MID-ATLANTIC FISHERY MANAGEMENT COUNCIL

Mid-Atlantic Fishery Management Council
800 North State Street, Suite 201, Dover, DE 19901
Phone: 302-674-2331 | FAX: 302-674-5399 | www.mafmc.org
Michael P. Luisi, Chairman | G. Warren Elliott, Vice Chairman
Christopher M. Moore, Ph.D., Executive Director

MEMORANDUM

Date: November 27, 2019

To: Council

From: Brandon Muffley, Staff

Subject: Risk Policy Framework Meeting #2 – Meeting Materials

The Council will review and select the preferred alternative(s) for the omnibus risk policy framework action on Monday, December 9, 2019. Materials listed below are provided for Council consideration of this agenda item.

Materials behind the tab:

1. Risk policy discussion document and staff recommendation
2. *Fine-tuning the ABC control rule for Mid-Atlantic fisheries* report by Dr. John Wiedenmann
3. *Economic Trade-offs of Additional Alternative ABC Control Rules for Summer Flounder and Implications for Scup and Butterfish* draft report by Dr. Cyrus Teng and Dr. Doug Lipton

Omnibus Acceptable Biological Catch and Risk Policy Framework Adjustment

Framework Meeting 2 Discussion Document

December 9, 2019

Annapolis, Maryland

Introduction:

In 2011, the Mid-Atlantic Fishery Management Council (Council) implemented the current risk policy and Acceptable Biological Catch (ABC) control rule to comply with the 2006 re-authorization of the Magnuson-Stevens Act (MSA)[1]. The risk policy specifies the Council's acceptable level of risk (i.e., the probability of overfishing, P*) and works in conjunction with the Scientific and Statistical Committees (SSC) application of the ABC control rule to account for scientific uncertainty to determine an ABC for a specific stock. Five years after implementation, the Council agreed to conduct a review of the current risk policy and determine if any modifications were necessary to meet the Council's goals and objectives for its managed fisheries. During the risk policy review, the Council expressed interest in evaluating not only biological factors but to also more comprehensively consider economic and social factors and the potential implications of any risk policy alternatives. The Council specified that the evaluation should assess the short and long-term trade-offs between stock biomass protection, fishery yield, and economic benefits. In addition, the Council agreed that any alternatives considered would retain the biologically based foundation of the existing risk policy of specifying a probability of overfishing (P*) that is conditional on the current stock biomass relative to B_{MSY} and would not explicitly include but consider economic factors, targets or thresholds.

In 2019, a workgroup comprised of NOAA Fisheries staff, SSC members, academia and Council staff was formed and tasked with further developing and analyzing the current risk policy and any potential alternatives. Members of the workgroup built off their existing biological[2] and economic[3] management strategy evaluation (MSE) models. These models were updated to include the summer flounder benchmark assessment data, the new MRIP recreational catch information and refined to address specific Council objectives. The workgroup met on five separate occasions to review and discuss risk policy alternatives, conduct new and additional analyses needed to evaluate the biological and economical trade-offs associated with each alternative, and provide any recommendations and considerations.

The Council held the first framework meeting in August 2019[4] and reviewed and approved nine different alternatives for further analysis and evaluation. The Council is scheduled to take final action on the omnibus risk policy framework at their December 2019 meeting. provide feedback and approve draft alternatives for further analysis and evaluation.

This discussion document contains an overview of the different risk policy alternatives being considered by the Council, a summary of the results of the biological and economic MSE analyses, and the staff recommendation to help support Council deliberations. Comprehensive

[1] For more information on the development and implementation of the risk policy and ABC control rule, please see the omnibus amendment at: http://www.mafmc.org/s/2011-Omnibus-ABC-AM-Amendment.pdf
[2] For more information on the biological MSE, see summary report and presentation in the February 2018 Council meeting materials at: http://www.mafmc.org/briefing/february-2018.
[3] For additional details on the summer flounder economic MSE, please see summary report and presentation in the December 2018 Council meeting materials at: http://www.mafmc.org/briefing/december-2018.
[4] See the August 14, 2019 omnibus acceptable biological catch and risk policy framework adjustment discussion document. Available at: http://www.mafmc.org/s/Tab09_Risk-Policy-Framework_2019-08.pdf

final reports outlining the methods, model structure, and results of the biological and economic models are included as materials in the December briefing book.

Overview of Alternatives:

There are nine different risk policy alternatives, including *status quo*, for Council consideration. Six of the alternatives (Alternatives 1 – 5 and 9) were previously provided to the Council during the initial framework review in 2017. Three new alternatives were identified and analyzed during this framework process. Alternatives 6 and 7 were developed by the workgroup and presented to the Council as part of framework meeting 1. During that review and discussion, the Council developed a new alternative (Alternative 8) that combined certain aspects of Alternatives 6 and 7. Alternative 9, removal of the typical/atypical designation, does not specify a risk policy but could be applied to any of the other eight alternatives.

Under any of the risk policy alternatives provided below, the existing language on the application of the risk policy to stocks under a rebuilding plan or for those stocks with no OFL, or OFL proxy, would remain as currently implemented (see page 3 of the August 2019 risk policy discussion document for more details).

Below is the rationale and description on how the risk policy would be applied for each alternative.

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1. **Current risk policy/*status quo* – linear ramping with a maximum P* of 0.4 when the B/B_{MSY} ratio is equal to or greater than 1.0**

This alternative would retain the existing risk policy with the acceptable probability of overfishing (P*) for a given stock conditional on current stock biomass relative to B_{MSY} and a maximum P* set at 0.4 (see Figure1). The stock replenishment threshold defined as the ratio of B/B_{MSY} = 0.10, is utilized to ensure the stock does not reach low levels from which it cannot recover. The probability of overfishing is 0 percent (i.e., no fishing) if the ratio of B/B_{MSY} is less than or equal to 0.10. The P* increases linearly as the ratio of B/B_{MSY} increases, until the inflection point of B/B_{MSY} = 1.0 is reached. A maximum P* of 0.4 or 0.35 is utilized (typical or atypical stock, respectively) for ratios equal to or greater than 1.0. The SSC determines whether a stock is typical or atypical each time an ABC is recommended.

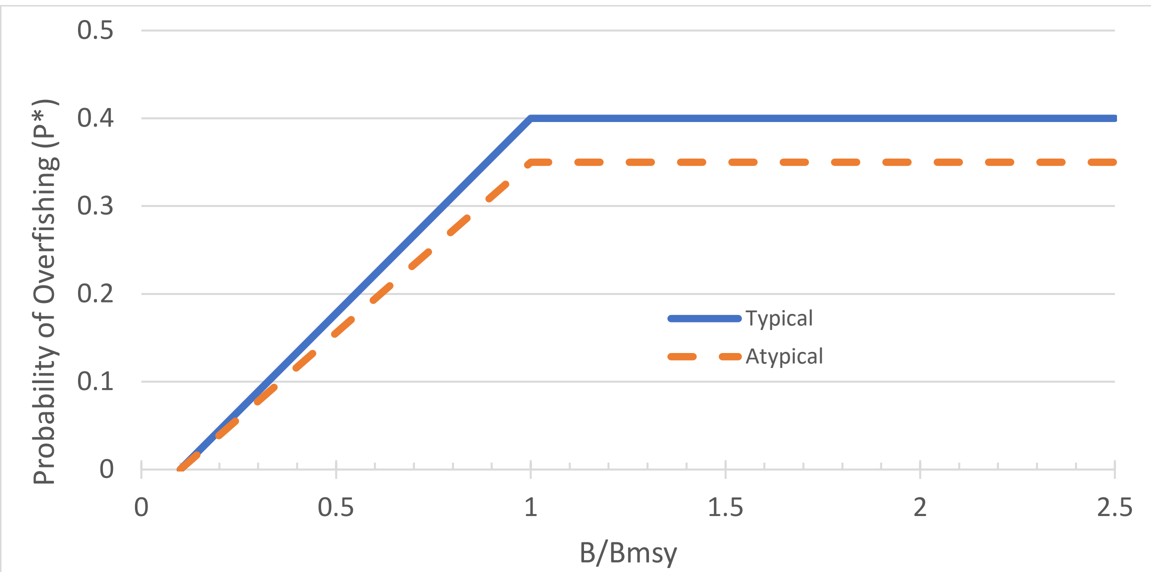

Figure 1: Alternative 1, *status quo* – the current Mid-Atlantic Fishery Management Council risk policy.

2. **Linear ramping with a maximum P* of 0.45 when the B/B_{MSY} ratio is equal to or greater than 1.0**

Under this alternative, the Council would assume a higher level of risk (P*=0.45) than the current policy (P*=0.40) in cases where the stock biomass was greater than the B_{MSY} target. Under this alternative, the P* would be variable and conditioned on current stock biomass when stock size falls below B_{MSY} as per the current risk policy but would be held constant at 0.45 when stock size exceeds B_{MSY} (Figure 2A). The maximum P* of 0.45 is higher than the current Council risk policy but is lower than the 0.50 maximum allowed under the MSA.

A P* of 0 percent if the ratio of B/B_{MSY} is less than or equal to 0.10 would remain to ensure a stock does not reach low levels from which it cannot recover. It is worth noting that by increasing the maximum P* to 0.45 under this alternative, the slope of linear ramping portion to determine a P* for stocks whose biomass is less than B_{MSY} is also modified (Figure 2B). Therefore, when compared to the current risk policy, this alternative would result in slightly higher P* values (higher risk of overfishing) under the same current stock biomass when less than B_{MSY}.

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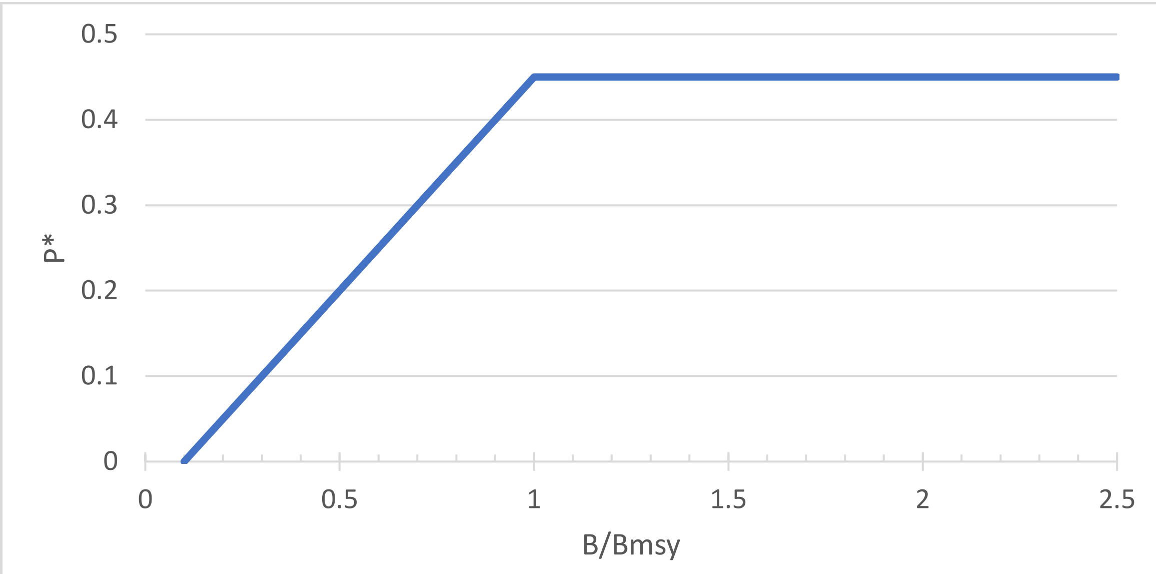

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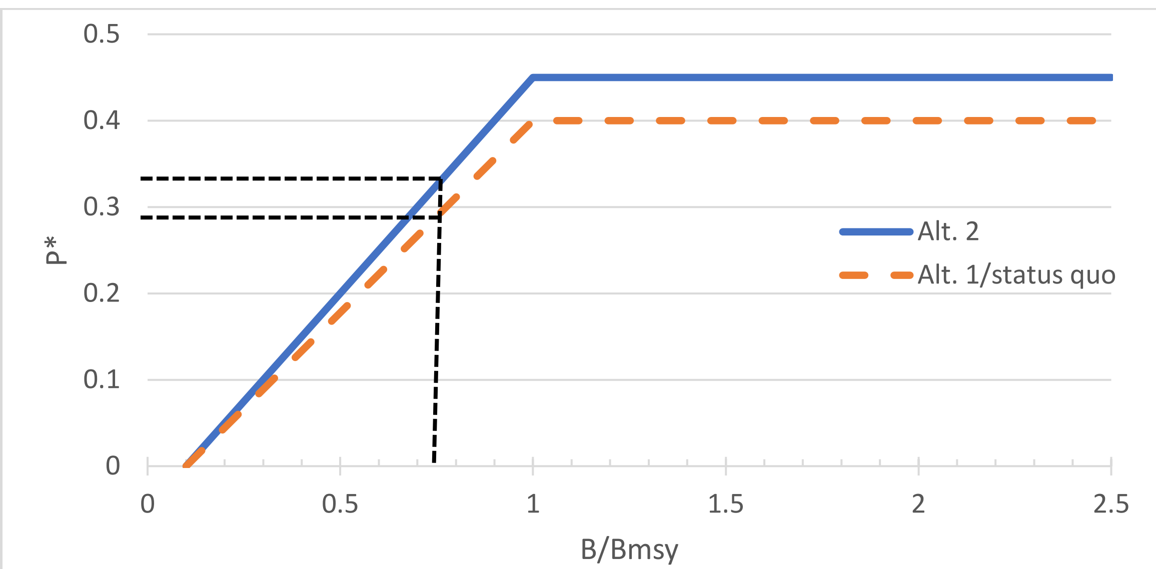


Figure 2: A) Alternative 2 with a variable probability of overfishing (P*) up to a maximum P* of 0.45 when the B/B_{MSY} ratio is equal to or greater than 1.0. **B)** Comparison between Alternative 1/*status quo* (typical life history) and Alternative 2. Dashed lines show the difference between the two alternatives in the P* calculation under the same biomass ratio.

3. **Constant P* equal to 0.40**

Under this alternative, the variable P* as a function of stock biomass would be removed and a constant P* equal to 0.4, the current maximum P* value, would be maintained under all circumstances (Figure 3). The P* of 0.4 would be applied regardless of current stock biomass, rebuilding status, life history etc. The current ramping of the P* conditioned on biomass is an attempt to prevent stocks from being overfished by reducing the probability of overfishing as stock size falls below B_{MSY}. However, this feature of the current risk policy is not a mandatory requirement of the MSA.

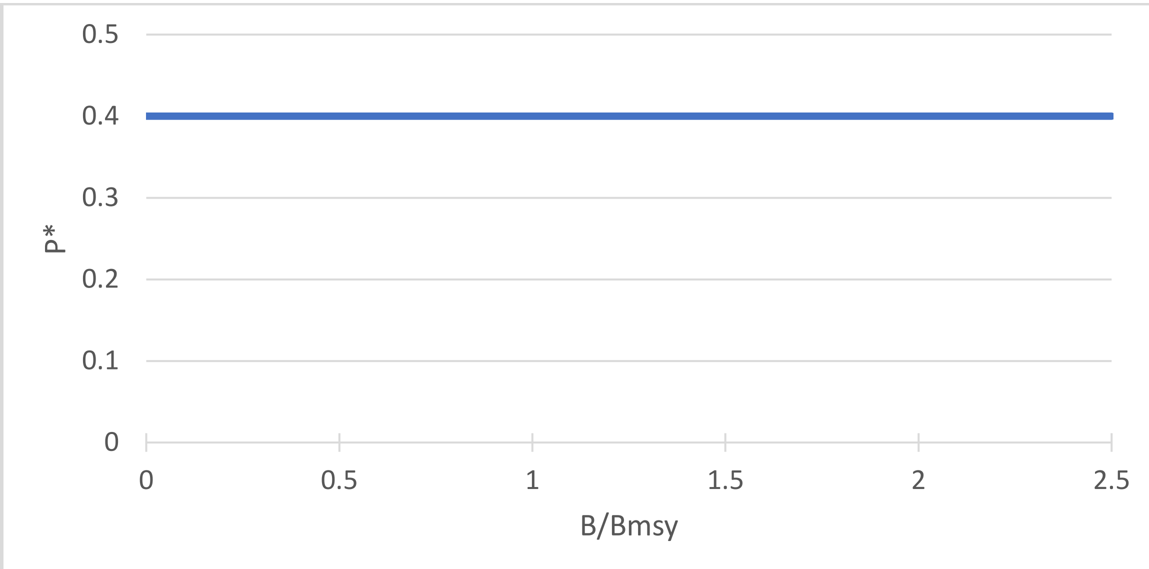


Figure 3. Alternative 3 with a constant P* equal to 0.40 under all stock biomass conditions.

4. **Two step P* - constant P* equal to 0.40 for B/B_{MSY} ratios less than 1.0 and a constant P* at 0.45 for B/B_{MSY} ratios equal to or greater than 1.0**

Under this alternative, current stock biomass relative to B_{MSY} would be considered but instead of applying a variable P* associated with the current policy, a constant P* equal to 0.40 or 0.45 would be applied depending upon the B/B_{MSY} ratio (Figure 4). For stocks whose biomass is less than B_{MSY} (B/B_{MSY} ratio less than 1.0), a constant P* equal to 0.40, the current maximum P* value, would be applied. For stocks whose biomass is equal to or greater than B_{MSY} (B/B_{MSY} ratio equal to or greater than 1.0), a constant P* equal to 0.45 would be applied. This maximum P* value is higher than the current Council risk policy maximum but lower than the 0.50 maximum allowed under the MSA.

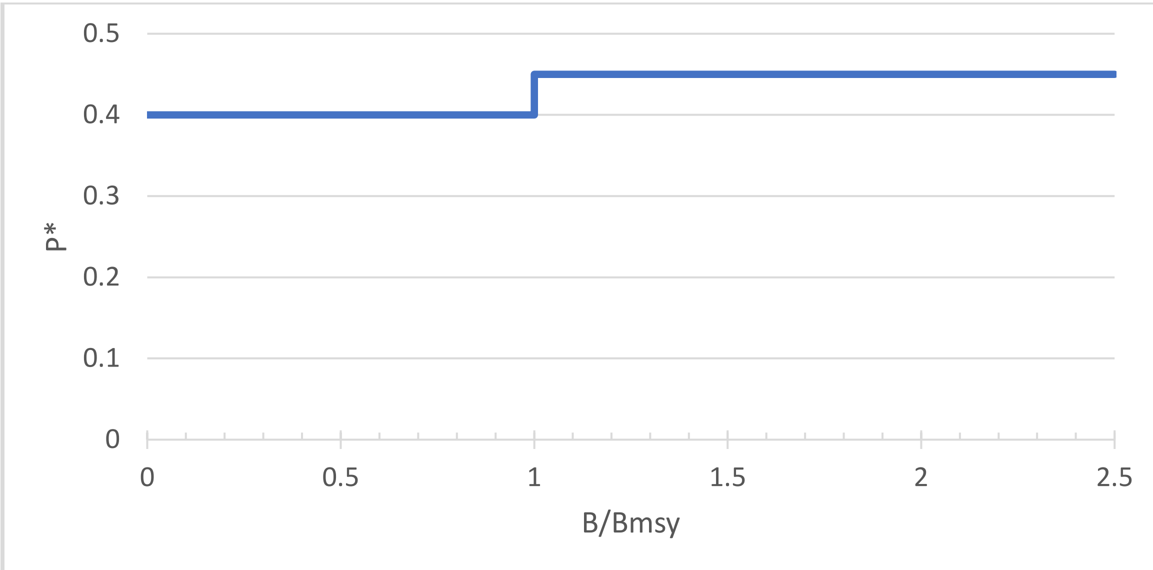


Figure 4. Alternative 4, a two-step P* with a constant P* equal to 0.40 when the B/B_{MSY} ratio is less than 1.0 and a constant P* equal to 0.45 when the B/B_{MSY} ratio is equal to or greater than 1.0.

5. **Three step P* - constant P* equal to 0.35 when the B/B_{MSY} ratio is less than 0.75, constant P* of 0.40 when the B/B_{MSY} ratio is between 0.75 and 1.0 and a constant P* of 0.45 when the B/B_{MSY} ratio is equal to or greater than 1.0**

Similar to Alternative 4, under this alternative, current stock biomass relative to B_{MSY} would be considered but instead of applying a variable P* associated with the current policy, a constant P* equal to 0.35, 0.40 or 0.45 would be applied depending upon the B/B_{MSY} ratio (Figure 5). For stocks whose biomass is more than 25 percent below B_{MSY} (B/B_{MSY} ratio less than 0.75), a lower risk would be assumed and a constant P* equal to 0.35 would be applied. When stock biomass is less than B_{MSY} but equal to or less than 25 percent below B_{MSY} (B/B_{MSY} ratio equal to or greater than 0.75 but less than 1.0), a constant P* of 0.40 would be applied. For stocks whose biomass is equal to or greater than B_{MSY} (B/B_{MSY} ratio equal to or greater than 1.0), a higher risk would be assumed and a constant P* equal to 0.45 would be applied. This alternative considers current stock biomass and would implement a lower risk tolerance under lower stock biomass conditions and increasing risk with increasing stock biomass.

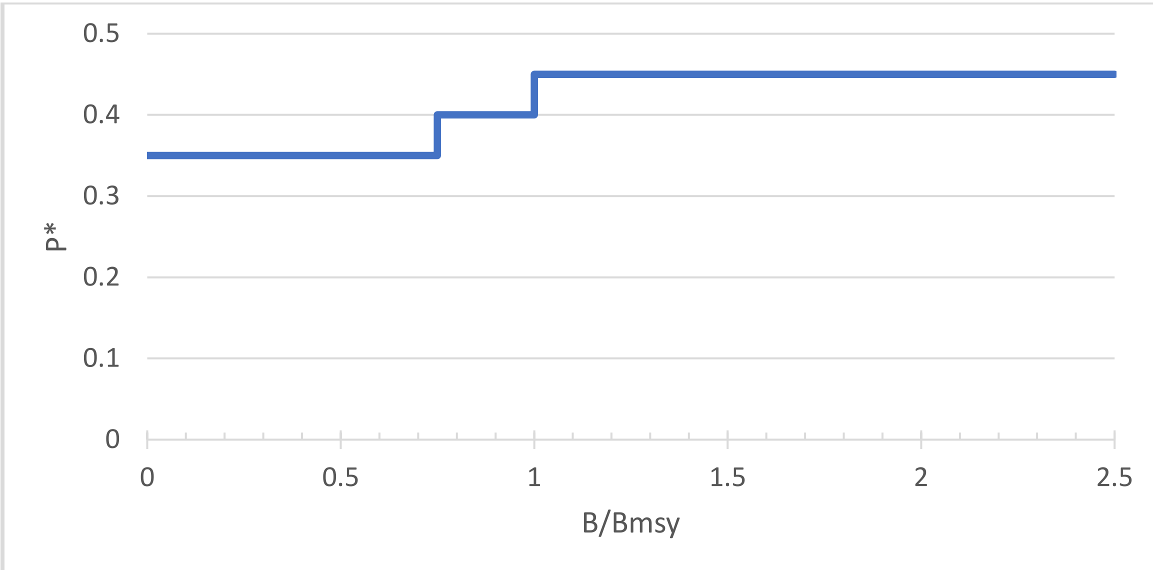


Figure 5. Alternative 5, a three-step P* with a constant P* equal to 0.35 when the B/B_{MSY} ratio is less than 0.75, a constant P* equal to 0.40 when the B/B_{MSY} ratio is greater than or equal to 0.75 but less than 1.0, and a P* equal to 0.45 when the B/B_{MSY} ratio is greater than or equal to 1.0.

6. **Linear ramping with a maximum P* of 0.40 when the B/B_{MSY} ratio is less than or equal to 1.0 and a linear ramping with a maximum P* of 0.49 when the B/B_{MSY} ratio is equal to or greater than 1.5**

Under the alternative, linear increases in the P* would occur as the ratio of B/B_{MSY} increases to a maximum of 0.40 at the inflection point of B/B_{MSY} = 1.0. This is consistent with the current risk policy. Once stock biomass exceeds B_{MSY} and the B/B_{MSY} ratio is equal to or greater than 1.0, linear increases in the P* would then occur to a maximum P* of 0.49 at the inflection point of B/B_{MSY} = 1.5. The maximum P* of 0.49 would then be applied when B/B_{MSY} ratios are equal to or greater than 1.5 (Figure 6). This alternative seeks to prevent stocks from being overfished by reducing the probability of overfishing as stock size falls below $B_{MSY;}$ while also allowing for increased risk under high stock biomass conditions that are 1.5 times greater than B_{MSY}. Consistent with the current risk policy, this alternative would also implement a P* of 0 percent if the ratio of B/B_{MSY} is less than or equal to 0.10 would remain to ensure the stock does not reach low levels from which it cannot recover.

A B/B_{MSY} ratio of 1.5 indicates a very robust stock with favorable conditions that are substantially above the B_{MSY} target, even with uncertainty in the terminal year biomass estimate. These very high biomass conditions have not been observed frequently throughout the Council's management history. Currently, only scup and black sea bass have a B/B_{MSY} ratio greater than 1.5. Butterfish, surfclam and ocean quahog have B/B_{MSY} ratios between 1.0 and 1.5 which, under this alternative, would result in a P* between 0.4 and 0.48.

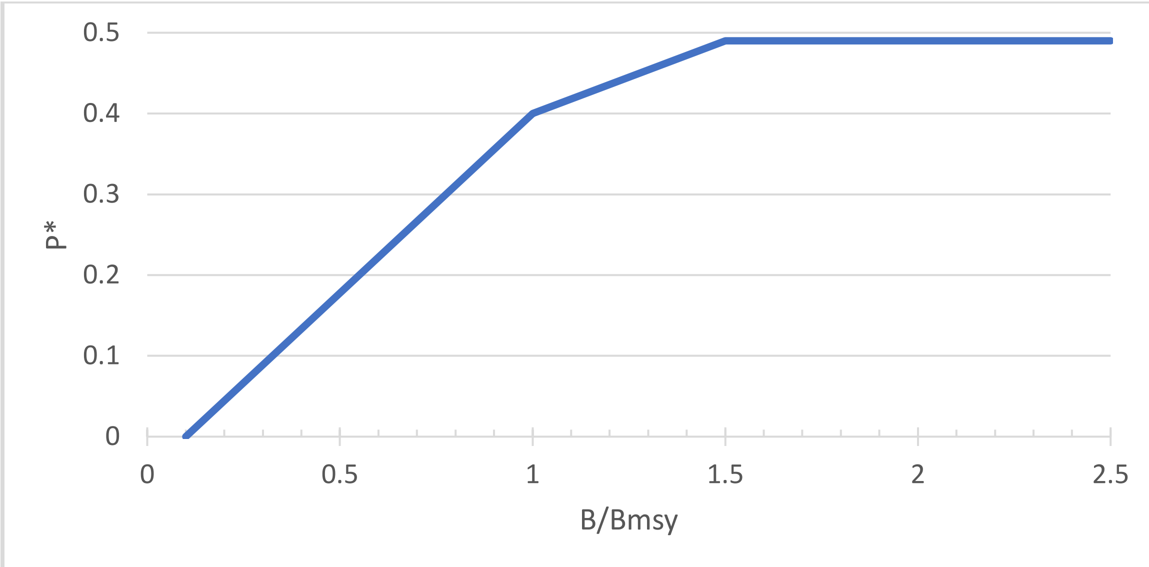


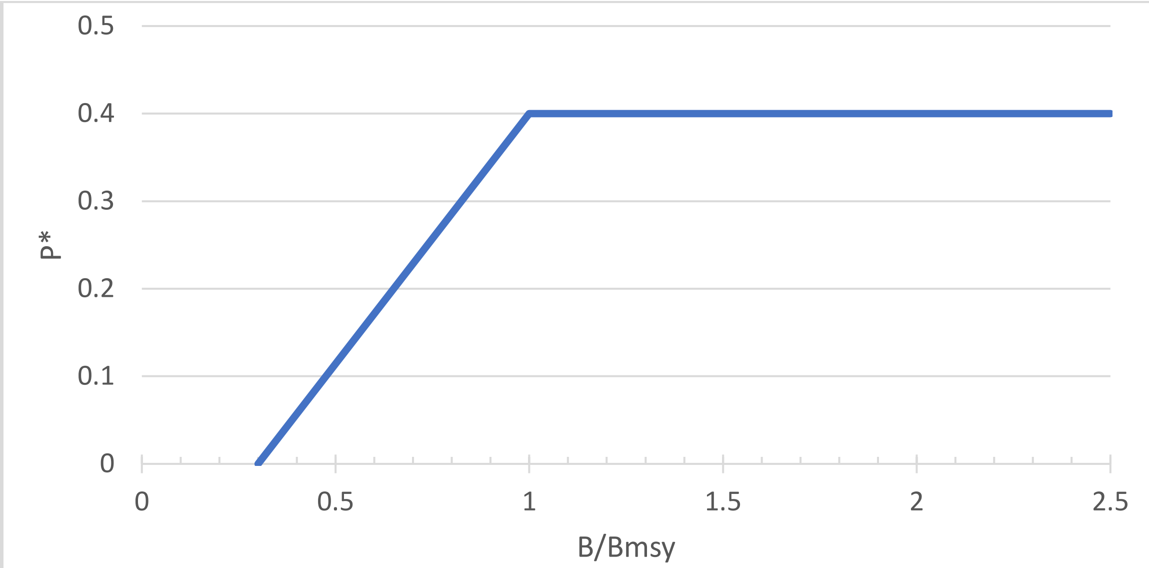
Figure 6. Alternative 6, linear ramping with a maximum P* of 0.40 when the B/B_{MSY} ratio is less than 1.0 and a linear ramping with a maximum P* of 0.49 when the B/B_{MSY} ratio is equal to or greater than 1.5.

7. Current risk policy with a stock replenishment threshold equal to 0.3

Under this alternative, the current risk policy would remain with the P* for a given stock conditional on current stock biomass relative to B_{MSY} and a maximum P* set at 0.4 when the B/B_{MSY} ratio is equal to or greater than 1.0; however, the P* will be set equal to 0 percent (i.e., no fishing) if the ratio of B/B_{MSY} is less than or equal to the stock replenishment threshold of 0.3 instead of the current threshold of 0.1 (Figure 7A). This alternative is more risk adverse than the current risk policy and attempts to minimize the likelihood of getting to an overfished condition and increase the probability of stock recovery in shorter period of time (Figure 7B).

The current stock replenishment threshold was determined by expert opinion but was not quantitively derived and may be too low to adequately provide for stock recovery. This alternative allowed for a comprehensive evaluation to quantify the implications and trade-offs associated with the cost of closing a fishery and minimizing the risk of reaching an overfished condition under different stock replenishment thresholds. However, it should be noted that once the B/B_{MSY} ratio is less than 0.5, the stock is declared overfished and a rebuilding plan is implemented. Therefore, some caution in evaluating the implications of the different stock replenishment thresholds under very low biomass levels is needed since the standard application of the risk policy, as depicted in the figures, may not be used under a rebuilding plan.

A)



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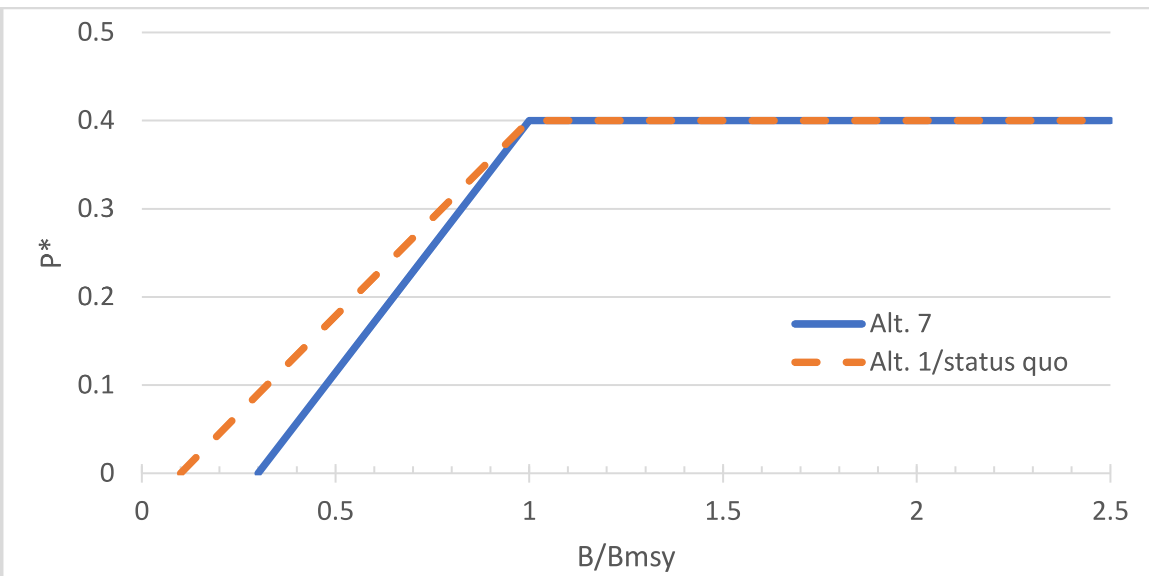
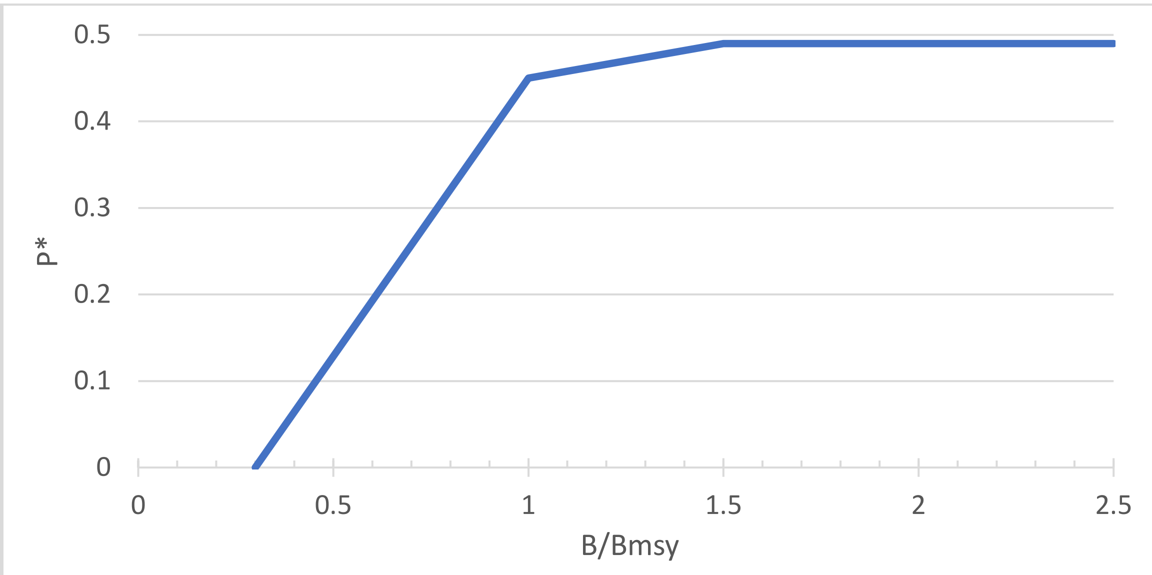


Figure 7: A) Alternative 7 with a variable probability of overfishing (P*) up to a maximum P* of 0.40 when the B/B_{MSY} ratio is equal to or greater than 1.0 and a P* of 0 if the ratio of B/B_{MSY} is less than or equal to the stock replenishment threshold of 0.3. **B)** Comparison between Alternative 1/*status quo* (typical species) and Alternative 7.

8. **Linear ramping with a maximum P* of 0.45 when the B/B_{MSY} ratio is less than or equal to 1.0, and a linear ramping to a maximum of 0.49 when the B/B_{MSY} ratio is equal to or greater than 1.5 and a P* equal to 0 when the B/B_{MSY} ratio less than or equal to 0.3**

This alternative was developed by the Council during framework meeting 1 deliberations and integrates certain elements of Alternatives 6 and 7 (Figure 8A). Similar to Alternative 6, this alternative would have two different linear ramping functions with a maximum P* = 0.49 when the B/B_{MSY} ratio is greater than or equal to 1.5. However, this alternative allows for linear increases in the P* as the ratio of B/B_{MSY} increases to maximum P* of 0.45 at the inflection point of B/B_{MSY} = 1.0, while Alternative 6 sets the maximum P* = 0.40 at this biomass ratio. Similar to Alternative 7, this alternative would set the P* = 0 (i.e., no fishing) if the ratio of B/B_{MSY} is less than or equal to the stock replenishment threshold of 0.3. This alternative provides for increasing risk under higher stock biomass, particularly when biomass is near or above the target, and would be more risk adverse as a stock biomass declines to minimize the risk of reaching an overfished condition (Figure 8B).

A)



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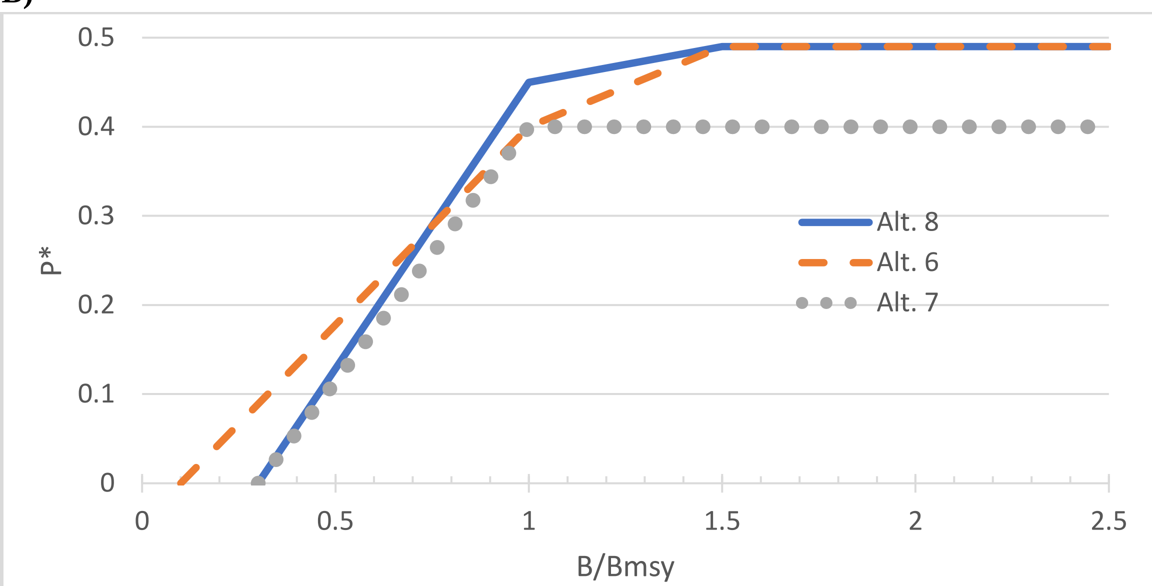

Figure 8: A) Alternative 8 with a linear ramping to a maximum P* of 0.45 when the B/B_{MSY} ratio is less than or equal to 1.0, and a linear ramping to a maximum of 0.49 when the B/B_{MSY} ratio is equal to or greater than 1.5 and a P* = 0 when the B/B_{MSY} ratio is less than or = 0.3. **B)** Comparison between Alternatives 6 and 7 and Alternative 8, a modified hybrid alternative that incorporates elements of both Alternatives 6 and 7.

9. Eliminate the typical/atypical distinction in the risk policy

Similar to the approach taken with the current risk policy for "typical" species, the P* associated with an "atypical" species is conditional on current stock biomass relative to B_{MSY} but has a maximum P* set at 0.35 instead of 0.4 (Figure 1). This measure was originally implemented by the Council reflecting the Council's lower risk tolerance for species whose life histories make them more vulnerable to over-exploitation. Currently, ocean quahog is the only stock in which the SSC applied the atypical designation when making an ABC recommendation. Under this option, the P* would be the same for all species regardless of their life histories. Eliminating or retaining the typical/atypical designation could be implemented in conjunction with either fixed or variable P* alternatives considered here.

Summary of Management Strategy Evaluation Results:

The updated MSE conducted by Dr. John Wiedenmann from Rutgers University considered the biological and fishery yield implications of the different risk policy alternatives[5]. The MSE was conducted for summer flounder, scup, and butterfish and included updated stock assessment information, the new MRIP estimates, assessment timing base on the new NRCC assessment schedule, an assumed 100% OFL CV distribution, and variable natural mortality, recruitment and stock assessment bias to evaluate the robustness of the risk policy alternatives to changing stock conditions.

Consistent with previous analyses, the results of the updated MSE indicate that all of risk policy alternatives generally limited the risk of overfishing under "average" and "good" conditions; while the linear ramping P* alternatives (i.e., those like the current Council risk policy) were better at preventing overfishing and reduced the risk of a population declining to low levels particularly under "poor" conditions (i.e. above average natural mortality and below average recruitment). On the other hand, the constant and stepped alternatives generally produced higher catch, greater economic welfare, and limited catch variability, particularly within the first five years of projections. However, these results are highly dependent upon the starting condition of the stock.

For scup, where the biomass is nearly twice the B_{MSY} target, all of the alternatives performed equally well at limiting risk to the stock with only a 1% - 2% difference between the ramped alternatives and the constant and stepped alternatives. Short and long-term catch of scup was also

[5] To find more information on the biological MSE conducted by Dr. Wiedenmann, please see the full report at: http://www.mafmc.org/briefing/december-2019.

similar among the alternatives, except for Alternative 7 which resulted in consistently lower catch. The maximum P* value (0.4, 0.45, or 0.49) played a larger role in short and long-term scup yield than any specific control rule shape.

For butterfish, where the starting biomass is about 41% higher than the B_{MSY} target, the results show very distinct differences between the risk policy alternatives. The constant and stepped alternatives consistently resulted in higher short and long-term catch across all productivity scenarios. Butterfish catch was typically 50% greater, and in some cases as much as 10 times greater, under the constant and stepped alternatives. However, the constant and stepped alternates also resulted in higher risk and were consistently higher, sometimes significantly, than the ramped alternatives. In a number of scenarios the constant and ramped alternatives resulted in exceeding the 50% probability of overfishing or the stock becoming overfished. Butterfish stock dynamics, such as highly variable recruitment, play a large role in these results with the ramped alternatives providing for greater stock protection and stability.

For summer flounder, where the starting biomass is 22% below B_{MSY} target, the results are mixed. All alternatives performed well under average and good stock productivity conditions but under poor stock productivity scenarios the constant and stepped alternatives resulted in situations close to or exceeding the 50% probability of overfishing. Overall, the constant and stepped alternatives were 31% higher on average in the probability of overfishing and 11% higher on average in the probability of becoming overfished than the ramped alternatives. Since summer flounder biomass is below the B_{MSY} target, the ramped alternatives have a lower starting P* than the constant and stepped alternatives and therefore, consistently result in lower short-term catch under all stock productivity scenarios. However, as stock biomass increases and stabilizes over time, the long-term catch and economic welfare is generally the same across all alternatives, except for *status quo* and Alternative 7 which produced the lowest catch and economic welfare.

The results also highlight the importance and potential biological and management implications of assessment bias. When a stock assessment underestimates terminal year biomass, all of the risk policy alternatives perform well, except for butterfish where other stock dynamics play a greater role in the outcomes. However, consistently overestimating the terminal year biomass can substantially increase the probability of a stock becoming overfished regardless of the risk policy implemented. This situation could undermine management actions to control catch and prevent overfishing and should be closely monitored and evaluated following each stock assessment.

Dr. Doug Lipton (NMFS Office of Science and Technology) and Dr. Cyrus Teng (post-doctoral fellow with the University of Maryland) where then able to utilize the summer flounder outputs from the biological MSE and integrate with a summer flounder economic model to evaluate the economic effects of the different risk policy alternatives[6]. The results indicate differences in the total net economic benefits between the risk policy alternatives with the current policy and Alternative 7, the two most conservative approaches, providing the lowest net economic benefit.

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[6] To find more information on the economic MSE conducted by Dr. Lipton and Dr. Teng, please see the full report at: http://www.mafmc.org/briefing/december-2019.

Similar to the results noted above, the differences between the alternatives were highly influenced by the starting condition of the summer flounder biomass with lower catch and, therefore, lower net economic benefit for some harvest control rules when stock biomass is below the B_{MSY}. As biomass stabilizes around B_{MSY}, there was a much smaller difference in the long-term net economic benefits between all of the alternatives as they effectively become equivalent to each other at higher biomass levels. Based on the quantitative assessment conducted for scup, the total economic welfare is likely to be much more similar across the alternatives given the overall similarity in short and long-term catch across the alternatives and the lower market price and lower sensitivity to recreational trips for scup. Drawing specific economic welfare conclusions for butterfish is more difficult given its low commercial price flexibility.

Staff Recommendation:

Based on a review of the both MSE model results, evaluating the biological and economic trade-offs associated with each alternative, and considering Council goals and objectives for its managed fisheries, staff recommend the Council adopt Alternative 2, linear ramping with a maximum P* of 0.45 when the B/B_{MSY} ratio is equal to or greater than 1.0. This alternative performed well across all three species and all stock productivity scenarios evaluated and best balanced biological and fishery trade-offs by minimizing overall risk while allowing for moderate increases in yield and economic welfare when compared to the current risk policy.

There were five different linear ramping alternatives, including the current/*status quo* alternative, evaluated during this risk policy review (Alternatives 1, 2, 6, 7, and 8). These linear ramping alternatives are intended to prevent stocks from becoming overfished by reducing the probability of overfishing as the stock size falls below the B_{MSY} target. The risk policy MSE analyses conducted for this action support the effectiveness of this approach as the linear ramping alternatives generally performed better than the constant or stepped alternatives, particularly under poor stock productivity scenarios. As previously noted by staff, these ramped risk policy alternatives may provide for additional stock protection as environmental conditions become increasingly variable and continue to change in the Mid-Atlantic as a result of climate change and therefore, the use and implementation of the linear ramping approach should continue.

When comparing the ramped alternatives, Alternative 2 did result in slightly higher risk (higher probability of overfishing and becoming overfished) when compared to the *status quo* and Alternative 7, the most risk adverse alternative, but was lower than the other two ramped alternatives. However, even with this slight increase in risk, there was no scenario in which Alternative 2 resulted in a probability of overfishing that exceeded 50% and only under persistent poor stock productivity conditions did the probability of becoming overfished exceed 50%, which occurred for all alternatives considered (Tables 1A, 2A, and 3A). Alternative 2 also resulted in greater benefits to the fishery (catch, economic benefit and stability) by 6% on average when evaluating across all species and all scenarios compared to the *status quo* alternative and, according to the economic model, would result in an annual increase in economic welfare of $7.2 million ($36 million over five years) to the summer flounder fisheries over the *status quo* alternative. Except for short-term catch of scup, Alternative 2 outperformed all other ramped alternatives for all three species under the different stock productivity scenarios in terms of short or long-term catch and economic welfare by 3% - 13% on average (Tables 1B, 2B, and 3B). In addition, Alternative 2 minimized catch variability when compared to the other ramped alternatives, providing the additional benefit of increased stability.

When comparing Alternative 2 to the constant and stepped alternatives (Alternatives 3, 4, and 5), the results were more mixed but did a better job overall at balancing the biological and economic trade-offs. Alternative 2 outperformed all three alternatives, particularly Alternatives 4 and 5, from risk of overfishing and becoming overfished across all three species. However, Alternatives 4 and 5 consistently resulted in higher short-term catch and economic welfare for all three species compared to Alternative 2. Given the higher maximum P* associated with Alternative 2 compared to Alternative 3, 0.45 and 0.40 respectively, short-term catch of scup was higher for Alternative 2. Long-term catch performance between Alternative 2 and the constant and stepped alternatives was driven by starting biomass conditions. Alternative 2 performed slightly better or same for summer flounder, slightly worse or similar for scup, and worse for butterfish. The constant and stepped alternatives consistently resulted in lower catch variability on both an annual basis and in the maximum change in catch, a positive benefit of these risk policy alternatives.

Mid-Atlantic stock assessments and modeling approaches continue to make significant improvements and advancements and can more appropriately account for and address a species vulnerability to over-exploitation. These stock assessment improvements have also resulted in better quantitatively derived biological reference points to appropriately capture the unique life-history characteristics of a particular species. In addition, the new Northeast Region Coordinating Council (NRCC) stock assessment process designed to support research and stock assessment improvements will further enhance the regions stock assessment science to more comprehensively account for a species life-history dynamics. Given these improvements in accounting for a species vulnerability to over-exploitation and the limited use of the atypical designation by the SSC, staff recommends the Council adopt Alternative 9 to remove/eliminate the typical/atypical designation.

Staff also recommends the Council retain a single risk policy that is applied to all Council-managed stocks. The different analyses conducted to date do not show any measurable or specific benefit to implementing a different risk policy for each species, species groups, or based on different life histories. A consistent application of the risk policy across all species provides a more comprehensible and predictable process with understood outcomes. Different harvest policies using the same risk policy can occur across Council-managed species given stock assessment results that incorporate different life history parameters within approved biological and fishing mortality reference points.

If a new risk policy is recommended by Council, staff would recommend retaining the new risk policy for a several years (anywhere from 7-10 years) in order to fully evaluate its performance prior to any future review. The current risk policy has been in place for eight years and all of the alternatives considered during this review, including *status quo*, generally performed similarly well over the long-term, particularly under average conditions. In addition, the new NRCC stock assessment process will also allow for increased opportunities for the Council and SSC to receive updated stock status information and respond to stock changes, through the risk policy and ABC control rule, in a timely manner. Future reviews could then consider more fully implementing economic factors into the risk policy and other potential EAFM risk policy considerations such as a forage-based policy. These approaches would require the development of new and different models and analyses and will require significant time and input from the Council, SSC and stakeholders.

Table 1 – Summer flounder: A) Summary results from the biological MSE showing the probability of overfishing and the probability of becoming overfished for the eight risk policy alternatives under different stock productivity or assessment bias scenarios. **B)** Summary results from the economic and biological MSE showing short and long-term economic welfare compared to *status quo* and the average annual change and maximum annual change in catch. **C)** Average metric value across all productivity and/or assessment bias scenarios for both biological and economic metrics. For all tables, shading represents the relative difference and direction (better or worse) between an alternative compared to the *status quo* – white/light cells indicate the metric performs better or similar to the *status quo* and the darker the cell the worse it performed compared to *status quo* (black cells in Table A indicate the alternative exceeded the 50% probability of overfishing or being overfished).

A)

Metric Description	**Productivity or Assessment Error**	Alternative ***Status Quo***	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**	**Alt. 6**	**Alt. 7**	**Alt. 8**
Prob. of Overfishing	Average	0.13	0.23	0.13	0.19	0.19	0.19	0.1	0.26
	Good	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.06
	Poor	0.32	0.39	0.58	0.58	0.48	0.32	0.32	0.39
	Underestimate Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.06
	Overestimate Biomass	0.32	0.47	0.39	0.52	0.48	0.45	0.32	0.48
Prob. of Becoming Overfished	Average	0.14	0.23	0.15	0.24	0.23	0.24	0.14	0.27
	Good	0.03	0.05	0.03	0.05	0.05	0.06	0.02	0.06
	Poor	0.72	0.8	0.87	0.87	0.84	0.75	0.71	0.78
	Underestimate Biomass	0.0	0.01	0.0	0.02	0.01	0.02	0.0	0.04
	Overestimate Biomass	0.29	0.5	0.32	0.5	0.48	0.5	0.3	0.57

B)

Metric Description	**Productivity**	Alternative ***Status Quo***	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**	**Alt. 6**	**Alt. 7**	**Alt. 8**
Cumulative Short-Term (5-Year) Economic Welfare (in millions USD)	Average	0	36	72	82	67	7	-20	16
	Good	0	45	74	91	76	16	-20	30
	Poor	0	27	68	73	58	3	-19	6
Cumulative Long-Term (20-Year) Economic Welfare (in millions USD)	Average	0	7	6	11	9	0	-1	9
	Good	0	50	0	49	50	43	1	59
	Poor	0	3	14	13	12	-2	-4	-3
Avg. Change in Catch	Average	0.14	0.15	0.12	0.13	0.14	0.16	0.15	0.17
	Good	0.09	0.09	0.08	0.09	0.09	0.11	0.09	0.11
	Poor	0.18	0.2	0.14	0.15	0.16	0.19	0.2	0.23
Max Change in Catch	Average	0.36	0.42	0.26	0.31	0.34	0.45	0.4	0.51
	Good	0.31	0.34	0.27	0.3	0.31	0.4	0.32	0.4
	Poor	0.47	0.52	0.3	0.33	0.35	0.51	0.56	0.64

C)

Metric Description	Productivity or Assessment Error	Alternative							
		Status Quo	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**	**Alt. 6**	**Alt. 7**	**Alt. 8**
Prob. of Overfishing	Avg. across all	0.15	0.22	0.22	0.26	0.23	0.20	0.15	0.25
Prob. of Becoming Overfished	Avg. across all	0.24	0.32	0.27	0.34	0.32	0.31	0.23	0.34
Cumulative Short-Term (5-Year) Economic Welfare (in millions USD)	Avg. across all	0	36	71	82	67	9	-20	17
Cumulative Long-Term (20-Year) Economic Welfare (in millions USD)	Avg. across all	0	20	7	24	24	14	-1	22
Avg. Change in Catch	Avg. across all	0.14	0.15	0.11	0.12	0.13	0.15	0.15	0.17
Max Change in Catch	Avg. across all	0.38	0.43	0.28	0.31	0.33	0.45	0.43	0.52

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Table 2 – Scup: A) Summary results from the biological MSE showing the probability of overfishing and the probability of becoming overfished for the eight risk policy alternatives under different stock productivity or assessment bias scenarios. **B)** Summary results from the biological MSE showing short and long-term catch compared to the *status quo* and the average annual change and maximum annual change in catch (note: there is no quantitative economic model for scup). **C)** Average metric value across all productivity and/or assessment bias scenarios for both biological and catch metrics. For all tables, shading represents the relative difference and direction (better or worse) between an alternative compared to the *status quo* – white/light cells indicate the metric performs better or similar to the *status quo* and the darker the cell the worse it performed compared to *status quo* (black cells in Table A indicate the metric exceeded the 50% probability of overfishing or being overfished).

A)

Metric Description	**Productivity or Assessment Error**	Alternative ***Status Quo***	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**	**Alt. 6**	**Alt. 7**	**Alt. 8**
Prob. of Overfishing	Average	0.1	0.26	0.1	0.23	0.23	0.29	0.1	0.32
	Good	0.0	0.0	0.0	0.0	0.0	0.06	0.0	0.06
	Poor	0.32	0.39	0.39	0.45	0.42	0.39	0.32	0.39
	Underestimate Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Overestimate Biomass	0.47	0.55	0.52	0.58	0.58	0.55	0.45	0.58
Prob. of Becoming Overfished	Average	0.21	0.26	0.21	0.26	0.26	0.27	0.21	0.27
	Good	0.05	0.08	0.05	0.09	0.09	0.1	0.05	0.11
	Poor	0.55	0.61	0.57	0.63	0.62	0.6	0.55	0.63
	Underestimate Biomass	0.01	0.03	0.01	0.03	0.03	0.03	0.01	0.03
	Overestimate Biomass	0.44	0.51	0.45	0.51	0.51	0.53	0.44	0.54

B)

Metric Description	Productivity or Assessment Error	Alternative *Status Quo*	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Short-term (5-year) Catch	Average	0	992	0	992	992	1,861	0	1,861
	Good	0	1,079	0	1,079	1,079	2,000	0	2,000
	Poor	0	939	0	939	939	1,749	0	1,749
	Underestimate Biomass	0	2,844	3,257	5,386	4,707	1,844	-1,207	2,616
	Overestimate Biomass	0	2,489	2,673	5,419	5,019	2,807	-820	3,013
Long-Term (20-year) Catch	Average	0	584	84	746	685	670	-14	944
	Good	0	1,592	20	1,628	1,628	2,428	0	2,670
	Poor	0	111	473	502	355	-153	-28	9
	Underestimate Biomass	0	2,483	4,632	6,318	5,123	1,861	-1,526	1,787
	Overestimate Biomass	0	2,354	3,281	4,910	3,970	2,239	-962	2,482
Avg. Change in Catch	Average	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.12
	Good	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08
	Poor	0.12	0.13	0.12	0.12	0.12	0.14	0.13	0.15
	Underestimate Biomass	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Overestimate Biomass	0.14	0.14	0.13	0.14	0.14	0.15	0.14	0.15
Max Change in Catch	Average	0.27	0.28	0.26	0.27	0.27	0.3	0.27	0.3
	Good	0.24	0.25	0.24	0.25	0.25	0.27	0.24	0.27
	Poor	0.32	0.34	0.28	0.29	0.3	0.36	0.35	0.42
	Underestimate Biomass	0.23	0.24	0.23	0.23	0.24	0.26	0.23	0.26
	Overestimate Biomass	0.34	0.37	0.32	0.34	0.34	0.38	0.34	0.4

C)

Metric Description	Productivity or Assessment Error	Alternative *Status Quo*	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Prob. of Overfishing	Avg. across all	0.18	0.24	0.20	0.25	0.25	0.26	0.17	0.27
Prob. of Becoming Overfished	Avg. across all	0.25	0.30	0.26	0.30	0.30	0.31	0.25	0.32
Short-Term (5-year) Catch	Avg. across all	0	1,669	1,186	2,763	2,547	2,052	-405	2,248
Long-Term (20-year) Catch	Avg. across all	0	1,425	1,698	2,821	2,352	1,409	-506	1,578
Avg. Change in Catch	Avg. across all	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.12
Max Change in Catch	Avg. across all	0.28	0.30	0.27	0.28	0.28	0.31	0.29	0.33

Table 3 – Butterfish: A) Summary results from the biological MSE showing the probability of overfishing and the probability of becoming overfished for the eight risk policy alternatives under different stock productivity or assessment bias scenarios. **B)** Summary results from the biological MSE showing short and long-term catch compared to the *status quo* and the average annual change and maximum annual change in catch (note: there is no quantitative economic model for butterfish). **C)** Average metric value across all productivity and/or assessment bias scenarios for both biological and catch metrics. For all tables, shading represents the relative difference and direction (better or worse) between an alternative compared to the *status quo* – white/light cells indicate the metric performs better or similar to the *status quo* and the darker the cell the worse it performed compared to *status quo* (black cells in Table A indicate the metric exceeded the 50% probability of overfishing or being overfished).

A)

Metric Description	**Productivity or Assessment Error**	Alternative ***Status Quo***	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**	**Alt. 6**	**Alt. 7**	**Alt. 8**
Prob. of Overfishing	Average	0.06	0.13	0.16	0.19	0.19	0.13	0.06	0.15
	Good	0.2	0.2	0.6	0.6	0.5	0.16	0.1	0.13
	Poor	0.13	0.19	0.32	0.35	0.29	0.19	0.16	0.23
	Underestimate Biomass	0.0	0.1	0.1	0.2	0.1	0.1	0.0	0.13
	Overestimate Biomass	0.19	0.27	0.26	0.35	0.32	0.26	0.19	0.29
Prob. of Becoming Overfished	Average	0.54	0.64	0.65	0.71	0.69	0.64	0.51	0.65
	Good	0.03	0.04	0.15	0.16	0.12	0.02	0.02	0.02
	Poor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Underestimate Biomass	0.5	0.57	0.6	0.66	0.63	0.55	0.4	0.57
	Overestimate Biomass	0.7	0.8	0.77	0.82	0.83	0.83	0.68	0.82

B)

Metric Description	Productivity or Assessment Error	Alternative *Status Quo*	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Short-term (5-year) Catch	Average	0	2,754	3,823	5,575	4,592	2,077	-895	2,257
	Good	0	5,248	14,250	15,755	12,452	676	-4,287	633
	Poor	0	1,306	3,930	4,591	3,553	671	-497	891
	Underestimate Biomass	0	2,844	3,257	5,386	4,707	1,844	-1,207	2,616
	Overestimate Biomass	0	2,489	2,673	5,419	5,019	2,807	-820	3,013
Long-Term (20-year) Catch	Average	0	2,464	4,547	5,981	5,022	1,699	-1,200	1,894
	Good	0	3,852	37,255	36,008	31,631	995	-43,270	-10,495
	Poor	0	1,094	2,979	3,623	2,828	790	-183	1,063
	Underestimate Biomass	0	2,483	4,632	6,318	5,123	1,861	-1,526	1,787
	Overestimate Biomass	0	2,354	3,281	4,910	3,970	2,239	-962	2,482
Avg. Change in Catch	Average	0.16	0.16	0.12	0.12	0.13	0.17	0.18	0.19
	Good	0.15	0.15	0.1	0.1	0.09	0.15	0.26	0.18
	Poor	0.2	0.21	0.12	0.13	0.14	0.21	0.25	0.27
	Underestimate Biomass	0.15	0.16	0.11	0.12	0.12	0.17	0.17	0.19
	Overestimate Biomass	0.17	0.18	0.13	0.14	0.15	0.19	0.18	0.2
Max Change in Catch	Average	0.38	0.41	0.27	0.27	0.29	0.44	0.45	0.52
	Good	0.5	0.51	0.32	0.32	0.31	0.49	0.64	0.59
	Poor	0.51	0.55	0.27	0.29	0.31	0.57	0.73	0.78
	Underestimate Biomass	0.37	0.39	0.26	0.27	0.28	0.43	0.44	0.51
	Overestimate Biomass	0.41	0.44	0.29	0.3	0.32	0.47	0.46	0.55

C)

Metric Description	Productivity or Assessment Error	Alternative *Status Quo*	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Prob. of Overfishing	Avg. across all	0.11	0.18	0.29	0.33	0.29	0.17	0.11	0.19
Prob. of Becoming Overfished	Avg. across all	0.55	0.61	0.63	0.67	0.65	0.61	0.53	0.61
Short-Term (5-year) Catch	Avg. across all	0	2,928	5,586	7,345	6,065	1,615	-1,541	1,882
Long-Term (20-year) Catch	Avg. across all	0	2,449	10,539	11,368	9,715	1,517	-9,428	-654
Avg. Change in Catch	Avg. across all	0.17	0.17	0.12	0.12	0.13	0.18	0.21	0.21
Max Change in Catch	Avg. across all	0.43	0.46	0.28	0.29	0.30	0.48	0.54	0.59

Fine-tuning the ABC control rule for Mid-Atlantic fisheries

John Wiedenmann

Department of Ecology, Evolution, and Natural Resources
Rutgers, the State University of New Jersey

Report to the Mid-Atlantic Fishery Management Council

November 27th 2019

Table of Contents

Executive Summary

Eight ABC control rule alternatives for Mid-Atlantic fisheries were tested using a management strategy evaluation model for scup, summer flounder, and butterfish. These control rules varied in their maximum allowable P*, and how the P* changed as biomass declined. Performance of the control rules relative to one another was evaluated by comparing short- and long-term yields to the fishery, average and maximum variability in yield, the risk of overfishing, and the risk of driving the population to low levels. Variability in future stock productivity was incorporated in the model, and comparison of control rule performance was evaluated across 1) the baseline model run of average productivity, 2) under good future productivity only, and 3) under poor future productivity. Control performance varied by stock and by future conditions, but in general, the fixed and stepped Alternatives (produce greater benefits to the fishery, with high stable short- and long-term catches across stocks and productivity levels. However, with greater reward comes greater risk, as these control rules also had the greatest risks of overfishing and causing the stocks to become overfished, and in some cases the risk of overfishing exceeded the 50% threshold. Ramped control rules, on the other hand, had lower risks of overfishing and of becoming overfished, particularly under average and poor productivity conditions across stocks. In general, ramped options with higher maximum P* had higher yield, on average, particularly under average and good productivity. Ramped control rules had greater variability in yield overall, with the greatest variability occurring for options with more rapid changes in the target P* with biomass. For summer flounder, ramped control rules had considerably lower short-term yield than the fixed and stepped options, owing to the fact that summer flounder biomass is currently below the S_{MSY} target. Of the ramped control rules, Alternative 2 seemed the best able to balance the tradeoffs in management objectives, resulting in relatively high catch, low risks of overfishing and becoming overfished, and lower variability in catch.

Introduction

This project seeks to evaluate alternative acceptable biological catch (ABC) harvest control rules in consideration by the Mid-Atlantic Fisheries Management Council (MAFMC). The control rules are all variants of the P* approach (Shertzer et al. 2008), whereby a distribution for the overfishing limit (OFL) is created by using the point estimate from the assessment and projection models as the median of a lognormal distribution with an assumed uncertainty (determined by a specified coefficient of variation, or CV), and selecting some percentile of the distribution at or below the median (target P* ≤ 0.5). The MAFMC currently uses a control rule whereby the target P* depends on the estimated biomass, with a target P* of 0.4 when current spawning biomass for a stock is at or above the biomass target ($S \geq S_{MSY}$), and the target P* declining linearly as biomass falls below S_{MSY}, with the fishery shut down (target P* = 0) when biomass as below 10% of S_{MSY}. The assumed CV of the OFL varies by stocks, but CVs 1.0 are typically used by the SSC for Mid-Atlantic stocks.

This work is an extension of previous work for the Council, where a total of five control rules were evaluated for summer flounder, scup, and butterfish. The original five control rules explored are shown in Figure 1A and 1B. Two of these were "ramped" with the target P* declining linearly as biomass falls below the target spawning biomass (S_{MSY}), with the difference between these options the maximum P* at or above S_{MSY} (0.4 or 0.45). The ramped P* with a maximum P* of 0.4 (herein called Alternative 1) is current control rule. Three of the control explored either had a fixed P* of 0.4 across all levels of biomass (Alternative 3), or were fixed over ranges of biomass, with stepped changes as the estimated biomass crossed specified threshold (herein called the stepped control rules, or Alternative 4 and 5; Figure 1B). The Council was interested in exploring additional control rules, particularly ones that allowed for higher catches when the biomass is above the target. Both of these options have a maximum P* of 0.49, but differ in the biomass at which the fishery closes (10% of S_{MSY} for Alternative 6 and 30% for Alternative 8), but there are also differences in the target P* once the stock biomass exceeds S_{MSY}; Figure 1 C). The final control rule include here (Alternative 7) is another ramped option with a maximum P* of 0.4, but with closure of the fishery occurring at 30% of S_{MSY}. In addition to three controls being added to the analysis, this work included updated information from assessments for each stock (NEFSC 2017, Adams, NEFSC 2019). The previous work also split out model runs based on average trends in natural mortality and recruitment to characterize different levels of future productivity. The current work differs in that larger changes in natural mortality and recruitment were explicitly included as different formulations of the operating model (described in more detail in the Methods below). Performance of each control rule across a range of management objectives was assessed by calculating metrics that summarized risk (e.g., the probability of overfishing or of becoming overfished) and reward (e.g., high, stable yield).

Methods

The MSE simulation used for this analysis model is an extension of the work of Wiedenmann et al. (2017), which was developed to test control rule performance for generic species with different life history strategies (i.e., short, medium, and long-lived). The current model was tailored to the specific dynamics of butterfish, summer flounder and scup, with species-specific parameters obtained from recent stock assessment for each stock (NEFSC 2017, Adams, NEFSC 2019). The MSE model dynamics were nearly identical for each stock, although there were some differences, described below.

The model is a closed-loop MSE (Butterworth and Punt 1999) with three main components (operating, assessment and management submodels), and was developed in AD Model Builder (Fournier 2012). The foundation of the MSE simulation is the operating model, which determines the population dynamics of the stock and how data are generated. Data generated in the operating model are based on the true state of the population with some specified amount of observation error. The operating model generated data on fishery harvests, as well as a fishery-independent index of abundance. These data were then used in the assessment model to estimate stock status and biological reference points. The assessment model was a statistical catch at age (SCAA) model, and output from the assessment was used in the management model to determine the catch limit using a particular ABC control rule. The catch limit estimated in the management model was removed from the population, without implementation error, and the simulation loop continues for a set number of years. This process was repeated 1000 times stochastically for each stock to account for the variability in the population dynamics, data generation, and assessment estimation. At the end of each run, the true and estimated values summarizing the population and fishery dynamics were stored and used to evaluate the ability of a control rule to meet multiple management objectives.

Operating, Assessment, and Management Models

The operating model was split into two periods, the historical period and the management period. Population and fishery dynamics during the historical period are based on information obtained from stock assessments for each stock (NEFSC 2017, Adams, NEFSC 2019), including the estimated abundance and selectivity at age, the observed catch, weight and maturity ate age, and the assumed natural mortality rate. The length of the management period was 30 years, while length of the historical period varied for each stock based on the number of years of estimates available in the most recent stock assessment.

Equations governing the population and data-generating dynamics are presented in Table 1, with definitions of the variables in Table 2, and parameters defined in Table 3. A key distinction between the population dynamics between the historical and management periods is that variability in the population dynamics in the historical period is constrained around values estimated in the stock assessment. Numerical abundance at age in the historical period was fixed across ages at the estimated values from the assessment. Variability in stock size in the management period is driven by variability in recruitment, natural mortality, and fishing mortality, with the variability in fishing mortality resulting from error in assessment estimates and the specific control rule being applied. Fishery and survey data generation occurs throughout both the historical and management periods, as data generated in both periods are fed into the assessment model to estimate abundance in repeated assessments.

Equations governing the dynamics in the management period are referenced by their number in Table 1, such that the formula for calculating recruitment is referred to as Eq. T1.1. Recruitment followed the Beverton-Holt stock-recruit relationship, with bias-corrected lognormally distributed and autocorrelated deviations (Eq. T1.1). Parameters for the stock-recruit relationship were estimated using a maximum likelihood approach with the estimates of spawning biomass and recruitment from each assessment for each stock (Figure 3). Total spawning biomass in a given year was calculated by summing the product of the proportion mature, weight at age and abundance at age over all recruited age classes (Eq. T1.2). Annual abundance of recruited ages was determined from the abundance of that cohort the previous year, decreased by continuous natural and fishing mortality (Eq. T1.3). Total mortality at age was the sum of fishing and natural mortality (Eq. T1.4). Natural mortality was independent of age, but varied over time following an autocorrelated process on the log scale (Eq. T1.5). Fishing mortality at age was the product of fishing intensity of fully selected ages and selectivity at age. The model contained a single fishery with a selectivity function that could either be dome-shaped on or asymptotic (logistic). Dome-shaped selectivity was assumed for scup and summer flounder, while logistic selectivity was assumed for butterfish. The selectivity ogive varied over time as the parameters that determines the first age at peak selectivity for the dome-shaped relationship and 50% selectivity in the logistic relationship varied annually in an autocorrelated manner (Eq. T1.6). This variability was included because selectivity in a fishery can vary in response to changing regulations, fishing practices, or changes in growth, although the source for the changes was not modeled explicitly. Weight and maturity at age were fixed over time in the historical period at the observed values, and fixed during the management period as the average over the most recent five years for a given age class.

The data used in the assessment were the fishery catch (both total and proportions at age) and a fishery-independent index of abundance (both total and proportions at age). These data sets were generated by applying observation error to the true values using lognormal errors for the total index and catch, and multinomial distributions for the age compositions (Eqs. T1.7 - T1.11). The amount of observation error in the generation of the data was varied by stock, with greater variability in survey CVs for scup and butterfish, and also fewer ages sampled. The effect of doing this is that the assessment estimates are more uncertain for these stocks. The rationale for this is that there is greater variability within and across years in the survey indices for these stocks compared to summer flounder, perhaps because the survey is better suited for catching summer flounder.

The time series of catch and survey data were input into the SCAA model to estimate the abundance at age, fishing mortality rates in each year, and reference points for management. Model parameters within the SCAA were estimated using a maximum likelihood approach, with the specific parameters estimated the abundance at age in the first year, recruitments and fishing mortality rates (across years), fishery selectivity parameters, survey selectivity parameters, and survey catchability. Survey catchability and age at peak selectivity in the fishery are assumed constant over time in the assessment model, even though they were varied with time in the operating model. Natural mortality was assumed to be constant over age and time at the mean value for the given stock (Table 3). All other required SCAA inputs (i.e., maturity and weight at age) are set to the true values specified in the operating model. The SCAA model also estimated the spawning potential ratio (SPR) – based reference points for scup and summer flounder, using SPR limits of 0.4 and 0.35, respectively, as these are the ratios that define the F_{MSY} proxy for these species. For butterfish, the F_{MSY} proxy is 2/3 of the assumed M in the assessment, and the S_{MSY} proxy is calculated with Monte Carlo projections as the median spawning biomass in the final year after fishing for 50 years at F_{MSY}. Including a Monte Carlo simulation following each assessment in the MSE was computationally intensive, so deterministic projections were done using the mean estimated recruitment. Comparisons were made outside of the MSE between S_{MSY} estimates from this deterministic approach to stochastic projections, and estimates of S_{MSY} were within ± 10% of one another, with most being within ± 5%.

In the management model, a harvest control rule was applied using the estimated biomass projected from the terminal assessment year over the interval between assessments (2 years for scup and summer flounder, 3 years for butterfish). The projected biomass in the first year was calculated using the terminal abundance at age, fixed weight at age, assumed M and estimated F at age in the terminal year, with recruitment assumed equal to the estimated mean. Biomass over the remaining years was estimated in the same manner, but by fishing at the estimated F_{MSY} to produce estimates of the OFL. A given control (Figure 1) then applies a buffer to set the ABC, with the size of the buffer in most of the control rules being biomass-dependent. In such cases, the estimated spawning biomass ratio (S / S_{MSY}) in each projected year is used to calculate the size of the buffer in the control rule. Note that this approach ignores the changes in abundance that might occur by setting the ABC < OFL, which would result in $F < F_{MSY}$ with accurate estimates of abundance. As a result, the deterministic projections provided more conservative estimates of the OFL because the F associated with the OFL is higher than the F associated with the ABC in most cases. The estimated ABC is then removed from the population the following year, and the resulting F is calculated using the Baranov catch equation. Control rules were applied for 30 years for each stock.

Parameterization and Model Runs

For each stock and for each control rule, the model was run for 30 years under the parameters in Table 3. To test the potential impacts that changes in productivity would have on control rule performance, two additional configurations of the operating model were explored for each stock / control rule combination. A “good” productivity run was explored where over the 30 year period the control rule is applied the mean natural mortality rate is reduced by 25% and the mean recruitment increases by 25 (although both vary over time around each mean). A “poor” productivity run was also explored where the mean natural mortality increased by 25% and the mean recruitment decreased by 25%.

Performance Measures

At the end of each run, multiple performance measures were calculated to summarize the ability of each control rule to meet a suite of management objectives (Table 4). The primary performance measures used to assess control rule performance were fishery yield, variability in fishery yield, frequency of overfishing, and the proportion of runs where the biomass dropped below the overfished threshold ($S < 0.5\ S_{MSY}$). Fishery yield was calculated over short- and long-term timespans, representing the first 5 and final 20 years, respectively. Inspection of the distribution of biomass and catch was done to ensure that transitory dynamics were not occurring in the final 15 years. The probability of overfishing was calculated as the proportion of years during the management period in which F exceeded F_{MSY}. Year-to-year variability in fishery yield was summarized by calculating the relative change yield from one year to the next, averaged across all 30 years, but also by estimating the maximum change between any two years over the entire management period.

Results

Model runs are grouped by the average, good, and poor future productivity, and median performance measures are presented by stock and productivity level in Table 4 and are also shown in Figures 3-18. Runs were also categorized based on whether the stock assessment over- or underestimated the terminal abundance, on average across assessments in the 30 year period, but for the average productivity runs only. Median performance measures by stock and assessment error are presented in Table 6. Short and long-term catch performance measures were calculated as the difference relative to the current control rule, while all other performance measures represent the actual magnitude for each Alternative. Discussion of performance here is grouped by whether the control rules were fixed or stepped (Alternatives 3, 4, and 5), or whether they were ramped (Alternatives 1, 2, 6, 7, 8).

Fixed and Stepped P Control Rules (Alternatives 3, 4 and 5).*

In general, the fixed P* and ramped P* control rules performed well across the range of objectives for all stocks, particularly under average and good future productivity. For butterfish across all productivity levels, Alternatives 4 and 5 (with a max P* of 0.45) produced the highest long-term catch (Figure 6; Table 5). These Alternatives also produced some of the highest yields for summer flounder under average and poor future productivity, and high yields (but not the highest) for scup across all productivities, and for summer flounder under good future productivity (Figures 4 and 5). Short-term catch was also calculated, but because summer flounder was the only stock below the biomass target of S_{MSY}, this was the only stock where overall control rule performance differed between short- and long-term catch. Alternatives 3 and 4 had the highest short-term yield for summer flounder, followed by Alternative 5 which had a lower target P* of 0.35 when the stock is below 75% of S_{MSY} (Figure 3). When assessments either under-or overestimated biomass, Alternatives 4 and 5 often had the highest short- and long- term catch across stocks and productivity scenario (Table 6).

The fixed and stepped control rules also had the benefit of having the lowest variability in catch, with the fixed P* of 0.4 control rule (Alternative 3) having the most stable catch overall, with average changes of 10-12% for butterfish, 8-14% for summer flounder, and 8-12% for scup across productivity scenarios. Alternative 3 also had the lowest maximum change in catch between years, with changes of 27-32% for butterfish, 26-30% for summer flounder, and 24-28% for scup across productivity scenarios. Differences in catch variability between Alternatives 3, 4, and 5 and the ramped control rules were less pronounced for Scup under average and good productivity, owing to the biomass starting well above S_{MSY} and tending to remain there over much of the 30-year period (Table 5).

Although the fixed and stepped P* control rules resulted in the most stable catch, and often very high if not the highest catch for given stock and productivity scenario, they resulted in some of the highest risks of overfishing and of causing a stock to become overfished. For scup and summer flounder under average and poor productivity, Alternatives 3-5 had a risk of overfishing below 0.5, with higher risk for control rules with a higher maximum P* (Alternatives 4 and 5) under average productivity (Figures 13 and 15; Table 5)). Similarly, the risk of becoming overfished for these stocks increased with higher maximum P* targets, and were between 15-24% for summer flounder and 21-26% for scup under average productivity (Figures 14 and 16; Table 5). Under poor productivity for summer flounder and scup, Alternative 3-5 had the highest risk of overfishing compared to the ramped control rules, and for summer flounder Alternatives 3 and 4 had a probability of overfishing above 0.5, meaning overfishing was more likely to occur than not. For summer flounder under poor productivity, these Alternative also had the highest risk of causing the stock to become overfished (87% for 3 and 4 compared to the lowest risk of 71% for Alternative 7; Figure 14). For scup under poor productivity, Alternatives 4 and 5 had risk of becoming overfished of 63 and 62%, respectively, but there was less difference overall between these and the ramped control rules (Figure 16). When assessments for scup and summer flounder tended to overestimate biomass, the risks of overfishing and of becoming overfished increased with the maximum P* allowed, so Alternative 4 and 5 had some of the highest risks overall, and exceeded the 50% overfishing threshold for summer flounder for Alternative 4, and Alternatives 3, 4, and 5 for scup (Table 6).

For butterfish across productivity scenarios, Alternatives 3,4, and 5 also had the highest risk of overfishing and of becoming overfished (Figures 17 and 18; Table 5). However, the highest risk of overfishing occurred under good productivity, with a risk of 61% for Alternative 3 and 4 and 52% for Alternative 5, compared to a risk of 10-19% for the ramped control rules (Table 5). Under good productivity for butterfish, assessment error increased leading to inflated estimates of the OFL, but this did not occur of summer flounder or scup. Although the risk of overfishing was very high under good productivity, the risk of becoming overfished was only 12-16% for these control rules, since the increased productivity kept biomass relatively high. Under average productivity for butterfish the risk of becoming overfished for Alternative 3, 4, and 5 was 65, 71, and 69%, respectively, and under poor productivity all control rules (Alternatives 1-8) resulted in a 100% chance of the stock becoming overfished (Table 5).

Ramped Control Rules (*Alternatives 1, 2, 6, 7, and 8*)

Performance across the ramped control rules was more variable across productivity runs for each stock, owing to large differences in the size of the buffer above and below S_{MSY} (Figure 1). For butterfish, Alternative 2 had consistently high long-term yield compared to the other Alternatives. Because butterfish biomass is inherently more variable due to its high natural mortality and recruitment variability, Alternative 7 and 8, which are the most conservative as the stock declines, tended to have the lowest yield for butterfish (Figure 6). For summer flounder, Alternative 2 had the highest short-term yield of all ramped control rules across productivity levels (Figure 3). Alternative 2 also had the highest long-term yield of the ramped control rules for summer flounder under poor productivity, and near the highest yield under average productivity. Under good productivity, however, Alternatives 6 and 8 with a maximum P* of 0.49 had the highest long-term yield (Figure 4; Table 5). Similarly for scup, which had biomass well above S_{MSY} at the start of the management period, highest catches occurred for Alternatives 8 and 6 under average and good productivity. Under poor productivity, however, Alternative 2 had the highest long-term yield for scup (Figure 5). When assessments tended to underestimate biomass, Alternative 2 performed well with high long-term yield across stocks compared to other ramped control rules. When assessments overestimated biomass, Alternative 2 also produced high long-term yield, but so did Alternatives 8 and 6 (Table 6).

The ramped control rules resulted in greater variability in catch compared to the fixed and stepped P* control rules. In general, the more rapidly the target P* changed with biomass, the more variable the catch was overall, particularly for stocks under poor productivity. As a result, options 7 and 8 had the greatest average variability in catch, as well as the greatest maximum change in catch between years across stocks, whereas Alternatives 1 and 2 had the lowest (Figures 7-12; Table 5). For butterfish ramped control rules resulted in average interannual changes between 15-27%, and maximum changes between 45-78% across productivity levels. For summer flounder they resulted in average interannual changes between 9-23%, and maximum changes between 31-64% across productivity levels. Finally for scup, ramped control rules resulted in average changes in catch of 8-15% and maximum changes of 24-42% (Table 5).

In general, the risks of overfishing and of becoming overfished were lower for the ramped control rules, although the differences relative to Alternative 3, 4, and 5 varied by stock and productivity scenario. Across productivity levels for each stock, all of the ramped control rules resulted in a risk of overfishing below the 50% threshold (Table 5), with higher risk with higher maximum target P*. When assessments overestimated biomass for scup, however, only the ramped options with a maximum P* of 0.4 did not cross the 50% threshold (Alternatives 1 and 7; Table 6). The risk of becoming overfished also increased with the maximum P* target, and was lowest for Alternatives 1 and 7 across stocks and productivity levels. The exception to pattern was butterfish under poor productivity, where the risk of becoming overfished was 100% across all control rules (Table 5).

Conclusions

A range of ABC control rule alternatives were tested using an MSE for scup, summer flounder, and butterfish. These control rules varied in their maximum allowable P*, and in how the P* changed as biomass declined (Figure 1). Performance of the control rules relative to one another was evaluated by comparing short- and long-term yields to the fishery, variability in yield, the risk of overfishing, and the risk of driving the population to low levels (below 50% S_{MSY}). Variability in future stock productivity (recruitment and natural mortality) were incorporated in the model, and comparison of control rule performance was evaluated across 1) the baseline (average productivity) model runs, 2) under good future conditions only, and 3) under poor future conditions. Runs were also separated based on assessment error into those that tended to under- or overestimate biomass, on average.

In general, the fixed and stepped Alternatives (3,4,5) produce greater benefits to the fishery, with high stable short- and long-term catches across stocks and productivity levels. However, with greater reward comes greater risk, as these control rules also had the greatest risks of overfishing and causing the stocks to become overfished. In some cases the risk of overfishing exceeded the 50% threshold, occurring for summer flounder and scup under poor productivity, and for butterfish under good productivity. The risk of overfishing also exceed 50% for summer flounder under Alternatives 3, and 4, and Alternative 5 for scup when the assessment overestimated biomass. Ramped control rules, on the other hand, had lower risks of overfishing and of becoming overfished, particularly under average and poor productivity conditions across stocks. In general, ramped options with higher maximum P* had higher yield, on average, particularly under average and good productivity. An exception this pattern was for butterfish under Alternative 8, which had a maximum P* of 0.49, but was also more conservative as the stock declined below S_{MSY}. For summer flounder, which started below S_{MSY}, the ramped control rules had larger differences in short-term yield with Alternatives 3, 4, and 5 compared to long-term yield. Ramped control rules had greater variability in yield overall, with the greatest variability occurring for options with more rapid changes in the target P* with biomass (Alternatives 6, 7, and 8). Of the ramped control rules, Alternative 2 seemed the best able to balance the tradeoffs, resulting in relatively high catch, low risks of overfishing and becoming overfished, and lower variability in catch compared to most of the ramped Alternatives.

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Table 1. Equations governing the population and data-generating dynamics in the operating model.

	Equation	Description
	Population, life history and fishing dynamics	
1	$R(t) = \frac{S(t-a_R)}{\alpha + \beta S(t-a_R)} e^{\varepsilon_R - 0.5\sigma_R^2}$ $\alpha = \frac{S_0(1-h)}{4hR_0} \qquad \beta = \frac{5h-1}{4hR_0}$ $\varepsilon_R(t) = \rho_R \varepsilon_R(t-1) + \sqrt{1-\rho_R^2}\varphi_R(t)$ $\varphi_R(t) \sim N(0, \sigma_R^2)$	Stock-recruit relationship
2	$S(t) = \sum_a m(a)w(a)N(a,t)$	Spawning biomass
3	$N(a,t) = \begin{cases} R(t) & a = a_R \\ N(a-1,t-1)e^{-Z(a-1,t-1)} & a_R < a < a_{max} \\ N(a-1,t-1)e^{-Z(a-1,t-1)} + N(a,t-1)e^{-Z(a,t-1)} & a = a_{max} \end{cases}$	Numerical abundance at age
4	$Z(a,t) = M(t) + s(a,t)F(t)$	Total mortality

5	$M(t) = \bar{M} e^{\varepsilon_M(t) - 0.5\sigma_M^2}$ $\varepsilon_M(t) = \rho_M \varepsilon_M(t-1) + \sqrt{1-\rho_M^2}\varphi_M(t)$ $\varphi_M(t) \sim N(0, \sigma_M^2)$	Time-varying natural mortality
6a	$s(a,t) = \frac{1}{1+e^{-\frac{a-s_{50}(t)}{s_{slope}}}}$ $s_{50\%}(t) = \bar{s}_{50\%} e^{\varepsilon_s(t) - 0.5\sigma_s^2}$ $\varepsilon_s(t) = \rho_s \varepsilon_s(t-1)1) + \sqrt{1-\rho^2}\varphi(t))$ $\varphi(t) \sim N(0, \sigma_s^2)$	Logistic selectivity at age in fishery or survey, with time varying selectivity only in the fishery
6b	$s(a,t) = \begin{cases} e^{\frac{-(a-a_{mid})}{s_{up}}} & a \leq a_{mid} \\ e^{\frac{-(a-a_{mid})}{s_{down}}} & a > a_{mid} \end{cases}$ $s_{mid}(t) = \bar{s}_{mid} e^{\varepsilon_s(t) - 0.5\sigma_s^2}$ $\varepsilon_s(t) = \rho_s \varepsilon_s(t-1)1) + \sqrt{1-\rho^2}\varphi(t))$ $\varphi(t) \sim N(0, \sigma_s^2)$	Dome-shaped selectivity at age in fishery

7	$C(a,t) = \frac{s(a,t)F(t)}{Z(a,t)} w(a)N(a,t)\left(1 - e^{-Z(a,t)}\right)$ $C(t) = \sum_a C(a,t)$	Annual catch at age and total catch
	Data-generating dynamics	
8	$C_{obs}(t) = C(t)^{\varepsilon_C(t) - 0.5\sigma_C^2}$ $\varepsilon_C(t) \sim N(0, \sigma_C^2)$	Observed catch
9	$I(a,t) = q(t)s_s(a)N(a,t)$ $I(t) = \sum_a I(a,t)$ $q(t) = qe^{\varepsilon_q(t) - 0.5\sigma_q^2}$ $\varepsilon(t) \sim N(0, \sigma_q^2)$	True index of abundance
10	$I_{obs}(t) = I(t)^{\varepsilon_I(t) - 0.5\sigma_I^2}$ $\varepsilon_I(t) \sim N(0, \sigma_I^2)$	Observed index of abundance
11	$\mathbf{p}_{obs}(t) = \frac{1}{n}\mathbf{\Theta}(t)$ $\mathbf{\Theta}(t) \sim Multinomial(n, \mathbf{p}(t))$ $\mathbf{p}(t) = \frac{1}{I(t)}(I(a_R,t), \dots, I(a_{max},t))$	Observed vector of proportion at age in fishery *f*

Table 2. Description of the index and state variables used in equations in the model (presented in Table 1). Parameter descriptions and values used are presented in Table 3.

Symbol	Description
Index variables	
t	Year
a	Age
State variables	
N	Numerical abundance
S	Spawning biomass (kg)
L	Length (cm)
w	Weight (kg)
m	Maturity (proportion)
s_s	Survey selectivity (proportion)
s_f	Fishery selectivity (proportion)
F	Fishing mortality rate (year^{-1})
M	Natural mortality rate
Z	Total mortality rate (year^{-1})
C	Total fishery catch (kg)
C_{obs}	Observed fishery catch (kg)
p_C	Proportions at age in catch
$p_{C,obs}$	Observed proportion at age in catch
I	Survey numerical index of abundance
I_{obs}	Observed survey numerical index of abundance
q	Survey catchability
p_I	Proportions at age in survey
$p_{I,obs}$	Observed proportion at age in survey

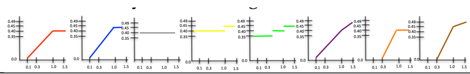
Table 3. Parameter values used in the model for each species. Note that for butterfish, the F_{MSY} reference point is set at 2/3 • M and is not based on a SPR calculation.

Parameter	Description	Butterfish	Summer flounder	Scup
a_R	Age at recruitment (to population)	1	1	1
a_{max}	Maximum age (a plus group)	5	8	8
$\overline{M}$	Mean natural mortality rate	1.22	0.25	0.2
σ_M	standard deviation of time-varying *M*	0.1	0.1	0.1
ρ_M	autocorrelation in *M*	0.3	0.3	3
h	Steepness	0.85	0.9	0.92
R_0	Virgin recruitment	7877266	48000	134111
S_0	Unfished spawning biomass	93747	150000	320732
σ_R	standard deviation of stock-recruit relationship	0.5	0.5	0.5
ρ_R	autocorrelation in recruitment	0.44	0.44	0.6
$\overline{s}_{f,peak}$	Age at maximum selectivity in dome-shaped function	3.0	5.0	4.0
$s_{f,up}$, $s_{f,down}$	Controls how rapidly selectivity increases / decreases	1.5 / 20.0	1.73 / 5.44	3.67 / 2.09
σ_s	standard deviation of age at 50% or peak selectivity	0.01	0.15	0.1
ρ_s	autocorrelation in selectivity	0.3	0.2	
$\overline{s}_{s,50\%}$	mean age at 50% selectivity in survey	0.5	0.5	0.5
$s_{s,slope}$	Slope of survey selectivity function	1	1	1
σ_C	standard deviation of catch estimates	0.29	0.2	0.2
σ_I	standard deviation of survey estimates	0.47	0.29	0.63
$\overline{q}$	mean catchability in survey	5×10^{-5}	5×10^{-5}	5×10^{-5}
σ_q	standard deviation of catchbility random walk	0.01	0.05	0.05
n_C	effective sample size of the catch	50	100	50
n_I	effective sample size of the survey	50	100	50
SPR_{lim}	Spawning potential ratio (SPR) that defines overfising	-	0.35	0.4
F_{MSY}	Fishing mortality rate that defines overfishing	0.81	0.3	0.22

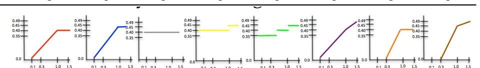
Table 4. Performance measures calculated for different time periods at the end of each model run. The average change in the catch is calculated following Punt (2003) as $\sum_{t>1}|C(t) - C(t-1)| / \sum_t C(t)$

Performance Measure	Description	Time Period(s)
Initial catch	Mean catch	first 5 years
Long-term catch	Mean catch	final 20 years
Average change in catch	Average relative interannual variation in catch	all years
Maximum change in catch	Maximum relative change in catch between any two years of the 30-year period	all years
Probability of overfishing (P_{OF})	Proportion of years when $F > F_{MSY}$	all years
Risk of becoming overfished	Proportion of runs where the stock becomes overfished ($S < 0.5\ S_{MSY}$)	all years

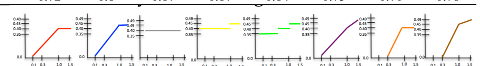
Table 5. Median performance measures for each stock by productivity scenario. Short- and long-term catch values are calculated as the difference between each control rule and the current control rule (Alt. 1), with positive and negative values meaning higher and lower catch, respectively, on average.



	Performance Measure	Productivity	Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6	Alt.7	Alt.8
Butterfish	Short-term catch	Average	0	2,754	3,823	5,575	4,592	2,077	-895	2,257
	Short-term catch	Good	0	5,248	14,250	15,755	12,452	676	-4,287	633
	Short-term catch	Poor	0	1,306	3,930	4,591	3,553	671	-497	891
	Long-term catch	Average	0	2,464	4,547	5,981	5,022	1,699	-1,200	1,894
	Long-term catch	Good	0	3,852	37,255	36,008	31,631	995	-43,270	-10,495
	Long-term catch	Poor	0	1,094	2,979	3,623	2,828	790	-183	1,063
	Max. change in catch	Average	0.38	0.41	0.27	0.27	0.29	0.44	0.45	0.52
	Max. change in catch	Good	0.5	0.51	0.32	0.32	0.31	0.49	0.64	0.59
	Max. change in catch	Poor	0.51	0.55	0.27	0.29	0.31	0.57	0.73	0.78
	Avg. change in catch	Average	0.16	0.16	0.12	0.12	0.13	0.17	0.18	0.19
	Avg. change in catch	Good	0.15	0.15	0.1	0.1	0.09	0.15	0.26	0.18
	Avg. change in catch	Poor	0.2	0.21	0.12	0.13	0.14	0.21	0.25	0.27
	Overfishing prob.	Average	0.06	0.13	0.16	0.19	0.19	0.13	0.06	0.15
	Overfishing prob.	Good	0.16	0.19	0.61	0.61	0.52	0.16	0.1	0.13
	Overfishing prob.	Poor	0.13	0.19	0.32	0.35	0.29	0.19	0.16	0.23
	Overfished prob.	Average	0.54	0.64	0.65	0.71	0.69	0.64	0.51	0.65
	Overfished prob.	Good	0.03	0.04	0.15	0.16	0.12	0.02	0.02	0.02
	Overfished prob.	Poor	1	1	1	1	1	1	1	1

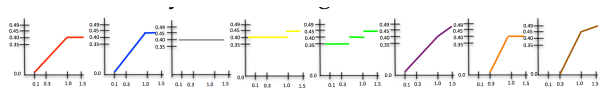


	Performance Measure	Productivity	Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6	Alt.7	Alt.8
Summer flounder	Short-term catch	Average	0	564	1,226	1,226	1,110	0	-319	216
	Short-term catch	Good	0	575	1,222	1,222	1,025	0	-304	178
	Short-term catch	Poor	0	548	1,169	1,169	1,000	0	-309	178
	Long-term catch	Average	0	579	94	566	639	451	-6	574
	Long-term catch	Good	0	1,566	-114	1,526	1,530	2,108	29	2,381
	Long-term catch	Poor	0	194	357	390	293	31	-83	169
	Max. change in catch	Average	0.36	0.42	0.26	0.31	0.34	0.45	0.4	0.51
	Max. change in catch	Good	0.31	0.34	0.27	0.3	0.31	0.4	0.32	0.4
	Max. change in catch	Poor	0.47	0.52	0.3	0.33	0.35	0.51	0.56	0.64
	Avg. change in catch	Average	0.14	0.15	0.12	0.13	0.14	0.16	0.15	0.17
	Avg. change in catch	Good	0.09	0.09	0.08	0.09	0.09	0.11	0.09	0.11
	Avg. change in catch	Poor	0.18	0.2	0.14	0.15	0.16	0.19	0.2	0.23
	Overfishing prob.	Average	0.13	0.23	0.13	0.19	0.19	0.19	0.1	0.26
	Overfishing prob.	Good	0	0	0	0	0	0.03	0	0.06
	Overfishing prob.	Poor	0.32	0.39	0.58	0.58	0.48	0.32	0.32	0.39
	Overfished prob.	Average	0.14	0.23	0.15	0.24	0.23	0.24	0.14	0.27
	Overfished prob.	Good	0.03	0.05	0.03	0.05	0.05	0.06	0.02	0.06
	Overfished prob.	Poor	0.72	0.8	0.87	0.87	0.84	0.75	0.71	0.78

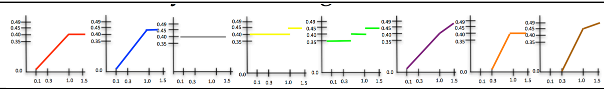


	Performance Measure	Productivity	Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6	Alt.7	Alt.8
Scup	Short-term catch	Average	0	992	0	992	992	1,861	0	1,861
	Short-term catch	Good	0	1,079	0	1,079	1,079	2,000	0	2,000
	Short-term catch	Poor	0	939	0	939	939	1,749	0	1,749
	Long-term catch	Average	0	584	84	746	685	670	-14	944
	Long-term catch	Good	0	1,592	20	1,628	1,628	2,428	0	2,670
	Long-term catch	Poor	0	111	473	502	355	-153	-28	9
	Max. change in catch	Average	0.27	0.28	0.26	0.27	0.27	0.3	0.27	0.3
	Max. change in catch	Good	0.24	0.25	0.24	0.25	0.25	0.27	0.24	0.27
	Max. change in catch	Poor	0.32	0.34	0.28	0.29	0.3	0.36	0.35	0.42
	Avg. change in catch	Average	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.12
	Avg. change in catch	Good	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08
	Avg. change in catch	Poor	0.12	0.13	0.12	0.12	0.12	0.14	0.13	0.15
	Overfishing prob.	Average	0.1	0.26	0.1	0.23	0.23	0.29	0.1	0.32
	Overfishing prob.	Good	0	0	0	0	0	0.06	0	0.06
	Overfishing prob.	Poor	0.32	0.39	0.39	0.45	0.42	0.39	0.32	0.39
	Overfished prob.	Average	0.21	0.26	0.21	0.26	0.26	0.27	0.21	0.27
	Overfished prob.	Good	0.05	0.08	0.05	0.09	0.09	0.1	0.05	0.11
	Overfished prob.	Poor	0.55	0.61	0.57	0.63	0.62	0.6	0.55	0.63

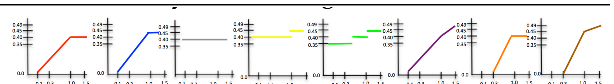
Table 6. Median performance measures for each stock for runs separated by whether or not the assessment tended to over- or underestimate biomass, on average over the 30 year period. Short- and long-term catch values are calculated as the difference between each control rule and the current control rule (Alt. 1), with positive and negative values meaning higher and lower catch, respectively, on average.



Stock	Performance Measure	Aseesment Error	Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6	Alt.7	Alt.8
	Short-term catch	Under	-	2,844	3,257	5,386	4,707	1,844	-1,207	2,616
	Short-term catch	Over	-	2,489	2,673	5,419	5,019	2,807	-820	3,013
	Long-term catch	Under	-	2,483	4,632	6,318	5,123	1,861	-1,526	1,787
	Long-term catch	Over	-	2,354	3,281	4,910	3,970	2,239	-962	2,482
	Max. change in catch	Under	0.37	0.39	0.26	0.27	0.28	0.43	0.44	0.51
Butterfish	Max. change in catch	Over	0.41	0.44	0.29	0.3	0.32	0.47	0.46	0.55
	Average change in catch	Under	0.15	0.16	0.11	0.12	0.12	0.17	0.17	0.19
	Average change in catch	Over	0.17	0.18	0.13	0.14	0.15	0.19	0.18	0.2
	Overfishing prob.	Under	0.03	0.1	0.1	0.16	0.13	0.1	0.03	0.13
	Overfishing prob.	Over	0.19	0.27	0.26	0.35	0.32	0.26	0.19	0.29
	Overfished prob.	Under	0.47	0.57	0.59	0.66	0.63	0.55	0.43	0.57
	Overfished prob.	Over	0.7	0.8	0.77	0.82	0.83	0.83	0.68	0.82



Stock	Performance Measure	Aseesment Error	Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6	Alt.7	Alt.8
	Short-term catch	Under	-	462	1,643	1,651	1,245	43	-394	24
	Short-term catch	Over	-	866	771	901	899	218	-106	699
	Long-term catch	Under	-	846	115	917	878	712	-19	1,026
Summer	Long-term catch	Over	-	335	141	402	476	182	92	349
Flounder	Max. change in catch	Under	0.34	0.37	0.24	0.28	0.31	0.41	0.37	0.45
	Max. change in catch	Over	0.4	0.46	0.3	0.35	0.39	0.51	0.43	0.58
	Average change in catch	Under	0.13	0.14	0.11	0.12	0.13	0.15	0.14	0.16
	Average change in catch	Over	0.15	0.16	0.13	0.14	0.15	0.19	0.16	0.19
	Overfishing prob.	Under	0	0	0	0	0	0	0	0.06
	Overfishing prob.	Over	0.32	0.47	0.39	0.52	0.48	0.45	0.32	0.48
	Overfished prob.	Under	0	0.01	0	0.02	0.01	0.02	0	0.04
	Overfished prob.	Over	0.29	0.5	0.32	0.5	0.48	0.5	0.3	0.57



Stock	Performance Measure	Aseesment Error	Alt.1	Alt.2	Alt.3	Alt.4	Alt.5	Alt.6	Alt.7	Alt.8
	Short-term catch	Under	-	2,844	3,257	5,386	4,707	1,844	-1,207	2,616
	Short-term catch	Over	-	2,489	2,673	5,419	5,019	2,807	-820	3,013
	Long-term catch	Under	-	2,483	4,632	6,318	5,123	1,861	-1,526	1,787
	Long-term catch	Over	-	2,354	3,281	4,910	3,970	2,239	-962	2,482
	Max. change in catch	Under	0.23	0.24	0.23	0.23	0.24	0.26	0.23	0.26
Scup	Max. change in catch	Over	0.34	0.37	0.32	0.34	0.34	0.38	0.34	0.4
	Average change in catch	Under	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Average change in catch	Over	0.14	0.14	0.13	0.14	0.14	0.15	0.14	0.15
	Overfishing prob.	Under	0	0	0	0	0	0	0	0
	Overfishing prob.	Over	0.47	0.55	0.52	0.58	0.58	0.55	0.45	0.58
	Overfished prob.	Under	0.01	0.03	0.01	0.03	0.03	0.03	0.01	0.03
	Overfished prob.	Over	0.44	0.51	0.45	0.51	0.51	0.53	0.44	0.54

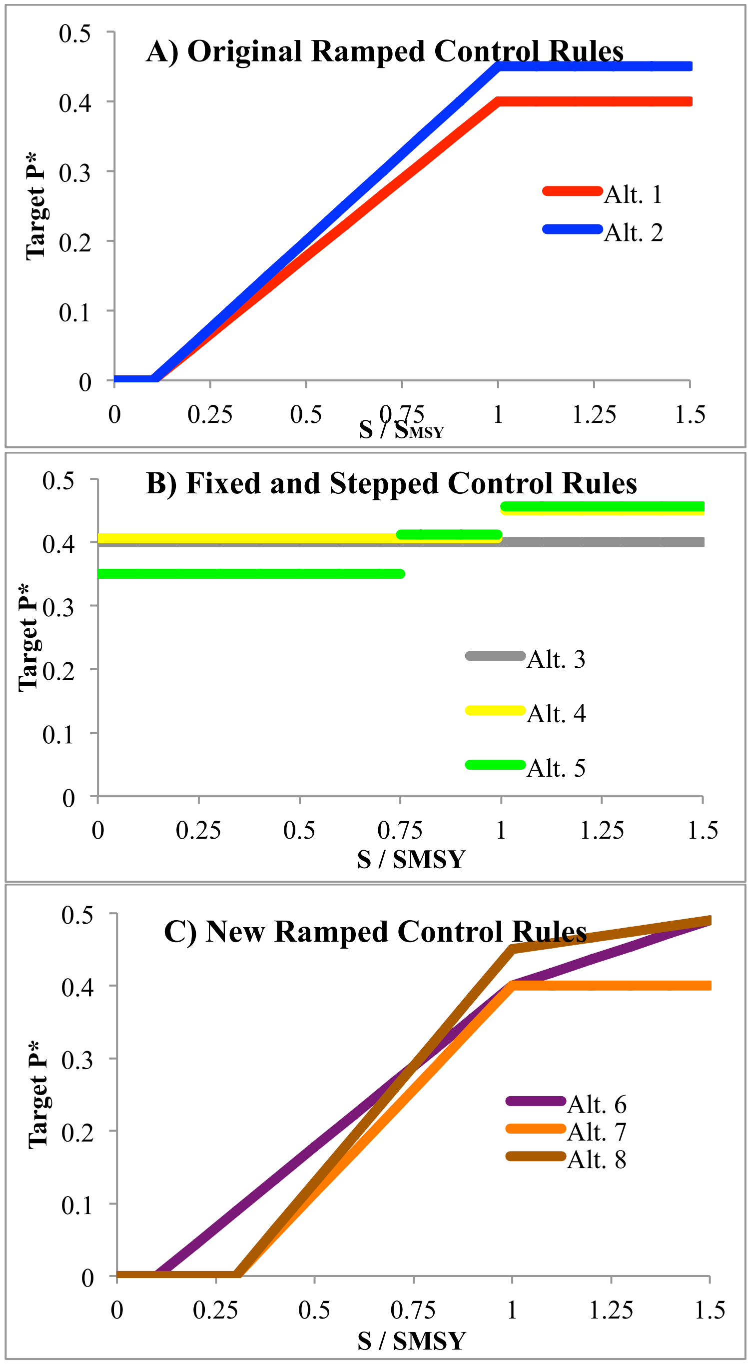


Figure 1. Control rules explored in this work, showing the target P*. Those in panel C are new from the previous work. Alternatives 3-5 (panel B) are offset slightly to prevent overlap. Colors for all control rules will be used consistently throughout this report.

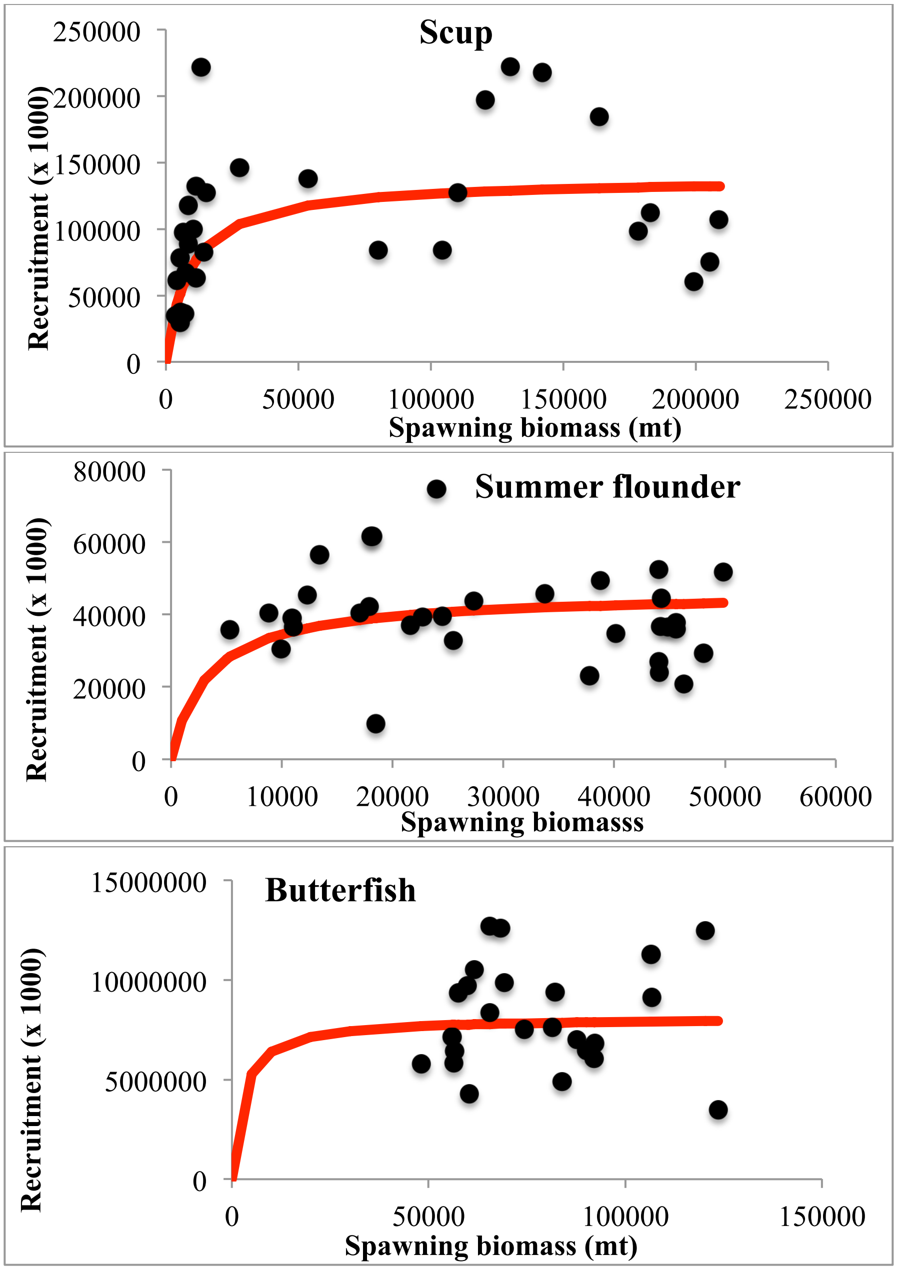


Figure 2. Stock-recruit relationship for each stock based on maximum likelihood fits of the Beverton-Holt model (red line) to the estimates of spawning biomass and recruitment (black circles) from the most recent stock assessment for each stock.

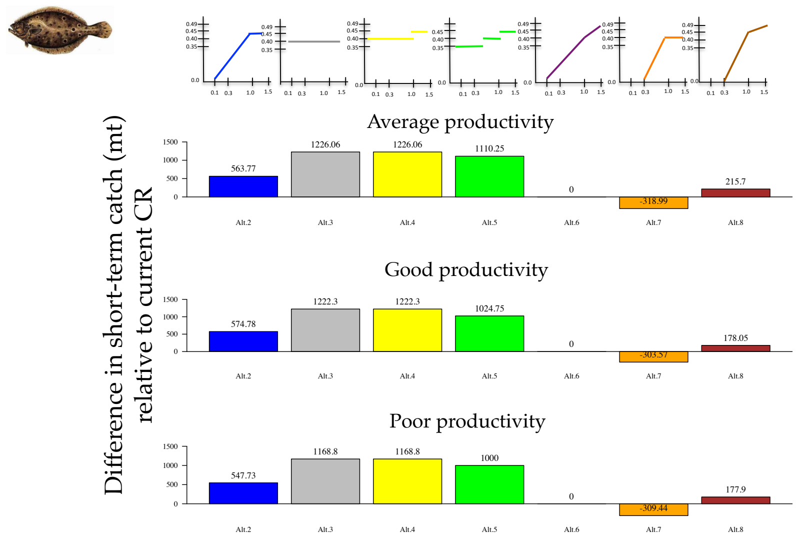


Figure 3. Difference in average catch in first 5 years of control rule implementation for summer flounder for each alternative control rule relative to the current control rule.

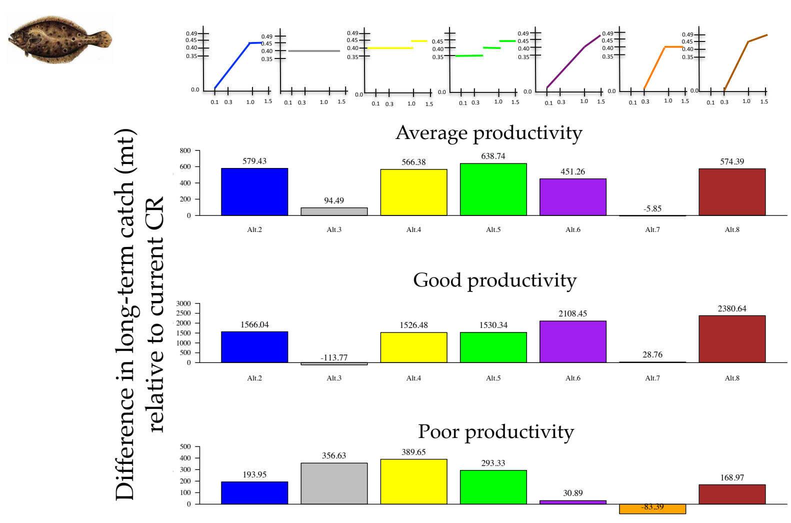


Figure 4. Difference in average catch in final 20 years of control rule implementation for summer flounder for each alternative control rule relative to the current control rule.

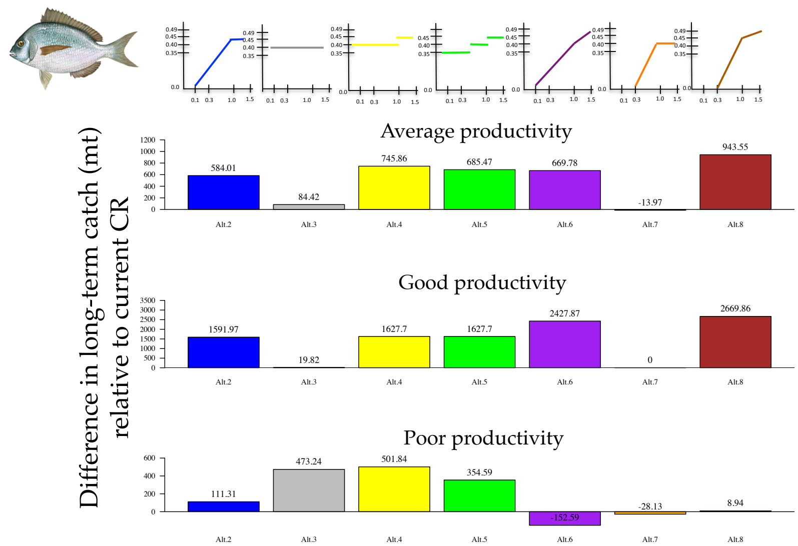


Figure 5. Difference in average catch in final 20 years of control rule implementation for scup for each alternative control rule relative to the current control rule.

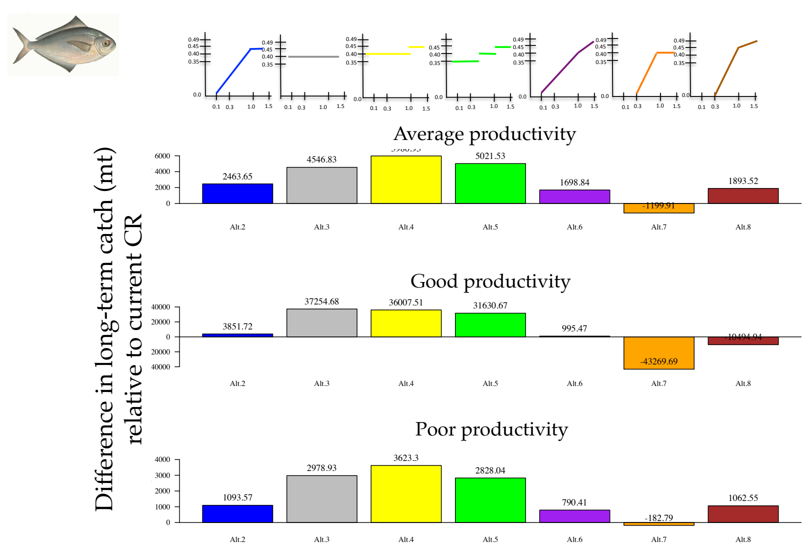


Figure 6. Difference in average catch in final 20 years of control rule implementation for butterfish for each alternative control rule relative to the current control rule.

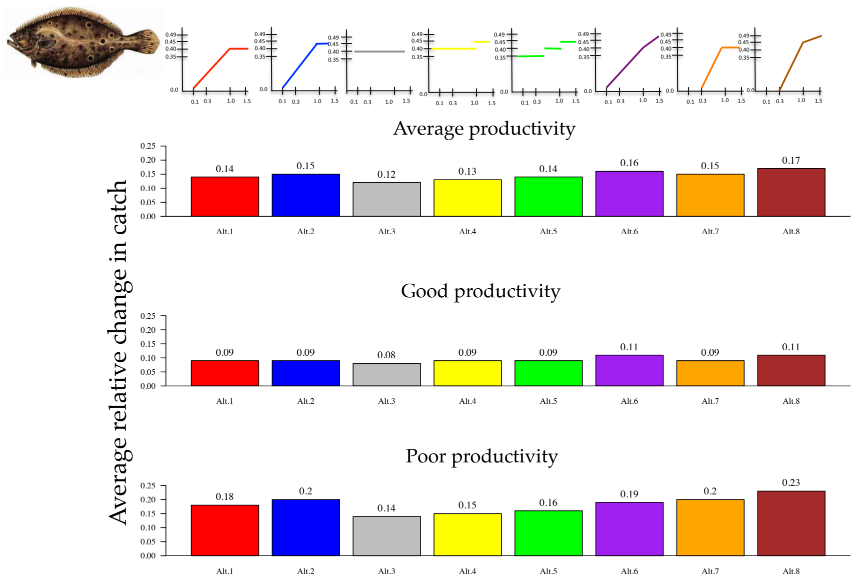


Figure 7. Change in relative catch for summer flounder between years averaged over the entire 30 year period.

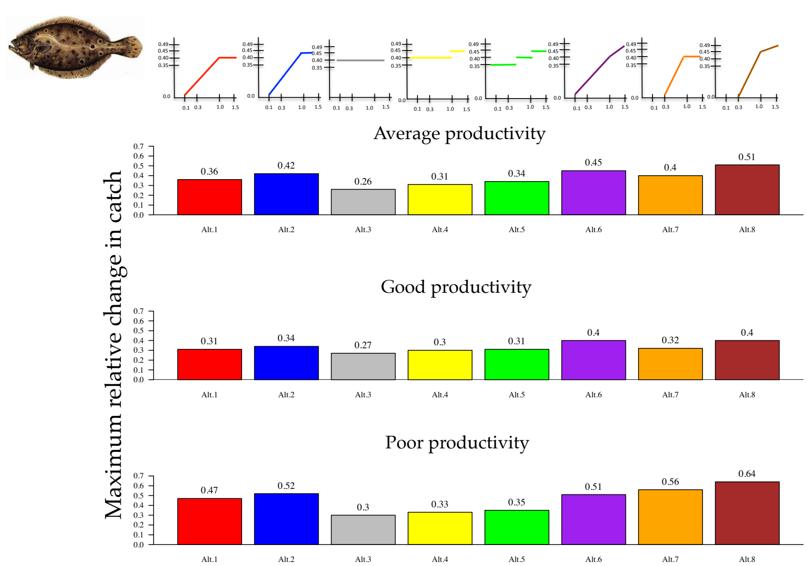


Figure 8. Maximum change in relative catch for scup between any two years over the entire 30-year period.

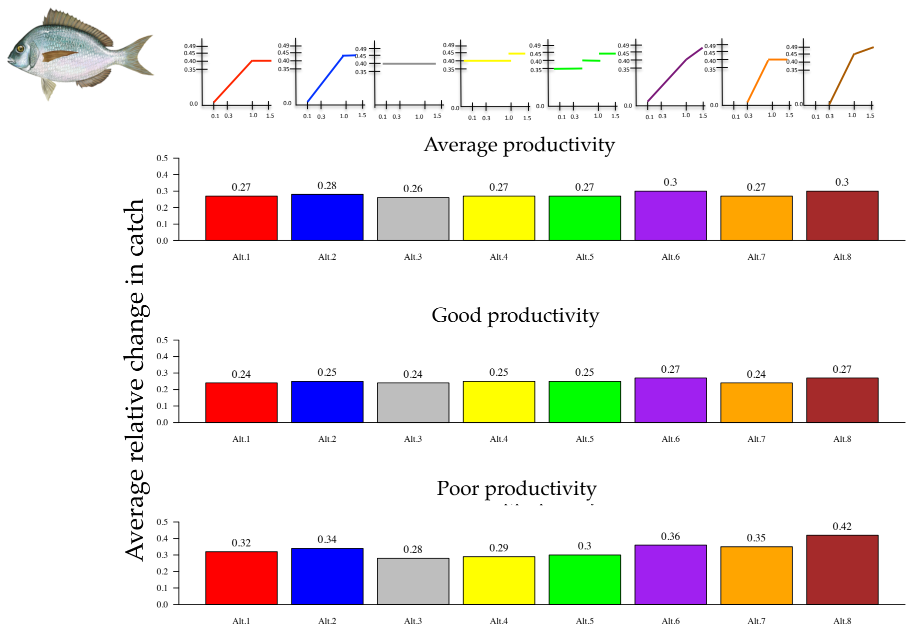


Figure 9. Change in relative catch for scup between years averaged over the entire 30-year period.

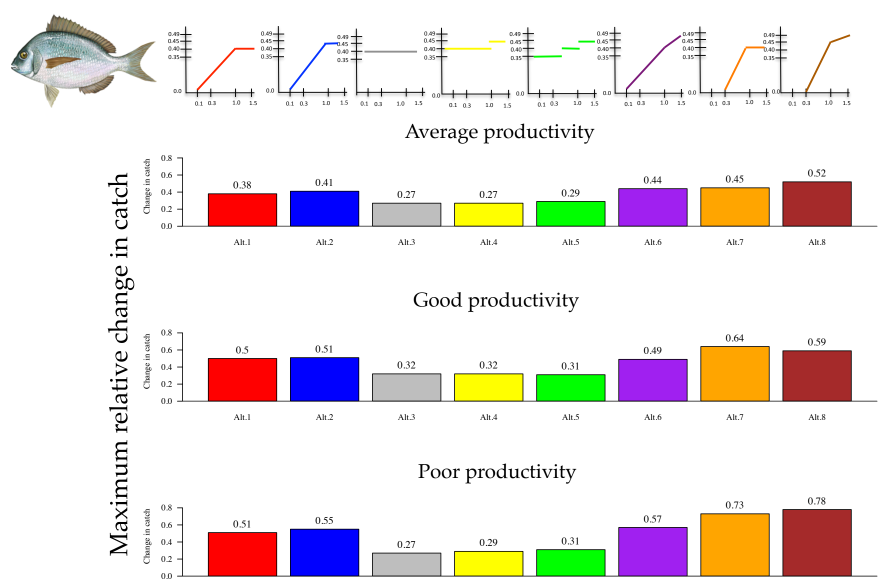


Figure 10. Maximum change in relative catch for scup between any two years over the entire 30-year period.

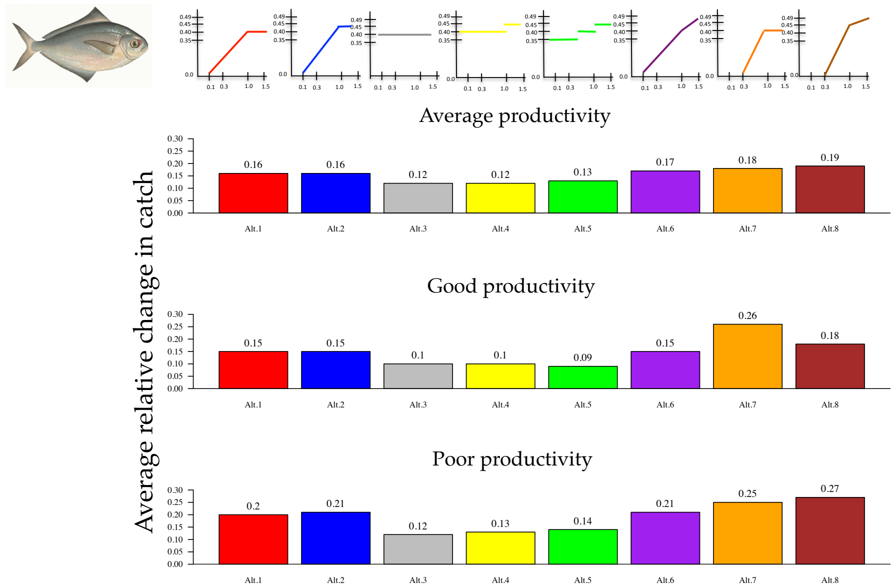


Figure 11. Change in relative catch for butterfish between years averaged over the entire 30-year period.

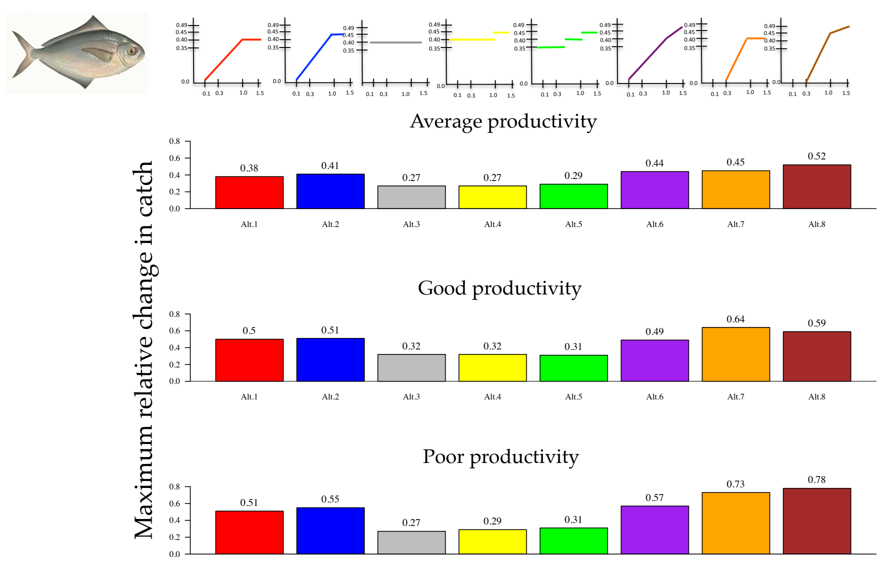


Figure 12. Maximum change in relative catch for scup between any two years over the entire 30-year period.

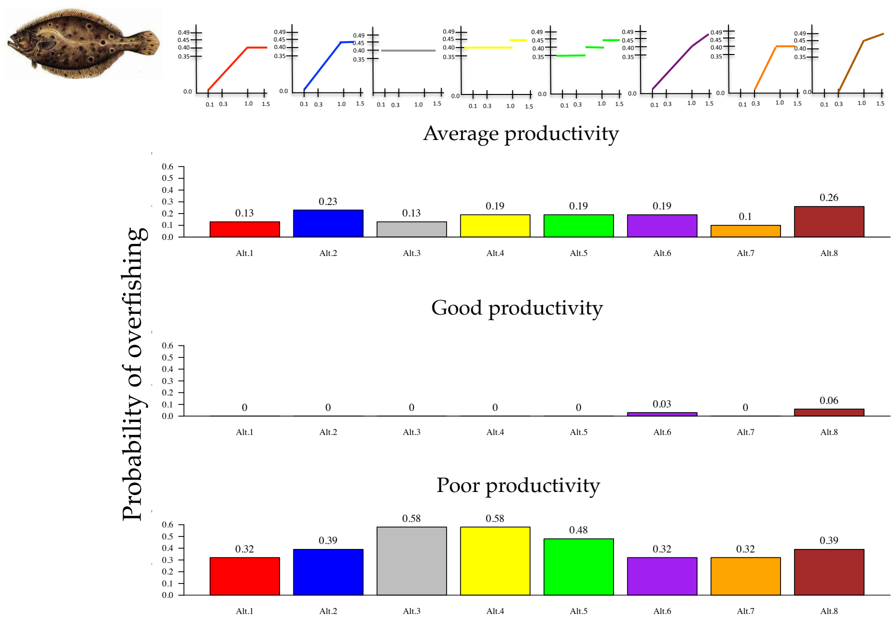


Figure 13. Median probability of overfishing for summer flounder by control rule.

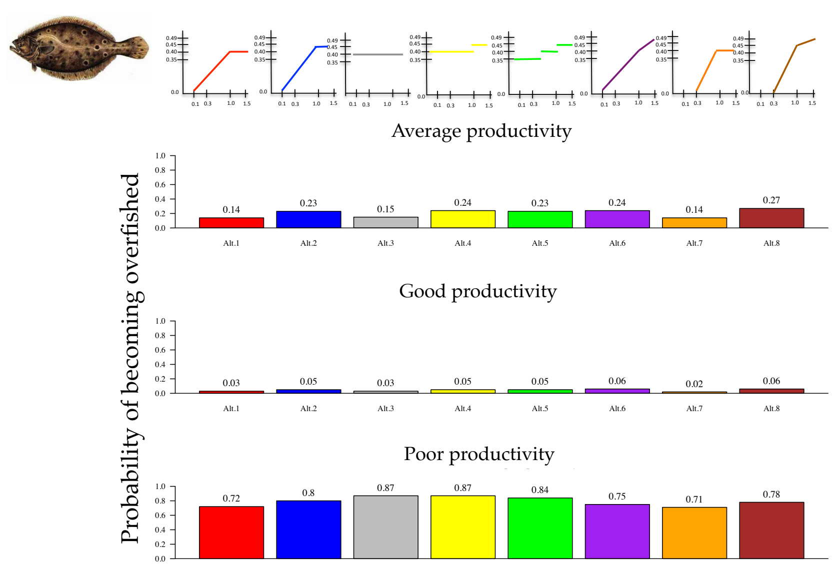


Figure 14. Median probability of becoming overfished for summer flounder by control rule.

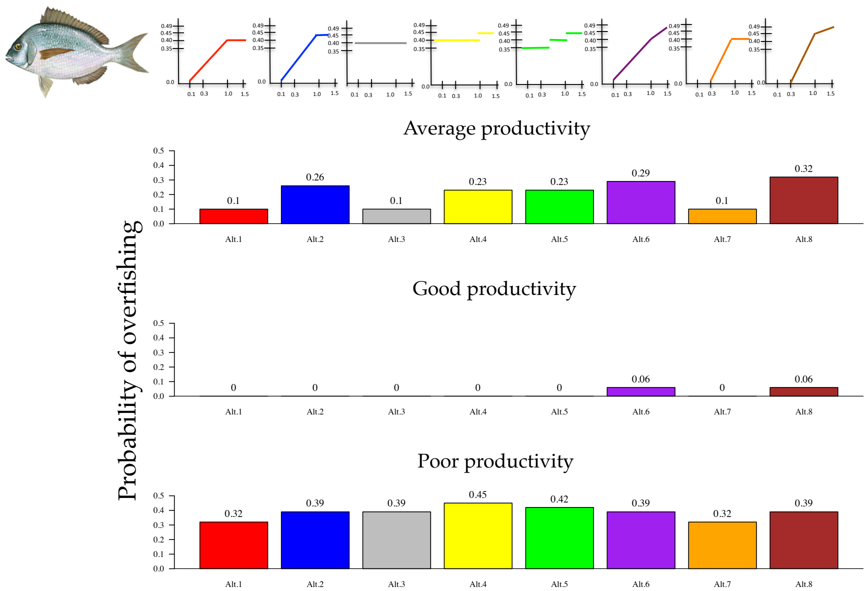


Figure 15. Median probability of overfishing for scup by control rule.

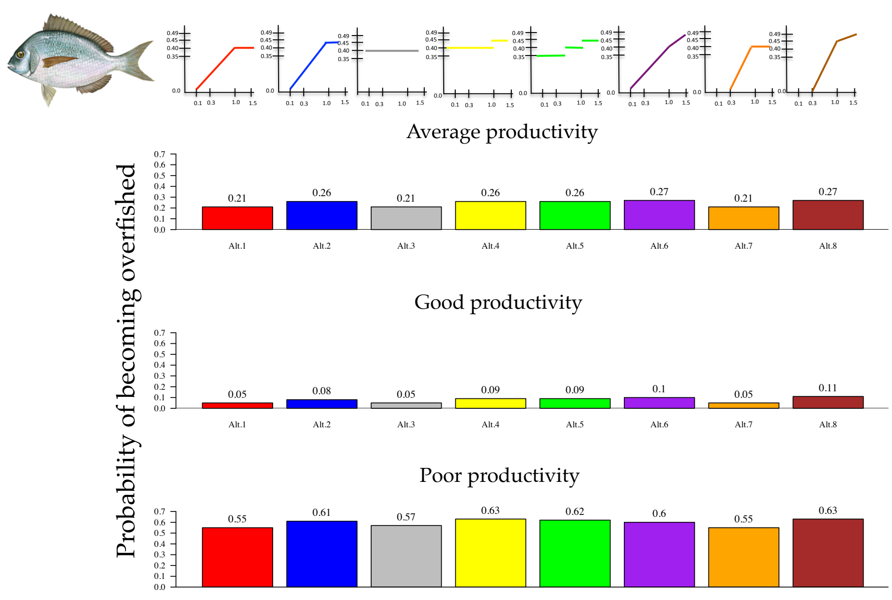


Figure 16. Median probability of becoming overfished for scup by control rule.

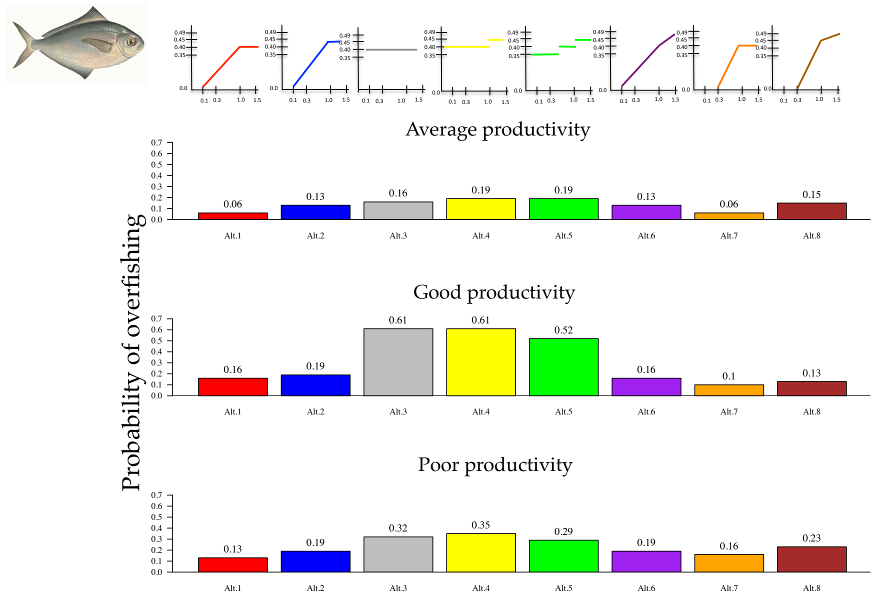


Figure 17. Median probability of overfishing for butterfish by control rule.

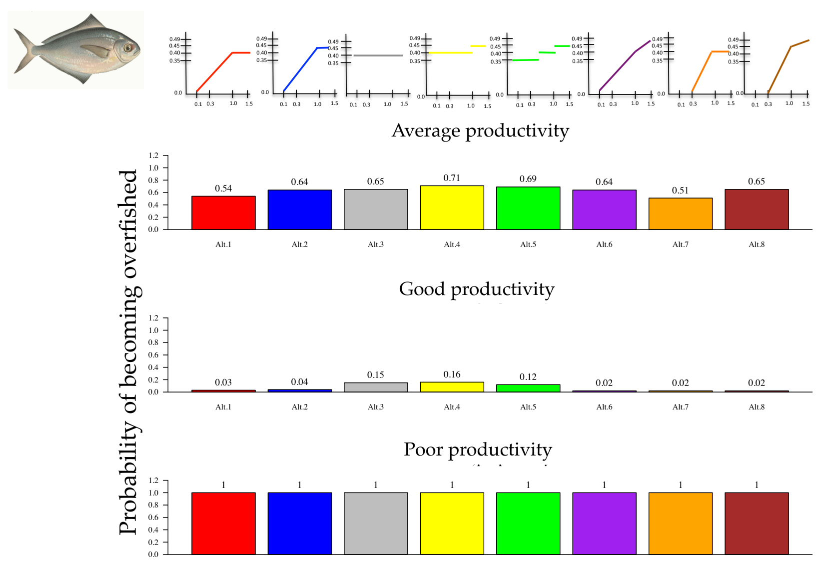


Figure 18. Median probability of becoming overfished for butterfish by control rule.

DRAFT

Economic Trade-offs of Additional Alternative ABC Control Rules for Summer Flounder and Implications for Scup and Butterfish

Cyrus Teng (University of Maryland College Park)
Doug Lipton (NOAA Fisheries Senior Scientist for Economics)

Preliminary Report to the Mid-Atlantic Fishery Management Council

December 9, 2019

Introduction

At the February 2018 Mid-Atlantic Fishery Management Council (MAFMC) meeting, John Wiedenmann presented his results on the “Evaluation of Alternative ABC Control Rules for Mid-Atlantic Fisheries” (Wiedenmann 2018). In that study, control rules were varied as to how the probability of overfishing (P*) was implemented: fixed, 2-step, 3-step, and ramped. Using a management strategy evaluation (MSE) simulated over 30 years for scup, summer flounder and butterfish; performance of the control rules was evaluated in terms of the average biomass, long-term and initial catch, probability of overfishing, probability of becoming overfished, risk of very low biomass, mean F/F_{MSY}, and year-to-year catch variability. The study found that the chosen control rule’s performance mattered more, in term of the variables being evaluated, under poor future conditions such as high natural mortality, low recruitment and overestimates of stock size.

Given the biological consequences of the different control rules, Council members expressed additional interest in the economic trade-offs among control rules or other ways in which economic considerations could be accounted for in harvest control rules. At that time, two of the authors (i.e., Hutniczak and Lipton) were working with Wiedenmann on an economic analysis of the timing of stock assessment updates and data management lags building on another MSE study (Wiedenmann et al. 2017). That study (Hutniczak et al. 2018), used a suite of economic models built around the summer flounder fishery, to demonstrate that annually updating the summer flounder stock assessment produced summer flounder economic benefits greater than the cost of updating. We found that the difference between a two year stock assessment update interval with a data lag of one year (base scenario), and a five year update interval with a two year data lag is only 10,000 metric tons of summer flounder harvested over a 27 year period. Our analysis estimates, however, that the difference in economic benefits between the two scenarios is about $102.7 million which is more than the added cost of updating every two years. We offered to the Council that, at least for summer flounder, we could modify the harvest control rules in our base scenario to match the simulations in the Wiedenmann (2018) report, and determine the differences in economic benefits from the fishery for the scenarios analyzed in that report.

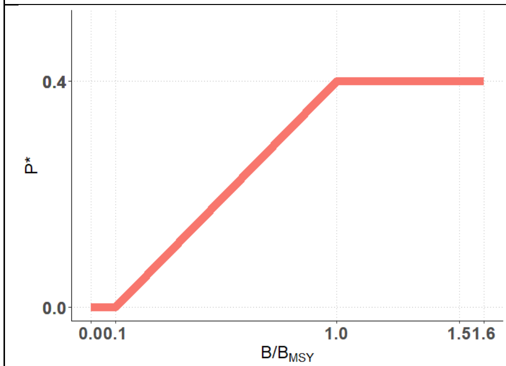
Results of that economic analysis were presented to the Council in its December 2018 meeting and summarized in the report “Economic Trade-offs of Alternative ABC Control Rules for Summer Flounder”, dated December 10, 2018. The analysis found that the current policy (Alternative 1 in this study) was the most conservative and leads to the lowest economic welfare, while the 2-step policy (Alternative 3 in this study) performed the best. The gap in performance between these two control rules increased with time. In the beginning of the period, when B/B_{MSY} of the summer flounder resource is below one, the current policy restricted harvest which resulted in its underperformance. In later years, the 2-step policy was better able to take advantage of the increased biomass, again resulting in the underperformance fo the current policy.

Subsequent to the December 2018 report Risk Policy Working Group identified three additional control rules for evaluation (hereafter referred to as Alternatives 6, Alternative 7, and Alternative 8). In addition to these newly proposed control rules, another development also necessitated the re-evaluation of economic performances of alternative control rules. In July 2018, the Marine Recreational Information Program (MRIP) replaced the existing estimates of recreational catch of summer flounder with a calibrated 1982-2017 times series that corresponds to new survey methods that were fully implemented in 2018. Additionally, a benchmark stock assessment incorporating the new MRIP estimates was implemented. The new MRIP estimates resulted in significant increases in estimated recreational summer flounder catch and overall biomass. As a result, we expect economic welfare to increase significantly overall and for the recreational sector.

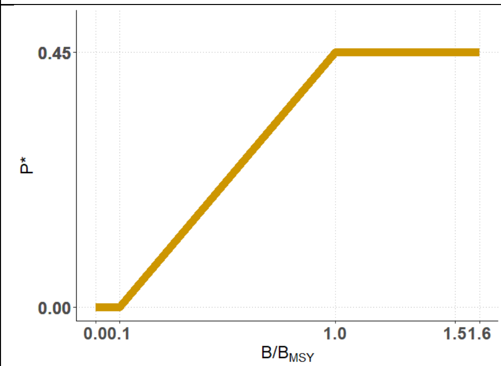
As part of this re-evaluation, additional MSE simulations were performed by John Wiedenmann under five control rules previously considered (Alternatives 1 through 5) as well as under the three new proposed control rule alternatives (Alternatives 6 through 8). Table 1 shows the control rule alternatives. Corresponding economic welfare analysis were performed on the MSE outputs according to the methods outlined in the next section.

Table 1. Control Rule Alternatives

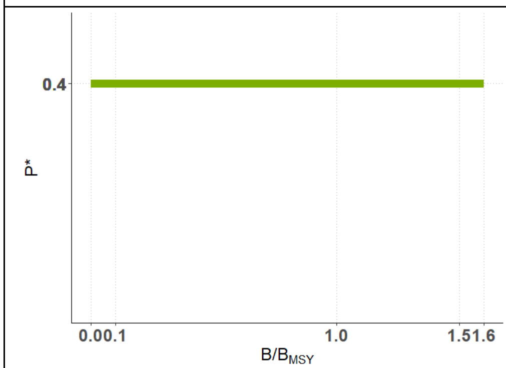
Alternative 1



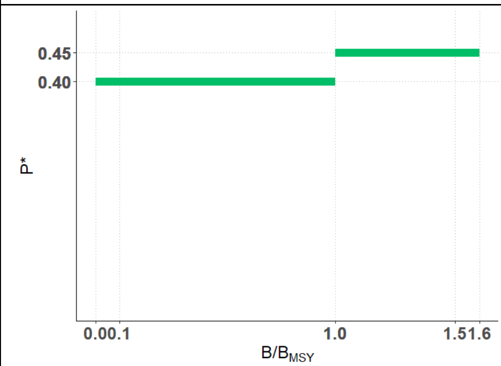
Alternative 2



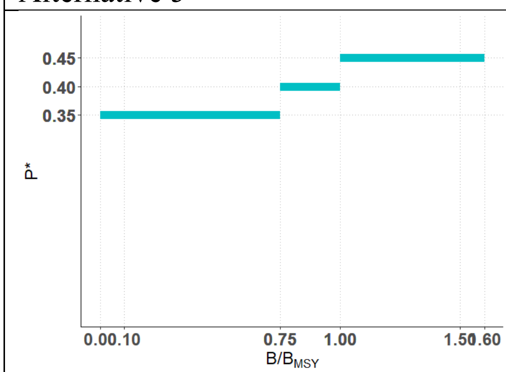
Alternative 3



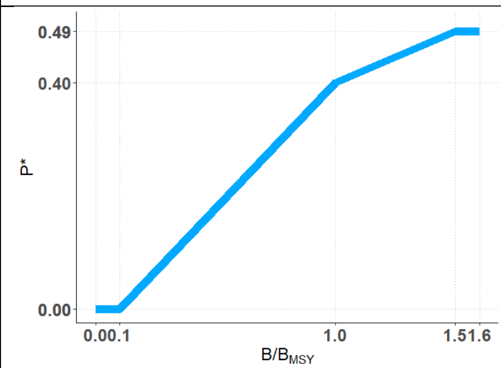
Alternative 4



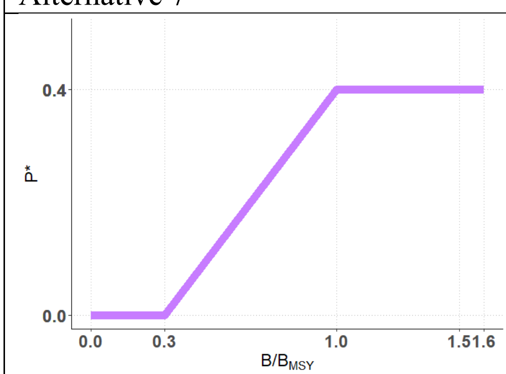
Alternative 5



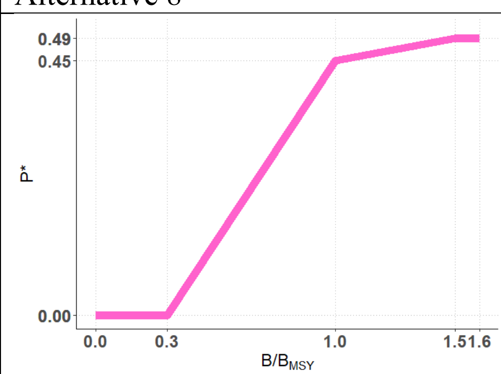
Alternative 6



Alternative 7



Alternative 8



Methods

Figure 1 shows the conceptual framework by which the catch projections and spawning stock biomass (SSB) estimates from Wiedenmann's MSE serve as inputs to three economic submodels to calculate total economic benefits from the fishery. Details of the economic models are available in Hutniczak et al 2018.

The economic estimates are generated from estimating models for summer flounder price from an inverse demand model, summer flounder net fishing revenue from a model that relates multispecies days at sea to changes in the total allowable catch and stock biomass, and a summer flounder recreational fishing valuation model.

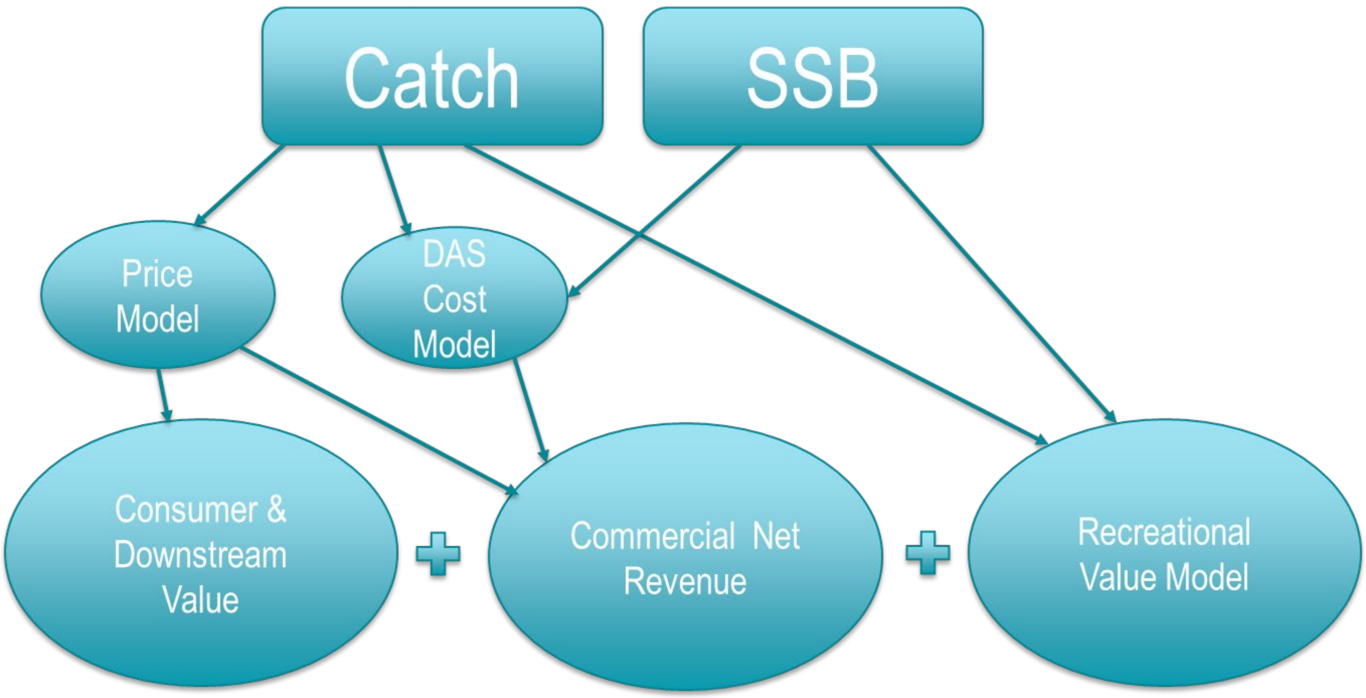


Figure 1. Conceptual approach showing how catch and spawning stock biomass from MSE feed into economic submodels (DAS=days at sea). For details of economic models, see Hutniczak et al. 2018).

The scenarios analyzed follow those in Wiedenman's MSE outputs which contain 500 simulated catch and biomass projections over 30 years for each of the eight control rule alternatives. In addition to the base scenario of average summer flounder fishery productivity, there are two additional scenarios corresponding to higher than average recruitment and lower than average natural mortality (good productivity scenario) and to lower than average recruitment and higher than average natural mortality (poor productivity scenario). Additionally, economic welfare comparisons were performed for each of the three scenarios for the initial five years as well as for the final 20 years of projections. This is to distinguish between periods in which summer flounder relative biomass is below target (initial 5 years) and above target (final 20 years). All scenarios assume a coefficient of variation (CV) of 1.0.

Results – 30 Year Projections

Figures 2 shows the summer flounder estimated SSB from the MSE for the average productivity scenario over 30 years. Conservative control rule Alternatives 1 and 7 results in the highest SSB levels for the entire projection period. Alternative 6, which is identical to Alternative 1 when B/B_{MSY} is below one, performs well in the initial five years but underperforms at higher B/B_{MSY} where it is less conservative. The non-ramped Alternatives 3 through 5 performs the worst in the initial five years. However, Alternative 3, with a conservative constant P* of 0.4 even at B/B_{MSY} > 1, has the third highest SSB level over the 30-year projection period.

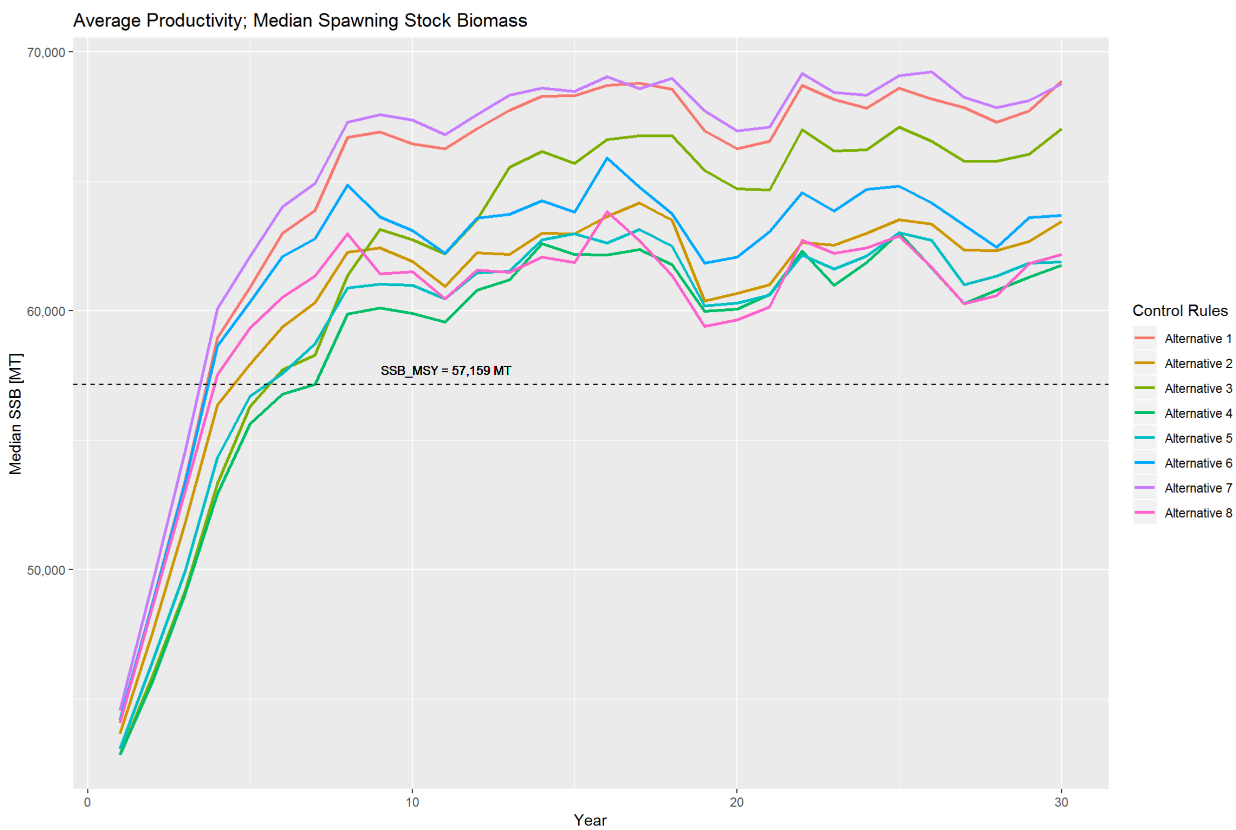
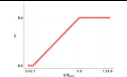
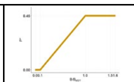
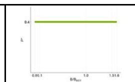
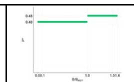
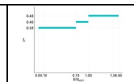
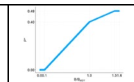
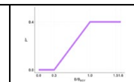
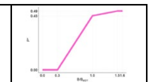


Figure 2. Simulated summer flounder median spawning stock biomass used as input for the average productivity scenario as input to the economic submodels.

In our initial set of projections, we run the economic models using the full 30-year dataset of projections of catches and SSB. In addition to the average productivity scenario, we present the economic projections for the good and poor productivity scenarios. Table 2 shows the mean cumulative total economic welfare under the three productivity scenarios for each of the control rule alternatives, as well as the increases relative to Alternative 1, and the rankings.

Table 2. Mean Cumulative 30-Year Total Economic Welfare (Millions, 3% PV) / Increase over Alternative 1 / Rank

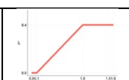
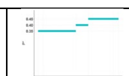
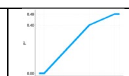
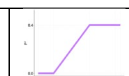
Control Rule								
Average Productivity	4,312	4,390	4,380	4,427	4,414	4,352	4,295	4,379
	0	78	68	115	102	40	-17	67
	7	3	4	1	2	6	8	5
Good Productivity	7,434	7,670	7,476	7,693	7,685	7,723	7,423	7,768
	0	236	42	259	251	289	-11	334
	7	5	6	3	4	2	8	1
Poor Productivity	2,515	2,544	2,632	2,632	2,606	2,513	2,478	2,503
	0	29	117	117	91	-2	-37	-12
	5	4	1	1	3	6	8	7

Discussion

Table 2 shows that Alternatives 4 and 5, the stepped control rules, perform well under all productivity scenarios, ranking no worse than third and fourth, respectively, among all alternatives. Alternative 7 is the worst performer, ranking last in all three productivity scenarios. Alternatives 8 and 6, which have maximum P* of 0.45 at 1.5 B/B_{MSY}, perform relatively well under the good productivity scenario, ranking first and second, respectively. However, both perform poorly under the poor productivity scenario, ranking seventh and sixth, respectively. Alternative 3, the constant 0.4 P* control rule performs the best under poor productivity scenario but ranks sixth under the good productivity scenario. Alternative 1, the status quo, ranks no better than fifth, and is second to last in the average and good productivity scenarios.

To see how the various control rule alternatives may affect the welfares of consumers, commercial fishermen, and recreational fishermen differently, we broke out the three measures of economic welfare for the average productivity scenario in Table 3. It shows that the alternatives with the most positive impacts on consumer and recreational welfare tend to have the most negative impacts on producer welfare, and vice versa.

Table 3. Mean Cumulative 30-Year Economic Welfares (Millions, 3% PV) / Increase over Alternative 1

Control Rule								
Producer Welfare	421	399	410	392	395	403	423	393
	0	-22	-11	-29	-26	-18	2	-28
Consumer Welfare	1,044	1,075	1,076	1,096	1,089	1,059	1,036	1,068
	0	31	32	52	45	15	-8	24
Recreational Welfare	2,846	2,916	2,894	2,939	2,930	2,891	2,836	2,918
	0	70	48	93	84	45	-10	72
Total Welfare	4,312	4,390	4,380	4,427	4,414	4,352	4,295	4,379
	0	78	68	115	102	40	-17	67

Figures 3 shows the distribution of the present value of total economic welfare over 30 years of the 500 simulated runs under the poor productivity scenario. It shows that Alternatives 3 through 5, the control rules with piecewise constant P*, have lower variability in total economic welfare compared to control rules with ramped P* under poor productivity conditions. This pattern is not as pronounced in either the average or the good productivity scenarios.

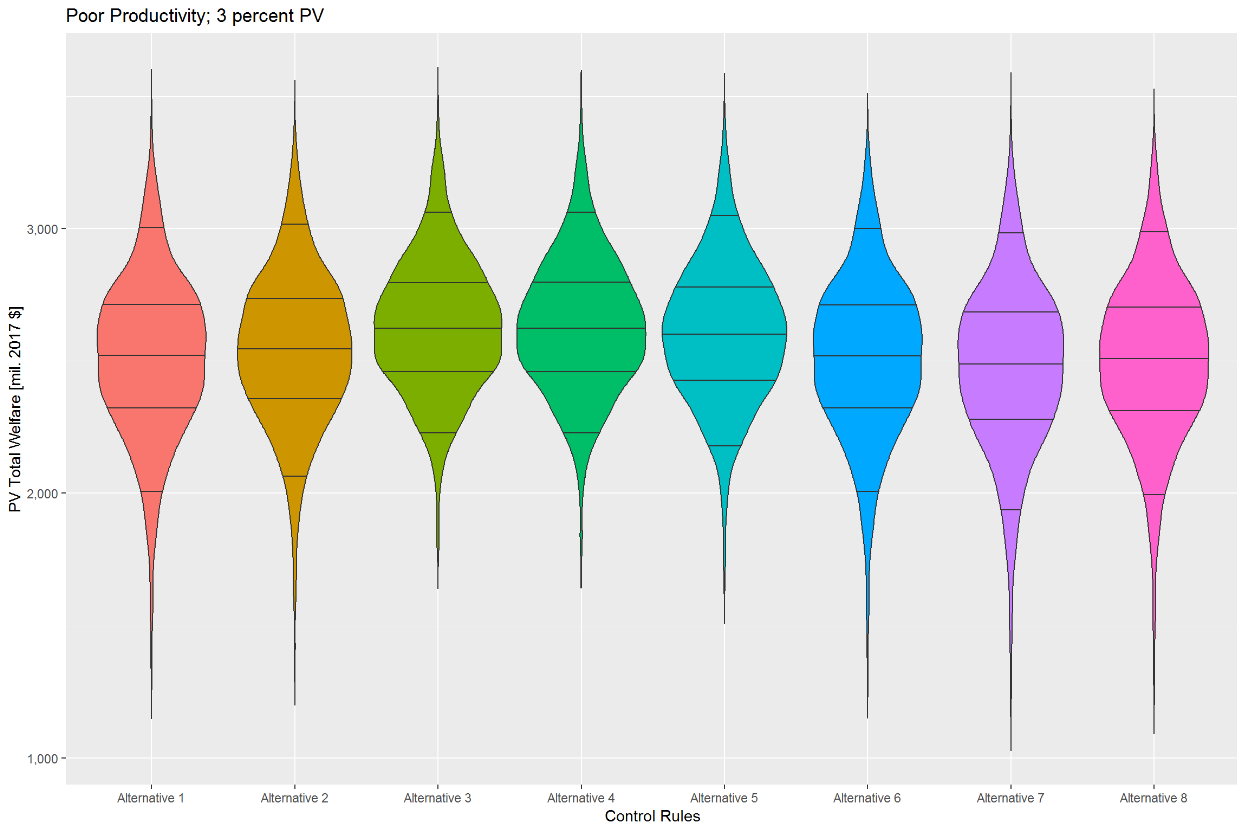
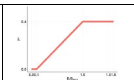
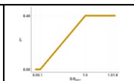
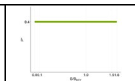
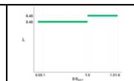
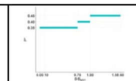
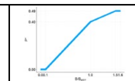
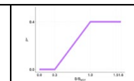
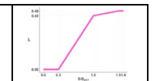


Figure 3. Violin plots of model runs showing the 5%, 25%, 50%, 75%, and 95% quantiles of the present value of total economic welfare over 30 years for the poor productivity scenario.

Results – Initial 5 Years Projections

The economic performance of the various control rule alternatives in the initial five years is summarized in Table 4.

Table 4. Mean Cumulative Initial 5-Year Total Economic Welfare (Millions, 3% PV) / Increase over Alternative 1 / Rank

Control Rule								
Average Productivity	758	794	830	840	825	765	738	774
	0	36	72	82	67	7	-20	16
	7	4	2	1	3	6	8	5
Good Productivity	892	937	966	983	968	908	872	922
	0	45	74	91	76	16	-20	30
	7	4	3	1	2	6	8	5
Poor Productivity	638	665	706	711	696	641	619	644
	0	27	68	73	58	3	-19	6
	7	4	2	1	3	6	8	5

Discussion

It is rather simple to rank the performance of the alternative control rules in the initial five-year period: Alternative 4 is the best in all productivity scenarios. Alternatives 3 and 5 ranks either second or third. The bottom five rankings remain constant in all productivity scenarios with Alternative 2 in fourth, Alternative 8 in fifth, Alternative 6 in sixth, Alternative 1 in seventh, and Alternative 7 in last place.

Figures 4 shows the distribution of the present value of total economic welfare over the initial five years of the 500 simulated runs under the average productivity scenario. It shows that Alternatives 3 through 5, the control rules with piecewise constant P*, have lower variability in total economic welfare compared to control rules with ramped P*. This pattern is also observed under both good and poor productivity scenarios.

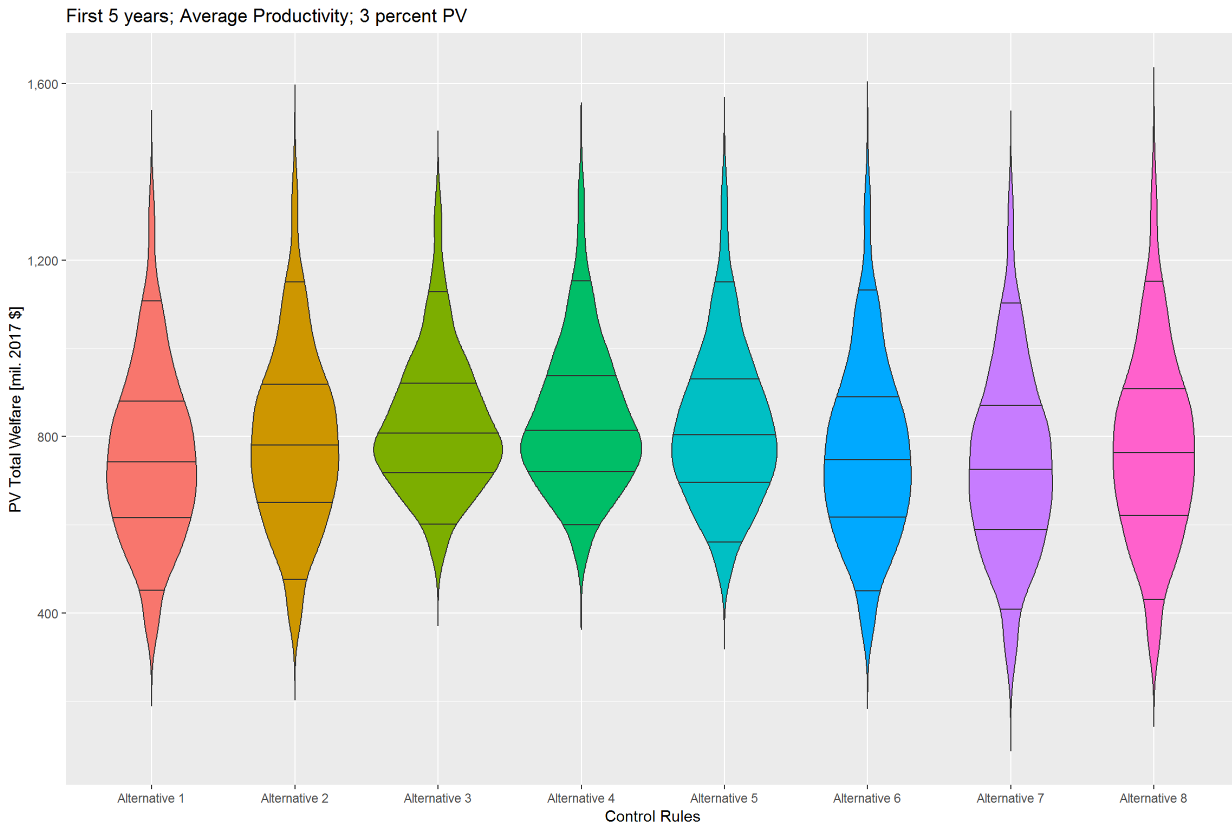
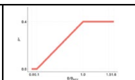
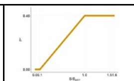
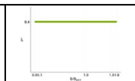
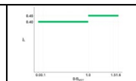
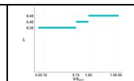
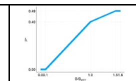
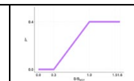
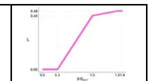


Figure 4. Violin plots of model runs showing the 5%, 25%, 50%, 75%, and 95% quantiles of the present value of total economic welfare over the initial 5 years for the average productivity scenario.

Results – Final 20 Years Projections

The economic performance of the various control rule alternatives in the final 20 years is summarized in Table 5.

Table 5. Mean Cumulative Final 20-Year Total Economic Welfare (Millions, 3% PV) / Increase over Alternative 1 / Rank

Control Rule								
Average Productivity	1,147	1,154	1,153	1,158	1,156	1,147	1,146	1,150
	0	7	6	11	9	0	-1	3
	6	3	4	1	2	6	8	5
Good Productivity	2,265	2,315	2,265	2,314	2,315	2,308	2,266	2,324
	0	50	0	49	50	43	1	59
	7	2	7	4	2	5	6	1
Poor Productivity	578	581	592	591	590	576	574	575
	0	3	14	13	12	-2	-4	-3
	5	4	1	2	3	6	8	7

Discussion

Table 5 shows that there is relatively little difference among the control rule alternatives in the final 20 years when B/B_{MSY} is greater than one. The rankings in Table 5 are similar to those in Table 2. They show that Alternatives 2, 4, and 5 perform well under all productivity scenarios, ranking no worse than fourth, fourth, and third, respectively, among all alternatives. Alternative 7 is the worse performer, ranking sixth in the good productivity scenario but last in the remaining two scenarios. Alternatives 8 ranks first under the good productivity scenario but second to last under the poor productivity scenario. Alternative 3, the constant 0.4 P* control rule performs the best under poor productivity scenario but ranks seventh under the good productivity scenario. Alternative 1, the status quo, ranks no better than fifth, and ranks second to last in the good productivity scenario.

Figures 5 shows the distribution of the present value of total economic welfare over the final 20 years of the 500 simulated runs under the poor productivity scenario. It shows that Alternatives 3 through 5, the control rules with piecewise constant P*, have lower variability in total economic welfare compared to control rules with ramped P* under poor productivity conditions. This pattern is not as pronounced in either the average or the good productivity scenarios.

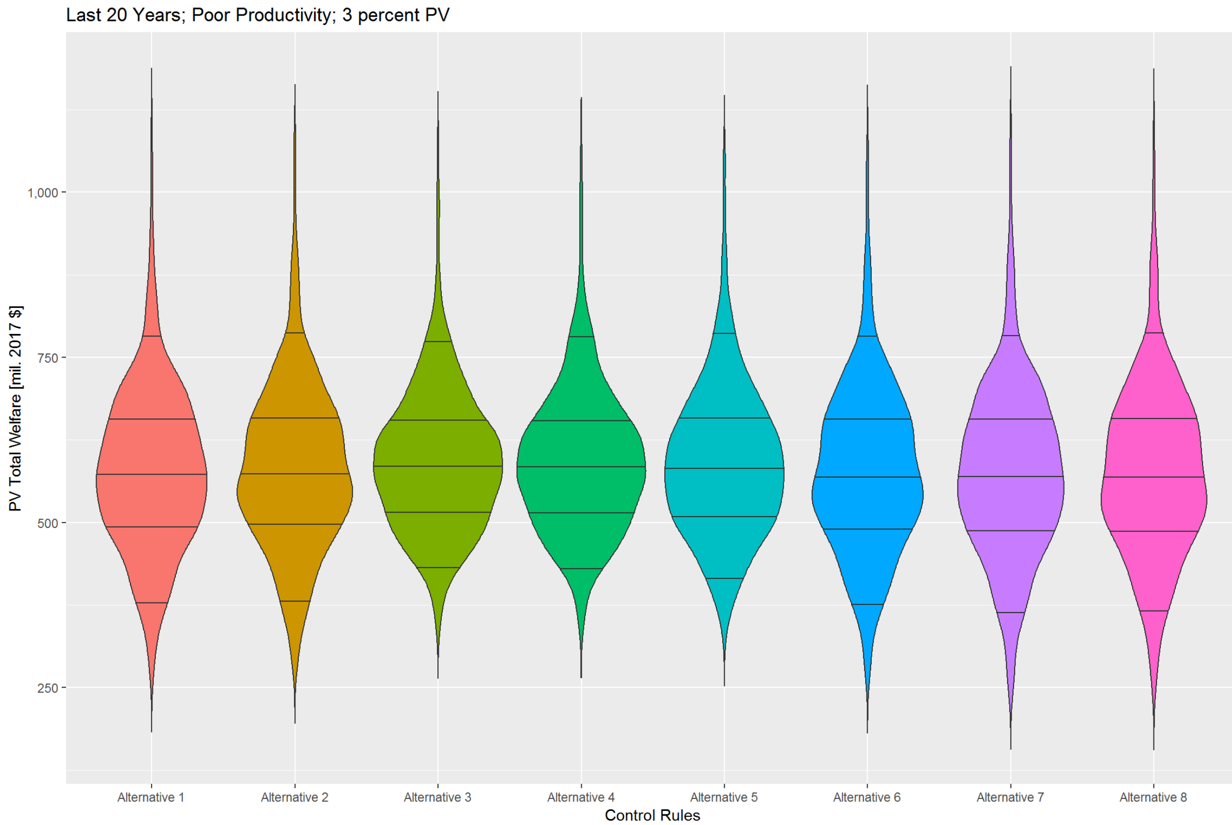


Figure 5. Violin plots of model runs showing the 5%, 25%, 50%, 75%, and 95% quantiles of the present value of total economic welfare over the final 20 years for the poor productivity scenario.

Discussion

Similar to results from the December 2018 report, we found that total economic welfare correlates strongly with allowable catch. Alternatives 4 and 5, which are less conservative when B/B_{MSY} is below one, perform the best under average and poor productivity scenarios, and in the initial five years when the summer flounder resource has below target biomass. Their relative performance is not as strong under good productivity scenarios. The current policy, Alternative 1, and its close variant, Alternative 7, which are most conservative under all B/B_{MSY} levels, perform rather poorly, often ranking in the bottom two. Alternative 3, with a constant 0.4 P* performs relatively well under poor productivity scenarios and in the initial five years, but relatively poorly under good productivity scenarios. In contrast, Alternative 8 performs relatively well under good productivity scenarios but relatively poorly under poor productivity scenarios and in the initial five years. Our results also show that Alternatives 3 through 5, the least restrictive alternatives under low B/B_{MSY} levels, produce the lowest variability in economic welfare, particularly under poor productivity scenarios, and in the initial five years.

A Note About Other Species Economic Impacts of Harvest Control Rules

Since we do not have quantitative economic models developed for the other two species, scup and butterfish, analyzed in the Wiedenmann study, we looked at factors indicative of how these species might deviate from summer flounder in their economic performance relative to the different harvest control rules analyzed.

Recreational Value

The presence of a major recreational fishery for summer flounder and scup increases the overall magnitude of the economic impact of the harvest control rules compared to fisheries without a recreational sector (i.e., butterfish). According to revised MRIP estimates, directed trips for scup (trips for which the individual indicated they were targeting scup as their first or second choice) averaged 1.3 million trips per year from 2009-2018 compared to an average of just over 1.0 million trips per year for summer flounder (Figure 1).

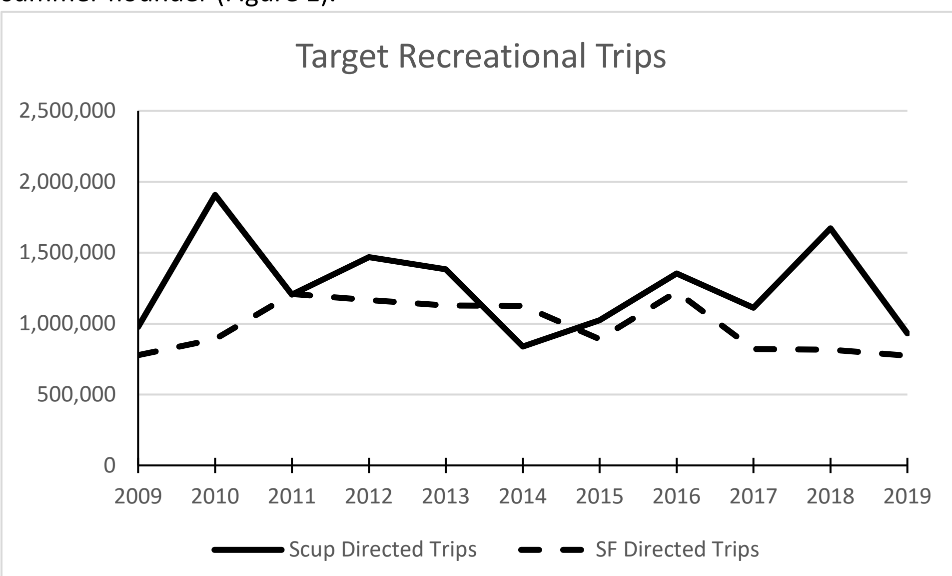


Figure 3. Trips targeting scup and summer flounder.

In our detailed summer flounder analysis, the harvest control rules affect both the value of a trip (due to catch rate changes related to biomass) and the number of trips taken (due to changes in the recreational quota). We do not have estimates of the value (willingness-to-pay) for scup trips to compare with summer flounder trips. Evidence would suggest, however, that the number of scup trips taken is not as sensitive to the quota level as it is for summer flounder. Figure 2 shows the relationship between TAC and the number of directed trips for scup and summer flounder. As expected, there is a positive relationship ($r^2 = 0.225$) between trips and TAC for summer flounder, but no relationship ($r^2 = 0.001$) for scup.

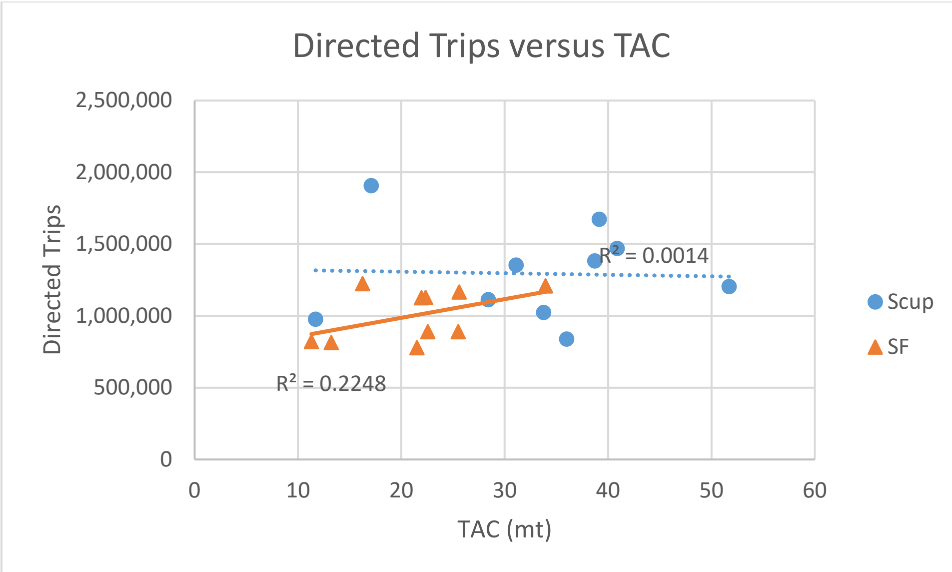


Figure 4. Relationship between scup and summer flounder directed trips and quota

Given the lack of sensitivity of directed trips for scup to the quota, it is expected that the recreational economic impacts of the different harvest control rules considered will be significantly less than the impacts for the summer flounder fishery. However, if scup biomass, and thus TAC, attains extremely low values, this might lead to sharp reductions in trips taken, and thus a more significant economic impact could ensue. The implication for the harvest control rule performance for scup recreational value is that due to the trip to quota relationship, the rules that avoid extremely low quota are more beneficial; whereas, there is little increased recreational benefit from control rules that lead to significantly higher than average quotas.

Commercial Value

We looked at commercial landings and price data from 2009-2017 for scup and butterfish in comparison to summer flounder (Figure 3) in order to examine qualitatively how commercial fishing value analyses for these species diverge from the summer flounder model presented elsewhere. Over the period examined, average summer flounder ex-vessel price is over 4 times that of scup and butterfish.

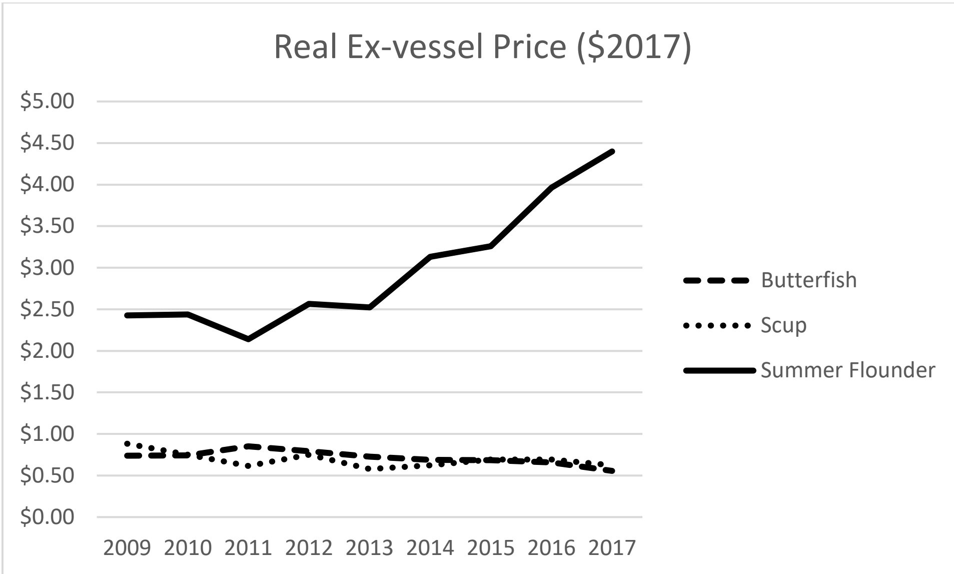


Figure 5. Real (2017 dollars) ex-vessel price for butterfish, scup and summer flounder.

Figures 4, 5 and 6 provide simple price-quantity relationships for summer flounder, scup and butterfish, respectively. The summer flounder model in our detailed harvest control rule analysis contains a more sophisticated summer flounder inverse demand model, but for comparison purposes, we are using the simplified relationships for all three species here.

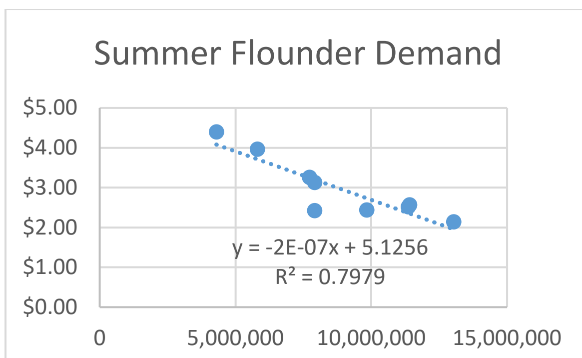


Figure 6. Simple summer flounder demand relationship.

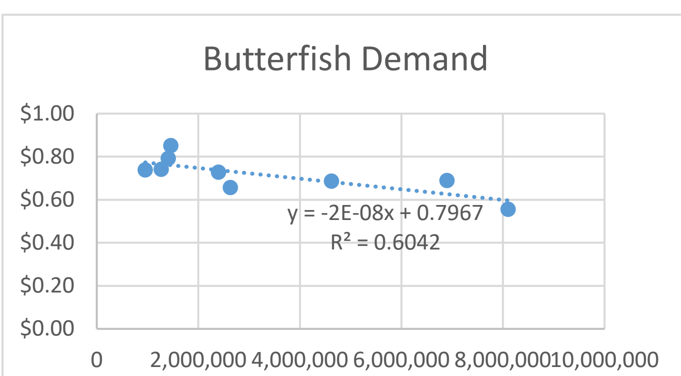


Figure 7. Simple butterfish demand relationship.

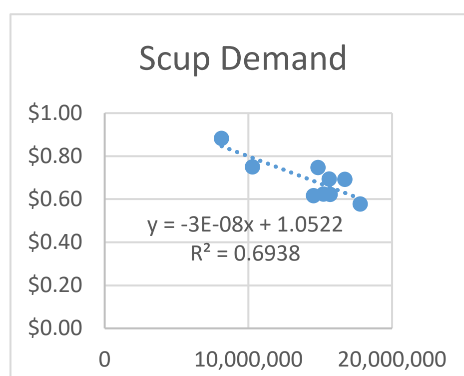


Figure 6. Simple scup demand relationship.

The demand relationship affects the performance of the harvest control rules in two significant ways. First, the price flexibilities[1], will impact the total commercial revenue of the fishing fleet. The calculated flexibility at the mean of summer flounder quantity and prices is 0.59, 0.62 for scup and 0.09 for butterfish. Since all three flexibilities are less than 1.0, at the mean, fleet total revenues will decline when the quota is lowered from the mean and revenues will rise when the quota is raised (assuming all quota is landed). Given our linear demand estimation, as one moves down the demand curve due to higher quotas and landings, prices become more flexible. At high quotas and landings, a reduction in quota is compensated for by a higher price, but an increase in quota means that prices decrease at a greater percentage than landings increase and total revenue declines. For summer flounder and scup, the price flexibilities calculated at the highest level of landings over the sample period –during 2011 for summer flounder and 2013 for scup, were both greater than 1.0. This means that had quotas and landings been set any higher, revenues would have fallen. This price effect dampens the benefits from control rules that allow significantly higher catch for these species. This effect is captured in the more detailed summer flounder analysis. Butterfish, on the other hand, exhibits low price flexibility, even at maximum catch, compared with scup and summer flounder. Industry total revenues, will thus, follow more closely the trends in predicted biologically driven results from the Wiedenmann model.

In the detailed summer flounder model, we also use the summer flounder demand curve estimation to calculate consumer surplus, the net economic welfare from downstream effects of summer flounder as it reaches the final consumer. The greater the slope of the demand curve, the greater the consumer surplus. Since the butterfish demand curve is relatively flat (near horizontal), the differences between harvest control rules leading to changes in quota setting will have a muted impact on the net benefit estimation. Consumer surplus for scup will vary similarly to summer flounder in direction, but will be significantly lower for scup due to the overall lower demand for that species.

Conclusion

From the above qualitative analysis, it can be expected that if we had conducted a comprehensive analysis of the scup fishery, similar to our analysis of summer flounder, the differences between harvest control rules would be similar to those found for summer flounder. However, the absolute magnitude of the impacts would be significantly lower due to its lower market price and the lack of sensitivity of recreational trips to the quota level. Butterfish, lacking a recreational fishery and having low price flexibility, would have a different economic response than summer flounder or scup. For butterfish, the difference in performance of the harvest control rules in terms of allowable catch and biomass as derived from the Wiedenmann study, should serve as an indicator of economic performance.

[1] Price flexibility is defined as the percentage change in price for a 1% change in quantity. This is the inverse of price elasticity and are used in fisheries models because often the quantity supplied to the market is fixed by a quota or environmental factors and we are interested in how the price adjusts. A flexibility > 1 means that total revenue will increase with a decrease in quantity supplied. In a linear demand relationship, the flexibility will vary along the point on the demand curve where it is calculated. The usual practice is to provide the value at the sample mean of prices and quantity.

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Wiedenmann, J., M. Wilberg, A. Sylvia, and T. Miller. 2017. An evaluation of acceptable biological catch (ABC) harvest control rules designed to limit overfishing. Canadian Journal of Fisheries and Aquatic Sciences. doi: 10.1139/cjfas-2016-038

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