Apportionment strategy evaluation methods

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Sablefish (*Anoplopoma fimbria*) are a valuable, highly mobile groundfish species of the north Pacific. The portion of the Alaska sablefish stock (hereafter 'Alaska sablefish') in the federal exclusive economic zone are managed on an Alaska-wide scale because movement rates among management regions are high and exploitation rates are relatively low.

Each year the sablefish stock assessment model estimates ABC and OFL values that are subsequently apportioned among six management areas (Aleutian Islands (AI), Bering Sea (BS), Western Gulf of Alaska (WG), Central GOA (CG), West Yakutat (WY), and East Yakutat/Southeast Outside (EY)). Beginning in December 1999, the North Pacific Fisheries Management Council apportioned the 2000 ABC and OFL based on a 5-year exponential weighting of the fishery and survey abundance indices. This apportionment method was used from 2000-2013. In 2014 apportionments were fixed at the 2013 proportions because the objective of reducing variability in apportionment was not being achieved using the 5-year exponential weighting method.

To explore apportionment options, we initiated a series of simulation analyses that test how alternate apportionment methods perform now and into the future. To evaluate alternative apportionment strategies, we developed a simulation-estimation framework that includes a spatial operating model combined with a modified stock assessment estimation model. The operating model was intended to provide a 'best' approximation of our understanding of Alaska sablefish population dynamics. Through simulation analysis, we examine sablefish biomass responses to varying fishing mortality rates among management regions and the influence of alternative apportionment strategies on harvest opportunity across time. The methods section of this work is presented in this document for SSC review and feedback. This document represents the most current methods for the apportionment simulation work, and have changed slightly since the stakeholder meeting in February.

Methods

We used simulation to evaluate the performance of 10 methods for apportioning allowable biological catch (ABC) among management areas. These apportionment simulation analyses contain two primary components, an operating model (OM) developed in R (R Core Team 2019) and an estimation model (EM) developed in AD Model Builder (Fournier et al. 2012). The OM has six spatial areas representing the six management areas used for Alaska sablefish and movement between areas conditioned on findings from a long-term (1979-2009) sablefish tagging study. The EM estimates parameters for Alaska sablefish as a single, panmictic unit using data aggregated across the six management areas. Both the OM and EM have an annual time step (y), are age-structured, and two have sexes (h). See the appendix for a reference list of variables and definitions. Ages 2-30 are modeled in both the OM and EM, with age 30 serving as a plus group, accumulating fish aged 30 and greater.

EM

The EM is similar to the operational assessment model currently used for sablefish management (Hanselman et al. 2019), but has a few key differences. The EM begins in 1977 instead of 1960, and is not informed by length composition data or a trawl survey index of abundance. In addition, the EM incorporates new longline survey age composition data in the same year as each added year of the longline survey index, without the one-year processing lag that exists in the assessment model used for sablefish management. This change was made to improve model convergence and EM recruitment estimation, which were compromised due to the combination of no length composition data being simulated in the OM and the lack of terminal year age composition data. Age composition data for fixed gear fleet were included with a one-year lag as in the current assessment model used for sablefish management.

The EM estimates fishing mortality, selectivity, and catchability for two commercial fleets, fixed gear (pot, longline) and trawl gear. Three abundance or CPUE indices were fit by the EM, a US longline survey (1990-2038), a US-Japanese cooperative longline survey (1979-1994), and a longline fishery catch per unit effort (CPUE) index (1990-2037). The longline fishery CPUE index is broken into two time blocks with separate selectivity and catchability estimated, coinciding with the implementation of the individual fishing quota (IFQ) program and resulting changes in fishing practices; differing selectivity for the fixed gear fleet was estimated for pre-IFQ years (1977-1994) and post-IFQ years (1995 onward). Further details about the EM are available in Hanselman et al. (2019).

OM

The OM is spatially explicit so potential area-specific dynamics in fleet or fish behavior (e.g. catchability, selectivity, or fish movement) can be simulated. The OM simulates data in two periods, a deterministic conditioning period for years 1976-2018 that is the same across simulation replicates, and a stochastic forward projection period which updates the OM and runs the EM iteratively each year for years 2019-2038. The OM and EM models include ages 2-30, with age 30 serving as a plus group, accumulating fish aged 30 and greater. For each of the 10 apportionment types examined, 200 replicates were simulated.

Conditioning period (1976-2018)

We conditioned the OM to closely match our best estimates of sablefish population dynamics using parameter estimates from the operational assessment model used for management (Hanselman et al. 2019) and using a spatially-explicit, age-structured assessment model (Fenske et al. *in prep*) developed for sablefish as a research model. Two fishing fleets were simulated, a fixed gear fleet that combines pot and longline gears, and a trawl fleet. A longline survey index and a fishery catch per unit effort index were simulated with randomly generated lognormal observation error, described below.

Abundance in numbers at age for the first year, y, of the OM conditioning period was the product of an initial total population abundance value N_{init} that was a fixed input, and the proportions of abundance ρ by sex h at age a as estimated by the operational stock assessment model used for management. Abundance was then split into spatial management areas m using the mean proportion of age-2 sablefish observed from the longline survey (1981-2017) in each management area Þ_m. N_{init} was assumed to be 93.4 million, which is the 1977 estimate of total abundance from the stock assessment model used for management. N_{init},, ρ, and Þ are the same across simulation replicates i, for the conditioning period. Note, the subscript i for replicates is excluded from equations below for simplicity.

$$N_{y=1976,h,a,m,} = N_{init} * \rho_{y=1976,h,a} * \text{Þ}_m.$$

Biomass for the initial year $B_{y=1976,h,a,m}$ and all subsequent years was calculated from abundance, as the product of abundance and mean weight at age $w_{h,a}$ for each sex. Weight at age was assumed to be equal across spatial management areas and is equivalent to the EM and the assessment model used for management.

For subsequent years within the conditioning period, 1977-2017 recruitment R_{cond} or abundance of the first age in the model was fixed at the values estimated by the stock assessment model used for management. Recruitment for 2018 was assumed to be approximately equal to the mean recruitment estimated from the model used for management over year 1995-2017 (16.5 million recruits), but sensitivity to this was also examined. Recruitment for the conditioning period was the same for the 200 replicates and 10 apportionment types. Recruitment was divided into management areas using the mean proportion $Þ_m$ of age-2 sablefish observed from the longline survey (mean 1977-2018) and split equally between sexes.

$\widehat{N}_{y,h,a=1,m} = 1/2 * R_{cond,y} * Þ_m$.

Abundance in each area for subsequent ages is a function of gear-specific total fishing mortality *F*, and natural mortality *M*. *M* was fixed at 0.1 for all ages and both sexes in these simulations.

$$\widehat{N}_{y,h,a,m} = N_{y-1,h,a-1,m} e^{-(F_{y-1,h,a-1,m} + M_{h,a-1})}$$

Abundance for the plus group (*a*=*A*, age 30+) was the sum of new entrants to the plus group and those already in the plus group that survived fishing and natural mortality,

$\widehat{N}_{y,h,a=A,m} = N_{y-1,h,a-1,m} e^{-(F_{y-1,h,a-1,m} + M_{h,a-1})} + N_{y-1,h,a=A,m} e^{-(F_{y-1,h,a=A,m} + M_{h,a=A})}$.

Movement of fish (in numbers) between areas occurred in a single pulse after fishing and natural mortality. $N_{y,h,a,m} = \left(\widehat{N}_{y=y,a=a,h=h,m} * \Phi^T_{i,j,a=a-1}\right)$, where Φ is an age-dependent movement matrix (Table 1). Elements of Φ are transition probabilities among regions, where rows (i) describe the starting region and columns (j) represent the regions to which movement occurs, where each row sums to 1. For each year, age, and sex, the vector of abundance in numbers by area is multiplied by the transpose of the movement (transition probability) matrix.

Total annual age and sex-specific fishing mortality *F* for each area is summed across fishing fleets *g*,

$$F_{y,h,a,m} = \sum_{\mathrm{g}} (f_{y,m,\mathrm{g}} * S_{h,a,m,\mathrm{g}})$$

and is the product of year, area and gear-specific fishing mortality rates $f_{y,m,g}$ and selectivity by sex, age, area, and fleet $S_{h,a,m,g}$.

The realized fishing mortality rate *f* for each year's observed fleet- and area-specific catch during the conditioning period (1976-2018) was found such that the model predicted catch $\hat{C}_{y,\mathrm{g},m}$ was equal to observed catch $C_{y,g,m}$ in each year by the bisection method,

$\hat{C}_{y,\mathrm{g},m} = \sum_h \sum_a w_{h,a} \left(\widehat{N}_{y,h,a,m} * \left(F_{y,h,a,m,\mathrm{g}} / \left(F_{y,h,a,m,\mathrm{g}} + M_{h,a}\right)\right) * \left(1 - e^{-(F_{y,h,a,m,\mathrm{g}} + M_{h,a})}\right)\right)$ and where *F* was

$F_{y,h,a,m,\mathrm{g}} = f_{y,\mathrm{g},m} * S_{h,a,m,\mathrm{g}}$.

Input or observed catch values $C_{y,g,m}$ were the same across replicates and apportionment types for the conditioning period.

Sex and age-specific selectivity *S* for each fleet or survey *g*, was input to the OM. Input selectivities were fixed at values estimated by the sablefish spatially-explicit research estimation model (Fenske et al. *in prep*). Fixed gear and survey selectivity was a two-parameter asymptotic function, trawl selectivity was two-parameter dome shaped gamma function (Punt et al. 1996). Selectivity for each fleet or survey was the same across simulation replicates and apportionment types.

Fixed gear fishery selectivity was input with two time blocks *t*, representing pre-IFQ years 1977-1994 and post-IFQ years 1995-2018. For the pre-IFQ years, selectivity was the same for all areas. For the post-IFQ fishery, selectivity was fixed for BS, AI, and WG areas combined, CG, and EY-WY combined.

$$S^{fixed\,fishery}_{t<1995,h,a,\mathrm{g}} = 1/\left(1 + e^{-\delta_{t<1995,h,\mathrm{g}}(a-a_{50,t<1995,h,\mathrm{g}})}\right),$$

$$S^{fixed\,fishery}_{t\geq 1995,h,a,m,\mathrm{g}} = 1/\left(1 + e^{-\delta_{t\geq 1995,h,\mathrm{g}}(a-a_{50,t\geq 1995,h,m,\mathrm{g}})}\right).$$

Dome shaped trawl fishery selectivity was the same across areas,

$$S^{trawl\,fishery}_{h.a.\mathrm{g}} = \left(\frac{a}{a_{max}}\right)^{a_{max}/p} e^{(a_{max}-a)/p}, \text{ where } p = 0.5\left[\sqrt{{a_{max}}^2 + 4{\delta_{h,\mathrm{g}}}^2} - a_{max}\right].$$

Longline survey selectivity was the same across areas,

$$S^{survey}_{h,a,\mathrm{g}} = 1/\left(1 + e^{-\delta_{h,\mathrm{g}}(a-a_{50,h,\mathrm{g}})}\right).$$

Catchability parameters *q* were fixed at values estimated by the sablefish spatial research model (Fenske et al. *in prep*). For the pre- and post-IFQ periods of the fixed gear fishery, catchability was fixed in the same area groupings as fixed gear selectivity. The longline survey catchability was the same across spatial management areas.

The OM population abundance (relative population number *RPN*, for longline survey) and biomass (relative population biomass *RPW*, for the fixed gear fishery) were sampled assuming random lognormal errors to obtain the relative abundance and biomass indices. For both indices, error σ, was assumed to be 0.3 for BS and AI area, and 0.15 for all other areas. The longline survey *RPN* index is a function of abundance, catchability *q* for each area for fleet or survey *g*, and selectivity *S*, and summed across sex, age, and areas for the EM.

$$RPN_y = \sum\nolimits_{h,a,m}\left[N_{h,y,a,m}q_{m,\mathrm{g}}S_{h,a,m,\mathrm{g}} * e^{(\mathrm{N}_{(\mu=0,\sigma_m)}-{\sigma_m}^2)/2)}\right].$$

The longline survey alternates years in the Bering Sea and Aleutian islands. In a year without a survey the unsurveyed area is filled in using the ratio of current year survey abundance for the Gulf of Alaska (GOA) areas (summed *RPNs* for WG, CG, WY, EY) to the previous year's GOA *RPN* abundance, and multiplied by the last survey relative population number for the unsurveyed area:

$$RPN_{y,m=BS\ or\ AI} = (RPN_{y,m=GOA}/RPN_{y-1,m=GOA})RPN_{y-1,m=BS\ or\ AI}$$

The *RPW* equation for the fishery CPUE index is the same as for *RPN*, but is derived from biomass *B*, has selectivity in the two time blocks specified previously and with a one-year lag (*y*-1) in availability to the EM.

Age compositions for each year and area for the longline survey and fixed gear fishery were sampled from the OM abundance or catch in biomass (respectively) with multinomial error assuming an effective sample size of 200. Composition data for each year was summed over areas and sexes then proportions at age calculated. For the fishery age comps, the aggregated age compositions were weighted by catch in numbers in each area.

Projection period (2019-2038)

In the forward projection period, the OM and EM were run as an iterative loop. The conditioning period for the OM set up the population and populated the necessary EM data input file, the EM was run and the year+1 projected ABC was extracted and apportioned to management areas using the apportionment type being tested. For the forward projection period, the catch in each area was assumed to equal ABC apportioned to each area every year and the fishing mortality required to harvest that catch was calculated in the same way as the conditioning period, and subsequently used by the OM to simulate abundance in the next year.

Total recruitment R_{proj} for each year y and replicate and apportionment type in the forward projection period was the same across apportionment types. A recruitment value was drawn from a normal distribution (process error) with a mean of 16.5 million recruits ($\overline{Rec}$), standard deviation $\sigma_r = 0.8$ as $dev_y \sim Normal(0, \sigma_r^2)$ and no autocorrelation, including the appropriate log-normal correction,

$$R_{proj,y} = \overline{Rec} * e^{\left(dev_y - (\sigma^2/2)\right)}.$$

Total recruitment was then split into OM areas to seed abundance by area for the first age of the OM based on random draws from a multinomial distribution based on mean proportions $Þ_m$ of age-2 fish from the longline survey (1981-2017), an effective sample size of 100, restandardized to proportions and split equally between sexes.

$$N_{y,h,a=1,m} = 1/2 * R_{proj,y} * Þ_m.$$

Abundance N, biomass B, abundance indices, and age compositions for subsequent years and ages were calculated the same as for the conditioning period. In addition, we did not correct for whale depredation in the ABC or survey index and the NPFMC Tier 3 harvest control rules were used for determining ABC in the EM.

Apportionment types

Apportioned *ABC*, ψ, was divided in management area-specific to each management area, *m* for each year *y*. In the analyses presented in this document, we examine 10 alternative apportionment types.

Equal: Each of the six management areas receives 1/6 of the ABC_y,

$$\psi_{y,m} = 1/6\, ABC_y$$

Fixed: The apportionment proportions from the 2013 assessment that have been applied as fixed proportions for 2014-present (i.e. the status quo).

$\psi_{y,m} = ABC_y * \rho_m$, where $\rho_m$for this apportionment type was a vector equal to 0.10, 0.13, 0.11, 0.34, 0.11, 0.21 for areas Bering Sea, Aleutian Islands, Western GOA, Central GOA, West Yakutat, and East Yakutat/SE Outside.

Equilibrium: Proportions in each area are based on mean proportions, ρ_m, apportioned to each area from years 2005-2013.

$\psi_{y,m} = ABC_y * \rho_m$, where $\rho_m$for this apportionment type was a vector equal to 0.14, 14, 0.11, 0.31, 0.11, 0.19 for areas Bering Sea, Aleutian Islands, Western GOA, Central GOA, West Yakutat, and East Yakutat/SE Outside.

NPFMC: A 5-yr exponentially weighted moving average of fishery and survey abundance indices ($I_{fish,y,m}$ and $I_{surv,y,m}$, respectively) for each year y and area *m*. The survey index has double the weight (w_{surv}=2) of the fishery index (w_{fish}=1). This was the method accepted by the NPFMC for apportioning sablefish ABC for 2000-2013.

$$\psi_{y,m} = ABC_y * 1/(w_{surv} + w_{fish}) * \left[\left(w_{surv} * \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{surv,y=y-k+1,m}} \Big/ {\sum_m I_{surv,y=y-k+1,m}} \right)\right) + \left(w_{fish} \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{fish,y=y-k,m}} \Big/ {\sum_m I_{fish,y=y-k,m}} \right)\right)\right],$$

where the exponential weighting factor ($\overrightarrow{\rho_k}$) for this apportionment type was a vector equal to 0.5, 0.25, 0.125, 0.0625, 0.0625 for years *y*, *y*-1, *y*-2, *y*-3, *y*-4 for the survey index and years *y*-1, *y*-2, *y*-3, *y*-4, *y*-5 for the fishery CPUE index.

Exp_survey_wt: Similar to 'NPFMC' apportionment type but using survey index only. $\vec{\rho}_k$ for this apportionment type was a vector equal to 0.5, 0.25, 0.125, 0.0625, 0.0625 for years *y*, *y*-1, *y*-2, *y*-3, *y*-4.

$$\psi_{y,m} = ABC_y * \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{surv,y=y-k+1,m}} \Big/ {\sum_m I_{surv,y=y-k+1,m}} \right)$$

For this apportionment method, the BS and AI survey each contain five years of survey data and not approximated survey data for the alternating years where there's not a survey in those areas, so the year references above are adjusted accordingly.

Blended: Half of ABC is apportioned using Equilibrium type, half apportioned using NPFMC,

$$\psi_{y,m} = \left({}^{1}\!/_{2}\, ABC_y * \rho_m\right) + {}^{1}\!/_{2}\ ABC_y * 1/(w_{surv} + w_{fish}) * \left[\left(w_{surv} * \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{surv,y=y-k+1,m}} \Big/ {\sum_m I_{surv,y=y-k+1,m}} \right)\right) + \left(w_{fish} \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{fish,y=y-k,m}} \Big/ {\sum_m I_{fish,y=y-k,m}} \right)\right)\right],$$

where $\rho_m$for this apportionment type was a vector equal to 0.14, 14, 0.11, 0.31, 0.11, 0.19 for areas Bering Sea, Aleutian Islands, Western GOA, Central GOA, West Yakutat, and East Yakutat/SE Outside and ρ_k for this apportionment type was a vector equal to 0.5, 0.25, 0.125, 0.0625, 0.0625 for years *y*, *y*-1, *y*-2, *y*-3, *y*-4.

Non-Exp_NPFMC: A 5-yr moving average of fishery and survey indices, all years equally weighted; BS and AI survey each contain five years survey data.

$$\psi_{y,m} = ABC_y * 1/(w_{surv} + w_{fish}) * \left[\left(w_{surv} * \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{surv,y=y-k+1,m}} \Big/ {\sum_m I_{surv,y=y-k+1,m}} \right)\right) + \left(w_{fish} * \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{fish,y=y-k,m}} \Big/ {\sum_m I_{fish,y=y-k,m}} \right)\right)\right],$$

where ρ_k for this apportionment type was a vector equal to 0.2, 0.2, 0.2, 0.2, 0.2 for years *y*, *y*-1, *y*-2, *y*-3, *y*-4.

For this apportionment method, the BS and AI survey each contain five years of survey data and not approximated survey data for the alternating years where there's not a survey in those areas, so the year references above are adjusted accordingly.

Age_based: Based on the proportional abundance of fish at an age of 50% ($a_{50\%}$) maturity in each area - i.e. if the $a_{50\%}$ is 6 years old, areas with greater proportion of fish age 6 or greater will be apportioned a greater proportion of ABC. For the base simulation $a_{50\%} = 6$.

$$\psi_{y,m} = \left(\sum_{h,a=a_{50\%}}^{h,a=30+} N_{h,a,m} \,/ \sum_{h,a=1}^{h,a=30+} N_{h,a,m}\right) / \sum_{m} \left(\sum_{h,a=a_{50\%}}^{h,a=30+} N_{h,a,m} \,/ \sum_{h,a=1}^{h,a=30+} N_{h,a,m}\right)$$

Term_LLsurv: Terminal year of longline survey (no exponential weighting).

$$\psi_{y,m} = ABC_y * {}^{I_{surv,y,m}}\!\big/_{\sum_m I_{surv,y,m}}$$

Scenarios examined – sensitivity analyses, comparisons made (retrospective, OM set ups)

The methods described above represent the ‘base’ simulation scenario; we also examined multiple alternative scenarios for the OM and EM to better understand the effect of key decisions made in selecting a base scenario (Table 2). The following sensitivity scenarios were conducted for all ten apportionment types:

- A) Survey age composition available for EM with one year lag
- B) ABC ‘carryover’ for years when the EM failed to converge
- C) No/extremely low observation error for OM abundance indices and age compositions (i.e. perfect information provided to the EM)
- D) OM conditioning period recruitment for 2018 was 218.5 million fish

For scenario A, we compared the effect of a one-year lag in availability of the survey age composition data. This scenario best matches the stock assessment used for management. Scenario B carried over ABC from the previous year (y-1) when the EM in year y failed to converge, which we defined as a EM maximum gradient component greater than 0.01 (absolute value). Any year with ABC carried over was ‘flagged’ in an output file to examine frequency of carryover. Scenario C had observation error 0.001 for abundance indices (instead of 0.3 for BS and AI and 0.15 for WG, CG, WY, and EY for base simulation), and had age composition effective sample size of 2000 instead of 200 for random multinomial errors. Scenario D used the 2018 recruitment value estimated by the stock assessment model used for management (218.5 million) instead of the recent mean recruitment.

We also examined three movement scenarios (base movement, no movement, ‘well mixed’ movement) with either a 6-area OM or a 1-area OM, and with/without OM observation error (like scenario C, above). No movement means all fish stay in the area where they recruit (diagonal of the transition matrix is 1, off diagonal is 0). ‘Well mixed’ movement had a transition matrix of 1/6 for each element, so from a given area, there were equal probabilities of staying or moving any other area. This full set of 12 scenarios (3 movement types * 2 OM spatial configurations * 2 observation error types) was conducted for a sole apportionment type (‘NPFC’ apportionment), to save on computing time. Additional simulation scenarios may be examined as future work (Table 3), but will not likely be completed for fall 2020.

Following the apportionment simulation methods review by the SSC, we plan to complete the analyses and present the results to the NPFMC Groundfish Plan Team, and other Council bodies as deemed necessary, in fall 2020. It is intended that these analyses may inform the NFPMC as they provide guidance on sablefish apportionment of ABC for management.

Lit Cited

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Fenske K.H., D.H. Hanselman, C.J. Cunningham. *In prep*. Incorporating movement in a spatial stock assessment to examine regional biomass and references points for North Pacific sablefish (*Anoplopoma finbria).*

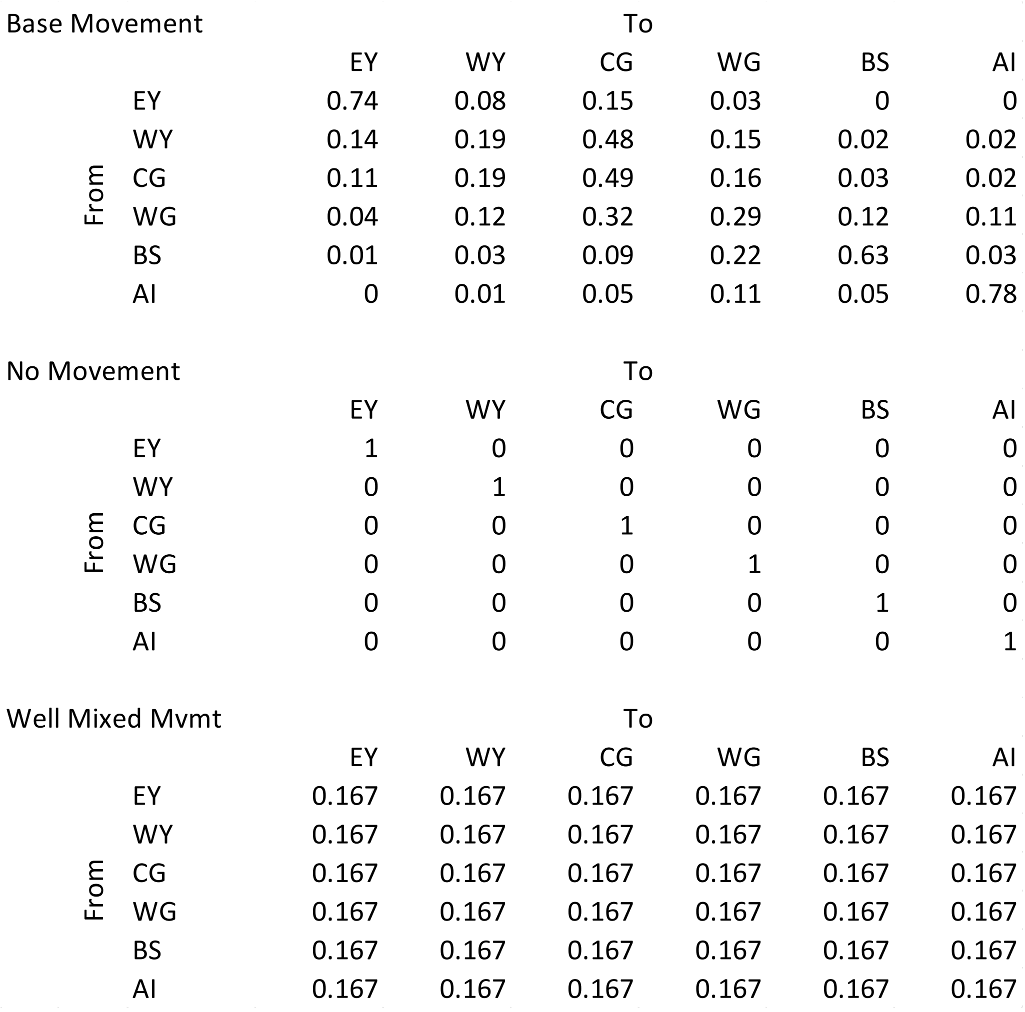
Hanselman, D.H., C.R. Rodgveller, K.H. Fenske, S.K. Shotwell, K.B. Echave, P.W. Malecha, and C.R. Lunsford,. 2019. Assessment of the sablefish stock in Alaska, in: Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306 Anchorage, AK. 99501.

Punt, A.E., A. Pulfrich, D.S. Butterworth, and A.J. Penney. 1996. The effect of hook size on the size-specific selectivity of hottentot Pachymetopon blochii (Val.) and on yield per recruit. S. Afr. J. Mar. Sci. 17(1): 155-172.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. https://www.R-project.org.

Tables

Table 1. Movement rates used in the base operating model and in two sensitivity analyses. Movement rates were the same across ages, but the operating model structure has the capacity for age-based movement rates.



Base Movement		To					
		EY	WY	CG	WG	BS	AI
From	EY	0.74	0.08	0.15	0.03	0	0
	WY	0.14	0.19	0.48	0.15	0.02	0.02
	CG	0.11	0.19	0.49	0.16	0.03	0.02
	WG	0.04	0.12	0.32	0.29	0.12	0.11
	BS	0.01	0.03	0.09	0.22	0.63	0.03
	AI	0	0.01	0.05	0.11	0.05	0.78

No Movement		To					
		EY	WY	CG	WG	BS	AI
From	EY	1	0	0	0	0	0
	WY	0	1	0	0	0	0
	CG	0	0	1	0	0	0
	WG	0	0	0	1	0	0
	BS	0	0	0	0	1	0
	AI	0	0	0	0	0	1

Well Mixed Mvmt		To					
		EY	WY	CG	WG	BS	AI
From	EY	0.167	0.167	0.167	0.167	0.167	0.167
	WY	0.167	0.167	0.167	0.167	0.167	0.167
	CG	0.167	0.167	0.167	0.167	0.167	0.167
	WG	0.167	0.167	0.167	0.167	0.167	0.167
	BS	0.167	0.167	0.167	0.167	0.167	0.167
	AI	0.167	0.167	0.167	0.167	0.167	0.167

Table 2. List of simulation scenarios that have been conducted or are intended to be completed.

Apportionment Simulation Scenarios

For Fall 2020, base model simulation and comparisons

Model Name	OM	EM	OM-EM Match or mismatch?	Movement	ABC carryover	Stock-Rec relationship	2018 rec. input (millions)	Obs. Error	Obs. Error seeds	Age comp lag
Base Model (1)	spatial	single	mismatch	base	no	no	16.5	base	by area, by type	no lag
2	spatial	single	mismatch	base	no	no	16.5	base	by area, by type	1-yr lag
3	spatial	single	mismatch	base	yes	no	16.5	base	by area, by type	no lag
4	spatial	single	mismatch	base	no	no	16.5	very low error	by area, by type	no lag
5	spatial	single	mismatch	base	no	no	218.5	base	by area, by type	no lag

Other explorations and comparisons

Effect of alternative movement: models 6-15 done with 'NPFMC' apportionment type only

6	single	single	match	base	no	no	16.5	very low error	by area, by type	no lag
7	single	single	match	base	no	no	16.5	base	by area, by type	no lag
8	single	single	match	well mixed	no	no	16.5	very low error	by area, by type	no lag
9	single	single	match	well mixed	no	no	16.5	base	by area, by type	no lag
10	single	single	match	no	no	no	16.5	very low error	by area, by type	no lag
11	single	single	match	no	no	no	16.5	base	by area, by type	no lag
12	spatial	single	mismatch	well mixed	no	no	16.5	very low error	by area, by type	no lag
13	spatial	single	mismatch	well mixed	no	no	16.5	base	by area, by type	no lag
14	spatial	single	mismatch	no	no	no	16.5	very low error	by area, by type	no lag
15	spatial	single	mismatch	no	no	no	16.5	base	by area, by type	no lag
4	spatial	single	mismatch	base	no	no	16.5	very low error	by area, by type	no lag
Base Model (1)	spatial	single	mismatch	base	no	no	16.5	base	by area, by type	no lag

Effect of seed choice for observation error (indices, age compositions)

16	spatial	single	mismatch	base	no	no	16.5	base	same across areas, types	no lag
Base Model (1)	spatial	single	mismatch	base	no	no	16.5	base	by area, by type	no lag

Table 3. Simulation scenarios that may be developed in the future, but not delivered for fall 2020.

Model Name	OM	EM	OM-EM Match or mismatch?	Movement	ABC carryover	Stock-Rec relationship	2018 rec. input (millions)	Obs. Error	Obs. Error seeds	Age comp lag
Effect of a Stock-Recruitment relationship instead of mean recruitment and 'base' partitioning of recruitment to areas										
17	spatial	single	mismatch	base	no	yes, common S-R across OM areas	16.5	base	by area, by type	no lag
18	spatial	single	mismatch	base	no	yes, common S-R across OM areas	16.5	base	by area, by type	no lag
19	spatial	single	mismatch	base	no	yes, separate S-R for each area	16.5	base	by area, by type	no lag
Base Model (1)	spatial	single	mismatch	base	no	no	16.5	base	by area, by type	no lag
Effect of lower or higher mean recruitment (ie regime shift)										
20	spatial	single	mismatch	base	no	no, lower OM recruitment mean	16.5	base	by area, by type	no lag
21	spatial	single	mismatch	base	no	no, higher OM recruitment mean	16.5	base	by area, by type	no lag
Base Model (1)	spatial	single	mismatch	base	no	no	16.5	base	by area, by type	no lag

Appendix

Indexing variables

y	year
h	sex
a	age
A	plus group age
m	area (spatial management area)
g	fleet/gear
i	replicate (200 replicates per apportionment type)
t	time blocks in selectivity

Variables

N_{init}	Initial abundance, in 1977 (does this need a hat?)
Þ_m	Proportion of abundance in each area, based on the mean age-2 survey abundance estimates, used for dividing N_{init} and R_{cond} into 6 OM areas
ρ	proportions of abundance by sex used in dividing N_{init} into sexes at start of OM conditioning
$\widehat{N}$	abundance before movement occurs
N	abundance after movement occurs
B	biomass
w	weight
R_{cond}	recruitment for the OM conditioning period
R_{proj}	recruitment for the OM forward projecting period
F	Total fishing mortality
f	fleet/gear specific fishing mortality
M	natural mortality
C	Observed catch, used in OM conditioning period
$\hat{C}$	predicted catch, use in the OM to solve for/estimate F
S	selectivity
a_{50}	age at 50% selectivity
$\mathrm{a}_{\mathrm{max}}$	age parameter in the dome shaped selectivity function
δ	dome shaped selectivity function shape parameter
Φ	movement/transition matrix
T	indicates 'transpose' in the abundance movement equation
RPN	relative population number; longline survey index of abundance
RPW	relative population weight; fixed gear fishery CPUE index
q	catchability

ABC	total allowable biological catch
Ψ	apportioned (to areas) ABC
I	Index of abundance used in ABC apportionment calculations
$\vec{\rho}_k$	vector of weights for weighting I over years
w_{surv}	weight of survey index I in apportionment calculations
w_{fish}	weight of fishery CPUE index I in apportionment calculations