Empirical standard mass equation for Salmo marmoratus


*Dipartimento di Biologia Cellulare e Ambientale, Università di Perugia, Via Elce di Sotto, 06123 Perugia, Italy, ‡Aquaprogram s.r.l., Via L. Della Robbia, 48-36100, Vicenza, Italy, §Dipartimento di Scienze della Vita, Università di Trieste, Via Giorgieri, 10-34127, Trieste, Italy, ¶Bioprogramm sc, Via Lisbona, 28/a, 35127, Padova, Italy, ∥Center for Stock Assessment Research, National Marine Fisheries Service, 110 Shaffer Road, Santa Cruz, CA 95060, U.S.A. and **Biological Station of Tour Du Valat, 13200 Le Sambuc, France

(Received 23 May 2012, Accepted 21 August 2012)

Total length (LT) (range 24–1000 mm; mean ± s.e. = 170·21 ± 0·36 mm) and mass (W) (range 0·10–9590 g; mean ± s.e. = 76·03 ± 0·87 g) of 36 460 specimens of marble trout Salmo marmoratus were used to compute a standard mass (Ws) equation for this species by means of the empirical percentile (EmP) method. The EmP Ws equation calculated was: log10 Ws = −5·208 + 3·202 log10 LT − 0·046 (log10 LT)2 (LT range 90–570 mm) and it is valid throughout the species’ area of distribution across Europe.

Key words: condition indices; EmP method; marble trout; relative mass.

Marble trout Salmo marmoratus Cuvier 1829 is a salmonid of particular conservation interest, being endemic to a restricted geographical area of the Adriatic Basin, including the Po, Adige, Brenta, Tagliamento and Isonzo River basins in Northern Italy (Turin et al., 2006; Pujolar et al., 2011) and the Adriatic River system of the western Balkans (Povž, 1995; Crivelli et al., 2000). Many authors have reported a progressive restriction of its original distribution area (Sommani, 1961; Tortonese, 1967; Crivelli et al., 2000) and now the species is considered one of the most endangered freshwater fish of the Adriatic Basin (Povž et al., 1996; Crivelli et al., 2000). Specifically, it is listed in Annex II of the European Union Habitats Directive (E.U., 1992) as a species requiring designation of special areas of conservation and considered as endangered according to the Red List of Italian freshwater fishes (Bulgari et al., 1998; Zerunian, 2002). Hybridization with brown trout Salmo trutta L. 1758, displacement by alien rainbow trout Oncorhynchus mykiss (Walbaum 1792) (Vincenzi et al., 2011) and habitat alteration (Crivelli et al., 2000) are the most serious

†Author to whom correspondence should be addressed. Tel.: +39 075 585 5707; email: danielagiannetto@libero.it
causes of concern for the survival of *S. marmoratus*. Accordingly, any management tools that could assist in conserving its populations would be advantageous for the survival of the species. Body condition indices provide a measure of the health of a fish population assuming that heavier fish of a given length are in better condition (Froese, 2006). They have become useful tools for fisheries management because, being based only on measurements of length and mass, they do not require sacrifice of specimens (Anderson & Neumann, 1996; Blackwell et al., 2000). Relative mass ($W_r$) (Wege & Anderson, 1978) is one of these indices and is based on the comparison between the actual mass of a specimen and the standard mass ($W_s$), which is the mass of an ideal fish of the same species and same length in good physiological condition predicted by a $W_s$ equation typical of the species. The aim of this research was to develop a $W_s$ equation for *S. marmoratus*. $W_r$ provides a rapid, accessible and non-invasive metric useful to assess the overall health and fitness of this species as well as population-level response to ecosystem disturbance. Until recently, the most widely used method to develop the $W_s$ equation was the regression line percentile (RLP) method (Murphy et al., 1991). Gerow et al. (2004) however, found significant length-related biases for $W_s$ equations developed using the RLP method and introduced a new method called the empirical percentile (EmP) method (Gerow et al., 2005), which uses empirical data (instead of modelled data). Currently, the debate on the validity and choice of the method is still open (Gerow, 2010; Ranney et al., 2010), but the results of recent studies suggest that the $W_s$ equation developed by the EmP method is not affected by length-biases and encourage the use of this methodology (Angeli et al., 2009; Ogle & Winfield, 2009; Giannetto et al. 2011, 2012).

Data on *S. marmoratus* [total length ($L_T$, mm) and mass ($W$, g)] were collected across the entire range of the species during different programmes of rehabilitation (Crivelli et al., 2000; Specchi et al., 2004) and monitoring (Turin et al., 2006) carried out to assess the conservation status of the species. Accordingly, all fish were returned to their rivers immediately after measurements. Only specimens recognized as phe-notypic *S. marmoratus* were used in calculations. Those showing characteristics of hybrid forms were removed. Body lengths measured only in terms of fork length ($L_F$) were converted to $L_T$ by applying a general linear conversion model calculated by using all fish from the datasets in which at least two types of length measurement were recorded. The general conversion model used was: $L_T = 1.008 L_F + 4.721$ ($r^2 = 0.999$, $P < 0.01$, $n = 99$). Then the total dataset was cleaned and screened by using the procedure suggested by Giannetto et al. (2011). After that, a suitable length range for the application of the $W_s$ equation was calculated. According to Willis et al. (1991) by plotting the variance:mean ratio for log10$W$ on 10-mm $L_T$ intervals, the minimum sample size was determined as the value at which this ratio sharply decreased and was <1% (Murphy et al., 1991); a maximum $L_T$ was assigned as the length class for which at least three fish populations were present in the dataset (Gerow et al., 2005). All fish outside the suitable length range were not utilized for the next analysis. After this, the dataset was divided into statistical populations: 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 small numbers of fish ($n < 20$) (Ogle & Winfield, 2009). Subsequently, the dataset was divided into two datasets: a large development dataset to

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calculate the $W_s$ equation and a validation dataset to assess potential length-bias in the $W_s$ equation (Rypel & Richter, 2008; Ogle & Winfield, 2009). The EmP method proposed by Gerow et al. (2005) was applied to the development dataset to estimate the $W_s$ equation for $S. marmoratus$. In order to validate the EmP $W_s$ equation thus obtained and detect potential length-related biases, two different techniques were applied: the empirical quartile (EmpQ) method (Gerow et al., 2004) as modified by Ogle & Winfield (2009) by the FSA package (Ogle, 2009) to determine whether the quadratic regression of the third quartile of the mean $W$ standardized by $W_s$ against $L_T$ had a slope of zero; and the Willis method (Willis et al., 1991), whereby a $\chi^2$ test was used to determine whether the proportion of populations with a significant positive slope in the $L_T$ and $W_r$ equation was equal to the proportion of those with a significant negative slope.

A total of 36 460 specimens was collected throughout the area of distribution of the species (Fig. 1) and analysed. The total sample ranged in $L_T$ from 24 to 1000 mm (mean ± s.e. = 170.21 ± 0.36 mm) and in $W$ from 0.10 to 9590 g (mean ± s.e. = 76.03 ± 0.87 g). The log$_{10}$-transformed $L_T$ and $W$ relationship of the total dataset is shown in Fig. 2).

The total sample was divided into 197 populations (177 from Italy and 20 from Slovenia), but according to Froese (2006), four populations showing an $r^2$ value <0.90 or for which a value of slope $b$ fell outside the range of 2.5–3.5 were eliminated. Then, the total dataset was divided into a large development dataset (34 343 specimens and 153 populations) and a small validation dataset (766 specimens and 40 populations) to use a sample as large as possible to calculate the $W_s$ equation.
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Fig. 2. Log_{10}-transformed regression between total length ($L_T$) and mass ($W$) for the total sample of *Salmo marmoratus*. The curve was fitted by: $y = -4.992 + 2.989x$ ($r^2 = 0.988$, $P < 0.001$, $n = 36460$).

(Rypel & Richter, 2008); the data were selected so that both datasets contained populations distributed geographically throughout the range of the species (Ogle & Winfield, 2009). The minimum $L_T$ for the application of the $W_s$ equation was determined as 90 mm, while the maximum $L_T$ was assigned to be 570 mm. The EmP $W_s$ equation calculated for *S. marmoratus* was: $\log_{10}W_s = -5.208 + 3.202 \log_{10}L_T - 0.046 (\log_{10}L_T)^2$ ($r^2 = 0.998$, $P < 0.01$).

Applying the EmpQ method to the validation dataset, even if the plot showed a slight negative slope (Fig. 3) (because of the small number of populations in the higher $L_T$ classes), the value of the slope was not significantly different from zero for both terms of the equation ($p_{\text{quadratic}} = 0.85$, $p_{\text{linear}} = 0.22$) indicating that $W_s$ was not influenced by fish $L_T$. According to the Willis method using $\chi^2$ analysis, the number of relationships with significant positive slopes (eight) was not significantly different from those with significant negative slopes (six) ($\chi^2 = 0.286; P > 0.05$).

*Salmo marmoratus* is a species of great interest for its conservation value and relevance for sport fishing (Vincenzi *et al.*, 2011). The viability of *S. marmoratus* is currently threatened because of its restricted geographical distribution and the risk of hybridization with the introduced *S. trutta* (Povž *et al.*, 1996). Since the late 1980s, rising awareness about the decline of *S. marmoratus* have led to the development of rehabilitation projects in both Italy (Specchi *et al.*, 2004) and Slovenia (Crivelli *et al.*, 2000). For these reasons, the use of a measure of body condition such as $W_r$ could be very useful to increase the knowledge on the population ecology of the species and, in conjunction with other demographic measures and life-history traits (e.g. age and growth), to provide a reference point and an indirect measure of the effects of management conservation actions (Murphy *et al.*, 1991; Blackwell *et al.*, 1999).
Fig. 3. Plots showing the results of the application of the empirical quartiles (EmpQ) method used to investigate potential length bias in the standard mass ($W_s$) equation for *Salmo marmoratus*. ($W_r$, standardized 75th percentile mean masses calculated by $W_s$ equation; $L_T$, total length).

2000). The EmP $W_s$ equation calculated in this study was free from length-related bias and its use to compute $W_r$ for *S. marmoratus* is suggested.

References


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**Electronic References**
