Length-weight, length-length and a proposed empirical standard weight equations for the Italian endemic cyprinid species *Sarmarutilus rubilio*

by

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Abstract. – Length and weight data of 21,040 specimens of the Italian endemic species *Sarmarutilus rubilio* (Bianco & Ketmayer, 2014) were collected throughout the area of distribution of the species and used to calculate total length-weight (TL-W), standard length-total length (SL-TL), fork length-total length (FL-TL), and standard weight (W_s) equations. The SL-TL equation was TL = 1.153 SL + 4.121; the FL-TL equation was TL = 1.037 FL + 0.288. The log-transformed TL-W equation was: $\log_{10}W = -5.201 + 3.117 \log_{10}TL$. The W_s equation was $\log_{10}W_s = -4.043 + 1.919 \log_{10}TL + 0.315 (\log_{10}TL)^2$ (length-range 60-200 mm). The resulted W_s equation was not biased by length and its use is suggested as a way to calculate the relative weight (W_r) for the species throughout the area of distribution of the species. These equations represent the first reference for the species from its native distribution range and they will be useful tools to increase the basic knowledge on population ecology of this species.

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Résumé. – Relations longueur-poids, longueur totale-longueur standard et proposition d'équation pour le poids standard (W_s) chez le cyprinidé endémique italien *Sarmarutilus rubilio*.

Les données de longueur et de poids de 21 040 spécimens de l'espèce endémique italienne *Sarmarutilus rubilio* (Bianco & Ketmayer, 2014) ont été recueillies sur toute l'aire de répartition de l'espèce et ont été utilisées pour calculer les relations longueur totale-poids (TL-W), longueur standard- longueur totale (SL-TL), longueur à la fourche-longueur totale (FL-TL), et une équation poids standard (W_s). L'équation SL-TL est TL = 1,153 SL + 4,121 ; l'équation FL-TL est TL = 1,037 + 0,288 FL. Pour l'équation $\log_{10}TL - \log_{10}W$ on obtient $\log_{10}W = -5{,}201 + 3{,}117 \log_{10}TL$. Enfin, l'équation permettant le calcul du W_s résultant est $\log_{10}W_s = -4{,}043 + 1{,}919 \log_{10}TL + 0{,}315 (\log_{10}TL)^2$ (gamme de longueur de 60 à 200 mm). L'équation W_s n'est pas biaisée par la longueur et son utilisation est proposée comme un moyen de calculer le poids relatif (W_r) pour l'espèce dans toute son aire de répartition. Ces équations constituent les premières références pour l'espèce dans son aire d'origine et elles devraient permettre d'améliorer les connaissances de base sur l'écologie des populations de cette espèce.

Key words
Cyprinidae
Sarmarutilus rubilio
Relative weight
Condition indices
Length-weight relationship
Endemic species

South European roach, formerly known as *Rutilus rubilio* (Bonaparte, 1837) is a cyprinid species endemic of Italy (Tyrrhenian slope from Magra to Bussento drainages, Adriatic slope from Chienti to Trigno drainages and Ofanto drainage) (Fig. 1) (Crivelli, 2006). Recently a revision of the species taxonomy has been proposed and, according to Bianco and Ketmayer (2014), the species must be assigned to a separated genus and named *Sarmarutilus rubilio* (Bonaparte, 1837). *Sarmarutilus (Rutilus) rubilio* was assessed as "Near threatened" according to the IUCN Red List of Endangered Species (Crivelli, 2006) and the IUCN Red List of Italian Vertebrates (Rondinini *et al*., 2013); it is listed in Annex II of the European Union Habitats Directive 92/43/CEE as a species requiring designation of Special Areas of Conservation and in the Annex III of Bern Convention. The species has disappeared from many lakes (Bianco, 1990; Mearelli *et al*., 1990) and is decreasing in many rivers. The introduction of alien species – specifically *Protochondrostoma genei* (Bonaparte, 1839) and *Rutilus aula* (Bonaparte, 1841) – represents the most serious causes of concern for the survival of this species (Crivelli, 2006).

Although this, the knowledge on the biology and ecology of this species in its original distribution range is still limited.

Relative weight (W_r) (Wege and Anderson, 1978) is an index of condition proposed to measure the well-being of fish. Among all the other condition indices, W_r has the advantage to enable comparison of fish condition of different lengths and belonging to different populations, because it is not influenced by changes in body shape (Murphy *et al*., 1991). W_r is based on the comparison between the actual weight of a fish and a standard weight (W_s). W_s is the weight

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Figure 1. - Area of distribution of *Sarmarutilus rubilio* (in grey) (from IUCN, 2013 modified) and localization of sampling stations (black points).

of an ideal fish of the same species and of the same length in good physiological condition, predicted by a species-specific W_s equation developed for the species using a wide sample of specimens collected throughout its area of distribution.

The aim of this research was to provide length-weight and length-length equations for South European roach and a W_s equation for the evaluation of body condition applicable to the entire area of distribution of the species.

MATERIALS AND METHODS

Dataset selection and development of length-length and length-weight equations

Data of length (total length, TL; standard length, SL; fork length, FL, to the nearest 1 mm) and weight (W to the nearest 0.1 g) of South European roach were collected from 140 locations on 87 different watercourses distributed across the area of distribution of the species (Fig. 1). The entire database was accumulated by different monitoring studies carried out from 2005 to 2013 to assess the conservation status of the main Italian freshwaters fish species. According to this, all fish were returned to their rivers immediately after measurements and no specimens were sacrificed.

The first step was to validate the total dataset by removing all fish that were large outliers (values diverging more than double from the expected value) on the TL-W regression, since these were probably the result of wrong measurements (Giannetto *et al.*, 2011).

Specific SL-TL and FL-TL linear conversion regressions were developed by using the fish (189 specimens) of the dataset, in which at least two types of length measurement were recorded.

The next stage was the determination of a suitable length range. The minimum TL was determinate by the relationship between the variance/mean ratio for $\log_{10}W$ on 10-mm total length intervals as the length at which this ratio sharply decreased (Willis *et al.*, 1991) and was less than 0.01 (Murphy *et al.,* 1991). The maximum TL was identified as the length class for which at least three fish in three different populations were available in the dataset (Gerow *et al.*, 2005). All fish outside this suitable length-range were excluded from dataset.

The total dataset was thus separated into a larger development dataset (used to compute the W_s equation) and a smaller validation dataset (utilised to investigate potential length-related biases in the W_s equation developed) (Lorenzoni *et al.,* 2012).

The development dataset was divided into statistical populations: data derived from separate locations on large waterways were considered as different populations; data collected in different years from the same location were also considered different statistical populations, with the exception of locations with small numbers of fish (n < 10) (Ogle and Winfield, 2009; Giannetto *et al.,* 2012a).

Thus, a logarithmic TL-W regression was plotted separately for each statistical population (Bister *et al.*, 2000) and, according to Froese (2006), all populations showing an R^2 value less than 0.90 or a slope (b) value outside the range of 2.5-3.5 were removed.

Development and validation of W_s equation

The W_s equation for South European roach was estimated by means of the Empirical Percentile (EmP) method proposed by Gerow *et al.* (2005).

To evaluate the reliability of the EmP W_s equation developed, two different techniques were applied: 1) the Empirical Quartile (EmpQ) method (Gerow *et al.,* 2004) as modified by Ogle and Winfield (2009) by means of FSA package (Ogle, 2009); 2) the analysis of distribution of residuals versus fitted values of the W_s equation (Giannetto *et al.*, 2011).

RESULTS

Determination of length-length and length-weight equations

A total of 21,040 specimens, size ranging from 20 to 198 mm (mean ± SE = 78.72 mm ± 0.19) and weight ranging from 0.10 to 95 g (mean ± SE = 7.47 g ± 0.06), were

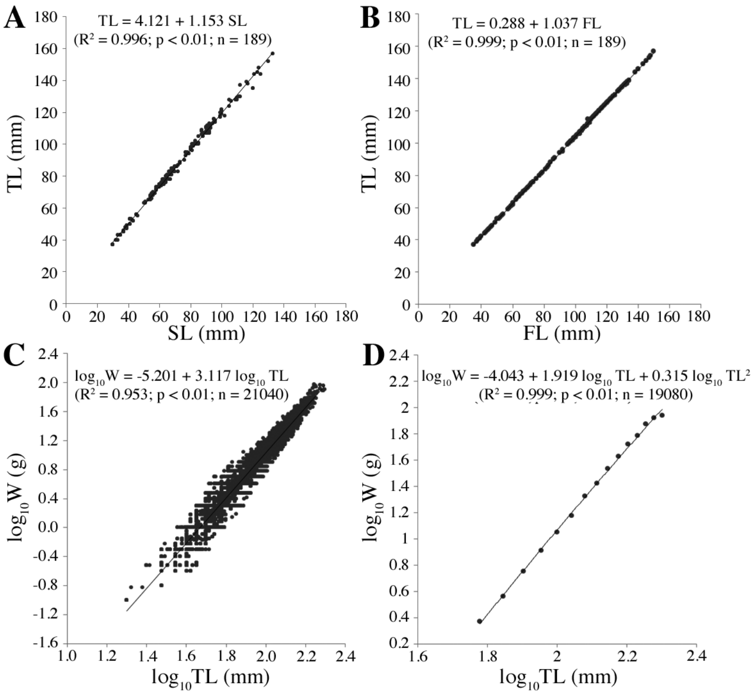

Figure 2. – **A**: Plots of total length (TL)-standard length (SL); **B**: Plots of TL-fork length (FL); **C**: Plots of logarithmic total weight (W)-TL; **D**: Plots of logarithmic standard weight (W_s) TL equations for *Sarmarutilus rubilio*. For each plot: coefficient of determination (R^2); value of correlation (p); number of specimens (n).

analysed. The standard length (SL)-TL and the fork length (FL)-TL equations were (Fig. 2A, B):

$$TL = 1.153\ SL + 4.121\ (R^2 = 0.996;\ p < 0.01;\ n = 189)$$

and

$$TL = 1.037\ FL + 0.288\ (R^2 = 0.999;\ p < 0.01;\ n = 189).$$

For the total dataset, the log-transformed TL-W equation was (Fig. 2C):

$$\log_{10} W = -5.201 + 3.117 \log_{10} TL$$
$$(R^2 = 0.953;\ p < 0.01;\ n = 21040)$$

The value of *b* (3.117) resulted highly statistically different by 3 at *t*-test (Ricker, 1975) ($t = 654.648$; $p < 0.01$).

The development dataset consisted of 19,080 specimens and the small validation dataset was formed of 1960 specimens. The suitable length range of application was identified as 60-200 mm (Tab. I).

Among the 197 statistical populations of the development dataset, seven populations were eliminated according to Froese (2006) (four because had an R^2 value less than 0.90 while three because the value of the *b* was higher than 3.5).

Determination and validation of the W_s equation

The EmP W_s equation for South European roach was (Fig. 2D):

$$\log_{10} W_s = -4.043 + 1.919 \log_{10} TL + 0.315 (\log_{10} TL)^2$$
$$(R^2 = 0.999;\ p < 0.01;\ n = 19080).$$

The plot between residuals and fitted values did not show any correlation between W_s and TL. The EmpQ method could only be applied to fish less than 170 mm (the largest TL class of the validation dataset with at least three specimens in three different populations) and, according to this method, the slope values were not significantly different from zero for both terms of the W_s equation ($p_{quadratic} = 0.835$; $p_{linear} = 0.512$).

DISCUSSION

The use of standardized methods to study biological characteristics of fish populations can allow comparison with populations of the same species inhabiting different habitats or biotopes. The indices of condition were proposed to evaluate any changes in the status of physiological well-being of the fish using a standardized methodology (Copeland *et al*., 2008). The chance to evaluate the well-being, indeed, represents an important tool for the conservation of threatened species, since it allows evaluating the effects of any action planned for management and conservation of their populations. The use of easy and not cruel tools such as the relative weight could contribute to the management and conservation status of

Table I. - Total length (TL) composition per each 10 mm of development and validation datasets used to calculate and validate the standard weight (W_s) equation for *Sarmarutilus rubilio* according to the Empirical Percentile (EmP) Method. Number of individuals per each 10-mm TL class.

	Number of individuals	
TL (mm)	Development dataset	Validation dataset
60	2743	773
70	2444	441
80	2366	301
90	2153	158
100	1866	108
110	1461	100
120	914	45
130	588	11
140	321	9
150	197	7
160	93	5
170	38	3
180	14	–
190	6	–
200	3	–

these species and it is strongly recommended (Murphy *et al.*, 1991; Blackwell *et al.*, 2000, Didenko *et al.*, 2004).

By comparing data of different periods, the application of the proposed equations will be useful to detect the decline in condition of the species and identify potential at risk populations at local scale probably as a result of environmental alterations (Ogle and Winfield, 2009). Indeed, according to Bister *et al.* (2000) because of the positive correlation existing between fish growth and environmental quality, W_r could be an easy and powerful tool to recognize environmental (Gabelhouse, 1991; Hubert *et al.*, 1994; Liao *et al.*, 1995) or ecological changes just as the incidence of phenomena of inter- or intra-species competition (Johnson *et al.*, 1992; Giannetto *et al.*, 2012b).

In this study the W_s equation developed for South European roach can be used for evaluation of W_r of the species across the entire area of distribution. In addition length-length and length-weight equations were also provided for South European roach. These equations represent the first reference for the species from its native distribution range since the only length-weight equations available in the literature are those provided by Russo *et al.* (1997) from to a Sicilian lake (Lake Arancio) where the species was introduced or refer to environments outside the original range of the species (Lake Trichonis and Lake Mikri Prespa in Greece, Kleanthidis *et al.*, 1999) where other species were wrongly recognized as *R. rubilio* (Bianco and Ketmayer, 2014).

The results obtained, then, together with other population metrics (e.g., age and growth), will be useful tools to increase the basic knowledge on population ecology of this species (Murphy *et al.,* 1991; Blackwell *et al.*, 2000). Moreover, according to Froese (2006), only when length-weight estimates are reasonably cover geographic and inter-annual variation, it is possible to discuss isometric versus allometric growth of the species as a whole by using the value of *b*. In this study length and weight data were collected throughout the entire range of distribution of South European roach. The *b* value of the TL-W resulted highly significantly higher than 3 and this supported the assumption of a positive allometric growth for South European roach.

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