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ARTICLE

Proposed Empirical Standard Weight Equation for Brook Chub *Squalius lucumonis*

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Abstract

Relative weight (W_r) is an index of condition that enables evaluation of the well-being of fish by comparing the actual weight of a specimen with the ideal weight of a specimen of the same species and the same length that is in good physiological condition (i.e., the standard weight [W_s]). This index was primarily developed to assess the status of sport fishes. Recently, however, many authors have encouraged the use of this index as a fisheries assessment tool for nongame species as well, especially those that are endangered or threatened. Length and weight data on brook chub *Squalius lucumonis*, an Italian endemic species listed as endangered by the International Union for the Conservation of Nature, were collected across its area of distribution and used to compute a standard weight (W_s) equation by means of the empirical percentile method. The W_s equation thus obtained ($\log_{10} W_s = -7.75 + 5.75 \log_{10}$[total length {TL}] – 0.66 [$\log_{10}$TL]^2; TL range of application = 90–210 mm) was not biased by length and is recommended as a way to compute W_r for brook chub.

Indices of condition are commonly utilized by fisheries personnel to provide a measure of the health of a fish population assuming that "fatter is fitter" (sensu Glazier 2000). According to this approach, body fatness is positively related to the well-being of an animal. Relative weight (W_r; Wege and Anderson 1978) is one of these indices and, unlike several other indices available in the literature (i.e., condition factor: Fulton 1911; Le Cren 1951), is not influenced by changes in body shape. Hence it enables comparison of the condition of fish of different lengths and belonging to different populations (Murphy et al. 1991).

As given by Wege and Anderson (1978), relative weight is calculated by the equation

$$W_r = 100\, W / W_s,$$

where W is the actual weight of a fish and W_s is the predicted standard weight for that same fish as calculated by a standard weight equation that is species specific. For this reason, before computing W_r for individual fish and populations, a W_s equation must be developed for the species using a wide sample of specimens collected throughout its area of distribution.

Until recently, the most widely used method to develop a W_s equation was the regression line percentile (RLP) method (Murphy et al. 1990), which uses the 75th percentile of the mean weights estimated among populations on the basis of the length–weight regression of each population (Blackwell et al. 2000). However, Gerow et al. (2004) provided a critique of the RLP method describing significant length-related biases for W_s equations developed using the RLP method. Gerow et al. (2005)

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introduced the empirical percentile (EmP) method, which is based on the 75th percentile of the observed weights of fish by 10-mm length increments (not weights estimated from regression models, as in the RLP). Furthermore, the EmP method uses a curvilinear relationship between length and weight, while the RLP method uses a linearized $\log_{10}$ transformed relationship.

Currently, the debate on the validity of the various methods and the choice between them is still open (Ogle and Winfield 2009; Gerow 2010; Ranney et al. 2010). Nevertheless, the results of recent studies encourage the development of future W_s equations by the EmP method because it is not length biased (Richter 2007; Rennie and Verdon 2008; Rypel and Richter 2008; Angeli et al. 2009; Ogle and Winfield 2009; Giannetto et al. 2011a, 2011b).

Relative weight has been used primarily to evaluate the status of sport fishes and species of commercial value (Willis et al. 1991; Blackwell et al. 2000). However, because of the positive relationship existing between fish growth and environmental quality, Bister et al. (2000) suggested that W_r can also be helpful in the assessment of populations of native, nongame fishes of conservation interest.

The brook chub *Squalius lucumonis* (Bianco 1983) is an Italian endemic species restricted to the Tuscany–Latium district in three river basins located in central Italy: the Tiber, Arno, and Ombrone–Serchio (Bianco and Ketmaier 2003; Crivelli 2006). It is one of the rheophilic cyprinid species inhabiting the secondary water courses (i.e., brooks, creeks, and small streams) within the barbel zone (Mearelli et al. 1995), which is characteristic of the intermediary sectors of the river basins in central Italy (Lorenzoni et al. 2006).

Many authors have reported a progressive decline in the brook chub's original range (Bianco and Taraborelli 1984; Mearelli et al. 1996; Bianco and Ketmaier 2001), and its disappearance is mainly due to habitat modification and competition with nonnative species (Bianco and Ketmaier 2003). Thus, the brook chub has been considered threatened (Bianco and Ketmaier 2003) and is listed as endangered on the International Union for the Conservation of Nature's (IUCN) Red List (the world's most comprehensive inventory of the global conservation status of biological species) because its estimated area of occupancy is less than 500 km^2, it is subject to loss of habitat, and it has a small number of populations (Crivelli 2006). The brook chub is also listed in Appendix III of the Bern Convention and in Annex II of the European Union Habitats Directive as a species requiring designation of Special Areas of Conservation.

For these reasons, any management tools that can assist in conserving the populations of this species would be advantageous. Relative weight can provide a rapid, accessible, and noninvasive metric with which to identify potentially at-risk brook chub populations (e.g., those with a low mean W_r) and to assess the overall health and fitness of brook chub populations as well as population-level responses to ecosystem disturbance.

The objective of this research was to develop a W_s equation for this species using the EmP method and to assess its potential length bias.

METHODS

Data set selection and development of the W_s equation.— Data on brook chub (total length [TL, mm] and weight [W, g]) were solicited and collected across the entire range of the species (Figure 1), and the following steps were taken to determine the W_s equation (Angeli et al. 2009; Giannetto et al. 2011a, 2011b). The first step was to "clean" the data so as to exclude all fish that were large outliers (i.e., those with values diverging by more than a factor of two from the expected value) from the regression of TL on W, since these were probably the result of incorrect measurements (Giannetto et al. 2011b).

Then, the initial data set was divided into two sets randomly selected on the basis of location: a large developmental data set (4,065 specimens) and a small validation data set (549 specimens) (Rypel and Richter 2008; Ogle and Winfield 2009). Both sets covered the distribution area of the species. The small size of the validation data set was chosen with the intent to use as large a sample as possible to develop the W_s equation.

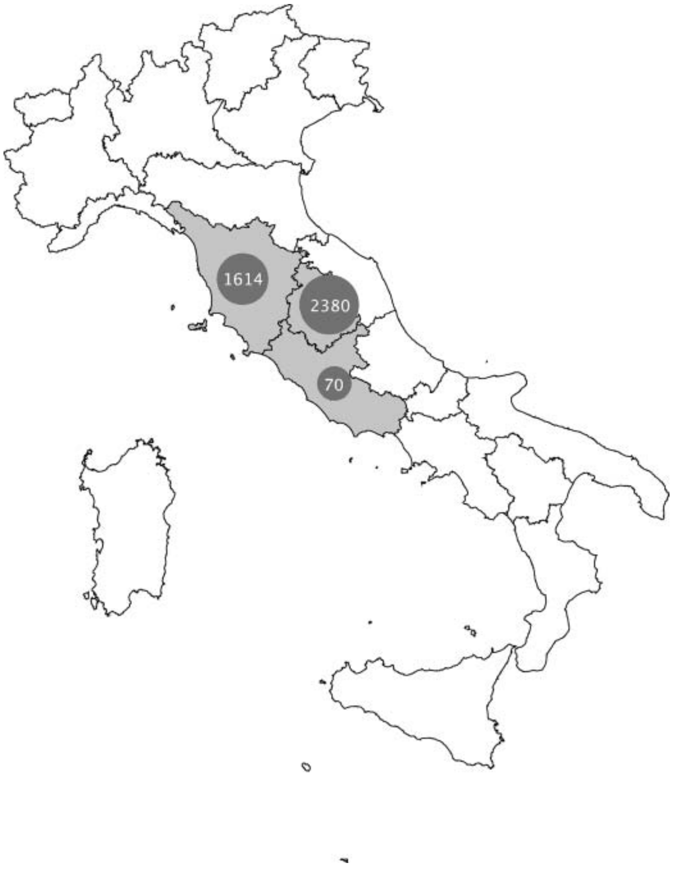

FIGURE 1. Areas from which brook chub data were obtained (the gray shading represents the geographic range of the species; the values within the circles are the number of specimens caught in the different areas).

TABLE 1. Data used to develop the W_s equations for brook chub, including the number of specimens (N), the minimum (Min) and maximum (Max) TL, the minimum and maximum weight (W), and the estimated statistics and parameters (r^2, intercept [$\log_{10}a$], and slope [b]) of the TL–W regression for each population.

		TL (mm)		W (g)		TL–W equation		
Population code	N	Min	Max	Min	Max	r^2	$\log_{10}a$	b
LAZCORE 01	26	85.0	175.0	6.4	57.0	0.950	–5.497	3.219
LAZRMAR 01	25	75.0	190.0	3.6	67.6	0.974	–5.419	3.188
LAZTEVE 01	19	80.0	200.0	4.9	90.1	0.943	–5.550	3.243
TOSAFRO 01	30	46.0	173.0	0.5	63.0	0.981	–5.806	3.409
TOSAGNA 01	27	65.0	201.0	3.0	96.0	0.964	–4.990	2.991
TOSAMBR 01	28	67.0	170.0	4.0	43.0	0.963	–4.687	2.865
TOSAMBR 02	39	62.0	193.0	3.0	64.0	0.958	–4.585	2.822
TOSARCH 01	24	119.0	204.0	18.0	106.0	0.951	–5.375	3.186
TOSARNO 02	48	67.0	181.0	3.0	79.0	0.988	–5.166	3.133
TOSARNO 03	34	45.0	165.0	1.0	54.0	0.979	–5.302	3.193
TOSARNO 04	23	38.0	169.0	1.0	65.0	0.975	–4.539	2.837
TOSARNO 05	79	72.0	162.0	4.0	52.0	0.956	–5.245	3.130
TOSARNO 07	12	45.0	174.0	0.6	52.0	0.987	–5.662	3.360
TOSASCO 01	78	45.0	186.0	1.0	82.0	0.980	–5.235	3.155
TOSCAPO 01	17	67.0	215.0	2.0	102.0	0.981	–6.328	3.609
TOSCAPO 02	52	56.0	181.0	1.5	55.0	0.977	–4.932	2.982
TOSCAPO 03	109	55.0	213.0	1.0	109.0	0.975	–5.139	3.058
TOSCAST 02	212	40.0	195.0	1.0	82.0	0.971	–4.037	2.572
TOSCERF 02	21	93.0	157.0	10.0	45.0	0.971	–4.900	2.991
TOSCERF 03	21	86.0	173.0	8.0	51.0	0.971	–4.739	2.923
TOSCERF 04	15	77.0	202.0	3.0	96.0	0.958	–5.549	3.262
TOSCHIAS 01	18	89.0	189.0	6.0	71.0	0.984	–5.677	3.311
TOSCHIAS 02	14	90.0	145.0	8.0	36.0	0.945	–4.471	2.802
TOSCIUF 01	25	86.0	192.0	8.0	72.0	0.978	–4.454	2.773
TOSCIUF 02	27	75.0	178.0	5.0	72.0	0.985	–4.976	3.026
TOSCIUF 03	15	71.0	207.0	3.0	87.0	0.984	–5.429	3.184
TOSCIUF 04	82	70.0	209.0	2.0	87.0	0.956	–5.240	3.119
TOSCORS 01	17	70.0	185.0	3.0	69.0	0.977	–5.351	3.178
TOSCORS 02	54	55.0	188.0	1.0	70.0	0.928	–5.215	3.121
TOSCORS 03	12	83.0	187.0	7.0	82.0	0.981	–4.956	3.011
TOSLUSI 01	48	51.0	202.0	1.0	85.0	0.953	–5.067	2.996
TOSLUSI 02	16	60.0	130.0	2.0	25.0	0.972	–5.122	3.098
TOSMIMO 03	24	35.0	112.0	0.5	19.0	0.933	–4.580	2.798
TOSNEST 01	11	30.0	127.0	0.5	26.0	0.968	–4.322	2.668
TOSSALI 01	64	47.0	183.0	1.0	57.0	0.940	–4.960	2.972
TOSSALI 02	64	45.0	145.0	1.0	39.0	0.966	–5.477	3.282
TOSSALI 03	71	60.0	205.0	3.0	97.0	0.987	–4.583	2.829
TOSSOVA 01	26	40.0	153.0	0.5	37.0	0.970	–5.470	3.203
TOSSOVA 02	17	94.0	174.0	9.0	68.0	0.946	–5.473	3.259
TOSTALL 01	13	58.0	195.0	2.0	92.0	0.986	–4.926	3.016
TOSTEGO 01	50	30.0	210.0	0.5	89.0	0.973	–4.790	2.893
TOSTEGO 02	37	87.0	210.0	5.0	109.0	0.966	–5.424	3.214
TOSTROV 01	10	72.0	162.0	4.0	54.0	0.988	–5.195	3.131
TOSOMBR 01	31	45.1	193.2	1.0	68.0	0.989	–5.257	3.100
UMBAGGI 02	43	40.0	160.0	1.0	52.0	0.965	–4.688	2.850
UMBAGGI 03	33	48.0	158.0	2.0	44.0	0.963	–4.505	2.796
UMBAIAA 01	15	40.0	100.0	0.5	12.0	0.929	–5.758	3.428
UMBALBE 01	43	90.0	210.0	8.0	91.0	0.953	–4.870	2.954

TABLE 1. Continued.

		TL (mm)		W (g)		TL–W equation		
Population code	N	Min	Max	Min	Max	r^2	$\log_{10}a$	b
UMBALNO 01	90	60.0	210.0	2.0	137.0	0.958	–5.104	3.075
UMBANTI 01	18	80.0	145.0	6.0	38.0	0.965	–4.852	2.972
UMBANTI 02	70	50.0	176.0	1.3	45.0	0.947	–4.784	2.886
UMBARGE 01	31	50.0	165.0	1.0	55.0	0.946	–5.509	3.305
UMBARGE 02	51	45.0	153.0	1.0	42.0	0.952	–5.362	3.179
UMBASSI 01	43	66.0	171.0	2.0	56.0	0.924	–5.368	3.210
UMBASSI 02	40	55.0	210.0	2.0	115.0	0.974	–5.165	3.114
UMBCALV 01	27	68.0	140.0	3.0	30.0	0.933	–5.065	3.073
UMBCARP 01	43	52.0	196.0	2.0	100.0	0.904	–5.374	3.218
UMBCARP 02	29	62.0	143.0	2.0	46.0	0.971	–5.278	3.203
UMBCERF 01	43	58.0	146.0	2.0	32.0	0.927	–5.313	3.192
UMBCHIA 01	35	67.0	182.0	3.0	69.0	0.995	–5.302	3.157
UMBCHIA 02	16	70.0	158.0	4.0	63.0	0.938	–5.586	3.323
UMBCHIA 03	11	70.0	125.0	4.0	28.0	0.979	–4.927	3.020
UMBCHIA 04	25	71.0	134.0	3.0	28.0	0.905	–5.417	3.195
UMBCHIA 06	62	55.0	165.0	1.5	58.0	0.973	–5.050	3.069
UMBCHIA 07	55	60.0	188.0	2.0	66.0	0.979	–5.184	3.110
UMBFERS 01	126	50.0	190.0	1.0	67.0	0.962	–5.383	3.230
UMBFERS 02	57	45.0	210.0	1.5	116.0	0.960	–4.662	2.866
UMBFERS 03	122	50.0	210.0	1.5	97.0	0.956	–4.722	2.906
UMBFERS 04	98	30.0	181.0	0.3	58.0	0.965	–5.450	3.228
UMBFERS 05	67	42.0	144.0	1.0	32.0	0.934	–5.202	3.121
UMBFERS 06	104	57.0	203.0	2.0	96.0	0.972	–4.734	2.937
UMBFERS 07	111	50.0	198.0	1.0	69.0	0.985	–5.224	3.105
UMBFOSS 01	39	70.0	156.0	3.0	45.0	0.948	–5.598	3.344
UMBGRAA 01	50	55.0	156.0	1.0	43.0	0.858	–4.872	2.943
UMBGRAB 01	11	75.0	120.0	1.0	21.0	0.571	–6.405	3.741
UMBIERN 01	20	62.0	156.0	2.0	43.0	0.955	–5.495	3.273
UMBLAMA 01	52	70.0	205.0	3.0	93.0	0.935	–4.842	2.962
UMBNEST 01	33	62.0	202.0	2.0	97.0	0.966	–5.180	3.118
UMBNEST 02	116	61.0	200.0	2.0	93.0	0.946	–5.208	3.154
UMBNEST 03	39	55.0	135.0	1.0	33.0	0.945	–4.818	2.952
UMBNICC 01	100	57.0	136.0	2.0	27.0	0.945	–5.046	3.056
UMBPASS 01	73	60.0	167.0	3.0	46.0	0.924	–5.084	3.053
UMBPUGL 01	15	77.0	156.0	5.0	47.0	0.963	–4.654	2.861
UMBROME 01	38	30.0	160.0	1.0	73.0	0.964	–4.402	2.765
UMBSERP 01	45	35.0	210.0	1.0	117.0	0.970	–4.782	2.928
UMBSERP 02	39	75.0	167.0	4.0	56.0	0.957	–5.382	3.223
UMBSOAR 01	70	55.0	182.0	2.0	74.0	0.982	–4.936	3.008
UMBSOVA 01	50	62.0	145.0	2.0	36.0	0.952	–4.864	2.970
UMBTEVE 02	24	76.0	157.0	6.0	46.0	0.950	–4.570	2.845
UMBVENT 01	58	65.0	169.0	3.0	62.0	0.914	–4.959	3.024

The developmental data set was divided into populations. Data derived from separate locations were considered to have come from separate populations; samples collected from the same location in different years were also considered to have come from separate populations except for locations with small numbers of fish over several years (Ogle and Winfield 2009; Giannetto et al. 2011a). Population samples with fewer than 10 individuals were excluded from further analysis (Rypel and Richter 2008).

In order to identify all anomalous values, a logarithmic regression of TL on W) was plotted for each population separately, and all values that diverged by more than a factor of two from the value expected from the regression were removed since these were probably the result of incorrect measurements (Bister et al. 2000). These equations were then analyzed, and all populations with an R^2 value 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 analysis (Froese 2006). This was done because, according to Carlander (1977), anomalous values of b or R^2 are often derived from samples with narrow size ranges (Froese 2000).

Finally, by linear plots of the slopes (b) against the intercepts (a) of all populations, it was possible to detect populations whose length–weight regression was questionable (because of, for example, a narrow size range, a few data with high variances, or outliers in the sample [Pope et al. 1995]), and all the populations identified as outliers were excluded from subsequent analysis (Froese 2006).

The next step was determination of a suitable length range to be used in the computation of the W_s equation. The minimum TL is required in order to account for the variability associated with the polymorphism and weighing inaccuracies often associated with small fish (Murphy et al. 1990; Richter 2007; Rypel and Richter 2008). Plotting the ratio between the variance and the mean of $\log_{10}W$ for 10-mm length intervals, we assigned the minimum TL as the length at which this ratio stabilized (Willis et al. 1991) and exceeded 0.01 (Murphy et al. 1990).

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. This value was identified as the largest TL-class for which at least three fish populations were available (Gerow et al. 2005; Giannetto et al. 2011a).

The EmP method proposed by Gerow et al. (2005) was used to develop the W_s equation for brook chub. According to this method, $\log_{10}$ transformed TL and W were used to calculate the mean empirical W for each 10-mm length-group from the developmental data set. The third quartile mean empirical W for each length-group was then regressed against TL using a quadratic regression weighted by the number of populations to develop the EmP W_s equation, as suggested by Gerow et al. (2005).

Then, on the basis of the W_s equation obtained, the W_r of each specimen from each population was calculated by the equation provided by Wege and Anderson (1978), given as

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

Validation of the W_s equation.—The principal property of a good condition index is that it be free from length-related biases in order to enable accurate comparisons between the measures of condition of different fish (Murphy et al. 1991; Anderson and Neumann 1996; Blackwell et al. 2000). The validation data set was used to validate the proposed W_s equation and to investigate potential length-related bias (Gerow et al. 2005). First, the W_r values were calculated by means of the proposed W_s equations, and analysis of the distribution of the residuals against $\log_{10}$TL (Ogle and Winfield 2009; Giannetto et al. 2011a) was used to visually discern any evident patterns that might exist. Moreover, the distribution of the residuals was assessed by means of Levene's test, according to which analysis of variance (ANOVA) is used to test whether the variances of the data are equal (homoscedasticity) or not (heteroscedasticity). Thereafter, the empirical quartiles (EmpQ) method proposed by Gerow et al. (2004) was applied by means of the Fisheries Stock Assessment package (version 0.0-14) developed by Ogle (2009) using R software (R version 2.11.1; R Development Core Team 2009) to determine whether the quadratic regression of the third quartile of the mean W standardized by W_s against length intervals of 10 mm had a slope of 0 (Ogle and Winfield 2009; Giannetto et al. 2011b).

RESULTS

The total data set comprised 4,614 specimens that ranged in size from 30 to 213 mm (mean $\pm$ SE $= 105.28 \pm 0.55$ mm) and in weight from 0.30 to 137 g (mean $\pm$ SE $= 17.76 \pm 0.28$ g).

Regressing W on TL for all specimens resulted in the log-transformed equation

$$\log_{10}W = -4.93 + 2.99\log_{10}\text{TL}\ (n = 4{,}614,\ R^2 = 0.96).$$

The developmental data set comprised 90 populations from throughout the area of distribution of brook chub (Table 1), but three populations (with $R^2 < 0.90$ or $b < 2.5$) were eliminated.

When we regressed b on $\log_{10}a$, the resulting equation was

$$b = 0.67 - 0.47\ \log_{10}a\ (n = 87\ \text{populations}, R^2 = 0.98),$$

and no populations were identified as outliers (Figure 2).

We determined the minimum TL to be 90 mm (Figure 3), which was the value at which the ratio of the variance to the

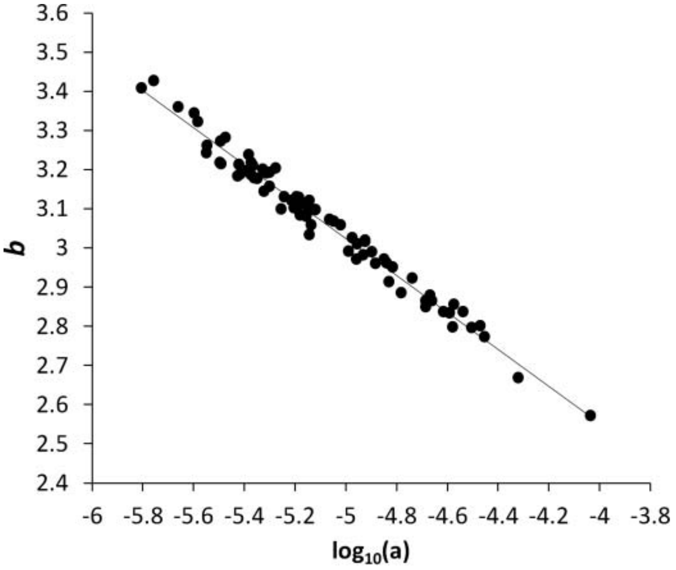

FIGURE 2. Plot of the slopes (b) against the intercepts (a) from the linear regressions for all populations of brook chub.

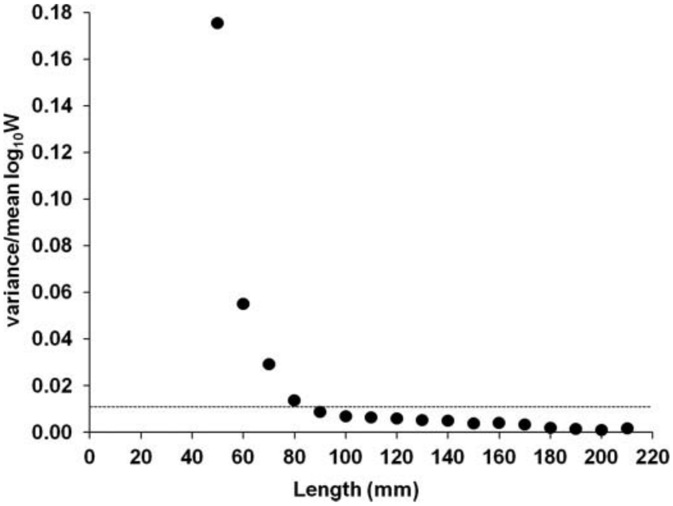

FIGURE 3. Relationship between the ratio of the variance to the mean for the $\log_{10}$ transformed weight (W) and TL by 10-mm intervals that was used to determine the minimum TL of brook chub.

mean value of $\log_{10}W$ by 10-mm length-classes (Willis et al. 1991) stabilized and was less than 0.01 (Murphy et al. 1990; Didenko et al. 2004). All fish smaller than 90 mm were eliminated from subsequent analysis. We assigned 210 mm as the maximum TL for the computation of W_s (Table 2); this was the TL of the largest individual fish in the sample, and it accords with the maximum length reported for this species in the literature (Bianco and Ketmaier 2001; Kottelat and Freyhof 2007). Therefore, the length range judged to be suitable for application of the W_s equation to brook chub was 90–210 mm.

The EmP W_s equation for brook chub thus obtained was

$$\log_{10}W_s = -7.75 + 5.75\,\log_{10}\text{TL} - 0.66(\log_{10}\text{TL})^2 (R^2 = 0.99).$$

TABLE 2. Number of populations and individuals of brook chub used to develop the W_s equation per 10-mm length-class (TL).

TL (mm)	Populations	Individuals
90	77	470
100	75	484
110	78	392
120	77	369
130	77	295
140	71	234
150	61	191
160	47	115
170	38	91
180	34	72
190	24	47
200	18	36
210	13	19

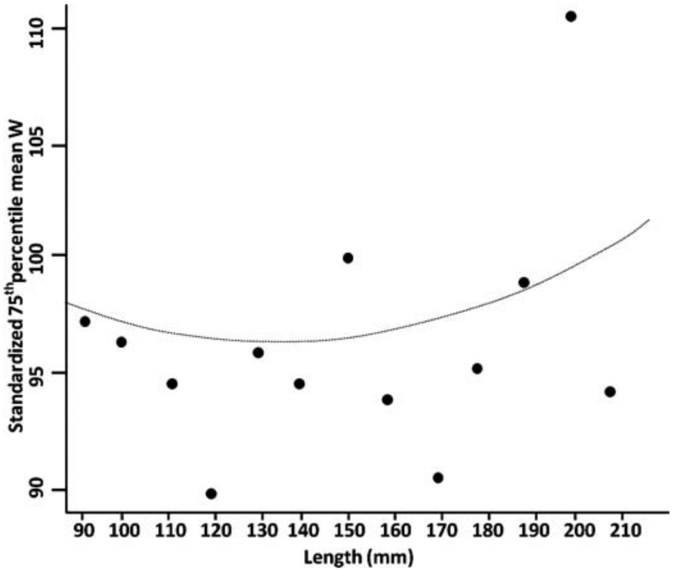

FIGURE 4. Residuals plot from applying the empirical quartiles method to the validation data set to investigate potential TL bias in the W_s equation for brook chub calculated by the empirical percentile (EmP) method.

When we applied the EmpQ method (Gerow et al. 2004) to the validation data set, the W_s equation did not appear to be influenced by fish length because, even if the quadratic regression of the third quartile of the mean W standardized by W_s on length showed a slight slope (Figure 4), the results were not significantly different from 0 (linear term: df = 1, $F = 0.087$, $P = 0.774$; quadratic term: df = 1, $F = 1.676$, $P = 0.225$). Moreover, analysis of the residuals of the W_s equation did not reveal apparent patterns, although they were homoscedastic according to Levene's test (ANOVA: $F = 0.007$, $P = 0.934$; Figure 5).

DISCUSSION

Relative weight provides a measure of the general health of fish (Brown and Murphy 1991, 2004; Jonas and Kraft 1996; Kaufman et al. 2007; Rennie and Verdon 2008) as well as of the environment (Liao et al. 1995; Blackwell et al. 2000; Rennie and Verdon 2008). According to Anderson and Neumann (1996), under given circumstances and conditions, W_r can be a robust predictor of fecundity, reproduction, growth, and mortality rates. Thus, W_r may be an indicator of environmental or ecological changes (Gabelhouse 1991; Hubert et al. 1994; Liao et al. 1995) and can be used as an indirect assessment tool to evaluate ecological relationships as well as inter- or intraspecies competition (Johnson et al. 1992; Giannetto et al. 2012) and the effects of management strategies (Murphy et al. 1991; Blackwell et al. 2000).

Reports of declining brook chub populations (Bianco and Ketmaier 2003) and the species' listing as endangered on the IUCN Red List (Crivelli 2006) are of concern. The use of a measure of body condition such as W_r could play an important role in obtaining a basic knowledge of the population ecology

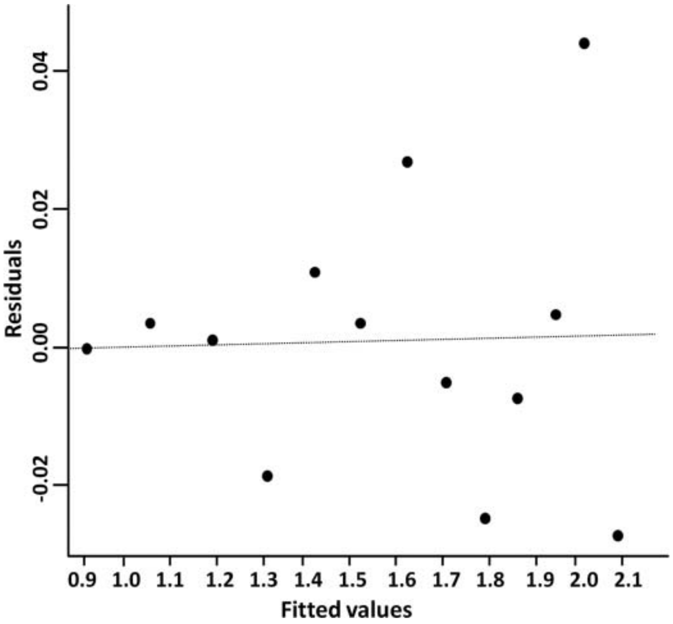

FIGURE 5. Distribution of standardized residuals of the regression applied to the validation data set to explore potential TL bias in the W_s equation for brook chub calculated by the EmP method.

of brook chub and, in conjunction with other population metrics (e.g., age and growth), in determining the effects of management and conservation actions. Moreover, because of the conservation interest in brook chub, the use of long-term data sets describing lengths and weights as well as comparisons between W_r values for the same population in different periods could aid in the detection of any long-term declines in condition that have occurred as a result of environmental changes.

In the present study, the W_s equation for brook chub was developed by means of the EmP method developed by Gerow et al. (2005) as an alternative to the RLP method proposed by Murphy et al. (1990). The EmP method requires a more-demanding phase of data collection (being based on the measured weights of fish), while, according to the RLP method, the old length–weight equation proposed in the literature for each species can be used to develop a W_s equation. Nevertheless, based on the results of recent studies, the EmP method is the most reliable one with which to develop W_s equations because it provides a measure of the condition of fish independent of their length. Specifically, in our study the W_s equation developed by means of the EmP method was free of length-related biases and is recommended for use in calculating W_r values for brook chub throughout the species' distribution.

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REFERENCES

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447–481 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Angeli, V., A. Bicchi, A. Carosi, M. P. Spigonardi, G. Pedicillo, and M. Lorenzoni. 2009. Proposed standard weight equations for brown trout (*Salmo trutta* Linnaeus, 1758) and *Barbus tyberinus* Bonaparte, 1839 in the River Tiber basin (Italy). Electronic Journal of Ichthyology 2:21–29.

Bianco, P. G. 1983. *Leuciscus lucumonis* n. sp. from Italy (Pisces: Cyprinidae). Senckenbergiana Biologica 64:81–87.

Bianco, P. G., and V. Ketmaier. 2001. Anthropogenic changes in the freshwater fish of Italy with reference to the central region and *Barbus graellsii*, a newly established alien species of Iberian origin. Journal of Fish Biology 59(Supplement A):190–208.

Bianco, P. G., and V. Ketmaier. 2003. Threatened fishes of the world: *Leuciscus lucumonis* Bianco, 1983 (Cyprinidae). Environmental Biology of Fishes 68:370.

Bianco, P. G., and T. Taraborelli. 1984. *Leuciscus lucumonis* Bianco, 1983 nel bacino del Tevere, e altri reperti di pesci d'acqua dolce in Italia (Pisces, Cypriniformes). [*Leuciscus lucumonis* Bianco, 1983 in the Tiber Basin and other finds of freshwater fish in Italy (Pisces Cypriniformes).] Natura (Milan) 75:110–116.

Bister, T. J., D. W. Willis, M. L. Brown, S. M. Jordan, R. M. Neumann, M. C. Quist, and C. S. Guy. 2000. Proposed standard weight (W_s) equations and standard length categories for 18 warmwater nongame and riverine fish species. North American Journal of Fisheries Management 20:570–574.

Blackwell, B. G., M. L. Brown, and D. W. Willis. 2000. Relative weight (W_r) status and current use in fisheries assessment and management. Reviews in Fisheries Science 8:1–44.

Brown, M. L., and B. R. Murphy. 1991. Relationship of relative weight (W_r) to proximate composition of juvenile striped bass and hybrid striped bass. Transactions of the American Fisheries Society 120:509–518.

Brown, M. L., and B. R. Murphy. 2004. Seasonal dynamics of direct and indirect condition indices in relation to energy allocation in largemouth bass *Micropterus salmoides* (Lacèpede). Ecology of Freshwater Fish 13:23–36.

Carlander, K. D. 1977. Handbook of freshwater fishery biology, volume 2. Iowa State University Press, Ames.

Crivelli, A. J. 2006. Squalius lucumonis. IUCN (International Union for Conservation of Nature) red list of threatened species, version 2011.1, IUCN, Gland, Switzerland. Available: www.iucnredlist.org. (September 2011).

Didenko, A. V., S. A. Bonar, and W. J. Matter. 2004. Standard weight (W_s) equations for four rare desert fishes. North American Journal of Fisheries Management 24:697–703.

Froese, R. 2000. Evaluating length–weight relationships. Page 133 *in* R. Froese and D. Pauly, editors. FishBase 2000: concepts, design and data sources. ICLARM (International Center for Living Aquatic Resource Management), Los Baños, Laguna, Philippines.

Froese, R. 2006. Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology 22:241–253.

Fulton, T. W. 1911. The sovereignty of the sea: an historical account of the claims of England to the dominion of the British seas, and of the evolution of the territorial waters. William Blackwood, Edinburgh, Scotland.

Gabelhouse, D. W. 1991. Seasonal changes in body condition of white crappies and relations to length and growth in Melvem Reservoir, Kansas. North American Journal of Fisheries Management 11:50–56.

Gerow, K. G. 2010. Biases with the regression line percentile method and the fallacy of a single standard weight. North American Journal of Fisheries Management 30:679–690.

Gerow, K. G., R. Anderson-Sprecher, and W. A. Hubert. 2005. A new method to compute standard-weight equations that reduce length-related bias. North American Journal of Fisheries Management 25:1288–1300.

Gerow, K. G., W. A. Hubert, and R. Anderson-Sprecher. 2004. An alternative approach to detection of length-related biases in standard-weight equations. North American Journal of Fisheries Management 24:903–910.

Giannetto, D., A. Carosi, E. Franchi, G. La Porta, and M. Lorenzoni. 2011a. Proposed standard weight (W_s) equation for European perch (*Perca fluviatilis* Linnaeus, 1758). Journal of Applied Ichthyology 28:34–39.

Giannetto, D., A. Carosi, E. Franchi, L. Ghetti, G. Pedicillo, L. Pompei, and M. Lorenzoni. 2012. Assessing the impact of non-native freshwater fishes on native species using relative weight. Knowledge and Management of Aquatic Ecosystems [online serial] 404:article 03. DOI: 10.1051/kmae/2011081.

Giannetto, D., G. La Porta, G. Maio, E. Pizzul, P. Turin, and M. Lorenzoni. 2011b. Proposed standard mass equations for European chub *Leuciscus cephalus* in Italy. Journal of Fish Biology 78:1890–1899.

Glazier, D. S. 2000. Is fatter fitter? body storage and reproduction in ten populations of the freshwater amphipod *Gammarus minus*. Oecologia 122:335–345.

Hubert, W. A., R. D. Gipson, and R. A. Whaley. 1994. Interpreting relative weight values of lake trout stocks. North American Journal of Fisheries Management 14:212–215.

Johnson, S. L., F. J. Rahel, and W. A. Hubert. 1992. Factors influencing the size structure of brook trout populations in beaver ponds in Wyoming. North American Journal of Fisheries Management 12:118–124.

Jonas, J. L., and C. E. Kraft. 1996. Assessment of seasonal changes in energy density and condition in age-0 and age-l muskellunge. Transactions of the American Fisheries Society 125:203–210.

Kaufman, S. D., T. A. Johnston, W. C. Leggett, M. D. Moles, J. M. Casselman, and A. I. Schulte-Hostedde. 2007. Relationship between body condition indices and proximate composition in adult walleyes. Transactions of the American Fisheries Society 136:1566–1576.

Kottelat, M., and J. Freyhof. 2007. Handbook of European freshwater fishes. Publications Kottelat, Cornol, Switzerland.

Le Cren, E. D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). Journal of Animal Ecology 20:201–219.

Liao, H., C. L. Pierce, D. H. Wahl, J. B. Rasmussen, and W. C. Leggett. 1995. Relative weight (W_r) as a field assessment tool: relationships with growth, prey biomass, and environmental conditions. Transactions of the American Fisheries Society 124:387–400.

Lorenzoni, M., M. Mearelli, and L. Ghetti. 2006. Native and exotic fish species in the Tiber River watershed (Umbria – Italy) and their relationship to the longitudinal gradient. Bulletin Français de la Pêche et de la Pisciculture 382:19–44.

Mearelli, M., G. Giovinazzo, M. Lorenzoni, M. L. Petesse, and A. Carosi. 1995. Zonazione ittica dei corsi d'acqua del bacino del fiume Tevere. [River zonation of the watercourses of the Tiber River basin.] Atti Società Italiana Ecologia 16:669–671.

Mearelli, M., M. Lorenzoni, A. Carosi, G. Giovinazzo, and M. L. Petesse. 1996. Carta ittica della Regione Umbria. [Fish map of the Umbria Region.] Università di Perugia, Perugia, Italy.

Murphy, B. R., M. L. Brown, and T. A. Springer. 1990. Evaluation of the relative weight (W_r) index, with new applications to walleye. North American Journal of Fisheries Management 10:85–97.

Murphy, B. R., D. W. Willis, and T. A. Springer. 1991. The relative weight index in fisheries management: status and needs. Fisheries 16(2):30–38.

Ogle, D. H. 2009. Data to support fish stock assessment package: package FSA, GPL version 2 or newer. Available: www.rforge.net/FSA./ (October 2011).

Ogle, D. H., and I. J. Winfield. 2009. Ruffe length–weight relationships with a proposed standard weight equation. North American Journal of Fisheries Management 29:850–858.

Pope, K. L., M. L. Brown, and D. W. Willis. 1995. Proposed revision of the standard-weight (W_s) equation for redear sunfish. Journal of Freshwater Ecology 10:129–134.

R Development Core Team. 2009. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. Available: www.R-project.org. (October 2011).

Ranney, S. H., M. J. Fincel, M. R. Wuellner, J. A. VanDeHey, and M. L. Brown. 2010. Assessing length-related bias and the need for data standardization in the development of standard weight equations. North American Journal of Fisheries Management 30:655–664.

Rennie, M. D., and R. Verdon. 2008. Development and evaluation of condition indices for the lake whitefish. North American Journal of Fisheries Management 28:1270–1293.

Richter, T. J. 2007. Development and evaluation of standard weight equations for bridgelip suckers and largescale suckers. North American Journal of Fisheries Management 27:936–939.

Rypel, A., and T. J. Richter. 2008. Empirical percentile standard weight equation for the blacktail redhorse. North American Journal of Fisheries Management 28:1843–1846.

Wege, G. J., and R. O. Anderson. 1978. Relative weight (W_r): a new index of condition for largemouth bass. Pages 79–91 *in* G. D. Novinger and J. G. Dillard, editors. New approaches to the management of small impoundments, volume 5. American Fisheries Society, Special Publication 5, Bethesda, Maryland.

Willis, D. W., C. S. Guy, and B. R. Murphy. 1991. Development and evaluation of a standard weight (W_s) equation for yellow perch. North American Journal of Fisheries Management 11:374–380.