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Empirical Standard Weight Equation for the Aegean Chub Squalius fellowesii, an Endemic Freshwater Fish Species of Western Anatolia, Turkey

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ARTICLE

Empirical Standard Weight Equation for the Aegean Chub *Squalius fellowesii*, an Endemic Freshwater Fish Species of Western Anatolia, Turkey

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Abstract
Data on length and weight of Aegean chub *Squalius fellowesii*, an endemic species distributed in the Aegean drainages of Anatolia, Turkey, were used to calculate a standard weight (W_s) equation by means of the empirical percentile (EmP) method. The resulting W_s equation was $\log_{10}W_s = -3.801 + 1.783\cdot\log_{10}TL + 0.329\cdot(\log_{10}TL)^2$. Over the range of application (70–220 mm TL), the EmP W_s equation was not biased by length, and the use of this equation is suggested as a way to calculate the relative weight (W_r) of Aegean chub throughout the species' distribution area.

Analysis of length–weight relationships can provide important insights into the ecology of a species and can help in the assessment of populations of that species (Froese 2006). Body condition indexes are useful tools derived from length–weight relationships for a species (Blackwell et al. 2000) and provide a measure of the health of a fish population under the assumption that for fish of a given length, heavier individuals are in better condition than lighter individuals (Froese 2006). Because these indexes are based only on measurements of length and weight, there is no need to sacrifice any of the specimens, and large numbers of fish can be processed with minimal mortality (Fechhelm et al. 1995). Thus, body condition indexes have become important tools for fisheries management (Anderson and Neumann 1996; Blackwell et al. 2000).

Among the condition indexes proposed in the literature (e.g., Fulton's [1911] condition factor and Le Cren's [1951] condition factor), relative weight (W_r; Wege and Anderson 1978) has the advantage of not being affected by length biases and changes in body shape. Therefore, the use of W_r allows comparative condition assessments of fish from different length-groups and from different populations (Murphy et al. 1991). Relative weight is calculated as the comparison between the actual weight of a specimen (W) and the standard weight (W_s), which is the weight of an ideal conspecific individual having the same length and exhibiting good physiological condition (Murphy et al. 1991). The W_s is predicted by a W_s equation, which is a length–weight regression that is typical of the species. Since its creation, the W_r index has been widely used to perform condition analyses of many species (Blackwell et al. 2000). However, its applicability is limited by the lack of species-specific W_s equations, as these equations must be developed by using samples of specimens collected throughout the area of distribution for the species of interest.

The Aegean chub *Squalius fellowesii* (Figure 1) is a cyprinid species that is endemic to the Aegean drainages of Anatolia, Turkey (Figure 2). The *Squalius* populations from the Esen, Dalaman, Büyük Menderes, Gediz, Bakır, and Madra drainages belong to this species (Özuluğ and Freyhof 2011). The Aegean

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FIGURE 1. Photograph of an Aegean chub (from Özuluğ and Freyhof 2011). [Figure available in color online.]

chub is one of the most common freshwater fish species in its area of distribution (Balık et al. 2004; Şaşı 2004; Dirican and Barlas 2007), and it is caught both as a game species and for consumption (Şaşı and Balık 2003; Koç et al. 2007). However, to date, only a few watercourses have been studied and such work has focused on limited basic biological features of this species, such as age, growth, and sex ratio (Şaşı and Balık 2003; Balık et al. 2004; Dirican and Barlas 2007; Koç et al. 2007).

Originally described as *Leuciscus fellowesii*, the Aegean chub was recently accepted as a valid species by Özuluğ and Freyhof (2011). Durand et al. (2000) and Sanjur et al. (2003) found molecular differences in chub populations from western Anatolia; those authors suggested that the group of "short-snouted chubs," identified as a subspecies of the European chub *Squalius* (*Leuciscus*) *cephalus*, could be divided into different species within the genus *Squalius*. Özuluğ and Freyhof (2011) confirmed this hypothesis and reported the occurrence of 10 different *Squalius* species (four of them only recently described) in western and central Anatolia, and among these species was the Aegean chub.

The objective of this research was to develop a W_s equation for Aegean chub. The empirical percentile (EmP) method proposed by Gerow et al. (2005) was used to develop the W_s equation, as recent studies have encouraged the development of W_s equations by use of this method (Richter 2007; Rennie and Verdon 2008; Rypel and Richter 2008; Angeli et al. 2009; Ogle and Winfield 2009; Gerow 2010; Giannetto et al. 2011, 2012a). Availability of a W_s equation for the Aegean chub could be useful in the management of this endemic species, which has a restricted distribution and is threatened mainly by habitat loss (changes in land use), water pollution, nonnative species introductions, and seasonal droughts (Önsoy et al. 2011). At a broader scale, data on the condition of Aegean chub populations throughout the species' distribution could be crucial in identifying important areas for species conservation. More specifically, those populations showing a high body condition could be considered as potential sources for future restocking practices, whereas populations with lower body condition should be selected for programs of conservation for the species or habitat rehabilitation.

FIGURE 2. Distribution area (dark gray shading) of the Aegean chub in Turkey.

METHODS

Data set selection.—Data on the TL (mm) and weight (W; g) of Aegean chub were collected throughout the distribution area of this species. The total data set was validated by using the procedure suggested by Giannetto et al. (2011, 2012c). First, the TL–W regression of the total sample was examined, and all fish that were represented by large outliers were excluded, as these outliers were probably derived from incorrect measurements. All lengths that were measured only in terms of SL or FL (mm) were converted to TL (mm) by applying a general linear conversion model developed based on all fish from the data sets in which at least two types of length measurement were recorded (Ogle and Winfield 2009).

The general conversion models were

$$\text{TL} = -2.159 + 0.951 \cdot \text{FL}$$
$$(R^2 = 0.965,\ P < 0.001;\ n = 1,380) \text{ and}$$
$$\text{TL} = -2.822 + 0.854 \cdot \text{SL}$$

($R^2 = 0.987$, $P < 0.001$; n = 1,388). The data set was then separated into populations, with each catch location deemed a separate statistical population. For locations with a large number of sampled fish, the samples taken in different years were also considered to be different populations; locations with a sample size of fewer than 10 specimens were removed from the data set (Rypel and Richter 2008; Ogle and Winfield 2009).

The $\log_{10}W$ was plotted against $\log_{10}$TL for each population. Based on recommendations made by Froese (2006), all populations with an r^2 value less than 0.90 or a slope value outside the range of 2.5–3.5 were removed from the data set because such values are often associated with samples that represent narrow size ranges (Froese and Pauly 2000).

The next step in computing the W_s equation was the determination of an applicable length range. A minimum TL is required

TABLE 1. Number of Aegean chub populations and individuals (per 10-mm length-class) that were used to develop the standard weight equation.

Length-class (mm TL)	Number of populations	Number of individuals
70	29	161
80	38	199
90	43	240
100	39	193
110	37	190
120	35	163
130	35	138
140	34	91
150	28	64
160	21	52
170	19	30
180	12	32
190	8	12
200	4	11
210	6	6
220	4	4

because of the high potential error that occurs in the measurement of small specimens in the field (Murphy et al. 1991); in addition, small fish display high variance in the weights values due to the differences in growth forms that arise in the juvenile stages. In accordance with Willis et al. (1991), the minimum TL was determined by examining the relationship between (1) the variance : mean ratio for $\log_{10} W$ and (2) TL at 10-mm intervals. The length at which the variance : mean ratio is stabilized and does not exceed 0.01 is identified and used as the minimum (Murphy et al. 1991). According to Gerow et al. (2005), the use of the EmP method for the development of a W_s equation also requires a maximum TL. The maximum was identified as the greatest length-class for which at least three fish populations were available in the data set (Table 1). All fish outside of this suitable length range were excluded from further analysis. Once the total data set was cleaned and validated, it was divided into two data sets: (1) a larger development data set, which was used to compute the W_s equation; and (2) a smaller validation data set, which was utilized to investigate potential length-related biases in the calculated W_s equation (Rypel and Richter 2008; Ogle and Winfield 2009; Giannetto et al. 2012c).

Development of the empirical percentile standard weight equation.—The mean empirical W (for each 10-mm TL-group) was calculated by using the $\log_{10}$ transformed TL and W of each population included in the development data set. The third quartile (i.e., 75th percentile) of these mean empirical W-values was then regressed against TL to develop the EmP W_s equation by using a weighted quadratic model (Gerow et al. 2005).

The resulting EmP W_s equation was used to calculate the W_r of each specimen from each population based on the equation provided by Wege and Anderson (1978):

$$W_r = 100 \times (W/W_s),$$

where W is the weight (g) of an individual and W_s is the standard weight predicted by the W_s equation.

Validation of the empirical percentile standard weight equation.—An important characteristic of a good condition index is that it should be free from length-related biases, thus allowing comparison of condition assessments among fish of different sizes (Murphy et al. 1990; Anderson and Neumann 1996; Blackwell et al. 2000). Two different methods were used to validate the EmP W_s equation calculated for Aegean chub: (1) the analysis of residuals of the W_s equation to investigate whether the distribution of residuals exhibited evident patterns; and (2) the empirical quartiles (EmpQ) method (Gerow et al. 2004; as modified by Ogle and Winfield 2009) to determine whether the quadratic regression of the 75th-percentile mean W standardized by W_s against TL (at 10-mm intervals) had a slope of zero (Ogle and Winfield 2009; Giannetto et al. 2011). The EmpQ method was performed by using the FSA package (Ogle 2009) in R software.

RESULTS

The total sample comprised 2,188 individual Aegean chub with a mean TL of 103 mm (SD = 4; minimum = 24 mm; maximum = 225 mm) and a mean weight of 18 g (SD = 21; minimum = 1 g; maximum = 175 g). Among the 57 populations that made up the total sample, one population was excluded (in accordance with Froese 2006) because the slope of its $\log_{10} W$–$\log_{10}$TL relationship was less than 2.5. The $\log_{10} W$–$\log_{10}$TL equation calculated for the total sample was

$$\log_{10} W = -5.244 + 3.154 \cdot \log_{10} \mathrm{TL}$$

($R^2 = 0.988$, $P < 0.001$; $n = 2{,}188$). The development data set consisted of 1,900 fish, and the validation data set included 288 fish. In accordance with Rypel and Richter (2008), the small size of the validation data set was chosen so that the data set used to develop the EmP W_s equation would be as large as possible. The data were selected so that both data sets contained Aegean chub populations that were distributed throughout the geographical range of the species (Ogle and Winfield 2009).

The minimum TL for application of the W_s equation was identified as 70 mm (Figure 3); as a result, all specimens smaller than this size were excluded from subsequent analysis. The maximum TL was 220 mm, the length of the largest fish present in the development data set; this length was consistent with the maximum length reported for Aegean chub in the literature (Özuluğ and Freyhof 2011). Thus, the length range that was judged to be suitable for the EmP W_s equation was 70–220 mm TL.

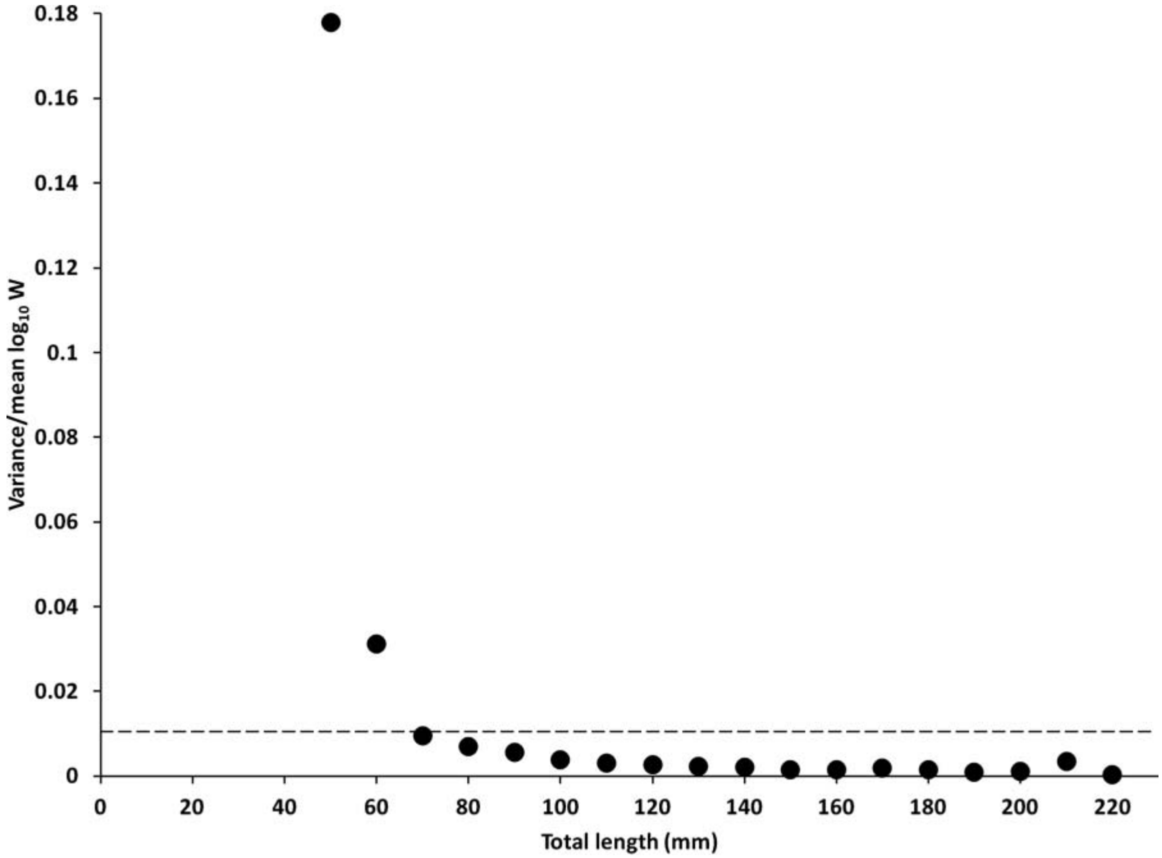

FIGURE 3. Relationship between the variance : mean ratio for $\log_{10}$(weight [W]) and the TL (10-mm intervals) of Aegean chub; this relationship was used to determine the minimum TL for development of the standard weight equation. The dotted line indicates the value of 0.01 (see Methods).

The Aegean chub W_s equation calculated by means of the EmP method was

$$\log_{10} W_s = -3.801 + 1.783 \cdot \log_{10} \mathrm{TL} + 0.329 \cdot (\log_{10} \mathrm{TL})^2$$

($R^2 = 0.999$, $P < 0.001$). When we examined the residual values from this EmP W_s equation to determine potential length-related biases, the residuals appeared to be distributed randomly and did not exhibit any evident patterns (Figure 4a). When the EmpQ method (Gerow et al. 2004) was applied to the validation data set, the EmP W_s equation calculated for Aegean chub did not appear to be influenced by fish length since the slope of the quadratic regression of 75th-percentile mean W standardized by W_s against TL was not significantly different from zero for either the linear term or the quadratic term of the equation ($P_{\mathrm{quadratic}} = 0.706$, $P_{\mathrm{linear}} = 0.713$; Figure 4b).

DISCUSSION

According to Bister et al. (2000), because of the positive correlation between fish growth and environmental quality, W_r could be an easy and powerful tool for recognizing environmental changes (Gabelhouse 1991; Hubert et al. 1994; Liao et al. 1995) or ecological changes, such as interspecies or intraspecies competition (Johnson 1992; Giannetto et al. 2012b). Previous studies have clearly indicated habitat-dependent variations in age and growth features of Aegean chub (Balık et al. 2004; Dirican and Barlas 2007). This was more obvious in differences between Aegean chub in lentic and lotic areas, suggesting that growth conditions were better for the lentic populations than for lotic populations, and such differences have been observed in other *Squalius* species distributed in different regions of Anatolia (Şaşı and Balık 2003; Torcu et al. 2007). However, at present, there are no W_s equations available in the literature for other *Squalius* species distributed in Anatolia or for the European chub. For this reason, the application of W_r to compare conditions among these species is currently limited.

Based on our results, the use of the EmP equation to determine W_r for the Aegean chub throughout its area of distribution is recommended. Further research is encouraged to extend this methodology to other species distributed in the Aegean chub's range; particular attention should be given to species that are endemic, rarely studied, and, at this time, threatened by the presence of an increasing number of nonnative species that are commonly introduced into Turkish waters by stocking practices with the aim of increasing fish production and sportfishing

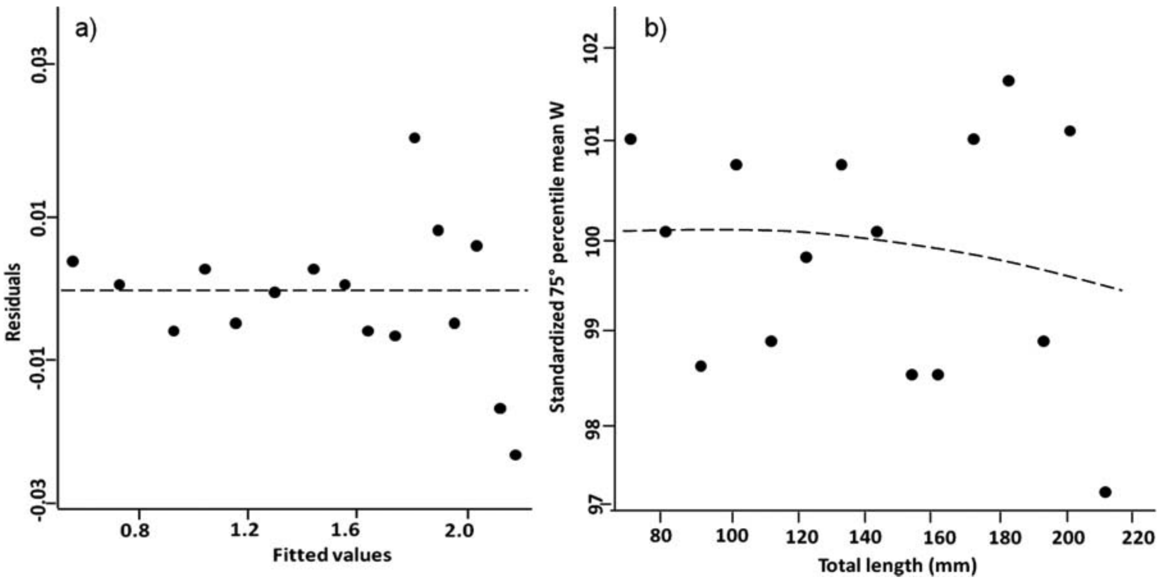

FIGURE 4. Plots showing **(a)** the distribution of standardized residuals from the standard weight (W_s) equation (fitted values = values obtained by the model fit) and **(b)** the results of applying the empirical quartiles (EmpQ) method to investigate potential length-related bias in the W_s equation for Aegean chub (standardized 75th-percentile mean weight [W] was calculated with the W_s equation).

(Innal and Erk'akan 2006; Aydın et al. 2011; Önsoy et al. 2011; Tarkan et al. 2012). Nonnative species introductions, together with habitat degradation, are probably responsible for the recent notable decline in Aegean chub density throughout this species' distribution area (Önsoy et al. 2011). For this reason and as was previously demonstrated by Giannetto et al. (2012b), the methodology proposed here can be very useful in assessing the impact of nonnative species on natural and endemic species. For example, Giannetto et al. (2012b) used covariance analysis to compare the mean W_r of native fish species of the Tiber River basin (central Italy) in the absence and presence of nonnative species (assuming a status of same ecological conditions by using the environmental variables as a covariate); the condition of some of the endemic species was found to be significantly worse when nonnative species were present than when nonnative species were absent.

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