AMENDMENT 8

to the
Atlantic Herring Fishery Management Plan

Including a
Draft Environmental Impact Statement (DEIS)

Volume II - Appendices

Prepared by the
New England Fishery Management Council
in cooperation with the
National Marine Fisheries Service
Cover Image: Downloaded from FishWatch, www.FishWatch.gov. NOAA Fisheries website with up-to-date information on U.S. seafood.
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Summary of Public Scoping Comments

for

Amendment 8

to the

Atlantic Herring Fishery Management Plan

December 21, 2015

Compiled by the
Herring Plan Development Team
INTRODUCTION

The New England Fishery Management Council (Council) has proposed developing Amendment 8 to the Atlantic Herring Fishery Management Plan (FMP) to consider long-term harvest strategies for herring, including an acceptable biological catch (ABC) control rule that addresses the biological needs of the herring resource and explicitly accounts for herring’s role in the ecosystem. The original public scoping period was February 26 – April 30, 2015. During this time, oral and written comments were received at three in-person hearings and a webinar. Written comments were also submitted directly to the (Council). In June 2015, the Herring Committee and Council received a brief summary of public comments by the Plan Development Team (PDT) Chairman. Partially in response to concerns expressed through scoping about localized depletion of Atlantic herring, the Council then decided to expand the focus of Amendment 8 to consider this issue. A supplemental scoping period was held August 21 - September 30, 2015. Comments were received in writing and at one in-person hearing.

All of the written and oral comments are available for review by the Council and the public. This report provides a summary of the demographics of commenters and the key themes that emerged from the scoping periods. This report does not constitute a response to the comments; rather, it is intended to serve as a guide for Council members and the public as they review the comments and develop Amendment 8. It should not substitute for reading the comments directly. This summary was compiled by the Herring Plan Development Team, primarily Rachel Feeney.
2.0 PURPOSE OF SCOPING

2.1 ORIGINAL PURPOSE
Amendment 8 was initiated by the Council in November 2014 “to consider control rules for the Atlantic herring fishery that account for herring’s role as forage in the ecosystem.” Through scoping, the Council sought public input on the following questions, though comments were not limited to these topics:
1. What alternatives for ABC control rules should the Council consider for Atlantic herring in Amendment 8?
2. How should the Council account for the role of Atlantic herring in the ecosystem when it develops the ABC control rule?
3. What specific issues are most important when evaluating the tradeoffs associated with managing the Atlantic herring fishery in an ecosystem context?

2.2 SUPPLEMENTAL SCOPING
In June 2015, upon preliminary review of scoping comments, the Council developed goals for Amendment 8 that expanded the scope of this action to include consideration of the spatial and temporal availability of Atlantic herring.

The goals of Amendment 8 are:
1. Account for the role of herring within the ecosystem, including its role as forage;
2. Stabilize the fishery at a level designed to achieve optimum yield; and
3. Address localized depletion in inshore waters.

The Council also recommended that an objective for Amendment 8 be to develop and implement an ABC control rule that manages herring within an ecosystem context and addresses the above goals. The supplemental scoping period solicited comments on Goal #3.

3.0 DESCRIPTION OF COMMENTERS
The demographic information available about the commenters is summarized here. Several commenters stated that they represent multiple stakeholder types. In those cases, a primary stakeholder type was assigned based on certain assumptions. For those who indicated that they fish both commercially and recreationally, the primary stakeholder type was assigned as commercial fisherman, since the person would presumably have greater financial stake in a commercial rather than recreational fishery. For those who submitted comments on behalf of themselves and a non-governmental organization (NGO), the primary stakeholder type was assigned as a NGO, since the NGO presumably represents a larger group of people. For those who represent a regional or national NGO as well as an NGO of “other fishing interests”, the primary stakeholder type assigned was regional/national NGO, since that, again, presumably represents a larger group of people. For simplicity, the comment themes were summarized by just primary stakeholder type.
3.1 ORAL COMMENTS
In total, the five public hearings were attended by about 115 stakeholders (duplicates possible), and 29 individuals provided oral comments (duplicates removed; Table 1). Oral comments were received from four commercial herring fishermen, 11 other commercial fishermen, four charter fishermen, and ten representatives of NGOs (Table 2). All but one of the oral comments was provided during the initial scoping period.

### Table 1 - Public hearing attendance

<table>
<thead>
<tr>
<th>Scoping Period</th>
<th>Location</th>
<th>Attendees</th>
<th>Speakers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>Rockland, ME</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Danvers, MA</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Mystic, CT</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>webinar</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Supp.</td>
<td>Boston, MA</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>115 (1)</td>
<td>29 (1)</td>
<td></td>
</tr>
</tbody>
</table>

1 Approximate; excludes Council members or staff.  
2 Duplicates possible.  
3 Duplicates removed.

### Table 2 - Stakeholder type of speakers

<table>
<thead>
<tr>
<th>Primary stakeholder type</th>
<th>Speakers (n,%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial fishery - herring</td>
<td>4 (14%)</td>
</tr>
<tr>
<td>Commercial fishery – other1</td>
<td>11 (38%)</td>
</tr>
<tr>
<td>Charter fisherman</td>
<td>4 (14%)</td>
</tr>
<tr>
<td>NGO - Commercial</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>NGO - Environmental local</td>
<td>2 (7%)</td>
</tr>
<tr>
<td>NGO - Env. national/regional</td>
<td>4 (14%)</td>
</tr>
<tr>
<td>NGO - Other fishing interests</td>
<td>3 (10%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>29 (100%)</strong></td>
</tr>
</tbody>
</table>

Note: Duplicates removed. Each speaker assigned here to their primary stakeholder type.  
1Includes groundfish, striped bass, tuna, and unknown.

3.2 WRITTEN COMMENTS
For the initial comment period, there were 111 written comments (Table 3), not including the written comments read into the record at an oral hearing (counted as oral comments in Section 3.1). Written comments were received from 62 individuals or businesses, eight small groups of individuals (2-35 signers), 35 NGOs, and three government agencies. There were also three form letters from NGOs signed by about 28,000 people (duplicates possible). Of those, about 2,500 people included brief personal comments with their signature. For the supplemental comment period, there were 150 written comments received from: 130 individuals or businesses, nine small groups of individuals (6-37 signers), nine NGOs, and two government agencies. In total, there were 261 written comments submitted, not including the brief personal comments attached to the form letters.

### Table 3 - Written comments received

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>Supplemental</th>
<th>Total Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individuals or businesses</td>
<td>62 (56%)</td>
<td>130 (87%)</td>
<td>192 (74%)</td>
</tr>
<tr>
<td>Small groups of individuals</td>
<td>8 (7%)</td>
<td>9 (6%)</td>
<td>17 (7%)</td>
</tr>
<tr>
<td>Non-governmental organizations</td>
<td>35 (32%)</td>
<td>9 (6%)</td>
<td>44 (17%)</td>
</tr>
<tr>
<td>Government agencies</td>
<td>3 (3%)</td>
<td>2 (1%)</td>
<td>5 (2%)</td>
</tr>
<tr>
<td>Large form letters1</td>
<td>3 (3%)</td>
<td>-</td>
<td>3 (1%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>111 (100%)</strong></td>
<td><strong>150 (100%)</strong></td>
<td><strong>261 (100%)</strong></td>
</tr>
</tbody>
</table>

1The large form letters included about 2,500 brief personal comments.
### 3.3 ORAL AND WRITTEN COMMENTS COMBINED

Through the 290 comments (i.e., 29 oral and 261 written), 468 people gave input (duplicates removed) on Amendment 8, in addition to the 28,000 people (duplicates possible) who signed the three large form letters. However, many comments were given by people who represent businesses or organizations, and the total number of people those commenters represent cannot be determined. Of the 468 people, 13 people only submitted oral comments, 439 people only submitted written comments, and 15 people submitted both. Not including the three large form letters, 45 people signed between 2 and 5 letters each, and 408 people signed just one letter. Of the 468 people, 161 only commented during the initial period, 274 only commented during the supplemental period, and 33 commented during both periods. The 468 people submitting comments (i.e., not including the three large form letters) represent a variety of different interests: 422 represented themselves or a business, 37 represented a NGO, five represented a government agency, and four commented on behalf of themselves and a NGO.

The 468 people submitting comments represent a variety of stakeholder types (Table 4). Several commenters stated that they represent multiple stakeholder types, so a primary stakeholder type was assigned with some assumptions (as noted above). The majority (83%) of the 468 people submitting comments were fishermen (Table 4): seven herring fishermen, 95 other commercial fishermen (e.g., groundfish, tuna), 53 charter fishermen, 98 private anglers, and the precise type of fisherman could not be identified for 134, though based on the comments, are likely to not be herring fishermen. People representing NGOs (commercial, environmental (local, national/regional), other fishing interests) comprised 8% of the commenters. The specific organizations are listed in Appendix I. Other stakeholder types were state or local government (1%), scientist (2%), fishery support services (1%), whale watching industry (0.4%), and unknown (4%). In terms of stakeholder types of commenters, all of the NGOs with a local environmental focus commented in the initial period. The biggest difference percentage wise was in comments from private anglers, which comprised 5% of the initial commenters and 30% of the supplemental.

Home state could be identified for 79% of the 468 people who submitted comments (excluding the three large form letters (Table 5). The majority (72%) was from New England, primarily Massachusetts (49%). Commenters hailed from at least 15 states.

Due to time and information constraints, it was not possible to analyze the demographics of the over 28,000 people (duplicates possible) who signed the three large form letters, at least to the same degree as the other submissions. General characterizations were made:

- **Pew Environment Group form letter**: This letter had 12,381 signatories with 1,259 people adding brief personal comments. Signatories were primarily from the United States (95%), and hailed from all 50 states and the District of Columbia. About 8% were from New England states.
- **Earth Justice form letter**: This letter had 13,424 signatories with 1,072 people adding brief personal comments. Signatories were all from the United States, though more specifics could not be determined based on the format of the information.
- **Ocean River Institute form letter**: This letter had 2,443 signatories with many people adding brief personal comments. Signatories were from about 45 U.S. states and the District of Columbia. About 5% were from New England states.
### Table 4 – Primary stakeholder type of commenters, n=468

<table>
<thead>
<tr>
<th>Primary stakeholder type</th>
<th>Commenters (n, %)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Supplemental</td>
<td>Total(^1)</td>
<td></td>
</tr>
<tr>
<td>Commercial fishery - herring</td>
<td>5 (3%)</td>
<td>2 (1%)</td>
<td>7 (1%)</td>
<td></td>
</tr>
<tr>
<td>Commercial fishery – other(^2)</td>
<td>31 (16%)</td>
<td>74 (24%)</td>
<td>95 (20%)</td>
<td></td>
</tr>
<tr>
<td>Charter fisherman</td>
<td>30 (15%)</td>
<td>31 (10%)</td>
<td>53 (11%)</td>
<td></td>
</tr>
<tr>
<td>Private angler</td>
<td>10 (5%)</td>
<td>92 (30%)</td>
<td>98 (21%)</td>
<td></td>
</tr>
<tr>
<td>Fisherman – type unknown(^3)</td>
<td>59 (30%)</td>
<td>80 (26%)</td>
<td>134 (29%)</td>
<td></td>
</tr>
<tr>
<td>State or local government</td>
<td>3 (2%)</td>
<td>2 (1%)</td>
<td>5 (1%)</td>
<td></td>
</tr>
<tr>
<td>NGO - Commercial</td>
<td>6 (3%)</td>
<td>1 (0.3%)</td>
<td>7 (1%)</td>
<td></td>
</tr>
<tr>
<td>NGO - Environmental local</td>
<td>17 (9%)</td>
<td>-</td>
<td>17 (4%)</td>
<td></td>
</tr>
<tr>
<td>NGO - Environmental national/regional</td>
<td>6 (3%)</td>
<td>2 (1%)</td>
<td>6 (1%)</td>
<td></td>
</tr>
<tr>
<td>NGO - Other fishing interests</td>
<td>9 (5%)</td>
<td>4 (1%)</td>
<td>11 (2%)</td>
<td></td>
</tr>
<tr>
<td>Scientist</td>
<td>5 (3%)</td>
<td>3 (1%)</td>
<td>8 (2%)</td>
<td></td>
</tr>
<tr>
<td>Fishery support services</td>
<td>1 (1%)</td>
<td>4 (1%)</td>
<td>5 (1%)</td>
<td></td>
</tr>
<tr>
<td>Whale watching industry</td>
<td>2 (1%)</td>
<td>1 (0.3%)</td>
<td>2 (0.4%)</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>9 (5%)</td>
<td>11 (4%)</td>
<td>20 (4%)</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>194 (100%)</strong></td>
<td><strong>307 (100%)</strong></td>
<td><strong>468 (100%)</strong></td>
<td></td>
</tr>
</tbody>
</table>

Note: Those people signing the three large form letters are not included here. Each person assigned here to their primary stakeholder type.

\(^1\) Duplicates removed.

\(^2\) Includes groundfish, striped bass, tuna, and unknown.

\(^3\) Unknown if commercial other, private or party/charter.

### Table 5 - Home state of commenters, n=468

<table>
<thead>
<tr>
<th>State</th>
<th>Commenters (n, %)</th>
<th>State</th>
<th>Commenters (n, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME</td>
<td>52 (11%)</td>
<td>VA</td>
<td>2 (0.4%)</td>
</tr>
<tr>
<td>NH</td>
<td>30 (6%)</td>
<td>DC</td>
<td>1 (0.2%)</td>
</tr>
<tr>
<td>MA</td>
<td>230 (49%)</td>
<td>FL</td>
<td>3 (1%)</td>
</tr>
<tr>
<td>RI</td>
<td>17 (4%)</td>
<td>TX</td>
<td>1 (0.2%)</td>
</tr>
<tr>
<td>CT</td>
<td>11 (2%)</td>
<td>CO</td>
<td>1 (0.2%)</td>
</tr>
<tr>
<td>NY</td>
<td>15 (3%)</td>
<td>CA</td>
<td>2 (0.4%)</td>
</tr>
<tr>
<td>NJ</td>
<td>4 (1%)</td>
<td>OR</td>
<td>1 (0.2%)</td>
</tr>
<tr>
<td>PA</td>
<td>1 (0.2%)</td>
<td>Unknown</td>
<td>66 (21%)</td>
</tr>
<tr>
<td>MD</td>
<td>1 (0.2%)</td>
<td></td>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

Note: Includes commenters from both scoping periods, duplicates removed, not including the people who signed the three large form letters.

### 4.0 COMMENT SUMMARY

All comments received during both public comment periods are summarized here. This includes the 261 written comments and summaries of each hearing that contain close (but not exact) transcriptions of the 29 oral comments. All comments were converted into text-searchable formats and imported into a *QSR NVivo 10* project for sorting and synthesis. Using this software, topics in the text were highlighted and assigned to a label or “node.” Nodes were also created for each person who signed a letter. The comments were then queried to determine how many discussed each topic. Where an individual or NGO commented orally and in writing about a
topic, they are counted once in the “people commenting” column and twice in the “comments” column.

The three large form letters included brief personal comments from about 2,500 people. Due to time constraints, these comments were not coded in the software. A review of these personal comments confirmed that their themes are consistent with those of their associated form letter. The form letters themselves were included in the summarizing process described above.

It should be noted that some commenters focused on describing current problems verses desired outcomes or vice versa. Thus, there may be more commenters who would agree with particular points than the number of commenters who specifically discussed them.

### 4.1 GENERAL SUPPORT FOR AMENDMENT 8 GOALS

Most all of the comments supported addressing concerns about localized depletion and developing an approach for managing herring that explicitly accounts for its role in the ecosystem. Many thanked the Council for undertaking Amendment 8. Comments spoke of a need for precaution to ensure sufficient supply of herring as predators and prey in the ecosystem to, in part, benefit all fisheries that depend on herring (e.g., groundfish, tuna, as well as herring).

“It is critical that the Council and NOAA take the necessary steps to ensure the sustainability of the herring stock, and give this species special attention because of its unique role in the ecosystem.”

“It is very encouraging that this step is being taken. I feel like the biological perspective of herring has long been ignored.”

“Ultimately, we need a harvest policy that addresses some of the special and temporal concerns repeatedly raised by fishermen. We need to ensure there are enough herring when and where the predators need them.”

### 4.2 GENERAL CONCERNS WITH AMENDMENT 8 GOALS

Concerns about the goals of Amendment 8 were expressed by six members of the herring industry and two commercial NGOs via five written and four oral comments. Regarding the ABC control rule, commenters were concerned that accounting for herring as forage in the control rule may be “double-dipping,” indicating that accounting for it in the assessment is adequate. Some indicated that the focus should be on improving the assessment rather than the development of Amendment 8. A few noted that there is no mandate for accounting for herring as forage in the control rule and doing so may violate the National Standards if optimum yield is not achieved or if there is unnecessary duplication of management. One commenter specified that the Lenfest control rule is overly restrictive and would jeopardize optimum yield. A few commented that leaving more herring in the ocean does not necessarily improve the abundance of other species, that physical ocean conditions are the primary drivers of forage availability, and that less herring catch would negatively impact end users such as the lobster industry.

Regarding localized depletion, some noted that localized depletion has not been clearly defined despite efforts to do so elsewhere (e.g., ASMFC has attempted to address this topic with menhaden) and that there is no scientific consensus that localized depletion can be identified. Certain commenters said that Atlantic herring naturally migrates too much to be considered depleted on discrete spatial and/or temporal scales, and that more research would be needed to
identify Atlantic herring stock components. One commenter indicated that what is being called a “localized depletion” problem is actually a matter of gear conflicts, and that management should focus on resolving the gear conflicts.

“...enough of the herring biomass necessary to ensure the proper forage of these species has already been accounted for in the estimate of sustainable catch for the fishery. To duplicate this exercise in the form of a “forage fish” control rule would be to account for consumption estimates twice.”

“...we STRONGLY feel that any reclassification of herring into the forage stock will be yet, another devastating blow to the commercial lobster industry here in New England.”

“My experience fishing in Area 2 for herring – I don’t think you can have localized depletion in an area where you don’t have a resident population. That’s Area 2. There are no herring there now, and there won’t be until mid-December, and they will be gone by April. These are migrating fish that pass through there.”

**4.3 PERCEPTIONS OF CURRENT PROBLEMS**

Virtually all commenters articulated one or more issues that they perceive are current problems with herring management. Table 6 provides most of the topics describing current problems, indicating the number of individuals and NGOs and the number of comments received on each topic. The more commonly cited problems are described below.

**4.3.1 Atlantic Herring Resource**

A common problem, articulated by 251 individuals and 26 NGOs through 17 oral and 109 written comments, is that declines in the Atlantic herring resource have negative impacts on other species that rely on herring as prey, and in turn, the associated industries that rely on predators (e.g., tuna, groundfish whale-watching). Some comments included attention to the potential movement of tuna, and therefore quota, south where menhaden is available as prey, or to Canada where herring is more plentiful. More generally, 51 individuals and three NGOs said in three oral and 24 written comments that Atlantic herring is less abundant today than in the past.

“...without herring, we don’t really have a fishery. It goes hand in hand with every other fishery – groundfish, stripers, and the recreational guys.”

“...the nation has lost out on a $35 million a year commercial bluefin tuna industry; these highly migratory fish now pass along our shoreline and summer over in Canadian waters due to the lack of the abundance of very nutritious Atlantic sea herring in American waters!”

Likewise, 17 individuals and 14 NGOs in seven oral and 23 written comments, said that declines in other forage species (e.g., river herring, mackerel, menhaden) have resulted in more pressure to harvest Atlantic herring to, for example, supply bait markets. Herring is considered to be the last major bait source, one reason why people felt that explicitly considering its role in the ecosystem is important.

“Because of the loss of river herring and shad in my area, there is an increased focus on Atlantic herring as the most important forage fish in the region.”
Table 6 – Perceptions of current problems, as articulated in comments

<table>
<thead>
<tr>
<th>Topic</th>
<th>People commenting (#)</th>
<th>Comments (#)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NGO</td>
<td>Other</td>
</tr>
<tr>
<td>All current problems combined</td>
<td>37</td>
<td>414</td>
</tr>
<tr>
<td>Atlantic herring resource</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herring is less abundant today than in the past</td>
<td>3</td>
<td>51</td>
</tr>
<tr>
<td>Herring declines negatively impact predators (e.g., smaller, less</td>
<td>26</td>
<td>251</td>
</tr>
<tr>
<td>abundant)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Declines in other forage species has increased effort on Atlantic</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>herring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schooling behavior and migration in response to environmental</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>conditions makes herring particularly vulnerable to overfishing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data and stock assessment shortcomings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inaccurate Atlantic herring catch data</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Insufficient data or models to account for herring as forage in the</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>control rule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insufficient commercial herring fishery bycatch data (e.g., river</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>herring, groundfish)</td>
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<td></td>
</tr>
<tr>
<td>General concerns about Atlantic herring stock assessment</td>
<td>7</td>
<td>45</td>
</tr>
<tr>
<td>Management/fishery impacts on the herring resource/ecosystem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACLs set too high</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>ACL or sub-ACL overages</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Allowing the commercial herring industry to fish in groundfish</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>closed areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insufficient precaution/accounting for herring as forage</td>
<td>17</td>
<td>114</td>
</tr>
<tr>
<td>Management has primarily benefited the directed fishery, not other</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>users of the resource</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile gear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General concerns (e.g., bycatch, too much effort)</td>
<td>4</td>
<td>149</td>
</tr>
<tr>
<td>Spatial/temporal localized depletion from mobile pulse fishing</td>
<td>18</td>
<td>294</td>
</tr>
<tr>
<td>Gear conflicts</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Unfair that fisheries for herring predators are restricted while</td>
<td>4</td>
<td>83</td>
</tr>
<tr>
<td>herring fishery can flourish</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Too much bycatch in the commercial herring fishery</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>“Shifting baselines syndrome” – Over time, perceptions change</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>about what is considered a healthy herring resource</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-species management inappropriate</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate change</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Herring more valuable to the ecosystem than the low-value food</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>export market</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decline in river herring abundance</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Ocean acidification</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Public participation in Atlantic herring management has been</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>difficult</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Comments specified a number of (non-human) predators that the herring resource is important for (Table 7). Tuna, striped bass, and cod were the most frequently cited predators, noting that the terms used in public comment vary in the level of specificity (e.g., “minke” vs. “whales” vs. “mammals”).

Table 7 - Important predators of Atlantic herring, as articulated in comments

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Frequency</th>
<th>Descriptor</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuna</td>
<td>114</td>
<td>Pollock</td>
<td>6</td>
</tr>
<tr>
<td>Striped bass</td>
<td>72</td>
<td>Sharks</td>
<td>6</td>
</tr>
<tr>
<td>Cod</td>
<td>57</td>
<td>Dogfish</td>
<td>6</td>
</tr>
<tr>
<td>Whales</td>
<td>56</td>
<td>Puffin</td>
<td>4</td>
</tr>
<tr>
<td>Seabirds</td>
<td>36</td>
<td>Dolphins</td>
<td>3</td>
</tr>
<tr>
<td>Groundfish</td>
<td>21</td>
<td>Terns</td>
<td>3</td>
</tr>
<tr>
<td>Mammals</td>
<td>14</td>
<td>Gannets</td>
<td>2</td>
</tr>
<tr>
<td>Bluefish</td>
<td>13</td>
<td>Tern</td>
<td>1</td>
</tr>
<tr>
<td>Haddock</td>
<td>13</td>
<td>Razorbill</td>
<td>1</td>
</tr>
<tr>
<td>Humpback</td>
<td>8</td>
<td>Cunner</td>
<td>1</td>
</tr>
<tr>
<td>Seals</td>
<td>7</td>
<td>Osprey</td>
<td>1</td>
</tr>
<tr>
<td>Minke</td>
<td>6</td>
<td>Sculpins</td>
<td>1</td>
</tr>
<tr>
<td>Porpoise</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: “frequency” is the number of times a predator was cited in the comments. Some terms are more general and encompass other terms.

“In July the arrival of herring turns Stellwagen Bank into Chuckwagen Bank. Feeding whales and plunge-diving gannets means happier whale watchers, resulting in better fed more robust local economies. From whales bubble-netting herring to net financial gains for area businesses.”

4.3.2 Data and Stock Assessment Shortcomings

There was a general concern stated by 45 individuals and seven NGOs through seven oral and 17 written comments about the accuracy with which the Atlantic herring stock assessments estimate biomass, including specific concerns with the retrospective pattern that reemerged in the 2015 Operational Update. Commenters urged managers to use caution when basing decisions off of assessment results, feeling that the assessment should be more robust to accurately account for all sources of natural mortality. One herring industry member felt that it would be prudent to not move forward with developing a control rule that accounts for herring’s role as forage until after an operational assessment has been completed and the retrospective pattern issue has been resolved. Others thought that developing a forage-based control rule would help mitigate assessment shortcomings. A few comments wanted improved data on herring catch and bycatch.

“I don’t have a significant issue with considering herring as a forage fish. I just wish that we were doing a concrete operational or benchmark assessment for herring, so that I wasn’t looking at a situation where our quota could conceivably be half of what is now without the information about what the biomass is.”

“...fish and mammal behavior evolves and changes with time and climate change, rules and gear types labeled as historic may not be sustainable in our quest for a futuristic healthy marine ecosystem. We all have to step outside of the box now..."
and then, take an overall view of the current conditions, weigh in on the risk and reward outcome, and have the courage to make changes if need be, to maintain a healthy ecosystem for the future generations.”

4.3.1 Management/Fishery Impacts on the Herring Resource/Ecosystem

While many commenters were concerned with the current approach to Atlantic herring management, 114 individuals and 17 NGOs through seven oral and 51 written comments specifically expressed that there has been insufficient precaution or accounting for herring as forage. To them, the role of herring as forage has not been appropriately accounted for in the herring specifications. Some described factors such as a substantial natural variability in the herring population, the number of predators, and vulnerability to overharvest due to schooling behavior.

“...the overall management scheme is too optimistic already. It needs to be much more conservative and assume that there isn’t anything else out there for a lot of these species to eat.”

The most commonly cited problem, by 294 individuals and 18 NGOs through 13 oral and 124 written comments, was that the current regulations allow for concentrations of fishing effort by mobile gear, primarily midwater trawls, on the Atlantic herring resource in certain times and locations. These commenters were concerned that the herring fishery has been causing localized herring depletion, particularly of the inshore resource. They urged that there should be enough herring in the times and places that predators need them. There were also more general concerns about mobile gear, that there is too much bycatch and/or fishing effort to be sustainable. A common opinion was that allowing the herring fishery to flourish has hampered rebuilding of predators such as groundfish, which has been detrimental to fisheries that depend on predators.

“We had a great fishery last year in October right off southern Jeffreys. It all got wiped out in two nights by the midwater boats. We need to keep the herring going. They were spawning there, and that was a great fishery.”

“...anywhere from Hyannis to Monomoy, we have a robust fishery in the spring. It begins with squid and krill, and then the herring comes in, and the striped bass fishery is busy. We book two trips a day up until the herring fleet goes to work. At that corner where 1B, 2, and 3 meet – when the fleet comes in and works that corner – when the fleet is done fishing, our striped bass move up past P-Town or down to Block Island. We lose them because our forage has been broken up”

“I am very concerned with the effects of the mid-water trawlers on the herring population and subsequent game fish they feed on them. Striped bass in the spring and then bluefin tuna key later on in the summer key on these baitfish. The benefits to local economies of protecting and increasing the population of these baitfish is obvious.”
4.4 DESIRED OUTCOMES OF AMENDMENT 8

Virtually all commenters articulated desired outcomes of Amendment 8. Table 8 provides most of the desired outcomes, indicating the number of individuals and NGOs and the number of comments received on each topic. The more commonly desired outcomes are described below.

Table 8 - Desired outcomes, as articulated in comments

<table>
<thead>
<tr>
<th>Topic</th>
<th>People commenting (#)</th>
<th>Comments (#)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NGO</td>
<td>Other</td>
</tr>
<tr>
<td>All desired outcomes combined</td>
<td>42</td>
<td>422</td>
</tr>
<tr>
<td>Improve Atlantic herring resource</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintain wide size and age distribution of herring</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Leave more herring in the ocean</td>
<td>9</td>
<td>32</td>
</tr>
<tr>
<td>Protect spatial and temporal availability of herring</td>
<td>18</td>
<td>270</td>
</tr>
<tr>
<td>Improve data and stock assessment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improve fishery catch monitoring</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Improve stock assessment</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>Reduce management/fishery impacts on the herring resource/ecosystem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adopt an EBFM approach to managing herring</td>
<td>35</td>
<td>151</td>
</tr>
<tr>
<td>Entire ecosystem benefits from more herring</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Use more precaution in control rule</td>
<td>25</td>
<td>94</td>
</tr>
<tr>
<td>Improve policy on forage fish</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Meet management objectives</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Pave the way for EBFM in other fisheries</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Use risk policy</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improve abundance and economic value of predators</td>
<td>9</td>
<td>143</td>
</tr>
<tr>
<td>Protect essential fish habitat</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Reduce bycatch</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Improve river herring abundance</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Better respond to climate change</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

4.4.1 Improve Atlantic Herring Resource

With localized depletion viewed by many commenters as one of the most compelling current problems in herring management, it is not surprising that 270 individuals and 18 NGOs through nine oral and 98 written comments noted that it is important to protect spatial and temporal availability of herring for forage, such as southern Jeffrey’s Ledge, Stellwagen Bank and on the backside of Cape Cod (where Management Areas 1B, 2 and 3 meet). Commenters also wanted more Atlantic herring left in the ocean, with a few commenting that there should be a wide age and size distribution within the population.

“It is also very important that the Council considers ways to take spatial concerns into consideration when designing the new control rule. No one area should have to bear the burden of too high a percentage of the overall catch. This would protect discreet spawning stocks as well as localized dependency on herring.”

“Amendment 8 should provide the Council with tools to make spatial and temporal adjustments in catch patterns in order to safeguard feeding grounds of herring predators.”
“Amendment 8 should include alternatives that explicitly aim to keep Atlantic herring present in sufficient quantities when and where they are needed most by predators.”

4.4.2 Improve Data and Stock Assessment
A small number of comments identified improved stock assessments as a desired outcome, 13 individuals and five NGOs through ten oral and six written comments. Most of these commenters wished for improved accounting for natural mortality (e.g., predator needs), whether in the assessment or in the control rule used to set Acceptable Biological Catch. Some viewed improving the assessment as an issue outside the Council process and the development of Amendment 8. Some pointed out that the sources of uncertainty need to be accounted for (including forage) and directly affect herring fishermen and other stakeholders.

“Currently, the operational herring assessment update is undergoing review and encountering difficulty. It would not be prudent to establish a control rule until the operational update itself has been completed/fixed.”

“The Council, scientists, and managers in charge of our incredible and diverse marine resources need better models. We also need models that can provide real-time information and don't accept the "2-3 year lag period" that pervades fisheries science.”

4.4.3 Reduce Management/Fishery Impacts on the Herring Resource/Ecosystem
Comments on the desired outcomes for management and the fishery through Amendment 8 focused on the adoption of an ecosystem-based approach to herring management, as noted by 151 individuals and 35 NGOs in 23 oral and 95 written comments. Herring as an essential forage component of the ecosystem was frequently mentioned, and 94 individuals and 25 NGOs through 13 oral and 50 written comments wished for more precaution to account for predator needs in the control rule. The more specific comments suggested that the control rule should ensure that: the herring population be well above Maximum Sustainable Yield, allowable catch be reduced when a certain threshold of biomass is reached, and that sufficient herring be left in the water so there is some of the right size and age in the right place and time for the predators. These comments noted the importance of attaining a spread of year classes. Another point of view was that the control rule should be based on the ability to meet management objectives of a high, stable and long-term yield. One person explained that a conservative biomass target and modest harvest rate would likely make the fishery more stable, accounting for the known volatility of forage abundance and scientific uncertainty.

“Herring is probably the largest biomass of prey material out there other than plankton and that sort of thing. I think it’s very important to show how all of the components work together so that all the fisheries that have something to do with herring get their fair share out of it.”

“The harvest policy for this stock should have the capacity to generate multiple components of the ABC, in order to support sub-regional and or temporal specification of catch levels to meet ecological goals for forage fish embodied in the amended FMP”
4.4.4 Other Desired Outcomes
With improvements in the Atlantic herring resource, 142 individuals and nine NGOs, through two oral and 85 written comments wished to see benefits to the predator fish resources (e.g., groundfish, tuna) and the fisheries (recreational, charter, commercial) that rely on them. Comments emphasized the economic value to the communities with businesses that rely on herring as prey. Through shifting herring fishing effort offshore, other commenters hoped that essential fish habitat for juvenile fish would be better protected (e.g., in the Inshore Juvenile Cod Habitat Area of Particular Concern), bycatch of juvenile groundfish would be reduced, and river herring abundance would be improved.

“I urge the Council to explicitly analyze the value of all the fisheries that rely on having a healthy herring resource when developing the amendment. This number will dwarf the value of this species to the directed herring fishery.”

“. . .abundance of forage food and how it supports the commercial fishermen in the groundfish fishery and in the charterboat business, the most important fact is the economic benefits for the surrounding communities that feed on these businesses.”

4.5 SPECIFIC IDEAS FOR AMENDMENT 8

4.5.1 Goals and Objectives
Two individuals and 11 NGOs through two oral and 13 written comments offered ideas for Amendment 8 goals and objectives, many of which align with the goals and objectives that the Council identified in June 2015:

- Design and implement a strategy for managing Atlantic herring in an ecosystem context that accounts for and protects its ecological role as forage.
- Establish a control rule that protects the role of Atlantic herring in the ecosystem while providing for the biological needs of the herring resource and sustainable levels of fishing.
- Prevent localized depletion of population components (spawning sub-groups) to protect the spatial and temporal availability of prey.
- Establish ecological reference points, targets and thresholds, that maintain herring biomass significantly above B_{MSY}, in accordance with a consensus that has emerged from the scientific community and consistent with the National Standard 1 guidance referenced in the scoping document.
- Facilitate the use of climate science to create a strategy that is robust and responsive to changing climate conditions.
- Ensure that the harvest policy allows for a size and age distribution in the population throughout their natural range that does not suffer from truncation- providing a full size and age spectrum for predators (feeding strategies, migratory routes, seasonal timing) and for reproduction of herring (i.e., older animals).
### 4.5.2 Alternatives

Specific ideas for Amendment 8 alternatives were suggested by 305 individuals and 25 NGOs through ten oral and 186 written comments. Table 9 provides most of the specific ideas for alternatives, indicating the number of individuals and NGOs and the number of comments received on each topic. The more commonly desired approaches are described below. Ideas primarily concern the development of a control rule that accounts for herring’s role in the ecosystem and for limiting herring fishery effort inshore.

**Table 9 – Specific ideas for alternatives, as articulated in comments**

<table>
<thead>
<tr>
<th>Topic</th>
<th>People commenting (#)</th>
<th>Comments (#)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NGO</td>
<td>Other</td>
</tr>
<tr>
<td>All ideas for alternatives combined</td>
<td>25</td>
<td>305</td>
</tr>
<tr>
<td><strong>ABC control rule and other reference points</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revise biomass target</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Revise fishing mortality rate</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Create biomass cut-off</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Consider forage needs on a sub-regional basis</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Create rules for data-poor situations</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Maintain stability of catch when stock conditions are normal</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Herring fishery effort</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midwater trawl restrictions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expand Area 1A closure to year-round</td>
<td>7</td>
<td>82</td>
</tr>
<tr>
<td>Make inshore closure year-round throughout New England</td>
<td>3</td>
<td>242</td>
</tr>
<tr>
<td>Create new buffer off Cape Cod and RI</td>
<td>7</td>
<td>116</td>
</tr>
<tr>
<td>Ban midwater trawls</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Other area restrictions</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lower Annual Catch Limits</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Promote use of fixed gear</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Ban commercial herring fishing</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Create day or trip limits inshore</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Limit capacity of seiners’ carrier vessels</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Other ideas</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revise observer coverage requirements</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Allocate a set-aside of herring for predators</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Create socioeconomic guidelines for the SSC to consider</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

| **4.5.2.1 ABC Control Rule and Other Reference Points**               |           |       |      |         |

Commenters, primarily environmental NGOs, offered specific ideas for revising the ABC control rule to account for ecosystem needs. The most specific comment about how to do so suggested that multiple components of the ABC be generated, so that sub-regional or temporal specifications of catch levels could be included, with attention to both forage needs aspects and spawning aggregations.

Ideas for the biomass target (B) include:

- Keep it above \( B_{MSY} \) to enhance and protect the marine ecosystem.
- Make it at least 75% of virgin biomass (\( B_0 \)).

Ideas for the fishing mortality rate (F) include:

- Set F proportional to B (reduce fishing as biomass declines).
• Recalibrate F annually based on B size.
• Set F at 50% of F_MSY or 50% of natural mortality (that is, the smaller of the two).
• Halt fishing (i.e., create biomass cut off) if B <40% B_0.
• Set the probability of overfishing to under 50% (<30% suggested a few times), applied stock-wide and to the individual sub-areas.

Other comments included that there should be a data poor control rule as a backstop if there is no acceptable assessment. An example was given that F may not exceed 0.2 when neither total mortality nor F_MSY can be reliably estimated. Another was to set catch at the median catch for the most recent time period (3 or 10 years suggested). However, the data poor control rule should be considered temporary, only to be used for up to three years to allow time for a new benchmark assessment.

One herring industry NGO supported allowing herring catch to remain stable (e.g., the current constant quota approach) when the reference points are within a normal range of conditions (e.g., not overfished).

“Evaluation and selection of a final control rule should be based on a suite of pre-established performance metrics such as average and mean biomass, mean and average catch, percent of years with no catch and variability in year-to-year catch.”

“[Estimating natural mortality] cannot ensure predator needs are satisfied adequately, nor can they tell you if herring is available to predators in the times and places they need it. Defining "forage adequacy" based on achievable criteria should be a centerpiece of the control rule.”

4.5.2.2 Herring Fishery Effort

Most of the comments with specific ideas for alternatives regarded limiting effort in the Atlantic herring fishery. These ideas stemmed from concerns about inshore localized depletion of Atlantic herring, bycatch, and the impacts of harvesting what is perceived to be a large volume of herring per tow by midwater trawl vessels.

Ideas for limiting fishery effort include:

• Extend the current five month closure of Area 1A (January-May) to a year-round closure.
• Create a year-round closure for midwater trawl vessels:
  o For 30 up to 50 miles from shore throughout the Northeast.
  o For 30 up to 50 miles off Cape Cod and Rhode Island.
• Ban the use of midwater trawls in the Atlantic herring fishery.
• Ban the directed fishery for Atlantic herring inshore by any gear type.
• Create in-season closures should herring fishery effort concentrate into small areas.
• Ban fishing for Atlantic herring in groundfish closed areas.
• Lower Annual Catch Limits.
• Promote use of fixed gear.
• Ban commercial herring fishing all together.
• Create day or trip limits to constrain effort inshore.
• Limit the capacity of carrier vessels used by purse seine vessels to constrain effort.
4.5.2.3 Other Ideas

Other ideas for measures were proposed, though some may be outside the scope of the Council’s Amendment 8 goals:

- Observers:
  - Require 100% observer coverage for midwater trawl vessels.
  - Require midwater trawl vessels to pay 100% of observer costs.
  - Require 100% industry-funded observer coverage when fishing in Area 1A.
- Create an ACL set-aside to account for the needs of marine predators rather than in an uncertainty buffer.
- Create guidelines for the Science and Statistical Committee to consider the socioeconomic implications of reference points.

4.5.3 Scientific Studies Referenced

An exhaustive review of the scientific studies cited by nine individuals and 19 NGOs through 26 written and six oral comments is beyond the scope of this memo. There were citations to support specific measures recommended (Section 4.5.2). Several stakeholders mentioned an “emerging scientific consensus” that fishing mortality rate (F) should not exceed 75% of the unfished biomass (maximum spawning potential).

On the other hand, those stakeholders wary of considering herring as forage in the control rule cited scientific studies to support their perspective. They emphasized international studies that show that the stock size of forage species is determined by long-term environmental factors (especially climate and temperature), not fishing pressure. Furthermore, one stakeholder commented that recommendations of some of the cited literature are based on maximization of conservation values rather than the multi-faceted objectives of the Magnuson-Stevens Act.

“The Antarctic Krill policy, sometimes called the ‘predator criterion’, is consistent with the fact that low trophic level forage species, or prey species with high predation rates, are less resilient to intensive fishing mortality than higher trophic levels and thus merit more precaution.”

“Simply feeding a species more does not mean that it will increase in numbers.”

4.5.4 Examples of how other Fisheries are Managed

Several examples were noted by five individuals and 11 NGOs through 13 written and six oral comments of other fisheries that have implemented measures similar to those envisioned for Amendment 8. It was noted that the Pacific, North Pacific and Mid-Atlantic Councils have models that recognize the importance of protecting forage fish when setting ABC. Examples included Antarctic krill, Alaska herring, and Pacific sardine and mackerel. Commenters noted that these fish are managed such that fishing ceases if the stock abundance declines below 40% the virgin biomass (or higher in some cases). Krill has been managed since 1991 by the Commission for the Conservation of Antarctic Marine Living Resources to account for the requirements of predators. Canada’s Policy on Fisheries for Forage Species states that harvest should not be concentrated such that localized depletion occurs.
4.6 TRADEOFFS
About 33 NGOs and 150 individuals through 17 oral and 120 written comments articulated tradeoffs that the Council should consider when developing Amendment 8. Fairness and equity echoed in these comments.

4.6.1 Value of Herring to Ecosystem
The importance of herring to the ecosystem was commented on by 25 individuals and 16 NGOs. Comments focused on herring as a cornerstone species in the ecosystem. More specifically, herring’s role as a predator was commented on by five individuals and seven NGOs.

“When you take an ecosystem approach, you consider herring’s role as forage, as a predator, as a competitor in a system. I think that is something that should be equally-balanced.”

4.6.2 Value of Herring to Herring and Lobster Fisheries
The importance of herring to the herring and lobster fisheries was commented on by 13 individuals and seven NGOs. The value of the lobster fishery to New England and local communities was emphasized in a variety of comments. A fear of jeopardizing optimum yield and the herring industry was also expressed.

“Many of the small villages that make up the iconic coast of New England would financially collapse if not for lobstering.”

“...Amendment 8, an action that can have potentially significant impacts on the herring industry and already hard-hit fishing communities like Gloucester.”

“...we STRONGLY feel that any reclassification of herring into the forage stock will be yet another devastating blow to the commercial lobster industry here in New England.”

4.6.3 Value of Herring to Other Fisheries and Stakeholders
The importance of herring to other fisheries (e.g., groundfish, striped bass, tuna) and stakeholders (e.g., whale watching businesses) was commented on by 139 individuals and 25 NGOs. The comments noted that herring had value beyond fisheries, including as noted above, affecting whale and bird-watching. There were reminders that the economic value of predators should be included in the analyses of management measures, including the value of whale and bird watching, recreational fisheries, and commercial fisheries.

“The Council should also include a full analysis on herring's value to our region as a food source in the water.”

“But when you have 60-70 guys in a 5-6 mile area fishing, getting a little fish to make a living. And then all of a sudden, all the herring is being caught. And then there is no bait, and with no bait, there is no fish, no money, no living. I think there should be a little more emphasis or consideration for all of the fishermen in one area so that everyone can make money.”
5.0 STAKEHOLDER NETWORKS

In addition to the form letters signed by multiple people, about 60 of the written comments signed by over 200 people used similar text, indicating collaboration and networking among stakeholders in developing comments. There were six to eight versions of text, and many people opted to personalize the letters. For example, there were 19 letters that included a phrase like “any fisherman can tell you that herring plays a critical role as a forage source.” These duplicate or quasi-duplicate letters may have been written by an organization(s) as a template and then distributed. These letters were submitted primarily by fishermen other than herring fishermen. A few letters from stakeholders with commercial herring interests opted to say that they agree with a particular letter rather repeat specific comments.
## Appendix I - Non-governmental Organizations that Commented

<table>
<thead>
<tr>
<th>Category</th>
<th>Organizations</th>
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<tr>
<td><strong>Commercial interests</strong></td>
<td>Ad Hoc Pelagics Coalition</td>
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<td>American Bluefin Tuna Association</td>
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<td>Cape Cod Commercial Fishermen’s Alliance</td>
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<td>Massachusetts Lobstermen’s Association</td>
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<td>Maine Coast Fishermen’s Association</td>
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<td></td>
<td>Sustainable Fisheries Coalition</td>
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<td><strong>Environmental – state/local focus</strong></td>
<td>Audubon Society of Rhode Island</td>
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<td>CT Fund for the Environment, Save the Sound</td>
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<td>Global Awareness Local Action</td>
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<td>Gotham Whale</td>
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<td>Great Egg Harbor Watershed Assoc. &amp; Council</td>
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<td>Greater Boston Chapter, Trout Unlimited, Inc.</td>
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<td>Ipswich River Watershed Association</td>
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<td>Mystic River Watershed Association</td>
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<td>Nantucket Land Council, Inc.</td>
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<td>New Hampshire Animal Rights League</td>
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<td>New Hampshire Audubon</td>
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<td>Parker River Clean Water Association</td>
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<td>Red Lily Pond Project Association</td>
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<td>Save the Bay</td>
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<td>Seacoast Science Center</td>
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<td>Wood-Pawcatuck Watershed Association</td>
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<td><strong>Environmental – National/regional focus</strong></td>
<td>Conservation Law Foundation</td>
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<td>Earth Justice</td>
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<td>Ocean River Institute</td>
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<td></td>
<td>Pew Charitable Trusts</td>
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<td>Wild Oceans</td>
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<td><strong>Other fishing interests</strong></td>
<td>Coalition for the Atlantic Herring Fishery's Orderly, Informed and Responsible Long Term Development</td>
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<td>Coastal Conservation Association of NH</td>
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<td>CT-RI Coastal Fly Fishermen</td>
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<td></td>
<td>Delaware River Shad Fishermen’s Association</td>
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<td>Herring Alliance (103 member organizations)</td>
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<td>ME Association of Charterboat Captains</td>
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<td>Northeast Charterboat Captains’ Association</td>
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<td>Penobscot East Resource Center</td>
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<td>Recreational Fishing Alliance</td>
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<td>Rhode Island Saltwater Angler’s Association</td>
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<td>Stellwagen Charter Boat Association</td>
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BACKGROUND INFORMATION ON ACCEPTABLE BIOLOGICAL CATCH CONTROL RULES AND MANAGEMENT STRATEGY EVALUATION PROCESS USED IN NEW ENGLAND
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1.0 ACCEPTABLE BIOLOGICAL CATCH CONTROL RULE

An Acceptable Biological Catch (ABC) control rule is a formulaic approach for establishing an annual limit or target fishing level that is based on the best available scientific information. It provides guidance to the Science and Statistical Committee (SSC) regarding how to specify the ABC for Atlantic herring based on scientific uncertainty, stock status, and the Council’s risk tolerance. Moreover, the ABC control rule can create a buffer between the overfishing limit (OFL) and ABC to account for scientific uncertainty such that there is a low risk in any given year that the OFL for Atlantic herring will be exceeded.

A control rule specifies a target amount of catch or fishing mortality rate depending on some measure of recent stock abundance. Many control rules exist, and they vary in their ability to achieve fishery objectives, but there are three generic types of control rules (Figure 1). A ‘constant catch’ control rule harvests the same amount of fish regardless of abundance. Consequently, as abundance declines, the fishing mortality rate (i.e., catch divided by abundance) increases, because the fishery is removing a larger proportion of the stock. (Note that a true constant catch control rule removes the same amount of fish in perpetuity, which is different from applying the same amount for 3-year periods as has been done recently for Atlantic herring.) A ‘constant fishing mortality’ control rule removes the same fraction of the population regardless of abundance, and consequently catch increases linearly with abundance (e.g., 75% FMSY). A ‘biomass based’ control changes the fishing mortality rate depending on abundance, typically with the fishing mortality rate increasing with abundance to some maximum rate. The linear change in fishing mortality can vary in steepness, and fishing mortality does not necessarily need to equal zero at a particular level of abundance.

Many control rule variants exist, but these are the basic types. Variations to these basic types can produce a broad range of results. In the U.S., some characteristics of an ABC control are defined by law. For example, ABC cannot have a greater than 50% chance of exceeding the catch associated with FMSY (i.e., the Overfishing Limit (OFL)), and so FMSY should likely serve as an upper bound for any control rule considered. Beyond that, previous research can likely inform decisions about what control rules might be eliminated a priori as unlikely to meet fishery objectives.
1.1 HISTORY OF ATLANTIC HERRING ABC CONTROL RULES

The ABC control rule currently in place for the Atlantic herring fishery (Section 1.1.3) does not fit neatly into any one of these generic types, but combines approaches:

*Atlantic herring ABC will be specified annually as the catch that is projected to produce a probability of exceeding $F_{MSY}$ in the third year that is less than or equal to 50%.*

Essentially, a fishing mortality rate is applied, and the catch associated with it is set for a three-year period. However, below a certain biomass threshold, a stock rebuilding program would be required, which has no intuitive relationship between biomass and $F$, because it depends on assumptions that go into determining rebuild time.

1.1.1 Amendment 4 and 2010-2012 Atlantic Herring Fishery Specifications

In April 2011, several modifications to the Atlantic herring fishery specifications process were made through Amendment 4 to the Atlantic Herring FMP (NEFMC 2010), in compliance with the 2007 authorization of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). Most relevant to Amendment 8, Amendment 4 established an interim ABC control rule and revised the specifications process.
During the 2010-2012 Atlantic herring fishery specifications process, developed concurrently with Amendment 4, the SSC pointed out two of sources of considerable scientific uncertainty:

1. At the time, the latest Atlantic herring stock assessment (TRAC 2009) had a strong retrospective pattern, in which estimates of stock size are sequentially revised downward as new data are added to the assessment; and
2. Maximum Sustainable Yield (MSY) reference points estimated from the biomass dynamics model were inconsistent with the age-based, stochastic projection; such that fishing at the estimate of F_{MSY} was expected to maintain an equilibrium biomass that is less than the current estimate of B_{MSY}.

Given this scientific uncertainty, the SSC determined that a permanent herring ABC control rule cannot be established until a benchmark assessment is conducted to address these issues. In the meantime, the Council recommended that Amendment 4 contain an interim ABC control rule based on the SSC’s 2010–2012 herring ABC recommendation:

That ABC be based on recent catch in the herring fishery (e.g., the single-most recent year or a three- or five-year average), and that the Council determines the desired risk tolerance in setting the ABC.

The 2010-2012 Atlantic herring ABC specification were adopted using the following control rule:

That ABC be based on the recent three-year average catch in the herring fishery (2006-2008; 106,000 mt).

The Council considered this to be a placeholder until a benchmark stock assessment for Atlantic herring could be completed and a more appropriate long-term control rule for Atlantic herring could be developed by the Council.

### 1.1.2 Related Lawsuits

On August 2, 2012, the U.S. District Court for the District of Columbia issued a remedial order in the civil action Flaherty, et al. v. Blank, et al. (i.e., Flaherty I) to address deficiencies with respect to Amendment 4 to the Herring FMP. A letter from NMFS to the Council on August 31, 2012, described the legal deficiencies identified by the Court:

- NMFS did not satisfy its obligation to independently determine whether the Council’s designation of “stocks in the fishery” complied with the MSFCMA;
- NMFS did not adequately consider whether Amendment 4 complied with the National Standard 9 requirement to minimize bycatch to the extent practicable; and
- NMFS failed to consider the environmental impacts of alternatives to the ABC control rule and accountability measures in Amendment 4.

In this letter, NMFS also recommended that the Council, as part of the 2013-2015 Atlantic herring fishery specifications, consider a range of alternatives for the Atlantic herring ABC control rule and AMs and explain how the measures adopted in Amendment 5 to the Herring FMP minimize bycatch, to the extent practicable, in the Atlantic herring fishery.
1.1.3 2013-2015 Atlantic Herring Fishery Specifications

To address both the August 2012 letter from NMFS and the need to reconsider the interim ABC control rule established in Amendment 4, the Council considered a wider range of ABC control rule alternatives for the 2013-2015 Atlantic herring fishery specifications. Following the benchmark stock assessment (NEFSC 2012), the Council considered three alternatives (including No Action) for a herring ABC control rule for the 2013-2015 fishing years (NEFMC 2012b). One control rule set ABC at 75% $F_{MSY}$ for 2013-2015, while the other control rule applied a constant catch over these years. In this particular situation, these two approaches resulted in an Atlantic herring ABC over the three years which was approximately the same. When the SSC reviewed these ABC control rules it could not find any scientific reason to prefer one approach over the other and considered them to be comparable in terms of risk of overfishing, given the available information. All considerations led the SSC to conclude that either approach could be applied for the next three years with low probability of overfishing or causing the Atlantic herring resource to become overfished. In turn, the SSC recommended that the Council consider either approach for specifying Atlantic herring ABC for 2013-2015.

The Council ultimately selected its preferred alternative of 114,000 mt for the 2013-2015 ABC at its September 2012 meeting, applying a constant catch over a three-year period:

Atlantic herring ABC will be specified annually as the catch that is projected to produce a probability of exceeding $F_{MSY}$ in the third year that is less than or equal to 50%.

However, after further discussion and consideration of the Amendment 4 Court Order and August 2012 NMFS correspondence, the Council requested the SSC to consider two additional ABC control rule alternatives specifically, the “Lenfest” and “Pacific” control rules, based on harvest control strategies for other forage fish. These two alternatives were recommended for consideration by EarthJustice in its comments to the Council regarding the 2013-2015 herring fishery specifications. In November 2012, the Council tasked the SSC with considering these additional alternatives.

The SSC evaluated the two additional ABC control rule alternatives in November 2012 in terms of: 1) the short-term catch advice, i.e., the 2013-2015 herring fishery specifications, and 2) development of long-term control rules to address the issue of whether the increased natural mortality rate in the assessment fully captured all the ecosystem needs (including humans) related to forage species. Regarding the short-term catch advice, the SSC stated that it would be difficult to adopt the Pacific control rule, because the specific values of the biomass cutoff, buffer, and fraction have not been developed for Atlantic herring. This rule also would produce large and sudden changes in ABC based on small changes in biomass, which the SSC felt should be avoided. The SSC noted that the spawning stock biomass expected in 2015 under either of the previously-reviewed alternatives was well above the targeted 40% unfished amount suggested in the Pacific control rule. Similarly, the ABC alternatives already under consideration (75% $F_{MSY}$ and constant catch) were broadly consistent with the biomass aspect of the Lenfest control rule (maximum fishing mortality threshold of 50% $F_{MSY}$) at currently estimated stock sizes and associated reference points.

Thus, the SSC affirmed its original recommendations for specifying ABC for the 2013-2015 fishing years and concluded that the original alternatives considered by the Council were broadly consistent with the intent of the other control rules included for consideration (NEFMC 2012a).
The SSC noted that more analysis is needed to implement long-term harvest strategies, like the Lenfest and Pacific control rules, and suggested that control rules for forage species should be part of a broader national workshop that involves the community that advises the Council system (NEFMC 2012a).

Further discussion by the Council indicated that because of uncertainties associated with adopting either of these control rules in the 2013-2015 Atlantic herring specifications and the need for additional analysis, these alternatives should be considered but rejected in the specifications package. However, the Council agreed that these alternatives may be revisited.

1.1.4 Lawsuit Developments

In November 2013, the plaintiffs in the Flaherty I lawsuit filed a new lawsuit, Flaherty II, challenging the 2013-2015 Atlantic herring specifications. Flaherty II claimed that NMFS failed to follow the Court’s Order from Flaherty I to:

- Consider an ABC Control Rule based on the best available science for herring and other forage fish;
- Set annual catch limits to prevent overfishing based on best available science, because the ABC is the same for all three years of the specifications and is equal to the OFL in the final year of the specifications; and
- Consider a reasonable range of ABC Control Rule alternatives.

In February 2014, the Court ruled that NMFS had complied with the remedial order (From Flaherty I) and deficiencies with respect to Herring Amendment 4 had been sufficiently addressed.

In March 2014, the same plaintiffs filed another lawsuit, Flaherty III, following the implementation of Amendment 5 to the Herring FMP. The suit claimed that Amendment 5 failed to include:

- River herring and shad as stocks in the fishery,
- Measures to prevent overfishing, and
- A hard look at the definition of the fishery.

1.1.5 2016-2018 Specifications

Following the April 2015 Atlantic Herring Operational Assessment (Deroba 2015), the SSC developed recommendations for the Atlantic herring OFL and ABC for the 2016-2018 fishing years. The SSC reviewed a number of projections and possible approaches for specifying ABC and recommended that the Council specify ABC for the 2016-2018 fishing years using the interim ABC control rule for Atlantic herring as adopted for 2013-2015. This approach produced an ABC of 111,000 mt for 2016, 2017 and 2018, and associated OFLs of 138,000 mt in 2016, 117,000 mt in 2017, and 111,000 mt in 2018. The SSC provided the following rationale for this recommendation:

- Key attributes of the stock and assessment (SSB, recruitment, F, survey indices, etc.) have not changed substantially since the benchmark assessment, on which the current control rule was based. However, survey indices suggest that the 2011 year class is the second largest in time series and will contribute significantly to the total population abundance and biomass in 2016-2018.
The most substantial change since the benchmark stock assessment (NEFSC 2012) is that the retrospective pattern has become worse in the operational assessment. The assessment implemented a Mohn’s rho correction to SSB in an attempt to account for the retrospective pattern, but there is no guarantee that the retrospective pattern will persist in sign and magnitude.

Although the probability of overfishing may reach 50% in the third year, the probability of the stock becoming overfished is close to 0% in all years.

The realized catch in the Atlantic herring fishery is generally well below the ABC, which reduces the expected risk of overfishing.

In the assessment model, the current ratio of catch to estimated consumption is 1:4, which means that fishing is likely not the largest driver of stock abundance at present, however this does not negate the need to manage the fishing removals on this stock.

A constant catch strategy is the preferred approach of the Council and the industry.

These considerations led the SSC to conclude that ABC should remain relatively constant for 2016-2018, or perhaps be reduced modestly. The recommended ABC of 111,000 mt, compared with status quo estimate of 114,000 mt, achieves that outcome. Additionally, the SSC noted that the current high herring biomass, bolstered by two very large year classes, likely meets ecosystem goals, including forage considerations, by default and not design, as ecosystem goals are not explicitly identified in the current ABC control rule (NEFMC 2015b).

### Further Lawsuit Developments

On June 14, 2016, the U. S. District Court for the District of Columbia issued a ruling on the *Flaherty II* case, concluding that the ABC control rule and ACLs in the 2013-2015 Atlantic herring specifications complied with National Standards 1 and 2. The Court reasoned that there was no evidence that the specifications would fail to prevent overfishing and that they relied on the best available science concerning herring’s role as forage. Further, the Court held there was no evidence that the Lenfest and Pacific ABC control rules were superior to the 2013-2015 specifications’ constant catch ABC control rule.

If granted, *Flaherty III* would limit the alleged deficiencies in Amendment 5 to including river herring and shad as stocks in the herring fishery and taking a hard look at the definition of the fishery.

### ECOSYSTEM BASED FISHERY MANAGEMENT (EBFM) CONSIDERATIONS

In December 2014, when the Council approved herring work priorities for 2015, it tasked the Ecosystem Based Fishery Management (EBFM) PDT and Committee with developing ecological guidance for the Herring PDT on managing forage fish within an ecosystem context and developing appropriate control rule and reference points for potential consideration in Amendment 8. The PDT requested additional guidance at the January Council 2015 Council meeting in part due to concerns raised by the public about ecological issues at smaller scales than a stock-wide control rule may address. The Council advised the EBFM PDT focus on a stock-wide control rule that does not impair the productivity of herring predators. The Council discouraged consideration of spatial availability of herring by changing the structure of the control rule.
The conclusions of the EBFM PDT are summarized in Section 3.1 of its June report (NEFMC 2015a). Overall, the indirect effects on productivity of other species and trophic interactions are difficult to quantify, especially when considering the various potential populations levels of a single forage species, such as herring. The EBFM PDT explored various models and potential control rule alternatives, but many models do not provide a prey feedback loop, which is critical for evaluating how various levels of herring biomass affect predator productivity. However, it was concluded that control rules which lower the risk of depleting herring will reduce risk to related predator stocks, but the response of predator populations to differences in herring biomass are difficult to identify, particularly for a wide variety of predators. The Northwest Atlantic system is comparatively complex and many of the herring predators are generalists, so there are effects from the abundance and nutritional value of alternative prey species as well (e.g., sand lance, squid, silver hake).

Overall, there may be indirect benefits from having greater abundance and availability of herring as forage for fish, marine mammals, and seabirds. Collectively, forage fish provide an important supporting ecosystem service as energy transfer between very small prey like zooplankton, and larger animals in the ecosystem including commercial fisheries, marine mammals, seabirds, and other protected species. The important role of forage fish in fueling production of valuable predator fisheries is recognized (Smith et al., 2011), but the broader role in sustaining productivity and structure of marine ecosystems is less understood (Engelhard et al, 2014). Many forage fish are highly productive and short-lived, and some exhibit “boom and bust” cycles. In addition, decadal-scale variability in abundance of major forage fish is often associated with climate drivers and ocean regime shifts that change ecosystem productivity (Alheit et al, 2009). However, fishing pressure can also affect forage fish abundance, increasing the possibility of collapse when environmental conditions are unfavorable (Murphy 1967, 1977; Pinsky et al., 2011).

Preceding the EBFM process, the NEFMC also discussed ABC control rules with the Risk Policy Working Group, a group that met several times in 2013-2015 to assist the Council with developing a risk policy to address risk and uncertainty across fishery management plans, including ABC control rules. At the November 2014 Council meeting, the Council formally adopted the Risk Policy Statement below:

Recognizing that all fishery management is based on uncertain information and that all implementation is imperfect, it is the policy of the New England Fishery Management Council (Council) to weigh the risk of overfishing relative to the greatest expected overall net benefits to the Nation.

The risk policy has four strategic approaches: 1) it will take into account both the probability of an undesirable outcome and the negative impact of the outcome; the probability of a long-term negative impact on ecosystem function should be low; 2) the cumulative effects of addressing risks at all levels will be taken into account; 3) will consider stability in the face of uncertain information and inherent variability in the ecosystems; and 4) implementation will be analysis-based, using methods that consider the tradeoffs, detect signal from noise so that management and fisheries are less sensitive to uncertainty, and the process should be dynamic allowing review and modification where warranted.

The NEFMC Risk Policy also included different tracks for implementation. The ultimate or final track is to prepare an MSE. Section 4.0 of the Risk Policy Road Map (NEFMC, 2016)
summarizes what an MSE is, the potential benefits and best practices, and several case studies. The MSE conducted as part of this action, Amendment 8, was a commitment by NEFMC with the NEFSC to develop a stakeholder driven MSE in this region to operationalize the Council’s Risk Policy. The MSE completed to support this action has provided the risk-based analysis needed to support decision making that evaluates the tradeoffs of management objectives with respect to net benefits to the nation.

1.3 MANAGEMENT STRATEGY EVALUATION

The Council developed Amendment 8 alternatives for the control rule using Management Strategy Evaluation (MSE). MSE is a decision-making process to determine preferred management approaches. MSE involves simulation testing of how various management approaches (e.g., ABC control rules) may perform relative to identified management objectives. AS part of this process, the Council held public workshops to generate stakeholder input to identify objectives for the MSE operating models.

The MSE conducted as part of this action, Amendment 8, was a commitment by NEFMC with the NEFSC to develop a stakeholder driven MSE in this region to operationalize the Council’s Risk Policy. The MSE completed to support this action has provided the risk-based analysis needed to support decision making that evaluates the tradeoffs of management objectives with respect to net benefits to the nation.

Of particular importance to the MSE process is identification of fishery objectives and corresponding quantitative performance metrics, and relevant uncertainties (related to the biology, ecosystem, assessment, management, etc.). An example fishery objective might be maintaining enough herring as forage, with a corresponding performance metric of a minimum abundance of herring. Example uncertainties might include those related to stock assessment, fish reproduction (i.e., stock-recruitment), and the strength of interactions between predator and prey.

With this information, a simulation is constructed that involves a mathematical representation (i.e., operating model) of the necessary biological aspects of the system, the fishery, assessment, and management (e.g., a level of ABC). The operating model should account for the uncertainties identified (here, through workshops). In some cases, uncertainty about a process may be so large as to warrant construction of multiple operating models that attempt to bound the plausible range of the given process. For example, the degree to which predator abundance depends on herring abundance might be poorly understood, and so two operating models might be constructed with a high and low degree of predatory dependence, respectively. With each operating model, the performance of the ABC control rules is simulated. Performance metrics are then compared for the control rules under each operating model to evaluate which control rules are more or less robust to the uncertainties.

Ideally, a preferred management alternative or range of alternatives (ABC control rules in this case) is identified by the MSE process that will perform reasonably well for the fishery objectives regardless of the operating model (i.e., regardless of what is happening in reality). Another benefit of the MSE process is improved common understanding of what is or is not well understood about the system, which can help inform research priorities and future refinement of the MSE. In the end, the MSE will only be as useful as the degree to which those involved
collaboratively work to create a useful approximation of reality that bounds the major uncertainties.

1.3.1 Blending MSE with the Council process

In 2015, the Council initiated, conducted public scoping, and set the goals of Amendment 8 to the Atlantic Herring Fishery Management Plan. In January 2016, the Council approved conducting a Management Strategy Evaluation (MSE) to support the development of alternatives regarding the ABC control rule. The Council aimed to use MSE as a collaborative decision-making process, involving more upfront public input and technical analysis than usually occur through the amendment development process. MSE is being used here to help determine how a range of control rules may perform relative to potential objectives. The MSE proceeded with four distinct phases (See timeline in Figure 2). MSEs typically take several years to complete and involve a closed, small group (15-25) of stakeholders. The Council diverged from this norm for two reasons. First, the Council aims to use the ABC control rule adopted through Amendment 8 in developing the fishery specifications for 2019-2021. Thus, this MSE proceeded under more constrained time limits than perhaps is normally the case. Second, the Council decided to have all points of stakeholder input (e.g., workshops) completely open to the public, to have the MSE process mirror the open Council process as much as possible. The Council completed the MSE within two years, proceeding in six distinct phases.

Phase 1 – Identify parameters to be tested (January-June 2016)

An initial public workshop was held in May 2016 to develop recommendations to the Council for a range of potential objectives of the Atlantic herring ABC control rule, how progress towards these objectives may be measured (i.e., associated performance metrics), and the range of control rules that would undergo testing. About 70 individuals participated in the first workshop including a diverse group of stakeholders from fishing industries, private recreational anglers, scientists, managers, non-profit organizations, and other user groups. In June 2016, upon review of the workshop recommendations and additional input from the Atlantic herring Plan Development Team (PDT), Advisory Panel (AP), and Committee, the Council approved moving forward with the MSE. These bodies did not recommend specific changes to the input provided by the workshop. Although there was not universal support for all of the recommendations, these groups supported evaluation of the full range of concepts.

Phase 2 – Simulation testing (July-November 2016)

With the fishery objectives, performance metrics and control rules that would undergo testing approved in June 2016, technical work proceeded over the summer. The Northeast Fisheries Science Center (NEFSC) technical team identified, refined, or developed models of Atlantic herring, predators, and fishery economics and tested control rule performance relative to the performance metrics. This work proceeded up until the second public workshop in December 2016.

Phase 3 – Review results, identify additional improvements (December 2016)

The Council convened a second public workshop in December 2016 to review the results of the technical work and to provide continued opportunities for public input. This workshop drew about 65 participants, again from diverse stakeholder groups. Both workshops were completely open to the public and anyone could attend and provide input at the meeting. Herring Advisors,
Committee members, and PDT members were encouraged to attend, but it was not an invitation workshop and was completely open to the public.

The input from the second workshop was intended to inform both the finalization of this MSE as well as the development of alternatives in Amendment 8. Relative to this MSE, participants were asked to identify what, if any, additional MSE simulation work (or presentation of outcomes) would be informative for establishing a long-term ABC control rule. The workshop identified which of the ideas generated could potentially be accomplished within this current, first MSE and which may be incorporated into future iterations of the MSE with future improvements to data and/or modeling capacity. Relative to the development of alternatives, participants were asked to identify acceptable ranges of performance for various metrics (to help the Council balance tradeoffs) and how the number of control rules simulated could be narrowed into an appropriate range for consideration in Amendment 8.

Phase 4 – Prepare for Peer Review MSE (January-February 2017)

Based on the input received at the December 2016 workshop, the NEFSC technical team made refinements to the simulations and presentation of outcomes, finalizing a summary of the technical methods and outcomes in February 2017. The methods and outcomes were then subject to a peer review in March 2017.

Phase 5 – Peer review (March 2017)

The Council decided to have an external peer review of the MSE model and process used. Several technical models were developed to evaluate the performance of herring ABC control rules, and this was the first MSE used in this region. The goal of the peer review was to review the MSE methods, data, and results developed and determine if they are sufficient for the Council to use when identifying and analyzing a range of ABC control rule alternatives in Amendment 8 to the Atlantic Herring Fishery Management Plan.

Four external peer reviewers were selected to serve on the peer review that took place over 2.5 days in March 2017. The terms of reference required the Panel to: 1) assess the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules, 2) evaluate whether the methods, data, and results of the MSE are sufficient for the NEFMC to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan, and 3) provide recommendations for future improvements to the process.

The Panel recognized that a tremendous amount of work was completed in a rigorous manner under the time and resource constraints of this MSE process. The Panel agreed that the NEFSC technical team constructed a series of models (Atlantic herring, predator, and economic) appropriate for evaluating ABC control rules for the Atlantic herring fishery in the context of herring’s role as a forage fish. The Panel detailed areas of strength and areas for improvement in the MSE workshop process, modeling, and synthesis. The Panel concluded that the data, methods, and results of the MSE are sufficient for the Council to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. Overall, the Panel concluded that the Atlantic herring MSE represents the best available science at this time for evaluating the performance of herring control rules and their potential impact on key predators. The Panel reached consensus regarding their conclusions on all terms of reference. The results of the peer review were presented to the Council in April 2017. More
information about the peer review including the final reports can be found at:

Phase 6 - Incorporation into DEIS (January-September 2017)

Simultaneous to Phases 4 and 5, the Council developed a range of ABC control rule alternatives, approving the range in April 2017. With feedback from the peer review, the results from the MSE models were further refined and integrated into this document. Impact analysis of the alternatives, during summer 2017, proceeded with the help of a contractor to present MSE results in more user-friendly formats. The Council approved, for public hearings, the portions of the DEIS related to the ABC control rule.

Figure 2 – MSE timeline used for Amendment 8

<table>
<thead>
<tr>
<th>Timeframe</th>
<th>Council/MSE process</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Amendment 8 initiated; public scoping; review scoping comments; develop amendment goals and objectives</td>
</tr>
<tr>
<td>2016</td>
<td>Jan.</td>
</tr>
<tr>
<td></td>
<td>Feb.-Jun.</td>
</tr>
<tr>
<td></td>
<td>Jul.-Nov.</td>
</tr>
<tr>
<td></td>
<td>Dec.</td>
</tr>
<tr>
<td>2017</td>
<td>Jan.</td>
</tr>
<tr>
<td></td>
<td>Feb.</td>
</tr>
<tr>
<td></td>
<td>Mar.</td>
</tr>
<tr>
<td></td>
<td>Apr.-Sept</td>
</tr>
</tbody>
</table>

1.4 ABC CONTROL RULES USED IN OTHER FISHERIES

1.4.1 New England Fishery Management Council

A wide variety of ABC control rules are used in New England often based on the degree of information known about a particular species and fishery, as well as the risk tolerance of a management body for that particular resource. Table 1 summarizes the ABC control rules currently used in the FMPs managed by the NEFMC. Some are exclusively based on average catch (i.e., red crab) when there is little information available about the biomass of a particular...
species. Other control rules are more sophisticated and explicitly account for uncertainty (i.e., whiting and red hake).

Table 1 – Summary of ABC control rules used in NEFMC Fishery Management Plans

<table>
<thead>
<tr>
<th>Species</th>
<th>ABC CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herring</td>
<td>3 year average with 50% probability of overfishing in Year 3</td>
</tr>
<tr>
<td>Scallops</td>
<td>Catch associated with fishing rate that has no more than a 25% chance of exceeding OFL (including discards)</td>
</tr>
<tr>
<td>Skate</td>
<td>Aggregate ABC for all 7 species combined; Long-term median catch/biomass ratio x 3-year avg. biomass</td>
</tr>
</tbody>
</table>
| Monkfish                | B\text{CURRENT} \times \text{Avg expl. rate 1996-2006 (North)}  \
|                         | B\text{CURRENT} \times \text{Avg expl. rate 2000-2006 (South)}  \
|                         | CR not used in the 2017-2019 specifications based on SSC advice.  \
|                         | SQ ABC used based on recent data. This method may be used until age validation research is complete. |
| Whiting (silver and offshore hakes) | P^*^1 = 25th percentile of estimated scientific uncertainty for silver hake. 4% added to southern whiting stock ABC to account for mixed catch including offshore hake |
| Red Hake                | P^* = 40th percentile of estimated scientific uncertainty             |
| Red crab                | long-term average catch                                               |
| Groundfish stocks       | For most stocks with approved assessment: 75% Fmsy x B current  \
|                         | Other methods used for stocks with rejected assessment or other issues |

1.4.2 Other regions

Similar to New England, a variety of ABC control rules are used in other regions as well. This section summarizes a few examples of ABC control rules used for other forage species.

Another important prey species in this region is Atlantic mackerel. The Mid-Atlantic Fishery Management Council is responsible for managing Atlantic mackerel. The mackerel ABC is currently (2016-2018) set based on the SSC’s review of data-limited approaches for mackerel ABCs generated as part of a limited Management Strategy Evaluation conducted for mackerel in 2015.\(^2\) Pending finalization of the new assessment, ABCs beginning in 2019 will likely be based on a stock rebuilding timeline developed for mackerel (Jason Didden, MAFMC staff, personal communication). Absent a rebuilding timeline, ABCs for typical MAFMC species are generated

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\(^1\) P* is a measure of the scientific uncertainty that an ABC is less than estimated fishing mortality that is consistent with producing MSY. P*=50% means that there is a 50/50 chance. Lower P* values are associated with less risk.

\(^2\) The MAFMC uses general control rules based on their risk policy that has different control rules based on stock status. The regulations for the risk policy and control rules are available at: [https://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&SID=1e9b02ffdf0b0b05d8243d4b657fae956c&rgn=div5&view=text&node=50:12.0.1.1.5&idno=50#se50.12.648_121](https://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&SID=1e9b02ffdf0b0b05d8243d4b657fae956c&rgn=div5&view=text&node=50:12.0.1.1.5&idno=50#se50.12.648_121)
based on a sliding scale of overfishing tolerance, where at/above Bmsy the SSC recommends ABCs associated with a 40% chance of overfishing, decreasing linearly to a zero percent chance of overfishing when the ratio of B/Bmsy = 0.10.  

The MAFMC also recently approved an amendment to prohibit the development of new and expansion of existing directed commercial fisheries on unmanaged forage species in Mid-Atlantic federal waters, effective September 2017. The action designated 13 species and species groups as ecosystem components (ECs) and implemented an incidental possession limit for those species. It also implemented a separate annual landings limit and possession limit for Atlantic chub mackerel, which was not designated as an EC. Annual catch limits were not set for any of the species included in the amendment.

Atlantic menhaden is another important forage species found in estuaries and coastal waters from northern Florida to Nova Scotia. This species is managed by the Atlantic States Marine Fisheries Commission (ASMFC). The Commission allocates an annual TAC on a state-by-state basis based on landings history, with 1% set-aside for episodic events. The TAC setting process used by ASMFC for this species has two approaches. The preferred approach is a model-based projection method, and the second is an ad-hoc approach used for more data-limited species. Finally, there is an “indecision clause”, which maintains the current TAC for the subsequent year if the Board is unable to decide on a TAC by the end of the year. The current process used in recent years is the ad-hoc approach.

In 2015, ASMFC initiated Amendment 3 to consider development of ecological reference points (ERPs) and revisit allocation methods. ERPs are intended to account for changed in the abundance of prey and predator species when setting overfished/overfishing thresholds and targets, because menhaden is an important forage fish. Amendment 3 was approved for public comment in August 2017 and final action was taken in November 2017. ASMFC decided to maintain the current single-species biological reference points until the review and adoption of menhaden specific ERPs in the 2019 benchmark assessment. The 2018 and 2019 TACs were set in Amendment 3 using the method outlined in the 2015 stock assessment that is based on reference points in relative to maximum spawning potential (MSP), age 2-4 fish. This comes out to about 216,000 MT for 2018 and 2019, but the TAC may be adjusted based on the new ERPs being developed.

Amendment 3 included a detailed summary of general guidelines that have been developed by external groups regarding potential management of forage fish (Section 2.6.3 of Amendment 3: http://www.asmfc.org/files/Meetings/AtlMenhadenBoardNov2017/AtlMenhadenBoardSupplemental_Nov2017.pdf ). Text from this action has been paraphrased below as background on guidance that exists in literature, but the recommendations are not specific to Atlantic herring.

One guideline for the management of forage fish species is the “75% rule”, which recommends that forage fish populations be maintained at three-fourths of their unfished biomass levels to lower impacts on marine ecosystems (Smith et al., 2011). The peer-reviewed analysis investigated five regions around the world to determine ecosystem impacts of fishing low trophic level species. While results varied, overall the analysis found that the proportion of ecological groups impacted increased with the depletion of forage fish. The study concluded that a target of

75% unfished biomass for forage fish species would reduce impacts on other species while maintaining fisheries yields at roughly 80% of their current levels. Atlantic herring was not a species included in this study.

The Lenfest Ocean Program, a grant-making program managed by The Pew Charitable Trusts, has also developed guidelines for the development of forage fish ERPs. In their 2012 report by Pikitch et al., Lenfest describes how they used a suite of 10 previously published Ecopath with Ecosim models to assess the impacts of forage fish harvest on a variety of ecosystems (http://www.lenfestocean.org/en/research-projects/lenfest-forage-fish-task-force). The Chesapeake Bay as well as the Gulf of Maine were regions described in the report, but no species from the Gulf of Maine (i.e. Atlantic herring) were modeled in the analysis. Various management strategies which specify fishing mortality were run to determine impacts on predator populations. From these results, a general equation was developed to predict predator responses to forage fish harvest. The analysis recommends a “hockey stick” control rule, one where fishing mortality is dependent on stock size but would not exceed half of the forage species natural mortality rate. Maximum allowable fishing mortality would occur when the stock is at carrying capacity (unfished biomass) and F declines linearly to zero when biomass falls below 40% of unfished biomass. This report was reviewed by three external reviewers; however, the full report has not been reviewed by a scientific journal.

The modeled results found that the degree of ecological impact on predators varied among species and ecosystems. However, consistent impact patterns were found based on diet dependency, predator type, and intensity of fishing effort. Overall, fishing at Fmsy led to highly significant effects for many dependent predators. The authors concluded that when stock size is uncertain, the “hockey stick” control rules perform better than other strategies tested (constant fishing mortality, constant yield, and “step” function control rules). The report includes nine key findings and several overall recommendations for determining catch levels for forage fish based on the level of information known about the stock.

Although generalized forage fish models may provide interim guidance on potential ways to manage prey species, some experts have argued that harvest policies for lower trophic level species should be based on models specific to the species of interest, even in the interim. Hilborn et al. (2017) investigated eleven species of U.S. forage fish, this time including Atlantic herring, to determine what factors should be analyzed when assessing the impacts of fishing lower trophic level species on predators. Given spawner-recruit data indicates good year classes can come from both small and large stock sizes, Hilborn et al. (2017) concludes that recruitment is likely dependent on environmental conditions, and stock abundance may be variable even in the absence of fishing. This research argues that precautionary guidelines may not consider the size of prey eaten by various predator species, versus those that are harvested by the fishery. Hilborn et al. (2017) also notes that the spatial distribution of forage fish in relation to the location of predators may be a critical factor, particularly if there are ‘core’ areas of forage fish abundance on which predators are dependent. As a result, Hilborn et al. (2017) argues that harvest control strategies should include these factors (i.e. natural variability of forage fish abundance, size selectivity of predators, spatial distribution of forage fish) when assessing the impact of forage fish harvest on predator species.
In summary, there is varied advice on best practices for setting catch targets for forage fish species. Some research supports the use of precautionary guidelines to manage forage fish until specific predator-prey models can be developed, and others conclude that species-specific models are needed to account for natural population variability and changes in spatial distribution. This action, Amendment 8, has utilized a system specific age-structured simulation model for Atlantic herring that considers key uncertainties for this species and ecosystem.
Technical Details of the Management Strategy Evaluation

Introduction

This document provides the technical details of the MSE. The document has three distinct sections with details that pertain to: 1) Atlantic herring (Deroba), 2) Atlantic herring predators (Gaichas), and 3) economics (Lee). Symbol definitions and terminology may vary among sections. This inconsistency is the outcome of meeting deadlines, but also a lack of standardization in the scientific community such that the same term may be defined differently by a fisheries biologist or an economist. Consequently, each section should be read somewhat independently. The models of predators and economics, however, do rely on outputs from the Atlantic herring simulations, and these dependencies are highlighted in each section. The Atlantic herring section also includes the majority of results, and so some cross-referencing among sections may be necessary to understand the interpretation of some performance metrics.
Technical Details of Operating Models and Harvest Control Rules used in the Georges Bank/Gulf of Maine Atlantic herring Management Strategy Evaluation

Jonathan J. Deroba

Introduction

Attention has been given to applying a harvest control rule to Atlantic herring *Clupea harengus* that considers a fishery objective related to their role as a forage fish. The fishery also has other competing objectives, however, such as attaining relatively high and stable yields. The information available to evaluate the relative performance of control rules at meeting these competing fishery objectives is limited to analyses that are not specific to the system (Pikitch et al., 2012; Deroba and Bence 2008). While “borrowing” control rules from other systems or species might be a valid last resort, it is not the ideal method (Deroba and Bence 2008). Applying generic control rules may have unintended consequences, may not achieve fishery objectives, and may not adequately consider uncertainty in the way in which the control rules were derived (Deroba and Bence 2008). Control rules and the parameters that define them are best chosen based on stochastic simulations that consider key uncertainties for the specific system (e.g., management strategy evaluation; MSE; Deroba and Bence 2008). This document describes a system specific MSE for Atlantic herring that may be used by the New England Fishery Management Council to choose a harvest control rule.

Methods

Basics.—An MSE was developed specific to Gulf of Maine – Georges Bank Atlantic herring. The MSE was a modified version of that used in Deroba (2014), and symbols are largely consistent with Deroba (2014; Table 1). The MSE was based on an age-structured simulation that considered fish from age-1 through age-8+ (age-8 and older), which is consistent with the age ranges used in the 2012 and 2015 Atlantic herring stock assessments (NEFSC 2012; Deroba 2015). The abundances at age in year one of all simulations equaled the equilibrium abundances produced by the fishing mortality rate that would
reduce the population to 40% of $SSB_{F=0}$. Abundance in each subsequent age and year was calculated assuming that fish died exponentially according to an age and year specific total instantaneous mortality rate:

$$N_{a+1,y+1} = N_{a,y}e^{-Z_{a,y}};$$

$$Z_{a,y} = F_{a,y} + M_{a}.$$  

Recruitment followed Beverton-Holt dynamics:

$$R_{1,y+1} = \frac{(SSB_{F=0} 1-h)}{4h}SSB_{y} e^\epsilon_{Ry} \frac{\sigma^2_R}{2};$$

$$\epsilon_{Ry} = \omega \epsilon_{Ry-1} + \sqrt{1 - \omega^2} \chi_y; \chi_y \sim N(0, \sigma^2_R);$$

$$SSB_y = \sum_{a=1}^{8+} N_{a,y}m_aW_a;$$

(Francis 1992). The variance of recruitment process errors ($\sigma^2_R$) equaled 0.36 and the degree of autocorrelation ($\omega$) equaled 0.1, which are values consistent with recruitment estimates from a recent Atlantic herring stock assessment (Deroba 2015).

Assessment Error.—A stock assessment was approximated (i.e., assessment errors) similar to Punt et al. (2008) and Deroba (2014):

$$\tilde{N}_{a,y} = [N_{a,y}(\rho + 1)]e^{\epsilon_{\varphi y} - \frac{\sigma^2_{\varphi}}{2}};$$

where:

$$\epsilon_{\varphi y} = \vartheta \epsilon_{\varphi y-1} + \sqrt{1 - \vartheta^2} \tau_y; \tau_y \sim N(0, \sigma^2_{\varphi}).$$
The variance of assessment errors ($\sigma^2_\phi$) equaled 0.05 and autocorrelation ($\vartheta$) equaled 0.7. Rho ($\rho$) allowed for the inclusion of bias in the assessed value of abundance (see below; Deroba 2014). Assessed spawning stock biomass ($SSB_y$) was calculated similarly to $SSB_y$ except with $N_{a,y}$ replaced with $\bar{N}_{a,y}$, and assessed total biomass ($\bar{B}_y$) was calculated as the sum across ages of the product of $\bar{N}_{a,y}$ and $W_a$.

*Operating Models.*—The stakeholder workshops identified uncertainties about herring life history traits and stock assessment, and the effect of some of these uncertainties on harvest control rule performance was evaluated by simulating the control rules for each of eight operating models (Table 2; Figures 1-2). The uncertainties addressed by the eight operating models included: Atlantic herring natural mortality and recruitment, Atlantic herring weight-at-age, and possible bias in the stock assessment beyond the unbiased measurement error ($\epsilon_{\phi y}$).

The specific values used in the operating models for each of the uncertainties were premised on data used in recent stock assessments or estimates from fits of stock assessment models (Deroba 2015). Natural mortality in recent stock assessments has varied among ages and years, with $M$ being higher during 1996-2014 than in previous years (NEFSC 2012; Deroba 2015). Natural mortality in the stock assessments also has relatively minor amounts of interannual variation in $M$ because the $M$ values were calculated using a relationship with weights at age (Lorenzen 1996), which vary slightly among years. Natural mortality, however, has also been identified as an uncertainty in the stock assessments and sensitivity runs have been conducted without higher $M$ during 1996-2014, such that $M$ is nearly constant among years (NEFSC 2012; Deroba 2015). To capture uncertainty in $M$ in the MSE, operating models were run with either relatively high or low $M_a$ (Table 2; Figure 1). Relatively high $M_a$ values equaled the age-specific natural mortality rates averaged over the years 2005-2014 that are inputs to the stock assessment with higher rates in recent years (i.e., higher $M_a$ during 1996-2014). Relatively low $M_a$ values in the MSE equaled the age-specific natural mortality rates averaged over the years 2005-2014.
that are inputs to the stock assessment with nearly constant natural mortality among years (i.e., the assessment without higher $M$ during 1996-2014). In the MSE, $M_α$ was always time invariant.

Uncertainty in estimates of stock-recruit parameters were represented in the MSE by using the parameters estimated by stock assessments fit with and without the higher $M$ during 1996-2014. Stock assessment fits with higher $M$ during 1996-2014 produced estimates of steepness and unfished $SSB$ that were lower than in stock assessment fits without higher $M$ during 1996-2014 (Table 3; Figure 1). Thus, operating models with relatively high $M_α$ always had relatively low steepness and unfished $SSB$, and the opposite held with relatively low $M_α$ (Table 2).

Uncertainty in Atlantic herring size-at-age was accounted for by having operating models with either fast or slow growth (i.e., weights-at-age; Table 2; Figure 3). Atlantic herring weight-at-age generally declined from the mid-1980s through the mid-1990s, and has been relatively stable since. Reasons for the decline are speculative and no causal relationships have been established. Thus, fast growth operating models had weights-at-age that equaled the January 1 weights-at-age from the most recent stock assessment averaged over the years 1976-1985, while the slow growth operating models averaged over the years 2005-2014 (Deroba 2015). In the MSE, weight-at-age was always time invariant.

Differences in $M$, stock-recruit parameters, and weights-at-age led to differences in unfished and $MSY$ reference points among operating models (Table 3). The effect of $M$ and stock-recruit parameters was larger than the effect of differences in weight-at-age (Table 3).

To address concerns about possible stock assessment bias, operating models with and without a positive bias were included. In operating models without bias, $ρ = 0$ and the only assessment error was that caused by the unbiased measurement errors ($ε_{py}$). In operating models with bias, $ρ = 0.6$, which was based on the degree of retrospective pattern in $SSB$ from the most recent stock assessment (Deroba 2015).
Harvest Control Rules.—Several basic control rules were evaluated, including a biomass based control rule (Katsukawa 2004), a constant catch rule, and a conditional constant catch rule (Figure 3; Clark and Hare 2004; Deroba and Bence 2012). The biomass based control rule was defined by three parameters: the proportion ($\psi$) of $F_{MSY}$ that dictates the maximum desired fishing mortality rate ($\bar{F}$), an upper SSB threshold ($SSB_{up}$), and a lower SSB threshold ($SSB_{low}$). The $\bar{F}$ equaled the maximum when $SSB$ was above the upper threshold, declined linearly between the upper and lower thresholds, and equaled zero below the lower threshold:

$$\bar{F}_y \begin{cases} 
F_{msy} \psi & \text{if } SSB_y \geq SSB_{up} \\
F_{msy} \psi \frac{SSB_y - SSB_{low}}{SSB_{up} - SSB_{low}} & \text{if } SSB_{low} < SSB_y < SSB_{up} \\
0 & \text{if } SSB_y \leq SSB_{low}
\end{cases}$$

The $\bar{F}_y$ was then used to set a quota in year $y + 1$:

$$Q_{y+1} = \sum_{a=1}^{8+} \frac{\bar{F}_{a,y}}{\bar{F}_{a,y} + M} \hat{B}_{a,y} \left(1 - e^{-\left(\bar{F}_{a,y} + M_a\right)}\right)$$

where $\bar{F}_{a,y}$ equaled $\bar{F}_y$ times $S_a$, and $S_a$ was time and simulation invariant selectivity at age equal to the values for the mobile gear fishery reported in Deroba (2015; Table 1). $\bar{F}_y$ was used to set a quota in the following year to approximate the practice of using projections based on an assessment using data through year $y - 1$ to set quotas in the following year(s). Furthermore, although $\bar{F}_y$ was set using $SSB_y$, the quota was based on $\hat{B}_y$ because the fishery selects some immature ages. The fully selected fishing mortality rate that would remove the quota from the true population ($\bar{F}_y$) was found using Newton-Raphson iterations.

Several variations of the biomass based rule were also evaluated. These variations included applying the control rule annually, using the same quota for three year blocks such that the control rule is applied every fourth year (i.e., $Q_{y+1} = Q_{y+2} = Q_{y+3}$), using the same quota for 5 year blocks, and using the same quota for three year blocks but restricting the change in the quota to 15% in either
direction when the control rule was reapplied in the fourth year. Thus, four variants of the biomass
based control rule were evaluated: 1) annual application, 2) three year blocks, 3) five year blocks, and 4)
3 year blocks with a 15% restriction.

For each biomass based control rule variant, a range of values for the three parameters defining
the control rule were evaluated. The proportion ($\psi$) of $F_{MSY}$ that dictates the maximum desired fishing
mortality rate was varied from $0.1F_{MSY}$ to $1.0F_{MSY}$ in increments of 0.1, while the upper and lower $SSB$
threshold parameters ($SSB_{up}, SSB_{low}$) were varied from $0.0SSB_{MSY}$ to $4SSB_{MSY}$ but with inconsistent
increments (i.e., 0.0, 0.1, 0.3, 0.5, 0.7, 0.9, 1.0, 1.1, 1.3, 1.5, 1.7, 2.0, 2.5, 3, 3.5, 4). The full
factorial of combinations for the three biomass based control rule parameters produced 1,360
shapes (note $SSB_{low}$ must be $\leq SSB_{up}$) and each of these shapes was evaluated for each of the four
biomass based control rule variants described above. The control rule used to set Atlantic
herring allowable biological catch for the years 2013-2018 (i.e., the status quo control rule used
to set quotas) was defined as a biomass based control rule that used three year blocks with:

$\psi = 0.9, SSB_{up} = 0.5, and SSB_{low} = 0.0$. This shape was chosen for the status quo because for years 2013-
2018 the quota for herring was set to a constant value for three year blocks (2013-2015; 2016-2018;
NEFSC 2012; Deroba 2015), the average proportion of $F_{MSY}$ achieved by the quotas over those years
equaled 0.9, the stock enters a rebuilding plan with reduced fishing mortality at $SSB_{up} = 0.5$ (i.e., half of
$SSB_{MSY}$), and the fishery would never entirely close and so $SSB_{low} = 0.0$. The linear decline in $\tilde{F}$
between $SSB_{up} = 0.5$ and $SSB_{low} = 0.0$ may not exactly match what would occur in reality because
entering a rebuilding plan may induce non-linear changes in $\tilde{F}$, but adding this reality requires short-
term projections be conducted within the MSE and this is not a trivial task and could not be completed
in the given time frame.
The constant catch control rule is defined by one parameter, a desired constant catch (i.e., quota) amount (Figure 3). The constant catch amounts were varied from 0.1 MSY to 1.0 MSY in increments of 0.1.

The conditional constant catch rule used a constant desired catch amount unless removing that desired catch from the assessed biomass caused the fully selected fishing mortality rate to exceed a predetermined maximum, in which case the desired catch was set to the value produced by applying the maximum fully selected fishing mortality rate to the assessed biomass (Figure 3). Thus, the conditional constant catch rule has two policy parameters: a desired constant catch amount, and a maximum fishing mortality rate. The constant catch amounts were varied from 0.1 MSY to 1.0 MSY in increments of 0.1, while the maximum fishing mortality rate equaled 0.5 \( F_{MSY} \). When the maximum fishing mortality rate portion the conditional constant catch rule was invoked, a quota was set in the same manner as when \( SSB_y \geq SSB_{up} \) in the biomass based control rule described above.

**Implementation Error.**—Implementation errors were also included in a similar way as in Punt et al. (2008) and Deroba and Bence (2012):

\[
F_{a,y} = \bar{F}_y S_a e^{\epsilon_y \theta - \frac{\sigma^2}{2}}; \quad \epsilon_y \sim N(0, \sigma^2_\theta).
\]

The variance of implementation errors \( (\sigma^2_\theta) \) equaled 0.001.

**Performance metrics.**—For each combination of control rule shape and operating model, 100 simulations were conducted, each for 150 years. Preliminary simulations suggested that this number of simulations and years was sufficient for results to be insensitive to starting conditions and short-term dynamics caused by auto-correlated processes. Median SSB, \( \frac{SSB}{SSB_{F=0}} \), \( \frac{SSB}{SSB_{MSY}} \), yield, \( \frac{yield}{MSY} \), biomass of herring dying due to \( M \), and the proportion of the herring population comprised of age-1 fish over the last 50 years of each simulation were recorded as performance metrics. Additional performance metrics
included the proportion of the last 50 years of each simulation with $SSB < SSB_{MSY}$, $SSB < \frac{SSB_{MSY}}{2}$ (i.e., proportion of the last 50 years that are overfished), $SSB < 0.3SSB_{F=0}$, $SSB < 0.75SSB_{F=0}$, fully-selected $F > F_{MSY}$ (i.e., proportion of the last 50 years that overfishing occurred), and $Q = 0$ (i.e., proportion of the last 50 years that the fishery was closed). Interannual variation in yield ($IAV$) was also recorded over the last 50 years of each simulation:

$$IAV = \sqrt{\frac{1}{50} \sum_{y=1}^{50} (Y_{y+1} - Y_y)^2 / \left( \frac{1}{50} \sum_{y=1}^{50} Y_y \right)}.$$  

These performance metrics were highlighted to be of interest at the stakeholder workshops.  

Two types of two-dimensional tradeoff plots for some pairs of performance metrics were used to graphically summarize results. 1) For comparing large numbers of control rule shapes, tradeoff plots were generated for individual operating models and were based on the median among simulations, such that each control rule shape was represented by a single point. These types of plots were generally used to introduce the broad topic of tradeoffs, convey the extent of performance that each general control rule could achieve, and to highlight the pairs of metrics with relatively strong tradeoffs. While focusing on a single operating model and relying solely on the median ignores variation in results, simultaneously plotting the range of performance among operating models with multiple percentiles for thousands of control rule shapes was ineffectual. 2) For comparing relatively few control rule shapes (e.g., < ~6), tradeoff plots were generated using shaded areas that ranged from the 25$^{th}$ to the 75$^{th}$ percentile of each performance metric among all the operating models for each control rule shape. These types of plots were generally used to introduce the concept of “robustness”, i.e., that some control rule shapes are more certain to produce a given result or tradeoff than other control rule shapes. These two types of tradeoff plots are presented in separate Results sections below.

Results presented here also include performance metrics for Atlantic herring predators, the details of which can be found in Gaichas’ technical document. Results for economic metrics are not
The results described here are intended to serve as examples of how various graphics were used to convey information, and are not comprehensive. Results for control rule shapes that achieve specified objectives (e.g., achieve 80% of MSY) are also not presented because the New England Fishery Management Council is in the process of selecting preferred control rules, and this process has not yet identified such preferred objectives or performance.

1) Comparing large numbers of control rule shapes—Yield relative to MSY (i.e., $\frac{\text{Yield}}{\text{MSY}}$) generally exhibited a dome-shaped relationship with $\frac{SSB}{SSB_{f=0}}$, and the severity of this relationship varied among operating models (Figure 4, which occurs on multiple pages). Generally, the biomass based control rule variants achieved higher levels of yield and maintained higher biomass than the constant catch or conditional constant catch rules (Figure 4).

A broad range of $\frac{\text{Yield}}{\text{MSY}}$ could be achieved across a broad range of IAV, and while this relationship varied among operating models, the general pattern held. So for the sake of brevity, results were only presented for the operating model with a combination of Hi $M$, low steepness, slow growth, and an unbiased assessment (Figure 5). The biomass based rule applied with 3 year blocks and a 15% restriction, the constant catch, and the conditional constant catch rules more consistently achieved low IAV than the other biomass based alternatives, but this came at the cost of fewer alternatives that could achieve relatively high yield (Figure 5).
The frequency with which tuna weight was greater than average was driven almost entirely by whether Atlantic herring grew fast or slow (Figure 6). Results were only presented for operating models with a combination of Hi $M$, low steepness, and an unbiased assessment (Figure 6).

The frequency with which tern production was $> 1$ (i.e., that terns were able to maintain replacement) was generally $\sim 85\%$ or higher and Atlantic herring biomass was generally higher for the biomass based alternatives without the 15% restriction than for the biomass based rule with three year blocks and a 15% restriction, constant catch, and conditional constant catch rules (Figure 7). Results were only presented for the operating model with a combination of Hi $M$, low steepness, slow growth, and an unbiased assessment (Figure 7).

Results for the frequency with which dogfish were $> 0.5B_{MSY}$ were similar to results for that of tern production (Figure 8). The frequency with which dogfish were $> 0.5B_{MSY}$ was nearly 1.0 and Atlantic herring biomass was generally higher for the biomass based alternatives without the 15% restriction than for the biomass based rule with three year blocks and a 15% restriction, constant catch, and conditional constant catch rules (Figure 8). Results were only presented for the operating model with a combination of Hi $M$, low steepness, slow growth, and an unbiased assessment (Figure 8).

2a) Comparing relatively few control rule shapes—Results in this section pertain to four specific biomass based control rule shapes (Figure 9). These four shapes were chosen ad hoc and are for demonstration purposes. Unless otherwise noted, the same colors correspond to the same biomass based shapes throughout the figures. Whether the control rules were applied annually, with three year blocks, or with five year blocks was noted in figure captions,
as was whether the results cover operating models with unbiased assessments or both biased
and unbiased assessments.

Control rules that were more certain to provide relatively high yield were more certain
to produce smaller amounts of herring $SSB$, more frequently resulted in herring becoming
overfished, and were more certain to produce less variation in yield than control rules less
certain to provide relatively high yield (Figure 10). Control rules that resulted in herring
becoming overfished less frequently also produced more frequent fishery closures than other
control rules (Figure 10).

The frequency with which tuna weight was greater than average was driven almost
entirely by whether Atlantic herring grew fast or slow, and so results for each control rule
varied from 0-1 in that metric (Figure 11). Control rules less certain to maintain the frequency
of tern production at levels $\leq 1$ were also more certain to reduce herring $SSB$, although in the
worst case the frequency with which tern production was $> 1$ was still $\approx 80\%$ (Figure 11). The
frequency with which dogfish were $> 0.5B_{MSY}$ did not vary among the four control rule shapes
(Figure 11).

2b) Comparing the sensitivity of relatively few control rule shapes to assessment bias—
All of the control rules produced less herring $SSB$ in biased assessment operating models than in
unbiased assessment operating models (Figure 12). Some control rules, however, were more
certain to generate less yield in the biased than in the unbiased operating models, while other
control rules were actually more certain to produce higher yield in the biased than unbiased
assessment operating models (Figure 12). All of the control rules were more certain to result in
greater frequencies of herring becoming overfished in biased than in unbiased assessment
operating models, but control rules that were more certain to produce relatively high yield in the unbiased operating models were more sensitive to assessment bias (Figure 12). Other tradeoff plots were not included for the sake of brevity.

2c) Evaluating the effect of applying biomass based control rules annually, in three year blocks, or five year blocks—The same four control rules analyzed in sections 2a and 2b (Figure 9) were also evaluated for their sensitivity to applying each of the control rules annually, in three year blocks, or in five year blocks. The four control rules responded similarly to the various blocks, and so results are only presented for the status quo biomass based shape (see Harvest Control Rules section above).

The short-term stability provided by using the same quota in three or five year blocks resulted in less long-term yield, less herring SSB, greater frequencies of herring becoming overfished, and increases in long-term variation in yield (i.e., IAV) than if quotas were varied annually (Figure 13). The effects were greatest on the frequency that herring became overfished (Figure 13).

Caveats

This MSE assumed that the reference points used to define the harvest control rules (i.e., $F_{MSY}$ and $SSB_{MSY}$) were known without error. The bias and precision of such reference points, however, can depend on life history characteristics, exploitation history, and autocorrelation in recruitment (Brodziak et al., 2008; Haltuch et al., 2008; Haltuch et al., 2009). Incorporation of errors in these reference points into an MSE is not a trivial task (see discussion in Deroba and Bence 2012), but should be a topic of future research.

Assessment errors in this MSE were induced by applying multiplicative error to the underlying true abundance, but incorporation of a full stock assessment model (e.g., statistical catch-at-age) into
MSEs can affect control rule performance (Cox and Kronlund 2008). Incorporation of the assessment models intended for use in making management recommendations should be the goal of this MSE. While some life-history parameters varied among operating models, they were all treated as time invariant within each operating model. Time varying life history parameters can affect control rule performance (Walters and Parma 1996; Deroba and Bence 2008; Hawkshaw and Walters 2015), however, and this should also be a topic of future research.

References


Figure 1.—Hi and lo natural mortality rates and stock-recruit relationships used in Atlantic herring MSE operating models. Hi natural mortality was always used with lo steepness in the operating models, and the opposite also held true.
Figure 2.—Fast and slow growth values used in Atlantic herring MSE operating models.
Figure 3.—Example relationships between fishing mortality or catch and biomass for each basic type of control rule evaluated.
Figure 4.—Tradeoff plot for median yield relative to MSY versus SSB relative to unfished SSB. BB is the annually applied biomass based control rule, BB3yr is the biomass based policy with 3 year blocks, BB5yr is the biomass based policy with 5 year blocks, BB3yrPerc is the biomass based three year block policy with a 15% restriction, CC is constant catch (filled dots in far right panel) and CCC is conditional constant catch (open circles in the far right panel). The red triangle is the performance of the status quo shape (see main text). The green dots simultaneously achieve 80% of MSY and 65% of unfished SSB.

Hi $M$, low steepness, fast growth, biased assessment

Hi $M$, low steepness, slow growth, biased assessment
Figure 4 (continued).—

Hi $M$, low steepness, fast growth, unbiased assessment

Hi $M$, low steepness, slow growth, unbiased assessment
Lo $M$, Hi steepness, fast growth, biased assessment

Lo $M$, Hi steepness, slow growth, biased assessment
Figure 4 (continued).—

Lo $M$, Hi steepness, fast growth, unbiased assessment

Lo $M$, Hi steepness, slow growth, unbiased assessment
Figure 5.—Tradeoff plot for median yield relative to MSY versus IAV (Variation in Yield) for the operating model with Hi M, low steepness, slow growth, and an unbiased assessment. All else is as in Figure 4.
Figure 6.—Tradeoff plot for median frequency with which tuna weight was greater than average (Prob Wt>Avg) versus SSB relative to unfished SSB for the operating model with Hi $M$, low steepness, and an unbiased assessment. All else is as in Figure 4.

Hi $M$, low steepness, fast growth, unbiased assessment

Hi $M$, low steepness, slow growth, unbiased assessment
Figure 7.—Tradeoff plot for median frequency with which tern production was $\geq 1$ (Prob Tern Produ$\geq 1$) versus SSB relative to unfished SSB for the operating model with Hi $M$, low steepness, slow growth, and an unbiased assessment. All else is as in Figure 4.
Figure 8.—Tradeoff plot for median frequency with which dogfish biomass was > 0.5B_{MSY} (Prob GF>0.5Bmsy) versus SSB relative to unfished SSB for the operating model with Hi M, low steepness, slow growth, and an unbiased assessment. All else is as in Figure 4.
Figure 9.—Four biomass based control rule shapes, the results for which will be presented in Figures 10-12.
Figure 10.—Tradeoff plots for yield relative to MSY versus SSB relative to unfished SSB, yield relative to MSY versus frequency herring become overfished, yield relative to MSY versus IAV (Variation in Yield), and frequency herring become overfished versus the frequency of fishery closure. The range of colors cover the extremes of the 25th and 75th percentiles for all operating models except those with biased stock assessments, and pertain to four biomass based control rule shapes applied with three year blocks. Triangles are the median of operating models with low $M$ and hi steepness, while circles are medians for operating models with hi $M$ and low steepness.
Figure 11.—Tradeoff plots for frequency with which tuna weight was greater than average, frequency with which tern production was $> 1$, and frequency with which dogfish biomass was $> 0.5B_{MSY}$ versus herring SSB relative to unfished SSB. All else is as in Figure 10.
Figure 12.—Tradeoff plots for yield relative to MSY versus SSB relative to unfished SSB and yield relative to MSY versus frequency herring become overfished. The solid colors cover the extremes of the 25th and 75th percentiles for operating models with unbiased assessments (i.e., as in Figure 10), while the hatched colored ranges are for operating models with biased assessments. All else is as in Figure 10.
Figure 13.—Tradeoff plots for yield relative to MSY versus SSB relative to unfished SSB, yield relative to MSY versus frequency herring become overfished, and yield relative to MSY versus IAV (Variation in Yield). Results are only for the status quo biomass based control shape and for operating models with unbiased assessments, and the colors are indicative of whether quotas were varied annually (red), using three year blocks (blue), or five year blocks (yellow). Colors are not indicative of different control rule shapes as they were in Figures 10-12. All else is as in Figure 10.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(y)</td>
<td>Year</td>
</tr>
<tr>
<td>(a)</td>
<td>Age</td>
</tr>
<tr>
<td>(N)</td>
<td>True abundance</td>
</tr>
<tr>
<td>(F)</td>
<td>Actual fishing mortality rate applied to the population</td>
</tr>
<tr>
<td>(M)</td>
<td>Natural mortality</td>
</tr>
<tr>
<td>(Z)</td>
<td>Total mortality</td>
</tr>
<tr>
<td>(R)</td>
<td>Recruitment</td>
</tr>
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<td>(h)</td>
<td>Steepness of the stock-recruitment relationship</td>
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<tr>
<td>(SSB)</td>
<td>Spawning stock biomass</td>
</tr>
<tr>
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<td>Process error for the stock-recruitment relationship</td>
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<td>(\sigma^2_{RR})</td>
<td>Variance of the stock-recruitment process errors</td>
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<td>Autocorrelation coefficient for stock-recruitment process errors</td>
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<td>Errors for (\varepsilon_R)</td>
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<tr>
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</tr>
<tr>
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<td>(\vartheta)</td>
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<td>(\widehat{B})</td>
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<tr>
<td>(SSB_{MSY})</td>
<td>Spawning stock biomass at maximum sustainable yield</td>
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<tr>
<td>(\bar{F})</td>
<td>Desired fishing mortality rate</td>
</tr>
<tr>
<td>(S)</td>
<td>Selectivity</td>
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<tr>
<td>(Q)</td>
<td>Desired quota</td>
</tr>
<tr>
<td>(\bar{F})</td>
<td>Fishing mortality rate that would produce the desired quota when applied to the true population</td>
</tr>
<tr>
<td>(\varepsilon_{\theta})</td>
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<td>(SSB_{up})</td>
<td>Upper biomass parameter of the biomass based control rule</td>
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<td>(SSB_{10%})</td>
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<tr>
<td>(IAV)</td>
<td>Interannual variation in yield</td>
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Table 2.—General properties of the eight Atlantic herring operating models.

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<th>Growth</th>
<th>Assessment bias</th>
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Table 3.—Unfished and *MSY* reference points for the Atlantic herring operating models.

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<th>Natural Mortality</th>
<th>Growth</th>
<th>Unfished SSB</th>
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<th>MSY</th>
<th>F\textsubscript{MSY}</th>
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<tr>
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<td>0.79</td>
<td>Low</td>
<td>Slow</td>
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<tr>
<td>0.79</td>
<td>Low</td>
<td>Fast</td>
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<td>405485</td>
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Introduction

This document explains the predator modeling component of the Herring Management Strategy Evaluation (MSE). Predator modeling balanced the New England Fishery Management Council (Council) scope and timeline specified for the Herring Amendment 8 ABC control rule analyses with the objectives identified for predators during the first stakeholder workshop. The Council required evaluation of an annual, stock-wide Atlantic herring harvest control rule that considered herring’s ecological role as forage, to be completed within less than one year. Stakeholders were interested in evaluating potential effects of herring harvest control rules on multiple predator types including highly migratory species (tuna), groundfish, seabirds, and marine mammals.

Herring’s ecological role as forage

The food web of the Northeast US continental shelf large marine ecosystem is characterized by many diverse predators and prey (Fig. 1). Atlantic herring is group 37 in the figure, sharing the role of forage with other groups such as sand lance (36), river herring (38), Atlantic mackerel (39), and butterfish (40) (Jason Link 2002).

Figure 1: US Northeast shelf food web from Link 2002
In the Northeast US, there is wealth of scientific information to characterize predator-prey relationships, including feeding ecology data for fish predators (e.g., B. E. Smith and Link 2010), seabirds (Hall, Kress, and Griffin 2000), bluefin tuna (Chase 2002; W. J. Golet et al. 2013; Logan, Golet, and Lutcavage 2015; W. Golet et al. 2015), and marine mammals (L. A. Smith et al. 2015). Consumption of herring by predators has been extensively studied in this ecosystem (W. J. Overholtz, Link, and Suslowicz 2000; W. J. Overholtz and Link 2007), and multiple methods were evaluated to include this consumption within the most recent herring benchmark stock assessment (NEFSC 2012). Much of this information was presented at the first stakeholder workshop in May 2016.

**Predator modeling objectives for the herring MSE**

We note that the general objective for the Council was to answer “how do changes in herring population abundance affect predator populations?” This is a different and more complex question than that addressed in the 2012 herring assessment “how much herring is consumed by predators?” Council specifications and time constraints and did not permit development of integrated multispecies models (existing models account for predation mortality on herring, but not “bottom up” herring impacts on predators), nor spatial or seasonal models accounting for migrations of wide-ranging predators into or out of the Northeast US shelf ecosystem. At the initial stakeholder workshop, it was agreed that separate “general predator” models linked to herring would be a reasonable approach, with the goal of developing one model for each of the four predator categories: highly migratory fish, groundfish, seabirds, and marine mammals.

Predators were therefore modeled with fairly simple delay-difference population dynamics that allowed different predator population processes to be dependent on some aspect of herring population status, following (Plagányi and Butterworth 2012). Each predator model takes output from the herring OM as input, and outputs performance metrics identified at the stakeholder workshop as in Fig. 2. While this allows “bottom up” effects of herring on predators to be examined, this configuration does not consider “top down” effects of predators on herring, or simultaneous interactions of multiple predators with herring.

![Herring MSE design](image)

Figure 2: Herring MSE information flow
Summary of herring MSE predator modeling objectives

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**Predator models ARE:**
* Focused on evaluating stock-wide herring ABC harvest control rules applied annually
* Developed balancing Council/stakeholder specifications and time constraints of MSE
* Based on information from the Northeast US shelf and most recent stock assessments

**Predator models ARE NOT:**
* Spatial, do not address local scale or seasonal dynamics
* New or full stock assessments
* Accounting for any impacts on predators other than changes due to herring control rules
* Intended to predict actual predator population dynamics

---

**Methods**

There are two components of predator modeling for the herring MSE: a predator population model, and a herring-predator relationship model to link herring with predator populations. Here, we give an overview of the modeling process, and we describe the decisions made in parameterizing individual predator models and herring-predator relationships in the following sections. The overall population in numbers for each predator each year $N_y$ is modeled with a delay-difference function:

\[ N_{y+1} = N_y S_y + R_{y+1}, \]  \hspace{1cm} (1)

where annual predator survival $S_y$ is based on annual natural mortality $v$ and exploitation $u$

\[ S_y = (1 - v_y)(1 - u), \]  \hspace{1cm} (2)

and annual recruitment $R_y$ (delayed until recruitment age $a$) is a Beverton-Holt function:

\[ R_{y+a} = \frac{\alpha B_y}{\beta + B_y}. \]  \hspace{1cm} (3)

Predator recruitment parameters are defined with steepness $= h$, unfished recruitment $R_{F=0}$, and unfished spawning biomass $B_{F=0}$ as

\[ \alpha = \frac{4hR_{F=0}}{5h - 1}, \text{ and} \]  \hspace{1cm} (4)

\[ \beta = \frac{(B_{F=0}/R_{F=0})(1 - h)/(4h)}{(5h - 1)/(4hR_{F=0})}. \]  \hspace{1cm} (5)

Predator population biomass is defined with Ford-Walford plot intercept ($FWint$) and slope ($FWslope$) growth parameters

\[ B_{y+1} = S_y(FWint N_y + FWslope B_y) + FWint R_{y+1}. \]  \hspace{1cm} (6)
Parameterizing this model requires specification of the stock-recruitment relationship (steepness h and un-
ished spawning stock size in numbers or biomass), the natural mortality rate, the fishing mortality (exploita-
tion) rate, the initial population size, and the weight at age of the predator (Ford-Walford plot intercept and
slope parameters). For each predator, population parameters were derived from different sources (Tab. 1).

Table 1. Predator population model specification and parameter sources

<table>
<thead>
<tr>
<th></th>
<th>Highly migratory</th>
<th>Seabird</th>
<th>Groundfish</th>
<th>Marine mammal</th>
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<tr>
<td>Stakeholder preferred species</td>
<td>Bluefin tuna</td>
<td>Common tern</td>
<td>not specified</td>
<td>not specified</td>
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<tr>
<td>Species modeled</td>
<td>Bluefin tuna</td>
<td>Common tern (Gulf of Maine colonies as defined by the GOM Seabird Working Group)</td>
<td>Spiny dogfish (GOM and GB cod stocks also examined)</td>
<td>none, data limited (Minke &amp; humpback whales, harbor porpoise, harbor seal examined)</td>
</tr>
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<td>Stock-recruitment</td>
<td>Current assessment and literature</td>
<td>Derived from observations</td>
<td>Current assessment and literature</td>
<td>No time series data for our region</td>
</tr>
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<td>Natural mortality</td>
<td>Current assessment</td>
<td>Literature</td>
<td>Current assessment</td>
<td>Derivable from assessment?</td>
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<tr>
<td>Fishing mortality</td>
<td>Current assessment</td>
<td>n/a</td>
<td>Current assessment</td>
<td>Derivable from assessment?</td>
</tr>
<tr>
<td>Initial population</td>
<td>Current assessment</td>
<td>Derived from observations</td>
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<td>Derivable from assessment?</td>
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<td>Weight at age</td>
<td>Literature</td>
<td>Literature</td>
<td>Literature</td>
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</tr>
</tbody>
</table>

Predator population models were based on either the most recent stock assessment for the predator or from
observational data from the Northeast US shelf. Herring-predator relationships were based on either peer-
reviewed literature or observational data specific to the Northeast US shelf. We did not include process
or observation error in any of these modeled relationships. This is obviously unrealistic, but the primary
objective of the herring MSE is to evaluate the effect of herring management on predators. Leaving out
variability driven by anything other than herring is intended to clarify the effect of herring management.

To develop the herring-predator relationship model, specific herring population characteristics (e.g. total
abundance or biomass, or abundance/biomass of certain ages or sizes) were related to either predator growth,
predator reproduction, or predator survival. Our aim was to use information specific to the Northeast US
shelf ecosystem, either from peer-reviewed literature, from observations, or a combination.

In general, if support for a relationship between herring and predator recruitment was evident, it was modeled
as a predator recruitment multiplier based on the herring population \( H_{pop_y} \) relative to a specified threshold \( H_{thresh} \):

\[
R_{y+a} = \frac{\alpha B_y}{\beta + B_y} \left( \frac{\gamma (H_{pop_y}/H_{thresh})}{(\gamma - 1) + (H_{pop_y}/H_{thresh})} \right),
\]

(7)

where \( \gamma > 1 \) links herring population size relative to the threshold level to predator recruitment.

If a relationship between predator growth and herring population size was evident, annual changes in growth
were modeled by modifying either the Ford-Walford intercept \( AnnAlpha_y \) or slope \( AnnRho_y \):

\[
B_{y+1} = S_y (AnnAlpha_y N_y + FWslope B_y) + AnnAlpha_y R_{y+1},\quad \text{or}
\]

(8)

\[
B_{y+1} = S_y (FWint N_y + AnnRho_y B_y) + FWint R_{y+1}.
\]

(9)
Finally, herring population size $H_{pop_y}$ could be related to predator survival using a multiplier on constant predator annual natural mortality $v$:

$$v_y = v e^{-(H_{pop_y}/H_{pop_F=0})\delta}$$

(10)

where $0 < \delta < 1$ links herring population size to predator survival.

After specifying the population model parameters and herring-predator relationship, we applied the (Hilborn and Walters 2003) equilibrium calculation for the delay difference model with $F=0$ to get the unfished spawners per recruit ratio. This ratio was then used in a new equilibrium calculation with the current predator exploitation rate to estimate Beverton-Holt stock recruitment parameters, equilibrium recruitment and equilibrium individual weight under exploitation. Then, each model was run forward for 150 years with output from the herring operating model specifying the herring population characteristics.

Highly migratory species

Bluefin tuna were identified at the stakeholder workshop as the recommended highly migratory herring predator.

Tuna population model

Western Atlantic bluefin tuna population parameters were drawn from the 2014 stock assessment (ICCAT 2015), the growth curve from (Restrepo et al. 2010), and recruitment parameters from a detailed examination of alternative stock recruit relationships (Porch and Lauretta 2016). Ultimately, the “low recruitment” scenario was selected to represent bluefin tuna productivity in the Gulf of Maine, which defines Bmsy as 13,226 t and therefore affects measures of status relative to Bmsy. Continuation of the current tuna fishing strategy (F<0.5Fmsy under the low recruitment scenario) is assumed. All predator population model parameters are listed in Table 2.

Herring-tuna relationship model

Tuna diets are variable depending on location and timing of foraging (Chase 2002; W. J. Golet et al. 2013; Logan, Golet, and Lutcavage 2015; W. Golet et al. 2015), but for the purposes of this analysis, we assumed that herring is an important enough prey of tuna to impact tuna growth in the Northeast US shelf ecosystem. A relationship between bluefin tuna growth and herring average weight was implemented based on information and methods in W. Golet et al. (2015). The relationship between tuna condition anomaly (defined as proportional departures from the weight-at-length relationship used in the assessment) and average weight of tuna-prey-sized herring ($H_{avgwt_y}$, herring >180 mm collected from commercial herring fisheries) was modeled as a generalized logistic function with lower and upper bounds on tuna growth parameters:

$$AnnAlpha_y = (0.9FWint) + \frac{(1.1FWint) - (0.9FWint)}{1 + e^{(1-\lambda)\times 100(H_{avgwt_y}-T)/T}}$$

(11)

where $\lambda > 1$ links herring average weight anomalies to tuna growth.

The inflection point of $T = 0.15$ kg average weight matches the 0 tuna weight anomaly in W. Golet et al. (2015) (p. 186, Fig 2C), and upper and lower bounds were determined by estimating the growth intercept with weight at age 10% higher or lower, respectively from the average weight at age obtained by applying the length to weight conversion reported in the 2014 stock assessment (ICCAT 2015) to the length at age estimated from the Restrepo et al. (2010) growth curve (Fig 3). When included in the model with $\lambda = 1.1$ in equation 11, the simulated variation in tuna weight at age covered the observed range reported in W. Golet et al. (2015).
Seabirds

Common terns were identified at the stakeholder workshop as the recommended seabird herring predator.

Tern population model

There is no published stock assessment or population model for most seabirds in the Northeast US. Therefore, Gulf of Maine Common and Arctic tern population parameters were drawn from accounts in the Birds of North America (Hatch 2002; Nisbet 2002) and estimated from counts of breeding pairs and estimates of fledgling success summarized by the Gulf of Maine Seabird Working Group (GOMSWG; data at http://gomswg.org/minutes.html), as corrected and updated by seabird experts from throughout Maine. While we analyzed both Arctic and Common tern information, the stakeholder workshop identified Common terns as the example species for modeling, and this species has more extensive data and a generally higher proportion of herring in its diet based on that data. Therefore, the model is based on common terns in the Gulf of Maine.

Adult breeding pairs by colony were combined with estimated productivity of fledglings per nest to estimate the annual number of fledglings for each year. A survival rate of 10% was applied to fledglings from each year to represent “recruits” to the breeding adult population age 4 and up (Nisbet 2002). This “stock-recruit” information was used to estimate steepness for the delay difference model based on common tern information only. Fitting parameters with R nls (R Core Team 2016) had variable success, with the full dataset unable to estimate a significant beta parameter (cyan line, Fig. 4) for common terns, and a truncated dataset resulting in low population production rates inconsistent with currently observed common tern trends (bright green line overlaid with black, Fig. 4). Therefore, steepness was estimated to give a relationship (black line, Fig. 4) falling between these two lines. The resulting stock recruit relationship set steepness at 0.26, a theoretical maximum breeding adult population of 45,000 pairs (Nisbet (2002), 1930’s New England population), and a theoretical maximum recruitment of 4,500 individuals annually (reflecting approximately a productivity of 1.0 at “carrying capacity” resulting in a stable population). Average common tern productivity is 1.02 (all GOM colony data combined). Adult mortality was assumed to be 0.1 for the delay difference model (survival of 90% (Nisbet 2002) for adults).

Figure 3: Modeled herring average weight-tuna growth relationship
The resulting model based on common tern population dynamics in the Gulf of Maine (with no link to herring) predicts that the population will increase to its carrying capacity under steady conditions over a 150 year simulation. The actual population has increased at ~2% per year between 1998 and 2015 (Fig. 5). Given the lack of detailed demographic information in the delay-difference model, this was considered a good representation of the average observed trend in current common tern population dynamics.
Figure 5: Population trends for Gulf of Maine terns, no herring link

Herring-tern relationship model

The relationship between herring abundance and tern reproductive success was built based on information from individual colonies on annual productivity, proportion of herring in the diet, and amount of herring in the population as estimated by the current stock assessment. Since little of this information has appeared in the peer-reviewed literature, we present it in detail here. First, productivity information was evaluated by major diet item recorded for chicks over all colonies and years. In general, common tern productivity was higher when a streamlined fish species was the major diet item relative to invertebrates, but having herring as the major diet item resulted in about the same distribution of productivities as having hake or sand lance as the major diet item for these colonies (Fig. 6).
Individual colonies showed different trends in number of nesting pairs, productivity, and proportion of herring in the diet (plots available upon request). When both Arctic and Common terns shared a colony, interannual changes in productivity were generally similar between species, suggesting that conditions at and around the colony (weather, predation pressure, and prey fields) strongly influenced productivity rather than species-specific traits. Only two colonies (Machias Seal Island near the Canadian Border and Stratton Island in southern Maine) showed a significant positive correlation between the proportion of herring in the chick diet and productivity. Other islands showed either non-significant (no) relationships, or in one case (Metinic Island) a significant negative relationship (Fig. 7).

Figure 6: Major diet items for Gulf of Maine tern fledgelings
The estimated population size of herring on the Northeast US shelf had some relationship to the amount of herring in tern diet at several colonies (4 of 13 common tern colony diets related to herring Age 1 recruitment, 6 of 13 common tern colony diets related to herring total B, and 4 of 13 common tern colony diets related to herring SSB; detailed statistics and plots available upon request). However, statistically significant direct relationships between herring population size and tern productivity were rare, with only Ship Island productivity increasing with herring total B, and Eastern Egg Rock, Matinicus Rock, Ship, and Monomoy Islands productivity increasing with herring SSB. Given that Monomoy Island tern chicks consistently received the lowest proportion of herring in their diets of any colony (0-11%), we don’t consider this relationship further to build the model.

Based on tern feeding observations, we would expect the number of age 1 herring in the population to be most related to tern productivity since that is the size class terns target, but this relationship was not found in analyzing the data. Herring total biomass was positively related to tern diets at nearly half of the colonies, and reflects all size classes including the smaller sizes most useful as tern forage, but was only directly related to tern productivity at one colony. Herring SSB was not considered further as an index of tern prey because it represents sizes larger than tern forage.

To represent the potential for herring to influence tern productivity, we parameterized a tern “recruitment multiplier” based on herring assessed total biomass and common tern productivity across all colonies (except Monomoy where terns eat sandlance). This relationship includes a threshold herring biomass where common tern productivity would drop below 1.0, and above that threshold productivity exceeds 1.0 (Fig. 8). The threshold of ~400,000 tons is set where a linear relationship between herring total biomass and common tern productivity crosses productivity=1 (black dashed line in Fig. 8). However, the selected threshold is uncertain because there are few observations of common tern productivity at low herring total biomass (1975-1985). The linear relationship does not have a statistically significant slope; a curve was fit to represent a level contribution of herring total biomass to common tern productivity above the threshold. The curve descends below the threshold, dropping below 0.5 productivity at around 50,000 tons and representing the extreme assumption that herring extinction would result in tern productivity of 0. Although the relationship
of tern productivity to herring biomass at extremely low herring populations has not been quantified, control rules that allow herring extinction do not meet stated management objectives for herring, so this extreme assumption for terns will not change any decisions to include or exclude control rules.

![Graph showing tern production and herring biomass relationship](image)

Figure 8: Modeled influence of herring total biomass on tern reproductive success

When included in the model using $\gamma = 1.09$ in equation 7, this relationship adjusts the modeled common tern population increase to match the current average increase in common tern nesting pairs observed in the data (Fig. 9). There is still considerable uncertainty around this mean population trajectory which cannot be reflected in our simple model.
Figure 9: Population trends for Gulf of Maine terns with simulated herring-common tern productivity relationship

Groundfish

Because no specific groundfish was identified as a representative herring predator during the stakeholder workshop, the first decision was which groundfish to model. Annual diet estimates (based on sample sizes of ~100+ stomachs) are available for the top three groundfish predators of herring (those with herring occurring in the diets most often in the entire NEFSC food habits database): spiny dogfish, Atlantic cod, and silver hake. Cod and spiny dogfish were considered first because their overall diet proportions of herring are higher, and because silver hake has the least recently updated assessment. Diet compositions by year were estimated for spiny dogfish, Georges Bank cod, and Gulf of Maine cod to match the scale of stock assessments. Full weighted diet compositions were estimated, and suggest considerable interannual variability in the herring proportion in groundfish diets (filled blue proportions of bars in Fig. 10).
Figure 10: Annual diet compositions for major groundfish predators of herring estimated from NEFSC food habits database

Some interannual variation in diet may be explained by changing herring abundance. Dogfish and both cod stocks had positive relationships between the amount of herring observed in annual diets and the size of the herring population according to the most recent assessment (statistics and plots available upon request). This suggests that these groundfish predators are opportunistic, eating herring in proportion to their availability in the ecosystem. However, monotonically declining cod populations for both GOM and GB cod stocks resulted in either no herring-cod relationship, or a negative relationship between herring populations and cod populations (Fig. 11). Only dogfish spawning stock biomass had a positive relationship with the proportion of herring in dogfish diet. Therefore, we selected dogfish as the groundfish predator for modeling.
Figure 11: Relationship of assessed groundfish spawning stock biomass (SSB) with the proportion of herring in diet.

Dogfish population model

The dogfish model stock recruitment function, initial population, and annual natural mortality were adapted from information in (P. J. Rago et al. 1998; P. J. Rago and Sosebee 2010; Bubley et al. 2012; P. Rago and Sosebee 2013). Due to differential growth and fishing mortality by sex, our model best represents female dogfish (a split-sex delay difference model was not feasible within the time constraints of this MSE). Further, dogfish stock-recruit modeling to date based on Ricker functions (P. J. Rago and Sosebee 2010) captures more nuances in productivity than the Beverton-Holt model we used. Our recruitment parameterization reflects a stock with generally low productivity and relatively high resilience, which we recognize is a rough approximation for a species such as dogfish. The annual fishing exploitation rate applied is average of the catch/adult female biomass from the most recent years of the 2016 data update provided to the Mid-Atlantic Fishery Management Council (Rago pers comm).

Herring-dogfish relationship model

There was a weak positive relationship between dogfish total biomass and herring total biomass from the respective stock assessments (Fig. 12), but no clear relationship between dogfish weight or dogfish recruitment and herring population size. During the recent period of relatively low dogfish recruitment (1995-2007), there is a positive relationship between dogfish pup average weight and herring proportion in diet, suggesting a potential growth and or recruitment mechanism; however this relationship does not hold throughout the time series (Fig. 12).
Figure 12: Dogfish population relationships with herring total biomass (left) and herring proportion in diet (right).

Therefore, to simulate a potential positive relationship between herring and dogfish, we assumed that dogfish survival increased (natural mortality was reduced) by an unspecified mechanism as herring abundance increased (Fig. 13). Because dogfish are fully exploited by fisheries in this model, the impact of this change in natural mortality on total survival has small to moderate benefits to dogfish population numbers and biomass. Using a $\delta = 0.2$ in equation 10 results in weak increases in dogfish biomass with herring abundance consistent with observations.

Figure 13: Modeled herring relative population size-dogfish natural mortality relationship

Marine mammals

Because no specific marine mammal was identified as a representative herring predator in the stakeholder workshop, as with groundfish, the first decision was which marine mammal to model. Diet information for a wide range of marine mammals on the Northeast US shelf suggests that minke whales, humpback whales, harbor seals, and harbor porpoises have the highest proportions of herring in their diets (L. A. Smith et al. 2015), and therefore may show some reaction to changes in the herring ABC control rule.
While some food habits data existed for marine mammals, consultation with marine mammal stock assessment scientists at the Northeast Fisheries Science Center confirmed that no data were available to parameterize a stock-recruitment relationship for any of these marine mammal species in the Northeast US region, and no such information was available in the literature for stocks in this region. Although it may be possible to develop stock-recruitment models for one or more of these species in the future, it was not possible within the time frame of the herring MSE. Therefore, we were unable to model marine mammals within the same framework as other predators.

Potential effects of changes in herring production and/or biomass on marine mammals were instead evaluated using an updated version of an existing food web model for the Gulf of Maine (Jason Link et al. 2008; Jason Link et al. 2009; J.S. Link et al. 2006) and incorporating food web model parameter uncertainty. Overall, food web modeling showed that a simulated increase in herring production in the Gulf of Maine may produce modest but uncertain benefits to marine mammal predators, primarily because increased herring was associated with decreases in other forage groups also preyed on by marine mammals. Please see Appendix 1 of this document for full analyses and results.

Summary of predator model input parameters

Table 2. Predator model input parameters

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<th>Parameter</th>
<th>Tuna</th>
<th>Tern</th>
<th>Dogfish</th>
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<tr>
<td>Numbers or Weight?</td>
<td>Weight</td>
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<td>Weight</td>
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<tr>
<td>Unfished spawning pop</td>
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<tr>
<td>Prey-growth link</td>
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<td>1 (off)</td>
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</tr>
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</table>

Output metrics

Predator performance metrics included those described at the stakeholder workshop, as well as several others drawn from MSE best practices (Punt et al. 2016). The herring MSE included 8 herring operating models (described fully in Deroba’s Technical Details document); for each operating model 5,460 control rules were tested. For each control rule, 100 replicate simulations reflecting stochastic herring recruitment variability were run for 150 years each. Each of these simulated time series was passed to each predator model, resulting in outputs as described below using the equations above.

All predator performance metrics were calculated based on the final 50 years of each replicate simulation. For all metrics other than “frequency of good status” metrics, we took the median value over the final 50 years of each replicate simulation. Then, the 25th percentile, the median, and the 75th percentile of these 100 medians were calculated to represent the performance metric for a particular control rule. Results reported here focus on the median.
Biomass, Abundance, Recruitment

Population abundance and recruitment in numbers were output for all modeled predators. Population biomass was output for tuna and dogfish. These quantities were directly output by the models.

Predator condition

Stakeholders expressed interest in predator condition for fish and marine mammal predators at the first workshop. While delay difference models do not track individuals or age cohorts, a measure of population average weight (population biomass/population numbers) was output for tuna and dogfish.

Predator productivity

Productivity, the number of fledglings per breeding pair, was output for the tern model. Productivity was calculated as recruitment times 10 (to account for the 10% survival rate of fledglings to adults) divided by tern abundance 4 years earlier in the simulation.

Status relative to thresholds

Stakeholders were interested in different measures of population status depending on the predator. For commercially fished species, status relative to current management reference points was preferred. Tuna and dogfish biomass was divided by a biomass reference point specified in current stock assessments: tuna \( SSB_{MSY} \) was 13226 (ICCAT 2015), and dogfish \( SSB_{MSY} \) was 159288 (P. J. Rago and Sosebee 2010). Because dogfish were fully exploited in our model, they did not reach \( SSB_{MSY} \), so we also evaluated status relative to 0.5 \( SSB_{MSY} \) ("overfished"). Tuna condition status was assessed by dividing the output population average weight with the equilibrium average weight. Common tern colonies are managed to improve productivity, so stakeholders suggested that a common tern productivity level of 0.8 would be a minimum threshold, while a productivity of 1.0 would be a target. In addition, total population status was measured relative to current population numbers using the rationale that maintaining at least the current population was desirable. The average common tern population of nesting pairs (including Monomoy) from 1998-2015 was 16000.

Frequency of good status

Evaluating the frequency of desirable or undesirable states over the course of a simulation is suggested by Punt et al. (2016). We calculated two metrics for each of the status determinations. First, we calculated the minimum number of years in any individual simulation that a metric was above a given threshold. This is a “worst case scenario” metric. Second, we calculated the median proportion of years across all simulations for a control rule that were above the threshold. This is an “average performance” metric addressing how often good status is maintained.

Results

Predator metrics had different levels of sensitivity to herring population changes resulting from different ABC control rules combined with the uncertainties represented in each herring operating model. Here we summarize all predator metric results across all herring operating models and control rules to demonstrate the rationale for keeping only the most sensitive predator metrics in the full MSE results.
**Tuna general results**

Simulated tuna biomass, numbers, and recruitment were similar across all herring operating models and control rules. Biomass was the only metric that changed with different herring control rules due to changes in average weight. There was some variation in biomass status, but the median was always above the threshold. Tuna average weight was both above and below the equilibrium weight threshold across all models. Metrics for frequency of good status also reflected the sensitivity of tuna average weight (Fig. 14).

**Figure 14:** Summary of tuna performance metrics across all herring operating models and control rules

A comparison of the most sensitive tuna metric, average weight status, across herring operating models demonstrates that operating model configuration drives tuna average weight. Separating operating models with historical herring weight at age (OldWt) from those with recent weight at age (RecWt) demonstrates the primary contrast in tuna results. After this difference in operating models is accounted for, there is far less contrast in the median performance of different control rules for tuna (Fig. 15).
Figure 15: Tuna average weight status by herring operating model group and control rule type

**Tern general results**

Simulated tern population metrics were more variable across all operating models and control rules than tuna metrics. However, the median values for these metrics generally indicated relatively high population levels (above current levels), with good recruitment and productivity at or over 1 for most control rules. Summary plots show fairly long tails of median values well below good status for the metrics for some control rules (Fig. 16).
Examining tern productivity results by operating model shows little contrast across operating model uncertainties, but differences in performance between control rule types. The biomass-based control rule implemented for 3 years with a constraint of 15% change between specifications (BB3yrPerc) showed a wide range of variability in performance across control rule variants, as did the constant catch (CC) control rules (Fig. 17). For terns, herring weight at age had little effect on results, so those operating models are combined here.
Figure 17: Tern productivity by herring operating model group and control rule type

Dogfish general results

Simulated dogfish population metrics showed less variation across all herring operating models and control rules combined relative to tuna and terns. Median biomass status never reaches 1 (above Bmsy) but never drops below 0.5 (overfished status; Fig. 18).
Cases of poor status observed for dogfish were limited to two control rule types within the herring operating models specified with high natural mortality and low stock-recruit steepness (HiM) representing a poor herring productivity state. The control rule types performing poorly for dogfish under poor herring productivity were the same performing poorly for tern productivity: the biomass-based control rule implemented for 3 years with a constraint of 15% change between specifications (BB3yrPerc) and the constant catch (CC) control rules (Fig. 19). Also similar to terns, herring average weight did not affect these results, so those operating models are combined here.
Figure 19: Dogfish proportion of years not overfished across all herring operating models and control rules

Discussion

This document has explained the predator models used in the herring MSE. These models simulate different predator relationships with Atlantic herring in the Northeast US, and suggest different effects of herring control rules based on these relationships. As has been found in other MSE analyses (Punt et al. 2016), the results may be more useful for eliminating poor control rule options than for optimizing herring control rules to improve predator metrics. There are several reasons for this. First, this is a complex question. Predator populations are affected by many factors, while we attempted to isolate factors associated with prey. Further, in the Northeast US, predators have many prey options, while we attempted to evaluate relationships with just one prey, herring. Finally, time limitation enforced model simplicity for these complex relationships. Our approach was to use the best-supported relationship for each predator based on observations from the Northeast US ecosystem. We discuss the pros and cons of this approach for each predator below.

Western Atlantic bluefin tuna migrate widely and forage throughout North Atlantic; their population footprint is much larger than that of Northeast US Atlantic herring. However, tuna feed seasonally in the Gulf of Maine, exploiting high energy concentrated prey to maximize growth (W. J. Golet et al. 2013). Because tuna growth is key in the Northeast US, and because there is a well-supported relationship between herring weight and tuna growth here (W. Golet et al. 2015), we used this relationship. Other relationships were also investigated. Available data do not support implementing a positive relationship between herring and tuna populations in our models for this MSE; according to assessments, Northeast US shelf herring have increased during a period of bluefin tuna decline (NEFSC 2012; ICCAT 2015). Stakeholder observations and fine-scale analyses (e.g., W. J. Golet et al. 2013) suggest that bluefin tuna follow herring in the Gulf of Maine and likely aggregate around herring while feeding. However, our models designed to address ABC control rules
at the Northeast US shelf scale do not address herring/tuna interactions in a specific place or time, and we can draw no conclusions from our modeling about predator/prey co-occurrence or availability at smaller, local scales. Similarly, without additional observations, we cannot extrapolate local scale co-occurrence to population level relationships.

Common terns, in contrast, are central-placed foragers seasonally near their island breeding colonies in the Gulf of Maine. Their foraging footprint during chick production season is much smaller than the scale of the Northeast US Atlantic herring population. However, because tern productivity is a key management objective for tern colonies in the Gulf of Maine, and with substantial data to explore a relationship between herring and tern reproductive success, we worked to develop this relationship. However, many factors other than herring abundance affect tern production. According to Gulf of Maine Seabird Working Group minutes, predation by mammals, gulls, and other birds is a major factor that most colony management aims to control. Further, timing of weather events and timing of prey availability is important but difficult to quantify from current data. Similarly, the relatively small scale spatial and depth distribution of prey affects tern foraging success as well as the overall abundance of prey. At one colony during the same year, the proportion of herring in tern chick diets was much lower than the proportion of herring in razorbill diets at the same colony; razorbills are capable of deeper dives than terns (GOMSWG minutes). Spatial variability of predation, weather, and prey distribution may drive the high variation in observed herring population-tern productivity relationship among colonies. This high variance in the observations is not considered by the modeled herring-tern relationship. Further, the tern model is optimistic about population trajectory because it considers only herring total biomass impacts on terns, and does not model predation, habitat quantity and quality, etc.

Spiny dogfish may have the best spatial footprint match with Atlantic herring in the Northeast US of the three predators modeled. Dogfish forage through same range as herring for most of the year. Considerable information on dogfish diet has been collected over time in the region, and there are adequate data to conduct a stock assessment. However, the dogfish relationship assumes herring abundance improves dogfish survival because no clear relationship was found with recruitment or growth. Increased survival may not be the mechanism for the observed positive influence of herring in diet on the dogfish population.

Conclusions

Our models are designed for evaluating alternative herring control rules, not predator stock assessment and population prediction. We caution against generalizing results for these particular predators to other predators, as population parameters and herring relationships differ.

Overall lessons from this process can inform future work. First, isolating a clear herring-predator relationship from observations is difficult or impossible when other factors dominate predator dynamics (e.g. cod). Second, even with good observations, the modeled herring-predator relationship may require strong assumptions and not be statistically significant due to the many other factors affecting predators (e.g. terns). Third, apparent positive herring-predator relationships may not arise from the modeled mechanism (e.g. dogfish). Finally, a clear herring predator relationship is not satisfactory when it does not answer the question of interest to stakeholders (e.g. tuna).

Although we selected predators with high herring diet proportions, observed predator population responses to herring alone do not dominate dynamics, and our herring-predator relationship models reflect that. Predator responses to aggregate prey dynamics are likely to be much clearer than responses to individual prey in the Northeast US ecosystem given its food web structure. While modeling this is a more complex and time-consuming undertaking, the results may give clearer advice for managers making decisions regarding multiple simultaneously exploited prey and predators within the ecosystem.
References


Nisbet, Ian C. T. 2002. “Common Tern (Sterna Hirundo).” Edited by A. Poole and F. Gill. The Birds of


1 Introduction

This document explains the economic component of the Herring Management Strategy Evaluation. This was developed during the spring and summer of 2016; the goal of this component is to allow some aspects of economic performance to be included in the MSE. The economic analysis focuses on two revenue metrics and stability of those metrics. Taking cues from the herring dynamics section of the MSE, we report these metrics over the final terminal 50 years of the simulation.

2 Background

On an annual basis, the quantity supplied in the herring market is likely to be driven by the TAC, ACL, or sub-ACLs. Sub-ACLs for herring usually limit catch. They are occasionally not constraining; however seems to occur for regulatory reasons (such as a closure for catch of haddock in the Georges Bank fishery instead of for market reasons.

The fishery is managed spatially, with sub-ACLs for four Herring Management Areas. Herring is caught by purse seine, midwater- and paired-midwater trawls, and small mesh bottom trawls. Purse seine vessels typically fish in the Gulf of Maine (HMA 1A), particularly during the summer. Small-mesh bottom trawl vessels typically fish southern New England and the Mid-Atlantic (HMA 2). Midwater trawl gear fishes in areas 1B, 2, and 3 and is excluded from Area 1A during the summer months. Recently, the purse seine fishery has caught 30% of total landings while the midwater- and bottom-trawl fisheries have caught the remainder.

Herring is often (but no exclusively) used for bait; typically for the lobster fishery. In 2014, approximately 75% of landed herring was utilized as bait. Other uses include animal food and human consumption. From 2010-2015, annual prices were fairly fairly constant (dashed line in figure 1). Prices often spike during the winter months when landings are very low. 2016 is a bit different: large portions of Area 3 were closed due to haddock bycatch until April 30, 2016.

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3 Methods

In brief, the economic component of the model converts Yield from the biological component into Gross and Net Operating Revenues. Gross Revenues are simply yield multiplied by price. Net operating Revenues subtract out the variable operating costs. We summarize Gross and Net Revenue metrics by reporting the median of terminal 50-year medians. Variability is captured by using interannual variability over the final 50 years (Amar, Punt, and Dorn 2009; Deroba 2014) and reporting the frequency with which Net Revenue metric satisfies the statistical property of stationarity (Dickey and Fuller 1979).

Real prices, when used, have been normalized to 2015 real dollars using the Bureau of Labor Statistics (BLS) Producer Price Index (PPI) for “Unprocessed and Packaged Fish” (WPU0223).

The economic component of the model is simple and does not capture aspects of reality that are (likely to be) important, including:

- Herring landings being different from Yield,
- Fixed and quasi-fixed costs,
- Entry- or Exit of participants,
- Effects on fishing communities (both herring and other) or the regional economy,
- The direct and indirect benefits and costs of changes in herring biomass, including
  - economic impacts of changes in predator, biomass on users of those predators, and
  - economic impacts of changes in the location of herring biomass.

We will discuss these caveats and limitations later in the document.

Available at https://fred.stlouisfed.org/series/WPU0223
3.1 Changes since the second workshop

- We have used real instead of nominal prices for menhaden and herring.
- We have slightly different estimates of cost-per-day based on updated data.
- We have assumed an elasticity of price with respect to quantity supplied of -0.5, instead of -1.

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<tr>
<td>Trawl ($ per day)</td>
<td>2,600</td>
<td>3,000</td>
</tr>
<tr>
<td>elasticity of price</td>
<td>-1</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

Table 1: Summary of different parameters

3.2 Prices and Gross Revenues

We assume that the elasticity of price with respect to quantities is -0.5.

\[
\frac{\partial p}{\partial q} = -0.5 \tag{1}
\]

Following [Lehuta, Holland, and Pershing (2013)], we assume that an unlimited quantity of menhaden is available as a perfect substitute at real price of $375 per metric ton. Menhaden is likely to be a good substitute in the bait market, but a poor substitute in the human consumption market. $360 per mt is equal to the average real price over the most recent 5 years ($242 per metric ton) plus a transportation markup of $133 per metric ton. This puts an upper bound on the ex-vessel price of herring when quantities are low. At the second MSE workshop, we presented results based on an elasticity of −1. This was not a particularly good choice.

Given an initial value for the price of herring and the quantity of herring, this allows us trace out a demand curve for herring. We average over the same time period to produce a nominal starting price of $305 per metric ton at 87,117 mt of landings.

We assume that \( Yield_y \) in year \( y \) is equivalent to quantity supplied in year \( y \) (\( q_y \)). Therefore, Gross revenues are simply:

\[
GR_y = p(q_y)q_y \tag{2}
\]

3.3 Costs and Net Operating Revenues

We construct costs separately for the purse seine and trawl fleets.

We assume that the purse seine fleet will continue to land 30% of landings and the trawl fishery could land the remainder. We use observer data from 2010-2014 to construct catch-per-day (\( CPU_E_p \) and \( CPU_E_t \) for the purse seine and trawl fleet respectively). For each fleet, landings are divided by CPUE day to compute days

\(^4\)Preliminary data from 2016 (which was not available when this work was started) suggests that a backstop price of $375 per mt may not be appropriate (See Figure).
fished. These are multiplied by costs-per-day \((\text{cost}_p \text{ and } \text{cost}_t \text{ respectively})\) to compute variable operating cost. Net Operating revenues are computed by subtracting the variable operating costs from Gross revenues:

\[ NR_y = p(q_y)q_y - 0.3q_y\text{CPUE}_p\text{cost}_p - 0.7q_y\text{CPUE}_t\text{cost}_t \]  

(3)

Figure 2: Assumed demand curve for herring

The two fleets have surprisingly similar catch-per-day metrics, although the trawl fleet takes much longer trips than the purse seinе fleet and therefore has higher catch-per-trip. We present catch-per-trip in table 2 and 3 because it may be interesting to the reader although they are not used directly in the simulation.

<table>
<thead>
<tr>
<th>Year</th>
<th>Observed catch (mt)</th>
<th>trips</th>
<th>days</th>
<th>catch per trip</th>
<th>CPUE (mt/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>8,565</td>
<td>242</td>
<td>283</td>
<td>141</td>
<td>49</td>
</tr>
<tr>
<td>2011</td>
<td>17,278</td>
<td>276</td>
<td>338</td>
<td>158</td>
<td>63</td>
</tr>
<tr>
<td>2012</td>
<td>19,514</td>
<td>290</td>
<td>342</td>
<td>143</td>
<td>62</td>
</tr>
<tr>
<td>2013</td>
<td>23,218</td>
<td>318</td>
<td>355</td>
<td>124</td>
<td>54</td>
</tr>
<tr>
<td>2014</td>
<td>27,103</td>
<td>318</td>
<td>355</td>
<td>133</td>
<td>64</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td>66</td>
<td>57</td>
</tr>
</tbody>
</table>

Table 2: Observed herring catch, trips, days, and CPUE metrics for the Purse Seine fishery (2010-2014).

Costs were also extracted from the observer data. These included fuel, damage, supply, water, and oil costs. “Supply” (boots, knives, gear, etc), food, and bait costs were not included in construction of trip costs. Crew pay was also not included. Like many fisheries, fuel expenses are a large portion of total expenses. Fuel prices have changed a bit during the 2010-2015 time period. Average prices were approximately $3 per gallon in 2010 and 2015 and $4 per gallon in 2011-2014. Rather than averaging costs over these time periods with very different fuel prices, we used the 2015 cost figures; sensitivity of of net revenue metrics under the alternative assumption of $4 fuel is possible\(^5\).

\(^5\)For both fleets, daily costs in 2011-2014 are 30-50% higher than in 2015, which roughly corresponds to the fuel price difference over these time periods.
<table>
<thead>
<tr>
<th>Year</th>
<th>Observed catch (mt)</th>
<th>trips</th>
<th>days</th>
<th>catch per trip</th>
<th>CPUE (mt/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>54,189</td>
<td>385</td>
<td>1,107</td>
<td>141</td>
<td>49</td>
</tr>
<tr>
<td>2011</td>
<td>59,932</td>
<td>380</td>
<td>956</td>
<td>158</td>
<td>63</td>
</tr>
<tr>
<td>2012</td>
<td>63,122</td>
<td>442</td>
<td>1,016</td>
<td>143</td>
<td>62</td>
</tr>
<tr>
<td>2013</td>
<td>62,458</td>
<td>504</td>
<td>1,148</td>
<td>124</td>
<td>54</td>
</tr>
<tr>
<td>2014</td>
<td>60,187</td>
<td>454</td>
<td>938</td>
<td>133</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>139</td>
<td>58</td>
</tr>
</tbody>
</table>

Table 3: Observed herring catch, trips, days, and CPUE metrics for the trawl fishery (2010-2014).

### East Coast No 2 Diesel Retail Prices, Monthly

<table>
<thead>
<tr>
<th>Year</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>3.08</td>
</tr>
<tr>
<td>2011</td>
<td>3.98</td>
</tr>
<tr>
<td>2012</td>
<td>4.13</td>
</tr>
<tr>
<td>2013</td>
<td>4.08</td>
</tr>
<tr>
<td>2014</td>
<td>4.01</td>
</tr>
<tr>
<td>2015</td>
<td>2.89</td>
</tr>
</tbody>
</table>

(b) Annual Average New England Number 2 Diesel Retail

![Fuel prices from EIA](image)

Figure 3: Fuel prices from EIA.

<table>
<thead>
<tr>
<th>year</th>
<th>trips</th>
<th>days</th>
<th>cost per day</th>
<th>cost per trip</th>
<th>days per trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>79</td>
<td>74</td>
<td>1,667</td>
<td>1,562</td>
<td>0.9</td>
</tr>
<tr>
<td>2012</td>
<td>40</td>
<td>45</td>
<td>1,290</td>
<td>1,454</td>
<td>1.1</td>
</tr>
<tr>
<td>2013</td>
<td>50</td>
<td>40</td>
<td>1,279</td>
<td>1,035</td>
<td>0.8</td>
</tr>
<tr>
<td>2014</td>
<td>24</td>
<td>27</td>
<td>1,330</td>
<td>1,510</td>
<td>1.1</td>
</tr>
<tr>
<td>2015</td>
<td>14</td>
<td>15</td>
<td>811</td>
<td>864</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Table 4: Observed costs for the purse seine fishery (2011-2015). In the simulation models, the cost of a purse seine day is assumed to be $810

<table>
<thead>
<tr>
<th>year</th>
<th>trips</th>
<th>days</th>
<th>cost per day</th>
<th>cost per trip</th>
<th>days per trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>149</td>
<td>387</td>
<td>4,519</td>
<td>11,728</td>
<td>2.6</td>
</tr>
<tr>
<td>2012</td>
<td>179</td>
<td>533</td>
<td>4,607</td>
<td>13,711</td>
<td>3.0</td>
</tr>
<tr>
<td>2013</td>
<td>103</td>
<td>365</td>
<td>3,955</td>
<td>14,032</td>
<td>3.5</td>
</tr>
<tr>
<td>2014</td>
<td>122</td>
<td>298</td>
<td>4,181</td>
<td>10,218</td>
<td>2.4</td>
</tr>
<tr>
<td>2015</td>
<td>19</td>
<td>48</td>
<td>3,001</td>
<td>7,633</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 5: Observed costs for the Trawl fishery (2011-2015). In the simulation models, the cost of a trawl day was assumed to be $3,000.
3.4 Stability

Stakeholders were interested in understanding “stability” of the herring industry. Following the herring dynamics section, we computed Interannual Variation (IAV) of Net Revenues and report the median (across replicates) of median (across the final 50 years) of IAV. IAV is a summary metric of variability in the time series over a time period, but does not provide insight into stationarity of the time series. We assess stationarity using a Dickey-Fuller, one of many econometric tests of stationarity.

3.4.1 Interannual Variability

Here is the equation for interannual variability over the final 50 years [Amar, Punt, and Dorn 2009; Deroba 2014]:

\[
IAV = \sqrt{\frac{1}{50} \sum_{y}^{50} (NR_{y+1} - NR_{y})^2} \quad \text{(4)}
\]

3.4.2 Stationarity

We assessed stability over the final 50 years using an econometric test for stationarity of Net Revenues [Dickey and Fuller 1979]. In this application, a finding of stationarity implies that the system is in a stable equilibrium. Alternatively, this implies that Net Revenues has a measure of central tendency that does not depend explicitly on time. Yet in another alternative interpretation, it means that shocks or perturbations are not persistent: a “good” year (defined as a year above average) is equally likely to be followed by a “good” or “bad” year.

In contrast, a finding of non-stationarity (or a unit-root process) implies that the system is not in a stable equilibrium. The Net Revenue metric has a measure of central tendency that does depend explicitly on time. Alternatively, it can be interpreted as a system in which shocks or perturbations are not persistent: a “good” year more likely to be followed by a good year than a bad year. Similarly, a “bad” year is likely to be followed by another bad year.

\[
NR_{y} = a + \rho NR_{y-1} + \delta y + u_{y} \quad \text{(5)}
\]

We are primarily interested in testing for a unit-root or non-stationarity. Econometric evidence that \( \rho = 1 \) is evidence of a unit root while statistical rejections of \( H_0 : \rho = 1 \) is evidence of stationarity of the time-series.

Equation 5 is difficult to estimate using Ordinary Least Squares because \( u_t \) is often serially correlated (\( E[u_y u_{y-1}] \neq 0 \)), which invalidates inference about \( \rho \). Instead, equation 5 is typically transformed by differencing. Letting \( \Delta \) be the first difference operator (\( \Delta NR_y = NR_y - NR_{y-1} \)), the general form of the augmented dickey fuller regression is:

\[
\Delta NR_{y} = a_0 + \beta NR_{y-1} + \delta y + \sum_{j=1}^{k} \xi_j \Delta NR_{y-j} + \varepsilon \quad \text{(6)}
\]

In this formulation, econometric evidence that \( \beta = 0 \) is evidence of a unit root while statistical rejections of \( H_0 : \beta = 0 \) is evidence of stationarity of the time-series. In an homage to Sala-i Martin (1997), we estimate equation 6 for the final 50 years for each simulation. We estimate a version of equation 6 in which \( a \) and
\[ \xi_j \quad \forall j \geq 4 \text{ are restricted to zero} \]

\[ \Delta NR_y = \beta NR_{y-1} + \delta y + \sum_{j=1}^{3} \xi_j \Delta NR_{y-j} + \varepsilon \]  

(7)

We classify a simulation as stationary if we reject the null hypothesis \( H_0 : \beta = 0 \) at the 10% significance level. We then compute the number of simulation (out of 100) that are stationary for each of the 8 operating models and 5,460 control rules.

### 3.4.3 Stationarity in Graphical Form

During the second workshop, we presented some illustrative graphics about stationary and non-stationary Net Revenues.

![Stationary, Low IAV](image1)

![Non-Stationary, Low IAV](image2)

![Stationary, High IAV](image3)

![Non-Stationary, High IAV](image4)

Figure 4: Stationarity is independent of IAV

---

6 This is implemented in Stata using `dfuller NR, trend lags(3)`.
4 Methods we tried that didn’t quite work out

We attempted to construct a rigorous model of prices for herring. It didn’t quite work. This section provides a short overview of those methods. We focused on four species: herring, mackerel, menhaden, and lobster. Mackerel may be jointly produced with herring. Menhaden is a likely substitute for herring in the bait market. The lobster industry is a major consumer of herring (as bait). While other market interactions (for example: squid, redfish racks, and “livestock byproducts”) are likely, we focused on a small number to start.

Here are a few summary scatterplots based on annual data.

The relationship between landings and herring prices, particularly real prices, looks like a downward sloping demand curve. The relationship looks stronger for real prices compared to nominal prices. However, all of the high prices and low quantities are recent (2008-2015) while the lower prices and higher quantities are mostly old (1996-2006). This raises the possibility that either (a) structural changes in the underlying market have occurred or (b) something else that is correlated with time is an important determinant of herring prices.
We constructed monthly landings and prices of herring, mackerel, menhaden, and lobster from NMFS’s commercial fisheries database system (1996-2015 calendar years) aggregated at the state level. Herring data was supplemented with the “cleaned” state of Maine database provided by Maine DMR. Menhaden landed in Virginia was treated separately from menhaden landed in other states. Prices were normalized using the Bureau of Labor Statistics (BLS) Producer Price Index (PPI) for “Unprocessed and Packaged Fish” (WPU0223). For this particular exercise, the base year was set to 2014 because the 2015 PPI data were not finalized.

We estimated a bunch of panel (cross-section, time-series) models that attempted to explain the prices of herring as a function of substitute prices or quantities. We also tried to estimate time-series models on data aggregated at the region. We were unable to estimate a model that meets basic goodness-of-fit criteria. Then we ran out of time and just assumed that the elasticity (at the annual level) was -0.5.

5 Problems with these methods

5.1 Prices

This treatment of prices is not particularly good. It can (charitably) be seen as a sensitivity analysis benchmarked against a “constant price” that can be deduced by comparing Gross revenues with Yield.

5.2 Costs

We did not include fixed costs. If firms do not enter or exit, then the exclusion of fixed costs from the model has minimal qualitative effects: the Net Revenue outcomes for all control rules and operating models would shift down by the same amount and the relative rankings would be the same. The stationarity metric would be unaffected; this shift would be differenced out in equation (7). IAV constructed without fixed costs will be smaller than IAV constructed with fixed costs:

\[
IAV = \sqrt{\frac{1}{50} \sum_{y}^{50} ((NR_{y+1} - F) - (NR_{y} - F))^2} \\
\frac{1}{50} \sum_{y}^{50} (NR_{y} - F) 
\]

\[
= \sqrt{\frac{1}{50} \sum_{y}^{50} (NR_{y+1} - NR_{y})^2} - F + \frac{1}{50} \sum_{y}^{50} NR_{y} 
\]

Because the denominator of (8) is smaller when fixed costs are accounted for, we can deduce that IAV computed when properly accounting for fixed costs is larger than IAV as computed in this simulation.

If firms can enter and exit, then exclusion of fixed costs from the model could result in misleading recommendations. We did not model firm entry and exit; this is a difficult decision to model. Firms should may exit if they anticipate negative profits over a particular planning horizon. The number of active vessels in the herring fishery has declined a bit over, which could provide some data necessary to estimate a model of exit. Properly doing this would probably require accounting for payments to crew (which can readily be done).
Alternatively, we could follow the assumptions of Lehuta, Holland, and Pershing (2013) and include a zero-economic profit condition at the annual level.

5.3 Stability
A drawback of the stationary metric is that the “system” can be stable at zero net revenue. This would not be good.

6 Caveats, Extensions, and Future Research
Yet another assumption of this model is that herring landings are equal to yield. This is not really likely for many reasons. In particular, if we believe the demand curve described in figure 2, then firms are likely to find landing large amounts of herring at low prices to be unprofitable and will not do this. This will break the link between yield and landings (and therefore net revenue). When this happens, it also implies that biomass in subsequent years will be slightly higher than biomass in the model; the magnitude of this effect depends on the amount of yield that is not converted to landings.


We did not attempt to value in-situ herring or compute the social benefits or costs derived from changes in biomass. Brown, Berger, and Ikiara (2005); Finnoff and Tschirhart (2003) describe methods to trace the effects of changes in harvest or biomass of one species on ecosystems or predators. Finally, we note that increases in predator biomass can have negative impacts on prey and harvesters of prey. Flaaten and Stollery (1996).

In a more holistic model, with multiple predators, prey, and variability in the “desirability” of predators, it is possible that increases in biomass of a particular prey could be bad for society. For example, biomass of a predator that is low-valued but skilled at consuming herring could result in disproportionate increases in that low-valued predator. If that low-valued predator is not a complete specialist (in consuming herring), it may also drive down the biomass of high-valued predators.

Stated another way, the ability to manipulate the ecosystem with an ABC control rule to achieve desirable outcomes would depend on the rates at which increases in prey are converted into social utility: this depends on the ecosystem “technology” (conversion of prey into additional biomass of valued predators), human technology (conversion of prey and predator biomass into catch or tourism), and human preferences (converting catch or tourism into utility). Many of these technologies are not particularly well understood at this time.

There are undoubtedly more extensions that would increase the realism of this model. However, time is up and our pencils must be put down.
References


Herring MSE Appendix 1: Food web modeling
Sarah Gaichas
August 31, 2017

Introduction

This document explains the food web modeling done in support of the Herring Management Strategy Evaluation (MSE). Potential effects of changes in herring production and/or biomass on marine mammals were evaluated using an updated version of an existing food web model for the Gulf of Maine and incorporating food web model parameter uncertainty. This analysis is intended to illustrate potential changes in multiple predator and prey groups as a result of high and low levels of herring biomass within the full Gulf of Maine ecosystem. This modeling is supplementary to the predator modeling reported in “Herring MSE: Predator models.”

Methods

Food web models can quantify changes ecosystems by tracking the biomass gains and losses for each functional group in the system as they interact with predators (including fisheries) and prey. Generally, static system snapshots are developed by integrating information on the biomass, production and consumption rates, diet compositions, and removals by fishing or other human activities for each group in the model during a certain time period (Polovina 1984, Walters et al. 1997). This static system snapshot can then be used to initialize a dynamic model of the system tracking the changes in biomass of each functional group over time resulting from changes to the baseline conditions (Christensen and Walters 2004, Walters and Martell 2004). Groups are linked by functional relationships predicting how predator consumption of prey is altered by changing biomass in both groups (Abrams and Ginsberg 2000, Ahrens et al. 2012). A summary of model equations and methods used here are presented in (Gaichas et al. 2015).

Food web model updates

A food web model for the Gulf of Maine (Link et al. 2006, 2008, 2009) is available to evaluate potential effects of different levels of herring biomass. The model baseline reflects early 2000’s conditions, which include a generally comparable level of herring biomass to the present (we consider the model group “Small pelagics-commercial” to be primarily herring in the Gulf of Maine). For a full description of the species included in the other aggregate groups, please see Link et al. (2006).

For this analysis, several modifications to the original model were necessary, including updating diet compositions for marine mammal groups to reflect improved knowledge, adjusting biomass and/or production of two data poor groups to accommodate updated mammal diets, correcting detritus accounting for dynamic modeling, and adjusting one detritus feeding group’s diet composition as a result of this correction. We describe each modification in detail below.

Diet information for a wide range of marine mammals on the Northeast US shelf suggests that minke whales, humpback whales, harbor seals, and harbor porpoises have the highest proportions of herring in their diets (Smith et al. 2015), and therefore may show some reaction to changes in the herring ABC control rule. The Gulf of Maine EMAX model was updated to include this recent information. Species-specific diet compositions from (Smith et al. 2015) were aggregated into the three Gulf of Maine EMAX model groups (Baleen whales, Odontocetes, and Pinnipeds) as weighted by the estimated biomass of each species during the early 2000s in the Northeast US shelf ecosystem (L. Smith, pers comm). Prey categories were translated from (Smith et al. 2015) to the Gulf of Maine model groups (Link et al. 2006) according to assumptions
listed in Table 1. We note that the “Shrimp” category in (Smith et al. 2015) represents both Euphausiids (krill) and decapod shrimp, so this prey category was considered to be all Euphausiids (Micronekton in the food web model) for baleen whales, but an equal mix of both categories for the other marine mammals. The resulting updated diet compositions are reported in Table 2.

Table 1. Matching the relevant subset of Gulf of Maine food web model groups from (Link et al. 2006) with marine mammal prey categories from (Smith et al. 2015) for each mammal group.

<table>
<thead>
<tr>
<th>Gulf of Maine Model Group</th>
<th>Pinniped and Odontocete prey</th>
<th>Baleen Whale prey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Copepods</td>
<td>0</td>
<td>Zooplankton</td>
</tr>
<tr>
<td>Micronekton</td>
<td>0.5 Shrimp</td>
<td>Shrimp</td>
</tr>
<tr>
<td>Macrobenthos-crustaceans</td>
<td>0.5 Benthic Inverts</td>
<td></td>
</tr>
<tr>
<td>Macrobenthos-molluscs</td>
<td>0.5 Benthic Inverts</td>
<td></td>
</tr>
<tr>
<td>Shrimp et al.</td>
<td>0.5 Shrimp</td>
<td></td>
</tr>
<tr>
<td>Small Pelagics-commercial</td>
<td>Clupeids + Scombrids</td>
<td>Clupeids + Scombrids</td>
</tr>
<tr>
<td>Small Pelagics-other</td>
<td>Mesopelagics + Sandlance</td>
<td>Mesopelagics + Sandlance</td>
</tr>
<tr>
<td>Small Pelagics-squid</td>
<td>Squid</td>
<td>Squid</td>
</tr>
<tr>
<td>Demersals-benthivores</td>
<td>Flatfish + 0.5 Sm. Gadids + 0.25</td>
<td>Flatfish + 0.5 Sm. Gadids + 0.25</td>
</tr>
<tr>
<td></td>
<td>Misc. Fish</td>
<td>Misc. Fish</td>
</tr>
<tr>
<td>Demersals-ommovores</td>
<td>0.25 Misc. Fish</td>
<td>0.25 Misc. Fish</td>
</tr>
<tr>
<td>Demersals-piscivores</td>
<td>Lg. Gadids + 0.5 Sm. Gadids +</td>
<td>Lg. Gadids + 0.5 Sm. Gadids +</td>
</tr>
<tr>
<td></td>
<td>0.5 Misc. Fish</td>
<td>0.5 Misc. Fish</td>
</tr>
</tbody>
</table>

Table 2. Updated marine mammal diet compositions (proportions) used as inputs to the Gulf of Maine food web model.

<table>
<thead>
<tr>
<th>Gulf of Maine Model Group</th>
<th>Pinnipeds</th>
<th>Baleen Whales</th>
<th>Odontocetes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phytoplankton</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bacteria</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Microzooplankton</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Small copepods</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Large Copepods</td>
<td>0</td>
<td>0.153928001</td>
<td>0</td>
</tr>
<tr>
<td>Gelatinous Zooplankton</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Micronekton</td>
<td>0.00313569</td>
<td>0.502485518</td>
<td>0.000274618</td>
</tr>
<tr>
<td>Macrobenthos-polychaetes</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Macrobenthos-crustaceans</td>
<td>0.005412052</td>
<td>0</td>
<td>0.002591398</td>
</tr>
<tr>
<td>Macrobenthos-molluscs</td>
<td>0.005412052</td>
<td>0</td>
<td>0.002591398</td>
</tr>
<tr>
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<tr>
<td>Pinnipeds</td>
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These updated marine mammal diet compositions resulted in excess consumption relative to the originally estimated production of two model groups: Small pelagics-squid and Small pelagics-other. Production is the product of the input biomass and the input production rate (production to biomass ratio). Small pelagics-other includes sand lance and mesopelagic fishes. These groups (and squids) are poorly sampled by existing surveys relative to other groups in the model, such that biomass estimates are highly uncertain. Therefore, input biomass was increased for both groups (from 1.24 to 1.275 tons per square km for Small pelagics-other and from 0.275 to 0.29 tons per square km for Small pelagics-squid). In addition, the production to biomass ratio for Small pelagics-other was increased from 0.42 to 0.44. Small pelagics-other originally had the lowest production to biomass ratio of all the small pelagics groups in the model; this adjustment placed their productivity roughly equal to that of Small pelagics-anadromous but still well below that of Small pelagics-commercial or Small pelagics-squid.

An additional correction to the original model was necessary to achieve a baseline unperturbed dynamic run with no changes in biomass over time. Detritus accounting requires specification of a proportion of a group’s unconsumed, non-living biomass to each detritus pool in the model. Fishery discards are specified to flow into a dedicated discard detritus pool, with all non-fishery detritus going to a separate pool. In the original model, a small portion of all groups’ detritus fate was allocated to the fishery discard detritus pool (regardless of whether the group was fished), which caused instability in the unperturbed dynamic model. We corrected this so that only the fishery discard entered the discard detritus pool, with all other group’s detritus fate going 100% into the general detritus pool.

As a result of the correction to discard accounting, the fishery discard detritus pool was over-consumed by a single predator group, seabirds. While seabirds (in particular gulls) have been observed to consume fishery discards, the proportion in the diet aggregated over all seabird species is uncertain. Further, diet information collected at Gulf of Maine seabird colonies which was unavailable when the model was constructed suggested a much higher proportion of juvenile fish in the diet than the model reflected. Therefore, we adjusted the seabird diet so that Discards (formerly >12%) were <1%, Demersals-benthivores went from 0 to 2% (based on observations of hake in tern diets) and Larval-juv fish-all went from 0 to 10% (also based on tern diets; see “Herring MSE: Predator models.”)

After these adjustments, marine mammal diets represented the best available science, the food web model was “balanced” (all consumption needs were met in the ecosystem), and the unperturbed dynamic baseline run was stable.

**Incorporating uncertainty in food web model parameters**

As noted above, food web models require information on biomass, production and consumption rates, diet compositions, and fishery catch and discard for all groups in the ecosystem. Some food web model inputs are well-informed by observational data, while others are highly uncertain. Information about the uncertainty of food web model input parameters was included in a “pedigree” when the Gulf of Maine EMAX model was constructed. The pedigree rates the uncertainty of each input parameter according to a set of criteria specific to that input, with low uncertainty reflected by values closer to 0 and higher uncertainty by values closer to 1. (Values of 0 generally indicate that the parameter is not relevant for the group; 0.1 is the lowest uncertainty rating available, representing the best information.) We did not modify the model pedigree for this analysis. The pedigree for Gulf of Maine input parameters is reported in Table 3.

**Table 3. Data uncertainty ratings (pedigree) input to the Gulf of Maine food web model.**
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<thead>
<tr>
<th>Gulf of Maine Model Group</th>
<th>Biomass</th>
<th>Production</th>
<th>Consumption</th>
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These input parameter uncertainty ratings from the model pedigree are used to construct prior distributions centered on the model parameters such that a well-informed parameter (pedigree=0.1) would have a narrow distribution while an uncertain parameter (pedigree>0.5) would have a wide distribution. New parameter values can then be drawn from each distribution and combined into a new food web model that resembles the original model but allows for a range of uncertain input parameters. Further, dynamic predator-prey functional response parameters are generally unknown, but greatly influence model behavior (Gaichas et al. 2012). These parameters can also be drawn from distributions to construct alternative food web models reflecting both uncertainty in inputs and in dynamic behavior.

However, only sensible combinations of parameters should be used; some parameter combinations will result in unrealistic and unsustainable food web models where predators greatly outnumber their prey, or chaotic predator-prey interactions take place. We drew 32,000 parameter sets as described above, and tested each set by running the model for 50 years to determine if any groups went extinct. Only parameter sets resulting in food web models that allowed all groups to persist for 50 years were kept for further analysis (5,677). These methods are reported in detail in (Gaichas et al. 2015). The full ensemble of 5,677 food web models was then used in perturbation analysis.
Perturbation analyses

To evaluate how changes in individual group production propagate through the food web, and which groups might be most sensitive, a preliminary analysis systematically perturbed each group in the ensemble of food web models, allowing the remaining groups in the ecosystem to adjust to the new state of the perturbed group. The perturbation was a forced 10% increase in production relative to the base model for an individual group over the course of 100 years to allow the system to achieve a roughly stable state. Increased production was achieved by reducing unaccounted mortality by 10%. At the end of 100 years, production for all groups in the ecosystem was evaluated by averaging the final 10 years of the run (to smooth any oscillations). All perturbation results are subtracted from the results of an unperturbed 100 year baseline run for each ensemble member so that the results reported are proportional differences from the base state.

A second set of perturbation analyses were conducted to simulate the ecosystem effects of the highest and lowest long term average herring biomass projected looking across all the tested herring ABC control rules. These rather extreme scenarios were intended to provide insight into system behavior at these bounds, with the understanding that actual herring management under a selected control rule would be expected to lie somewhere in between. A visual inspection of herring model outputs for total biomass suggested that the minimum herring biomass in the system might be approximately half of the current (2000 model baseline) biomass, while the maximum spawning stock biomass might be 150% of current biomass. Therefore, a “low herring” run was set up that forced Small pelagics-commercial biomass from current to half of current over 10 years and then held it at half of current for the remainder of the 100 year run. Similarly, a “high herring” run was set up that forced Small pelagics-commercial biomass from current to 150% of current over 10 years and then held it at 150% of current biomass for the remainder of the 100 year run. Here, “current” biomass is slightly different in each ensemble member but the perturbation was relative to each ensemble’s baseline, rather than an absolute amount of biomass. As above, all runs were compared to the unperturbed baseline run for each ensemble member, and proportional differences in each group’s production from base (averaged over the final 10 years of the run) are reported.

Results

Food web model updates

Small pelagics-commercial (which contain Atlantic herring) comprised less than 25% of diet for marine mammal groups. Relative to diets included in the original Gulf of Maine food web model (Link et al. 2006, 2008, 2009), updated Pinniped diets were more varied and less concentrated on Small pelagics-commercial, Baleen whale diets included more Small pelagics-commercial, and Odontocetes had a similar diet proportion of Small pelagics-commercial. These shifts required no changes to the original parameterization of Small pelagics-commercial in the food web model.

Perturbation analysis

The initial perturbation analysis looked at the full food web response to a permanent 10% increase in herring production; the response of each group in terms of production is reported here. These results include uncertainty in both the input food web parameters and the dynamic predator prey functional response parameters. Results are reported as interquantile ranges across ensemble members (50% within the box, 90% between the error bars).

There is a mixed and largely uncertain response to increased Small pelagics-commercial (herring) production at mid to high trophic levels in the ecosystem (Figure 1). However, lower trophic levels (primary producers through large zooplankton and most benthic organisms) show almost no response to the perturbation. The largest response is the positive response of Small pelagics-commercial, which is the perturbation (though the median response to a forced 10% increase in production was less than a 10% increase in production, likely
due to predator feedbacks). Predator groups with the strongest positive responses were Medium pelagics, Demersals-piscivores (groundfish including cod and dogfish), and Baleen whales. Demersals-piscivores were the only group where 90% of ensemble members showed a positive response (lower error bar remains above the dashed line representing 0 change, Figure 1). The strongest negative responses included all of the other Small pelagics groups (other, squid, and anadromous) as well as Shrimp et. al. and Larval/juvenile fish. Overall, high uncertainty in system response is indicated by the large 90% interquantile ranges, many of which overlap the dashed line representing 0 change. In particular, there are uncertain responses for predators dependent on multiple forage groups as prey (e.g. Sharks-pelagic, Pinnipeds, Baleen whales, Odontocetes, Seabirds, and HMS which includes tunas and billfish) in response to the herring increase, likely due to the decrease in other forage groups. The direction of change in response to modestly increased herring production is uncertain for many groups, in particular HMS where even the 50% interquantile range includes both increased and decreased production. However, all other ecosystem groups had a smaller range of potential change than the perturbed group (Small pelagics-commercial), suggesting that responses to changes in herring tend to be damped rather than amplified by food web interactions.

Figure 1: Relative change in group production from a forced 0.1 production increase for Small pelagics-commercial. Boxes represent 50 percent of model results and error bars encompass 90 percent of model results within the 5,677 member ensemble.

Similar patterns in group sensitivity and uncertainty are reflected in the results of perturbations for both high and low herring simulations. However, the uncertainty in outcomes increases greatly with these larger perturbations, even for the directly perturbed group. When Small pelagics-commercial biomass was decreased to 50% of baseline, there are no groups with a clear increase or decrease for 90% of ensemble members, and only Small pelagics-commercial have a clear decrease for 50% of ensemble members (Figure 2). Keeping this uncertainty in mind, the simulation suggests that all other forage groups might have increased production with this substantially decreased herring biomass, with more than half of ensemble results showing an in-
crease for Shrimp et al, Larval and juvenile fish, and the other three Small pelagics groups: other, squid, and anadromous. However, the extent of increased production is highly uncertain, with half the ensemble results lying between trace and at most 25-27% increases (Figure 2). Similarly, some predator groups might have decreased production under this scenario with more than half of ensemble model results for Medium pelagics, Demersals-piscivores, and Baleen whales, which showed decreases ranging from trace to 13-23%. Other predator groups also showed potential decreased production, although with more uncertain results as even the 50% interquantile ranges included both increased and decreased production. Similar to the more modest perturbation reported above, no group had a wider range of response than the perturbed group (Small pelagics-commercial), suggesting that responses to decreases in herring biomass are damped rather than amplified by food web interactions.

![Figure 2: Relative change in group production from a forced 0.5 x base biomass reduction for Small pelagics-commercial. Boxes represent 50 percent of model results and error bars encompass 90 percent of model results within the 5,677 member ensemble.](image)

Results for the increased herring (Small pelagics-commercial) biomass simulation largely mirror those of the previous simulations, although the uncertainty in response is much higher for all groups in this scenario (Figure 3). When Small pelagics-commercial were held at 150% of baseline biomass, the 50% interquantile ranges of productivity for the other forage groups generally decreased and those for the same predators groups generally increased. It is notable that the 90% interquantile ranges for Small pelagics-commercial, HMS, and Seabirds are extremely large, indicating a range from -70% to -40% decreased productivity to 600%-1300% increased productivity for this scenario. This is the only scenario where the range of responses by a non-perturbed group (HMS) exceeded those of the perturbed group (Small pelagics-commercial). However, the 50% interquantile range was still largest for the perturbed group and smaller for all others. This suggests that in about half of model runs the response to increased herring biomass was damped rather than amplified by the food web, but in the remaining half of model runs the uncertainty in response was amplified for the
Figure 3: Relative change in group production from a forced 1.5 x base biomass increase for Small pelagics-commercial. Boxes represent 50 percent of model results and error bars encompass 90 percent of model results within the 5,677 member ensemble.

In comparing all three scenarios (using only the 50% interquantile ranges) it becomes clear that the two biomass scenarios (red and blue) represent rather extreme changes in the ecosystem relative to the 10% change in production (green, Figure 4). Further, increasing herring biomass in the ecosystem (red) had a wider range of results, and therefore uncertainty, relative to decreasing herring biomass (blue).
Figure 4: Relative change in group production from all three perturbation scenarios for Small pelagics-commercial: a 0.1 production increase (green), a 0.5 biomass decrease (blue), and a 1.5 biomass increase (red). Boxes represent 50 percent of model results within the 5,677 member ensemble.

Discussion

Overall, food web modeling showed that a simulated increase in herring production in the Gulf of Maine may produce modest but uncertain benefits to marine mammal predators, primarily because increased herring was associated with decreases in other forage groups also preyed on by marine mammals. The reduced herring biomass scenario was largely a mirror-image of the increased productivity scenario in terms of other species’ responses, although uncertainty was increased and the reactions were more pronounced because the scenario represented a larger change from baseline conditions. In all but the extreme increase in herring biomass scenario, responses of predator productivity (including those of marine mammals) was damped relative to the change in herring production. The 1.5x herring biomass increase scenario resulted in generally similar patterns of response across species as the more modest 10% production increase scenario, although the uncertainty in response increased disproportionately as indicated by the extent of the 90% interquartile range of productivity. This suggests that the impacts of greatly increased herring biomass in the Gulf of Maine ecosystem may be more uncertain than greatly decreased herring biomass.

The advantage of using a full food web model to address the impacts of changing herring biomass is that it integrates both bottom up and top down food web responses and tradeoffs between species that could not be considered in the more detailed modeling of herring relationships with individual predators. In particular, the tradeoff between increased herring and decreased productivity of other forage groups demonstrated in these scenarios has the potential to diminish any expected benefits to predators from “leaving more herring in the water” when herring is considered in a single species context, even as an important forage fish. Predators
in the Gulf of Maine and throughout the Northeast US shelf ecosystem tend to be opportunistic and rely on many prey, so tradeoffs between prey types caused by management for one prey species should be weighed carefully.

The disadvantage of this particular model is that groups are aggregated, although Small pelagics-commercial is mostly herring in the Gulf of Maine. Further, the predator groups with the highest proportions of herring in diets are aggregated with those with lower proportions, so that responses at the group level reflect an average species response. Individual species within each group would be expected to react either more strongly or weakly depending on the proportion of herring in individual diets.

Given additional time and resources, further work with the food web model could provide additional insight into the performance of herring ABC control rules in an ecosystem context. For instance, for a smaller subset of control rules the expected variation in herring biomass could be simulated as a perturbation using the same methods applied here. This would provide insight into a more realistic range of outcomes than was possible using this approach of minimum and maximum expected herring biomass, and could complement or bound the results from the simpler bottom up only set of operating models and help temper conclusions with full food web interactions and uncertainty.

References


EXTERNAL PEER REVIEW OF ATLANTIC HERRING MANAGEMENT STRATEGY EVALUATION

March 13-15, 2017
Embassy Suites, Boston Logan Airport
Boston, Massachusetts

Panel Members
Dr. Lisa Kerr (Chair)
Dr. Gavin Fay
Dr. Douglas Lipton
Dr. John Wiedenmann
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ToR 2: Evaluate whether the methods, data, and results of the MSE are sufficient for the New England Fishery Management Council to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. Comment on any constraints that may hinder use of the MSE in the development of management alternatives ............................................. 12

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**EXECUTIVE SUMMARY**

The Atlantic Herring Review Panel (hereafter referred to as the “Panel”) was convened by the New England Fishery Management Council (NEFMC) on March 13-15, 2017 in Boston, MA to review the Atlantic herring management strategy evaluation (MSE) process. The MSE was carried out by NEFMC and Northeast Fisheries Science Center staff from 2016-2017 and was a collaborative process, involving stakeholder input through two public workshops. The MSE was developed to support the goals of Amendment 8 to the Atlantic Herring Fishery Management Plan which aims to develop and implement a long-term harvest control rule for specifying the acceptable biological catch (ABC) for the Atlantic herring fishery with consideration for the role of herring within the ecosystem. The Panel was composed of four scientists: Dr. Lisa Kerr (Chair, Gulf of Maine Research Institute), Dr. Gavin Fay (University of Massachusetts, Dartmouth), Dr. Douglas Lipton (NOAA), and Dr. John Wiedenmann (Rutgers University).

The Panel reviewed the written materials and presentations on the Atlantic herring MSE process and addressed three terms of reference. The terms of reference required the Panel to: 1) assess the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules, 2) evaluate whether the methods, data, and results of the MSE are sufficient for the NEFMC to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan, and 3) provide recommendations for future improvements to the process. The Panel recognized that a tremendous amount of work was completed in a rigorous manner under the time and resource constraints of this MSE process. The Panel agreed that the NEFSC technical team constructed a series of models (Atlantic herring, predator, and economic) appropriate for evaluating ABC control rules for the Atlantic herring fishery in the context of herring’s role as a forage fish. The Panel detailed areas of strength and areas for improvement in the MSE workshop process, modeling, and synthesis. The Panel concluded that the data, methods, and results of the MSE are sufficient for the Council to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. Overall, the Panel concluded that the Atlantic herring MSE represents the best available science at this time for evaluating the performance of herring control rules and their potential impact on key predators. The Panel reached consensus regarding their conclusions on all terms of reference.
BACKGROUND

The Atlantic Herring Review Panel (hereafter referred to as the “Panel”) was convened by the New England Fishery Management Council (NEFMC) on March 13-15, 2017 in Boston, MA to review the Atlantic herring management strategy evaluation (MSE) process. The MSE was conducted by NEFMC and Northeast Fisheries Science Center (NEFSC) staff from 2016-2017 to evaluate the performance of alternative acceptable biological catch (ABC) control rules for Atlantic herring. The MSE was developed to support the goals of Amendment 8 to the Atlantic Herring Fishery Management Plan which aims to develop and implement a long-term harvest control rule for specifying the ABC for the Atlantic herring fishery that manages herring within an ecosystem context. The MSE process was designed to provide information to evaluate the competing objectives of attaining high and stable yields for the herring fishery with recognition of herring’s important role as a forage fish. The NEFMC aimed to use MSE as a collaborative decision making process, involving stakeholder input through two public workshops.

REVIEW PANEL

The Panel consisted of Dr. Lisa Kerr (Chair), Dr. Gavin Fay, Dr. Douglas Lipton, and Dr. John Wiedenmann. Dr. Kerr is currently Vice Chair of the NEFMC Science and Statistical Committee (SSC) and a research scientist with the Gulf of Maine Research Institute. Dr. Gavin Fay is a member of the NEFMC Ecosystem Based Fishery Management Plan Development Team and Assistant Professor in the Department of Fisheries Oceanography at the School for Marine Science and Technology, University of Massachusetts Dartmouth. Dr. Doug Lipton is a member of the Mid Atlantic Fisheries Management Council SSC and a Senior Scientist for Economics at NOAA Fisheries in Silver Spring, Maryland. Dr. John Wiedenmann is a member of the NEFMC SSC and Assistant Professor in the Department of Ecology, Evolution, and Natural Resources at Rutgers University. More information about each panelist’s research and scientific expertise can be found at: http://s3.amazonaws.com/nefmc.org/1.Herring-MSE-peer-review-overview_170217_125209.pdf.

As Chair of the Panel, Dr. Kerr facilitated the meeting and made sure that all the terms of reference were reviewed. She also led the preparation of the Peer Review Panel Summary Report. Drs. Fay, Lipton, and Wiedenmann participated in the review and contributed to the Peer Review Panel Summary Report. All panelists submitted Individual Peer Review Reports (Appendix A).

REVIEW ACTIVITIES

During the review, the NEFMC asked the Panel to address three terms of reference (Appendix B). The terms of reference required the Panel to: 1) assess the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules, 2) evaluate whether the methods, data, and results of the MSE are sufficient for the NEFMC to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan, and 3) provide recommendations for future improvements to the process.
Prior to the in-person meeting, the Panel was provided written materials describing the MSE process and outcomes to review. During the meeting, the NEFSC and NEFMC technical team (including Drs. Jon Deroba, Rachel Feeney, Sarah Gaichas, and Min-Yang Lee) presented on the MSE stakeholder workshops, as well as Atlantic herring, predator, and economic model details and results of model simulations under different harvest control rules (Appendix C). The review was a public meeting that had several designated times on the agenda for public comment and was open for participation through webinar (Appendix D). The Panel appreciated the participation of the NEFMC staff and NEFSC scientists in the review meeting and their role in addressing questions by the Panel.

The following written materials were reviewed by the Panel:
1. Atlantic Herring MSE Peer Review Overview
2. Terms of Reference for the Herring MSE Peer Review
3. Herring MSE Process, February 24, 2017
4. Atlantic Herring MSE Technical Methods and Outcomes, February 24, 2017
8. Background information on the Atlantic Herring Resource, Management Plan and Fishery, February 17, 2017
9. Correspondence

Presentations covered the following topics were reviewed by the Panel during the in-person meeting: 1) MSE process, 2) herring models, 3) predator models, 4) economic models, and 5) MSE results. All written materials and presentations were made available at the NEFMC website (http://www.nefmc.org/calendar/mar-13-15-2017-herring-mse-peer-review).

**EVALUATION OF TERMS OF REFERENCE**

**ToR 1: Evaluate the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules. Provide suggestions for improvements to the methods where appropriate.**

1a. Methods to identify objectives, performance metrics, and control rules for testing (e.g. workshops to solicit stakeholder input)

The Panel reviewed the written materials and presentations on the methods used to identify objectives, performance metrics, and control rules for testing in the Atlantic herring MSE. The objectives, metrics, and control rules were largely based on stakeholder input provided in the forum of two public workshops. The Panel identified several strengths associated with the workshop process, including the outreach to stakeholders and the collaborative, inclusive, and flexible nature of the process that enabled stakeholder input. The Panel also recognized the value of the educational content on MSE presented during the workshop and the benefit of a lead workshop facilitator with expertise in MSE. The Panel identified areas for improvement in this aspect of the MSE and made recommendations relevant to the Atlantic herring MSE, as well as future MSEs conducted by the NEFMC. The Panel recommended additional meetings with stakeholders, expanded education on MSE, expertise in survey design, facilitators with MSE.
expertise, more focus on human dimensions, outreach to underrepresented groups, opportunity to modify herring operating models, and further consideration of the approach used to incorporate stakeholder input (public workshop vs. working group). There was consensus among Panel members that although areas for improvement were identified, this aspect of the Atlantic herring MSE was generally conducted in accordance with best practices for MSE. Key areas of strength and areas for improvement are described in further detail below.

Areas of Strength:

- **Timeline Aligned Science with Management Needs:** A tremendous amount of work was conducted in one year in order to meet the NEFMC timeline and have the MSE completed for the purpose of selecting an ABC control rule for application in setting Atlantic herring ABCs for 2019-2021.

- **Outreach to Stakeholders:** The stakeholder workshops associated with the MSE were open to the public. A significant effort went into the notification of potential participants and attempts were made to reach diverse stakeholders for participation in workshops. The inclusion of a diversity of stakeholders (e.g., Atlantic herring industry representatives, bluefin tuna fishery representatives, and other wildlife managers) was a strong aspect of this process. Benefits included increased communication between different stakeholder groups and between these groups and NEFSC and NEFMC staff. In addition, stakeholder interactions led to identification of additional datasets to inform the MSE process and analytical work.

- **Collaborative Process:** An important aspect of MSE is identifying objectives, performance metrics, and control rules of particular interest to stakeholders. A key strength of the NEFMC Atlantic herring MSE was that these were established with stakeholder involvement through the workshop process. The NEFSC technical team incorporated the range of objectives, metrics, and control rules generated at the workshop into the MSE and, when this was not possible, tried to explain why certain scenarios or outcomes could not be considered. The Panel felt the range of control rules evaluated and performance metrics used was appropriate for the purpose of this MSE. This was not just an academic/desktop MSE, but a collaborative process that allowed stakeholders to provide direct input which has the potential to increase buy-in with respect to the outcomes of the MSE.

- **Educational Process:** During the workshops held by the NEFMC there was time invested in educating stakeholders on MSE. This was the first MSE conducted by the NEFMC and education was necessary for an efficient and effective process. This was recognized as a positive outcome of the MSE process that should be continued in the future.

- **Flexible and Transparent Process:** The workshops held by the NEFMC encouraged stakeholders to think broadly about the objectives, metrics, and control rules for Atlantic herring. These aspects of the MSE were not prescribed by the NEFSC technical team or council staff. Rather, there was an open discussion with stakeholders regarding what control rules they would like to see tested.

- **Facilitators and Technical Experts:** The feedback from stakeholders involved in workshops indicated that having an expert in MSE as the lead facilitator provided useful guidance for the process.
Areas for Improvement and Recommendations:

- **Less Constrained Timeline:** This MSE was conducted on a very tight timeline (~ 1 year) compared to other MSEs which have typically been conducted over the course of multiple years. It was apparent that time constrained some of the potential scope of modeling and alternative inputs to models that might have otherwise been considered in the MSE.

- **Additional Meetings with Stakeholders:** There was limited time built into Atlantic herring MSE workshops to iterate through different scenarios and control rule options with stakeholders. An additional meeting with stakeholders would have allowed the NEFSC technical team to present intermediary findings to stakeholders, prior to the final results workshop, and allowed more in-depth evaluation of trade-offs with stakeholders.

- **Additional Education on MSE:** Additional education on the scope, anticipated benefits, and potential limitations of the Atlantic herring MSE process may have helped in managing stakeholder expectations. For example, some stakeholders were disappointed with questions that could not be addressed due to the goals and timeline of this MSE process. Some of these questions cannot be answered with existing data and would require additional time and resources to collect the information needed. Presentation of a similar case study may have helped get stakeholders up to speed more quickly.

- **Public Workshop vs. Working Group:** The inclusiveness of the Atlantic herring MSE process was clearly a benefit and aligned with best practices in MSE, however, the large number of people participating at each workshop with diverse backgrounds and understanding of MSE made it challenging to achieve all the desired goals of the workshops. The panel questioned how sensitive the outcome of MSE workshops was to the composition of workshop attendees and the role individual voices played in influencing the direction of the process. The MSE process may have benefitted from a scoping meeting involving all stakeholders and more select involvement of stakeholders in the context of a working group as the MSE moved into more technical considerations.

- **Expertise in Survey Design:** Surveys of stakeholders were conducted at the workshops to garner input on the acceptable performance of alternative control rules. However, the synthesis of survey responses did not appear to support a clear consensus. This outcome may accurately represent the divergent opinions of stakeholders. However, additional expertise in survey design might have been able to design a survey that would better reveal participant preferences for control rule performance. It was unclear how the NEFMC intended to use the survey responses in the context of decision making on control rules. A clear intention for and design of the survey to achieve specific objectives would have made this aspect of the MSE process more effective.

- **Additional Facilitators with MSE Expertise:** The breakout groups could have benefited from facilitators with MSE expertise. The Panel recognized the potential for bias in the facilitation process and the reporting out from break-out groups. Experts with experience facilitating an MSE process could effectively limit this bias.

- **Additional Focus on Human Dimensions:** Social science objectives and metrics did not receive much time or attention during the workshop process and were left to the end of the agenda. This may have compromised the level of stakeholder engagement on this aspect of the MSE. The Panel recommended additional focus on human dimensions in future iteration of the MSE.
- **Outreach to Under Represented Groups:** Some key stakeholders in fisheries and businesses that rely on herring (e.g., lobster fishery) were under-represented in the MSE stakeholder process. Additional targeted outreach and education of these stakeholders may have facilitated their participation in the process.
- **Opportunity to Modify Atlantic Herring Operating Models:** Although there was opportunity to comment on the Atlantic herring operating models during public workshops, there was limited ability to modify operating models at that stage. Additional time for iteration of herring operating models with stakeholders would enhance the MSE process and promote better understanding of data limitations.

### 1b. Methods to construct the Atlantic herring, predator, and economic models (e.g., structure and use of data)

The Panel carefully reviewed the methods used to construct Atlantic herring, predator and economic models that were the foundation of the MSE. The models were constructed by the NEFSC technical team (Drs. Deroba, Gaichas, and Lee) under the direction of the NEFMC and informed by stakeholder input. The Panel recognized that a tremendous amount of work was completed in a rigorous manner under the time constraints of this MSE process. The Panel agreed that the NEFSC technical team constructed models appropriate for considering the NEFMC’s goal to simulate population dynamics of Atlantic herring and evaluate the response to alternative control rules as well as consider the role of herring as forage. The methods, assumptions, and caveats of models were clearly described. The Panel made specific suggestions for improvements to each model. Several of the weaknesses identified by the Panel could be addressed through additional time and iteration of the MSE; however, others were related to data limitations. Key areas of strength and areas for improvement are described in further detail below.

**Areas of Strength:**
- **Rigorous Methods:** A considerable amount of work was completed in a rigorous manner by the NEFSC technical team, particularly with respect to the timeline of the MSE process.
- **Transparent:** The NEFSC technical team effectively communicated the technical details of each modeling approach and the caveats and assumptions of methods.
- **Responsive to Management Goals:** The NEFSC technical team successfully addressed the NEFMC desire to model the response of Atlantic herring to different control rules as well as the impact of changes in herring biomass on key predators in the ecosystem.
- **Responsive to Stakeholder Input:** Models were built based on stakeholder input to the extent possible.
- **Models Informed by Regional Data:** The models within the MSE were closely tied to regional data and established relationships supported by data (e.g. predator-prey relationships). There was no drawing from literature on other species and systems to inform models.
- **Specification of Atlantic Herring Operating Models:** The Panel felt the decision to identify key uncertainties in aspects of Atlantic herring life history and to simulate these alternative realities was a good approach. This generated a small set of alternative
operating models that were intended to bound uncertainty in understanding of Atlantic herring population dynamics.

- **Ecosystem Approach:** The Panel felt the approach of modeling Atlantic herring biomass/growth impacts on predators was appropriate given the available data, current understanding of predator-prey relationships, and the goal of Amendment 8. This approach allowed for examination of the impacts of alternative control rules on Atlantic herring in isolation, as well as in the context of impacts on key predators.

- **Economic Stability Analysis:** The use of the net revenue model to look at stationarity and stability of herring fleet revenues was an appropriate approach to developing economic outputs to inform the MSE process. The Panel suggested that the stability analysis might be applicable for looking at some of the biological outcomes from the model.

**Areas for Improvement and Recommendations:**

*Atlantic Herring Operating Models*

- **Expand Range of Atlantic Herring Operating Model Scenarios:** While alternative specifications of several life history parameters were explored, the Panel suggested consideration of an expanded range of operating model scenarios to ensure bounding the full range of uncertainty in Atlantic herring population dynamics as well as potential future states of nature (e.g., climate change impacts or natural mortality scenario considering rebuilt Atlantic cod populations).

- **Include Spatial Considerations:** Spatial distribution and structure of Atlantic herring was not included in the operating model. The feasibility of a spatially explicit operating model was explored by the NEFSC technical team. However, the analysis/supporting documentation of this exploratory work was not part of the report, so it was not available for review. If the data available will not support a spatially explicit operating model, additional modeling approaches could be conducted to complement the MSE and enable examination of questions related to localized depletion (e.g. species distribution modeling).

- **Incorporate Stock Assessment Model:** Although assessment error and bias were considered in the Atlantic herring MSE, there was no explicit modeling of a stock assessment. The Panel recommends including a full stock assessment in the future as this would align with best practices in MSE.

- **Expanded Modeling of Error:** The simulated stock assessment and implementation error incorporated in the MSE were on the low end of values typically considered in MSE. The Panel was concerned that these low values may not fully capture the uncertainty in the assessment process. Future runs with greater assessment error were recommended by the Panel.

- **Consideration of Non-Stationarity:** The inputs to the Atlantic herring operating model were time invariant (e.g. natural mortality, weight at age). Inclusion of time-varying parameters would enable accounting for non-stationarity of key life history processes. There is the potential for inclusion of density dependent effects on growth and catchability in the MSE. Incorporating time-varying parameters will alter reference points and this will require reevaluation of how to assess the performance of control rules in these scenarios.

- **Evaluate Robustness to Misspecification of Reference Points:** The Panel suggested switching reference points across alternative operating model scenarios to evaluate the
robustness of control rules to misspecification of reference points. Alternatively, including a stock assessment internal to the MSE would allow for evaluation of the sensitivity of results to misspecification of reference points.

- **Evaluate Robustness to Climate Change:** There is no direct link to environmental drivers in the Atlantic herring model. The Panel recommends consideration of the impact of climate variability and change on Atlantic herring in the MSE in order to evaluate the robustness of control rules robust to climate variability and change.

**Predator models:**

- **Further Development of Predator Models:** The Panel felt the focus on modeling the impact of herring on a suite of individual species was a reasonable first approach and responsive to NEFMC objectives. However, modeling the impact of herring biomass on predators is a complex challenge and it is unclear whether these models, which are relatively simple, are able to emulate the impact of changes in herring biomass/growth on predators in the system.

- **The Panel reviewed the food web modeling that was not included in the final MSE and suggested further exploration of this work. Ultimately, a combination of approaches, with ecosystem/food web modeling providing a broader system-wide view of the importance of herring as forage, and individual species models providing information on the specific impacts on key predators, may provide a more holistic evaluation of ecosystem impacts.**

- **Consideration of the Impact of Predators on Herring:** There was no explicit link modeling the impact of predators on Atlantic herring in the models (i.e., no top-down effects on Atlantic herring). The Panel suggested integration of a feedback between predator biomass and Atlantic herring as a long-term goal in model development, noting however that the data requirements to do so are substantial.

- **Dependence of Predators on Herring:** The models focused on the direct link between herring and predators, but did not consider the capacity for and impacts of availability of alternative prey. In future iterations of predator models, it will be important to consider how to capture the dependence of predators on prey and their capacity to shift to alternative prey.

- **Expanded Consideration of Predator-Prey Relationships:** The predator-prey relationships were somewhat simplistic (i.e., one type of isolated impact was captured for each species). Time and data availability constrained the ability to explore additional potential mechanistic relationships.

- **Consideration of Natural Variability:** Consideration of the natural variability of predator dynamics (e.g., the probability of predator biomass decreasing below B_{MSY} with and without a change in herring biomass) is needed to put the potential impact of herring on predators in context. In addition, process error should be incorporated in predator models.

**Economic Model:**

- **Further Development of Economic Model:** The economic model was not as developed as the other models in the MSE. For practical and appropriate purposes, it was limited to an examination of herring ex-vessel price demand that feeds into a net revenue model of the fishery. The Panel felt that this work could be expanded upon with additional time.

- **Improve Herring Demand Model:** The direct herring demand model that was attempted did not perform well econometrically and, therefore, expert opinion was used to select an elasticity of -0.5 as a proxy until better estimates can be determined from the statistical
The Panel felt that this was a reasonable and appropriate course of action, but that work should continue to improve the demand model estimate.

- **Incorporation of Interactions:** The demand model is challenging because of the rapidly changing lobster fishery that relies on herring for bait, and the availability (or lack thereof) of menhaden as a substitute bait. Attempts have been made to account for these interactions and these should continue to be refined.

- **Develop Derived Demand Models:** Modeling of derived demand for herring as an input in the production of economically valuable prey species such as tuna, groundfish, or seabirds is data and time intensive. These types of analyses should be pursued in the future when comprehensive production relationships are developed that can predict absolute changes in predator abundance that can potentially be valued in an economic model.

### 1c. Methods to evaluate the control rules and performance metrics

The Panel evaluated the methods used to evaluate control rules and performance metrics. The Panel identified several areas of strength and areas for improvement, including:

#### Areas of Strength:

- **Presentation of MSE results:** The presentation of MSE results provided an effective, high-level view of the performance of alternative control rules. From these graphs it was apparent which control rule types (i.e., biomass based, constant, and conditional constant) were suboptimal and didn’t perform well for specific tradeoffs (e.g., yield vs. SSB). Additionally, the outcome of predator models in the form of box plots aggregated over simulations provided insight regarding what aspect of the MSE was driving particular outcomes (i.e. was it the influence of the operating model or control rule).

- **Range of Control Rules Considered:** The Panel agreed there was sufficient coverage of a range of harvest control rules evaluated in the MSE. There were no suggestions for additional control rules that needed to be tested based on the goals of the MSE.

- **Performance Metrics to Consider:** Given the time-frame for the MSE work, the suite of performance metrics considered was sufficient. There are other socio-economic metrics that could be developed in the future such as those developed at the NEFSC related to fishing community vulnerability.

#### Areas for Improvement and Recommendations:

- **Presentation of MSE Results:** A tremendous amount of output was generated from the Atlantic herring MSE. It is a recognized challenge to communicate the results of MSE, but further consideration should be given as to how to do this most effectively for the intended audiences. It was noted that stakeholders had difficulty interpreting figures and understanding results. The Panel recognized that there is not a single presentation approach that would be appropriate for interpretation by all stakeholders involved given their varied experience with MSE. However, the Panel suggested presenting results in a variety of different ways to aid interpretation of results, more specific input is provided below.

  - There was little text associated with figures. The addition of written text describing results and guidance on the interpretation of figures and how to view overall outcomes across metrics would aid understanding of the MSE results.
Medians of simulation output were reported, however percentiles or quartiles could also be reported to provide insight on variability. This could be accomplished in the short term.

The current presentation of results makes it very challenging to compare tradeoffs across a single ABC control rule.

Boxplots, spider and rose plots were suggested as a good visualization approaches that could be applied.

Additional figures plotting control rules across all operating models would enable simultaneous comparison.

Another option in presenting results would be optimizing for one aspect and plotting outcomes for other objectives.

A brief summary of results with infographics could help communicate this information to a general audience.

- **Selection of Control Rules:** A large number of control rules were evaluated which may make narrowing in on a single option challenging. Initial removal of illegal/suboptimal outcomes for all performance metrics would be a straight-forward approach to begin narrowing down control rule options. Development of a scoring system that weights control rules based on performance across a range of measures could help in vetting options.

- It is clear to see how the outcomes of herring tradeoffs could inform current decision-making (i.e., yield vs. SSB plots). However, it is more challenging to understand how predator impacts will be viewed in the decision-making process. The purpose of this MSE was to evaluate the impact of desirable control rules for herring on predators. There may be challenges in how to weight the impact on predators and managers will be required to make decisions regarding the level of impact on predators that is acceptable.

- **Model parameters:** The panel suggested inclusion of analysis to understand how control rule parameters influence the performance of control rules (e.g. GLM analysis of outcomes).

**ToR 2:** Evaluate whether the methods, data, and results of the MSE are sufficient for the New England Fishery Management Council to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. Comment on any constraints that may hinder use of the MSE in the development of management alternatives.

The Panel agreed that the MSE represents the best available science at this time for evaluating alternative ABC control rules for Atlantic herring. The MSE provides a strong basis for evaluating the performance of control rules over a range of possible states of nature for Atlantic herring (i.e., alternative operating model scenarios). A suite of independent predator models enable evaluation of the impact of changes in herring biomass/growth on key predators in the ecosystem. Economic considerations are included in the form of a net revenue model of the fishery. The Panel agreed that this represented a strong first iteration of a MSE for Atlantic herring, and while more development could be done to improve different aspects of the MSE, the methods and results of the current iteration are sufficient for the NEFMC to evaluate ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. The Panel concluded that the Atlantic herring MSE represents a marked advancement in the information available for decision-making on Atlantic herring catch advice.
The Panel identified several areas for improvement of the MSE; however, none were viewed as a constraint that would prevent application of the MSE for evaluating management alternatives. For example, the Panel made several suggestions for improvements to Atlantic herring operating models, but the current operating models are considered a good approximation of herring dynamics and not considered a constraint. There was discussion by the Panel regarding the biological realism of the herring—predator relationships used to inform predator models. Given the time constraints and data availability, the Panel felt this was an appropriate treatment of the impact of Atlantic herring on predators. The Panel recognized that more could have been done with economic considerations, but no major issues were identified that would constrain developing management alternatives. Thus, while improvements to these models were suggested, the Panel agreed that the MSE addressed the specific objectives of the NEFMC to the extent possible given time constraints and data availability.

The Panel strongly suggested that the NEFMC consider the need to revisit the MSE for several possible reasons related to the implementation and monitoring of ABC control rules. These suggestions are drawn from best practices for MSE and include:

1. Retrospective evaluation of the performance of the selected ABC control rule against expectation from MSE. In particular, if the ABC control rule is performing very poorly there may be a need to reconsider the outcomes of the MSE (e.g., the International Whaling Commission considered poor performance of the control rule as “exceptional circumstances” that would require reconsideration of harvest control rules and revisiting MSE).
2. If there are considerable improvements/changes made to operating models, predator-prey relationships, or economic models, there would be a need reevaluate the robustness of the current control rule or a small number of preferred ABC control rules.
3. If there is a shift in the ecosystem that is outside of expectations based on the historical view of the system, there may be a need to revisit the performance of ABC control rules under this new state.

**ToR 3: Provide any recommendations for future improvements. Comments should include the following:**

3a. How to address any data limitations or needs

There is a need for additional data to inform an MSE for Atlantic herring with full consideration of Atlantic herring dynamics (e.g., mechanistic links between life history processes and environment), as well as herring’s role as forage (e.g., marine mammal abundance and consumption data). In some cases, these data gaps would require more data collection; however, resources may be limited and require choices as to where it would be best to invest time and effort. One important application of MSE is to identify data gaps that can impede informed decision-making. The Panel suggests further examination of the key uncertainties in the Atlantic herring MSE and application of this information to inform prioritization of future data collection to support this work.

In some cases, suggested improvements to the MSE recommended by the Panel are beyond the scope of the currently available data. In other cases, additional time and technical capabilities would have permitted addressing an area of weakness.
3b. How to conduct future Atlantic Herring MSEs
The Panel highlighted specific areas for improvement that should be considered as work proceeds on the Atlantic herring MSE. The Panel categorized its recommendations as either short-term activities that could be accomplished with limited time and effort or long-term endeavors that would require significant time and effort. The Panel also provided more general advice that is both relevant to the Atlantic herring MSE as well as to future MSEs conducted in the region. For more detailed descriptions of these suggested improvements see the full description under ToR 1.

Suggested Future Improvements to the Atlantic Herring MSE:

**Atlantic Herring Model**

*Short term:*
1. Expand the range of stock assessment error and implementation error informing the MSE.
2. Incorporate density dependent impacts in operating model.
3. Evaluate robustness of control rules to misspecification of reference points.

*Long term:*
1. Expand the range of Atlantic herring operating model scenarios.
2. Include spatial considerations in Atlantic herring operating model.
3. Incorporate a stock assessment of Atlantic herring in the MSE.
4. Include non-stationarity in life history processes (beyond density-dependent effects listed above).
5. Evaluate robustness of control rules to climate change.

**Predator Models**

*Short term:*
1. Expand the analysis and integration of food web modeling in the MSE.
2. Expand the consideration of predator-prey relationships (some of this work is ongoing at the NEFSC).

*Long term:*
1. Model feedback of predators on Atlantic herring through consumption.
2. Address spatial concerns regarding predator-prey interactions (i.e. local depletion). This may require parallel modeling outside of the framework of the MSE (e.g. species distribution modeling).
3. Incorporate consideration of the dependence of predators on Atlantic herring in the context of availability of alternative prey.
4. Include consideration of natural variability in predator biomass.

**Economic model**

*Short term:*
1. Improve the demand model for Atlantic herring.
2. Incorporate interaction with menhaden and changes in the lobster fishery.
3. Model entry and exit for the herring fleets.

*Long term:*
1. Develop derived demand models (economic valuation of herring impacts on predators).
2. Include non-economic social science evaluating the impact of control rules on fishing communities (e.g. social well-being of resource users).
3. Develop values/weights for ecosystem aspects (stated preference choice experiments) from regional survey.

Considerations for Future MSEs by the NEFMC:

- **Longer Timeline:** It was clear that the MSE process would have benefited from more time. Changing the expectations for the time-frame over which MSEs can be completed is necessary to maximize the potential of the MSE process. If tighter timelines are needed to address management objectives, expanded partnerships with others who work on MSE within the region could provide additional capability to achieve goals more quickly.

- **Technical Capacity in Region:** Additional training of students and post-doctoral researchers in MSE is needed, as well as collaboration among experts in the region. Increased technical capacity could expand the application of MSE within New England.

- **More Education on MSE:** Additional education on MSE for fisheries stakeholders in the region could have helped the Atlantic herring process and would make future applications more efficient and effective. This education could happen through council sponsored meetings or possibly through the MREP training program.

- **Workshop Facilitation with Expertise in MSE:** The Panel recognized that additional people with expertise in MSE would aid in the facilitation of stakeholder meetings.

- **Approach to Stakeholder Involvement:** There were recognized benefits to holding public meetings, but also drawbacks due to the different composition of attendees between the first and second workshop. There may be a role for both large, public scoping meetings to generate objectives, metrics, and control rules, and a smaller working group that addresses technical details of the MSE.

- **Expanded Social Science Expertise:** The addition of a MSE team member with expertise in social science (non-economist) would expand the scope of the MSE.

- **Improved Communication of MSE Results:** Effective communication of results is a recognized challenge in the field of MSE. The Atlantic herring MSE would benefit from additional time spent on synthesis and graphical display of data, with the aim of translating MSE results to different audiences. The Panel suggested the potential for development of interactive web-based tools (e.g. R Shiny App.) that would allow for broad accessibility of the output of MSE. Providing an interface for stakeholders to “play” with output would help them evaluate and understand tradeoffs.

- **Lessons learned:** The Panel suggested that best practices should be summarized from the Atlantic herring MSE to inform future MSE work within the region.

- **Where does MSE fit in future fishery management process?** A plan should be developed by the NEFMC for future iteration and application of the Atlantic herring MSE. The Panel recommends continued research to inform the Atlantic herring MSE. There was a suggestion that MSE be conducted in a benchmark/update structure similar to the stock assessment process or that evaluation of the performance of control rules using the MSE could be conducted within the context of stock assessments.
3c. How to clarify the current and future MSE final reports, including input on best practices for translating MSE results for a general audience

In general, the discussion of modeling methods were clear and concise in MSE reports, however, the results were more difficult to interpret. The Panel made recommendations for clarifying current and future MSE final reports and categorized its recommendations as either short-term activities that could be accomplished with limited time and effort or long-term endeavors that would require significant time and effort. Below are suggestions by the Panel for effectively communicating MSE results to a broad range of stakeholders.

**Short term:**
- The Panel suggested that summary text synthesizing results be added to the report and text that guides readers on how to interpret figures (i.e. trade-off evaluation) be included in the report.
- The Panel suggested more user friendly figure display and more descriptive figure captions.
- The Panel suggested that the workshop recordings and slides be made available for those who would like to review this information online.
- The Panel suggested that the NEFMC produce a web-based summary report with infographics that could help communicate the content of reports to stakeholders.

**Long term:**
- The Panel suggested that the NEFSC and NEFMC staff work with experts in data visualization to communicate MSE findings more effectively.
- The Panel suggested presenting data in multiple formats in order to reach a broader audience (e.g. reports, website, video).
- The Panel suggested that NEFMC staff conduct focus groups with stakeholders to understand how this data can be best translated to the intended audiences.

**Conclusions**

The Panel reviewed the written materials and presentations on the Atlantic herring MSE and addressed three terms of reference. The terms of reference required the Panel to: 1) assess the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules, 2) evaluate whether the methods, data, and results of the MSE are sufficient for the NEFMC to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan, and 3) provide recommendations for future improvements to the process. The Panel recognized the tremendous amount of work that was completed in a rigorous manner under the time constraints of this MSE process. The Panel detailed areas of strength and areas for improvement in the MSE workshop process, modeling, and synthesis. The involvement of stakeholders in identifying objectives, metrics, and control rules was a strong aspect of the MSE process and aligned with best practices for MSE. The Panel agreed that the NEFSC team constructed models appropriate for considering the NEFMC’s goal to develop and implement a long-term harvest control rule for specifying ABC for the Atlantic herring fishery that manages herring within an ecosystem context. The Panel concluded that the data, methods, and results of the MSE are sufficient for the Council to use when identifying and
analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. The Atlantic herring MSE provides the NEFMC with a structured decision making approach for setting Atlantic herring catch advice. Overall, the Panel concluded that the Atlantic herring MSE represents the *best available science* at this time for evaluating the performance of herring control rules and their potential impact on key predators. The Panel reached consensus regarding their conclusions on all terms of reference.
APPENDIX A: Individual panelist reviews

Atlantic Herring MSE Individual Panelist Report: Dr. Lisa Kerr

EXECUTIVE SUMMARY
The Atlantic herring management strategy evaluation (MSE) was conducted to evaluate the performance of alternative acceptable biological catch (ABC) control rules for the Atlantic herring fishery that consider the role of herring as forage. The Northeast Fisheries Management Council (NEFMC) convened a Review Panel to evaluate the Atlantic herring MSE, including stakeholder involvement through the workshop process, models, and the synthesis of results. The MSE conducted by the NEFSC technical team represents a considerable amount of work, conducted within a relatively short time-line. The Atlantic herring MSE was a collaborative process that included stakeholders in the establishment of objectives, performance metrics and control rules. The methods used to construct the Atlantic herring, predator, and economic models were appropriate and the data limits, caveats and assumptions associated with these models were described in a clear manner. Overall, I find that the MSE is sufficient for use by the NEFMC to identify and analyze a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. No major constraints were identified in the current MSE that would hinder its use in the development of management alternatives; however, recommendations were made regarding areas for improvement in the Atlantic herring MSE. The Panel summary reflects the consensus of the entire panel and this reviewer.

BACKGROUND
The Northeast Fisheries Management Council (NEFMC) is developing Amendment 8 to establish a long-term control rule for specifying the acceptable biological catch (ABC) for the Atlantic herring fishery. The goal of Amendment 8 is to develop and implement a control rule that manages herring within an ecosystem context. A management strategy evaluation (MSE) was conducted 2016-2017 to evaluate the performance of alternative ABC control rules. The MSE process was aimed at resolving control rules that address the competing objectives of attaining high and stable yields for the fishery and the role of herring as a forage fish. The NEFMC aimed to use MSE as a collaborative decision making process, involving public input.

The NEFMC convened a Review Panel in Boston, MA on March 13-15 to evaluate the Atlantic herring MSE process. The panel reviewed both written materials as well as in-person presentations by the NEFSC team. The Panel was charged with providing feedback on three terms of reference, including: 1) evaluate the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules, 2) evaluate whether the methods, data, and results of the MSE are sufficient for the NEFMC to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan, and 3) provide recommendations for future improvements to the process. Each panelist was asked to summarize their independent findings, identifying points of agreement with the panel consensus and where the view of the individual panelists differs from the rest of the panel.
**FINDINGS**

**Terms of Reference**
Evaluate the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules. Provide suggestions for improvements to the methods where appropriate.

a. **Methods to identify objectives, performance metrics, and control rules for testing (e.g., workshops to solicit stakeholder input)**

A key aspect of MSE is determining fishery objectives, performance metrics and relevant uncertainties. In the NEFMC Atlantic herring MSE, these were established with stakeholder involvement through the workshop process. The NEFSC team was responsive to the suggestions of workshop participants and directly incorporated their input into the MSE process. This was not just an academic MSE, but a truly inclusive and collaborative process. This inclusion of stakeholders in the MSE process should be recognized as a key area of strength. Overall, the range of performance metrics and control rules considered was appropriate given the objective of the NEFMC, however, consideration of economic metrics was limited.

The Atlantic herring MSE was completed on a very tight timeline (~ 1 year) and this constrained the extent to which stakeholders could be involved in understanding the results and weighing tradeoffs. With only two public workshops, there wasn’t a lot of time built into the process to iterate through initial results with stakeholders and discuss alternative scenarios they would like to see simulated in the MSE. For example, there was limited opportunity during workshop meeting to provide input on operating model structure of Atlantic herring. Given that this was the first MSE conducted in the region, additional meetings may have helped in navigating both the education and application of MSE with stakeholders.

b. **Methods to construct the Atlantic herring, predator, and economic models (e.g., structure and use of data)**

The MSE conducted by the NEFSC technical team represents a considerable amount of work, conducted within a relatively short time-line. Overall, the methods used to construct the Atlantic herring, predator, and economic models were appropriate and the data limits, caveats and assumptions associated with these models were described in a clear manner. The NEFSC team effectively structured models to allow both a fishery and ecosystem focus, enabling consideration of changes in herring harvest on the fishery as well as key predators in the ecosystem. Below I have highlighted several areas for improvement within Atlantic herring, predator, and economic models that could be considered in future iteration of the MSE.

**Atlantic herring model:**
- **Single stock area:** There was no consideration of spatial structure of Atlantic herring in the operating model. Atlantic herring are heterogeneous in distribution and known to exhibit complex population structure. Future work should include exploration of whether the data available could support a spatially explicit operating model.
- **Stationarity of Parameters:** The inputs to operating model were time invariant (M, WAA). Incorporation of time-varying parameters would likely increase the biological realism of the model and allow for consideration of potential links to environmental forcing.
• **No environmental influence**: There was not explicit modeling of environmentally driven processes in the MSE. Evidence of environmental impacts on recruitment, growth, or distribution of Atlantic herring may warrant inclusion in future iteration of the MSE. This would enable evaluation of potential impacts of climate change on management performance.

• **No stock assessment**: There was no explicit modeling of a stock assessment within the MSE. Future work should include incorporation of a stock assessment to accurately represent the fishery management process for Atlantic herring. Currently, assessment error was modeled over a limited range, however, a broader range of error should be considered. MSE outcomes were sensitive to assessment bias and additional modeling incorporating different levels of bias (i.e. beyond rho = 0.6) should be pursued.

• **Reference points without error**: The MSE assumes reference points are known without error. Incorporation of error should be pursued in future iterations of the MSE.

*Predator-prey model:*

• **Predator models**: Modeling the impact of herring harvest on predators is a complex challenge. It is unclear how accurately these models capture the reality of predator dynamics in the way they consider the herring-predator relationship in isolation (i.e. absence of other forage). Future collaboration with stock assessment scientists who work on the assessments of predators modeled in the herring MSE (e.g. Bluefin tuna, spiny dogfish) could improve these models.

• **Top Down Impacts**: No top-down effects of predator biomass on herring were included in the model.

• **Predator-prey relationships**: The predator-prey relationships were relatively simplistic. Additional time to explore data for further evidence of these complex interactions could lead to better informed models.

• **Bluefin tuna model**: Exploration of the impact of herring availability on bluefin tuna availability to the fishery would be valuable. This could not be accomplished within the current structure the MSE, but could be explored through parallel modeling efforts (i.e. joint species distribution modeling).

*Economic model:*

• **Economic model**: Overall the description of the economic model was less detailed and the modeling seemed less developed than other aspects of the MSE. Limited results were provided.

• **Valuation of herring to predators**: It is difficult to fully assess tradeoffs when no value is put on in-situ herring for predators. Future work should consider including valuation of herring to predators.

• **Impact on other fisheries**: The lobster fishery is reliant on the herring fishery for bait. Future modeling should incorporate this relationship and simulate economic impacts on the lobster fishery.

c. **Methods to evaluate the control rules and performance metrics**

Overall, the performance measures applied to evaluate the outcome of alternative ABC control rules were appropriate. In the reporting of results, more focus was given to herring and predator resource and herring yield metrics and consideration of economic metrics was limited (i.e. net revenue). Trade-offs were evaluated through two dimensional plots that displayed different
performance metrics on each axis. The presentation of results in plots of Atlantic herring yield versus SSB was effective for visualizing which control rules performed well for this specific tradeoff. In general, figures provided insight regarding harvest strategy options to rule out and those that performed well. As the number of control rules considered is narrowed down, trade-off plots across a single harvest control rule would enable in-depth look at their performance across metrics.

2. Evaluate whether the methods, data, and results of the MSE are sufficient for the New England Fishery Management Council to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. Comment on any constraints that may hinder use of the MSE in the development of management alternatives.

The Atlantic herring MSE represents the best available science for setting catch advice. This was a strong first iteration of MSE for Atlantic herring and, although more development could be done to improve different aspects of the MSE, the current iteration provides insight regarding the performance of alternative harvest control rules for Atlantic herring and their impact on key predators. Overall, I find that the MSE is sufficient for use by the NEFMC to identify and analyze a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. No major constraints were identified in the current MSE that would hinder its use in the development of management alternatives. There is room for improvement in Atlantic herring operating models, however, the current models do address major uncertainties and likely are good approximations of reality. We have suggested improvements to predator models and the herring—predator relationships, however, these models are able to provide perspective on potential impacts of herring control rules on predators. The current approach to modeling economic impacts is appropriate, but more could be done to develop this aspect of the MSE. Proposed improvements are described in further detail in ToR 1 and 3.

3. Provide any recommendations for future improvements.
   a. How to address any data limitations or needs
   There were data needs that influenced the scope of Atlantic herring, predator, and economic models. For example, Atlantic herring are not sampled well by the trawl survey and this could limit development of a spatially explicit model. In addition, marine mammals are key predators on Atlantic herring; however, there is not a robust time series of marine mammal data in our region. Furthermore, inclusion of social science data on the Atlantic herring fishery, as well as associated fisheries that rely on herring, could have enhanced the MSE and enabled modeling of fishing community impacts. MSE is a useful tool in identifying key uncertainties in understanding a system and can be helpful in prioritizing which data gaps can be addressed with limited resources. Some of the limitations of the current MSE are associated with the constrained time-line and resources dedicated to this process. Future MSE processes should consider the need for additional time and/or staff for workshops with stakeholders, model development and simulation, and synthesis and communication of results.

   b. How to conduct future Atlantic Herring MSEs
   There were lessons learned during the Atlantic herring MSE process that can inform future iterations of the Atlantic herring MSE, as well as future MSEs conducted in this region. The outreach to stakeholders through workshops was a strong aspect of the Atlantic herring MSE and
as the MSE process continues to evolve there should be continued outreach and communication with stakeholders. Feedback to workshop participants in the form of a clear synthesis of MSE results and how results will be used in decision making is needed to make the process fully transparent. The MSE was completed on a very tight timeline which allowed this effort to keep pace with management needs. However, the timescale did limit the scope of the Atlantic herring, predator and economic models that could be considered in the MSE (e.g. alternative operating model scenarios). Outreach to stock assessment scientists who lead assessments on predators modeled in the MSE (e.g. bluefin tuna, spiny dogfish) could help inform these models. The economic modeling did not receive the time and attention needed for such an important aspect of the study and should be expanded upon. This effort represents the first MSE conducted through the NEFMC and future MSEs are anticipated. Additional, education on MSE is needed in the region to allow stakeholders to effectively engage in the process. The NEFMC should establish a clear plan for future iteration and improvement of the MSE.

c. How to clarify the current and future MSE final reports, including input on best practices for translating MSE results for a general audience

It is a challenge to communicate the large number of results produced from a MSE; however, further consideration should be given to the best approach for synthesis of the tremendous amount of work completed through the Atlantic herring MSE process. The synthesis of findings in final reports was done mainly through figures with little associated text. In their current format, I don’t find the reports to be easily understandable for a broad audience. Additional effort is needed to produce summary documents appropriate for council members and the broad range of stakeholders who contributed to the MSE process. Future synthesis of the MSE could be conducted through development of a web-based tool (such as a Shiny App. similar to IPHC MSE). A web-based tool would allow for broad accessibility of the output of the MSE and the ability to “play” with model settings to understand their impact. I highly recommend more effort to communicate MSE outcomes at different levels (e.g. brief summary documents, more in-depth reports, web-based tools).

CONCLUSIONS AND RECOMMENDATIONS

The MSE conducted by the NEFSC technical team represents a considerable amount of work, conducted within a relatively short time-line. The Atlantic herring MSE was a collaborative process that included stakeholders in the establishment of objectives, performance metrics and control rules. The methods used to construct the Atlantic herring, predator, and economic models were appropriate and the data limits, caveats and assumptions associated with these models were described in a clear manner. Overall, I find that the MSE is sufficient for use by the NEFMC to identify and analyze a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. No major constraints were identified in the current MSE that would hinder its use in the development of management alternatives. However, recommendations were made regarding areas for improvement in future iteration of the Atlantic herring MSE. The Panel summary reflects the consensus of the entire panel and this reviewer.
Executive Summary

The Atlantic herring management strategy evaluation (MSE) conducted by the Northeast Fisheries Science Center and the New England Fisheries Management Council was an ambitious undertaking to develop recommendations for harvest control rules for Atlantic herring that account for its role as a prey species. An attempt was made to use extensive stakeholder input in developing candidate harvest control rules and performance metrics. The peer review panel examined the MSE process including two stakeholder workshops, herring operating models, simulations under different harvest control rules and output performance related to the herring fishery, effects on predators and economic performance. Given the limited time and resources available to conduct the MSE, the panel felt that the project was a success and would provide useful information for the Management Council to use in setting Atlantic herring total allowable catch that is informed by the ecosystem considerations included in the analysis. Although the panel identified numerous areas for improvement, some that could be applied in the short run, and many that will require more time and resources to complete, these were not seen as constraining to the use of the MSE by the Council. The chairs report reflects the consensus of the entire panel and this reviewer.

Background

The purpose of the peer review was to examine both the process of performing the herring MSE as well as the underlying models to determine their appropriateness in achieving the goals of the task as well as evaluating their scientific rigor. The panel also reviewed the outputs from the analysis to determine if they reflected the underlying science, were appropriately communicated and, ultimately, whether they would be useful for management decisions.

The panel was presented with background materials and presentations on the overall MSE process, including stakeholder workshops, a range of operating models of Atlantic herring, simulations of different harvest control rules, predator models and an economic model. These models were used to evaluate performance against a number of metrics that were developed at the stakeholder workshops.

Findings

1. Evaluate the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules. Provide suggestions for improvements to the methods where appropriate. Evaluation should include the following:
   a. Methods to identify objectives, performance metrics, and control rules for testing (e.g. workshops to solicit stakeholder input)

The MSE project entailed holding two stakeholder workshops to identify the management objectives, performance metrics and control rules that would be included in the MSE. A description and results of the individual workshops were provided to the panel, and a presentation about the workshops was given to the panel. The workshops which had about 60 attendees at each were a major undertaking. With limited resources and time to plan and conduct the workshops, the organizers did an excellent job in getting broad stakeholder
involvement and driving the meeting to the results needed for the next step in the process. Some of the strengths were:

- Able to reach a diverse set of stakeholders, not all of whom are regularly engaged in fisheries management council activities.
- Leveraged a diverse, talented and knowledgeable set of workshop facilitators and organizers.
- Served as an educational opportunity for stakeholders (and the technical team), particularly to learn about the concerns and interests of other stakeholder groups.

There is always room for improvement in these types of activities. Some of the weaknesses or concerns about the approach were:

- Workshop participants may not be representative of the true stakeholder community, with some groups over-represented and others under-represented.
- There was a lot of material to cover in just two workshops, so there was probably some information overload.
- Large turnover of participants between workshops.
- Some stakeholders may have had greater expectations for the final product than was communicated and may have come away disappointed that the analysis did not go further than they would have liked.

b. Methods to construct the Atlantic herring, predator, and economic models (e.g., structure and use of data)

The panel was provided background materials and presentations on the underlying operating models for the Atlantic herring fishery, predator-prey interactions and the economic model. Justifications were given for the approaches taken which included data limitations, and time and resource constraints. It is my judgement that the decisions made by the modeling team were appropriate and the best that could be accomplished at this time.

Specifically for the economic model, the study was limited to the economic performance of the herring fishery in terms of net revenues and stability of performance over time. Effort was made to develop a suitable demand model for herring, and although initial success was lacking, it appears that a reasonable model will be developed in the near future with a proxy value for demand elasticity being used in the current analysis. Many of the suggestions made by the panel and in public comments about improvement for the demand model were already considered or are being explored.

This panelist agrees with the decision to not pursue some of the more advanced economic analyses that would inform a future MSE, such as calculating indirect demands for herring (as prey for directly valued species such as tuna or groundfish) or for other ecosystem components such as the health of seabird populations. These analyses have heavy data requirements or the data may not be readily available, and thus, should only be attempted when the time and resource are sufficiently allocated to the effort to ensure success.

c. Methods to evaluate the control rules and performance metrics
As captured in the panel recommendations, the use of the net revenue model to look at stationarity and stability of herring fleet revenues was an excellent approach to developing economic outputs to inform the MSE process. It was suggested that the stability analysis might be useful in looking at some of the biological outcomes from the model. The notion being that multi-year patterns of all low (or high) net revenue have different impacts on entry-exit behavior of the fleet than the same variability with completely random annual fluctuations.

2. Evaluate whether the methods, data, and results of the MSE are sufficient for the New England Fishery Management Council to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. Comment on any constraints that may hinder use of the MSE in the development of management alternatives.

As an individual, and the panel as a whole, felt that the package of materials that constitute the MSE to this point are sufficient to inform the process of setting ABC control rules for Atlantic herring and will provide improved guidance as compared to the status quo. The major challenge in utilizing this information will be maintaining all the caveats, and limiting the interpretation of the findings to the level they are intended. This is a communications challenge to the MSE team, and one that they recognize as evidenced by the interests in examining different graphic representation of results, among other communication challenges.

3. Provide any recommendations for future improvements. Comments should include the following:
   a. How to address any data limitations or needs
      - Continue working on improvement of herring demand model.
      - Develop model of entry-exit in the herring fleet.
      - Develop derived demand model for herring in relation to predator species (long term)
      - Consider development of a region-specific stated preference choice experiment for valuation of trade-offs across multiple objectives (long-term).
   b. How to conduct future Atlantic Herring MSEs
      - Track and monitor implementation of current MSE and use that analysis as the launching point for any new MSE or MSE update.
      - Work on “closing the loop” on a few key species which would entail full production analysis of the predators as well as their feedback on herring populations
   c. How to clarify the current and future MSE final reports, including input on best practices for translating MSE results for a general audience
      - Look to related “communities of practice” for best practices such as the IEA community

Conclusions and Recommendations
The MSE for Atlantic herring represents the best scientific information available, and the data, models and outputs should be used by the New England Fisheries Management Council in setting herring catch specifications. This reviewer and the committee made many recommendations for improvements on all aspects of the project, but these should be construed as needed for future improvements in implementation and not an impediment for utilizing the MSE in current deliberations. This is a complex and challenging task, and the MSE team has done an excellent job in advancing the scientific basis for herring management.
A management strategy evaluation (MSE) was conducted to test a range of control rules for setting the acceptable biological catch (ABC) for Atlantic herring, accounting for the role of herring as forage. The MSE included two stakeholder workshops to obtain input on the control rules and performance measures of interest, as well as key predators to consider in the model. The MSE model contained a single-species herring model that quantified the responses of the herring population to control rules, accounting for uncertainty in herring population dynamics (natural mortality, growth, and reproductive success at low stock size). The biomass estimates of herring from each model run were used in population models for select herring predators and in an economic model to understand the broader impacts that changes in herring biomass may have on the ecosystem and the fishery. The review panel concluded that the MSE was appropriate for use by the New England Fishery Management Council (NEFMC) to select an ABC control rule for herring. The panel identified a number of key strengths of the whole MSE process, as well as some areas for improvement, both short and long term. The report by the chair captures the consensus of the review panel, and some individual thoughts on each Term of Reference (ToR) are provided here, with an emphasis on the herring and predator operating models.

1. Evaluate the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules. Provide suggestions for improvements to the methods where appropriate. Evaluation should include the following:

   a. Methods to identify objectives, performance metrics, and control rules for testing (e.g., workshops to solicit stakeholder input)

Through two workshops, stakeholder input was obtained to identify 1) ABC controls to be tested, 2) important herring predators for consideration in the model, and 3) desirable outcomes to be used as performance measures in the MSE to evaluate control rule performance. Having stakeholder input is an essential component for a MSE addressing an issue with divergent stakeholder interests, as is the case with herring. The workshops had a large number of attendees (60+) representing herring, tuna, groundfish, and lobster fisheries, as well as NGOs with interests in sea bird and marine mammal conservation, among others. The workshops were successful in engaging stakeholders, and were very effective at addressing objectives 1-3 listed above. Some issues identified with the workshop process were that not all groups were equally represented and that participation was not consistent at both workshops, that some voices may have been more dominant than others, and some individuals may have biased their answers on questionnaires to counter opposing viewpoints in the workshop. However, none of these issues take away from the overall utility of the workshops.

b. Methods to construct the Atlantic herring, predator, and economic models (e.g., structure and use of data)

The herring, predator, and economic models were rigorously developed given the logistical constraints (i.e., time and data availability) facing the analysts. The herring model consisted of multiple operating models representing different observed states of nature for the population dynamics of herring. Having the population dynamics based on observed changes in herring is a key strength of the model, although consideration of some more extreme changes would have

Atlantic Herring MSE Individual Panelist Report: Dr. John Wiedenmann
evaluated control rule robustness across scenarios outside the realm of what has been observed for herring. In addition, there appeared to be a negative correlation between the total biomass of herring and size at age of herring, suggesting possible density-dependent growth. Inclusion of such a mechanism is warranted in future model runs, as there may be some interesting interactions with the performance of particular control rules. The herring model used a “simple” assessment approach that mimicked a full assessment by generating assessment estimates of abundance as an autocorrelated error process about the true herring abundance. This simple assessment approach is an effective alternative to including a full assessment model, particularly when it is not feasible to do so, and it also allows for the inclusion of bias in estimates (as was done for herring) without explicit knowledge of the potential sources of that bias. In the case of herring, time constraints and the large number of control rules being tested prevented the inclusion of a full assessment model. However, the level of error assumed in the simple assessment approach was low compared to some other studies, and additional exploration of the greater assessment error is suggested.

Time series’ of biomass estimates from the herring model were then used in models of predator population dynamics to understand the potential impacts of changes in herring abundance on the predators. Thus, the link between herring and predators was unidirectional, i.e., changes in predator abundance did not impact the natural mortality rate of herring. Although such an inclusion would be more biologically realistic, all herring predators would need to be included (not just the select ones that were chosen), and the data and time to do so were not available. Predators were selected with input from stakeholders at the workshop (Bluefin tuna, common terns, and spiny dogfish), and were treated as representative of other predators in region, and different mechanisms were explored to try to link predator success with herring abundance. This assumption is useful for the purposes of the MSE and necessary given the limited information for many species in the region. A key strength of the approach used is that the analyses for selected predators were limited the available data for each predator, such that assumptions were not borrowed from other species / regions when information was lacking. However, in some cases additional analyses could have been conducted to identify links between predators and herring. For example, growth anomalies were considered for tuna but not groundfish. Rather than using abundance of predators as a dependent variable to identify relationships with herring, it may be more useful to consider deviations in surplus production of a predator population in response to herring biomass or proportion of herring in the diet.

Overall the herring and predator models were developed rigorously with sufficient consideration given to the available species, datasets and predator-prey linkages. Although there is room for improvement in both models, the current limitations identified do not prevent the use of this model in making decisions about ABC control rules for herring.

c. Methods to evaluate the control rules and performance metrics

The methods in the MSE to evaluate control rule performance were robust, and the performance measures were an effective means of summarizing results. A large number of control rules were tested and many performance measures were calculated for each run of the model. As such, it was not feasible to review all performance measures across each control rule from each operating model, and the panel was only presented a subset of performance measures with control rules grouped into broad categories. From this sample of results some of the tradeoffs were apparent, and some general patterns emerged of performance across the broad control rule groupings. For
the predator models the results were grouped by broad control rule category and by operating model, making it clear when results were more sensitive to the herring operating model or to the different control rules being evaluated. Although performance measures were clear to the review panel, they may not be clear to managers and stakeholders, and how the model results can be best presented to a broader audience should be given considerable thought. Effectively summarizing output from a complex MSE model is a common challenge, and this will likely be a very useful exercise in learning how to best translate model results to a broader audience.

2. Evaluate whether the methods, data, and results of the MSE are sufficient for the New England Fishery Management Council to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. Comment on any constraints that may hinder use of the MSE in the development of management alternatives.

The panel agreed that the entire MSE process was sufficient for the Council to evaluate ABC control rules options for the herring fishery. However, the primary caveat associated with the MSE is that control rule performance is sensitive to the many assumptions in the herring and predator models. These assumptions must be carefully articulated to managers and stakeholders so that model results are not over-interpreted. For example, herring population dynamics may deviate dramatically from various operating models considered (which were based on the observed dynamics), or certain predator populations not considered due to data limitations may be more sensitive to herring abundance. This caveat does not hinder the use of the MSE, but it does highlight the need for careful and consistent evaluation of the MSE predictions against reality.

3. Provide any recommendations for future improvements. Comments should include the following:

a. How to address any data limitations or needs

There were many data limitations identified throughout the review process, including limited spatial / seasonal information on herring distribution and predator overlap, and more generally on the abundance and diets of other herring predators. In most cases new data would need to be collected to expand the herring and predator models, but it may be possible to find existing datasets and incorporate them into the model. The dataset on common tern abundance and foraging habits in the Gulf of Maine was identified in the workshop process, and efforts to find similar datasets could be fruitful.

b. How to conduct future Atlantic Herring MSEs

The panel felt that MSEs (for herring or future stocks) should be viewed as an iterative process. This first attempt for herring was successful in the creation of the model, and also in the learning that occurred throughout the process for Council staff, the analysts, and stakeholders. It is essential for the MSE to be updated with new information as it becomes available so that control rule performance can be tested with the new information. Large stakeholder meetings may not be necessary for future herring updates, and it might be useful to establish a working group with representatives of various stakeholder groups to discuss future model revisions and results. More generally, any future MSEs undertaken by the Council should be given sufficient time, as many
of the issues identified in the herring MSE review were the result of the short timeframe. In cases where short timeframes are unavoidable, it may be necessary to partner with outside researchers to ensure sufficient effort can be devoted to complete the task.

c. How to clarify the current and future MSE final reports, including input on best practices for translating MSE results for a general audience

The current and future reports would benefit from detailed description of the results and what the implication are of those results, particularly in the figure captions. Captions in the current report are brief, making it difficult to interpret results, particularly for someone without any background in MSE or other fisheries models. Creation of some info-graphic to aid stakeholders and managers in how the MSE works would also be very helpful, and could be included in all future MSE reports or on the Council’s website. In addition, an interactive web tool that allows users to visualize the performance measures calculated for particular control rules across operating models would be very helpful.
The New England Fishery Management Council (NEFMC) conducted a Management Strategy Evaluation (MSE) of Atlantic herring to evaluate the performance of acceptable biological catch (ABC) control rules for Atlantic herring, accounting for the role of herring as forage. As part of the MSE, two large stakeholder workshops were convened to identify objectives, performance measures, and alternative control rules. The NEFSC technical team conducted a considerable amount of work, performing a rigorous set of analyses. Configurations of a single-species operating model of herring population dynamics model considered uncertainty in herring productivity and natural mortality. The stock assessment process was approximated in the MSE by considering bias and imprecision in biomass estimates from the operating model, with control rules using these biomass estimates to specify ABC within the model projections. Outputs from the herring model were used in models for herring predators given linkages between herring dynamics and predator productivity to quantify possible impacts of changes in herring population on the ecosystem. Herring operating model output was also linked to an economic analysis to understand consequences for the fishery. Results from the MSE analyses were presented in the form of tradeoff plots against the performance measures identified during the stakeholder workshops.

The review panel concluded that the MSE was appropriate for use by the New England Fishery Management Council (NEFMC) to select an ABC control rule for herring, with strengths of the process and areas for improvement. The Chair report reflects the consensus of the review panel, with additional individual comments on each term of reference below.

1. Evaluate the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules. Provide suggestions for improvements to the methods where appropriate. Evaluation should include the following:

1a. Methods to identify objectives, performance metrics, and control rules for testing (e.g. workshops to solicit stakeholder input)

The participatory approach taken during the MSE (public workshops) provided a platform for engaging a large range of stakeholders in identifying objectives and performance metrics, and is considered best practice for MSEs. There was considerable investment in education on MSE during the process and this will pay off in terms of building capability in stakeholders, scientists, and managers understanding of MSE in the region. It was noted that the technical team and facilitators at the workshops were very responsive to questions about the MSE process and the specifics of the models for herring and the predators. Having a lead facilitator at the workshops that was well-versed in MSE seemed successful.
A lot was accomplished in a single year in a successful and rigorous fashion, however the timeline certainly constrained the analyses and process. In other instances where MSE has incorporated public workshops the MSEs have typically been a multi year process, including sometimes not even with as extensive stakeholder participation. Conducting MSEs with large public involvement is a resource-heavy process and efforts that could be made to streamline the process might be helpful. Consideration of additional workshops (perhaps with smaller groups) or training opportunities, coupled with a refinement of the information gathering procedure, might help. In part, the investment in to MSE training as part of this initial herring MSE should go a long way towards improving process in future MSEs. Presentation of the technical analyses at the 2nd workshop seemed to be a lot, it is possible that an additional intermediate workshop, whether with the full group or smaller sessions (or even through an alternative venue – online?) might provide an opportunity for participants to digest the information more fully. No input was requested at the public workshops about the specifications for the operating model scenarios. This was due to the specific objectives of the MSE and the constrained timeframe. Scoping of the scenarios to be considered might have improved buy-in to the process, but this is unclear. Even if a refinement of the public process is undertaken, it is important to stress the value of a large range of engagement at the scoping phase. A benefit stressed by stakeholders was that the process allowed some a chance to participate in the Council process who felt like they don’t normally have an opportunity to participate. In general, holding public workshops as part of MSE can have/achieve multiple goals: education, buy-in to process, engagement, as well as garnering information in a participatory approach. That this appears to have occurred during the herring MSE process should be recognized as a success.

It was not clear how the information gathered through surveys at the workshop is going to be used. The technical team seemed disappointed with a lack of consensus in responses on values for performance metrics, etc. and there was indication that the results may have been the result of people misunderstanding the usage of these information, or based on expectation of other’s responses to questions (e.g. trying to game the result). Some additional investment in expertise in survey methodology, with regard to structuring worksheet questions that reveal preferences may be useful, depending on how the Council wishes to use these information when choosing among options. Consultation of literature or experts on methods for expert elicitation might be useful.

There was less time devoted to societal and economic indicators and models at the workshop than for the ecological components and objectives. Additional focus here would not only have increased the holistic nature of the analyses but may have been more aligned with stakeholder interests.

**1b. Methods to construct the Atlantic herring, predator, and economic models (e.g., structure and use of data)**

The details of model development and use of data was clearly articulated; the technical team did an excellent job of explaining model assumptions and caveats. In addition to presenting the
models and results to the Panel, the importance of effective messengers in MSE should be recognized, the technical team, Council staff, and facilitators involved in this process were very good and committed to lead people through the technical details of the MSE. The technical team took a rigorous and practical approach to including key uncertainties and creating models that allowed the control rules to be evaluated against the objectives, given the constraints (time and data availability).

Atlantic herring models:

The technical team created alternative operating models for herring dynamics that bracketed values for key uncertainties, rather than developing population dynamics models with complex time-varying dynamics of growth and mortality. This approach to considering uncertainty via extreme scenarios allows for clear treatment of the effect of the uncertainties in herring productivity on the model results and was an effective, practical choice that allowed the technical team to achieve a large amount of work within the project period. Robustness of control rules to extremes may not however be the same as robustness to time-varying dynamics. When identifying candidate control rules it will be important to consider performance of alternatives across the full range of operating models, and a control rule chosen based on its performance in a given ‘regime’ of herring productivity may need to be revisited if information suggests that the system has changed.

The stock assessment process within the MSE was represented by generating (possibly biased) abundance estimates, that were combined with knowledge of the fishing mortality rate at maximum sustainable yield in the harvest control rules. This simple approach to approximating a stock assessment was practical, and is frequently done. Inclusion of a full stock assessment model into the MSE simulations would be more representative of the process of assessing herring status, better integrate uncertainty with the estimation process, and would be a clear avenue for future applications of MSE for herring.

Mis-specification of reference points in the assessment was not considered; the control rules were applied using the known true value for the fishing mortality rate at maximum sustainable yield. An important advantage of frameworks like MSE is that it can evaluate how methods (assessments and control rules) may perform when the assumptions made are wrong. The technical team did consider this in terms of the abundance estimates, with scenarios considering the effects of bias in the abundance estimate. This might be an important thing to consider for the value of the fishing mortality rate reference point used too. A relatively simple option that might be able to be explored in the near term could be to use the reference points from the wrong operating model (rather than model bias and imprecision), a simple swap of reference points between operating model scenarios. This would be an extreme version of likely candidates for estimates of the reference points but may provide some insight into possible implications. Such a check could be done once a set of candidate control rules are identified. The technical team and panel noted that there could be a plausibility inconsistency between the information coming from
the operating model and assuming the wrong reference points, which might suggest that in practice one wouldn’t use the extreme values for the wrong reference points because the data from the system would be informative about system productivity. The values for $F_{\text{MSY}}$ from the high and low production operating models are substantially different from each other.

Note that including an assessment model within the MSE as mentioned above could provide an alternative to having to pre-define estimates for fishing mortality reference points (as they may be estimated within the model).

**Predator models:**

Models for herring predators were created based on evaluating the impacts of changes in herring dynamics on a set of predator species for which data were available, with these species being used as representations for the likelihood of impacts of herring ABC control rules on predators. The technical team took a data-driven approach to modeling and hypothesis creation, and models and scenarios were built off of what people asked for during the workshops. Data for the three predator species models (bluefin tuna, common terns, and spiny dogfish) and the mechanistic links between herring and predators were then based on regional information rather than using assumptions from other areas or species. The linkages between the herring and predator models were limited to the effect of herring on the predators, rather than including effects of predators on herring mortality in the herring operating models. This predator model approach was appropriate to the goal – identifying how ABC control rules for herring might impact predators. While two-way predator-prey modeling is more realistic, the data (needed for all predators) and time to develop such models was not available.

Preliminary explorations using a food web model (EwE) were done to explore systemic effects of changes in herring biomass, but the technical team emphasized that these analyses would need additional attention to develop to a comparable level for the other herring models. Nevertheless, this approach could provide some context for the detailed MSE analyses, by providing guidance on possible system response given a small subset of scenarios for herring fishing (that might approximate alternative ABC control rules). An intermediate level of ecosystem model (MICE model) that included feedbacks would be different from these models and require data for different species because the predators causing mortality on herring are not necessarily those that are most dependent on herring.

The predator models used available data to quantify mechanistic links between herring and predators, but did not consider the effects of availability of alternative prey. Capturing the dependence of predators on herring given variability in the presence or otherwise of other prey might be important in future versions of predator models for a herring MSE. Including variability (process error) in predator population dynamics models would also allow for the potential impact of herring on predator dynamics to be placed in context – predator populations may drop below reference points due to variability not associated with changes in herring abundance.
Overall the herring and predator models were well-developed with appropriate consideration of uncertainty in dynamics, links, and data availability for the species. While the panel identified some caveats, these do not prevent the use of these models for making decisions among alternative ABC control rules for herring.

1c. Methods to evaluate the control rules and performance metrics

The control rules and performance metrics were developed through stakeholder input at the public workshops; the panel agreed this was a good approach. The range of performance metrics for evaluating the MSE results that were considered covered the normal range of metrics that are typically used, although these focused (by objective) on long-term performance rather than short-term effects. The metrics used for the predators were appropriate. The ‘streakiness’ metric seems useful and could be applied to quantities besides the economic component of the analyses (e.g. quantifying the number of years in a row that overfishing occurs, or number of years in a row that tern productivity is less than 1). Reflective of the workshop process, the control rule shapes investigated were the types of control rules that stakeholders said they were interested in.

A challenge common to all MSEs is how to effectively summarize and evaluate the quantity of output – a large number of control rules were tested for each scenario, and many performance metrics were calculated for each. The methods used to evaluate the results and tradeoffs among performance metrics were effective, but the large number of options meant that the panel was not presented with opportunity to evaluate the performance of individual control rules across all scenarios and metrics. Pre-filtering options before a final workshop may be appropriate in terms of reducing the number of candidates, and this can probably be done to some degree without making value judgements about preferred values for performance metrics (some options will produce unviable or illegal outcomes).

Boxplots were used effectively to show how performance of control rules varied across the different factors in the analyses, and more use of these could be made to present the results across additional factors (e.g. shape of control rule, location and magnitude of breakpoints, etc.). The technical team also presented results in terms of trade off plots for the average behavior (medians of performance metrics) of individual control rules for particular shapes, as well as ‘window’ plots that show the variability in performance within a particular control rule. These window plots were shown for a arbitrary set of control rule shapes, however they could be useful in exploring tradeoffs once the number of candidate control rules has been narrowed down significantly (it may be difficult to view more than 5 of these at once). An additional way of presenting the sensitivity of control rules could be to display additional quantiles, or the interquartile range, for performance metrics, rather than the median. A strength of the presentation of results is that the technical team showed the performance of the status quo control rule along with the many alternatives. This allows the performance of alternative ABC
control rules for herring to be viewed in the context of how the current management approach could be expected to perform.

When choosing among options, care should be taken to not disregard individual control rules that may meet objectives but are presented with others that do not – for example, viewing the output solely by control rule type may lead to removal of candidate control rules that perform well if the control rules as a whole are judged on the apparent aggregate behavior of the group.

How the model results can be communicated effectively to broader audiences will require some thought and additional time. A scoring procedure for control rules could be applied to help evaluate options – if the responses from workshop surveys about the preferences for metrics stated at the workshop are deemed representative, then it would be possible to summarize performance of control rules with respect to the degree to which they meet these preferences. In general, multiple media may work best in presenting information and evaluating control rules.

2. Evaluate whether the methods, data, and results of the MSE are sufficient for the New England Fishery Management Council to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. Comment on any constraints that may hinder use of the MSE in the development of management alternatives.

The structured approach to decision-making provided by the MSE analyses provides a better means for weighing options than currently exists. The panel agreed that the MSE methods, data, and results were sufficient for the Council to evaluate ABC control rule alternatives for the herring fishery. Many of the above suggestions and improvements would require additional time, and none of the constraints above should prevent the NEFMC from using the results to select/choose among ABC control rule alternatives. However, it is important that control rules are evaluated in the context of the assumptions against which they were tested. Decisions could be made about how to identify when to iterate or revisit the operating model dynamics, perhaps when observations are made that lie outside the realm of what was tested in the MSE. One approach for identifying these could be to obtain the predictive distribution for the range of biomasses that were observed in the MSE.

A possible constraint could be the ability to weight objectives and state preferences for particular values for the performance measures when trying to choose among alternatives. Evaluation of performance should be against stated objectives, so as a filtering step in identifying alternatives it may be OK to remove options that don’t do well in any of the cases for any metric. When choosing among options, a potential difficulty may arise when a given control rule might not be robust to operating model uncertainty but perform well in some cases. Once a small set of candidate control rules are chosen, there may be value in testing these against a set of additional uncertainties (identified by the panel in the Chair report) to evaluate sensitivity of performance.
3. Provide any recommendations for future improvements. Comments should include the following:

3a. How to address any data limitations or needs

The panel recognized that there were several data limitations and needs for further development of the models and MSE analyses. Some of these were linked to the time constraints of the process, but in some cases additional data may need to be collected. Some data may be available already, but time would be needed for compilation and synthesis. Given additional time and resources, a discussion on operating models and operating model scenarios at workshops would be recommended. It is probable that data and analysis needs can be separated into short- and long-term needs. A strategic approach to investment in work to address these needs could be made based on the expectation of adding value to the product. The MSE analyses themselves could be used to identify areas where addressing uncertainty could aid in understanding performance of control rule options. Many analyses that could be undertaken to provide information to address key uncertainties could be done separately from the MSE process, for example: statistical analysis of seabird data, updates to foodweb models, spatial dependence of prey and predators, etc. The economic models would benefit from further analyses and some of these are already planned.

3b. How to conduct future Atlantic Herring MSEs

The panel agreed that this first MSE for Atlantic herring had been successful and instructive for implementation of MSE in the region, and that a considerable amount of education and training had occurred in the region on understanding of what MSE is and how it can be used. Additional training opportunities could be done through other regional programs or be achieved through additional material ahead of meetings, perhaps in the form of instructional videos (e.g. recordings of presentations from the 2016 public workshops).

Additional iterations of MSEs for herring should consider the overall timing of the process, with perhaps a change in the expectations for the timeframe needed to complete the process and analyses. The panel recognized that MSE is an iterative process and that future MSEs for Atlantic herring should build from experience and analyses conducted in this first MSE, with development/updates of models when data becomes available. Part of the next iteration should include an evaluation of the workshop process, what worked and what didn’t, with discussion on alternatives for this process that maintain both broad participation but also provide specific relevant and useful advice. An increased emphasis on the economic and social science components of the analyses should be made during stakeholder workshops. The technical team mentioned that support for preparation of visuals for workshops and reports was needed.

Future MSEs for herring should more fully consider dimensions and more options for various sources of uncertainty. This would include the implications of getting things wrong in the assessment and management procedure. Consideration of alternative operating models could also
extend to the predators, and human parts of the modeling analyses too, in addition to herring. In addition, alternative model frameworks (MICE models, foodweb modeling, spatial modeling) could also be considered. Spatiotemporal issues are clearly important to stakeholders. All these analyses will require time, resources, and compilation of existing and collection of new data, and priorities must be balanced based on objectives and needs. However, these may provide the opportunity to extend analyses beyond thinking about MSE as a way of setting a ABC control rule but more about management of the socio-ecological system surrounding the herring fishery as a whole.

3c. *How to clarify the current and future MSE final reports, including input on best practices for translating MSE results for a general audience*

The current reports provided concise and clear descriptions of the modeling methods. The presentation of the vast quantity of results could be improved by adding more text summarizing the results and more descriptive Figure captions that walk readers through the tradeoff analyses. Several alternative presentations of the results might aid a range of audiences and it is likely that different versions of the report and results might be the best way of effectively communicating the results to the different intended audiences. Once a set of candidate control rules have been selected, some additional Figures and Tables summarizing the performance of these against all operating model scenarios and uncertainties will be needed. Infographic-type summaries of MSE and the results could be presented on the Council website. Summary reports should be focused around key questions to help guide users/readers through the results. Creation of a user-friendly, interactive format for visualization of results, say through a web-based tool (e.g. R Shiny app) that allows users to compare control rules and tradeoffs among metrics, would be very useful for this and other MSEs.
APPENDIX B: Terms of reference for peer review

TERMS OF REFERENCE FOR THE PEER REVIEW
of the
Management Strategy Evaluation (MSE) of
Atlantic Herring Acceptable Biological Catch (ABC) Control Rules

The peer review shall be conducted based on the following Terms of Reference (TORs):

1. Evaluate the strengths and weaknesses of the MSE methods used to evaluate Atlantic herring ABC control rules. Provide suggestions for improvements to the methods where appropriate. Evaluation should include the following:
   a. Methods to identify objectives, performance metrics, and control rules for testing (e.g. workshops to solicit stakeholder input)
   b. Methods to construct the Atlantic herring, predator, and economic models (e.g., structure and use of data)
   c. Methods to evaluate the control rules and performance metrics

2. Evaluate whether the methods, data, and results of the MSE are sufficient for the New England Fishery Management Council to use when identifying and analyzing a range of ABC control rule alternatives for the Atlantic Herring Fishery Management Plan. Comment on any constraints that may hinder use of the MSE in the development of management alternatives.

3. Provide any recommendations for future improvements. Comments should include the following:
   a. How to address any data limitations or needs
   b. How to conduct future Atlantic Herring MSEs
   c. How to clarify the current and future MSE final reports, including input on best practices for translating MSE results for a general audience
APPENDIX C: Peer review meeting agenda

AGENDA\(^1\)

of the

NEFMC External Peer Review

Management Strategy Evaluation of

Atlantic Herring Acceptable Biological Catch Control Rules

Location: Embassy Suites Boston, MA

Date: March 13-15, 2017

**Day 1: Monday, March 13, 2017**

9:00 Executive Director’s Welcome – *Tom Nies*

9:05 Panel Chairman’s Opening Remarks – *Dr. Lisa Kerr*

- Introductions
- Agenda overview
- Conduct of meeting

9:15 Review Terms of Reference – *Deirdre Boelke*

9:30 Introduction to the Management Strategy Evaluation of Atlantic Herring ABC Control Rules – *Dr. Rachel Feeney*

- Management context
- Timeline
- Process for stakeholder input

9:50 Report of Technical Group – *Dr. Jon Deroba, Dr. Sarah Gaichas, Dr. Min-Yang Lee*

- Herring operating models, control rules, output metrics
- Predator models and output metrics
- Economic model and output metrics

10:30 Break

10:40 Report of the Technical Group CONTINUED

12:00 Lunch

\(^1\) All times are approximate, and may be changed at the discretion of the Chairman. The meeting is open to the public. During scheduled “Public Comment” periods, the Chairman will welcome questions, clarifications, and opinions when noted. Each person will have a time limit set by the Chair.
1:00  Report of the Technical Group CONTINUED
2:30  Public Comment on presentations (clarifying questions and corrections only)
2:45  Break
3:00  Panel Discussion – TOR #1
4:30  Public Comment on TOR #1 only (questions and opinions invited)
4:45  Conclude Day 1, Charge for Day 2 - Chairman
5:00  Adjourn

Day 2: Tuesday, March 14, 2017
9:00  Charge for Day 2 - Chairman
9:05  Panel Discussion – TOR #1 CONTINUED
10:00 Panel Discussion of TOR #2
10:45 Break
11:00 Panel Discussion of #2 CONTINUED
11:45 Public Comment on TOR #2 only (questions and opinions invited)
12:00 Lunch
1:00  Panel Discussion of TOR #3
2:30  Break
2:45  Public Comment on TOR #3 only (questions and opinions invited)
3:00  Report Writing\(^2\) (with presenters in attendance)
5:00  Adjourn

Day 3: Wednesday, March 15, 2017
9:00  Review Key Findings - Chairman
9:30  Report Writing CONTINUED
1:00  Adjourn

\(^2\) The “Review Key Findings” session scheduled for the afternoon on Day 2 and the morning of Day 3 is primarily intended for the Panel to discuss and write its report. This agenda item is open to the public to observe, but there will not be a public comment period.
APPENDIX D: Public Attendance at MSE Peer Review

March 13, 2017

In-Person:

Morgan Callahan
Bill Hartford
Jeff Kaelin
Rich Ruias
MaryBeth Tooley
Chris Weiner
Greg Wells

About 20 individuals participated via webinar.

March 14, 2017

In-Person:

Jeff Kaelin
MaryBeth Tooley
Greg Wells

About 15 individuals participated via webinar.

March 15, 2017

In-Person:

None

About 5 individuals participated via webinar.
Management Strategy Evaluation (MSE)
Preface


The document first gives a background to what Management Strategy Evaluations are, and when they might be useful, before focusing on the specifics of the herring analyses.

Acknowledgements:
Amanda Hart and Gavin Fay, University of Massachusetts Dartmouth
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## Management Strategy Evaluation

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## Atlantic Herring MSE

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What is Management Strategy Evaluation (MSE)?

Process for:
• Comparing the performance of options for management (strategies) under multiple (& often conflicting) objectives
• Examining impacts, tradeoffs, & robustness of management options
• Understanding how outcomes from management may be sensitive to uncertainty

MSEs typically involve computer simulations with the entire fisheries management process represented within the model. This includes:
• the dynamics of the fished resource
• results of monitoring and stock assessment
• management actions with feedback to fishery

MSEs can act like a flight simulator or crash test for management: try different choices for management in the computer and see how they do.

MSEs require:
• clearly specified objectives
• metrics to determine performance against objectives
• what management choices to test

Stakeholder processes can help define these objectives and performance measures, allowing diverse set of interests and goals within the evaluation.
Why do MSEs?

- Evaluate full management cycle
- Compare relative effectiveness of management strategies for **achieving multiple management objectives**, and to quantify tradeoffs.
- Identify sensitivity of management performance to system drivers and key uncertainty
- Simulation cheap, Experimentation expensive
- Play out ‘what if’ scenarios when truth is known, and there are no real negative consequences of poor options

Conceptual overview of adaptive management cycle. MSE comprises the right and lower sections.
Advantages

- Forces explicit consideration of objectives
- Increases participation
- Allows testing of likely performance of a broad range of management actions
- Feedback control allows whole management cycle to be evaluated
- Can quantify tradeoffs in management performance across multiple management objectives
- Identify management strategies that are unlikely to meet objectives.

Considerations

- Complex, specialized expertise required
- Challenge to communicate complicated results
- Development can be lengthy
- Social factors are hard to handle
Identifying Management Objectives

Clearly specified management objectives are extremely important for management strategy evaluations.

MSE is at the interface between science and decision making
  • Scientists:
    – Identify the hypotheses to be represented.
    – Represent the objectives quantitatively.
    – Identify factors that could be used in management strategies.
  • Stakeholders / decision makers / advocates:
    – Identify management objectives.
    – Identify candidate management strategies.
    – Make decisions on the final management strategy.

Clear objectives make it easier to assess how well a given management option performs compared to others.

Broad high-level objectives (e.g. conserve the stock, maximize yield) can be unpacked into operational objectives that can be quantified with performance statistics.

Objectives are unlikely to be self-consistent (e.g. maximize yield and minimize risk). This is OK.

Ideally, objectives should be selected by the decision makers and stakeholders.
### Typical Management Process

| Who sets management objectives? | • Fishery managers |
| What management objectives can be compared simultaneously? | • Biomass  
• Yield  
• Frequency of fishery closure  
• Revenue |
| | • Biomass  
• Yield & interannual variability  
• Frequency of fishery closure  
• Revenue  
• Predator considerations  
• Habitat  
• Bycatch  
• Employment  
• Others |

Not all MSEs will consider all objectives all the time.
Testing Management Options

Operating Models
Operating models reflect different possible states of nature, allowing us to account for uncertainty in our understanding of system dynamics.

Operating models can address uncertainty in:

- Fish population parameters: How fast are fish growing? How productive is the stock?
- Monitoring: How accurate are observations from the fishery?
- Assessment bias: How well does the stock assessment do at estimating true population size?
- Predator-prey interactions: How are we accounting for causes of mortality other than fishing?
- Fishing mortality: How well is the fishing process characterized in the model? (e.g. are incidental and discard mortality included)
- Response to management actions: How is the fishery able to adjust to changes in management, are there other constraints?
- Effects of environmental drivers: Do fish recruitment, availability, growth, etc. depend on environmental conditions?
- Stock and spatial structure: Does the spatial extent of the assessment and management match the fish population structure and the geographic makeup of the fishery?

Not feasible to capture every uncertainty, but perhaps can focus on elements most important for management questions and that are more likely to be primary sources of uncertainty in outcomes. Looking across a range of uncertainty helps understand whether management options perform well even when true dynamics are not well understood.
Management Options

Management strategies (options) comprise specifications for:

- What data will be available to make decisions
- What estimation procedure (e.g. stock assessment) will be applied to these data
- A control rule that determines how the assessment results are translated into management action.

Assessment procedures can be simple (e.g. based on empirical data) or complex (e.g. based on result of complicated stock assessment model). Simple procedures are often incorporated into the control rule.

Control rules (generally) specify a target amount of catch or fishing mortality rate based on some measure of recent stock abundance (biomass).

Many control rules exist. Three generic types include:

- ‘constant catch’: the same amount of fish is harvested regardless of abundance. So as abundance declines, the fishery removes a larger proportion of the stock.
- ‘constant fishing mortality’: the same fraction of the population is harvested regardless of abundance. Catch increases linearly with abundance.
- ‘biomass based’: the fishing mortality rate changes depending on fish abundance. Typically fishing mortality rate increases with abundance to some maximum rate. The change in fishing mortality can vary; fishing mortality does not need to equal zero at a particular level of abundance.
Variations to these basic control types can produce a broad range of results.

Some characteristics of a control will be defined by law.

Previous research may also inform decisions about what control rules to not try in the MSE because they are unlikely to meet fishery objectives.
Evaluating Management Performance

The definition of management success depends on the priorities of different stakeholders, represented by a range of management objectives that are often in conflict. A major benefit of Management Strategy Evaluation is the ability to consider such trade-offs between conflicting management objectives.

How do we examine trade-offs between conflicting management objectives?

Performance statistics/measures are used to relate the analysis results to the management objectives.

- e.g. if an objective is to ‘keep the stock above a specific biomass limit’, a performance measure might be how often the stock remained above that limit.

Performance statistics are quantitative measures that can be used to score results against particular objectives.

- e.g. if an objective is to keep year to year changes in catch low, then a performance statistic could be the average percentage change in annual catch (or interannual catch variability), and lower values would score higher.

Desirable to identify threshold values for the performance statistics that correspond to satisfying an objective (e.g. values associated with “minimum performance”, “desirable outcomes”, etc.). This encourages focus on identifying satisfactory solutions across objectives rather than trying to optimize outcomes for particular objectives.
• e.g. if an objective is to ‘maximize catch relative to maximum sustainable yield’, minimum performance level of (say) 65% could be set, with no consideration of control rules that produced values lower than this. But another threshold of (say) 80% could be used to identify control rules that perform better.

The range of performance statistics should cover the full range of the objectives being considered.

The values for performance statistics obtained from different management options can then be compared with each other using graphic output, decision tables, and tradeoff plots.
Evaluating Management Performance: Radar Plots/Web Diagrams

How to read:
- **Worst performance** = Option appears closer to the center
- **Best performance** = Option appears toward the outer edge
- **Metrics may:**
  1. Show consistent performance across management options
  2. Have a consistent gradient of performance from bad to good depending on management option
  3. Have variable performance based on management options

Things to keep in mind when considering the results:
- These plots show **relative performance**, the best and worst performing management options may all fall within acceptable performance ranges.
- The performance of different management options may differ based on the chosen operating model, indicating that our understanding of nature may impact the success of management. An option that does well regardless of operating model is **robust**.
Evaluating Management Performance: Decision Tables

How to read:

- Each table contains values for a single performance metric which reflects a single management objective, evaluated across a range of management options and states of nature (operating model).

- Next to the performance metric title, an icon that indicates the valued ecosystem component(s) associated with the metric. Example valued ecosystem components are: the species targeted by a particular fishery; the non-target or bycatch species caught incidentally; impacts on predators if the target species is a prey item, etc.

- Each vertical column represents a different management option.

- Each horizontal row is an operating model representative of a different state of nature.

- **Worst performance** = lightest shade of green in each row.

- **Best performance** = darkest shade of green in each row.

- The actual value of each performance metric is printed below the colored bars for each operating model and management option combination.

- The last row in the table summarizes the relative rank of management options across all operating models.
  
  - **Best possible summarized rank** (management option performs best for all operating models) = 72 (a max of 8 across all operating models and a max of 9 for the top rank across all management options (8x9 = 72).

  - **Worst possible summarized rank** (management option performs worst for all operating models) = 8.
Things to keep in mind:

- Colored bars show relative performance, the best and worst performing management options may, in actuality, have very similar performance with very similar values for the metric. Even if an alternative ranks last, or the worst, it may still perform satisfactorily for a particular metric, just not as well compared to the other options considered.
## Evaluating Management Performance: Decision Tables

### Operating Models: Possible states

<table>
<thead>
<tr>
<th>Operating Models</th>
<th>Control Rule Options 1</th>
<th>Control Rule Options 2</th>
<th>Control Rule Options 3</th>
<th>Control Rule Options 4A</th>
<th>Control Rule Options 4B</th>
<th>Control Rule Options 4C</th>
<th>Control Rule Options 4D</th>
<th>Control Rule Options 4E</th>
<th>Control Rule Options 4F</th>
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<tr>
<td><strong>Summary</strong></td>
<td>36</td>
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<td>50</td>
<td>51</td>
<td>40</td>
<td>51</td>
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</tbody>
</table>

### Valued Ecosystem Component icon

### Management Options

**Yield Relative to MSY**

- **A**
- **B**
- **C**
- **D**
- **E**
- **F**
- **G**
- **H**

**Summary Row**
Evaluating Management Performance: Valued Ecosystem Component (VEC) Tables

How to read:

- These are a select number of metrics chosen to represent an overall impact for a particular valued ecosystem component.
- Each column represents a different management option
- Each row represents the ranked summary of a single performance metric across operating models
- Within each row:
  - Best performance = darkest shade of green
  - Worst performance = lightest shade of green
- The best possible summarized rank value for a management option that performed best across all operating models = 72
- The worst possible summarized rank value for a management option that performed worst across all operating models = 8

Things to keep in mind:

- These ranked summaries can also be found in the last row of individual performance metric decision tables.
- Colored bars show relative performance of different management options, the best and worst performing management options may all fall within acceptable performance ranges.
- Valued Ecosystem Component (VEC) Tables contain the ranked summary of performance metrics across possible states of nature. To understand differences in performance across the states of nature, individual performance metric tables should be examined.
Evaluate Management Performance: Valued Ecosystem Component (VEC) Tables

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Control Rule Options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Probability of Overfished, B &lt; 0.5 Bmsy</td>
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<tr>
<td>Prop Year Overfishing Occurs, F &gt; Fmsy</td>
<td>8</td>
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<tr>
<td>Yield Relative to MSY</td>
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<tr>
<td>Yield</td>
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<td>Prop Year Closure Occurs</td>
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<td>Net Revenue for Herring</td>
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<td>Prop Year Net Revenue at Equilibrium</td>
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<tr>
<td>Interannual Variation in Yield</td>
<td>26</td>
</tr>
</tbody>
</table>
Glossary


2. Operating model (OM): model which represents the real world resource and fishery dynamics, used as the basis for testing management options. Multiple operating models can be considered, each representing a possible state of nature.

3. Management strategy: Combination of monitoring, assessment, and management control rule used as the basis for management advice. In the MSE, the output from the management strategy is applied to the operating model to update the system dynamics.

4. Assessment model: Method for determining stock status, the results of which are used by the control rule.

5. Harvest control rule: Relationship describing how the results of the assessment are translated into advice for management (i.e. turns the assessment result into an allowable biological catch).

6. Management Objective: Desirable outcomes from management. Objectives can include ecological, economic, societal goals. High level goals/objectives (e.g. what would like) can be unpacked into operational objectives (e.g. how much?).

7. Performance metric: Specific quantitative measure that represents a management objective and can be used to evaluate progress towards that objective.

8. Trade-off: Degree to which performance against a set of management objectives are related. A strong tradeoff between two objectives implies that gaining on one means forgoing the other.

9. Valued Ecosystem Component: an element of the environment that has scientific, economic, social or cultural significance. Example valued ecosystem components are: the species targeted by a particular fishery; the non-target or bycatch species caught incidentally; impacts on predator species.
Amendment 8 Herring Management Strategy Evaluation (MSE)
Herring MSE Timeline

The MSE conducted as part of Amendment 8 was a commitment by NEFMC with the NEFSC to develop a stakeholder driven MSE in New England.

The MSE completed to support this has provided extensive analysis needed to support decision making that evaluates the tradeoffs of management objectives with respect to net benefits to the nation.

In 2015, the Council initiated, conducted public scoping, and set the goals of Amendment 8 to the Atlantic Herring Fishery Management Plan.

In January 2016, the Council approved conducting a MSE to support the development of alternatives regarding the Allowable Biological Catch (ABC) control rule.

The Council aimed to use MSE as a collaborative decision-making process, involving more upfront public input and technical analysis than usually occurs through the amendment development process.

MSE was used here to help determine how a range of control rules may perform relative to potential objectives.
MSEs typically take several years to complete and involve a closed, small group (15-25) of stakeholders. The Council diverged from this norm for two reasons:

1. The Council aims to use the ABC control rule adopted through Amendment 8 in developing the herring fishery specifications for 2019-2021, resulting in a constrained time limit.

2. The Council decided to have all points of stakeholder input (e.g., workshops) completely open to the public, to have the MSE process mirror the open Council process as much as possible.

The Council completed the MSE within two years, proceeding in six distinct phases:

**Herring Amendment 8 Timeline**

- **Amendment 8** initiated to consider a long-term ABC control rule that accounts for role as forage and optimum yield
- Public workshops identify performance metrics for Management Strategy Evaluation (MSE)
- Narrow number of control rules to consider from 40,000 to 9
- Interpret & visualize results of the Management Strategy Evaluation (MSE)
- Council review MSE results & public comment
- In the future: Select and implement a long-term ABC control rule

2015 2016 2017 2018
Amendment 8 ABC Control Rule Alternatives

9 Control rule alternatives plus No Action:

15 Ways to evaluate impacts on the ecosystem:

2 Alternatives for control rule implementation:

- Herring
- Economic
- Predators

1 Year
Set for 3 years
but ABC can vary

3 Year
Set for 3 years at constant ABC
Picking Objectives and Performance Metrics

Management objectives that could be addressed in the MSE were identified in stakeholder workshops. Fourteen performance metrics were selected to represent these objectives. A fifteenth metric looking at stationarity of net revenue was recommended by the analysts performing the MSE.

Below is the resulting list of metrics:

**Herring**
- Proportion of years $B < B_{\text{MSY}}$
- Probability of overfished $B < 0.5 B_{\text{MSY}}$
- SSB relative to unfished biomass
- Proportion of years SSB $30-75\%$ of SSB zero
- Surplus production
- Proportion of years when overfishing occurs $F > F_{\text{MSY}}$

**Economic**
- Yield relative to MSY
- Yield
- Proportion of years when closure occurs
- Interannual variation in yield
- Net revenue for herring
- Stationarity of net revenue

**Predators**
- Tuna Weight Status
- Proportion of years with good dogfish biomass
- Proportion of years when tern production $> 1$
Testing Management Options: Operating Models

The operating model comprised three models:
- a Gulf of Maine/Georges Bank Atlantic herring model,
- a model of Atlantic herring predators,
- and an economic model.

NEFSC MSE analysts developed these models using all available data on herring and other species in the region.

Herring models: 8 age-structured herring operating models were created to evaluate the effects of uncertainties identified through the first public workshop.

Each operating model had 3 components:
1. Growth: recent/old
2. Assessment bias: biased/unbiased
3. Productivity: high/low

<table>
<thead>
<tr>
<th>Operating Model</th>
<th>Growth</th>
<th>Assessment Bias</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Old</td>
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<td>Low</td>
</tr>
<tr>
<td>B</td>
<td>Recent</td>
<td>Biased</td>
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<td>C</td>
<td>Old</td>
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<td>D</td>
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<td>H</td>
<td>Recent</td>
<td>Unbiased</td>
<td>High</td>
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</table>
**Predator models:** The predator modelling was based on public input at the first workshop, as well as the scope and timeline specified by the Council. The primary predator types identified at the workshop were: highly migratory species (tuna), groundfish, seabirds, and marine mammals.

Three predator population models (for bluefin tuna, common tern, and spiny dogfish) were developed and an existing food web model (for marine mammals) was used, with several noted data limitations and assumptions for each.

The purpose here was to help compare the relative performance of control rules, not necessarily to create perfect population models for the predators.

Predator models in this MSE identified how a predator may react to having different amounts of herring in the ecosystem, which is driven by the chosen control rule.

Not all predator metrics reacted to the control rules, in some cases because of data/model limitations and in other cases there was evidence to support that they would not be expected to react.

**Economic models:** A “New Price” model was created that used the herring price and fishery costs data and assessed yield and profit for the herring fleet as well as stationarity, or stability in herring yield.
Testing Management Options: Harvest Control Rules

Several basic control rule categories were evaluated (e.g. constant catch, biomass based, etc.), as well as several variations in the time frame these control rules were applied revising the ABC within the MSE simulations (e.g. annual, every three years, etc.).

For each combination of control rule shapes and operating model, 100 simulations were conducted, each for 150 years, and the results summarized for the last 50 years of the model projections to produce the sets of performance metrics (e.g. proportion of years overfishing occurs).

Over 40,000 control rule shapes were evaluated. Of these, 9 control rules were chosen for consideration.

Things to keep in mind:

- Control rules 1 & 2 represent strawman harvest control rules
- Control rule 3 represents a “no-action” alternative
- Control rules 4A-4F represent harvest control rules which met the criteria of good performance for:
  - High yield relative to MSY
  - Low interannual variation in yield
  - Low proportion of years when fishery closes
  - Low probability that stock is overfished (Biomass is below 0.5 B_{MSY})
- Control rules 4A-4D have similar shapes & perform similarly to one another
- Control rules 4E – 4F have similar shapes & perform similarly to one another
Testing Management Options: Harvest Control Rules

![Graph showing different control rules and their effects on SSB/SSB_{MSY} ratio]

- **Control Rule 1 (Strawman A)**
- **Control Rule 2 (Strawman B)**
- **Control Rule 3 (Parameters upfront)**
- **Control Rule 4A-4D (Meet Criteria 1-4)**
- **Control Rule 4E-4F (Meet Criteria 5-6)**
Evaluating Management Performance: Where to Start

15 Performance metrics reflect management objectives in three categories:

1. Herring metrics

2. Economic metrics

3. Predator metrics

5 Valued Ecosystem Component (VEC) tables broadly reflect these categories and provide a summarized rank of harvest control rule performance across operating models.

Individual performance metric decision tables provide more details on metrics of interest.

Things to keep in mind:

- Decision tables and VEC tables coloring reflect relative performance. The best and worst performing management options may all fall within acceptable performance ranges, so it is worth looking closely at performance metric values for metrics of particular interest to you.

- Performance of different management options may differ based on the chosen operating model, indicating that our understanding of nature may impact the success of management.
Evaluating Management Performance: Where to Start

Valued Ecosystem Components

<table>
<thead>
<tr>
<th>Category</th>
<th>Icon</th>
<th>Description</th>
<th>Full Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological</td>
<td></td>
<td>Herring Resource</td>
<td>pg #287</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Predator species (non-protected)</td>
<td>pg #332</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Protected resources &amp; ecotourism</td>
<td>pg #339</td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td>Herring, mackerel, &amp; lobster fisheries</td>
<td>pg #379</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Predator fisheries</td>
<td>pg #380</td>
</tr>
</tbody>
</table>
Evaluating Management Performance: Where to Start

**Herring Metrics**
1. Proportion of years $B < B_{MSY}$ (pg #232)
2. Probability of overfished ($B < 0.5 \, B_{MSY}$) (pg #234)
3. SSB relative to unfished biomass (pg #240)
4. Proportion of years SSB 30-75% of SSB zero (pg #242)
5. Surplus production (pg #238)
6. Proportion of years when overfishing occurs ($F > F_{MSY}$) (pg #236)

**Economic Metrics**
7. Yield relative to MSY (pg #245)
8. Yield (pg #247)
9. Proportion of years when closure occurs (pg #251)
10. Interannual variation in yield (pg #249)
11. Net revenue for herring (pg #253)
12. Stationarity of net revenue (pg #255)

**Predator Metrics**
13. Tuna Weight Status (pg #259)
14. Proportion of years with good dogfish biomass (pg #261)
15. Proportion of years when tern production $> 1$ (pg #257)
Atlantic Herring Plan Development Team
Work in support of the Herring Committee
Regarding Localized Depletion and User Conflicts

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**INTRODUCTION**

In January 2016, the Herring Plan Development Team (PDT) was tasked by the Herring Committee (Committee) to provide data and analyses to support the development of a problem statement and related measures in Amendment 8 regarding localized depletion of Atlantic herring. Localized depletion has been a topic discussed in the herring management arena since at least the mid-2000s, when Amendment 1 to the Atlantic Herring FMP was developed. Through Amendment 1, midwater trawl (MWT) gears were excluded from Herring Management Area 1A in June-September. At that time, no data linking MWTs to localized depletion were used to support that action. The Council’s rationale was to ensure access to herring for the purse-seine and fixed gear components of the fishery and to address concerns raised by the public and the Scientific and Statistical Committee about concentrated catch inshore and need for precaution due, in part, to lack of data on the inshore resource. There was a concern that MWT was particularly prone to causing localized depletion (NEFMC 2006).

For the development of Amendment 8, the following definition of localized depletion has been used, as described in the Council’s public scoping document for Amendment 8:

“In general, localized depletion is when harvesting takes more fish than can be replaced either locally or through fish migrating into the catch area within a given time period.”

The occurrence of localized Atlantic herring depletion suggests that the removal of herring from a given area would either leave its relatively immobile predators (e.g., monkfish) with insufficient prey for some time, or that relatively mobile predators (e.g., cod, tuna) would leave the area in search of alternative prey. To the degree that temporal and spatial fishery catch data are available, it is relatively simple to describe where and when fishing has occurred for herring and its predators. It is more challenging to empirically identify if and how herring’s predators and their fisheries have been impacted by herring catches. There are many constraints that determine where and when a fishery is prosecuted (e.g., area closures, weather windows, mobility of fish) that need to be understood in an investigation of whether there is causality to any correlations.

In the March 25, 2016, PDT memo to the Committee on localized depletion, the PDT noted many limits to existing data that may hinder a full evaluation of the existence and extent of localized depletion:

“Even if correlations are found between herring removals and a signal in a predator fishery or business (i.e., whale watching) that may suggest that localized depletion is occurring, the PDT expects it will be difficult to identify a causal link, using just the data available. It is not a trivial undertaking.”

On March 30 2016, the Committee considered the PDT input and developed the following problem statement, which was approved by the Council in April:

“Scoping comments for Amendment 8 identified concerns with concentrated, intense commercial fishing of Atlantic herring in specific areas and at certain times that may cause detrimental socioeconomic impacts on other user groups (commercial, recreational, ecotourism) who depend upon adequate local availability of Atlantic herring to support business and recreational interests both at sea and on shore. The Council intends to further explore these concerns through examination of the best available science on localized depletion, the spatial nature of the fisheries, reported conflicts amongst users of the resources and the concerns of the herring fishery and other stakeholders.”
The Committee further tasked the PDT with additional analyses to support the development of measures in Amendment 8 regarding localized depletion of Atlantic Herring. This appendix summarizes the PDT work on these tasks, which was also contained in memos to the Committee dated March 25 and August 9, 2016. In addition to the regular PDT members, Dr. Walt Golet (University of Maine/Gulf of Maine Research Institute); Mr. Brad McHale, Ms. Dianne Stephan and Mr. Dean Szumylo (NMFS GARFO); and Dr. John Manderson and Mr. Chris Sarro (NEFSC) contributed to this work.

March 25, 2016 Memo

This memo is intended to improve understanding of herring management and the footprint in time and space of the herring fisheries as well as fisheries or businesses (e.g., whale-watching) that rely on the predators of herring. The memo also identifies limits to existing data that may hinder a full evaluation of the existence and extent of localized depletion. The work herein is not intended to be definitive and should likely be amended (e.g., applied at different spatial and temporal scales) or expanded (e.g., use different datasets) to be more definitive.

In this memo, the PDT defines localized depletion as described in the Council’s public scoping document for Amendment 8:

“In general, localized depletion is when harvesting takes more fish than can be replaced either locally or through fish migrating into the catch area within a given time period.”

The occurrence of localized depletion suggests that the removal of prey from a given area would either leave relatively immobile predators (e.g., monkfish) with insufficient prey for some time, or that relatively mobile predators (e.g., cod, tuna) would leave the area in search of alternative prey.

To the degree that temporal and spatial fishery catch data is available, it is relatively simple to describe where and when fishing has occurred for predator fisheries. As described below, this may not be so straightforward for tuna fisheries and perhaps striped bass fisheries. It is challenging to identify if and how other fisheries have been impacted by herring catches. There are many constraints that determine where and when a fishery is prosecuted (e.g., area closures, weather windows, mobility of fish) that need to be understood in an investigation of whether there is causality to any correlations.

In Amendment 1 and more recently, much attention has been given to midwater trawls as the gear responsible for causing localized depletion. The method of removal, however, should not be relevant to the evaluation of localized depletion. If predators are responding only to herring abundance in an area, then given the same amount of catch, the same level of depletion occurs regardless of gear type and would subsequently have the same effect on predators. That said, as a relatively large and mobile gear, MTWs likely have different effects on predators than other gears commonly used to harvest similar amounts of herring (e.g., purse seines). Both gear types can be used to fish in a concentrated fashion. Issues of gear conflict should be kept distinct from issues of localized depletion. Are herring predators responding to depletion of herring (which should not depend on the gear used to remove herring), or are the predators responding to a trawl gear passing through an area (and would respond the same way regardless of herring depletion)? The former is localized depletion while the latter is not. These issues are also not mutually exclusive. Conducting field research would help determine if correlations indicate causality and avoid speculation.
**TASK #1: Forage needs**

Clarify how much herring is currently set aside (e.g., in the stock assessment) to account for the forage needs of predators? What is the best estimate of how much herring is needed for forage?

In the Atlantic herring stock assessment, the amount of herring assumed to be taken by predators (e.g., piscivorous fish, seabirds, highly migratory species, marine mammals) has varied annually (
Figure 1, dashed line). The 2015 stock assessment assumed that, during 2009-2013, an annual average of 852,000 mt of Atlantic herring was eaten by predators, which equaled 44% of average total biomass (1.92 million mt) over the same period. The amount of herring assumed to be consumed by predators in the assessment is based on natural mortality rates and estimates of herring consumption largely based on gut contents data, which also vary annually ( 
Figure 1, solid line), with an annual average of 268,000 mt during that time. The gut contents data are from NMFS surveys, and are highly imprecise and likely biased. The short-term projections used to provide catch advice (overfishing limit, acceptable biological catch) assume a similar amount of herring are consumed as assumed in the stock assessment. More information is available in the 2015 Atlantic Herring Operational Assessment report (Deroba 2015).

The Ecosystem-Based Fishery Management PDT report on scientific advice for accounting for ecosystem forage requirements (NEFMC 2015a) and assessment reports (e.g., Deroba 2015) may be referenced for sample estimates of predator consumption. In recent years, marine mammal consumption of herring is similar to commercial fishery landings, averaging 105,000 mt/year. Bluefin tuna and blue sharks have recently consumed 20-25,000 mt/year. Seabirds consume a relatively small amount of herring, conservatively estimated at about 3-5 mt/year. According to the NEFSC diet database, herring constitutes roughly 20% of the diet of cod and spiny dogfish. There is also some evidence which suggest it is not just volume of herring available, but the age structure of that forage base that is important in the energy budgets of predators (Diamond & Devlin 2003; Golet et al. 2015).

The PDT assumes that the amount of Atlantic herring needed for forage is the amount below which predators are negatively impacted. Estimates of this need do not currently exist and would vary by the abundance of predators and other prey. To summarize, consumption estimates can be generated, but that is different than what is necessary – which is a difficult question to answer definitively.
Figure 1 - Atlantic herring consumption by predators


**TASK #2: Footprint of the Atlantic herring and predator fisheries**

Identify herring fishing locations, by season and gear type; identify any evidence of pulse fishing (i.e., multiple herring vessels in a concentrated time/area).

Within the 12 nm territorial sea line, identify areas (e.g., Ipswich Bay, Nantucket Shoals) where herring fishing seasonally intensifies.

Determine and compare midwater trawl trip catches over time in each area, considering variation in tow-specific catches (accounting for tow time, number of tows, and trip duration).

Determine if, over the time of intensified fishing, catches could only be maintained by longer tows, more tows and/or longer trips, thereby indicating local depletion (e.g., $F$ much higher than $F$ set for entire stock).

Identify predator fishery (e.g., striped bass, tuna) locations, by season and gear type.

Due to time constraints, the PDT has partially completed these tasks as reported here. Data for the bottom trawl fishery are not included here, neither is an analysis of tow-specific catches over time, or predator fisheries by gear type. Information at other time scales could be provided in future as well. Data limitations are noted.

**Heat maps**

To locate effort by different fisheries in recent years, the PDT developed “heat maps” of herring revenue by midwater trawl vessels from 2000 to 2014, using a method generated by the NEFSC Social Sciences Branch (DePiper 2014). These maps use a statistical model to match Vessel Trip Report (VTR) data with observer data. The model compares haul-level observer data with the VTR point location to model the probability that an observed haul is within a particular distance.
of a VTR point. The model results are then applied to the VTR data to construct concentric rings. The lat/lon data of the trip is used along with other data, primarily days absent.

A benefit to this approach is that it does not just take a VTR point and expand it to a stat area, but takes into account the trip length, gear used, and general area of the ocean. All subtrips with a lat/lon point are used, not just observed trips. This approach is a way to resolve the limitations of having one VTR point per trip.

This probability mapping approach is a means to use the VTR position data on a grid finer than statistical area, but there should be caution in interpreting results and ensuring appropriate time scales are used. It is not possible, however, to identify catch per tow. These maps can be generated for different gears and time intervals, and for all fisheries that are in the VTR database. Maps for revenue and effort (trips) are also readily available.

Map 1 to Map 12 show, by month, the estimated landings by geographic areas fished for the herring MWT and herring purse seine (PUR) fisheries, as well as the commercial fisheries for cod, pollock), and spiny dogfish.

In January, there is a bit of overlap between the MWT fleet and both cod and pollock fisheries east of Cape Cod. It also overlaps with cod near Block Island. The same patterns exist from February through April, but there is a bit less fishing for herring than in January.

In May, there is a bit of overlap between the MWT fleet and both cod and pollock fisheries east of Cape Cod.

In June, the MWT fishery has moved mostly to Georges Bank and maybe a bit of MWT fishing in the Great South Channel. There may be a bit of overlap between the trawl fishery in block 113 with both cod and pollock fisheries. Spiny dogfish are being caught east and southeast of Cape Cod (Blocks 114 and 98), but the herring fishery is not using these areas extensively in June. July is qualitatively similar.

In August, herring, cod, pollock, and spiny dogfish are all being caught in Block 114, east of Cape Cod. There is also may be a bit of overlap between the pollock and purse seine gear just northeast of the Western Gulf of Maine Area. September is similar.

By October, the MWT fishery has moved back into Area 1A, so there is some overlap between herring MWT vessels and the three predator fisheries. This continues into November. By December, there may be a bit of overlap again, east of Cape Cod.
Map 1 - January landings 2010-2014 (pounds landed per quarter km\(^2\)). For reference, the 30 minute squares are shown.
Map 2 - February landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.

midwater trawl

purse seine

cod

pollock

dogfish
Map 3 - March landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.
Map 4 - April landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.
Map 5 - May landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.
Map 6 - June landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.
Map 7 - July landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.

- Midwater trawl
- Purse seine
- Cod
- Pollock
- Dogfish
Map 8 - August landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.
Map 9 - September landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.

- midwater trawl
- purse seine
- cod
- pollock
- dogfish
Map 10 - October landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.
Map 11 - November landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.
Map 12 - December landings 2010-2014 (pounds landed per quarter km²). For reference, the 30 minute squares are shown.
Area 1A

The Atlantic herring fishery has undergone multiple changes to its management structure in Area 1A and elsewhere since 2007. Chiefly, midwater trawls were excluded from Area 1A in June-September, starting in 2007. Additionally quota reduction in Area 1A and elsewhere have also impacted the fishery. To identify how catch and effort distributions have changed, a series of plots and graphs were produced. The goal was to examine catch and effort by area and season both before and after the series of management changes. The VTR (Vessel Trip Report) System was queried for catch and effort by gear type, location, and date. Data were only queried for catch >6,600 lbs to represent the directed fishery. From this data set, a series of graphs and maps were produced to examine changes in catch and effort across the fishery.

Examination of catch by area (Figure 2) suggests a marked change in removals by area. Post 2007 catches in the offshore areas (Areas 2 & 3) increased while catches inshore decreased. This is likely due to a number of factors, including the reduction in Area 1A quota from ~60,000 mt in 2005 to ~27,000 by 2010. Catches over all have decreased and then increased, due in part to changes in Optimum Yield and overall quotas fishery-wide.

Overall catch fishery wide has declined since 2000, while price has increased from $0.05 to over $0.15 per pound, a three-fold increase (Figure 3). This increase is thought to be largely due to the reductions in overall catch, the shift to more off-shore harvest and consolidation of the fleet given management action to control access.

Within Area 1A, catch and number of active permits has declined, due in part to reductions in quota, limited access, and exclusion of MWTs June through September (Figure 4). Despite those reductions, catch by purse seine gear per trip has increased since 2010 (Figure 5), but is variable over the time series since 2000. This suggests that, while the number of trips by purse seiners has remained fairly stable, purse seine catch has increased overall since 2010 (Figure 6, Figure 7). However, it should be noted that catch per trip by purse seine gear in Area 1A is less than what it was prior to the seasonal removal of the mid-water fleet (Figure 5). Care should be taken to not draw conclusions on stock status from catch-per unit effort data.

In Area 1A June to September, the overall number of active permits has declined, in part due to management changes listed above. However, total removal by permits has increased (Figure 8). Given the aforementioned change in price per pound, this translates into a larger ex-vessel revenue per permit since 2010: from $100,000 per permit to over $800,000 per permit in June through September (Figure 9).

An examination of map prior to and after 2007 shows some interesting changes for the purse seine fleet. Overall, catch locations have remained the same, but there seems to be an indication of a move south and west along the Maine coast in terms of intensity (Figure 10 to Figure 12). This change appears consistent June through September.
Figure 2 – Atlantic herring catch by all gear types by herring management area by year

Note: Only catches >6,600 lbs are included. Area 1B excluded.

Figure 3 – Atlantic herring catch and price per lbs, all gears all areas

Note: Only catches >6,600 lbs are included.
Figure 4 – Atlantic herring catch and number of active permits in Area 1A by year, June-September

Note: Only catches >6,600 lbs are included.

Figure 5 - Average Atlantic herring catch per trip for purse seine vessels in Area 1A, June through September

Note: Only catches >6,600 lbs are included.
Figure 6 - Annual Atlantic herring catch in Area 1A for purse seines and all gears

Note: Only catches >6,600 lbs are included.

Figure 7 - Annual number of trips in Area 1A for purse seines and all gears
Figure 8 – Atlantic herring catch and number of active permits in Area 1A, June through September by year

Figure 9 - Number of active permits and average total revenue (average catch times average price/lbs summed) in Area 1A, June through September by year
Figure 10 - Area 1A kernel density plots of herring seiner landings (>6,000lbs/trip) locations for May-June, 2000-2007 and 2008-2014.
Figure 11 - Area 1A kernel density plots of herring seiner landings (>6,000lbs/trip) locations for June-July, 2000-2007 and 2008-2014
Figure 12 - Area 1A kernel density plots of herring seiner landings (>6,000lbs/trip) locations for August to September, 2000-2007 and 2008-2014
Atlantic herring catch data from the area directly seaward of Cape Cod (Figure 13) was examined to observe the spatial-temporal distribution of effort within about 12 nautical miles of Cape Cod, to provide background to the Council for Amendment 8. For this area, Atlantic herring catches generally occur early in spring or very late in the fall to early winter. Overall, catches are episodic (Figure 11), and rarely occur more than two weeks in a row. Given that most of the catches occur during the spring and fall herring migration, it is likely that the fishery exploits herring while they are in the vicinity, but that schools of herring move too quickly through the area for sustained catches to occur; unlike the summer-time catch in the Gulf of Maine when the herring are more resident.

**Figure 13 - Map showing area of inquiry (red line) to the east of Cape Cod, Massachusetts**

*Source: Google earth (2016).*

**Figure 14 – Atlantic herring catch by week for vessels catching >6,600 lbs of Atlantic herring from the area within 12 nautical miles of Cape Cod, 2008-2014**
**Striped bass**

Information about the striped bass fishery is limited. For the recreational fishery, which occurs within the state waters of Maine, New Hampshire, and Massachusetts, the only data are collected through the Marine Recreational Information Program (MRIP). However, MRIP includes no spatial data for catch. There is no commercial fishery for striped bass in Maine, New Hampshire, Rhode Island, and Connecticut. The Massachusetts commercial fishery occurs within state waters in the summer.

The Massachusetts Division of Marine Fisheries manages the fishery using 14 statistical areas within state waters. Figure 15 and Figure 16 map the landings and CPUE (pounds per fishing hours) within each area from 2010 to 2014. Area 9, to the east of Cape Cod, has had relatively high landings throughout the time series, and areas to the east and south of Cape Cod have had relatively high CPUE. Figure 17 tracks the landings and CPUE over time each year, showing that most of the landings have occurred between mid-July and mid-August. Decreased CPUE over the length of the season could be an indicator of decreased striped bass availability, but the landings data do not show consistent increases or decreases in CPUE across seasons.

Striped bass are typically present in Massachusetts waters between May and October, yet the commercial fishery (the only source of spatial fishery-dependent data) occurs over a much narrower timeframe (Kneebone et al. 2014b). Prior to 2014, the commercial striped bass fishery began each year on July 11 and closed when the quota was exhausted, which was typically in 5-7 weeks. In 2013, the fishery closed after 5 weeks, and then reopened for an additional two weeks in late August, after it became evident that there was quota remaining. In 2014, regulations changed the fishery start date to June 23rd, and a reduced trip limit led to a more protracted season (11 weeks).

Neither recreational nor commercial striped bass fishing is allowed outside of state waters, per federal law. However, striped bass are abundant in federal waters and frequently cross this state/federal jurisdictional boundary (Kneebone et al. 2014a). Coastwide, the recreational fishery accounts for 60-70% of total removals in recent years. In Massachusetts, the recreational/commercial ratio is approximately 85%/15%.

As part of an effort to estimate the predation mortality of striped bass on Atlantic menhaden, all available data sources for diet composition of striped bass were assembled and summarized (SEDAR 2015). A total of 28 data sources were identified that included over 40,000 individual stomachs examined. On a coastwide and annual basis, herring species comprise <10% of striped bass diets. At specific times and regions (e.g., Gulf of Maine in summer/fall), Atlantic herring may comprise up to 30% of the diet.

While there are no specific rules that explicitly prevent herring MWTs in Massachusetts state waters, there are regulations that effectively prohibit this activity: 1) There is no exemption from the 6” minimum mesh size for herring fishing (as there is for the whiting and squid fisheries); and 2) A "coastal access permit" is required to fish with mobile gear in MA state waters, which has a maximum vessel length of 72 feet. There are very few coastal access permits (CAP), and there has been a moratorium on issuing new CAP permits since 1995.
Figure 15 - Spatial pattern in landings (pounds) for Massachusetts striped bass commercial fishery, 2010-2014

Source: MADMF (2016).

Figure 16 - Spatial pattern in CPUE (pounds / fishing-hours) for Massachusetts striped bass commercial fishery, 2010-2014

Source: MADMF (2016).
Figure 17 - Seasonal profile of Massachusetts commercial striped bass fishery, 2010-2014

Source: MADMF (2016).
Bluefin Tuna

Unless specifically stated in an exempted fishing permit, commercial bluefin tuna fisheries in the Gulf of Maine begin June 1st. There are three main gear types in the Gulf of Maine: general (rod and reel), harpoon, and purse seine. Bluefin tuna fishermen work off an annual TAC which is divided up amongst the categories. The general category receives the largest allocation and has within season allocations (e.g., X% of quota can be caught between June 1 and August 31). If the catch limit is reached before August 31, the fishery will close and reopen again in September. September has its own quota as does October, and then there is a winter allocation. The fishery has not closed due to reaching any of these within season quotas since the 1990s. Historically, the bluefin season runs from June through October, even into November and, in recent years, December. The length of the season is dependent on the catch rate in any particular year.

The bluefin tuna fishery is located throughout the entire Gulf of Maine. Historically, large catches of bluefin have been landed in the Kettle, Cape Cod Bay, Stellwagen Bank, Jeffreys Ledge, Great South Channel, Ipswich Bay, Platts Bank, Cashes Ledge, Georges Bank, Wilkinson’s Basin, and the Schoodic Ridges. This is not a comprehensive list, rather a highlight of some of the areas which have yielded large landings.

The Highly Migratory Species Division has informed the PDT that high resolution spatial data for bluefin tuna catches is limited. There is some spatial data for the recreational fishery as collected by the Large Pelagic Survey. The commercial catch location is recorded in the bluefin dealer data and trip reports, but the bluefin tuna reporting areas are broader in scope and differ from GARFO Statistical areas. There is some level of overlap with vessels holding both bluefin tuna and GARFO permits thereby triggering the VTR requirement, but that overlap and consistency in reporting bluefin in the VTRs has yet to be assessed.

Dr. Walt Golet (GMRI/UMO) has not examined localized depletion questions specifically, but has done a lot of research on bluefin migration and diet, and has identified correlations between Atlantic herring and bluefin tuna schools (Golet et al. 2013). Golet has been given access by tuna fishermen and dealers to their logbooks, which has spatial catch data at a finer resolution than what is submitted to NMFS. However, these data are proprietary and not available to the PDT. The fishermen have told him that there has been some confusion over time whether they were supposed to report to NMFS the area that they fished or the area of their homeport (it’s supposed to be the former). He indicated that an investigation of localized depletion would be possible, but would need to draw on many areas of expertise and involve using acoustics, vessels, and the logbook data, be a long-term project, and involve a diverse array of investigators to ensure that causality is appropriately attributed (e.g. tuna fishermen are constrained by weather windows). The biggest concern is study design; this would have to be carefully thought out and by a diverse team. Such an open process is critical for the transparency of results, the most efficient use of any funds which may be available to support this work, and for proper study design (e.g. to ensure causality is correctly identified).

Through current and prior work, Golet and colleagues have identified linkages between bluefin tuna and herring (Golet et al. 2013; Golet et al. 2015). Aggregations of bluefin and herring are associated with each other, though not all herring aggregations have bluefin present (Schick et al. 2004; Schick & Lutcavage 2009). Bluefin rely on herring for a substantial portion of their diet and come to the Gulf of Maine specifically to feed on herring as a lipid source (Golet et al. 2013; Logan et al. 2015). Bluefin has declined in mean weight and lipid reserves over time, and these
changes appear connected to declines in herring weight and size-at-age, despite high herring abundance (Golet et al. 2015; Logan et al. 2015). Golet et al (2013) have correlated herring and tuna schools, but a more thorough analysis could be completed. To date, the data have not been examined on sufficiently fine spatial and temporal scales to determine the specifics of co-location.

Whale-watching

The GARFO Protected Species office has informed the PDT that whale watch companies do not report to NMFS where they go and what protected species they see. Many, if not all, whale watch vessels carry naturalists on board to collect data. The naturalists are from research or conservation organizations. The PDT contacted Mr. Zach Klyver, a current Herring Advisory Panel member and employee of Bar Harbor Whale Watch Company. This company has been collecting data (e.g., number of humpbacks and finbacks, location and date) since the 1990s, but in 2003, started carrying scientists from Allied Whale on every trip. Their data is digitized, and he has offered to help obtain the data. The Blue Ocean Society, The Whale and Dolphin Conservation, Provincetown Center for Coastal Studies, and College of the Atlantic also provide scientists for trips by other companies that do excursions to Jeffries Ledge, Stellwagen Bank, and other areas. Due to time limitations, the PDT was unable to pursue these potential data sources further.

Key whale species of interest to the whale watching industry are humpback, finback, and minke whales. Humpback whales are known to feed on herring, particularly in the Gulf of Maine. Humpbacks feed during the spring, summer and fall in the western North Atlantic (Waring et al. 2015). Their distribution in this region is largely correlated with prey species, though behavior and bathymetry are factors as well (Payne et al. 1986; Payne et al. 1990). Prey include herring, sand lance and other small fish (Waring et al. 2015).

Map 13 shows commercial whale watching areas from the Northeast Ocean Data portal. As described on the portal, the map:

“depicts activity areas mapped by whale watch industry experts in the Northeast Coastal and Marine Recreational Use Characterization Study which was conducted by SeaPlan, the Surfrider Foundation, and Point 97 under the direction of the Northeast Regional Planning Body. Whale watch owners, operators, naturalists, and data managers attended participatory mapping workshops to map areas where whale watching takes place in the region, while also providing information about seasonality, species, and overall industry trends.”
Map 13 - Commercial whale watching areas


Notes quoted from the Data Explorer:

“The data are classified by the following categories:

- **General use areas** [light orange] reflect the full footprint of whale watch activity in the last 3 – 5 years (2010 – 2014) regardless of frequency or intensity
- **Dominant use areas** [dark orange] include all areas routinely used by most users most of the time, according to seasonal patterns.
- **Transit routes** [lines] include areas used for transit to and from general or dominant use areas
- **Supplemental areas** [yellow] depict areas used for closely-related activities and infrequent specialty trips.
- **RI Ocean Special Area Management Plan areas** [hatched] were mapped as part of the Rhode Island Ocean Special Area Management plan and are symbolized separately to reflect different data collection methodologies.”
**TASK #3: Relationships between catches of herring and predators**

Expand the PDT analysis presented to the Committee in January 2016, which examined whether there are correlations between catches of herring and predators.

Examine Area 1A in years prior to 2006 (i.e., Amendment 1 implementation).

Examine catch of predators in the second week after herring catches (across the full time range).

Here, both the original information (January 2016) and more recent analysis are presented.

**Methods**

This analysis focused on the localized depletion scenario in which relatively mobile herring predators would leave a depleted area in search of alternative prey. Vessel Trip Reporting System (VTR) data were used to compare the catch of Atlantic cod, pollock, and spiny dogfish subsequent to herring catch. Catch per trip (CPT) of these three predators were calculated during the week of reported herring catch and compared with predator CPT for the first and second weeks following herring catches:

\[ D_{y,s,p,w} = \frac{C}{T_{y,s,p,w+1}} - \frac{C}{T_{y,s,p,w}} \]

where \( C \) is the catch and \( T \) is the number of trips that caught any of the predators (\( p \)) in each year (\( y \)), statistical area (\( s \)), and week (\( w \)). \( x \) equaled either 1 or 2, depending on whether the analysis was conducted using a one week or two week lag. Map 14 shows the herring management areas and statistical areas for reference. These three predators were included because they are of commercial interest and gut contents data from National Marine Fisheries Service bottom trawl surveys suggest that these species prey heavily on herring.

A linear regression then was conducted with \( D_{y,s,p,w} \) as the dependent variable and the catch of herring (\( h \)), \( C_{y,s,h,w} \), as the independent variable. A consistent negative relationship would support localized depletion, while any other relationship would provide no evidence for localized depletion.

Analyses were also restricted to the years 1997-2014 to capture a range of years before and after Amendment 1, and to keep the number of comparisons manageable, and because each of these years has an adequate number of observations for the chosen statistical areas.

The analysis described above was also repeated: 1) for only predator trawl gears with the number of trips in the CPT estimate replaced with the number of tows, 2) using predator CPT from only bottom otter trawls, 3) using predator CPT from only bottom otter trawls, 4) using predator CPT from only sink gillnets, and 5) using predator CPT from only longlines. These additional analyses were intended to serve as a test of whether the effects of herring catches on the predators may vary depending on the gear type used to catch the predators. For example, if harvesting herring serves to scatter predators over a broader area, then a mobile trawl gear may maintain CPT (or per tow) by towing longer over a broader area, whereas maintaining CPT with fixed gillnets and longlines would require the predators to reaggregate in a given location. The fixed gears might also increase soak times, but that is not accounted for here.
Results among statistical areas were similar. Consequently, results from one statistical area from herring management areas 1A, 2, and 3 are provided (statistical areas 513, 521, and 537; Figure 18 to Figure 23). The gear-specific results were generally similar to those from using CPT from all predator gears combined, and so results for these sensitivities were not presented.

None of the regressions of were statistically significant except for statistical area 537 in 2012 and 2013 with a two week lag, (Figure 18 to Figure 23). The direction of the relationship between $D_{y,s,p,w}$ and $C_{y,s,h,w}$ was inconsistent (i.e., positive in some years and negative in others). These results provide no evidence of localized depletion for these predators at the scale of statistical area and one or two week time intervals.

Discussion
This analysis has several caveats. The spatial and temporal scale at which localized depletion operates has no specific definition and may depend on the predator. Here, localized depletion was examined on the scale of statistical area and week. So, if conditions within a statistical area were unchanged after one or two weeks, then no evidence of localized depletion would be found. This analysis also focused on three predators and combined them for analysis, but different predators may respond differently to the removal of herring. Conducting analysis by individual predator or groups of predators thought to react similarly to herring removals should likely be
considered in the future. Likewise, varying the temporal and spatial scale of analysis by predator might also be considered, and other predators of interest could be examined. This analysis also used VTR data, which is self-reported and may contain errors (e.g., incorrect spatial assignments). Other data sources might be considered in the future. This method assumes that CPT is an index of predator abundance.

Data from all times of year were combined in this analysis, but perhaps analysis by season should be considered. Herring migrate during certain times of year, so localized depletion is unlikely to occur during these times because the herring will be in a different location in the near future regardless of catches. Analysis of a time of year when herring are likely to be confined in a single region might be more appropriate (summer feeding grounds or fall spawning). However, having included data from all times of year in this analysis would only increase the chances of finding a negative correlation, which may support the occurrence of localized depletion. Follow up analyses could include examining the data at finer time intervals than by year.
Figure 18 – Predator catches in sequential weeks, Statistical Area 513 (Area 1A)
Figure 19 - Predator catches two weeks apart, Statistical Area 513 (Area 1A)
Figure 20 - Predator catches in sequential weeks, Statistical Area 521 (Area 3)
Figure 21 - Predator catches two weeks apart, Statistical Area 521 (Area 3)
Figure 22 - Predator catches in sequential weeks, Statistical Area 537 (Area 2)
Figure 23 - Predator catches two weeks apart, Statistical Area 537 (Area 2)
**TASK #4: Potential midwater trawl closures**

Examine potential impacts (biological, economic, social) to different fisheries (herring, tuna, striped bass, etc.) of closing the following 30-minute squares to midwater trawl gear year-round: 99, 100, 114, 115, and 123. Calculate the percent of the total Atlantic herring stock area that these 30-minute squares comprise.

Each 30 minute square comprises <1% of the total Atlantic herring stock area. Within each herring management area, the squares of interest here (99, 100, 114, 115, and 123) comprise <2%, with the exception of Area 1B (Map 15, Table 1, Table 2). These area calculations were done in ArcGIS using the UTM19N projection. Sliver portions of the squares were excluded where there were landmass intersections or artifacts from geoprocessing. The areas excluded were exceptionally small in relation to the overall areas and did not influence the percentages.

**Map 15 - Atlantic herring management areas and 30 minutes squares**
No analysis was done to quantify landings from these 30 minute squares. The PDT feels that the model used to generate the “heat maps” presented earlier (starting p. 7) would be the most appropriate method to do so, and can be done.

The size of a square relative to a stock or management area has little relevance to a discussion of potential biological, economic, and social impacts of closing a particular square year round, since both fish and fishing effort are not evenly distributed throughout the stock area. The PDT is uncertain the degree to which an accurate assessment of future impacts can be made regarding area closures, as future changes in environmental conditions, and fish distribution, and fisheries would factor in.

For bluefin tuna, portions of the 30-minute squares in question have been important foraging grounds. However, much of the Bluefin fishery catches in recent years have been further north, and in some cases east, of these squares. If herring biomass increases in an area, bluefin could be attracted. However, the areas in question are known to be a migratory corridor for herring, so they only remain there for limited time periods. Foraging and spawning requirements move herring outside these areas.

**TASK #5: Cod and herring in Ipswich Bay**

Examine predator/prey relationships between cod and herring in Ipswich Bay.

The NMFS food habits database is sizeable, but only a small portion of the data is from Ipswich Bay. The sources for the data are the spring and fall bottom trawl surveys. Cod are known to be omnivorous, and around 10% of their diet is herring.
**TASK #6: Analytical ideas from public scoping**

Examine ideas for analysis identified in the public scoping comments for Amendment 8.

Using the thematic coding that the PDT previously conducted to summarize scoping comments (NEFMC 2015b), the topics listed below were identified. Some of the topics are explored or explained within this memo, some are the subject of current research, while others could be tasked to the PDT in the future.

- **Stock assessment/modeling**
  - Determine why there is a retrospective pattern in the stock assessment.
  - Revise modeling based on closer to real-time data (not 2-3 year lag).
- **Formally explain and/or determine how much herring is used by predators.**
  - Consider differences in age/size/nutritional value for different predators.
  - What other species also serve as prey to fish that eat herring? Is there a difference in their ability to fulfill prey role?
  - Role of herring in the ecosystem.
  - What is required to measure/account for scientific uncertainty?
- **Look at the effects of inshore closures waters to herring fishing (Area 1A, Canada)**
- **Where are MWTs allowed world-wide; where is it banned? What has been the effect?**
- **Consider socio-economic impacts on businesses and communities of changes in herring regulations, considering economic value of other businesses that depend on herring (tuna, whale watch, recreational fishing).**
- **Devise tools to analyze localized depletion.**
- **Has abundance of herring declined inshore (e.g., off Nantucket)?**
- **Reconstruct the history of environmental factors such as ocean temperatures, salinity, shifts in oceanic and climatic regimes (here and elsewhere) to determine impacts on pelagic species.**
- **Better understand herring schooling behavior.**
- **Are the effects of herring seining different from midwater trawling? Why/How?**

**Summary and next steps**

The PDT has focused here on characterizing the spatial and temporal footprint of the herring fishery and predator fisheries and businesses as time and data have allowed. Additional work could occur on finer scale resolutions and other fisheries or gear types not reported here (e.g., small mesh bottom trawl). Several overlaps were identified. Even if correlations are found between herring removals and a signal in a predator fishery or business (i.e., whale watching) that may suggest that localized depletion is occurring, the PDT expects it will be difficult to identify a causal link, using just the data available. It is not a trivial undertaking.

The PDT has not yet examined the Study Fleet data relative to the current tasking, but the data may be useful for estimating catch rates on a given trip, though only a subset of the fishery participates in Study Fleet. It would need to be determined how many herring trips that have participated in Study Fleet have occurred within the area of interest (e.g., 12 nm). Within 12 miles, there is very little trawl fishing for herring, except on the back side of the Cape, around Block Island, and in Area 1A (fall only). Herring fishing on the back side of the Cape is primarily done in the spring and fall and is episodic. The fishery around Block Island is primarily prosecuted in the winter, and is unlikely to have much interaction with other fisheries (e.g., tunas are only present from about May-September, primarily in the Gulf of Maine and Georges Bank).
Method to identify herring fishery locations at sea

As described on p. 7, the best approach to identifying the locations of Atlantic herring fishing is to use the method that combines Vessel Trip Report and observer data developed by DePiper (2014). The following is an abbreviated description of the method. First, VTR data are matched to observer data. Second, a statistical model is estimated to explain the distance between hauls and the corresponding VTR coordinate. Days absent and gear used are major explanatory factors. Third, the results are used to expand the VTR coordinate to a circular region. Fourth, portions of circular regions that cannot be fished (such as land or areas closed to fishing) are removed and landings or fishing time from the VTR data are assigned to the remaining region. Finally, the individual trips are aggregated to the appropriate level.

This approach has been used in Tasks #1-3 below. Note that the model output is the location of herring landings rather than catch. Thus, landings are reported here where catch was requested. However, for the Atlantic herring fishery, landings generally approximate catch, as Atlantic herring discards represent a very small fraction of total Atlantic herring catch (generally <0.3%). Because the landings data are model outputs, the data should be considered estimates. Further, the PDT was cautious to ensure there are no data confidentiality issues with the data presented.

**TASK #1: Mapping herring fishery**

Make zoomed in heat maps of herring effort overlaid with all current and proposed spatial regulations to better identify the importance of areas to the fishery and potential impacts of measures developed through Amendment 8, such as: groundfish closed areas (with 15 mi move along), distances 12, 30, 50 mi from shore, stat areas/30-min squares, herring management areas, bathymetry (100 fathom or 200 m depth), ASMFC spatial regulations (spawning closed areas), RH/S bycatch cap areas, and haddock AM areas.

The Greater Atlantic Regional Fisheries Office (GARFO) has created an online “story map” describing current management areas for the scallop fishery, and a similar interactive map product has been developed for the Atlantic herring fishery, particularly in support of Amendment 8. The interactive map of the Atlantic herring fishery is available at: [http://noaa.maps.arcgis.com/apps/webappviewer/index.html?id=5d3a684fe2844eedb6beacf1169ca85](http://noaa.maps.arcgis.com/apps/webappviewer/index.html?id=5d3a684fe2844eedb6beacf1169ca85)

Herring fishery locations are mapped using the method that combines Vessel Trip Report and observer data developed by DePiper (2014). Many caveats are needed to understand the maps. For example, fishery locations and intensity should not be confused as measures of abundance (or depletion) given the numerous regulations constraining a fishery (e.g., catch limits, time/area closures).

Some aspects of the map are still underdevelopment. For example, GIS layers of herring catch by month will be uploaded soon, and the PDT is developing communication tools to explain the various spatial/temporal regulations that have influenced where fishing has occurred. It is possible to create interactive maps, using this approach, for other federal fisheries for species that are predators of herring (e.g., groundfish). Please send feedback or questions to Rachel Feeney (rfeeney@nefmc.org).
**TASK #2: Herring fishing within specific 30-minute squares**

Identify herring catch from the following 30-minute squares, by season or month back to 2000: 99, 100, 114, 115, and 123. Calculate the percent of the total Atlantic herring stock area that these 30-minute squares comprise.

**Methods**

Landings by 30-minute square were estimated using the VTR-observer method developed by DePiper (2014). After aggregating the model output at the monthly level, landings from each of the relevant 30-minute squares were extracted. As noted above, landings are reported here rather than catch.

ArcGIS (with the UTM19N projection) was used to calculate the percent of an Atlantic herring stock area that these 30-minute squares comprise. The PDT went a step further, to also calculate the size of the squares relative to the Atlantic herring management areas. Sliver portions of the squares were excluded where there were landmass intersections or artifacts from geoprocessing, though the areas excluded were exceptionally small in relation to the overall areas and did not influence the outcomes.

**Data**

For the selected 30-minute squares (Map 15, p. 45), Figure 24 and Figure 25 show the share of the fishery-wide monthly landings occurring within each square during the time periods 2000-2009 and 2010-2015. For example, almost 25% of herring landings in May for the years 2010-2015 was from square 114, and under 2% was from the other squares reported here. Table 3 provides detail for just square 114.

Each 30-minute square reported here comprises under 0.5% of the total Atlantic herring stock area (Table 2, p. 46). Within each herring management area, these squares comprise <2% of the stock area they reside within, with the exception of the squares within Area 1B (Table 1, p. 46).

<table>
<thead>
<tr>
<th>Month</th>
<th>2000-2009</th>
<th>2010-2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kept (mt)</td>
<td>Share</td>
</tr>
<tr>
<td>1</td>
<td>3,959</td>
<td>5.63%</td>
</tr>
<tr>
<td>2</td>
<td>1,999</td>
<td>3.68%</td>
</tr>
<tr>
<td>3</td>
<td>469</td>
<td>1.74%</td>
</tr>
<tr>
<td>4</td>
<td>877</td>
<td>4.50%</td>
</tr>
<tr>
<td>5</td>
<td>2,956</td>
<td>5.19%</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>7</td>
<td>18</td>
<td>0.01%</td>
</tr>
<tr>
<td>8</td>
<td>31</td>
<td>0.02%</td>
</tr>
<tr>
<td>9</td>
<td>629</td>
<td>0.50%</td>
</tr>
<tr>
<td>10</td>
<td>4,024</td>
<td>3.33%</td>
</tr>
<tr>
<td>11</td>
<td>13,573</td>
<td>16.57%</td>
</tr>
<tr>
<td>12</td>
<td>20,564</td>
<td>39.74%</td>
</tr>
</tbody>
</table>

C = confidential
Discussion

Of the 30-minute squares areas reported here, 114 (to the east of Cape Cod) is the only square where over 10% of the fishery-wide landings in a given month through the time series have occurred. In 2000-2009, the landings in 114 were primarily in the early winter, about 17% (~14K mt) and 40% (~21K mt) of the fishery landings for November and December, respectively. Landings in 114 for all other months were under 6% of the total for the month. In this time range, November and December in 114 had both the highest landings and the highest share of landings.

In 2010-2015, square 114 continued to be important, but the fishery timing shifted, such that January (23%, ~13K mt) and May (31%, ~6K mt) were months with the highest shares of and actual landings. April was third highest in terms of share of landings (19%) and September was the third highest in terms of actual landings (~4.6K mt).

A few points to note:

- For a given month and square, the percent of catch coming from that area is independent of actual catch, depending rather on the total fishery-wide catch for the month.
- Square 114 is currently split almost in half by Areas 1B and Area 3 (Map 15, p. 45), and the January-April Area 1B closure became effective in 2014. Thus, most but not all of the data presented here comprise a time period when herring fishing was allowed in all of square 114. However, these data would not necessarily be representative of future time series, given this closure.
- The Atlantic herring ACL between management areas has shifted over time. The percent of catch allowed from Area 3 was about 33% through 2006, then increased, ranging from about 38-42% ever since. From Area 1B, the percent sub-ACL decreased in 2010, ranging from about 6-7% prior to 3-5% since.
- The boundary between Areas 1B, 3 and 2 shifted in 2007, increasing Area 3 shoreward.
- The size of a square relative to a stock or management area has little relevance to a discussion of potential biological, economic, and social impacts of closing a particular square year round, since both fish and fishing effort are not evenly distributed throughout the stock area.
- If the Committee is interested in closing certain areas, it is generally the case that it is difficult to accurately predict future impacts of area closures, as future changes in environmental conditions, and fish distribution, and fisheries would factor in. With an area closure, a fishery could move and concentrate in other areas, with unintended consequences.
Figure 24 - Share of monthly Atlantic herring landings (all gears) by 30-minute square, 2000-2009 calendar years

Figure 25 - Share of monthly Atlantic herring landings (all gears) by 30-minute square, 2010-2015 calendar years
**TASK #3: Evaluate herring effort inshore**

Within both 6 and 12 miles from shore, examine herring effort, including the amount of catch. Identify areas (e.g., Ipswich Bay, Nantucket Shoals) where herring fishing seasonally intensifies.

a. Determine and compare midwater trawl trip catches over time in each area, considering variation in tow-specific catches (accounting for tow time, number of tows, and trip duration).

b. Determine if, over the time of intensified fishing, catches could only be maintained by longer tows, more tows and/or longer trips, thereby indicating local depletion (e.g., $F$ much higher than $F$ set for entire stock).

**Cautionary note/data limitations**
For schooling, pelagic fish, catch per unit effort (CPUE) should not be used as an indicator of fishery impacts on abundance, particularly in a discrete geographic area, because CPUE could vary, either due to depletion, immigration, or emigration. Thus, a decline in CPUE would not necessarily indicate localized depletion. Furthermore, identifying localized depletion is very difficult, because the rate of herring removal relative to the rate of herring immigration to an area must be identified. It would be difficult to find evidence on a spatial scale that is smaller than the scale that herring can move in a day (about 15 nm/day). Because of fish movement, tow time should not be used to estimate the density of a herring school.

VTR data could be used to approximate the amount of time spent fishing in determining catch rates. The VTR data include tow-hours for midwater trawl trips and the VTR tow-hour data for the trawl fisheries are fairly reliable. However, there have been an insufficient number of MWT tows in discrete areas (e.g., in Ipswich Bay 6 or 12 miles from shore) to make robust conclusions.

**Methods**
Given these limitations, the Herring PDT at least identified inshore herring landings using the method of DePiper (2014). Monthly herring landings were aggregated for all gear types and by MWT gear (PTM and OTM) for five years (2010-2014). The landings within 6 nm and 12 nm were extracted.

**Data**
Table 4 and Table 5 include total landings of herring by all gear types and by MWT gear within 6 and 12 nm from shore, along with landings from all areas for each month of 2010-2014. For example, over 56% of the herring landings in January for the years 2010-2014 was from within 6 nm of shore and over 77% was from within 12 nm of shore.

**Discussion**
- A decline in CPUE would not necessarily indicate localized depletion.
- There have been an insufficient number of MWT tows in discrete areas (e.g., Ipswich Bay, 6 or 12 miles from shore) to make scientifically robust conclusions regarding CPUE.
• The nearshore fishery is particularly important between October and February. For both all gear types combined and for just MWTs, under 30% on the landings from March through September came from within 6 or 12 nm from shore.

Table 4 - Total landings of herring by all gear types within 6 and 12 nm from shore along with total landings from all areas, 2010-2014

<table>
<thead>
<tr>
<th>Month</th>
<th>Kept (mt)</th>
<th>Share</th>
<th>Kept (mt)</th>
<th>Share</th>
<th>Kept all areas (mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27,775</td>
<td>56.33%</td>
<td>38,307</td>
<td>77.69%</td>
<td>49,304</td>
</tr>
<tr>
<td>2</td>
<td>7,190</td>
<td>30.69%</td>
<td>10,908</td>
<td>46.56%</td>
<td>23,425</td>
</tr>
<tr>
<td>3</td>
<td>1,065</td>
<td>7.54%</td>
<td>2,140</td>
<td>15.14%</td>
<td>14,131</td>
</tr>
<tr>
<td>4</td>
<td>732</td>
<td>13.37%</td>
<td>1,296</td>
<td>23.67%</td>
<td>5,472</td>
</tr>
<tr>
<td>5</td>
<td>2,007</td>
<td>13.17%</td>
<td>3,756</td>
<td>24.66%</td>
<td>15,232</td>
</tr>
<tr>
<td>6</td>
<td>1,755</td>
<td>5.17%</td>
<td>4,782</td>
<td>14.09%</td>
<td>33,940</td>
</tr>
<tr>
<td>7</td>
<td>3,208</td>
<td>5.42%</td>
<td>9,496</td>
<td>16.05%</td>
<td>59,155</td>
</tr>
<tr>
<td>8</td>
<td>8,368</td>
<td>12.83%</td>
<td>22,586</td>
<td>34.63%</td>
<td>65,230</td>
</tr>
<tr>
<td>9</td>
<td>5,407</td>
<td>9.21%</td>
<td>17,183</td>
<td>29.25%</td>
<td>58,742</td>
</tr>
<tr>
<td>10</td>
<td>11,475</td>
<td>22.99%</td>
<td>31,035</td>
<td>62.17%</td>
<td>49,921</td>
</tr>
<tr>
<td>11</td>
<td>2,845</td>
<td>23.42%</td>
<td>6,126</td>
<td>50.42%</td>
<td>12,149</td>
</tr>
<tr>
<td>12</td>
<td>18,315</td>
<td>70.46%</td>
<td>22,276</td>
<td>85.70%</td>
<td>25,992</td>
</tr>
<tr>
<td>TOTAL</td>
<td>90,142</td>
<td>21.84%</td>
<td>169,891</td>
<td>41.17%</td>
<td>412,693</td>
</tr>
</tbody>
</table>

Table 5 - Total landings of herring by midwater trawl gear within 6 and 12 nm from shore along with total landings from all areas, 2010-2014

<table>
<thead>
<tr>
<th>Month</th>
<th>Kept (mt)</th>
<th>Share</th>
<th>Kept (mt)</th>
<th>Share</th>
<th>Kept all areas (mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20,053</td>
<td>52.54%</td>
<td>28,855</td>
<td>75.60%</td>
<td>38,169</td>
</tr>
<tr>
<td>2</td>
<td>5,072</td>
<td>26.24%</td>
<td>8,028</td>
<td>41.53%</td>
<td>19,331</td>
</tr>
<tr>
<td>3</td>
<td>448</td>
<td>4.06%</td>
<td>1,192</td>
<td>10.81%</td>
<td>11,027</td>
</tr>
<tr>
<td>4</td>
<td>576</td>
<td>12.33%</td>
<td>1,024</td>
<td>21.90%</td>
<td>4,676</td>
</tr>
<tr>
<td>5</td>
<td>1,853</td>
<td>12.73%</td>
<td>3,504</td>
<td>24.08%</td>
<td>14,556</td>
</tr>
<tr>
<td>6</td>
<td>83</td>
<td>0.37%</td>
<td>110</td>
<td>0.49%</td>
<td>22,518</td>
</tr>
<tr>
<td>7</td>
<td>227</td>
<td>0.59%</td>
<td>413</td>
<td>1.07%</td>
<td>38,516</td>
</tr>
<tr>
<td>8</td>
<td>991</td>
<td>2.83%</td>
<td>2,273</td>
<td>6.49%</td>
<td>35,035</td>
</tr>
<tr>
<td>9</td>
<td>1,830</td>
<td>4.70%</td>
<td>4,423</td>
<td>11.36%</td>
<td>38,924</td>
</tr>
<tr>
<td>10</td>
<td>8,310</td>
<td>22.99%</td>
<td>22,141</td>
<td>61.26%</td>
<td>36,144</td>
</tr>
<tr>
<td>11</td>
<td>2,258</td>
<td>20.50%</td>
<td>5,309</td>
<td>48.20%</td>
<td>11,014</td>
</tr>
<tr>
<td>12</td>
<td>12,967</td>
<td>66.83%</td>
<td>16,326</td>
<td>84.15%</td>
<td>19,401</td>
</tr>
<tr>
<td>TOTAL</td>
<td>54,667</td>
<td>18.90%</td>
<td>93,600</td>
<td>32.35%</td>
<td>289,311</td>
</tr>
</tbody>
</table>
**TASK #4: Study Fleet habitat suitability model**

Determine if the Study Fleet habitat suitability model could be useful to understanding localized depletion.

**Study Fleet overview**
The Study Fleet program began in 2002, but its fully-functioning electronic logbook program (i.e., the “FLNDRS” system) began in 2010 with fishermen recording tow-by-tow data (some vessels still report at the sub-trip level rather than tow-by-tow). Herring fishery participation started with a few small-mesh bottom trawl vessels in Area 2. Then in 2013, funds from the Pacific States Marine Fisheries Commission helped expand participation that year to include eight herring midwater or pair trawl vessels and to 14 of these vessels in 2014, but participation has declined a bit since.

**Study Fleet habitat suitability modeling to date**
Dr. John Manderson of the NEFSC has been working with the Study Fleet data and participants to develop models of suitable habitat for Mid-Atlantic species such as mackerel and butterfish, to help understand the physical forces that affect fish habitat. Fish metabolic processes are affected by water properties, like temperature and oxygen, which have spatial and temporal variation. A number of tools in the Mid-Atlantic are contributing to improved ocean modeling including satellites, radar, gliders, and buoys. The mechanistic models are informed by real-time data, such as from the Study Fleet program. On a fine-scale, individual Study Fleet vessels have collaborated on experiments to, for example, understand movements of water fronts and their impacts on fishery catch and bycatch. There is a lot of dialogue with participants on their knowledge of the ecosystem.

The rationale for the fishing fleet’s particular location is complex (e.g., weather, area management, global economics), so using the Study Fleet data has its challenges. This past winter, for example, there was no mackerel fishing until a storm in mid-January caused a cold snap that mixed water over Nantucket Shoals to allow the cold water corridor from the Gulf of Maine to form and move mackerel down to the Mid-Atlantic for the fishermen to access for a short time period. The mackerel model helped identify and understand this event.

**Utility of the Study Fleet data and modeling for Amendment 8**
The habitat models describe probabilities of fish occupancy in space and time, given: 1) the accuracy of the information, 2) the space-time scales at which the data were acquired, 3) the space time scales of the projections, which are a function of the biological data used to inform them, and the resolution of the ocean models and other habitat data used to project them. They do not predict absolute concentrations of animals (population size/habitat volume). In the ocean, the habitat volumes are changing shape, volume and geographic position even for demersal species and particularly when climate changes are affecting the properties of the ocean liquid.

It is possible to determine the timing and volumes of habitat overlap between species at some resolution determined again by the data informing them and the models used to project them. For high resolution, high resolution data are needed describing habitat partitioning amongst species. Studying fine scales of habitat partitioning are possible by working with the Study Fleet in a way that is really not possible with offshore research cruises that would require a tremendous amount of funding.
Species vary in terms of how important bottom temperature is to their distribution. This work has been pioneered for mackerel. Cold blooded animals, generally are fairly responsive to temperature in setting the metabolic rates. Having this prediction tool would be helpful for herring management (e.g., in developing river herring catch caps), but it has yet to be developed for herring, the bycatch species in the fishery, or for herring’s predators. The oceanographic model that the mackerel model is built on is now being expanded to the Scotian Shelf. The model for each species is different and would take some effort and funding to develop.

Identifying fields of preferred herring temperature habitats would inform analysis of localized depletion, but the fishery may not necessarily mirror where the habitat is, though the industry could using it to better target the resource. The PDT cautioned that improving fishery efficiency is not a goal that has been the identified for Amendment 8, and that the Committee should remain focused on what is most relevant for Amendment 8. A more direct approach to understanding where the fisheries operate would be to use the fishery data rather than models of temperature suitability. It may be useful in estimating where the fishery could go if they were closed out of an area. For the different predators, whether and how they may be impacted by the localized depletion of herring would depend, in part, on their reliance on herring, and their degree of tolerance for different thermal environments.

The Study Fleet data may be useful for estimating catch rates on a given trip, though only a subset of the fishery participates in Study Fleet. Most of Study Fleet trips by herring vessels have been in Herring Management Area 2, but in 2015 there were a fair number of trips in Area 3. Providing data at the 10-minute square level would be the finest scale possible without breaching confidentiality restrictions. It would need to be determined how many herring trips that have participated in Study Fleet have occurred within the area of interest (e.g., 12 nm). Within 12 miles of shore, there is very little trawl fishing for herring, except on the back side of the Cape, around Block Island, and in Area 1A (fall only). Herring fishing on the back side of the Cape is primarily done in the spring and fall and is episodic. The fishery around Block Island is primarily prosecuted in the winter, and is unlikely to have much interaction with other fisheries (e.g., tunas are only present from about May–September, primarily in the Gulf of Maine and Georges Bank).

Discussion

- Such modeling tools do not yet exist for Atlantic herring. Even if funding and resources were in place, a model could not be developed within the timeline of Amendment 8 development.
- A Study Fleet-informed temperature habitat suitability model may be useful to understand the distribution of herring (or their predators), predicting where fish are likely to occur.
- However, it would not inform localized depletion questions, as it is unable to measure a response in a population to removals; it only predicts where fish are likely to occur given a habitat model (temperature).
- This type of model could inform bycatch monitoring/avoidance.
TASK #5: Marine Recreational Information Program striped bass data

The MRIP charter and private rental data include intercept site. Look at catch per trip for striped bass from private rental and charter intercept sites on Back side of Cape (0-3 mi from shore); compare to herring catches.

Introduction

In January 2016, the Committee tasked the PDT with identifying the location of fisheries for herring’s predators, by season and gear type. In March, the PDT reported that, although the striped bass fishery is largely recreational (60-70% of total striped bass removals in recent years), the only data for catch locations at sea are from the commercial fishery. The PDT provided data on the commercial spatial patterns of landings and CPUE within Massachusetts state waters – to the finest spatial scale possible. In New England, the only commercial fisheries for striped bass occur in Massachusetts and Rhode Island, around 8% and 1% of total commercial harvest in recent years, respectively) (ASMFC 2015). In Massachusetts, the recreational fishery is more predominant than average, accounting for about 85% of total removals (recreational and commercial striped bass fishing is prohibited in federal waters). Recreational fishery data are collected by the Marine Recreational Information Program (MRIP).

Data limitations/Methods

MRIP angler intercept data were reviewed for the possibility of identifying a response in striped bass catch rate from herring fishing in nearby waters. MRIP staff interview fishermen at “intercept sites” as fishermen complete their trip, typically at a boat ramp. On outer Cape Cod particularly, towns can be adjacent to Cape Cod Bay, Nantucket Sound, and/or the Atlantic Ocean.

MRIP does not collect catch location data, so it is not possible to identify where recreational striped bass fishing occurred at sea and then relate that to herring fishing locations. This is a very relevant point to any interpretation of a comparing herring catches and striped bass CPUE from the MRIP database, particularly for outer Cape Cod. MRIP only collects the category of location (bay, sound, river, etc). It is assumed here that when a fisherman says something other than bay/river/sound, they were fishing on the “backside” of Cape Cod. However, they could have easily launched from Provincetown or Chatham and fished elsewhere (e.g., Stellwagen Bank, Nantucket Sound). The primary boat ramps for the Outer Cape in particular (e.g., towns of Chatham and Provincetown) could be access points to go to many fishing locations.

In an effort to infer striped bass fishing locations from MRIP interview data, relevant trips were assumed to occur on the “back side” or east of Cape Cod if:

1. The intercept occurred in one of the outer Cape Cod towns (Provincetown, Truro, Eastham, Wellfleet, Orleans, Chatham);
2. Fishing did not occur in a river, bay or sound; and
3. Striped bass was the target fishery.

There were 360 recreational fishing trips targeting striped bass met these criteria between 2008 and 2014 (Figure 26, Table 6); 76% of the trips occurred in June to August. However, given the above assumption, the number of trips actually occurred to the east of Cape Cod may be lower.

To narrow the herring fishery data, an “area of interest” was defined as the area out to about 12 nm from shore within the 30-minute square 114, which is to the east of Cape Cod (Figure 13).
VTR data was used to identify the directed commercial Atlantic herring trips (landing 6,600+ pounds of Atlantic herring per trip) that reported landings from within the area of interest. Over the same time period (2008-2014), the directed commercial fishery for Atlantic herring took 139 fishing trips from the ‘area of inquiry’ (Table 7); 10% of the trips occurred in June to August.

To identify the relative co-occurrence of striped bass and herring trips more finely, of the 360 recreational striped bass trips, there were 67 that occurred within +/- one week of just nine of the 139 commercial herring trips (Table 8). Of those nine herring trips, just one had striped bass trips occur both prior to (n=1) and following (n=2) the herring trip.

To correlate a change in striped bass CPUE with herring removals, there would need to be sufficient MRIP data from before and after multiple herring trips. Unfortunately, these data do not exist; there are no herring trips with enough associated MRIP striped bass trips to characterize a change in CPUE. Again, the number of striped bass trips reported here as occurring to the east of Cape Cod are likely an over estimate.

**Discussion**

Multi-year telemetry studies have shown that striped bass are typically present in Massachusetts waters between May and October (Kneebone et al. 2014b). As such, even if paired observations of herring removals (from federal waters) and MRIP CPUE (from state waters) were available, it would be difficult to attribute a change in striped bass catch rate to herring depletion, given the fluctuating seasonal pattern of the striped bass fishery and the fact that the fisheries occur in separate areas, state and federal waters. It is possible that a substantial portion of the striped bass population occurs in adjacent federal waters (i.e., beyond three miles from shore) where much of the herring fishing occurs. Striped bass tagged with acoustic transmitters have been shown to frequently cross this state/federal jurisdictional boundary (Kneebone et al. 2014a). However, since fishing for striped bass in federal waters is prohibited, there are no fishery dependent data to address the potential interaction with the herring fishery beyond three miles from shore.

For the area directly seaward of Cape Cod out to about 12 nm (Figure 13, p. 29), Atlantic herring landings generally occur early in spring or very late in the fall to early winter. Overall, landings are episodic (Figure 27), and rarely occur more than two weeks in a row. Given that most of the landings occur during the spring and fall herring migration, it is likely that the fishery exploits herring while they are passing through the area, and that schools of herring move too quickly through the area for sustained catches to occur; unlike the summer-time in the Gulf of Maine when the herring are more resident. The periodic/migratory nature of the herring fishery in this area, combined with the lack of spatial information for the striped bass fishery, makes it difficult to draw conclusions about the effects of localized depletion in this case.

- There are insufficient number of striped bass trips with the MRIP data and commercial herring trips likely co-occurring to the east of Cape Cod to make scientifically robust conclusions about correlations.
- During 2008-2014, there is some overlap between these fisheries, but relatively few herring trips have occurred in June-August (10%), when the striped bass trips most common (76%).

AVI - 57
Figure 26 - MRIP sites that had interviews with fishermen that targeted striped bass in Barnstable County (2008-2014)

Note: Green circles indicate sites in the towns of outer Cape Cod (Provincetown, Truro, Wellfleet, Eastham, Orleans, and Chatham) that had fishermen who reported they did not fish in a river, bay or sound (therefore assumed to have fished to the east of Cape Cod, though this is likely an overestimate).

Table 6 - Number of MRIP angler interviews where fishing likely occurred to the east of Cape Cod and striped bass was the target species (green circles from Figure 26)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<td>2</td>
<td>7</td>
<td>9</td>
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<td>18</td>
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</table>

Note: Number of MRIP trips may be an overestimate.
Table 7 - Number of commercial fishing trips that landed 6,600+ pounds of Atlantic herring from within 12 miles of shore in 30-minute square 114

<table>
<thead>
<tr>
<th>YEAR</th>
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<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
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<td>23</td>
<td>0</td>
<td>2</td>
<td>16</td>
<td>139</td>
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</table>

Table 8 - MRIP sampled trips targeting striped bass (n=67) that occurred within +/- one week of commercial fishing trips that landed 6,600+ pounds of herring from the area within 12 nm east of Cape Cod (n=9)

<table>
<thead>
<tr>
<th>Herring trip date</th>
<th>MRIP trips</th>
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<td>Week before</td>
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<tr>
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<td>0</td>
</tr>
<tr>
<td>5/19/2010</td>
<td>1</td>
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<tr>
<td>7/25/2010</td>
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</tr>
<tr>
<td>6/2/2011</td>
<td>0</td>
</tr>
<tr>
<td>9/4/2011</td>
<td>0</td>
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<tr>
<td>9/25/2011</td>
<td>11</td>
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<tr>
<td>5/26/2013</td>
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<td>8/16/2013</td>
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<tr>
<td>Total</td>
<td>15</td>
</tr>
</tbody>
</table>

Note: Number of MRIP trips may be an overestimate.
Figure 27 – Atlantic herring landings by week for vessels catching >6,600 lbs of Atlantic herring from the area within 12 nautical miles east of Cape Cod, 2008-2014

**TASK #6: Tuna fishery catch per unit effort**

*Describe catch per unit effort in the tuna fishery over time.*

**Bluefin tuna fishery overview**

The bluefin tuna fishery consists of a variety of permits (Table 9) and gear types, with many management measures specific to the permit or gear (e.g., area closures, trip limits). Although the majority of permits issued are recreational, the majority of landings in 2015 were from the commercial fishery, particularly the handgear and charter/headboat fisheries. Of the commercial landings in 2015, about 90% are attributed to the Northeast reporting areas (Figure 28, Areas 1-6),

**Table 9 - Bluefin tuna fishery**

<table>
<thead>
<tr>
<th>Permit category</th>
<th>Permits issued in 2016 (#)</th>
<th>2015 landings (mt)</th>
</tr>
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<tbody>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longline/Trap</td>
<td>275/5</td>
<td>71.4/0</td>
</tr>
<tr>
<td>Harpoon</td>
<td>17</td>
<td>43.8</td>
</tr>
<tr>
<td>Purse seine</td>
<td>5</td>
<td>33.9</td>
</tr>
<tr>
<td>General category (rod &amp; reel, handline, harpoon)</td>
<td>3,100</td>
<td>614.8</td>
</tr>
<tr>
<td>Charter/Headboat</td>
<td>3,600</td>
<td></td>
</tr>
<tr>
<td>Recreational</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angling</td>
<td>21,000</td>
<td>113.1</td>
</tr>
</tbody>
</table>

*Source: NMFS HMS office*
Commercial data limitations

It is not currently possible to calculate catch per unit effort (CPUE) for the U.S. commercial bluefin tuna handgear fishery. The effort data for the commercial fishery are insufficient; most bluefin tuna fishermen are not required to report tuna trips with no landings, which can be quite common as there are many trips with no landings in this fishery. Vessels with Highly Migratory Species (HMS) permits are not required to submit Vessel Trip Reports (VTRs); there is no harvester reporting requirement unless the vessel holds a permit that requires a VTR be submitted (VTRs are for all species). There is some overlap between the VTR data and tuna trips, but it is a subset of the tuna trips. The only commercial bluefin tuna vessels required to report trip data (and have a Vessel Monitoring System) are the pelagic longliners (with log books). Purse seine vessels must also have VMS. Since 2015, the handgear fishermen are required to report catch (landings and discards), but there is no requirement to report trips with no catch.

In consultation with the HMS office at GARFO, the PDT examined how the number of zero trips might be identified for the commercial bluefin fishery, but concluded that a robust estimate is not possible under current reporting requirements. The NEFSC observer program does not observe the tuna fishery (i.e., no observer coverage for handgear fishermen), apart from when a trip is fishing under an Experimental Fishing Permit. The longline fishery (pelagic and bottom) is observed by the Southeast Fisheries Science Center (SEFSC) pelagic observer program.

Even if commercial CPUE could be calculated, there are limitations as to what could be concluded, particularly relative to localized depletion. Commercial bluefin tuna landings have been sensitive to the bag limit, which has varied over time.
Recreational data

The Large Pelagics Survey (LPS) intercept recreational fishermen for bluefin tuna (and other large pelagics) from Maine to Virginia at boat ramps or over the telephone. Here, “recreational” includes charter, private, and party boat. It is similar to the MRIP program for other recreational fisheries, and is administered by NMFS Science and Technology office at Headquarters. The LPS data are the best for characterizing the recreational bluefin tuna fishery and include catch and effort information, including data from zero landings trips. Recreational anglers are also required to report to the HMS office (online or with paper catch cards) when they land a tuna.

The SEFSC takes the lead on bluefin science for NMFS; all CPUE calculations and information that contribute to stock assessments are conducted by the SEFSC. The SEFSC uses CPUE and other fishery information to estimate relative abundance indices for three size classes of tuna (small school, large school, and large), because each size class has unique daily catch limits and fishery closures. Estimations of relative abundance include a number of factors, such as number of anglers fishing, number of lines in the water, hours fished, fishing method, fishing area, and month. Only annual CPUE calculations are made from the LPS data, not by month or other time intervals. Fishing effort is defined as hours fished.

Lauretta and Brown (2015) include annual CPUE for the U.S. bluefin tuna rod and reel/handline fishery by size class. Figure 29 to Figure 31 contain the CPUE and relative abundance indices for the three size classes since 1993. Indices, particularly the negative binomial index generally fit with the CPUE, with the exception of the Large School (115-144 cm SFL) size class in recent years, likely due to the northerly shift in LPS samples to areas where these fish are likely less abundant. Large (>177 cm SFL) and Small School (66-114 cm SFL) CPUE and indices have less inter-annual change since 2003 and 2006 and are generally lower than in the years, respectively be generally lower than in the 1990s.

Discussion

Most discussions about the rod and reel indices have focused on the divergence between the Canadian and the U.S. indices of abundance - that the Canadian indices have been increasing while the U.S. has remained relatively constant in recent years. There is no scientific consensus about what may be driving this divergence. Possible factors/hypotheses include:

- The availability/timing of tuna may have shifted to northern latitudes due to climate change and/or shifts in availability of prey.
- The U.S. handgear fishery may be hampered due to large volumes of dogfish eating bait in the rod and reel fishery.
- The LPS as a survey tool has undergone several changes in administration and survey design that may be influencing the outcomes.
- Changing regulations (e.g., trip limits, area closures) influence the ability to catch the target fishery.

These issues are a matter of ongoing discussion in the tuna science and management community. None of the data signal one hypothesis over another.

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1 http://www.st.nmfs.noaa.gov/recreational-fisheries/Surveys/survey-details
Figure 29 - Comparison of small school bluefin tuna (SMSM) standardized time series with nominal catch rate data and previous delta-Poisson model

Source: Lauretta and Brown (2015).

Figure 30 - Comparison of large school bluefin tuna (LGSM) standardized time series with observed mean and previous delta-Poisson model

Source: Lauretta and Brown (2015).
Figure 31 - Comparison of large bluefin tuna (LGMD_LG) standardized time series with observed mean and previous delta-Poisson model

Source: Lauretta and Brown (2015).

REFERENCES


INTRODUCTION
The Council has identified that a need for Amendment 8 to the Atlantic Herring Fishery Management Plan is “to minimize possible detrimental biological or socioeconomic impacts on other user groups (commercial, recreational, ecotourism) who depend upon adequate local availability of Atlantic herring to support business and recreational interests both at sea and on shore.” Alternatives in Amendment 8 include several time/area closures for the Atlantic herring fishery, particularly the midwater trawl (MWT) herring fishery. These closures would likely reduce the potential for user conflicts between the MWT herring fishery and groups that are focused on the predators of herring, including the tuna, groundfish, and striped bass fisheries, as well as commercial whale watching.

The objective of this analysis was to identify the seasons and areas that have been important to the MWT herring fishery and these other user groups, as this is when and where the greatest conflict is expected to occur. For fishery-dependent data, total reported landings were used to represent the ‘importance’ to a fishery. For commercial whale watching, maps compiled from a survey of industry experts served to identify areas of importance.

Midwater trawling for Atlantic herring was previously restricted in 2007 to minimize the localized depletion of forage fish through Amendment 1. That action prohibited MWT herring fishing in Herring Management Area (HMA) 1A during the months of June through September. As such, the current analysis evaluated the overlap between user groups under three different time periods: 1) pre-Amendment 1 (2000-2006); 2) post-Amendment 1 (2007-2015); and 3) recent (2013-2015).

DATA SOURCES
Midwater Trawl Herring Fishery
All trips using MWT to harvest Atlantic herring are reported to NOAA Fisheries via vessel trip reports (VTRs). These reports include one pair of coordinates (lat/lon) for each statistical reporting area fished per trip, assumed to represent the average location of fishing effort. A significant fraction of these trips are also documented by the Northeast Fisheries Observer Program (NEFOP), providing reliable tow-level locations. Using a statistical model of the relationship between VTR and NEFOP positions for this fishery, the Northeast Fisheries Science Center (NEFSC) can provide maps of the estimated location of herring catch by year and month. Essentially, this method integrates the completeness of the VTR census data with the positional accuracy of the NEFOP data (DePiper 2014).
Groundfish Predator Fishery

Based on NEFSC diet data, Atlantic cod, Pollock and spiny dogfish were the “groundfish” species considered to have Atlantic herring as a major part of their diet. VTR records for these species were prepared in an identical way to the MWT herring data, except that no gear distinction was made (i.e., all gears were included).

Striped Bass Fishery

The overlap between the striped bass fishery and the MWT herring fishery cannot be evaluated for several reasons. While only coarse spatial information (statistical reporting areas) is collected from the Massachusetts commercial bass fishery, no spatial information is available to describe where recreational fishing takes place at sea. Regardless, striped bass fishing is prohibited in federal waters, and the MWT fishery is prohibited from operating in Massachusetts state waters. Midwater trawling does occur in Rhode Island state waters, but primarily in December-January when striped bass have migrated out of New England coastal waters. In short, we lack sufficient spatial data to quantify the overlap between these two fisheries, but it is expected to be minimal.

Bluefin Tuna Fishery

While the bluefin tuna fishery is required to report all landings to the Highly Migratory Species (HMS) division of NOAA, these data lack any information about fishing location, apart from very coarse zones (ten from ME to TX). Seafood dealers that purchase bluefin tuna directly from fishermen are required to report the statistical reporting area where the fish were caught; however, these data are of a spatial resolution too coarse to be useful here. Commercial tuna fishermen with VTR reporting requirements (e.g., groundfishermen) are required to submit coordinates (lat/lon) associated with all commercial fishing trips, including those targeting tuna. Within this group of fishermen, charter/party permit holders report differently (number of fish landed) than general commercial permit holders (pounds of fish landed). Lacking a reasonable method for combining these disparate data types, this analysis focused exclusively on the commercial VTRs, which represent the larger portion of VTR tuna records. Collectively, these commercial tuna VTR records include almost 10,000 trips between 2000 and 2016 (Figure 2), and account for ~10-20% of the total annual bluefin tuna landings reported to HMS in a given year. Although VTR records encompass a relatively small portion of the entire fishery, they represent the only source of data with sufficient spatial resolution to inform this overlap analysis. The raw VTR coordinates were used to represent harvest location, because there are no NEFOP data for this fishery from which to construct a VTR-NEFOP spatial model, as was done with groundfish and herring. Reported bluefin tuna landings from all gear types were included in this analysis.

Commercial Whale Watching

As part of the Northeast U.S. ocean planning process, a survey of 32 industry experts was conducted in 2014 to record the spatial and seasonal distribution of whale watching activity in the Northeast U.S. (Bloesner et al. 2015). Participants were asked to identify “dominant use” areas that represent all the areas routinely visited by most users over the past 3-5 years, as well as the seasons these areas were important.

Several steps were required to prepare the whale watch data, so that it could be used in an overlap analysis with the MWT herring fishery. If a ‘dominant use’ whale watch area had a season associated with it, it was assigned to specific months using the following definitions:
- Spring = April-June;
- Summer = July-September;
- Fall = October-December.

If no season was associated with an area, it was assumed to apply to all months April-December. No significant whale watching activity was assumed to occur between the months of January-March. Lacking a description of the relative importance of whale watch areas over time, the seasonal/spatial pattern was assumed to be constant across all years.

**Overlap Analysis**

Each data source was subset by month and summarized to a common raster grid with 10 km x 10 km cells (Figure 3 to Figure 6). For fishery-dependent data (herring and groundfish), the average pounds landed per month in each grid cell was divided by the sum of the average annual landings over the entire domain (within the Herring Management Areas), so that the collection of monthly raster grids summed to 1.0. For whale watch data, no quantitative distinction was made between areas; instead, any cell that was identified as ‘dominant use’ in a given month was assigned a value of 1, with all other areas given a value of 0. As with the fishery data, the monthly whale watch rasters were normalized to sum to 1.0 over the year.

A simple overlap index was then calculated between each pair of normalized datasets (i.e., MWT herring vs. other): for each grid-cell x month combination, the minimum value across the two datasets was identified (Figure 1). This yields a set of monthly rasters that show the relative intensity of spatial and seasonal overlap. Summing the cell values across a set of monthly overlap rasters yields an index value that ranges from 0 (no overlap) to 1 (complete overlap), allowing for a description of the relative change in overlap over time, across seasons or between dataset pairs.

A comparison of each of the relevant alternatives from Amendment 8 was made with respect to the results of the overlap analysis for the full post-Amendment 1 time period (2007-2015; Figure 12), as well as the most recent three years (2013-2015; Figure 13). For each alternative and sub-option, the fraction of the total overlap encompassed by the measure was calculated. It is important to note that this analysis does not address the potential re-allocation of MWT herring effort that is displaced by an alternative.

**Results**

**Summary of overlaps:** The level of overlap between the MWT herring fishery and all predator users analyzed dropped significantly in 2007 with the passing of Amendment 1 (Figure 10). The seasonal profile of overlap has also changed since 2007 (Figure 11), with less overlap in summer months in recent years. These changes in seasonal overlap are due, in part, to Amendment 1, but also to changes in the distribution of predator-based activities caused by modifications to the spatial management system (e.g., groundfish closed areas).

**Overlap with commercial groundfish fishery:** In all three time periods, the greatest amount of overlap between the MWT herring and groundfish predator fisheries occurred near Cape Ann in October-November (Figure 7). Prior to Amendment 1, significant overlap also occurred in this area during the summer months; however, this interaction has been minimal since 2007. In the recent time period, the most important herring-groundfish overlap outside of HMA 1A occurred...
along the northern edge of Georges Bank in May, off outer Cape Cod in July-August, the Great South Channel in September, and near Block Island in December-January.

**Overlap with bluefin tuna fishery:** In all three time periods, the overlap between the MWT herring and bluefin tuna fisheries was greatest during October near Cape Ann (Figure 8). Prior to Amendment 1, overlap between these two fisheries also occurred in HMA 1A during July-September. More recently, there has also been relatively high overlap along the northern edge of Georges Bank during November.

**Overlap with the whale watch industry:** Prior to Amendment 1, the greatest overlap between the MWT herring fishery and commercial whale watch operators occurred in several areas within HMA 1A from May-November (Figure 9). As with the other user groups focused on herring predators, the summer HMA 1A overlap no longer exists and currently the area with the greatest overlap is near Cape Ann during October-November. It should be noted that any inference about the change over time in overlap with whale watching comes entirely from the MWT herring dataset, as the spatial/seasonal pattern for whale watching was assumed time-invariant.

**Overlap relative to the alternatives:** Alternative 3 (year-round prohibition of MWT herring fishing in HMA 1A) and the widest shoreline buffer alternatives (Alt 5 and Alt 6) with the year-round sub-option encompassed the largest portion of overlap with the groundfish predator fisheries (up to 20-45%; Figure 12 and Figure 13). For the commercial tuna fishery, Alternative 3 by far encompassed the greatest portion overlap with the MWT herring fishery (50-60%), with all other alternatives covering <20%. Similarly, Alternative 3 encompassed >90% of the overlap with the whale watching industry, with all other alternatives covering <10%.

**REFERENCES**


Figure 1 - Three examples of overlap calculation between the MWT herring fishery and a predator-user: A) no overlap; B) complete overlap; and C) some overlap

**Example A: no overlap**

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<tr>
<td></td>
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</table>

Σ = 7   Σ = 14

<table>
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</tr>
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</table>

Σ = 1   Σ = 1   Σ = 0

**Example B: complete overlap**

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Σ = 7   Σ = 14

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Σ = 1   Σ = 1   Σ = 1

**Example C: some overlap**

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<td></td>
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Σ = 7   Σ = 14

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<th>Overlap</th>
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</tr>
<tr>
<td></td>
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</table>

Σ = 1   Σ = 1   Σ = 0.5
Figure 2 - Spatial distribution VTR-reported bluefin tuna landings, 2000-2016

Note: The size of the bubbles is proportional to the pounds landed. The purpose of this figure is to demonstrate the volume of tuna VTR data used in this analysis. Because this fishery is spatially concentrated at certain times of year (many overlapping VTR points), the summarized raster layers representing total annual landings are dominated by just a few 10 km x 10 km grid cells (Figure 5).
Figure 3 - Average annual reported landings (lbs/km²) of Atlantic herring by MWT trawl, as estimated by VTR-NEFOP spatial model

Avg MWT Herring Landings - 2000-2006

Avg MWT Herring Landings - 2007-2015

Avg MWT Herring Landings - 2013-2015
Figure 4 - Average annual reported landings (lbs / km²) of groundfish predators of herring, as estimated by VTR-NEFOP spatial model

* Avg Cod, Pollock, & Dogfish Landings - 2000-2006

* Avg Cod, Pollock, & Dogfish Landings - 2007-2015

* Avg Cod, Pollock, & Dogfish Landings - 2013-2015
Figure 5 - Average annual reported landings (lbs/km²) of bluefin tuna, as reported by VTR and summarized to the 10km x 10km grid
Figure 6 - Dominant use whale watch areas by month, as recorded by Bloesner (2015)

Dominant Use Whale Watch Areas
Figure 7 - Overlap between the MWT herring fishery and the fishery for groundfish predators of herring (cod, pollock and dogfish)
Figure 8 - Overlap between the MWT herring and the commercial tuna fisheries

Overlap: MWT Herring - Comm Tuna VTR - 2000-2006


Overlap: MWT Herring - Comm Tuna VTR - 2013-2015
Figure 9 - Overlap between the MWT herring fishery and commercial whale watch operations
Figure 10 - Annual index of overlap between the MWT herring fishery and other predator-focused user groups
Figure 11 - Seasonal index of overlap between the MWT herring fishery and other predator-focused user groups, under three different time periods

Seasonal Overlap Index with MWT Herring

2000-2006

2007-2015

2013-2015

Overlap Index
Figure 12 - Percent of the total overlap between the MWT herring fishery and predator-focused user groups encompassed by each alternative, 2007-2015

Figure 13 - Percent of the total overlap between the MWT herring fishery and predator-focused user groups encompassed by each alternative, 2013-2015
Localized depletion literature review
By the Atlantic Herring Plan Development Team

INTRODUCTION
A purpose of Amendment 8 to the Atlantic Herring Fishery Management Plan is:

“to propose measures to address potential localized depletion of Atlantic herring.”

The corresponding need is:

“to minimize possible detrimental biological impacts or socioeconomic impacts on other user groups (commercial, recreational, ecotourism) who depend upon adequate local availability of Atlantic herring to support business and recreational interests both at sea and on shore (NEFMC 2017).”

The term localized depletion has many definitions in the literature, but relative to Amendment 8 to the Atlantic Herring Fishery Management Plan (FMP), the NEFMC defined localized depletion as (Amendment 8, Section 1.4):

“In general, localized depletion is when harvesting takes more fish than can be replaced either locally or through fish migrating into the catch area within a given time period.”

The occurrence of localized depletion, as here defined, suggests that fishing for a prey species (e.g., herring) from a given area would either leave relatively immobile predators (e.g., monkfish) with insufficient prey for some time, or that relatively mobile predators (e.g., cod, tuna, whales) would leave the area in search of alternate prey.

Localized depletion has been a topic discussed in the herring management arena since at least the mid-2000s, when Amendment 1 to the Atlantic Herring FMP was developed. Through Amendment 1, midwater trawl (MWT) gears were excluded from management Area 1A from June-September. At that time, no evidence or data linking midwater trawling to localized depletion, however, was used to support that action. The Council’s rationale was to ensure access to herring for the purse seine and fixed gear components of the fishery and to address concerns raised by the public and the SSC about concentrated catch inshore and need for precaution due, in part, to lack of data on the inshore resource. There was a concern that midwater trawl gear was particularly prone to causing localized depletion (NEFMC 2006).

There has been limited research on whether and to what extent the Atlantic herring fishery causes localized depletion. This appendix summarizes the literature on this topic and cases where localized depletion has been addressed in fisheries management, including other potentially relevant examples of how user conflicts have been addressed and precautionary measures taken to ensure prey availability.

In addition, a large body of scientific literature has been considered by the Atlantic Herring Plan Development Team (PDT) when developing the DEIS for Amendment 8. Many references were provided by the public as this action has developed. Some contain useful background about the...
information available concerning the relationships between Atlantic herring and its predators in this region. Others focus on other regions, but may have some degree of applicability. This appendix aims to include an exhaustive list of the references gathered by the PDT and provided by the public. In compiling this appendix, the PDT consulted staff of each Regional Fishery Management Council and/or NMFS regional staff to assist in identifying relevant cases, included references submitted by the public during scoping, and conducted its own literature search.

**Overall, there is very limited direct research of this subject for this fishery and region. To date there is not scientific consensus on the impacts of herring fishing on the abundance of predators in this system, which are mostly generalists that depend on multiple prey species, and have the ability to adapt to changes in herring abundance.**

**ATLANTIC HERRING FISHERY-RELATED RESEARCH**

The Atlantic Herring PDT is aware of five cases in which hypotheses related to localized depletion of Atlantic herring were examined. These are summarized here. Some negative correlations between herring fishing activity and predator abundance (or whale watch search times) have been identified. However, additional research is still necessary to determine if and how the herring fishery (or midwater trawls specifically) is causing localized depletion of herring to the detriment of predators. It has been challenging for the PDT to evaluate the potential impacts of localized depletion due to many data limitations. If more direct research was available about the potential impacts on predators in this region, it would be very useful for herring management. To that end, the PDT has recommended adding evaluation of localized depletion to lists of research priorities.

Two studies were presented at the 2005 conference on the Biology of Marine Mammals. Weinrich et al. (2005) found correlations between the presence of herring fishing (particularly midwater and pair trawls) and the absence of humpback whales during the years 1988-2004. The number of individual whales identified per year and the number of identified whale sightings decreased significantly in the years since the advent of trawling in the Gulf of Maine (1998-2004). Milette et al. (2005) found that whale sightings and herring landing were not significantly correlated, yet whale sightings decreased in the Inner Schoodic Ridge areas in 2000-2004 relative to 1995-1999. These authors suggest a relationship between herring fishing and the presence of whales that is a function of gear type. The Atlantic Herring PDT is unaware if either of these studies have been published or if any additional work has been conducted by these authors relative to this subject.

In 2008, the Atlantic Herring Research-Set-Aside Program funded a project to address the RSA priority “Define localized depletion of herring on a spatial and temporal scale; further develop hydroacoustic surveys to provide an independent means to estimate stock sizes and/or define localized depletion (long-term research possibilities)”. Stockwell et al. (2011) attempted a before-after-control-impact study in 2009 based on pilot work in 2008. However, the project was hampered by logistical and budget constraints that resulted in low sample sizes. The project focus shifted to methods development, evaluating the use of acoustics on commercial fishing boats for assessing the possible impacts of midwater trawling on herring aggregations (Stockwell et al. 2013).

Lee (2010) examined localized depletion by analyzing the search times of commercial whale-watching vessels relative to herring fishing in 2002-2006, to test the hypothesis that intensive
fishing effort increases the search time of whale-watching companies. A correlation between increased herring fishing and increased search times was found, but the degree was fairly small.

In 2015-2016, the Atlantic Herring PDT examined Vessel Trip Report data to compare the catch of Atlantic cod, pollock, and spiny dogfish subsequent to herring catch. Within each statistical area, catch per trip (CPT) of these three predators were calculated during the week of reported herring catch and compared with predator CPT for the first and second weeks following herring catches. The years 1997-2014 to capture a range of years before and after Amendment 1. The results provide no evidence of localized depletion for these predators at the scale of statistical area and one or two week time intervals. Appendix X contains additional details about this work.

To help ensure that localized depletion questions get resolved, the Council included the following research priority in its 2017-2021 research priorities:

“Define localized depletion of spawning components on a spatial and temporal scale for Atlantic herring.” (www.nefmc.org)

Additionally, the Council has recommended that localized depletion be included on the narrower list of Herring Research-Set-Aside priorities for 2019-2021.

“Studies to evaluate the influence of localized depletion of herring on their predators. For example, projects that directly measure the potential influences of depleting herring on predator distributions, such as a before-after control impact study (BACI experiment), or other related research.” (www.nefmc.org)

**MANAGEMENT CASES - CONSTRAINING PREY FISHERIES**

Below are management cases analogous to what the NEFMC is considering, where a management entity considered taking action to constrain a directed fishery for a prey species, addressing concerns that the fishery may be negatively impacting the prey availability for a predator, with follow-on impacts to the user groups of the predator (e.g., directed fishery, ecotourism).

**Longfin squid**

In 2010, the Massachusetts Division of Marine Fisheries (MADMF) issued letters of authorization (LOA) to a small number of draggers to fish within state waters south of Martha’s Vineyard and Nantucket after the regular season that occurs April 23 – June 9, keeping the fishery open through December 31. In January 2014, MADMF proposed codifying this extension into regulation, rather than annually issuing LOAs, after receiving no public opposition to doing so. The extended season for the fishery occurred in 2014. In December 2014, MADMF proposed rescinding this exemption, prompted by concerns raised by island fishermen on the impacts of squid fishing on forage availability, benthic habitat impacts, and bycatch (MADMF 2014). In February 2015, a memo from the Director indicated that, “While there is similarly no concrete evidence of impacts on forage availability, it’s commonsense that any consistent level of fish extraction concentrated on a single species will cause some amount of local depletion of that species” (MADMF 2015b). For 2015, as well as 2016, MADMF modified the regulation to extend the small-mesh trawl fishery by about a week after June 9, rather than through the end of the year, balancing user conflicts with the late run of squid and continued commercial interest in the squid fishery (MADMF 2015a; 2016).
The Mid-Atlantic Fishery Management Council (MAFMC) recently developed a “Squid Capacity Amendment” to the Atlantic Mackerel, Squid, and Butterfish FMP, which considers measures to reduce latent longfin and Illex squid permits and to modify how Trimester 2 (May-August) of the longfin squid fishery is managed. In response to public scoping, the Council considered an additional objective to consider a longfin squid buffer zone (i.e., time-area closure) in the area south of Martha’s Vineyard/Nantucket. Scoping comments indicated public concern that longfin squid fishing effort concentrated in this area may be negatively impacting fishing for predators in Nantucket Sound, due to localized depletion of prey and/or bycatch of recreationally-targeted species. In June 2016, the FMAT developed preliminary analysis of predators (striped bass, bluefish, black sea-bass, summer flounder) and prey (longfin squid, alewife, blueback herring, butterfish) in Nantucket Sound. The FMAT had difficulty linking any trends in abundance between predators and prey, indicating that it “will likely not be able to deduce any cause and effect associations given the myriad of factors that impact local fish abundances” (MAFMC 2016). In December 2016, the MAFMC decided to discontinue developing alternatives regarding localized depletion in this action. Rationale included the difficulty with quantifying impacts and a desire to focus on addressing other issues, some of which may limit squid effort in the area of interest (MAFMC 2017a).

The MAFMC has continued discussion of this issue. In 2017, there was preliminary work to develop a framework action that would consider buffer options to address concerns about longfin squid fishing effort/catch south of Massachusetts’ state waters off Martha’s Vineyard and Nantucket. In December 2017, the MAFMC discussed the framework’s goals and potentially approve preliminary alternatives for further analysis (MAFMC 2017b). However, the MAFMC opted to discontinue work on the framework. The squid amendment includes a closure to the directed fishery once the Trimester 2 quota has been reached. The MAFMC opted to see if this summertime closure would ameliorate public concerns prior to pursuing a follow-on action.

Atlantic menhaden

In 2005, the Atlantic States Marine Fisheries Commission approved Addendum II to Amendment 1 of the Atlantic Menhaden Management Plan to implement a catch cap for Atlantic menhaden in Chesapeake Bay. This action was taken because the fraction of coast-wide landings was increasing for Chesapeake Bay and there was concern for the potential for localized depletion. The cap was set equal to recent average landings and was effective for 2006-2010. At the time, the ASMFC determined that there was insufficient scientific data to satisfactorily determine whether localized depletion is occurring in the Bay or to identify specific reasons for predator finfish deficiencies or low larval menhaden recruitment. To address this, Addendum II established research priorities it examine the possibility of localized depletion (ASMFC 2005).

Subsequently, the catch cap has remained in place, extended through a few subsequent ASMFC actions, though the absolute value of the cap has changed relative to the stock-wide catch limit (ASMFC 2009; 2012). NOAA Chesapeake Bay Office, ASMFC, Maryland, and Virginia and others initiated the Atlantic Menhaden Research Program to address the ASMFC research priorities (ASMFC 2009). In 2009, the Center for Independent Experts convened a peer review of the program and projects funded to date (about 15). The three reviewers concluded that the projects were valuable and well executed, some studies pointed to the possibility of localized depletion, but on the whole, it had not yet been demonstrated to occur in Chesapeake Bay (Haddon 2009; Maguire 2009; Roel 2009). This review was the culmination of the research.
program, and the ASMFC has not been involved in sponsoring any additional localized depletion-related projects in Chesapeake Bay (M. Ware, ASMFC, pers. comm., 2017).

Other references related to Atlantic menhaden
- In 2006-2008, menhaden larval ingress, age at ingress, feeding incidence and success, and growth all experienced some degree of inter-annual variability in Chesapeake Bay (Lozano 2011)
- ASMFC research program further described by the EBFM Menhaden Species Team (2009).

North Pacific Stellar Sea Lions and other predators
The western Distinct Population Segment (WDPS) of Steller sea lions has been listed as endangered since 1997. Factors for the decline may include intentional shooting, disease, ecosystem change, and interactions with fisheries (competition, disturbance, direct and incidental mortality; https://www.npfmc.org/bering-seaaleutian-islands-groundfish/). Witherell et al. (2000) review the measures taken (as of 2000) by the North Pacific Fishery Management Council (NPFMC) to reduce potential impacts of localized depletion of prey for Stellar sea lions, as well as Pacific walrus. Regulations have focused on reducing potential effects of competition, and minimizing localized depletion of their prey (e.g., pollock, Pacific cod, Atka mackerel, salmon, octopus). There are protections for terrestrial habitat (e.g., no-transit zones near certain rookeries/haul-outs), but the most consequential measures spread the catch of pollock over time and space. Gulf of Alaska pollock are managed in four seasonal allocations across four areas. In contrast, cod is managed with two seasons and all other groundfish with one season across two areas.

Although studies have correlated Steller sea lion shore-based habitat with forage fish “hot spots,” (Gende & Sigler 2006), there has not been scientific consensus regarding impacts of fishing on Stellar sea lions. Conners and Munro (2008) investigated the suspicion that the trawl fishery for Pacific cod was causing localized depletion, with negative consequences for Stellar sea lions in the Bering Sea. For this study, localized depletion was defined as the hypothesis “that intense fishing pressure may cause small-scale effects on local densities of the target fish—effects that are disproportionate to the managed overall harvest mortality rate.” Their results were inconsistent with the “hypothesis of strong stationary localized depletion,” that the spatial scale of the current no trawl zones were was much smaller than “the relevant scale of fish movement”. In 2010, NMFS issued an ESA section 7 biological opinion (BiOp), which found that NMFS could not insure that the authorization of the groundfish fisheries was unlikely to jeopardize the continued existence of the WDPS of Steller sea lions or adversely modify or destroy designated critical habitat. Accordingly, NMFS issued an interim final rule with restrictions to the Atka mackerel and Pacific cod fisheries to reduce prey competition. A legal challenge to the interim final rule resulted in NMFS preparing an EIS to allow sufficient public participation under the National Environmental Policy Act (NMFS 2014). The 2010 BiOp was subject to several external scientific reviews, which were all critical of the scientific justification used therein, indicating that there was insufficient evidence for a negative correlation between fishing and sea lions – a conclusion on which the BiOp was based (Bernard et al. 2011). NMFS did prepare an EIS, in consultation with the NPFMC, and in April 2014, NMFS issued a new BiOp with less restrictive measures for the fisheries, concluding that these
measures would not jeopardize the continued existence of the WDPS of Steller sea lions (NMFS 2014).

“BC’s [British Columbia’s] area allocation of TAC was done for biological reasons as a precautionary measure to prevent excessive concentration of fishing effort and localized depletion of fishing resources near fishing ports. Stakeholders in BC were concerned that the IVQ trawl fishery entitlement and tradable IVQ shares could allow such concentration of effort” (PFMC 2004).

**Antarctic krill**

The fishery for Antarctic krill is managed by the Commission for the Conservation of Antarctic Marine Living Resources (external to the U.S. fishery management system). In the late 2000s, the krill fishery had become more spatially and temporally concentrated (Bransfield Strait within Subarea 48.1) due to changes the krill population distribution (impacted by sea-ice cover and water temperature; ASOC 2011). The CCAMLR considered options for dividing the krill catch limits among small-scale management units, balancing a risk to predator populations and fishery performance (Hewitt et al. 2004; Hill et al. 2009; Watters et al. 2008). Since the 2010-2011 fishing season, a krill catch limit has been is set within four management subareas (Areas 48.1 – 48.4) to avoid concentrating catch in any one area and reducing the risk of impacting local ecosystems. In setting the trigger level for 2016-2017, the Commission noted:

“The need to distribute the krill catch in Statistical Area 48 in such a way that predator populations, particularly land-based predators, would not be inadvertently and disproportionately affected by fishing activity” (CCAMLR 2016, p. 219).

It does not appear that other management measures (beyond a catch limit) are in place within a subarea (e.g., time/area closures), to prevent localized depletion. Also interesting is the Commission’s recognition of the need to develop management based on data availability:

“In 2015, the Commission agreed that we need management approaches that are not dependent upon data unlikely to be available at the spatial and temporal scales required for a particular management approach (e.g. regular estimates of total krill biomass and total predator demand for krill for the whole of the Scotia Sea). This might seem pretty obvious, but it reflects the need to design management processes that are practical and can be implemented in the real world” (CCAMLR 2017).

**Other references related to Antarctic krill**

- A model with spatial structure was developed to address concerns of localized depletion of krill in the vicinity of land-based predator breeding colonies (Plagányi & Butterworth 2012).
- A behavioral model, used previously to understand the interactions between penguins and krill, was extended to determine the indirect effect of krill fisheries on penguin foraging success and behavior in adjacent breeding sites (Alonzo et al. 2003).
- Constable and Nicol (2002) discuss the principles and approach required for developing small-scale management units that account for predators’ needs when managing the Antarctic krill fishery.
- Hinke et al. (2017) assessed the degree of overlap between predators and the Antarctic krill fishery to examine how different data aggregations affect the extent and location of overlap.
- Santora et al. (2009) “found a negative relationship between abundance and patchiness of krill and predators, indicating that when krill is less abundant, its predators are less abundant and concentrated.”
- Relationships between penguin and krill (Werner 2015).
- Croll and Tershy (1998) demonstrated seasonal and spatially overlaps of the krill fishery with peak penguin and fur seal prey demands, which may affect prey availability to penguins and fur seals.

**North Sea sand lance (Sand eel)**

Sand eels are a very important prey species for many predators in the North Sea, especially seabirds that breed on the Shetland Islands. Sand eels were first harvested in the North Sea by small inshore fishing vessels in the 1970s. The fishery peaked in 1982 and several species of seabirds showed signs of serious decline in the mid-to late 1980s (Euan Dunn from the Royal Society for the Protection of Birds, personal communication). The fishery was closed for three years in 1991-1994, and precautionary management measures were developed before the fishery reopened in 1998 with seasonal closures, restricted TACs, and port of landings restrictions. Since that time, additional closures and lower catch limits have been implemented through the ICES, the International Council for the Exploration of the Sea. There is strong evidence that several predators are highly vulnerable to changes to local food supply (i.e., Kittiwake seabird); therefore, closures and reduced catch limits have been in place for the commercial sand eel fisheries (ICES 2017).

**Management Cases - Preventing Development of Prey Fisheries**

The following examples are management actions taken to help ensure prey availability, though not directly a result of localized depletion concerns.

**North Pacific forage fish**

In 1997, the NPFMC prohibited directed fishing for forage fish including capelin and euphausiids (krill), though exempted herring, because of an existing fishery (Witherell et al. 2000).

**Pacific krill**

In 2006, the Pacific Fishery Management Council (PFMC) proposed a ban on the commercial fishery for all krill species in west Coast federal waters. At the time, there was no krill fishery in PFMC waters, or in California, Oregon or Washington state waters. There was no specific concern about localized depletion, but the PFMC made this recommendation in recognition of the importance of krill as a food source in the marine food chain. This proposal was implemented by NMFS in July 2009, noting that there was no indication that the status of the krill resource has contributed to status of predator species (NOAA 2009).

**Mid-Atlantic unmanaged forage fish**

NMFS is accepting public comment through May 30, 2017 in an omnibus amendment proposed by the MAFMC to prevent the development of new, and the expansion of existing commercial fisheries on certain forage species.
MANAGEMENT CASES - RESOLVING WITHIN-SPECIES USER CONFLICTS

Below are examples where a management entity considered taking action to constrain a directed fishery for a species, to address concerns about the availability of that species for a fishery by another user group. Again, all cases identified by staff of other regions are included here.

Dolphin and wahoo management

The original Dolphin and Wahoo FMP established by the South Atlantic Fishery Management Council (SAFMC) in 2004 included concerns about localized depletion in its problem statement and FMP objectives. However, SAFMC staff indicates that the SAFMC has not taken a specific action in this FMP to address localized depletion (K. MacLauchlin, pers. comm., 2017).

A SAFMC concern: “Owing to the significant importance of the dolphin/wahoo fishery to the recreational fishing community in the Atlantic, the goal of this fishery management plan is to maintain the current harvest level of dolphin and insure that no new fisheries develop. With the potential for effort shifts in the historical longline fisheries for sharks, tunas, and swordfish, these shifts or expansions into nearshore coastal waters to target dolphin could compromise the current allocation of the dolphin resource between recreational and commercial user groups. Further, these shifts in effort in the commercial fishery, dependent on the magnitude (knowing that some dolphin trips may land over 25,000 pounds in a single trip), could result in user conflict and localized depletion in abundance.”

A problem the FMP aims to address: “Localized reduction of fish abundance due to high fishing pressure.”

A FMP objective: “Address localized reduction in fish abundance. The Councils remain concerned over the potential shift of effort by longline vessels to traditional recreational fishing grounds and the resulting reduction in local availability if commercial harvest intensifies.” (Plummer et al. 2012; SAFMC 2003).

Snapper grouper management

The Snapper Grouper FMP was established by the SAFMC in 1983. In 1994, through Amendment 7 to the FMP, the following was added to the list of problems:

“Localized depletion where a species’ abundance in an area is reduced by high fishing effort can cause conflict among fishermen.”

Amendment 7 indicates that “high fishing mortality rates have resulted in localized depletion of some species in certain areas” and that overfishing rates for certain areas is higher than the rate for the range of the species. However, no specific examples were included. Snapper and grouper species were “suspected to be experiencing localized depletion.” Amendment 7 also indicates that:

“The issue of localized depletion needs to be addressed. However, the evidence to support actions to institute corrective measures is lacking.”

“The Council approved adding this new problem so that it can be evaluated and if action is needed, necessary regulation could be implemented through the framework.” SAFMC (1994, p.82-83).
The objective, “Evaluate and minimize localized depletion” has remained ever since. However, SAFMC staff indicates that the SAFMC has not taken a specific action in this FMP to address localized depletion (K. MacLauchlin, pers. comm., 2017).

Alaska Halibut
Meyer and Stock (2001) has some background on addressing localized depletion concerns in the late-1990s for Alaska halibut, and associated user conflicts among charter and commercial harvesters.

Other References Potentially Pertinent to Amendment 8
Below is a list of references considered by the PDT when developing the DEIS for Amendment 8. Many references were provided by the public as this action has developed. Some contain useful background about the information available concerning the relationships between Atlantic herring and its predators in this region. Others focus on other regions, but may have some degree of applicability. To the extent possible, the PDT included some of this information in the analysis of potential impacts of alternatives considered in this action.

Groundfish
- Northwest Atlantic
  - Relationship between cod and herring documented in historical records (Ames 2010).
  - Richardson et al (2014) described and the availability of herring and sand lance. Haddock predation on herring eggs (Richardson et al. 2011).
  - Herring and other prey for gadids (Ames & Lichter 2013).
  - Sherwood et al. (2007) found that “among and within populations [of Newfoundland and Labrador cod] the benefits of a more pelagic diet in medium-sized (30–69 cm) cod included higher somatic condition, higher liver index (lipid stores) and greater spawning potential (decreased incidence of atresia).”
- Other
  - Neat et al. (2014) provide evidence that “cod living around the British Isles are comprised of at least one more distinct population unit that is currently recognized for stock management purposes. Failure to recognize this complexity of stock structure in past management plans is likely to have been a contributory factor to the over-exploitation of cod stocks around the British Isles.”
  - Hanselman et al (2007) investigated localized depletion for three Alaska rockfish species (Pacific ocean perch, northern rockfish, and dusky rockfish), which are sedentary and patchy population distributions. The study examined fishery CPUE within small areas between 1991-2004. Pacific Ocean perch exhibited intra-annual localized depletion (i.e., CPUE declines) most often, but the depletion did not persist across years. Northern and dusky rockfish showed less depletion and occasional significant increases in CPUE occurred. Northern rockfish showed potential serial depletion in one area. However, these results could be affected by hyperstability (large local populations), migration, or switching of target fisheries mid-year.
  - Barbeaux et al. (2014) estimated location and scale specific fishing exploitation rates of eastern Bering Sea walleye pollock.
Bluefin tuna

- Tuna diet
  - Golet et al. (2015) found that tuna prefer larger herring relative to more herring.
  - Butler et al. (2015) demonstrate feeding activity of Atlantic bluefin tuna on the Gulf of Mexico spawning grounds, with diets including teleosts, cephalopods, crustaceans and a pelagic tunicate.
  - Logan et al. (2015) compared diet composition of tuna between the late 1980s to early 2000s.
  - Other (Chase 2002; Estrada et al. 2005; Logan & Lutcavage 2013; Logan et al. 2011; Logan et al. 2013; Logan et al. 2007).
- Tuna fishery (Fromentin & Powers 2005).

Whales/marine mammals

- Relationship with sand eels (Payne et al. 1986).
- EBFM (Heltzel et al. 2011).

Sea birds

- Northwest Atlantic
  - Relationship with Atlantic herring (Breton & Diamond 2014; Hall et al. 2000; Kress et al. 2016).
- North Sea
  - Relationship with sand eels (Daunt et al. 2008; Frederiksen et al. 2008; Frederiksen et al. 2004).
- Marine Protected Areas
- Sea birds other (Bertrand et al. 2012; Cury et al. 2011; Goyert 2015; Paredes et al. 2012; Rindorf et al. 2000; Robertson et al. 2014; Rock et al. 2007).

Atlantic herring

- Consumption by predators (Overholtz & Link 2007).
- Role in ecosystem (Bakun et al. 2009).

Other
• Fishery impacts
  o Hilborn et al. (2017) explored the impact of fishing low trophic level “forage” species on higher trophic level marine predators including other fish, birds and marine mammals
  o Cianneli et al. (2013) reviewed the theory, consequences and evidence of eroding population spatial structure in harvested marine fishes.
  o Englehard et al. (2008) explored the effects of fishing mortality versus natural predation on sandeels
  o Walker (1999) examined density-dependent responses to the effects of shark stock reduction.
  o Bearzi et al. (2008) found that the decline in short-beaked common dolphins from western Greece was caused largely by prey depletion resulting from overfishing.
  o Historical baselines of human impacts (Erlandson & Rick 2010; Thornton et al. 2010; Thurstan et al. 2016)
  o Potentially coupled with climate change (Last et al. 2011; McCay et al. 2011; Trenkel et al. 2014)
  o Brazilian monkfish fishery (Perez et al. 2005)
• Stellwagen Bank (NOAA 2010)
• Managing forage fish (DFO 2009; Essington & Plagányi 2014; Pikitch et al. 2012)
• Managing stock components/spatial structure (Kerr et al. 2017; Molton et al. 2013; Ying et al. 2011)
• Role of marine protected areas (McGilliard et al. 2011)
• Shark philopatry (Hueter et al. 2005)
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