Evaluation of Alternative Sablefish Apportionment Strategies

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Background

Sablefish (*Anoplopoma fimbria*) in Alaska are managed as one stock 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 and ABC is 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. A series of ongoing simulation analyses were initiated to examine the performance of several alternative apportionment types.

Apportionment types

In the analyses presented in this document, we examine 10 alternative apportionment types (listed below). See the ‘Feedback from public meeting’ section of this document for a summary of proposed changes to this list of apportionment types that are the subject of ongoing research.

1) ***Equal***: Each region receives 1/6 of the ABC.
2) ***Fixed***: The ABC proportions from the 2013 assessment that have been applied as fixed proportions for 2014-2018.
3) ***Equilibrium***: Proportions in each area are based on the long-term equilibrium proportions using movement estimated from tagging data, assuming among-area movement rates are constant.
4) ***NPFMC***: A 5-yr exponentially weighted moving average of fishery and survey indices; where survey is weighted 2x the fishery weight (NPFMC accepted method, used 2000-2013).
5) ***Exp_survey_wt***: Equivalent to ‘NPFMC’ option but using survey index only.
6) ***Exp_fishery_wt***: Equivalent to ‘NPFMC’ option but using fishery index only.
7) ***Non-Exp_NPFMC***: A 5-yr moving average of fishery and survey indices, all years equally weighted, but survey is weighted 2x the fishery weight.
8) ***Partial_fixed***: BS and AI receive 10% of the ABC each, apportionment to WG, CG, WY, and EY regions is based on the ‘NPFMC’ method.
9) ***Age_based***: Based on the proportions of fish at age of 50% maturity in each area - i.e. areas with greater proportion of fish at age of 50% maturity or greater will be apportioned a greater proportion of ABC. Results shown in this document are for an age at 50% = 6.
10) ***Term_LLsurv***: Terminal year of longline survey (no exponential weighting).

Analyses

In order to evaluate these different apportionment strategies, we conducted a simulation analysis. These apportionment simulation analyses contain two primary components, a 6-area operating model (OM) and a 1-area estimation model (EM) that is similar in structure to the current operational age-structured stock assessment model. The six OM areas correspond to the six sablefish management areas. 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 1977-2018 that is the same across apportionment simulations, and a stochastic forward projection period which runs for years 2019-2041. We conditioned the OM to closely match our best estimates of sablefish population dynamics. Recruitment in the forward projection period is common across apportionment types, drawn from a log-normal distribution with a specified mean and standard deviation, and no autocorrelation. The EM is similar to the operational assessment model currently used for sablefish management, but begins in 1977 instead of 1960, does not include length compositions, and does not include a trawl survey index of abundance. After the conditioning period, data are generated with the OM; fishery and survey indices and age compositions are simulated from the OM population with observation error, and these simulated data are combined into a single area dataset that is passed as input to the single-area EM.

In the forward projection period, the OM-EM is iterative, looping through years. For each of the 10 apportionment methods explored, 175 replicate simulations covering years 2019-2041 are run with different process (recruitment) and observation error deviates in reach realization.

The following are assumptions in these simulations:

1) We assume ABC=TAC and 100% of apportioned ABC is caught in each region.

2) We do not correct for whale depredation in the ABC or survey index.

3) Recruitment occurs at age 2 and recruitment is split equally between males and females. Recruitment draws for the incoming recruitment classes during the forward projections are capped at 50 million. The large 2014 year class in the conditioning period has also been reduced from 150 million fish to 50 million.

4) The NPFMC Tier 3 harvest control rules are still in place and used for determining ABC in the EM; we are only simulating different methods for apportioning ABC to management areas.

For more information on the methods and simulation analyses, please refer to Appendix 3D of the 2019 Alaska Sablefish stock assessment (available at: https://archive.afsc.noaa.gov/refm/docs/2019/sablefish.pdf). For an OM equation list, please contact the first author of this document.

Results and conclusions

The tradeoffs to ABC apportionment types are presented in three categories; Sustainability, Stability, and Other.

Sustainability

We examined the performance of apportionment types by comparing ratio of spawning stock biomass (SSB) in the terminal simulation year to the biomass of sablefish at the B40% reference point, $SSB/B_{40\%}$. For this metric, a higher $SSB/B_{40\%}$ ratio means that stock status is better than a lower value. All 10 apportionment types performed similarly over the 23 year forward projection period (Figure 1; Summary

Table A, row 1), with similar range and median outcomes for the simulation replicates. These results suggest that the NPFMC's harvest control rule, which decreases fishing exploitation rates when SSB/B40% falls below one is performing as intended. Because the apportionment types perform so similarly, it is unlikely that one apportionment type is substantially better than others from the perspective of ensuring sustainability of the Alaska-wide stock.

The simulation framework for these analyses sets up a 'known' population of sablefish in the OM which gives the opportunity to compare the OM 'true' underlying population dynamics (e.g. abundance, biomass) and distribution to the proportion of ABC apportioned to each management area for the 10 apportionment types. We calculated the mean absolute percent similarity between the apportionment proportions to areas and the SSB proportions by area for a simple performance metric quantifying how well ABC matches exploitable spawning biomass (Table 3). The apportionment methods that are static (fixed proportions) over time result in ABC apportionment proportions by area that generally do not track the underlying population spawning biomass as well as apportionment types tied to a fishery or survey index. Apportionment methods that adjust apportionment to management areas using the survey index of abundance tend to provide a closer match between ABC apportioned to areas and the proportion of spawning biomass in each area. If there are benefits to maintaining spawning biomass in all spatial areas (e.g., if there were spatial differences in fecundity about which we are unaware, or if spawning occurs in specific areas), an apportionment type with more similarity to the OM population distribution would be preferable.

Stability

Stability refers to the absolute annual change in ABC, either total ABC or ABC apportioned to management areas. A concern over lack of stability (i.e. instability) in ABC apportioned to areas was a large driver of the decision to freeze ABC apportionment to areas starting with the 2014 fishing season. While total ABC generally changes from year to year (total ABC absolute mean percent change is ~8% for 2005-2019), apportionment types that are not fixed proportions among areas may result in some areas exhibiting very large changes in ABC from year to year. Figure 2 shows the absolute percent change in ABC for each management area and apportion type.

As an alternative stability metric, we calculated the proportion of years and simulation replicates where ABC (for total ABC and ABC apportioned to areas) changed by less than 20% (Summary Table 1, rows 4-10; Table 4 for conditionally formatted view). For this metric, the outcomes ranged from 85.8% (for Terminal LL survey apportionment type) to 91.8% (for the Equilibrium type) of year, area, and replicates having less than 20% change in ABC. This is not a very large range and indicated a high probability of achieving <20% year-to-year change under all apportionment types. However, this stability metric presented by area (Table 4), shows that the most stable apportionment type differs by area and some apportionment types have greater disparity in the evenness of ABC stability. The range (maximum – minimum percent of replicates and years) of stability values across areas for each apportionment type shows the disparity in stability between management areas. The Age-based and Terminal LL survey apportionment types show the greatest spatial disparity in stability, while the Equal, Fixed, Equilibrium, and Non-exponential NPFMC methods exhibit more stability between management areas.

Other

Total ABC has a wide range of potential outcomes across the simulation replicates for all apportionment types (Figure 3). The central tendencies (mean, median) exhibit some differences between the apportionment types for individual years, but across many years, the apportionment types all preform similarly (Table 1, row 11). The mean ABC proportions apportioned to each management areas differs by apportionment type (Table 1, rows 12-17). Over all forward projection years, the Equal and Age-based apportionment types have the least amount of different in mean proportion ABC apportioned to areas, whereas the Exponential Survey Wt and Terminal LL Survey apportionment methods have the most disparity (least equality in ABC proportions to areas).

The age distribution and mean age of fish in each management area differs, due to a combination of recruitment, movement, selectivity, and other factors. These differences in age (and thus, size) can lead to differences in gross value of catch among areas (Table 1, rows 18-23, represented as proportions by area). Using market value data (2012-2018) we generated a range of potential scenarios for fish price at age, and analyzed four price/kg scenarios, ‘high’, ‘medium’, ‘low’, and ‘recent’, accounting for recovery rates. The ‘high’, ‘medium’, and ‘low’ scenarios use the maximum, mean, and minimum price/kg for 2012-2018 for each market category, respectively. The ‘recent’ value is the 2018 market price/kg for each market category. For brevity, the ‘medium’ scenario results are presented. There was a much greater difference in the proportion of mean value of catch between management areas than across apportionment types (Table 1, rows 18-23), indicating a general lack of sensitivity in mean values to the apportionment type simulated. However, there were differences in the proportion of mean value of catch between apportionment types that may be meaningful to stakeholders and the Council.

In summary, there are tradeoffs associated with each apportionment type. The apportionment types that perform best at matching apportioned ABC to the underlying population structure (i.e. SSB) generally show less overall stability. The wide range of potential outcomes across individual forward simulation replicates appear to swamp the relatively small influence of apportionment type.

Given the result that all apportionment types perform similarly *on average* under the SSB/B40 sustainability metric, we contend that the decision about how to apportion ABC to management areas will likely require input from fishery managers. We caution against an apportionment type that would allow ABC proportions by area to stray too far from the underlying distribution of SSB, as estimated through a well-designed fishery independent survey. We further caution that this simulation analysis makes a number of assumptions by necessity; if any of these assumptions or uncertainties are incorrect, outcomes may be different. Some of these uncertainties include that our knowledge about fish movement is perfect, and it isn’t changing over time, recruitment will follow historical patterns and is not cyclical or exhibiting a directional trend over time, and spawning is distributed evenly throughout management areas. Because of these uncertainties, an apportionment strategy that would create localized depletion or reduced productivity because of uncertainties in reproduction and growth could have unintended consequences and would be undesirable from the perspectives of resources sustainability and fishery value.

Feedback from public meeting

On February 20, 2020, AFSC hosted an all-day meeting at ABL (in person and via webinar) to describe the results presented here and receive input on the analytical process. The meeting was attended by stakeholders, and staff from the AFSC, AKRO, and NPFMC, and was intended to get feedback on the analyses.

The meeting was successful in gathering feedback identifying four primary, and potentially conflicting, areas of concern about apportionment that will be important to consider:

1) Inter-annual stability in ABC is important and desired,
2) An apportionment method that doesn't lead to apportionment proportions-to-areas that are very different from observed sablefish spatial distribution over time was important,
3) Concerns remain about the potential to harvest too many immature fish, and
4) There are concerns about the 'transition' year as we move from the current 'fixed' apportionment method to a new method and suggestions that if the change in apportionment to regions is large, it may require a multi-year plan to make the change gradually.

There were also recommendations about the apportionment types to be carried forward for final analyses, to be completed by fall 2020. Based on this feedback we plan to discontinue consideration of two apportionment types (‘Partially Fixed’ and ‘Exp_fishery_wt’). The ‘Partially Fixed’ method was thought to be too inflexible and permanent, too likely to be biased against the BS and AI regions given uncertainty in climate, and required too much potential negotiation to choose appropriate values for a fixed apportionment proportion to the BS and AI regions. The ‘Exp_fishery_wt’ type was not favored for future consideration due to uncertainty in observer coverage, particularly in the BS, and the reliance on only fishery data. It was further discussed that the ‘Equilibrium’ method had scientific merit, but that the actual observed distribution over time was more transparent to stakeholders. Thus, the ‘Equilibrium’ apportionment type will be changed to use the mean proportions of apportioned ABC to areas from years 2000-2013 as the basis for apportionment. The ‘Non-Exp_NPFMC’ method will be slightly modified to include an equal number of years input for the BS and AI regions survey data (inequality comes from the alternating year survey design for those regions). Finally, a new apportionment type will be added. This new ‘Blended’ method will apportion half of ABC using the ‘NPFMC’ apportionment type and half of ABC using the ‘Equilibrium’ type (new definition). We are working to incorporate these, and other, feedback from the public meeting into the final analyses.

The above changes would result in these nine apportionment types being brought forward for fall 2020:

1) Equal: Each region receives 1/6 of the ABC.
2) Fixed: The apportionment proportions from the 2013 assessment that have been applied as fixed proportions for 2014-2018.
3) Equilibrium: Proportions in each area are based on mean proportions apportioned to each area from years 2005-2013.
4) NPFMC: A 5-yr exponentially weighted moving average of fishery and survey indices; survey weight is 2x fishery weight (NPFMC accepted method, used 2000-2013).
5) Exp_survey_wt: Similar to ‘NPFMC’ option but using survey index only; BS and AI survey contains five years survey data.
6) Blended: Half of ABC is apportioned using Equilibrium type, half apportioned using NPFMC.
7) Non-Exp_NPFMC: A 5-yr moving average of fishery and survey indices, all years equally weighted; BS and AI survey contains five years survey data.
8) Age_based: Based on the proportions of fish at age of 50% maturity in each area - i.e. areas with greater proportion of fish at age of 50% maturity or greater will be apportioned a greater proportion of ABC. Results shown in this document are for an age at 50% = 6.
9) Term_LLsurv: Terminal year of longline survey (no exponential weighting).

Figures

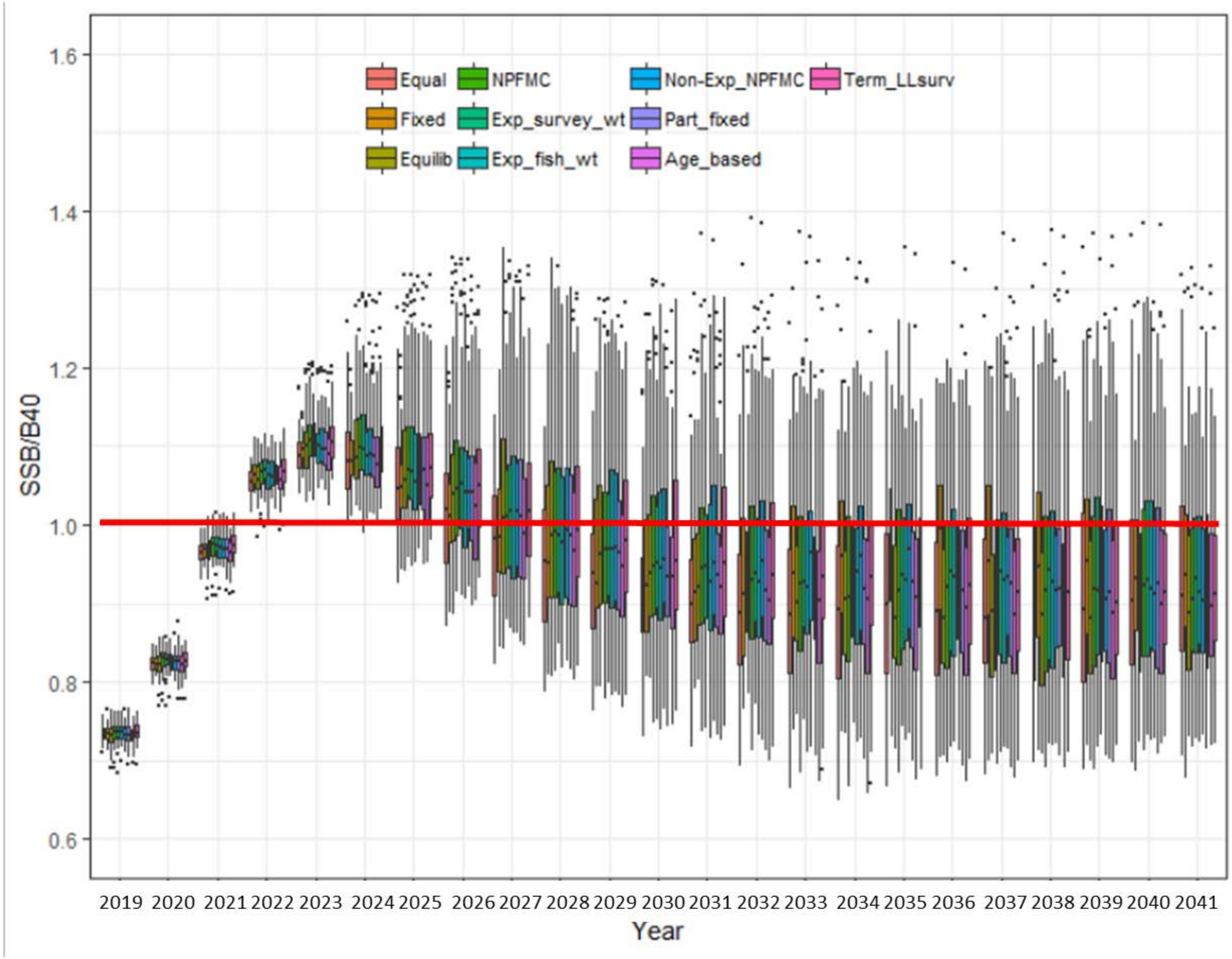

Figure 1. Spawning biomass/B40 for each year of forward projecting simulations and each apportionment method.

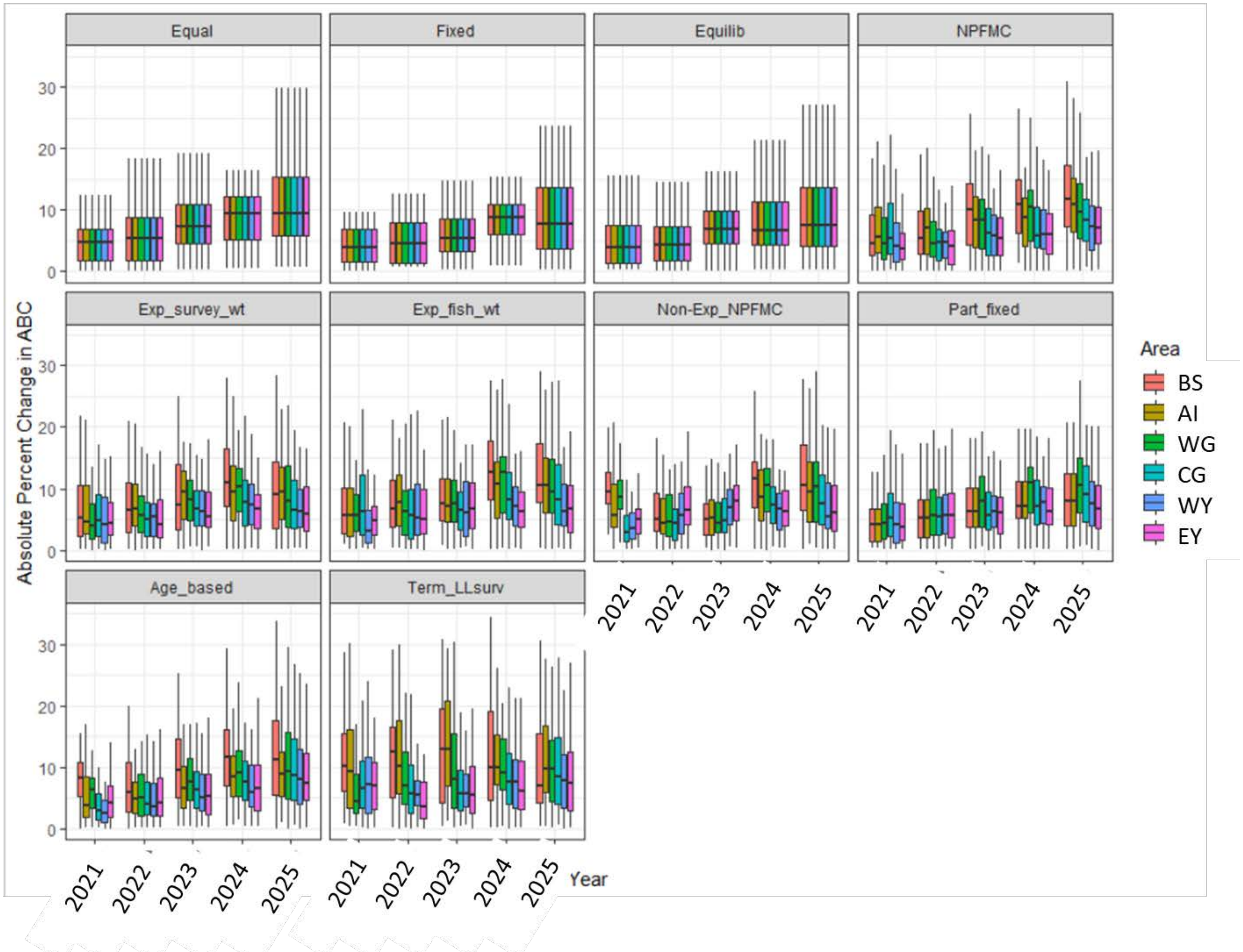

Figure 2. Absolute percent change in ABC by management area and apportionment type for years 2021-2025, across simulation replicates.

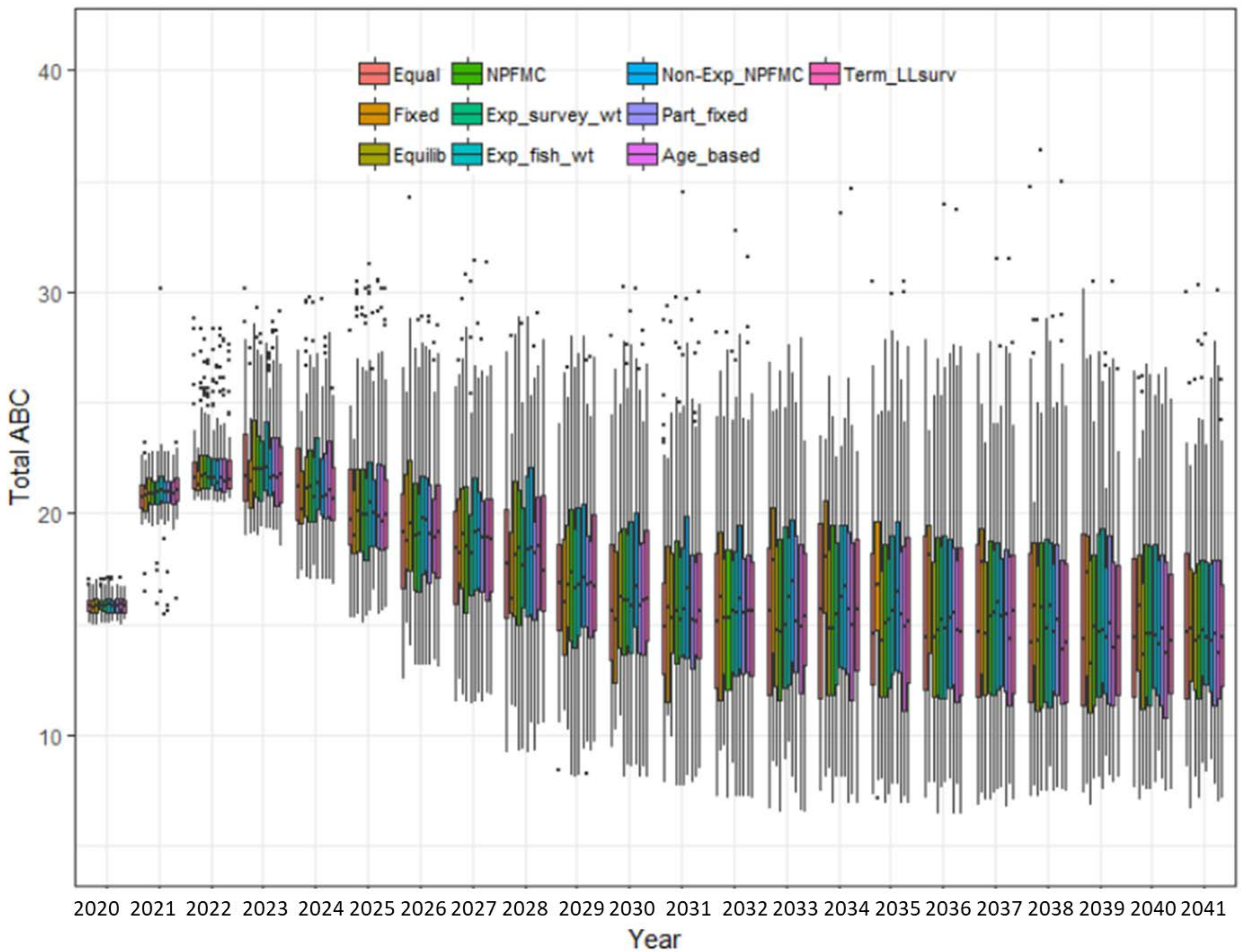

Figure 3. Total ABC (kt) by year for each apportionment type.

Tables

Summary table 1. The following table is a comparison of performance metrics to help understand the pros and cons of each apportionment type.

Row 1: ‘Mean SSB/B40’, is the mean across replicates and areas of the percent of terminal year Spawning Stock Biomass (SSB) to B40 estimated by the terminal year estimation model for each apportionment type. Values closer to 100 are better.

Rows 2-3: ‘Apportionment match to SSB’ (and also for total biomass) gives the mean absolute percent difference between SSB proportions by area (using OM data) and the proportions of ABC each area would receive under the respective apportionment methods. Higher values indicates the apportionment method more closely matches the true population biomass in each area.

Row 4: The values in the ‘ABC Stability’ performance metric are the percentage of replicates, years, and areas where the ABC changes by less than 20% from one year to the next. Higher values indicate more stability.

Rows 5-10: The values in the ‘ABC Stability’ performance metric are the percentage of replicates and years where the ABC changes by less than 20% from one year to the next for that area. Higher values indicate more stability.

Row 11: "Mean ABC’ is the mean ABC (in kilotons) across replicates and areas (for ‘all areas’).

Rows 12-17: The percent ABC apportioned to each area under each apportionment type. Higher percentage means more of the total ABC is apportioned to that area.

Rows 18-23: The ‘Mean value of catch’, as a percent across areas for each apportionment type. For a given apportionment type, a higher value indicates more value received from catches (due to price/lb and size of fish caught) to that area compared to areas with a lower percent value.

Row	Sustainability	Equal	Fixed	Equilib	NPFMC	Exp survey wt	Exp fish wt	Non-Exp NPFMC	Partially fixed	Age based	Term-LLsurv
1	Mean SSB/B_{40} (%)	94.0	96.8	95.3	96.4	96.9	96.4	97.0	95.8	94.8	96.9
2	Apportionment match to SSB (%)	41.8	69.0	71.3	83.4	89.4	69.8	83.7	77.3	52.0	89.1
3	Apportionment match to total biomass (%)	31.9	51.1	54.0	62.5	66.6	54.4	62.2	58.4	40.2	67.0
	ABC Stability										
4	Percent of years and replicates where ABC changes by less that 20% (all areas)	86.4	90.6	91.8	90.4	90.5	89.1	90.0	91.2	88.0	85.8
5	BS - % Percent ABC changes by less that 20%	82.3	86.9	87.4	83.9	84.1	83.1	87.6	88.2	78.2	75.1
6	AI - % Percent ABC changes by less that 20%	82.3	86.9	87.4	85.5	85.5	84.0	87.6	84.4	85.3	77.9
7	WG - % Percent ABC changes by less that 20%	82.3	86.9	87.4	86.3	87.2	84.9	85.8	82.0	82.2	84.2
8	CG - % Percent ABC changes by less that 20%	82.3	86.9	87.4	87.1	87.1	85.9	87.0	87.4	85.7	85.9
9	WY - % Percent ABC changes by less that 20%	82.3	86.9	87.4	87.2	87.3	89.9	87.0	83.6	88.1	86.0
10	EY - % Percent ABC changes by less that 20%	82.3	86.9	87.4	87.5	87.1	90.3	87.4	84.2	89.7	85.1

Row	Value/Other	Equal	Fixed	Equilib	NPFMC	Exp survey wt	Exp fish wt	Non-Exp NPFMC	Partially fixed	Age based	Term-LLsurv
11	Mean ABC (kt) - all areas	17.29	17.69	17.34	17.40	17.39	17.76	17.66	17.40	17.31	17.32
12	Mean ABC (%, by area) - BS	16.7	10.0	9.2	8.1	6.9	10.4	8.1	10.0	12.5	6.9
13	Mean ABC (%, by area) - AI	16.7	13.0	13.7	9.4	10.0	8.1	9.3	10.0	16.7	10.0
14	Mean ABC (%, by area) - WG	16.7	11.0	13.1	13.9	11.8	18.1	13.8	13.5	14.3	11.8
15	Mean ABC (%, by area) - CG	16.7	34.0	26.8	29.6	31.2	26.4	29.6	28.6	16.9	31.2
16	Mean ABC (%, by area) - WY	16.7	11.0	13.8	14.1	14.6	13.1	14.2	13.7	18.5	14.6
17	Mean ABC (%, by area) - EY	16.7	21.0	23.4	24.9	25.5	23.8	25.1	24.2	21.1	25.5
18	Mean value of catch (%, by area) - BS	11.0	9.0	8.8	8.5	8.1	9.2	8.5	9.0	9.8	8.1
19	Mean value of catch (%, by area) - AI	10.5	9.4	9.6	8.3	8.5	7.9	8.3	8.5	10.5	8.5
20	Mean value of catch (%, by area) - WG	12.6	10.8	11.5	11.7	11.1	13.1	11.7	11.6	11.9	11.1
21	Mean value of catch (%, by area) - CG	29.8	35.1	32.9	33.8	34.3	32.7	33.7	33.5	29.9	34.3
22	Mean value of catch (%, by area) - WY	13.9	12.1	13.0	13.1	13.2	12.8	13.1	12.9	14.5	13.2
23	Mean value of catch (%, by area) - EY	22.2	23.5	24.2	24.7	24.8	24.3	24.7	24.5	23.5	24.8

Summary Table 2

Sustainability	Best	2nd best	worst
Mean SSB/B_{40} (%)	Non-Exp NPFMC	Term_LLsurvey & Exp_survey_wt (tie)	Equal
Apportionment match to SSB (%)	Exp_survey_wt	Term_LLsurvey	Equal
Apportionment match to total biomass (%)	Term_LLsurvey	Exp_survey_wt	Equal
ABC Stability			
Percent of years and replicates where ABC changes by less that 20% (all areas)	Equilibrium	Partially_fixed	Term_LLsurvey
BS - % Percent ABC changes by less that 20%	Partially_fixed	Non-Exp NPFMC	Term_LLsurvey
AI - % Percent ABC changes by less that 20%	Non-Exp NPFMC	Equilibrium	Term_LLsurvey
WG - % Percent ABC changes by less that 20%	Equilibrium	Exp_survey_wt	Age-based
CG - % Percent ABC changes by less that 20%	Equilibrium & Partially_fixed (tie)	Exp_survey_wt	Equal
WY - % Percent ABC changes by less that 20%	Exp_fish_wt	Age-based	Equal
EY - % Percent ABC changes by less that 20%	Exp_fish_wt	Age-based	Equal

If you care about:	**Apportionment Type that is:**		
Sustainability	**Best**	**2nd best**	**worst**
Value/Other			
Mean ABC (kt) - all areas	Exp_fish_wt	Fixed	Age-based
Mean ABC (%, by area) - BS	Equal	Age-based	Exp_survey_wt & Term_LLsurvey (tie)
Mean ABC (%, by area) - AI	Equal & Age-based (tied)	Equilibrium	Exp_fish_wt
Mean ABC (%, by area) - WG	Exp_fish_wt	Equal	Fixed
Mean ABC (%, by area) - CG	Fixed	NPFMC & Non-exp_NPFMC (tie)	Equal
Mean ABC (%, by area) - WY	Age-based	Equal	Fixed
Mean ABC (%, by area) - EY	Exp_survey-wt & Term_LLsurvey (tie)	Non-Exp NPFMC	Equal
Mean value of catch (%, by area) - BS	Equal	Age-based	Exp_survey_wt & Term_LLsurvey (tie)
Mean value of catch (%, by area) - AI	Equal & Age-based (tied)	Equilibrium	Exp_fish_wt
Mean value of catch (%, by area) - WG	Exp_fish_wt	Equal	Fixed
Mean value of catch (%, by area) - CG	Fixed	Exp_survey_wt & Term_LLsurvey (tie)	Equal
Mean value of catch (%, by area) - WY	Age-based	Equal	Fixed
Mean value of catch (%, by area) - EY	Exp_surv_wt & Term_LLsurvey (tie)	NPFMC & Non-exp_NPFMC (tie)	Equal

Table 3. Mean absolute percent match between 'true' SSB proportions by area and ABC proportion apportioned by area. A high percent similarity indicates ABC is being apportioned similarly to how the OM fish are actually distributed. Red highlighting indicates a poor match between apportionment proportions and the OM population, blue indicates a better match.

Apportionment type	% Similarity
Equal	41.8
Fixed	69.0
Equilib	71.3
NPFMC	83.4
Exp_survey_wt	89.4
Exp_fish_wt	69.8
Non-Exp_NPFMC	83.7
Part-fixed	77.3
Age_based	52.0
Term_LLsurv	89.1

Table 4. Percent of years and replicates where ABC changes by less than 20%, by management area (rows) for each apportionment type (columns). Within a given row blue shades indicate a 'better' (more stable) ABC for a given management area. The bottom row values are the range (maximum - minimum percent) for each apportionment type and provides the disparity in stability across areas for each apportionment type.

	Equal	Fixed	Equilib	NPFMC	Exp surv_wt	Exp fish_wt	Non-Exp NPFMC	Part-fixed	Age-based	Term LLsurv
BS	82.3	86.9	87.4	83.9	84.1	83.1	87.6	88.2	78.2	75.1
AI	82.3	86.9	87.4	85.5	85.5	84.0	87.6	84.4	85.3	77.9
WG	82.3	86.9	87.4	86.3	87.2	84.9	85.8	82.0	82.2	84.2
CG	82.3	86.9	87.4	87.1	87.1	85.9	87.0	87.4	85.7	85.9
WY	82.3	86.9	87.4	87.2	87.3	89.9	87.0	83.6	88.1	86.0
EY	82.3	86.9	87.4	87.5	87.1	90.3	87.4	84.2	89.7	85.1
Spatial Disparity	0.0	0.0	0.0	3.6	3.2	7.2	1.8	6.2	11.5	10.9