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Length–weight and length–length relationships for three endemic cyprinid species of the Aegean region (Turkey) with proposed standard weight equations

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Abstract: Empirical standard weight equations and length–weight and length–length relationships were estimated for *Barbus pergamonensis*, *Capoeta bergamae*, and *Ladigesocypris irideus*, three endemic cyprinid species of Turkey that are still not widely studied. To the best knowledge of the authors, empirical standard weight equations for the three species and L–W parameters for *L. irideus* are given here for the first time. In this study, length and weight data for *B. pergamonensis*, *C. bergamae*, and *L. irideus* were collected throughout the watercourses of Muğla Province and were used to develop species-specific W_s equations. The results were for *B. pergamonensis* (total length [TL] range: 6–22 cm) $\log_{10}W_s = -5.713 + 3.718 \log_{10}TL - 0.166 (\log_{10}TL)^2$, for *C. bergamae* (TL range: 8–29 cm) $\log_{10}W_s = -5.224 + 3.311 \log_{10}TL - 0.083 (\log_{10}TL)^2$, and for *L. irideus* (TL range: 6–10 cm) $\log_{10}W_s = -13.298 + 12.116 \log_{10}TL - 2.471 (\log_{10}TL)^2$. This study also reported new maximum TLs for the three species, together with species-specific length–weight and length–length equations.

Key words: Condition indices, endemic species, Muğla Province, relative weight, EmP method

1. Introduction

The Mediterranean basin is considered one of the planet's biodiversity hotspots, with about 253 endemic species inhabiting the area (Smith and Darwall, 2006). Nevertheless, Mediterranean freshwater ecosystems are under particularly high pressure caused mostly by human-mediated environmental interference (Crivelli, 1995) and, as a result, more than 56% of endemic freshwater fish are currently classified as threatened (IUCN, 2012). Within the Mediterranean basin, Turkey has been assessed as an important area for fish biodiversity because of the high number of endemic and threatened species hosted (Smith and Darwall, 2006). The segregation of freshwater fish fauna of Turkey that occurred over geological eras led to the diversification of several isolated fish populations (Balık, 1995). Notably, almost half of the endemic species in Turkey are classified as Critically Endangered and 32% as Endangered (Fricke et al., 2007).

Together with the other Turkish regions bordering the Mediterranean and the Aegean Sea, Muğla Province, located in the basins of the Büyük Menderes, Dalaman, and Eşen rivers, falls inside the Mediterranean hotspot for fish biodiversity. Although several studies on freshwater species inhabiting Muğla watercourses are available in the literature (Barlas and Dirican, 2004; Onaran et al., 2006; Yılmaz et al., 2006; Özcan, 2007; Önsoy et al., 2011; Tarkan et al., 2012; Özdemir et al., 2015), knowledge on native and endemic freshwater fish species inhabiting the area is still limited.

Bergama barbel *Barbus pergamonensis* Karaman, 1971 is an endemic cyprinid fish species of Aegean drainages (Turkey) and Lesbos Island (Greece) (Kottelat and Freyhof, 2007). Although Freyhof and Kottelat (2008) suggested that the species is restricted from the Bakır to the Great Menderes rivers in Turkey, its presence has also been widely documented for the drainages of Muğla Province in the southern Aegean region (Gaygusuz et al., 2013; Özdemir et al., 2015). Because of the lack of information, *B. pergamonensis* has been assessed as "data deficient" in the Red List of threatened and declining species of Turkey (Fricke et al., 2007). The only information on *B. pergamonensis* reported in the literature indeed refers to its distribution area (Stoumboudi et al., 2006; Kottelat and Freyhof, 2007) and a length–weight equation of the species

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(Gaygusuz et al., 2013; Erk'akan et al., 2014). Although currently no other data on the biology of this species are available, the species is assessed as being of "least concern" according to the IUCN Red List of Threatened Species (Freyhof and Kottelat, 2008).

Aegean scraper *Capoeta bergamae* Karaman, 1969 is an endemic cyprinid species of southwestern Anatolia (Turkey), which is known in the area from Bakır to Dalaman streams (Özcan and Turan, 2009). However, according to Levin et al. (2012), the specimens of the species collected in the watercourses of Muğla Province showed different characteristics from a molecular point of view than *C. bergamae* collected in other localities, so the true classification of the species needs further assessment. However, Fricke et al. (2007) assessed *C. bergamae* as "endangered" in the Red List of threatened and declining species of Turkey. According to the IUCN Red List of Threatened Species, this species, previously assessed as "vulnerable" by Crivelli (2006), is currently listed as "near threatened" by Freyhof (2014). However, the information available in the literature on the biology and ecology of this species is also very limited and is restricted to a few studies only: Gaygusuz et al. (2013) provided a length–weight equation for *C. bergamae*, and Özcan (2008) and Özcan and Balık (2009) reported a length–weight relationship and data on growth and reproductive biology of the species from the Kemer Reservoir (Aydın).

Anatolian ghizani *Ladigesocypris irideus* (Ladiges, 1960) is a cyprinid species endemic to the Aegean region of Turkey (the Bergama to Dalaman rivers) (Freyhof, 2014). In the past, the species was recognized as *L. ghigii* (Ladiges, 1960), endemic to Rhodes Island (Greece) (Stoumboudi et al., 2002) and the Aegean region of Turkey. However, the taxonomical classification of this species was recently changed, and Durand et al. (2002) reported that *L. ghigii* should be considered *Squalius ghigii* (Gianferrari, 1927) restricted only to Rhodes, while the records from Turkey should refer to two different species: *L. mermere* (Ladiges, 1960), which should be restricted to Lake Marmara (Froese and Pauly, 2012), and *L. irideus*. *L. irideus* was assessed as "critically endangered" in the Red List of threatened and declining species of Turkey (Fricke et al., 2007); currently it is listed as Near Threatened in the IUCN Red List of Threatened Species (Freyhof, 2014). No data on population trends or the biology of the species are currently available in the literature.

Actions for the conservation of endemic species cannot be separated from a detailed study of their biological and ecological characteristics. Together with reproductive biology, growth, and population structure, the estimation of fish condition represents a special tool for the study of fish populations (Blackwell et al., 2000; Froese, 2006).

Different standardized methods, termed indices of condition, are available in the literature to evaluate the well-being of one or more populations as compared to "standard" conditions (Murphy et al., 1990; Copeland, 2004).

Relative weight (W_r) (Wege and Anderson, 1978) is one of these indices; it is calculated by comparing the measured weight of a specimen (W) with a standard weight (W_s) representing the weight at the same length of an ideal fish of the same species in good physiological condition (Murphy et al., 1991). W_s is assessed by a standard weight equation, which is a length–weight regression typical of the species (Wege and Anderson, 1978).

The aim of this study was to develop empirical standard weight equations for three endemic species of Muğla Province in the Aegean region: *B. pergamonensis*, *C. bergamae*, and *L. irideus*. A further aim was to provide specific length–weight and length–length relationships for these species.

2. Materials and methods

2.1. Validation of the datasets and development of specific length–weight and length–length equations

Data on length and weight of *B. pergamonensis*, *C. bergamae*, and *L. irideus* were collected throughout the watercourses of Muğla Province by electrofishing between 2008 and 2014. After collection, length measurements (total length, TL; standard length, SL; and fork length, FL) to the nearest mm and wet weight (W) to the nearest 0.1 g were measured for each specimen.

For each of the three species, the total dataset was screened and validated by following the procedure suggested by Giannetto et al. (2011). First, a TL–W regression was developed for the total sample and all individuals; any resulting large outliers, probably derived from wrong measurements, were removed. Species-specific length–length relationships were then developed. The next step was to divide the dataset into statistical populations, accomplished on the basis of the date and location of collection of the specimens (Giannetto et al., 2012a). For each statistical population, a plot of $\log_{10}$TL – $\log_{10}$W was then calculated separately to identify and eliminate anomalous measurements (values deviating by more than double the expected value by the regression curve) (Bister et al., 2000). As suggested by Froese (2006), all statistical populations showing an R^2 value of less than 0.90 or a value of the slope (*b*) outside the range of 2.5–3.5 were omitted from further examination, since such values usually belong to populations composed of few specimens or samples with a narrow length range (Pope et al., 1995; Froese, 2006).

2.2. Assessment of the applicable total length ranges for the W_s equations

The last preliminary step for the development of W_s equations was the assessment of a suitable application for total length range for each species. According to Murphy

et al. (1990), the estimation of a minimum TL for the application of the W_s equation is indispensable because juveniles show a high variance due to the differences in growth forms that arise in the early stages, and also because of the potential error associated with their measurement in the field (Lorenzoni et al., 2012). By the plot between variance/mean ratio of $\log_{10}W$ on 1-cm TL classes (Willis et al., 1991), the minimum total length was estimated as the TL at which the value of the ratio was less than 0.01 (Murphy et al., 1990).

As suggested by Gerow et al. (2005), the development of a W_s equation also requires the assessment of a suitable maximum TL for the estimation of quartiles. For each of the three species, the maximum TL was assessed as the length class for which at least three statistical populations were present in the dataset, three being the smallest sample size required for the estimation of quartiles (Gerow et al., 2005). For all the species considered, all specimens outside the estimated suitable length range were not used for further analyses.

2.3. Development of W_s equations

The W_s equations for *B. pergamonensis*, *C. bergamae*, and *L. irideus* were developed by using the empirical percentile (EmP) method proposed by Gerow et al. (2005). According to this method, the mean empirical W for each 1-cm TL class was estimated by the $\log_{10}$-transformed TL and W of each population; to develop the EmP W_s equation, the third quartiles of the mean empirical W estimated for each length class were plotted on TL by means of a weighted quadratic model (Gerow et al., 2005).

2.4. Validation of the W_s equations

A robust condition index should be free from length-related biases to enable comparison among fish of different lengths belonging to different populations (Murphy et al., 1991; Anderson and Neumann, 1996; Blackwell et al., 2000). Thus, to evaluate the reliability of the EmP W_s equations developed for *B. pergamonensis*, *C. bergamae*, and *L. irideus* and to detect potential length-related biases, the validation was carried out by means of two different methods: the residuals analysis of the W_s equations (to observe whether the distribution of residuals showed evident patterns) (Ogle and Winfield, 2009; Giannetto et al., 2012a) and the empirical quartiles (EmpQ) method (Gerow et al., 2004), applied using the FSA package (Ogle, 2009) of R software to evaluate if the value of the slope of the quadratic regression between the third quartile of the mean W standardized by W_s on 10-mm TL classes resulted in zero (Ogle and Winfield, 2009; Giannetto et al., 2012a).

3. Results

3.1. Validation of the datasets and development of specific length–weight and length–length equations

A total of 229 *B. pergamonensis*, 624 *C. bergamae*, and 372 *L. irideus* specimens were collected during the research throughout the watercourses of Muğla Province (Figure 1). The descriptive statistics of TL, FL, SL, and W for each species are summarized in Table 1. For *B. pergamonensis* and *C. bergamae*, new maximum total lengths were recognized: 22.9 cm and 34.8 cm, respectively. For *L. irideus*, the maximum total length of 11.4 cm found during the research represented the first reference for the

Figure 1. Map of Muğla Province (dark gray area) with localization of water bodies (white dots) sampled during the research.

Table 1. Descriptive statistics of total length (TL), fork length (FL), standard length (SL) and weight (W) with number of specimens (n), minimum (Min), maximum (Max), and mean value and standard deviation (Mean ± SD) for *B. pergamonensis*, *C. bergamae*, and *L. irideus.*

	Barbus pergamonensis (n = 229)			*Capoeta bergamae* (n = 624)			*Ladigesocypris irideus* (n = 372)		
	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
TL (cm)	2.7	22.9	11.2 ± 4.1	5.4	34.8	15.3 ± 5.7	2.4.	11.4	5.9 ± 1.2
FL (cm)	2.6	21.4	10.3 ± 3.9	4.9	31.9	13.9 ± 5.2	2.2	10.7	5.4 ± 1.3
SL (cm)	2.2	18.5	9.1 ± 3.5	4.1	26.5	11.7 ± 4.5	1.9	9.2	4.7 ± 10.3
W (g)	0.14	143.2	23.1 ± 25.4	1.52	526.8	56.7 ± 66.1	0.2	17.1	2.9 ± 2.1

species. For each species, the logarithmic TL–W equation calculated on the total sample and the SL–TL and FL–TL equations are summarized in Table 2.

The datasets of each of the three species were then divided into statistical populations: specifically, 18 for *B. pergamonensis*, 19 for *C. bergamae*, and 16 for *L. irideus.* For all species no population was identified as an outlier. For all of them, the value of R^2 was >0.95 and the *b* value was within the range of 2.5–3.5.

3.2. Assessment of the applicable total length ranges for the W_s equations

For *B. pergamonensis*, the minimum TL for the application of the W_s equation was assessed as 6 cm, while the maximum TL was 22 cm (Table 3). For *C. bergamae*, the minimum TL result was 8 cm, while 29 cm was the TL for which at least three different populations were present (Table 3). For *L. irideus*, a minimum TL of 6 cm and maximum TL of 10 cm (Table 3) were assessed.

3.3. Development of W_s equations

The W_s equations developed for the three species by means of the EmP method are reported below.

For *B. pergamonensis* (TL range: 6–22 cm):

$\log_{10}W_s = -5.713 + 3.718 \log_{10}TL - 0.166 (\log_{10}TL)^2$ ($R^2 = 0.999$).

For *C. bergamae* (TL range: 8–29 cm):

$\log_{10}W_s = -5.224 + 3.311 \log_{10}TL - 0.083 (\log_{10}TL)^2$ ($R^2 = 0.999$).

For *L. irideus* (TL range: 6–10 cm):

$\log_{10}W_s = -13.298 + 12.116 \log_{10} TL - 2.471 (\log_{10}TL)^2$ ($R^2 = 0.999$).

3.4. Validation of the W_s equations

For all three species, the residual values of the EmP W_s equations displayed a random distribution and did not exhibit evident patterns (Figure 2).

The proposed W_s equations were also not affected by length-related bias according to the EmpQ method. For all species, the value of the slope of the quadratic regression between the third quartile of the mean W standardized by W_s and length intervals of 10 mm resulted in no significant difference from zero for both terms of the equation (for *B. pergamonensis*: $P_{quadratic} = 0.524$, $P_{linear} = 0.937$; for *C. bergamae*: $P_{quadratic} = 0.163$, $P_{linear} = 0.495$; for *L. irideus*: $P_{quadratic} = 0.233$, $P_{linear} = 0.417$).

4. Discussion

Although several studies on the fish fauna of Muğla Province have been carried out (e.g., Özdemir et al., 2015), there is still a paucity of information on native and endemic species inhabiting this area. Our results derived from the present study provide new data for *B. pergamonensis*, *C. bergamae*, and *L. irideus*, which have poorly been studied. Given that all species under scrutiny require special attention as they are classified as vulnerable or near-threatened (IUCN, 2014), studies on

Table 2. Parameters of total length–weight (TL–W), total–standard length (TL–SL), and total–fork length (TL–FL) equations for *B. pergamonensis*, *C. bergamae*, and *L. irideus.*

Species	TL–W					SL–TL			FL–TL		
	a	Range a (95% CI)	b	Range b (95% CI)	R^2	A	b	R^2	a	b	R^2
Barbus pergamonensis	0.009	0.008–0.009	3.129	3.091–3.167	0.989	–0.197	0.832	0.988	–0.06	0.929	0.997
Capoeta bergamae	0.009	0.009–0.010	3.073	3.051–3.095	0.986	–0.828	0.769	0.984	–0.14	0.915	0.996
Ladigesocypris irideus	0.014	0.013–0.016	2.922	2.858–2.986	0.956	–0.042	0.816	0.972	–0.12	0.939	0.988

Table 3. Number of populations for each length class of 1 cm for the three species *B. pergamonensis*, *C. bergamae*, *L. irideus.*

TL (cm)	*B. pergamonensis*	*C. bergamae*	*L. irideus*
6	3	-	15
7	6	-	14
8	10	11	7
9	14	14	3
10	9	13	3
11	12	10	1
12	9	10	-
13	10	9	-
14	9	14	-
15	9	14	-
16	5	15	-
17	6	14	-
18	5	12	-
19	5	15	-
20	3	12	-
21	3	12	-
22	3	12	-
23	1	6	-
24	-	7	-
25	-	4	-
26	-	6	-
27	-	3	-
28	-	3	-
29	-	4	-
30	-	1	-
31	-	-	-
32	-	2	-
33	-	4	-
34	-	1	-
35	-	1	-

their ecology and biology should be increased; the present study encourages future studies in that regard. Indeed, recent evidence has strongly suggested that *C. bergamae* could be a different species (Levin et al., 2012); hence, the information obtained in the present study would constitute the first biological data for the species. In this context, the W_s equations proposed for the first time for these three endemic species will represent essential tools for the conservation and management of the species, since they will permit researchers to estimate the well-being of their populations. All of this information will assist in the design and implementation of protective measures and strategies for conservation and proper management of these endemic species in the region.

From the results of the validation analyses conducted, the W_s equations developed for *B. pergamonensis*, *C. bergamae*, and *L. irideus* were found not to be affected by length-related bias; their use in evaluating the W_r of the species across the watercourses of Muğla Province is thus recommended. These equations provide very useful species-specific tools to compare and evaluate the condition (well-being status) of endemic species living in different habitats and specimens of different lengths (e.g., Sülün et al., 2014). Furthermore, these data could be

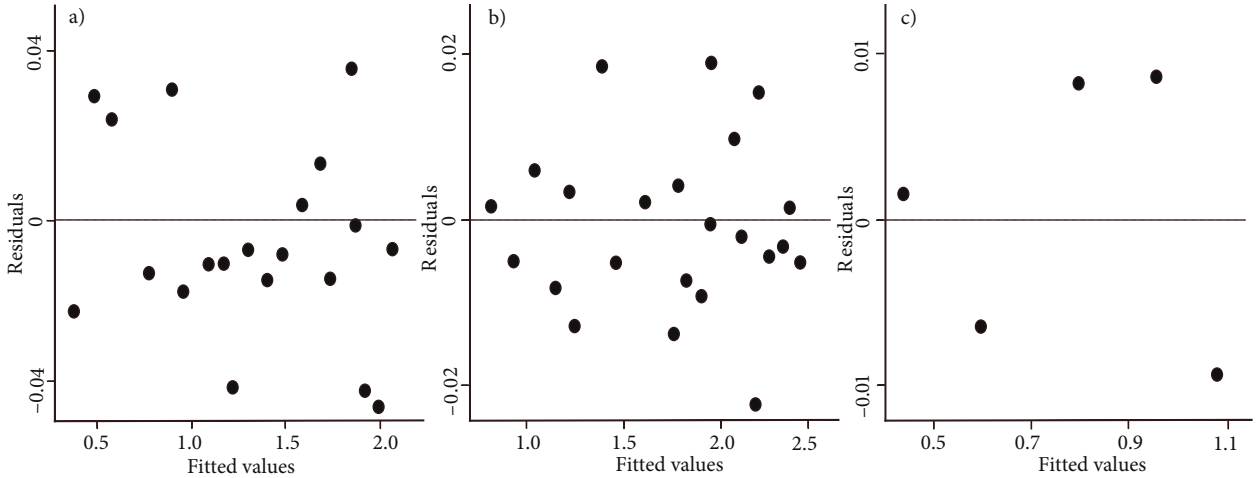

Figure 2. Plots of the analyses of residuals of the standard mass (W_s) equation for *B. pergamonensis* **(a)**, *C. bergamae* **(b)**, and *L. irideus* **(c)**. Residuals = standardized residuals of the regression; fitted values = values obtained by the model fit.

very informative for identifying important conservation areas where the species' conditions are high for special restocking practices, and for species' conservation and habitat rehabilitation for populations with lower body conditions (e.g., Giannetto et al., 2012c).

In this study, length–weight and length–length equations were also provided for the three species. For *L. irideus*, the provided TL–W equation and the maximum TL of 11.4 cm represent the first references reported for this species. For both *B. pergamonensis* and *C. bergamae*, new maximum total lengths were also found in the present study. For *B. pergamonensis*, Gaygusuz et al. (2013) previously reported a maximum TL of 20.9 cm; the specimens of 22.9 cm caught from the Tersakan River in the present study represent the new maximum reported TL for the species. For *C. bergamae*, an earlier maximum TL of 28.8 cm was stated (Gaygusuz et al., 2013), but in the samples analyzed during the present research, a new maximum TL of 34.8 cm was recognized from the Tersakan River. Although these large specimens could be unusual, these results have underlined the current lack of data on these species.

Moreover, the slope values of the length–weight relationships found in this study were higher than those reported in the literature (considering also the 95% confidence limits). More specifically, for *B. pergamonensis*, the value of *b* found in the present study was higher than those reported by Gaygusuz et al. (2013) (3.129 vs. 3.095) and Erk'akan et al. (2014) (3.129 vs. 2.997); for *C. bergamae* the value of *b* of the present study also was higher than values reported by Özcan (2008) for the Kemer Reservoir (3.073 vs. 2.63) and by Gaygusuz et al. (2013) (3.073 vs. 2.952). The reasons for these variances could be the different TL ranges and different sample compositions (more small or large specimens) of the statistical populations analyzed in the different studies (Froese, 2006).

Turkey has 78 endemic fish species, which are often restricted to very small areas and not yet intensively studied, as in the case of the three species analyzed in the present research. All these species are currently threatened by habitat disturbance (IUCN, 2012) and by the presence of a large number of nonnative species introduced into Turkish waters (Aydın et al., 2011; Tarkan et al., 2015). With regard to Muğla Province, the presence of nonnative fish species represents a serious threat for the native fish populations (Barlas et al., 2001; Önsoy et al., 2011; Özdemir et al., 2015). In this regard, the use of easy and humane tools such as relative weight measurements could contribute to the management and conservation status of these species (Murphy et al., 1991; Blackwell et al., 2000) and aid in assessing population-level responses to ecosystem disturbances due to environmental alterations or biological disturbance (i.e. the presence of nonnative species) (Giannetto et al., 2012b). The use of condition indices such as relative weight to evaluate the status of threatened rare or less-studied species is indeed strongly recommended (Didenko et al., 2004), since they are not invasive methods and do not require the sacrifice of the specimens (Fechhelm et al., 1995).

Relative weight is currently widely used to perform condition analysis of many species, but its applicability is often limited by the lack of species-specific standard weight equations. With reference to endemic Turkish species, specific W_s equations were developed for Aegean chub *Squalius fellowesii* (Giannetto et al., 2012c), another endemic species in the same region as the species studied in the present work, and Pursak chub *S. pursakensis* from the Marmara region (Sülün et al., 2014).

Further research is encouraged to extend the use of this methodology to other Turkish species and to promote monitoring and research to increase knowledge on the native fish fauna, with particular consideration to endemic species.

More specific studies of sampled areas could also assist in identifying local conditions that may affect important life history traits, food availability, and growth rates of these endemic species. Moreover, long-term studies of populations might be conducted to provide more knowledge of those species' conservation and population dynamics.

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