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Ruffe Length–Weight Relationships with a Proposed Standard Weight Equation

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Abstract.—Ruffe *Gymnocephalus cernuus* length–weight data from 141 data sets were obtained from a variety of waters across Europe and the Laurentian Great Lakes for summarization and development of standard weight (W_s) equations. The mean slopes of the length–weight relationships from all populations and for all percentiles except the 95th percentile were not different from 3.0, suggesting that ruffe growth is generally isometric. The W_s equations developed using the regression line percentile, linear empirical percentile (EmP), and Froese's methods exhibited length-related biases. The quadratic EmP W_s equations for the 75th and 50th percentiles did not exhibit length-related biases and thus can be used to compute the relative weight of ruffe. The EmP 75th percentile W_s equation was $\log_{10}(W_{s75}) = -2.5800 + 0.6210 \cdot \log_{10}$(total length, TL) $+ 0.6073 \cdot [\log_{10}(\text{TL})]^2$, and the 50th percentile W_s equation was $\log_{10}(W_{s50}) = -3.3524 + 1.3969 \cdot \log_{10}(\text{TL}) + 0.4054 \cdot [\log_{10}(\text{TL})]^2$ when constrained to ruffe between 55 and 205 mm TL. We propose that the minimum TL for a five-cell length categorization system used to compute stock indices for ruffe be 55, 90, 120, 140, and 175 mm TL. These results provide a method for computing relative weight indices for typical (50th percentile) and above-average (75th percentile) ruffe; this method will allow comparisons of body condition across time, among habitats, among bodies of water, and among length categories.

The ruffe *Gymnocephalus cernuus* is a percid that is native to systems throughout most of Europe and Asia (Ogle 1998). In recent decades, ruffe have been accidentally introduced into a number of lakes in Europe (Matthey 1966; Ogle 1998; Winfield et al. 2002; Lorenzoni et al. 2007) and the Laurentian Great Lakes in North America (Pratt et al. 1992; Gunderson et al. 1998). Ruffe may form a large part of the overall fish biomass in native or invaded systems (Duncan 1990; Bronte et al. 1998; Winfield et al. 2007), serve as a primary prey component for some predators (Adams 1991; Dorner et al. 2007), prey upon the eggs of other species (Selgeby 1998; Winfield et al. 2004), and compete with other fish for limited food resources (Dieterich et al. 2004; Schleuter and Eckmann 2006; Lorenzoni et al. 2007).

Modeling the relationship between length and weight of a species of fish has been considered a routine analysis for which the results do not warrant publication (Froese 2006) or has been scorned as being of little value (Hilborn and Walters 2001). However, the recent review of methods and the meta-analysis of a large number of length–weight relationships by Froese (2006) demonstrated that a synthetic analysis of length–weight relationships for a species can provide important insights into the ecology of that species.

One important and commonly used metric that can be derived from summaries of length–weight relationships for a species is relative weight (W_r; Wege and Anderson 1978). Summaries of W_r can be used as a surrogate measure of the general "health" of the fish (Brown and Murphy 1991; Neumann and Murphy 1992; Jonas et al. 1996; Brown and Murphy 2004; Kaufman et al. 2007; Rennie and Verdon 2008; but also see Copeland et al. 2008) as well as the environment (Liao et al. 1995; Blackwell et al. 2000; Rennie and Verdon 2008). Thus, W_r summaries may be used as an indirect means for evaluating ecological relationships and the effects of management strategies (Murphy et al. 1991; Blackwell et al. 2000).

Relative weights are computed as the ratio of observed weight to standard weight (W_s; Wege and Anderson 1978). Standard weight equations are computed using the regression line percentile (RLP) method (Murphy et al. 1990, 1991; Blackwell et al. 2000), the empirical percentile (EmP) method (Gerow et al. 2005), or the method proposed by Froese (2006; hereafter, the Froese method). Both the RLP and EmP methods attempt to construct a W_s equation such that the equation "yield(s) approximately the 75th percentile of mean weights among populations of the target species for fish of all lengths within the range of applicable lengths" (Gerow et al. 2005). In contrast, the W_s equation from the Froese method is an attempt to represent the "mean weight derived from a mean

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length–weight relationship for the respective species" (Froese 2006). Until recently, the RLP method had been considered the "accepted method for W_s equation development" (Blackwell et al. 2000). Gerow et al. (2004, 2005) provided a critique of the RLP method and introduced the EmP method as a potential improvement. Empirical results from recent studies are equivocal about whether the RLP or EmP method produces W_s equations without a length-based bias (Richter 2007; Rennie and Verdon 2008).

The use of the 75th percentile as the standard for developing the W_s equation has also come under some scrutiny (Froese 2006; W. Hubert, U.S. Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, personal communication). While the choice to use the 75th percentile may seem arbitrary, it may be reasonable in the context of managing an exploited fishery where an objective might be to maintain a population of fish that are in better-than-average body condition. However, this metric may be inappropriate when the goal of using the metric is to gain understanding of the ecology of the species. For example, given its general nuisance status, it is difficult to imagine a management goal of maintaining a population of ruffe characterized by larger-than-average body condition. In these instances, it may make more sense for the standard to be a mean or median rather than the 75th percentile. The Froese method uses a mean as the standard, and both the RLP and EmP methods can be easily modified to use the median as the standard.

A global measure for assessing body condition for ruffe would help in understanding its impact on ecosystems in invaded waters and its response to management actions. Thus, our primary objectives were to develop W_s equations for ruffe by using the RLP, EmP, and Froese methods and to examine the characteristics of the developed W_s equations for computing W_r of ruffe. For the RLP and EmP methods, we developed equations for both the traditional 75th percentile and the 50th percentile as an option to those researchers who want to summarize the body condition of ruffe relative to a median fish rather than an "above-average" 75th percentile fish. Finally, we also summarized the length–weight regressions from all available populations to provide a general characterization of ontogenetic changes in ruffe body shape.

Methods

Data set selection.—In addition to our own data, data describing paired length–weight measurements were obtained from researchers across the geographical range of ruffe. Researchers that provided data were asked to include information about the year and month in which the sample was collected, length measurement type (i.e., standard length [SL], fork length [FL], or total length [TL]), and the precision of measured lengths and recorded weights. Data from separate locations on geographically large (e.g., Lake Superior) or long (e.g., Danube River) bodies of water were considered as separate analytical units. Data from multiple years from the same location were also considered as separate analytical units, with the exception of most data from locations in Sweden that were pooled across years because there were generally very small numbers of fish from several years. Data from different years were considered separately because in many instances, these data were from locations where ruffe were recently introduced and were collected in the years soon after their discovery (i.e., all data from the Great Lakes, UK, and Lake Piediluco; with notable exceptions of Lake Peipsi, Saidenbach Reservoir, and Lake Vortsjarv). As ruffe populations generally increase dramatically after introduction (Maitland and East 1989; Bronte et al. 1998; Winfield et al. 2004), we assumed that density-dependent factors would be important and would reduce year-to-year dependence. In addition, this choice will allow the W_s equations we develop to better represent the variability in mean weights present across both spatial and temporal scales.

The data sets that we received were cleaned and screened by following nine sequential steps in order to implement quality control across the wide variety of collection methods.

First, all fish with an unknown capture date and those captured in April or May were excluded to reduce the possible effect of mature gonads on the length–weight relationship. Second, all fish that were measured imprecisely ($>\pm 1$ mm) were excluded. Third, all fish for which the precision of the weighing scale was less than or equal to 20% of the fish's weight were excluded to reduce the effect of imprecise weighing of fish (Gutreuter and Krzoska 1994).

Fourth, fish that were large outliers on the location-specific plot of $\log_{10}(W)$ versus $\log_{10}(\text{TL})$—1.0% of the individuals at this stage of the cleaning—were excluded because it was not feasible to check the original data records for corrections. All excluded individuals were either outside the 99% prediction interval or were one of a very few number of individuals (three or less) that were substantially shorter than the bulk of the individuals for the data set.

Fifth, fish measured with only SL or FL were converted to TL by using a location-specific linear conversion model or a general linear conversion model developed from all fish from all data sets where at least two types of length measurements were recorded. The location-specific conversion models used were

$$\mathrm{TL} = 2.3710 + 1.1731 \cdot \mathrm{SL}$$
$$[\text{mean square error (MSE)} = 2.144,\ R^2 = 0.9877]$$

for Lake Peipsi and

$$\mathrm{TL} = 1.5680 + 1.1904 \cdot \mathrm{SL}$$
$$(\mathrm{MSE} = 1.397;\ R^2 = 0.9905)$$

for Lake Vortsjarv.

The general conversion models used were

$$\mathrm{TL} = 2.5706 + 1.1732 \cdot \mathrm{SL}$$
$$(\mathrm{MSE} = 2.140;\ R^2 = 0.9915)$$

and

$$\mathrm{TL} = 1.0858 + 1.0517 \cdot \mathrm{FL}$$
$$(\mathrm{MSE} = 1.185;\ R^2 = 0.9985).$$

The conversion was made by using the appropriate model to predict TL from the given SL or FL and then adding a random value derived from a normal distribution with a mean of zero and SD equal to the square root of the residual MSE of the linear conversion model.

Sixth, all remaining data sets with fewer than 20 individuals were excluded. Seventh, we plotted the variance : |mean| ratios for $\log_{10}(W)$ by 5-mm TL increments (Guy et al. 1990; Murphy et al. 1990) using pooled data from all remaining data sets to determine that the variance : |mean| ratio sharply decreased and remained suitably small (less than 2%) for fish larger than 55 mm TL. Thus, all fish with a TL less than 55 mm were excluded.

Eighth, all remaining data sets with fewer than 20 individuals were excluded. Ninth, all remaining data sets with an R^2-value less than 0.900 from the linear regression of $\log_{10}(W)$ on $\log_{10}(\mathrm{TL})$ were excluded.

Once the data sets were cleaned and screened as defined above, the log-transformed length–weight regression was fit to each data set. An examination of the plot of estimated slopes versus estimated intercepts (Figure 1; Pope et al. 1995; Brown and Murphy 1996; Froese 2006) did not indicate any outlier data sets that should be further excluded from analysis. The 141 data sets that met all of these criteria were then randomly divided into two sets (results of the length–weight regressions can be found in Appendix Tables A.1 and A.2 of the online version of this article available at http://dx.doi.org/10.1577/M08-176.A1). The development set of 91 data sets was used to develop the W_s equations, and the validation set of 50 data sets was used to assess potential length bias in the W_s equations. The different number of data sets in the development and validation sets was purposely chosen so that the larger number of development data sets assured wide geographic and water type (e.g., rivers, lakes) coverage when developing the W_s equations while allowing enough validation data sets to adequately assess the potential for length-related biases in the W_s equations.

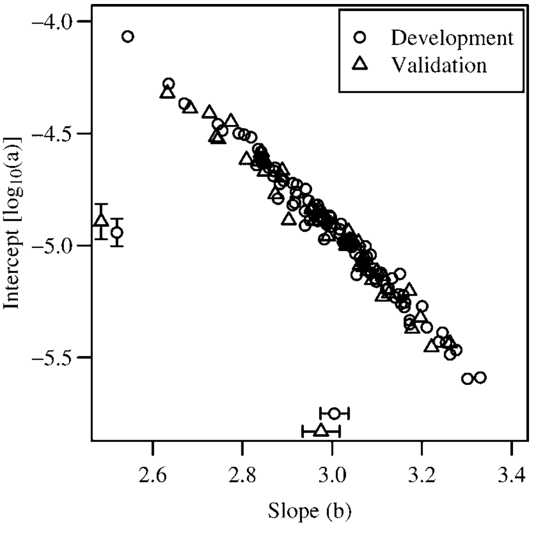

FIGURE 1.—Estimated intercepts $\log_{10}(a)$ versus estimated slopes (b) for the $\log_{10}$ transformed length–weight regressions of ruffe from all data sets in both the development and validation sets. Confidence intervals (95%) are shown along each axis for each parameter from both the development and validation sets.

Length–weight regression summaries.—The estimated intercept and slope values from the length–weight regression for each individual cleaned data set were summarized to provide a general description of the length–weight relationship for ruffe. We used a one-sample t-test to determine if the mean slope computed from all 141 data sets differed from three, which would suggest ontogenetic changes in the shape of ruffe (Froese 2006). In addition, we fit quantile regressions (Koenker and Bassett 1978; Cade and Noon 2003) to all quantiles between 0.05 and 0.95 in steps of 0.05 from each of the 141 cleaned log-transformed length–weight data sets to provide insights into the length–weight relationship throughout the distribution of paired length–weight data rather than just at the central tendency as with linear regression. A difference from three for the mean slope for each quantile computed across all data sets was tested by whether the confidence interval (CI) for the slope contained 3.0 or not.

Significant differences in mean slope or mean intercept between data sets in the development and validation sets were tested for with a two-sample t-test.

In addition, we used a chi-square test to determine if there was a difference in the proportions of data sets that exhibited a slope that was significantly less than three, equal to three, or significantly greater than three between the development and validation sets.

All tests were computed with the R version 2.9.0 statistical programming language (R Development Core Team 2009) and used a 0.05 level of significance. Quantile regressions were conducted with quantreg version 4.27 (Koenker 2009) for R.

Developing the W_s equation.—The RLP technique, as developed by Murphy et al. (1990), and the EmP technique, as developed by Gerow et al. (2005), were applied with functions written in R (R functions are available from D.H.O.). Because it is median unbiased regardless of the distribution of the data (Hyndman and Fan 1996), we used quantile definition 8 from Hyndman and Fan (1996) rather than definition 6 used by Murphy et al. (1990) or definition 9 used by Gerow et al. (2005). We used 10-mm-wide TL categories for both the RLP and EmP methods and a quadratic regression of the log-transformed length–weight data with the EmP method as suggested by Gerow et al. (2005). The W_s equations developed with the RLP and EmP methods using the 75th and 50th percentiles were labeled as W_{s75} or W_{s50}, respectively. The Froese method was applied by computing the mean slope and mean intercept from the length–weight regressions for each data set as described in Froese (2006). The W_s equation developed from the Froese method is labeled as W_{smean}.

Assessing length-related bias.—We assessed potential length bias in the derived W_s equations with two methods. First, we used the method of Willis et al. (1991; hereafter, the Willis method) in which a chi-square test is used to determine if the distribution of significant positive and negative slopes from the regression of W_r (calculated with the proposed W_s equation) against TL for each fish in each data set in the validation set is even. Second, we used a modification of the empirical quartiles method (EmpQ; Gerow et al. 2004) to determine if the quadratic regression of 75th or 50th percentile (for RLP and EmP W_s equations) or mean (for the Froese W_s equation) of the mean weights standardized by the proposed W_s equation against the TL category midpoints had a slope of zero. The dependent response variable in the EmpQ regression differed between the RLP–EmP and Froese methods because of the nature of the standard for the different methods. In contrast to Gerow et al. (2004), our quadratic regression was weighted by the number of data sets used to determine the 75th percentile, 50th percentile, or mean of the mean weight in each length category. An even distribution of positive and negative slopes (Willis method) and linear and quadratic coefficients that are equal to zero (EmpQ method) indicate the lack of a length bias (Murphy et al. 1990; Gerow et al. 2004).

Five-cell length categories for stock density indices.—Murphy et al. (1991) suggested that the overall mean W_r for a data set should not be computed unless it can be shown that the mean W_r does not differ for fish among the cells of the five-cell length categorization system proposed by Gabelhouse (1984) for the calculation of stock density indices. We applied Gabelhouse's (1984) criteria to develop minimum TL of ruffe for each of the five cells by using a "world record" TL that was the largest TL observed in all data sets available to us, rounded up to the nearest 10-mm value. We modified the names of the five length categories to be more appropriate for the nongame ruffe.

Results and Discussion

Data Sets

For all 141 data sets, the mean slope was 2.9944 (95% CI = 2.9698–3.0190) and the mean intercept was −4.9245 (95% CI = −4.9724 to −4.8766). The mean slope from all 141 data sets was not statistically different from 3.0 ($t = -0.4473$; df = 140; $P = 0.6554$). Among all 141 data sets, 32 data sets had a slope significantly less than 3.0, and 26 had a slope significantly greater than 3.0. A mean slope determined from a large number of data sets generally covering the geographic range of the ruffe and several years of samples (Froese 2006) and that was not different from 3.0 suggests that ruffe growth is generally isometric (Ricker 1958). Furthermore, the mean slope appeared to differ from 3.0 for only the largest quantile (0.95; Figure 2). Thus, the conclusion of isometric growth appears to hold throughout the distribution of the length–weight relationships, with the exception of the largest fish in the upper end of the distribution.

The development set consisted of 14,833 individual fish in 91 data sets. The validation set consisted of 7,979 individual fish in 50 data sets. Both sets contained data sets that were distributed geographically throughout the range of ruffe in Europe and the Great Lakes (Figure 3). There was no significant difference in the mean slope ($t = 1.1483$, df = 139, $P = 0.2528$; Figure 1), mean intercept ($t = -0.9527$, df = 139, $P = 0.3424$; Figure 1), or proportions of data sets with a slope statistically less than, equal to, or greater than 3.0 ($\chi^2 = 0.6328$; df = 2; $P = 0.7288$) between the development and validation sets.

Development of the RLP W_s equation was restricted to fish less than 215 mm, a value that is 1 mm smaller than the largest observed TL in all data sets.

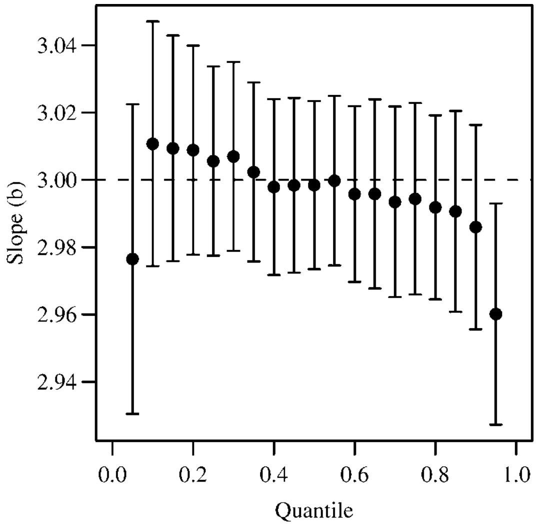

FIGURE 2.—Mean slopes (b; with 95% confidence intervals) for the length–weight regressions of ruffe for quantiles between 0.05 and 0.95 (in increments of 0.05) from all data sets in both the development and validation sets. The horizontal line at a slope of 3.00 is shown for reference.

Development of the EmP W_s equation was restricted to fish less than 205 mm, which was the endpoint of the largest length-class in the development set with at least three data sets (Table 1; Gerow et al. 2005), excluding the 210–220-mm length-class ($n = 3$ data sets) because it produced a large outlier when fitting the EmP models. The EmpQ method could only be applied to fish less than 185 mm because that was the endpoint of the largest length-class in the validation set with at least three data sets.

TABLE 1.—Number of data sets and number of individual ruffe per 10-mm total length (TL) category (e.g., 60 = 55.0–64.9-mm TL). Length categories marked with an asterisk were not used in the development of the linear empirical percentile standard weight equations.

TL midpoint (mm)	Data sets	Individuals
60	63	1,317
70	69	1,564
80	84	2,111
90	88	2,326
100	84	2,041
110	84	1,605
120	77	1,367
130	60	969
140	48	634
150	31	434
160	24	206
170	22	152
180	12	65
190	8	29
200	4	9
210*	3	3
220*	1	1

Standard Weight Equations

The RLP W_{s75} equation (Table 2) had residuals (Figure 4A) that exhibited a clear nonlinearity and a length-related bias as detected with both the EmpQ and Willis methods (Table 2). The EmpQ method showed a tendency for longer ruffe to exhibit a larger standardized W_s (Figure 4B); thus, the RLP W_{s75} equation tended to underpredict the W_s for relatively long fish.

The EmP W_{s75} equation (Table 2) had residuals (Figure 4A) that exhibited no obvious pattern, although there were slightly larger residuals in some of the larger length-classes. No length-related bias was detected with the Willis or EmpQ methods (Table 2; Figure 4B).

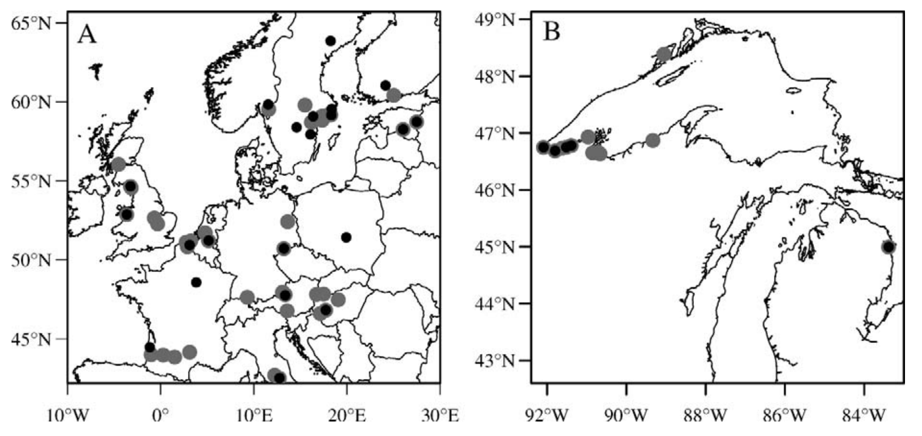

FIGURE 3.—Geographic distribution of **(A)** European and **(B)** Great Lakes data sets used to develop (gray) and validate (black) the standard weight equations for ruffe. Some plotted points represent multiple data sets (i.e., same locations sampled in different years).

TABLE 2.—Parameter estimates ($\log_{10}[a]$ = intercept, b_{linear} = linear slope coefficient, $b_{\text{quadratic}}$ = quadratic coefficient), results of the Willis et al. (1991) length bias detection test (neg = number of data sets with significantly negative slopes; pos = number of data sets with significantly positive slopes), and P-values for the significance of the linear and quadratic terms in the empirical quartiles (EmpQ) length bias detection test for each ruffe standard weight (W_S) equation (75 = 75th percentile; 50 = 50th percentile).

	Parameters[b]			Willis test			EmpQ test	
Equation[a]	$\log_{10}(a)$	b_{linear}	$b_{\text{quadratic}}$	Neg	Pos	P	P_{linear}	$P_{\text{quadratic}}$
RLP W_{S75}	−4.9588	3.0286		15	5	0.0414	0.3620	0.0034
EmP W_{S75}	−2.5800	0.6210	0.6073	15	7	0.1338	0.4401	0.9174
EmP Ws_{75}	−5.0206	3.0612		16	1	0.0003	0.5308	0.0024
RLP W_{S50}	−4.9573	3.0154		14	5	0.0636	0.2272	0.0750
EmP W_{S50}	−3.3524	1.3969	0.4054	12	8	0.5034	0.4838	0.9368
EmP W_{S50}	−4.9818	3.0259		14	5	0.0636	0.3844	0.0685
Froese $W_{S\text{mean}}$	−4.9416	3.0050		13	6	0.1671	0.4151	0.0011

[a] Equation types are regression line percentile (RLP), linear empirical percentile (EmP), and Froese (from Froese's [2006] method).
[b] All $P < 0.0005$ with the exception of b_{linear} for EmP W_{S75} ($P = 0.1140$).

An EmP W_{s75} equation developed without the quadratic term exhibited a significant length-related bias (Table 2). Thus, the quadratic term in the EmP method appeared to be warranted.

The RLP W_{s50} equation (Table 2) had residuals (Figure 5A) that exhibited nonlinearity, and a large residual was present for the smallest length-class. A slight but nonsignificant length-related bias was detected with both the EmpQ and Willis methods (Table 2). Although the length-related bias was not significant, it was visually apparent that longer ruffe tended to exhibit a larger standardized W_s with the RLP W_{s50} equation (Figure 5B).

The EmP W_{s50} equation (Table 2) had residuals (Figure 5A) that exhibited no obvious pattern. A length-related bias was not detected with either the Willis or EmpQ method (Table 2; Figure 5B). The EmP W_{s50} equation developed without the quadratic term exhibited a slight but nonsignificant length-related bias according to both the Willis and EmpQ methods (Table 2).

The Froese $W_{s\text{mean}}$ equation had a significant curvilinear trend as detected with the EmpQ method (Table 2). A length-related bias was not detected with the Willis method (Table 2), however. The $W_{s\text{mean}}$ equation tended to underpredict W_s for relatively long fish (Figure 6).

Murphy et al. (1991) noted that an adequate W_s equation must accurately represent the growth form of the species. They noted that misrepresentation of the growth form may be avoided by using a large number of data sets when developing the W_s equation. The W_s equations presented here were derived from 91 data sets, exceeding the minimum of 50 data sets suggested

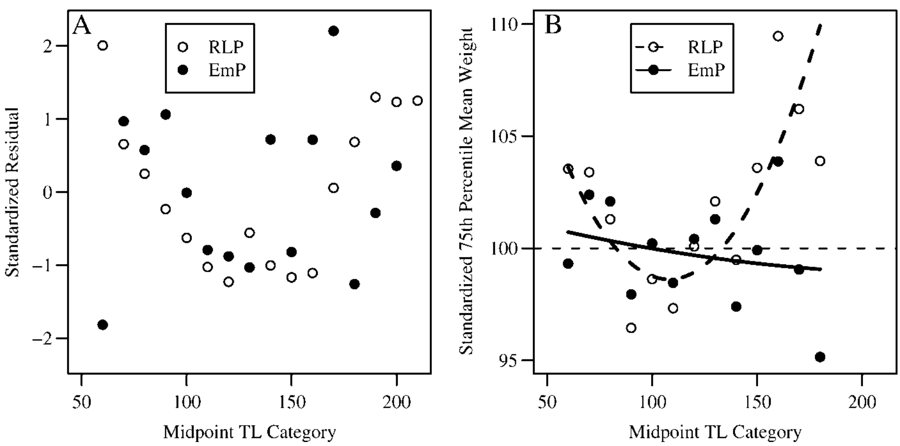

FIGURE 4.—Residual plot from the (A) model fits and (B) standardized 75th percentile mean weights versus total length (TL) category midpoints, with weighted quadratic regression fits for the regression line percentile (RLP) and linear empirical percentile (EmP) methods for obtaining ruffe 75th percentile standard weight equations. The horizontal line at 100 is shown for reference.

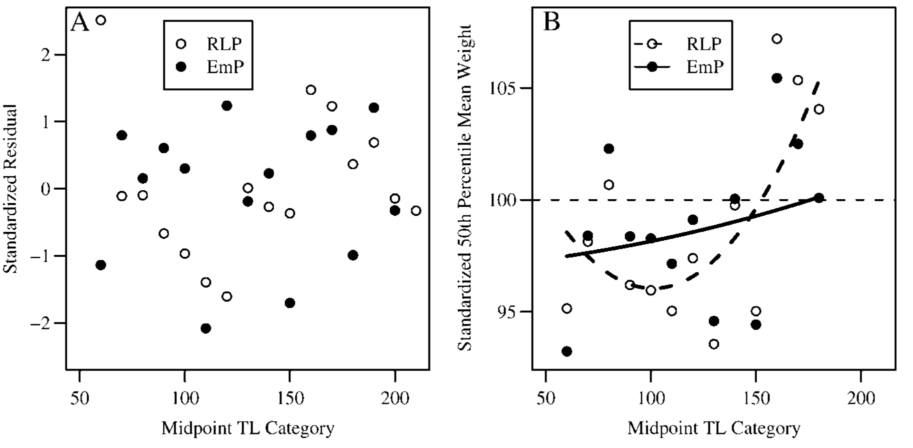

FIGURE 5.—Residual plot from the **(A)** model fits and **(B)** standardized 50th percentile mean weights versus total length (TL) category midpoints, with weighted quadratic regression fits for the regression line percentile (RLP) and linear empirical percentile (EmP) methods for obtaining ruffe 50th percentile standard weight equations. The horizontal line at 100 is shown for reference.

by Brown and Murphy (1996) and by the results of Gerow et al. (2005). In addition, the data sets used to develop the W_s equations covered most of the geographic range of the ruffe and a variety of years and thus should represent the range of growth forms found among ruffe populations. Murphy et al. (1991) also noted that the W_r values computed from a W_s equation should be globally independent of fish length. In other words, W_r values computed from individual data sets may be related to fish length, but there should be no consistent relationship with fish length across a large number of data sets. Of the seven proposed W_s equations here, the two quadratic EmP W_s equations best met this criterion. Therefore, we suggest that only the quadratic EmP W_s equations should be used to derive W_r values for ruffe populations.

Five-Cell Length Categories for Stock Density Indices

The longest fish observed in our data sets was a 216-mm TL specimen. Assuming a world record ruffe TL of 220 mm, we propose that the minimum TL should be 55 mm for "small" ruffe (42.5% of 22,827 fish observed); 90 mm for "medium" ruffe (38.1%); 120 mm for "large" ruffe (11.9%); 140 mm for "very large" ruffe (6.9%); and 175 mm for "extremely large" ruffe (0.71%).

Management Implications

Relative weight is a metric that has been primarily used to measure body condition of fishes of sport or commercial interest (see list of W_s equations in Blackwell et al. 2000) for the purpose of setting and assessing management goals. Recently, W_s equations have been developed for several nongame fishes (Bister et al. 2000; Didenko et al. 2004; Richter 2007) so that W_r could be used in population and community assessments (Bister et al. 2000). As the ruffe has no sport or commercial utility, the use of a W_s equation for ruffe falls in this latter category. Use of our proposed EmP-derived W_s equations will provide researchers with another metric to understand the impact of ruffe in invaded waters; compare relative body condition of ruffe among years, bodies of water, or habitats; and explore the effects of community

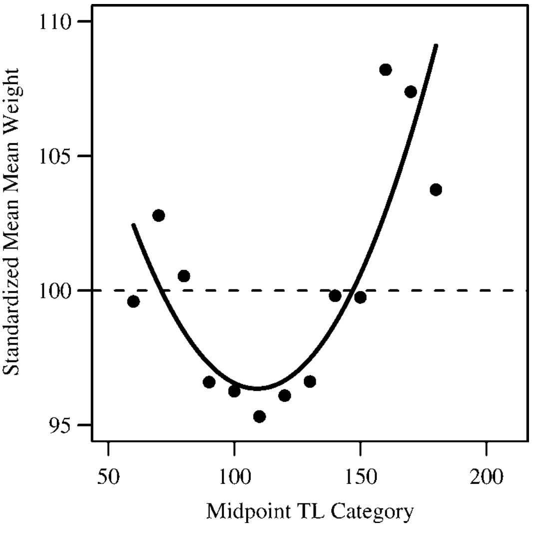

FIGURE 6.—Standardized mean of mean ruffe weights versus total length (TL) category midpoints with the weighted quadratic fit for the Froese (2006) method of obtaining standard weight equations.

dynamics (such as the densities of prey, competitors, or predators) on ruffe body condition.

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Appendix: Ruffe Data Sets and Standard Weight Equations
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Appendix: Ruffe Data Sets and Standard Weight Equations

TABLE A.1.—Country; specific location; sample size (n); minimum (min) and maximum (max) total length (TL); minimum and maximum weight (W); and estimated intercept ($\log_{10}[a]$), estimated slope (b), and R^2 for $\log_{10}$ transformed length–weight regressions from 91 ruffe data sets used to develop standard weight (W_S) equations. Locations shown without a year were pooled across several years (abbreviations in the location names are as follows: K. = Kanaal, L. = Lake, R. = River, Res. = Reservoir, and W. = Water).

			TL		W		Length–weight equation		
Country	Location (year)	n	Min	Max	Min	Max	$\log_{10}(a)$	b	R^2
Austria	Mattsee (2006)	282	55	160	1.9	51.0	−4.98270	3.02415	0.990
	Millstätter See (2007)	124	55	215	2.0	106.7	−4.84594	2.97449	0.992
	Mondsee (2004)	38	90	185	7.0	88.0	−5.42884	3.23821	0.981
	Mondsee (2006)	49	70	189	3.7	87.0	−5.12067	3.08453	0.983
	Neusiedler See (2006)	125	55	119	1.9	20.0	−5.07473	3.06950	0.994
	Obertrumer See (2006)	261	55	149	1.5	39.0	−4.86747	2.96021	0.985
Belgium	K. Van Brugge (2006)	25	69	131	4.2	28.6	−4.87298	2.99694	0.992
	K. Van Dessel (1999)	34	60	117	2.6	22.4	−4.86622	2.99387	0.943
	K. Van Ieper (2002)	147	57	134	2.1	34.1	−4.90320	3.01958	0.956
	Nieuwpoort (2007)	96	62	132	3.2	29.2	−5.23175	3.14119	0.921
Estonia	L. Peipsi (1996)	64	57	131[a]	2.2	21.4	−4.45834	2.74536	0.971
	L. Peipsi (1997)	59	59	125[a]	2.1	23.0	−5.13035	3.05463	0.935
	L. Peipsi (1999)	400	63	157[a]	2.5	44.0	−4.88615	2.95047	0.910
	L. Peipsi (2001)	170	64	131[a]	2.6	22.9	−4.27777	2.63550	0.940
	L. Peipsi (2002)	68	58	118[a]	2.2	14.6	−4.36597	2.67063	0.979
	L. Vortsjarv (2002)	101	59	104[a]	2.1	12.3	−4.81922	2.91203	0.988
Finland	L. Tuusulanjärvi (1996)	38	82	184	6.0	73.0	−5.33363	3.17309	0.989
France	Albarèdes (2005)	152	55	121	1.9	21.7	−4.87001	2.97616	0.969
	Lacroux (2005)	201	55	133	2.1	32.0	−4.56951	2.83529	0.945
	Rivières-sur-tarn (2005)	86	58	123	2.5	26.0	−4.51678	2.81953	0.982
	Villemur-sur-tarn (2005)	110	55	122	2.1	25.4	−4.50468	2.80426	0.955
Germany	L. Constance (2004)	48	56	96	1.9	12.1	−4.94753	3.01699	0.925
	L. Mueggelsee (1998)	189	61	110	2.6	15.1	−4.68950	2.86920	0.958
	Saidenbach Res. (1999)	32	55	125	1.8	22.2	−5.25967	3.15395	0.986
	Saidenbach Res. (2000)	53	55	125	1.5	24.3	−5.14601	3.09569	0.983
	Saidenbach Res. (2001)	28	55	123	1.8	25.0	−5.12102	3.08653	0.975
	Saidenbach Res. (2002)	30	55	136	1.8	30.5	−5.25417	3.16234	0.983
	Saidenbach Res. (2003)	88	56	122	2.0	24.8	−5.18931	3.12577	0.976
Hungary	L. Balaton (2001)	60	56	113[a]	1.9	19.5	−4.99272	3.04832	0.958
	L. Balaton (2006)	97	55	125[a]	1.6	23.2	−5.05412	3.06208	0.917
	Danube R. (Budapest) (1993)	50	75	161	5.3	61.0	−5.27084	3.20066	0.977
	Danube R. (Szigetköz) (1993)	37	69	143	4.2	40.1	−4.97112	3.03468	0.980
	L. Major (2005)	64	82	140	7.9	41.8	−4.74744	2.94113	0.914
	L. Major (2006)	58	67	138	3.2	25.9	−4.98823	3.03216	0.958
	L. Major (2007)	54	66	130	3.8	30.3	−4.92748	3.01712	0.985
Italy	Corbara Res.	41	80	150	6.0	40.0	−4.79958	2.94738	0.933
	L. Piediluco (2002)	43	115	196	17	110	−5.58912	3.33028	0.961
	L. Piediluco (2004)	382	80	208	6	110	−5.19615	3.12096	0.923
	L. Piediluco (2005)	100	122	203	22	100	−5.10303	3.09197	0.951
Netherlands	De Gijster (2002)	40	64	145	3.0	38.3	−5.21708	3.14826	0.989
	Honderd en Dertig (2002)	35	57	160	1.6	50.8	−5.36501	3.21103	0.991
Norway	L. Rødenessjøen (1982)	82	75	165	5.5	40.0	−4.06648	2.54431	0.961
Sweden	Årsjön	51	57	168	1.8	56.2	−4.80898	2.91698	0.981
	Björken (2001)	72	56	135	1.9	24.0	−4.97188	2.98253	0.980
	Flaten	24	87	127	6.0	25.0	−5.48598	3.26289	0.911
	Lien	94	60	131	2.1	19.0	−4.91084	2.93970	0.946
	Skärgölen (2003)	27	59	122	2.3	20.3	−5.16067	3.09865	0.975
	Stora Envättern	31	59	131	2.4	22.0	−4.84600	2.93925	0.970
UK	Bassenthwaite L. (2006)	76	74	141[b]	6.0	27.0	−4.49913	2.79174	0.937
	Derwent W. (2006)	45	79	128[b]	6.0	26.0	−5.46620	3.27673	0.909
	Grafham W. (1996)	335	77	175[b]	6.0	70.0	−5.00635	3.04353	0.952
	Llyn Tegid (1991)	104	81	159[b]	6.0	43.0	−5.27450	3.16102	0.958
	Llyn Tegid (2003)	21	84	172[b]	6.0	53.0	−5.59442	3.30173	0.959
	Loch Lomond (2004)	36	77	134	6.0	31.0	−5.03572	3.05184	0.901
	Loch Lomond (2007)	160	76	164	6.0	59.0	−5.12193	3.10906	0.953
	Rutland W. (1996)	63	71	192[b]	6.0	113.0	−5.12628	3.15131	0.957
Canada	L. Superior (Thunder Bay; 2003)	515	73	212	6.0	125.9	−5.14632	3.13365	0.986
	L. Superior (Thunder Bay; 2006)	29	80	174	5.9	71.2	−5.38871	3.24607	0.979

TABLE A.1.—Continued.

Country	Location (year)	n	TL Min	TL Max	W Min	W Max	Length–weight equation $\log_{10}(a)$	b	R^2
USA	Amnicon R. (1995)	441	55	168	1.6	58.1	−4.98040	3.02688	0.967
	Amnicon R. (1996)	104	56	148	2.1	54.1	−4.81835	2.96791	0.984
	Amnicon R. (1997)	117	55	105	1.9	13.8	−4.63340	2.84721	0.973
	Amnicon R. (2002)	32	55	142	1.5	33.6	−5.35072	3.17307	0.958
	Amnicon R. (2006)	22	61	124	2.3	21.2	−4.79019	2.87939	0.971
	Bad R. (1997)	95	55	174	1.6	70.2	−5.04108	3.08570	0.992
	Bad R. (2001)	26	56	160	1.7	53.4	−5.07302	3.07020	0.990
	Brule R. (1995)	176	57	111	2.2	15.1	−4.72447	2.88385	0.942
	Brule R. (1996)	46	56	120	2.4	23.5	−4.66750	2.87124	0.974
	Brule R. (1997)	42	58	107	2.9	13.9	−4.65250	2.87267	0.957
	Flag R. (2004)	36	55	130	2.3	25.8	−4.89855	2.98958	0.986
	Iron R. (1996)	106	55	150	1.8	40.3	−5.04983	3.07705	0.975
	Iron R. (1997)	78	55	149	1.7	38.9	−4.91599	2.99657	0.978
	Iron R. (2005)	29	77	144	5.4	37.3	−4.88997	2.96752	0.944
	Kakagon R. (1997)	20	56	110	2.2	17.1	−4.58117	2.84154	0.986
	Kakagon R. (1998)	62	85	137	7.8	35.7	−4.98343	3.03236	0.914
	L. Huron (Thunder Bay; 1997)	46	59	99	2.6	11.9	−4.72154	2.91233	0.957
	L. Superior (Chequamegon Bay; 1998)	73	55	137	1.8	32.5	−4.90600	2.98804	0.939
	Ontonagon R. (2002)	25	55	165	2.2	51.2	−4.87533	2.97546	0.989
	Sand R. (1995)	46	60	105	2.6	11.8	−4.48644	2.75512	0.917
	Sand R. (1996)	24	55	122	1.6	23.8	−5.22233	3.15861	0.985
	St. Louis R. (1988)	2,273	69	175	5.0	85.0	−5.00334	3.07453	0.978
	St. Louis R. (1992)	485	55	192	1.9	93.1	−4.72900	2.92147	0.984
	St. Louis R. (1993)	1,591	55	182	1.8	68.8	−4.76026	2.91946	0.985
	St. Louis R. (1994)	1,332	55	176	1.7	55.0	−4.83416	2.95776	0.987
	St. Louis R. (1995)	301	55	162	1.8	55.0	−4.62039	2.84202	0.982
	St. Louis R. (1996)	328	55	154	2.0	47.6	−4.65257	2.85903	0.985
	St. Louis R. (1998)	81	57	141	2.3	35.0	−4.88354	2.97801	0.981
	St. Louis R. (2000)	429	55	147	1.8	38.7	−4.60498	2.83855	0.980
	St. Louis R. (2001)	267	55	143	1.8	36.0	−4.71061	2.98915	0.981
	St. Louis R. (2004)	106	56	174	1.9	82.4	−4.88635	2.98915	0.981
	St. Louis R. (2006)	35	58	118	2.2	21.0	−5.43304	3.25396	0.969
	St. Louis R. (2007)	36	56	134	2.3	24.6	−4.64023	2.83090	0.958

[a] Total length was obtained from observed standard length.
[b] Total length was obtained from observed fork length.

TABLE A.2.—Country; specific location; sample size (n); minimum (min) and maximum (max) total length (TL); minimum and maximum weight (W); and estimated intercept ($\log_{10}[a]$), estimated slope (b), and R^2 for $\log_{10}$ transformed length–weight regressions from 50 ruffe data sets used to validate standard weight (W_S) equations. Locations shown without a year were pooled across several years (abbreviations in location names are as follows: K. = Kanaal, L. = Lake, R. = River, Res. = Reservoir, and W. = Water).

Country	Location (year)	n	TL Min	TL Max	W Min	W Max	Length–weight equation $\log_{10}(a)$	b	R^2
Austria	Wolfgangsee (2007)	39	56	183	1.4	71.0	−5.04980	3.07162	0.981
Belgium	K. Van Dessel (2003)	129	59	137	2.5	32.6	−4.88363	2.98792	0.945
	K. Van Roeselare (2004)	27	60	122	3.1	23.8	−4.66488	2.88851	0.979
Estonia	L. Peipsi (1998)	472	57	176[a]	2.3	66.9	−4.66943	2.84956	0.945
	L. Peipsi (2000)	257	55	126[a]	1.5	26.2	−4.89027	2.95962	0.968
	L. Peipsi (2003)	42	55	121[a]	1.8	18.2	−4.38830	2.68314	0.980
	L. Vortsjarv (1999)	238	55	114[a]	1.7	13.5	−4.77084	2.87314	0.967
	L. Vortsjarv (2000)	252	63	123[a]	2.7	14.8	−4.52564	2.74586	0.949
	L. Vortsjarv (2001)	298	55	121[a]	1.6	17.6	−4.51660	2.74096	0.902
	L. Vortsjarv (2003)	34	81	123[a]	5.7	15.0	−4.32023	2.63271	0.915
Finland	L. Äimäjärvi	49	60	120	2.0	16.0	−5.22778	3.11226	0.983
France	Cazaux (2005)	634	55	114	1.5	16.5	−4.61438	2.84737	0.971
	Richardménill (2006)	308	71	140	5.1	37.0	−4.58312	2.84312	0.909
Germany	Saidenbach Res. (2004)	270	55	151	1.7	36.7	−5.08665	3.06165	0.974
	Saidenbach Res. (2005)	151	55	143	1.7	29.5	−4.95846	2.99085	0.977
	Saidenbach Res. (2006)	50	57	116	2.0	21.2	−5.11416	3.07906	0.942
	Saidenbach Res. (2007)	59	55	141	1.4	37.3	−5.21442	3.12651	0.982

TABLE A.2.—Continued.

Country	Location (year)	n	TL Min	TL Max	W Min	W Max	Length–weight equation $\log_{10}(a)$	b	R^2
Hungary	L. Balaton (1999)	33	57	107[a]	1.5	15.8	−5.32163	3.19659	0.951
	L. Balaton (2002)	53	55	124[a]	1.6	20.6	−5.11512	3.09997	0.959
Italy	L. Piediluco (2001)	215	82	204	5.5	115.0	−5.43621	3.26253	0.975
Norway	L. Bjørkelangen (1982)	66	75	132	5.1	24.0	−4.40985	2.72627	0.958
Poland	Sulejow Res. (2003)	28	55	106	2.1	15.9	−5.20309	3.17198	0.986
Sweden	Älgsjön	39	76	177	4.9	56.0	−4.62402	2.83708	0.982
	Allgjuttern	85	60	151	2.2	33.0	−4.61714	2.80905	0.925
	Remmarsjön	73	86	170	6.0	47.0	−4.88692	2.90322	0.932
	Stensjön	88	75	145	4.0	31.0	−5.37162	3.17838	0.949
	Tärnan	59	56	138	1.9	33.0	−5.09696	3.07050	0.982
	Vättern	33	90	171	6.0	65.0	−5.45431	3.22154	0.915
UK	Bassenthwaite L. (2003)	92	74	129[b]	6.0	28.0	−4.76806	2.92242	0.931
	Bassenthwaite L. (2004)	87	79	132[b]	6.0	29.0	−4.99200	3.04163	0.931
	Bassenthwaite L. (2005)	105	82	143[b]	6.0	33.0	−4.99957	3.03086	0.948
	Llyn Tegid (1992)	32	78	140[b]	6.0	39.0	−4.83983	2.96990	0.949
USA	Amnicon R. (2004)	22	57	109	2.3	16.2	−5.13687	3.11331	0.944
	Flag R. (1995)	160	56	169	2.0	64.0	−5.06374	3.07582	0.988
	Flag R. (1996)	86	55	178	1.9	76.9	−4.98219	3.04466	0.987
	Flag R. (1997)	56	56	165	1.8	63.0	−4.97830	3.04478	0.981
	Flag R. (2002)	144	56	155	1.6	39.2	−5.00123	3.03278	0.978
	Flag R. (2005)	27	60	168	2.4	61.0	−5.07303	3.06869	0.994
	Iron R. (1995)	47	67	141	3.1	33.9	−4.69564	2.88603	0.953
	Iron R. (2002)	134	55	121	1.2	21.2	−5.15433	3.08890	0.900
	Iron R. (2004)	34	57	120	2.4	22.5	−4.82683	2.95485	0.976
	L. Huron (Thunder Bay; 1996)	30	72	142	4.2	35.6	−4.97624	3.03891	0.979
	L. Huron (Thunder Bay; 1998)	43	63	104	3.3	16.9	−4.58596	2.84075	0.933
	L. Huron (Thunder Bay; 1999)	112	82	152	7.3	43.1	−4.44818	2.77430	0.950
	St. Louis R. (1989)	1,411	55	176	1.7	80.8	−4.98605	3.05867	0.987
	St. Louis R. (1990)	457	55	207	2.1	125.9	−4.93698	3.03622	0.989
	St. Louis R. (1997)	299	55	163	1.6	48.3	−4.63004	2.85004	0.975
	St. Louis R. (1999)	266	55	170	1.9	63.9	−4.83335	2.95576	0.980
	St. Louis R. (2002)	160	55	141	1.7	35.3	−4.83789	2.95389	0.980
	St. Louis R. (2003)	94	55	156	1.5	54.2	−4.90613	3.00449	0.980

[a] Total length was obtained from observed standard length.
[b] Total length was obtained from observed fork length.