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Development of empirical standard weight equation for Pursak chub *Squalius pursakensis*, an endemic cyprinid species of Northwest Anatolia

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Abstract: Indices of condition enable the evaluation of the well-being of fish, with the assumption that heavier fish of a given length are in a better condition. Relative weight (W_r) is one of these indices; it is calculated by comparing the actual weight of a specimen with the ideal weight of a specimen in good physiological condition of the same length from the same species, i.e. standard weight (W_s). In this research, length and weight data over the distribution range for Pursak chub *Squalius pursakensis*, an endemic species distributed in the Sakarya and Porsuk drainages in Northwest Anatolia (Turkey), were used to compute a W_s equation by means of the empirical percentile (EmP) method. The W_s equation obtained was $\log_{10} W_s = -4.657 + 2.614 \log_{10} TL + 0.127 (\log_{10} TL)^2$, and the total length range of application was 80–340 mm. Since the EmP W_s equation was not influenced by length variation, the use of this equation to compute the relative weight (W_r) for *S. pursakensis* throughout its area of distribution is suggested.

Key words: Condition indices, endemic species, *Squalius*, relative weight

1. Introduction

Indices of condition are commonly used by fisheries to evaluate the well-being of fish, starting with the assumption that "fatter is fitter" (sensu Glazier, 2000). Thus, comparing specimens of the same length, fish with a higher weight are in better condition than those with a lower weight (Anderson and Neumann, 1996; Blackwell et al., 2000). These indices are important tools for fishery management (Anderson and Neumann, 1996; Blackwell et al., 2000) and have been used in fishery research since the beginning of the 20th century (Froese, 2006). According to Fechhelm et al. (1995), the use of indices of condition to monitor the well-being of fish is cost-effective because, being based only on length and weight measurements, indices do not require the sacrifice of the specimens and allow evaluation of the condition of fish with minimal mortality.

Relative weight (W_r) (Wege and Anderson, 1978) is one of these indices and, compared to the others available in literature [i.e. Fulton's (1911) condition factor and Le Cren's (1951) condition factor], it has the great advantages of not being influenced by changes in body shape and of allowing for comparing the condition of fish of different lengths belonging to different populations (Murphy et al., 1991). Relative weight is based on the comparison between the actual weight of a specimen and the standard weight (W_s), which is the weight in the same length of an ideal fish of the same species that is in good physiological condition (Murphy et al., 1991). W_s is predicted by a standard weight equation, that is, a length–weight regression typical of the species (Wege and Anderson, 1978). Since its development, 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 standard weight equations that have to be developed using a wide sample of specimens collected throughout the area of distribution of each species (Bister et al., 2000).

Pursak chub *Squalius pursakensis* (Hankó, 1925) is a cyprinid species endemic to the Sakarya and Porsuk drainages (Turkey), which flow into the Black Sea (Northwest Anatolia) (Özulug and Freyhof, 2011) (Figure 1). The species, originally described as *Leuciscus orientalis pursakensis* Hankó, 1925, was recently rehabilitated as a valid species by Özulug and Freyhof (2011). On the basis of molecular differences found in chubs from West

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Anatolia, Durand et al. (2000) suggested that the group of "short snouted chubs", previously identified as a subspecies of *Squalius cephalus* (Linnaeus, 1758), could be divided into different species. Recently, Özulug and Freyhof (2011) confirmed this hypothesis and identified the presence of 10 different species of the genus *Squalius* in West and Central Anatolia (4 of them only recently described), including *S. pursakensis*.

This species is consumed by local people of the basin and is used for recreational purposes (Erk'akan, 1981; Ekmekçi, 1996; Emiroğlu et al., 2001). As both basins (Sakarya and Porsuk) where *S. pursakensis* occurs have recently been severely polluted and are affected by serious habitat destruction, mainly damming and water abstraction, the species has suffered from these changes (Bostancı and Polat, 2009; Innal, 2010).

Two different methods have been proposed in the literature for the computation of W_s equations: the regression line percentile (RLP) method, proposed by Murphy et al. (1990), and the empirical percentile (EmP) method, developed by Gerow et al. (2005). Until recently, the most widely used method was the RLP (Blackwell et al., 2000). However, according to Gerow et al. (2004), some of the W_s equations developed using the RLP method showed significant length-related biases; moreover, the results of recent studies have encouraged the use of the EmP method in developing W_s equations (Rennie and Verdon, 2008; Ogle and Winfield, 2009; Gerow, 2010; Giannetto et al., 2011, 2012a).

The aim of this research was to develop a standard weight equation by means of the EmP method for *S. pursakensis*, which could allow estimating the relative weight throughout the entire area of distribution of this species. Given that the species is under threat from habitat disturbance and biotic degradations by nonnative species, which are commonly increasing in the area, the proposed standard weight equation would serve as an important tool for conservation of this endemic species in its restricted distribution area.

2. Materials and methods

2.1. Dataset selection

Specimens of *S. pursakensis* were collected throughout the area of distribution of the species (Figure 2) by means of electrofishing (SAMUS 725G) between 2009 and 2012. After collection, each fish was measured for length [total length (TL), standard length (SL), and fork length (FL)] to the nearest 1 mm and wet weight (W) to the nearest 0.1 g in situ, with fish being returned to the water.

According to Giannetto et al. (2011, 2012c), the following methods were used to validate the total dataset. First, by the TL–W regression of the total sample, all specimens that were large outliers were excluded, as they were probably derived from incorrect measurements. The dataset was then separated into statistical populations on the basis of the data and location of collection (Ogle and Winfield, 2009). In this regard, a stock (population) was regarded as different according to sampling years and periods from the same location because of emigration/immigration, recruitment, and mortality (Begg and Waldman, 1999). Populations with fewer than 10 specimens were removed from the dataset (Ogle and Winfield, 2009; Lorenzoni et al., 2012). Hence, in order to identify all anomalous values, data were further validated by plotting the $\log_{10}TL - \log_{10}W$ regression for each population separately; all values that diverged by more than double the expected value from the regression curve were removed (Bister et al., 2000). These equations were then analyzed, and all populations showing an R^2 value of less than 0.90 or for which the value of the slope (b) fell outside the range of 2.5–3.5 were excluded from further analyses (Froese, 2006).

Figure 1. *Squalius pursakensis* from Seydi Suyu in Sakarya Basin (445 mm TL).

The last step for the validation was to plot the slopes (b) of all populations against all intercepts ($\log_{10} a$) (Pope et al., 1995) to identify the outliers of this regression, represented by populations composed of a few fish or samples with a narrow length range (Froese, 2006).

2.2. Determination of the applicable total length range for the W_s equation

Once the dataset was validated, the next step was to determine a suitable length range for the application of the W_s equation. A minimum length is preferred because small fishes show a high variance due to the differences in growth forms that arise in the juvenile stages, and due to the potential for error associated with their measurement in the field (Murphy et al., 1990; Rypel and Richter, 2008). In accordance with Willis et al. (1991), the minimum total length was determined by plotting the variance/mean ratio for $\log_{10}W$ on 10-mm total length intervals, and the minimum length was determined as the size at which the value of the ratio was less than 0.01 (Murphy et al., 1990).

Since the EmP method was utilized to develop the W_s equation, a maximum length for the application of that equation was also required (Gerow et al., 2005). This length was determined as the length class for which at least

Figure 2. Area of distribution of *Squalius pursakensis* (dark gray area).

3 fish populations were present in the dataset, because 3 represents the smallest sample size that allows estimation of quartiles (Gerow et al., 2005). Any fish outside the suitable length range were not utilized for further analyses.

Next, the dataset, thus validated, was divided into 2 sets: a larger development dataset (used to compute the W_s equation) and a smaller validation dataset (used to assess potential length-related biases in the W_s equation) (Rypel and Richter, 2008; Ogle and Winfield, 2009; Giannetto et al., 2012c).

2.3. Development of the W_s equation

The EmP method proposed by Gerow et al. (2005) was used to develop the W_s equation for *S. pursakensis*. The mean empirical W for each 10-mm length-group was calculated by the $\log_{10}$-transformed TL and W of each population of the development dataset; the third quartiles of these mean empirical W values for each length-group were then regressed against TL to develop the EmP W_s equation by using a weighted quadratic model (Gerow et al., 2005).

Using the W_s equation obtained, the W_r of each specimen from each population was then calculated by means of the equation provided by Wege and Anderson (1978): $W_r = 100\ (W\ /\ W_s)$, where W is the weight of an individual in grams and W_s is the standard weight predicted by the W_s equation.

2.4. Validation of the EmP W_s equation

The principal attribute of a good condition index is that, in order to enable accurate comparisons of condition assessments of fish of different sizes, the measure of the condition should be free from length-related biases (Murphy et al., 1991; Anderson and Neumann, 1996; Blackwell et al., 2000). To this aim, 3 different methods were used to detect potential length-related biases and to validate the EmP W_s equation calculated for *S. pursakensis*: the analysis of the residuals of the W_s equation, to investigate whether the distribution of residuals exhibits evident patterns (Ogle and Winfield, 2009; Giannetto et al., 2012a); the Willis method (Willis et al., 1991), whereby a chi-square test is used to determine whether the proportion of populations with a significant positive slope in the TL–W_r equation is equal to the proportion of those with a significant negative slope; and the empirical quartiles (EmpQ) method (Gerow et al., 2004) as modified by Ogle and Winfield (2009), applied to the validation dataset by using the FSA package (http://www.rforge.net/FSA) of R Software to determine if the slope of the quadratic regression of the third quartile of the mean W standardized by W_s against length intervals of 10 mm had a value of zero (Ogle and Winfield, 2009; Giannetto et al., 2011, 2012a, 2012c).

3. Results

3.1. Dataset selection

A total of 2590 *S. pursakensis* specimens were collected during the research. The total length of specimens collected ranged from a minimum of 26.000 mm to a maximum of 445.000 mm (mean length: 152.562 ± 51.348 mm) and the weight from a minimum of 0.200 g to a maximum of 1263 g (mean weight: 62.174 ± 82.197 g). A new maximum total length (445 mm) for this species was recognized.

The log-transformed TL–W equation calculated for the total sample was:

$\log_{10}(W) = -5.304 + 3.176 \log_{10} TL$ (mm) ($R^2 = 0.985$, $P < 0.001$; $n = 2590$).

The SL–TL and FL–TL equations resulted as follows:

TL = 5.724 + 1.157 SL (R^2 = 0.997; n = 1684)

and

TL = 3.225 + 1.053 FL (R^2 = 0.998; n = 1684).

The total dataset was then divided into 78 statistical populations. By the linear plot between $\log_{10}(a) - b$, no populations were identified as outliers, and for all 78 the value of R^2 was >0.95 and the *b* value was within the range of 2.5–3.5.

3.2. Determination of the applicable total length range for the W_s equation

The minimum TL for the application of the W_s equation was determined as 80 mm (Figure 3). The maximum TL was assigned to be 340 mm because, despite the presence in the dataset of fish longer than this size, 340 mm was the length at which at least 3 values were present (Table). According to this, the length range judged to be suitable for the EmP W_s equation was 80–340 mm.

The total sample was then divided into 2 datasets: a development dataset made up of 2210 specimens, and a validation dataset of 380 fish.

3.3. Development of W_s equation

By applying the EmP method to the development dataset, the W_s equation for *S. pursakensis* resulted as follows:

$\log_{10} W_s = -4.657 + 2.614 \log_{10} TL + 0.127 (\log_{10} TL)^2$ (R^2 = 0.999, P < 0.001).

3.4. Validation of the EmP W_s equation

The residual values of the EmP W_s equation showed a random distribution and did not exhibit evident patterns (Figure 4). Applying the Willis method, the number of TL–W relationships with significant positive slopes (12) resulting was not significantly different from the number of those with significant negative slopes (5) according to the chi-square test (χ^2 = 2.882, P = 0.089), showing independence of the W_r values calculated by means of the EmP W_s equation developed by the size of the fish.

Applying the EmpQ method, the value of the slope was not significantly different from zero for both terms of the equation ($P_{quadratic}$ = 0.508, P_{linear} = 0.763), indicating that the EmP W_s equation was not influenced by fish length (Figure 4).

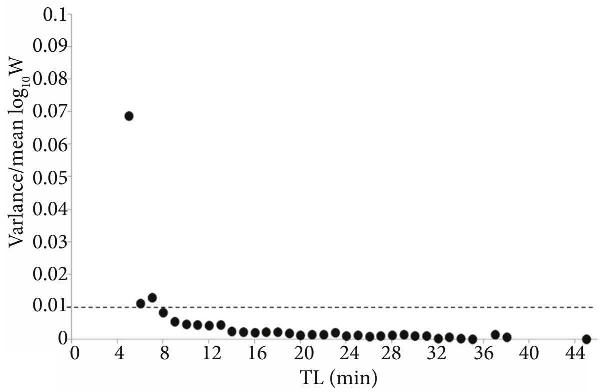

Figure 3. Relationship between variance/mean for $\log_{10}$ of weight (W) and total length at 10-mm intervals for the determination of the minimum total length of *Squalius pursakensis*. The dotted line indicates the value of 0.01.

4. Discussion

In this study, a standard weight equation was developed for *S. pursakensis*, an endemic species of the Sakarya and Porsuk drainages in Northwest Anatolia (Turkey). Moreover, a new maximum total length (445 mm) for this species was found from Seydi Suyu in Sakarya Basin. Therefore, it can be argued that the representativeness of the dataset used in the present study has contributed to strengthen the validity of the findings. Maximum total length was previously reported as 392 mm from Sarıyar Reservoir by Ekmekçi (1996). Although it is well known that individuals in populations exposed to high levels of fishery pressure reach relatively smaller lengths (Emiroğlu et al., 2012), this is not the case for *S. pursakensis*, as there is no high fishery pressure on the species other than the insignificant effect of local anglers in its distribution range. The finding of large specimens of a species could be incidental or attributed to inadequate current knowledge on the species. However, given that congeneric species of *S. pursakensis* may reach 600 mm SL (*S. cephalus*) (Kottelat and Freyhof, 2007), it can grow above the maximum length found in the present study.

Relative weight is currently widely used to perform condition analysis of many species, but its applicability is often limited by the lack of species-specific standard weight equations. With regard to Turkey, the only W_s equations available are those for European perch *Perca fluviatilis* (Giannetto et al., 2012a) and Aegean chub *Squalius fellowesii* (Giannetto et al., 2012c).

Previous studies on *S. pursakensis*, which was cited mainly as *Leuciscus cephalus*, focused on some basic reproduction and growth features, including condition indices (Erk'akan, 1981; Ekmekçi, 1996; Emiroğlu et al., 2001; Bostancı and Polat, 2009; Innal, 2010). Interestingly, most of the previous studies were conducted in artificial water bodies (reservoirs and ponds) (e.g., Ekmekçi, 1996; Bostancı and Polat, 2009; Yiğit et al., 2008; Innal, 2010) with the exception of 2 studies, which were from the Sakarya (Erk'akan, 1981) and Porsuk (Emiroğlu et al., 2001) rivers. Yiğit et al. (2008) analyzed different condition indices with the aim of finding the best-fitting condition factor for *S. pursakensis* and found that the one based on the height of fish along with length and weight proposed by Jones et al. (1999) was the best-fitting condition factor. However, this factor is not useful for broad comparisons due to the lack

Table. Number of populations and individuals for each length class of 10 mm in the development dataset of *Squalius pursakensis*. The length classes in bold are those removed from the dataset because they had fewer than 3 populations.

TL (mm)	Populations	Individuals	TL (mm)	Populations	Individuals
80	31	62	270	15	18
90	35	70	280	13	19
100	42	105	290	7	10
110	52	153	300	6	9
120	67	203	310	7	10
130	63	209	320	3	5
140	70	257	330	3	5
150	59	189	340	3	4
160	62	184	**350**	**1**	**1**
170	54	133	**360**	-	-
180	49	121	**370**	**3**	**3**
190	41	93	**380**	**2**	**3**
200	40	71	**390**	-	-
210	39	60	**400**	-	-
220	38	68	**410**	-	-
230	26	41	**420**	-	-
240	20	26	**430**	-	-
250	24	27	**440**	-	-
260	21	24	**450**	**1**	**1**

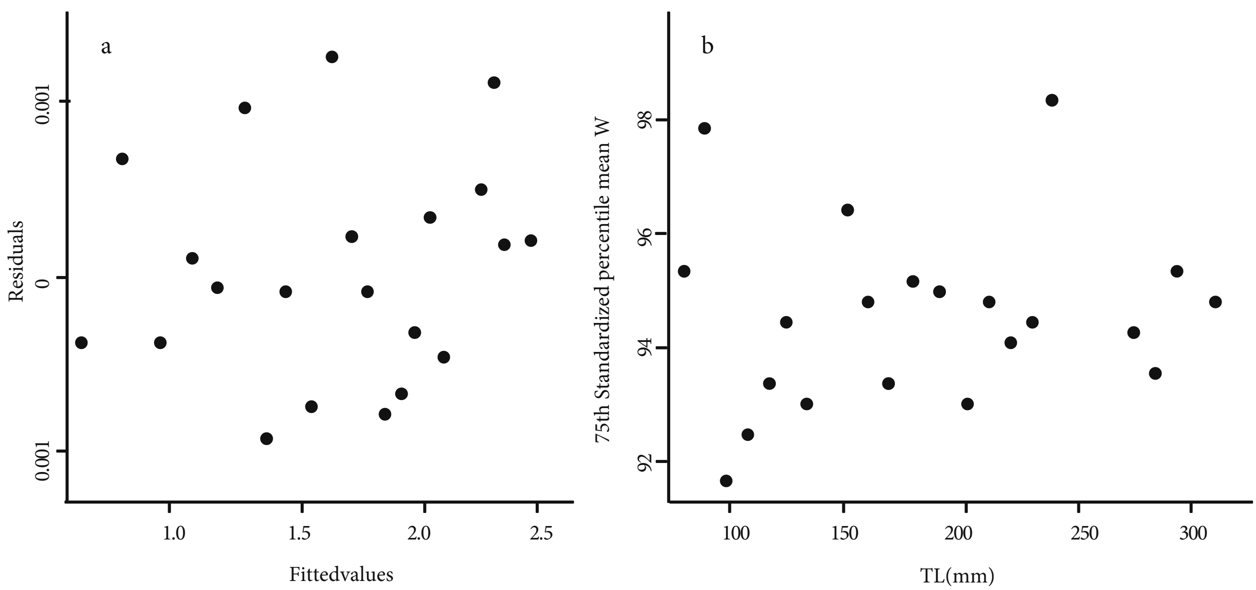

Figure 4. Plots showing the distribution of the residuals (a) and the results of the application of the empirical quartiles (EmpQ) method (b) used to investigate potential length bias in the standard mass (W_s) equation for *Squalius pursakensis*. Residuals = standardized residuals of the regression; fitted values = values obtained by the model fit; standardized 75th percentile mean W = standardized 75th percentile mean weights calculated by W_s equation.

of available data (i.e. height is usually not measured) and its uncommon use (i.e. this condition factor should be site-specific). Indeed, this was the case for Yiğit et al. (2008), as they could use only the Fulton condition factor (*K*) for comparisons with other studies, though it had the lowest coefficient factor among all analyzed condition indices. In this context, relative weight is the best alternative to condition factors commonly used in fishery biology, because it provides a single species-specific equation for the species, which allows reliable comparisons among different locations and specimens of different lengths.

Further research is encouraged to extend the use of this methodology to other species, with particular attention to those that are endemic. Turkey is an important area for fish biodiversity, being characterized by a high number of endemic species (78 species). Notably, almost half of the endemic species in Turkey are classified as 'Critically Endangered' and 32% as 'Endangered' (Fricke et al., 2007). These species often have a very small area of distribution (like *S. pursakensis*), are rarely studied, and currently are threatened by the presence of an increasing number of nonnative species introduced by stocking practices that have become very common in Turkish waters to increase fish production and sport fishing (Innal and Erk'akan, 2006; Aydın et al., 2011; Önsoy et al., 2011; Tarkan et al., 2012). For these reasons, all management tools that can assist in conserving the populations of these endemic species, such as *S. pursakensis*, would be advantageous in assessing the population-level responses to ecosystem disturbance.

The relative weight, together with other population metrics (e.g., age and growth), could allow researchers to increase basic knowledge of the population ecology of *S. pursakensis*, which will be useful in improving its management and conservation status (Murphy et al., 1991; Blackwell et al., 2000). Low values of relative weight will permit, by comparison of data of different periods, detection of any decline in the condition of specimens, probably due to environmental alterations or biological disturbance (e.g., presence of nonnative species) (Giannetto et al., 2012b). The results of previous studies reported clear habitat-based variations in age and growth features for other chub species, such as Aegean chub (Balık et al., 2004; Dirican and Barlas, 2007). These variations are more prominent between populations inhabiting lentic and lotic areas (Şaşı and Balık, 2003; Koç et al., 2007). Because of the positive correlation between fish growth and environmental quality (Bister et al., 2000), relative weight could be an easy and powerful tool for identifying ecological changes, such as the incidence of phenomena of intraspecies competition (Johnson, 1992), impact of nonnative species Giannetto et al., 2012b), or environmental disturbances (Gabelhouse, 1991; Hubert et al., 1994; Liao et al., 1995). Considering that *S. pursakensis* is commonly found in reservoirs, which are considered as unfavorable and variable environments for fish species (Tarkan, 2007; Emiroğlu et al., 2012), monitoring ecological changes via simple and effective tools such as relative weight is useful.

The EmP W_s equation developed for *S. pursakensis* is not biased by fish length according to all methods used for the validation (Willis, EmpQ, and analysis of the residuals of the equation). The results highlighted the reliability of the EmP method in developing standard weight equations, confirming those obtained by previous studies (Rennie and Verdon, 2008; Ogle and Winfield, 2009; Giannetto et al., 2011, 2012a, 2012c; Lorenzoni et al., 2012). On the basis of these results, the use of the EmP equation to determine W_r for *S. pursakensis* throughout its area of distribution is suggested.

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