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Statistical behavior of retrospective patterns and their effects on estimation of stock and harvest status

Timothy J. Miller*, Christopher M. Legault

Northeast Fisheries Science Center, National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543, USA

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ABSTRACT

The presence of retrospective patterns in stock assessments is problematic for determining stock and harvest status because current estimates of stock size or fishing mortality are consistently lower or higher than those when the assessment model is updated with new data. A statistical measure of evidence for retrospective patterns is needed, but a requisite method to estimate variance of retrospective patterns is lacking. We evaluated the statistical behavior of a parametric bootstrap-based variance estimator for retrospective patterns that arise due to a change in natural mortality using a simulation experiment patterned after an assessment of yellowtail flounder on Georges Bank. We also evaluated effects of retrospective patterns on accuracy of stock assessment results and adjustments to terminal stock attributes intended to correct for retrospective patterns. We focused our analyses on Mohn's ρ, but the bootstrap approach could be used with any measure of retrospective pattern. We found that coverage for confidence intervals of Mohn's ρ were adequate, particularly for commonly specified percentage levels near 95%. We also found increased statistical efficiency of terminal year stock attributes that are adjusted for estimated retrospective patterns when the model structures used to simulate observations and estimate the parameters were inconsistent. Furthermore, this increase in efficiency was generally greater than the decrease in efficiency of adjusted stock attributes when models for simulated data and parameter estimation were consistent. However, the utility of adjustments for estimating stock and harvest status depended on our expectation for future productivity of the stock and using confidence interval coverage of Mohn's ρ to determine whether to adjust terminal stock attributes provided no greater benefit than simply always adjusting.

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1. Introduction

A retrospective pattern in a fisheries stock assessment is a consistent directional change in estimates of important metrics such as stock size or fishing mortality rate as years of data are added or removed from a stock assessment model. Measures of these retrospective patterns are often provided in practical applications of assessment models because incorrect structural assumptions can cause biased estimation of various population attributes in the terminal years of the model. Bias in the estimation of terminal year attributes, such as stock size or fishing mortality, is particularly important because these estimates strongly influence catch advice. For example, an overestimated stock size will result in an actual fishing mortality rate greater than intended (Brooks and Legault, 2016). The severity of the bias also depends on the type of model misspecification. There are many types of structural misspecification that will induce terminal year bias. The most commonly investigated forms of misspecification are unaccounted for shifts in natural mortality, survey catchability or catch (e.g., ICES, 2008). However, the true form of misspecification is never known in practice.

The most common measure of retrospective patterns, which was first proposed by Mohn (1999) and therefore affectionately termed Mohn's ρ, is calculated from fits of the model to data sets where the terminal year is sequentially removed (peels). For a parameter θ, the original estimator of Mohn's ρ is

$$\hat{\rho}(\theta) = \sum_{t=1}^{P} \rho_t(\theta) \quad (1)$$

where for annual parameters,

$$\rho_t(\theta) = \frac{\hat{\theta}_{T-t,T-t} - \hat{\theta}_{T-t,T}}{\hat{\theta}_{T-t,T}} = \frac{\hat{\theta}_{T-t,T-t}}{\hat{\theta}_{T-t,T}} - 1,$$

* Corresponding author.
E-mail address: timothy.j.miller@noaa.gov (T.J. Miller).

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T is the final year of the full time series of data, P is the number of years removed (or peeled), and $\hat{\theta}_{T-t,k}$ is the parameter estimate for year $T-t$ from fitting the assessment model to data with terminal year k (Mohn, 1999). However, the current standard estimator is the average of the peel-specific components,

$$\hat{\bar{\rho}}(\theta) = \frac{1}{P}\sum_{t=1}^{P}\rho_t(\theta) \tag{2}$$

because it is then comparable across any number of peels. The number of peels used in the estimator varies and can be dictated by data limitations or model specification. For example, if there are estimated parameters associated with observations that only occur in the last 4 years, then they are not estimable for peels with terminal year before that. There is a tendency to use 7 peels in the Northeast US (Deroba, 2014). In stock assessments, retrospective patterns in terminal year stock size and fishing mortality are primarily of interest, but Mohn's ρ could be calculated for any assessment parameters or outputs.

Retrospective patterns have led to assessment models being rejected for management, but more often some remedial action is taken. One approach has been to adjust terminal abundance, fishing mortality, and spawning stock biomass (SSB) by Mohn's ρ for status determination and setting quotas. Stock and harvest status, which are primary goals of stock assessments, are determined by comparing terminal year stock size and fishing mortality to corresponding reference points. For θ being stock size or fishing mortality in the terminal year, the corresponding status estimator is

$$\hat{O}(\theta) = \frac{\hat{\theta}}{\hat{\theta}_{\text{ref}}} \tag{3}$$

where $\hat{\theta}_{\text{ref}}$ is the estimated reference point. If there is model misspecification that leads to a retrospective pattern, estimation of terminal stock size or fishing mortality as well as these measures of stock and harvest status could be severely biased. Terminal year values are adjusted by Mohn's ρ when retrospective patterns are thought to exist using

$$\hat{\theta}_{\text{adj}} = \frac{\hat{\theta}}{1+\hat{\bar{\rho}}\left(\theta\right)} \tag{4}$$

and the adjusted value is compared to the corresponding reference point to determine status using

$$\hat{O}(\theta_{\text{adj}}) = \frac{\hat{\theta}_{\text{adj}}}{\hat{\theta}_{\text{ref}}} \tag{5}$$

(Brooks and Legault, 2016).

Although ICES (2008) found through simulation studies that management advice was improved when some action was taken to address the retrospective pattern, there is no evidence that ρ-adjustment (Eq. 4) provides more accurate estimation of status or terminal estimates. Deroba (2014) investigated effects of adjusting SSB by Mohn's ρ on yield through management strategy evaluation with a particular harvest control rule. However, the true Mohn's ρ was used rather than estimates of Mohn's ρ obtained by fitting assessment model peels. In practice, the true Mohn's ρ is the expected value of Eqs. (1) or (2) over the stochastic data-generation and assessment model-fitting process. This is the only practical definition for a true Mohn's ρ because it is unknown and cannot generally be specified for generation of data used to fit assessment models. Even in the best case where the model is correctly specified, true Mohn's ρ may not be zero because of bias in estimation of various parameters or outputs for which Mohn's ρ is calculated.

Hurtado-Ferro et al. (2015) suggest a rule of thumb on the magnitude of Mohn's ρ for determining whether a retrospective pattern exists, but the magnitude of the Mohn's ρ estimate means little without some associated measure of uncertainty (e.g., standard error, confidence interval). Even with a correct model structure and no process errors, Mohn's ρ and ρ-adjusted terminal values vary due to the stochasticity arising from sampling performed to obtain the observations used as inputs to the assessment model. Therefore, Mohn's ρ estimates will never be exactly zero even if they may be zero on average for a correctly specified model. The only quantitative method that has been proposed for determining significance of retrospective patterns is a comparison of the ρ-adjusted stock status with confidence intervals of the unadjusted status that has been done in the northeast US (NEFSC, 2008). However, this approach does not account for uncertainty in the ρ-adjusted value. As such, a less ad-hoc method for assessing the significance of retrospective patterns and an evaluation of the statistical behavior of ρ-adjustment are warranted. Furthermore, it would be useful to know whether adjusting a given quantity by the estimated Mohn's ρ improves our estimation of stock status.

Unfortunately, a variance estimate for Mohn's ρ or ρ-adjusted terminal values is not readily available because of the complexity of the estimation of the components of the Mohn's ρ estimator. The variance of Mohn's ρ (Eq. (2)) is

$$\begin{aligned}\text{Var}\left[\hat{\bar{\rho}}\left(\hat{\theta}\right)\right] &= \frac{1}{P^2}\text{Var}\left[\sum_{t=1}^{P}\frac{\hat{\theta}_{T-t,T-t}}{\hat{\theta}_{T-t,T}}-1\right]\\ &= \frac{1}{P^2}\sum_{t=1}^{P}\sum_{u=1}^{P}\text{Cov}\left[\frac{\hat{\theta}_{T-t,T-t}}{\hat{\theta}_{T-t,T}},\frac{\hat{\theta}_{T-u,T-u}}{\hat{\theta}_{T-u,T}}\right]\end{aligned} \tag{6}$$

where $\text{Cov}(x, y)$ is the covariance of x and y. The covariance of the ratios for different terminal years is due to their derivation from at least a subset of the same data. There are also covariances of the numerator and denominator of each ratio. If we had estimates of these covariances we could form an estimate of the variance of Mohn's ρ for a given parameter by substituting them into the variance equation. However, a closed form for the covariances of the different components of Mohn's ρ is intractable and alternative methods are necessary for variance estimation.

Our objective was to evaluate effects of one type of model misspecification and two types of observation uncertainty on the statistical behavior of Mohn's ρ and other status-related statistics when a statistical catch-at-age (SCAA) model is used to assess the stock. We evaluated these effects through a simulation study. We imposed model misspecification by changing the true natural mortality in the last 10 years of the assessment to be greater than that assumed when fitting the model. The two types of uncertainty were for aggregate abundance indices and catch observations, and age composition observations. Of particular interest was reliability of confidence intervals for Mohn's ρ constructed using bootstrap-based estimates of corresponding standard errors and comparisons of statistical efficiency of stock and harvest status estimation using terminal estimates or ρ-adjusted estimates.

2. Methods

Our analyses were based entirely on a large simulation study. First we describe an alternative approach to status estimation using the confidence interval of Mohn's ρ estimates as a criterion for ρ-adjusting the terminal year stock size or fishing mortality estimates. We then describe a parametric bootstrap method we used for estimation of uncertainty in Mohn's ρ estimates and confidence interval construction. We also briefly explain a SCAA model we used as the assessment model in all analyses and end with a description of the simulation study that used all of the previously described components.