North American Journal of Fisheries Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ujfm20

Assessing Length-Related Biases in Standard Weight Equations: Response to Comment

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Version of record first published: 19 Sep 2012.

To cite this article: Michael D. Rennie & Richard Verdon (2012): Assessing Length-Related Biases in Standard Weight Equations: Response to Comment, North American Journal of Fisheries Management, 32:5, 953-955

To link to this article: http://dx.doi.org/10.1080/02755947.2012.678967

North American Journal of Fisheries Management 32:953–955, 2012

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2012.678967

COMMENT

Assessing Length-Related Biases in Standard Weight Equations: Response to Comment[1]

While length-based estimates of fish condition have been used for over a century in the fisheries literature (Nash et al. 2006), continued developments in the field have nurtured ongoing debate over the advantages and disadvantages of the various methods as applied to fisheries science. Rennie and Verdon (2008) developed and evaluated a number of length-based estimators of condition for the lake whitefish *Coregonus clupeaformis*. A major component of that work was the evaluation of length-based estimates of condition against more direct measures of the physiological status of fish: energy density, percent lipid, and percent dry mass. Another component of the work was the evaluation of the relationships between the condition indices and fish length (reported as length-related bias); indices that were found to vary significantly and systematically with fish length were identified as demonstrating length-related bias.

Recently, Gerow (2011) was critical of Rennie and Verdon (2008) for reporting length-related bias in their relative weight (W_r) equation, which was estimated using the empirical percentile (EmP) method. Gerow (2011) argues that what was reported as bias was a spurious result due to the application of ordinary least squares (OLS) regression to determine a relationship between EmP W_r and fish length, whereas the regression method used to determine the EmP standard weight (W_s) equation utilized weighted least squares (WLS) regression. Gerow (2011) further argues that a proper estimation of length-related bias for this condition estimator would include the original weighting factors in the evaluation of the relationship for EmP W_r or, equivalently, the residuals from the empirical third-quartile estimates of the mean weights within a length class (Q_3) used to generate the EmP equation, regressed against the original midpoints of length class used. He presents a case in which a significant negative relationship is indeed detected between the residuals of a WLS regression with length by application of OLS to the residuals, but that the inclusion of the original weighting factors in a WLS estimation of the same residuals results in a nonsignificant relationship (Gerow 2011, his Figure 1A, B).

For reasons outlined below, we maintain our original conclusion that there is a length-related bias in the EmP W_r estimates for lake whitefish. First, we clarify what we interpret as being presented as "length-related bias" in both Rennie and Verdon (2008) and Gerow (2011). Second, we conduct a thought experiment demonstrating the validity of concerns about length-related bias in the lake whitefish EmP W_s equation when it is applied as a single reference point for estimating fish condition. Last, we point out that recent developments in the EmP method are designed to address variation in the standard weight equation (or equations) with length and finish by reminding readers that the choice of any particular condition index over others depends a great deal on the research or management question being asked.

Most statistical texts define the statistical estimators of population parameters as being unbiased if, on average, those sample estimates accurately describe the population parameter in question (Sokal and Rohlf 1995; Zar 1999). Within the context of length-related bias, Gerow (2011) cites the use of a weighted polynomial regression (as opposed to linear regression) when fitting a relationship between Q_3 and fish length as reducing the effect of leverage on the estimated statistical model due to the influence of data points at the extremities of the distribution with lower empirical support. The application of a weighted polynomial regression therefore allows the predicted or estimated values from the standard weight equation to more closely match the empirically estimated Q_3 for each length class (i.e., the "true" values of Q_3 as defined in Gerow et al. 2004, 2005). Thus, when the "true" Q_3 values are standardized (divided by) by those predicted from the EmP W_s equation and expressed as a percentage (i.e., the W_r for the length class is estimated), the estimated values should approximate 100 across the entire range of lengths used to derive the equation. In other words, the estimated equation should closely match the population parameters, indicating no bias.

When the evaluation of bias described above was made for the EmP W_s equation developed for lake whitefish, the W_r values for length classes greater than approximately 500 mm total length were systematically lower than 100 (Rennie and Verdon 2008). Perhaps incorrectly, this was demonstrated by the authors by fitting an OLS regression through the EmP W_r values with

[1]The comment to which this is a response appeared in the *North American Journal of Fisheries Management* in 2011 (31:656–660) along with another response.

length. Gerow (2011) argues that our detection of bias was a direct result of not including the original weights in the evaluation of the trend (e.g., a WLS regression should have been employed in assessing the trend of W_r with length rather than an OLS regression). This does not, however, eliminate the systematic underestimation of the observed EmP W_r, indicating empirical Q_3 values lower than those predicted by the EmP W_s equation for fish greater than 500 mm. Given the mismatch between the values estimated from the EmP standard weight equation and those defined as "true" population parameters (Q_3), our conclusion that there is length-related bias does not appear to be unfounded.

The negative trend detected in the lake whitefish EmP W_r by Rennie and Verdon (2008) presents a problem to managers when this method is used to compare condition among different-sized fish within or among populations, as may be demonstrated by the following thought experiment: A manager is examining lake whitefish collected from a population whose weights and lengths precisely match the empirical weights (Q_3) and length midpoints used to generate the EmP W_s (because the EmP method claims to deal with length-related bias, this should be an entirely appropriate application). If this manager estimated the condition of these fish based on the EmP W_s and asked whether condition varied with size by fitting the values against length using linear regression, he/she would find a significant negative relationship. This relationship, however, has no biological significance—it is an artifact of the difference between the empirical and predicted estimates in the EmP W_s equation for this species. The original weighting factors do not play a role in this application: managers do not have access to the weighting factors used to develop the EmP equations (insofar as they are not typically reported in papers where such equations are derived, e.g., Gerow et al. 2005), and this method of estimating W_r at present does not require the use of weighting factors in the calculation. Thus, managers applying EmP-derived equations in the field are better alerted to the fact that apparent trends in EmP W_r condition with respect to fish length may be artifactual (Rennie and Verdon 2008).

Recent developments in EmP methods have suggested the use of multiple reference points to account for the variation in length with EmP-derived standard weight equations (Gerow 2010); this has been proposed as a means of evaluating condition against these multiple reference points, allowing for variation in the standard weight equations with length. A potential extension of this application would be to use the multiple reference lines (e.g., EmP-derived standard weight equations describing the 25th, 50th, and 75th percentiles) to define categorical assignments of condition for fish of any particular length (e.g., low, moderate, good, or excellent) while allowing for variation in the weight quartiles with size.

A major criticism of both relative weight methods (regression length percentile [RLP] and EmP) is that the development of a standard weight equation tends to ignore the fact that allometric growth exponents (i.e., the slopes of log-transformed length vis-à-vis log-transformed weight) can and do vary among and within populations (Rennie and Verdon 2008, Appendix 1; Cade et al. 2011). Further, neither relative weight method reflects individual variation in length and weight but rather is based on population-specific modeled or mean weights within a specified length class (Cade et al. 2011). In contrast, alternative methods of evaluating condition have been proposed that employ statistical models that explicitly rely on individual length–weight data in order to account for the variation in allometric growth exponents. Methods like quantile regression (e.g., Cade et al. 2008) make comparisons of condition among populations or regions at multiple length classes in order to account for the differences in allometric growth among groups and may provide more meaningful comparisons of populations in space or time. However, work still needs to be done to evaluate these methods against physiological measures of condition in fish. Ultimately, the choice of index used will depend greatly on the question being asked by the manager or researcher.

Regardless of the method used, we firmly believe that it is important that any length-based condition measure correspond to more direct physiological estimates of body condition (e.g., Schulte-Hostedde et al. 2005). In the case of lake whitefish, Fulton's K was found to be most strongly correlated to physiological measures (energy density, percent fat, and percent dry mass), primarily because all of these variables scaled significantly with body size (Rennie and Verdon 2008). Considering just relative weight equations, lake whitefish RLP W_r explained more variation in energy density, percent fat, and percent dry mass than did EmP W_r. As various methods continue to emerge regarding length-based indices of condition (e.g., quantile regression), we encourage the developers of such methods to relate these indices back to more direct measures of physiological status.

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