A proposed Tier 4 approach to the rougheye and blackspotted rockfish complex in the Gulf of Alaska

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Executive Summary

We recommend retiring the Tier 3 statistical catch-at-age (SCAA) for the Gulf of Alaska (GOA) rougheye and blackspotted (REBS) rockfish complex and adopt a Tier 4 per-recruit framework (Tier 5 as a transparent fallback). Tier 4 better reflects species-specific biology, is tractable with available data, and avoids the unresolved scale/fit problems in the current SCAA.

Rationale:

1. Species biology mismatch: The SCAA treats rougheye and blackspotted rockfish as one stock with averaged life history parameters, despite clear differences in growth and maturity; this obscures risk to the lower-productivity species and creates unacceptable uncertainty in SCAA results.

2. Infeasible data demands: Validated, species-specific time series of catch, survey indices, and compositions are necessary for a two-species SCAA; however, developing these time series is unlikely under current data collection programs due to the persistent misidentification between the two species.

3. Model scale/fit problems: The SCAA exhibits persistent identifiability and scaling issues (retrospective bias, poor fits, unstable catchability), and relies heavily on length compositions that are weakly informative for very long-lived rockfishes.

Since 2007, the GOA REBS rockfish complex has relied on a Tier 3 integrated statistical catch-at-age (SCAA) model (Shotwell et al., 2007). Prior to 2008, when the two species were formally verified as distinct (Orr and Hawkins, 2008), the assessment only recognized rougheye rockfish. Since then, the two species have been modeled as a single stock unit with combined input data and averaged biological parameters (Shotwell et al., 2008; Sullivan et al., 2023). The SSC and Groundfish Plan Team have repeatedly flagged risks with this approach given high rates of field misidentification and the absence of validated, species-specific catch, survey, and composition time series (Appendix A).

The 2023 stock assessment further highlighted major concerns related to assessment methods and population dynamics, resulting in a recommended reduction from the maximum permissible ABC (Sullivan et al., 2023). These concerns included strong retrospective bias, poor fits to abundance and composition data, high uncertainty in the scale and trend of the stock, and downward trends in the trawl survey and longline survey abundance indices in recent years. These issues are especially problematic under the combined-species approach, where risk to the lower productivity species is not quantified.

Recent research on REBS maturity provides a pathway toward resolving these issues (Sullivan et al., in prep). Validation of historical maturity samples using otolith morphometrics confirms that blackspotted and rougheye rockfish differ substantially in age and length at maturity, as well as in the frequency of skipped spawning events. Moreover, functional maturity, which accounts for skip spawning, delays realized reproduction relative to biological maturity. Incorporating these species-specific maturity relationships into assessment models fundamentally changes estimates of spawning biomass per recruit (SBPR) and the spawning potential ratio (SPR) reference points used in harvest control rules.

To better capture species-specific differences in maturity and growth, we recommend a shift from the current Tier 3 SCAA model to a Tier 4 yield per recruit (YPR) and SBPR analysis. A Tier 4 model based on updated biological or functional maturity schedules allows direct evaluation of species-specific reproductive potential without the need to assume averaged biology. Under this approach, SBPR is calculated for each species individually based on species-specific growth, and maturity, but assumes a single natural mortality based on available data (M=0.042; Sullivan et al. 2023), and a combined fishery and selectivity curve. We recommend complex-level SPR reference points (e.g., $F_{40\%}$, $F_{35\%}$) that maintain both species at management targets. The base case assumes equilibrium recruitment is split 50:50 between species, the implications of which can be explored with sensitivity analyses. The $F_{40\%}$ and $F_{35\%}$ reference points are then multiplied by the predicted biomass obtained using the two-survey random effects (REMA) model as currently configured for GOA REBS apportionment. This REMA model uses management area (eastern, central, and western GOA) estimates of REBS GOA bottom trawl survey biomass since 1990 and AFSC longline survey relative population weights (RPWs), estimates a single, GOA-wide process error, and estimates area-specific scaling parameters (ϙ). Finally, we also show a Tier 5 alternative, which uses the same REMA model and M=0.042, where F_{ABC}=0.75*M and F_{OFL}=M.

Summary of Changes in Assessment Inputs

Changes in the input data:

All results presented in September are based on the input data used in the last full assessment model, which was current through 2023. Life history information has been updated for the Tier 4 and 5 candidate model as specified in the Analytical Approach section.

Assessment model numbering and definitions

1) Model 23.1b: the base SCAA model using the same data as the 2023 assessment.
2) Model 25.1a: Tier 4, species-specific biological maturity.
3) Model 25.1b: Tier 4, species-specific functional maturity.
4) Model 25.2: Tier 5

Summary of Results

Reference values for the REBS rockfish stock complex are summarized in the following table for each candidate model, with the ABC and OFL values in bold.

Quantity	*As estimated or recommended in 2023*:		**Quantity**	*As estimated or recommended in 2023:*		
	2024	2025		2024/25		
Model	Model 23.1b		Model	Model 25.1a	Model 25.1b	Model 25.2
M (natural mortality rate)	0.042	0.042	M	0.042	0.042	0.042
Tier	3a	3a	Tier	4	4	5
Projected total (ages 3+) biomass (t)	46,029	46,109	REBS estimated biomass (t) from REMA model	28,531		
Projected female spawning biomass (t)	12,986	13,005				
$B_{100\%}$	21,878	21,878				
$B_{40\%}$	8,751	8,751				
$B_{35\%-}$	7,657	7,657				
			Rougheye F_{OFL}	0.058	0.067	
			Rougheye F_{ABC}	0.048	0.055	
			Blackspotted F_{OFL}	0.033	0.037	
			Blackspotted F_{ABC}	0.028	0.031	
F_{OFL}	0.045	0.045	F_{OFL}	0.033	0.037	0.042
$maxF_{ABC}$	0.038	0.038	$maxF_{ABC}$	0.028	0.031	0.032
F_{ABC}	0.030	0.030	F_{ABC}	0.028	0.031	0.032
OFL (t)	**1,555**	**1,566**	OFL (t)	**942**	**1,056**	**1,198**
maxABC (t)	1,302	1,310	maxABC (t)	799	884	913
ABC (t)	**1,037**	**1,041**	ABC (t)	**799**	**884**	**913**
Status	As determined *this* year for:					
	2022	2023				
Overfishing	No	n/a				
Overfished	n/a	No				
Approaching overfished	n/a	No				

Summary of 2023 stock assessment results

In 2023, the GOA REBS stock complex was assessed using a SCAA model using Tier 3 harvest controls rules (Sullivan et al., 2023). However, there were elevated risk ratings in both the Assessment and Population Dynamics categories of the risk table. Recent trends show declines in both indices: the 2023 longline survey abundance is the lowest on record (34% below the time-series mean), while the 2023 trawl survey rebounded from the 2021 minimum yet remains below average; these patterns triggered “Level 2 – Major Concern” for population dynamics.

The long-used base model (Model 15.4) exhibited a severe one-way positive retrospective pattern (Mohn's ρ worsened from 0.61 in 2021 to 1.05 in 2023) with large shifts in survey catchabilities, *M*, and recruitment. The 2023 recommended and accepted model (Model 23.1b) stabilized estimation by constraining catchability priors and fixing *M*, improving the retrospective metric ($\rho \approx 0.14$), but at the cost of degraded fits and biomass trajectories inconsistent with the recent survey declines, indicating remaining misspecification. Supporting diagnostics highlight why: the unconstrained SCAA allowed highly correlated scaling parameters to drift to implausible values (e.g., trawl $q \approx 2.4$; longline $q > 1.5$) and forced compensatory cuts to mean recruitment, underscoring identifiability problems and likely underestimation of uncertainty when parameters are fixed.

Harvest advice reflected these risks: a reduction from the maximum permissible ABC, where we split the difference between the 2024 ABC specified in the 2022 assessment and the 2024 maximum ABC estimated for the 2023 assessment. We applied the same logic to obtain the reduction for 2025 during the 2024 harvest projection assessment, splitting the difference 2025 ABC specified in the 2023 assessment and the 2025 maximum ABC estimated during the 2024 assessment.

Analytical Approach

Species-Specific Biological and Functional Maturity Curves

The species-specific biological and functional maturity curves used in this analysis were developed in Sullivan et al. (in prep). In this paper, we aimed to address recent GOA Plan Team and SSC recommendations (Appendix B) to incorporate maturity data not previously used and to explore alternative methods that account for skip spawning. This study involved using otolith morphometrics to retrospectively validate species identity of histology-based maturity samples from Conrath (2017), re-evaluating maturity and skip spawning estimates, and assessing the implications for stock management. We fit generalized additive models (GAMs) to otolith-validated specimens to provide more flexible, non-monotonic biological maturity curves. Additionally, we used a simulation-based approach to estimate functional maturity, defined as the probability of being both biologically mature and actively spawning. This involved modeling species-specific skipped spawning probabilities using GAMs fit to otolith-validated specimens (Figure 1) and combining them with biological maturity predictions. The resulting species-specific biological and functional maturity curves used in this report are presented in Figure 2. A full copy of the draft manuscript is available upon request (jane.sullivan@noaa.gov).

Biomass Estimation for Tiers 4 and 5

Biomass for Tier 4 and 5 is estimated using the current REMA model used for apportionment in the GOA REBS stock assessment (Sullivan et al., 2023). This relies on the *rema* R library, which was endorsed by the GOA Groundfish Plan Team (GPT) and Scientific and Statistical Committee (SSC) in 2022.

Inputs

We use species-combined REBS design-based estimates of GOA bottom trawl survey biomass since 1990 and AFSC longline survey RPWs stratified by eastern GOA, central GOA, and western GOA (Table 1).

The distribution and proportion of rougheye and blackspotted rockfish biomass in the Gulf of Alaska (GOA) is an important consideration. While both species are found throughout the GOA, their distribution varies. Species-specific biomass estimates, based on field identification from the bottom trawl survey, have been available since 2007 (Table 2), but these data are not used in the model due to high rates of misidentification. For example, in the Harris et al. (2019) study based on 2009 and 2013 genetic samples from the GOA bottom trawl survey, up to 40% of the field-identified rougheye rockfish were genetically blackspotted, while only 4% of field-identified blackspotted rockfish were genetically rougheye. We present time series of field-based, species-specific biomass from the bottom trawl survey, separated by management area (Appendix C, Figure 1). This figure suggests rougheye are the dominant species in the eastern and central GOA, whereas blackspotted are dominant in most years in the western GOA. We also provide the distribution of genetic specimens from Harris et al. (2019), which shows some species differentiation by depth and by location within management areas (Appendix C, Figure 2). These data also support the dominance of blackspotted rockfish in the western GOA, though sample sizes are limited.

Model Parameters

This REMA model estimates a single, GOA-wide process error, and estimates area-specific scaling parameters (ϙ).

Tier 4 Model

The Tier 4 approach uses a YPR/SBPR equilibrium model. The analysis was implemented using a custom life history simulation function in R that tracked survivorship, yield, and spawning contribution of individual fish.

Inputs

Species-specific life history parameters inputs were used when available, including von Bertalanffy growth (Harris et al., 2019) and weight-at-length (estimated using genetic data from Harris et al., 2019; rougheye rockfish: α=0.00001143, β=3.10; blackspotted rockfish: α=0.00000813, β=3.18). Natural mortality was fixed at M=0.042 for both species based on a comprehensive analysis from the most recent full stock assessment (Sullivan et al., 2023). for both species based on a comprehensive analysis from the most recent full stock assessment (Sullivan et al., 2023). That analysis, which followed longevity M estimator recommendations from Then et al. (2015) and Hamel and Cope (2022), used the five oldest rougheye and blackspotted specimens collected in the GOA bottom trawl survey and fishery (Table 3). Four of these specimens were collected before 2007, when the two species were not differentiated in the field. Only one of the five oldest specimens had a confirmed species ID (rougheye). Given the potential for misidentification and the lack of species-specific data for the oldest specimens, we could not confidently estimate separate maximum ages for each species. Therefore, it was more appropriate to use a single complex-level M. Similarly, fishery selectivity-at-age S_a was assumed to be identical for both species and was obtained from the most recent stock assessment (Model 23.1b), with full selection occurring around age 13. We use the fishery selectivity-at-age from the most recent assessment because its shape and age at full selection are identified primarily by fishery composition data and mixed gear dynamics, not by the scaling parameters that drive the SCAA's retrospective/scale issues.

We modeled two age-based maturity variants:

1. Biological maturity (**Model 25.1a**)
2. Functional maturity, incorporating skipped spawning (**Model 25.1b**)

YPR/SBPR equilibrium model inputs of growth, maturity, and fishery selectivity are shown in Figures 3 and 4, respectively.

Model specification

We simulated yield and spawning biomass across a range of fishing mortality values (F = 0 to 0.4, by 0.001). Female spawning biomass per recruit under fishing ($SBPR_F$) was calculated as:

$$SBPR_F = \sum_a N^f_{a,F} \cdot w_a \cdot m_a$$

where $N^f_{a,F}$ is the number of females at age a under fishing mortality F, w_a is weight-at-age, and m_a is maturity-at-age. The unfished spawning biomass per recruit ($SBPR_0$) was calculated similarly, assuming F=0. The spawning potential ratio $SPR(F)$ was then defined as:

$$SP\mathrm{R}(F) = \frac{SBPR_F}{SBPR_0}$$

The reference points $F_{40\%}$ and $F_{35\%}$ are the fishing mortalities at which $SPR(F_{40\%})$=0.4 or $SPR(F_{35\%})$=0.35, respectively.

The female abundance at age under fishing ($N^f_{a,F}$) was calculated recursively:

$$N^f_{1,F} = R_0 \cdot s$$

$N^f_{a,F} = N^f_{a-1,F} \cdot e^{-Z_{a-1}}$, for $a = 2, \ldots, A-1$

$N^f_{A,F} = \frac{N^f_{A-1,F} \cdot e^{-Z_{A-1}}}{1-e^{-Z_A}}$,

where s=0.5 is the assumed sex ratio, R_0=1 is the unit-less equilibrium mean recruitment, $Z_a = M + F \cdot S_a$ is total mortality at age, and A=52 is the maximum age class (same as Model 23.1b).

Numbers caught by age were calculated using the Baranov catch equation:

$C_{a,F} = \frac{F \cdot S_a}{F \cdot S_a + M} \cdot (1 - e^{-Z_a}) \cdot N_{a,F}$.

Total equilibrium YPR was obtained by summing the product of yield-at-age and weight-at-age.

Tiers 4 and 5 Harvest Control Rules

For Tier 4 stocks, F_{OFL} and F_{ABC} are defined as $F_{35\%}$ and $F_{40\%}$, respectively. These SPR-based reference points are defined in the previous section for the YPR/SBPR model. Here, species-specific $F_{35\%}$ and $F_{40\%}$ are estimated for rougheye and blackspotted rockfish, and the complex-level $F_{35\%}$ and $F_{40\%}$ that maintains both species at or above their species-specific targets is recommended. In practice, this means managing the complex to blackspotted rockfish, the lower productivity species in the complex.

For Tier 5 stocks, F_{OFL} and F_{ABC} are defined as M and $0.75M$, respectively, where M=0.042 for both species.

For both Tiers 4 and 5, OFL and ABC are calculated by multiplying F_{OFL} and F_{ABC} by the terminal year biomass estimated by the REMA model.

Results

Biomass Estimation

Process error and area-specific estimates of the longline survey scaling parameters are shown in Table 4 and appear to be well-identified by the REMA model. Additionally, the REMA model appears to fit the available data well, although there is some conflict between the bottom trawl and longline surveys (Figure 5). For example, in the terminal year, the trawl survey biomass estimate showed an increase, whereas the longline survey showed a large decrease, which is not captured by the model. Overall, the GOA-wide estimated biomass trajectory shows declines since approximately 2010 (Figure 6). The estimated biomass in 2023 is 28,531 t, which is a 38% decrease from the time series high of 46,095 t estimated in 2007 (Table 5). The 2023 estimated biomass is used in Tier 4 and 5 harvest advice.

Tier 4 YPR/SBPR Model

The species-specific $F_{35\%}$ and $F_{40\%}$ values for the Tier 4 alternatives are reported in the summary table of the Executive Summary and in the following table:

Tier 4	**Rougheye $F_{35\%}$**	**Rougheye $F_{40\%}$**	**Blackspotted $F_{35\%}$**	**Blackspotted $F_{40\%}$**
Model 25.1a (biological maturity)	0.058	0.048	0.033	0.028
Model 25.1b (functional maturity)	0.067	0.055	0.037	0.031

When comparing results under biological and functional maturity scenarios, the higher $F_{40\%}$ values observed for functional maturity can be directly explained by the relationship between maturity and fishery selectivity curves (Figure 4). Functional maturity curves are depressed relative to biological curves at the ages where fishery selectivity is already very high (ages ~15-30). Age-specific contributions to SBPR under fished and unfished conditions show how differences between functional and biological maturity reduces the overlap between vulnerable ages and reproductive output (Figure 7). This means that in the unfished state, fewer spawners contribute at those vulnerable ages under functional maturity than under biological maturity, and fishing therefore removes relatively less spawning potential under the former (Figure 8). As a result, the SPR ratio declines more gradually with fishing mortality under functional maturity, shifting the F-SPR curve slightly to the right and producing higher SPR reference points (e.g., $F_{40\%}$) compared to biological maturity (Figure 9).

Importantly, a higher *F* target under functional maturity does not imply greater reproductive capacity or advocacy for higher removals; it reflects how the SPR-based control rule is defined. In Tier 4 we set *F* to maintain a fixed proportion of each species' unfished spawning biomass per recruit (e.g., SPR = 0.40). Because functional maturity lowers $SBPR_0$ most strongly at ages where fishing exposure is highest, a given *F* removes a smaller proportion of total SBPR than in the biological scenario. Consequently, the *F* that achieves the same proportional target (SPR = 0.40) is higher. The true absolute productivity and maximum sustainable yield may still be lower under functional maturity, but this is not accounted for in the SPR-based reference point under Tier 4.

Tier 5

F_{OFL} for GOA REBS under Tier 5 is set equal to M=0.042. F_{ABC} is set to 0.75M=0.032.

Recommendations

We recommend retiring the Tier 3 SCAA for the GOA REBS complex and moving to a Tier 4 (or Tier 5 if needed) YPR/SBPR framework built on species-specific biology. The current SCAA treats rougheye and blackspotted as a single stock with averaged life history, even though the species differ markedly in growth and maturity. Because we do not know how much each species contributes to recruitment or to the fishery catch in a given year, the SCAA's single-species representation creates unresolvable species composition and scaling problems. Given existing resources, it is not realistic to develop validated, species-specific time series of catch, survey indices, and age/length compositions that would better inform a two-species SCAA. Even setting those issues aside, the SCAA has persistent technical deficiencies (unstable scale, identifiability, and difficulty fitting the data). The model relies heavily on length compositions that are only weakly informative about age structure for very long-lived rockfishes with variable growth and early attainment of maximum length; deeper exploration of selectivity can improve fits but cannot fix the scale problem. These concerns mirror the West Coast REBS assessment findings, which highlight strong scale sensitivity to modeling assumptions, very large uncertainty, and added complications from treating a two-species complex with demonstrated differences in growth and maturity (Cope et al., 2025).

A Tier 4 approach directly addresses these weaknesses while remaining transparent and tractable with available data. We model each species' per-recruit quantities separately (species-specific growth and maturity; shared fishery selectivity) and then choose one complex-level *F* such that each species meets or exceeds its SPR target. (i.e., $SPR_{RE}(F) \geq SPR_{x\%}$ and SPR_BS(F) ≥ SPR_T (with $SPR_{x\%}$ = 0.40 for $F_{40\%}$

or 0.35 for $F_{40\%}$). Operationally, this is equivalent to setting $F_{complex}$, = min($F_{40\%,RE}$, $F_{40\%,BS}$) (or min($F_{35\%,RE}$, $F_{35\%,BS}$), because SPR declines monotonically with *F* (Figure 9). The model assumes a 50:50 split of equilibrium recruitment (neutral prior) with sensitivities on recruitment species composition and fishery selectivity. Catch advice would be derived from this shared *F* applied to the complex biomass, with clear reporting of how species-mix assumptions affect performance (Sullivan et al., in prep. indicate that staying at target SPR likely requires the majority of removals to be rougheye rockfish).

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Tables

Table 1. Design-based estimates with coefficient of variation (CV) of Gulf of Alaska (GOA) rougheye and blackspotted rockfish bottom trawl survey biomass (t) and longline survey relative population weights (RPW) in the eastern GOA (EGOA), central GOA (CGOA), and western GOA (WGOA). These are inputs to the two-survey random effects model.

Year	Biomass (CV)			RPW (CV)		
	EGOA	CGOA	WGOA	EGOA	CGOA	WGOA
1990	1,329 (0.476)	35,467 (0.258)	8,041 (0.193)	-	-	-
1991	-	-	-	-	-	-
1992	-	-	-	-	-	-
1993	10,891 (0.785)	41,616 (0.275)	9,358 (0.207)	7,771 (0.440)	7,134 (0.304)	20,556 (0.272)
1994	-	-	-	5,601 (0.374)	3,547 (0.303)	29,844 (0.229)
1995	-	-	-	15,462 (0.385)	11,576 (0.267)	16,192 (0.226)
1996	3,449 (0.346)	28,396 (0.233)	14,067 (0.226)	7,168 (0.453)	7,948 (0.322)	24,484 (0.185)
1997	-	-	-	10,775 (0.466)	10,020 (0.365)	40,529 (0.279)
1998	-	-	-	8,998 (0.306)	8,443 (0.371)	21,323 (0.124)
1999	6,156 (0.513)	20,781 (0.174)	12,622 (0.257)	8,117 (0.287)	8,623 (0.346)	24,469 (0.217)
2000	-	-	-	13,812 (0.367)	11,863 (0.285)	34,658 (0.196)
2001	6,945 (0.548)	24,740 (0.238)	-	11,883 (0.380)	13,658 (0.310)	20,450 (0.230)
2002	-	-	-	14,647 (0.340)	10,387 (0.349)	17,999 (0.161)
2003	8,921 (0.341)	24,610 (0.197)	9,670 (0.363)	9,573 (0.353)	7,398 (0.378)	23,794 (0.194)
2004	-	-	-	13,088 (0.425)	5,581 (0.350)	21,238 (0.174)
2005	3,621 (0.258)	32,898 (0.254)	11,356 (0.164)	4,660 (0.569)	8,417 (0.332)	16,414 (0.269)
2006	-	-	-	6,930 (0.328)	10,780 (0.346)	15,586 (0.180)
2007	3,773 (0.268)	39,419 (0.243)	16,697 (0.232)	14,374 (0.391)	11,853 (0.274)	23,325 (0.173)
2008	-	-	-	8,607 (0.382)	10,309 (0.249)	27,974 (0.176)
2009	2,765 (0.265)	33,154 (0.211)	14,855 (0.297)	8,738 (0.361)	16,821 (0.415)	18,012 (0.134)
2010	-	-	-	15,383 (0.354)	9,279 (0.325)	25,531 (0.143)
2011	3,305 (0.428)	32,181 (0.211)	8,228 (0.168)	17,197 (0.453)	9,865 (0.329)	30,819 (0.271)
2012	-	-	-	10,853 (0.369)	7,171 (0.435)	22,500 (0.232)
2013	3,922 (0.242)	11,207 (0.293)	12,452 (0.302)	11,173 (0.439)	7,070 (0.328)	14,917 (0.225)
2014	-	-	-	10,757 (0.405)	9,304 (0.371)	29,602 (0.176)
2015	1,345 (0.219)	18,135 (0.200)	15,079 (0.224)	15,689 (0.446)	8,960 (0.443)	25,338 (0.204)
2016	-	-	-	12,610 (0.405)	7,965 (0.285)	17,695 (0.245)
2017	6,722 (0.451)	11,297 (0.212)	21,900 (0.277)	16,867 (0.349)	12,223 (0.438)	24,183 (0.196)
2018	-	-	-	10,999 (0.303)	7,897 (0.272)	17,118 (0.154)
2019	1,381 (0.337)	38,696 (0.686)	15,417 (0.277)	16,927 (0.402)	11,742 (0.321)	17,705 (0.161)
2020	-	-	-	8,237 (0.448)	4,820 (0.147)	18,753 (0.253)
2021	5,242 (0.280)	12,661 (0.171)	6,709 (0.195)	10,160 (0.371)	4,431 (0.246)	20,308 (0.157)
2022	-	-	-	8,251 (0.402)	7,574 (0.265)	20,352 (0.195)
2023	1,753 (0.564)	11,473 (0.161)	18,130 (0.118)	8,057 (0.383)	5,323 (0.282)	12,845 (0.137)

Table 2. Design-based estimates of total rougheye and blackspotted biomass (t) from the Gulf of Alaska bottom trawl survey. Species-specific estimates using field identification started in 2007 and are not used because of high rates of misidentification.

Year	Rougheye Biomass	Blackspotted Biomass	Total Biomass	Proportion Rougheye
2007	26,104	33,280	59,384	0.44
2009	32,205	17,732	49,937	0.64
2011	28,467	15,118	43,586	0.65
2013	17,005	10,168	27,173	0.63
2015	24,725	8,978	33,703	0.73
2017	28,227	11,400	39,627	0.71
2019	19,263	35,718	54,981	0.35
2021	16,369	7,778	24,147	0.68
2023	23,337	7,631	30,968	0.75

Table 3. Detailed sex (M = male, F = female), age, fork length (cm), and weight (kg) data for the five oldest specimens in the AFSC bottom trawl survey and fishery. The five oldest specimens are presented by species grouping, where REBS (rougheye/blackspotted) are not identified by species (includes pre-2007 trawl survey and all fishery specimens), and rougheye (RE) or blackspotted (BS) rockfish are identified to species in the field on the trawl survey starting in 2007. The specimens identified in the field are subject to high misidentification rates. Table reproduced from Sullivan et al. (2022).

Species	Region	Year sampled	Sex	Age (yr)	Fork length	Weight	Source/Gear
REBS	GOA	1993	M	132	60	NA	Trawl survey
REBS	GOA	1993	M	130	54	NA	Trawl survey
REBS	GOA	1999	M	129	59	2.962	Trawl survey
REBS	GOA	2008	M	126	50	1.9	Hook-and-line fishery
REBS	GOA	1993	M	121	58	NA	Trawl survey
RE	GOA	2009	M	135	64	3.342	Trawl survey
RE	GOA	2009	M	113	49	1.762	Trawl survey
RE	GOA	2013	M	113	52	2.146	Trawl survey
RE	GOA	2019	M	108	60	3.71	Trawl survey
RE	GOA	2009	F	98	48	1.57	Trawl survey
BS	GOA	2013	F	103	53	2.482	Trawl survey
BS	GOA	2009	M	97	47	1.622	Trawl survey
BS	GOA	2013	M	91	50	2.126	Trawl survey
BS	GOA	2009	M	90	54	2.406	Trawl survey
BS	GOA	2013	M	90	53	2.462	Trawl survey

Table 4. Parameter estimates, standard errors (SE), and lower and upper 95% confidence intervals (LCI, UCI) from the two-survey random effects (REMA) model.

Parameter	Estimate	SE	LCI	UCI
Process error	0.10	0.03	0.06	0.17
CGOA scaling parameter	0.38	0.03	0.32	0.44
EGOA scaling parameter	1.63	0.11	1.43	1.86
WGOA scaling parameter	3.27	0.35	2.64	4.04

Table 5. Predicted total biomass with lower and upper 95% confidence intervals (LCI, UCI) from the two-survey random effects (REMA) model.

Year	Estimated Biomass	LCI	UCI
1990	40,588	31,921	51,608
1991	40,242	32,076	50,487
1992	39,963	32,530	49,094
1993	39,750	33,377	47,341
1994	39,200	33,080	46,454
1995	40,462	34,410	47,579
1996	41,576	35,731	48,377
1997	42,129	35,916	49,417
1998	41,516	35,604	48,409
1999	41,754	36,231	48,120
2000	43,508	37,084	51,045
2001	43,178	36,629	50,899
2002	42,201	35,983	49,494
2003	41,762	36,042	48,390
2004	41,585	35,613	48,558
2005	42,455	36,491	49,393
2006	43,704	37,272	51,246
2007	46,095	39,231	54,160
2008	45,835	38,907	53,997
2009	44,918	38,368	52,587
2010	43,433	37,048	50,918
2011	41,130	35,498	47,655
2012	38,639	33,163	45,019
2013	36,461	31,410	42,325
2014	36,893	31,830	42,761
2015	35,890	31,234	41,239
2016	34,752	30,068	40,167
2017	33,800	29,420	38,831
2018	32,435	28,088	37,455
2019	31,426	27,255	36,235
2020	29,249	25,569	33,458
2021	28,180	24,829	31,982
2022	28,768	25,183	32,862
2023	28,531	25,095	32,437

Figures

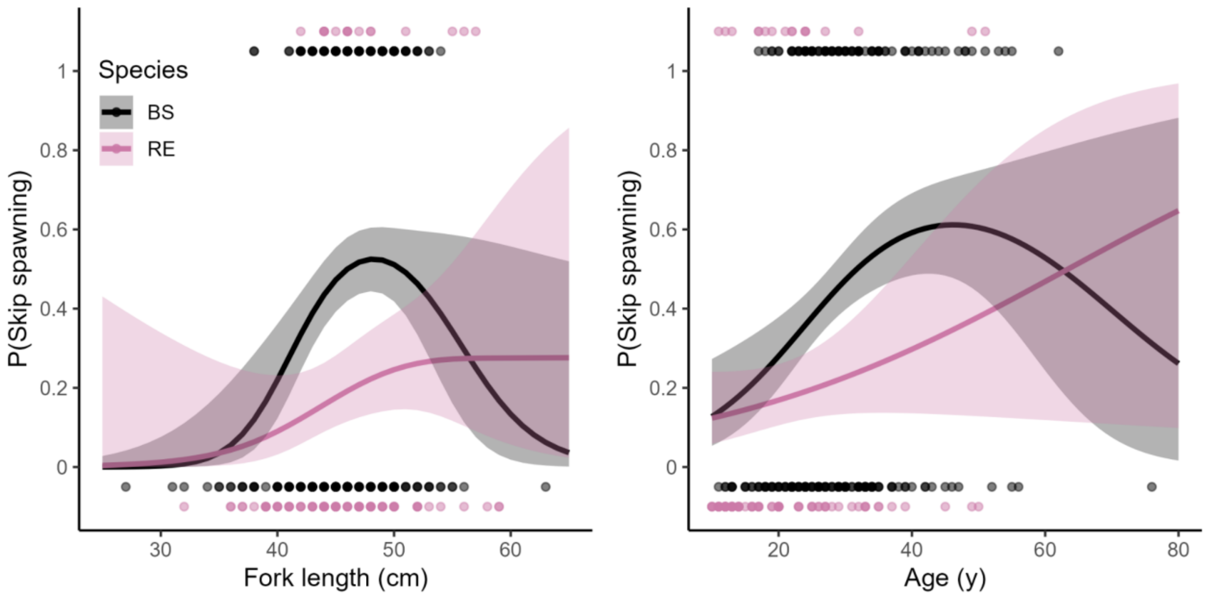


Figure 1. Generalized additive model (GAM) estimates of skip spawning probability by fork length (left panel) and age (right panel) for blackspotted (BS, black) and rougheye (RE, pink) rockfish using otolith-validated specimens from Sullivan et al. in prep. Solid lines represent the fitted GAM curves, and shaded regions denote 95% confidence intervals. Rug plots along the x-axis indicate the distribution of observations for each species, with upper (1s) and lower (0s) rows showing skipped and non-skipped spawners, respectively.

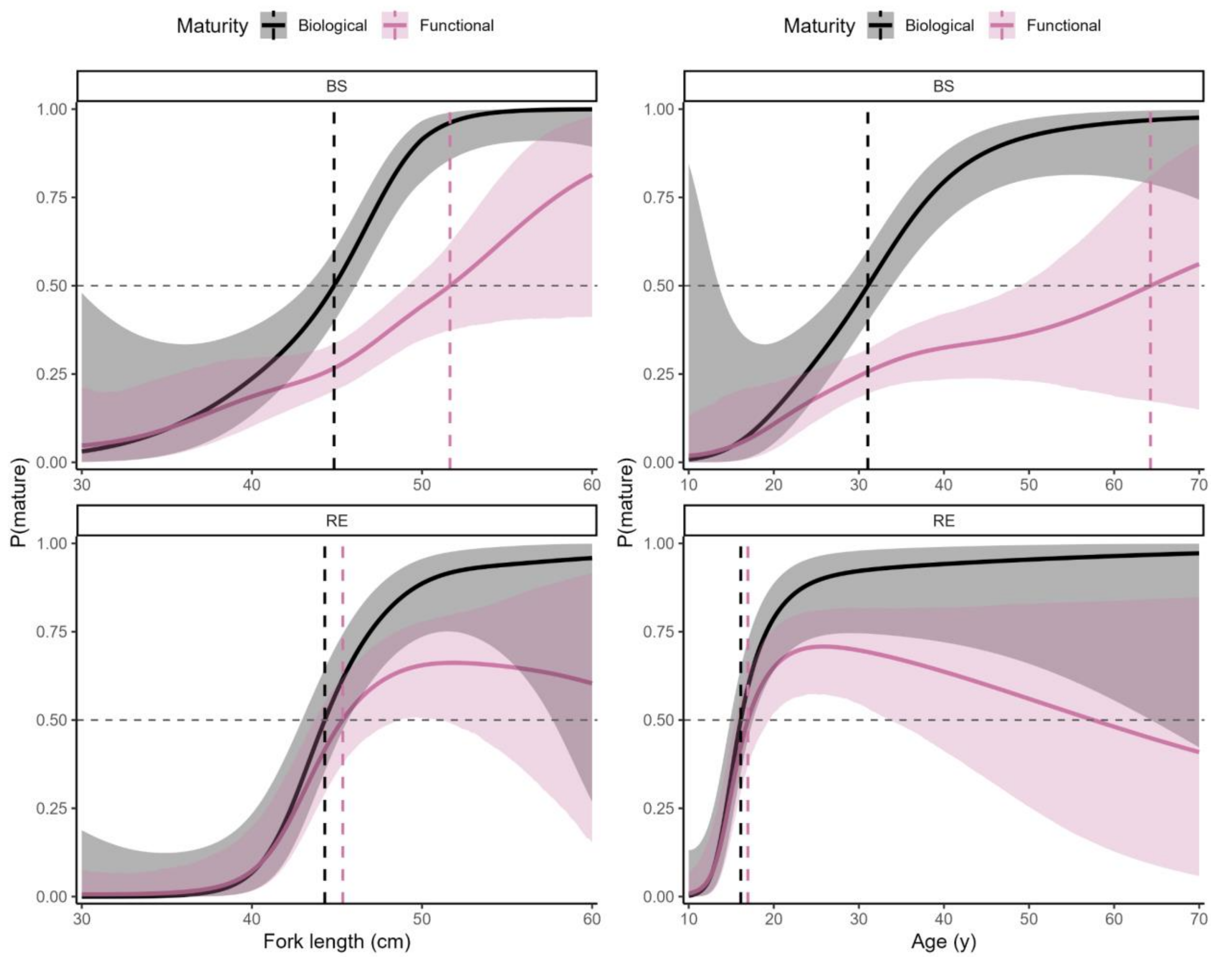


Figure 2. Comparison of biological (black) and functional (pink) maturity ogives for rougheye (RE) and blackspotted (BS) rockfish by fork length (left panels) and age (right panels) based on otolith-validated specimens from Sullivan et al. in prep. Functional maturity curves incorporate uncertainty in model predictions of both biological maturity and skipped spawning. Shaded ribbons represent 95% confidence intervals, and vertical dashed lines indicate A_{50} and L_{50} values.

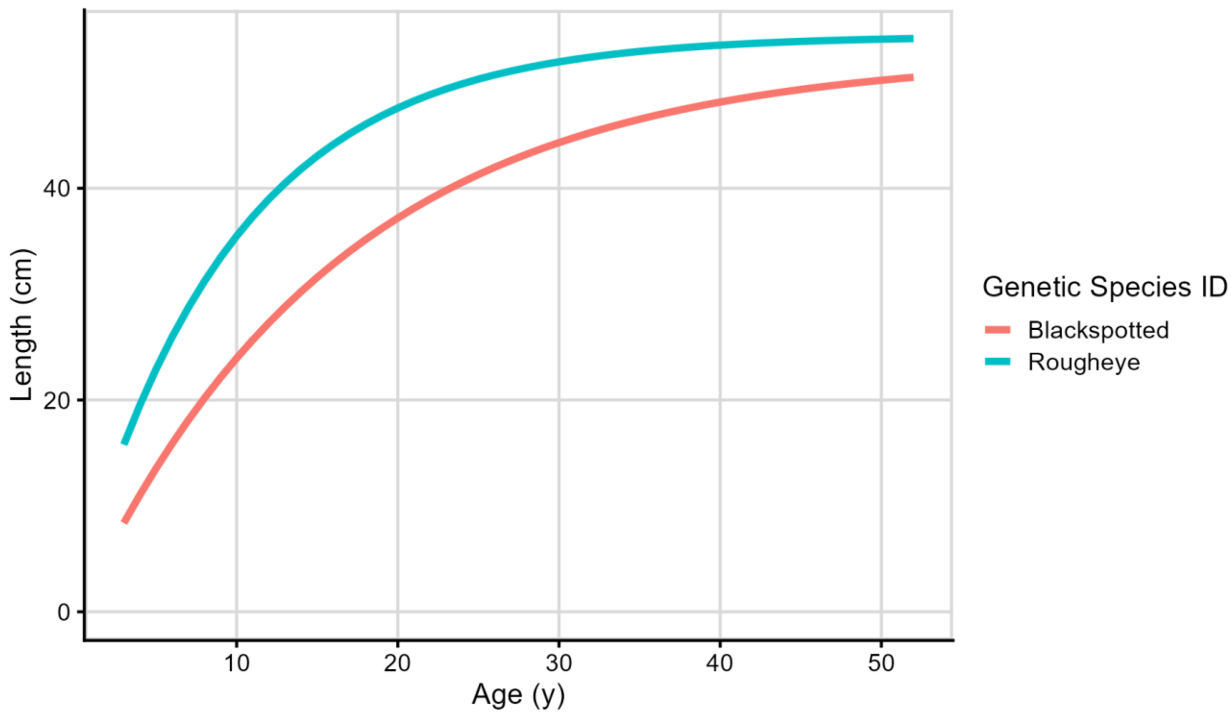


Figure 3. Estimates of rougheye and blackspotted rockfish growth from Harris et al. 2019, which used genetics for species identification. These growth curves are inputs to the yield-per-recruit and spawning biomass per recruit analysis for the Tier 4 alternative models.

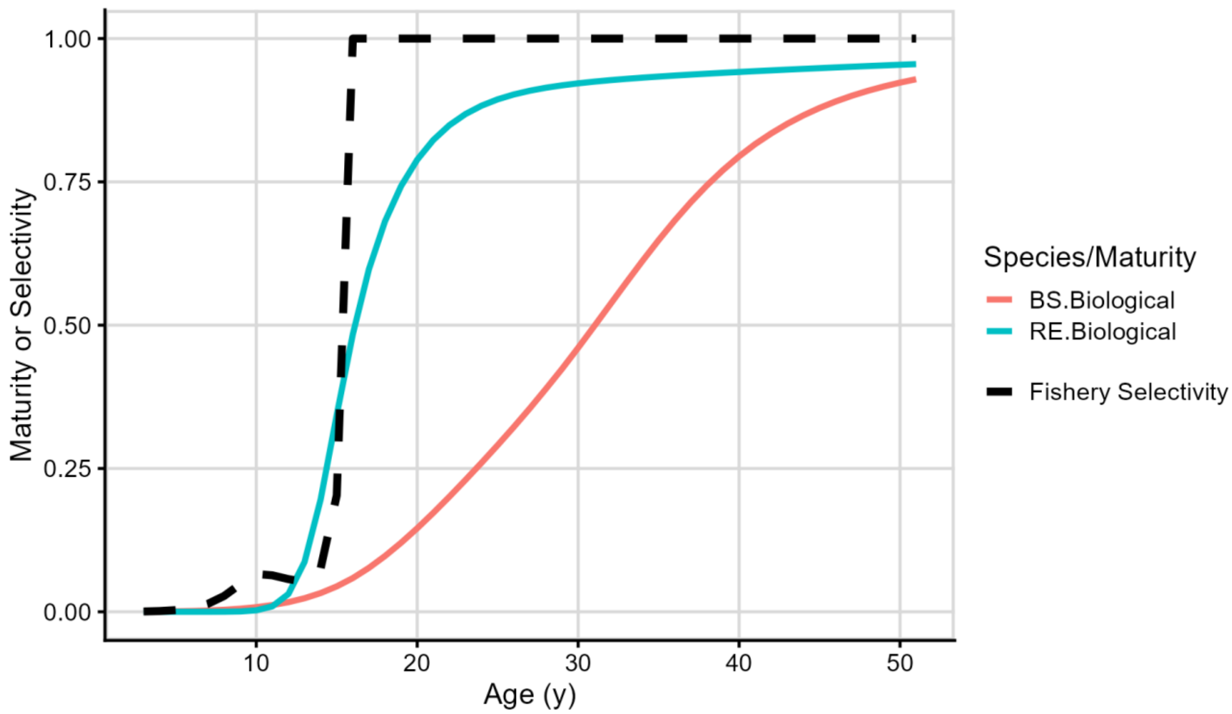


Figure 4. Estimates of rougheye (RE) and blackspotted (BS) rockfish biological and functional maturity from Sullivan et al. (in prep) and complex-level fishery selectivity from the 2023 stock assessment (Sullivan et al., 2023). These maturity and selectivity are inputs to the yield-per-recruit and spawning biomass per recruit analysis for the Tier 4 alternative models. Biological maturity curves correspond to Model 25.1a and functional maturity curves correspond to Model 25.1b.

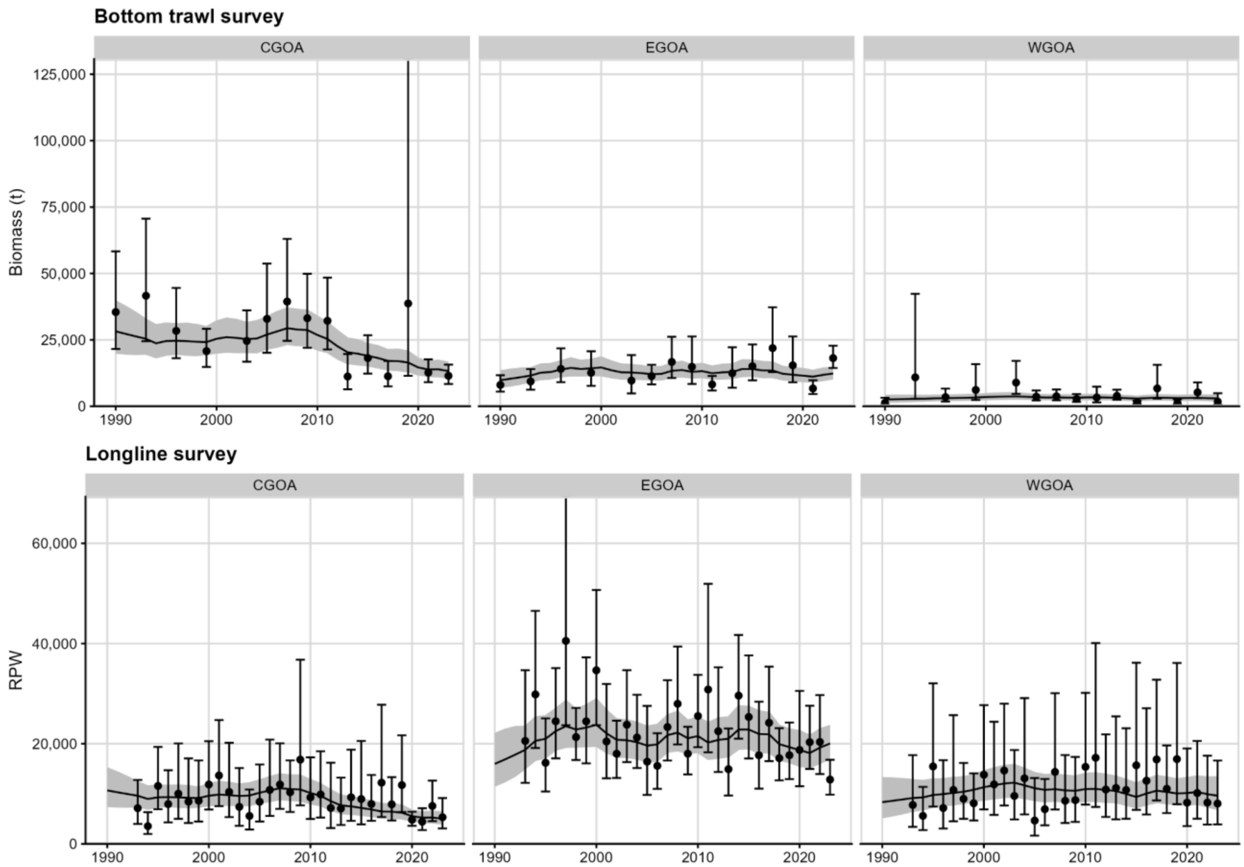


Figure 5. Two-survey random effects (REMA) model fits to the GOA bottom trawl survey (BTS) biomass (top panels) and longline survey relative population weights (RPWs; bottom panels) by central, eastern, and western Gulf of Alaska (CGOA, EGOA, WGOA) management area, where the points and error bars are the design-based survey estimates and the lines with shaded regions are the model predictions and 95% confidence intervals from the REMA model.

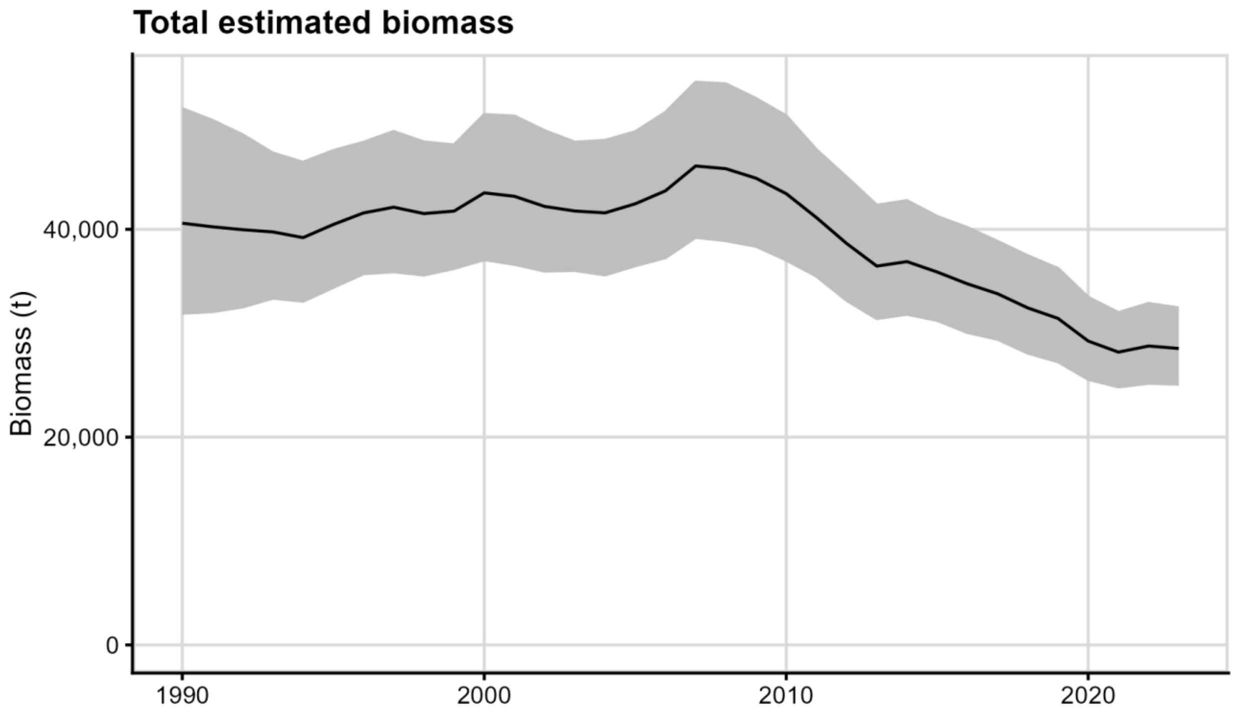


Figure 6. Total estimated biomass from the two-survey random effects (REMA) model.

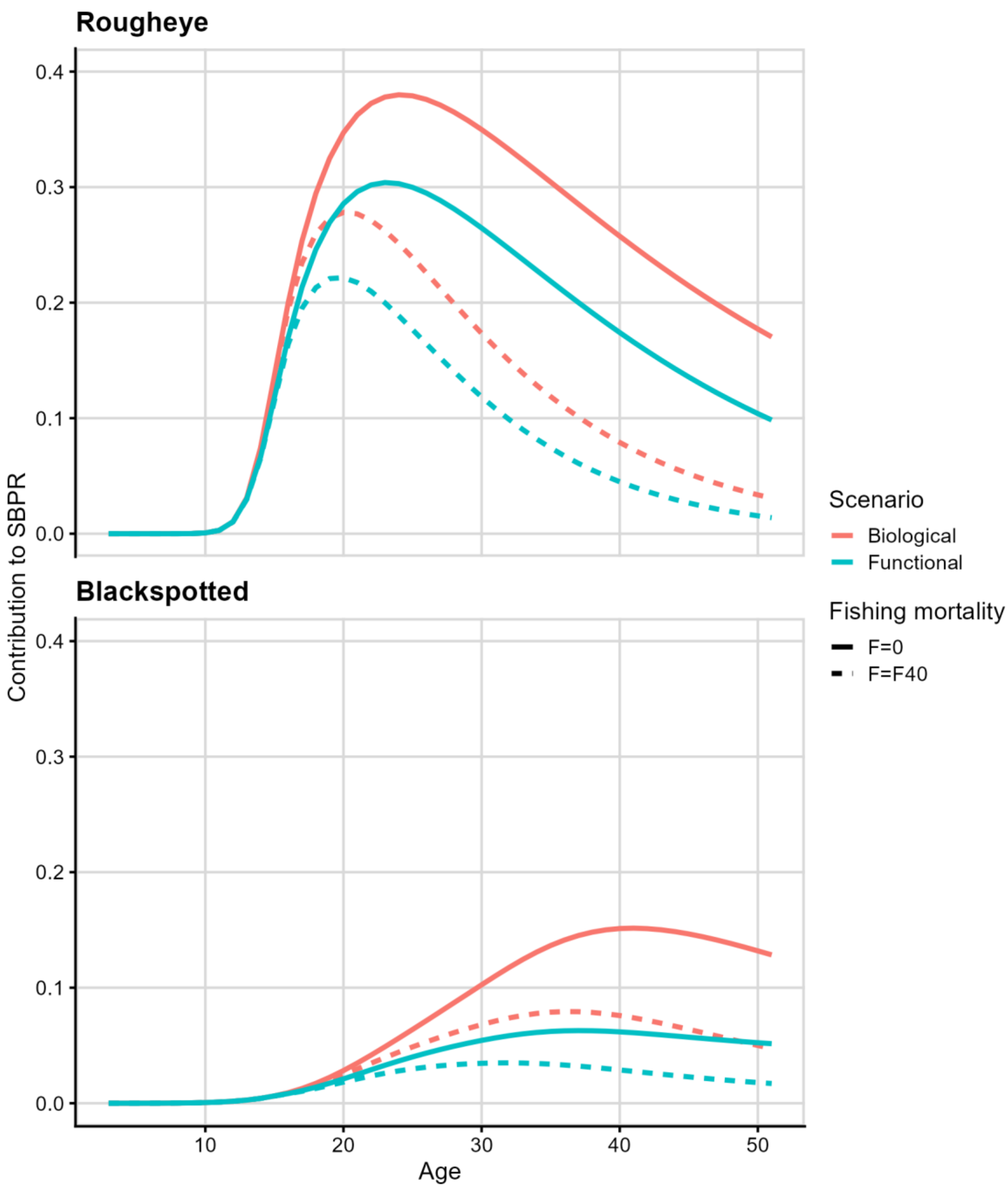


Figure 7. Age-specific contributions to SBPR (maturity × survivorship × spawning weight) for F=0 and F=$F_{40\%}$ under biological and functional maturity. Functional maturity depresses realized reproduction at younger, highly selected ages, shifting SBPR toward older ages. At $F_{40\%}$, the functional curves show larger reductions at those younger ages, explaining why the SPR-F curve is flatter initially and why $F_{40\%}$ is higher. Plus group (terminal age class) contributions are excluded from the panel for clarity.

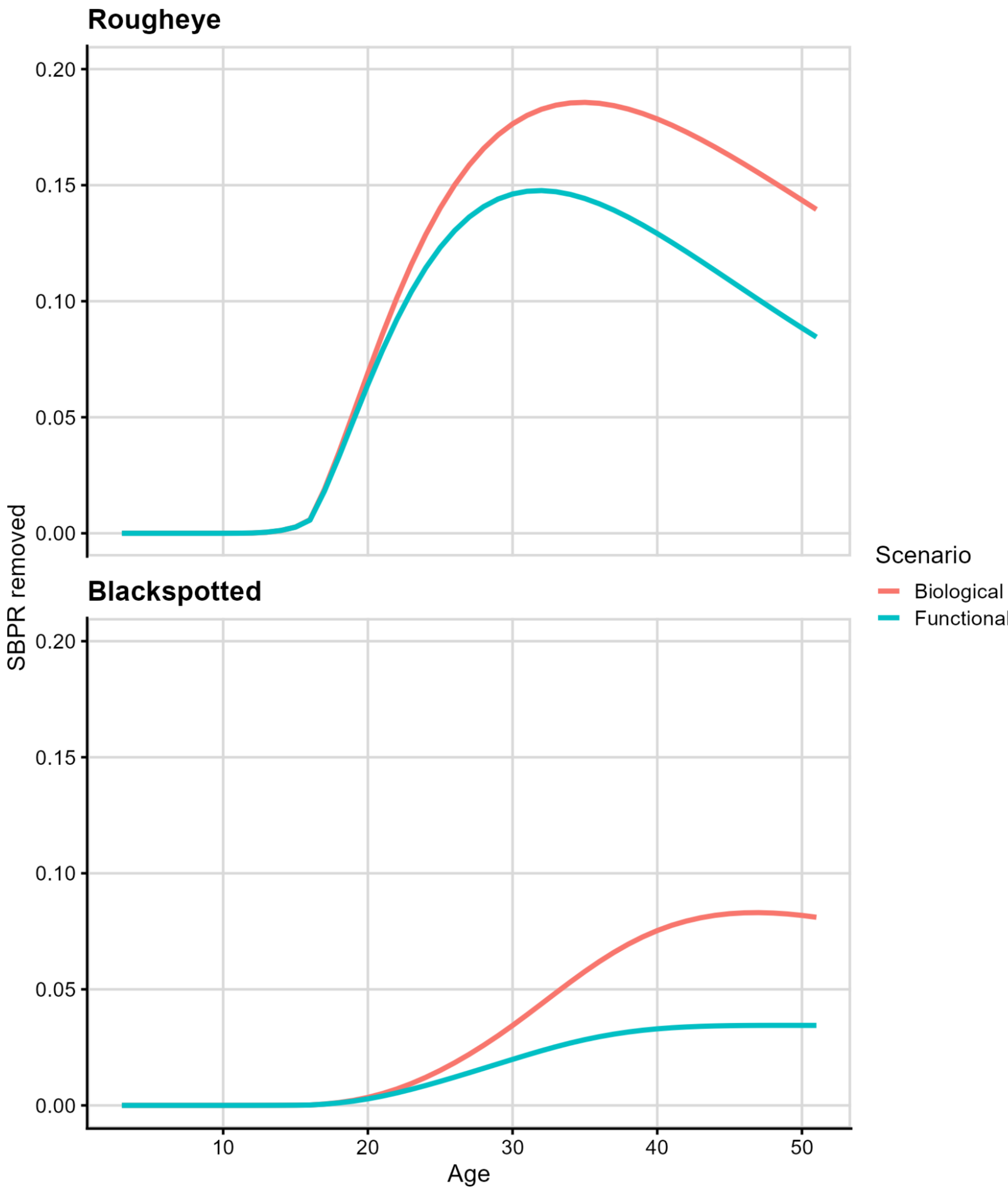


Figure 8. Amount of spawning biomass per recruit (SBPR) removed (F=0 - F=$F_{40\%}$) by age, for biological (red) and functional (blue) maturity. Less SBPR is removed under functional maturity from ages that are most vulnerable to the fishery, therefore a higher F is required to reach the same 40% SPR. Plus group (terminal age class) contributions are excluded from the panel for clarity.

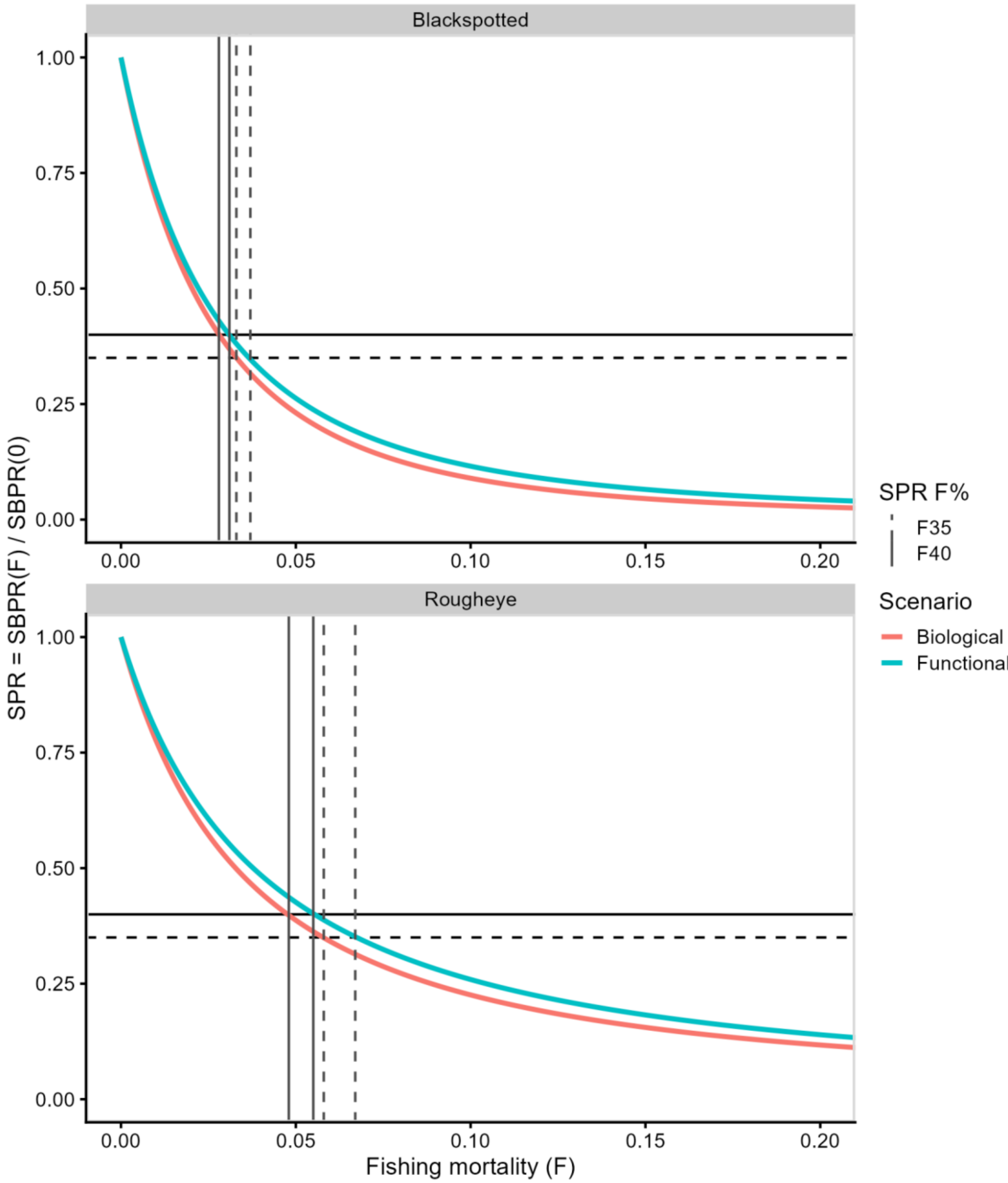


Figure 9. Spawning potential ratio (SPR = SBPR(F)/SBPR(0)) as a function of fishing mortality for blackspotted (top) and rougheye (bottom) rockfish. Horizontal lines mark the Tier 4 thresholds (SPR=0.40 solid; SPR=0.35 dashed). Vertical lines show $F_{40\%}$ (solid) and $F_{35\%}$ (dashed) for each scenario. Under functional maturity (blue), SPR declines more slowly with F; therefore, the curve sits to the right and *F*-based reference points are higher (rougheye $F_{40\%}$ increases from 0.048 to 0.055; blackspotted $F_{40\%}$ increases from 0.028 to 0.031).

Appendix A

Here we provide a comprehensive list of all SSC and Plan Team recommendations and comments since 2007 related to the current combined-species approach used in the GOA rougheye and blackspotted rockfish assessment. Selected author responses are included.

The SSC December 2007 minutes included the following comments concerning rougheye rockfish: "The SSC requests that the assessment authors work to bring forward a rationale for decisions regarding assessment of mixed species groups with attention to the potential for overfishing the weaker stock."

The SSC December 2009 minutes included the following comments concerning rougheye and blackspotted rockfish: "The SSC repeats its earlier request that the assessment authors bring forward separate models for the two rockfish species. The SSC recognizes that a key step towards the development of a split species model is the improvement in the accuracy of species identification by NMFS survey scientists and observers. A high priority should be placed on improving species identifications for rougheye and blackspotted rockfish through improvements in observer training and field identification guides (e.g., continued refinement of the species ID pamphlet that came out of Orr and Hawkins 2008 work)."

Author response from the 2010 assessment:

In December 2007 the SSC requested that the GOA rougheye and blackspotted rockfish authors "work to bring forward a rationale for decisions regarding assessment of mixed species groups with attention to the potential for overfishing the weaker stock."

In December 2008 the SSC endorsed the preparation of a new field identification pamphlet and stated that "identification of rockfish to species is a high research priority". We responded to the 2007 comment in the Responses to Council, SSC, and Plan Team Comments section of the 2008 GOA Rougheye and Blackspotted Rockfish Executive Summary. We elaborated on this response in the 2009 GOA Rougheye and Blackspotted Rockfish SAFE report in the Evidence of Stock Structure section of the Introduction. This section included a summary of the recent studies on the genetic and phenotypic differences between rougheye and blackspotted rockfish and a discussion of the current research regarding high at-sea misidentification rates and understanding species specific life history characteristics. We additionally include a complete stock structure evaluation of rougheye and blackspotted rockfish in Appendix A of this document. Preliminary results of the identification studies on the 2009 GOA trawl survey are included in the Distribution, Speciation, and Misidentification section of Appendix A. At present, the high misidentification rates preclude the development of separate models for rougheye and blackspotted rockfish in the GOA. The special project on the 2009 GOA trawl survey will enhance training and field identification guides, allow for accurately specifying misidentification rates, and begin estimating biological parameters such as growth and distribution by species. In the future, we plan to extend this sampling to commercial fisheries as a special project requested of the Observer Program. When combined with accurate species-specific catch and survey data, such information will help determine the utility of separate species models for examining if one species is a weaker stock and may be at greater risk of overfishing.

"The SSC agrees that currently using a mixed species model does not pose a conservation concern because directed fisheries are prohibited, and the incidental catch of rougheye and blackspotted rockfish remains well below the recommended ABC. However, the catch should be monitored to prevent

overfishing. In particular, the authors should monitor the bycatch trends in the sablefish, halibut longline fisheries, and look for evidence of "topping off" in the POP fishery."

Author response from the 2010 assessment:

Under ACL management in 2011, catch accounting of total removals is required in groundfish stock assessments. A multi-agency effort is underway to identify all sources of mortality and determine appropriate methods of bycatch estimation and weight calculations. An example is the halibut bycatch working group discussed in the GOA Plan Team comments concerning all stock assessments. Summaries of these efforts were presented to the Plan Teams in September 2010. When available, we intend to utilize the potential single source database (e.g. AKFIN as discussed previously) to monitor and report all sources of rougheye and blackspotted rockfish catch.

"As in previous years, the SSC encourages the author to explore methods to improve species identification in the fishery. The observed differences in spatial distributions and growth suggest that these rougheye and blackspotted rockfish should be assessed separately once the information is sufficient to make this change. With this in mind, the SSC requests that the author evaluate the available information to separately assess the two stocks and where there are data gaps." (SSC, December 2015)

Author response from the 2017 assessment:

Please refer to the "Current Research" subsection in the "Evidence of Stock Structure" section of the Introduction in last year's SAFE report for an update on the available data for evaluating misidentification rates and differing life history characteristics for the two species. Additionally, a comparison of the misidentification rates for the 2009, 2013, and 2015 trawl surveys was recently completed (Figure 2). Overall misidentification rates were 23%, 13%, and 18% for the three years, respectively. There appears to be continued improvement for correctly identifying blackspotted rockfish in the field (from 31% to 9%), while the opposite seems to be occurring for rougheye rockfish with increased misidentification rates over the three surveys (6% to 25%). We will continue to monitor the progress of evaluating the data from these special projects and may extend this sampling protocol to commercial fisheries as a one year special project requested of the Observer Program. Additionally, a promising approach using otolith morphology combined with genetics may enable the species composition in historical samples to be assessed. Such information will help determine the utility and cost-effectiveness of a split-species complex model or separate species models for examining if one species may be at greater risk to overfishing. At present, the area-specific harvest rates for RE/BS rockfish have been on average low and catches have consisted of approximately half the ABC in recent years. We consider current management specifications for this non-targeted complex to be sufficiently precautionary under current fishing practices and will continue to model rougheye and blackspotted rockfish as if they are a single species.

"The team recommends evaluating a Tier 5 approach with "worst-case scenarios that consider total catch comprised of one species." (Plan Team, November 2016)

"The Team recommends the authors work with the observer program to request a one year sampling program to collect tissue for genetic analysis during the otolith collection in the fishery." (Plan Team, November 2016)

"As in previous years, the SSC encourages the author to explore methods to improve species identification in the fishery. The observed differences in spatial distributions and growth suggest that these rougheye and blackspotted rockfish should be assessed separately once the information is sufficient to make this change. With this in mind, the SSC requests that the author evaluate the available information to separately assess the two stocks and where there are data gaps." (SSC, December 2015)

Author response from the 2017 assessment:

The two time series are 1) the “naïve” time series that assumes that survey ID is completely accurate (Figure 1), and 2) the “genetic” adjusted years (2009, 2011 and 2015) which have been corrected by misidentification rates derived from genetics (Figure 2). In these figures we can see that the genetics does change the biomass of the two species some (e.g., 2009 and 2013), but it goes in both directions and generally there is almost always more rougheye rockfish biomass than blackspotted rockfish biomass (except for the naïve estimates of survey biomass in 2007).

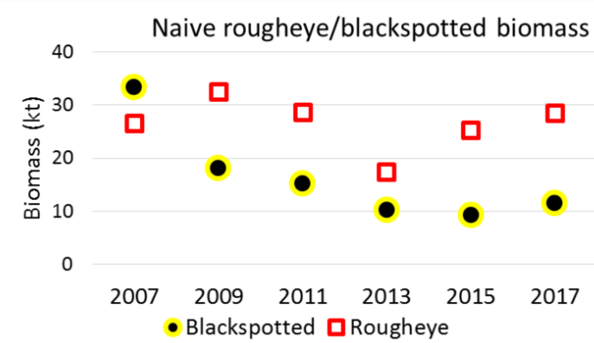


Figure 1.

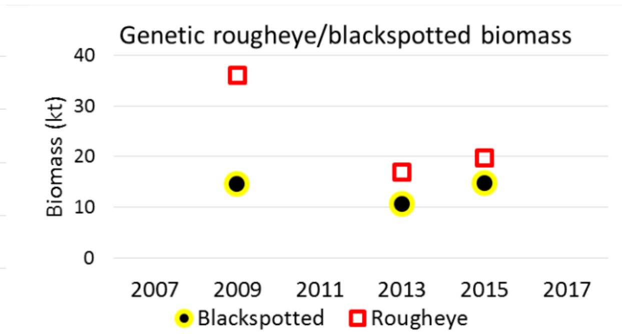
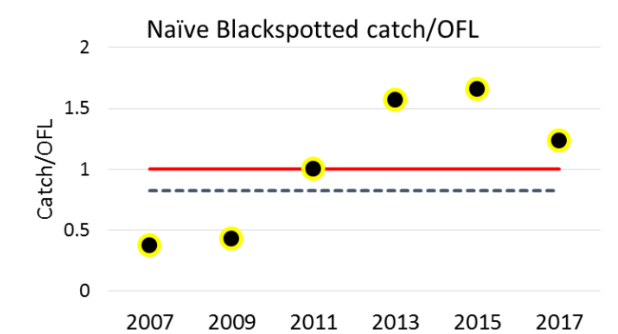


Figure 2.

We compare the total catches of the complex to hypothetical OFLs for each species as an extreme case for illustration. If all the catch were taken just from blackspotted rockfish, the hypothetical OFL would have been exceeded in some years in both the naïve ID and genetic ID cases (Figures 3 and 4). However, on average neither ID cases are over the OFL, but the genetic mean is very close (0.98).



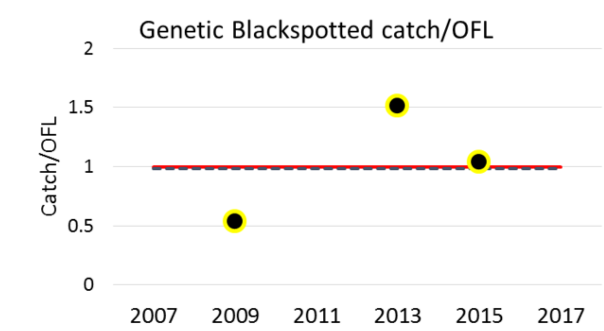


Figure 3, 4. Blue dashed line is the average ratio of catch to OFL. Red line is when catch is equal to OFL.

If all the complex catch were taken from the rougheye species, the hypothetical OFLs would never have been reached in any year, and on average were significantly below OFL (Figures 5 and 6).

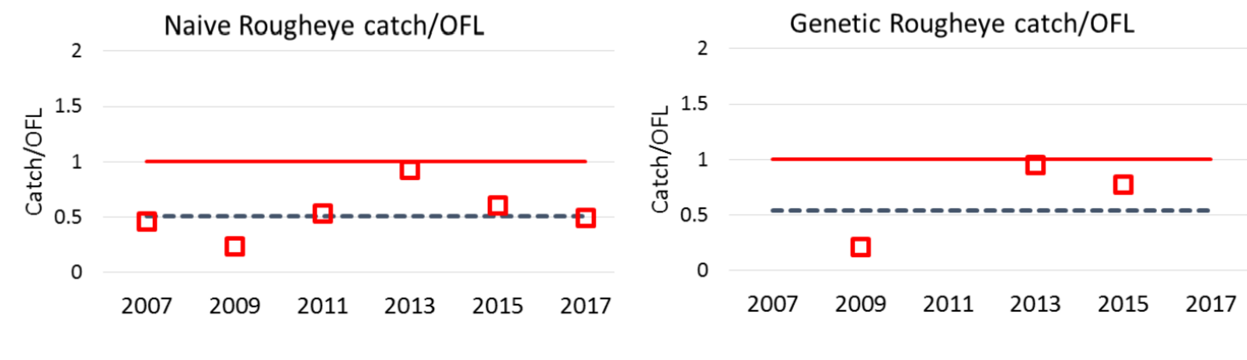


Figure 5, 6. Blue dashed line is the average ratio of catch to OFL. Red line is when catch is equal to OFL.

In summary, in the extreme case that every fish caught by the fishery were a blackspotted rockfish, we could approach or exceed Tier 5 OFLs for that species on a regular basis. However, given that they are caught together in trawl surveys, this extreme result is highly unlikely. It may still be worthwhile to have some type of test in the fishery to have a better idea what the ratio of blackspotted to rougheye is to better inform our fisheries data. A new study has been initiated to look at the otolith metrics for fishery ages of RE/BS rockfish and if combined with a genetic test in the fishery may be a potential avenue to gain a better understanding of the rougheye to blackspotted ratio in the fishery data.

"The Team recommend that the authors implement as worst case (bookended), dynamic weighting or apply genetically verified data to adjust the model for differences in maturity." (Plan Team November 2017)

"The SSC supports the Plan Team recommendation for an analysis that provides a more realistic range of management risk of combining RE/BS in one stock than is currently in the assessment. A variety of methods could be used, including catch composition analysis, genetic vs visual survey ids, maturity curve differences, etc." (SSC December 2017)

"Species identification continues to be a problem both in the survey and fishery data. The SSC appreciates the authors continued work on this issue and highlights the importance of improving species composition information. As noted in the assessment, there appears to be continued improvement for correctly identifying blackspotted rockfish in the field (from 31% to 9%), while the opposite seems to be occurring for rougheye rockfish with increased misidentification rates over the three surveys (6% to 25%). In addition to genetic methods, otolith morphology identification methods would be useful for evaluating historical and future data collections- near-infrared reflectance (NIR) spectroscopy maybe one area of further investigation. The SSC also looks forward to results on the AFSC observer program special project that collected multi-spectral images, paired with genetics, from survey samples of BS/RE for development of an image analysis application for species identification." (SSC December 2017)

"The SSC continues to be concerned about grouping species in the assessment without considering important differences in life history. Specifically, Conrath (2017) found age at maturity for the species fork length at 50% maturity was similar for rougheye rockfish (45.0 cm) and blackspotted rockfish (45.3 cm), but the age at 50% maturity was considerably younger for rougheye rockfish (19.6 years) than for blackspotted Rockfish (27.4 years). The SSC supports the authors' recommendation to evaluate maturity information and explore fitting separate maturity curves. This would allow treatment of the differences in maturity between the species within the assessment." (SSC December 2017)

Author response from the 2019 assessment:

We have provided a brief summary of the new maturity information from Conrath (2017) and future plans for using this information within the stock assessment in Appendix 13.B. At this time we do not evaluate the new maturity information within the current stock assessment model due to concerns over the samples not being identified to species. Additionally, there are more maturity samples from a December 2015 survey that should be incorporated into the analysis. We are investigating the potential to use morphometrics on the otoliths from this maturity study to identify the samples to species. This will provide a more accurate estimate of the species-specific age at 50% maturity and we will evaluate the potential for use within the operational stock assessment model when that information becomes available.

Multispecies stock assessment and species identification "The issues of how to meaningfully assess and manage a two species complex remains. The authors noted the SSC recommendation for an analysis that provides a more realistic range of management risk of combining RE/BS as one stock. Methods to enhance the assessment could include catch composition analysis, genetic species identification, and maturity curve differences. The author noted that it could be possible to use otolith morphometrics to address this in the future, but that methodology is not yet robust enough to use in the RE/BS model. The assessment includes an appendix that summarizes current efforts related to RE/BS stock i.d., growth, and maturity analyses. The Team recommended that the authors incorporate additional information about species identification obtained through otolith morphology in future assessments." (GOA Plan Team, November 2019)

"An important ongoing issue with this assessment is that it is a complex of two distinct species. The SSC appreciates the appendix that describes the current state of genetic research on mis-identification rates, otolith morphology, growth and maturity for this complex. It is clear that a number of positive steps are being made to understand how the species within this complex are both similar and different. As the author notes, many of these projects are ongoing. Of note is an updated maturity study on both species (Conrath 2017) that clearly demonstrates a difference in age at 50% maturity (19.6 years and 27.4 years for rougheye and blackspotted, respectively) between these species. The SSC continues to encourage effort to incorporate this information into the assessment as much as possible, to improve species-specific information in this assessment and move towards splitting this complex. Alternative model configurations that incorporate these data would be highly encouraged as a step in this direction." (SSC, December 2019)

"…the SSC registers some concern regarding age structure collections moving forward, particularly if otolith morphology is a valid method for differentiating these species. Special collections may be appropriate if otolith metrics become an operational tool for species differentiation." (SSC, December 2019)

Appendix B

Here we provide recent or outstanding SSC and Plan Team comments related to the GOA rougheye and blackspotted rockfish assessment.

<u>Skip spawning</u>

"The Team recommended using the authors approach. Additionally, the Team recommended alternative methods be explored that take skip spawning into account." (GOA GPT, September 2023)

"The SSC supports incorporating maturity data not previously used that comes from both rougheye and blackspotted rockfish determined through visual species identification and supports exploring alternative methods that account for skip spawning." (SSC, October 2023)

"The SSC also reiterates its October 2023 recommendation to investigate methods to incorporate the effects of skip spawning." (SSC, December 2023)

<u>Comments on Model Performance</u>

Relative to past assessments, the 2021 assessment model exhibited a strong positive retrospective pattern (Mohn's rho = 0.611). It is also notable that there has been an increase in Mohn's rho in each of the last three assessments (2017 = 0.009, 2019 = 0.167, 2021 = 0.611). This "one-way" retrospective pattern is a cause for concern and is likely due to the recent sudden declines in both population indices that are used in the assessment. The relatively noninformative priors used for catchabilities within this model result in some shifts in scale being accentuated with sudden changes in these indices. The authors recognized this and stated their intent to investigate catchability in future assessments and explore how that relates to this progressive retrospective pattern. (SSC, December 2021)

Finally, the SSC notes that if the current trend in retrospective bias continues after model and data issues (catchability in particular) are addressed, the author will need to revisit risk table ranks and reassess whether a reduction from maxABC is necessary. (SSC, December 2021)

"A key challenge in this model is stabilizing catchability (q) for both the trawl and longline surveys. Models 15.4 and 23.1 both showed an increasing trend for q in recent years, with values approaching or exceeding 2 for both the trawl and longline surveys. The authors indicate that a value of q over 2 for the trawl survey is implausible for this species and investigated potential reasons for this result. They concluded that high parameter correlation between catchability, M, and recruitment is a likely issue." (SSC, December 2023)

"Poor fit to the composition data, and lack of fit to the recent longline survey RPN as demonstrated by recent years missing upper 95% confidence bounds of the annual estimate. The SSC also notes the model has generally poor fit to survey trends, basically fitting an average value through the time series." (SSC, December 2023)

<u>Selectivity</u>

The dome-shaped trawl survey selectivity for this complex is expected given that adult habitat is typically in rocky areas along the shelf break where the trawl survey gear's sampling is limited. However, estimates in this assessment suggest that selectivity is changing considerably for older fish in the survey, which is unexpected given occupied habitat should not change above a certain age. For example, the

GOA GPT noted it was unclear why 40-year-old fish would be so much less selected than a 30-year-old fish. Future research could consider alternative parameterizations that would allow for more constrained estimates of selectivity at older ages. (SSC 2021)

The Team recommended that the author investigate how selectivity is modeled. In particular, there were some abrupt changes between ages in the average fishery selectivity." (Plan Team, November 2019)

"The SSC supports the author's plan for future work on the survey and fishery selectivity parameterization, and on weightings of compositional information. (SSC, December 2023)

Appendix C

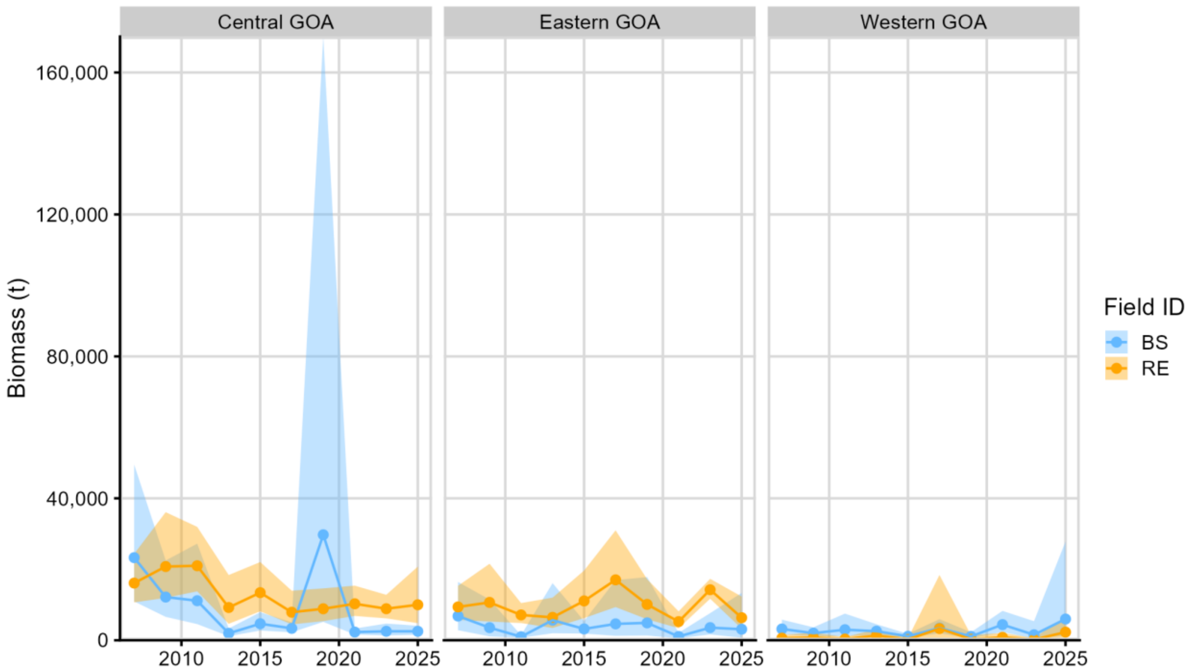


Figure 1. Time series of field-identified, species-specific biomass since 2007 in the Gulf of Alaska bottom trawl survey.

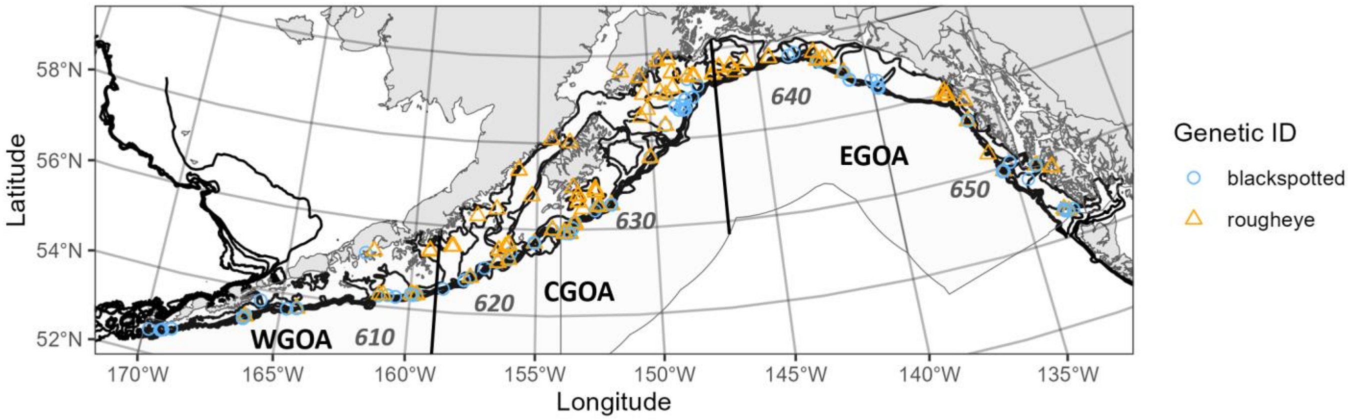


Figure 2. Genetically-identified specimens from Harris et al. (2019), which were collected during the 2009 and 2013 Gulf of Alaska bottom trawl surveys.