**TECHNICAL COMMENT**

**CLIMATE CHANGE**

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

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Pershing et al. (Science, 13 November 2015, p. 809) concluded that recent warming in the Gulf of Maine contributed to the collapse of Gulf of Maine cod. We argue that this conclusion is based on a flawed analysis of the population dynamics of this cod stock. We believe that understanding the potential role of climate change in the collapse of this stock requires more defensible analyses.

Pershing et al. claim to demonstrate that recent ocean warming has resulted in reduced recruitment and increased rates of natural mortality (M) (e.g., predation and starvation) of Gulf of Maine cod, contributing to the collapse of this stock. They calculated M using abundance estimates from the assessment model for Gulf of Maine cod (2) and fishery catch at age (CAA) (the number of cod caught in the fishery at each age and in each year) inputs to that model (equations 5 and 6 in their supplementary materials (SM)). They assumed that deviations between their calculated annual values of M and the value of M used in the assessment model reflected “extra mortality.” We assert that the values for M calculated by Pershing et al. do not accurately represent the true values of M.

Pershing et al. based their calculations on abundance estimates from a model that assumed constant M = 0.2 year−1 for all ages and years. If they had used the CAA predicted by this model in their calculations, their estimates of M would have been the same as this constant M value. However, unlike the model, they assumed that CAA was known without error, which is unreasonable given the numerous uncertainties and assumptions that go into determining CAA. The first implication is that their estimates of M will differ from the original model M used in the assessment, because the assessment model takes uncertainty in CAA into account. Therefore, the abundances used by the authors to calculate M, as well as the recruit and spawner abundances used in their stock-recruitment analyses (equations 1 to 4 in their SM), will not be consistent with the authors’ M values. Furthermore, if the values of M used in the assessment model are biased, as the authors imply, then these abundances will also be biased. Ignoring observation error in the catch and using biased abundance estimates will not produce unbiased estimates of M (or deviations in M as used by the authors, which were termed “extra mortality” or “mortality correction”). The correlations that the authors obtained between deviations in M and temperature thus are likely to be spurious. Likewise, abundance estimates that are thought to be biased should not be used for the authors’ stock-recruit modeling.

For readers not familiar with stock assessment models, we use a simple simulation to illustrate that values for M calculated using the procedures of Pershing et al. (equations 5 and 6 in their SM) will not resemble the true values. We based this simulation on the stock assessment of cod in the southern Gulf of St. Lawrence (3). This assessment uses a statistical CAA model (SCA) that estimates time-varying M. The southern Gulf of St. Lawrence cod stock provides a pertinent basis for the simulation because an increasing trend in M is identified for this stock, similar to the increase in M of Gulf of Maine cod hypothesized by Pershing et al. For the purpose of this simulation, we constructed a synthetic population based on the assessment model estimates. We constructed time series of fishery CAA and survey abundance indices at age using the model estimates of population abundance by age...
and year, fishing and natural mortality rates by age and year, and selectivity and catchability to the fishery and surveys. Error was added to these time series based on the assessment estimates of observation error in the survey biomass indices and the fishery and survey CAA data (see (4) for an example). Variability was added to the total fishery catch based on a coefficient of variation of 5%. We then fit an SCA model to these simulated time series, assuming a constant value of 0.2 for $M$ of all ages in all years (as in the Gulf of Maine cod model that produced the abundance estimates used in the authors’ calculations). Using the fishery CAA input to the $M = 0.2$ model and its abundance estimate outputs, we calculated values for $M$ using the method in Pershing et al. (equations 5 and 6 in their SM). We repeated this procedure 200 times. The calculated values for $M$ bore no resemblance to the “true” values (Fig. 1). Furthermore, the calculated values were negative in some simulations, which is not possible for true values of $M$.

In any type of modeling, it is inappropriate to take outputs from a model that is based on specific assumptions (e.g., constant $M$ of 0.2 and error in the CAA) and use them in analyses that implicitly or explicitly make fundamentally different assumptions. The results of those analyses will be consistent with neither the original nor the new assumptions. A more defensible way to estimate potential climate effects on natural mortality and recruitment would estimate variation in $M$ and recruitment within the assessment model (e.g., (5–7)), which would take various observation and process uncertainties into account. The reliability of model results should also be assessed by simulation (e.g., (6)) before making such strong claims about factors leading to the collapse of commercially and socially important fish stocks. Furthermore, consistent with best practice in fisheries science and science in general (8), multiple other working hypotheses about causes of changes to $M$ and recruitment should also be considered and their relative support assessed [e.g., (7)]. We believe that it is necessary to reserve judgment on the role of climate change in the collapse of Gulf of Maine cod until more defensible analyses are conducted to address this issue.

REFERENCES

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