ASSESSMENT OF THE DEMERSAL SHELF ROCKFISH STOCK COMPLEX IN THE SOUTHEAST OUTSIDE SUBDISTRICT OF THE GULF OF ALASKA

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Executive Summary

The Southeast Outside subdistrict (SEO) of the Gulf of Alaska (GOA) demersal shelf rockfish (DSR) complex (yelloweye, quillback, copper, rosethorn, China, canary, and tiger rockfish) is assessed on a biennial cycle, with a full stock assessment conducted every second year. Yelloweye rockfish (*Sebastes ruberrimus*) are managed as a Tier 4 stock, where $F_{OFL} = F_{35\%}$ and $F_{maxABC} = F_{40\%}$. The other species in the complex are managed as Tier 6. Historically, the stock assessment has been based on biomass estimates of yelloweye rockfish derived from Alaska Department of Fish and Game (ADF&G) submersible and ROV surveys and harvest recommendations have been established by applying an assumed mortality rate to the lower 90% confidence interval of the estimate as a hedge against uncertainty.

This assessment includes two new models that are viewed as improvements on past methods and are offered to the plan team for review at the September meeting. The first model is a two-survey random effects model (REMA) fit to the ADF&G biomass estimates and CPUE estimates of yelloweye rockfish in the International Pacific Halibut Commission (IPHC) longline survey. The second model is a Bayesian state-space surplus production model (SS-SPM) fit to catch data, including estimates of unobserved discards in the halibut fishery, and the same biomass and CPUE data used in the REMA model. **The department proposes setting acceptable biological catch (ABC) and overfishing limit (OFL) based on the SS-SPM because it synthesizes both abundance and catch data, allows for a risk analysis, and produces biological reference points.** The SS-SPM estimate of fishing pressure that results in maximum sustained yield, F_{msy}, is used as a proxy for natural mortality, M, and harvest recommendations are set where $F_{OFL} = M$ and $F_{ABC} = 0.75M$. The authors seek guidance from the plan team in ensuring that harvest limits are applied appropriately relative to the Tier designation. Adopting this model would involve substantial reductions in the OFL and ABC but those limits would remain above harvest levels in recent years.

Summary of Changes in Assessment Inputs

The following updates have been made to last year's assessment:

<u>Changes in the input data:</u>

For the full assessment in November 2022, the following changes in input data include:

1) Management region specific catch information and commercial fishery average weights updated for 2022 (Tables 1 and 2).
2) Relative abundance estimates from the ROV survey updated with new survey data for the Central Southeast Outside (CSEO) management unit.

3) Catch-per-unit-effort (CPUE) of yelloweye rockfish in the IPHC longline survey in numbers-per-hook for the four management areas in the SEO are incorporated into the assessment for the first time and are used as a secondary index of abundance in both the REMA and SS-SPM.

Changes in the assessment methodology:

In consideration for the full assessment in November 2022 we present updated methods for the status-quo methodology and two new models for consideration. The models presented use the following naming conventions:

1) **Model 21**: The historical status-quo methodology that has been applied to the SEO DSR assessment (Wood et al. 2021). This model estimates SEO biomass by calculating biomass for each of the four management areas using the most recent density estimate in conjunction with the average weight of landed yelloweye rockfish in the commercial fisheries and the estimated amount of yelloweye rockfish habitat. Biomass for the SEO is estimated by summing the four management areas. Traditionally, ABC and OFLs have been calculated using the lower 90% confidence interval of the SEO.
2) **Model 21.1**: An updated Model 21 that recalculates historical biomass estimates using published density estimates from past SAFE reports and updated weight data.
3) **Model 22.1**: A spatially-stratified, two-survey random effects model (REMA) fit to the ADF&G biomass estimates and CPUE estimates of yelloweye rockfish in the IPHC longline survey in the four management areas that comprise the SEO.
4) **Model 22.2**: Same as model 22.1 but with an extra variance term estimated for the biomass estimates.
5) **Model 22.3**: A spatially stratified SS-SPM fit to ADF&G biomass estimates, CPUE estimates in the IPHC longline survey, catch data and estimated discards in the halibut fishery. The SS-SPM produces estimates of stock status relative to B_{msy} (the biomass that produces maximum sustained yield, set at B_{40} in the model) and estimates of F_{msy} (the fishing pressure that leads to maximum sustained yield). Estimates of F_{msy} serve as a proxy for natural mortality, M. The SS-SPM analysis includes a risk analysis whereby the population is projected forward under various harvest scenarios to determine the probability that the population will be greater than B_{40} in 50 years.

The status-quo method has drawn criticism from the Team and the SSC for a lack of statistical rigor and the relatively large reduction in the ABC that is proposed relative to the point estimate of biomass. The new models presented here represent step-wise improvements on the status-quo methods. The REMA models provide a more statistically sound method of combining the management area-level biomass estimates, makes use of a secondary abundance index and assesses process error in such a way that annual fluctuations in abundance are more biologically plausible. The SS-SPM model further develops the assessment such that it incorporates catch data in addition to the abundance indices and provides estimates of productivity derived from the trade-off between the magnitude of removals and the change in biomass. Because the SS-SPM is distinct from most federal assessments, an in-depth presentation is made of the model development. The preferred model is presented as Model 22.3 and the authors solicit feedback from the plan team on alternative models to explore as part of the full assessment in November 2022.

Summary of Results

The alternative models result in the following estimates of biomass, OFL, and maximum permissible ABC (maxABC) for DSR in the SEO. DSR are not being subjected to overfishing, is not overfished, but is near an overfished condition.

	Last Year:		**Status-quo (Model 21.1)**		**REMA (Model 22.2)**		**SS-SPM (Model 22.3)**
	As estimated or *recommended this* year for:		mean	lower 90% CI	mean	lower 90% CI	SS-SPM
Quantity	2021	2022	2023	2023	2023	2023	2023
M (natural mortality)	0.02	0.02	0.02	0.02	0.02	0.02	0.013
Tier	4	4	4	4	4	4	4
Yelloweye Biomass (t)	12,388		18,471	12,135	17,846	14,520	18,026
$F_{OFL} = F_{35\%}$	0.032	0.032	0.032	0.032	0.032	0.032	F_{msy} 0.013
$maxF_{ABC}$	0.026	0.026	0.026	0.026	0.026	0.026	0.75* F_{msy} 0.00975
F_{ABC}	0.020	0.020	0.020	0.020	0.020	0.020	0.9* $maxF_{msy}$ 0.00876
DSR OFL (t)	**422**	**422**	591	388	571	465	234
DSR max ABC (t)	342	342	480	316	464	378	176
Recommended ABC (t)	**268**	**268**	369	243	357	290	158
Status	As determined this year for:						
	2020	2021					
Overfishing	No	n/a					

Density and status-quo biomass estimates have demonstrated a long-term decline in the SEO yelloweye rockfish stock over time with a slight increase in recent years. There is high variability in pre-ROV density estimates (prior to 2012) and estimates of biomass using status-quo methodology were not reproducible for early years. The upward trend in recent years is associated with no directed commercial fishing for DSR and increasingly strict sport fishing regulations.

The REMA models demonstrated an increase in the stability of biomass estimates over time and more consistent apportionment by area when compared to status-quo methods. The best-fitting model was Model 22.2, which shares a single process error parameter across all management areas and estimates additional observation error for the biomass survey. The Model 22.2 biomass trajectory was smoother than status-quo methods and thus less likely to respond to noise in the survey data.

The SS-SPM produced similar biomass estimates to those derived using status-quo methods in recent years and extremely similar biomass estimates and trends to those produced in the REMA models (Figure 1). However, estimates of F_{msy} (used as a proxy for natural mortality, *M*) were significantly lower than the 0.02 applied in status-quo methodology. The SS-SPMs performed well, with satisfactory posterior predictive checks, a lack of systematic discrepancies between the data and model output and required minimal assumptions regarding priors. Yelloweye rockfish CPUE in the IPHC longline survey demonstrated similar trends to that of the ADF&G submersible surveys and demonstrated less deviation from estimated biomass than the submersible surveys prior to 2012. The model displayed a high degree of uncertainty around biological reference points, however, the analysis indicated that the SEO population is currently near B_{40} (equal to B_{msy} in the SS-SPM) and that three of the four management areas are likely above B_{40}.

The risk analysis reflected the uncertainty evident in the model but demonstrated that 50 years of fishing at max F_{ABC} set at 0.75*F_{msy} and based on projected 2023 biomass will likely reduce abundance in the SEO such that the population is 50% likely to remain above B_{40} in 2073. Those management areas currently above B_{40} will likely decrease towards B_{40} while the management area currently below B_{40} will likely recover to some degree. The risk analysis indicated that fishing at the status-quo recommended ABC is more likely (64%) to reduce the population below B_{40} in the future. The fishing pressure recommended by the SS-SPM are significantly lower than the status-quo method but are above the fishing level that has occurred since 2020 when the directed DSR commercial fishery was closed, and significant restrictions were employed in the sport fishery.

The department is presenting the results of this study to the plan team at the September meeting to solicit a review and feedback, garner advice on model applicability and to seek guidance on setting ABC limits.

There are no changes to the management of the Tier 6 DSR species and recommended harvests remain the same (Wood et al. 2021).

Quantity (Tier 6 for non-yelloweye DSR only)	As estimated or *specified last* year and *recommended this* year for:	
	2022	**2023**
OFL (t)	26	26
ABC (t)	20	20

Area Apportionment

The ABC and OFL are set for DSR in the SEO area of the Eastern Gulf of Alaska (EGOA). The State of Alaska manages DSR in the EGOA regulatory area with Council oversight and any further apportionment within the SEO is at the discretion of the State. Management area management targets will be specific to the output of the SS-SPM and the SEO goal is constructed as the sum of those quantities. Commercial catch data (t) for DSR in SEO have been updated as of September 7, 2022, using ADF&G fish ticket data (Table 2), although model results (and biomass projections) are up to date only through July 21, 2022.

Summaries for Plan Team

Species	Year	Biomass[1]	OFL	ABC	TAC[2]	Commercial catch[3]	Recreational mortality[4]	Total catch[5]
DSR	2019	10,592	411	261	254	145	59	221
	2020	10,620	375	238	231	111	4	128
	2021	10,648	405	257	250	108	6	121
	2022	12,388	422	268	261	107	6	127
	2023[6]	18,026[6]	216	158	151	-	-	-

[1] Biomass estimates were adjusted for 2019 to 2021 due to a coding error in the past analyses. The historic OFL, ABC, and TAC remain unchanged.

[2] TAC is for the commercial and recreational fisheries and is calculated after the subsistence estimated harvest is deducted from the ABC.

[3] Commercial catch data are updated through September 7, 2022.

[4] Sport mortality for SEO encompasses all components of mortality including harvest (retained catch) and release mortality; estimates of mortality since 2020 are dominated by release mortality , as retention of DSR in 2020 and 2021 was prohibited. The estimates of sport mortality for all years has been updated in 2021 using a new methodology (Howard et al. 2020) described in the recreational fishery removals section of this document[5] Total catch is from the commercial (incidental, directed, and estimated unreported catch from commercial halibut fishery), recreational,

subsistence, and research fisheries.

[6]2023 estimates are derived from the new SS-SPM in contrast to previous years calculated using the status-quo methods.

Introduction

Biology and Distribution

Rockfishes of the genus *Sebastes* are found in temperate waters of the continental shelf off North America and the demersal shelf rockfish (DSR) complex is comprised of the seven species of nearshore, bottom-dwelling rockfishes (yelloweye, quillback, copper, rosethorn, canary, China, and tiger rockfish; Table 3). All rockfish in the DSR complex are extremely long-lived, exhibit slow growth, and mature late. Yelloweye rockfish are on the extreme end of this spectrum with a maximum published age of 118 years (O'Connell and Funk 1987). Estimates of natural mortality are very low and all DSR are very susceptible to over-fishing and slow to recover once driven below the level of sustainable yield (Leaman and Beamish 1984, Francis 1985). Genetic data suggest that due to the long pelagic larval duration for *Sebastes* spp. (several months to one year) there is not significant genetic stock structure for the DSR complex in SEO (Siegle et a. 2013). However, the limited movements of yelloweye rockfish can lead to serial depletion of localized areas if overharvest occurs. Yelloweye rockfish from British Columbia reach age-at-50% maturity at 22 and 19 years for males and females respectively (Love et al. 2002) while age-at-maturity in Prince William Sound and Northern Gulf of Alaska (NGOA) occurs at 15 and 16 years for males and females, respectively (Arthur 2020). In Southeast Alaska, yelloweye rockfish begin recruiting to the commercial fishery at age-8.

SEO DSR Assessment history and a new approach

A long-term goal of both ADF&G and the SSC has been to develop an age-structured assessment of yelloweye rockfish in the SEO to replace the current management strategy (referred to as the status-quo method) that has been in use for more than a decade (Brylinskey et al. 2009; Green et al. 2015). The current method of applying assumed mortality rates to estimates of biomass that likely underestimates uncertainty and may be biased has been a source of frustration for both the department and the SSC. To hedge against the uncertainty surrounding the biomass estimates the department has attempted a conservative approach by using the lower 90% confidence interval of biomass estimates to establish OFL and ABCs, a policy which requires yearly justification before the Team and the Council.

An age structured assessment was in development in 2015 but issues of fit, stability and uncertainty prevented it's adoption (Green et al. 2015). In particular, the model's density and abundance trends exhibited high sensitivity to natural mortality estimates, *M*, and a lack of recruitment signals. Owing to turnover in ADF&G biometric staff, the model has not undergone further development since then.

The random effect models (RE) developed by NOAA (Hulson et al. 2021) have become a common assessment tool for data limited stocks and are applied to numerous Pacific rockfish assessments in the GOA and BSAI. These models are random effects time-series models that account for process error and observation error in the data and demonstrate an increase in stability of biomass estimates over time. These models were applied to the SEO yelloweye rockfish stock in 2013 and again in 2015 but not adopted over the status-quo method of setting harvest limits (Green et al. 2015). In both years the assessment authors sought to apply harvest rules to the lower 90% confidence interval of the RE model estimates given the uncertainty in biomass estimates underpinning the model. The first attempt to use the RE model in 2013 produced much lower harvest restrictions than the status-quo methods and the assessment authors requested more time to evaluate the results. The 2015 application of the RE model led to much larger estimates of variance and lower biomass estimates than the status-quo methods and was not adopted (Green et al. 2015). The random effects model has not been applied to SEO yelloweye rockfish since that time.

Given that the RE suite of models are regarded as superior to the status-quo method in use now, this assessment offers an updated application of the RE model to the SEO yelloweye rockfish stock. In particular, the original RE models have been expanded to include multiple strata (the REM model) and thus provide a more statistically sound way of integrating biomass estimates from the four management areas to make inferences about the SEO as a whole. Furthermore, the model has been expanded to include a secondary index of abundance (the REMA model) and as such, this assessment will incorporate CPUE estimates of yelloweye rockfish in the IPHC longline survey. This application has been undertaken in collaboration with the NOAA Alaska Fisheries Science Center (AFSC) and their development of a standardized R package (https://afsc-assessments.github.io/rema/).

This assessment also presents a new assessment model in the form of a Bayesian state-space surplus production model (SS-SPM). Surplus production models are simpler than age-structured assessments and have a general form such that the biomass in a given year is a function of the biomass in the past year, based on some production curve, and minus the catch. They may be a significant improvement over RE models as they include catch data in modelling fishery dynamics and produce estimates of biological reference points such as maximum sustained yield, MSY, B_{msy}, the biomass at which MSY is achieved and F_{msy}, the fishing pressure that leads to MSY (Schaefer 1954; Pella and Tomlinson 1969; Fox 1970; Hilborn and Walters 1992). Additionally, these models allow for population projections into the future under alternative harvest scenarios. SPMs are no longer the method of choice relative to age-structured assessments, but they are still employed in jurisdictions when data is limited to indices of relative abundance and catches such as for North Pacific swordfish (Brodziak and Ishimura 2009) and sea cucumbers off British Columbia (Hajas et al. 2011).

Surplus production models were originally applied with assumptions of equilibrium and were prone to overestimating sustainable catch, particularly when fishery CPUE was the only index of abundance or when the population was on a "one-way trip" of declining abundance throughout the time series (Haddon 2011). However, SPMs no longer require assumptions of equilibrium and nonequilibrium approaches to fitting the models have significantly improved their ability to represent fisheries dynamics. Process error (Polacheck et al. 1993) and observation error (Punt 1990) have been included in these models and both sources have been included in likelihood-based models using the Kalman filter (Freeman and Kirkwood 1995; Haddon 2011). However, attempts at estimating both process and observation error in a single, likelihood-based model have proven unsatisfactory without applying considerable constraints and, in general, observation-error only models are recommended (Polacheck et al. 1993; Haddon 2011). Conventionally, process-error only models are deemed most appropriate for short-lived species that exhibit large fluctuations in abundance where-as observation-error only models are most appropriate for long-lived species that are unlikely to exhibit large fluctuations in abundance, such as rockfish or whales (Ono et al. 2012).

The use of SPM's in a Bayesian state-space framework have led to further improvements and flexibility. Bayesian methods provide the ability to propagate and incorporate all sources of uncertainty in the data and parameters and provide information to conduct probabilistic decision analysis (Ono et al. 2012). In contrast, frequentist methods may require unrealistic assumptions such as linearity in the application of the Kalman filter (Punt 2003), require computational demands that are difficult to test (Ono et al. 2012) and are sensitive to uncertainty in catch data (Stewart et al. 2009). SS-SPMs have been shown to perform reasonably well in terms of bias and precision, while capturing model uncertainty and showing few signs of model failure. Furthermore, they are robust to violations of assumption about equality between process and observation error and allow greater flexibility in incorporating both error sources into the same model (Ono et al. 2012). The improved acknowledgement of uncertainty around parameter estimates are useful for making management decisions and conducting population projections and associated risk analysis.

Given staff limitations with ADF&G it is unclear when an age-structured assessment for yelloweye rockfish will be fully developed for use in an assessment. Age-structured assessments can be difficult to institute for extremely long-lived species with limited data such as rockfish, although several such species (i.e., dusky, northern, rougheye and blackspotted rockfish and Pacific Ocean Perch in the GOA) are currently managed with age-structured assessments (Fenske et al. 2019; Hulson et al. 2019[a,b]; Shotwell and Hanselman 2019). However, Pacific rockfish not assessed with age-structured models have been assessed with the RE suite of models (the "other" rockfish group, shortraker rockfish and the thornyhead complex; Tribuzio and Echave 2019; Echave and Hulson 2019 [a,b]) which do not produce estimates of biological reference points and are subject to the biases or inaccuracies in the biomass estimates used within the model. Age-structured assessments are in use for yelloweye rockfish in the Pacific Northwest, but these assessments struggle with uncertainty in estimates of spawning biomass resulting from sensitivity to the steepness parameter in the productivity curve and the magnitude of the catch time-series (Stewart et al. 2009; Gertseva and Cope 2017). These assessments report sparse and relatively uninformative data for yelloweye rockfish including a lack of signal in recruitment deviations, poorly informed parameters and some level of bias and imprecision in age data (Stewart et al. 2009; Gertseva and Cope 2017).

These factors are likely to be a challenge in developing an age-structured assessment for SEO yelloweye rockfish and make a SS-SPM a potentially useful and appropriate approach for assessing the stock. Much of the pre-1980 harvest of yelloweye rockfish in the SEO occurred in the foreign fleet fishery and as unreported bycatch in the halibut fishery and thus there is substantial uncertainty in the catch data for which Bayesian state-space models are particularly useful. Furthermore, the lack of recruitment signals in Pacific Northwest (Stewart et al. 2009; Gertseva and Cope 2017) and SEO yelloweye rockfish (Green et al. 2015) assessments suggests biomass dynamics that may be accurately captured by a simple surplus production model where-as the lack of recruitment signals are a challenge when modelling dynamics in an age-structured assessment.

The SS-SPM presented here represents a significant advancement in our understanding and assessment of the SEO yelloweye rockfish stock. While not as informed (from a data perspective) as a full age-structured assessment, this model incorporates considerably more data than either the status-quo methods or the RE models. The SS-SPM explicitly incorporates uncertainty in catch data, allows for the minimization of assumptions and propagates uncertainty throughout the assessment. The inclusion of catch data and the modelling of biomass and catch together allow for estimation of productivity in the stock and provides estimates of stock status relative to virgin biomass. In addition to incorporating the catch data, this model is also a large improvement on the status-quo methods given it is a more statistically sound way of integrating the management area biomass estimates and accommodating the uncertainty present in the data. Even if an age-structured assessment is developed in coming years, the adaptation of the SS-SPM model can help inform the catch history, provide baseline estimates of stock-status relative to virgin conditions and at the very least act as a source of contrast while an age-structured assessment is developed.

Fishery

Management Units

Prior to 1992, the DSR complex was recognized in the Fishery Management Plan (FMP) only in the waters east of 137° W. longitude. In 1992, the DSR complex was recognized in East Yakutat (EYKT) and management of DSR extended westward to 140° W. longitude. This area is referred to as SEO and is comprised of four management sections: EYKT, NSEO, CSEO, and SSEO (Figure 2). In the SEO, the State of Alaska and the National Marine Fisheries Service (NMFS) manage DSR jointly. The two internal state water Subdistricts, Northern Southeast Inside (NSEI) and Southern Southeast Inside (SSEI) are managed entirely by the State of Alaska and are not included in this stock assessment. See Appendix A for a more complete description of historical DSR management changes.

Fisheries and Fishery History

The directed commercial fishery for DSR began in 1979 as a small, shore-based, hook and line fishery in Southeast Alaska. This fishery was prosecuted nearshore, with fishing occurring primarily inside the 110 m depth contour. The early directed fishery targeted the entire DSR complex, which at that time also included silvergray, bocaccio, and redstripe rockfish. In more recent years, the hook and line fishery evolved into a longline fishery primarily targeting yelloweye rockfish. Over the past ten years, yelloweye rockfish accounted for 95 to 97% (by weight) of the total DSR catch (Table 4).

Directed DSR fisheries are opened only if there is sufficient quota available after estimating DSR mortality in other commercial fisheries. The directed fishery in northern SEO (NSEO) has been closed since 1995 and the other three subdistricts have been opened intermittently during the last 20 years (Wood et al. 2021). The directed DSR fishery was closed in all management areas in 2020 and has remained closed due to stock health concerns.

DSR have been taken as incidental catch in domestic longline fisheries, particularly the halibut fishery, for over 100 years. Some incidental catch was also landed by foreign longline and trawl vessels targeting slope rockfish in the eastern GOA from the late 1960s through the mid-1970s. Other sources of DSR incidental commercial catch occur in the lingcod, Pacific cod, sablefish, and salmon fisheries. However, the halibut longline fishery is the most significant contributor to the incidental mortality of DSR (94.1%; Figure 3). Full retention requirements in which fishermen are required to retain and report all DSR caught were passed by the North Pacific Fishery Management Council (NPFMC) in 1998, although these requirements did not go into effect until 2005. In July of 2000, the State of Alaska enacted a parallel regulation requiring DSR landed in state waters of Southeast Alaska to be retained and reported on fish tickets.

A Pacific ocean perch (POP) trawl fishery in the Gulf of Alaska developed in the early 1960's with large effort by the U.S.S.R and Japanese fleets. At the height of the fishery in 1965, the catches of all rockfish, including Pacific ocean perch (POP), exceeded 370,000 mt. Catches declined following this peak until foreign fishing was banned in the Gulf of Alaska in 1987. During the early period of this foreign fishery (1961-1974), catches of rockfish were often reported in crude management groups, including POP or “other rockfish”, with no differentiating between species. With implementation of a fishery observer program in 1975 and 1977 onward, species composition, including POP and yelloweye rockfish, of foreign catches became available.

Catch data prior to 1992 are also problematic due to changes in the DSR species assemblage, as well as the lack of a directed fishery harvest card prior to 1990 for central SEO (CSEO), southern SEO (SSEO), and NSEO, and prior to 1992 for eastern Yakutat (EYKT). The directed DSR catch in SEO was above 350 t in the early 1990s. Since 1998, directed landings have been below 250 t, and since 2005, have been less than 130 t (Figure 4). During the years reported, total harvest peaked at 980 t in 1994, and directed harvest peaked at 383 t in 1994. Although directed landings were higher in the 1990s, since 2000, 44.0% of the DSR total reported catch is from incidental catch of DSR in the halibut fishery.

DSR and yelloweye rockfish are also popular with recreational anglers and harvests comprise a significant portion of yelloweye rockfish catches in recent years (Figure 4). Regulation currently allocates 16% of the DSR TAC for SEO to the recreational fishery after deduction of the estimated subsistence harvest. The recreational fishery allocation includes estimated harvest and release mortality. Release mortality was estimated at 90% for guided and unguided fishermen prior to the required use of a deep-water release device, which was implemented for guided fishermen in 2013.

Biological Fishery Data

Submersible and ROV surveys

To assess yelloweye rockfish density and biomass ADF&G began conducting a fishery-independent, habitat-based stock assessment for DSR using visual survey techniques to record yelloweye rockfish observations in 1988. The surveys were designed to estimate yelloweye rockfish density using distance sampling methodology (Buckland et al. 2010), the results of which could be used to estimate abundance and biomass. Distance sampling methodology allows for the estimation of fish density based on the number of fish observed and their distance from the transect line. This is subsequently converted to biomass by multiplying density estimates by the average weight of yelloweye rockfish landed in the commercial fishery and the estimated area of the yelloweye rockfish habitat (O’Connell and Carlile 1993, Brylinsky et al. 2009). The DSR stock assessment surveys have historically rotated among management areas on a quadrennial basis as it would be time and cost-prohibitive to survey the entire SEO in one field season (Figure 5).

Prior to 2010, ADF&G employed a manned submersible to conduct surveys which involved counting fish on one side of the submersible and estimating distances from the transect line visually. In 2012, ADF&G transitioned to using a remotely operated vehicle (ROV) for visual surveys given the unavailability of a cost-effective and appropriate submersible. ROVs provided the department an improved surveying vehicle that allowed more accurate estimation of distances from the transect line using stereoscopic methods, more accurate viewing of the transect line itself, and a means to estimate fish length. Although the survey vehicle has changed, the basic methodology to perform the stock assessment for the DSR complex remained unchanged. Dive locations for these surveys are selected by randomly placing dives within the habitat delineation for yelloweye rockfish which are based on historical fishery data and estimated rock habitat. A Deep Ocean Engineering[1], Phantom HD2+2 ROV (property of ADF&G Division of Commercial Fisheries in Homer, AK) is used as the survey vehicle.

International Pacific Halibut Commission (IPHC) Surveys
Since 1998 the IPHC has conducted longline surveys at set stations to assess halibut abundance and biology and collect data on bycatch species (https://www.iphc.int). In this assessment, the IPHC survey data was used to estimate the catch-per-unit-effort (CPUE) of yelloweye rockfish in each of the SEO subdistricts based on the number of fish-per-hook at survey stations less than 250 fathoms in depth (yelloweye rockfish are largely absent from stations that sample at greater depth). The IPHC CPUE data is used as a secondary index of abundance in the REMA and SS-SPM assessments brought forward in this report.

Analytic Approach

Modeling Approach
A biomass-based approach is used to assess yelloweye rockfish stocks based on the results of distance sampling methodology applied to data from the ROV and submersible surveys. Density estimates are limited to adult and subadult yelloweye rockfish, the principal species targeted and caught in the directed DSR fishery. The ABC recommendations for the entire assemblage are based on adult yelloweye rockfish biomass. Biomass of adult yelloweye rockfish is derived as the product of estimated density, the estimate of rocky habitat within the 200 m contour, and the average weight of fish for each management area. Variances are estimated for the density and weight parameters, but not for area. Annual biomass estimates for the SEO are derived in the status-quo methods by summing biomass estimates across the four management areas which are calculated using the most recent density estimates. Because ROV surveys do not occur every year, a given density estimate may be used for several years. Weight data is updated annually while the amount of habitat remains fixed and without variance. As a result of this uncertainty, the department has historically hedged against overfishing by using the lower 90% confidence interval of the biomass estimate to set OFL and ABCs (Green et al. 2015; Wood et al. 2021).

Two new modeling approaches were applied for this assessment that are viewed as improvements to the status-quo methodology. First, the random effects model (REMA; Hulson et al. 2021) was applied to biomass estimates derived from submersible/ROV surveys and the CPUE of yelloweye rockfish in the IPHC longline survey. The REMA models biomass in a spatially stratified design with biomass and CPUE estimates distinct for each of the four management areas in the SEO.

Secondly, a state-space surplus production model (Ono et al. 2012) was constructed to model biomass/population dynamics by combining both indices of abundance with the catch data and was conducted in such a way as to propagate and assess uncertainty in model output. This model accommodated extra uncertainty in the biomass estimates derived prior to 2012 and accommodated the considerable uncertainty present in the catch history. Yelloweye rockfish and other DSR species have been subject to bycatch in other fisheries and the halibut longline fishery, in particular, is suspected of being a significant source of historical removals. As such, unobserved discards were estimated using data from the IPHC longline survey and known halibut catches.   Those estimates, and the corresponding uncertainty, were passed through the model and a risk analysis was included as part of the assessment to

[1] Product names appearing in this document are included for completeness, and do not imply an endorsement by the Alaska Department of Fish and Game.

determine how biases in the discard estimation procedure would affect biological reference points and recommended OFLs and ABCs.

Designated yelloweye rockfish habitat (DYRH) delineation:

The sampling area within each management unit (the DYRH) was established based on known yelloweye rockfish habitat preferences, ADF&G sonar data, spatial data from the directed DSR commercial fishery and from National Oceanic and Atmospheric Administration (NOAA) charts. The size of the DYRHs has evolved over time as new sonar surveys have been conducted and new data collected. The DYRHs were last updated in 2010 (Green et al. 2015) and methods are reviewed here for completeness.

The DYRHs were established by combining three data sources; 1) ADF&G sonar data, 2) areas identified in the directed DSR commercial fishery logbook data, and 3) substrate information from NOAA charts. In general, yelloweye rockfish prefer rocky habitat, and submersible surveys between 1992 and 2012 occurring between depths of 2 to 144 fathoms (4 to 263 meters) demonstrated that 90% of yelloweye rockfish observations occurred between 35 and 100 fathoms (64 to 183 m) (O'Connell and Carlile 1993; Brylinsky et al. 2009). Surveyed seafloor has been classified into habitat type by the Moss Landings Marine Laboratories' Center for Habitat Studies using bathymetry, backscatter, and direct observations from the *Delta* submersible and reduced to substrate induration categories of soft, mixed, or hard (Greene et al. 1999). Seafloor identified as hard substrate was considered yelloweye rockfish habitat and served as the basis of the DYRH designation (Appendix B, O'Connell and Carlile 1993, Brylinsky et al. 2009).

Adding to the baseline area established with sonar data, longline set locations from the directed DSR fishery with CPUE ≥ 0.04 yelloweye rockfish per hook were included. When set locations were only noted by their start position the point was buffered by 0.8 km to create a circular polygon. When both start and end locations of the commercial set were noted (as was most common) a polygon was created by buffering the entire set by 0.5 km. These distances were chosen based on observed travel of four tagged yelloweye rockfish in the Pacific Northwest (Green et al. 2015). The identified areas determined by the commercial fishery data were considered continuous and merged if no gaps > 0.9 km were present. Of those designated areas, those that were ≥ 2.3 km in length (the minimum size necessary to allow two, non-overlapping transects) were included in the DYRHs.

In the NSEO management area commercial fishery logbook data is more limited than the other management areas and the DYRH established by sonar data was augmented using NOAA charts. Features designated as coral, rock, or hard seafloor on NOAA charts were buffered by 0.8 km in ArcGIS and included in the DYRH if between 64 m and 180 m deep.

Total yelloweye rockfish habitat has been estimated for SEO at 3,892 km^2. The Fairweather grounds DYRH in EYKT management area is comprised of 739 km^2, 68% of which is derived from sonar, the NSEO DYRH is 442 km^2 with 25% derived from sonar, the CSEO DYRH is composed of 1,661 km^2 with 27% derived from sonar, and the SSEO DYRH is 1,056 km^2 with 30% defined by sonar (Figure 5, Appendix B, Green et al. 2015).

Yelloweye Rockfish Density Estimates from Submersible Surveys (1988–2009)

In a typical submersible dive, two transects were completed per dive with each transect lasting 30 minutes. During each transect, the submersible pilot attempted to maintain a constant speed of 0.5 km and to remain within 1 m of the bottom, terrain permitting. A predetermined compass heading was used to orient each transect line. Due to the configuration of the submersible, with primary view ports and imaging equipment on the starboard side, fish were only counted on the right side of the line. All fish observed from the starboard port were counted and their perpendicular distance from the transect line recorded (Buckland et al. 1993). An externally mounted video camera was used on the starboard side to record both habitat and audio observations. In 1995, a second video camera was mounted in a forward-facing position. This camera was used to ensure 100% detectability of yelloweye rockfish on the transect line; a critical assumption when using line transect sampling to estimate density. The forward camera also enabled the counting of fish that avoided the submersible as the vehicle approached, as well as removing the count of fish that swam into the transect from the left side because of interaction with the submersible.

Hand-held sonar guns were used to calibrate observer estimates of perpendicular distances. Observers calibrated their eye to making visual estimates of distance using the sonar gun to measure the distance to stationary objects (e.g., rocks) at the beginning of each dive prior to running the transect and between transects.

Beginning in 1997, the support ship was positioned directly over the submersible at five-minute time intervals and the corresponding Differential Global Positioning System (DGPS) fixes to determine line length was used. In 2003, the submersible tracking system was equipped with an SG Brown Meridian Gyro® compass, enabling more accurate tracking without positioning the vessel over the submersible. In 2007 and 2009, in addition to collecting the position of the submersible using five-minute time intervals, position data was also recorded every two seconds using the WinFrog® tracking software provided by *Delta*. Outliers were identified in the WinFrog® tracking software data by calculating the rate of travel between submersible locations. The destination record was removed if the rate of travel was greater than two meters per second. In 2007, a 9-point running average was used to smooth the edited WinFrog® tracking software data, after which smoothed data were visually examined in ArcGIS. If any additional irregularities in data were observed, such as loops or back tracks, the anomalies were removed, and the data resmoothed. After a 27-point smoother was applied to the data, the smoothed line transects were examined in ArcGIS. If any irregularities still existed in the line transects that were thought to be misrepresentations of the actual submersible movements, the anomalies were removed from the line transect and resmoothed.

The side facing and forward-facing video from the submersible dives were reviewed post-dive while listening to verbal recordings made by the observer in the submersible. The audio transcript included remarks regarding the species observed, and each individual fish's distance away from the submersible. These data were recorded in the database, as well as any additional yelloweye rockfish seen in either video camera that the observer may have missed while underwater. The observer was able to see farther out the window than the camera field of view, thus the verbal transcript was critical for data collection.

Yelloweye Rockfish Density Estimates from ROV Surveys (2012–present)

Random dive locations for line transects (Figure 5) were created in preferred yelloweye rockfish habitat using ArcGIS. Transects of 1-km length were mapped at each suitable random point with four possible orientations along the cardinal and intercardinal directions and crossing through the random point. A transect length of 1-km was selected after consideration of visual surveys conducted by other agencies or ADF&G groups (Robert Pacunski, Washington Department of Fish and Wildlife, personal communication, Mike Byerly, ADF&G, personal communication, Yoklavich et al. 2013), the encounter rate of yelloweye rockfish based on previous submersible surveys, and ROV pilot fatigue. The number of planned transects was based on yelloweye rockfish encounter rates from previous surveys and the precision goal (coefficient of variations, CVs, of less than 25%).

Transect line length was estimated by editing ROV tracking data generated from Hypack® software. Tracking data were filtered for outliers using Hypack® singlebeam editor (positioning errors are removed and data are filled in to one second intervals using linear interpolation). Video data undergo a quality review to remove any video segments where poor visibility would obscure yelloweye rockfish observations or when the ROV was not moving forward (i.e., stalled, or stopped due to logistical issues). Navigation data were mapped in ArcGIS after being smoothed with a spline in R (R Core Team 2020). Image quality segments were then joined with the navigation data in ArcGIS using linear referencing. The total line length for each transect was estimated using only the good quality image segments.

Fish were recorded on the left and right side of the "center line" of the line transect when reviewing video within the SeaGIS EventMeasure software (Seager 2012; SeaGIS Pty Ltd., EventMeasure version 5.42) (Figure 6). The video reviewer identified and enumerated yelloweye rockfish for density estimation, and other DSR, black rockfish, lingcod, halibut, and other large-bodied fish as time allows for species composition. Fish lengths were recorded for individual yelloweye rockfish, lingcod, halibut, and black rockfish. Fish behavior and life-stage were recorded for yelloweye rockfish only.

Sample Size and Design: The number of transects in a given year was based on yelloweye rockfish encounter rates from the previous survey in that management area and the targeted precision goal (CV ≤ 15%). Individual transects were 1-km in length and the total number of transects was determined by calculating the total survey distance necessary to obtain sufficient fish observations with a minimum of 20 individual transects (Buckland et al. 1993). Buckland et al. (1993) recommends selecting a total transect line length (i.e., the sum of all transect lines) long enough to obtain 60–80 samples (individual fish observations) such that:

$$L_{target} = \left(\frac{b}{\{cv_t(\widehat{D})\}^2}\right)\left(\frac{L}{n}\right) \tag{1}$$

where L_{target} is the target total transect length, cv_t is the target coefficient of variation of the density estimate $\widehat{D}$, L and n are the line-length and observed animal numbers from the previous survey in the management area, respectively, and b is a dispersion parameter. The dispersion parameter, b is estimated using the number of yelloweye rockfish observed (n) and the CV of the previous density estimate in that area ($cv(\widehat{D})$) such that.

$$\hat{b} \cong n \cdot \{cv(\widehat{D})\}^2 \tag{2}$$

Substituting eq (2) for *b* into eq (1) resolves to

$$L_{target} = \frac{L\{cv(\widehat{D})\}^2}{\{cv_t(\overline{D})\}^2} \tag{3}$$

This provides the target total line transect length for a given management area in a given year which is then divided into 1-km transects (Buckland et al. 1993).

Survey transect locations represent a simple random sample of the DYRH so that density estimates of the DYRH are considered unbiased. To determine the location of survey transects, random points were selected within the bounds of the DYRH such that there was a minimum distance of 1.9 km between each point using ArcGIS Pro and ET GeoWizards softwares (ET GeoWizards v12; ET Spatial Techniques 2017, ArcGIS Pro v2.5; Esri 2020; Appendix C). These random points served as the midpoint for the 1-km transects. The 1.9 km minimum distance was selected to avoid overlap among transects and in consideration of vessel running time between points. Random locations were removed from the survey design if they were in depths ≥180 m, the maximum operating depth for the ROV.

Transect lines of 1-km length were centered at each random point with four possible orientations along the cardinal and ordinal directions. This was done to accommodate logistical constraints in the field and allow the crew to choose a single transect at each point based on currents and winds at the time of the survey. In cases where a transect line was not completely within the DYRH, the line was shifted through the random point until the greatest proportion was in the DYRH while still including the random point.

Estimation of distance from transect line and fish length: To determine yelloweye rockfish distances from the transect line and measure the length of each fish, stereoscopic methodology was applied to measure the location of points in three-dimensions relative to the ROV and the transect line. The video was reviewed by staff and computer software (SeaGIS Pty Ltd., EventMeasure v5.42) used to enumerate yelloweye rockfish, calculate the distance the fish is from the transect line and estimate fish length. Total fish length (tip of the snout to the tip of the caudal fin) was recorded for individual yelloweye rockfish, black rockfish, lingcod, and halibut. Fish behavior (Appendix G) and maturity stage were recorded for yelloweye rockfish only, using coloration and other morphological characteristics.

Video Review and Quality Control: The video reviewer recorded yelloweye rockfish at first observation on the video to minimize any effect on fish movement in response to the ROV as it moved closer to the animal. Yelloweye rockfish may be observed at distances as great as eight meters from the ROV. 3D measurements were taken when the fish was visually well defined enough to produce quality estimates (defined as the root mean square (RMS) error of the variance <10 mm). In addition to the stereo cameras, the camera attached to the "belly" of the ROV was reviewed for yelloweye rockfish to ensure all yelloweye rockfish on or near the transect line are observed, an essential assumption of distance sampling. When a 3D point measurement could not be generated due to fish only being observed in the ROV's belly camera or in one stereo camera, the perpendicular distance was estimated using the two laser beams in the field of view. Care is taken to avoid double counting fish that swim into the field of view more than once (this behavior is obvious and rare for yelloweye rockfish). Other rockfish in the DSR complex, black rockfish, lingcod, and halibut were recorded as early as possible, but accuracy at first detection was less critical.

The distance between the fish and the transect line, as well as fish length, were estimated by the software using an x, y, and z coordinate system that describes a point in space relative to the ROV (Figure 6). Once the optimal fish image was selected (i.e., earliest view, prior to the fish reacting to the camera, and when best oriented to view length) the reviewer generated coordinates for the tip of the snout (x_1, y_1, z_1) and the tip of the tail (x_2, y_2, z_2). The distance of the fish from the transect line was generated by estimating the x component from the midpoint of the line connecting the fish snout and tail (i.e., the average of x_1 and x_2). If the fish was not oriented well enough to generate a length measurement the video reviewer used the x component from a single point near the center of the body. Fish length was estimated by calculating the difference between the snout and tail coordinates to generate Δx (difference between x_1 and x_2), Δy, and Δz and thus the length of the fish, d, is

$$d = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \tag{4}$$

and the standard deviation of fish length is

$$\sigma_d = \frac{1}{d}\sqrt{2(\Delta x^2\sigma_x^2 + \Delta y^2\sigma_y^2 + \Delta z^2\sigma_z^2)} \tag{5}$$

where σ_x, σ_y, and σ_z are the standard deviations of Δx, Δy, and Δz as estimated by the software (Seager 2008). The standard deviations of x and y are generally equivalent and small compared to the standard deviation of z. When a fish was parallel to the transect line $\Delta z = 0$ and there was no contribution to the error from Δz, but as a fish turns away from the camera, Δz increases resulting in a decrease in precision (σ_d). Fish that were not straight or could only be partially viewed were not measured.

Evaluation of Distance Sampling Assumptions

Distance sampling (Buckland et al. 1993) requires that three major assumptions are met to achieve unbiased estimates of density from line transect sampling: (1) objects on the transect line must be detected with certainty, (2) objects must be detected at their initial location (i.e., animals do not move toward or away from the transect line in response to the observer before distances are measured), and (3) distances from the transect line to each object are measured accurately. Failure to satisfy these assumptions may result in biased density estimates.

To ensure the first assumption is met, the probability detection function and histograms of the distance data were examined. If the detectability at the transect line is close to 100%, then the probability detection function has a broad shoulder at the line that drops off at some distance from the line (Buckland et al. 1993). In past submersible surveys, the observer looked out of the submersible port window to identify fish, and fish near the submersible were sometimes missed by the observer and the main camera. Therefore, a forward-facing camera was installed on the submersible to record fish directly on the transect line. The ROV stereo cameras are oriented forward, so the video reviewer can easily detect fish on the transect line. A “belly” camera was added in 2015 and has been used for every survey since. Review of this camera indicated few fish are missed using the stereo cameras.

The second assumption was evaluated by examining the probability detection function (PDF) and the behavioral response of yelloweye rockfish to the ROV. If undetected movements are random and slow relative to the speed of the ROV, then this assumption is not violated (Buckland et al. 1993). The shape of the PDF may indicate if there is yelloweye rockfish movement response to the ROV. If the PDF has a high peak near the origin line, this may indicate animal attraction to the ROV. If there are lower detections near the line and an increase in detection at some distance away from the origin of the line, this may indicate avoidance behavior by the animal. Byerly et al. (2015) found that yelloweye rockfish movement prior to detection by the ROV cameras was random. Previous survey results from this project indicated that most yelloweye rockfish were not moving in response to the ROV. Since the adoption of the ROV in 2012, it has been determined that an average of 78% of all yelloweye rockfish from the surveys moved minimally or slowly. Of those slow-moving specimens, approximately 70% did not display directional movements (i.e., milling, resting on the bottom). These results are consistent with those observed in other ROV surveys and indicate that yelloweye rockfish move slowly relative to the speed of the survey vehicle (Byerly et al. 2015).

The third assumption of distance sampling precision was met by using the SeaGIS software, as previously described in the methodology section. In the submersible surveys, the observer estimated the perpendicular distance from the submersible to a fish by eye, which was subject to measurement error despite observer calibration before each dive. For the ROV, a laser 3D point measurement of the specimen with coordinates of x, y, and z (Figure 6) was obtained from video footage using the SeaGIS software (Seager 2008). The ROV lasers are calibrated prior to each survey to ensure precise measurements, and the ability to reverse footage during video review improves collection of accurate measurements.

Density and Biomass Estimates

The density of yelloweye rockfish in the DYRH was estimated by fitting a detection function to the data (the distance of each fish from the transect line) that describes the probability a fish is observed given it's distance from the transect line. The detection function was used to estimate the density of fish within the width of the transect strip that is determined by the maximum distance that fish are observed from the transect line. Because the transects are simple random samples of the DYRH the density estimated within the transect strips are regarded as an unbiased estimate of fish density within the DYRH (Buckland et al. 2010). Analyses were conducted in R (R Core Team, 2020) and density was estimated using the package *Distance* (https://CRAN.R-project.org/package=Distance), which utilizes the following equations to estimate density such that:

$$\hat{D} = \frac{n\hat{f}(0)}{2L} \tag{6}$$

and the probability of detection evaluated at the origin of the transect line ($\hat{f}(0)$) is

$$\hat{f}(0) = \frac{1}{\mu} = \frac{1}{wP_a} \tag{7}$$

Where n is the number of subadult and adult yelloweye rockfish observed, L is the total transect line length, μ is the effective width of the transect strip, w is the width of the transect strip and P_a is the probability of observing an object in the defined area. Both adult and subadult yelloweye rockfish were included in the density estimates but juveniles were not.

For a given study area, several candidate models were fit to the distance data. Candidate models included different detection functions (uniform, half-normal and hazard rate) with various adjustment terms (cosine, simple polynomial, and Hermite polynomial adjustments) that describe the probability of a fish being detected based on its distance from the transect line. Beginning in 2018, two covariates, life stage (adult or sub-adult) and depth, were examined to determine if detection probabilities were influenced by these factors and worth inclusion in the model (Thomas et al. 2010). All models were run with the full data set and with a data set that is truncated to exclude 5% of observations furthest from the transect line. All models were examined visually to identify implausible detection functions that compare poorly to the histograms of the distance data. Goodness-of-fit was also examined with χ^2 tests (Thomas et al. 2010) and implausible detection function models eliminated from consideration.

To determine whether to truncate the data the goodness-of-fit tests were used to compare the truncated and non-truncated data sets for each model. Truncation of distance data frequently results in better fit of the data by eliminating long tails in the detection function that may require extra adjustment terms and reduces precision for little gain (Thomas et al. 2010). Truncated data was considered the default choice unless the majority of models demonstrated there was adequate fit without a loss of precision.

Once a determination was made regarding the truncation of data, detection models were ranked based on Akaike Information Criterion (AIC) value where the best fit results in the lowest AIC value (and thus a ΔAIC value of 0). If one model clearly outperformed the others (ΔAIC of the second best model > 4) density estimates from that model were selected. Prior to 2018 the model with the best fit was always used to estimate density. Beginning with 2018 a model averaging approach was adopted. Uncertainty in the shape of the true detection function was indicated by multiple models having similar AIC scores (ΔAIC < 6) and goodness-of-fit. As such a model averaging procedure was used to account for uncertainty in selecting the best detection function (Thomas et al. 2010).

To average the suite of best detection models as determined by AIC scores (ΔAIC < 6) a bootstrap procedure was used (Thomas et al. 2010; Williams and Thomas 2009). In this procedure, the transects represent the sampling unit and the bootstrap was performed by resampling the transects (as a whole) with replacement 1000 times. For each bootstrap replicate the candidate models (ΔAIC < 6 and good fit) were fit to the data, the best model selected based on AIC rankings and the density calculated. Estimates of density were taken as the mean of the bootstrap estimates (Thomas et al. 2010; Williams and Thomas 2009). Coefficients of variation (CVs) were calculated as standard deviation of the bootstrap estimates divided by the mean and the percentile method was used to obtain confidence intervals (Williams and Thomas 2009).

The total yelloweye rockfish biomass for the management area was estimated as the product of density in an area, average weight of rockfish sampled in ports (Table 1), and size of the DYRH (O'Connell and Carlile 1993). In the past, average weights were taken from the directed DSR fishery until it was closed, after which the author's used the weight of fish sampled in the halibut fishery (Green et al 2015; Wood et al. 2021). For consistency, the revised methods presented here used the average weight of all randomly sampled yelloweye rockfish taken in all fisheries (comprised mostly of the directed fishery and halibut bycatch). A second revision was to set a minimum sample size of 75 fish for generating annual weight estimates. In many years there were less than 75 samples available for each management unit and when this was the case, past year's samples were used to bring the sample size above the threshold (Table 1).

Biomass variance was calculated by combining the variance of the mean weight and fish density according to standard multiplicative rules. It is important to note here that the size of the DYRH does not have a variance component and the variance of the biomass estimates very likely underrepresents uncertainty in the estimate.

Status-quo SEO biomass estimation and setting ABC and OFL (Model 21 and 21.1)

Historically, the department has estimated the annual biomass for the SEO as a whole by updating the four management units with the most recent data available for each year. Thus, the latest density estimate was used in conjunction with the most up-to-date weight data from portside samples while the DYRH size remained constant. If a given management area had not had a recent survey then the most recent density estimate was carried forward and the weight data updated. The SEO as a whole was estimated by summing the four subdistricts.

Methods for estimating biomass have evolved over the course of the time series and the methodology from the early years has proven difficult to replicate. Prior to 2010 the density estimates were applied to the totality of yelloweye rockfish habitat *in all management units,* which produced noticeable volatility in biomass estimates owing to different densities in the four subdistricts. Furthermore, the estimate of DYRH used to convert density into abundance has evolved over time without detailed documentation. To standardize methods the status-quo biomass estimates presented in this report utilized the historical density estimates as reported in past SAFE reports (Brylinskey et al. 2009; Green et al. 2015; Wood et al. 2021) to estimate biomass in each subdistrict using the weight samples described above (Table 1) and applying the current DYRH estimates of area. This resulted in pronounced differences in past biomass estimates between the methods presented here and those reported in past reports.

Regardless of different methods used to calculate subdistrict biomass, the status-quo method for combining management area estimates into an SEO estimate has been recognized as lacking statistical rigor and has been a source of unease with the department, the plan team and the council. Examination of the density estimates for each of the management units alone reveals substantial variability in estimates from one survey to the next, which is unlikely for such a long lived and slow growing species. To hedge against uncertainty in the status-quo methods of estimating SEO biomass the department has recommended OFLs and ABCs be set based on the lower 90% confidence interval of the biomass estimates (Green et al. 2015; Wood et al. 2021). This has required yearly justification before the plan team and council.

IPHC survey yelloweye CPUE

The CPUE of yelloweye rockfish in the IPHC longline survey was used as a secondary index of abundance for both the REMA model and the surplus production model. For each SEO management area and year of the IPHC survey (1998 – 2021) the appropriate IPHC survey stations that were less than 250 fathoms deep were examined. For each survey station *i* the CPUE of yelloweye rockfish was calculated as

$$CPUE_{ye,i} = {}^{c_i}/_{h_i} \tag{8}$$

where c_i is the observed catch of yelloweye rockfish at station i and h_i is the observed effective hooks at station i. All qualifying stations within the management area were averaged and the CV, confidence intervals and variance calculated by bootstrapping across the stations.

Random effects model (REMA; Model 22.1 and 22.2)
The random effects model (RE) was developed by the North Pacific Management Council Groundfish Plan Team to assess biomass in data-limited groundfish stocks and apportion harvests by area (Hulson et al. 2021). The RE model has been expanded to fit multiple survey strata (i.e., management area, depth) simultaneously (REM), allow a secondary index of abundance (REMA; Hulson et al. 2021), and more recently to estimate additional observation error (Sullivan et al. 2022, available online under Tier 4/5 random effects: https://meetings.npfmc.org/Meeting/Details/2949).

For SEO yelloweye rockfish, the REMA model was applied to the subdistrict level biomass estimates described above and a secondary index of abundance derived from the catch-per-unit-effort (CPUE) of yelloweye rockfish in the IPHC longline survey. In the REMA model, there are separate observation likelihoods for the biomass and additional abundance indices, which are assumed to be log-normally distributed with known variance (i.e. observation error). True biomass is estimated as a series of random effects, where estimated process error parameters are constrained using a random walk model. In the two-survey REMA model, additional scaling parameters are estimated that scale the CPUE indices to predicted biomass. Models were fit in Template Model Builder (TMB; Kristensen et al. 2016) using a new R package *rema* developed at the NOAA Alaska Fisheries Science Center (AFSC; https://afsc-assessments.github.io/rema/). Detailed methods and structural equations for the observation and process error components of the model with extensions that estimate additional observation error are available online: https://afsc-assessments.github.io/rema/articles/rema_equations.html.

Several alternative REMA models were developed for SEO yelloweye rockfish, and model selection was informed using visual examination of fits to the data and Akaike Information Criteria (AIC), where the best-fitting models had the lowest AIC by at least two points. If models were within two AIC points, they were considered to have equal goodness of fit and the model with the fewest number of fixed effects parameters was selected. The Model 22.1 series included versions that either shared process error variance and scaling parameters across all management areas or estimated them for each area (up to 8 fixed effects parameters in total). The best-fitting model from the 22.1 series were then compared with the Model 22.2 series, which estimated extra observation error variance for either or both the biomass and CPUE data (up to 2 additional fixed effects from Model 22.1). For brevity, only results from the best-fitting models in the 22.1 and 22.2 series are presented.

State-space surplus production model (SS-SPM; Model 22.3)

Overview
To assess the SEO yelloweye rockfish population and obtain biological reference points for management a surplus production model in a Bayesian state-space framework (Kéry and Schaub 2012) was applied to biomass estimates and indices of abundance in combination with recorded and modelled catches. The Pella-Tomlinson production model, fixed such that B_{msy} occurred at B_{40} (Pella and Tomlinson 1969), was used as the base model. Biomass was estimated from the ROV/submersible estimates as well as the IPHC CPUE data. Catches were modelled from known harvests in all fisheries. Additionally, because bycatch in the halibut fishery is considered a major source of mortality, unreported discards were modelled by

applying IPHC survey data to halibut harvests to obtain an estimate of expected bycatch (Tribuzio et al. 2014) and unreported discards were modelled as the difference between expected bycatch and landed bycatch reported by the fishery.

The SS-SPM analysis involved a 3-stage approach to accommodate different spatial resolution over the course of known fisheries while accommodating and propagating uncertainty in both the biomass estimates and the catch history. Biomass estimates from the submersible surveys and IPHC survey data are available at the management unit spatial level (i.e., for the EYKT, NSEO, CSEO and SSEO) as are catch data beginning in 1980. However, catch and harvest data prior to 1980 was only available at the spatial level of the entire SEO. The goal of Stage-1 and -2 were to develop priors for carrying capacity (also referred to as virgin biomass), K, and the ratio between 1980 biomass and K, ϕ, that could be used to inform the final model used in Stage-3. The three stages of this analysis were as follows;

1) To produce estimates of biomass in the entire SEO for use in the Stage-2 model, the SS-SPM was modelled in a spatially stratified manner on data going back to 1980. Uninformative priors were applied to the intrinsic rate of increase, r, as well as K and ϕ so that biomass estimates were derived without making assumptions about the state of the population.
2) To develop a more informed assessment of virgin biomass and the stock status in 1980 relative to virgin biomass, the Stage-2 model was a simple, non-stratified, SS-SPM that used the posterior estimates of total SEO biomass between 1994 and 2022 (years when the surveys were undertaken) from Stage-1 and used a catch time-series that extended back to 1888 when the halibut fishery first began. This model used estimates of discards from the halibut fishery as well as estimates of removals in the foreign fleet fishery that occurred between 1961 and 1982. Because this model presumably went back to the start of significant removals of yelloweye rockfish, the biomass in 1888 was considered virgin biomass/carrying capacity, K. As with Stage-1, this model was not used to calculate biological reference points but was intended to develop more informed priors on K and ϕ to be used in a spatially stratified model similar to Stage-1.
3) Stage-3 applied the Stage-1 model using the original data but placed informative priors on r, K and ϕ that were developed from Stage-2 results. This was accomplished by creating hyper priors for the K and ϕ parameters from which management area estimates of K_s and ϕ_s were drawn. Additionally, several informed priors for r were developed using Bayesian simulations of a Leslie matrix (McAllister et al. 2001). This model was used to calculate biological reference points, simulate future population trajectories under alternate harvest scenarios and to make recommendations on OFLs and ABCs.

Data Source:
The state-space models incorporated the following input

1) Total known commercial removals of yelloweye rockfish from SEO management areas from 1980 – July 2022, including targeted commercial landings and recorded bycatch.
2) Total sport fishery removals from 1980-2021 and estimates for 2022 harvests derived from the average removals observed in 2020-2021 (when new restrictions were put in place).
3) Total subsistence removals from 1980-2022, with data since 2013 modelled using long term averages in the absence of recent subsistence surveys.

4) Estimates of unreported discards from the commercial halibut fishery from 1888- July 2022 derived from IPHC longline survey data and historical halibut landings.
5) Estimates of removals from the foreign fleet from 1961-1982.
6) Submersible and ROV based estimates of total yelloweye rockfish biomass by management area from 1994-2022.
7) Estimates of yelloweye rockfish CPUE in the IPHC longline survey in numbers-per-hook by management area from 1998-2021 (as described in the REMA section above).

Bycatch and unobserved discard estimation in the halibut fishery
To estimate the biomass of yelloweye rockfish discarded in the commercial halibut fishery, data from the IPHC longline surveys (https://www.iphc.int) was used to estimate the relative biomass of yelloweye rockfish landed per unit of legal halibut biomass caught and then applying that ratio to the total halibut landings reported for each of the four SEO management areas (Tribuzio et al. 2014).

Halibut harvests were reconstructed for the SEO using data from the IPHC. Data for 1982-2022 came via an IPHC data request (T. Khong and I. Stewart *pers. comm.*). Data for 1975-1982 came from IPHC Scientific report 67 (Hoag et al. 1983), data for 1929-1975 came from IPHC Technical report 14 (Myhre et al. 1977) and data from 1888-1928 came from Bell et al. (1952) and the IPHC online database (https://www.iphc.int). Because IPHC statistical areas do not align with ADF&G management areas it was necessary to reconstruct halibut harvests with some uncertainty. Three of the management areas (CSEO, SSEO and NSEO) were readily identifiable by IPHC regulatory area or region. However, the ADF&G EYKT management area comprises only a portion of IPHC regulatory area 3A and only a portion of the Yakutat IPHC region. As such, hindcast harvests were constructed using the average proportional relationship between the 3A or Yakutat harvests and the EYKT management area from 1982-2021. For years going back to 1929 this meant applying the proportional relationship between the EYKT and the Yakutat IPHC region (which comprises a portion of IPHC management area 3A). For years prior to 1929 this meant applying the proportional relationship between the EYKT and the entire 3A regulatory area. The variance in proportion estimates was calculated and applied to halibut harvest estimates in the SEO. This variance was carried forward when estimating yelloweye rockfish bycatch.

For each SEO management unit and year of the IPHC survey (1998 – 2021) the appropriate IPHC survey stations were examined. For each survey station *i* the CPUE of yelloweye rockfish was calculated as

$$CPUE_{ye,i} = {}^{c_i}/_{h_i} \tag{9}$$

where c_i is the observed catch of yelloweye rockfish at station *i* and h_i is the observed effective hooks at station *i*. The total catch of yelloweye rockfish at station *i*, $C_{ye,i}$, was

$$C_{ye,i} = CPUE_{ye,i} * H_i \tag{10}$$

where H_i is the total number of effective hooks fished for station *i*. Yelloweye rockfish catch was converted to weight in kilograms, $K_{ye,i}$, such that

$$K_{ye,i} = C_{ye,i} * \overline{w}_{ye} \tag{11}$$

where $\bar{w}_{ye}$ is the average weight of harvested yelloweye rockfish sampled portside (Table 1). For each station the *WCPUE* (the ratio of yelloweye rockfish biomass to legal sized halibut biomass) was calculated as

$$WCPUE_{ye,i} = {K_{ye,i}}/{K_{LHal,i}} \tag{12}$$

where K_{LHal} is the average weight of legal halibut landed in the survey stations. For each management area and year the average $WCPUE_{ye}$ of the IPHC stations within the management area was calculated and non-parametric bootstrapping was applied to generate variances, coefficients of variation (CVs) and confidence intervals to accommodate frequent zeros and non-normality in the data (Tribuzio et al. 2014).

Yelloweye rockfish occur regularly in the IPHC surveys and thus the mean of the $WCPUE_{ye,i}$ showed minimal bias relative to the mean of the bootstrap samples, at least with regard to the scale of the ADF&G SEO management areas. The *CV* for the $WCPUE_{ye}$ values were calculated using the bootstrap samples such that

$$CV\left(WCPUE_{ye}\right) \approx {\sqrt{var\left(WCPUE_{ye,boot}\right)}}/{\left(\overline{WCPUE_{ye,boot}}\right)} \tag{13}$$

where $var\left(WCPUE_{ye,boot}\right)$ is the variance of the bootstrap samples and $\overline{WCPUE_{ye,boot}}$ is the mean of the bootstrap samples.

For years prior to the IPHC survey (1980-1997) the long-term mean of the $WCPUE_{ye}$ for each management area was used. For these early years the maximum observed $CV\left(WCPUE_{ye}\right)$ between 1998-2021 for each management area was applied to the 1980-1997 data to pass maximum uncertainty through to the SS-SPM.

For each year and management area, the $WCPUE_{ye}$ values were applied to the biomass of landed halibut in the management area to produce an estimate of expected yelloweye rockfish bycatch, *EBy*, in the halibut fishery such that

$$EBy = WCPUE_{ye} * Ha \tag{14}$$

where *Ha* is the biomass of halibut landed in the management area of interest and the variance of expected bycatch is

$$var(EBy) = Ha^2 * var\left(WCPUE_{ye,boot}\right) \tag{15}$$

when halibut harvests are known and

$$\begin{aligned} var(EBy) = 2 * Ha * WCPUE_{ye} * cov\left(Ha * WCPUE_{ye}\right) + \\ var\left(WCPUE_{ye,boot}\right) * Ha^2 + var(Ha) * {WCPUE_{ye}}^2 \end{aligned} \tag{16}$$

when there is uncertainty in the halibut harvest reconstruction. Because some of the bycatch in the halibut fishery has been landed and recorded in recent years an estimate of unreported discards was derived by subtracting the known bycatch landings from the estimates of expected bycatch. When this produced negative values (as was evident during years of full retention beginning in 2000) discards were estimated as the minimum observed, or 1 mt. For each year the sum of the management area provided yearly estimates of yelloweye rockfish bycatch for the SEO as a whole.

To assess these methods, the expected bycatch estimates were compared to those directly observed in recent years. First, expected bycatch was compared to estimated bycatch in the halibut fishery by the NOAA fishery observer program and Catch Accounting System (CAS) between 2013 and 2021 (Alaska Fisheries Information Network). Secondly, the estimates of expected bycatch were compared to landed bycatch in the halibut fishery when full retention of rockfish in the halibut fishery became mandatory (2000 in state waters and 2005 for federal fisheries).

Foreign fleet harvest reconstruction
During the early period of this foreign fishery (1961-1974), foreign catches of rockfish were often reported in crude management groups, including Pacific ocean perch (POP) or “other rockfish”, with no differentiating between species. With implementation of a fishery observer program in 1975 and 1977 onward, species composition, including POP and yelloweye rockfish, of foreign catches became available.

From 1961-1974, catches by the foreign fleet were reported only as Gulf-wide, but the spatial resolution of foreign catch reporting improved in the second half of the fishery. In the later years of the Gulf of Alaska foreign fishery, catches were reported to International North Pacific Fisheries Commission (INPFC) areas. The Southeastern INPFCs area nearly aligns with the SEO, and for the purpose of the catch reconstruction, the two areas were treated as the same. The foreign fleet was banned from the Southeastern INPFC area earlier than any of the other INPFC areas in 1982. Catches were reconstructed for the Southeastern INPFC area, and by proxy, for the SEO subdistrict.

Removals of yelloweye rockfish in the foreign fleet were estimated in the years prior to accurate record keeping by applying proportional relationships derived from years when data was available (Table 5; Berger et al. 1984, 1985, 1987; Berger and Weikart 1988; Forrester et al. 1978, 1983; Nelson et al. 1983; Wall et al. 1978, 1979, 1980, 1981, 1982). This reconstruction remains a work in progress. First, non-POP harvests were estimated for 1961-1972 by applying the proportional relationship between non-POP and all rockfish in 1973-1984 data (Table 5). Secondly, yelloweye rockfish harvests were estimated for 1961-1974 by applying the proportional relationship between non-POP rockfish and known yelloweye rockfish in 1977-1985. Lastly, the Southeastern INPFC harvests for years prior to 1978 were estimated by applying the proportional relationship between Southeastern INPFC yelloweye rockfish harvests and gulf-wide yelloweye rockfish harvests in 1978-1981. During each step, non-parametric bootstrapping was used to estimate variance and cv’s and the uncertainty passed forward. A coefficient of variation of 0.75 was applied to final estimates to capture the high degree of uncertainty in catch reconstructions.

Stage 1 SS-SPM
The state-space model assumed a Pella-Tomlinson surplus production model fixed such that the shape of the production curve peaks at $B_{msy} = B_{40}$ (i.e, at biomass 40% of virgin biomass). Catches were modelled as the sum of the known catches and the unknown discards. Biomass estimates were modelled with estimates and CV*'s* from the submersible/ROV surveys and CPUE estimates from the IPHC survey. Uncertainty (observation error) in biomass estimates, CPUE estimates and unknown discards were passed through the model.

For the Pella-Tomlinson model, true biomass in year *t* and management area *s* was modelled with multiplicative log-normal error with variance σ^2_{proc} such that biomass was,

$$B_{s,t} = \left(B_{s,t-1} + \frac{r_s}{p} B_{s,t-1}\left(1 - \left({B_{s,t-1}}/{K_s}\right)^p\right) - C_{s,t-1}\right) e^{\varepsilon_t - \left({\sigma^2_{proc}}/{2}\right)};\ \varepsilon_t \sim N\left(0, \sigma^2_{proc}\right) \quad (17)$$

where *B* is biomass, r_s is the intrinsic rate of increase in the management area, K_s is the carrying capacity (virgin biomass) in management area *s*, $C_{s,t}$ is the catch and *p* is the parameter which alters the shape of the production curve. The *p* parameter was fixed at 0.18815 to ensure that B_{msy} occurred at B_{40}. The term $\frac{r}{p} B_{t-1}\left(1 - \left({B_{t-1}}/{K}\right)^p\right)$ represents the assumed relationship between surplus production and biomass. Process error was modelled without spatial heterogeneity such that annual deviations from predicted biomass occurred uniformly across management areas.

Because biomass in 1980 is some unknown proportion of carrying capacity, *K*, B_{1980} was modeled as

$$B_{s,1980} = \phi_s K_s \quad (18)$$

where ϕ_s was assumed to be between 0 and 1.

Biomass estimates from the submersible surveys were treated as estimates of true biomass such that observed biomass was

$$B.obs_{s,t} = B_{s,t} e^{\epsilon_{B.obs_{s,t}}} \quad (19)$$

where $B_{s,t}$ is the generic true biomass in management area *s* in year *t*, and in which $\{\epsilon_{B.obs_{s,t}}\} \sim N(0, \sigma^2_{B.obs_{s,t}})$ with

$$\sigma^2_{B.obs_{s,t}} = \ln\left(\left(CV(B.obs_{s,t})\right)^2 + 1\right) \quad (20)$$

Given that the biomass estimates from the submersible surveys contain a degree of uncertainty greater than the estimated *CV*'s, $CV\left(B.obs_{s,t}\right)$ for submersible surveys before 2012 (when the department switched to ROV's) was modelled with a variance inflation term τ_B, estimated within the model, such that

$$CV\left(B.obs_{s,t}\right) = \sqrt{CV\left(B.obs_{s,t}\right)^2 + \tau_B^2} \quad (21)$$

where $CV(B_{obs})$ is the *CV* of the estimated biomass from the submersible surveys. This effectively put less weight on biomass estimates from the submersible surveys relative to the more recent ROV surveys.

Similarly, the IPHC CPUE estimates were treated as indices of true abundance such that IPHC CPUE in management area *s* in year *t* was

$$I_t = infq_s B_{s,t} e^{\epsilon_{I_{s,t}}} \quad (22)$$

where q is a factor of proportionality relating true biomass to the index. To facilitate the algorhythm's ability to estimate posteriors an inflation term, *inf*, equal to $1x10^{-7}$ put the IPHC CPUE values on the same scale as the biomass estimates. $B_{s,t}$ is the generic true biomass in which $\{\epsilon_{I_{s,t}}\}{\sim}N(0,\sigma^2_{I,s,t})$ with

$$\sigma^2_{I,s,t} = \ln\left(\left(CV(I_{s,t})\right)^2 + 1\right) \tag{23}$$

As with the submersible surveys, variability in the CPUE estimates likely underestimated variability in relation to true biomass so the estimated *CV*'s, $CV(I_{s,t})$ was modelled with an inflation term τ_I, estimated within the model, such that

$$CV(I_{s,t}) = \sqrt{CV(I)^2 + \tau_I{}^2} \tag{24}$$

where *CV(I)* is the *CV* of the IPHC CPUE estimate. This also effectively down-weighted the likelihoods associated with the IPHC CPUE estimates relative to ROV based biomass estimates.

Catches in year t and management unit s, $C_{s,t}$, were modelled as the sum of the known catches and the unknown discards such that

$$C_{s,t} = \hat{C}^K_{s,t} + D_{s,t} \tag{25}$$

where $\hat{C}^K_{s,t}$ are known catches and $D_{s,t}$ are unknown discards. Estimated known catches $\hat{C}^K_{s,t}$ were modelled with log-normal error such that

$$\hat{C}^K_{s,t} = C^K_{s,t} e^{\epsilon_{Cs,t}} \tag{26}$$

in which $\{\epsilon_{Cs,t}\}{\sim}N(0,\sigma^2_{Cs,t})$ and

$$\sigma^2_{Cs,t} = \ln\left(\left(CV\left(C^K_{s,t}\right)\right)^2 + 1\right) \tag{27}$$

"Known" catches were assigned a *CV* of 0.1.

Discards, *D*, were modelled as the difference between expected bycatch in the halibut fishery, EBy, and landed bycatch recorded in fish ticket data, *landBy*, such that

$$D_{s,t} = \widehat{EBy}_{s,t} - landBy_{s,t} \tag{28}$$

where

$$\widehat{EBy}_{s,t} = EBy_{s,t} e^{\epsilon_{Bys,t}} \tag{29}$$

in which $\{\epsilon_{By,s,t}\}{\sim}N(0,\sigma^2_{By,s,t})$ and

$$\sigma^2_{By,s,t} = \ln\left(\left(CV\left(EBy_{s,t}\right)\right)^2 + 1\right) \tag{30}$$

$CV(EBy_{s,t})$ is the CV of expected bycatch estimated using the IPHC survey data. When landed bycatch exceeded estimates of expected bycatch, discards were calculated as 1.

Further uncertainty was added to the model to account for possible differences in the nature of the halibut fishery prior to becoming an Individual Fishing Quote (IFQ) system in 1995. Thus, discards in pre-IFQ years were modelled with extra uncertainty and variance such that

$$D_{s,t} = \widehat{EBy}_t e^{\varepsilon^D_{s,t} - \left(\sigma^2_{derby}/2\right)} - landBy_{s,t};\ \varepsilon^D_{s,t} \sim N\left(0, \sigma^2_{derby}\right) \tag{31}$$

where σ_{derby} was set to 0.1. This formulation facilitated a risk analysis of how under- or overestimating bycatch in the derby-style halibut fishery would affect biological reference points by making $\varepsilon^D_{s,t}$ normally distributed around -0.3 (indicating that WCPUE methods overestimate bycatch in the pre-IFQ halibut fishery by ~ 30%) or 0.3 (indicating that WCPUE methods underestimate bycatch in the pre-IFQ halibut fishery by ~ 30%). These values were chosen subjectively based on the amount of variation already included in the model.

Biomass, catch, discards and other quantities were calculated at the level of the entire SEO by summing across the management area estimates.

Biological reference points were calculated such that maximum sustained yield, *MSY*, is

$$MSY_s = {r_s * K_s}\Big/{(p+1)^{\left(p+1/p\right)}} \tag{32}$$

The biomass that produces *MSY*, B_{msy}, is equal to $0.4*K_s$ and the fishing pressure that leads to *MSY*, F_{msy}, is equal to MSY/B_{msy}. The status of the stock biomass relative to *K* was calculated in the state-space model and stock status was estimated within the model as B_{curr}/B_{40}. Biological reference points were calculated for management units and at the SEO level but harvest recommendations were calculated at the management area level.

Stage 1 Priors

In the first stage of the SS-SPM analysis non-informative priors were chosen where possible to minimize their effects on the posteriors (Table 6). Carrying capacity of the subdistricts, K_s, were given a non-informative, uniform prior on $\log(K_s)$ while ϕ_s, the proportional relationship between K_s and biomass in 1980, was given an uninformative beta prior describing a uniform distribution between 0 and 1. The extra variance terms linking true biomass to biomass estimates (τ_B) and IPHC indices (τ_I) were given uninformative, uniform priors.

The prior for process error was generated with a uniform distribution for the log(variance) associated with σ_{proc} but was restricted to a relatively narrow range with upper bounds of either -3 or -5 such that maximum σ_{proc} was set at 0.22 and 0.08, respectively. These two bounds are referred to as the moderate process error models (maximum σ_{proc} = 0.22) and minimal process error models (maximum σ_{proc} = 0.08). In general, SPM's perform better when estimating observation error and ignoring process error (Polacheck et al. 1993) and observation error only models are considered most appropriate for long-lived species for which large natural fluctuations are rare (Ono et al. 2012). The risk of overestimating MSY also increases with higher process error and restraining process error thus leads to a more conservative assessment (Zhang 2013). Although restrictive, allowing a small amount of process error was deemed appropriate given the extreme long life and slow growth of yelloweye rockfish.

The intrinsic rate of biomass increase, r_s parameters were fit to a common hyper prior, R, described by a beta distribution such that the beta shape parameters for each r_s allowed for uniform "shrinkage" between 0 and 0.95 towards the hyper prior mean (Table 6, Albert and Hu 2020). The prior placed on $log(\eta)$, the parameter determining the degree of shrinkage, was non-informative with a uniform distribution. However, to facilitate convergence the term was truncated to exclude shrinkage values between 0.95 and 1. These values were extremely rare in initial model runs as the bulk of the posterior indicated a much lower degree of shrinkage towards R. The truncation thus had no impact on the final shape of the posteriors and allowed for the models to converge in a more reasonable amount of time.

Stage 2 SS-SPM

The goal of the Stage-2 model was to take advantage of a complete catch history (and the associated uncertainty) of yelloweye rockfish for the SEO produce informed priors for the K_s and ϕ_s parameters in the Stage-3 model. This model presumed that the population was in it's virgin state in 1888 when the time series begins and used the posterior estimates of SEO biomass in years 1994-2021 (the years during which submersible and ROV surveys have occurred) from the Stage-1 model as "estimates" of biomass during those years. Although using the posteriors as estimates of true biomass in another model might be generally considered "poor form", it was deemed appropriate for extending the results from Stage-1 back to the virgin state for the purpose of developing priors that would only partially determine the posterior distribution of parameters in Stage-3 (the other determinant being the likelihoods) when the original, spatially stratified, data was reapplied.

The Pella-Tomlinson SS-SPM takes on the same form as equation 17, but without the subscript s denoting management area. Because it was assumed that this model begins in an unfished state B_{1880} was set equal to K. Biomass estimates from the Stage-1 posteriors were treated as estimates of true biomass such that posterior biomass was

$$B_t^{Stage.1} = B_t e^{\epsilon_{B_t^{stage.1}}} \tag{33}$$

where B_t is the generic true biomass in year t, and in which $\{\epsilon_{B.stage1_t}\} \sim N(0, \sigma^2_{B.stage1_t})$ with

$$\sigma^2_{B_t^{stage.1}} = \ln\left(\left(CV(B_t^{stage.1})\right)^2 + 1\right) \tag{34}$$

Catches in year t, C_t, were modelled as the sum of the known catches, unknown discards and removals from the foreign fleet that operated in SEO waters between 1961 and 1982 such that

$$C_t = \hat{C}_t^K + D_t + \hat{C}_t^F \tag{35}$$

where $\hat{C}_t^K$ are known catches, D_t are unknown discards, and $\hat{C}_t^F$ are estimates of catches by the foreign fleet. Estimated known catches $\hat{C}_t^K$ and D_t were modelled as described in Stage-1 (but at the SEO level rather than the management area level) and foreign catches were modeled similarly with log-normal error such that

$$\hat{C}_t^F = C_t^F e^{\epsilon_{C_t^F}} \tag{36}$$

in which $\{\epsilon_{C_t^F}\} \sim N\left(0, \sigma^2_{C_t^F}\right)$ and

$$\sigma^2_{C_t^F} = \ln\left((CV(C_t^F))^2 + 1\right) \tag{37}$$

CV's for the foreign removals were large owing to uncertainty in species identification and poor record keeping and were modelled with a value of 0.75.

Stage 2 priors

Stage 2 required fewer priors given it's simpler structure and uninformative priors were chosen so as to produce priors for Stage-3 that were not the result of undue assumptions. *K* was given an uninformative prior such that log(*K*) was uniformly distributed. Priors for process error (log variance) and halibut derby error were identical to that used in Stage-1 and the *R* prior was described with an uninformative beta distribution (Table 6).

Stage-3 SS-SPM and priors

The Stage-3 model is identical to the Stage-1 model and used the same data with the only difference being the change in priors for K, K_s, ϕ, and ϕ_s (Appendix C). Additionally, a suite of *R* priors developed with a projected Leslie matrix were examined (McAllister et al. 2001). The prior for *K* was derived by taking the mean and standard deviation of the posterior distribution of log(*K*) from Stage-2 such that Stage-3 log(*K*) was normally distributed around those values. *K* served as a hyper prior for management unit K_s in Stage-3 such that a Dirichlet distribution was used to describe the relationship between the four K_s parameters and *K* (Table 6). The Dirichlet distribution is often described as a multivariate version of the beta distribution such that any combination of more than two proportions must sum to 1. Thus the K_s parameters were equal to $pi_s* K_s$ where the pi_s parameters are values between 0 and 1 fit to an uninformative Dirichlet prior (Table 6).

The management area ϕ_s parameters were fit to a hyper prior ϕ that was derived from the posterior distribution of the biomass in 1980 relative to *K* in Stage-2. The hyper prior ϕ had a mean and standard error equal to that of the Stage-2 posterior and the ϕ_s were drawn from the hyper prior such that their prior was described with a mean of ϕ and a standard error set to an uninformative gamma distribution (Table 6; Albert and Hu 2020).

In general, SPMs are sensitive to the choice of prior on *r* (Magnusson and Hilborn 2007; Ono et al. 2012; Hilborn and Punt, etc.). Although Stage-1 models ran successfully with a non-informative prior on *R*, several informed priors were developed and examined to determine if more precise estimates of biological reference points could be produced. Informed priors for *R* were derived by projecting a Leslie matrix forward in the absence of density-dependent effects to reflect population growth at low population levels (McAllister et al. 2001). Using the Bayesian methods outlined by McAllister et al. (2001) a yelloweye rockfish population was simulated under several assumptions of natural mortality, *M*, larval daily mortality in the first year of life, *Z*, and age at maturity, *AaM* (Table 7). Fecundity, *f*, was modelled with a two-parameter model based on fish length using genera level parameters derived in Dick et al. (2017) and length-at-age was estimated using a Von Bertelanffy (LvB) growth curve fit to length-at-age data from port side sampling in Southeast Alaska. *M*, *AaM*, and the parameters determining *f* and *LvB* curves were estimated with error in the projected Leslie matrix with the standard error of the *f* parameters drawn from Dick et al. (2017). *LvB* parameters and associated uncertainty were derived by fitting the port sampling length and age data using the r package "*fishmethods*" (Nelson, G. A. 2022) (Table 7). Values for *M* and *AaM* were chosen based on literature (Love et al. 2002; Tsou and Wallace 2006; COSEWIC

2008; Yamanaka and Logan 2010; Lee et al. 2011; Arthur 2020). Values for Z were more subjective but centered around 0.05 given applications in other studies (Spencer et al. 2013). The matrix was projected forward 500 years to ensure a stable age distribution and the posterior distribution of the ratio of population change between year 499 and year 500 was taken as a prior for R. The results of different combinations of M, AaM, and Z were examined, and several priors were chosen based on the shapes of the distributions.

Eight candidate models were examined in Stage-3 to determine a preferred model. These models varied over the two levels of process error (minimal and moderate) and four priors on R including the uninformative prior and three informative priors derived with the projected Leslie matrix. Models were compared and evaluated using DIC and deviance scores as well as by comparing posterior distributions of model parameters.

Stage 3 projections and risk analysis

The Stage-3 model was used to project the population into the future under alternative harvest scenarios and under different scenarios of bycatch rates in the pre-IFQ halibut fishery. Biomass was projected into the future using the surplus production model and associated process error. Fishing rates in the future were based on the NPFMC guidelines such that the OFL was based on natural mortality, M, and biomass. In surplus production models F_{msy} is considered a proxy for M (Gulland 1970) and thus the F_{OFL} would be equal to F_{msy} and the maximum allowable F_{ABC} would be set at 0.75* F_{msy}. The point estimates of management area specific F_{msy} was taken from the preferred model and then used in separate model runs that projected the population forward 50 years. The preferred model was run under three scenarios that reflected the different bycatch rates in the pre-IFQ halibut fishery and incorporated the appropriate priors from Stage-2 models derived under those scenarios. Harvests were based on the median estimated biomass in each of the four management units and the area specific F_{msy} estimates from the preferred model. For each of the three states of nature (i.e., possible pre-IFQ bycatch rates) the projections were run with harvest rates calculated as the max F_{ABC} and proposed recommended F_{ABC}'s that represented a 10 and 25% reduction from the maximum allowable F_{ABC}. The risk analysis was also performed using the preferred model and ABCs derived from the status-quo method of multiplying 0.02 by the point estimates and lower 90% confidence intervals of biomass.

In addition to process error, future catches were given an extra error term to reflect deviations from the prescribed fishing pressure. Future catch was modelled with multiplicative log-normal error with variance σ_{FC}^2 such that

$$FC_{s,t} = F_{ABC} * B_{s,t} e^{\varepsilon_t^{FC} - \left(\sigma_{FC}^2/2\right)}; \ \varepsilon_t^{FC} \sim N(0, \sigma_{FC}^2) \tag{38}$$

with a prior on $\log(\sigma_{FC}^2)$ uniformly distributed between -10 and -4.

The risk table assessed the population status in the future relative to biomass at 40% of virgin biomass, B_{40}. For each of the projections the proportion of the posterior distribution of biomass in 2073 that was greater than B_{40} was used as the metric. The probability of the three "states of nature" that described the uncertainty surrounding the nature of bycatch in the pre-IFQ halibut fishery were assigned according to the relative fit of the models according to DIC scores.

Sampling from the posterior distribution and convergence checks
Bayesian models were implemented using the R platform (www.r-project.org) and implemented in the software program JAGS (Plummer 2003; Plummer 2013) and the JAGS wrapper package jagsUI. MCMC samples were drawn from the joint posterior probability distribution of all unknowns in the models. For results presented here, 3 Markov chains were saved. Stage-1 models were run for 1.4 million iterations with the first 500,000 discarded as burn-in. From the remaining samples every 900th sample was used to estimate the marginal posterior medians, standard deviations, and percentiles. Stage-2 models were run for 1.6 million iterations, the first 640,000 samples discarded as burn-in and every 960th sample used to approximate posterior distributions. Stage-3 models were run for 1.5 million iterations with the first 500,000 discarded as burn-in and every 1,000th sample used to estimate the posterior distributions.

Posterior distributions were checked for convergence by examining trace plots, Gelman-Rubin statistics (Gelman and Rubin 1992), autocorrelation, and Geweke convergence diagnostics, using the R-package ggmcmc (Marín 2016). The goodness of fit of models to the data was evaluated using posterior predictive analysis where values near 0.5 signify good fit (Gelman et al. 1996; Michielsens et al. 2006, Gelman 2013) and systematic discrepancies between observed and predicted data were examined. Gelman-Rubin statistics were examined to ensure they did not exceed 1.01 and trace plots were visually examined for a lack of autocorrelation and consistent patterns across the chains. Autocorrelation plots were examined to ensure a lack of autocorrelation in posterior samples. The chain length and burnin time described above were chosen to satisfy these conditions.

Results and Discussion

Density estimates
Density estimates demonstrated a high degree of volatility during the early years of submersible research, with more consistency present since the adoption of the ROV in the past decade. Overall density estimates indicated some decline in most management areas over the course of the time series but appear to have leveled off or display a slight upward trend in recent years (Table 8; Figure 7). The EYKT density estimates have shown a substantial decline since 2003 and the CSEO area has also exhibited a large decrease in density since 2003. SSEO has experienced a decline in density since 1999, with a significant drop apparent in 2013. Only three density estimates are available for the NSEO of which only two have been completed since the adoption of the ROV. For a more complete description of previous submersible estimates, refer to Brylinsky et al. (2009).

Status-quo Biomass Estimates (Model 21 and 21.1)
Biomass estimates for the SEO demonstrated a general downward trend over the course of the time-series, with a slight upward trajectory in recent years (Figure 8). The early portion of the time series differed considerably from past SAFE reports (Wood et al. 2021) due to efforts in this year's assessment to calculate biomass in a consistent way based on published management area estimates of density (Table 8) and the weight of harvested yelloweye rockfish (Table 1). Results from past reports were not immediately reproducible owing to staff turnover and a lack of documentation and will likely entail a large-scale retrospective study of archival data to resolve. Differences in estimated biomass in the early years are likely a product of evolving estimates of yelloweye habitat (i.e., the DYRH), differences in how

density estimates were applied to management areas and the entire SEO, and different weight data. Results were consistent from 2005 onward with minor deviations owing to changes in the weight sample. The status-quo biomass estimate for the SEO in 2022 was 18,471 mt (SE = 3,771, lower 90% confidence interval = 12,135 mt).

REMA results (Model 22.1 and 22.2)

The REMA models demonstrate an increase in the stability of biomass estimates over time and more consistent apportionment by area when compared to status-quo methods. The best-fitting model by AIC from the Model 22.1 series shared a single process error parameter across all management areas and estimated unique scaling parameters for each area for the CPUE index (Figure 9; Table 9). The model with both area-specific process errors and scaling parameters failed to converge, indicating there was insufficient data in each management area to warrant a more complex parameterization. The best-fitting model by AIC from the Model 22.2 series estimated one additional observation error variance for the biomass data (Figure 9; Table 9). The model with additional observation error for both biomass and CPUE survey data failed to converge, which suggests the there was insufficient data to parse measurement and process error for both survey indices.

Process error variance was estimated to be higher in Model 22.1 (Table 9), and consequently, the Model 22.1 biomass trajectory was more variable and thus more likely to respond to noise in the data (e.g., the 1995 CSEO or 2003 EYKT biomass estimates; Figure 9). As a result, the decline in biomass between the late 1990s and 2010 has a slightly different trajectory between the two models, though in recent years, they show a high level of agreement (Figure 1). Model selection results indicated that there was statistical support for the additional observation error for the biomass data in Model 22.2 (delta AIC > 9), which suggests that design-based estimates of variance in the survey may be an underestimate the true measurement error. The Model 22.1 total biomass estimate for SEO in 2022 was 18,258 t (SE = 1,879 t, lower 90% confidence interval = 15,176 t). The Model 22.2 total biomass estimate for 2022 was 17,846 t (SE = 2,028 t, lower 90% confidence interval = 14,520 t).

SS-SPM results (Model 22.3)

Bycatch and discard estimation: Despite substantial variability in WCPUE estimates (bycatch rates) over time and between SEO subdistricts, the rates demonstrated no consistent temporal trends and ranged from 2 to 13% since the IPHC began longline surveys (Figure 10). The WCPUE bycatch rates appeared to capture the magnitude and dynamics of bycatch rates in the halibut fishery during recent years when this data is available. Comparisons of SEO-wide WCPUE estimates and NOAA Catch Accounting System estimates of bycatch in the SEO align well since 2013 (Figure 11; Alaska Fisheries Information Network). Even during the two years where the data demonstrates some discrepancies, the difference between the two methods was ~1%. Secondly, full retention of rockfish in the halibut fishery was phased in between 2000 and 2005 and since that time estimates of expected bycatch derived from WCPUE estimates reflect the trend and magnitude of landed bycatch (Figure 12).

Estimating bycatch data where none exists is difficult and will deservedly come under scrutiny. Although expected bycatch estimates derived from the WCPUE rates largely agree in terms of scale and trend, discrepancies remain. Resolving some of those discrepancies may be possible by refining the derivation of expected bycatch estimates. For instance, tuning the WCPUE estimates to more accurately reflect the behavior of the halibut fishery would be useful. Information such as the depth profile and spatial pattern of the fishery could be two useful parameters in deriving WCPUE estimates that more accurately reflect the habitat being “sampled” by the halibut fleet. Furthermore, a more detailed examination of how the halibut fishery would have differed during the pre-IFQ years would be insightful.

This analysis also ignored the change in legal size of halibut from 26 to 32 inches in 1983, although this is likely a minor issue. IPHC survey data classifies sampled halibut as either over or under 32 in. so it was not possible to directly model that regulatory change. However, examination of how the WCPUE estimates would change when all captured halibut are included, rather than just legal halibut, demonstrated a small decrease in the WCPUE estimates. Given that the decrease in WCPUE would be less pronounced than that demonstrated by including all halibut in the estimate, it was decided that the uncertainty already included in the analysis would be sufficient at this time.

There are, however, limitations to what refinement is possible in deriving bycatch rates that are useful for estimating bycatch in the past. Given the longevity of the yelloweye rockfish and the history of the halibut fishery, it is unlikely that detailed data on the halibut fishery are available to make detailed refinements to these methods such as those suggested above. As such, it is important to propagate the uncertainty in bycatch through the analysis. For estimates of bycatch prior to IPHC surveys the maximum CV for each area’s WCPUE estimates was applied to pre-1998 bycatch estimates. Furthermore, for pre-IFQ years (pre-1995) an extra variance term was added to modelled bycatch to further reflect the uncertainty in those estimates. Lastly, a risk analysis was performed to determine the effects of over- or underestimating bycatch in pre-IFQ years.

Stage-1 model fit and performance: Stage-1 models performed satisfactorily with posterior predictive checks showing agreement and a lack of bias between simulated and observed biomass, P-values very close to 0.5 (Gelman 2013; Figure 13) and general agreement between posterior estimates and the data (Figure 14, 15 and 16).

The model failed to converge completely across all parameters, but results were deemed acceptable for the purposes of developing priors. Most parameters demonstrated good convergence, exhibiting desirable traceplot patterns, a lack of autocorrelation in posterior samples and Gelman-Rubin statistics less than 1.01. Most importantly, the information being passed forward to Stage-2, the biomass estimates, were completely converged. The alpha term in the beta prior for r_s, *rB1*, (Table 6) was the term that failed to reach complete convergence in Stage-1 models. However, examination of the posterior distribution and traceplots show that differences in MCMC chain values were due to a long, extremely thin tail in the distribution but that the chains nevertheless described the same distribution. More importantly, the r_s values derived from *rB1* and *rB2* parameters were fully converged. Other parameters that failed to converge were estimates of discards when the discards were near zero. Although not converged as measured by Gelman-Rubin statistics, the posterior distributions of the 3 chains were all at the minimum (1 mt) and thus did not influence the estimation of key parameters in the model.

Stage-1 models demonstrated minimal sensitivity to potential bias in the bycatch rates in the pre-IFQ halibut fishery. DIC scores demonstrated better fit when the model assumed bycatch rates were higher in the pre-IFQ fishery (Table 10), but posterior distributions of key parameters demonstrated minimal effects of under- or overestimating pre-IFQ bycatch rates (Figure 17). The scale of potential discards relative to know catches (which include landed bycatch) since 1980 partially explained these results as potential discards were a minor portion of the overall removals (Figure 18).

Most encouraging was that Stage-1 performed well in the absence of an informed prior for *R*. Surplus production models are sensitive to misspecification of this prior (Ono et al. 2012) and the model's ability to perform with an uninformative prior meant that generating priors for *K* and ϕ in Stage-2 could be accomplished without making undue assumptions. This also suggested there was sufficient information in the data for the model to estimate *R* and the model would be somewhat robust to the choice of prior. This was particularly encouraging given the uninformative priors also placed on K_s and ϕ_s in Stage-1.

Another relevant result of Stage-1 was the extra variance terms on pre-2012 submersible surveys (τ_B) and IPHC CPUE data (τ_I). What is readily apparent in figure 14 is the relatively poor fit of early biomass estimates to data derived from the early submersible estimates of density. Allowing the model to estimate the extra variance demonstrated a relatively high value for these data points (τ_B mean = 0.38, sd = 0.13). Although not directly comparable owing to CV values, the IPHC CPUE data demonstrated better fit to the data and an estimated extra variance term, τ_I of mean 0.14 (sd = 0.065). The poor fit of the early submersible biomass estimates is unsurprising given uncertainty surrounding the methodology and other factors associated with an evolving approach during the early years of the program. In the future it may be worthwhile to examine archival data to determine how these estimates were derived, or, alternatively, to explore censorship of these data points in future models. Regardless, it is apparent that one of the benefits of the SS-SPM approach is the incorporation of catch data that ultimately smooths out the jagged trajectory evident in the raw biomass estimates that is unlikely in a long-lived species.

Stage-2 model fit and performance: Stage-2 models performed satisfactorily with posterior-predictive checks showing agreement between simulated and observed biomass (P-value = 0.49 for all Stage-2 models) and general agreement to posterior estimates in agreement with the data (Figures 19 and 20). Stage-2 models incorporating minimum process error demonstrated good convergence across key parameters including *K* and biomass in 1980, used to establish the ϕ parameter for Stage-3. However, the models that used the moderate level of process error failed to converge completely across all parameters, and in particular the *K* parameter fell short of complete convergence. Failure to converge completely was likely the result of the higher degree of process error in the model coupled with the uninformative priors on parameters and large variances in the bycatch and catch data.

Despite the lack of full convergence, the posterior distribution of *K* and biomass in 1980 were deemed stable enough to develop priors for *K* and ϕ for use in Stage-3 (Figure 21). Posteriors of *K* in the minimal process error model fit cleanly into a log-normal distribution. Posteriors for *K* in the moderate process error model required some trimming of the tail to produce a clean log-normal distribution and the assumption is that running those models to complete convergence would likely result in similarly clean log normal distributions. The shape of the developed priors for *K* and ϕ were broad but nevertheless more informative than Stage-1 priors with the *K* prior lognormally distributed around 43,584 mt (sd = 14,450) for the minimal process error model and 50,084 mt (sd = 22,763) mt in the moderate process error model. The ϕ priors were normally distributed around 0.74 (sd = 0.18) for the minimal process error model and 0.68 (sd 0.21) for the moderate process error model (Figure 21). It is worth noting here that posterior estimates of ϕ included values above 1 indicating that there was a significant chance that the population remained near virgin biomass levels in 1980.

Stage-2 model results demonstrated more sensitivity to potential bias in bycatch estimates, but the differences were not drastic (Figure 21). Posterior distributions of *K* showed that a presumed underestimation of bycatch in the halibut fleet of 30% would result in estimates of *K* that were 8% and 13% higher in the moderate and minimal process error models, respectively, while overestimation of "true" bycatch rates would result in *K* estimates that were 9% and 5% lower in the moderate and minimal process error models. The effect on ϕ was the opposite. When "true" bycatch rates were 30% higher than predicted by WCPUE estimates ϕ was 7% and 9% lower in the moderate and minimal process error models where-as it was 8% and 4% higher in the two models when "true" bycatch was 30% lower than that predicted by WCPUE estimates. Posterior distributions of *R* were relatively unaffected by biases in bycatch rates (Figure 22). Assessing model fit with DIC ranking was inconclusive in Stage-2 models such that fit was best in the model with unbiased estimates of bycatch in the moderate process error model but the model with "true" bycatch higher than predicted was best in the minimal process error model (Table 10). Nevertheless, the posterior distributions and resulting priors demonstrated significant overlap (Figure 21).

R prior development: Projected Leslie matrices of simulated yelloweye rockfish populations produced a suite of potential priors to apply to the *R* hyper prior in Stage-3 (Figure 23). The main source of variability in the projections was the daily mortality rate applied to larval fish in the first year of life (*Z*). Variability in estimates of *R* were much less sensitive to changes in natural mortality, *M*, and age at maturity. This may be partially explained by the variability that *M* and age-at-maturity were modelled with in the projections while *Z* was modelled as a fixed value (Table 7). Of the four beta distributions derived from the Leslie matrix projections the three broadest were applied in Stage-3.

Stage-3 model fit and performance: As with Stage-1 and -2 models, Stage-3 models performed satisfactorily with posterior-predictive checks showing agreement, a lack of bias between simulated and observed biomass (P-values ranging between 0.46 and 0.54) and general agreement to posterior estimates of biomass and catch in agreement with the data (Figure 24. Catch fit plots are not shown but were nearly identical to Figure 15 and 16 from Stage-1). The model was also able to estimate process error within the narrow range allowed (Figure 25).

The models converged across most parameters and the models with minimal process error demonstrated better convergence. Of particular importance, r_s and K_s and the associated *R* and *K* estimates used to calculate biological reference points showed good convergence with Gelman-Rubin values below 1.01, desirable traceplot behavior and a lack of autocorrelation in posterior samples. The *invtau* parameter (Table 6) describing the variance in ϕ_s failed to converge in most models. Examination of traceplots and posteriors demonstrated desirable behavior but with rare outlier values (i.e., 1-3 per 1000 samples) resulting in a very long, thin tail in the posterior distribution. The fact that these values were so rare meant that they tended to occur in different parts of each MCMC chain which caused Gelman-Rubin statistics greater than 1.01, despite otherwise consistent distributions in the posterior. Future analysis should consider truncation for this term that would not affect the overall distribution of the parameter but allow for full convergence of the model.

Posterior estimates of biomass produced very similar estimates to that derived in the REMAs (Figure 1). Both approaches smoothed out the volatility evident in the status-quo methodology and are probably better representatives of the true dynamics in the population given the life history of yelloweye rockfish.

Both models used the biomass estimates from ADF&G submersible/ROV data and the IPHC CPUE index of abundance and the similar trends suggest the value of incorporating the IPHC CPUE index despite the uncertainty in those estimates.

Posterior estimates of key parameters and biological reference points demonstrated considerable breadth in credibility intervals despite using informed priors for K and ϕ. The posteriors were more precise than Stage-1 models, however (see Figure 14 versus Figure 24), and DIC scores indicated better fit of Stage-3 models relative to Stage-1 (Table 10). Although the eight candidate models demonstrated differences in point estimates, there was significant overlap in the posterior distributions among models. DIC scores demonstrated some interaction between process error and R hyper prior values (Table 4). The top ranked model was the moderate process error model combined with the broadest R prior derived from the projected Leslie matrix. However, the four next best models were all minimal process error models and were ranked above the moderate process error models for all R priors other than the broadly informative one. The best fitting minimal process error model had the uninformative R prior although the model with the narrowest R prior was ranked a close third.

Posterior distributions of key parameters showed robustness to differences in both process error and R priors (Table 11). In particular, biomass projections for 2023 demonstrated remarkable consistency across models in both the mean and overall distribution, suggesting high confidence in those estimates (Figure 26). Posterior estimates of R demonstrated some sensitivity to the prior and to the amount of process error, but considerable agreement in the overall distribution even when an uninformative prior was applied (Figure 27). More informative priors narrowed the posterior distributions as did lower process error. The top two models based on DIC ranking showed similar posterior distributions for R indicating some interaction between the amount of process error allowed in the model and the model's ability to estimate R. The r_s posterior distributions demonstrated more uncertainty and variability among models, although overall patterns were similar (Figure 27). The r_s values for the NSEO demonstrated the broadest posteriors given the management area has the fewest data points, whereas the model demonstrated the greatest resolution in the SSEO.

Estimates of virgin biomass demonstrated significantly more consistency between models both at the SEO level and the management area level (Figure 28). Minimal process error models demonstrated more precision in the posteriors and slightly lower mean values. Posterior distributions of pi_s, describing the proportional relationship of management area virgin biomass to SEO-wide virgin biomass, demonstrated consistency across all models (Figure 29).

Posterior estimates of ϕ_s also demonstrated broad consistency across models, although the estimates were imprecise even with the informed hyper prior placed on ϕ (Figure 30). The three largest management units were skewed heavily towards the upper bound of ϕ indicating that the model predicted 1980 biomass to be near virgin status and very likely above B_{40}. The area with the fewest data points, the NSEO, had the most uncertainty in ϕ_s estimates and the model favored values suggesting that NSEO biomass in 1980 was well below the virgin state. The NSEO was surveyed in summer of 2022 and video review and density estimates will be available to update the model in the winter of 2022-2023. Given that it will mark only the third ROV survey completed in the area, the data point has potential to influence model output both for the NSEO and how it relates to the other areas.

Posterior estimates of B_{msy} and F_{msy} demonstrated a large range of uncertainty around the estimates (Figures 31 and 32). Estimates of B_{msy} at the SEO level were fairly consistent between *R* priors while estimates were slightly lower and more precise in the minimal process error models. There was considerably more uncertainty in the management area B_{msy} estimates, although the same pattern relative to model specification remained (Figure 31). F_{msy} estimates varied between models and were lower when process error was lower and more precise in the presence of informed *R* priors (Figure 32). However, despite differences at the point estimate level, there was broad agreement in the distribution of the posteriors. Posteriors of F_{msy} were also heavily skewed and for that reason OFL and ABC limits were based on the median, rather than the mean, of the F_{msy} posterior distributions.

Estimates of stock status (how current biomass relates to B_{40} which is also B_{msy} in this model) indicated fairly broad agreement between models, but considerable imprecision (Figure 33). SEO-level posterior distributions were very consistent across models and indicate that the SEO as a whole is near B_{40}. Point estimates of the mean and median were slightly above that reference point, but with considerable uncertainty. At the management area level, there was more variability in stock status between models, with considerable uncertainty in all and overlap amongst the posterior distributions (Figure 33). The models indicated that the SSEO appears to be in the most robust shape with the highest probability of being over B_{40} while the NSEO appears to be in worst shape with the bulk of the posterior suggesting the population is below B_{40}. The EYKT and CSEO demonstrate an even chance that they are above B_{40} (Figure 33).

The preferred model selected for management recommendations and risk analysis was the model with max σ_{proc} of 0.08 and the uninformed *R* prior. This model was selected based on the better overall fit of minimal process error models, the suitability of applying minimal process error to long-lived species, and the lack of assumptions needed with regard to *R*. This model estimated projected biomass in 2023 to be 18,026 mt (SD = 1,859) and has a median F_{msy} of 0.013 (mean = 0.016, sd = 0.014). Median F_{msy} for the four management areas is 0.013 (mean = 0.019, sd = 0.02) for the EYKT, 0.019 (mean = 0.026, sd = 0.025) for the NSEO, 0.012 (mean = 0.016, sd = 0.016) for the CSEO and 0.011 (mean = 0.015, sd = 0.016) for the SSEO. This model was used to project the population 50 years into the future using a max $F_{ABC} = 0.75^* F_{msy}$ with the recommended F_{ABC} set at 10 and 25% below the max F_{ABC}.

Population projections and risk analysis:

Examination of the relative fit of Stage-3 models under various assumptions about the bycatch rate in the pre-IFQ halibut fishery demonstrated that the model with pre-IFQ halibut fishery bycatch rates higher than WCPUE rates had the best fit, followed by the model with unbiased assumptions and lastly the model that assumed that true bycatch in pre-IFQ halibut fishery was lower than WCPUE rates (Table 10). As such, the probability for the different states of nature were assigned such that the model that assumed pre-IFQ bycatch rates to be similar to IFQ bycatch rates was 40%, the model that assumed that bycatch was higher in the pre-IFQ fishery was assigned 40% and the model that assumed that bycatch was lower was assigned 20% (Table 12).

The risk analysis results reflected much of the uncertainty present in the data and SS-SPM but demonstrated clear trends that are useful for selecting management targets (Table 12). Estimates of Biomass in 2022 indicate that the population is more likely above B_{40} and three of the four management units are as well. Only the NSEO is more likely to be below B_{40} in 2022. When “true” bycatch in the pre-

IFQ halibut fishery was assumed to be higher than IPHC survey predictions the probability of being above B_{40} was lower than the unbiased model where-as the trend was reversed when the pre-IFQ halibut fishery bycatch was assumed to be lower than IPHC survey predictions.

The probability that the population remains above B_{40} in 50 years with constant fishing pressure set equal to the max F_{ABC} = 0.75*F_{msy} was generally lower than in 2022 with the exception of the NSEO (Table 12). With fishing pressure close to F_{msy} the management areas above B_{40} in 2022 will likely see some declines as they are fished towards B_{40}. Furthermore, because of uncertainty in the model many iterations of possible population states will be overfished in this approach. Because the NSEO is estimated to be below B_{40} in 2022 these fishing pressures are low enough to allow that population to increase towards a more likely probability of being above B_{40} in 2073. Reducing the F_{ABC} by 10% increased the probability that the SEO population remains above B_{40} in 2073 by 3.7% while reducing F_{ABC} by 25% increased that probability by 9.2%.

The risk analysis showed higher risk of overfishing if the status-quo method of setting F_{ABC} is continued. Using the lower 90% confidence interval of status-quo biomass and applying F=M=0.02 to those estimates resulted in a population that had only a 36% chance of remaining above B_{40} in 2073 (Table 12). Because the status quo method does not account for potentially different productivity among management areas (see r_s values in Figure 27) some management areas show sharp declines in model predictions. In particular, the SSEO shows high probability of overfishing with those fishing pressures. Unsurprisingly, fishing with F_{ABC} calculated using the point estimates of biomass and F=M=0.02 demonstrated a high probability (81.5%) that the population will be below B_{40} in this scenario (Table 12).

It is worth noting that the best ranked model according to DIC scores (moderate process error and the broad R prior, Table 10) provided higher estimates of R and r_s (Table 11) and thus F_{msy} (Figure 32), but the risk analysis ultimately suggests similar harvest rates to the preferred model. Although F_{msy} is higher in that model, the probability that the population is over B_{40} in 2022 is lower; 51.4% versus 59.9% in the preferred model. Thus, to achieve a similar probability of keeping the population over B_{40} in 2073 requires reductions to the F_{ABC} of over 25% ultimately resulting in similar harvest recommendations (Appendix D).

Using the results of the SS-SPM to establish F_{ABC} will result in a substantial reduction in the harvest limits relative to past years (See executive summary). However, those limits remain above the harvests that have occurred in recent years as a results of fishing restrictions in place since 2020. The apparent uptick in biomass in recent years suggests these limits may be appropriate and continued ROV surveys by the department will help to more precisely estimate appropriate fishing levels in the future.

SS-SPM Conclusions

Despite considerable uncertainty in the SS-SPM and risk analysis the results represent an honest appraisal of uncertainty in both the catch data and biomass estimates. The population appears to be in the vicinity of B_{40} and results suggest that the population is most likely not overfished. The model also strongly suggests very low r values, which translate to low F_{msy} values well below the 0.02 that has been applied to this stock over the last 15 years. The low r estimates coupled with the population's likely existence near B_{40} suggests that continued conservative management is the most appropriate approach going forward. The upward trend in biomass in recent years coincides with a closed directed fishery for DSR and restricted sport fisheries that has resulted in low harvests below the ABC being recommended by this assessment.

Continued research by the department will improve future assessments and should lead to more precise estimates of biological reference points. Despite uncertainty in potential bias of ROV based biomass estimates, the trends in the data since 2012 reflect plausible population dynamics for such a log-lived species. ROV surveys are scheduled to continue and the NSEO was surveyed in 2022 such that density estimates for this area will be available this winter. The department has also been evaluating the size of the DYRHs which will provide more accurate estimates of habitat availability and possibly produce variance estimates for that component of the biomass calculations. This is also the first year that the IPHC survey data has been incorporated in the assessment and the general agreement between ROV data and IPHC CPUE indices is promising for monitoring the stock going forward.

The SS-SPM has been presented to the plan team in recognition that it is somewhat unconventional relative to most federal assessments. If the model is accepted by the plan team and the SSC there are multiple avenues of model development that are worth exploring and refining. The SS-SPM presented here assumes the B_{msy} occurs at B_{40}, which may not be accurate for a slow growing, long lived species and thus it may be worth examining a traditional Schaefer model where B_{msy} occurs at B_{50} or estimating the p parameter in the model by applying an informed prior. Current versions of the model run very slowly (~12 hours for Stage-3) hindering the ability to perform a large suite of sensitivity tests. However, SPMs may perform faster if biomass is reparametrized such that $B_t = p_t*K$ owing to increased mixing speed in the Gibbs sampler (Ono et al. 2012). Further sensitivity testing is also warranted with regard to possible censorship of biomass estimates from the beginning of the time series. The 1994 surveys could be censured on the grounds that a belly camera was not installed in the manned submersible until 1995 (leading to possible bias in density estimates) while surveys before 2003 could be censured on the grounds that transect lengths were not accurately measured with GPS. Biologists operating the ROV have also suggested that biomass is being underestimated as there appears to be good yelloweye rockfish habitat outside of the DYRHs. While those areas have likely experienced similar depletions to that estimated in the model, underestimates of biomass may be restricting fishing more than necessary. The ADF&G Statewide Rockfish Initiative (SRI: ADF&G) is currently reevaluating the DYRHs and a sensitivity analysis examining the effects of underestimating biomass may be worthwhile.

Harvest Recommendations

Amendment 56 Reference Points

Amendment 56 to the GOA Groundfish Fishery Management Plan defines the "overfishing level" (OFL), the fishing mortality rate used to set the OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set the ABC (F_{ABC}) may be less than this maximum permissible level but not greater. Yelloweye rockfish are managed under Tier 4 and the rest of the DSR assemblage is managed under Tier 6 because reliable estimates of spawning biomass and recruitment are not available. In using a surplus production model, F_{msy} is taken as a proxy for natural mortality and thus OFL would be set as 234 t. The maxABC would be set at $0.75*M$ and thus 176 t. Based on results from the risk analysis and the probability that future biomass 50 years from now will be above B_{40} we recommend a further reduction in the recABC of 10% to 158 t in the executive summary *but solicit feedback from the plan team with regard to establishing these limits*. Continued conservatism in managing this fishery is warranted given the life history of the species, the uncertainty of the biomass estimates and uncertainty of biological reference points B_{msy}, *MSY*, and F_{msy}.

Specification of F_{OFL} *and the maximum permissible ABC*
In past years the following scenarios were used to establish permissible F_{ABC} under status-quo methodology:

Scenario 1: F equals the maximum permissible F_{ABC} as specified in the ABC/OFL definitions. For Tier 4 species, the maximum permissible F_{ABC} is $F_{40\%}$=0.026, corresponding to a yield of 342 t (including 20 t for other DSR species).

Scenario 2: F equals the stock assessment author's recommended F_{ABC}. In this assessment, the recommended F_{ABC} is F=M=0.02, and the corresponding yield is 268 t (including 20 t for other DSR species).

Scenario 3: F equals the 5-year average F from 2018 to 2022. The true past catch is not known for this species complex, so the 5-year average is estimated at F=0.02 (the proposed F in all 5 years), and the corresponding yield is 248 t (including 20 t for other DSR species).

Scenario 4: F equals 50% of the maximum permissible F_{ABC} as specified in the ABC/OFL definitions; 50% of $F_{40\%}$ is 0.013, and the corresponding yield is 171 t (including 20 t for other DSR species).

Scenario 5: F equals 0. The corresponding yield is 0 t.

With the new assessment brought forth this cycle the department is requesting guidance from the plan team to establish recommended F_{ABC}. Under Tier 4, projections of harvest scenarios for future years are usually not possible. However, the application of the SS-SPM to this stock provided the opportunity for projecting the population under various harvest scenarios. It is the understanding of the authors that using the SS-SPM would not satisfy the conditions necessary to move to Tier 3 and thus recommendations presented here are based on an assessment of shortraker rockfish that formerly employed surplus production models (Spencer and Reuter 2008). Given that F_{msy} from the SS-SPM is a proxy for natural mortality, M, the department proposes setting F_{OFL} to F_{msy} and the maximum allowable ABC to 0.75* F_{msy}. The department would like to choose a recommended F_{ABC} based on the results of population projections that maximize the chances that biomass in 50 years is more than likely to be greater than B_{40} (Table 12). *The authors request guidance from the plan team on how to structure this portion of the SAFE report if the plan team and SSC decide to accept the SS-SPM as the preferred model for yelloweye rockfish assessment*. The executive summary table compares proposed OFL and ABC's using the status-quo methods, the REMA model biomass estimates and the SS-SPM model.

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Tables, Figure and Appendices

Table 1. The average weights (kg), number sampled, and the standard deviation for yelloweye rockfish from East Yakutat (EYKT), Northern Southeast Outside (NSEO), Central Southeast Outside (CSEO), and Southern Southeast Outside (SSEO) management areas of the Southeast Outside subdistrict (SEO) of the Gulf of Alaska, 1984–July 2022.

Year	EYKT			NSEO			CSEO			SSEO		
	Average Weight	# YE	SD	Average Weight	# YE	SD	Average Weight	# YE	SD	Average Weight	# YE	SD
1984	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	3.19	1142	1.42	3.08	163	1.32
1989	-	-	-	3.26	50	0.95	3.20	767	1.44	3.48	89	1.04
1990	-	-	-	-	-	-	3.12	52	1.56	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	3.22	21	1.44
1993	-	-	-	-	-	-	-	-	-	-	-	-
1994	3.54	50	1.48	-	-	-	-	-	-	4.52	50	1.43
1995	3.44	200	0.98	-	-	-	3.16	390	1.32	3.71	150	1.21
1996	3.45	249	1.14	3.52	100	1.29	3.12	580	1.23	3.32	462	1.37
1997	3.81	396	1.30	-	-	-	3.01	389	1.11	3.16	205	1.24
1998	4.06	423	1.36	-	-	-	3.18	153	1.23	3.14	175	0.97
1999	3.78	260	1.03	-	-	-	3.16	557	1.13	3.37	103	1.29
2000	3.56	130	1.01	-	-	-	3.15	120	0.93	3.64	367	1.28
2001	4.54	108	1.39	-	-	-	3.42	225	1.20	3.34	171	1.12
2002	-	-	-	-	-	-	3.22	310	1.21	3.47	399	1.24
2003	-	-	-	-	-	-	3.03	277	1.16	3.45	73	1.33
2004	3.80	535	1.25	-	-	-	3.20	140	1.17	3.40	138	1.19
2005	4.30	274	1.59	-	-	-	-	-	-	-	-	-
2006[a]	-	-	-	-	-	-	-	-	-	-	-	-
2007[a]	-	-	-	-	-	-	-	-	-	-	-	-
2008	3.86	250	1.59	4.02	100	1.36	3.16	358	1.18	3.51	140	1.32
2009	4.18	264	1.60	3.55	85	1.28	3.53	467	1.18	3.53	170	1.32
2010	4.73	84	1.54	4.03	223	1.64	3.39	327	1.27	3.40	293	1.18
2011	4.23	151	1.62	3.84	195	1.43	3.17	420	1.14	3.37	137	1.23
2012	4.34	917	1.56	4.39	83	1.89	3.48	671	1.14	3.66	250	1.27
2013	4.19	455	1.54	-	-	-	3.25	466	1.15	3.52	429	1.33
2014	3.67	421	1.10	3.68	99	1.11	3.37	417	1.16	-	-	-
2015	4.00	375	1.44	4.10	202	1.39	3.47	455	1.18	-	-	-
2016	3.83	452	1.44	4.04	180	1.38	3.47	509	1.21	3.32	155	1.22
2017	3.87	550	1.35	-	-	-	-	-	-	-	-	-
2018	-	-	-	-	-	-	3.69	562	1.22	-	-	-
2019	4.08	182	1.67	3.37	40	1.20	3.49	493	1.23	3.49	553	1.25
2020	4.17	55	1.22	3.86	85	1.24	3.42	84	1.05	-	-	-
2021	4.22	607	1.53	3.43	126	1.24	3.46	300	1.09	4.19	46	1.12
2022	-	-	-	-	-	-	-	-	-	3.79	15	1.19

Table 2.–Catch (t) of demersal shelf rockfish from research, directed commercial, incidental commercial, estimated unreported discards from the halibut fishery, recreational, subsistence, and total catch from all fisheries in the Southeast Outside (SEO) Subdistrict, 1992–July 2022. Also included are allowable biological catch (ABC), overfishing level (OFL), and total allowable catch (TAC) for 1992–2022. Commercial catch includes redbanded rockfish from 1992–1996 and also include discards at sea/at the dock and catch retained for personal use.

Year	Research	Directed	Incidental	Unreported Discards	Recreational[b]	Subsistence[c]	Total	ABC[d]	OFL[d]	TAC[d]
1992	0	362	168	191	16	8	745	550	-	550
1993	15	342	230	267	20	8	882	800	-	800
1994	4	383	268	283	34	8	980	960	-	960
1995	14	155	123	72	25	8	398	580	-	580
1996	12	345	94	135	28	8	622	945	-	945
1997	16	267	105	217	38	8	651	945	-	945
1998	2	241	119	175	47	8	592	560	-	560
1999	2	240	125	175	33	8	584	560	-	560
2000	8	183	105	150	53	8	507	340	-	340
2001	7	173	145	113	49	8	495	330	-	330
2002	2	136	148	128	47	8	469	350	480	350
2003	6	102	168	95	48	8	427	390	540	390
2004	2	174	155	170	60	8	568	450	560	450
2005	4	42	192	157	72	8	475	410	650	410
2006[e]	2	0	204	49	87	8	350	410	650	410
2007[e]	3	0	196	48	82	8	337	410	650	410
2008	1	42	152	36	81	8	321	382	611	382
2009	2	76	140	34	47	8	306	362	580	362
2010	7	30	133	31	63	8	271	295	472	287
2011	5	22	88	12	50	6	183	300	479	294
2012	4	105	77	10	55	7	258	293	467	286
2013	4	129	84	11	47	7	282	303	487	296
2014	5	33	64	8	47	7	164	274	438	267
2015	4	33	70	9	57	8	181	225	361	217
2016	4	34	79	10	51	7	186	231	364	224
2017	5	32	94	12	54	7	204	227	357	220
2018	6	51	80	10	53	7	207	250	394	243
2019	10	45	89	11	59	7	221	261	411	254
2020[e]	6	0	99	12	4	7	129	238	375	231
2021[a,e]	6	0	99	12	6	7	121	257	405	250
2022	-	0	107	15	6	7	141	268	422	261

[a] Landings from ADF&G fish ticket database, updated through October 26, 2021.

[b] Recreational harvest for 1992–1998 referenced from Table 1 in Chadwick et al. 2017; recreational harvest for 1999–2021 include retained harvest plus estimated release mortality discard.

[c] These data were not available or deducted from the ABC prior to 2009. Harvest interviews have not been conducted since 2015 but were estimated for all years to account for subsistence harvest that occurred.

[d] ABC for CSEO, NSEO, and SSEO only (not EYKT) in 1993. ABC, OFL, and TAC based on lower 90% confidence interval.

[e] The directed commercial demersal shelf rockfish fishery was closed to harvest in SEO.

Table 3.–Catch data for Tier 6 calculations for non-yelloweye demersal shelf rockfish (DSR). These catch data represent for each species, the highest year (maximum sum) of commercial, subsistence, and recreational catch during 2010–2014. The 2010–2014 time period is used because the three-time series of catch data (commercial, recreational, and subsistence) overlap.

Species	**Scientific Name**	**Max catch (t) 2010–2014**	**OFL (t)**	**ABC (t)**
Canary rockfish	*S. pinniger*	5.6	5.6	4.2
China rockfish	*S. nebulosus*	1.4	1.4	1.1
Copper rockfish	*S. caurinus*	4.4	4.4	3.3
Quillback rockfish	*S. maliger*	13.9	13.9	10.4
Rosethorn rockfish	*S. helvomaculatus*	0.0	0.0	0.0
Tiger rockfish	*S. nigrocinctus*	0.8	0.8	0.6
Sum Tier 6 (t)			**26.1**	**9.6**

Table 4.–Commercial landings (t) of demersal shelf rockfish by species in Southeast Outside (SEO) Subdistrict, 2012–October 2021. Discards (at sea and at dock) and personal use included.

Species	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**[a]
Canary	3.35	3.21	0.55	0.69	1.17	0.82	2.94	1.12	0.69	0.64
China	0.03	0.05	0.03	0.02	0.11	0.05	0.06	0.08	0.15	0.04
Copper	0.04	0.04	0.03	0.02	0.15	0.13	0.09	0.06	0.09	0.15
Quillback	4.30	4.07	2.15	2.75	3.43	3.05	3.40	5.76	3.86	2.81
Rosethorn	0.03	0.04	0.01	0.03	0.17	0.28	0.17	0.07	0.20	0.09
Tiger	0.42	0.32	0.26	0.23	0.33	0.22	0.22	0.14	0.12	0.49
Yelloweye	183.97	217.05	102.55	108.83	118.57	133.59	135.01	137.84	106.27	97.86
Total (t)	192.14	224.78	105.57	112.56	123.94	138.14	141.88	145.07	111.38	102.08
Percent Yelloweye	95.75	96.56	97.14	96.68	95.67	96.71	95.16	95.02	95.42	95.87

[a] Preliminary commercial data from ADF&G fish ticket database, updated through October 26, 2021.

Table 5. Reported foreign catches (metric tons) in the Gulf of Alaska groundfish fishery, 1960-1987.

Year	All rockfish incl. P.O.P.	All rockfish excl. POP	Gulfwide Yelloweye	Southeastern Yelloweye
1960	NF	NF	NF	NF
1961	16,000	NA	NA	NA
1962	50,000	NA	NA	NA
1963	114,338	NA	NA	NA
1964	241,772	NA	NA	NA
1965	374,322	NA	NA	NA
1966	151,976	NA	NA	NA
1967	124,191	NA	NA	NA
1968	101,241	NA	NA	NA
1969	74,126	NA	NA	NA
1970	62,942	NA	NA	NA
1971	79,043	NA	NA	NA
1972	79,561	NA	NA	NA
1973	63,888	12,965	NA	NA
1974	54,174	10,262	NA	NA
1975	61,767	11,354	2,104	NA
1976	55,222	11,393	NA	NA
1977	23,577	8,970	294.1	NA
1978	10,058	1,893	38.4	0.1
1979	12,289	4,366	10.65	5.4
1980	16,649	8,975	34.4	20.1
1981	17,860	8,842	168.58	0.13
1982	9,680	6,436	13.38	NF
1983	7,867	6,086	60.91	NF
1984	3,178	1,615	4.15	NF
1985	13.4	7.7	0.32	NF
1986	4.2	4.1	1.1	NF
1987	NF	NF	NF	NF

NF – No foreign fishing.

NA – Not Available.

Sources: Berger et al. 1984, 1985, 1987; Berger and Weikart 1988; Forrester et al. 1978, 1983; Nelson et al. 1983; Wall et al. 1978, 1979, 1980, 1981, 1982

Table 6. Priors used in the Stage-1, -2 and -3 state-space surplus production models used to estimate biomass and biological reference points for management. MA stands for management area (i.e., EYKT, NSEO, CSEO and SSEO).

Parameter	Symbol	Spatial Scale	Stage	Prior(s)	Truncation
Intrinsic rate of increase	R	SEO (hyper prior)	1 and 2	Beta (1, 1)	(0.0001,0.2)
			3	Beta (1, 1) Beta (1.483, 22.908) Beta (1.247, 31.478) Beta (1.241, 53.481)	
	r_s	MA	1 and 3	Beta (*rB1*, *rB2*) $rB1 = R*\eta$ $rB2 = (1-R)*\eta$ $ln(\eta)$ ~ logis (ln(100), 1)	(-5,7.55)
Carrying capacity/ virgin biomass	$ln\ (K_s)$	MA	1	U (7, 11.5)	
	K_s	MA (from hyper prior)	3	$K_s = K*pi_s$ $pi_s \sim Dirichlet(1, 1, 1, 1)$	
	$ln\ (K)$	SEO	2	U (ln (5000), ln (175,000))	
		SEO (hyper prior)	3	Norm (*see figure 21*)	
Proportional relationship between K_s and B_{1980}	ϕ_s	MA	1	Beta (1,1)	
		MA (from hyper prior)	3	Norm (ϕ, *invtau*) *invtau* ~ gamma(1,1)	
Proportional relationship between K and B_{1980}	ϕ	SEO (hyper prior)	3	Norm *(see figure 21)*	
Process error	*ln(var)* for σ_{proc}	SEO	all	U (-10, -3) and U (-10, -5)	
	ε		all	Norm (0, σ_{proc}^2)	(-0.1,0.1)
Extra variance for submersible biomass estimates and IPHC CPUE	τ_B and τ_I	SEO	1 and 3	U (0.01, 1)	
"catchability" parameter scaling IPHC CPUE data to biomass	$ln(q_s)$	SEO	1 and 3	U (-10, 20)	
Extra error and bias in bycatch rates in pre-IFQ halibut fishery	$\varepsilon_{s,t}^{D}$	SEO	1, 2 and 3	Norm (0, 0.1) *or* Norm (-0.3, 0.1) *or* Norm (0.3, 0.1)	

Table 7. Parameter values used to project a Leslie matrix in a Bayesian framework to derive a prior for the *R* hyper prior in the SS-SPMs.

Parameter	**Distribution**	**Mean**	**Standard deviation**	**Notes**
M, natural annual mortality	Log normal	0.02, 0.025, 0.03, 0.04, 0.05	0.3	
Z, natural daily mortality of larval rockfish during their first year	Fixed	0.04, 0.045, 0.05, 0.055	NA	
AaM, average age at maturity	Normal	15, 17, 20	2	
fa, fecundity parameter *a* describing the relationship between egg/larval production and fish length[a]	Log normal	$6.538e^{-6}$	1.4	Truncated at lower and upper 95^{th} percent confidence intervals
fb, fecundity parameter *b* describing the relationship between egg/larval production and fish length[a]	Log normal	4.043	0.081	
Linf, parameter in the LvB equation[b]	Normal	655.415	1.425	
Kp, parameter in the LvB equation[b]	Normal	0.0420	0.000684	
t0, parameter in the LvB equation[b]	Normal	-9.886	0.425	

[a] from Dick et al. 2017
[b] Parameters estimated by fitting port side sampling yelloweye rockfish data to LvB curves with the "*fishmethods*" package in r.

Table 8.–Submersible (1994–1995, 1997, 1999, 2003, 2005, 2007, 2009) and ROV (2012–2013, 2015–2022) yelloweye rockfish density estimates with 95% confidence intervals (CI) and coefficient of variation (CV) by year and management area. The number of transects, yelloweye rockfish (YE), and meters surveyed included in each model are shown, along with the encounter rate of yelloweye rockfish.

Area	Year	Number transects	Number YE[b]	Meters surveyed	Encounter rate (YE/m)	Density (YE/km^2)	Lower CI (YE/km^2)	Upper CI (YE/km^2)	CV
EYKT[a]	1995	17	330	22,896	0.014	2,711	1,776	4,141	0.20
	1997	20	350	19,240	0.018	2,576	1,459	4,549	0.28
	1999	20	236	25,198	0.009	1,584	1,092	2,298	0.18
	2003	20	335	17,878	0.019	3,825	2,702	5,415	0.17
	2009	37	215	29,890	0.007	1,930	1,389	2,682	0.17
	2015	33	251	22,896	0.008	1,755	1,065	2,891	0.25
	2017	35	134	33,960	0.004	1,072	703	1,635	0.21
	2019	**33**	**288**	**33,653**	**0.009**	**1,397**	**850**	**2,286**	**0.27**
NSEO	1994[c]	13	62	17,622	0.004	765	383	1,527	0.33
	2016	36	125	34,435	0.004	701	476	1,033	0.20
	2018	30	95	29,792	0.003	637	395	969	0.59
	2022				**pending video review…**				
CSEO	1994[c]	-	-	-	-	1,683	-	-	0.10
	1995	24	235	39,368	0.006	2,929	-	-	0.19
	1997	32	260	29,273	0.009	1,631	1,224	2,173	0.14
	2003	101	726	91,285	0.008	1,853	1,516	2,264	0.10
	2007	60	301	55,640	0.005	1,050	830	1,327	0.12
	2012	46	118	38,590	0.003	752	586	966	0.13
	2016	32	160	30,726	0.005	1,101	833	1,454	0.14
	2018	35	193	33,700	0.006	910	675	1,216	0.14
	2022	**32**	**153**	**27,428**	**0.006**	**1,178**	**824**	**1,535**	**0.16**
SSEO	1994[c]	13	99	18,991	0.005	1,173	-	-	0.29
	1999	41	360	41,333	0.009	2,376	1,615	3,494	0.20
	2005	32	276	28,931	0.010	2,357	1,634	3,401	0.18
	2013	31	118	30,439	0.004	986	641	1,517	0.22
	2018	32	345	31.073	0.011	1,582	1,013	2,439	0.20
	2020	**33**	**349**	**32,828**	**0.011**	**1,949**	**1,459**	**2,604**	**0.15**

[a] Estimates for EYKT management area include only the Fairweather grounds, which is composed of a west and an east bank. In 1997, only 2 of 20 transects - and in 1999, no transects - were performed on the east bank that were used in the model. In other years, transects performed on both the east and west bank were used in the model.

[b] Subadult and adult yelloweye rockfish were included in the analyses to estimate density. A few small subadult yelloweye rockfish were excluded from the 2012 and 2015 models based on size; length data were only available for the ROV surveys (not submersible surveys). Data were truncated at large distances for some models; as a consequence, the number of yelloweye rockfish included in the model does not necessarily equal the total number of yelloweye rockfish observed on the transects.

[c] Only a side-facing camera was used in 1994 and earlier years to video record fish. The forward-facing camera was added after 1994, which ensures that fish are observed on the transect line.

Table 9. Parameter estimates and their associated standard errors (SEs) and 95% confidence intervals for the candidate random effects models. All values have been transformed to an arithmetic scale for ease of interpretation. Model 22.1 and Model 22.2 share the same structure (single process error, area-specific scaling parameter), but Model 22.2 estimates additional observation error for the biomass data.

Model	**Parameter**	**Estimate**	**SE**	**LCI**	**UCI**
Model 22.1	Process error	0.103	0.027	0.062	0.173
Model 22.1	CSEO scaling parameter (*q*)	0.00000492	0.00000039	0.00000421	0.00000575
Model 22.1	EYKT *q*	0.00000193	0.00000021	0.00000155	0.00000239
Model 22.1	NSEO *q*	0.00001178	0.00000249	0.00000779	0.00001781
Model 22.1	SSEO *q*	0.00000347	0.00000035	0.00000285	0.00000424
Model 22.2	Process error	0.088	0.025	0.050	0.154
Model 22.2	CSEO *q*	0.00000483	0.00000056	0.00000385	0.00000607
Model 22.2	EYKT *q*	0.00000197	0.00000028	0.00000150	0.00000259
Model 22.2	NSEO *q*	0.00001213	0.00000312	0.00000733	0.00002008
Model 22.2	SSEO *q*	0.00000360	0.00000051	0.00000274	0.00000475
Model 22.2	Extra biomass observation error	0.240	0.064	0.138	0.393

Table 10. Table of deviance and DIC scores for selected Stage-1, -2, and -3 state-space surplus production models.

Comparison	Stage	Model Variable(s)	Deviance	DIC
Bias in WCPUE estimates of pre-IFQ halibut fishery	1	"true" bycatch rate **higher** than wcpue est.	4674.496	5034.617
		"true" bycatch **lower** than wcpue est.	4674.239	5040.747
		"true" bycatch rate **same as** wcpue est.	4675.111	5041.186
	2	"true" bycatch rate **same as** wcpue est.	-1611.39	-1207.42
		"true" bycatch **lower** than wcpue est.	-1612.05	-1197.71
		"true" bycatch rate **higher** than wcpue est.	-1611.51	-1183.43
	3	"true" bycatch rate **higher** than wcpue est.	4675.943	5029.636
		"true" bycatch rate **same as** wcpue est.	4675.577	5039.202
		"true" bycatch **lower** than wcpue est.	4675.683	5044.781
Process error	2	Max $\sigma = 0.22$	-1611.39	-1207.42
		Max $\sigma = 0.08$	-1611.9	-1193.92
R and Process error	3	Max $\sigma = 0.22$; R ~ beta(1.483, 22.908)	4674.253	5030.483
		Max $\sigma = 0.08$; R ~ beta(1,1)	4675.088	5032.161
		Max $\sigma = 0.08$; R ~ beta(1.241, 53.481)	4676.055	5033.534
		Max $\sigma = 0.08$; R ~ beta(1.247, 31.478)	4676.549	5035.82
		Max $\sigma = 0.08$; R ~ beta(1.483, 22.908)	4675.918	5040.69
		Max $\sigma = 0.22$; R ~ beta(1.247, 31.478)	4674.472	5051.692
		Max $\sigma = 0.22$; R ~ beta(1,1)	4674.493	5059.275
		Max $\sigma = 0.22$; R ~ beta(1.241, 53.481)	4675.132	5066.28

Table 11. Mean, median and standard deviation of posterior estimates of key model parameters for Stage-3 state-space surplus production models run with minimal and moderate process error, four beta priors applied to the *R* hyper prior that ranged from an uninformative uniform distribution, through the broad, moderate and narrowest beta distributions derived from the projected Leslie matrix and model runs assuming that pre-IFQ bycatch rates in the halibut fishery were unbiased, biased low or biased high.

Parameter	Mean/ Median (SD)									
	Minimal Process Error (max σ_{proc} = 0.08)						Moderate Process Error (max σ_{proc} = 0.22)			
	Uniform R			Broad R	Mod. R	Narrow R	Uniform R	Broad R	Mod. R	Narrow R
	Unbiased WCPUE	WCPUE > "true" bycatch	WCPUE < "true" bycatch	Unbiased WCPUE						
R	0.032/0.023 (0.032)	0.034/0.024 (0.033)	0.027/0.019 (0.027)	0.027/0.022 (0.021)	0.02/0.017 (0.015)	0.016/0.014 (0.012)	0.04/0.031 (0.035)	0.032/0.027 (0.024)	0.025/0.022 (0.018)	0.019/0.016 (0.014)
r_{EYKT}	0.022/0.016 (0.023)	0.023/0.017 (0.025)	0.018/0.013 (0.019)	0.021/0.016 (0.02)	0.017/0.013 (0.017)	0.014/0.011 (0.014)	0.032/0.023 (0.031)	0.028/0.022 (0.025)	0.023/0.018 (0.021)	0.017/0.013 (0.016)
r_{NSEO}	0.031/0.023 (0.029)	0.033/0.025 (0.031)	0.026/0.019 (0.025)	0.028/0.022 (0.025)	0.024/0.019 (0.021)	0.02/0.016 (0.02)	0.039/0.031 (0.033)	0.035/0.029 (0.027)	0.03/0.025 (0.023)	0.023/0.019 (0.02)
r_{CSEO}	0.019/0.015 (0.019)	0.021/0.016 (0.02)	0.016/0.013 (0.015)	0.019/0.015 (0.016)	0.016/0.013 (0.014)	0.013/0.01 (0.012)	0.029/0.022 (0.026)	0.026/0.022 (0.02)	0.021/0.018 (0.017)	0.016/0.013 (0.014)
r_{SSEO}	0.018/0.013 (0.019)	0.019/0.013 (0.021)	0.014/0.01 (0.015)	0.017/0.013 (0.017)	0.014/0.01 (0.014)	0.011/0.008 (0.011)	0.027/0.02 (0.026)	0.024/0.019 (0.021)	0.019/0.015 (0.018)	0.014/0.01 (0.014)
K	41,497/ 40,367 (8,747)	39,845/ 39,107 (7,938)	46,334/ 44,992 (9,997)	41,906/ 40,935 (8,545)	42,649/ 41,577 (8,524)	43,736/ 42,566 (8,907)	45,802/ 43,993 (12,103)	46,400/ 44,718 (11,511)	47,443/ 45,607 (11,843)	49,999/ 48,160 (12,811)
K_{EYKT}	10,345/ 9,303 (3,901)	10,040/ 9,074 (3,593)	11,494/ 10,198 (4,638)	10,461/ 9,343 (3,973)	10,585/ 9,431 (3,995)	11,056/ 9,882 (4,374)	11,532/ 10,235 (4,997)	11,659/ 10,429 (4,702)	11,888/ 10,566 (5,022)	12,671/ 11,069 (6,159)
K_{NSEO}	4,847/3,739 (3,373)	4,583/3,520 (3,377)	5,909/4,396 (4,538)	5,231/3,970 (3,910)	5,377/4,060 (3,977)	5,592/4,313 (4,002)	5,221/3,824 (4,158)	5,351/4,047 (3,968)	5,676/4,179 (4,609)	6,324/4,701 (5,136)
K_{CSEO}	14,379/ 13,342 (4,538)	13,782 /12,760 (4,306)	15,903 /14,416 (5,575)	14,271/ 13,275 (4,141)	14,621/ 13,551 (4,434)	14,997 /13,795 (4,948)	15,836/ 14,404 (5,915)	15,983/ 14,509 (5,597)	16,210/ 14,779 (5,579)	17,175/ 15,474 (6,724)
K_{SSEO}	11,926/ 10,830 (4,158)	11,439/ 10,540 (3,676)	13,029/ 11,670 (4,967)	11,943/ 10,843 (4,050)	12,067/ 11,106 (4,008)	12,090/ 11,026 (4,014)	13,212/ 11,886 (5,111)	13,408/ 12,104 (4,996)	13,669/ 12,215 (5,340)	13,829/ 12,451 (5,333)
ϕ	0.739/0.753 (0.213)	0.77/0.778 (0.204)	0.688/0.689 (0.222)	0.741/0.751 (0.208)	0.743/0.756 (0.21)	0.742/0.751 (0.211)	0.691/0.707 (0.248)	0.691/0.701 (0.246)	0.68/0.692 (0.249)	0.683/0.691 (0.249)

τ_{ϕ}	1.705/1.155 (2.418)	1.66/1.134 (1.923)	1.665/1.177 (1.764)	1.692/1.139 (2.277)	1.758/1.148 (2.465)	1.725/1.159 (2.521)	1.764/1.181 (3.124)	1.799/1.147 (4.252)	1.751/1.152 (2.64)	1.683/1.174 (1.846)
ϕ_{EYKT}	0.764/0.777 (0.239)	0.763/0.78 (0.237)	0.733/0.743 (0.246)	0.761/0.777 (0.242)	0.765/0.785 (0.238)	0.75/0.761 (0.242)	0.735/0.748 (0.251)	0.732/0.745 (0.248)	0.738/0.75 (0.249)	0.723/0.736 (0.253)
ϕ_{NSEO}	0.55/0.52 (0.292)	0.554/0.525 (0.288)	0.52/0.481 (0.295)	0.527/0.487 (0.293)	0.536/0.5 (0.293)	0.522/0.485 (0.282)	0.542/0.506 (0.295)	0.525/0.477 (0.294)	0.529/0.487 (0.296)	0.511/0.466 (0.291)
ϕ_{CSEO}	0.829/0.849 (0.211)	0.836/0.865 (0.213)	0.799/0.82 (0.224)	0.833/0.856 (0.206)	0.829/0.854 (0.209)	0.824/0.847 (0.215)	0.809/0.84 (0.225)	0.805/0.829 (0.223)	0.806/0.83 (0.219)	0.79/0.818 (0.23)
ϕ_{SSEO}	0.812/0.845 (0.224)	0.825/0.847 (0.216)	0.793/0.824 (0.234)	0.815/0.841 (0.219)	0.816/0.841 (0.217)	0.819/0.842 (0.219)	0.799/0.826 (0.232)	0.798/0.825 (0.233)	0.791/0.813 (0.234)	0.801/0.829 (0.23)
σ_{proc}	0.056/0.058 (0.017)	0.056/0.058 (0.017)	0.056/0.058 (0.017)	0.056/0.058 (0.017)	0.055/0.058 (0.018)	0.054/0.055 (0.018)	0.122/0.12 (0.055)	0.122/0.119 (0.054)	0.114/0.109 (0.053)	0.109/0.101 (0.053)
η	253/109 (351)	243/108 (346)	232/103 (328)	258/119 (347)	276/127 (366)	271/135 (352)	267/131 (349)	301/150 (373)	316/169 (380)	295/153 (367)
rB1	6.026/2.133 (11.827)	6.407/2.12 (12.069)	4.604/1.67 (7.985)	5.979/2.35 (9.653)	5.264/1.938 (9.213)	4.258/1.698 (7.196)	8.929/3.503 (14.971)	8.886/3.858 (13.098)	7.833/3.315 (11.903)	5.757/2.151 (9.458)
rB2	247/107 (344)	237/105 (337)	227/101 (322)	252/117 (339)	271/125 (359)	267/133 (346)	258/126 (337)	292/146 (363)	309/165 (371)	289/149 (359)
Pi_{EYKT}	0.25/0.241 (0.068)	0.253/0.243 (0.069)	0.249/0.234 (0.077)	0.25/0.238 (0.07)	0.248/0.236 (0.07)	0.253/0.238 (0.076)	0.252/0.242 (0.073)	0.252/0.243 (0.069)	0.251/0.24 (0.074)	0.253/0.239 (0.081)
Pi_{NSEO}	0.115/0.094 (0.065)	0.113/0.092 (0.066)	0.125/0.101 (0.079)	0.122/0.098 (0.074)	0.123/0.1 (0.073)	0.125/0.103 (0.072)	0.111/0.089 (0.068)	0.113/0.093 (0.065)	0.116/0.093 (0.071)	0.124/0.101 (0.078)
Pi_{CSEO}	0.348/0.34 (0.075)	0.346/0.34 (0.073)	0.344/0.336 (0.086)	0.342/0.338 (0.072)	0.344/0.336 (0.076)	0.344/0.336 (0.08)	0.346/0.338 (0.076)	0.345/0.338 (0.076)	0.344/0.337 (0.078)	0.345/0.335 (0.088)
Pi_{SSEO}	0.288/0.279 (0.071)	0.288/0.281 (0.069)	0.282/0.271 (0.08)	0.286/0.278 (0.071)	0.284/0.276 (0.071)	0.278/0.269 (0.072)	0.291/0.285 (0.074)	0.29/0.283 (0.074)	0.289/0.281 (0.076)	0.279/0.269 (0.078)
q_{EYKT}	2.191/2.165 (0.309)	2.186/2.16 (0.303)	2.188/2.159 (0.299)	2.192/2.167 (0.309)	2.198/2.167 (0.3)	2.194/2.169 (0.305)	2.179/2.152 (0.302)	2.193/2.166 (0.308)	2.19/2.168 (0.31)	2.198/2.178 (0.308)
q_{NSEO}	11.137/10.997 (2.2)	11.172/10.948 (2.321)	11.163/10.887 (2.331)	11.154/10.931 (2.363)	11.051/10.787 (2.297)	11.049/10.822 (2.214)	11.067/10.842 (2.265)	11.27/11.009 (2.418)	11.152/10.932 (2.256)	11.034/10.855 (2.253)
q_{CSEO}	5.098/5.068 (0.489)	5.121/5.092 (0.488)	5.099/5.066 (0.495)	5.117/5.078 (0.496)	5.121/5.1 (0.494)	5.119/5.107 (0.488)	5.083/5.05 (0.499)	5.093/5.061 (0.49)	5.088/5.061 (0.492)	5.09/5.068 (0.482)
q_{SSEO}	3.621/3.596 (0.432)	3.611/3.58 (0.417)	3.608/3.587 (0.415)	3.614/3.596 (0.407)	3.618/3.602 (0.416)	3.636/3.621 (0.423)	3.615/3.586 (0.425)	3.597/3.582 (0.413)	3.614/3.589 (0.418)	3.607/3.58 (0.417)
τ_B	0.373/0.352 (0.128)	0.372/0.352 (0.128)	0.373/0.355 (0.127)	0.375/0.352 (0.133)	0.37/0.351 (0.128)	0.375/0.355 (0.132)	0.37/0.351 (0.127)	0.373/0.352 (0.131)	0.374/0.351 (0.133)	0.375/0.354 (0.132)
τ_I	0.14/0.141 (0.063)	0.14/0.141 (0.064)	0.14/0.141 (0.064)	0.138/0.138 (0.065)	0.143/0.144 (0.063)	0.139/0.141 (0.064)	0.134/0.134 (0.064)	0.136/0.136 (0.063)	0.136/0.137 (0.064)	0.135/0.137 (0.063)

Table 12**.** Risk table displaying the probability that yelloweye rockfish biomass is above B_{40} in 2022 and in 2073 under constant harvests. Results are based on the preferred state-space surplus production model (minimal process error and the uninformative *R* prior). Harvest rates are based on median F_{msy} values and projected 2023 biomass estimates from the preferred SS-SPM model or from the status-quo biomass and harvest recommendations.

	Management Area	**Pre-IFQ bycatch rate relative to WCPUE est.** 30% lower	same	30% higher	**Overall Probability**
Pre-IFQ Probability:		0.2	0.4	0.4	1.0
Probability $\mathbf{B_{2022}}$ is above B_{msy}/B_{40}	EYKT	76%	71%	63%	68.5%
	NSEO	47%	44%	34%	40.6%
	CSEO	68%	63%	52%	59.5%
	SSEO	86%	83%	76%	80.5%
	All SEO	74%	65%	48%	59.9%
Projections: Probability $\mathbf{B_{2073}}$ is above B_{msy}/B_{40} under constant harvest **Harvest Calculation:**					
$F_{ABC} = 0.75*F_{OFL}$	EYKT	60%	57%	51%	55.2%
	NSEO	56%	53%	43%	49.8%
	CSEO	61%	57%	49%	54.3%
	SSEO	64%	61%	52%	58.0%
	All SEO	57%	53%	43%	49.5%
Rec F_{ABC} = 10% reduction of F_{ABC}	All SEO	61%	56%	46%	53.2%
Rec F_{ABC} = 25% reduction of F_{ABC}	All SEO	66%	62%	52%	58.7%
Status-quo = 0.02*Biomass lower 90% CI	EYKT	52%	49%	43%	47.2%
	NSEO	66%	62%	53%	59.2%
	CSEO	49%	45%	38%	43.0%
	SSEO	35%	31%	25%	29.6%
	All SEO	43%	38%	30%	36.1%
Status-quo = 0.02*Biomass point estimate	All SEO	24%	20%	14%	18.5%

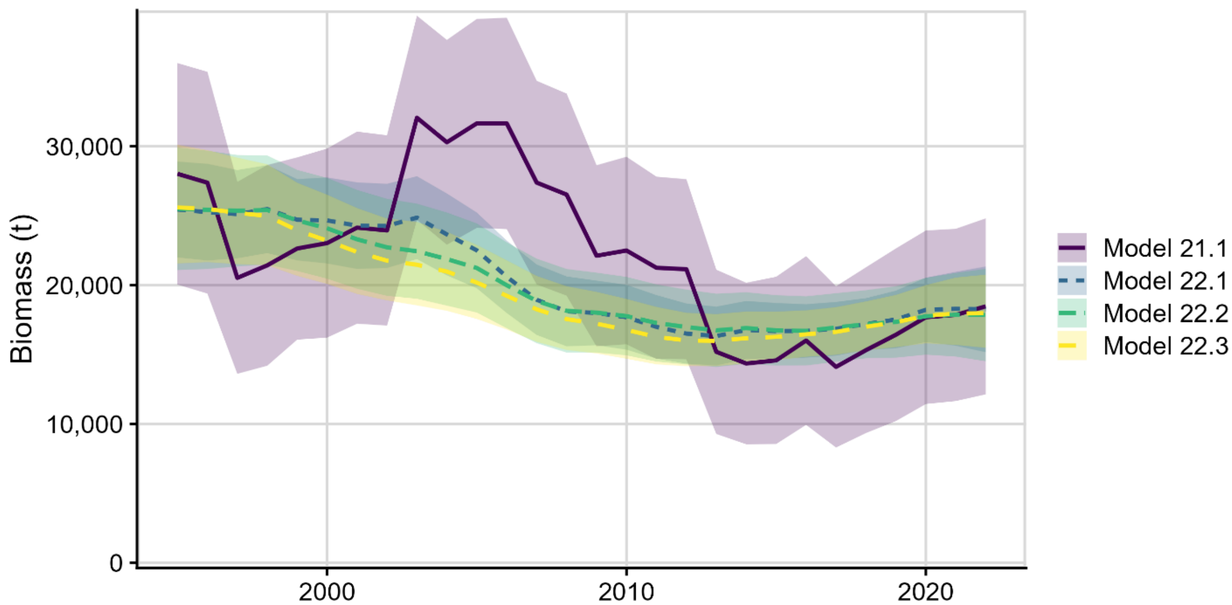

Figure 1. Total Southeast Outside (SEO) yelloweye rockfish biomass (t) with 90% confidence intervals from the four alternative models, 1995-2022. Model 21.1 uses status-quo methods with revised values calculated directly from published density estimates, Model 22.1 uses the two-survey random effects (REMA) model, Model 22.2 is Model 22.1 but estimates additional observation error for the biomass data, and Model 22.3 uses the Bayesian state-space surplus production model (SS-SPM).

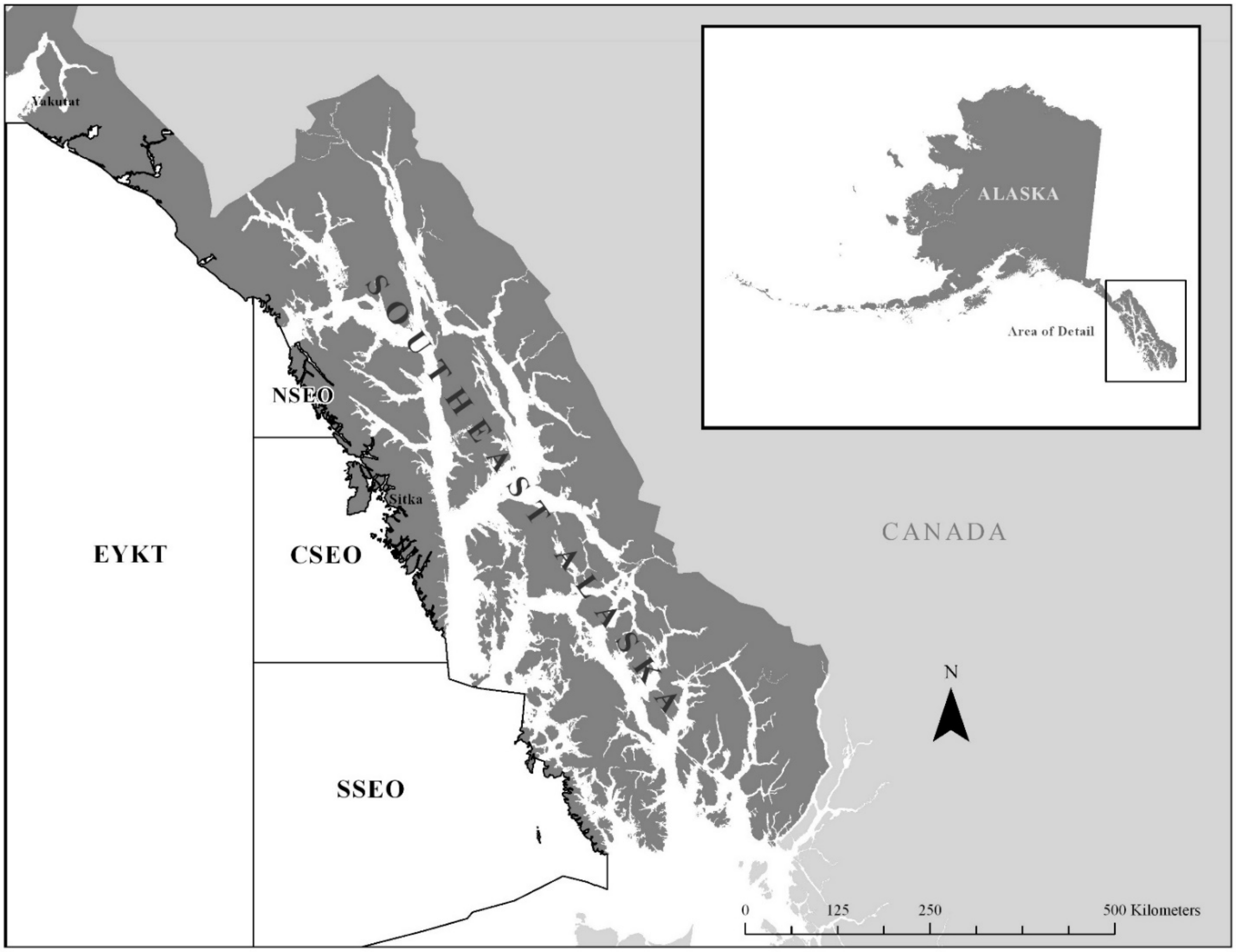

Figure 2.–The Southeast Outside Subdistrict of the Gulf of Alaska (SEO) with the Alaska Department of Fish and Game groundfish management areas used for managing the demersal shelf rockfish fishery: East Yakutat (EYKT), Northern Southeast Outside (NSEO), Central Southeast Outside (CSEO), and Southern Southeast Outside (SSEO) Sections.

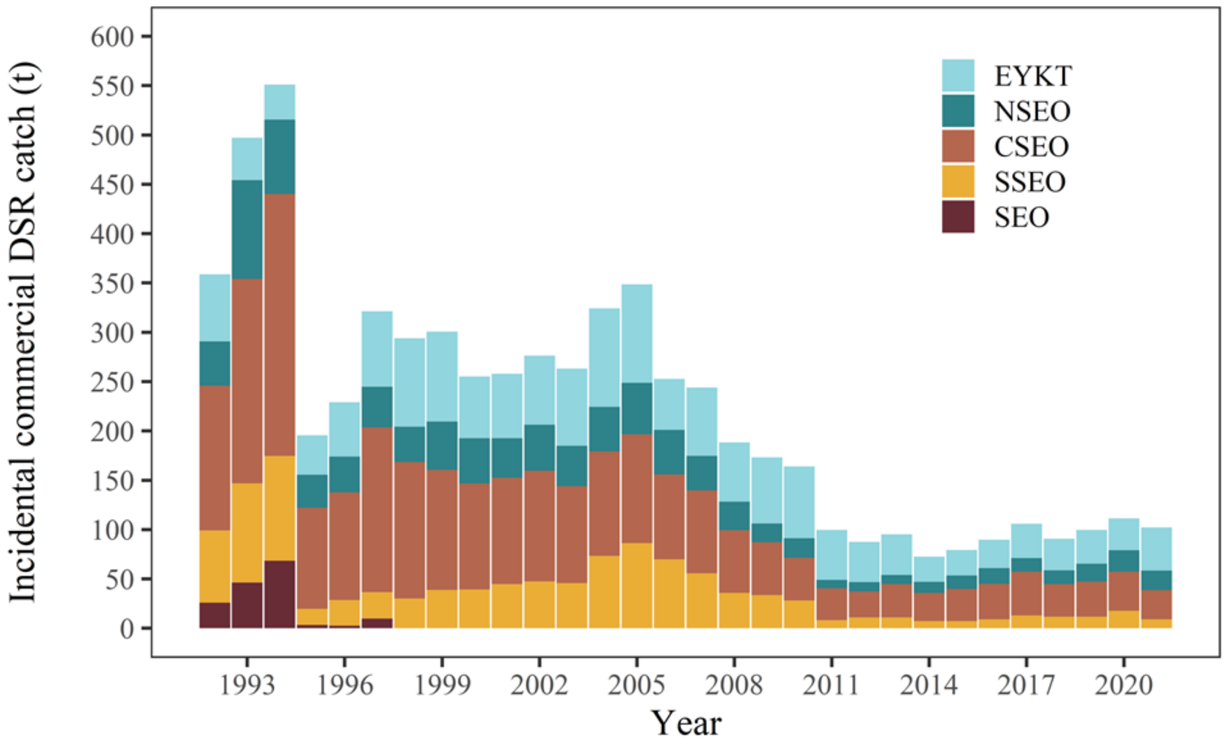

Figure 3.–Incidental commercial fishery catch (t) of demersal shelf rockfish (DSR) in the halibut, sablefish, lingcod, Pacific cod, miscellaneous finfish, and salmon fisheries for Southeast Outside (SEO) Subdistrict groundfish management areas: East Yakutat (EYKT), Northern Southeast Outside (NSEO), Central Southeast Outside (CSEO), and Southern Southeast Outside (SSEO) Sections, 1992–2021. Harvest in the SEO area could not be assigned to a management area due to fish ticket data limitations.

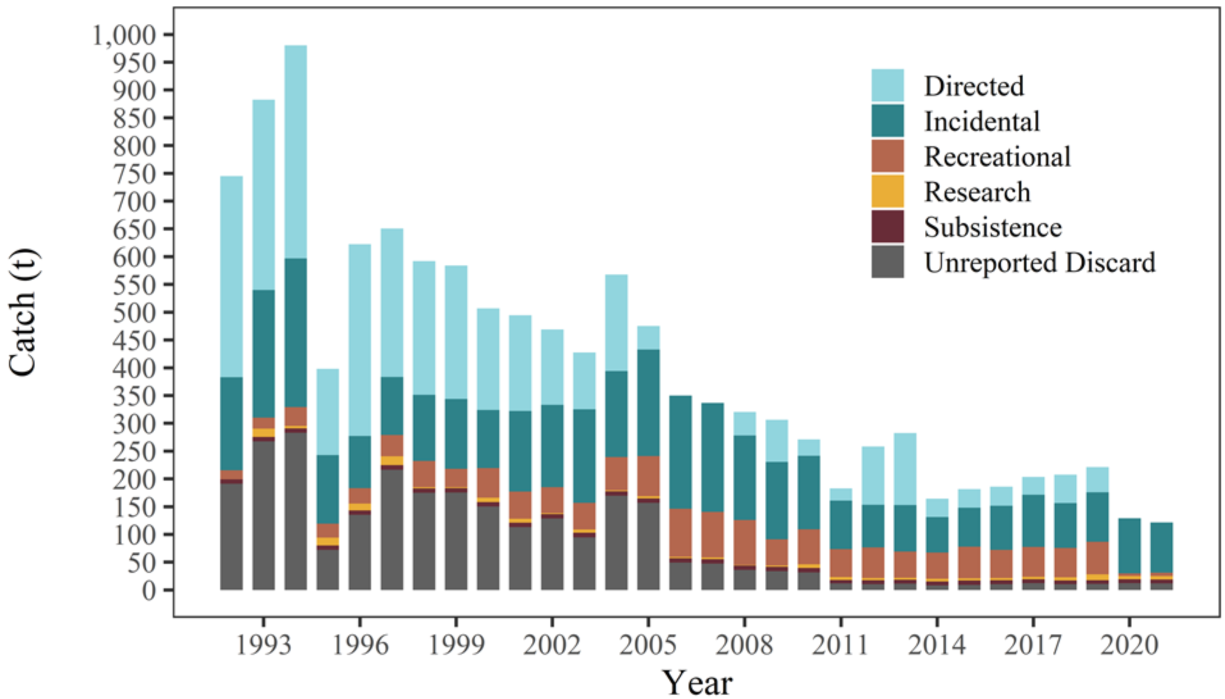

Figure 4.–Demersal shelf rockfish (DSR) catch (t) by fishery type: commercial (directed, incidental, and estimated unreported discards from the halibut longline fishery), recreational, research, and subsistence for the Southeast Outside (SEO) Subdistrict, 1992–2021. The directed DSR commercial and recreational fisheries were closed in SEO in 2006, 2007, 2020, and 2021; however, 2020 and 2021 recreational fishery catch include the estimated release mortality.

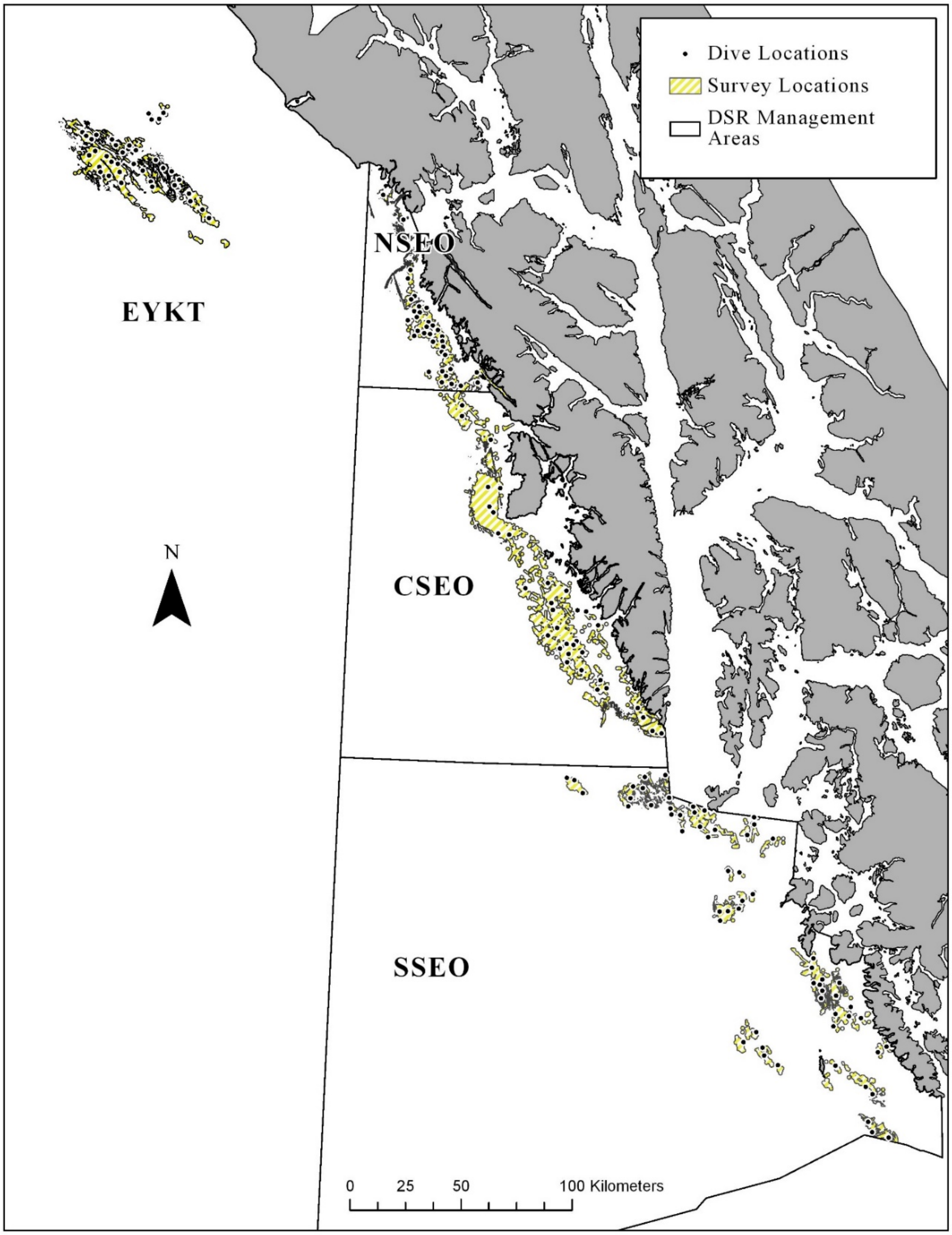

Figure 5. The designated yelloweye rockfish habitat (DYRH; yellow hatching) and example dive locations (black circles) for remote operated vehicle (ROV) surveys in the Southeast Outside Subdistrict (SEO) of the Gulf of Alaska.

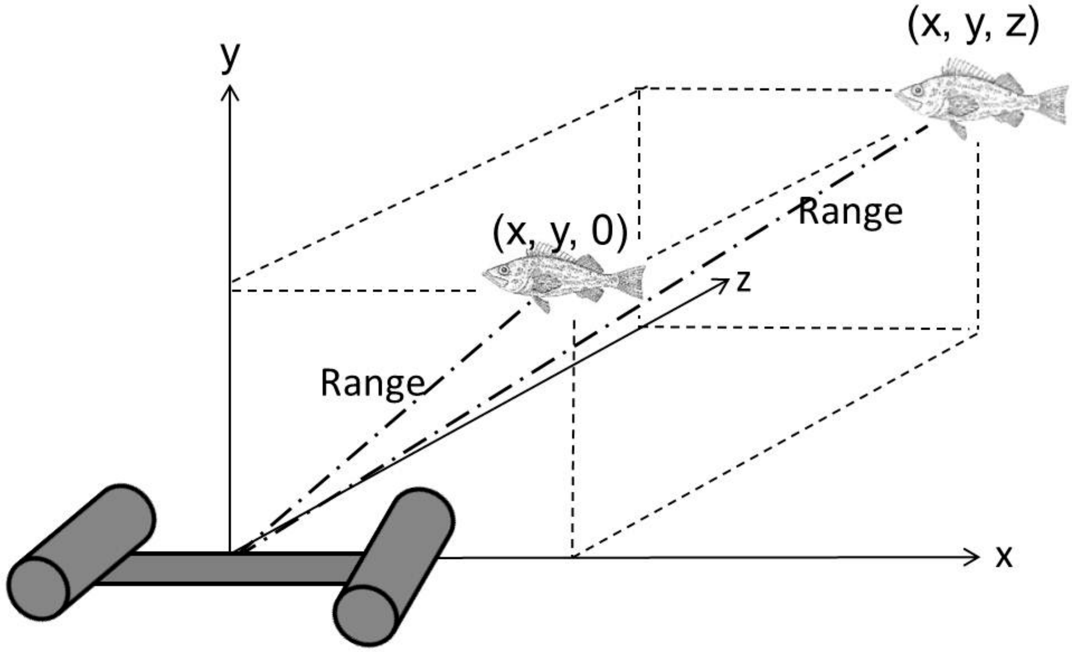

Figure 6.–The components of a 3D point measurement used in calculated fish size and distance from the transect line in ROV surveys of yelloweye rockfish in Southeast Outside (SEO) Subdistrict of the Gulf of Alaska. The ROV moves in the direction of the *z* plane and the *x* component represents the distance from the transect line.

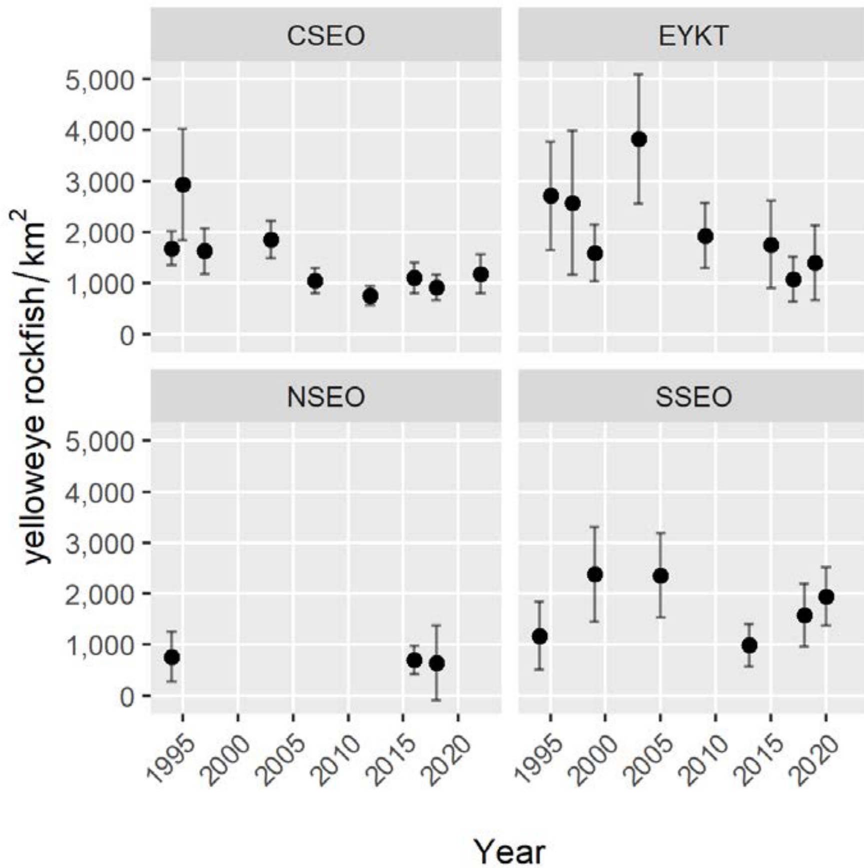

Figure 7. Estimates of yelloweye rockfish density in four management areas in the Southeast Outside district of the Gulf of Alaska (SEO): East Yakutat (EYKT), Northern Southeast Outside (NSEO), Central Southeast Outside (CSEO), and Southern Southeast Outside (SSEO) Sections, 1994–2022 as derived from submersible and ROV surveys and distance sampling methods. Error bars represent 95% confidence intervals.

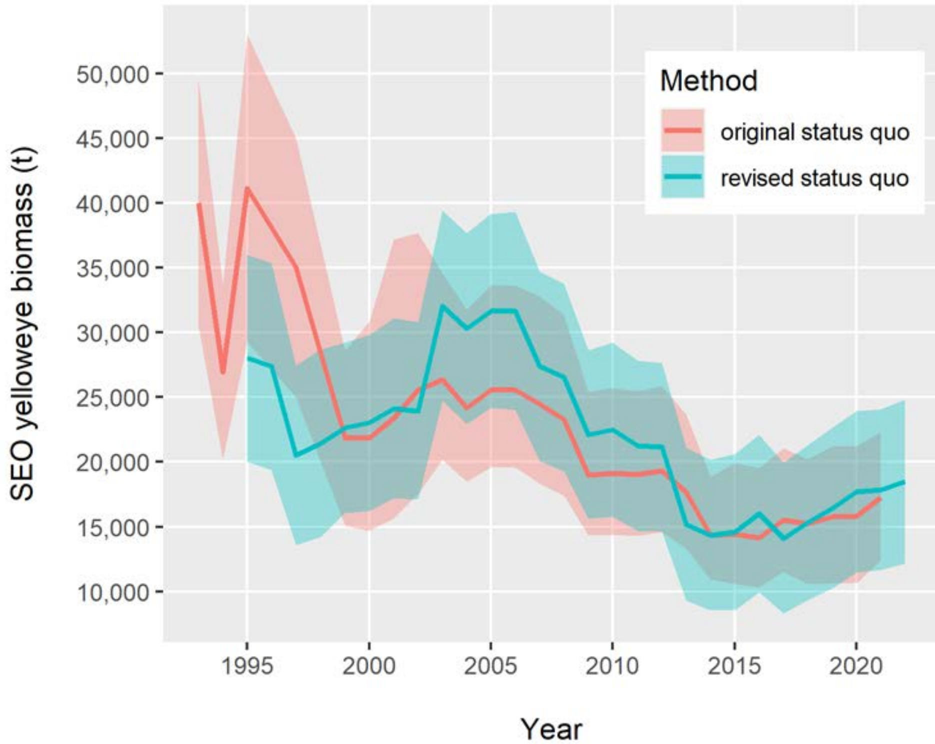

Figure 8: Estimated biomass of yelloweye rockfish in the Southeast Outside district of the Gulf of Alaska (SEO) as determined by the status-quo methods using historically published estimates (Model 21) and revised values calculated directly from published density estimates (Model 21.1).

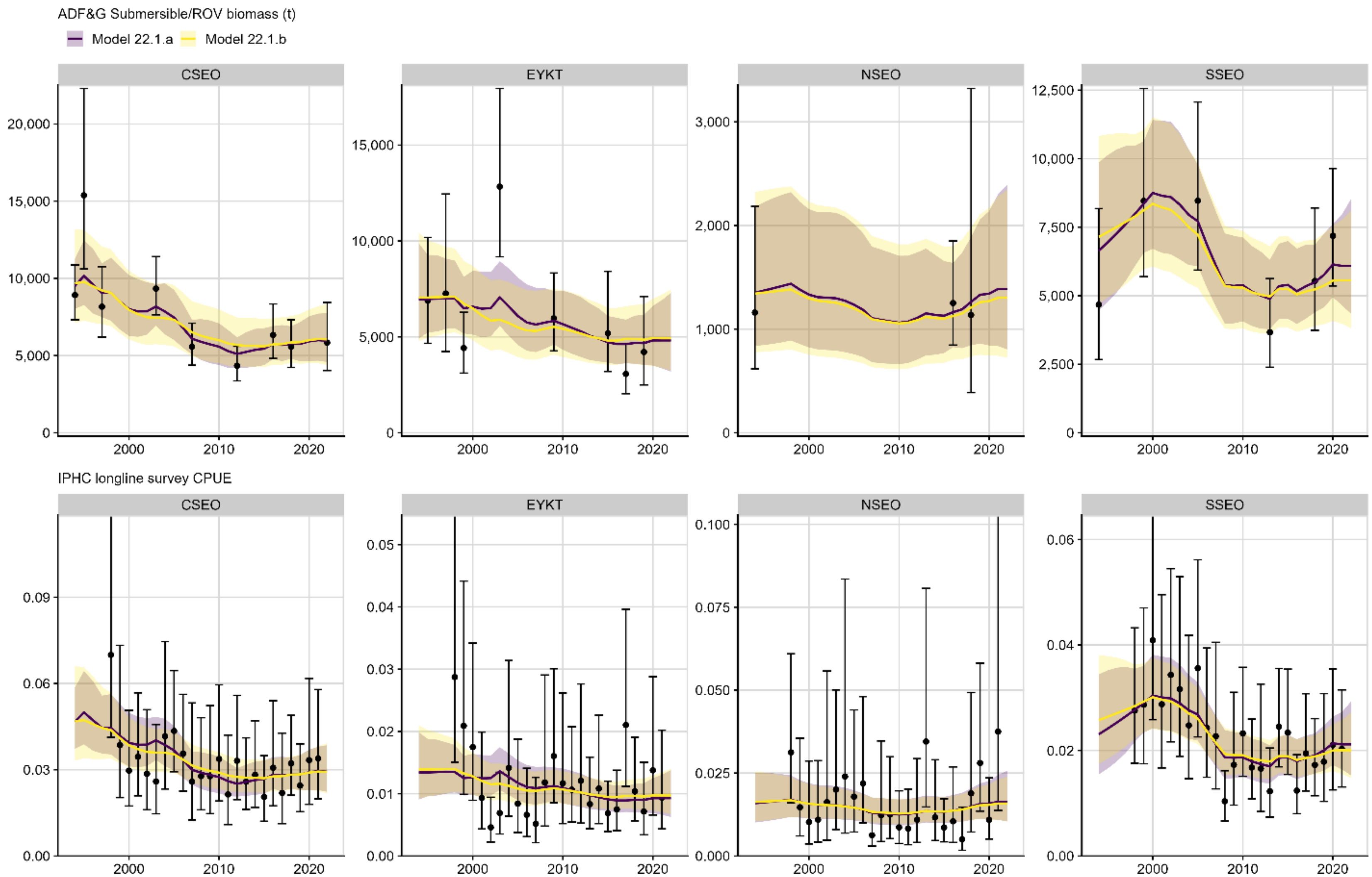

Figure 9. Two-survey random effects (REMA) model fits to the ADF&G submersible and ROV survey biomass (t; top) and IPHC longline survey CPUE (bottom). Model 22.1 and Model 22.2 share the same structure (single process error, area-specific scaling parameter), but Model 22.2 estimates additional observation error for the biomass data.

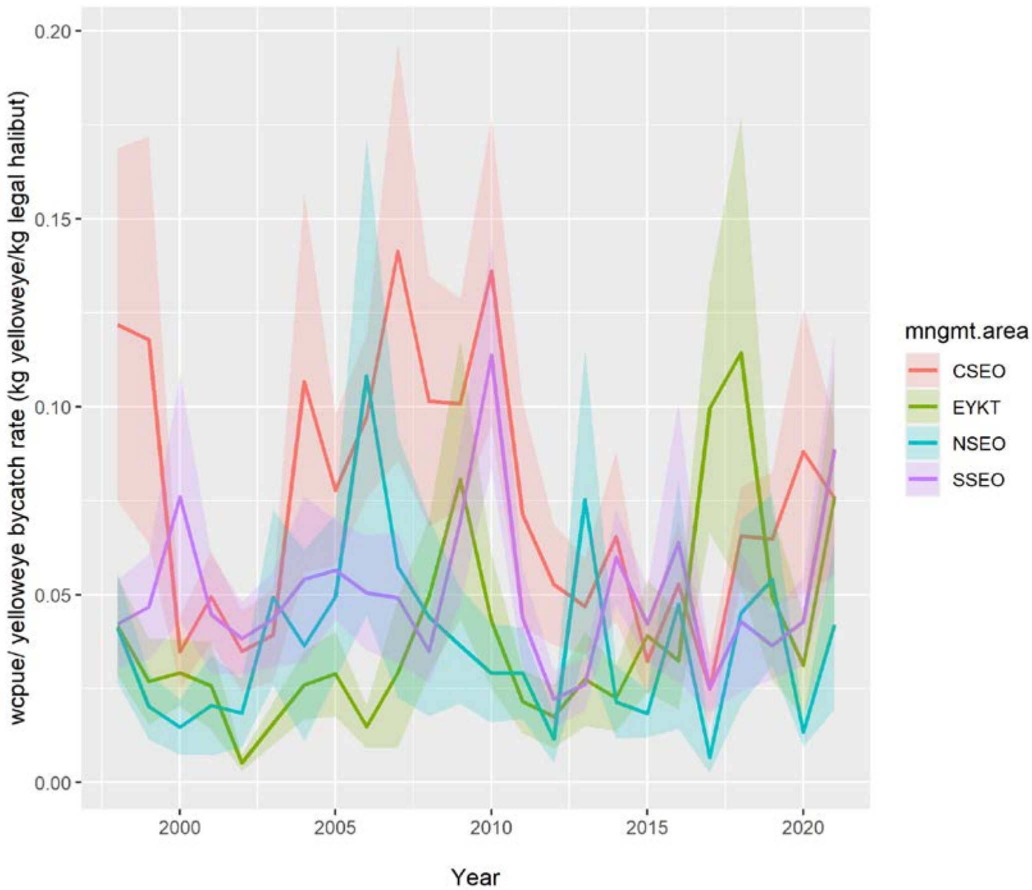

Figure 10: Estimated bycatch rates (WCPUE estimates) derived from the IPHC longline survey data in the four management areas of the Southeast Outside subdistrict (SEO) of the Gulf of Alaska 1998-2021. Error polygons represent 95% confidence intervals.

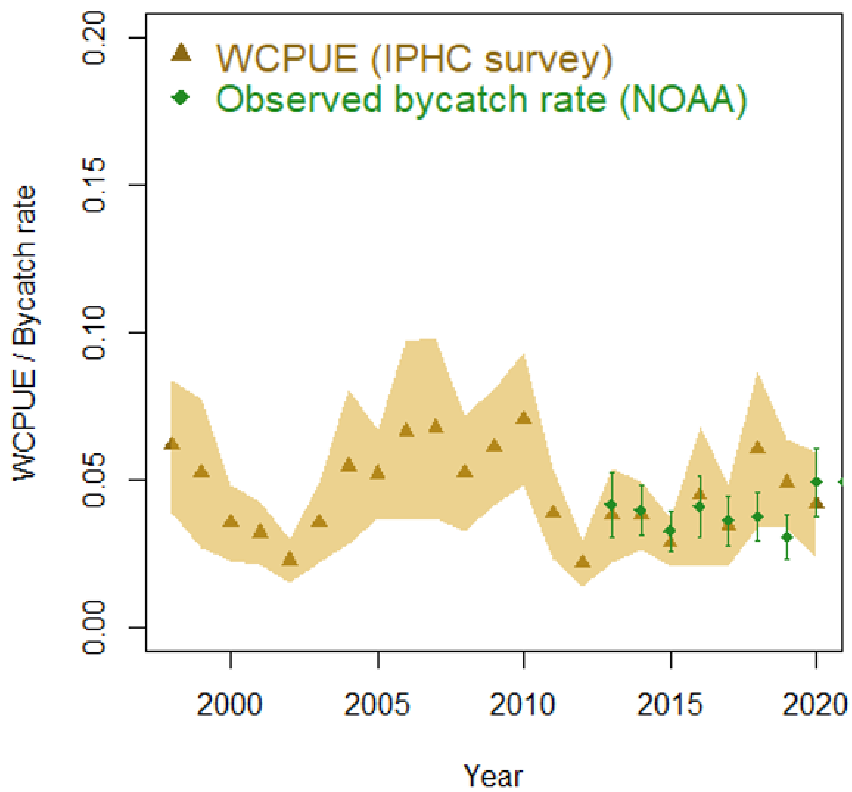

Figure 11: Estimated bycatch rates (wcpue estimates) in the Southeast Outside subdistrict (SEO) of the Gulf of Alaska (brown triangles) and bycatch rates from the NOAA Catch Accounting System (CAS; green diamonds). Error polygons and error bars represent 95% confidence intervals.

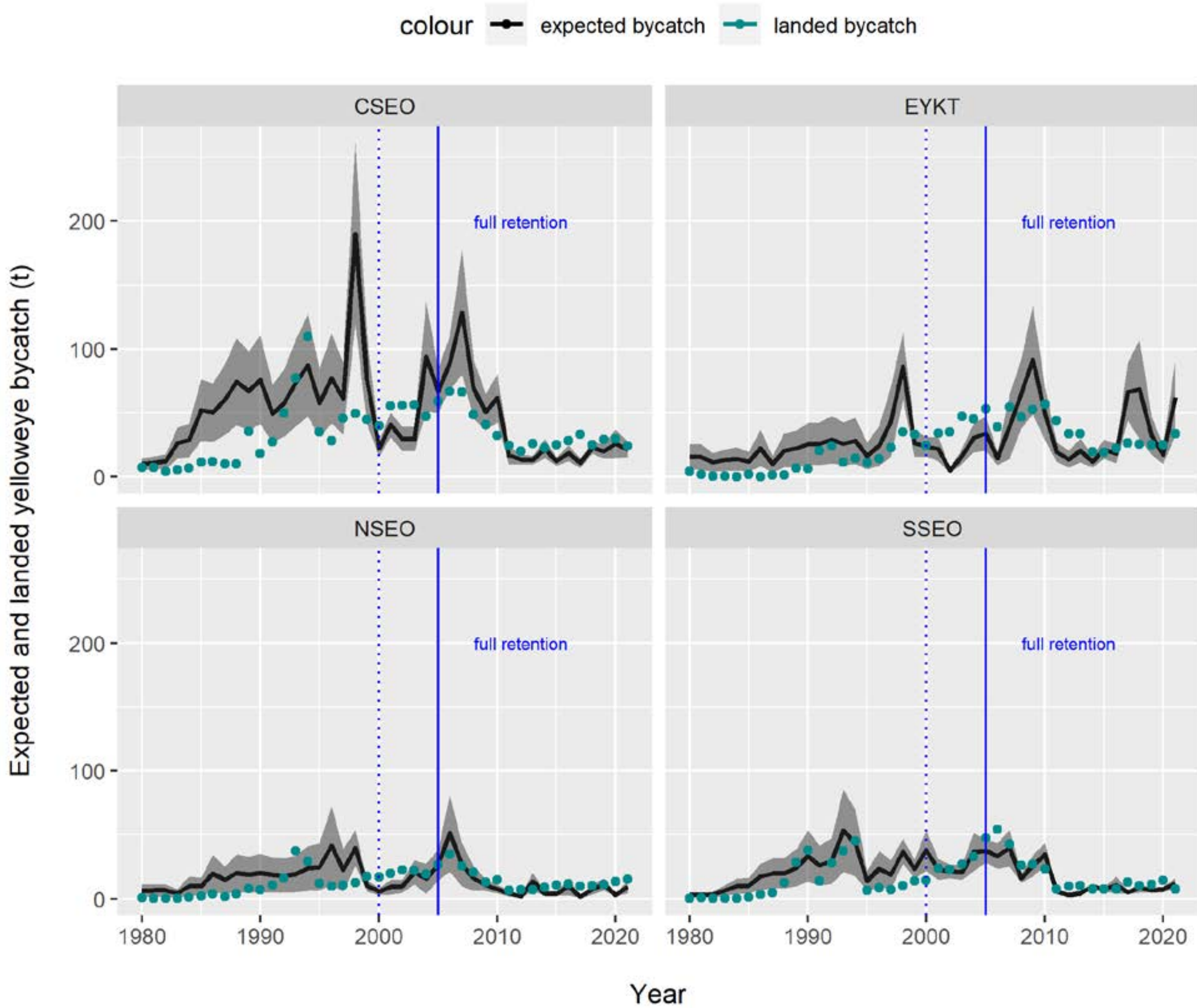

Figure 12: Estimates of expected bycatch of yelloweye rockfish in the halibut fishery derived from halibut harvests and bycatch rates calculated from the IPHC longline survey (black lines and grey error polygons) and landed yelloweye rockfish bycatch in the halibut fishery as recorded on fish tickets (blue dots) in each of four management areas in the Southeast Outside subdistrict (SEO). Error polygons represent 95% confidence intervals. Vertical blue lines highlight the transition to full retention rules for bycatch that was phased in between 2000 and 2005.

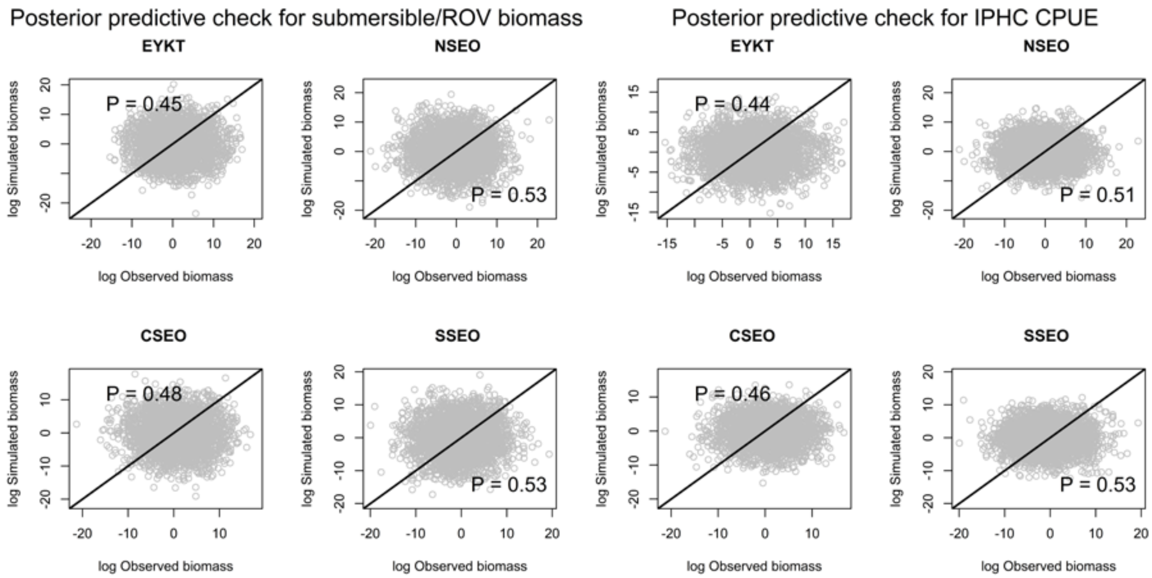

Figure 13: Posterior-predictive checks of Stage-1 SS-SPM observed and simulated biomass for the submersible and ROV biomass estimates (left side) and for the IPHC CPUE index (right side) in the four management areas of the Southeast Outside (SEO) district.

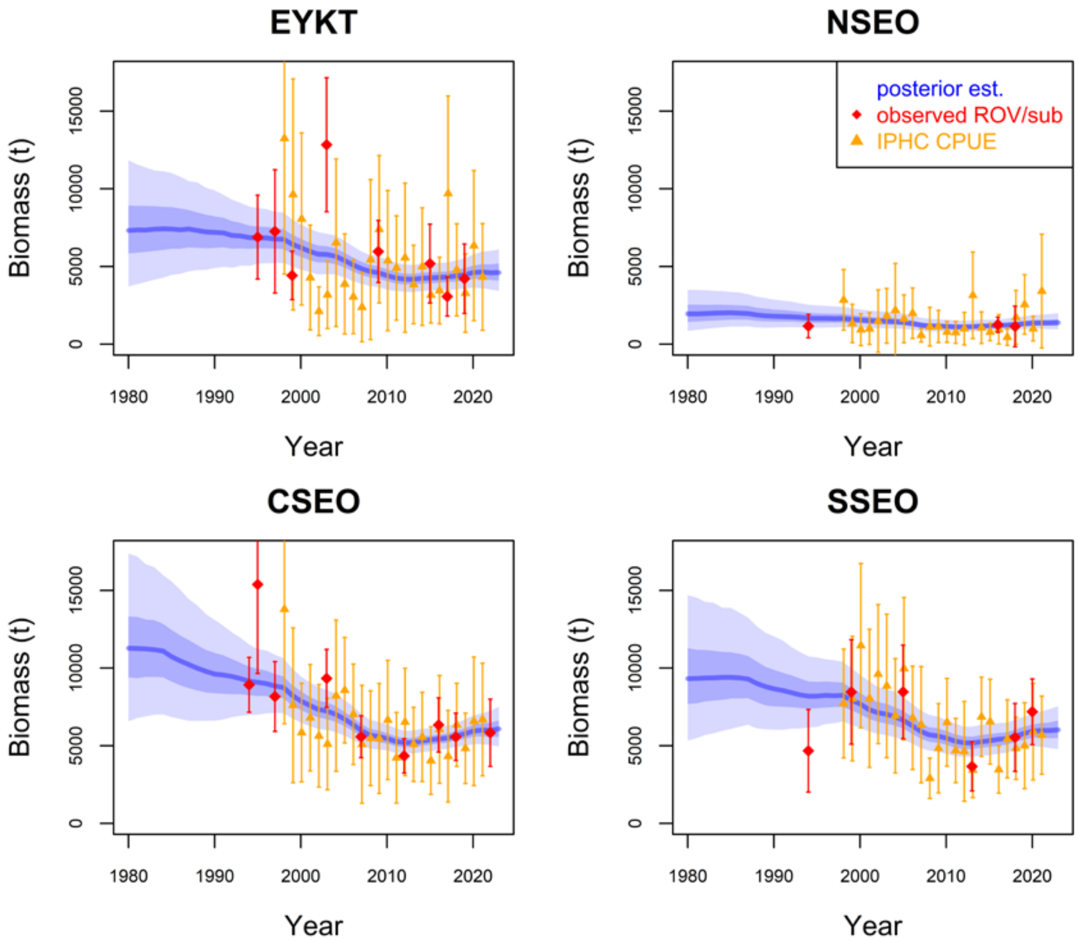

Figure 14. Estimates of yelloweye rockfish biomass from the Stage-1 SS-SPM in the four management areas in the Southeast Outside subdistrict (SEO) of the Gulf of Alaska (blue line with 50 and 95% credibility interval polygons), the biomass estimates from submersible and ROV surveys (red diamonds with 95% confidence interval error bars) and IPHC CPUE indices scaled with the mean estimate of q_s from the SS-SPM (orange triangles with 95% confidence interval error bars).

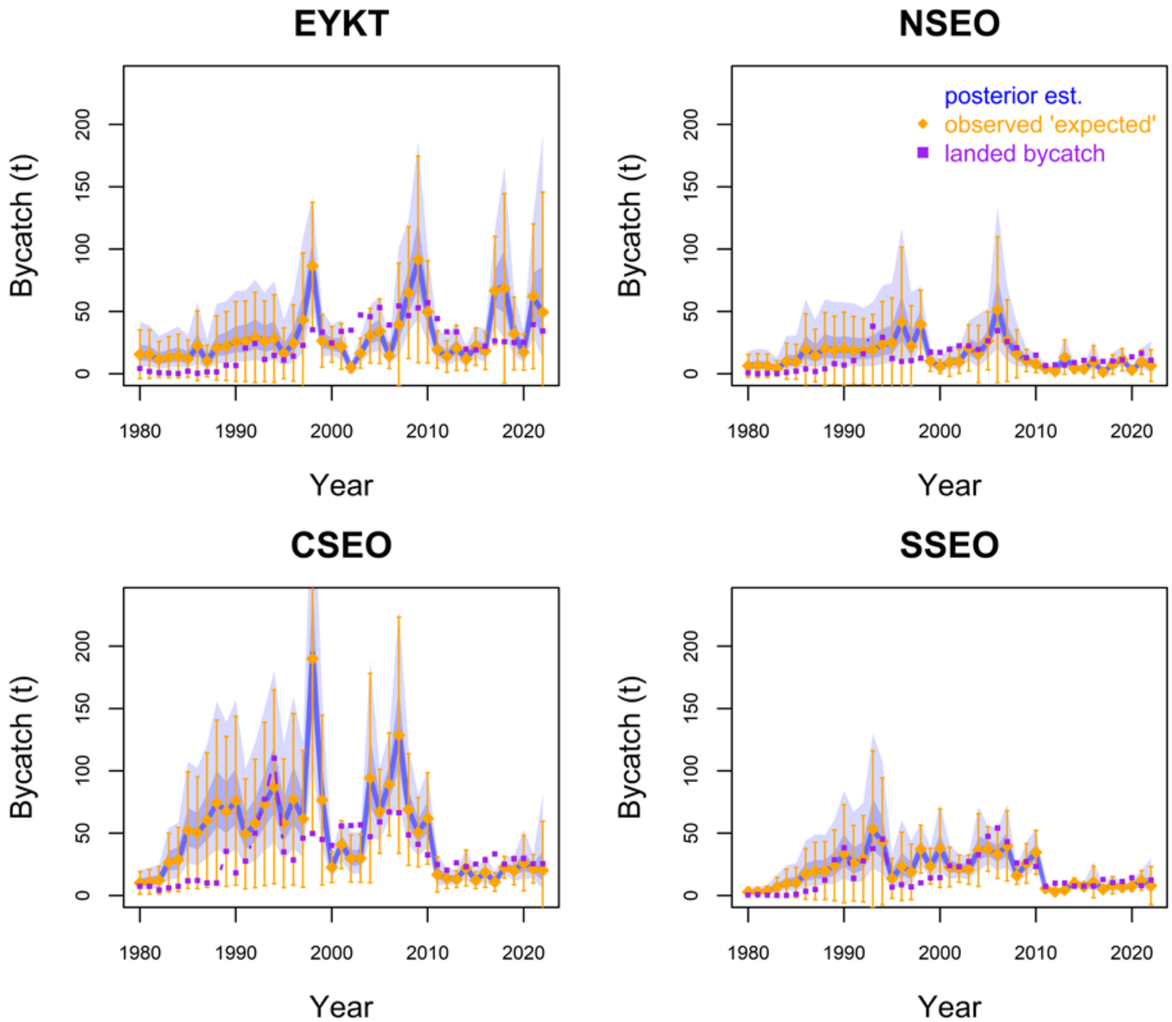

Figure 15. Estimates of yelloweye rockfish bycatch in the halibut fishery from the Stage-1 SS-SPM in the four management areas in the Southeast Outside subdistrict (SEO) of the Gulf of Alaska (blue line with 50 and 95% credibility interval polygons), the expected bycatch estimates from the IPHC longline survey (orange diamonds with 95% confidence interval error bars) and reported landings of yelloweye rockfish in the halibut fishery (purple squares). Note that error bars on the expected bycatch estimates are constructed parametrically where-as the SS-SPM applies log-normal error structure.

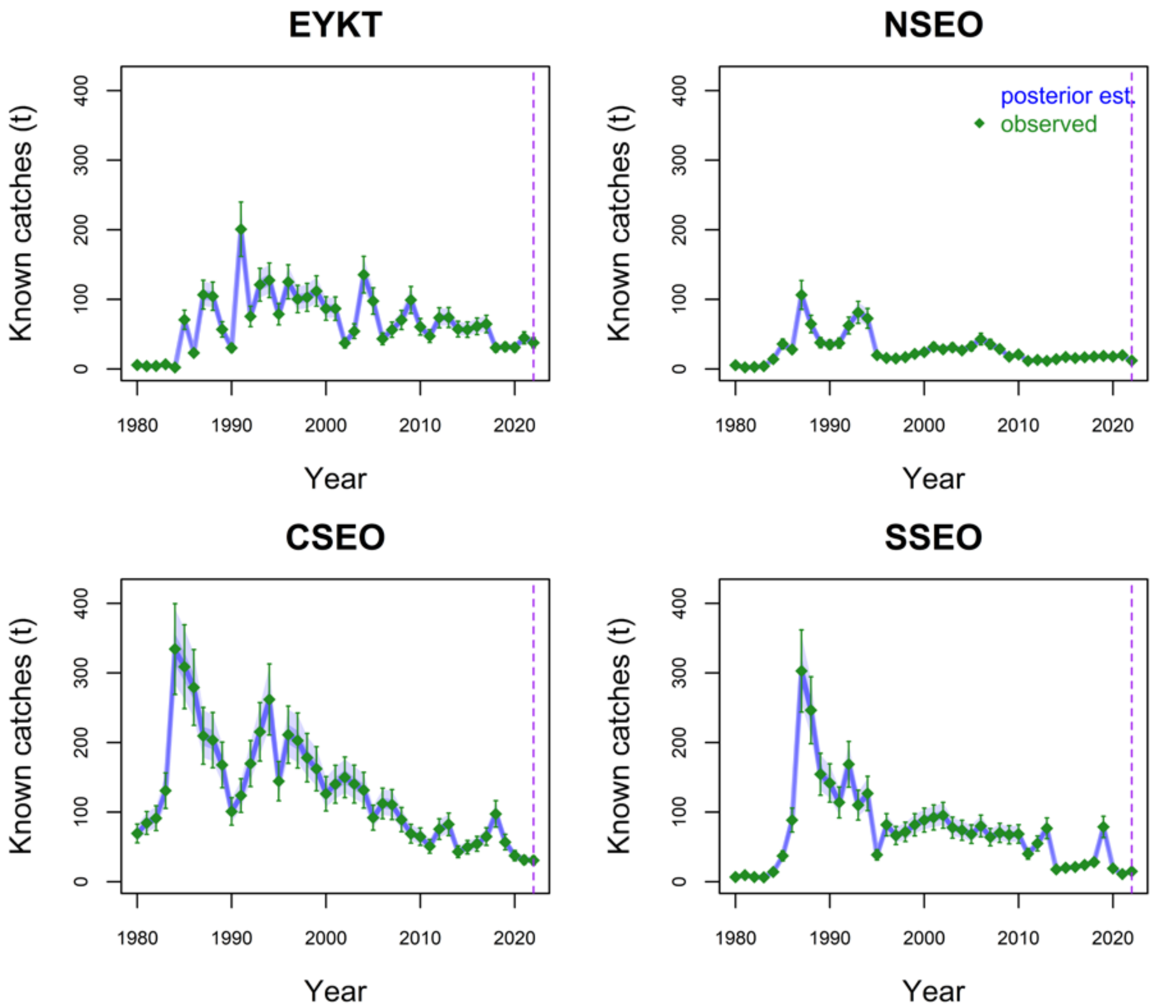

Figure 16. Estimates of yelloweye rockfish known catches from the Stage-1 SS-SPM in the four management areas in the Southeast Outside subdistrict (SEO) of the Gulf of Alaska (blue line with 50 and 95% credibility interval polygons) and the catch estimates from reported harvests (green diamonds with 95% confidence interval error bars).

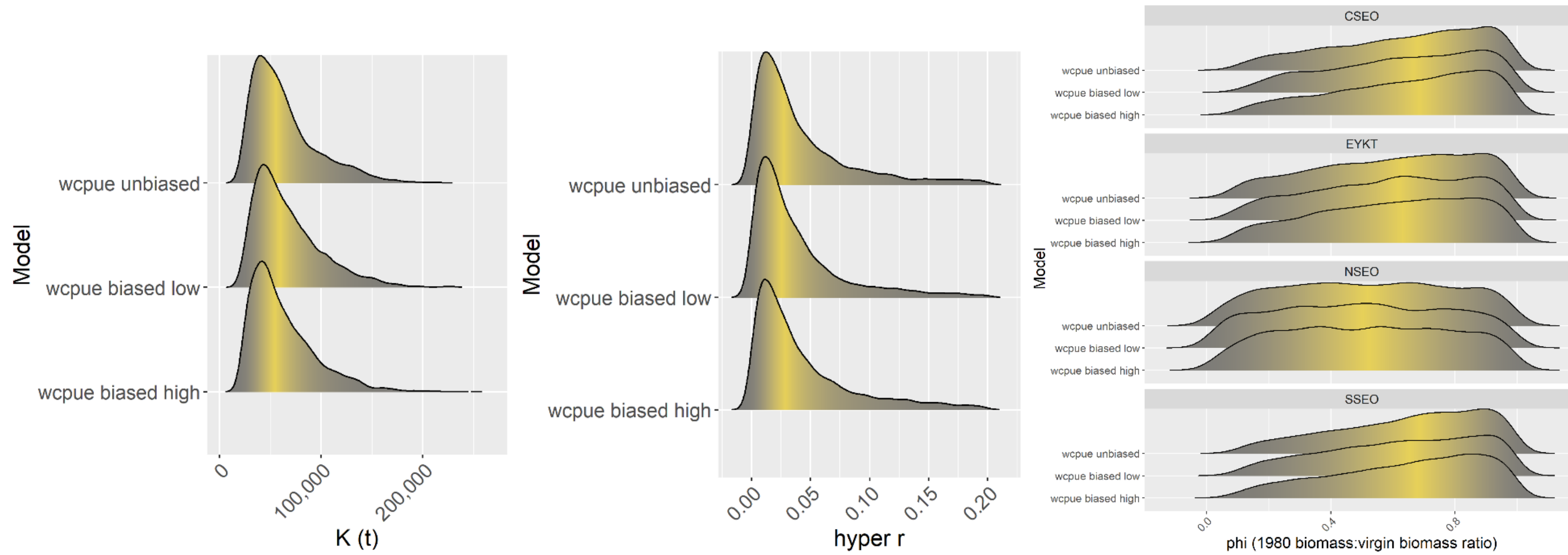

Figure 17. Posterior distributions of Stage-1 SS-SPM estimates of *K*, *R*, and ϕ_s, in the model variations that treated bycatch rates (WCPUE) calculated from IPHC longline survey data to be either unbiased, biased low by 30% and biased high by 30% relative to the "true" bycatch in the pre-IFQ halibut fishery.

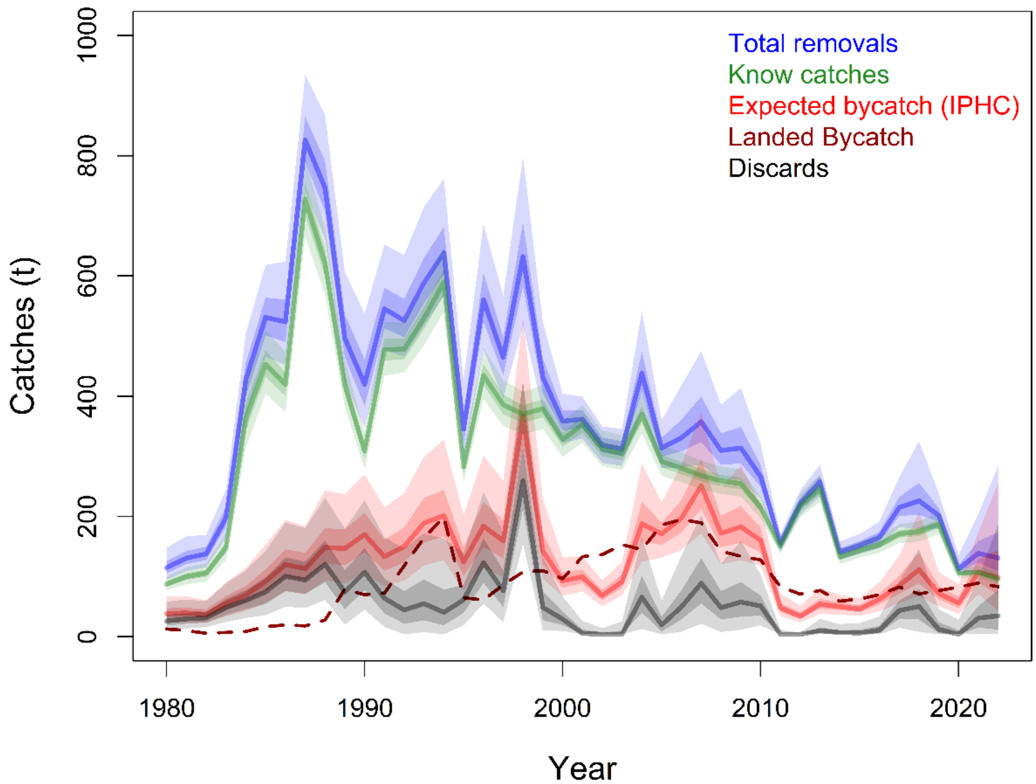

Figure 18. Posterior estimates of total yelloweye rockfish catch (blue lines with 50 and 95% confidence interval polygons), total known catches (green), estimated bycatch in the halibut fishery (red), recorded landings of yelloweye rockfish in the halibut fishery (red dashed line) and estimated discards of yelloweye rockfish in the halibut fishery (dark grey) from Stage-1 SS-SPMs. Estimates of discards are derived by subtracting recorded landings from estimated bycatch. Total catch (in blue) is derived as the sum of the total known catches (in green) and the estimated discards. Error polygons represent 50 and 95% credibility intervals.

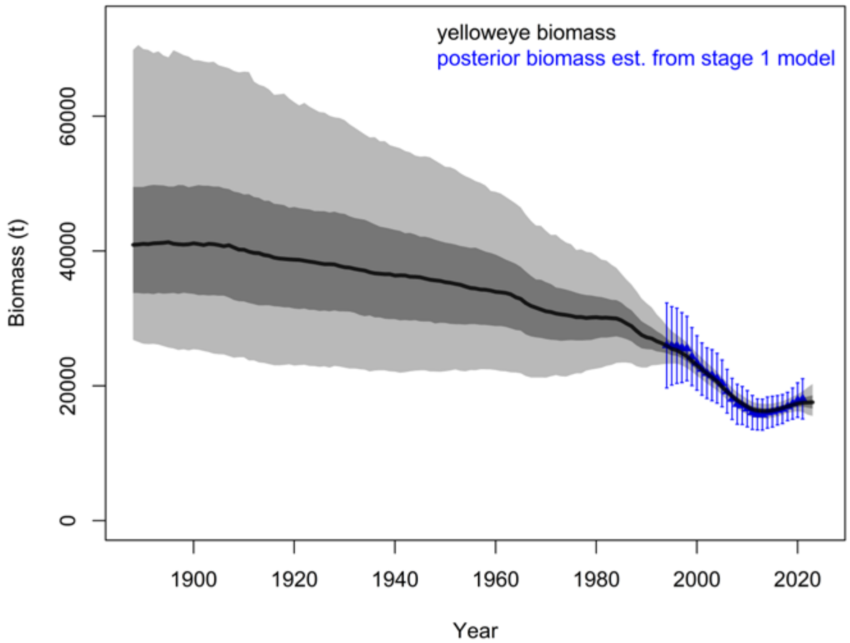

Figure 19. Estimates of yelloweye rockfish biomass in the Southeast Outside subdistrict (SEO) of the Gulf of Alaska from the Stage-2 SS-SPM (black line with 50 and 95% credibility interval polygons) and the estimates of biomass from Stage-1 SS-SPM (blue dots with 95% credibility interval error bars), 1888-2022.

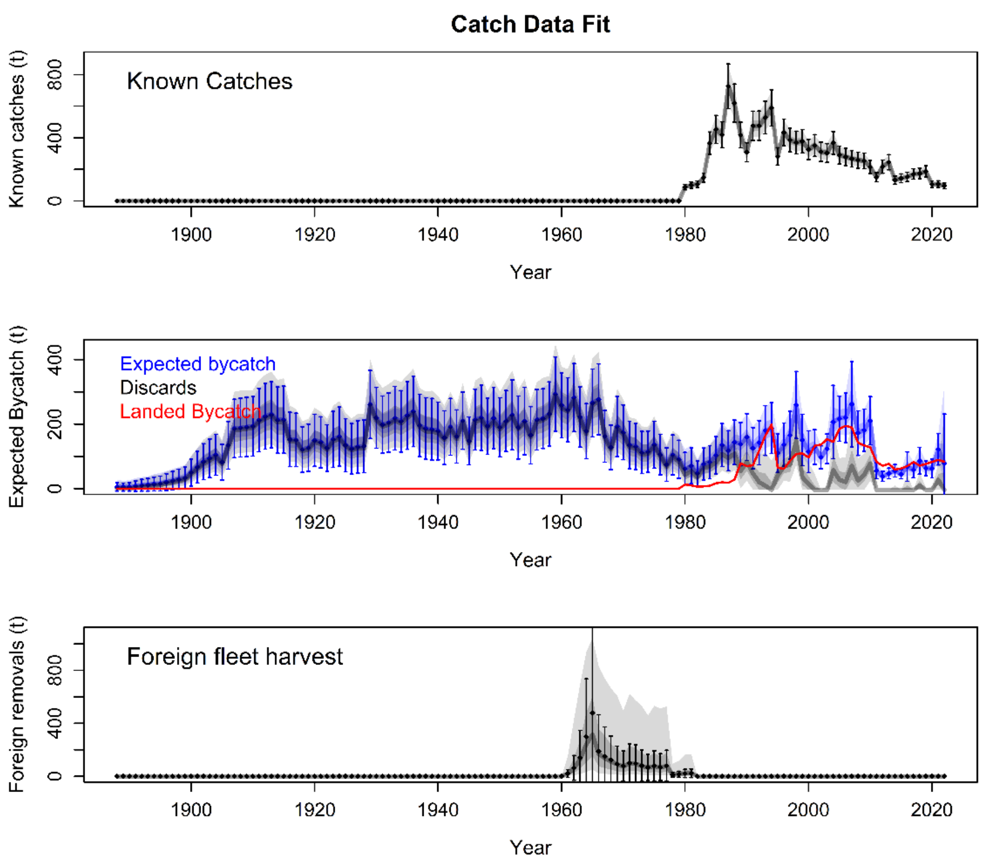

Figure 20. Posterior estimates of total removals of yelloweye rockfish in the Southeast Outside subdistrict (SEO) of the Gulf of Alaska from the Stage-2 SS-SPM with 50 and 95% credibility interval polygons (top plot) and the fit of known catches, expected bycatch and foreign fleet removals to data sources with 95% confidence interval error bars. Error bars from the data are plotted as normally distributed where-as posterior estimates from the SS-SPM are modelled as log-normal.

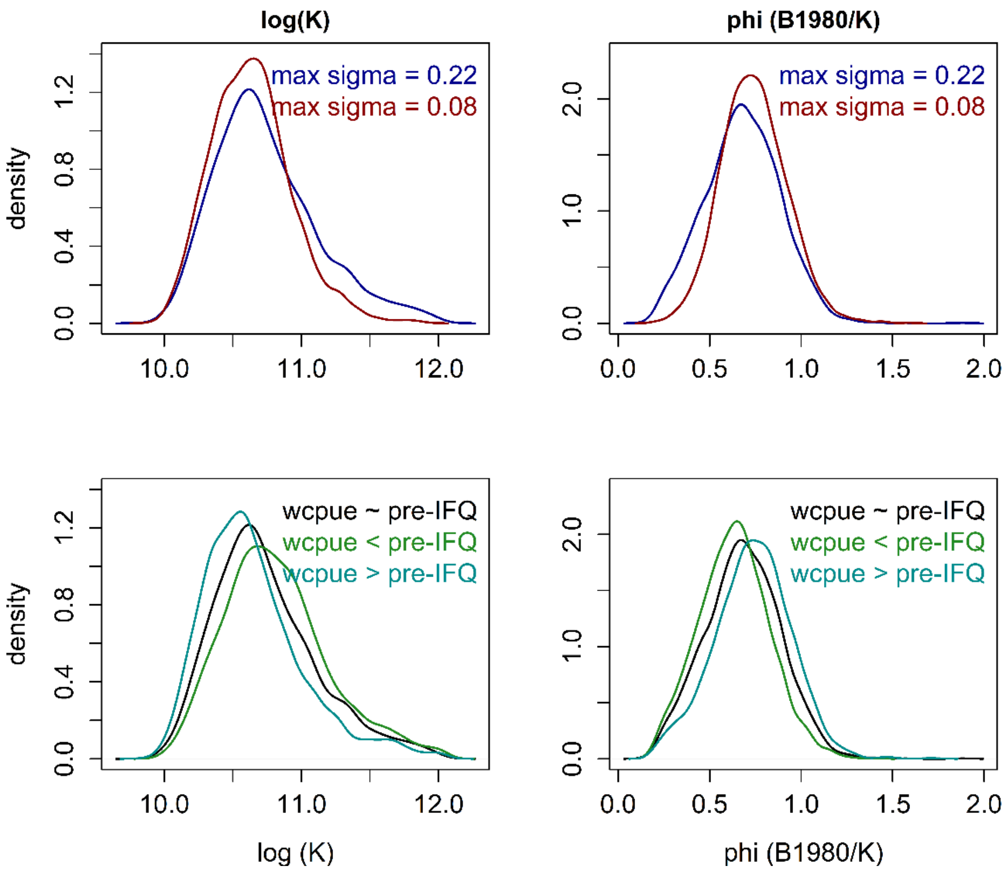

Figure 21. Posterior distributions of *log(K)* and the ratio of 1980 biomass to *K* (ϕ) from Phase-2 SS-SPMs modelled under moderate and minimal process error (top row) and variable assumptions about how bycatch rates of yelloweye rockfish in the pre-IFQ halibut fishery differed relative to WCPUE estimates derived from the IPHC longline survey (bottom row). These distributions were used to model priors on *K* and ϕ for Stage-3 models.

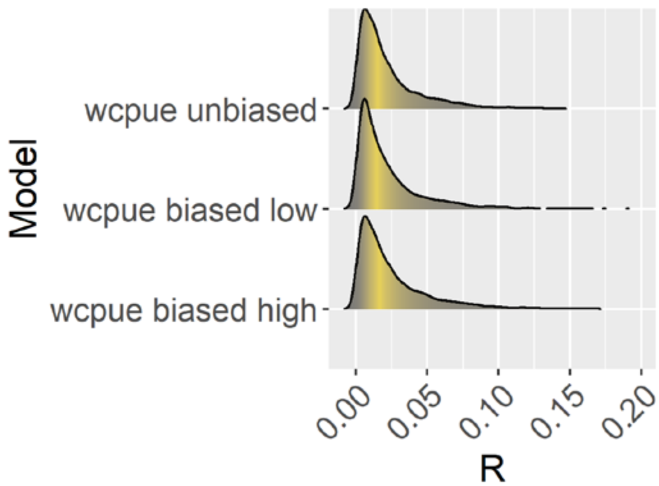

Figure 22. Posterior estimates of *R* from three Stage-2 SS-SPMs modelled with different assumptions about how bycatch rates of yelloweye rockfish in the pre-IFQ halibut fishery differed relative to WCPUE estimates derived from the IPHC longline survey.

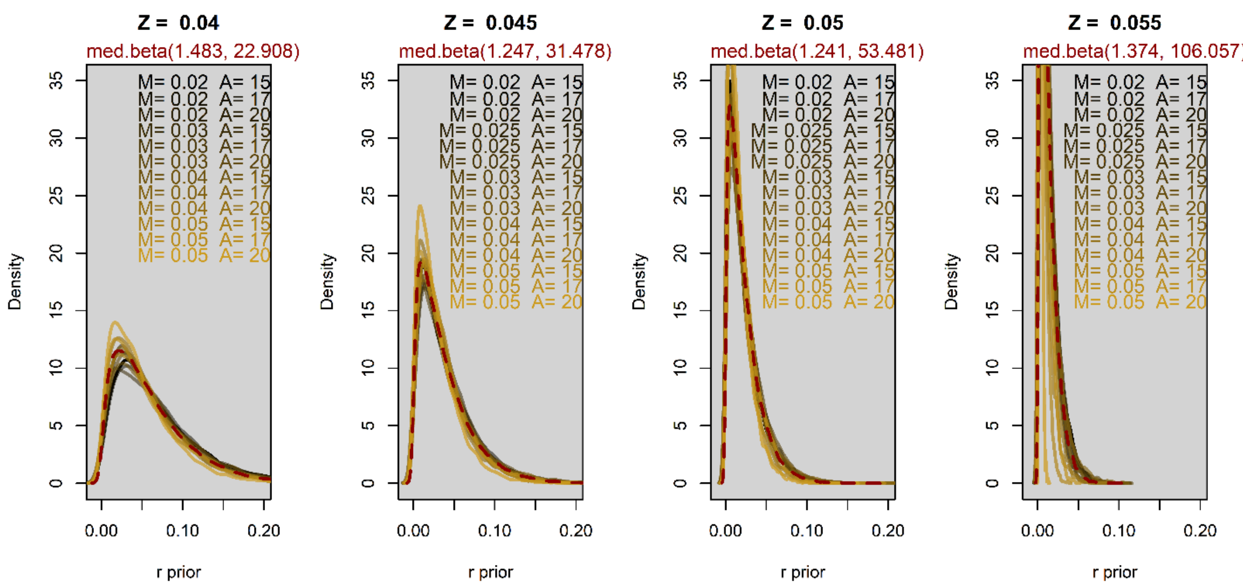

Figure 23. Posterior estimates of *R* derived from Bayesian projections of a Leslie matrix for yelloweye rockfish using various values for daily mortality of larval fish in their first year of life, *Z*, annual mortality, *M*, and average age-of-maturity, *A*. Average distributions for each panel are represented by the dashed red lines with the beta parameters listed above the panel.

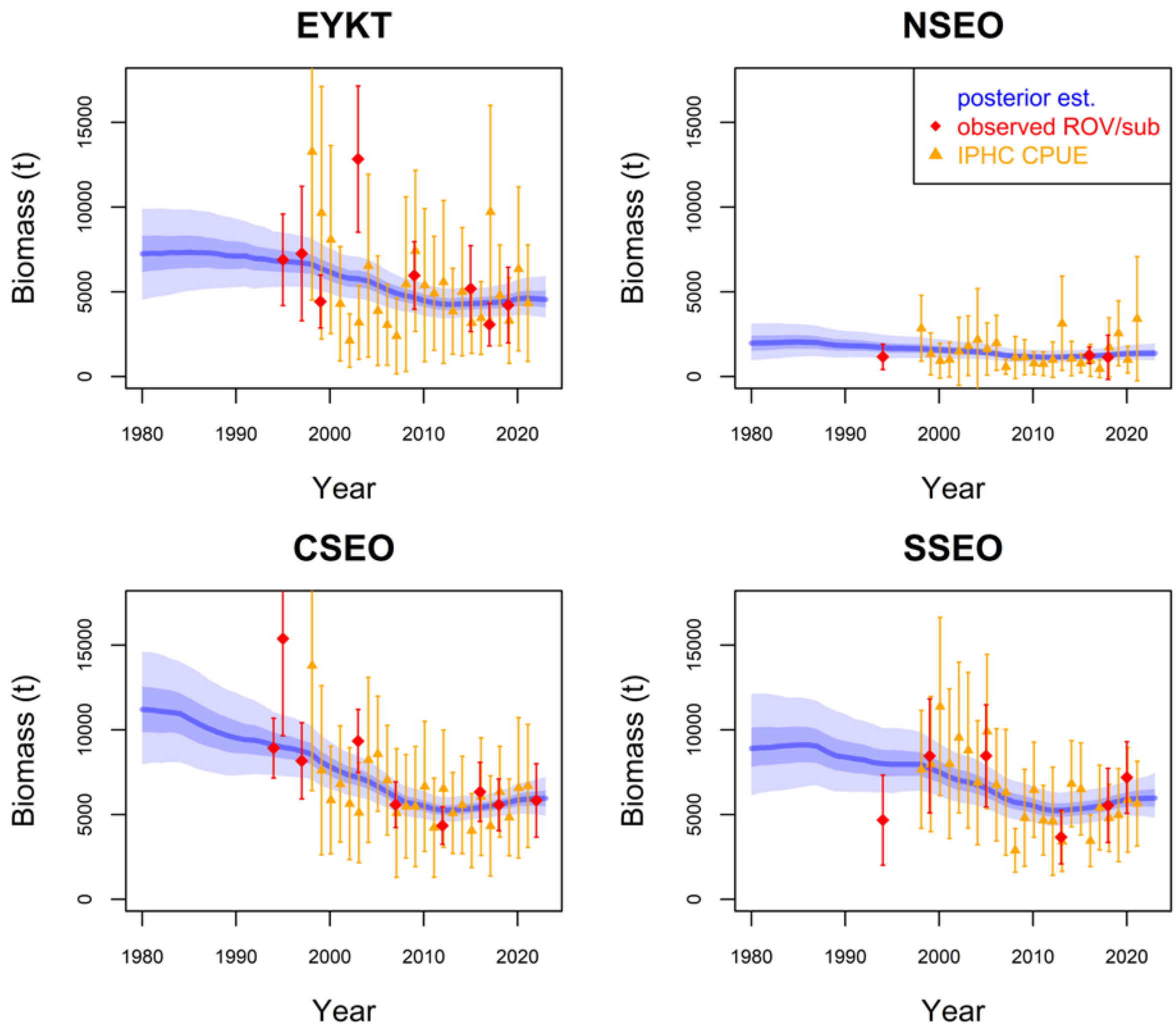

Figure 24. Estimates of yelloweye rockfish biomass from the Stage-3 SS-SPM in the four management areas of the Southeast Outside subdistrict (SEO) of the Gulf of Alaska (blue line with 50 and 95% credibility interval polygons), the biomass estimates from submersible and ROV surveys (red diamonds with 95% confidence interval error bars) and IPHC CPUE indices scaled with the mean estimate of q_s from the SS-SPM (orange triangles with 95% confidence interval error bars). These results are from the minimal process error model with an uninformative prior on *R*.

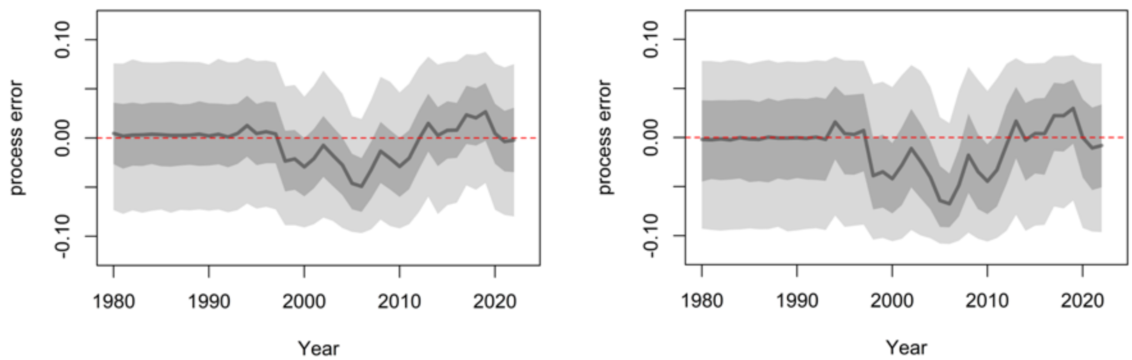

Figure 25. Posterior estimates of process error for Stage-3 SS-SPM models from the minimal process error model (max σ_{proc} = 0.08) on the left and the moderate process error model (max σ_{proc} = 0.22) on the right.

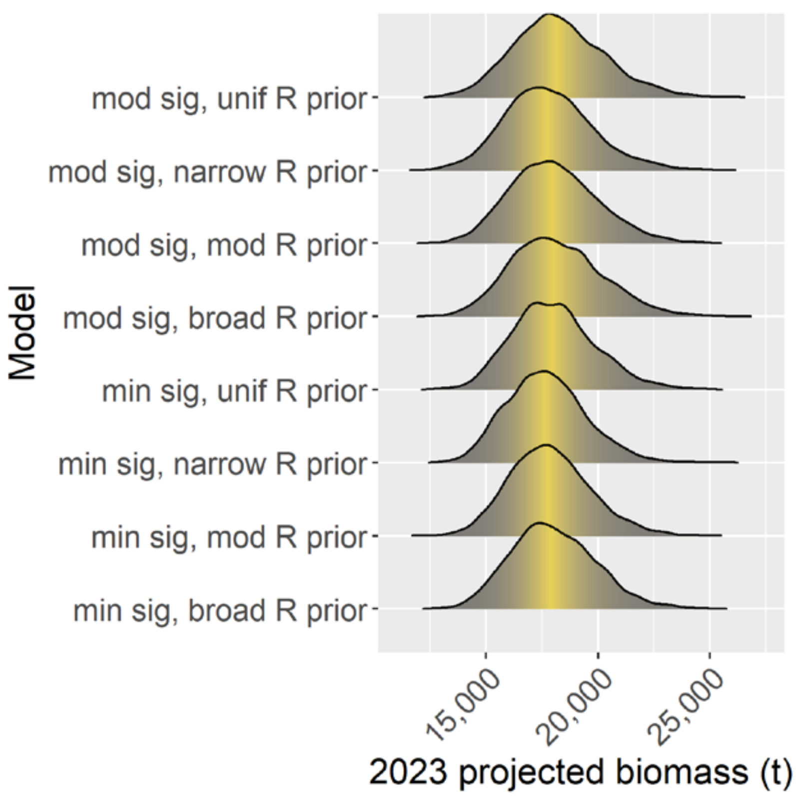

Figure 26. Posterior distributions of projected biomass for 2023 produced by eight Stage-3 SS-SPMs modelled with moderate (mod sig) and minimal (min sig) process error, σ_{proc}, and four priors for R ranging from an uninformative beta distribution (unif R) through the broadest (broad R), moderate (mod R) and narrowest (narrow R) beta distributions derived from the projected Leslie matrices (Figure 23).

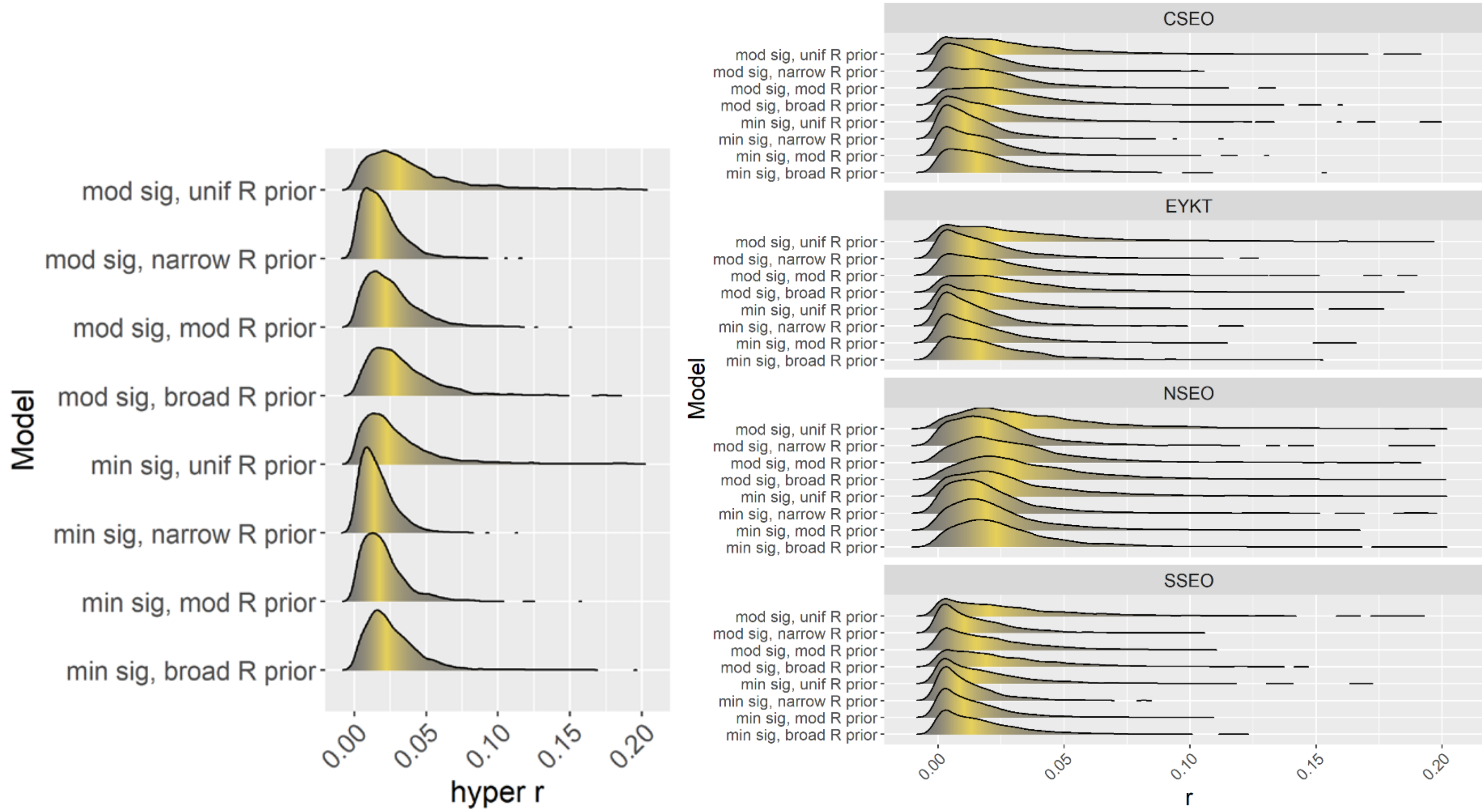

Figure 27. Posterior distributions of R (left side) and r_s (right side) produced by eight Stage-3 SS-SPMs modelled with moderate (mod sig) and minimal (min sig) process error, σ_{proc}, and four priors for R ranging from an uninformative beta distribution (unif R) through the broadest (broad R), moderate (mod R) and narrowest (narrow R) beta distributions derived from the projected Leslie matrices (Figure 23).

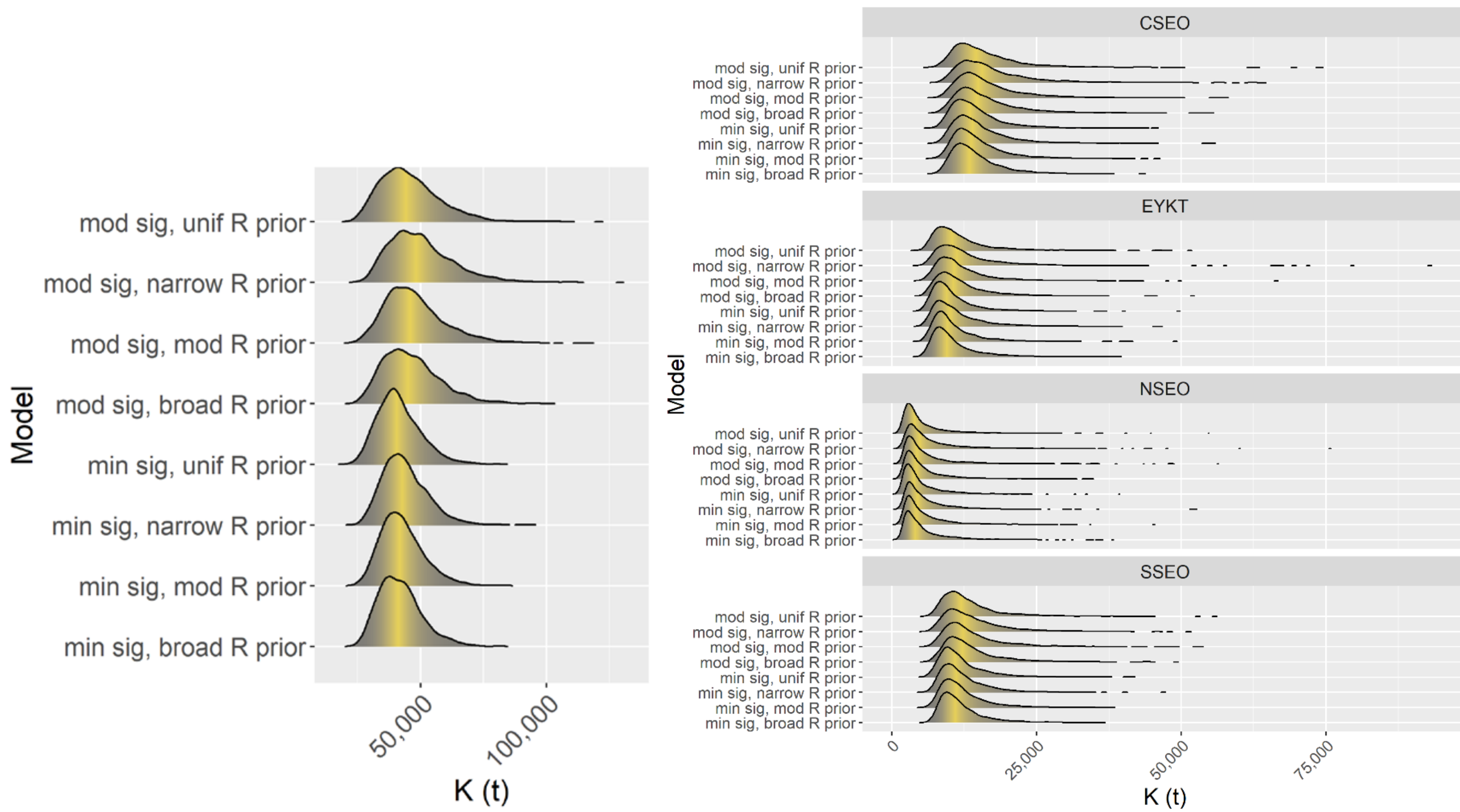

Figure 28. Posterior distributions of K (left side) and K_s (right side) produced by eight Stage-3 SS-SPMs modelled with moderate (mod sig) and minimal (min sig) process error, σ_{proc}, and four priors for R ranging from an uninformative beta distribution (unif R) through the broadest (broad R), moderate (mod R) and narrowest (narrow R) beta distributions derived from the projected Leslie matrices (Figure 23).

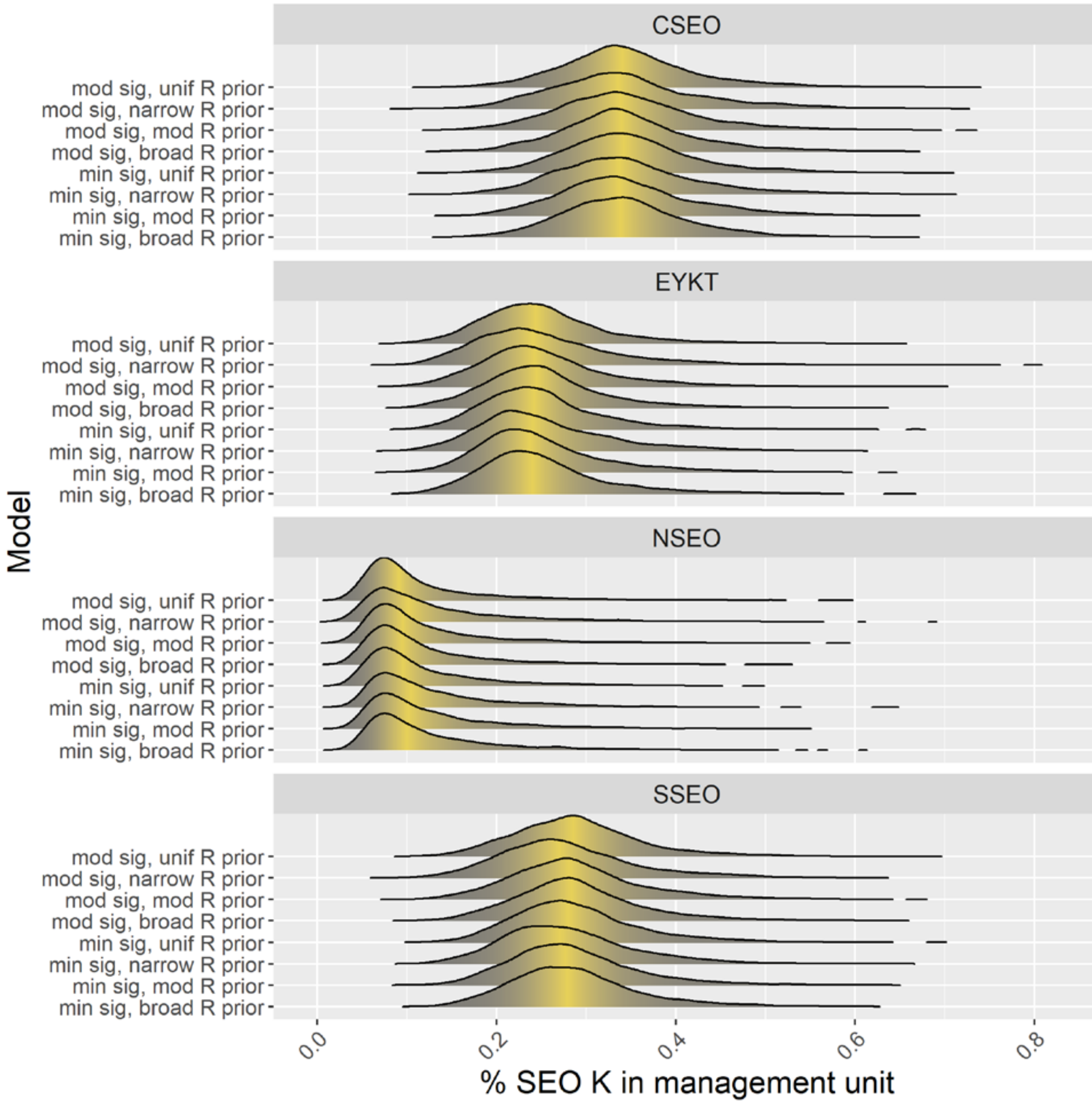

Figure 29. Posterior distributions of *pi*, the estimated proportion of *K* composed of the K_s estimates, produced by eight Stage-3 SS-SPMs modelled with moderate (mod sig) and minimal (min sig) process error, σ_{proc}, and four priors for *R* ranging from uninformative beta distribution (unif R) through the broadest (broad R), moderate (mod R) and narrowest (narrow R) beta distributions derived from the projected Leslie matrices (Figure 23).

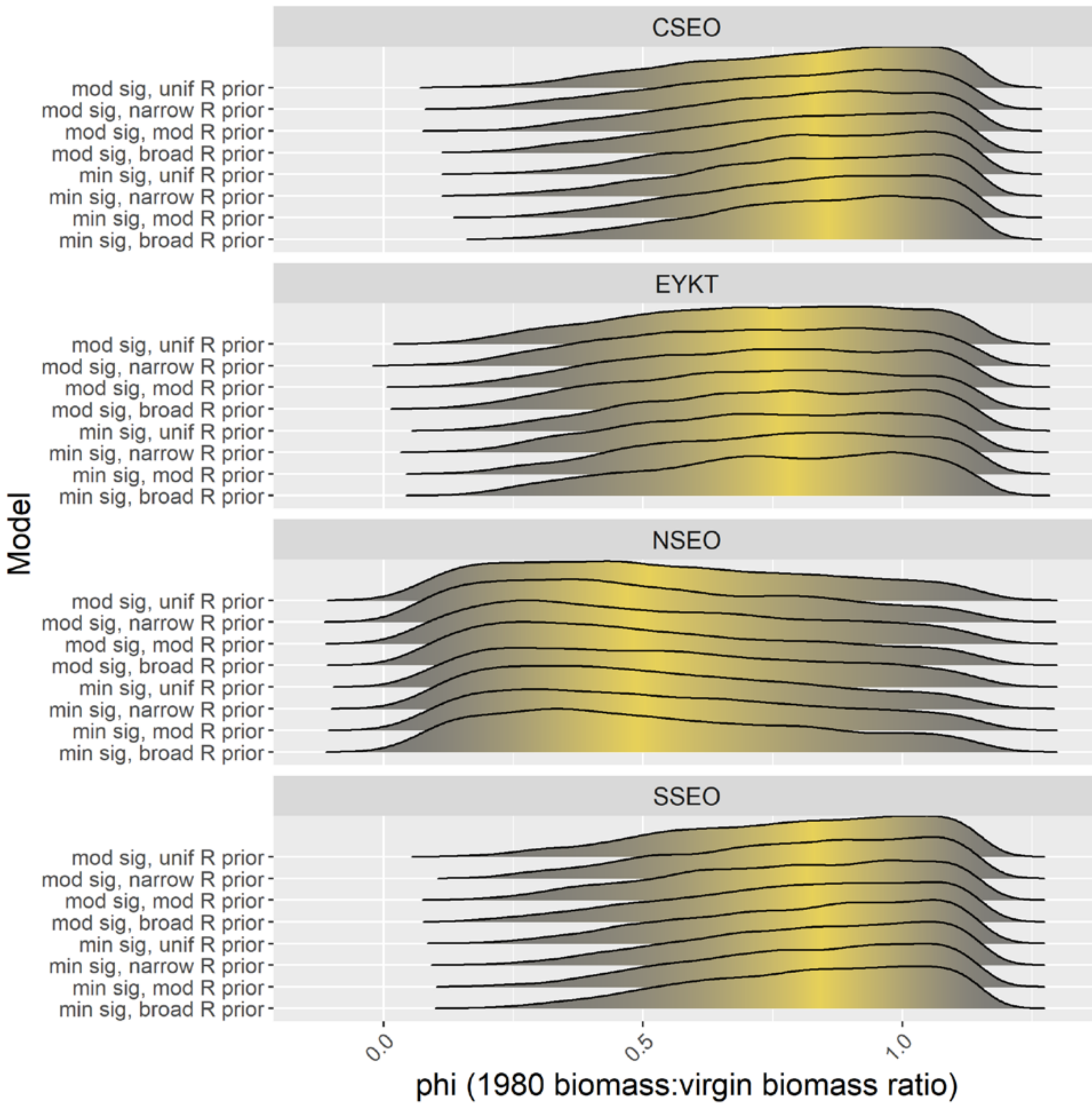

Figure 30. Posterior distributions of ϕ_s, the estimated proportion of K_s comprising biomass in 1980, produced by eight Stage-3 SS-SPMs modelled with moderate (mod sig) and minimal (min sig) process error, σ_{proc}, and four priors for R ranging from an uninformative beta distribution (unif R) through the broadest (broad R), moderate (mod R) and narrowest (narrow R) beta distributions derived from the projected Leslie matrices (Figure 23).

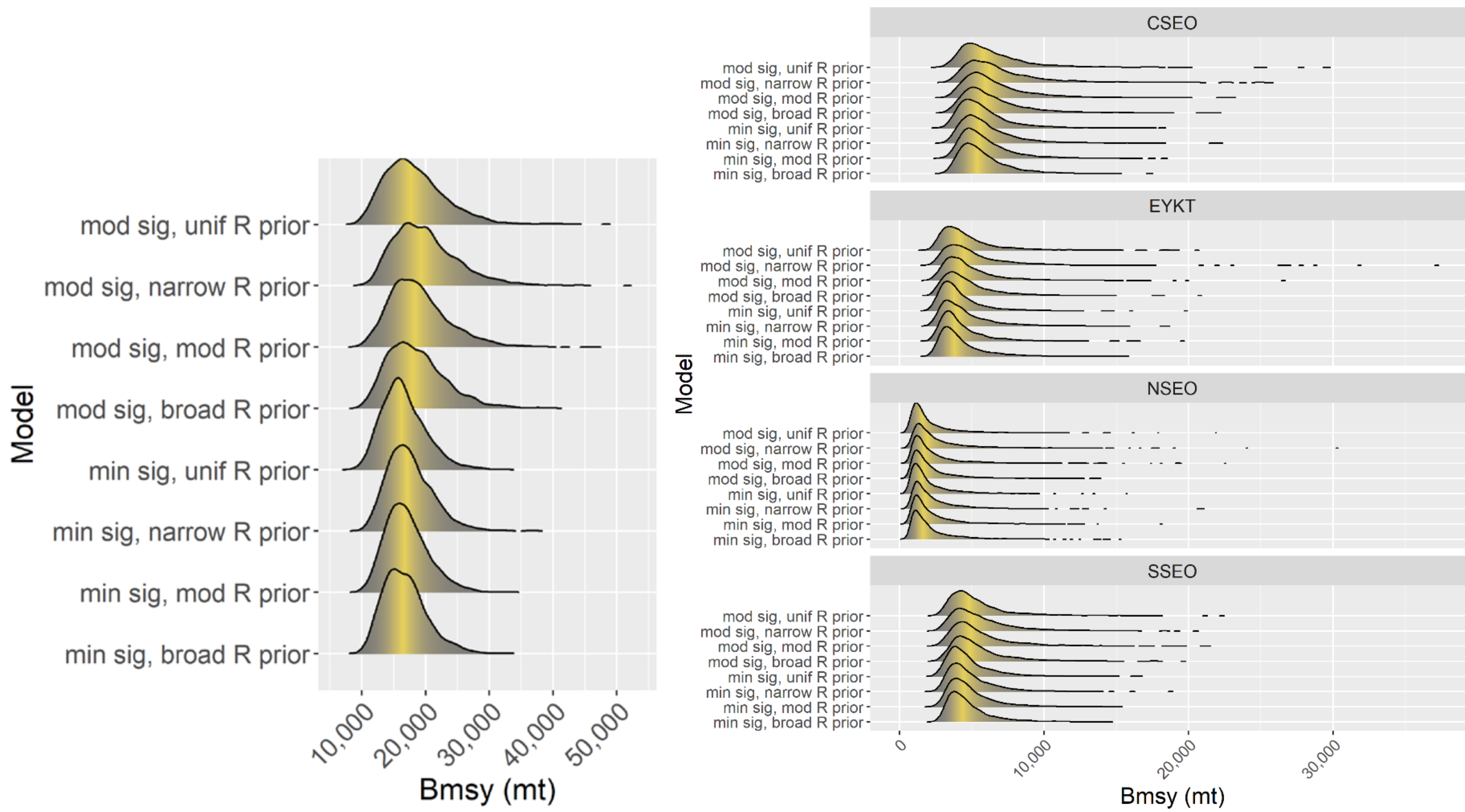

Figure 31. Posterior distributions of B_{MSY} for the Southeast Outside (SEO) district as a whole (left side) and for the management units (right side) produced by eight Stage-3 SS-SPMs modelled with moderate (mod sig) and minimal (min sig) process error, σ_{proc}, and four priors for R ranging from an uninformative beta distribution (unif R) through the broadest (broad R), moderate (mod R) and narrowest (narrow R) beta distributions derived from the projected Leslie matrices (Figure 23).

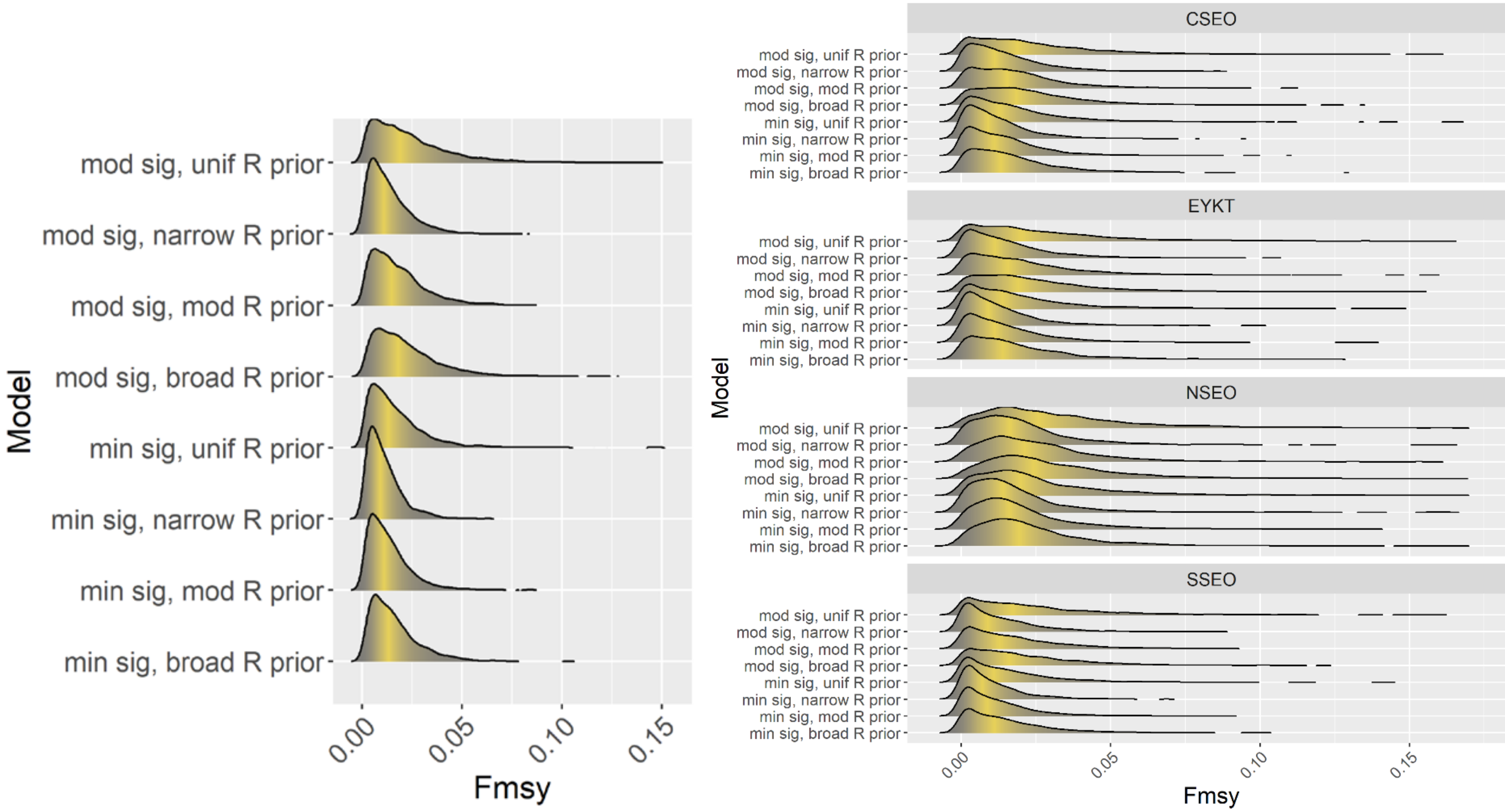

Figure 32. Posterior distributions of F_{MSY} for the Southeast Outside (SEO) district as a whole (left side) and for the management units (right side) produced by eight Stage-3 SS-SPMs modelled with moderate (mod sig) and minimal (min sig) process error, σ_{proc}, and four priors for R ranging from an uninformative beta distribution (unif R) through the broadest (broad R), moderate (mod R) and narrowest (narrow R) beta distributions derived from the projected Leslie matrices (Figure 23).

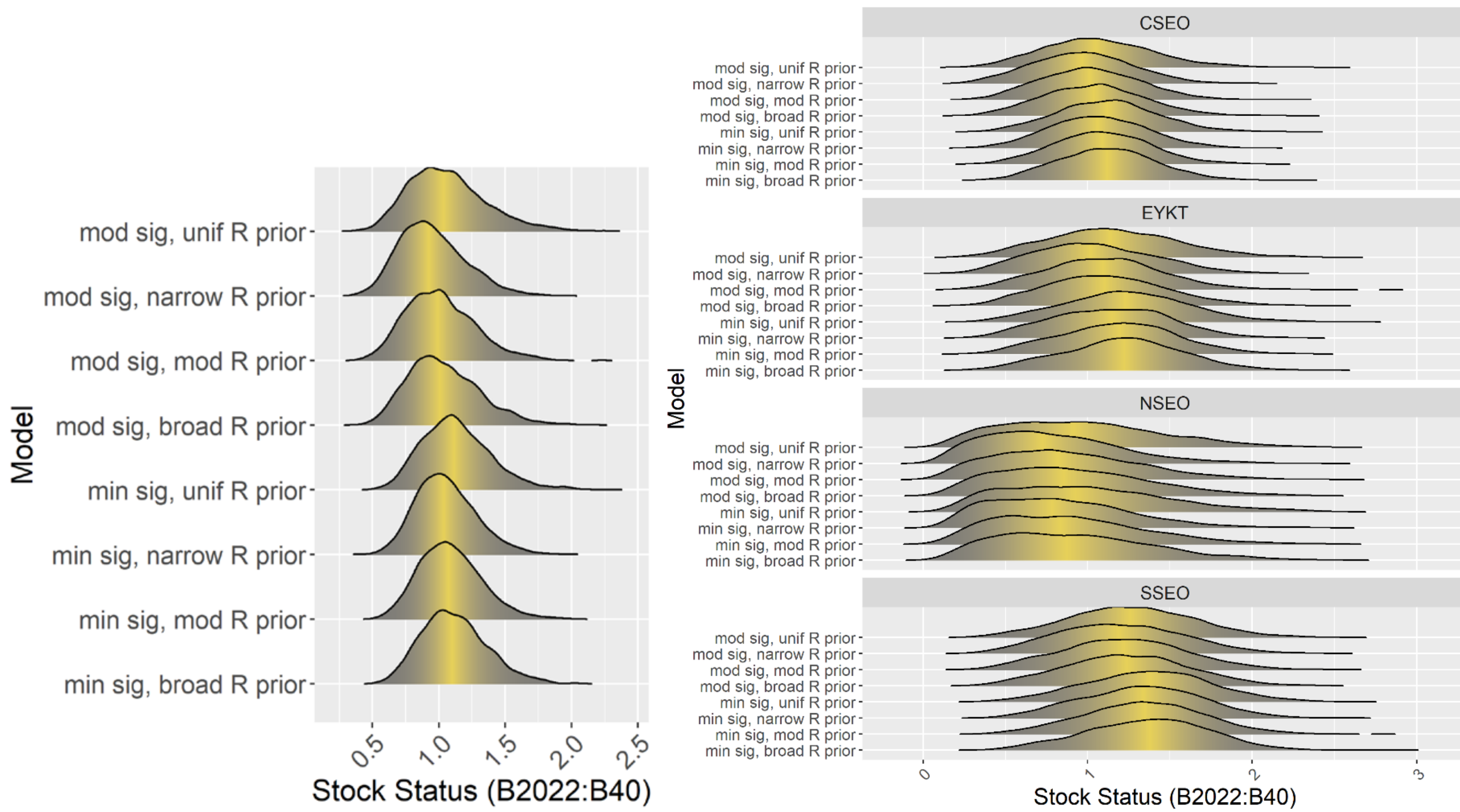

Figure 33. Posterior distributions of stock status (The ratio of biomass in 2022 relative to B_{msy}/B_{40}) for the Southeast Outside (SEO) district as a whole (left side) and for the management units (right side) produced by eight Stage-3 SS-SPMs modelled with moderate (mod sig) and minimal (min sig) process error, σ_{proc}, and four priors for R ranging from an uninformative beta distribution (unif R) through the broadest (broad R), moderate (mod R) and narrowest (narrow R) beta distributions derived from the projected Leslie matrices (Figure 23).

Appendix A.–History of demersal shelf rockfish (DSR) management action, Board of Fisheries (BOF), North Pacific Management Council (NPFMC) and Alaska Department of Fish and Game (ADF&G).

Year	Management Action
1984	600 t guideline harvest limit for 10 species of DSR in CSEO directed fishery. Marine reserves recommended to BOF by ADF&G – rejected. NPFMC defines 10 species assemblage as DSR (yelloweye, quillback, China, copper, canary, rosethorn, tiger, silvergrey, bocaccio, redstripe). October 1-Sept 30 accounting year.
1986	ADF&G restricts gear for rockfish in the Southeast Region to hook and line only. NPFMC gives ADF&G management authority for DSR to 137^0 W long. (Southeast Outside SEO). Guideline harvest limit (GHL) for directed fishery reduced to 300 t (CSEO). GHL for directed fishery set for SSEO (250 t), SSEI (225 t), NSEO (75 t), and NSEI (90 t).
1987	Sitka Sound closed to commercial fishing for DSR.
1988	NPFMC implements 660 t total allowable catch for all fisheries (TAC) for SEO.
1989	NPFMC TAC of 470 t (catch history average). Industry working group (IWG) discusses ITQ options with NPMFC (rejected). IWG recommends 7,500 lb trip limits, mandatory logbooks, and seasonal allocations (10/1-11/31 43%, 12/1-5/15 42%, 7/1-9/30 15%). Ketchikan area closure implemented. GHL for directed fishery reduced in all areas (CSEO 150 t, SSEO 170 t, NSEO 50 t).
1990	NPFMC TAC of 470 t. Directed permit card required for CSEO, SSEO, NSEO.
1991	NPFMC TAC of 425 t. Change in assemblage to 8 species (removed silvergrey, bocaccio, redstripe and added redbanded). Craig and Klawock closures implemented.
1992	NPFMC TAC of 550 t. East Yakutat (EYKT) area included in SEO (NPFMC extends ADF&G mgt authority to 140^0). Directed fishery permit card required in EYKT. Submersible line transect data used to set ABC in EYKT.
1993	NPFMC TAC of 800, yelloweye rockfish line transect data used to set TAC, NPFMC institutes a separate halibut prohibited species cap (PSC) for DSR, BOF changes seasonal allocation to calendar year: 1/1-5/15 (43%), 7/1-9/30 15%, and 10/1-12/31 (42%), DSR opened for 24-hour halibut opening 6/10 (full retention).
1994	NPFMC TAC 960 t using line transect yelloweye rockfish plus 12% for other species, trip limits reduced to 6,000 in SE and 12,000 lb trip limit implemented in EYKT, last time a directed fishery in NSEO was held.
1995	NPFMC TAC 580 t.
1996	NPFMC TAC 945 t.
1997	NPFMC TAC 945 t. Redbanded removed from assemblage definition.
1998	NPFMC TAC 560 t. Revised estimates of rock habitat in EYKT, 10% included for other species. Directed fishery season changed to prevent overlap with IFQ fishery 1/1-3/14 (67%), 11/16-12/31 (33%).
1999	NPFMC TAC 560 t.
2000	NPFMC TAC 340 t. Revised estimates of rock habitat in SEO. Regulation to require full retention for all DSR landed incidentally in the commercial halibut fishery was adopted for state waters.
2001	NPFMC TAC 330 t. Fall directed fishery season initially 24 hours in CSEO and SSEO due to small quota then re-opened 11/26 until quotas taken, no directed fishery NSEO.
2002	NPFMC TAC 350 t. No directed fishery in EYKT due to changes in estimated incidental mortality in that area, no directed fishery in NSEO.

Year	Management Action Cont.
2003	NPFMC TAC 390 t. No directed fishery in EYKT or NSEO. Protocol for classifying habitat revised resulting in changes in TAC. Registration required before participating in directed fishery.
2004	NPFMC TAC 450 t. Directed fishery reopened in EYKT, no directed fishery in NSEO.
2005	NPFMC TAC 437 t. NPFMC final rule to require full retention for all DSR landed incidentally in the commercial halibut fishery for federal waters.
2006	NPFMC TAC 407 t. BOF decision to allocate DSR TAC as follows: 84% to the commercial fishery, 16% to the recreational fishery. SEO DSR restricted to winter fishery only and must close before the start of the halibut fishery. All management areas remain closed to the directed fishery due to stock health concerns; EYKT, NSEO, CSEO, and SSEO.
2007	NPFMC TAC 410 t. All management areas remain closed to the directed fishery due to stock health concerns; EYKT, NSEO, CSEO, and SSEO.
2008	NPFMC TAC 382 t. SSEO and EYKT directed fisheries opened; CSEO and NSEO remain closed.
2009	NPFMC TAC 362 t. Subsistence catch to be deducted from the ABC before allocation of the TAC to the commercial and recreational sectors. SSEO and EYKT directed fisheries opened; CSEO and NSEO remain closed.
2010	NPFMC TAC 295 t. SSEO and EYKT directed fisheries opened; CSEO and NSEO remain closed.
2011	NPFMC TAC 294 t. SSEO and EYKT directed fisheries opened; CSEO and NSEO remain closed.
2012	NPFMC TAC 286 t. Rockfish release devices required on recreational charter vessels. SSEO, CSEO and EYKT directed fisheries opened; NSEO remained closed.
2013	NPFMC TAC 293 t. SSEO, CSEO and EYKT directed fisheries opened; NSEO remained closed.
2014	NPFMC TAC 267 t. EYKT directed fishery opened; SSEO, CSEO, and NSEO remain closed.
2015	NPFMC TAC 217 t. EYKT directed fishery opened; SSEO, CSEO, and NSEO remain closed.
2016	NPFMC TAC 224 t. EYKT directed fishery opened; SSEO, CSEO, and NSEO remain closed, decision to alternate opening each management area every three to four years depending on stock health in management area was made.
2017	NPFMC TAC 220 t. EYKT directed fishery opened; SSEO, CSEO, and NSEO remain closed.
2018	NPFMC TAC 243 t. CSEO directed fishery opened; EYKT, SSEO, and NSEO remain closed, BOF decision reduced the trip limit of DSR in the EYKT management area from 5.4 t to 3.6 t, clarified the language for trip limit amounts for all management areas in SEO, and rockfish release devices will be required for all recreational vessels in Southeast Alaska in 2020.
2019	NPFMC TAC 254 t. SSEO directed fishery opened; EYKT, NSEO, and CSEO remained closed.
2020	NPFMC TAC 231 t. Other than the subsistence and bycatch fisheries, all management areas remain closed to all fishery types due to stock health concerns; EYKT, NSEO, CSEO, and SSEO. Rockfish release devices are required for all recreational vessels in Southeast Alaska starting this year.
2021	NPFMC TAC 250 t. Other than the subsistence and bycatch fisheries, all management areas remain closed to all fishery types due to stock health concerns; EYKT, NSEO, CSEO, and SSEO.

Appendix B.–Area estimates for sonar locations and rocky habitat by management area in Southeast Alaska.

	Sonar Location	Sonared area (km^2)	Area rocky habitat (km^2)
EYKT	Fairweather West Bank	784	402
	Fairweather East Bank	288	98
Total sonar		1,072	500
Total rock (sonar & fishery)			739
Percentage rocky habitat from sonar			68%
NSEO	Cross Sound	849	109
Total sonar		849	109
Total rock (sonar & fishery)			442
Percentage rocky habitat from sonar			25%
CSEO	Cape Edgecumbe	538	328
	Cape Ommaney	294	114
Total sonar		832	442
Total rock (sonar & fishery)			1,661
Percentage rocky habitat from sonar			27%
SSEO	Hazy Islands	400	120
	Addington	84	47
	Cape Felix	140	78
	Learmouth Bank	530	77
Total sonar		1,154	322
Total rock (sonar & fishery)			1,056
Percentage rocky habitat from sonar			30%

Appendix C. RJAGS code for the Stage-3 state-space surplus production model of yelloweye rockfish in the Southeast Outside subdistrict of the Gulf of Alaska 1980-2022.

```
model {

#Bycatch Model and Discard Calculations ==========================================
for (i in 1:Subd){
for (t in 1:15) {   #Derby years pre-1995
  logBy[i,t] ~ dunif(-10,10)
  tau.log.By[i,t] <- 1 / log(cv.ExpByc[i,t]*cv.ExpByc[i,t] + 1)
  ExpByc[i,t] ~ dlnorm(logBy[i,t],tau.log.By[i,t]) #T(0.01,)
  By[i,t]<-exp(logBy[i,t])
  logD[i,t]<-log(max(1,(By[i,t]*exp(derb.err[t]))-Lnd.By[i,t]))
  D[i,t]<-exp(logD[i,t])
}
for (t in 16:N) {   #IFQ years 1995 on
  logBy[i,t] ~ dunif(-10,10)
  tau.log.By[i,t] <- 1 / log(cv.ExpByc[i,t]*cv.ExpByc[i,t] + 1)
  ExpByc[i,t] ~ dlnorm(logBy[i,t],tau.log.By[i,t])T(0.01,)
  By[i,t]<-exp(logBy[i,t])
  logD[i,t]<-log(max(1,By[i,t]-Lnd.By[i,t]))
  D[i,t]<-exp(logD[i,t])
}
}

tau.log.derb<-1/(DEsd*DEsd+1)
for (t in 1:N){
  derb.err[t] <- depsilon[t]-(DEsd*DEsd/2)
  depsilon[t] ~ dnorm(Derby.Eff,tau.log.derb)T(Derby.Eff-0.3,Derby.Eff+0.3)
}

#Known Catches
for (i in 1:Subd){
for (t in 1:N){
  logKnC[i,t] ~ dunif(-10,10)
  KnC.obs[i,t] ~ dlnorm(logKnC[i,t], tau.log.KnC[i,t])
  tau.log.KnC[i,t]<-1/log(cv.KnC[i,t]*cv.KnC[i,t]+1)
  KnC[i,t]<-exp(logKnC[i,t])

#Total catches
  logC[i,t]<-log(D[i,t]+KnC[i,t])
  C[i,t]<-exp(logC[i,t])
}
}

## POPULATION MODEL...======================================
#Process error
logvar ~ dunif(-10,upvar)
sigma <- sqrt(exp(logvar))
tau.log.pe<-1/log(sigma*sigma+1)
for (t in 1:(N+Fu)) {
```

```
  PE[t]<-epsilon[t]-(sigma*sigma/2)
  epsilon[t] ~ dnorm(0,tau.log.pe)T(-0.1,0.1) #epsilon truncation = +/- 10%
}

#Year 1
for (i in 1:Subd){
  logB[i,1] <-log(phi[i]*K[i])
  B[i,1]<-exp(logB[i,1])
}

#Year 2 through N
for (i in 1:Subd){
for( t in 2:N )   #PT with Biomass starting in year 2
  {
    logB[i,t]<-log(max(B[i,t-1]+(r[i]/p)*B[i,t-1]*(1-(B[i,t-1]/K[i])^p)-C[i,t-1],1)*exp(PE[t-1]))
    B[i,t]<-exp(logB[i,t])
  }
}

#surplus production
for (i in 1:Subd){
for (t in 1:N){
    Surplus[i,t]<-(r[i]/p)*B[i,t]*(1-(B[i,t]/K[i])^p)
}
}

#Biomass likelihoods...============================================
for (i in 1:Subd){
for (t in 1:30) {          #Submersible surveys
    use.cv1[i,t]<-sqrt(cv.B[i,t]*cv.B[i,t]+Tau1*Tau1)
    tau.log.B1[i,t] <- 1 / log(use.cv1[i,t]*use.cv1[i,t] + 1)
    B.obs[i,t] ~ dlnorm(logB[i,t],tau.log.B1[i,t])

    #PP.check.log
    subB.new[i,t] ~ dnorm(logB[i,t], tau.log.B1[i,t])  #draw from posterior
    subres.new[i,t] <- subB.new[i,t] - logB[i,t]
}

for (t in 31:N) {        #ROV surveys
    use.cv2[i,t]<-sqrt(cv.B[i,t]*cv.B[i,t]+Tau2*Tau2)
    tau.log.B2[i,t] <- 1 / log(use.cv2[i,t]*use.cv2[i,t] + 1)
    B.obs[i,t] ~ dlnorm(logB[i,t],tau.log.B2[i,t])

    #PP.check.log
    subB.new[i,t] ~ dnorm(logB[i,t], tau.log.B2[i,t])  #draw from posterior
    subres.new[i,t] <- subB.new[i,t] - logB[i,t]
}

for (t in 1:N){         #IPHC CPUE
    use.cv3[i,t]<-sqrt(cv.sCPUE[i,t]*cv.sCPUE[i,t]+Tau3*Tau3)
    log.qsCPUEsubmean[i,t] <- log(qsCPUE[i] * B[i,t])
```

```
    tau.log.sCPUE[i,t] <- 1 / log(use.cv3[i,t]*use.cv3[i,t] + 1)
    sCPUE[i,t] ~ dlnorm(log.qsCPUEsubmean[i,t],tau.log.sCPUE[i,t])

    #PP.check.log
    res[i,t] <- log(B.obs[i,t]) - logB[i,t]  #observed - predicted
    iphcB.new[i,t] ~ dnorm(logB[i,t], tau.log.sCPUE[i,t])  #draw from posterior
    iphcres.new[i,t] <- iphcB.new[i,t] - logB[i,t]
}
}

#derived parameters for PP.check
for (i in 1:Subd) {
  fit[i] <- sum(res[i,])       #maintain subdisrict stratification
  subfit.new [i]<- sum(subres.new[i,])
  iphcfit.new [i]<- sum(iphcres.new[i,])
}

#Subdistrict metrics=====================================================
for (i in 1:Subd){
    CBtoK[i]<-B[i,N]/K[i]
    FBtoK[i]<-B[i,N+Fu]/K[i]
    FBtoCB[i] <-  B[i,N+Fu]/B[i,N]
    MSY[i]<-r[i]*K[i]/((p+1)^((p+1)/p)) #r*K/4 for Schaefer
    Bmsy[i]<-0.4*K[i]  #0.5 for Schaefer
    Fmsy[i]<-MSY[i]/Bmsy[i]
    Hmsy[i]<-r[i]/(1+p)
    Stock.Status[i]<-B[i,N]/(0.4*K[i])

    for (t in 1:N){
    CtoB[i,t]<-C[i,t]/B[i,t]
    }
}

#SEO calculations and summations
for (t in 1:(N+Fu)){
   Bseo[t]<-sum(B[,t])
}

for (t in 1:N){
  Cseo[t]<-sum(C[,t])
  KnCseo[t]<-sum(KnC[,t])
  Byseo[t]<-sum(By[,t])
  Dseo[t]<-sum(D[,t])
  S.seo[t]<-sum(S[,t])
  Surplus.seo[t]<-sum(Surplus[,t])
}

Stock.Status.SEO<-Bseo[N]/(0.4*Kseo)
Bmsyseo<-sum(Bmsy)
Fmsyseo<-sum(MSY)/Bmsyseo
Fmsyseo2<-(Fmsy[1]*Bmsy[1]+Fmsy[2]*Bmsy[2]+Fmsy[3]*Bmsy[3]+Fmsy[4]*Bmsy[4])/Bmsyseo
```

```
FBtoKseo<-Bseo[N+Fu]/Kseo
CBtoKseo<-Bseo[N]/Kseo

Proj1_biomass<-Bseo[N+1]

#subdistrict level priors ====================================================
for (i in 1:Subd){
  r[i] ~ dbeta(rB1,rB2)T(0.0001,0.2)
  logqs[i] ~ dunif(-10,20)
  qsCPUE[i]<-exp(logqs[i])

  #new priors from Stage-2 output
  K[i] <- Kseo*pi[i]
  phi[i] ~ dnorm(bigphi,invtau2) T(0.01,1.15)
  }

#priors/hyper priors ========================================================
p <- 0.18815 #0.18815 = Bmsy =0.4K; 1=Schaefer; 1e-08 ~ modfied fox
Tau1 ~ dunif(0.01,1)
Tau2 <- 0 #ROV years with no extra variance
Tau3 ~ dunif(0.01,1)

#Rhyper prior...
R.hyp ~ dbeta(B1,B2)T(0.0001,0.2) #set to M=0.02,Z=0.05,AaM=17
eta<-exp(logeta)
logeta ~ dlogis(logn,1)T(-5,7.55)
logn<-log(100)
rB1<-R.hyp*eta
rB2<-(1-R.hyp)*eta

#new priors from Stage-2 model
bigKcv <- exp(bigKsigma)/exp(bigKmu)
bigKtau <- 1/(log(bigKcv*bigKcv+1))
logKseo ~ dnorm(bigKmu,bigKtau)
Kseo <- exp(logKseo)
alpha <- c(1,1,1,1)
pi[1:Subd] ~ ddirch(alpha)

phicv <- phisig/phimu
phitau1 <- 1/(log(phicv*phicv+1))
bigphi ~ dnorm(phimu,phitau1) T(0.01,1.15)
invtau2 ~ dgamma(a_t, b_t) #with 1s is uninformative...
a_t<-1
b_t<-1
phiTau<-sqrt(pow(invtau2, -1))
}
```

Appendix D**.** Risk table displaying the probability that yelloweye rockfish biomass is above B_{msy}/B_{40} in 2022 and in 2073 under constant harvests. Results are based on the state-space surplus production model (SS-SPM) with moderate process error and the broadest informative R prior. Harvest rates are based on median F_{msy} values and projected 2023 biomass estimates from the SS-SPM model or from the status-quo biomass and harvest recommendations.

	Management Area	**Pre-IFQ bycatch rate relative to WCPUE est.** 30% lower	same	30% higher	**Overall Probability**
Pre-IFQ Probability:		0.2	0.4	0.4	1.0
Probability $\mathbf{B_{2022}}$ is above B_{msy}/B_{40}	EYKT	70%	61%	59%	62.0%
	NSEO	45%	38%	33%	37.5%
	CSEO	63%	53%	48%	53.3%
	SSEO	80%	73%	69%	72.7%
	All SEO	65%	52%	44%	51.4%
Projections: Probability $\mathbf{B_{2073}}$ is above B_{msy}/B_{40} under constant harvest **Harvest Calculation:**					
$F_{ABC} = 0.75*F_{OFL}$	EYKT	47%	41%	39%	41.5%
	NSEO	48%	43%	39%	42.4%
	CSEO	47%	39%	36%	39.3%
	SSEO	46%	41%	36%	40.0%
	All SEO	43%	35%	30%	34.6%
Rec F_{ABC} = 10% reduction of F_{ABC}	All SEO	47%	39%	34%	38.6%
Rec F_{ABC} = 25% reduction of F_{ABC}	All SEO	53%	44%	40%	44.2%
Status-quo = 0.02*Biomass lower 90% CI	EYKT	53%	46%	44%	46.8%
	NSEO	66%	59%	55%	58.9%
	CSEO	48%	42%	38%	41.8%
	SSEO	35%	31%	26%	29.7%
	All SEO	42%	36%	30%	34.9%
Status-quo = 0.02*Biomass point estimate	All SEO	24%	20%	16%	19.1%