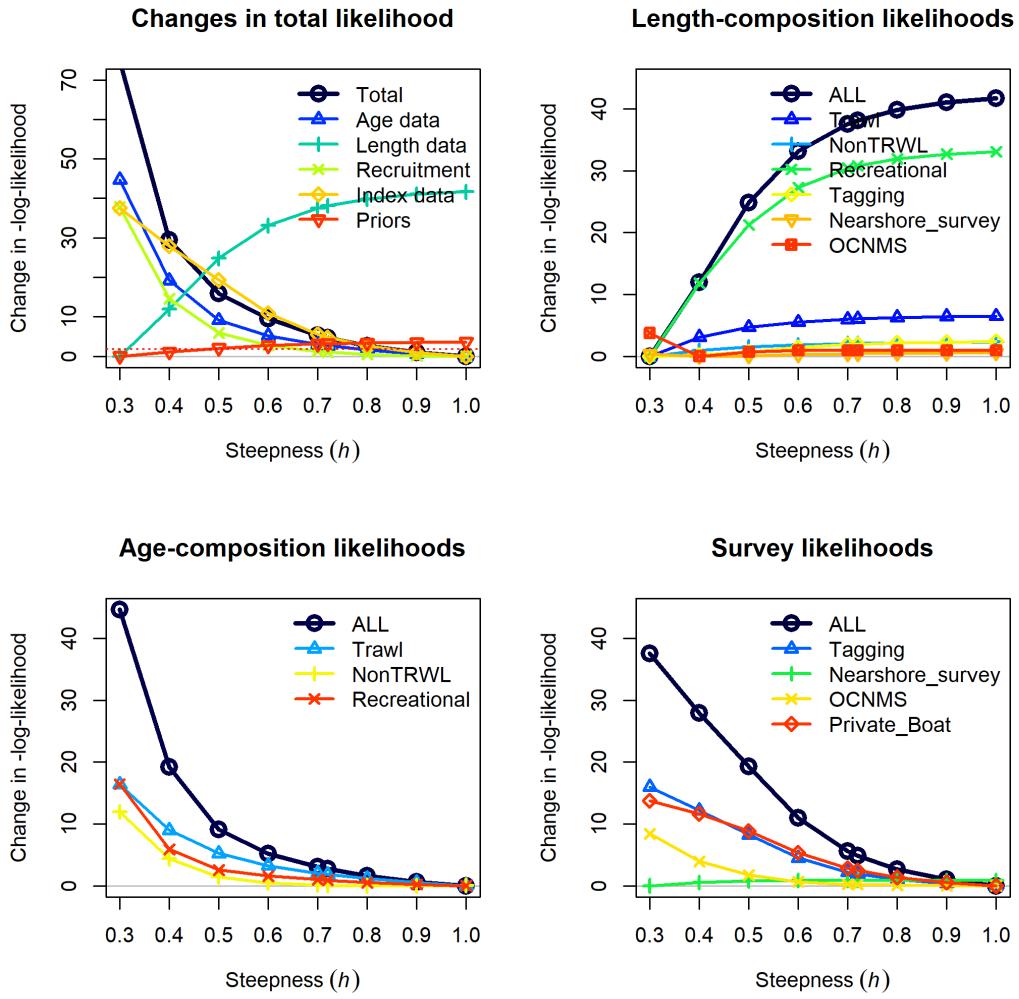
**Figure 58:** Initial recruitment ( $\ln R_0$ ) likelihood profile (change in the negative log-likelihood across a range of  $\ln(R_0)$  values) and derived quantities. Red line in the top left figure indicates the significance level in likelihood difference.



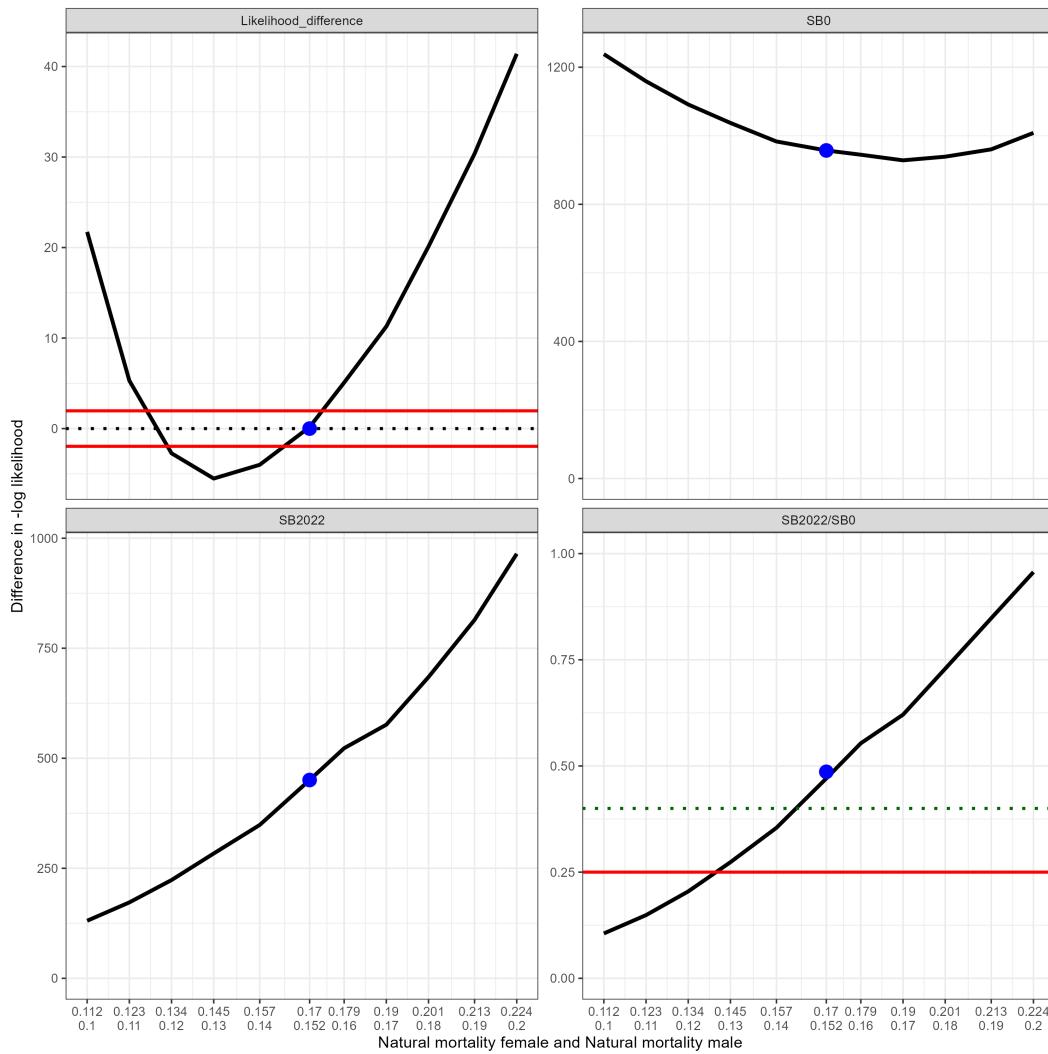
**Figure 59:** Initial recruitment ( $\ln(R_0)$ ) likelihood profile for each of the likelihood components.



**Figure 60:** Beverton-Holt steepness parameter likelihood profile (change in the negative log-likelihood across a range of steepness values) and derived quantities. Red line in the top left figure indicates the significance level in likelihood difference.

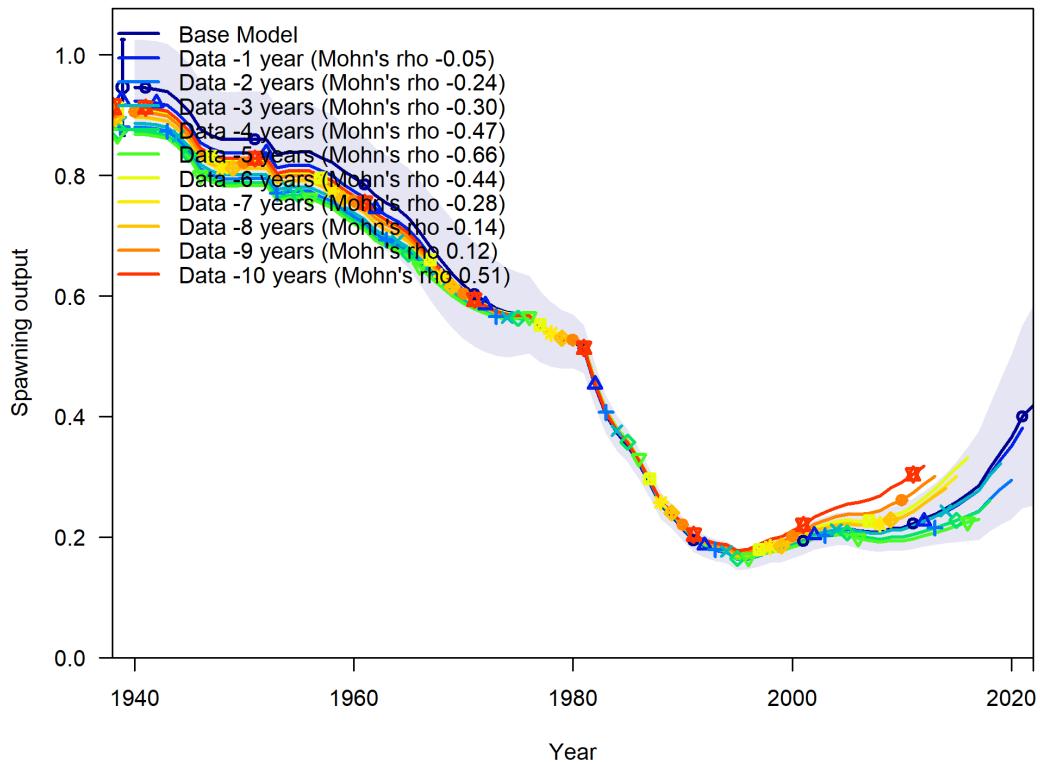


**Figure 61:** Beverton-Holt steepness parameter likelihood profile for each of the likelihood components.

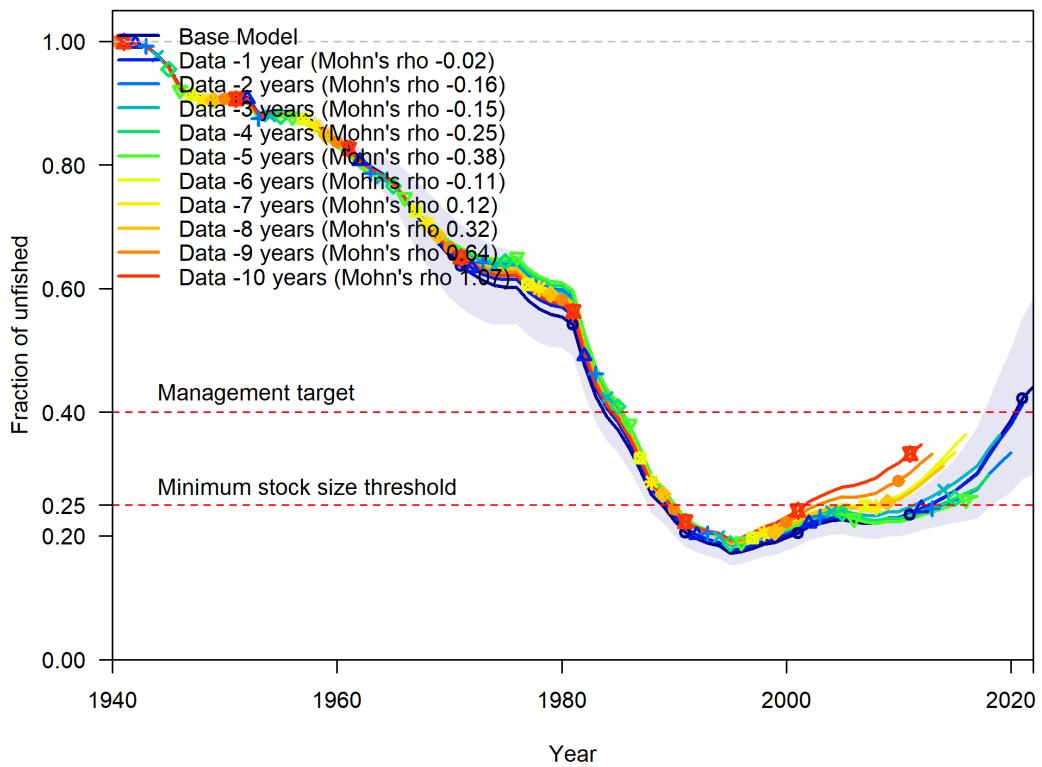


**Figure 62:** Female and male  $M$  multi-parameter likelihood profile and derived quantities. Red lines in the top left figure indicate significantly similar values compared to the reference model. Broken and solid lines in the bottom right figure indicate target and limit reference points, respectively.

### 9.3.10 Retrospectives

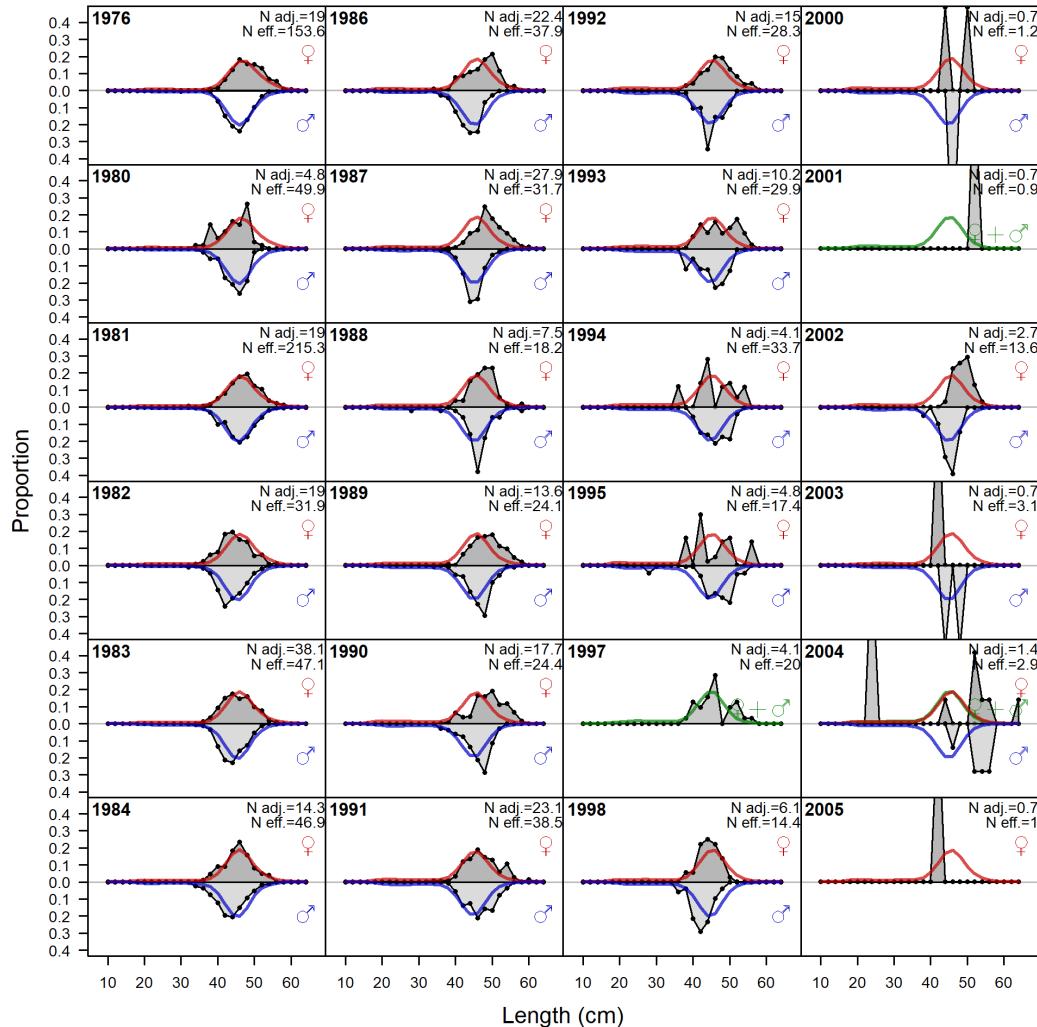


**Figure 63:** Change in the estimate of spawning output when the most recent 10 years of data area removed sequentially.

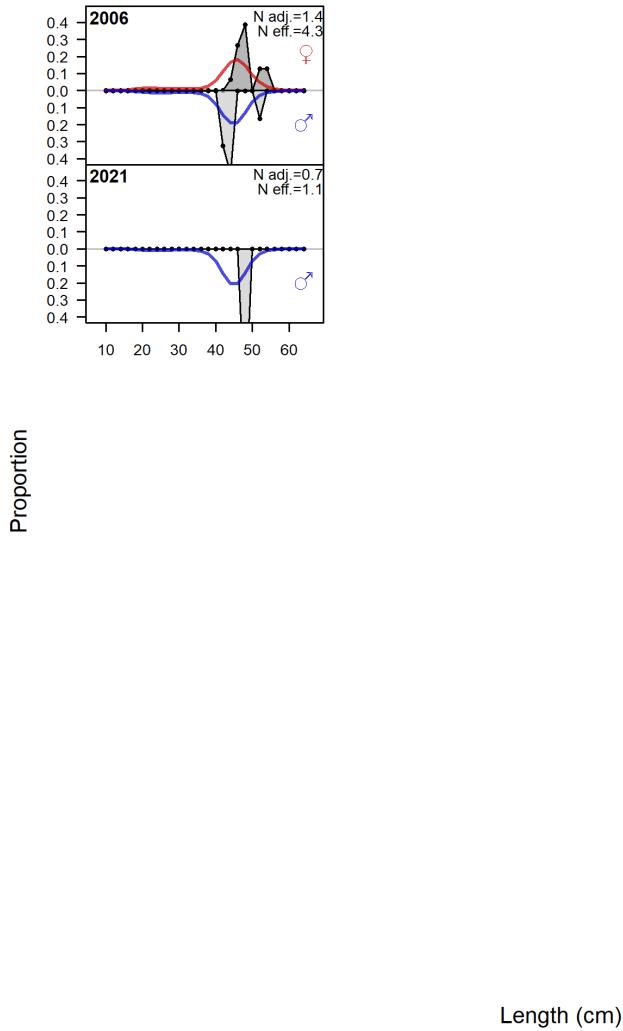


**Figure 64:** Change in the estimate of fraction unfished when the most recent 10 years of data are removed sequentially.

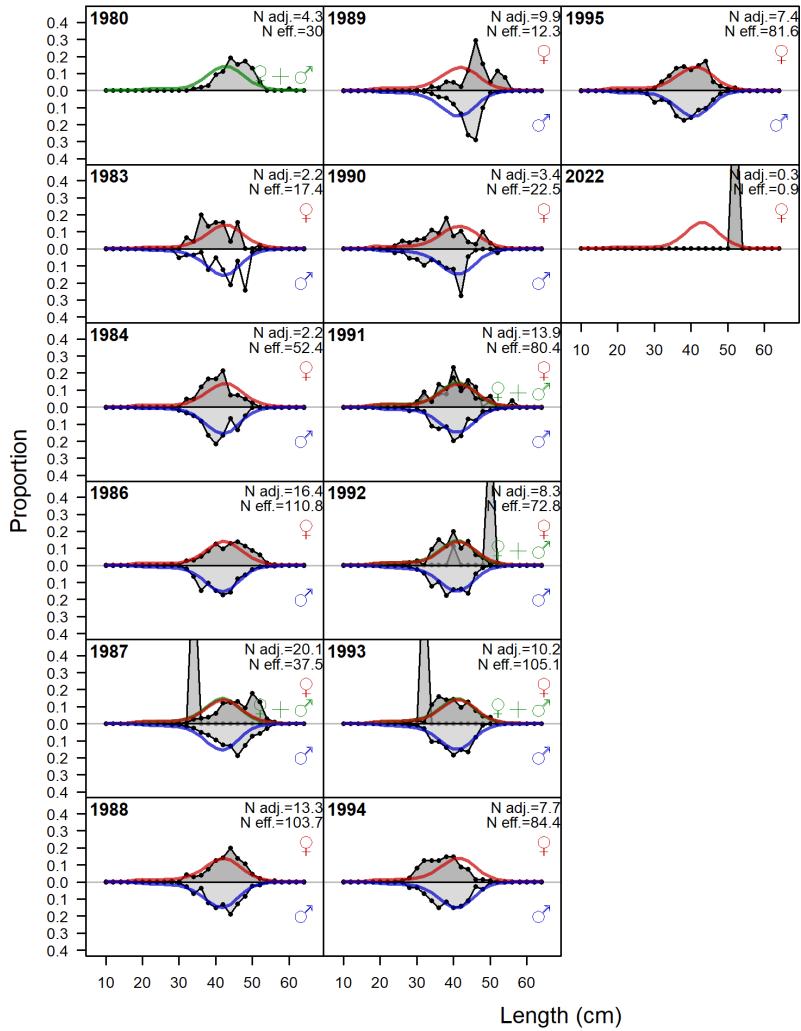
## 10 Appendix A: Detailed Fit to Length Composition Data



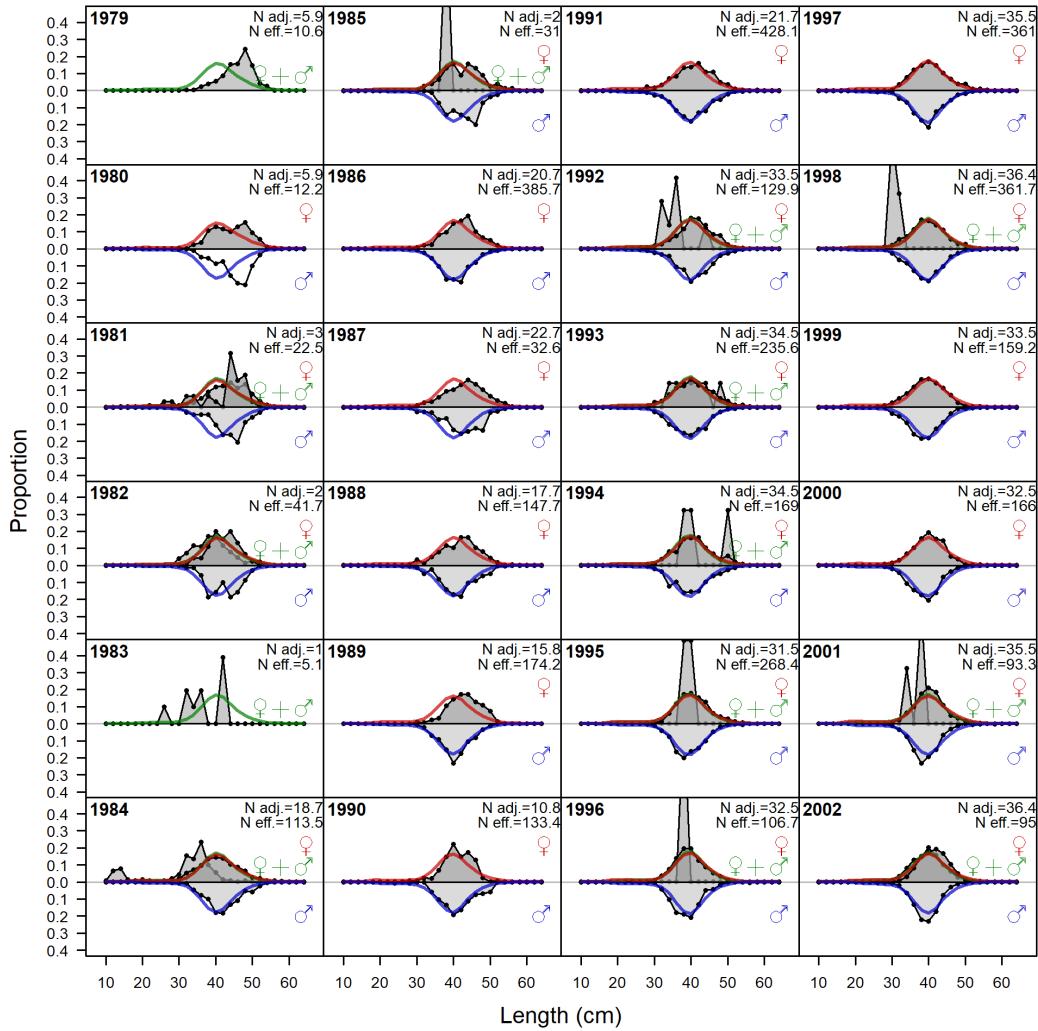
**Figure 65:** Length comps, whole catch, Trawl (plot 1 of 2). 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.



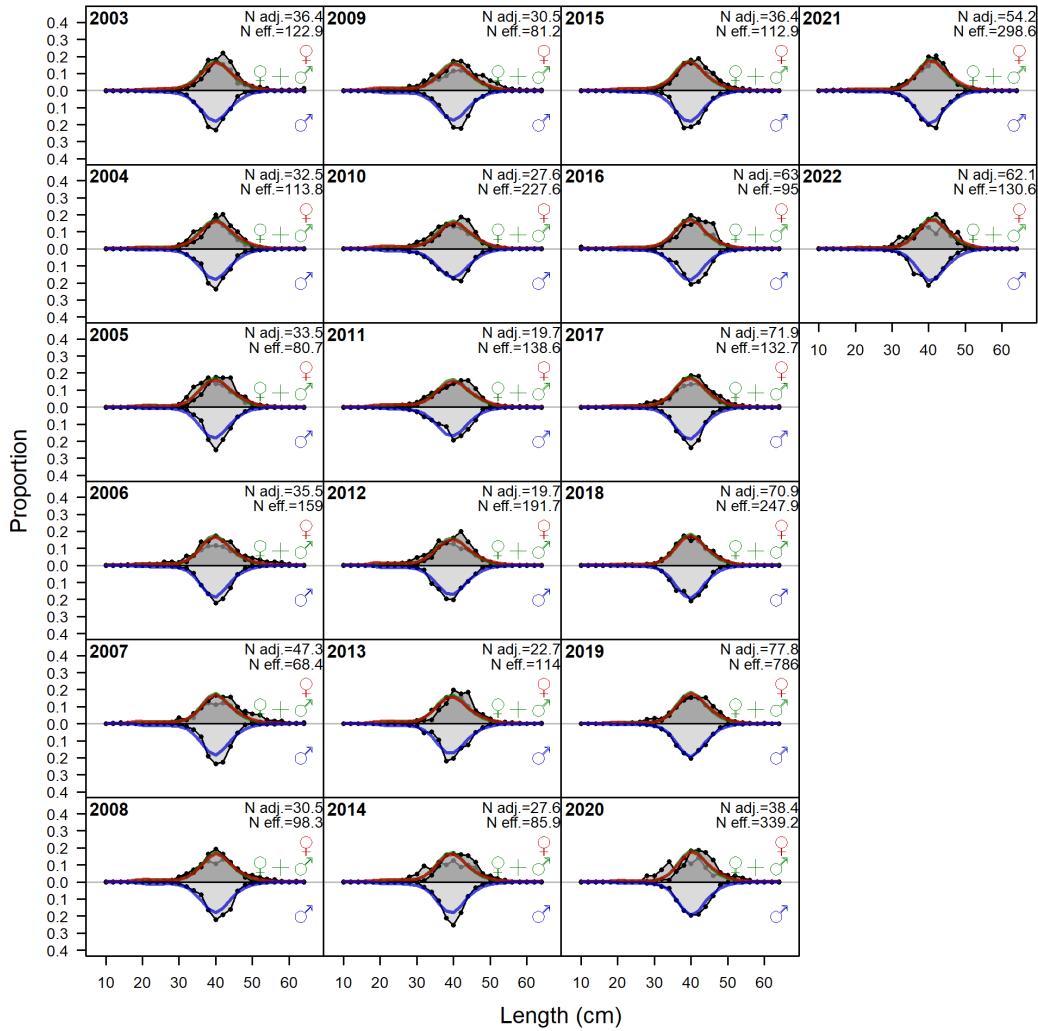
**Figure 66:** Length combs, whole catch, Trawl (plot 1 of 2). 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method. (plot 2 of 2).



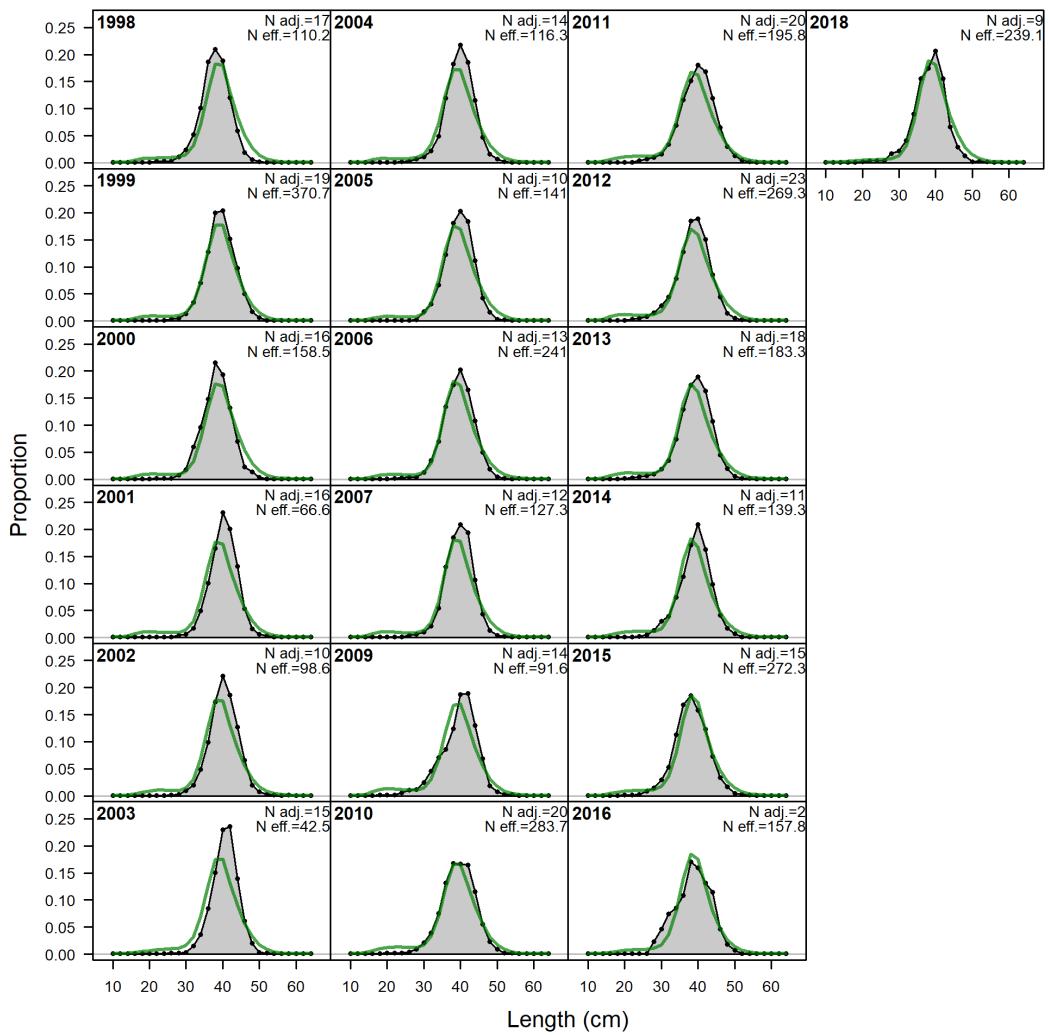
**Figure 67:** Length comps, whole catch, NonTRWL.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.



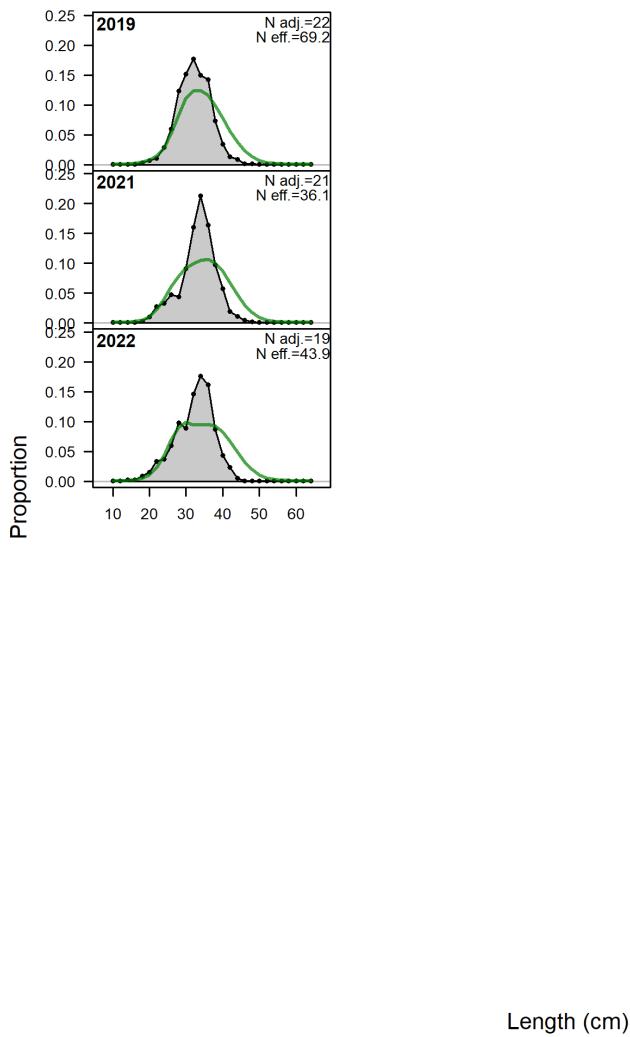
**Figure 68:** Length comps, whole catch, Recreational (plot 1 of 2). 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.



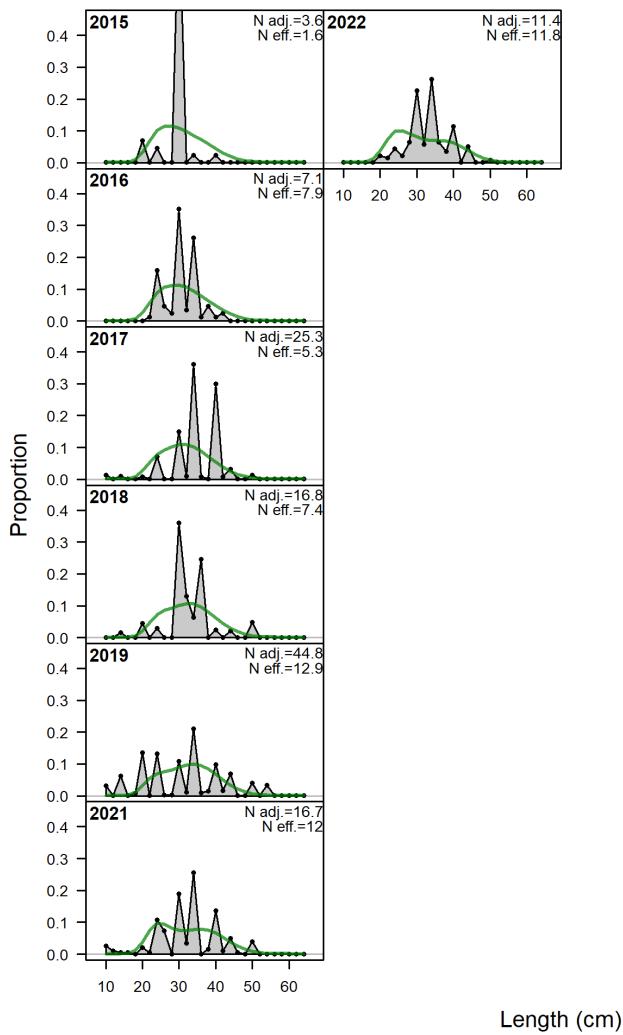
**Figure 69:** Length comps, whole catch, Recreational (plot 1 of 2). 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method. (plot 2 of 2).



**Figure 70:** Length comps, whole catch, Tagging.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

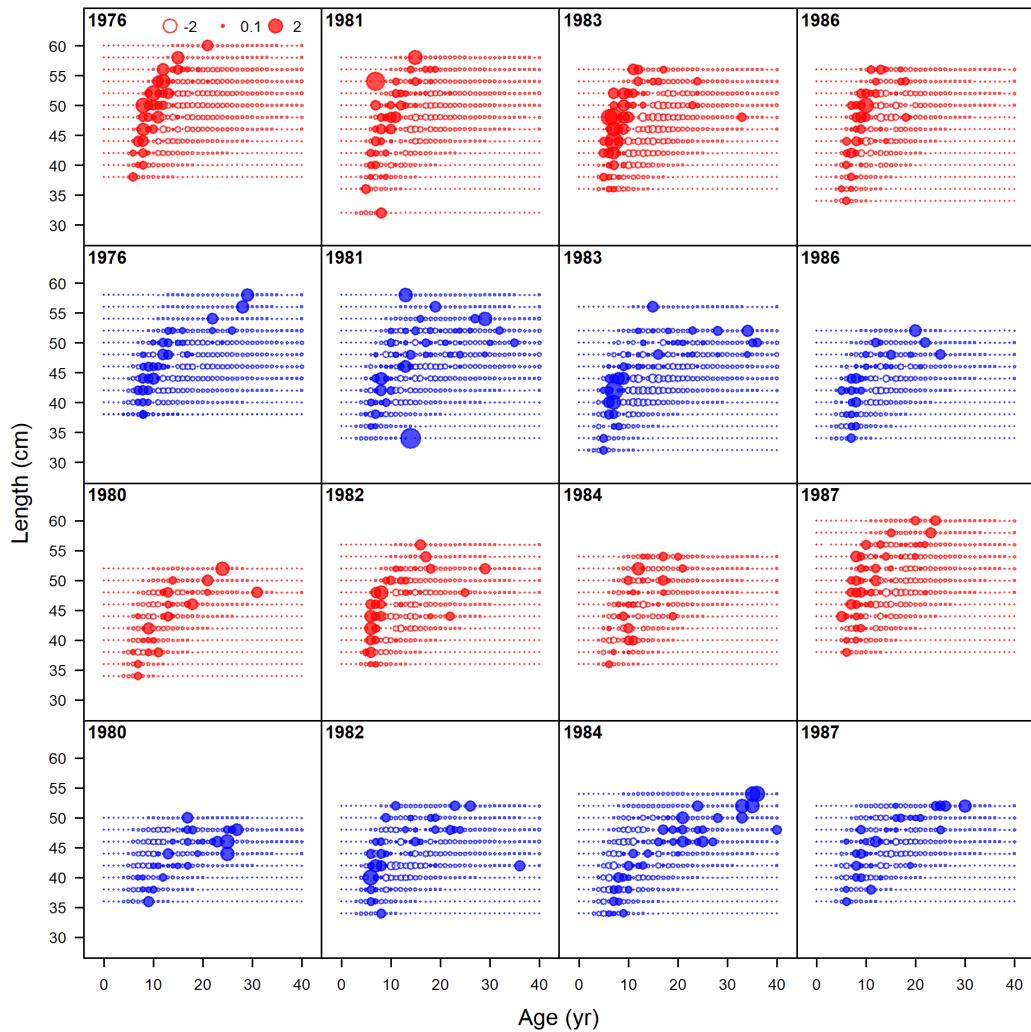


**Figure 71:** Length comps, whole catch, Nearshore\_survey.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

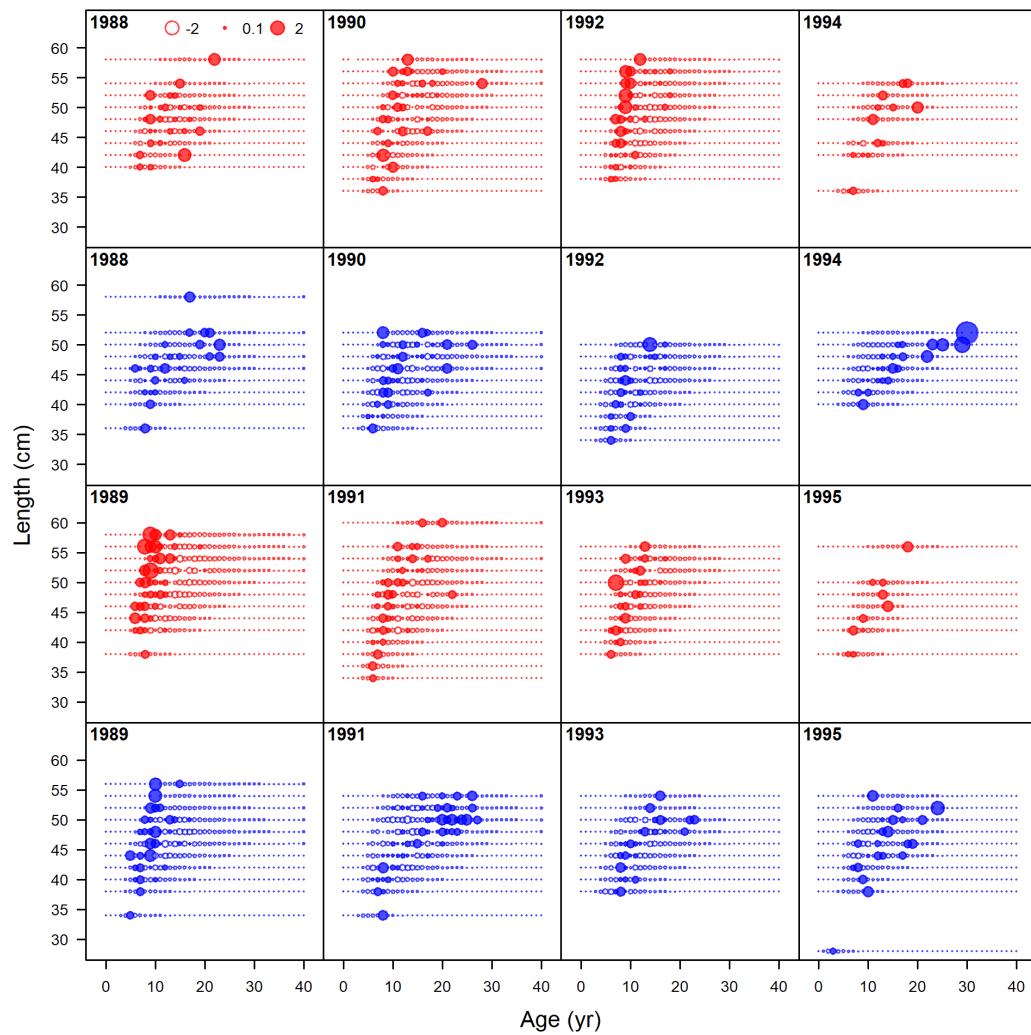


**Figure 72:** Length comps, whole catch, OCNMS.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

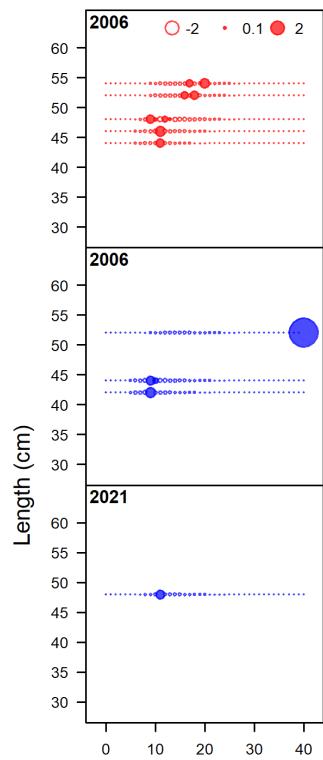
## 11 Appendix B: Fit to Conditional-Age-at-Length Composition Data



**Figure 73:** Pearson residuals, whole catch, Trawl (max=8.73) (plot 1 of 3).

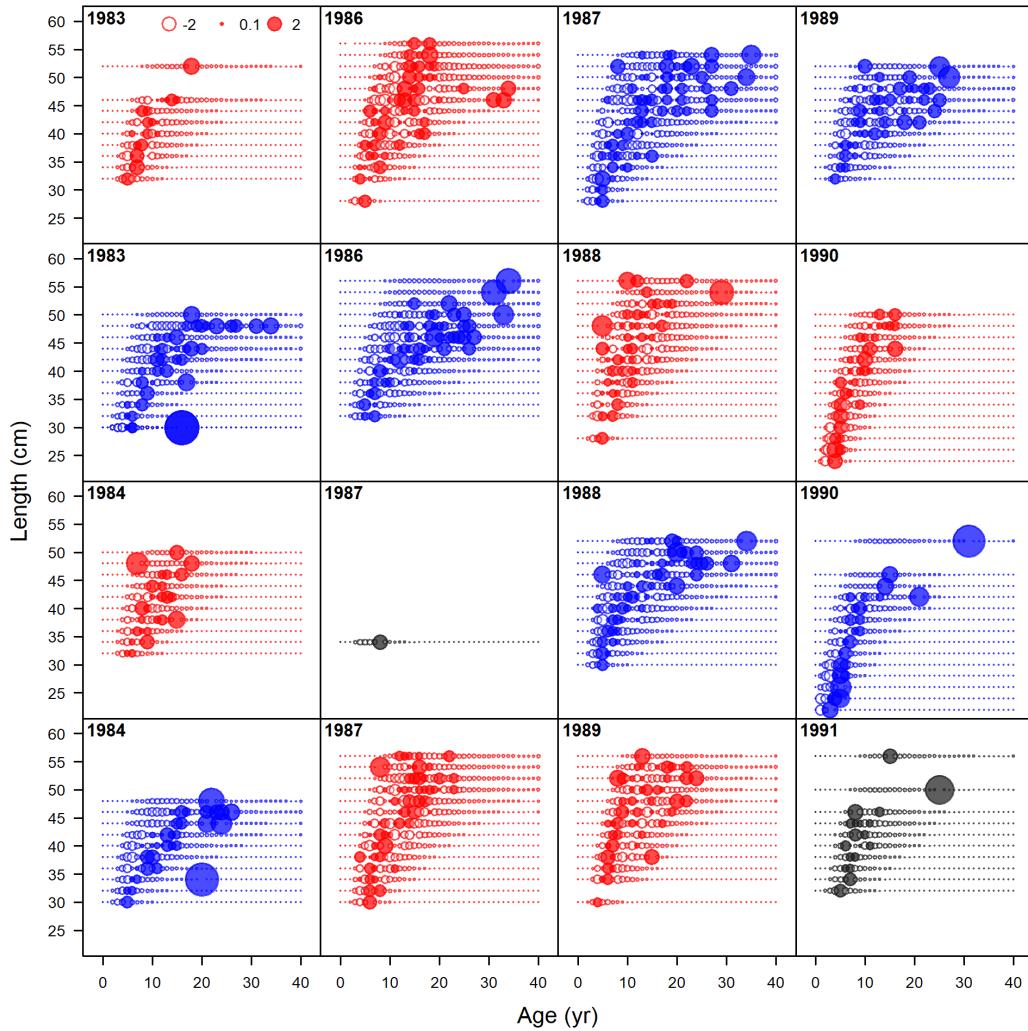


**Figure 74:** Pearson residuals, whole catch, Trawl (max=8.73) (plot 2 of 3).

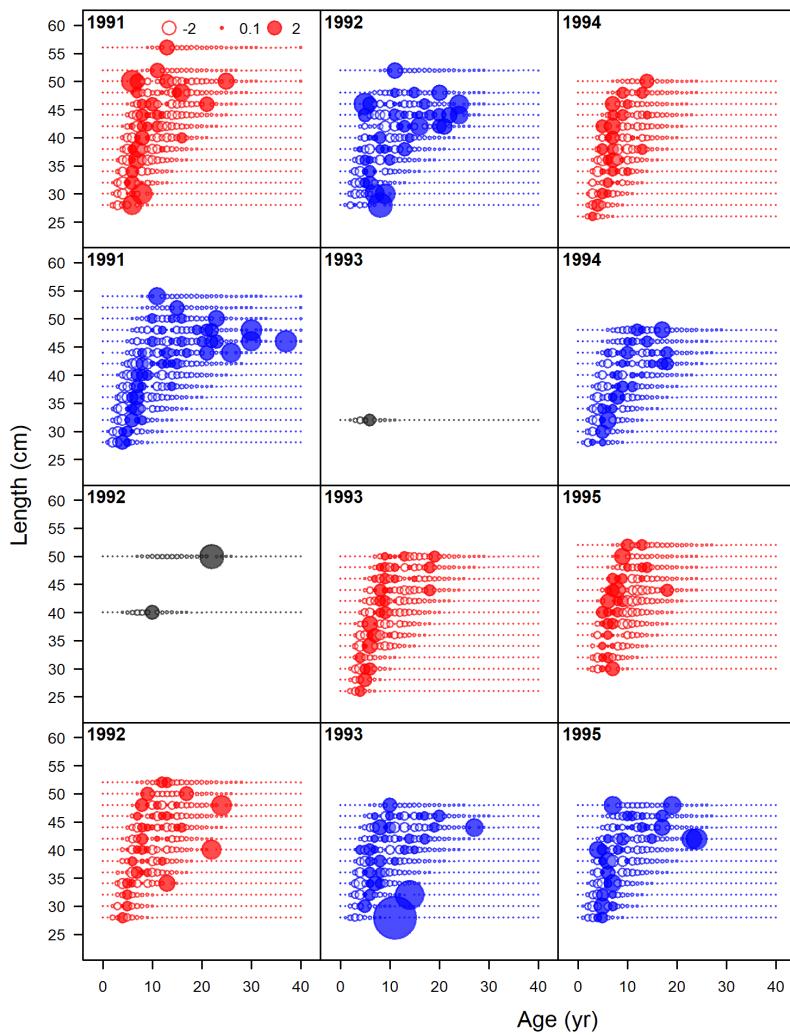


Age (yr)

**Figure 75:** Pearson residuals, whole catch, Trawl (max=8.73) (plot 3 of 3).

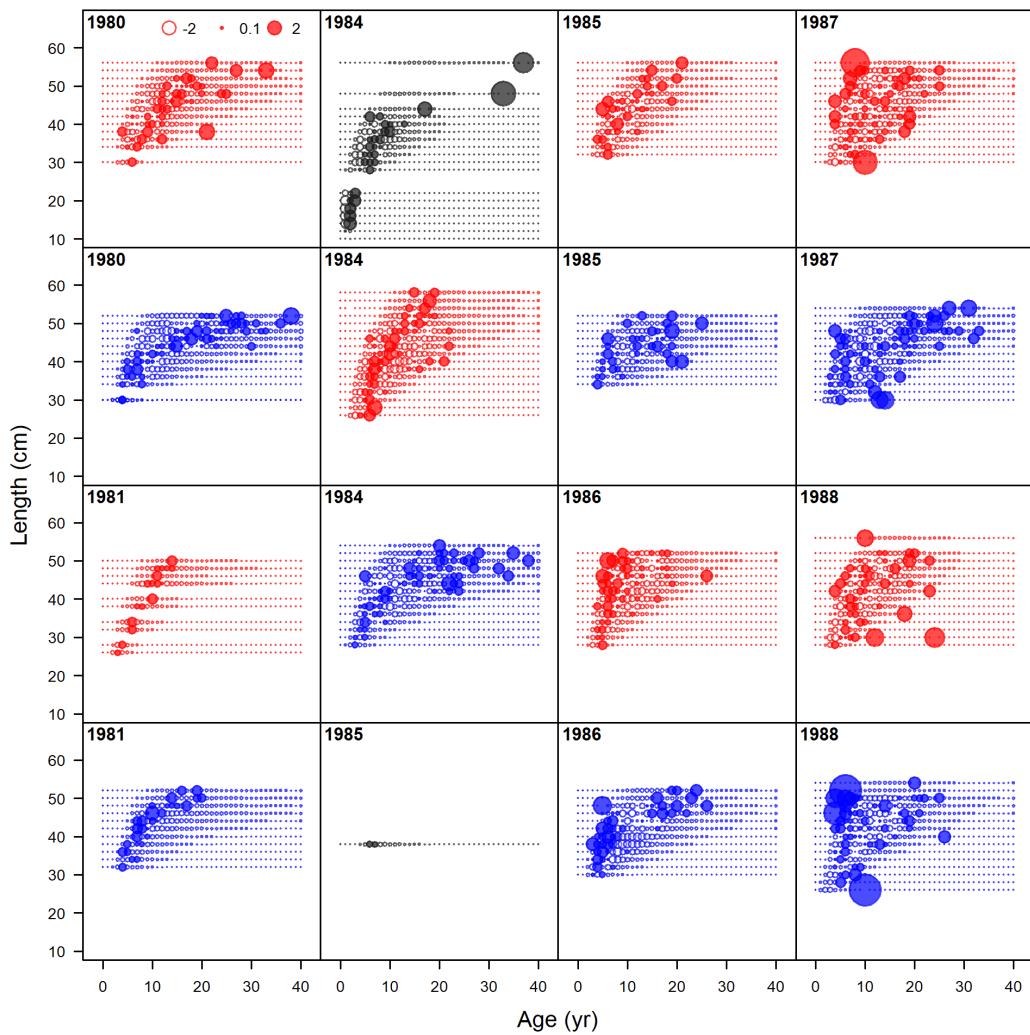


**Figure 76:** Pearson residuals, whole catch, NonTRWL (max=18.53) (plot 1 of 3).

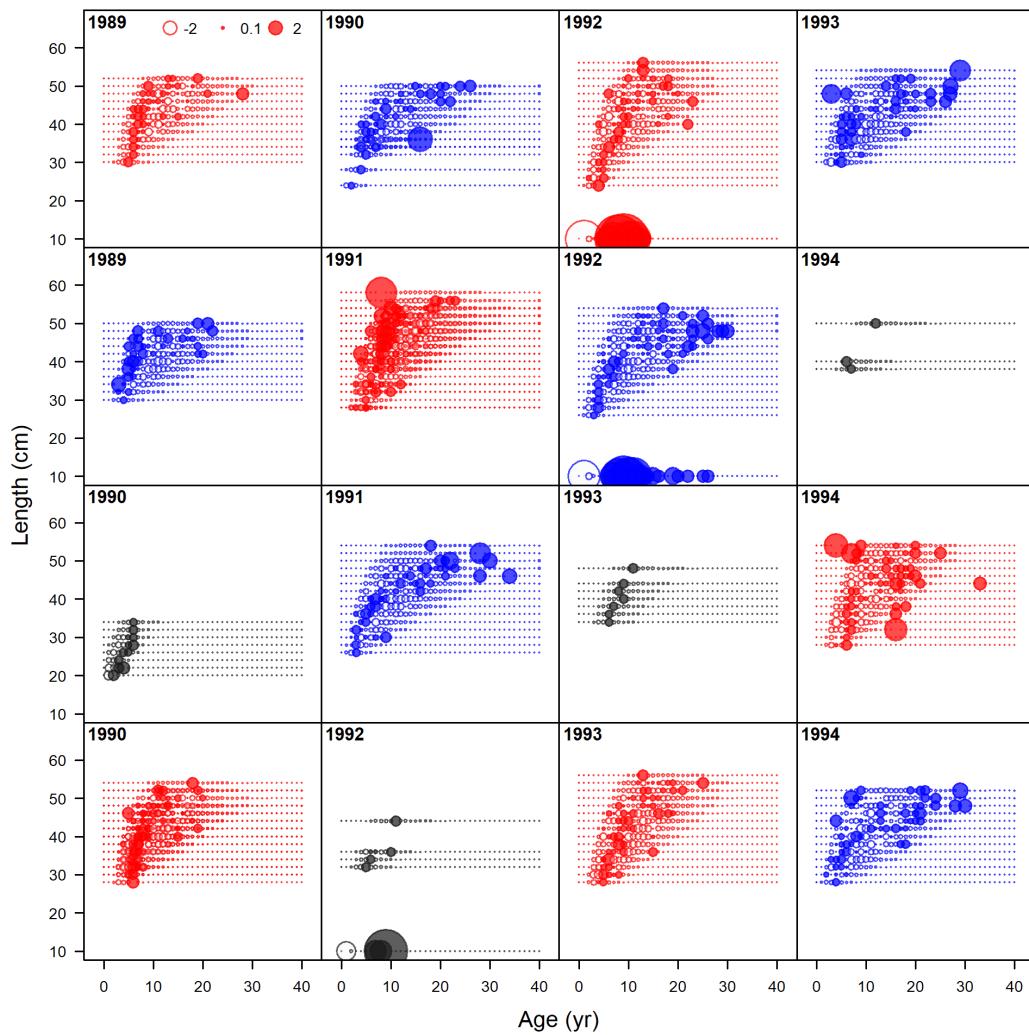


**Figure 77:** Pearson residuals, whole catch, NonTRWL (max=18.53) (plot 2 of 3).

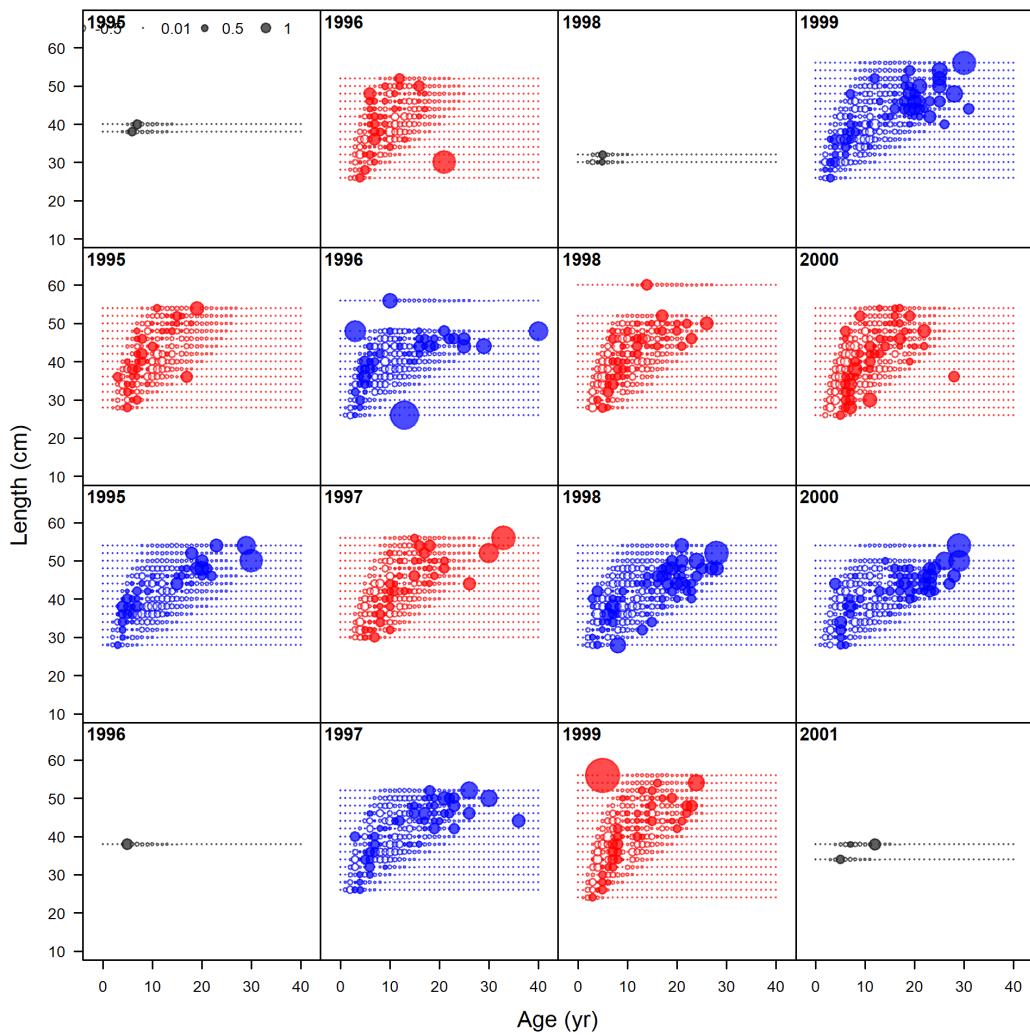
**Figure 78:** Pearson residuals, whole catch, NonTRWL ( $\text{max}=18.53$ ) (plot 3 of 3).



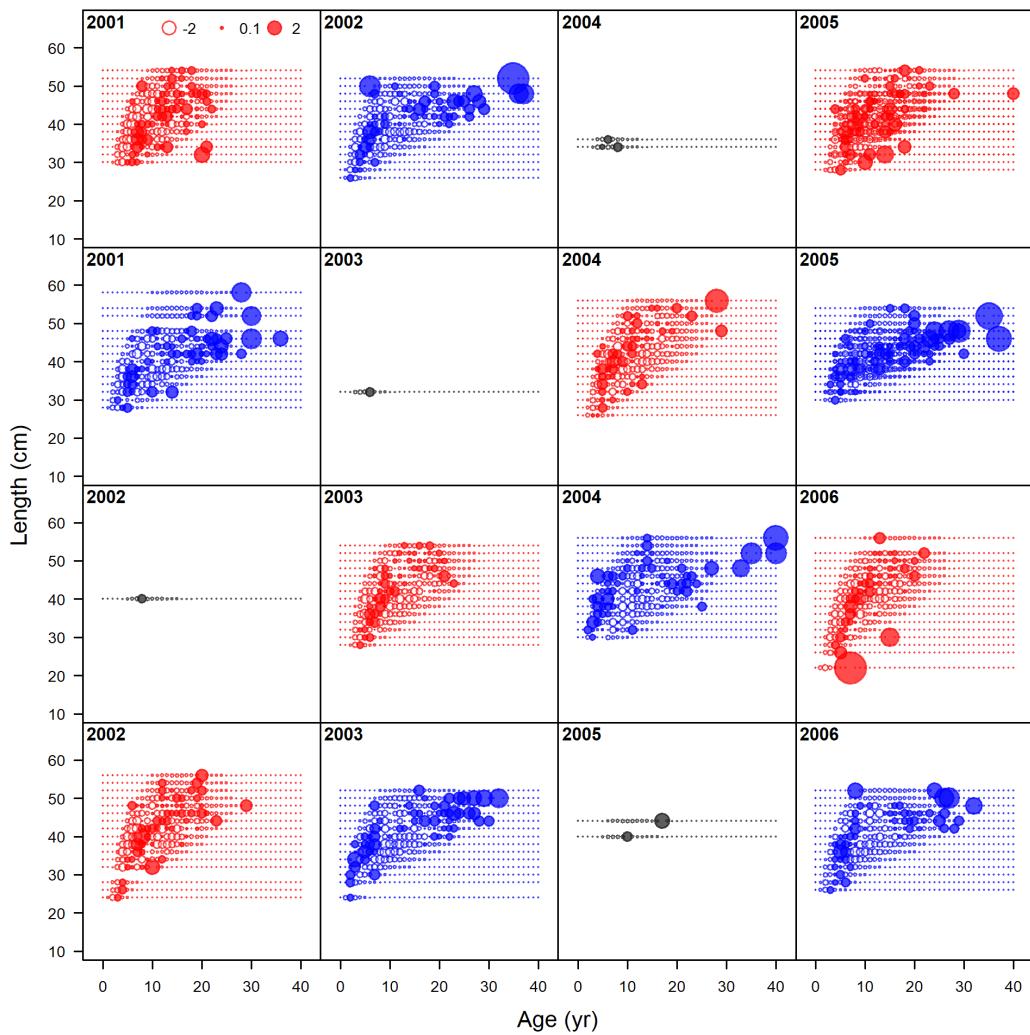
**Figure 79:** Pearson residuals, whole catch, Recreational (max=25.87) (plot 1 of 8).



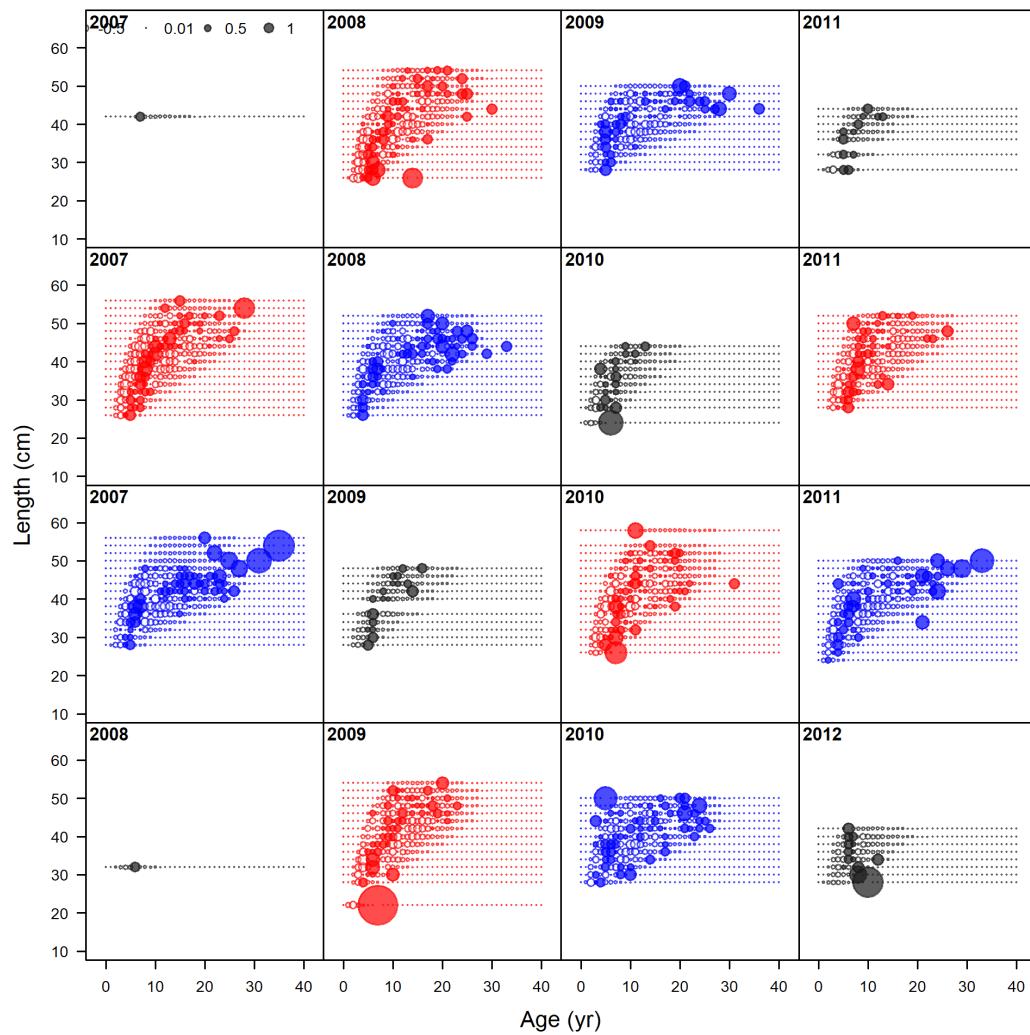
**Figure 80:** Pearson residuals, whole catch, Recreational (max=25.87) (plot 2 of 8).



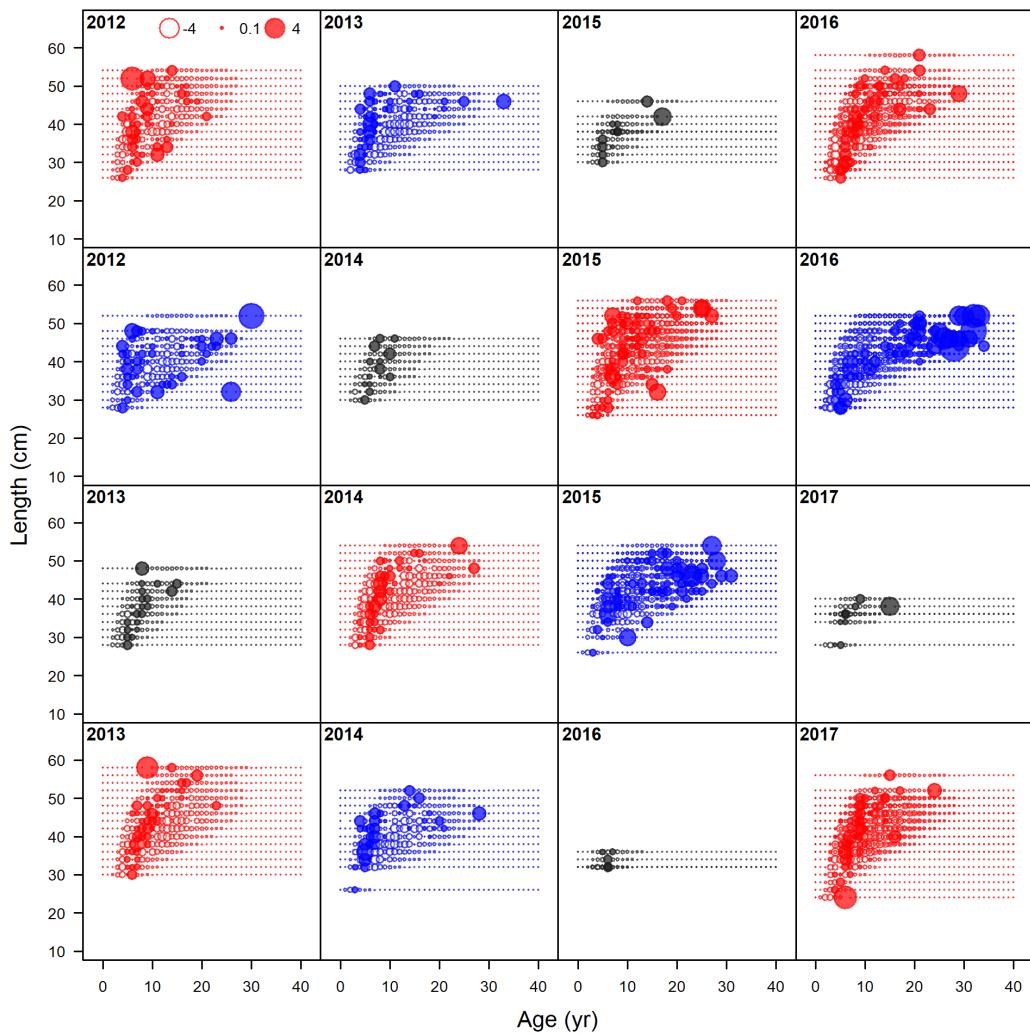
**Figure 81:** Pearson residuals, whole catch, Recreational (max=25.87) (plot 3 of 8).



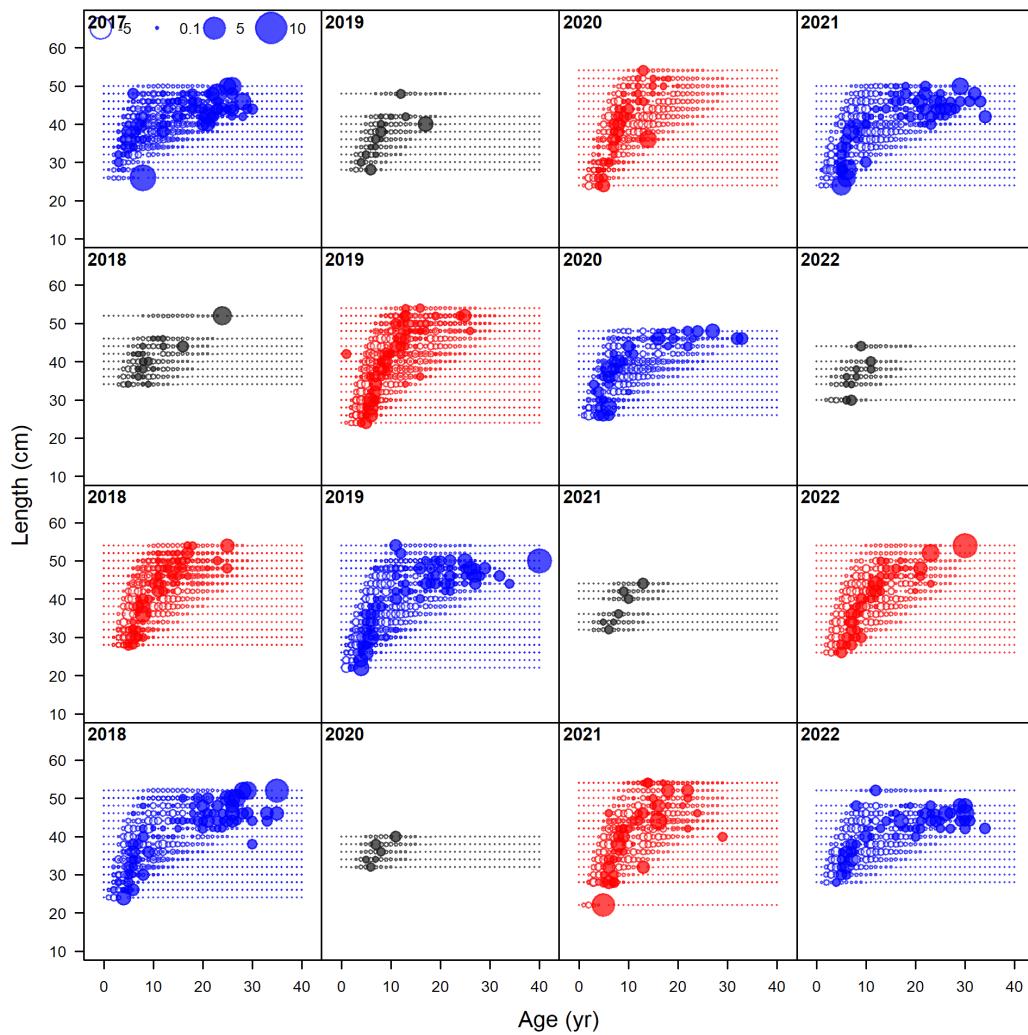
**Figure 82:** Pearson residuals, whole catch, Recreational (max=25.87) (plot 4 of 8).



**Figure 83:** Pearson residuals, whole catch, Recreational (max=25.87) (plot 5 of 8).



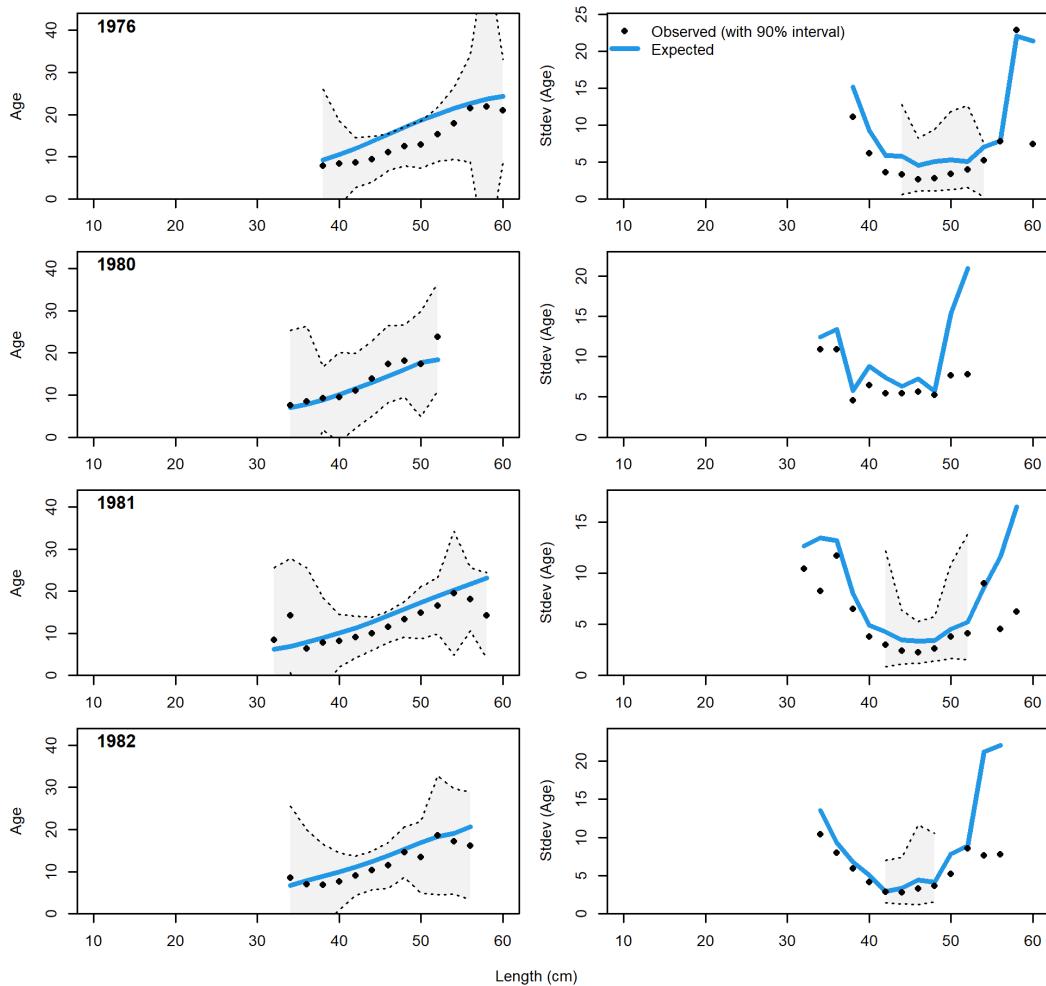
**Figure 84:** Pearson residuals, whole catch, Recreational (max=25.87) (plot 6 of 8).



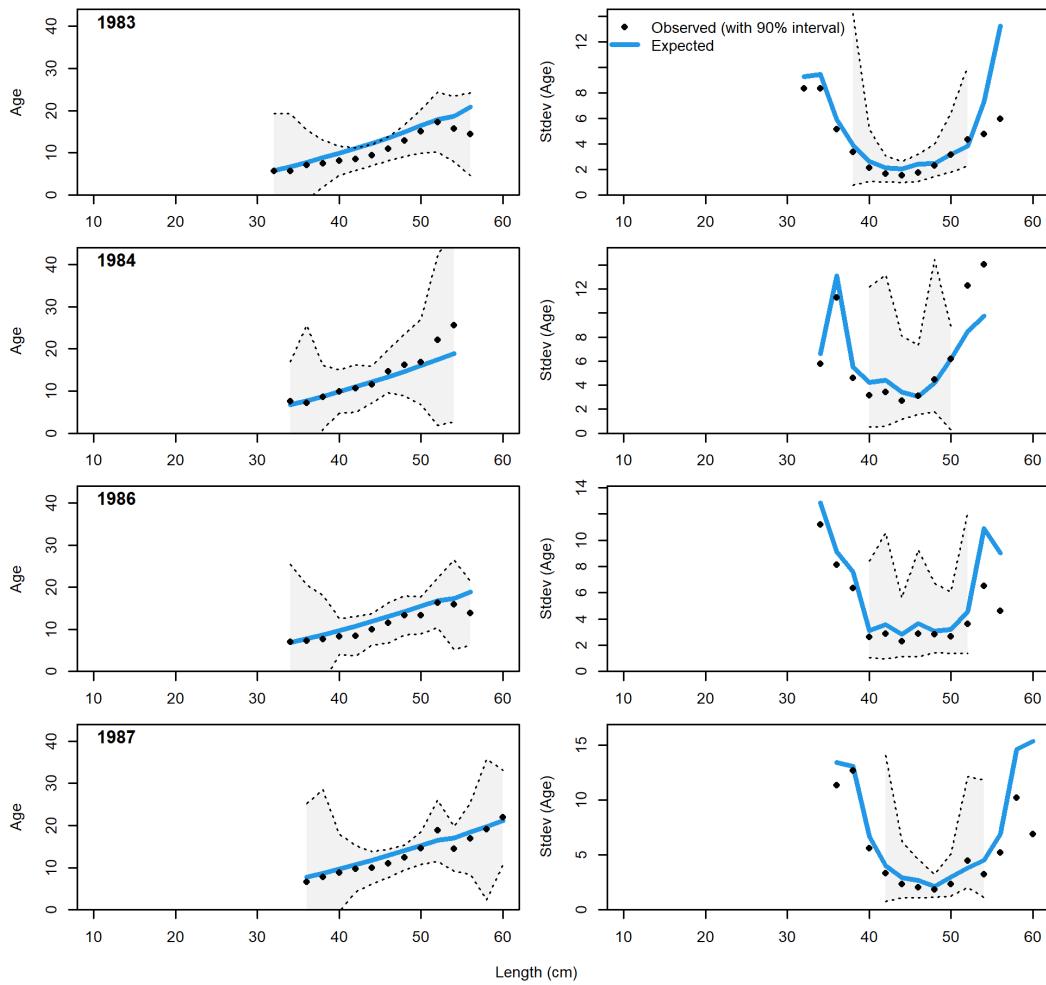
**Figure 85:** Pearson residuals, whole catch, Recreational (max=25.87) (plot 7 of 8).

**Figure 86:** Pearson residuals, whole catch, Recreational (max=25.87) (plot 8 of 8).

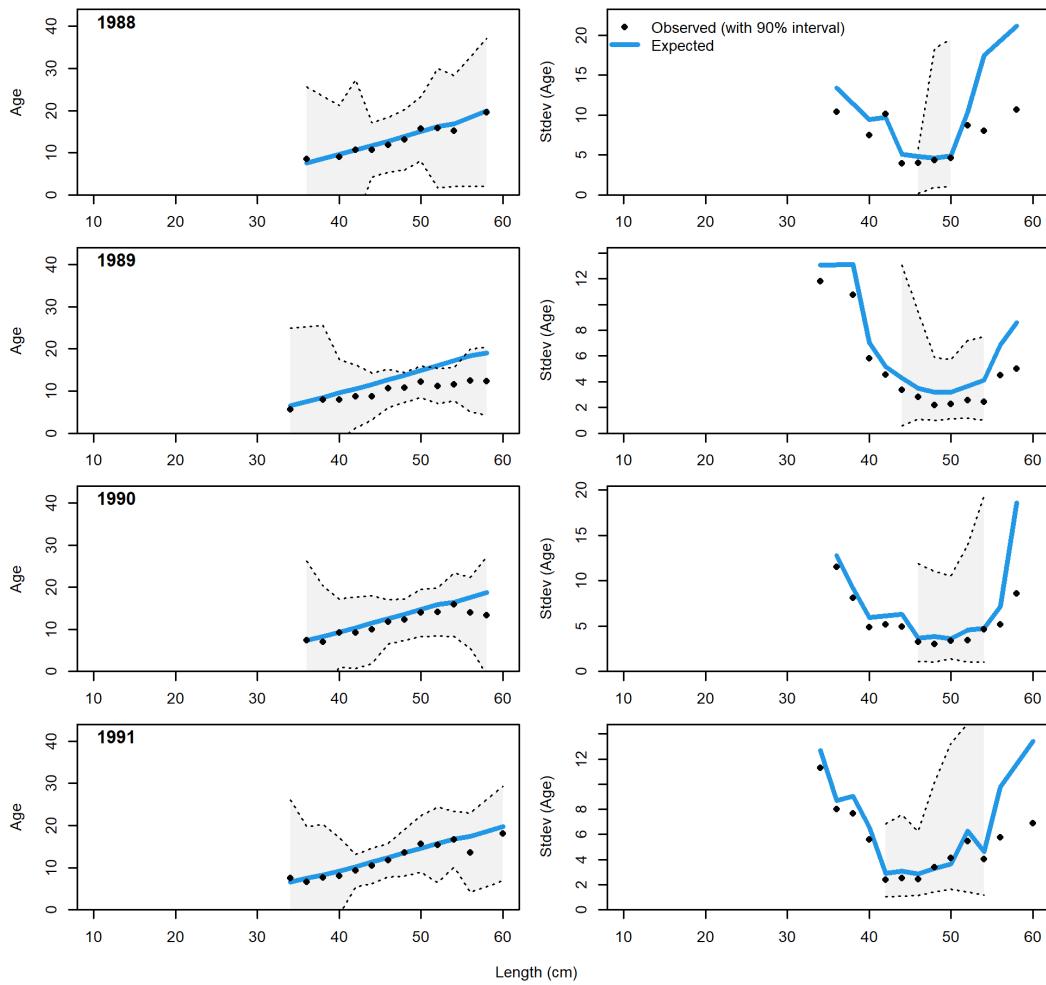
## 12 Appendix C: Fit to Conditional-Age-at-Length Composition Data



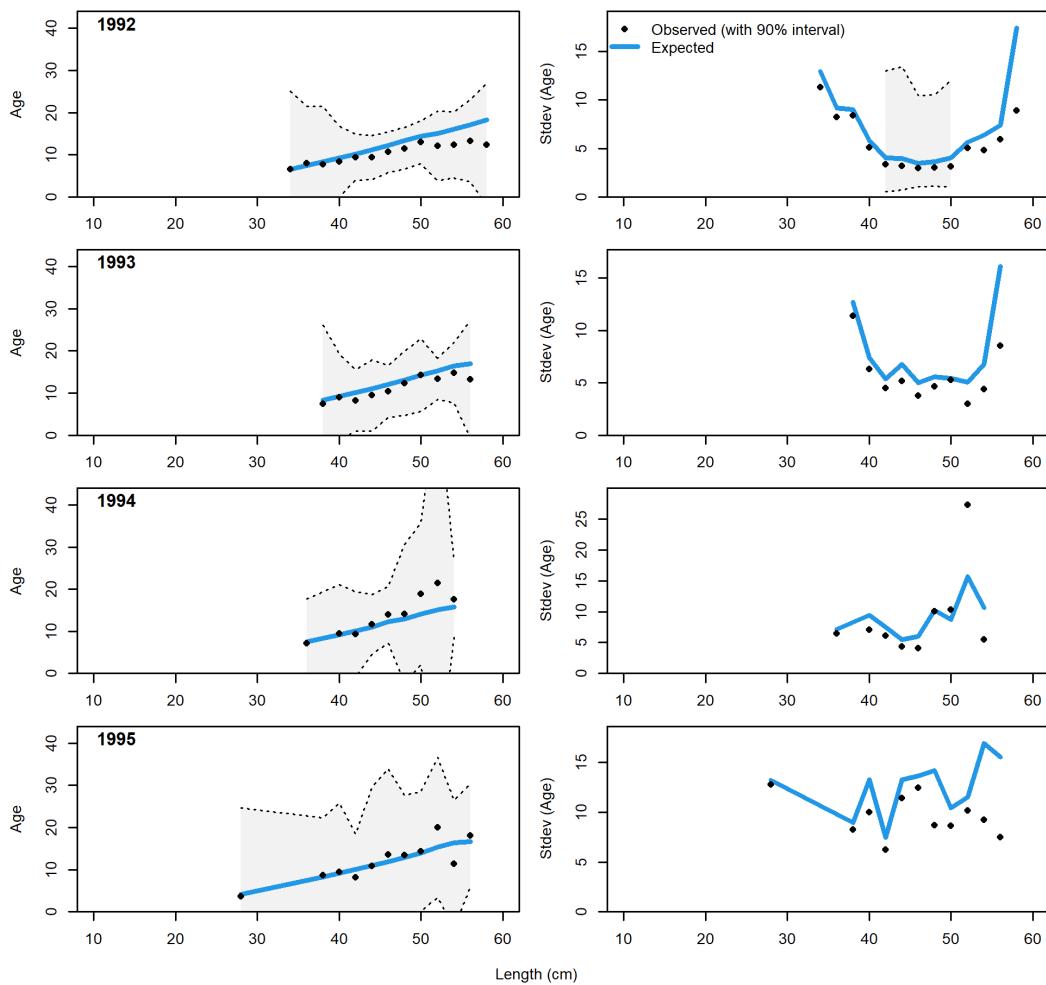
**Figure 87:** Trawl fishery conditional AAL plot (plot 1 of 5) showing mean age (left panel) and standard deviation (right panel. Shaded areas are 90 percent CIs).



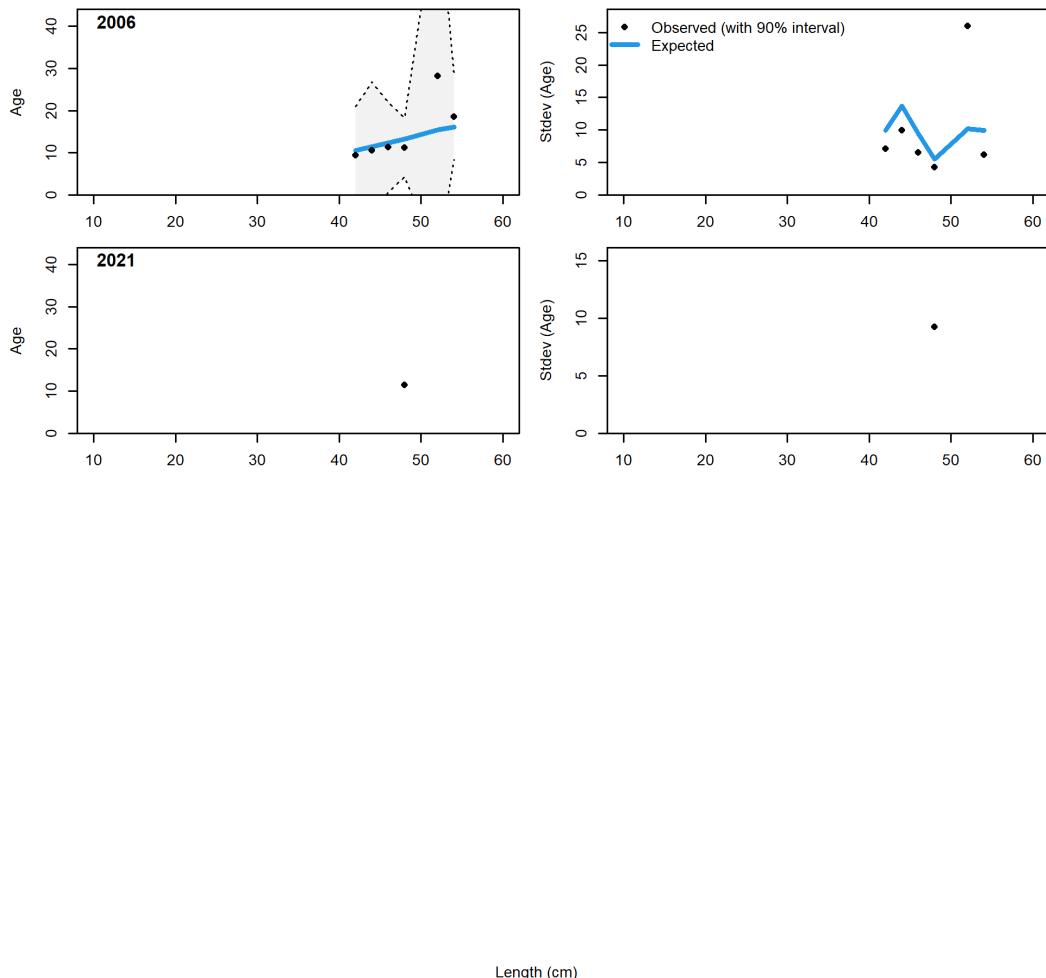
**Figure 88:** Trawl conditional AAL plot (plot 2 of 5).



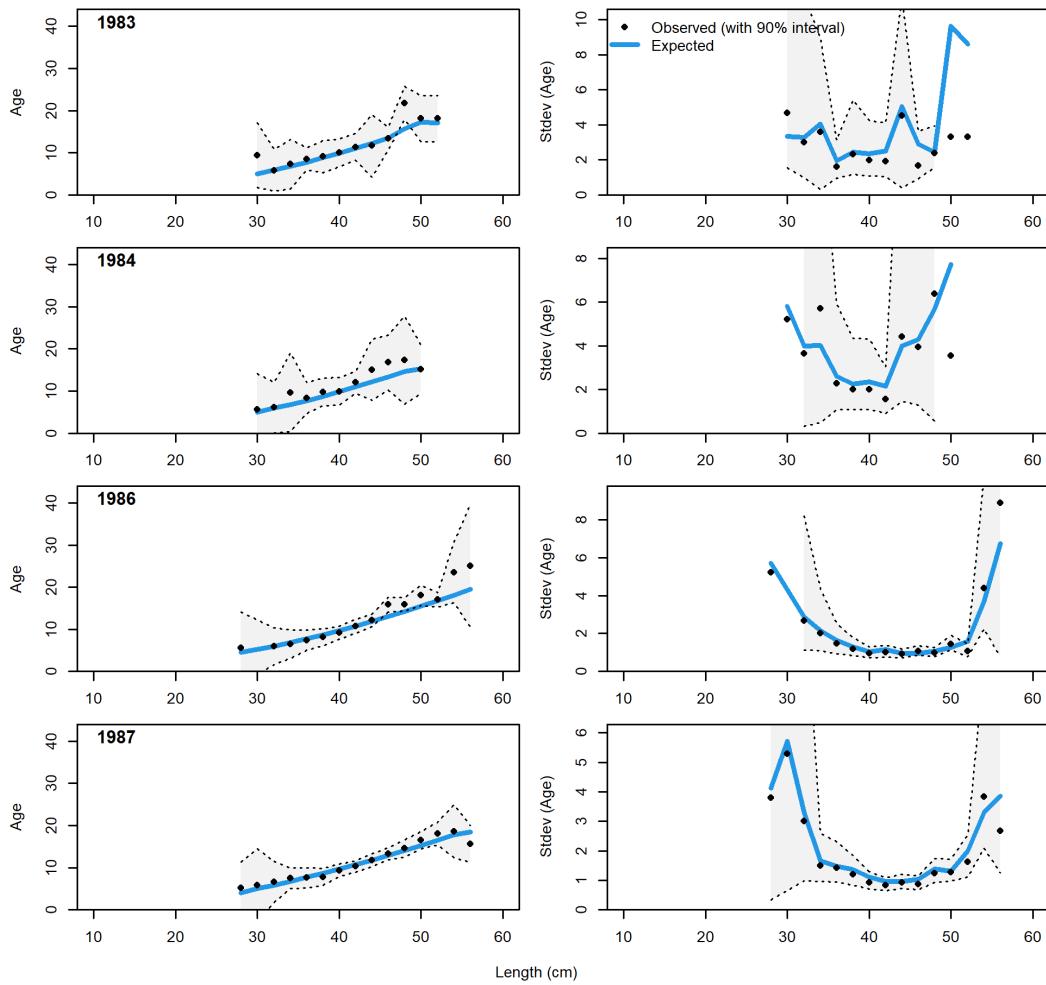
**Figure 89:** Trawl conditional AAL plot (plot 3 of 5).



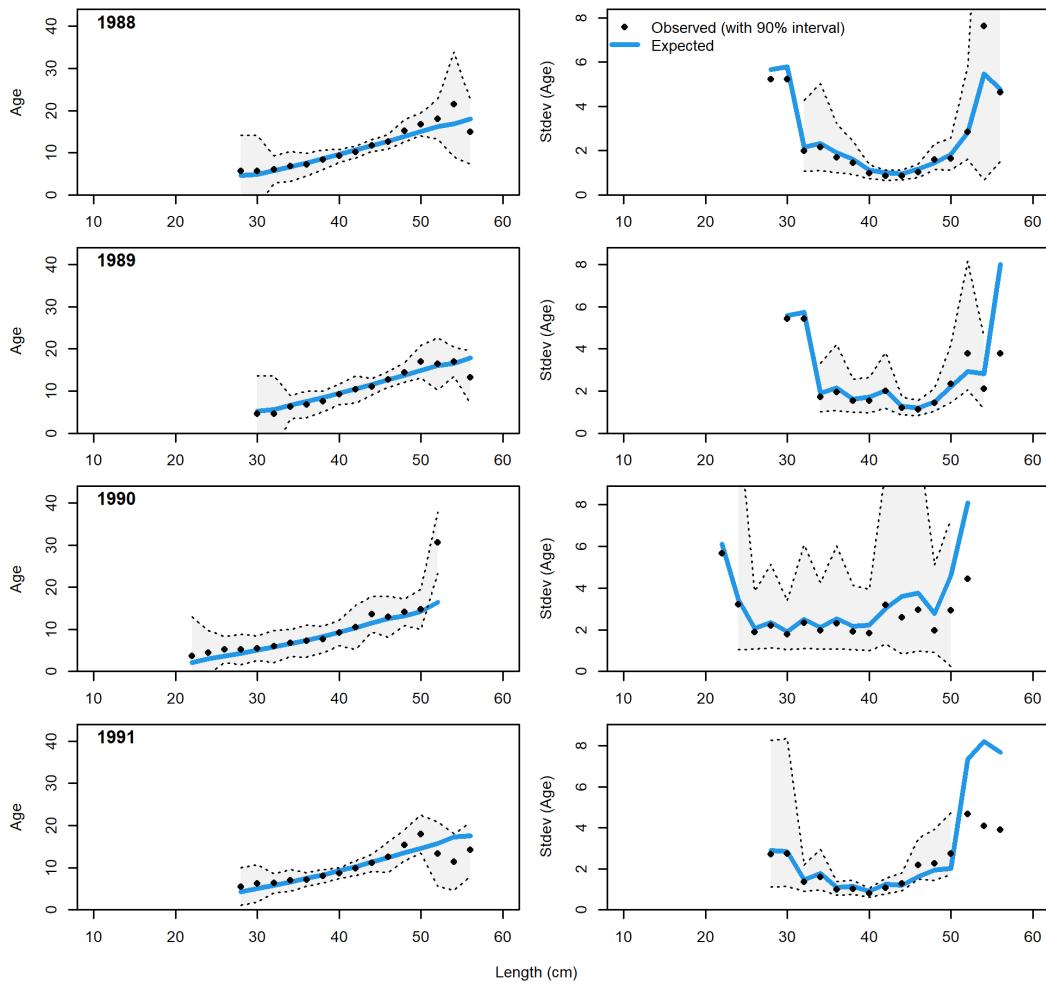
**Figure 90:** Trawl conditional AAL plot (plot 4 of 5).



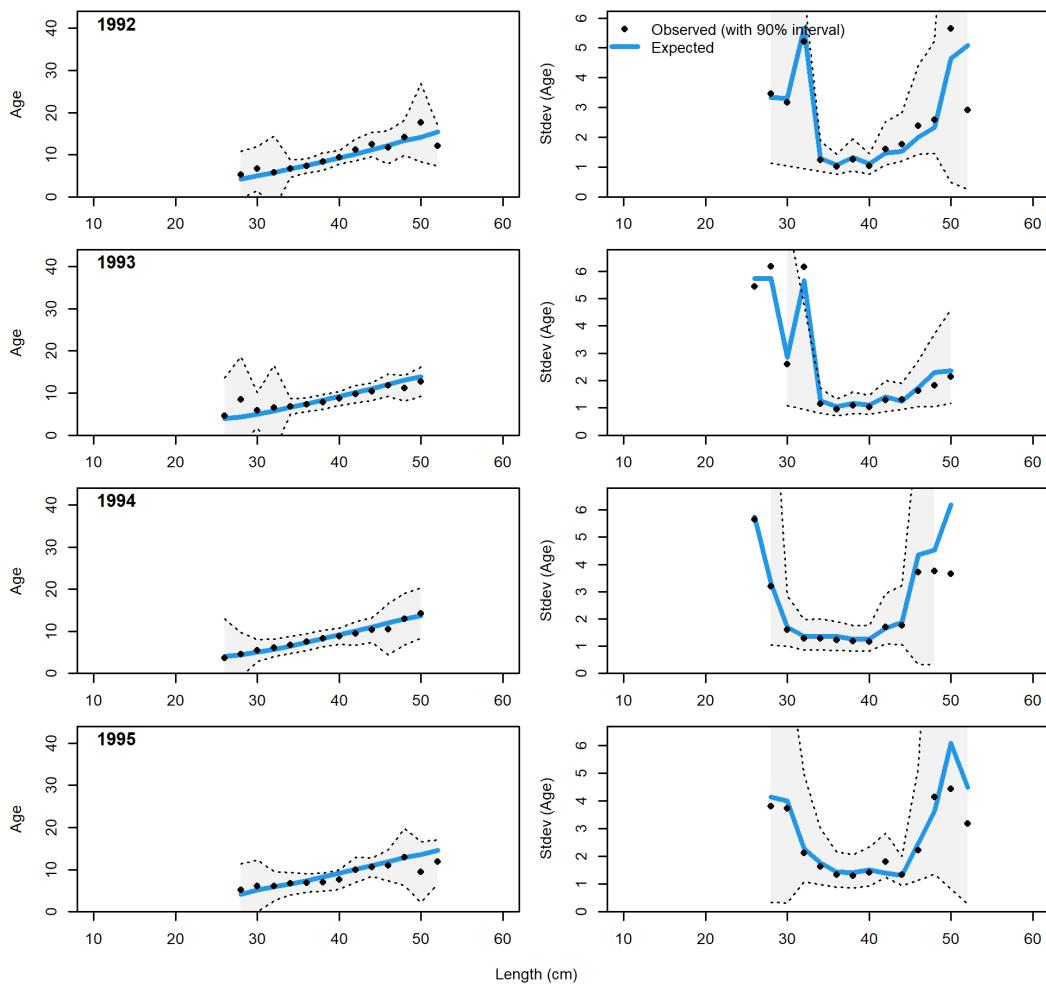
**Figure 91:** Trawl conditional AAL plot (plot 5 of 5).



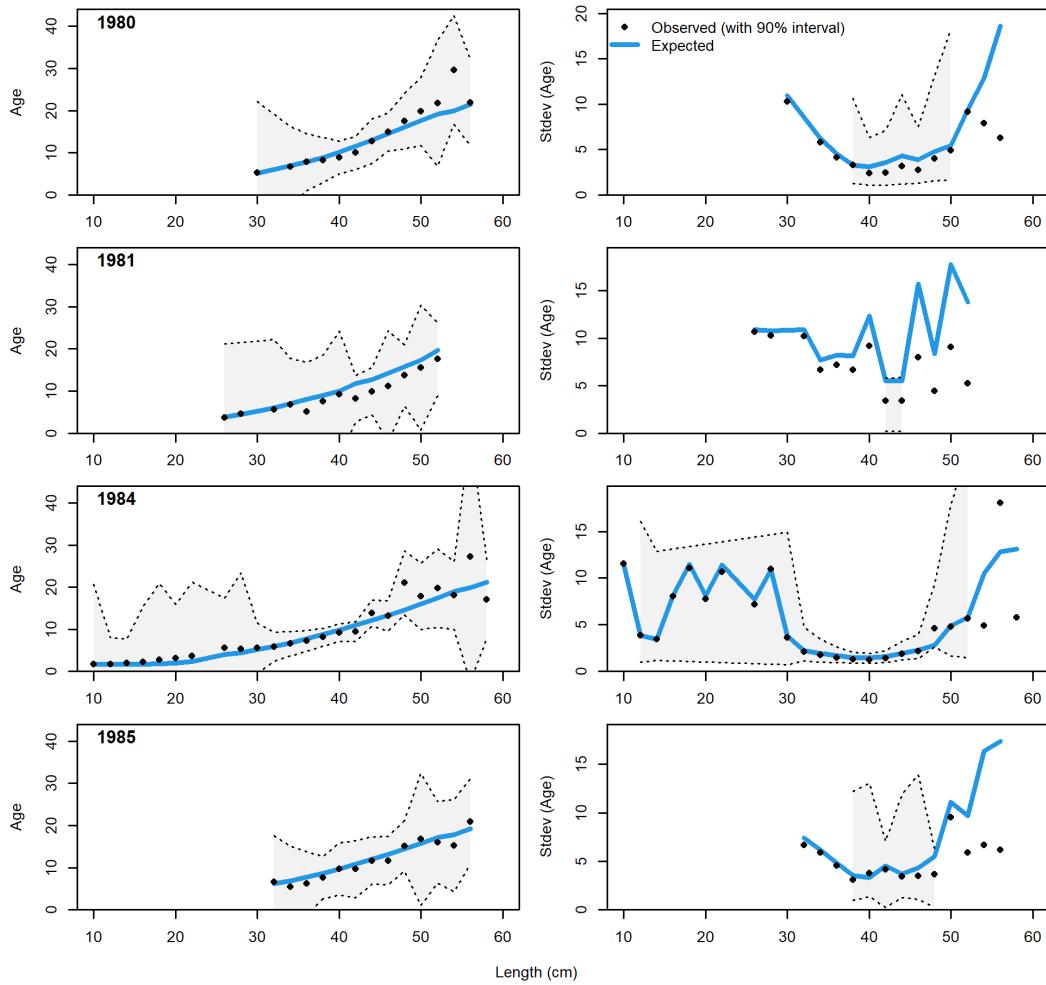
**Figure 92:** Non-trawl (jig) fishery conditional AAL plot (plot 1 of 2) showing mean age (left panel) and standard deviation (right panel. Shaded areas are 90 percent CIs).



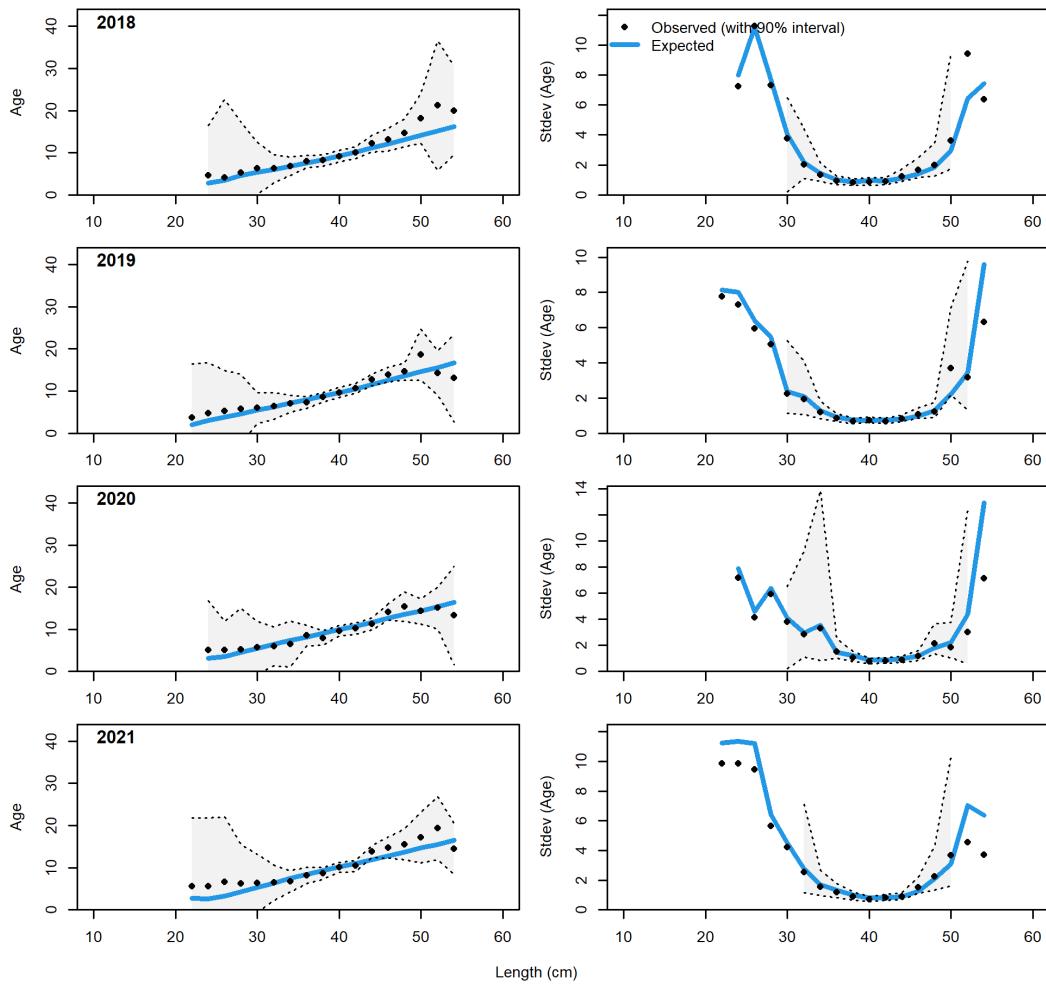
**Figure 93:** Non-trawl (jig) conditional AAL plot (plot 2 of 2).



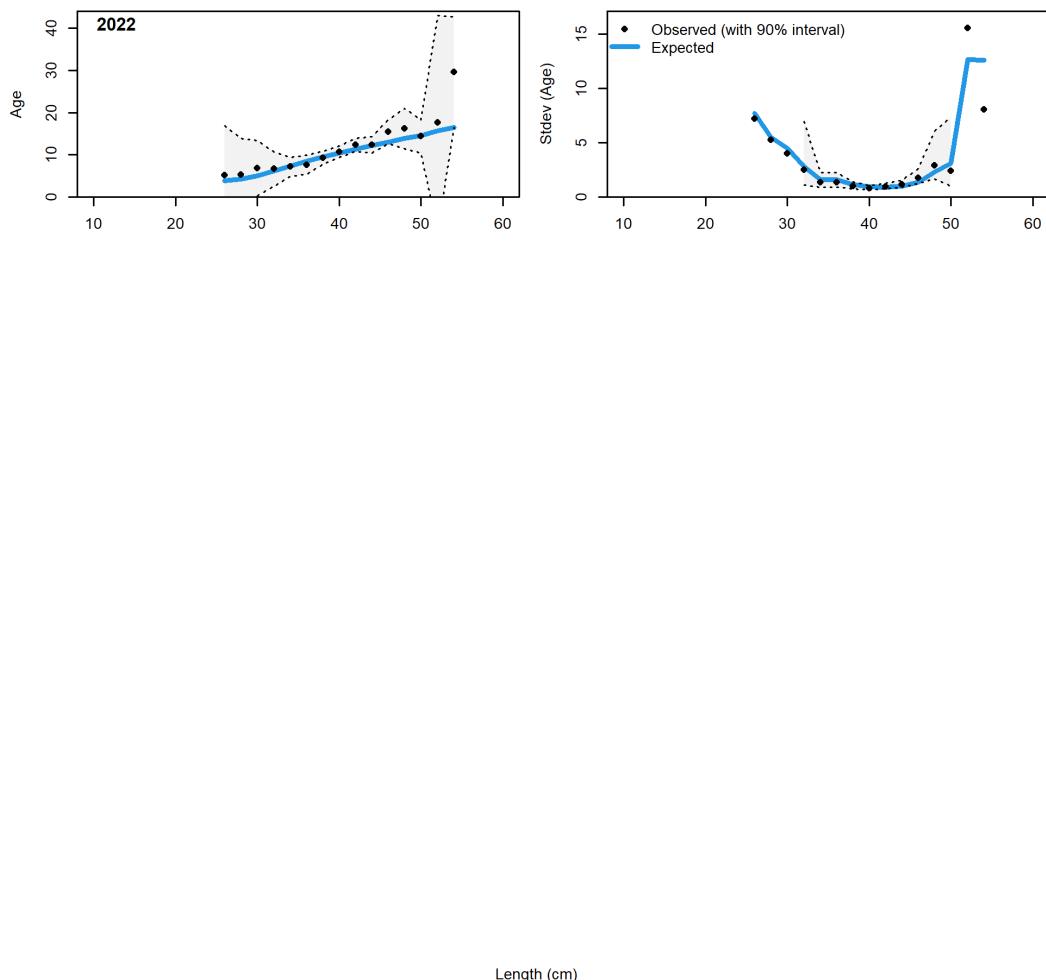
**Figure 94:** Non-trawl (jig) conditional AAL plot (plot 3 of 3).



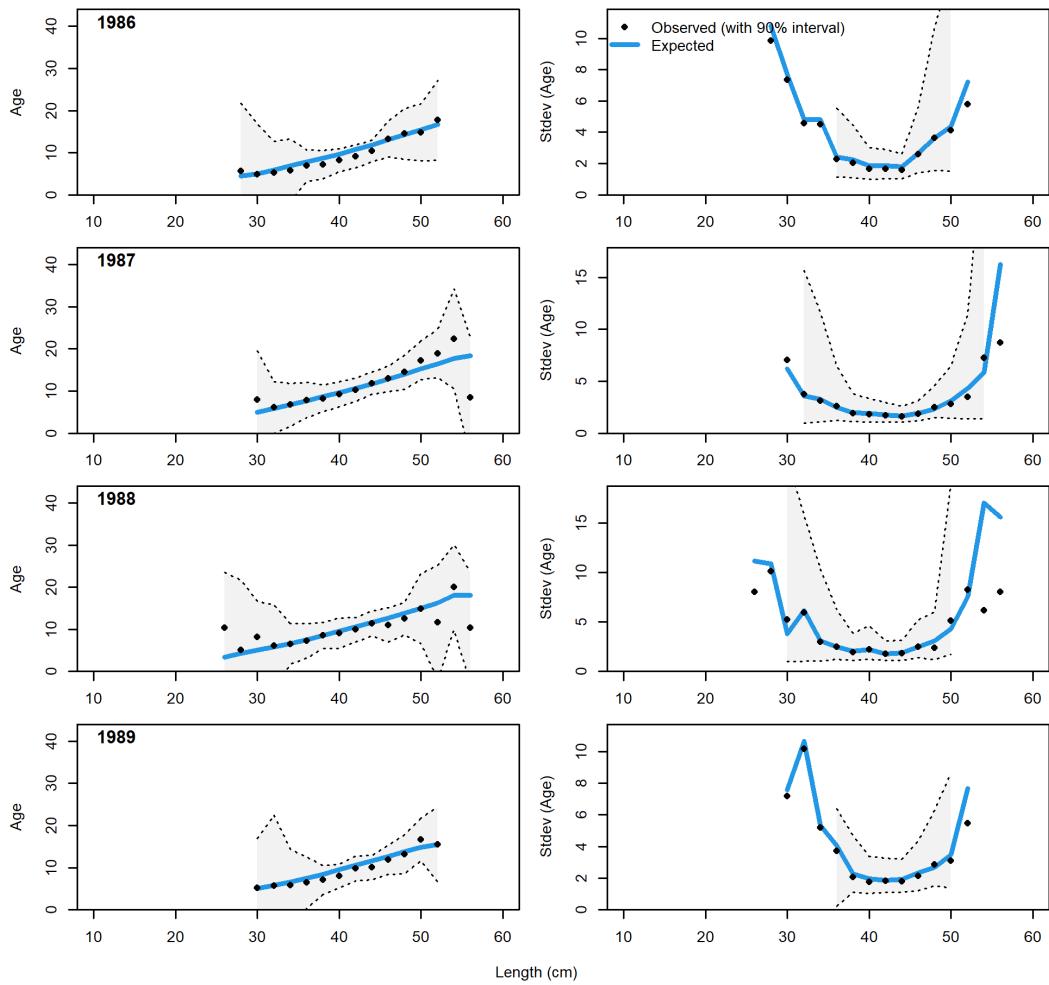
**Figure 95:** Ocean boat conditional AAL plot (plot 1 of 11) showing mean age (left panel) and standard deviation (right panel. Shaded areas are 90 percent CIs).



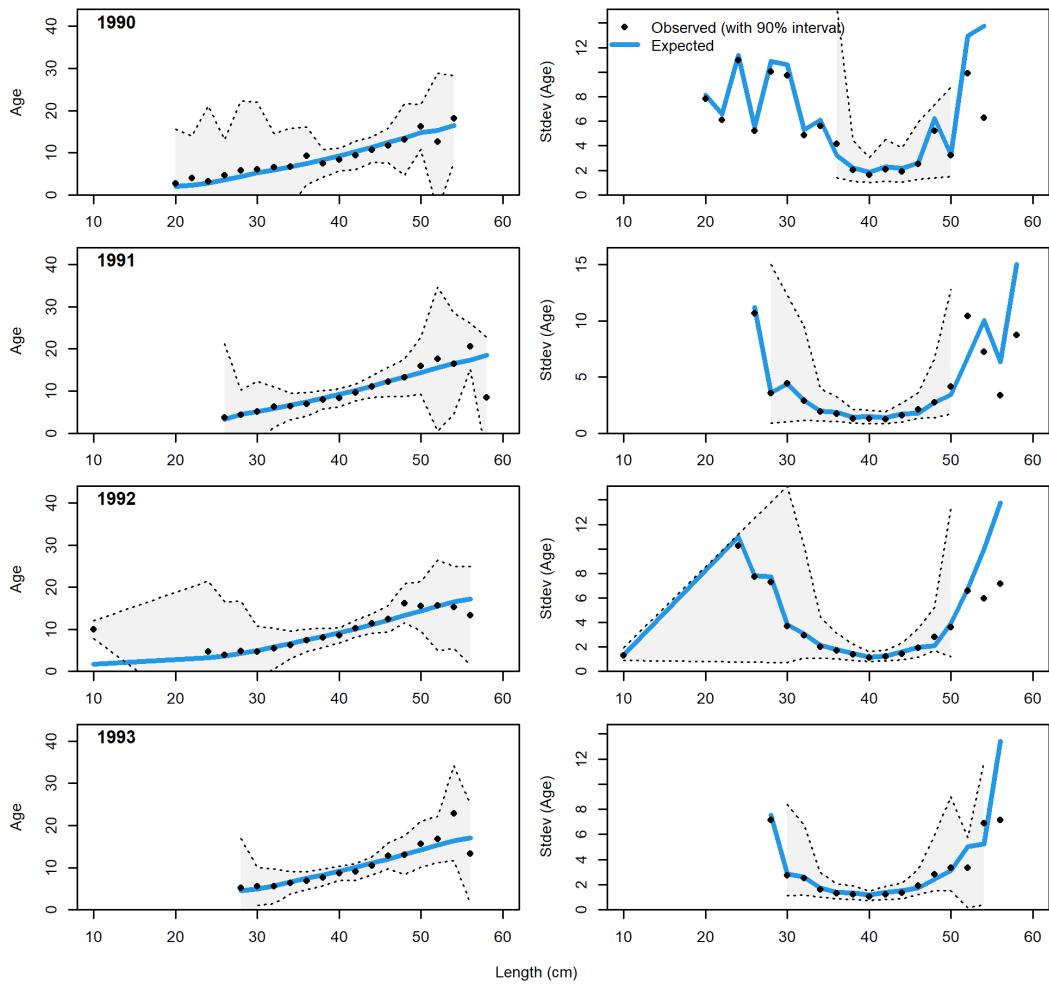
**Figure 96:** Ocean boat conditional AAL plot (plot 2 of 11).



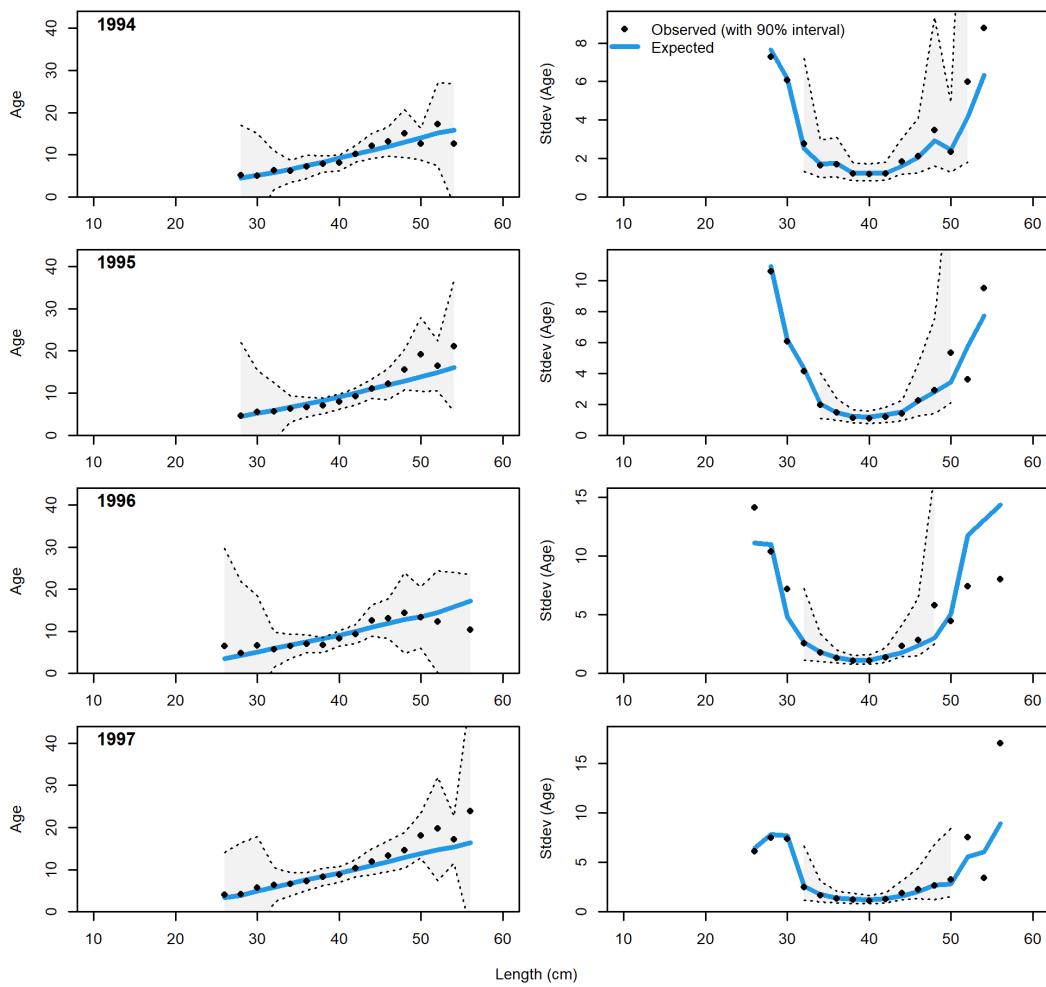
**Figure 97:** Ocean boat conditional AAL plot (plot 3 of 11).



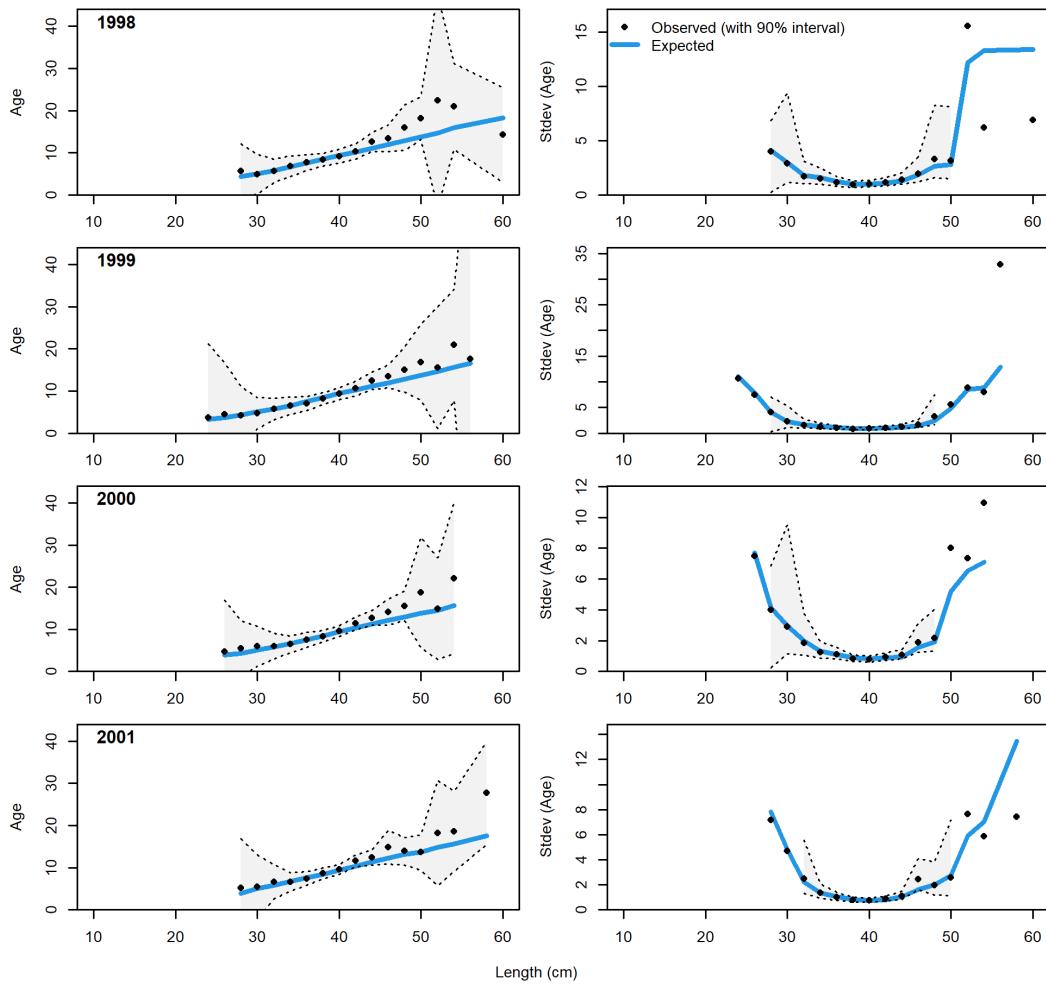
**Figure 98:** Ocean boat conditional AAL plot (plot 3 of 11).



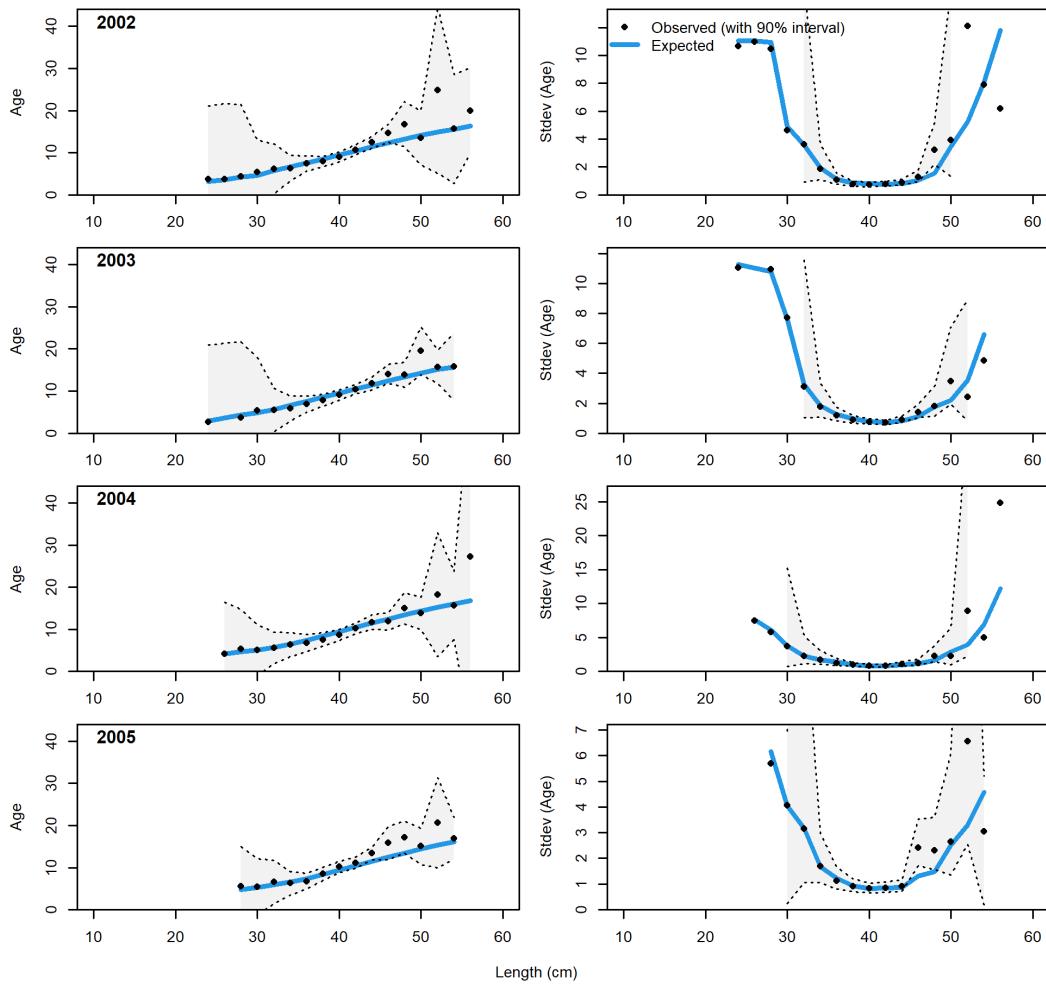
**Figure 99:** Ocean boat conditional AAL plot (plot 4 of 11).



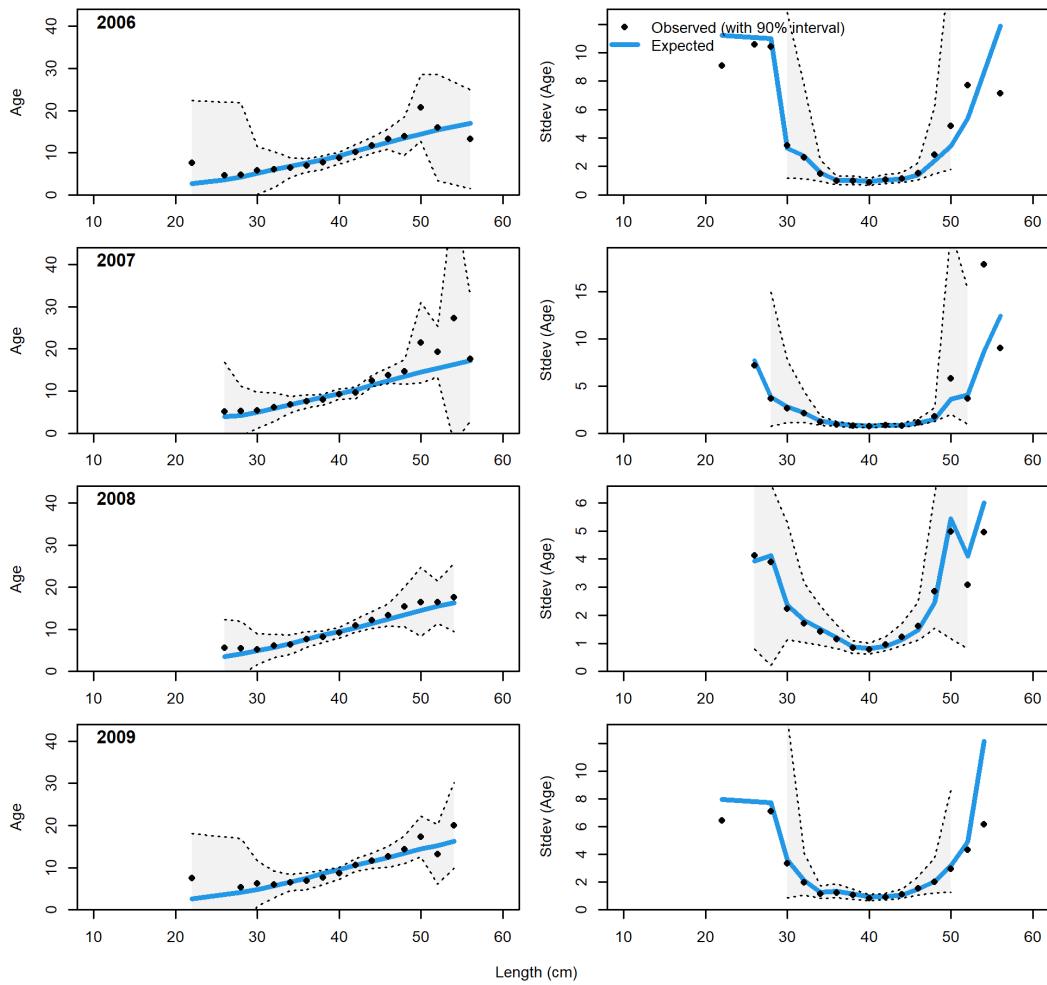
**Figure 100:** Ocean boat conditional AAL plot (plot 5 of 11).



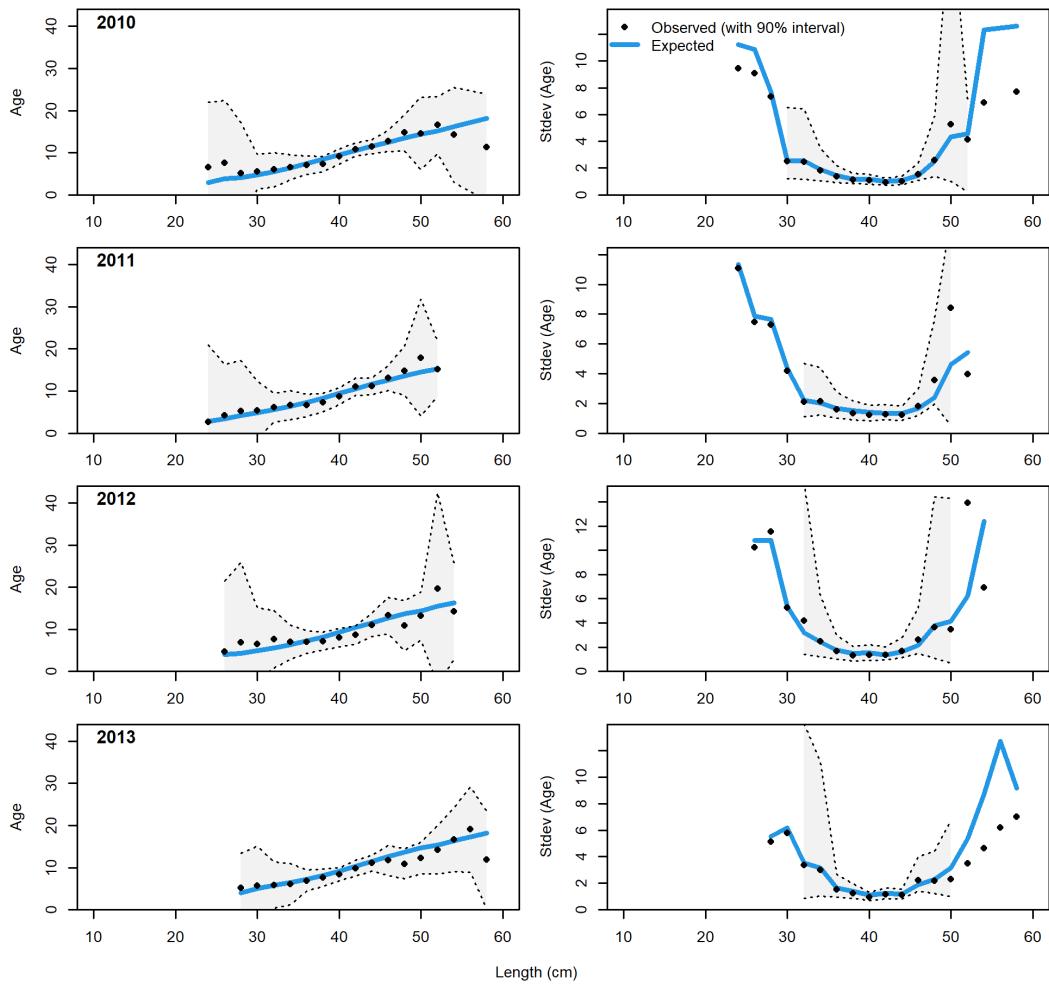
**Figure 101:** Ocean boat conditional AAL plot (plot 6 of 11).



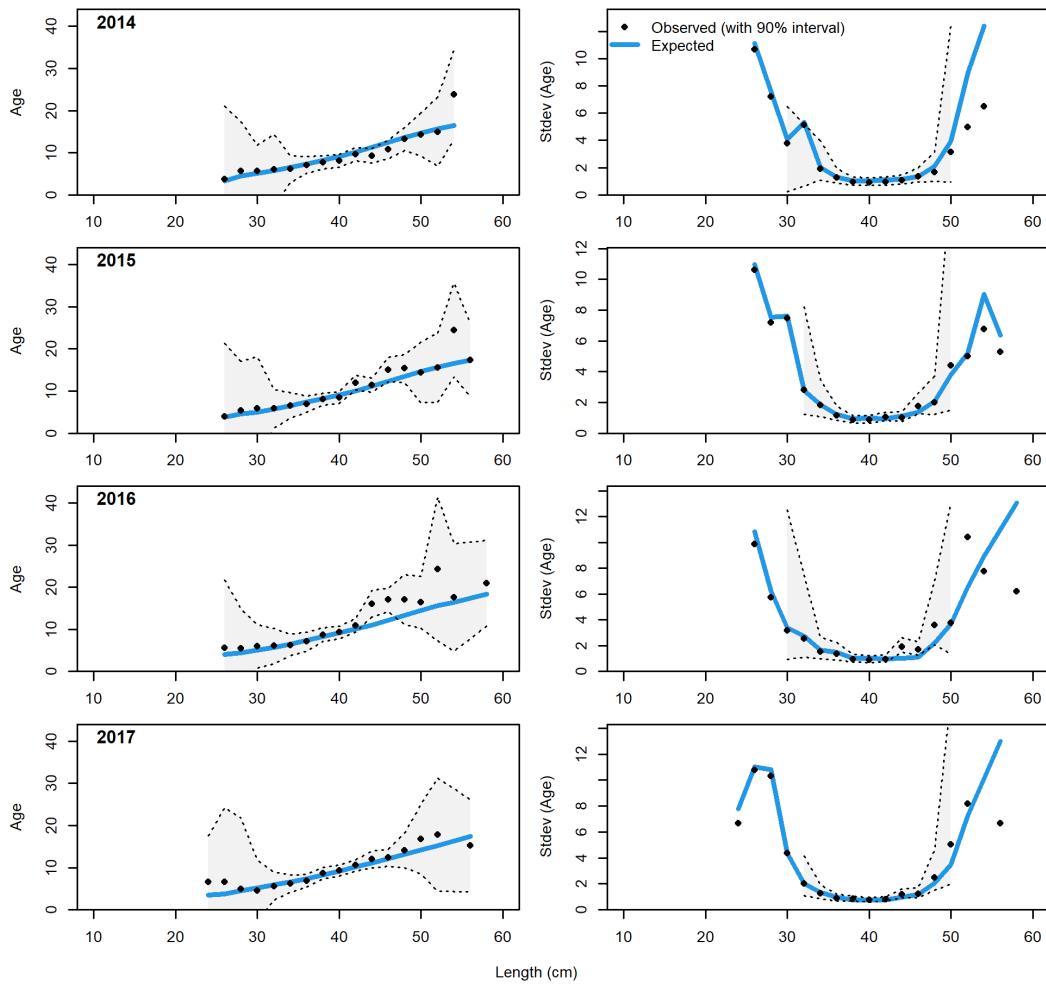
**Figure 102:** Ocean boat conditional AAL plot (plot 7 of 11).



**Figure 103:** Ocean boat conditional AAL plot (plot 8 of 11).

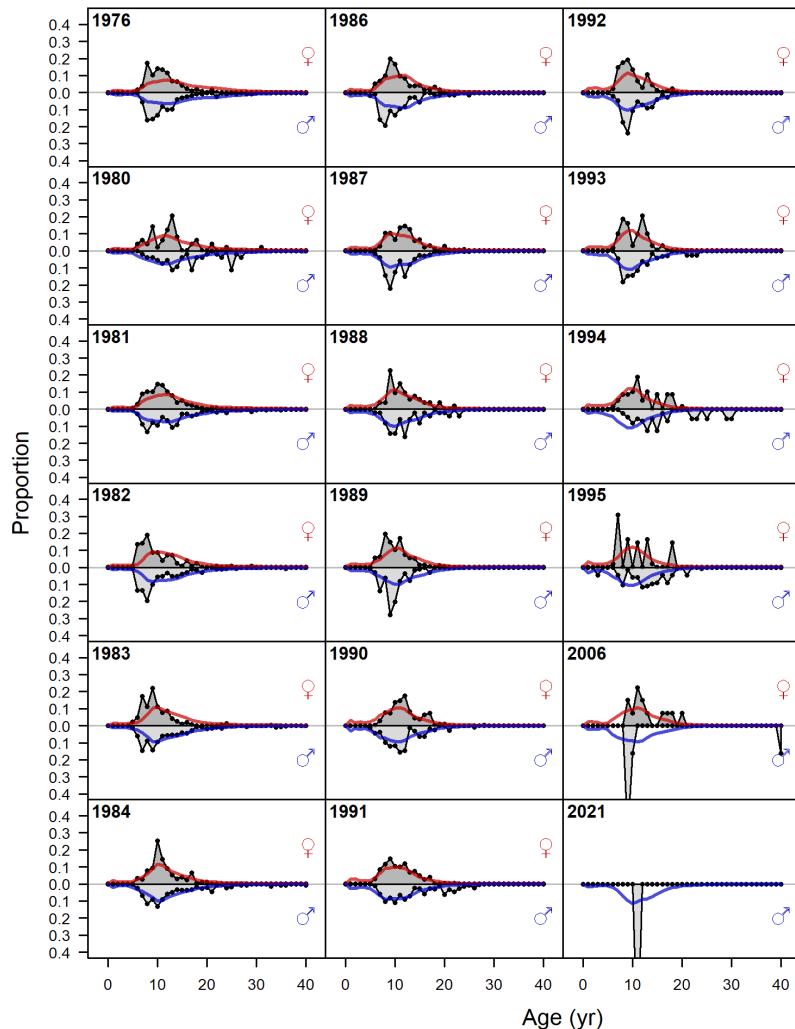


**Figure 104:** Ocean boat conditional AAL plot (plot 9 of 11).

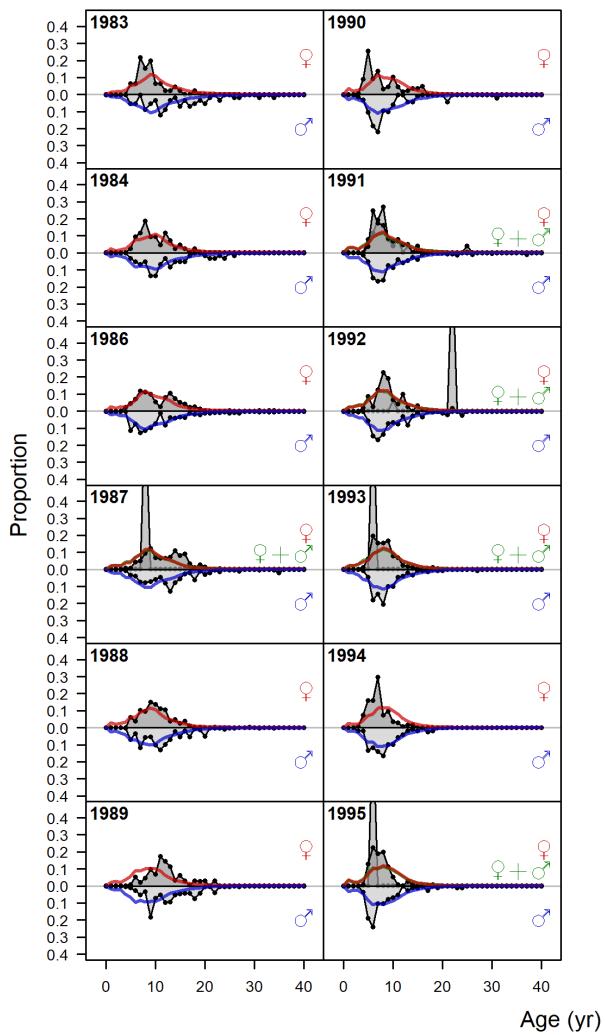


**Figure 105:** Ocean boat conditional AAL plot (plot 10 of 11).

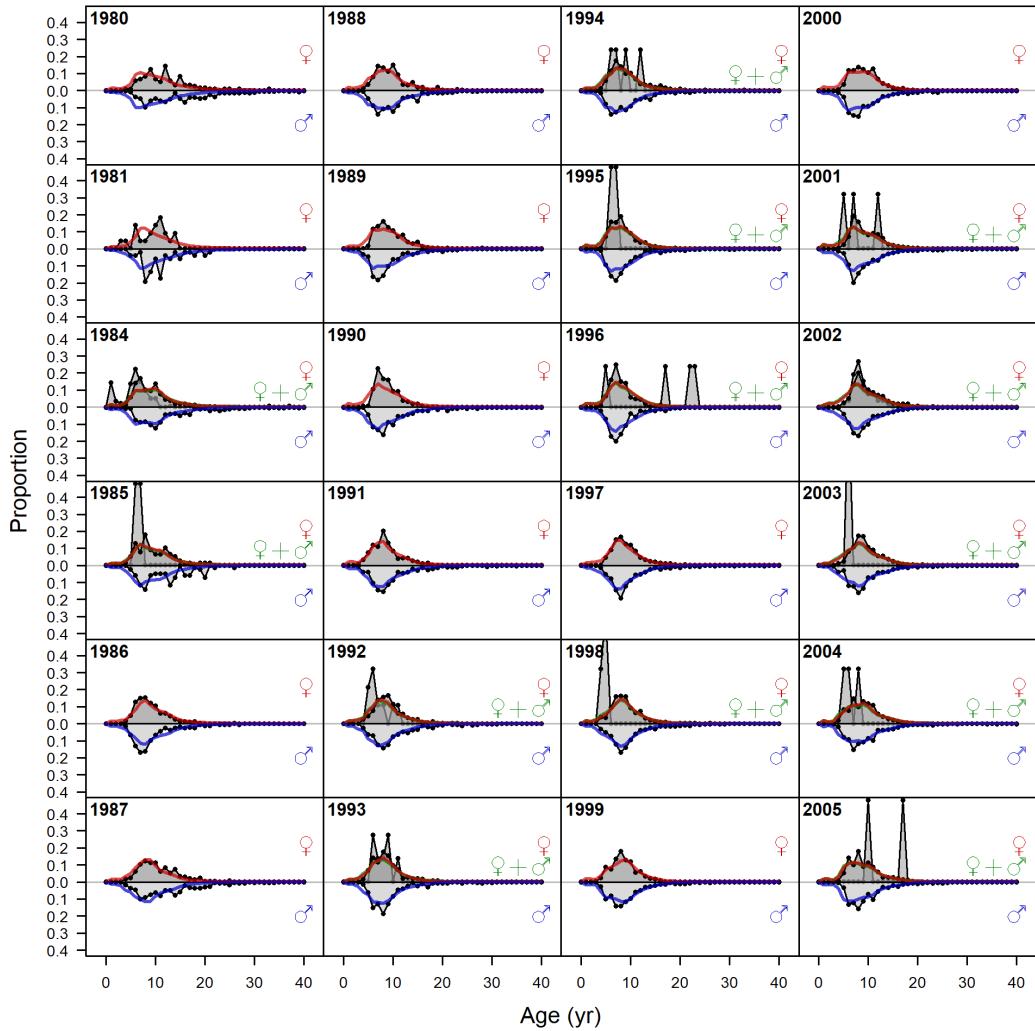
## 13 Appendix D: Passive Fit to Marginal Age Composition Data



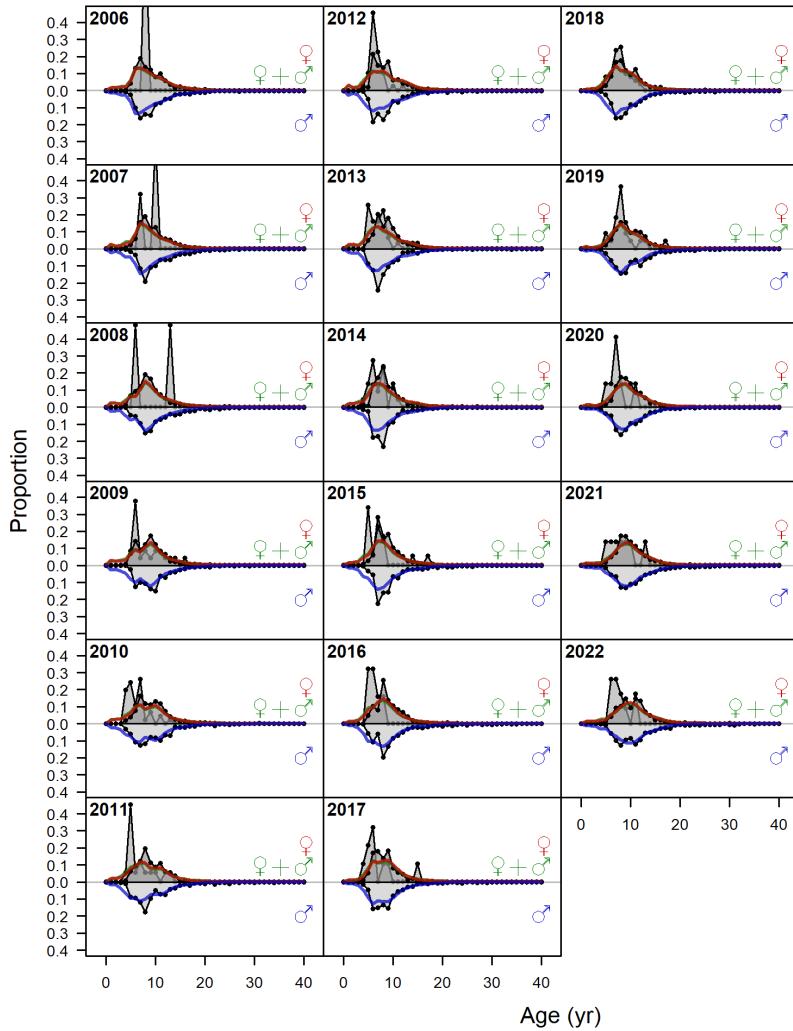
**Figure 106:** Excluded age comps, whole catch, Trawl.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.



**Figure 107:** Excluded age comps, whole catch, NonTRWL.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.



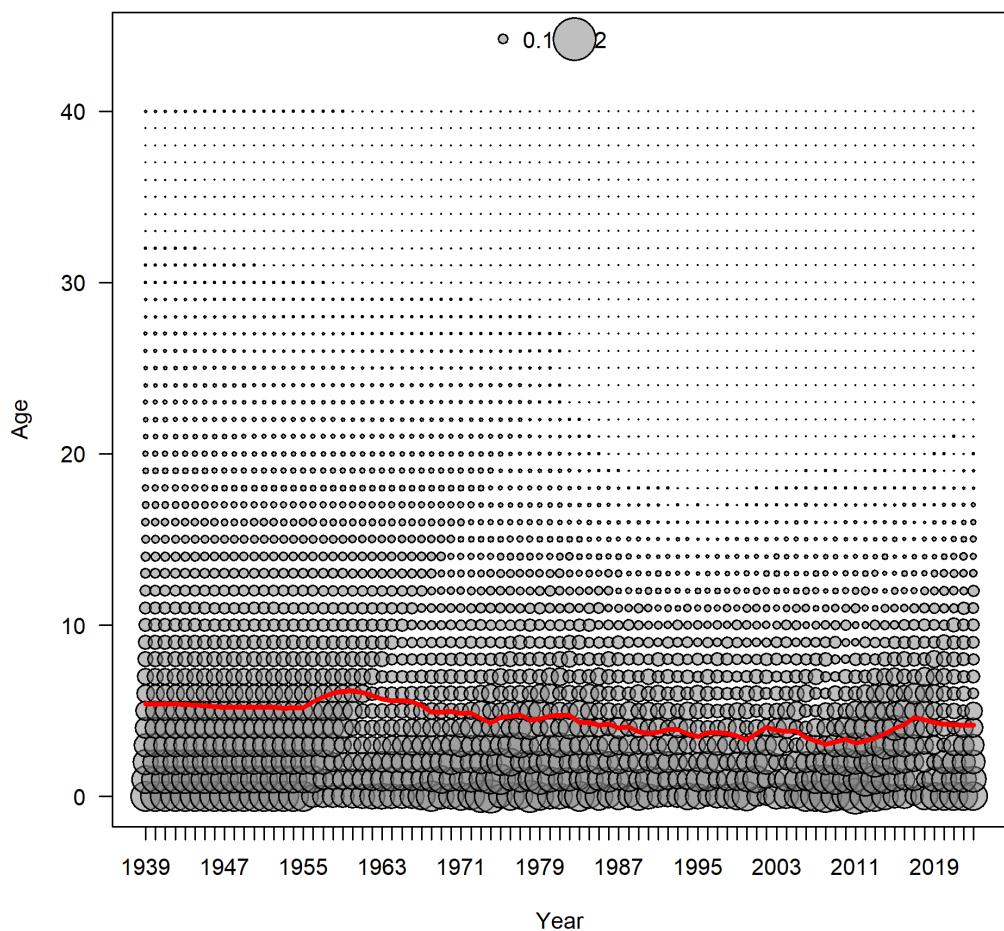
**Figure 108:** Excluded age comps, whole catch, Recreational (plot 1 of 2).‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.



**Figure 109:** Excluded age comps, whole catch, Recreational (plot 1 of 2).‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method. (plot 2 of 2).

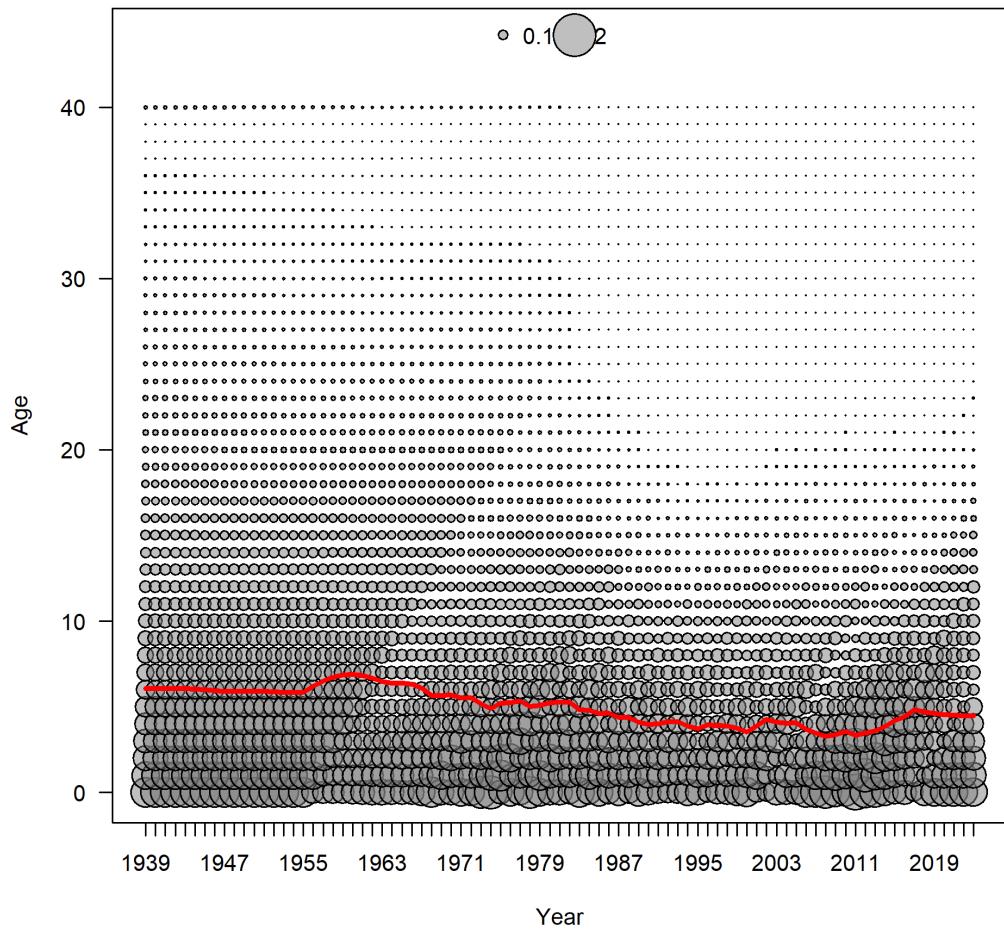
## 14 Appendix E: Numbers at Age Plot

### 14.1 Females



**Figure 110:** Female black rockfish mean age over time.

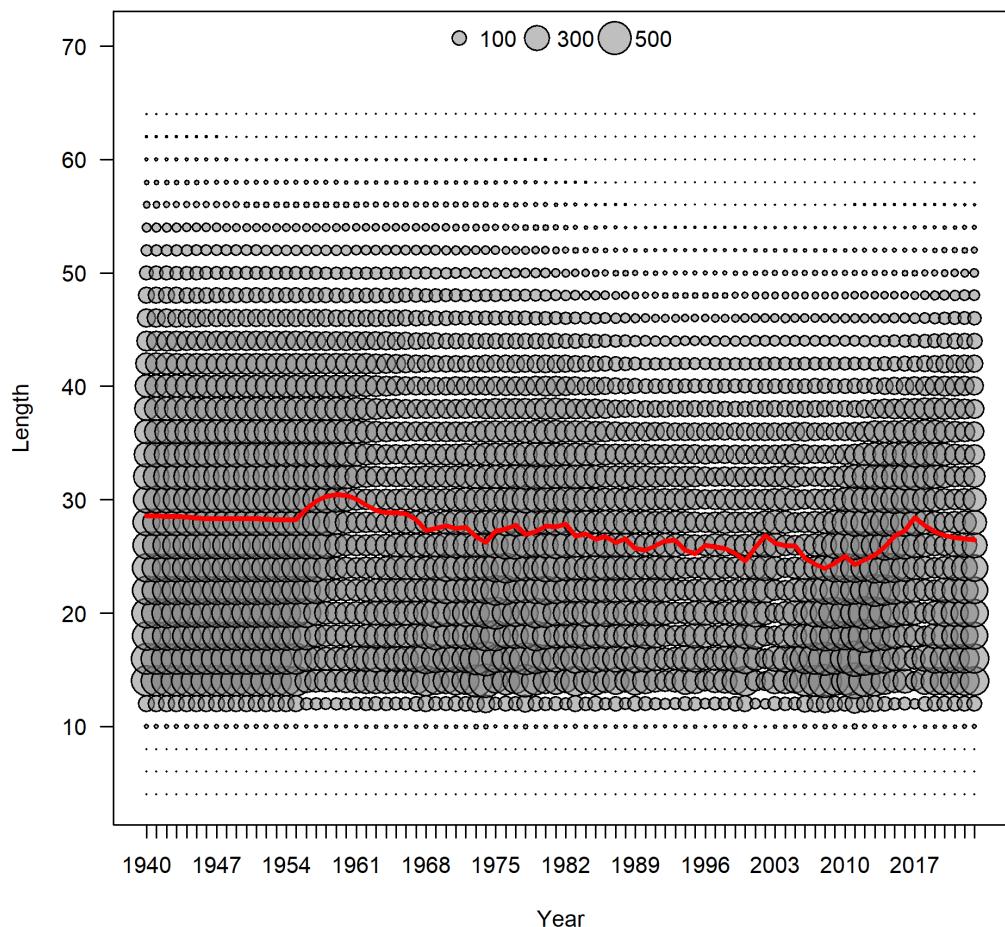
## 14.2 Males



**Figure 111:** Male black rockfish mean age over time.

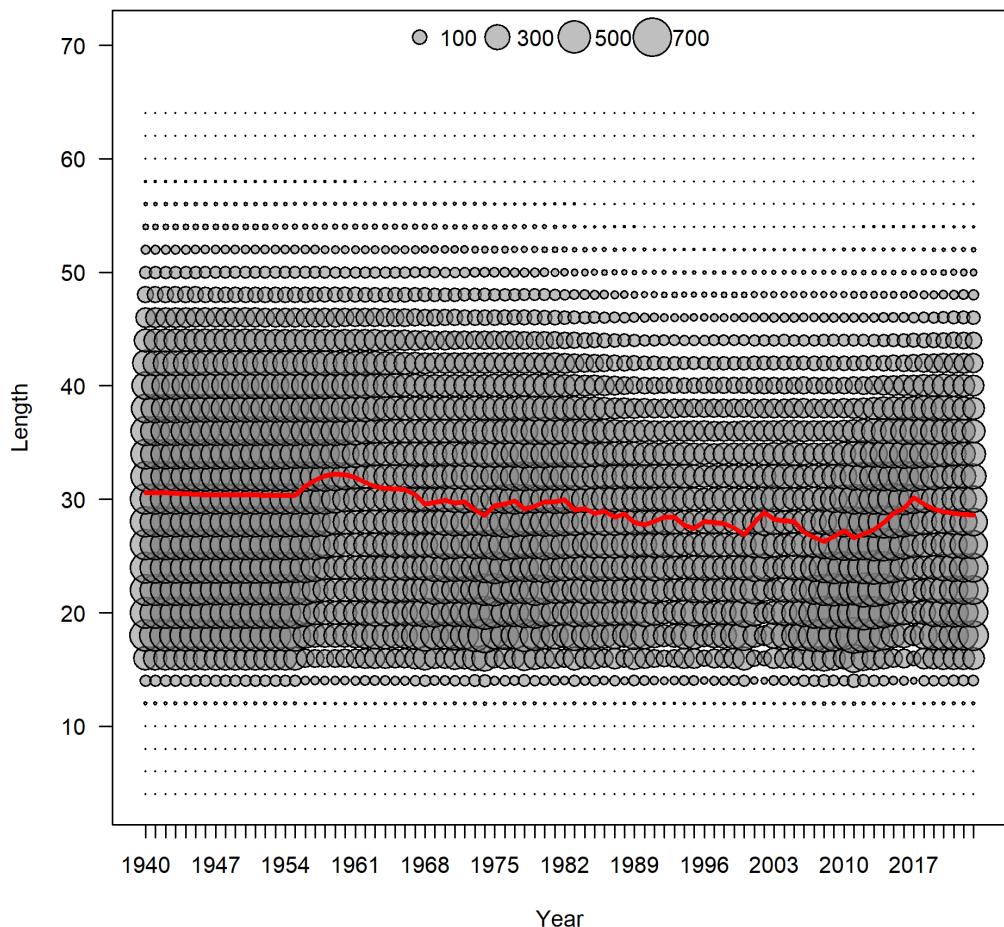
## 15 Appendix F: Numbers at Length Plot

### 15.1 Females



**Figure 112:** Female black rockfish mean length (cm) over time.

## 15.2 Males



**Figure 113:** Male black rockfish mean length over time.