Other Rockfish stock complex in the Gulf of Alaska: Updating Natural Mortality

Cindy A. Tribuzio, Jane Y. Sullivan, Katy B. Echave, Jason Cope, and Kristen L. Omori
September 2022

EXECUTIVE SUMMARY

The Other Rockfish (OROX) complex in the Gulf of Alaska (GOA) is assessed on a biennial stock assessment schedule to coincide with the availability of new trawl survey biomass estimates. The complex acceptable biological catch (ABC) and overfishing level (OFL) is the sum of the recommendations for the Tiers 4, 5, and 6 species. However, the 2021 full assessment model resulted in substantial (20%) reduction in the combined acceptable biological catch (ABC), which, when apportioned resulted in a 58% reduction in the combined Western/Central GOA ABC. The reduced ABCs from the 2021 author recommended model were substantially lower than the historical catch for this non-targeted complex. This reduction was due to a combination of:

1) The proportional biomass in the Western/Central GOA decreased, which shifted apportionment to the Eastern GOA.
2) Sharp declines in the 2021 bottom trawl survey biomass occurred for some of the primary Tier 5 species, in particular harlequin and redstripe rockfishes.
3) The weighted natural mortality estimates declined by 25% due to the reduction in survey biomass of select species and because of the way natural mortalities are weighted across different species in this complex.

Due to the unprecedented nature of this situation, the GOA PT and the SSC recommended rolling-over the 2021 harvest specifications:

"*The Team recommended rolling over harvest recommendations from 2021 due to the discrepancy between catch and survey biomass and the estimation of weighted M being influenced by a few species that have patchy distributions and survey catchability/availability issues.*"

"*The SSC concurs with the GOA GPT's recommendation to roll over OFL and ABC recommendations from 2021…….*"

Both the SSC and the GOA Groundfish Plan Team requested further analyses to help alleviate this phenomena in the future, which will be addressed in future full assessments. However, one comment was made across a number of rockfish species: revisit and updated natural mortality (*M*) estimates. To address that, a group of rockfish assessment authors reviewed available information and recent advancements in methods for estimating *M*, resulting in a tech memo (Sullivan et al. 2022). That analysis provided a suite of *M* estimates for a number of rockfish species, however, the best means of interpreting those results for use in stock assessments is up to the individual assessment authors. The purpose of the analysis presented here is to demonstrate a data driven and statistically supported method to interpret the updated *M* values in Sullivan et al. (2022) for use in future stock assessments, using GOA OROX as an example.

Estimates of *M* were provided for six species within the OROX stock complex in Sullivan et al. (2022). The process of updating *M* in the stock assessment built off of the detailed review of *M* estimator methods, the data considerations and the resultant suite of *M* estimates for each species (Sullivan et al. 2022) to develop a composite *M* for each of the six species (this analysis). We recommend a composite approach which incorporates both data and method uncertainty and provides estimates of uncertainty around the *M* estimates.

Current GOA OROX Catch

The 2022 estimated catch of GOA OROX is near average of the historical time series (as of 9/12/2022) and none of the sub-area ABCs have been exceeded (Figure 1). The combined 2022 estimated catch from the Central and Western GOA is slightly greater, but not significantly different from the historical average. The GOA OROX are primarily caught in the GOA rockfish fishery, followed by the longline fisheries for sablefish and halibut (Figure 2). Similarly, the catch by month reflects when the target fisheries are active, with much of the catch occurring between May and August (Figure 2).

Updating Species Specific Natural Mortality

Generating natural mortality (*M)* estimates for informing a stock assessment may result in being a multi-step process. Many assessments that don't estimate *M* in the model often rely on a single method or study that provides a specific *M* value. Sullivan et al. (2022) reviewed multiple natural mortality methods and data inputs that provide a range of updated *M* estimates for many individual rockfish species, including six of the OROX species. Here we consider the variety of *M* species-specific estimates, the data quality, and the methods themselves to estimate a single point estimate of *M* for each of these six species for use in the GOA OROX stock assessment.

The simplest approach for determining natural mortality would be to select a single point estimate of *M*, often based on the best available information or preferred method. However, that approach makes assumptions that a single data input is the best descriptor of the species and a single method is "right". Taking a median or mean of the available estimates is an option, however, that approach weights all inputs and methods the same, which may or may not be appropriate for a given species. In this analysis, we calculated a weighted mean *M* (Wt_M) value for each species, to address uncertainty in the input data or how "good" a method may be for a given species. However, the Wt_M values do not include uncertainty in the methods themselves. To include method uncertainty, we used the inverse variance method proposed by Hamel and Cope (in review) and provide four additional modeled *M* estimates, described below.

The Wt_M was calculated as the weighted mean of the individual *M* values. A two-stage weighting scheme was applied. First, each *M* estimate was weighted based on expert opinion of the representativeness of the input data and/or demonstrated biases in the input data (e.g., yelloweye maximum age). In cases where there are replicate *M* estimates for a given method and species (e.g., M_{tmax}), the replicate estimates were weighted such that the sum of the replications was equal to 1, and weights may be distributed to reflect the quality of the input data. The second stage weighted the *M* estimates by the applicability of the method, or other unique species-specific considerations. For example, methods that rely on the *M*/k ratio were down-weighted because while *Sebastes* species were used in the model derivation, they do not fit the model as cleanly as other teleost species (Hamel 2015, Thorson et al. 2017). The individual weighting choices will be described in each species section.

To incorporate the uncertainty in the *M* methods, we used the inverse variance method proposed by Hamel and Cope (in review) and available as part of the Natural Mortality Tool (Cope and Hamel in review, https://github.com/shcaba/Natural-Mortality-Tool). This approach creates a lognormal distribution based on the estimates and uses the variance of each of the *M* methods to weight the composite and estimate confidence intervals. This approach results in four models: 1) Hamel and Cope method (HC) is the base model, using the arithmetic mean of input *M*, equal weighting of estimates, and proxy CV values (HC); 2) HC but using the weighted *M* inputs (HC_Wt_M); 3) HC with arithmetic mean, equal weighting of estimates and informed CV values (HCCV); and 4) HC_Wt_M with informed CV values (HCCV_Wt_M). The CV for maximum age based estimates (CV = 0.31) was computed directly in Hamel and Cope (in review) and presumed to be a reasonable value for most methods that directly link to the biology to *M* (e.g., GSI, Gunderson 1997). Thus, CV = 0.31 is used for HC and HC_Wt_M. Whereas *M* estimators that are based on secondary (or further) relationships to *M*, such as those based on growth characteristics or environmental conditions, are assigned a lower CV of 0.85 (HCCV and HCCV_Wt_M).

Historically, all of the *M* values for OROX species were reported to two decimal places, with the exception of harlequin rockfish. Sullivan et al. (2022) reported all results to three decimal places. There are two concerns for consideration here: 1) extended decimal places may suggest precision in the inputs that may not be accurate; and 2) rounding to two decimal places (or less) can lead to different results, particularly in the Tier 4 or 5 single species stock assessments. The rounding error concern is dampened for complexes, however, it can result in shifting species between *M* groups. For the purposes of this report, all *M* values were rounded to three decimal places.

Harlequin Rockfish

The GOA OROX stock assessment currently assumes an *M* = 0.092 for harlequin rockfish as reported in Malecha et al. (2007). The estimate was based on a combination of approaches using growth parameters and maximum age (Alverson and Carney 1975, Hoenig 1983), which are precursors to the M_{tmax} and M_{VBGF} models used in Sullivan et al. (2022).

From Sullivan et al. (2022): *Harlequin rockfish life history parameter inputs were available for all four M estimators (M_{tmax}, M_{VBGF}, M_{temp}, and M_{GSI} estimators) in the GOA, but only maximum age data were available in the AI (Table 1). Estimates of M varied broadly across estimators, with the M_{GSI} estimator yielding the lowest M (0.049), and M_{VBGF} yielding the highest (0.359). The M_{tmax} estimator ranged from 0.068 in the AI to 0.131 in the GOA (Table 1), though the large difference in observed tmax between the GOA (47 y) and the AI (79 y) suggests these differences may be the result of sampling or exploitation history.*

Kastelle et al. 2020 validated ageing methods for harlequin rockfish and identified a 3-4 year systematic underageing for older specimens that was not considered in Sullivan et al (2022). In addition to the M_{tmax} from Sullivan et al. (2022), we included M_{tmax} estimates based on maximum ages of 51 and 83 in the GOA and Aleutian Islands, respectively, to represent the potential bias in ages.

The first stage weighting for harlequin rockfish was across the six M_{tmax} estimates. The AI M_{tmax} estimate based on the maximum age of 79 was given full weight because it is most likely the best representative of maximum age for the species, and the bias corrected AI M_{tmax} was given 0.75 weight. The AI M_{tmax} from the mean of the top 5 ages was given 0.5 weight. The GOA AFSC max age and mean top 5 M_{tmax} estimates were given a weight of 0.25 because those input values were well outside the range of the remaining maximum age input values and should be considered a minimum estimate of maximum age. The M_{GSI} and M_{VBGF} estimates were given full weight because the data are from recent research within the GOA. The M_{temp} estimate was weighted by 0.25 due to concerns over the precision and accuracy of the input data. For the second stage weighting, all of the *M* estimates were given full weight except for the M_{VBGF}, which was down-weighted because the *M*/*k* ratio is overly liberal for Sebastes (Hamel 2015, Thorson et al. 2017) and growth is at least a degree removed from *M* compared to longevity (Hamel and Cope, in review).

Redbanded Rockfish

The GOA OROX stock assessment currently assumes an *M* = 0.06 for redbanded rockfish. This value was estimated using data from other regions and proxy information (Echeverria 1987; O'Connell 1987; Munk 2001; Love et al. 2002).

From Sullivan et al. (2022): *Reliable life history information was only available to estimate M using M_{tmax}, M_{VBGF}, and M_{temp} estimators. Updated estimates of M ranged between M_{tmax} = 0.051 and M_{temp} = 0.155 (Table 1). Both M_{tmax} and M_{temp} estimators utilzed data from the GOA. The M_{VBGF} estimate (M = 0.123) used data from BC.*

The first stage weighting of the *M* estimates were across the three method inputs. The *M* estimate from maximum age was given full weight because it was based on recent, local data; VBGF inputs was down-weighted by 0.5 because the data were from outside of the GOA; temperature and dry weight inputs were weighted by 0.5 due to concerns over the precision and accuracy of the input data. The M_{VBGF} estimate was given 0.5 weighting in the second stage because of the *M*/*k* ratio concerns mentioned above. The M_{tmax} estimates were assigned full weight.

Redstripe Rockfish

The current GOA OROX assessment uses an *M* of 0.1 for redstripe rockfish, which is the highest M value of any species within the GOA OROX stock complex (Tribuzio et al. 2021). The redstripe *M* was computed from a catch curve analysis, under the assumption that this stock is lightly exploited and therefore *Z*=*M* (Archibald et al. 1981).

From Sullivan et al. (2022): *Only maximum age data was available to estimate M (M_{tmax}), using two values of maximum age from two regions (BC and GOA), as well as the mean of the top five ages from AFSC survey data. Updated M estimates ranged from 0.098 (BC, tmax = 55 yrs) to 0.138 (AFSC survey mean top 5, tmax = 39 yrs; Table 1). Ageing methods for redstripe rockfish have been validated, and were close to accurate with a small probability of underageing (Kastelle et al. 2020). Therefore, the maximum age estimates may be slightly underestimated for this species.*

The first stage weighting was across the three M_{tmax} estimates. The value from BC input data was downweighted by 0.5, and both of the GOA values were given full weights. All three estimates were given full second stage weighting.

Sharpchin Rockfish

The current GOA OROX assessment uses an *M* = 0.06 for sharpchin rockfish (Malecha et al. 2007). The Malecha et al. (2007) report examined two methods: Alverson and Carney (1975) and Hoenig (1983) and reported values ranging from 0.052 – 0.078. For comparison, the WC assessment use *M* = 0.08 based on updated Hoenig methods (Hamel 2015, Cope et al., 2015)

From Sullivan et al. (2022): *Sharpchin rockfish life history parameter inputs were available for three of the four M estimators (M_{tmax}, M_{VBGF}, and M_{temp} estimators) in the GOA. For comparison, life history parameters from BC for M_{VBGF} and the WC for M_{tmax} and M_{VBGF} were also available. Resultant M values ranged from 0.093 – 0.355. The maximum age estimates may be limited by samples in the GOA, the most recent of which were collected in 1996. Maximum age estimates from the WC may be more reflective of the maximum age of the species; however, it is unclear if that would be representative of the portion of the population within the GOA. Size ranges are similar, so for the purposes of this analysis, assuming a maximum age of 58 for the GOA is reasonable.*

The first stage weighting was across the three M_{tmax} estimates. All three values were given full weighting. The GOA values were given full weight because they are local. The WC value was also given full weight because it inlcudes recent data and a substantially larger sample size. The GOA M_{VBGF} estimate given full weight, while the BC and WC values were given 0.5 weight. The M_{temp} weighted by 0.25 because of concerns over the input data. In the second stage weighting all of the M_{VBGF} estimates were given 0.25 weighting.

Silvergray Rockfish

The current GOA OROX assessment uses an *M* = 0.05 for silvergray rockfish (Malecha et al. 2007), based on the Hoenig (1983) maximum age method. Growth parameters are available for the species, but the model would not converge without fixing the t_0 parameter, therefore the values were deemed not useful for this analysis.

From Sullivan et al. (2022): *Reliable life history information was only available to estimate M using* M_{tmax} *and* M_{temp} *estimators. Updated M estimates ranged from 0.067 – 0.180. This species is not often aged, and all of the GOA maximum age values are from trawl survey samples, the most recent being 2005. The AFSC is beginning to examine this species and updated maximum age values may be available in the next few years.*

The first stage weighting was across four M_{tmax} estimates. The BC value was downweighted by 0.5 due to being a neighboring area. All of the GOA values were given full weight. The M_{temp} estimate was given 0.25 weighting due to concerns over the input data. All values were given full weighting in the second stage weighting.

Yelloweye Rockfish

Yelloweye rockfish is currently a Tier 6 species in the OROX stock complex. However, the species is being evaluated as a candidate for Tier 4 or 5, and is a Tier 4 species in the Demersal Shelf Rockfish stock complex. Both the OROX and DSR stock assessments have reported $M = 0.02$ for this species (Wood et al. 2021, Tribuzio et al. 2021). The previous M value is based on a catch curve analysis of a lightly exploited stock in Southern Southeast Outside waters in 1984 (O'Connell and Brylinsky 2003), and the assumption that, being lightly exploited, Z is approximately equal to M.

From Sullivan et al. (2022): *Yelloweye rockfish life history parameter inputs were available for three of the M estimators (*M_{tmax}*,* M_{temp}*, and* M_{GSI} *estimators) in the GOA, as well as a maximum age from BC (Table 1). The estimated M from both the* M_{GSI} *and* M_{tmax} *methods were similar, ranging from M = 0.044 to 0.052, with no regional difference. Both methods are well informed with either recent, regional research, or validated ageing results (Arthur 2020, Kerr et al. 2004).*

The first stage weighting included both M_{temp} and M_{tmax} estimates. The M_{tmax} estimate based on a maximum age of 122 was given 0.25 weight because of demonstrated biases in the technique used at the time. The BC M_{tmax} estimate was also given 0.25 weight due to being from a neighboring area. The remaining M_{tmax} estimates were given full weight. The M_{temp} estimate was given 0.25 weight due to concerns over the input data. All methods were given full weight in the second stage.

Updated M Results and Conclusion

For most species, the modeled M values were greater than the current assessment value, some substantially so (e.g., sharpchin greater by up to 207%). The exception being harlequin rockfish in which the composite M values ranged -26% to +50% of the current value. The resultant composite M values are reported in Table 2 and Figure 2. For all composite M values we report the range, median and mean of the input values; and for all of the HC methods we report a lower and upper 95% confidence limit. For comparison, Table 2 includes the current assessment value, and the proportional change in each composite M is from the current assessment value.

For defining the "best" value of M for a given species, we make the following recommendations to use a method that:

1) accounts for the quality of the input data. Assumptions that the input data are accurate or known without error are likely violated;
2) evaluates the applicability of the method to a given species. An M estimator may have certain considerations for a given species that make it more or less applicable for a species, but still informative;
3) includes informed model uncertainty. Each M estimator model has its own associated uncertainty, which contributes to the total uncertainty in the resultant estimate of M.

We recommend updating current M values in the GOA OROX (and other assessments, as needed) using the HCCV_Wt_M approach, which satisfies the above recommendations and also provides estimates of uncertainty around the modelled *M* value. The HCCV_Wt_M considers secondary (or further) relationships to *M*, such as those based on growth characteristics or environmental conditions. Uncertainty in *M* is not currently used in the Tier 4 or 5 stock assessments; however, the information is valuable to the stock assessment process and will allow assessors to develop more informed recommendations.

Summary

There are "downstream" impacts on the harvest recommendations as a result of updating the *M* values used in the stock assessment. In the example presented here, some of the GOA OROX species *M* values changed substantially (e.g., sharpchin increased by 77%), and overall, updating the *M* values could result in a greater ABC. However, many considerations need to be taken into account before changes such as this can be implemented.

First, potential increase in total ABC will not alleviate the spatial apportionment issues for this stock complex. The extreme reduction in the combined Western/Central GOA ABC was largely due to the 2021 GOA bottom trawl survey not capturing a few key species.

Second, updating *M* is linked to how the weighted *M* is calculated and used within the complex. In the Tier 5 model, all of the species are grouped into *M*-groups by their presumed *M* values. The exception for the GOA OROX were the harlequin and redstripe, which had unique values and were single species *M*-groups. As a result of this analysis, silvergray was separated from widow rockfish (which was not updated in this analysis), and redbanded also moved out of a larger *M*-group to a single species *M*-group. If this analysis were used in the next full assessment, there would be seven *M*-groups (up from five in the 2021 assessment) from 16 species, and as *M* is evaluated for more species, it is likely that the number of *M* groups could increase. As the number of *M*-groups increases, the GOA OROX Tier 5 model would be tracking species specific biomass more than *M*-group biomass. Increasing the number of *M*-groups will not impact the total Tier 5 biomass, which is used for harvest recommendations, because the Tier biomass is for all of the species combined. However, the weighted *M* used for harvest recommendations is based on the proportional biomass of the different *M*-groups, and as the number of *M*-groups increases, the proportional biomass will likely be more influenced by noisy data.

Before the updated *M* values can be used in the next full GOA OROX assessment, the authors need to consider the impacts of a greater number of *M*-groups as well as the other analyses requested by the PT and SSC. However, the methods for generating an *M* value for use in stock assessments, both from Sullivan et al. (2022) and this analysis, are useful across assessments.

Literature Cited

Alverson, D.L. and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. ICES J. of Mar. Sci. 36(2), p. 133-143.

Archibald, C. P., W. Shaw, and B. M. Leaman. 1981. Growth and mortality estimates of rockfishes (Scorpaenidae) from B.C. coastal waters, 1977-1979. Can. Tech. Rep. Fish. Aquat. Sci. 1048. 57 p.

Arthur, D.E. 2020. The reproductive biology of yelloweye rockfish (*Sebastes ruberrimus*) in Prince William Sound and the northern Gulf of Alaska. M.S. Thesis, Univ. Alaska, Fairbanks, AK.

Cope, J., E.J. Dick, A. MacCall, M. Monk, B. Soper, C. Wetzel. 2015. Data-moderate stock assessments for brown, China, copper, sharpchin, stripetail, and yellowtail rockfishes and English and rex soles in 2013. Pacific Fishery Management Council, Portland, OR. https://www.pcouncil.org/documents/2015/01/data-moderate-stock-assessments-for-brown-china-copper-sharpchin-stripetail-and-yellowtail-rockfishes-and-english-and-rex-soles-in-2013-published-january-2015.pdf/

Cope, J.M. and O.S. Hamel. In review. Upgrading from M version 0.2: An application-based method for practical estimation, evaluation and uncertainty characterization of natural mortality. Fisheries Research Special Issue: *Natural Mortality: Theory, estimation and application in fishery stock assessment models*. Will be available at https://www.sciencedirect.com/journal/fisheries-research/special-issue/10NSQ74ZXD9.

Echeverria, T.W. 1987. Thirty-four species of California rockfishes: maturity and seasonality of reproduction. Fish. Bull., U.S. 85, 229–250.

Gunderson, D.R. 1997. Trade-off between reproductive effort and adult survival in oviparous and viviparous fishes. Can. J. Fish. Aquat. Sci. 54: 990–998.

Hamel, O.S. 2015. A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES J. of Mar. Sci. 72: 62–69.

Hamel, O.S. and J.M. Cope. In review. Development and considerations for application of a longevity-based prior for the natural mortality rate. Fisheries Research Special Issue: *Natural Mortality: Theory, estimation and application in fishery stock assessment models*. Will be available at https://www.sciencedirect.com/journal/fisheries-research/special-issue/10NSQ74ZXD9.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Kastelle, C., T. Helser, T. TenBrink, C. Hutchinson, B. Goetz, C. Gburski, and I. Benson. 2020. Age validation of four rockfishes (genera *Sebastes* and *Sebastolobus*) with bomb-produced radiocarbon. Marine and Freshwater Research, 71(10), p. 1355-1366.

Kerr, L.A., A.H. Andrews, B.R. Frantz, K.H. Coale, T.A. Brown, and G.M. Cailliet. 2004. Bomb carbon in the yelloweye rockfish, *Sebastes ruberrimus*, as a chronological benchmark for age validation of commercially important fishes. Can. J. Fish. Aquat. Sci. 61: 443–451.

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

Malecha, P.W., D.H. Hanselman, and J. Heifetz. 2007. Growth and mortality of rockfish (Scorpaenidae) from Alaska waters. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-172, 61 p.

Munk, K.M., 2001. Maximum ages of groundfishes in waters off Alaska and British Columbia and consideration of age determination. Alaska Fish. Res. Bull. 8(1):12-21.

O'Connell, V. M. 1987. Reproductive seasons for some Sebastes species in southeastern Alaska. Alaska Dept. Fish Game, Informational Leaflet No. 263.

O'Connell, V.M., and C. Brylinksy. 2003. The Southeast Alaska Demersal Shelf Rockfish fishery with 2004 season outlook. Alaska Department of Fish and Game, Division of Commercial Fisheries. Regional Information Report No. IJ03-43. Juneau, AK 99801.

Sullivan, J.Y., C.A. Tribuzio, K.B. Echave. 2022. A review of the available life history data and updated estimates of natural mortality for several rockfish species in Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-443, 45p.

Thorson, J.T., S.B. Munch, J.M. Cope, and J. Gao. 2017. Predicting life history parameters for all fishes worldwide. Ecological Applications, 27(8): 2262-2276.

Tribuzio, C. A., K.B. Echave, K. Omori. 2021. 16. Assessment of the Other Rockfish stock complex in the Gulf of Alaska. In: Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2022. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Wood, K., R. Ehresmann, P. Joy, M. Jaenicke. 2021. 14. Assessment of the Demersal shelf rockfish stock complex in the Southeast Outside subdistrict of the Gulf of Alaska. In: Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2022. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Tables and Figures

Table 1. Species specific parameter inputs, resultant *M* values and references from Sullivan et al. (2022). The Wt1, Wt2 and Final Wt columns are the first and second stage and final weights applied to each of the inputs.

Species	Region	Parameter(s)	Parameter values(s)	*M*	Reference	Wt1	Wt2	Final Wt
Harlequin	AI	Max age (y)	79	0.068	AFSC max age	0.333	1	0.333
Harlequin	AI	Max age (y)	63	0.085	AFSC mean top 5	0.167	1	0.167
Harlequin	AI	Max age (y)	83	0.065	TenBrink with Kastelle correction	0.25	1	0.25
Harlequin	GOA	GSI	0.027	0.049	pers. comm. TenBrink 2022	1	1	1
Harlequin	GOA	Max age (y)	47	0.115	AFSC max age	0.083	1	0.083
Harlequin	GOA	Max age (y)	41	0.131	AFSC mean top 5	0.083	1	0.083
Harlequin	GOA	Max age (y)	51	0.106	TenBrink with Kastelle correction	0.083	1	0.083
Harlequin	GOA	Temperature (C) / Dry weight (g)	5.5 / 226	0.278	McCoy and Gillooly 2008	0.25	1	0.25
Harlequin	GOA	VBGF Linf (cm) / k	30.9 / 0.167	0.359	TenBrink pers comm	1	0.5	0.5
Redbanded	BC	VBGF Linf (cm) / k	54.8 / 0.050	0.123	Haigh and Starr 2006	0.5	0.5	0.25
Redbanded	GOA	Max age (y)	106	0.051	ADF&G Age Determination Unit website	1	1	1
Redbanded	GOA	Temperature (C) / Dry weight (g)	5.5 / 1,960	0.155	McCoy and Gillooly 2008	0.5	1	0.5
Redstripe	BC	Max age (y)	55	0.098	ADF&G Age Determination Unit website	0.2	1	0.2
Redstripe	GOA	Max age (y)	46	0.117	AFSC max age	0.4	1	0.4
Redstripe	GOA	Max age (y)	39	0.138	AFSC mean top 5	0.4	1	0.4
Sharpchin	BC	VBGF Linf (cm) / k	34.9 / 0.095	0.228	Archibald 1981	0.25	0.5	0.125
Sharpchin	GOA	Max age (y)	48	0.113	AFSC max age	0.333	1	0.333
Sharpchin	GOA	Max age (y)	43	0.124	AFSC mean top 5	0.333	1	0.333
Sharpchin	GOA	Temperature (C) / Dry weight (g)	6.0 / 533	0.232	McCoy and Gillooly 2008	0.25	1	0.25
Sharpchin	GOA	VBGF Linf (cm) / k	32.6 / 0.131	0.295	Malecha et al. 2007	0.5	0.5	0.25
Sharpchin	WC	Max age (y)	58	0.093	Cope et al. 2015	0.333	1	0.333
Sharpchin	WC	VBGF Linf (cm) / k	33.2 / 0.170	0.355	Cope et al. 2015	0.25	0.5	0.125
Silvergray	BC	Max age (y)	81	0.067	ADF&G Age Determination Unit website	0.143	1	0.143
Silvergray	GOA	Max age (y)	79	0.068	AFSC max age	0.286	1	0.286
Silvergray	GOA	Max age (y)	71	0.076	AFSC mean top 5	0.286	1	0.286

Silvergray	GOA	Max age (y)	75	0.072	Malecha et al. 2007	0.286	1	0.286
Silvergray	GOA	Temperature (C) / Dry weight (g)	7.0 / 1,960	0.18	McCoy and Gillooly 2008	0.25	1	0.25
Yelloweye	BC	Max age (y)	115	0.047	DFO 2018	0.167	1	0.167
Yelloweye	GOA	GSI	0.0285	0.052	Arthur 2020	1	1	1
Yelloweye	GOA	Max age (y)	122	0.044	ADF&G Age Determination Unit website	0.167	1	0.167
Yelloweye	GOA	Max age (y)	114	0.047	Bechtol 1998	0.333	1	0.333
Yelloweye	GOA	Max age (y)	118	0.046	O'Connell and Funk 1987	0.333	1	0.333
Yelloweye	GOA	Temperature (C) / Dry weight (g)	6.0 / 4,200	0.133	McCoy and Gillooly 2008	0.25	1	0.25

Table 2. Composite M estimate results. The Methods are the weighted mean (Wt_M), Hamel and Cope with inverse prior using arithmetic mean (HC), HC using Wt_M (HC_Wt_M), HC with the arithmetic mean and informed model coefficients of variation (HCCV) and HCCV using the Wt_M. Summary of input *M* values are included: minimum and maximum, median and arithmetic mean. The Composite *M* is the resultant *M* value from the given method with lower and upper 95% confidence limits, where applicable. The current Assessment *M* values and proportional change between the Composite *M* and Assessment *M* are provided.

Species	Method	Min	Max	Median	Mean	Composite	Lower 95%	Upper 95%	Assessment M	% Change
harlequin	Wt_M	0.049	0.359	0.106	0.14	0.138			0.092	50
harlequin	HC	0.049	0.359	0.113	0.113	0.113	0.092	0.138	0.092	23
harlequin	HC_Wt_M	0.049	0.179	0.084	0.085	0.084	0.062	0.114	0.092	-8
harlequin	HCCV	0.049	0.359	0.088	0.089	0.088	0.07	0.111	0.092	-4
harlequin	HCCV_Wt_M	0.049	0.179	0.068	0.069	0.068	0.045	0.102	0.092	-26
redbanded	Wt_M	0.051	0.155	0.123	0.11	0.091			0.06	52
redbanded	HC	0.051	0.155	0.099	0.101	0.099	0.07	0.141	0.06	65
redbanded	HC_Wt_M	0.031	0.078	0.05	0.05	0.05	0.035	0.07	0.06	-17
redbanded	HCCV	0.051	0.155	0.063	0.065	0.063	0.037	0.108	0.06	5
redbanded	HCCV_Wt_M	0.031	0.078	0.051	0.052	0.051	0.029	0.087	0.06	-16
redstripe	Wt_M	0.098	0.138	0.117	0.118	0.122			0.1	22
redstripe	HC	0.098	0.138	0.117	0.119	0.117	0.082	0.166	0.1	17
redstripe	HC_Wt_M	0.122	0.122	0.122	0.128	0.122	0.066	0.223	0.1	22
redstripe	HCCV	0.098	0.138	0.117	0.119	0.117	0.082	0.166	0.1	17
redstripe	HCCV_Wt_M	0.122	0.122	0.122	0.128	0.122	0.066	0.223	0.1	22
sharpchin	Wt_M	0.093	0.355	0.228	0.206	0.18			0.06	200
sharpchin	HC	0.093	0.355	0.184	0.186	0.184	0.146	0.232	0.06	207
sharpchin	HC_Wt_M	0.058	0.147	0.098	0.099	0.098	0.069	0.139	0.06	63
sharpchin	HCCV	0.093	0.355	0.125	0.127	0.125	0.091	0.173	0.06	108
sharpchin	HCCV_Wt_M	0.058	0.147	0.106	0.11	0.106	0.062	0.182	0.06	77
silvergray	Wt_M	0.067	0.18	0.072	0.093	0.093			0.05	86
silvergray	HC	0.067	0.18	0.085	0.086	0.085	0.065	0.112	0.05	70
silvergray	HC_Wt_M	0.045	0.071	0.057	0.058	0.057	0.037	0.087	0.05	13
silvergray	HCCV	0.067	0.18	0.073	0.074	0.073	0.054	0.098	0.05	46
silvergray	HCCV_Wt_M	0.045	0.071	0.068	0.071	0.068	0.038	0.12	0.05	35

Species	Method	Min	Max	Median	Mean	Composite	Lower 95%	Upper 95%	Assessment M	% Change
yelloweye	Wt_M	0.044	0.133	0.047	0.061	0.058			0.02	192
yelloweye	HC	0.044	0.133	0.056	0.056	0.056	0.044	0.072	0.02	180
yelloweye	HC_Wt_M	0.033	0.052	0.043	0.044	0.043	0.03	0.061	0.02	115
yelloweye	HCCV	0.044	0.133	0.048	0.049	0.048	0.037	0.063	0.02	142
yelloweye	HCCV_Wt_M	0.033	0.052	0.048	0.049	0.048	0.032	0.072	0.02	139

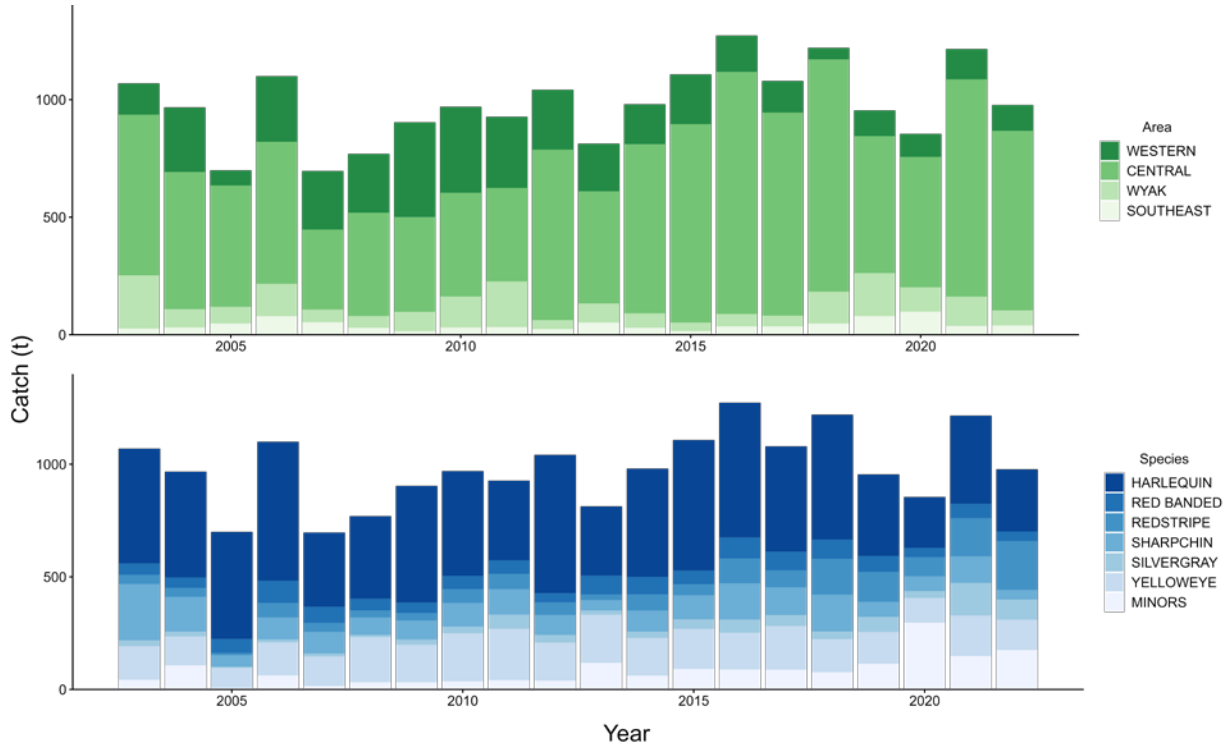

Figure 1. Estimated catch (metric tons) through 9/12/2022 for the Gulf of Alaska Other Rockfish stock complex, data provided by the Alaska Regional Office Catch Accounting System, queried through AKFIN. Top panel: estimated catch by Fishery Management Plan sub-areas. Bottom panel: estimated catch by species.

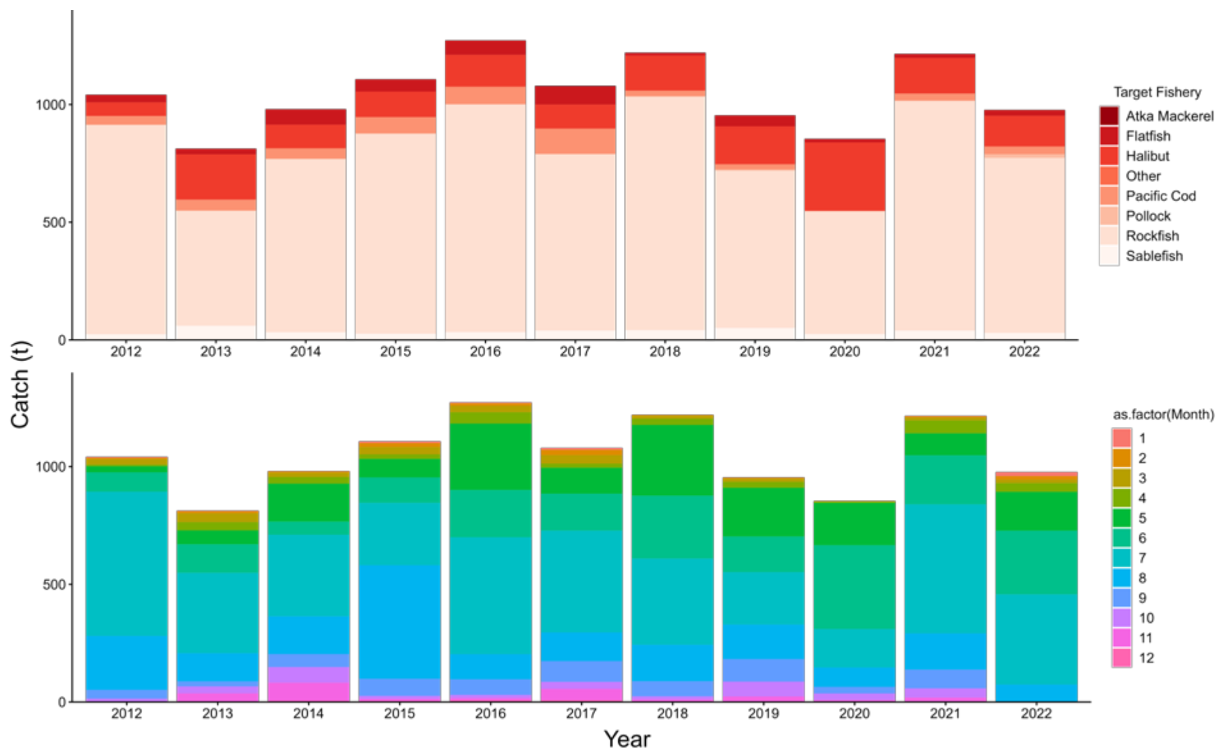

Figure 2. Estimated catch (metric tons) through 9/12/2022 for the Gulf of Alaska Other Rockfish stock complex, data provided by the Alaska Regional Office Catch Accounting System, queried through AKFIN. Top panel: estimated catch by target fishery. Bottom panel: estimated catch by month.

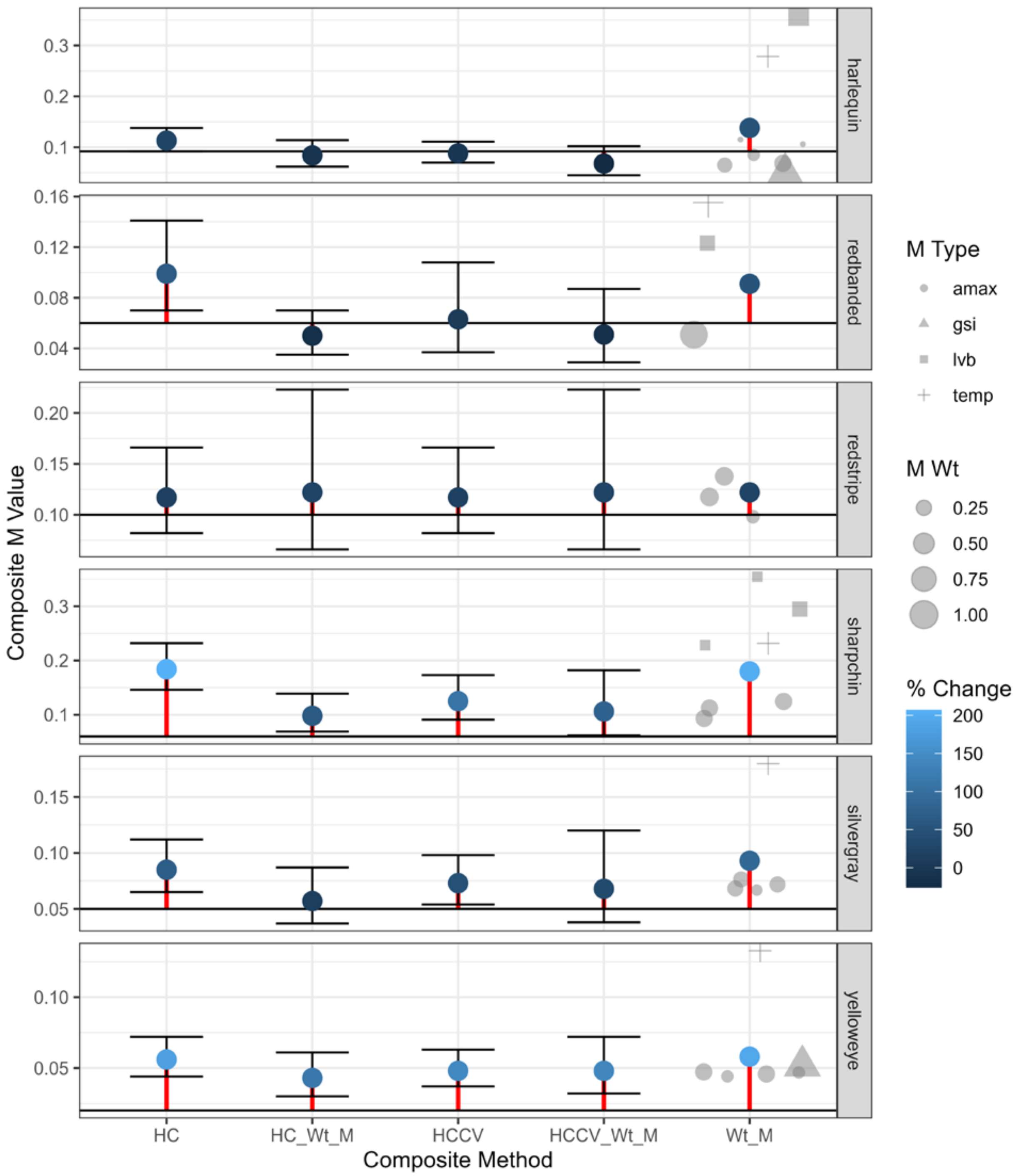

Figure 3. Current and updated composite M estimates. The black horizontal line is the M value used currently in the GOA OROX stock assessment. The left lollipop is the weighted mean composite M, with the gray shapes being the individual input M estimates and size indicating the weight for each. The right lollipop is the composite M generated using the Hamel and Cope inverse variance method and method specific coefficients of variation. The color of the lollipop indicates the absolute proportional change in value from the current assessment value (horizontal line).