Reevaluation of the OY range for groundfish in the Gulf of Alaska using single-species MSY estimates

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The current optimum yield (OY) specification for groundfish in the Gulf of Alaska was established by the North Pacific Fishery Management Council (Council) by Amendment 15 to the GOA FMP in 1987. Previously OYs for individual stocks were specified in the FMP and could only be modified by FMP amendment. The OY was specified as a range recognizing that stock and yields will fluctuate due to environmental variability while implementing sustainable harvest policies. The approach of specifying a multi-species OY to constrain harvest specifications for individual stocks is also implemented for EBS groundfish, but this approach has not been used by other Councils. The lower end of the range for GOA was specified as 116,000 mt, which was lowest aggregate groundfish catch during 1965-1985. The upper end of the range for OY was set based on the sum of single species MSY estimates. The aggregate MSY estimates during 1983 and 1987 ranged from 804,950 mt in 1983 to 1,137,750 mt for the 1987 fishing year. The average MSY over the five-year period was 873,070. An upper limit of 800,000 mt was established as 92 percent of the MSY five-year average. The rationale for the eight percent reduction is that it provides some allowance to ensure OY does not exceed MSY. The FMP notes that the "Magnuson-Stevens Act requires Councils to "review on a continuing basis, and revise as appropriate, the assessments and specifications made ... with respect to the optimum yield." In particular, OY may need to be respecified in the future if major changes occur in the estimate of MSY for the groundfish complex. Likewise, OY may need to be respecified if major changes occur in the ecological, social, or economic factors governing the relationship between OY and MSY."

Table 1. Key definitions in the Fisheries Management Plan for Groundfish in the Gulf of Alaska

Maximum sustainable yield (MSY) is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions, fishery technological characteristics (e.g., gear selectivity), and distribution of catch among fleets.
Optimum yield (OY) is the amount of fish which– a) will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems; b) is prescribed as such on the basis of the MSY from the fishery, as reduced by any relevant economic, social, or ecological factor; and c) in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the MSY in such fishery.
Maximum fishing mortality threshold (MFMT, also called the "OFL control rule") is the level of fishing mortality (F), on an annual basis, used to compute the smallest annual level of catch that would constitute overfishing. Overfishing occurs whenever a stock or stock complex is subjected to a level of fishing mortality or annual total catch that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis.
Overfishing limit (OFL) is the annual amount of catch that results from applying the MFMT to a stock or stock complex's abundance. The OFL is the catch level above which overfishing is occurring.

Methods

The objective of this reevaluation is to update the MSY estimates of the stocks currently considered "in the fishery," and repeat the same procedure to obtain a new estimate of the upper limit of the OY range. It is important to note that one of the goals of the ongoing GOA-CLIM project is evaluate the system-level productivity of the Gulf of Alaska using various methods, including an Atlantis end-to-end ecosystem model, and new regional ECOPATH models. The results reported here should be regarded as one contribution to this multi-model evaluation, and are not intended to be used independently to revise the OY range for Gulf of Alaska groundfish.

To estimate MSY we included all stocks listed as target species in Table 3.1 of the GOA groundfish FMP. Information from the most recent stock assessment was used to estimate MSY. Groundfish in the Gulf of Alaska are assigned a tier level according to the availability of information to estimate current biomass and biological reference points. Therefore, different approaches were applied for stocks in each tier. All stocks in the Gulf of Alaska are in tiers 3-6, in which proxies are used to estimate the MSY.

For tier three stocks, we used the equilibrium yield at FMSY proxy of F35% as an estimate of MSY (Clark 1991), which was considered most consistent with the definitions of MSY in the Gulf of Alaska FMP (as well as the National Standard One Guidelines). This quantity is found in output from the PROJ model used to project the OFL and the ABC. These output files were obtained from the lead assessment author for each of the most recent Tier 3 assessments, and represent the best current estimates of MSY. The overfishing level (OFL) is closely associated with MSY, but the OFL as defined for tier three stocks represents the application of a harvest control rule that is intended to maintain the capacity of stock to produce MSY, and features a ramped reduction in fishing mortality below B35%. This feature will reduce overall yield slightly relative to MSY, but promote more rapid recovery to the MSY stock level.

For stocks in tiers four and five, the OFL is obtained by multiplying current stock size by the either the natural mortality rate or the F35% fishing mortality rate. Many of the tier 4 and 5 stocks have historically been lightly exploited, consequently their abundance may be closer to unfished levels than the B_{MSY} stock size, and simply considering OFL values from recent assessment as estimates of MSY has the potential to substantially overestimate MSY. To address this issue, we developed an approach to adjust the MSY based on the depletion level of the stock. This approach is based on the Gompertz-Fox surplus production model (Fox 1970, Jensen 2005), which can be considered a special case of the more general Pella-Tomlinson surplus production model (Quinn and Deriso 1988) (Fig. 1).

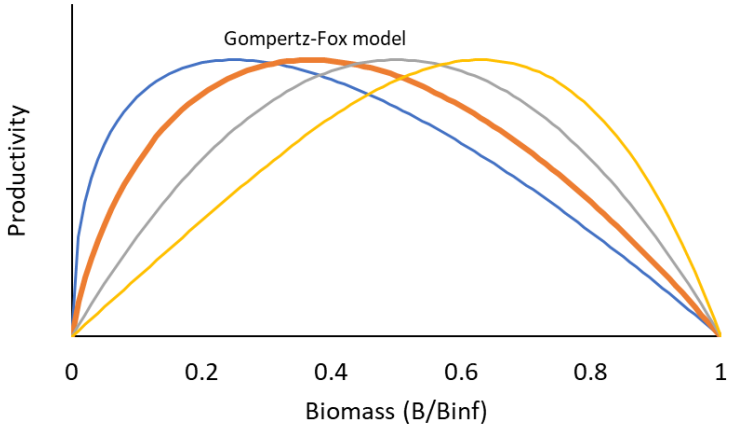

Figure 1. Productivity as a function of stock size for different cases of the Pella-Tomlinson production model showing the Gompertz-Fox model as a special case.

For the Gompertz-Fox production model, stock size at maximum productivity, i.e., MSY stock size, occurs at 1/e = 0.368 of unfished abundance, so this approach is approximately consistent with the tier 3 assumption of B35% as proxy for the biomass at MSY. Equilibrium yield for the Gompertz-Fox production model is given by

$$Y_e = k_{max} B_e \left[ln\left(B_{inf}\right) - ln(B_e) \right]$$

Assume $F_{MSY} = F_{35\%} = M = k_{max}$.
Assume $B_{inf} = 1$, so that B_e represents stock size relative to unfished
Assume the stock in equilibrium.
Define $h = Y_e/B_e$ = average catch/ average biomass.
Rearranging and simplifying gives

$$Depletion(B_e) = exp\left({}^{-h}/_{M}\right)$$

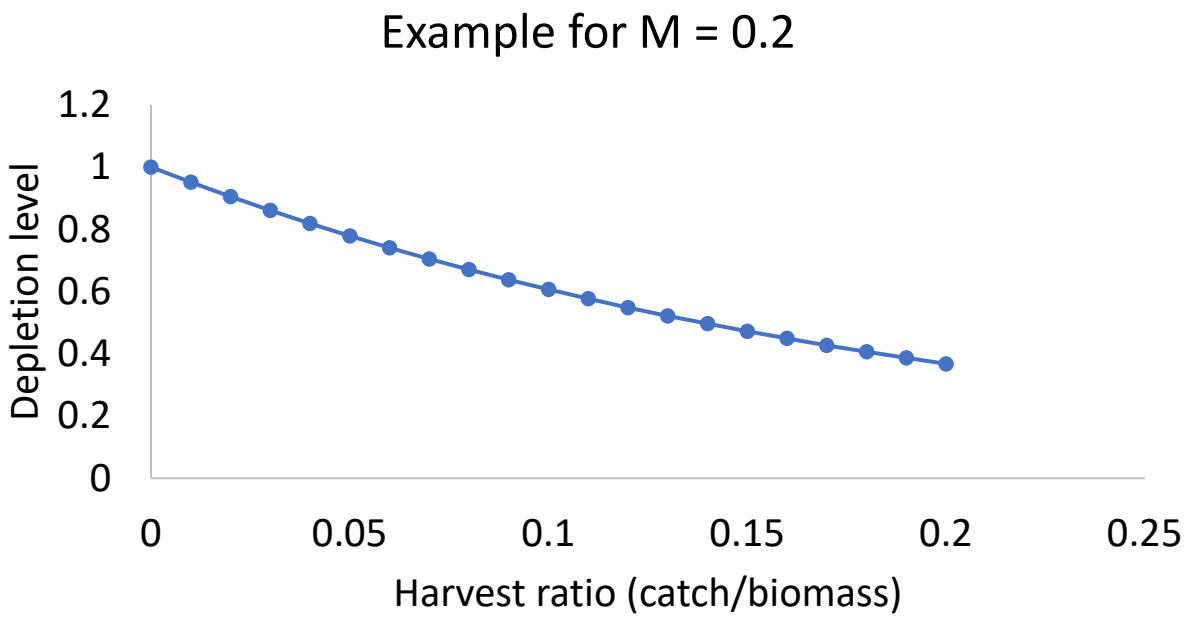

Fig 2. Relationship between harvest ratio (average catch/average biomass) and stock depletion for a stock where M = FMSY = 0.2 for the Gompertz-Fox production model.

Two estimates of MSY were produced to evaluate sensitivity to stock status, i.e., depletion. The first did not account for stock status and is given by: Average survey biomass * M (or F35% for tier 4 stocks). A long-term average was considered appropriate rather than current biomass or short-term mean because long-term average yields are more consistent with the concept of MSY. The second estimate adjusts the MSY by 0.35/estimated stock depletion to scale the MSY estimate to harvest that could be expected when the stock is at B35%. These calculations assume that the stock size is in equilibrium at the level of the long-term average harvest. Examination of biomass and catch time series for tier 4 and 5 stocks show some variability but no strong trends, suggesting that this assumption may be reasonable.

For tier 6 stocks, the default OFL is based on average catch during the period 1978-1995 unless an alternative value is established by the SSC. Most stocks use a different time period and/or maximum catch during a specific time period. This OFL is a constant value that is never updated; therefore, it was considered an appropriate proxy for MSY. Tier 6 stocks account for less than 2% of the aggregate MSY for groundfish, so while this approach has to be regarded as a rough approximation, overall results do not strongly depend on Tier 6 assumptions.

Results

Estimates of MSY for tier 3 stocks are given in Table 2. Comparison of FOFL, FABC, and M indicated that M tended to be lower than FOFL by 19%, though there was considerable variation between stocks (Figure 3). In some cases, such as arrowtooth flounder, and some populations of rock sole, M was higher than FOFL. Comparison of MSY estimates with a 5-year average (2018-2022) of the specified overfishing level indicated that the recent OFL tended to be higher than the

long-term MSY yield (Figure 4). One notable exception is Pacific cod, where the recent OFLs have been much lower than MSY due to the current depleted status of Pacific cod.
Estimates of MSY for tier 4 and 5 stocks are given in Table 3. Estimates of stock depletion based on an equilibrium assumption for the Gompertz-Fox production model indicated on average, that the biomass for these stocks was about twice the level associated with MSY (Figure 5). A notable exception is yelloweye rockfish, whose biomass is slightly lower than the MSY level (depletion = 0.32). The sum of depletion-corrected MSY estimates was 21,297 t, which was 42% percent of the uncorrected aggregate estimate of 50,976 t.

Estimates of MSY for tier 6 stocks based on the OFLs taken directly from the most recent stock assessments are given in Table 4. Aggregate MSY for these stocks is less than 2% of the aggregate MSY for all stock, indicating highly uncertain estimates have minimal impact on the overall estimate. The MSY for Atka mackerel is 70% of the total MSY for tier 6 stocks.

Conclusions:

- The sum of MSY estimates for all groundfish stocks in the FMP based on the most recent assessment information was 483,275 t.

- Reducing that quantity by 8%, as was done for the original OY value for GOA groundfish, gave an aggregate OY of 444,600 t, compared to the original estimate of 800,000 t.

- It is possible that original estimate of aggregate MSY may have been based on annual OFL estimates (according to the current definition) for stocks close to unfished levels and would not represent a long-term sustainable level of harvest for those stocks.

- Recent aggregate ABCs have been slightly higher than the new estimate of OY, but the aggregate TACs have been surprisingly similar (Figure 6).

- Reducing the TAC to the estimated long-term MSY for some lightly exploited stocks may be helpful for managing expectations for the potential harvest of groundfish in the Gulf of Alaska.

- The aggregate groundfish OY will be evaluated using other approaches as a part GOA-CLIM, so an immediate change in aggregate OY for Gulf of Alaska is not recommended.

References:

Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Canadian Journal of Fisheries and Aquatic Sciences 48:734–750.

Jensen, A. L. 2005. Harvest in a fluctuating environment and conservative harvest for the Fox surplus production model. Ecological Modelling 182:1–9.

Quinn, T.J., Deriso, R.B., 1999. Quantitative Fish Dynamics. Oxford University, New York.

Fox, W.W., 1970. An exponential yield model for optimizing exploited fish populations. Trans. Am. Fish. Soc. 99, 80–88.

Table 2. Estimates of MSY reference points (t) for Tier 3 stock in the Gulf of Alaska. COFL is the equilibrium catch at F35% and is considered as an estimate of MSY for the stock.

Stock	2021 Assessment status	Tier	COFL	CABC	FOFL	FABC	B35%	B40%	M
Pollock	Full	3	187127	171728	0.311	0.263	150089	171530	0.300
Pacific cod	Full	3	77533	72056	0.866	0.696	56849	64970	0.480
Sablefish	Full	3	16122	15103	0.094	0.080	74687	85356	0.100
Western NRS, N. and S. rock sole	Full	3	4320	3978	0.386	0.313	10046	11481	0.227
Central NRS, N. and S. rock sole	Full	3	2936	2731	0.181	0.153	7320	8365	0.216
Western SRS, N. and S. rock sole	Full	3	6142	5658	0.222	0.185	15326	17515	0.236
Central SRS, N. and S. rock sole	Full	3	8184	7554	0.268	0.224	18704	21376	0.227
Dover sole	Partial	3	2443	2235	0.111	0.093	6661	7613	0.116
Rex sole, western-central	Full	3	7417	6844	0.285	0.229	16369	18707	0.170
Rex sole, eastern	Full	3	1683	1546	0.309	0.247	3149	3599	0.170
Arrowtooth flounder	Full	3	84788	79182	0.225	0.185	356544	407478	0.275
Flathead sole	Partial	3	17619	16228	0.356	0.284	32043	36620	0.200
Pacific ocean perch	Full	3	26455	24717	0.120	0.100	116171	132767	0.075
Northern rockfish	Partial	3	5273	4931	0.073	0.061	29691	33933	0.059
Rougheye & blackspotted rockfish	Full	3	615	574	0.046	0.038	5172	5911	0.034
Dusky rockfish	Partial	3	4668	4362	0.114	0.093	21299	24342	0.070
Tier 3 total			453326	419427					

Table 3. Estimates of MSY reference points (t) for tier 4 and 5 stocks in the Gulf of Alaska

Stock/Stock complex	2021 Assessment status	Tier	M or FMSY	Average Biomass	Average Harvest	MSY (no B35% correction)	Stock depletion	MSY (Corrected to B35%)
Shallow water flatfish (excluding northern and southern rock sole)	Full	5	0.200	123149	1029	24630	0.9591	8988
Other rockfish, sharpchin rockfish only	Full	4	0.079	20167	101	1593	0.9384	594
Other rockfish, 17 Tier 5 stocks	Full	5	0.055	66552	632	3660	0.8414	1523
Demersal shelf rockfish, yelloweye rockfish only	Full	4	0.032	11062	403	354	0.3206	386
Thornyhead rockfish	None	5	0.030	77394	830	2322	0.6993	1162
Sharks, spiny dogfish only	None	5	0.040	222474	1412	8899	0.8533	3650
Skates	Full	5	0.100	95178	3853	9518	0.6671	4994
Tier 4 and 5 total						50976		21297

Table 4. Estimates of MSY reference points (t) for tier 6 stocks in the Gulf of Alaska

Stock/Stock complex	2021 Assessment status	Tier	OFL
Deepwater flatfish, except Dover sole	Partial	6	313
Other rockfish, Tier 6 only	Full	6	236
Demersal shelf rockfish, except yelloweye rockfish	Full	6	26
Atka mackerel	Full	6	6200
Octopus	Full	6	1307
Sharks, except spiny dogfish	None	6	570
Tier 5 total			8652

Table 5. Notes on MSY estimates for tier 3-5 stocks in the Gulf of Alaska.

Stock	2021 Assessment status	Tier	Notes
Pollock	Full	3	M is age-specific, 0.30 is the average above the age of maturity
Pacific cod	Full	3	Fishing mortality reference points are the sum of apical F
Sablefish	Full	3	GOA proportion of Alaska-wide OFL based on unweighted average (.7225) over 1990-2021.
Western NRS, N. and S. rock sole	Full	3	M is an average of female and male M (female M = 0.2, male M = .254)
Central NRS, N. and S. rock sole	Full	3	M is an average of female and male M (female M = 0.2, male M = .232)
Western SRS, N. and S. rock sole	Full	3	M is an average of female and male M (female M = 0.2, male M = .271)
Central SRS, N. and S. rock sole	Full	3	M is an average of female and male M (female M = 0.2, male M = .253)
Dover sole	Partial	3	M is an average of female and male M (female M = 0.113, male M = .119)
Rex sole, western-central	Full	3	
Rex sole, eastern	Full	3	
Arrowtooth flounder	Full	3	M is an average of female and male M (female M = 0.2, male M = .35)
Flathead sole	Partial	3	
Pacific ocean perch	Full	3	
Northern rockfish	Partial	3	
Rougheye & blackspotted rockfish	Full	3	
Dusky rockfish	Partial	3	
Shallow water flatfish (excluding northern and southern rock sole)	Full	5	Average survey biomass 1990-2021, average catches 2003-2021.
Other rockfish, sharpchin rockfish only	Full	4	RE average biomass 1990-2021, average catches 2003-2021.
Other rockfish, 17 Tier 5 stocks	Full	5	RE average biomass 1990-2021, average catches 2003-2021.
Demersal shelf rockfish, yelloweye rockfish only	Full	4	Average ROV biomass 2019-2022, average catches 2006-2021.
Thornyhead rockfish	None	5	RE average biomass 1990-2019, average catches 2003-2021.
Sharks, spiny dogfish only	None	5	RE average biomass 1990-2019 = 46720, catchability = 0.21, Average catches 2011-2021.
Skates	Full	5	RE average biomass from 1990-2021. Average catches 2004-2021.

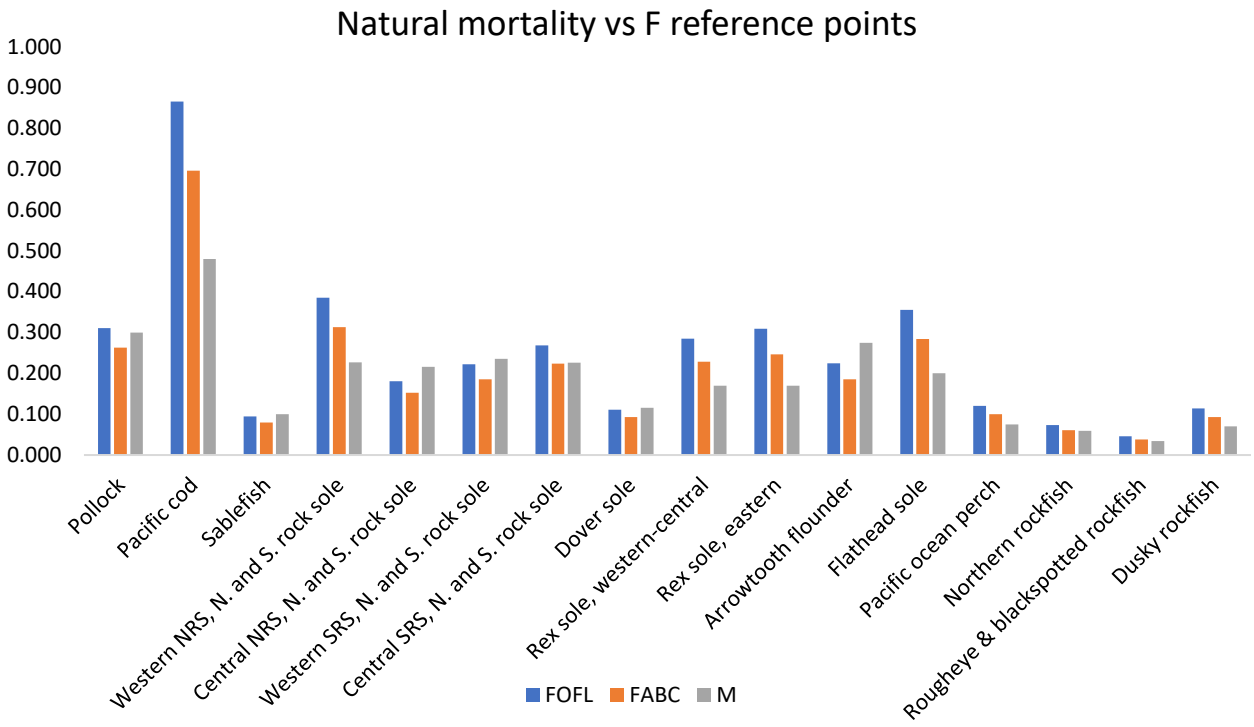

Figure 3. Relationships between FOFL, FABC and natural mortality for tier 3 stocks in the Gulf of Alaska.

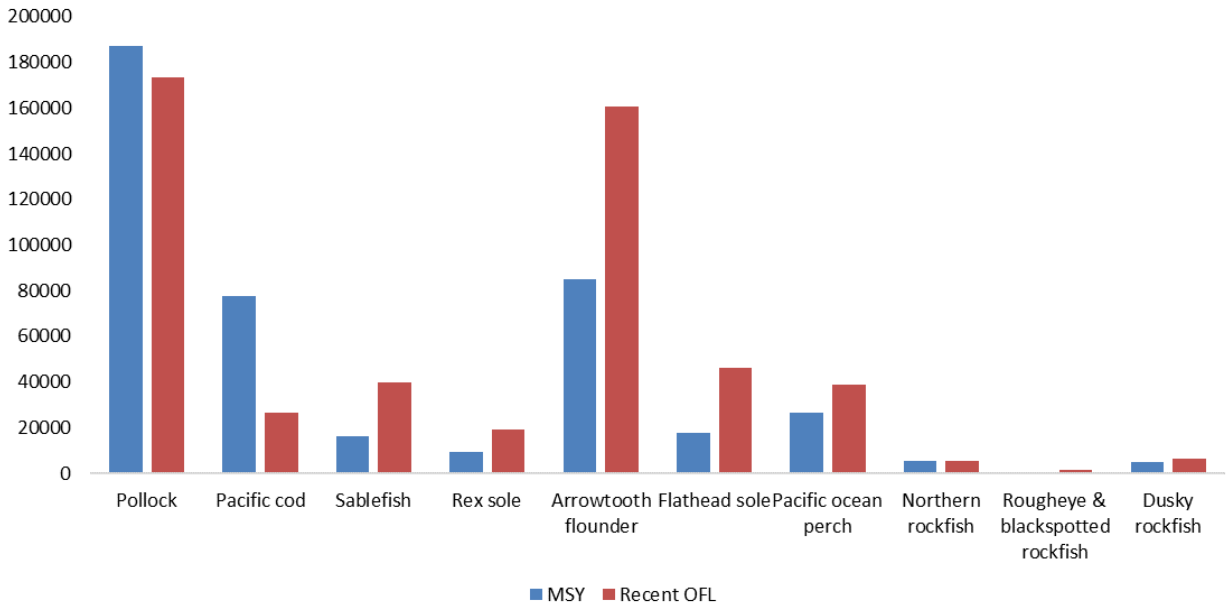

Figure 4. Comparison of MSY estimates with a 5-year average (2018-2022) of the specified overfishing level in the SAFE chapters for tier 3 stocks in the Gulf of Alaska.

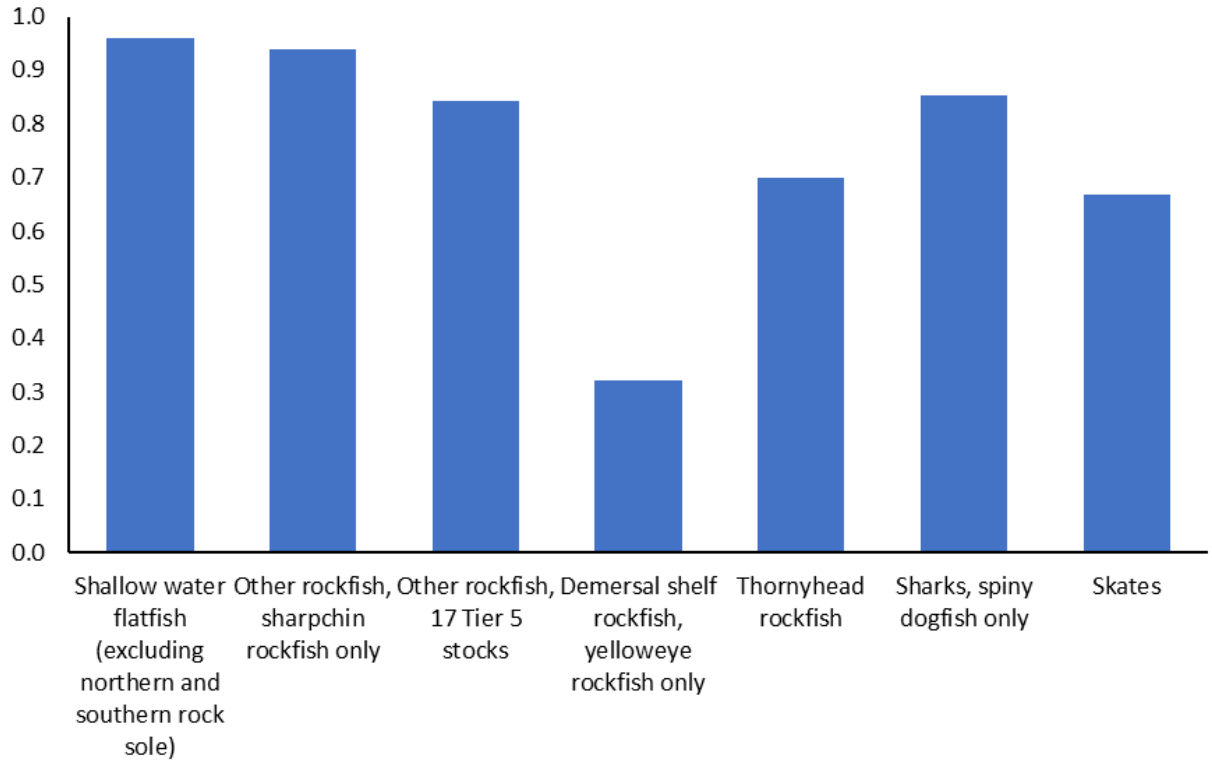

Figure 5. Estimated stock depletion (stock size relative to unfished stock size) for tier 4 and 5 groundfish stocks in the Gulf of Alaska.

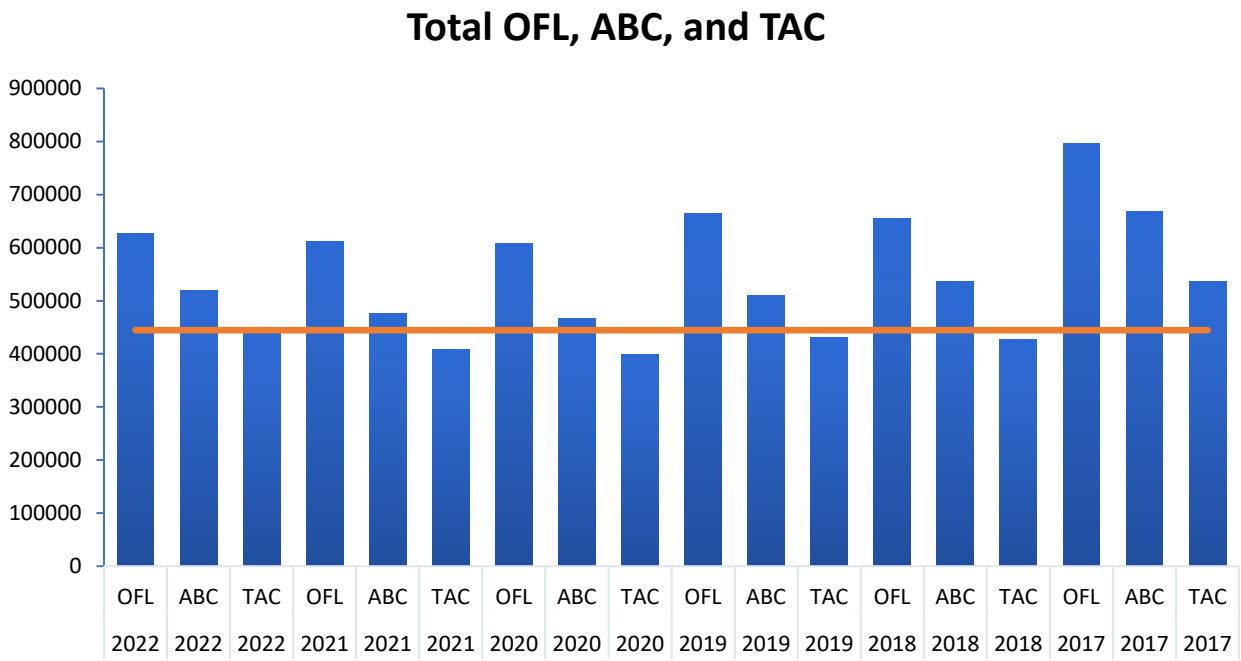

Figure 6. Comparison of aggregate OFL, ABC, and TAC for 2017-2022 for groundfish stocks in the Gulf of Alaska. Horizontal red line is the estimated aggregate MSY obtained by summing the MSY estimates for all stocks in the groundfish FMP and then reducing that quantity by 8% as was done for the original OY value for GOA groundfish.