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COMMENTARY

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Response to Turner 2017

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The Atlantic and Gulf Menhaden stocks (*Brevoortia tyrannus* and *Brevoortia patronus*) support the second largest fishery by weight in the US and serve a critical ecological role as forage (Hartman & Brandt, 1995; NOAA Fisheries, 2016; Sagarese et al., 2016). Stock assessment and management of these important stocks have experienced thorough scrutiny from multiple perspectives (Hilborn et al., 2017; Pikitch et al., 2012). Therefore, we feel compelled to comment on Turner's (2017) paper titled "Smaller size-at-age menhaden with coastal warming and fishing intensity." Our comment is based on three issues: misstatements regarding the stocks' assessment and management, inappropriate analyses, and limited acknowledgment of alternative hypotheses for the putative patterns.

Turner (2017) made several erroneous statements about US menhaden assessment and management. First, neither value described as "MSY" in Turner (2017) represents an accurate or reliable estimate of MSY for menhaden. The value labelled "MSY Atlantic" in Figure 1 and throughout the text is the total allowable catch, based on average landings from 2009 to 2011 (ASMFC, 2012). The value labelled "GOM MSY" in Figure 1 and throughout the text is the estimate of biomass at MSY (B_{MSY}) generated by a surplus production model not adopted for use in management (SEDAR, 2013). Developing MSY estimates for forage fish such as menhaden is problematic (SEDAR, 2013) and currently is not accepted for determining stock status on either coast. The model used to assess both species, the NMFS Beaufort Assessment Model, is a statistical catch-at-age model that estimates spawner-per-recruit reference points for management (SEDAR, 2013, 2015). Additionally, landings of both species shown in Figure 1 were inflated by a factor of 1,000.[1] Turner's conclusions regarding variation in size-at-age with fishing pressure (Figure 4, Table III) are not valid because incorrect estimates of menhaden MSY and landings were used in the analysis.

Inappropriate analyses included treatment of the data and model choice. By using mean estimates of size-at-age, analyses artificially reduced the estimated inter-annual variance and ignored potentially confounding factors. Using mean estimates serves to allocate the error variation to the linear regression component of the model, inflating the amount of variance explained. Reanalysing the Gulf data, we find that Turner's model formulation inflates the variance explained from 292% to 1,267%. By including the full weight- and length-at-age dataset, R^2 values range from <0.001 to 0.128 (Table S1). Such poor estimation of annual changes in length- and weight-at-age weakens support for Turner's conclusions. Also, menhaden demonstrate considerable spatial variation in their distribution by size and age that affects availability of older ages to the fishery. Proper interpretation of these fishery-dependent data must account for fleet dynamics, especially for Atlantic menhaden, which was historically caught coastwide but now between New Jersey and Virginia. Beyond treatment of data, we disagree with the use of a linear model to understand the inter-annual dynamics of length- and weight-at-age. A qualitative examination of the residual pattern indicates that a linear model does not properly incorporate the biological and environmental dynamics.

Turner's paper interpreted results with a narrow view on possible factors affecting size-at-age over time and failed to fully acknowledge alternative hypotheses. Density dependence, fishing mortality, selectivity, and environmental factors all have the potential to influence size-at-age. Turner's finding that not all age classes decreased in size is an important piece of evidence. Broad-scale mechanisms such as density and environmental factors (i.e., temperature) would be expected to cause changes on all age classes, while factors only acting on specific age classes (i.e., fishing mortality) would be expected to cause changes on only impacted age classes. For example, Atlantic menhaden growth varies widely over time with large swings; these changes have been plausibly linked to density dependence (Schueller & Williams, 2017). Also, observed changes in size-at-age over time may simply be due to variation in fishing locations and concomitant changes in the frequency of older menhaden encountered by the fishery over time (SEDAR, 2013, 2015). Additionally, time-varying dome-shaped selectivity and biased growth estimates based on fishery-dependent samples (Schueller, Williams, & Cheshire, 2014) have led to inadequate samples of older age classes. For example, the number of age 4+ Atlantic menhaden samples collected has declined from an average of 4,338/year in the 1950s to 267/year from 1960+. Although we acknowledge the possibility that climate change may be affecting menhaden dynamics and growth, Turner's analyses are insufficient to draw definitive conclusions.

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ENDNOTE

[1] This error was corrected online on 11 September 2018.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

Table S1. Linear model parameter estimates and summary statistics of temporal patterns in (a) weight-at-age and (b) length-at-age of Gulf Menhaden.

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