# Implications of Recreational Harvest Control Rules on ABC Specification

Submitted by
Mid-Atlantic Fishery Management Council, Scientific and Statistical Committee
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In response to the Council Motion

**Introduction**

The Mid-Atlantic Fishery Management Council (MAFMC) and the Atlantic States Marine Fisheries Commission (ASMFC) jointly manage several important fish species in the Mid-Atlantic region. A combination of biological reference points that specify maximum sustainable catch levels, and harvest control rules that specify the actual catch quota based on the current stock biomass is used to manage these species. Within the Council process, the MAFMC Statistical and Scientific Committee (SSC) is mandated to consider sources of scientific uncertainty to specify an acceptable biological catch (ABC) by applying the Council's risk policy. The Council's risk policy approach is a harvest control rule because it results in a catch, the ABC, specified as an amount in weight that varies according to stock biomass. Subsequently, Council and Commission staff, supported by Management Committees, develop catch quotas reflecting predetermined allocation decisions for the commercial (annual catch target, ACT) and recreational sectors (recreational harvest limit, RHL). In all cases, the combined ACT, RHL and dead discards must be equal to or less than the ABC.

In fulfilling their joint responsibility, the MAFMC and the ASMFC recently considered a number of proposed approaches to managing four key recreationally important species: Black Sea Bass, Bluefish, Scup, and Summer Flounder. The approaches proposed in the Addendum / Framework seek to prevent overfishing, be reflective of stock status, appropriately account for uncertainty in the recreational data, take into consideration angler preferences, and provide an appropriate level of stability and predictability in changes from year to year. The proposed Addendum / Framework presents five options (including one of no action or *status quo*) for how recreational harvest levels could be specified. In discussing the proposed approaches, a joint resolution was passed that sought input from the SSC to help Council and Commission members understand how the proposed approaches would affect catch levels before a final vote was taken. Specifically, the Council and Commission adopted the following motion:

> *"Request that the SSC provide a qualitative evaluation, in time for final action at the June 2022 Council/Policy Board meeting, regarding the potential effect of each of the five primary alternatives in the Harvest Control Rule Addendum/Framework on the SSC's assessment and application of risk and uncertainty in determining ABCs. The intent is to provide the Council and Policy Board with information to consider the tradeoffs among*

*the different alternatives with respect to the relative risk of overfishing, increasing uncertainty, fishery stability, and the likelihood of reaching/remaining at BMSY for each approach at different biomass levels (e.g., for 1⁄2 BMSY < B < BMSY, the relative risk among alternatives is (highest to lowest) E > C > B > A>D)."*

In response to this motion, the SSC created an *ad hoc* sub-committee comprising Drs. Lee Anderson, Cynthia Jones, Thomas Miller (chair), Paul Rago, Brian Rothschild, and Alexei Sharov. To fulfill the Council / Commission request, the sub-committee held three webinars (3/25, 4/13, 4/29). The webinars were public meetings. At each meeting, the sub-committee invited questions and comments from Council and Commission members and other stakeholders. The sub-committee extends its gratitude to Brandon Muffley and Julia Beatty (MAFMC staff) who supported the sub-committee by organizing meetings, providing relevant data, and answering queries from members of the sub-committee.

The sub-committee prepared this report through shared authorship and editing. The sub-committee's report was presented to the entire MAFMC SSC at their May 10th, 2022 meeting. Responses from the entire SSC were incorporated into the final report, and as such, this report represents the consensus view of the SSC.

The report is structured to address four key questions:

1. What is the impact of the proposed Addendum / Framework on the SSC's assessment and application of risk and uncertainty in determining ABCs?
2. Does the proposed Addendum / Framework represent a Harvest Control Rule?
3. What are some of the implications of the proposed Addendum / Framework?
4. What are the benefits and challenges of each proposed action within the proposed Addendum / Framework?

We answer each question in subsequent sections of this report.

**(1) What is the impact of the proposed Addendum / Framework on the SSC's assessment and application of risk and uncertainty in determining ABCs?**

The SSC operates under the Magnuson Stevens Fishery Conservation and Management Reauthorization Act (2007, as amended). A central goal of the MSA is to prevent overfishing. Achieving this goal requires concerted effort among all participants in fisheries management. Currently, responsibility for the management of that risk is partitioned among several groups. Stock assessment scientists estimate the overfishing limit. The Council establishes a risk policy that establishes probabilities of overfishing that are acceptable as a function of stock status. The SSC considers the nature and magnitude of scientific uncertainty and then combines this estimate and the Council's risk policy to set the ABC. Finally, management boards consider the nature and pattern of management uncertainty and set annual catch limits, which may be equal to or lower than the ABC. Each element of this management system has a role to play in ensuring fisheries operate with an acceptable risk of overfishing. Meeting goals for risk of overfishing is not the responsibility of any single group, but rather relies on the coordinated actions of all participants.

The SSC is legislatively mandated to provide the Council an ABC. An accepted stock assessment exists for each of the four species covered by the proposed Addendum / Framework that provides an estimate of the catch associated with the overfishing limit (OFL). The SSC uses a structured process that identifies key sources and magnitudes of scientific uncertainty and the Council's risk policy, termed as the p* approach, to determine the ABC. The MAFMC SSC's structured process involves consideration of scientific uncertainty in nine categories (Table 1).

*Table 1. Categories of scientific uncertainty used by the SSC in developing ABCs. The principal considerations are provided for each decision criteria, but the list of considerations is not comprehensive.*

| Decision criteria | Considerations |
|---|---|
| Data quality | Accuracy and precision of catch<br>Availability of age/length data<br>External data for key parameters (e.g., M) |
| Model appropriateness and identification | Comparison with alternative models<br>Match with life history |
| Retrospective analysis | Model misspecification, often due to undetected temporal trend |
| Comparison with empirical measures | External measure of population scale |
| Ecosystem factors | Stationarity of model parameters |
| Trends in recruitment | Evaluation of stanzas and trends |
| Prediction error | Validation of predictions with subsequent estimates |
| Assessment accuracy | Function of historical exploitation patterns |
| Simulation / MSE | Measures of robustness of assessment |

The proposed Addendum / Framework is triggered by determination of the ABC, and as such, the actual ACTs and RHLs are determined only after the ABC has been specified. Consequently, the proposed Addendum / Framework does not affect the structured process the SSC uses to specify the ABC. ***Under the current SSC ABC process, neither the no action option, nor any of the alternative approaches proposed in the Addendum / Framework directly affect the SSC's perception of scientific uncertainty and hence cannot directly affect the ABC the SSC develops.*** However, the SSC notes that if implementation of any of the alternatives described in the Addendum / Framework subsequently degrades or improves the quality of assessment data, these impacts would be addressed in future specifications through assessment of the accuracy and precision of the catch data and potentially through assessment of prediction error.

**(2) Does the proposed Addendum / Framework represent a Harvest Control Rule?**

Harvest control rules are quantitative relationships that specify how management endpoints, such as catch, should vary with stock biomass to achieve management objectives. One advantage of such control rules is that their performance can be evaluation through management strategy evaluation. As an example, the Council's risk policy is a harvest control rule because it combines the estimate of the catch at the overfishing level and the acceptable probability of overfishing to provide a quantitative expression for how catch should vary with stock biomass. The performance of the Council's risk policy has been validated in simulation testing. In contrast, the alternatives described in the Addendum / Framework for the recreational fishery do not specify harvest or other management endpoints. Instead, the alternatives provide a suite of decision triggers that will be used to determine whether the current regulations that determine recreational harvest, principally specifications of season length, size limits, and bag limits, should be maintained, liberalized, or reduced. The options contained in the Addendum / Framework constitute a decision framework for establishing whether action is needed, but as yet they do not specify action. *Neither the no action option, nor any of the alternatives described in the Addendum / Framework represent harvest control rules. The alternatives define the direction of adjustments to catch based on recent landings and population status, but fall short of specifying how season length, size limits, and bag limits should be altered, and thus cannot be considered harvest control rules. The proposed alternatives described in the Addendum / Framework are triggers for action only. Specification of how regulations on season length, size limits, and bag limits or other management endpoints would change is missing. Until such details are provided, the performance of the proposed alternatives cannot be determined.*

The sub-committee felt that the proposed alternatives failed to address explicitly the complexity of the problem of specifying a vector of how regulations around season, size, and bag limits would change. The expected resultant harvest depends upon the relative contributions of the different specifications as well as a host of biological and socioeconomic parameters. The current ABC process that uses the Council's risk policy involves control of a single variable, the ABC. However, there are at least three specifications that have to be set simultaneously for the proposed alternatives to be implemented. The sub-committee notes that this increases substantially the complexity and the difficulty of the challenge which the sub-committee believes should be explicitly stated so Council and Commission members have a solid grip on the decision they are being asked to make.

Marine recreational fisheries present significant management challenges because the relationships between regulatory decisions regarding season length, size limits, and bag limits and the realized catch are not simple. Figure 1 presents plots of the relationships between catch limits and landings for the commercial and recreational sectors for the four species included in the Addendum / Framework. As indicated by the solid blue lines in Figure 1, there are significant relationships between catch limits and landings in the commercial sector for three of the four species. In contrast, only one of the four relationships between catch limit and landings is significant in the recreational sector. The dashed line in each panel is the 1:1 line expected if landings were exactly equal to the catch limit. By comparing data to this expected line, only the fisheries for Summer Flounder appear to be managed to be near their target catches in both sectors. Inspection of the four panels suggests greater variation around the 1:1 line for the recreational sector in three of the four species. Indeed these data could be taken as motivating a need for improved harvest controls in the recreational sector, or a broader acceptance that recreational fisheries cannot achieve the same level of control as that achieved through in-season catch monitoring in the commercial sector. These patterns suggest that even if policies are well designed conceptually, compliance with the policy may lead to substantial differences between specified and realized harvests. This potential is not discussed in the Addendum / Framework.

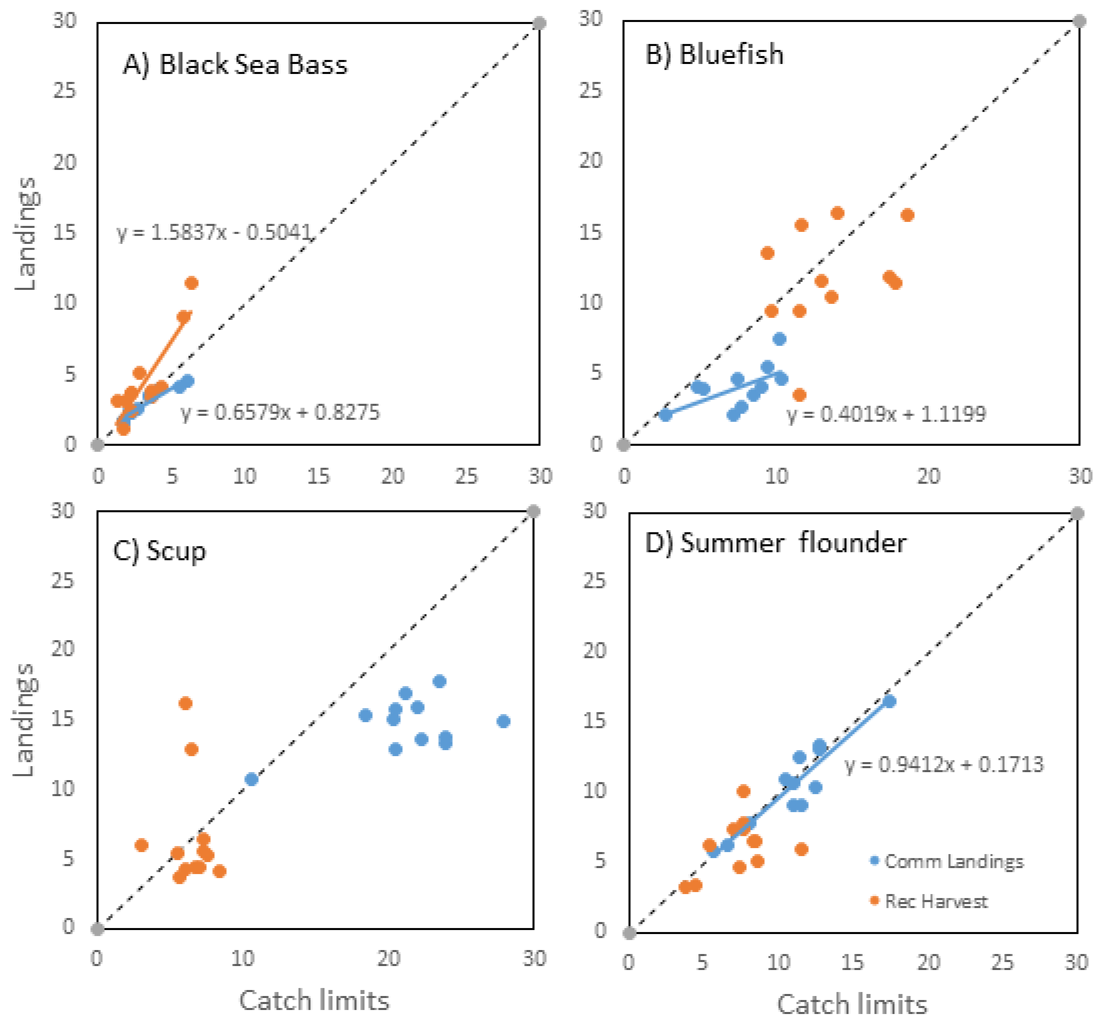



*Figure 1. Comparisons of catch limit and subsequent landings for the commercial (blue) and recreational sectors (orange) for A) Black Sea Bass, B) Bluefish, C) Scup and D) Summer Flounder. All figures are plotted on the same scale. Regression lines are plotted for significant (P < 0.05) linear relationships*

*between catch limit and subsequent landings by sector. Regression relationships are given for significant regressions. The expected 1:1 line is shown as a dashed line in each figure.*

There is a significant impact of angler behavior on the relationships shown in Figure 1. Angler behavior can be affected by many factors, causing deviations from expected relationships in both directions. High fuel prices can cause angler participation to decline, leading to lower than expected catches. Reports of good catches in traditional and social media can produce positive feedback that can lead to higher than expected catches. As a result, we understand why the workgroup who produced the alternatives described in the Addendum / Framework consciously chose not to produce recreational harvest control rules - and rather focused on directional rules that indicated how catches should change relative to a number of easily measurable stock characteristics. However, Council and Commission members should recognize that the proposed Addendum / Framework does not solve the problem of marine recreational fisheries management in the Mid-Atlantic, despite the apparent quantitative and sophisticated alternatives brought forward. The need for an approach to understanding how angler behavior and motivation affects angler avidity and ultimately catch remains. This is a significant social and natural science challenge.

**(3) What are some of the implications of the proposed Addendum / Framework?**

The proposed alternatives in the Addendum / Framework use a number of biological, stock and fisheries characteristics of the target species to define a process aimed at catch adjustment. Five alternatives are presented (Table 2)

*Table 2. Summary of the alternatives proposed in the Addendum / Framework.*

| Alternative | Approach |
|---|---|
| *Status Quo* | Compares MRIP to RHL, and recommends change in regulations based on expert judgment. |
| % Change | Maintains a MRIP vs RHL comparison. Bands or bins of % change defined based on magnitude of difference between MRIP and RHL as well as $B/B_{MSY}$ ratio. 15 different categories of action suggested. |
| Fishery Score | Applies multi-criteria decision making to fishery management. Action is based on the weighted average of multiple criteria, with weights based on "importance". Result is a continuous "aggregated" response variable, which is then binned into four categories of action. |
| Biological Reference Points | Use $B/B_{MSY}$ and $F/F_{MSY}$ to define bands or bins based on multiples of the reference point. Incorporates secondary measures, such as trends in recruitment or biomass to refine action. Current proposal has 34 different categories of action. |
| Biomass-based Matrix | Combines information on trends in biomass and stock status ($B/B_{MSY}$) to define 7 different categories of action. |

We identify the following generic concerns with the proposed alternatives that also are inherent to the *status quo* approach.

1) Repeated use of fishery / stock status at multiple points in the decision process increases variability of catches.

   A central goal of the proposed Addendum / Framework is to reduce reliance on MRIP as the sole index of whether regulations need to be altered. In achieving this goal the Addendum / Framework seeks to use readily available information such as $B/B_{MSY}$ and $F/F_{MSY}$. Estimated biomass relative to its reference point is used within the Council risk policy and in setting ABCs. The SSC notes that duplicated use of these indices will likely increase variability in fishery performance rather than dampen variability. As an example, if $B/B_{MSY} <1$, the Council's risk policy will lead to more precaution in setting the risk of overfishing. Under the Addendum / Framework, the $B/B_{MSY}$ value will likely lead to additional precaution in recreational catch limits. This leads to precaution on top of precaution based on the value of a single index. A similar situation arises if $B/B_{MSY}>1$ which would lead to an increased level of risk in ABC determination based on the Council's risk policy and an increased level in risk associated with catch in the recreational fishery. This situation leads to a positive feedback in risk.

   The SSC encourages the workgroup developing the Addendum / Framework to find ways in which such types of feedback do not become a structural element of decision making.

2) Indirect effects on ABCs

   Recently, the Council has requested the SSC to provide multiyear, often three-year, specifications of ABCs. In most cases, the SSC assumes that the ABC will be fully caught in the first year to estimate stock biomass in the second year. This stock biomass is used in the Council's risk policy to calculate the ABC for the second year. The SSC then assumes that the year-2 ABC will be fully caught to estimate stock biomass in year-3, applying once again the Council's risk policy to estimate the year-3 ABC. In most cases, the SSC has not had to consider circumstances in which the ABC is exceeded.

   However, overages in recreational Black Sea Bass catches have been significant. To account for this the SSC has provided projections in which it assumes the ABC will be exceeded, thereby further reducing stock biomass, leading to a reduction in subsequent ABCs. Any policy that leads to harvests that are substantially above the quota will likely lead to a similar approach from the SSC of reducing ABCs in multi-year projections.

   There are structural issues in several of the alternatives related to time lags in the availability and uncertainty in the level of recreational catches, and related binning of responses, that may lead to increased uncertainty in whether ABCs may be exceeded, which could lead to the SSC setting lower ABCs than it otherwise would in multi-year specifications.

We note that biennial stock assessments are expected for each of the four species involved in the proposed Addendum / Framework that would be expected to ameliorate this challenge, as 3-year ABC will likely be superseded by new assessment-derived ABCs

3) The Council risk policy assumes a continuous relationship between stock status and fishery responses, whereas many of the alternatives in the proposed Addendum / Framework presume a discrete, binned approach that may not be compatible with the risk policy.

   Fisheries management is an example of process control, and there is an extensive body of literature that considers the response characteristics of both sensors (inputs - in fisheries, the inputs are catches, recruitments and stock biomasses) and process changes (outputs - in fisheries, the outputs are catch limits). For example, a room thermostat is a simple example of process control. Appropriate matching of the sensitivity of the sensors (accuracy of the thermostat), the size of the signal that triggers a response, and the latency in the response (size of the room, capacity of the HVAC system) are all factors that determine the degree to which the process is well controlled. For HVAC systems, thermostats, HVAC capacity both have to be specified appropriately to operate efficiently and effectively to obtain a comfortable room.

   The sub-committee explored how a fishery operates as a process control, considering variability in recruitment (inputs), and control rules of the fishery management process on the performance of the fishery (Appendix A - Rago, MS). Preliminary conclusions from this simulation are that the impacts of binning and random recruitment lead to a marked increase in the likelihood that OFLs would be exceeded. Moreover, populations were not rebuilt as frequently as occurred with population-specific optimal fishing mortality rates. Perhaps more importantly, a greater fraction of populations that were previously above $B_{MSY}$ fell below ½ $B_{MSY}$ when controlled with a binned HCR.

   The subcommittee does not conclude from these simulations that binned approaches should be abandoned; rather we wish Council and Commission members to be aware of the uncertainty that may be introduced by the mismatch between the harvest control rule (Council risk policy) and the binned approach.

4) Impact of time lags in estimates of recreational catch on management decisions

   MRIP estimates are most precise at the annual level for a whole stock. Real-time estimates of recreational catch can be problematic for many species (NASEM 2017, 2021) because of the reduced precision of small-area estimation.

5) Angler behavior.

   As noted previously, accurately predicting how angler behavior will change under a set of regulations is a general challenge in marine recreational fishery management. The relationships between recreational catches and specific regulatory tools (i.e., season, size, and bag limits) are highly uncertain. This challenge is exacerbated by trying to determine such relationships when regulations change frequently, potentially leading to lower compliance. The extent to which anglers accept, believe in, and follow regulations is a complication. The committee discussed whether the complexity of some of the proposed alternatives might lead to reduced compliance because of the challenge of communicating some of the specific binned options that result in multiple contingent outcomes.

6) Limited control in one sector leads to "borrowing" of quota from other sectors, and given the role of historical data in determining allocation, this may lead to unintended management-driven shifts in allocation.

   The joint Council / Commission management process includes policy decisions about the allocation of catch among the principal sectors involved in the fishery. Allocation decisions are always the most controversial aspect of fishery management because they involve statements of economic and social value, about which simple dollar values are an insufficient foundation for decision-making.

   The sub-committee discussed the impacts of the performance of marine recreational fishery management on the allocation. Ideally, levels of under- and overharvesting should be small and approximately equal in both sectors (e.g., see Figure 1D). Under this scenario, realized catches will lead to patterns of allocation that are close to those adopted in policy. In contrast, if constraining one sector is more challenging, and leads to larger deviations from the specified catch targets, the patterns of allocation may be substantially different to those specified in the policy (e.g., see Figure 1A). This can lead to effective "borrowing" of quota from the more controlled sector, and thus to increased levels of contention in the fishery management process. The sub-committee recommends this aspect be evaluated in considering the adoption of the proposed Addendum / Framework.

**(4) What are the benefits and challenges of each proposed action within the proposed Addendum / Framework?**

The sub-committee provides its consensus summary of the benefits and challenges associated with each of the five options in Table 3

| Alternative | Benefits | Challenges |
|---|---|---|
| *Status Quo* | ● Immediate corrective action to avoid exceeding RHL and overall overfishing of the stock.<br>● Continuous response | ● Expectation of recreational catch in the upcoming year being equal to the one observed in one or two most recent years or their average is not supported by the experience.<br>● Angler groups and recreational anglers have expressed frustration with the current methods of setting |

| | | |
|---|---|---|
| | | harvest quotas. |
| % Change | • Uses data readily available already. Broad categories of $B/B_{MSY}$.<br>• Easily understandable by stakeholders/anglers.<br>• This and other new options are expected to provide more stability by employing a buffer concept, where an action is triggered only if the recent catch exceeds threshold values defined by specific alternatives. | • May suggest finer control of recreational catches than has been achieved historically<br>• Duplicating use of $B/B_{MSY}$ at this level may lead to increased variability of catches.<br>• Allows liberalization of rec.catch in some circumstances when $B/B_{MSY} < 1$<br>• If stock size is increasing and effort in year t+1 is the same as in year t, then the expected harvest will increase in year t+1. When you boost effort by 10, 20 or 40% you are likely to overshoot the RHL because you are increasing E(t+1) while B(t+1) is also increasing.<br>• Competition with commercial fleets underscores this challenge. Increasing E(t+1) inappropriately (e.g., + 40%) without a commensurate decrease in quota allocation to the commercial sector will result in increased probability of overfishing.<br>• Potential to induce instability - constantly under or over-shooting targets. The degree to which this occurs is related to the magnitude of the restrictions or liberalizations |
| Fishery Score | • Combines multiple sources of information - both data and performance.<br>• Fishery score approach is an example of a simple additive weighting multi-attribute decision-making. Selection of weights (expert opinion, optimal, eigenvalue weights, fuzzy) is important and is unspecified. | • We are unaware of examples of where a scoring system has been shown to control a population trajectory.<br>• Mapping multiple factors to one scalar may preclude necessary actions or forgo catch.<br>• Not clear if information is available to inform weights. Identifying *a priori* relative importance of |

| | | |
|---|---|---|
| | | various factors and appropriate selection of weights is difficult. Empirical adjustment based on multiple years of observations will be required for tuning,<br>● Strong correlation that is expected in $B/B_{MSY}$ and $F/F_{MSY}$ may lead to strong influence of this single measure. Such collinearity breaches the assumption of preferential independence.<br>● We are unclear whether all values of Fishery Score are likely/possible when this appears not to be the case from consideration of the input value distributions (e.g., distribution of $B/B_{MSY}$ that is under management control). |
| Biological Reference Points | ● Information readily available ($B/B_{MSY}$ & $F/F_{MSY}$) as primary determinants. | ● High number of categories might suggest a level of precision in data and management systems that appears unlikely.<br>● Within each bin of stock size and overfishing condition, regulations will be adjusted based on trends in biomass and recruitment. Apart from knowledge about year classes, how will such trends be evaluated? How many years needed to identify a trend?<br>● Does the averaging approach capture strong year classes?<br>● The stock assessment process used to derive the ABC already includes actions suggested in this Option. Biomass status determination separates the top 3 rows of Table 3 from the bottom row. F status determination separates the two columns. The top 3 rows in Table |

| | | |
|---|---|---|
| | | 3 are defined by the Council's Risk Policy. The projection process, imperfect as it is, accounts for the expected effects of historical recruitment and variation in future recruitment to develop an expected biomass trajectory.<br>● This option compares recent harvests performance to determine whether regulation should be liberalized or restricted. The decision variable should instead be a comparison of recent F due to recreational harvest with target F. This is particularly important in situations where a subsequent stock assessment revealed that biomass was underestimated. Under these conditions, the poor performance was in part due to an increase in abundance rather than an increase in F. Regulations are designed to control fishing mortality; decisions to adjust regulations should therefore rely on comparison between target and realized Fs. |
| Biomass-based Matrix | ● Uses existing data (B trend and $B/B_{MSY}$) | ● Not clear how this leads to stability<br>● Does not explicitly consider overfishing as a basis for action. Does this violate MSA? |

**Conclusions and Recommendations**

We conclude that the proposed Addendum / Framework options are unlikely, in the short term, to affect the determination of the degree of uncertainty used in the current SSC process of ABC specification. The current process for specifying ABC is based on a structured decision making process that results in a preselected level of variability (CV) applied to the most recent estimates of OFL and stock biomass through the Council's risk policy (an HCR). The ABC specification process is not directly influenced by the level of the subsequent catches in any sector.

The sub-committee also notes that the performance of the proposed alternatives in the Addendum / Framework will likely be limited in scope temporarily if biennial stock assessments continue to be available for the four target species. At this frequency of stock assessment, we expect adjustments of OFLs through the stock assessment process, and subsequent adjustments in ABCs through the SSC process, will likely limit the impacts of poor performance by any proposed specification process.

At the same time, the sub-committee notes that the actual efficacy of the proposed alternatives in the Addendum / Framework is unknown. This uncertainty comes from two sources. First, the actual measures that will be taken in response to any of the triggers identified in the Addendum / Framework are not specified. Additional detail is required to turn the options put forward in the Addendum / Framework into control rules - there need to be links to specific management end points, beyond the focus on directionality that characterize the options currently. Until such specificity is provided, quantitative evaluation of the performance of the options is not possible. Second, performance of the discontinuous nature of the options proposed in the Addendum / Framework has not been proven effective in other fisheries nor formally evaluated, to the knowledge of the sub-committee. Preliminary modeling conducted by the sub-committee to evaluate the impacts of the binning of population states, reliance on various metrics of stock condition and recent catch history, and implications of recruitment variability could result in an increased risk of overfishing and becoming overfished. This suggests that the appearance of precision in the process that leads to regulatory specifications does not necessarily translate into precision in catch performance and compliance. The sub-committee expresses the concern that some of the overly complex, contingent decision-making processes included in the proposed alternatives do not reflect the actual level of control likely achieved in marine recreational fishery management.

Finally, the sub-committee cautions that stability of regulations is not the same as stability of catch. If regulations are properly set to achieve a target F, then catches and CPUE will be expected to fluctuate with stock biomass. This is an inherent feature of exploited populations. It is entirely possible to set a constant catch policy. However, harvest limits under such a constant catch policy would likely have to be substantially lower than the ABC (and its attendant RHL) to account for interannual variability in population processes and angler avidity.

# Appendix A

## Potential Effects of HCR Methods on Overfished Status

Paul Rago

April 10, 2022

The Harvest Control Rule Amendment consists of five options for setting recreational harvest controls. Four of these methods rely on quantitative scoring to assign population status into multiple categories. Example categories include overfished vs not overfished, overfishing occurring vs overfishing not occurring, and so forth. Cut points of the categories are used to create up to 8 different bins of population status. Within each bin, a homogeneous set of recreational effort measures (e.g., bag limit, size limit, season length) is assigned to control fishing mortality. In theory, the measures would exert a constant fishing mortality on the population while it was in a given population state (i.e., bin). When the population changes state, another set of HCRs would be applied. For example, if the population went from not overfished to overfished, allowable effort would be reduced to help restore the population to the "not overfished" bin.

The HCR policies could have important implications for controlling the population and the variability of catch. The simulation study herein examines those possible effects for a population with a constant average recruitment, independent of stock size. This is the assumption used in nearly all of the stock assessments in the Northeast. The hypothesis implies a steepness of 1.0. The basis of this pattern has been the inability to define a parametric stock recruitment relationship in most assessments.

**Model**

Let $B_t$ represent the stock biomass at time t, Z represent the total mortality on the stock (Z= fishing mortality F + natural mortality M) and $R_t$ equal the recruitment to the stock biomass at time t.

The basic dynamics are thus governed by

$$\boldsymbol{B}_{t+1} = B_t e^{-Z} + R_t \qquad (1)$$

Recursive application of Eq. 1 yields

$$\boldsymbol{B}_{t+1} = B_t e^{-Z} + R_t$$

$$\boldsymbol{B}_{t+2} = B_{t+1} e^{-Z} + R_{t+1}$$

$$\boldsymbol{B}_{t+3} = B_{t+2} e^{-Z} + R_{t+2}$$

...

$$\boldsymbol{B}_{t+T} = B_{T-1} e^{-Z} + R_{T-1} \qquad (2)$$

The limit of this process as T approaches infinity converges to

$$B_\infty = \frac{R}{1-e^{-Z}} \qquad (3)$$

In the absence of fishing, the maximum population size is defined as

$$B_{MAX} = \frac{R}{1-e^{-M}} \qquad (4)$$

If we apply the usual convention that $B_{MSY}$=1/2 $B_{max}$, a little algebra will show that $F_{MSY}$ is defined as

$$F_{MSY} = -ln(2e^{-M} - 1) - M \qquad (5)$$

Applying the catch equation give MSY as

$$MSY = \frac{F_{MSY}}{F_{MSY}+M}\left(1 - e^{-(F_{MSY}+M}\right)B_{MSY} \qquad (6)$$

The behavior of a population governed by Eq. 1 is similar to a population governed by a logistic equation, although the density dependence is not explicit. Note also that the above definition of MSY is determined by the <u>assumption</u> that $B_{MSY}$ is ½ $B_{MAX}$[1].

Harvest control rules, in general terms, are designed to achieve some objective, subject to constraints. If a population is overfished, control rules should allow the population to increase to $B_{MSY}$ over some defined time period T. If a population is well above $B_{MAX}$, the objective is to allow as much fishing as possible subject to a constraint that $F_t$<$F_{MSY}$. In all other cases, a common objective is to move the population toward $B_{MSY}$. For the sake of this analysis, I assumed that the objective of the HCR was to achieve $B_{MS}$ in some time period T subject to the constraint that Ft<$F_{MSY}$.

Under these conditions the optimal fishing mortality is defined as the fishing mortality rate necessary to move the population from its current state to $B_{MSY}$ in a time horizon T. This can be written as two-point boundary value problem to find the solution to Eq 2 where $B_{t+T}$=$B_{MSY}$. Thus

$$\boldsymbol{B}_{t+1} = B_t e^{-F_{opt}-M} + R_t$$

$$\boldsymbol{B}_{t+2} = B_{t+1} e^{-F_{opt}-M} + R_{t+1}$$

$$\boldsymbol{B}_{t+3} = B_{t+2} e^{-F_{opt}-M} + R_{t+2}$$

…

[1] In a population truly governed by Eq. 1, the maximum sustainable yield would be to harvest the entire recruitment at each time period. No sense letting the biomass degrade in the $B_t$ pool!

$$B_{MSY} = B_{t+T} = B_{T-1}e^{-F_{opt}-M} + R_{T-1} \qquad (7)$$

The optimal fishing mortality can be found numerically by setting finding Fopt such that $B_{MSY}$-$B_{t+T}$=0. Two special conditions apply. First, it may not be possible to achieve $B_{MS}$ even when F=0. Second, Council policy and National Standards do not allow F to exceed $F_{MSY}$. Hence $F_{opt}$ has a maximum value of $F_{MSY}$. Under condition 1 the $F_{opt}$ is infeasible; under condition 2, the population will exceed $B_{MSY}$ at the end of the horizon t+T. An important aspect of Eq. 7 is that the future dynamics are not affected by the current level of F. $F_{opt}$ is a function of $B_t$, $B_{t+T}$, R and M only.

See Table 1 for a list of all model parameters.

*Table 1. Summary of model parameters and derived quantities used in simulations.*

| ***Parameter*** | ***Variable*** | ***Value*** |
|---|---|---|
| Natural Mortality | M | 0.2 |
| Initial Biomass | $B_0$ | 300 |
| Recruitment | $R_t$ | 100 |
| Planning Horizon (years) | T | 5 |
| Range of Recruitment | $R_{min}$, $R_{max}$ | 50, 150 |
| ***Derived Quantities*** | | |
| Maximum Biomass | $B_{MAX}$ | 551.6 |
| Biomass at MSY | $B_{MSY}$ | 275.8 |
| Fishing Mortality for MSY | $F_{MSY}$ | 0.2503 |
| Maximum Sustainable Yield | MSY | 55.6 |
| ***HCR Bins*** | | |
| Biomass: Very High | >1.5 $B_{MSY}$ | 413.7 |
| Biomass: High | [$B_{MSY}$,1.5 $B_{MSY}$) | [275.8, 413.7) |
| Biomass: Low | [0.5 $B_{MSY}$, $B_{MSY}$) | [137.9, 275.8) |
| Biomass: Too Low | <0.5 $B_{MSY}$ | <137.9 |

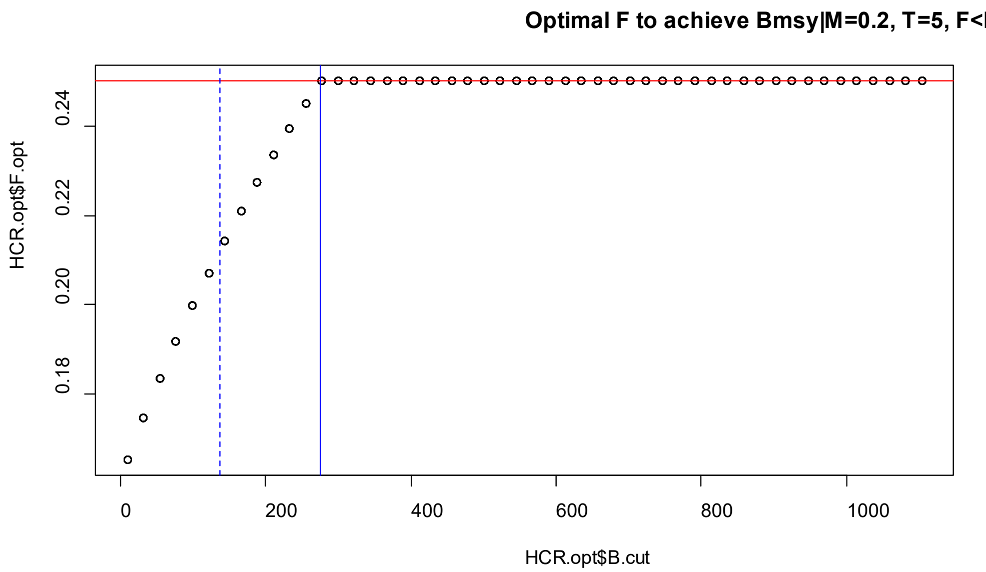



*Figure 1. Optimal F to achieve $B_{MSY}$ given initial biomass level Bt. See Eq. 7. Red line is $F_{MSY}$. Solid blue vertical line is $B_{MSY}$, dashed vertical line is ½ $B_{MSY}$.*

As shown in Fig. 1 the optimal policy does not depend on whether fishing mortality is, or is not occurring at time t. However, the magnitude of change in F for a given population state ($B_t$, $F_t$) does depend on Ft (i.e., $F_t$-$F_{opt}$). To illustrate this further, consider the $B_t$, $F_t$ phase plane used for Option D.

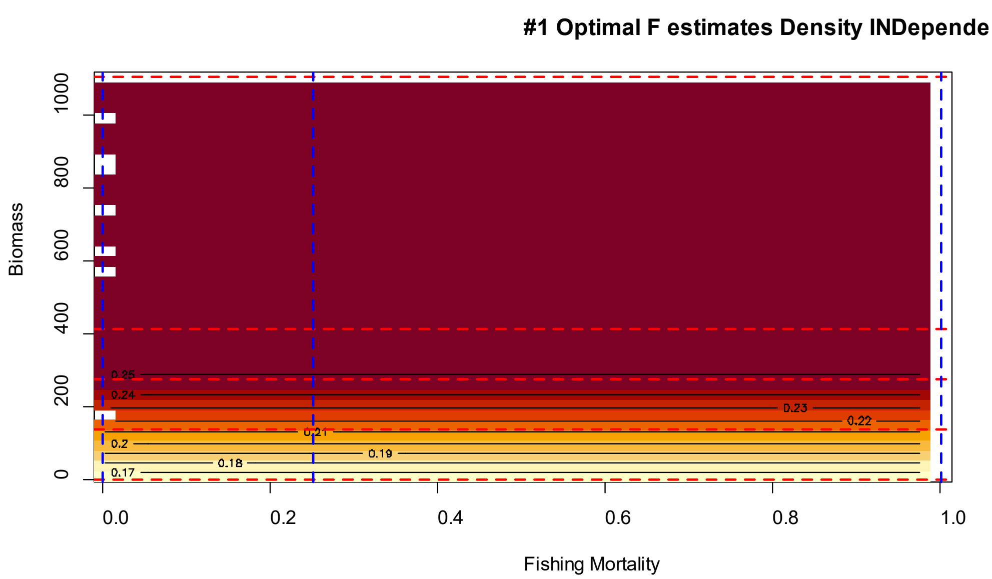



*Figure 2. Optimal F response surface vs biomass and fishing mortality.*

**Effects of Binning**

Equation 7 defines an optimal fishing mortality rate for every value of Bt. However, the HCR is based on the use of a common F strategy within bins of population states. These states include intervals of biomass, fishing mortality, biomass rates of change, a linear scoring approach, and expected differences between recent catch and RHL. One way of dealing with this binning is to use a measure of central tendency for all possible observations within the HCR category. For example, one could compute the average Fopt for all possible values of $B_t$ in the interval [$B_{MSY}$, $B_{MAX}$] or in the interval [0.5 $B_{MSY}$, $B_{MSY}$] etc. This process is illustrated in Fig. 3.

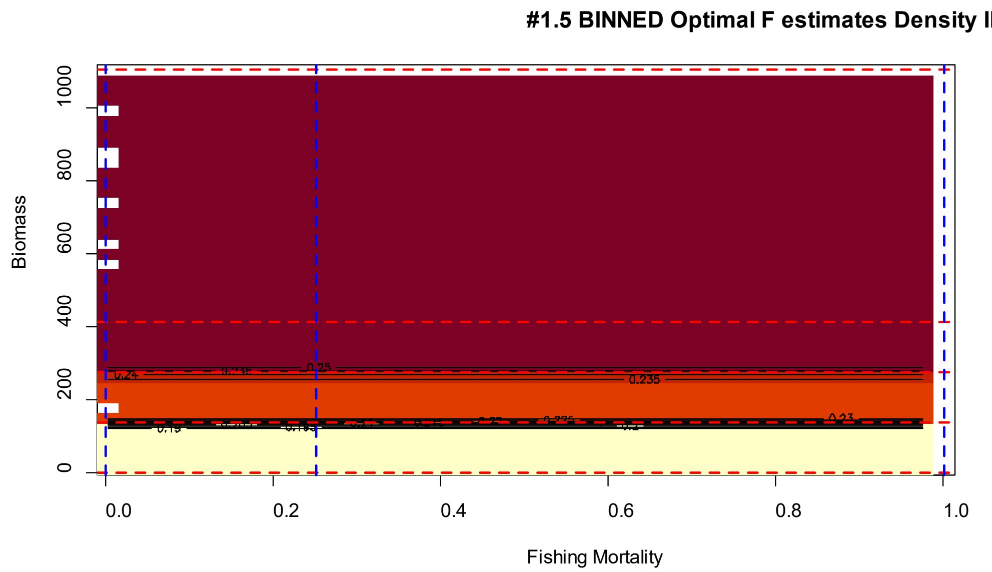



*Figure 3. Binned optimal F values representing the average Fopt within each population state defined by the horizontal and vertical cut points. Lighter colors represent lower average fishing mortality rates.*

Figure 3 illustrates that under a given population state, a common F would be applied. The use of averages of $F_{opt}$ for each bin implies slightly different cumulative catches over the period T. Figure 4 shows the cumulative catches with unique $F_{opt}$ values. Figure 5 shows the same response given average $F_{opt}$ values within bins.

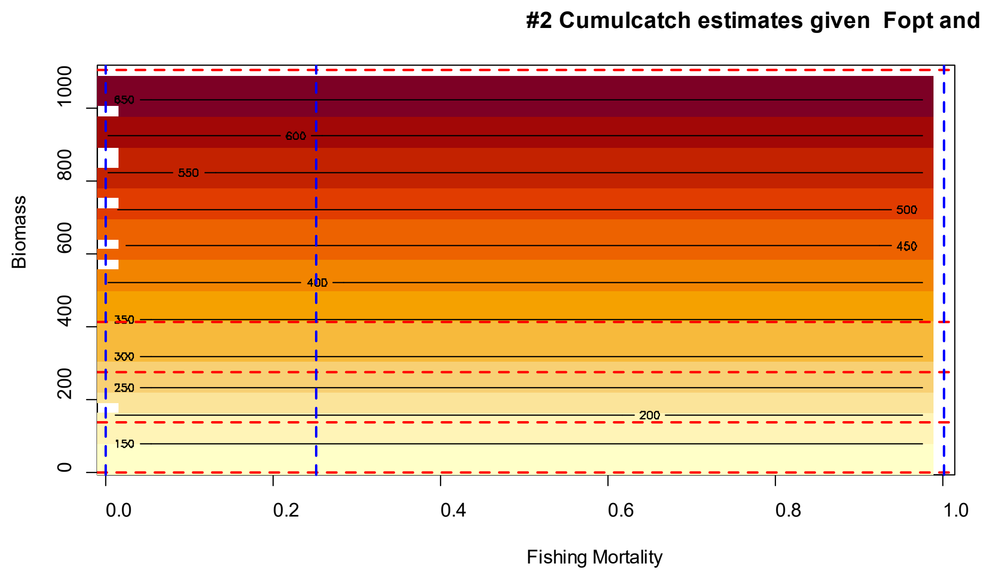



*Figure 4. Response surface for cumulative catches over a T=5 yr period give $F_{opt}$ for each level of initial biomass $B_t$ and initial Fishing mortality $F_t$. See Fig. 2. Note that cumulative catch is unaffected by $F_t$.*

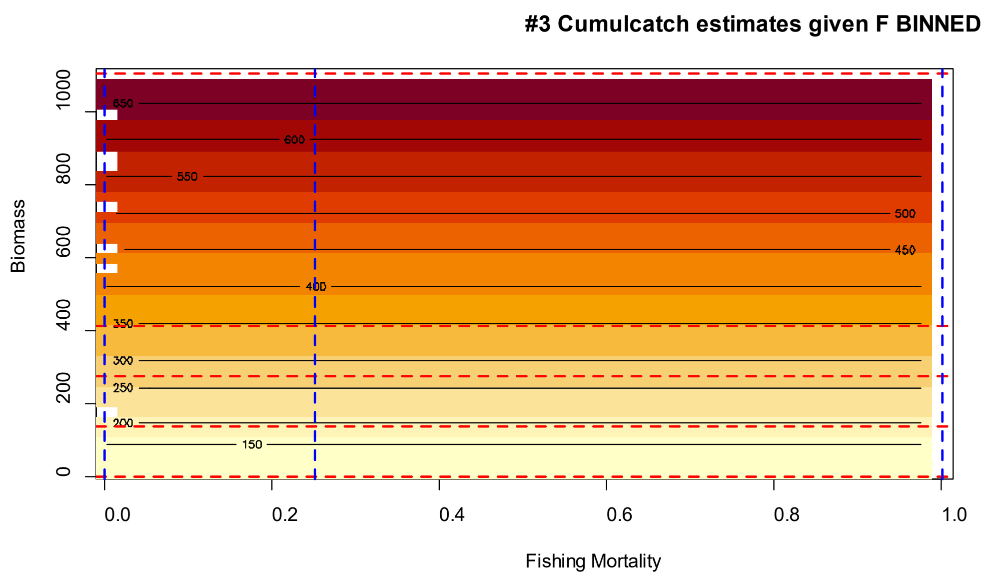
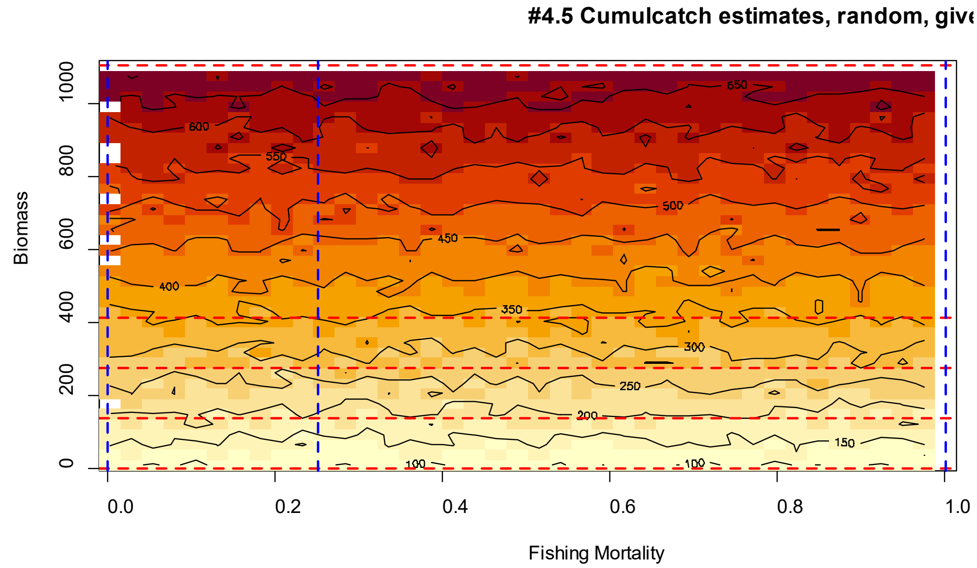



*Figure 5. Response surface for cumulative catches over a T=5 yr period given BINNED $F_t$ for category. See levels in Fig. 3. Note that cumulative catch is unaffected by $F_t$.*

**Effects of Random Recruitment and Binning**

Results thus far have considered a deterministic model only. Random recruitment, combined with binned HCR might be expected to increase the variability of the catches. Recruitment was modeled as a uniform random number between R.min and R.max. See Table 1 for list of all model parameters.

First, consider the implications of random recruitment on cumulative catch (Fig. 6 top).



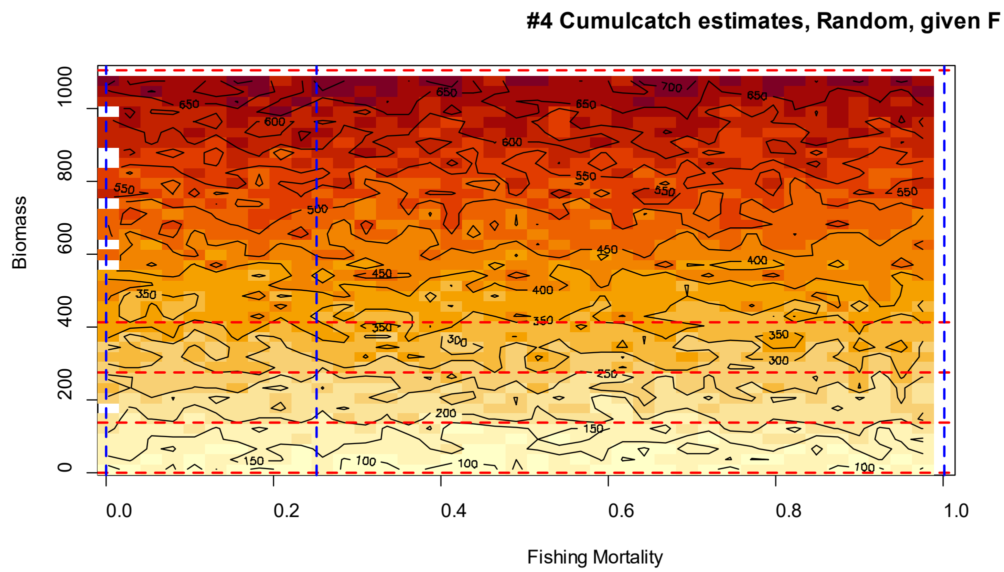
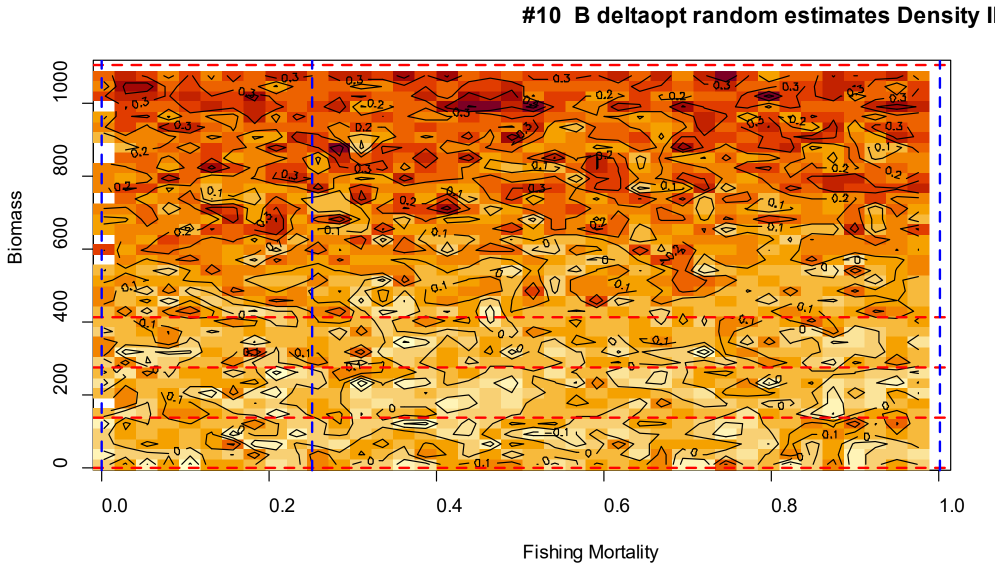




*Figure 6. Cumulative catch as a function of initial density with random recruitment only and optimal F based on initial density (top). Cumulative catch with random recruitment AND binned F control (Bottom).*

The mean and variance of cumulative catch did not change appreciably under the random Recruitment vs random recruitment with binned controls.

The efficacy of control measures can also be examined with respect to their ability to achieve target biomass levels. In this case the target was defined as being 90% or more of the $B_{MSY}$. In other words, successes were defined as outcomes where $B_t$>0.9 $B_{MSY}$.



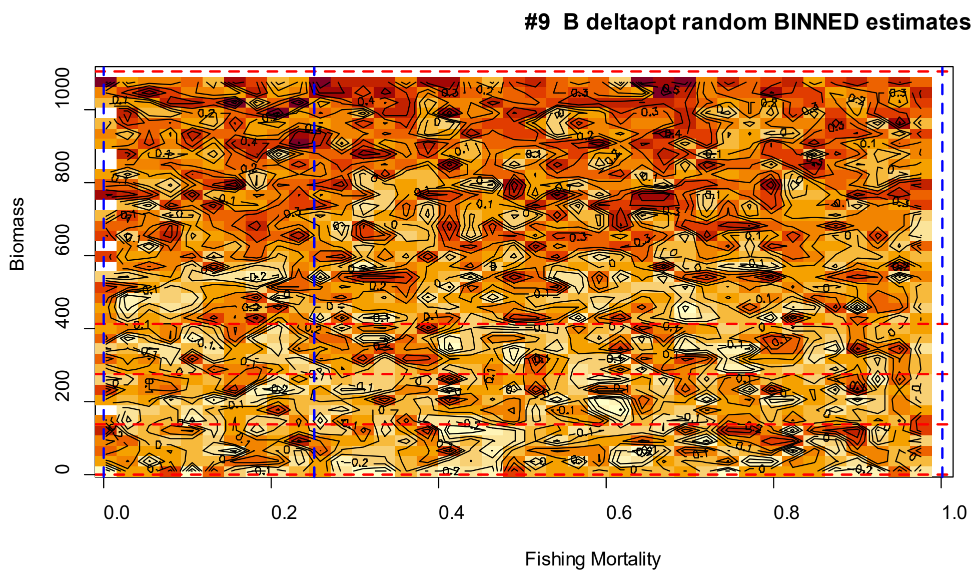




*Figure 7. Difference in terminal biomass $B_{t+T}$ and $B_{MSY}$ as a function of initial density with random recruitment only and optimal F based on initial density (top). Cumulative catch with random recruitment AND binned F control (Bottom).*

**Are Binned Measures Sufficient?**

One measure of the efficacy of binned controls is whether or not the measures achieve the desired target of achieving $B_{MSY}$ over the planning horizon T. This property was tested by comparing the initial state of the population with the final state of the population after 5 years. Ideally, the derived $F_{opt}$ should be sufficient to achieve $B_{MSY}$ irrespective of the binning or magnitude of random recruitment. For the deterministic case, Fopt was sufficient to return the population to a not overfished state.

The rows below represent the initial state of the biomass, the columns represent the final state of the population after 5 years of applying $F_{opt}$ for every biomass value or an average $F_{opt}$ depending on the initial bin.

```
> tapply(HCR.opt$F.opt,list(HCR.opt$B.status, HCR.opt$B.poststatus.det),length )
           Not Overfished
Overfished            300
Low                   300
High                  350
Very High            1550
```

```
> tapply(HCR.opt$F.opt,list(HCR.opt$B.status, HCR.opt$B.poststatus.det.bin),length )
           Not Overfished
Overfished            300
Low                   300
High                  350
Very High            1550
```

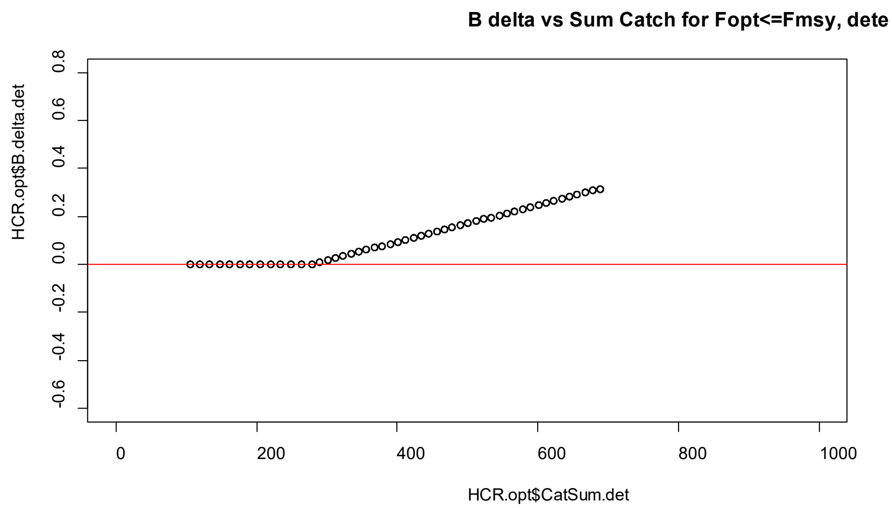
The effects of random variation in recruitment on the ability to recover the population degraded as shown in the table below. Note that populations that were initially overfished remained overfished in 69 of 300 cases (23% failure rate). A similarly high rate of failure occurred for populations that were low, but not overfished. Perhaps more disturbing, populations that were high had a 21% failure rate. Only 3.6% of the very high abundance populations became overfished.

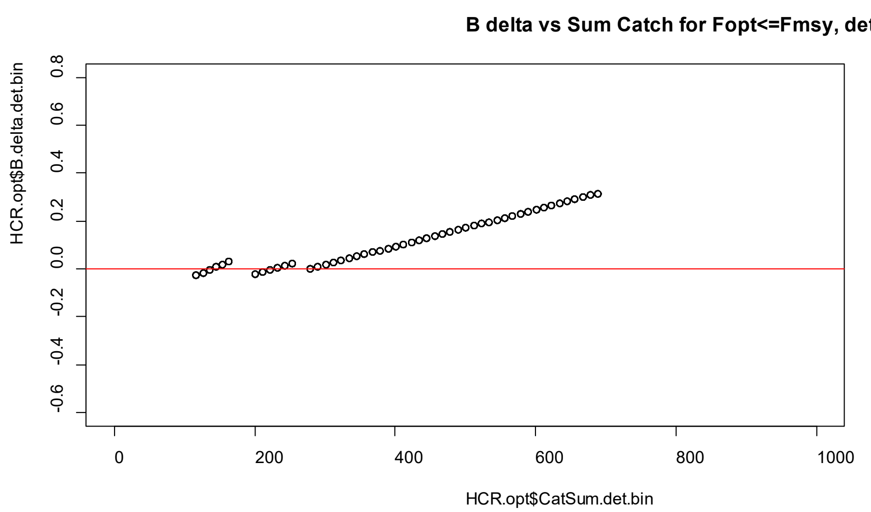
```
> tapply(HCR.opt$F.opt,list(HCR.opt$B.status, HCR.opt$B.poststatus.ran),length )
           Not Overfished Overfished
Overfished            231         69
Low                   231         69
High                  287         63
Very High            1494         56
```

The joint effects of random variation and binned controls are shown below. The success rate for achieving a not overfish population declined to 61.7% vs 77% when binning did not occur. The failure rate for stocks that were not initially overfished increased significantly with binned controls. For example, 19.1% of the populations initially at very high levels fell into an overfished condition. The ratio of failures when binned to unbinned controls is 296/56=5.3x. The odds ratio for this comparison is 6.3 =(1494*296)/(1254*56). The odds ratio for populations initially in a high population state is 2.5=(287*125)/(225*63).

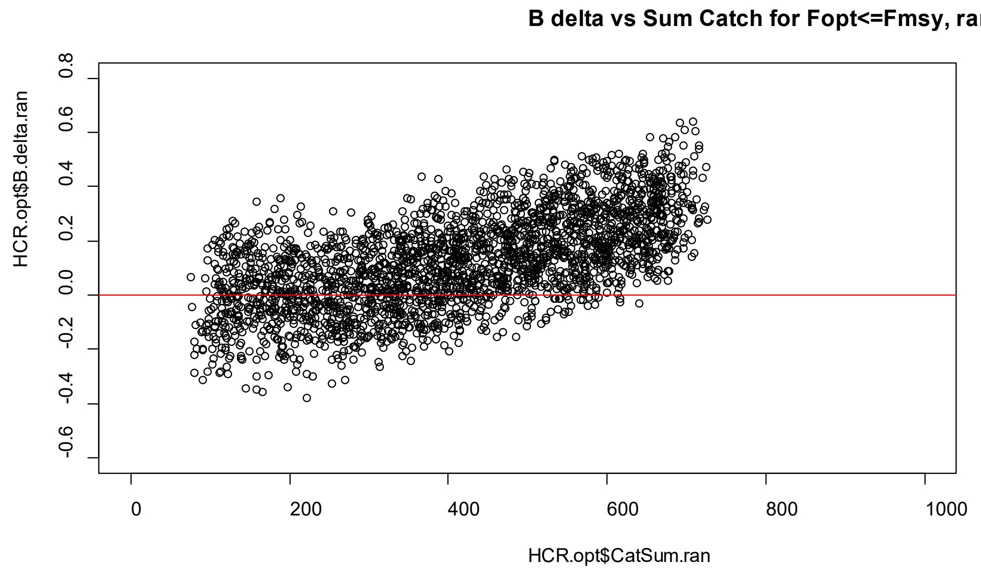
```
> tapply(HCR.opt$F.opt,list(HCR.opt$B.status, HCR.opt$B.poststatus.ran.bin),length )
           Not Overfished Overfished
Overfished            185        115
Low                   186        114
High                  225        125
Very High            1254        296
```

The following graphs illustrate the effects random Recruitment and binning on variation in $B_{delta}$ are shown below. Note that the effect of binning is to result in negative population trends when biomass is low within the bin.

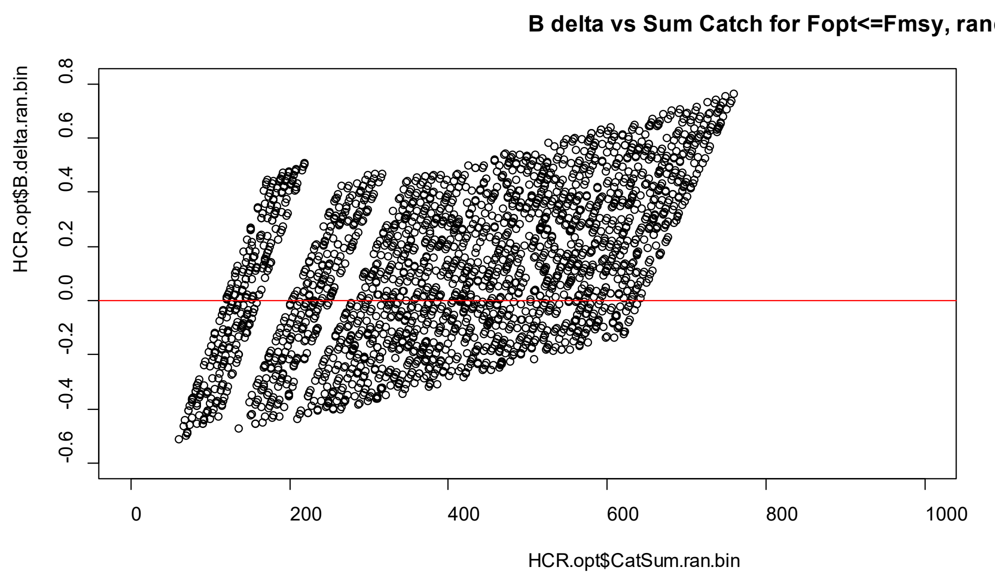

B delta vs Sum Catch for Fopt<=Fmsy, dete
HCR.opt$B.delta.det
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
200
400
600
800
1000
HCR.opt$CatSum.det


B delta vs Sum Catch for Fopt<=Fmsy, de
HCR.opt$B.delta.det.bin
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
200
400
600
800
1000
HCR.opt$CatSum.det.bin

When random variation is added to recruitment, the patterns become more interesting.




Note that the general "lazy J" pattern evident it the deterministic patter is preserved but the number and magnitude of population declines increases, especially when B is less than $B_{MSY}$. Superposition of binning on top of random variation (shown below) dramatically alters the resulting pattern with more "structure" induced by the bins and more failures.




**Preliminary Conclusions**

A simple population model was used to characterize the magnitude of uncertainty induced by binning of control rules. When combined with random variation, there was a marked increase in the failure rate of controls. Populations were not rebuilt as frequently as occurred with population specific optimal fishing mortality rates. Perhaps more importantly, a greater fraction of populations that were previously above $B_{MSY}$ fell below ½ $B_{MSY}$ when controlled with a binned HCR.

The model used herein, although highly simplified, has properties similar to models used for stock assessments in the Mid Atlantic regions. The HCR implementation is highly simplified and ignores the potential changes in population state that might occur when a population is driven by random recruitment. Specifically, one could adjust the fishing mortality to different population states within the 5-yr projection period. However, it should be noted that neither of the scenarios with random recruitment made such adjustments.

The simulations are indicative but not definitive. I did not evaluate Options B, C or E and the simulation of Option D does not include the additional considerations of whether B or R are increasing or decreasing. Option D includes 13 possible controls rather than the 8 used in this exercise. The simulations may be sufficient to justify the general hypothesis that binning of controls could be problematic if the bins are too wide and the duration between updated of controls is too long.