Comment on “Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery”

Michael C. Palmer,* Jonathan J. Deroba, Christopher M. Legault, Elizabeth N. Brooks

Pershing et al. (Reports, 13 November, p. 809) concluded that failure to account for temperature in the assessment and management of Gulf of Maine Atlantic cod caused overfishing. We argue that the “extra mortality” calculation driving this conclusion is an artifact. Environmental factors affect all stocks, but attribution of additional mortality to temperature alone by Pershing et al. is unsupported by the data.

The “extra mortality” in Pershing et al. was calculated by subtracting fishing and natural mortality from total mortality (Fig. 1). Total mortality was calculated as the difference in the log of abundances of adjacent age groups in sequential years, where abundance was estimated by the assessment model and assumed equal to 0.2 as in the assessment should lead to changes in the relationships between a reasonable representation of “extra mortality” and temperature. However, when the analysis is repeated with the M-ramp model, the results (as noted by Pershing et al. in their supplementary materials) are nearly identical because the M-ramp model provides nearly identical fits with similar residuals for the catch and age composition data as the $M = 0.2$ model. Thus, the spurious correlations reported in Pershing et al. are related to assessment residuals rather than changes in temperature.

Other factors contributed to the spurious relationships in Pershing et al. They restricted their analysis to the years 1993 to 2012 (6) due to “several obvious outliers” [supplementary materials for (7)] reported in the mortality estimates before 1993, but without providing any clear rationale. We repeated the analysis of “extra mortality” using all years and examined the results for the presence of outliers. Although there are several outliers in the time series, only two of the five outliers occur before 1993 (Fig. 1). We used a jackknife procedure (7) on the entire 1982 to 2012 time series (8) to evaluate the influence of these outliers on the subsequent “extra mortality” and sea surface temperature (SST) correlations. Ages 1 and 4 were the only two ages where a positive correlation between “extra mortality” and SST was consistently obtained across time blocks, although 98% of the age-1 and 80% of the age-4 relationships were not statistically significant (9). The only way to obtain significant positive relationships for age 4 across all time blocks was to exclude 1992 from the analysis, which was effectively done by Pershing et al. by starting the time series in 1993. Curiously, age 6 exhibited the most consistent significant correlations (except for the second quarter), but these were negative (“extra mortality” decreased with

---

Northeast Fisheries Science Center, Population Dynamics Branch, 166 Water Street, Woods Hole, MA 02543, USA.

*Corresponding author. Email: michael.palmer@noaa.gov

---

Fig. 1. Distribution of estimated Gulf of Maine Atlantic cod “extra mortality” by age. These box plots show the distribution of the 1982 to 2012 “extra mortality” estimates calculated by Pershing et al. The horizontal black bars represent the median values; gray boxes represent the interquartile range (IQR) (25th and 75th percentiles); and the whiskers represent $1.5 \times$ IQR. The “extra mortality” at age $j$ in year $t$ was calculated as $Z_{jt} = F_{jt} - M_{jt}$, where $M$ is assumed equal to 0.2 as in the 2014 assessment model. The $Z_{jt}$ in the “extra mortality” is calculated from the estimated numbers at age ($N$) from the stock assessment model $Z_{jt} = \log N_{jt} - \log N_{j(t+1)}$, premised on catch $C$ and fishing mortality $F$ containing error, and the $F_{jt}$ is derived from the observed catch (assumed error free): $F_{jt} = C_{jt}Z_{jt}/[N_{jt} - N_{j(t+1)}].$
increasing temperature). We conclude that there was no objective rationale for excluding the years before 1993. In fact, restricting the time series to only 1993 to 2012 reduced the most consistent relationship that existed within the time series (age 6 and SST), although this negative correlation runs counter to the central hypothesis of the paper.

Pershing et al. posit that the proposed biological mechanism for the age-4 relationship with temperature is an energetic bottleneck that occurs with the onset of reproduction and the transition from pelagic to benthic prey. The empirical evidence that Pershing et al. provide to support this hypothesis is recent below-average body mass at age (i.e., smaller fish) and poor condition of Gulf of Maine cod, all of which can be evaluated from information contained in the 2014 stock assessment (2). The age of 50% maturity is approximately 2.6 years, with nearly 90% of cod mature by age 4. If the energetic bottleneck associated with the onset of reproduction were causing higher mortality, then significant positive relationships with temperature should have been apparent at ages 2 or 3. Furthermore, the average body mass in Gulf of Maine cod younger than age 6 has not declined, nor are fish currently in poor condition as claimed (2). The biological mechanism proposed by Pershing et al. is not supported by the data.

Although it is tangential to the “extra mortality” hypothesis, Pershing et al. imply that errors in projected recruitment resulting from a failure to incorporate temperature effects in the stock-recruit relationship also contributed to the overfishing of this stock. The age at 50% selectivity to the fishery is 3.7 years for Gulf of Maine cod (2). Over the past decade, the catch projections have been updated before the projected recruits enter the fishery (30). Consequently, the quotas resulting from the stock projections were largely insensitive to errors in the projected recruitment estimates.

Environmental factors do affect fish stocks, although these are often difficult to disentangle from harvest decisions (11). We argue that the analyses of Pershing et al. provide no evidence to support the hypothesis that failure to account for increases in temperature led to overfishing of the Gulf of Maine Atlantic cod stock. Future explorations of environmental effects should be investigated by directly incorporating these within the stock assessment model, where assumptions are explicit and consistent and their merit can be appropriately evaluated.

REFERENCES AND NOTES

5. There are two accepted Gulf of Maine Atlantic cod assessment models used to manage the stock that vary only in their assumptions of natural mortality (M). The M = 0.2 model assumes an age- and time-invariant value of M = 0.2 throughout the assessment time series, and the M-ramp model assumes an age-invariant M that increases from 0.2 early in the time series (1982 to 1988) to 0.4 at the end of the time series (2003 to 2013). In the intervening years (1989 to 2002) M increases linearly.
6. Pershing et al. reported that their “extra mortality” analysis extended through 2013; however, an examination of the codM02.csv file provided in their supplementary materials revealed that the time series extended only to 2012. This is presumably due to the lack of population estimates in 2014 that would be needed to calculate total mortality in 2013, although the “extra mortality” could have been estimated from the fully selected fishing mortality, fishery selectivity, and assumed natural mortality available in the 2014 cod assessment using the equation \( F_M = C_M Z_{\text{fish}} (N_{\text{fish}} - e^{-M t}) \), where \( F_M \) is the fishing mortality, \( C_M \) is the observed catch, \( Z_{\text{fish}} \) is the “extra mortality,” and \( N_{\text{fsh}} \) is the numbers at age \( j \) in year \( t \). In our analyses, we have used only the 1982 to 2012 time series to ensure comparability with the Pershing et al. results.
8. In each iteration of the jackknife procedure, a single year was dropped from the time series and the correlation analysis was repeated until all years had been dropped from the analysis once.
9. Statistical significance is based on \( \alpha = 0.05 \), as in Pershing et al.
10. Since 2004, the maximum age of projected recruits has exceeded age 2 only three times (age 3 in 2005, 2008, and 2011). Gulf of Maine cod age 2 and younger are less than 5% selected to the fishery.

ACKNOWLEDGMENTS

We thank F. Serchuk and P. Rago for comments that improved this manuscript.

30 November 2015; accepted 25 March 2016
10.1126/science.aad9674

---

Table 1. Age-specific correlation coefficients (r) between the Pershing et al. “extra mortality” and the catch-at-age residuals from the 2014 Gulf of Maine Atlantic cod M = 0.2 stock assessment model. Residuals have been calculated as Pearson residuals \((O_{ij} - P_{ij})\sqrt{\{1-P_{ij}\}}\), where \(O_{ij}\) and \(P_{ij}\) are the observed and predicted catch at age \(j\) in year \(t\), respectively. The significance level \(P\) and sample size \(n\) are provided.

<table>
<thead>
<tr>
<th>Age</th>
<th>(r)</th>
<th>(P)</th>
<th>(n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.94</td>
<td>&lt;0.001</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>-0.90</td>
<td>&lt;0.001</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>-0.83</td>
<td>&lt;0.001</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>-0.91</td>
<td>&lt;0.001</td>
<td>31</td>
</tr>
<tr>
<td>5</td>
<td>-0.84</td>
<td>&lt;0.001</td>
<td>31</td>
</tr>
<tr>
<td>6</td>
<td>-0.90</td>
<td>&lt;0.001</td>
<td>31</td>
</tr>
<tr>
<td>7</td>
<td>-0.84</td>
<td>&lt;0.001</td>
<td>31</td>
</tr>
</tbody>
</table>
Comment on "Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery"

Michael C. Palmer, Jonathan J. Deroba, Christopher M. Legault and Elizabeth N. Brooks

Science 352 (6284), 423.
DOI: 10.1126/science.aad9674