Ruffe Length-Weight Relationships with a Proposed Standard Weight Equation[1][2]

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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 (Ws) equations. The mean slope of the length-weight relationship from all populations and all but the 95th percentile were not different from three, suggesting that ruffe growth is generally isometric. The Ws equations developed using the regression line percentile (RLP), linear empirical-percentile (EmP), and Froese's methods exhibited length-related biases. The quadratic EmP Ws 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 Ws equation was $log_{10}(Ws_{75})$ = -2.5800 + 0.6210$*log_{10}(TL)$ + 0.6073$*(log_{10}(TL))^2$ and the 50th percentile Ws equation was $log_{10}(Ws_{50})$ = -3.3524 + 1.3969$*log_{10}(TL)$ + 0.4054$*(log_{10}(TL))^2$ when constrained to ruffe between 55 and 205 mm total length (TL). We propose that minimum TL for a five-cell length categorization system used to compute stock indices for ruffe be 55, 90, 120, 140, and 175 mm, respectively. These results provide a method for computing relative weight indices for typical (50th percentile) and above average (75th percentile) ruffe that 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 on 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 (Wr; Wege and Anderson 1978). Relative weight summaries 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, relative weight sum-

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maries 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 to standard weight Wege and Anderson (1978). Standard weight (Ws) equations are computed using the regression-line-percentile method (RLP; Murphy *et al.* 1990, 1991; Blackwell *et al.* 2000), the empirical percentile method (EmP; Gerow *et al.* 2005), or the method proposed by Froese (2006) (hereafter called the Froese method). Both the RLP and EmP methods attempt to construct a Ws 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 Ws equation from the Froese method is an attempt to represent the "mean weight derived from a mean length-weight relationship for the respective species" (Froese 2006). Until recently, the RLP method had been considered the "accepted method for Ws 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 Ws equations without a length-based bias (Richter 2007; Rennie and Verdon 2008).

The use of the 75th percentile as the "standard" for developing the standard weight equation has also come under some scrutiny (Froese (2006); Wayne Hubert, U.S. Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, Wyoming, 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 of larger than average body condition. In these instances, it may make more sense for the "standard" to be a mean or median rather than 75th percentile. Froese's 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 Ws equations for ruffe using the RLP, EmP, and Froese methods and to examine the characteristics of the developed Ws equations for computing relative weights 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 of 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 that the sample was collected, how the fish were measured for length (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, which 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 in 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 reduce year-to-year dependence. In addition, this choice will allow the standard weight 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 with the following sequential steps in order to implement quality control across the wide variety of collection methods.

1. All fish with an unknown capture data and those captured in April or May were excluded to reduce the possible effect of mature gonads on the length-weight relationship.
2. All fish that were measured imprecisely ($> \pm 1$ mm) were excluded.
3. 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).
4. Fish that were large outliers on the location-specific plot of $log_{10}(W)$ versus $log_{10}(TL)$ (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 (≤ 3) that were substantially shorter than the bulk of the individuals for the data set.
5. 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 $TL = 2.3710 + 1.1731SL$ ($MSE = 2.144$, $R^2 = 0.9877$) for Lake Peipsi and $TL = 1.5680 + 1.1904SL$ ($MSE = 1.397$, $R^2 = 0.9905$) for Lake Vortsjarv. The general conversion models used were $TL = 2.5706 + 1.1732SL$ ($MSE = 2.140$, $R^2 = 0.9915$) and $TL = 1.0858 + 1.0517FL$ ($MSE = 1.185$, $R^2 = 0.9985$). 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 a standard deviation equal to the square-root of the residual mean square error of the linear conversion model.
6. All remaining data sets with fewer than 20 individuals were excluded.
7. 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.
8. All remaining data sets with fewer than 20 individuals were excluded.
9. All remaining data sets with an R^2 value from the linear regression of $log_{10}(W)$ on $log_{10}(TL)$ less than 0.900 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 (Pope *et al.* 1995; Brown and Murphy 1996; Froese 2006) did not indicate any outlier data sets that should be further excluded from analysis (**Figure 1**). The 141 data sets that met all of these criteria were then randomly divided into two sets[3]. The development set of 91 data sets was used to develop the Ws equations and the validation set of 50 data sets was used to assess potential length bias in the Ws 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 Ws equations while allowing enough validation data sets to adequately assess the potential for length-related biases in the Ws equations.

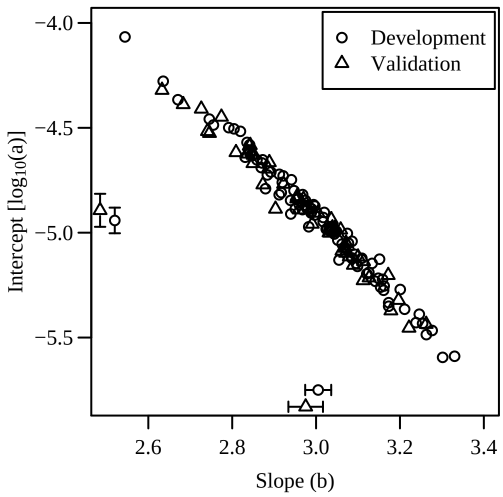

Figure 1. Estimated intercepts versus estimated slopes for the log_{10}-transformed length-weight regressions of ruffe from all data sets in both the development and validation sets. Confidence intervals (95%) are shown along each axis for each parameter from both the development and validation sets.

Length-Weight Regression Summaries

The estimated intercept and slope values from the length-weight regression for each individual cleaned

[3]Results of the length-weight regressions can be found in the appendices. Raw data can be obtained from the first author (DHO).

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 for the slope contained three 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 v2.7.1 statistical programming language (R Development Core Team 2008) and used a 0.05 level of significance. Quantile regressions were conducted with the quantreg v4.17 package (Koenker 2008) for R.

Developing Ws 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[4]. We used quantile Definition 8 from Hyndman and Fan (1996), because it is median unbiased regardless of the distribution of the data Hyndman and Fan (1996), rather than Definition 6 used by Murphy *et al.* (1990) and 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 standard weight equations developed with the RLP and EmP methods using the 75th and 50th percentiles were labeled as Ws_{75} or Ws_{50}, 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 standard weight equation developed from the Froese method is labeled as Ws_{mean}.

[4]All R functions are available from the first author (DHO).

Assessing Length-Related Bias

We assessed potential length bias in the derived Ws equations with two methods. First, we used the method of Willis *et al.* (1991) (hereafter called 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 Wr, calculated with the proposed Ws 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 Ws equations) or mean (for Froese Ws equation) mean weights standardized by the proposed Ws 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 from the Willis method and linear and quadratic coefficients from the EmpQ method that are equal to zero 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 relative weight for a data set should not be computed unless it can be shown that the mean relative weight 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 the Gabelhouse (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 non-game ruffe.

Results and Discussion

Data sets

For all 141 data sets the mean slope was 2.9944 (95% CI: 2.9698, 2.9698) and the mean intercept was -4.9245 (95% CI: -4.9724, -4.9724). The mean slope from all 141 data sets was not statistically different than three (t = -0.4473, df = 140, P = 0.6554). For all 141 data sets, 32 had a slope significantly less than three and 26 had a slope significantly greater than three. 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), that was not different from three suggests that ruffe growth is generally isometric (Ricker 1958). Furthermore, the mean slope appeared to differ from three 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.

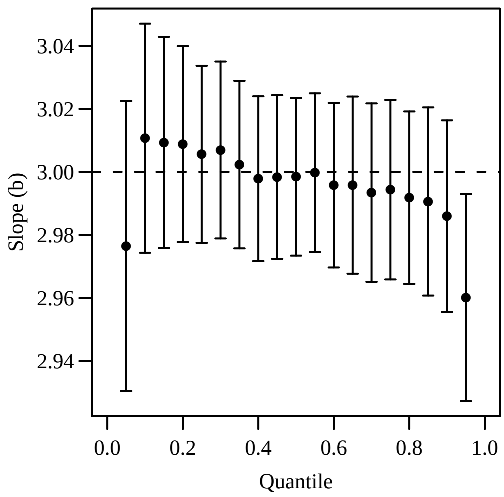

Figure 2. Mean slopes with 95% confidence intervals for the length-weight regressions of ruffe for quantiles between 0.05 and 0.95 in steps of 0.05 from all data sets in both the development and validation sets. The horizontal line at a slope of three is shown for reference.

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 (χ^2 = 0.6328, df = 2, P = 0.7288) between the development and validation sets.

Development of the RLP Ws equation was restricted to fish less than 215 mm, a value 1 mm smaller than the largest observed TL in all data sets. Development of the EmP Ws 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 individual ruffe per 10-mm length category (e.g., 60 = 55.0-64.9 mm). Length categories marked with an asterisk were not used in the development of the EmP Ws equations.

TL mid-point	Data sets	Individuals
60	63	1317
70	69	1564
80	84	2111
90	88	2326
100	84	2041
110	84	1605
120	77	1367
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

Ws equations

The RLP Ws_{75} equation (**Table 2**) had residuals (**Figure 4**A) that exhibited a clear non-linearity 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 Ws (**Figure 4**B); thus, the RLP Ws_{75} equation tended to underpredict the Ws for relatively long fish.

The EmP Ws_{75} equation (**Table 2**) had residuals (**Figure 4**A) that exhibited no obvious pattern,

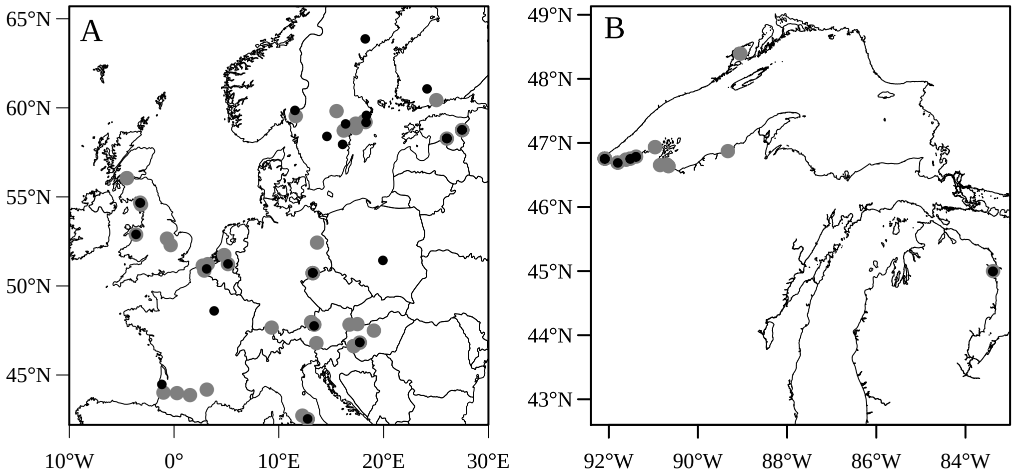

Figure 3. Geographic distribution of European (A) and Great Lakes (B) data sets used to develop (gray) and validate (black) the Ws equations for ruffe. Some plotted points represent multiple data sets (i.e., same locations, different years).

Table 2. Parameter estimates ($log_{10}(a)$ = intercept, b_{linear} = linear coefficient, $b_{quadratic}$ = quadratic coefficient), results of the Willis length-bias detection test (neg = number of data sets with significantly negative slope; pos = number of data sets with significantly positive slopes), and p-values for the significance of the linear and quadratic terms in the EmpQ length-bias detection test for each ruffe Ws equation.

	Parameters[a]			Willis			EmpQ	
Equation	$log_{10}(a)$	b_{linear}	$b_{quadratic}$	neg	pos	P	P_{linear}	$p_{quadratic}$
RLP Ws_{75}	-4.9588	3.0286	–	15	5	0.0414	0.3620	0.0034
EmP Ws_{75}	-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 Ws_{50}	-4.9573	3.0154	–	14	5	0.0636	0.2272	0.0750
EmP Ws_{50}	-3.3524	1.3969	0.4054	12	8	0.5034	0.4838	0.9368
EmP Ws_{50}	-4.9818	3.0259	–	14	5	0.0636	0.3844	0.0685
Froese Ws_{mean}	0.0000	3.0050	–	13	6	0.1671	0.4151	0.0011

[a] All P < 0.0005 with the exception of b_{linear} for EmP Ws_{75} ($P = 0.1140$).

though 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 4**B). An EmP Ws_{75} equation developed without the quadratic term exhibited a significant length-related bias **(Table 2)**. Thus, the quadratic term in the EmP method appeared warranted.

The RLP Ws_{50} equation **(Table 2)** had residuals (**Figure 5**A) that exhibited non-linearity and a large residual was present for the smallest length class. A slight but non-significant 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 Ws with the RLP Ws_{50} equation (**Figure 5**B).

The EmP Ws_{50} equation **(Table 2)** had residuals (**Figure 5**A) that exhibited no obvious pattern. A length-related bias was not detected with either the Willis or EmpQ methods (**Table 2**; **Figure 5**B). The EmP Ws_{50} equation developed without the quadratic term exhibited a slight but non-significant length-related bias according to both the Willis and EmpQ methods **(Table 2)**.

The Froese Ws_{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 Ws_{mean} equation tended to underpredict Ws for relatively long fish (**Figure 6**).

Murphy *et al.* (1991) noted that an adequate Ws 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 Ws equation. The Ws equations presented here were derived

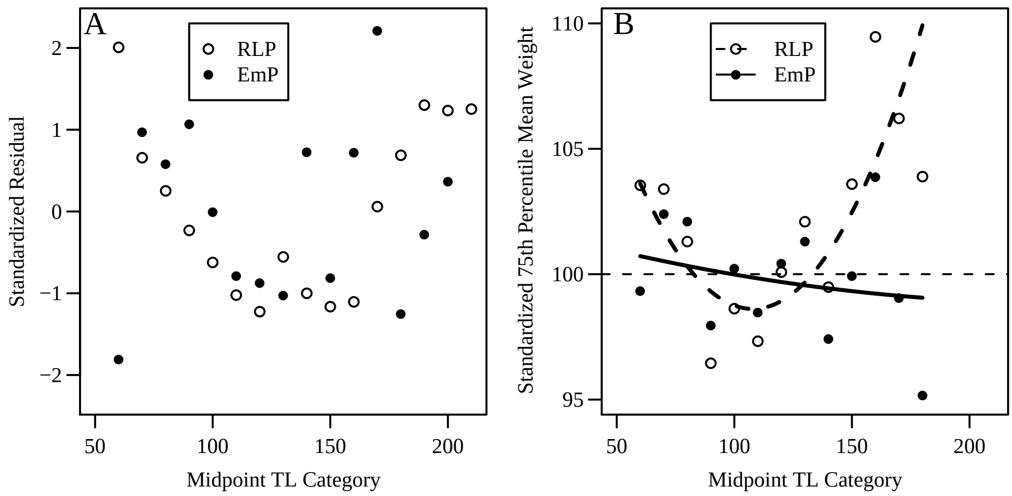

Figure 4. Residual plot from the model fits (A) and standardized 75th percentile mean weights versus total length category midpoints with weighted quadratic regression fits (B) for the RLP and EmP Ws_{75} methods for ruffe. The horizontal line at 100 is shown for reference.

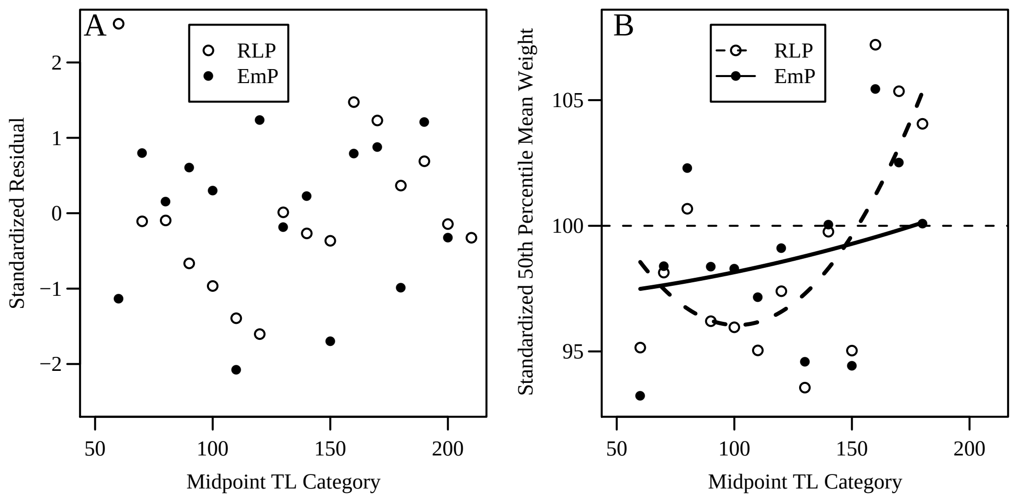

Figure 5. Residual plot from the model fits (A) and standardized 75th percentile mean weights versus total length category midpoints with weighted quadratic regression fits (B) for the RLP and EmP Ws_{50} methods for ruffe. The horizontal line at 100 is shown for reference.

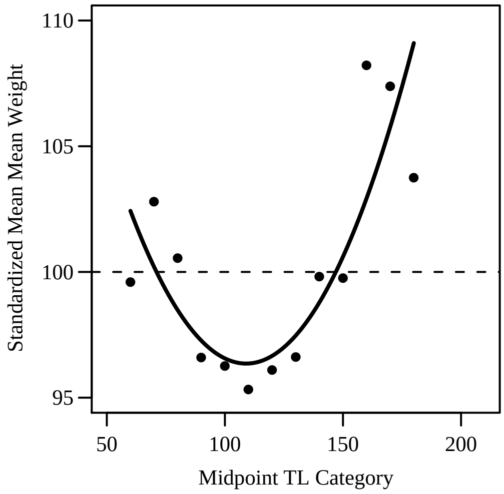

Figure 6. Standardized mean of mean weights versus total length category midpoints with the weighted quadratic fit for the Froese method for ruffe.

from 91 data sets, exceeding the minimum of 50 data sets suggested by Brown and Murphy (1996) and the results of Gerow *et al.* (2005). In addition, the data sets used to develop the Ws 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 Wr values computed from a Ws equation should be globally independent of fish length. In other words, Wr 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 Ws equations here, the two quadratic EmP Ws equations best met this criterion. Therefore, we suggest that only the quadratic EmP Ws equations should be used to derive Wr 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" TL for ruffe of 220 mm we propose that the minimum TL for "small" ruffe should be 55 mm (42.5% of 22,812 fish observed), "medium" ruffe should be 90 mm (38.1%), "large" ruffe should be 120 mm (11.9%), "very large" ruffe should be 140 mm (6.8%), and "extremely large" ruffe should be 175 mm (0.7%).

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 Ws equations in Blackwell *et al.* 2000) for the purpose of setting and assessing management goals. Recently, Ws equations have been developed for several non-game fishes (Bister *et al.* 2000; Didenko *et al.* 2004; Richter 2007) so that Wr 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 Ws equation for ruffe falls in this latter category. Use of our proposed EmP-derived Ws 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 dynamics, such as the densities of prey, competitors, or predators, on ruffe body condition.

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Table 3. Country; specific location; sample size (n); minimum and maximum total length (TL); minimum and maximum weight (W); and estimated intercept (log10(a)), estimated slope (b), and R^2 for log_{10}-transformed length-weight regressions for 91 ruffe data sets used to develop the Ws equations. Locations shown without a year were pooled across several years. Abbreviations in the location names: K. = Kanaal, L. = Lake, R. = River, Res. = Reservoir, and W. = Water.

Country	Location (Year)	n	min TL	max TL	min W	max W	log10(a)	b	R^2
Austria	Mattsee (2006)	282	55	160	1.9	51.0	-4.98270	3.02415	0.990
Austria	Millstatter See (2007)	124	55	215	2.0	106.7	-4.84594	2.97449	0.992
Austria	Mondsee (2004)	38	90	185	7.0	88.0	-5.42884	3.23821	0.981
Austria	Mondsee (2006)	49	70	189	3.7	87.0	-5.12067	3.08453	0.983
Austria	Neusiedler See (2006)	125	55	119	1.9	20.0	-5.07473	3.06950	0.994
Austria	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
Belgium	K. Van Dessel (1999)	34	60	117	2.6	22.4	-4.86622	2.99387	0.943
Belgium	K. Van Ieper (2002)	147	57	134	2.1	34.1	-4.90320	3.01958	0.956
Belgium	Nieuwpoort (2007)	96	62	132	3.2	29.2	-5.23175	3.14119	0.921
Canada	L. Superior (Thunder Bay) (2003)	515	73	212	6.0	125.9	-5.14632	3.13365	0.986
Canada	L. Superior (Thunder Bay) (2006)	29	80	174	5.9	71.2	-5.38871	3.24607	0.979
Estonia	L. Peipsi (1996)	64	57	131	2.2	21.4	-4.45834	2.74536	0.971
Estonia	L. Peipsi (1997)	59	59	125	2.1	23.0	-5.13035	3.05463	0.935
Estonia	L. Peipsi (1999)	400	63	157	2.5	44.0	-4.88615	2.95047	0.910
Estonia	L. Peipsi (2001)	170	64	131	2.6	22.9	-4.27776	2.63550	0.940
Estonia	L. Peipsi (2002)	68	58	118	2.2	14.6	-4.36597	2.67063	0.979
Estonia	L. Vortsjarv (2002)	101	59	104	2.1	12.3	-4.81922	2.91203	0.988
Finland	L. Tuusulanjarvi	38	82	184	6.0	73.0	-5.33363	3.17309	0.989
France	Albaredes (2005)	152	55	121	1.9	21.7	-4.87001	2.97616	0.969
France	Lacroux (2005)	201	55	133	2.1	32.0	-4.56951	2.83529	0.945
France	Rivieres-sur-tarn (2005)	86	58	123	2.5	26.0	-4.51678	2.81953	0.982
France	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
Germany	L. Mueggelsee (1998)	189	61	110	2.6	15.1	-4.68950	2.86920	0.958
Germany	Saidenbach Res. (1999)	32	55	125	1.8	22.2	-5.25967	3.15395	0.986
Germany	Saidenbach Res. (2000)	53	55	125	1.5	24.3	-5.14601	3.09569	0.983
Germany	Saidenbach Res. (2001)	28	55	123	1.8	25.0	-5.12102	3.08653	0.975
Germany	Saidenbach Res. (2002)	30	55	136	1.8	30.5	-5.25417	3.16234	0.983
Germany	Saidenbach Res. (2003)	88	56	122	2.0	24.8	-5.18931	3.12577	0.976
Hungary	Danube R. (Budapest) (1993)	50	75	161	5.3	61.0	-5.27084	3.20066	0.977
Hungary	Danube R. (Szigetkoz) (1993)	37	69	143	4.2	40.1	-4.97112	3.03468	0.980
Hungary	L. Balaton (2001)	60	56	113	1.9	19.5	-4.99272	3.04832	0.958
Hungary	L. Balaton (2006)	97	55	125	1.6	23.2	-5.05412	3.06208	0.917
Hungary	L. Major (2005)	64	82	140	7.9	41.8	-4.74744	2.94113	0.914
Hungary	L. Major (2006)	58	67	138	3.2	25.9	-4.98823	3.03216	0.958
Hungary	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
Italy	L. Piediluco (2002)	43	115	196	17.0	110.0	-5.58912	3.33028	0.961
Italy	L. Piediluco (2004)	382	80	208	6.0	110.0	-5.19615	3.12095	0.923
Italy	L. Piediluco (2005)	100	122	203	22.0	100.0	-5.10303	3.09197	0.951
Netherlands	De Gijster (2002)	40	64	145	3.0	38.3	-5.21708	3.14826	0.989
Netherlands	Honderd en Dertig (2002)	35	57	160	1.6	50.8	-5.36501	3.21103	0.991
Norway	L. Rodenessjoen (1982)	82	75	165	5.5	40.0	-4.06648	2.54431	0.961
Scotland	Loch Lomond (2004)	36	77	134	6.0	31.0	-5.03572	3.05184	0.901
Scotland	Loch Lomond (2007)	160	76	164	6.0	59.0	-5.12193	3.10906	0.953
Sweden	Arsjon	51	57	168	1.8	56.2	-4.80898	2.91698	0.981
Sweden	Bjorken (2001)	72	56	135	1.9	24.0	-4.97188	2.98253	0.980
Sweden	Flaten	24	87	127	6.0	25.0	-5.48598	3.26289	0.911
Sweden	Lien	94	60	131	2.1	19.0	-4.91083	2.93970	0.946
Sweden	Skargolen (2003)	27	59	122	2.3	20.3	-5.16067	3.09865	0.975
Sweden	Stora Envattern	31	59	131	2.4	22.0	-4.84600	2.93925	0.970
UK	Bassenthwaite L. (2006)	76	74	141	6.0	27.0	-4.49913	2.79174	0.937
UK	Derwent W. (2006)	45	79	128	6.0	26.0	-5.46620	3.27673	0.909
UK	Grafham W. (1996)	335	77	175	6.0	70.0	-5.00635	3.04353	0.952
UK	Rutland W. (1996)	63	71	192	6.0	113.0	-5.12628	3.15131	0.957
USA	Amnicon R. (1995)	441	55	168	1.6	58.1	-4.98040	3.02688	0.967
USA	Amnicon R. (1996)	104	56	148	2.1	54.1	-4.81835	2.96791	0.984
USA	Amnicon R. (1997)	117	55	105	1.9	13.8	-4.63340	2.84721	0.973
USA	Amnicon R. (2002)	32	55	142	1.5	33.6	-5.35072	3.17307	0.958
USA	Amnicon R. (2006)	22	61	124	2.3	21.2	-4.79019	2.87939	0.971
USA	Bad R. (1997)	95	55	174	1.6	70.2	-5.04108	3.08570	0.992
USA	Bad R. (2001)	26	56	160	1.7	53.4	-5.07302	3.07020	0.990
USA	Brule R. (1995)	175	57	111	2.2	15.1	-4.72447	2.88385	0.942
USA	Brule R. (1996)	46	56	120	2.4	23.5	-4.66750	2.87124	0.974
USA	Brule R. (1997)	42	58	107	2.9	13.9	-4.65250	2.87267	0.957
USA	Flag R. (2004)	36	55	130	2.3	25.8	-4.89855	2.98958	0.986
USA	Iron R. (1996)	106	55	150	1.8	40.3	-5.04983	3.07705	0.975
USA	Iron R. (1997)	78	55	149	1.7	38.9	-4.91599	2.99657	0.978
USA	Iron R. (2005)	29	77	144	5.4	37.3	-4.88997	2.96752	0.944
USA	Kakagon R. (1997)	20	56	110	2.2	17.1	-4.58117	2.84154	0.986
USA	Kakagon R. (1998)	62	85	137	7.8	35.7	-4.98343	3.03236	0.914
USA	L. Huron (Thunder Bay) (1997)	46	59	99	2.6	11.9	-4.72154	2.91233	0.957
USA	L. Superior (Chequam. Bay) (1998)	73	55	137	1.8	32.5	-4.90600	2.98804	0.939
USA	Ontonagon R. (2002)	25	55	165	2.2	51.2	-4.87533	2.97546	0.989
USA	Sand R. (1995)	46	60	105	2.6	11.8	-4.48644	2.75512	0.917

USA	Sand R. (1996)	24	55	122	1.6	23.8	-5.22233	3.15861	0.985
USA	St. Louis R. (1988)	2273	69	175	5.0	85.0	-5.00334	3.07453	0.978
USA	St. Louis R. (1992)	485	55	192	1.9	93.1	-4.72900	2.92147	0.984
USA	St. Louis R. (1993)	1591	55	182	1.8	68.8	-4.76026	2.91946	0.985
USA	St. Louis R. (1994)	1332	55	176	1.7	55.0	-4.83416	2.95776	0.987
USA	St. Louis R. (1995)	301	55	162	1.8	55.0	-4.62039	2.84202	0.982
USA	St. Louis R. (1996)	328	55	154	2.0	47.6	-4.65257	2.85903	0.985
USA	St. Louis R. (1998)	81	57	141	2.3	35.0	-4.88354	2.97801	0.981
USA	St. Louis R. (2000)	429	55	147	1.8	38.7	-4.60498	2.83855	0.980
USA	St. Louis R. (2001)	267	55	143	1.8	36.0	-4.71060	2.89217	0.979
USA	St. Louis R. (2004)	106	56	174	1.9	82.4	-4.88635	2.98915	0.981
USA	St. Louis R. (2006)	35	58	118	2.2	21.0	-5.43304	3.25396	0.969
USA	St. Louis R. (2007)	36	56	134	2.3	24.6	-4.64023	2.83090	0.958
Wales	Llyn Tegid (1991)	104	81	159	6.0	43.0	-5.27450	3.16102	0.958
Wales	Llyn Tegid (2003)	21	84	172	6.0	53.0	-5.59442	3.30173	0.959

Table 5. Country; specific location; sample size (n); minimum and maximum total length (TL); minimum and maximum weight (W); and estimated intercept (log10(a)), estimated slope (b), and R^2 for log_{10}-transformed length-weight regressions for 50 ruffe data sets used to validate the Ws equations. Locations shown without a year were pooled across several years. Abbreviations in the location names: K. = Kanaal, L. = Lake, R. = River, Res. = Reservoir, and W. = Water.

Country	Location (Year)	n	min TL	max TL	min W	max W	log10(a)	b	R^2
Austria	Wolfgang See (2007)	39	55	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
Belgium	K. Van Roeselare (2004)	27	60	122	3.1	23.8	-4.66488	2.88851	0.979
Estonia	L. Peipsi (1998)	472	57	176	2.3	66.9	-4.66943	2.84956	0.945
Estonia	L. Peipsi (2000)	257	55	126	1.5	26.2	-4.89027	2.95962	0.968
Estonia	L. Peipsi (2003)	42	55	121	1.8	18.2	-4.38830	2.68314	0.980
Estonia	L. Vortsjarv (1999)	238	55	114	1.7	13.4	-4.77084	2.87314	0.967
Estonia	L. Vortsjarv (2000)	252	63	123	2.7	14.8	-4.52564	2.74586	0.949
Estonia	L. Vortsjarv (2001)	298	55	121	1.6	17.6	-4.51660	2.74096	0.902
Estonia	L. Vortsjarv (2003)	34	81	123	5.7	15.0	-4.32023	2.63271	0.915
Finland	L. Aimajarvi	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
France	Richardmenil (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
Germany	Saidenbach Res. (2005)	151	55	143	1.7	29.5	-4.95846	2.99085	0.977
Germany	Saidenbach Res. (2006)	50	57	116	2.0	21.2	-5.11416	3.07906	0.942
Germany	Saidenbach Res. (2007)	59	55	141	1.4	37.3	-5.21442	3.12651	0.982
Hungary	L. Balaton (1999)	33	57	107	1.5	15.8	-5.32163	3.19659	0.951
Hungary	L. Balaton (2002)	53	55	124	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. Bjorkelangen (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	Algsjon	39	76	177	4.9	56.0	-4.62402	2.83708	0.982
Sweden	Allgjuttern	85	60	151	2.2	33.0	-4.61714	2.80905	0.925
Sweden	Remmarsjon	73	86	170	6.0	47.0	-4.88692	2.90322	0.932
Sweden	Stensjon	88	75	145	4.0	31.0	-5.37162	3.17838	0.949
Sweden	Tarnan	59	56	138	1.9	33.0	-5.09696	3.07050	0.982
Sweden	Vattern	33	90	171	6.0	65.0	-5.45431	3.22154	0.915
UK	Bassenthwaite L. (2003)	92	74	129	6.0	28.0	-4.76806	2.92242	0.931
UK	Bassenthwaite L. (2004)	87	79	132	6.0	29.0	-4.99200	3.04163	0.931
UK	Bassenthwaite L. (2005)	105	82	143	6.0	33.0	-4.99957	3.03086	0.948
USA	Amnicon R. (2004)	22	57	109	2.3	16.2	-5.13687	3.11331	0.944
USA	Flag R. (1995)	160	56	169	2.0	64.0	-5.06374	3.07582	0.988
USA	Flag R. (1996)	86	55	178	1.9	76.9	-4.98219	3.04466	0.987
USA	Flag R. (1997)	56	56	165	1.8	63.0	-4.97830	3.04478	0.981
USA	Flag R. (2002)	144	56	155	1.6	39.2	-5.00123	3.03278	0.978
USA	Flag R. (2005)	27	60	168	2.4	61.0	-5.07303	3.06869	0.994
USA	Iron R. (1995)	47	67	141	3.1	33.9	-4.69564	2.88603	0.953
USA	Iron R. (2002)	134	55	121	1.2	21.2	-5.15433	3.08890	0.900
USA	Iron R. (2004)	34	57	120	2.4	22.5	-4.82683	2.95485	0.976
USA	L. Huron (Thunder Bay) (1996)	30	72	142	4.2	35.6	-4.97624	3.03891	0.979
USA	L. Huron (Thunder Bay) (1998)	43	63	104	3.3	16.9	-4.58596	2.84075	0.933
USA	L. Huron (Thunder Bay) (1999)	112	82	152	7.3	43.1	-4.44818	2.77430	0.950
USA	St. Louis R. (1989)	1411	55	176	1.7	80.8	-4.98605	3.05867	0.987
USA	St. Louis R. (1990)	457	55	207	2.1	125.9	-4.93698	3.03622	0.989
USA	St. Louis R. (1997)	299	55	163	1.6	48.3	-4.63004	2.85004	0.975
USA	St. Louis R. (1999)	266	55	170	1.9	63.9	-4.83335	2.95576	0.980
USA	St. Louis R. (2002)	160	55	141	1.7	35.3	-4.83789	2.95389	0.980
USA	St. Louis R. (2003)	94	55	156	1.5	54.2	-4.90613	3.00449	0.980
Wales	Llyn Tegid (1992)	32	78	140	6.0	39.0	-4.83983	2.96990	0.949