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Proposed standard weight (W_s) equation for European perch (*Perca fluviatilis* Linnaeus, 1758)

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Summary

Relative weight (W_r) is an important and commonly used condition index that provides a measure of the well-being of a fish population by comparing the actual weight of a specimen with the ideal weight of a specimen of the same species and of the same length in good physiological condition, i.e. the standard weight (W_s). Two methods of calculating the standard weight are proposed in the literature: the RLP method and the EmP method. The aim of this study was to develop a standard weight equation for European perch by means of both methods, using length–weight data from 64 913 fish from 18 countries (across Europe and Oceania). The resulting equations were: $\log_{10}(W_s) = -3.1483 + 1.2663 \log_{10}(\mathrm{TL}) + 0.4291 [\log_{10}(\mathrm{TL})]^2$ for the EmP method and $\log_{10}(W_s) = -5.3493 + 3.2152 \log_{10}(\mathrm{TL})$ for the RLP method. The applicable length-range of the two W_s equations was restricted to 80–460 mm. A further research aim was to compare the performances of RLP and EmP. The resulting quadratic EmP W_s equation did not exhibit length-related biases, which suggests that it can be used to compute relative weight for European perch.

Introduction

Condition indexes are used for comparing the condition, fatness, or well-being of fish, on the assumption that heavier fish of a given length are in better condition (Froese, 2006). Because these indexes are not invasive (being based on length and weight measurements) they have become important tools for fisheries managers (Anderson and Neumann, 1996; Blackwell et al., 2000) and have been used in fisheries research since the beginning of the 20th century (Froese, 2006). Relative weight (W_r) (Wege and Anderson, 1978) is an important condition index calculated by the equation: $W_r = 100 (W / W_s)$, (W = weight of specimen in grams, W_s = standard weight). Standard weight is determined on the basis of the regression: $\log_{10} W_s = a + b \log_{10}\mathrm{TL}$.

Different techniques have been used to model the relationship between W_s and length in order to establish a simple expression of standard weight (Blackwell et al., 2000). Murphy et al. (1990) introduced the Regression Line-Percentile (RLP) method of computing W_s equations. However, Gerow et al. (2004) found length-related biases in W_s equations developed by the RLP method for several species, which prompted the development of a new method, the Empirical Percentile (EmP) method, based on quartiles of measured mean weights of fish (not weights estimated from regression models) in a given length-class among sampled fish populations.

However, standard weight-length relationships have been defined for only a few species in Europe. With regard to the genus *Perca*, the only standard weight equation proposed in the literature was developed in the United States for yellow perch (*Perca flavescens*) in accordance with the RLP method (Willis et al., 1991).

The European perch (*Perca fluviatilis*) is the most common and widely distributed member of the perch family, and is important both commercially and for sport fishing; widespread throughout Europe and Asia and, in addition to its native distribution, it has been successfully introduced in other parts of the world, mainly South Africa, Australia and New Zealand (Thorpe, 1977).

The aim of this research was to calculate a standard weight equation for European perch (*Perca fluviatilis*) and to compare the performance of the two methods (RLP and EmP).

Materials and methods

Dataset selection

The total dataset was obtained by combining length and weight data provided by researchers throughout the geographical range of the European perch. (Appendix 1; available at https://bio.unipg.it/download/Wr_perch/Appendix1.pdf). All data provided included details of the date when the sample was collected (month, year), length measurement type (standard, fork or total length), and accuracy of measurements.

In order to increase uniformity across the variety of collection methods, all datasets were also cleaned through sequential steps. First, fish that were large outliers on the total regression between TL and W were excluded, as they were probably measured incorrectly; then, lengths measured only in terms of standard or fork length were converted to total length (Ogle and Winfield, 2009). Because of the lack of enough data from each country in which at least two types of measurements were present, a general linear conversion model, developed by using all fish from the datasets in which at least two types of length measurement were recorded, was applied for each type of length.

The general conversion models were:

$$\mathrm{SL} = -0.4465 + 0.8894\,\mathrm{TL}\ (R^2 = 0.995)$$

and

$$\mathrm{FL} = -0.5587 + 0.9755\,\mathrm{TL}\ (R^2 = 0.997)$$

The next step was to divide the entire dataset into single populations. To this end, data derived from separate locations on large waterways were considered to refer to separate populations; data collected in different years from the same location were also regarded as referring to separate populations, with the exception of locations with very small numbers of fish.

Data were further validated by plotting the $\log_{10}$TL–$\log_{10}W$ relationship for each population separately, so that individual outliers could be identified. Then, from the linear regression of $\log_{10}$TL–$\log_{10}W$, every population for which R^2-value proved <0.90 or the value of the slope *b* fell outside the range of 2.5–3.5 was excluded (Froese, 2006). Subsequently, all slopes (*b*) were plotted as a function of intercepts (*a*) (Pope et al., 1995) to identify and remove population outliers caused by insufficient sample size, narrow length-range or misidentified length measurements other than TL (Froese, 2006).

Determination of the applicable total length-range for the W_s equation

To develop a W_s equation, an applicable length-range of the resultant W_s equation has to be determined on the basis of the structure of the dataset (Gerow et al., 2005). A minimum total length for use in the computation is necessary because the weight values of small fish are highly variable, presumably because the precision of their measurements tends to be low (Anderson and Neumann, 1996) or because body shape changes between the juvenile and adult stages (Willis et al., 1991). The minimum TL for W_s equations was determined by plotting the ratio between the variance and the mean of $\log_{10}W$ for 10-mm length intervals (Willis et al., 1991); the inflection point in this relationship was designated as the minimum length for the equation; this was the length value at which fish were included in the analysis.

Moreover, the EmP method also requires the determination of a maximum total length, identified as the length-class for which at least three fish populations were represented (Gerow et al., 2005). This is because there is the smallest sample size that allows estimation of a quartile. However, in order to allow comparison between the RLP and EmP methods, in this study the same applicable length-range was used to determine both the RLP and EmP W_s equations.

Development of the W_s equation

To develop the standard weight equation, reference was made to the procedures used by Murphy et al. (1991) for the RLP method and Gerow et al. (2005) for the EmP method. The main difference between the two methods is that EmP uses the third quartiles of measured mean weights, while RLP uses estimated weights; a further difference is that EmP uses a quadratic regression weighted on the number of populations, while RLP uses a linear regression. The equations thus obtained were used to calculate the relative weight of each specimen from each population. Relative weight (W_r) was determined from the equation: $W_r = 100\ (W/W_s)$ where W is the weight of an individual in grams and W_s is the standard weight predicted by the W_s equations (Wege and Anderson, 1978).

Comparison between the performance of RLP and EmP methods

Once W_r for each specimen had been calculated, the validity of the RLP and EmP methods was analyzed. Specifically: on the basis of the individual W_r values calculated with both methods the TL–W_r linear regressions were determined and the covariance analysis was applied to compare the two regressions; the mean $W_{r\text{-EmP}}$ and $W_{r\text{-RLP}}$ values were analyzed and they were compared by ANOVA; the resulting mean $W_{r\text{-EmP}}$ and $W_{r\text{-RLP}}$ values of each population were tested by evaluating how many populations had values within the target range of 95–105, which, according to Anderson (1980), indicates fish that are in good condition; the differences between the values of W_r yielded by the two methods, expressed as a percentage of the weight obtained on the basis of the TL-W regression of the total sample $[(W_{s\text{-EmP}} - W_{s\text{-RLP}})/W\ 100]$ were analyzed and the trend in these values as a function of TL was constructed.

Influence of fish length

Subsequent elaborations were aimed at testing the potential length bias in the W_s equations derived by means of the two methods. In particular three different methods were used: the Willis method (Willis et al., 1991), in which a chi-square test was applied in order to determine if, from the regression of W_r (calculated with the proposed W_s equation) against TL for each fish for each of 150 randomly selected populations (18 516 specimens), the proportions of significant positive and negative slopes were equal and whether there was a significant deviation from a 50 : 50 ratio (Willis et al., 1991); the EmPQ method (Gerow et al., 2004), as modified by Ogle and Winfield (2009) using the FSA package of R software, to determine whether the quadratic regression of the 3rd quartile of the mean weights standardized by W_s (calculated with the proposed W_s equations for both RLP and EmP methods) against the 10-mm TL interval classes had a slope of zero (Ogle and Winfield, 2009); the residuals analysis to see whether the distribution of residuals of the W_s equation exhibited evident patterns.

Results

The dataset consisted of 64 913 specimens from 762 populations distributed geographically throughout the range of perch in Europe and Oceania (Table 1). The mean total length was 148.468 mm (minimum six and maximum 500) and the mean weight was 68.265 g (minimum 0.002 and maximum 2563) (Table 2). The resulting total length–weight equation based on the total dataset was:

Table 1
Total data set with number of specimens per country

Country	*N*
Australia	353
Austria	11 226
Belgium	1395
Bulgaria	55
Czech Republic	3353
Denmark	86
England	5706
Finland	7724
France	7994
Germany	9055
Hungary	172
Italy	3623
Netherlands	11 888
New Zealand	157
Norway	78
Russia	103
Sweden	1790
Turkey	155
Total	64 913

Table 2
Descriptive statistics of the sample

	N	Mean	Min	Max	SD
TL (mm)	64 913	148.468	6.000	500.000	66.183
W (g)	64 913	68.265	0.002	2563.000	119.574

$$log_{10}(W) = -5.162 + 3.101\, log_{10}\,(\mathrm{TL})\ (R^2 = 0.985).$$

On the basis of R^2 and b-values of the linear regression of $\log_{10}$TL–$\log_{10}W$, 71 populations with $R^2 < 0.90$ or b-value outside the range of 2.5–3.5 were excluded (Appendix 1). The equation yielded by plotting the estimated slopes (b) as a function of all estimated intercepts [$\log_{10}$ (a)] was:

$$b = 0.785 - 0.4507\, log_{10}(a)\ (R^2 = 0.986)$$

As no populations were identified as outliers, no datasets were excluded from the subsequent analyses. Minimum total length was 80 mm (Fig. 1) and maximum total length at which at least three populations of fish were present was 460 mm. Accordingly, all specimens smaller than 80 mm and larger than 460 mm were removed from the dataset. In accordance with the procedures of the two methods, the corresponding W_s equations (Fig. 2) are:

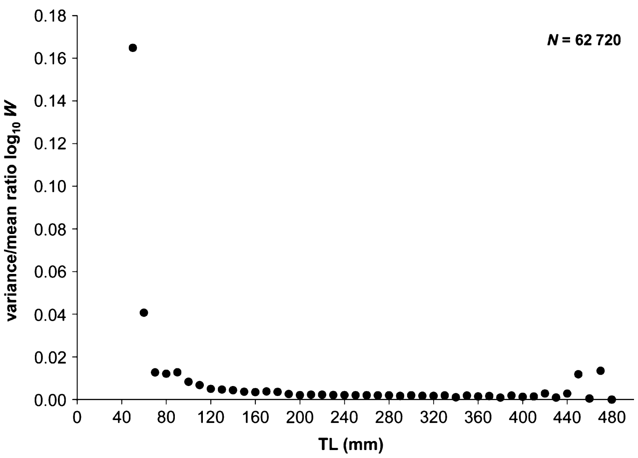

Fig. 1. Variance ⁄ mean ration for $\log_{10}W$ by 10 mm length-group

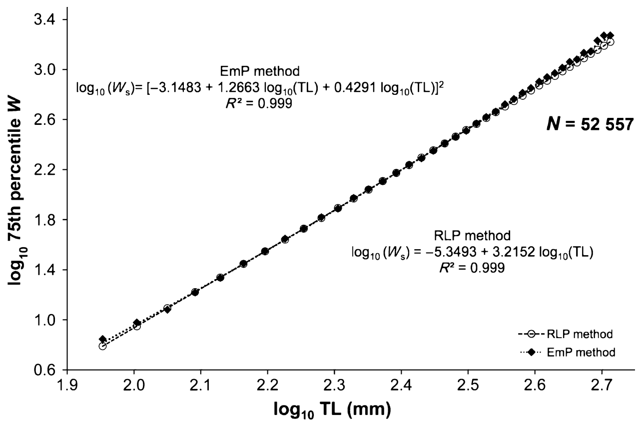

Fig. 2. EmP and RLP standard weight (W_s) equations

$$log_{10}(W_s) = -3.1483 + 1.2663\, log_{10}(\mathrm{TL}) + 0.4291\, [log_{10}(\mathrm{TL})]^2\ (R^2 = 0.999)\ (\mathrm{EmP\ method});$$

$$log_{10}(W_s) = -5.3493 + 3.2152\, log_{10}(\mathrm{TL})\ (R^2 = 0.999)\ (\mathrm{RLP\ method}).$$

Comparison between the performance of RLP and EmP methods

The TL–W_r equations for both methods were:

$$W_r = 93.352 - 0.034\,\mathrm{TL}\ (R^2 = 0.015; r = -0.123, \mathrm{P}<0.001)\ (\mathrm{RLP\ method});$$

$$W_r = 88.531 - 0.006\,\mathrm{TL}\ (R^2 = 0.001; r = -0.024, \mathrm{P}<0.001)\ (\mathrm{EmP\ method})$$

In both regressions, a statistically highly significant inverse correlation between length and W_r is present but, in the case of the EmP method, the slope of the line was less marked ($b = -0.006$). On ANCOVA, the differences between the two regressions were statistically highly significant ($F = 10.761$; $\mathrm{P} = 0.001$; mean covariate: TL = 161.810 mm). Separating the population on the basis of their mean W_r value, the population number inside the three values ranges ($W_r < 95$, $95 < W_r < 105$, $W_r > 105$) is different for the two methods (Table 3); moreover only a minority (about 25%) had values within a range of 95–105 which, according to Anderson (1980), indicates fish that are in good condition (Fig. 3).

On the whole sample, the mean values of $W_{r\text{-RLP}}$ and $W_{r\text{-RLP}}$ were very similar (Table 4). However, on t-test analyses, the differences between these values proved to be significant ($t = 3.229$, $\mathrm{P} = 0.001$). The differences between the standard weights calculated by both methods were more marked for fish of small sizes, for which the value of $W_{s\text{-EmP}}$ exceeded that of $W_{s\text{-RLP}}$ (Fig. 4); these differences canceled each other for the length-class of about 130 mm and, while in the intermediate size-classes the relationship was inverted ($W_{s\text{-RLP}} > W_{s\text{-EmP}}$), with a percentage difference of about 3% between the two methods. For fish larger than 280 mm it changed again ($W_{s\text{-EmP}} > W_{s\text{-RLP}}$), with a percentage difference of about 10% (Fig. 4).

Influence of fish length

On applying the Willis method when using the EmP method, 70 of the 150 TL–W_r relationships displayed slope values significantly different from zero ($\mathrm{P} < 0.05$). The number of

Table 3
Number of populations divided by W_r value yielded by both RLP and EmP methods

	EmP	RLP
$W_r < 95$	421	416
$95 < W_r < 105$	187	183
$W_r > 105$	78	89

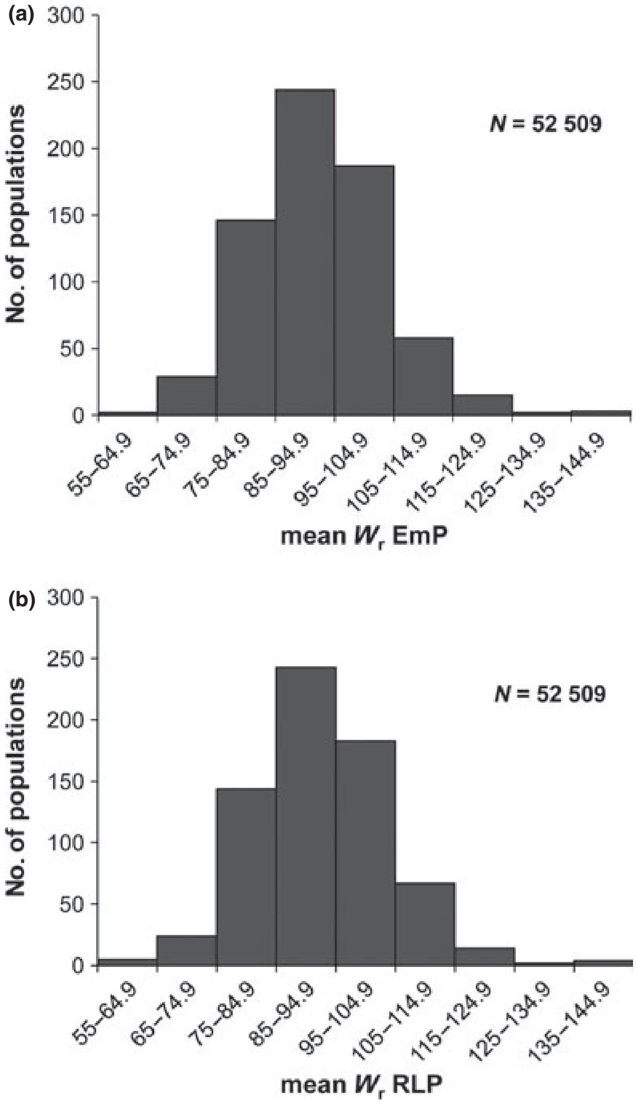

Fig. 3. Distribution of mean $W_{r\text{-EmP}}$ (a) and $W_{r\text{-RLP}}$ (b) values for all populations

Table 4
Descriptive statistics of W_r calculated by both RLP and EmP methods

	N	Mean	Min	Max	SD
$W_{r\text{-EmP}}$	52 509	87.488	40.626	199.522	15.546
$W_{r\text{-RLP}}$	52 509	87.805	40.265	219.853	16.182

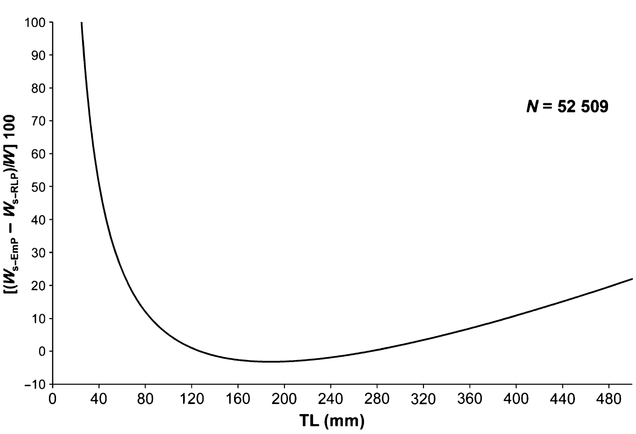

Fig. 4. Trend in percentage difference between $W_{s\text{-EmP}}$ (a) and $W_{s\text{-RLP}}$ as a function of total length (TL)

Table 5
Results of Willis and EmPQ methods applied to both EmP and RLP W_s equations

	Willis method			EmPQ method	
	Negative	Positive	P	P_{linear}	$P_{quadratic}$
EmP	28	42	0.094	0.5185	0.6269
RLP	42	34	0.359	0.7595	< 0.001

Negative, number of datasets with significantly negative slopes; Positive, number of datasets with significantly positive slopes; P, P values for significance of chi-square test; P linear and P quadratic, P values of linear and quadratic terms for the EmPQ method.

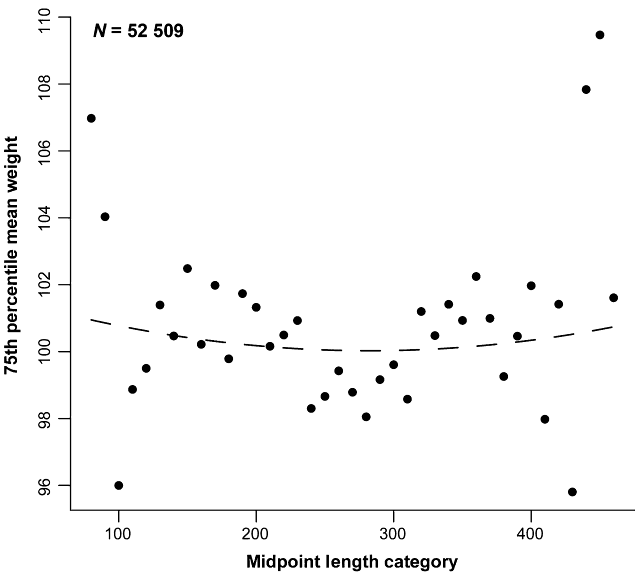

Fig. 5. Standardized 75th percentile mean weights calculated with proposed W_s equations for EmP method versus total length (TL)

relationships with positive slopes (42) was not significantly different from that with a negative slope (28) at chi-square analysis (χ^2 = 2.800; P = 0.094) (Table 5). For the RLP method, 76 of the 150 TL–W_r relationships randomly selected had slopes significantly different from zero ($P < 0.05$) and on chi-square analysis, the number of relationships with a positive slope (34) was not significantly different from that with a negative slope (42) (χ^2 = 0.842; P = 0.359) (Table 5). Applying the EmPQ method, the EmP W_s equation did not appear to be influenced by fish length (P = 0.627) (Table 5; Fig. 5), while the RLP W_s equation did appear to be influenced ($P < 0.001$) (Table 5; Fig. 6). According to residuals analysis, the EmP W_s equation did not exhibit an evident pattern (Fig. 7), while the residuals of the RLP W_s equation showed a clear nonlinear tendency (Fig. 8).

Discussion

Relative weight was developed to assess the status of sport fishes and the overall health and productivity of freshwater fish populations (Wege and Anderson, 1978; Murphy et al., 1991; Gerow et al., 2004). The European perch, like other species belonging to the Percidae family (i.e. yellow perch, pikeperch and walleye), has been intensively studied because of its importance to commerce and fisheries. As yet, however, there is no W_s equation available for this species in the literature. In order to compensate for this lack some authors have developed

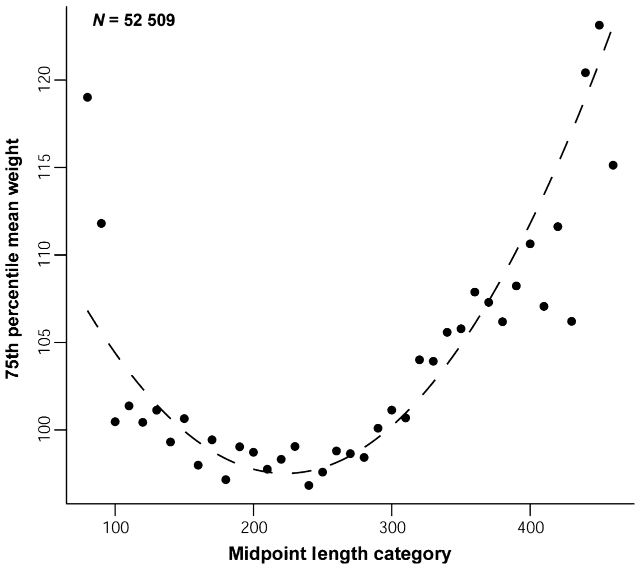

Fig. 6. Standardized 75th percentile mean weights calculated with proposed W_s equations for RLP method vs total length (TL)

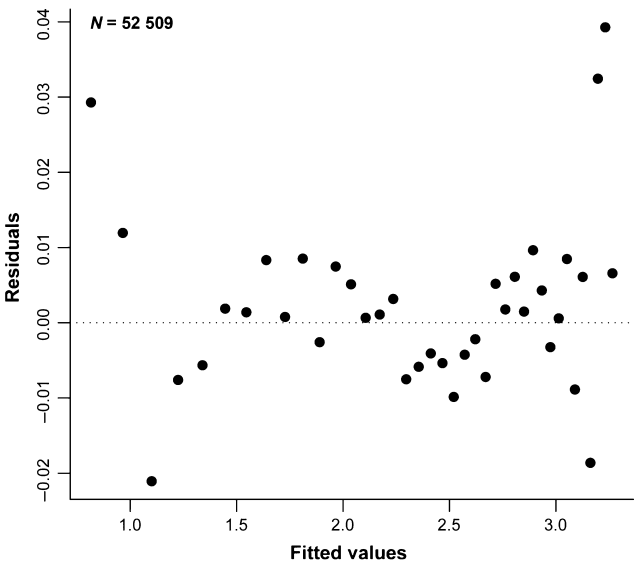

Fig 7. Residuals plot for EMP W_s equation

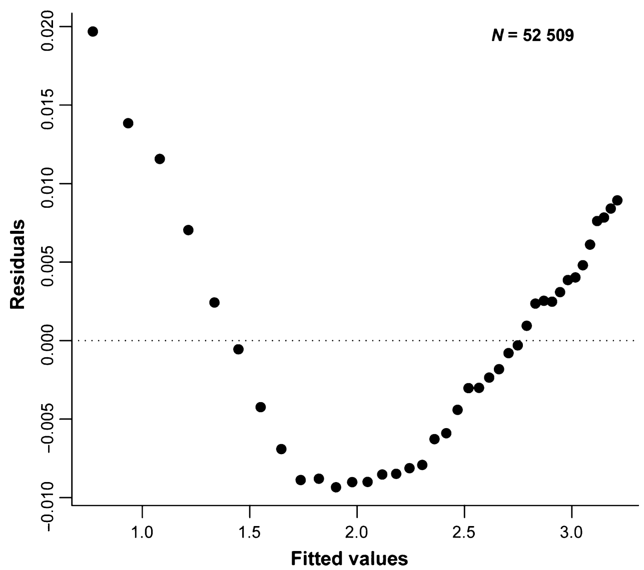

Fig. 8. Residuals plot for RLP W_s equation

local W_s equations to assess the condition of perch populations (Pronier, 2000) or used the W_s equation proposed for yellow perch by Willis et al. (1991) (e.g. Lorenzoni et al., 2007 in Lake Piediluco).

The results of this study showed that by comparing the performances of the two methods, while the differences between the EmP and RLP W_s regressions were very small, the differences between mean $W_{r\text{-EmP}}$ and $W_{r\text{-RLP}}$ proved significant on the *t*-test. The divergences between the two methods were more marked for fish of the smallest and largest sizes, impling that, for each population, the value of W_r calculated by means of both methods depends on the size-structure of the population itself, as observed by Angeli et al. (2009) for brown trout (*Salmo trutta* L.) and Tiber barbel (*Barbus tyberinus* Bp.). A further difference between the two methods is evident analyzing the mean W_r value of each population: the number of populations belonging to the three range values ($W_r < 95$, $95 < W_r < 105$, $W_r > 105$) is different for the two methods and, in relation to this, in some cases the choice of the method used to calculate W_r could also influence the judgment of the condition of each population. Moreover for both methods only a minority of perch populations (about 25%) fell within the target range of 95–105, which, according to Anderson (1980), indicates that fish are in good condition. In accordance with Willis et al. (1991), this result does not indicate that the proposed standard weight equation is not valid; rather, it indicates the broad range of body conditions that perch display across their area of distribution. Blackwell et al. (2000) suggests that targets for W_r should be established in line with management objectives for a given program. It is in any case important to underline that even if only a minority of perch populations fell within the range of 95–105, this does not mean that they are poor because both RLP and EmP methods applied in this study use the 3rd quartile of the weight that provide a measure of well-being above than average condition. According to Froese (2006) the use of the 3rd quartile as the standard for W_s equation may be inappropriate in some cases but, as suggested by Ogle and Winfield (2009) its use 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. In addition, because the main part of the W_s equation proposed in literature was developed using the 75th percentile and, in accordance with Richter (2007), the standardization of indices and analysis techniques would be useful for management of aquatic ecosystems, the same standard of 75th percentile was used in this study. At the same time, as suggested by Murphy et al. (1991), the use of an universal standard weight equation for each species may allow meaningful comparisons among populations and can be employed, in conjunction with other population metrics (e.g. age and growth), to aid in developing future management plans on a local scale.

To be a good index of condition, relative weight should be free from length-related biases, in order to enable accurate comparisons (Murphy et al., 1990; Anderson and Neumann, 1996; Blackwell et al., 2000). Since the EmP W_s equation thus proposed did not exhibit length-related biases we suggest that it can be used to compute the relative weight of European perch.

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