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# Length-weight, length-length and empirical standard weight equations for *Capoeta baliki*, *Capoeta sieboldii* and *Chondrostoma angorense*, three endemic cyprinid species of northwestern Anatolia

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**Abstract**

In this study, length and weight data for three endemic fish species of North-western Anatolia (*Capoeta baliki*, *Capoeta sieboldii* and *Chondrostoma angorense*) were collected throughout their distribution ranges and used to estimate length-length, total length (TL) – weight and empirical standard weight ($W_s$) equations. The obtained $W_s$ equations were: $\log_{10}W_s = -6.743 + 4.768 \log_{10} TL - 0.437 \log_{10} TL^2$ (TL range: 7-28 cm) for *C. baliki*; $\log_{10}W_s = -5.966 + 3.833 \log_{10}TL - 0.181 \log_{10} TL^2$ (TL range: 7-36 cm) for *C. sieboldii*; $\log_{10}W_s = -10.017 + 7.402 \log_{10}TL - 0.971 \log_{10}TL^2$ (TL-range: 7-24 cm) for *C. angorense.* For *C. angorense*, these data represent the first reference on length-weight relationship for this species. In addition, a new maximum length was reported for *C. baliki.*

**Keywords**: Body condition indices, Endemic species, *Capoeta baliki*, *Capoeta sieboldii*, *Chondrostoma angorense*, Relative weight.

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## Introduction

Anatolia is an important biodiversity hotspot for freshwater fish species and represents high level of endemism with nearly 300 native fish species of which more than one third endemic (Fricke *et al*., 2007). This endemic fauna is dramatically and constantly threatened mainly by pollution, introduction of non-native species, dam constructions, draining and over abstraction of water (Tarkan *et al.*, 2015). These factors have contributed to most of the endemic species in Turkey to be listed in the endangered status in IUCN (Hermoso and Clavero, 2011). Despite their importance, the available information on biology and ecology of endemic species is often very partial and this limits their proper conservation and management (Giannetto *et al.*, 2013).

The genus *Capoeta* is represented by nineteen species, seven of which are endemic to Turkey (Turan, 2008; Bektas *et al.*, 2017). Fourbarbel scraper *Capoeta baliki* Turan, Kottelat, Ekmekçi and Imamoglu, 2006 and Nipple-lip scraper *Capoeta sieboldii* (Steindachner, 1864) are two Turkish species endemic to Sakarya -Yeşilırmak drainages (Northwestern Anatolia, Turkey) (Freyhof, 2014 a, b) (Fig. 1). Both species are able to inhabit a wide range of water bodies (lakes, reservoirs and large rivers) and they are locally consumed as a low prized food fish. *C. baliki* and *C. sieboldi* are assessed as Least Concern according to the IUCN Red List of Threatened Species (Freyhof, 2014 a, b) despite they are strongly impacted by the massive presence of hydropower plants within their distribution range. Currently, there are no data on the population trends of these two species but it is suspected to be slowly declining (Freyhof, 2014 a, b).


**Figure 1: Distribution areas for *Capoeta baliki, Capoeta sieboldii* and *Chondrostoma angorense* (dark grey area) as reported by Freyhof (2014a,b,c) (modified).**

*Chondrostoma* is another cyprinid genus comprising around thirty freshwater species distributed throughout Europe and Asia (from the Iberian Peninsula to Iran) (Elvira, 1987; Nelva, 1988; Bogutskaya, 1997; Doadrio and Carmona, 2003). In Turkey the *Chondrostoma* genus occurs with eleven species five being endemic (Elvira, 1997; Geldiay and Balık, 2007; Özcan, 2009). Ankara nase *C. angorense* Elvira, 1987 is endemic to Sakarya and Kızılırmak River Basins (Northwestern Anatolia) (Freyhof, 2014c) (Fig. 1). The species of *Chondrostoma* reported from Sakarya River Basin were previously assessed as *C. nasus* (Linnaeus, 1758). Elvira (1987) described a new subspecies as *C. nasus angorensis.* There have been many reports of *C. nasus* from Turkey

(Mermer and Balık 1991; Aslan and Kiziroğlu 2003; Ünver and Ünver 2004), but the information on the biology and ecology of *C. angorense* is still very scarce. In this regard, Tarkan *et al.* (2007) noted that several old reports of *C. angorense* from Turkey might have been wrongly identified as *C. nasus*. Currently, *C. angorense* is accepted as a valid species and it is listed as Least Concern according to the IUCN Red List of Threatened Species (Freyhof, 2014c). Although the species is not assessed as threatened, it is principally impacted by hydropower development that it is largely diffused within the distribution area (Freyhof, 2014c). *C. angorense* is locally consumed as a low prized commercial species and, although specific data on population trends are not available, the species is expected to be slowly declining due to ongoing threats (Freyhof, 2014c).

All these endemic species are extremely affected by hydropower plants, especially those managed with peak floods, which could threaten their survival. Hydro-dam induces numerous changes in the aquatic ecosystems both upstream and downstream and can drastically change the fish community (Franchi *et al.*, 2014). In addition, the basins where the considered species occur have recently been severely polluted and affected by other serious habitat destruction such as water abstraction (Bostancı and Polat, 2009). To date, there are no conservation actions in place for these three species. Although the species are reported as abundant within the distribution area, monitoring of the populations should be considered to watch over declining populations. Detailed information on biology and ecology of these species are required for a proper management and to propose conservation actions where the information on their condition (well-being) represents a crucial component for this purpose (e.g. Blackwell *et al.*, 2000).

In this context, the estimation of the well-being of fish populations represents a useful tool for the study of fish populations (Anderson and Neumann, 1996; Blackwell *et al*., 2000; Froese, 2006). Relative weight ($W_r$) (Wege and Anderson, 1978) is an index of condition proposed to evaluate the well-being of one or more populations of fish compared to "standard" conditions (Gerow *et al.*, 2004). $W_r$ is estimated comparing the measured weight of a specimen (W) with a standard weight ($W_s$) that represents the weight in the same length of an ideal fish of the same species in good physiological condition (Blackwell *et al.*, 2000). $W_s$ is assessed by a standard weight equation that is a length-weight equation typical of the species. Then, the big advantage of $W_r$, when compared with the other condition indices proposed in the literature (i.e. Fulton's (1911) condition factor and Le Cren's (1951) condition factor), is that the species-specific $W_s$ equation allows to compare the condition of fish of different lengths and also belonging to different populations (Murphy *et al*., 1991).

The aim of this research was, thus, to develop length-length, length-weight

and empirical $W_s$ equations for these three endemic species of Northwest Anatolia (*C. baliki*, *C. sieboldii* and *C. angorense*) within their natural distribution ranges.

## Materials and methods

*Data collection and datasets validation*

Samples of the three species were collected during different monitoring studies carried out throughout the areas of distribution of the species (Table 1). Specimens were collected by means of electrofishing (SAMUS 725G) and each fish was measured for lengths (total (TL), standard (SL) and fork (FL) length) to the nearest mm and wet weight (W) to the nearest 0.1 g. The total dataset was then validated following the steps summarized by Giannetto *et al.* (2011). For each species a TL-W regression was computed for the total sample and all specimens that were large outliers were excluded, as they were probably derived from wrong measurements. Then, a log transformed TL-W regression and specific linear conversion models to convert SL and FL to TL were computed by means of the equations:

$\log_{10}W = \log_{10} a + b \log_{10} TL\ (mm)$,

$TL\ (mm) = a + b\ SL\ (mm)$

and

$TL\ (mm) = a + b\ FL\ (mm)$

where $a$ is the intercept on the Y-axis of the regression curve and $b$ is the regression coefficient.

**Table 1: List of the sampling stations for each species.**

| Species | GPS coordinates | River Basin |
|---|---|---|
| *C. baliki* | N 39 05 50; E 030 39 52 | Seydisuyu |
| | N 39 21 33; E 030 26 08 | Seydisuyu |
| | N 39 21 03; E 030 33 24 | Seydisuyu |
| | N 39 21 25; E 030 35 35 | Seydisuyu |
| | N 39 24 52; E 031 07 23 | Seydisuyu |
| | N 39 19 07; E 031 20 12 | Seydisuyu |
| | N 39 19 15; E 029 59 35 | Porsuk |
| | N 39 19 36; E 029 54 13 | Porsuk |
| | N 39 18 09; E 030 34 43 | Seydisuyu |
| *C. sieboldii* | N 39 19 15; E 029 59 35 | Porsuk |
| | N 39 19 36; E 029 54 13 | Porsuk |
| | N 39 16 24; E 029 13 44 | Emet |
| | N 39 28 11; E 029 15 17 | Emet |
| *C. angorense* | N 39 21 33; E 030 26 08 | Seydisuyu |
| | N 39 21 03; E 030 33 24 | Seydisuyu |
| | N 39 56 97; E 030 91 40 | Seydisuyu |
| | N 39 24 52; E 031 07 23 | Seydisuyu |

The validated dataset was separated into statistical populations according to Ogle and Winfield (2009). Data were further validated by computing a $\log_{10}TL$ - $\log_{10}W$ regression for each population (Bister *et al.*, 2000): all populations for which equation had $R^2$ value less than

0.90 or slope (*b* value) outside the range of 2.5-3.5 were removed from the dataset and excluded from further analyses (Froese, 2006). At last, the outliers from the regression between the value of slopes (*b*) and intercepts ($\log_{10}$ *a*) of all populations were removed because they probably represented the populations composed by few fish or samples with a narrow length-range (Froese, 2006).

*Selection of the applicable total length range for the $W_s$ equations*

The development of a $W_s$ equation requires a previous selection of a suitable applicable length-range (Willis *et al*., 1991). The minimum applicable length is required due to the high variance in the measurements of the small fishes: juvenile stages have different growth patterns and, in addition, a higher potential error is associated to the measurement of the small specimens in the field (Froese, 2006; Giannetto *et al*., 2012a). As suggested by Willis *et al.* (1991), the minimum applicable total length was assessed by the plot between the variance/mean ratio of $\log_{10}$W and TL intervals (1 cm) as the size at which the value of that ratio was smaller than 0.01.

As suggested by Gerow *et al.* (2005), the maximum application length was determined as the maximum size that occurs in at least three fish populations in the dataset being three the smallest number required for the estimation of quartiles. All specimens of the dataset with a length outside the selected applicable range were removed and not further utilized for analyses.

*Calculation of Empirical $W_s$ equation*

The Empirical Percentile (EmP) method proposed by Gerow *et al.* (2005) was used to develop the $W_s$ equation for *C. baliki*, *C. sieboldii* and *C. angorense*. According to this method, for every 1-cm length-class the mean empirical W was estimated by the logaritmic TL-W equation of the different populations; then the 75° percentile of these estimated mean empirical W were plot on TL by means of a weighted quadratic model.

*Validation of the developed EmP $W_s$ equations*

The $W_s$ equations developed for the three species were validated to detect any potential length-related biases. To this aim two different methods were applied: the residuals analysis of the $W_s$ equation (to investigate whether the distribution of residuals exhibits evident patterns) (Ogle and Winfield, 2009; Lorenzoni *et al*., 2012) and the Empirical Quartiles (EmpQ) method (Gerow *et al.*, 2004) by means of the FSA package version 0.3.2 (Ogle, 2012) of R Software (to determine if the slope of the quadratic regression of the 75° percentile of the mean W standardized by $W_s$ against length intervals of 1-cm had a value of zero) (Ogle and Winfield, 2009; Lorenzoni *et al.*, 2012).

**Results**

A total of 863 *C. baliki*, 177 *C. sieboldi* and 372 *C. angorense* collected across

the distribution ranges of the species were used in the research. The basic descriptive statistics (TL, FL, SL and W) of the samples used were summarized in Table 2. For *C. baliki* a new maximum total length was recognized as 40.7 cm. The estimated SL-TL, FL-TL and the log-transformed TL-W equations for the three species were summarized in Table 3.

**Table 2: Descriptive statistics of total length (TL), fork length (FL), standard length (SL) and weight (W) with minimum (Min), maximum (Max), mean value and standard deviation (Mean±SD) for *Capoeta baliki, Capoeta sieboldii* and *Chondrostoma angorense.***

| | ***Capoeta baliki*** | | | ***Capoeta sieboldii*** | | | ***Chondrostoma angorense*** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Min** | **Max** | **Mean±SD** | **Min** | **Max** | **Mean±SD** | **Min** | **Max** | **Mean±SD** |
| **TL (cm)** | 4.2 | 40.7 | 15.4±5.2 | 7.1 | 43.7 | 20.9±8.3 | 6.8 | 24.7 | 17.6±3.4 |
| **FL (cm)** | 3.7 | 37.3 | 14.1±4.7 | 6.3 | 39.8 | 18.8±7.5 | 6.2 | 22.4 | 16.3±3.1 |
| **SL (cm)** | 3.3 | 34.7 | 12.6±4.4 | 5.6 | 36.2 | 17.1±6.9 | 5.5 | 21.1 | 14.8±2.9 |
| **W (g)** | 1 | 753 | 50.2±60.9 | 3.0 | 842 | 130.2±147.9 | 2.4 | 137 | 55.5±22.9 |

**Table 3: Estimated parameters of logarithmic total length-weight (TL-W), total-standard length (SL-TL) and total-fork length (FL-TL) equations for *Capoeta baliki, Capoeta sieboldii* and *Chondrostoma angorense.***

| | **TL-W** | | | **SL-TL** | | | **FL-TL** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **$\log_{10}a$** | **b** | **$R^2$** | **a** | **b** | **$R^2$** | **a** | **b** | **$R^2$** |
| ***C. baliki*** | -4.875 | 2.9429 | 0.974 | 5.040 | 1.1755 | 0.996 | 1.4368 | 1.0873 | 0.996 |
| ***C. sieboldii*** | -5.063 | 3.0173 | 0.989 | 3.869 | 1.189 | 0.997 | -0.121 | 1.103 | 0.997 |
| ***C. angorense*** | - 5.581 | 3.241 | 0.986 | 0.5090 | 0.115 | 0.989 | 0.148 | 0.107 | 0.993 |

The datasets were separated into statistical populations: 26 for *C. baliki*, 10 for *C. sieboldii* and 16 for *C. angorense.* For all populations of the three species the value of $R^2$ was always bigger than 0.95 and the *b* value results within the range of 2.5 - 3.5 therefore no populations were removed from the datasets.

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

For *C. baliki* (TL-range: 7-28 cm):

$\log_{10}W_s$=-6.743+4.768 $\log_{10}$ TL-0.437 $(\log_{10}\text{TL})^2$ ($R^2$ = 0.999).

For *C. sieboldii* (TL-range: 7-36 cm)

$\log_{10}W_s$=- 5.966+3.833 $\log_{10}$TL-0.181 $(\log_{10}\text{TL})^2$ ($R^2$ = 0.999).

For *C. angorense* (TL-range: 7-24 cm):

$\log_{10}W_s$= -10.017 + 7.402 $\log_{10}$TL - 0. 971 $(\log_{10}\text{TL})^2$ ($R^2$ = 0.991).

The residuals values of the proposed $W_s$ equations displayed a random distribution and did not exhibit evident patterns for all the three considered species (Fig. 2a, b and c). Applying the EmpQ method, the value of the slope was not significantly different from zero for both terms of the equations (for *C. baliki*: $p_{quadratic}$=0.775, $p_{linear}$=0.921; for *C. sieboldii*: $p_{quadratic}$=0.958, $p_{linear}$=0.982; for *C. angorense*: $p_{quadratic}$=0.755, $p_{linear}$=0.879) suggesting the absence of any length related bias for the proposed $W_s$ equations.

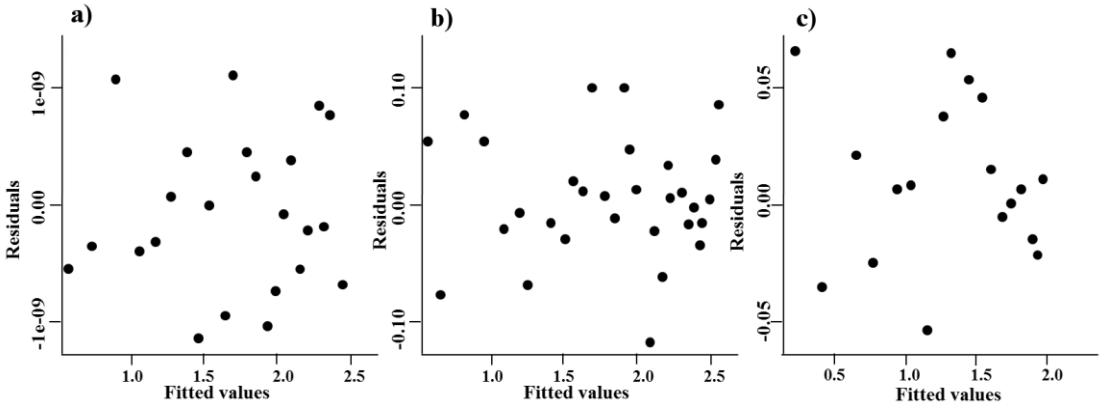


**Figure 2: Plots showing the distribution of the residuals used to investigate potential length-bias in the standard weight ($W_s$) equations for a) *Capoeta baliki,* b) *Capoeta sieboldii* and c) *Chondrostoma angorense*. (Residuals= standardized residuals of the regression; Fitted values= values obtained by the model fit).**

## Discussion

Condition indices have been used in fisheries research since the beginning of the 20th century (Froese, 2006) as an easy tool to assess the well-being of the specimens without sacrificing them. Among the condition indices proposed in literature, $W_r$ was found to be the most trustful being not influenced by changes in fish body shape (Gerow *et al*., 2004). Thus, variations in $W_r$ values can be primarily due to extant ecological factors (Blackwell *et al*.., 2000). Relative weight is currently widely used in the United States of America as a basic tool for fisheries management. With regard to Turkey, currently the sporadic utilization of this method is due to the lack of specific $W_s$ equations for each species that have to be developed considering a wide dataset representative of the length-range of the species and collected throughout its distribution area. Specific $W_s$ equations have been proposed only for a few endemic Turkish freshwater species: *Barbus pergamonensis, Capoeta bergamae* and *Ladigesocypris irideus* (Giannetto *et al*., 2015), *Squalius fellowesii* (Giannetto *et al*., 2012b) and *Squalius pursakensis* (Sulun *et al*., 2014).

On the basis of the results of the present study, the use of the proposed EmP equations to determine $W_r$ for the considered species throughout their area of distribution is suggested. Further research is encouraged to extend the use of this methodology to other species with particular attention to those endemic.

For *C. angorense*, the estimated TL-W represents the first reference for the species. To the authors' knowledge, any previous studies on this species have been carried out and this lack of basic knowledge on biology of this species is also remarked on Fishbase (Froese and Pauly, 2016).

For *C. baliki*, the *b* value of the TL-W equation estimated in this study (2.942) was lower than that reported by Gaygusuz *et al*. (2013a) from Sakarya River (3.017). In addition to the proposed equations, a new maximum total length (407 mm) was stated for

this species. This finding underlined the representativeness of the dataset used in the present study and contributed to strengthen the validity of the results. The new maximum total length was considerably higher than that previously reported for the species by Gaygusuz *et al*. (2013a) from Sakarya River (322 mm). This can be attributed to the low level of fishing pressure other than the negligible effects of the low number of anglers in the distribution range of the species. These new findings remark the current lack of information on the biology of these endemic species and suggest the need for more detailed studies.

With regard to *C. sieboldii*, the estimated value of the *b* found in the present study (3.107) was in line with the results of other previous studies reporting local length-weight relationships for some populations of the species (Ekmekci, 1996; Yildirim *et al*., 2008; Yılmaz *et al*., 2010). On the other hand, Gül *et al*. (2005) reported a lower value of *b* (2.71) for the population of the Delice Branch of Kızılırmak River. As noted by Bagenal and Tesch (1978), the parameters of the length-weight equations in fish can be affected by a number of factors including food availability, feeding rate, spawning period as well as season, sex and habitat. In addition, Froese (2006) remarked that lenght-weight equations could also be affected by the length-range and composition of the sample used to calculate. For all these reasons it is suggestible to estimate length-weight equations by using a large dataset covering a reasonable geographic range of the species and inter-annual variations. Indeed, according to Froese (2006), only in these cases it is possible to discuss isometric versus allometric growth of the species as a whole by using the value of *b*.

Gaygusuz *et al*. (2013b) provided relative condition factors of several native and endemic freshwater fish species from western Anatolia living with and without non-native species to reveal the potential impact of non-native species on native and endemic species and they found out that *C. sieboldii* had better conditions in the absence of non-native *Carassius gibelio*. However, relative condition index (Le Cren, 1951) has some restrictions that populations in comparison should be sampled at the same time of the year and preferably under similar environmental conditions (Lorenzoni *et al.*, 2015) whereas relative weight allows reliable comparisons among different locations and specimens of different lengths. Indeed, Giannetto *et al*. (2012c) successfully used mean relative weight of native fish species of Tiber River basin (Italy) with the same purpose and found very similar results (i.e. the condition of some of the endemic species had significantly worse when non-native species were present than when non-native species were absent). Non-native and invasive fish species have commonly been found (especially the one that is considered as most invasive species, *C. gibelio* in Anatolia) in the natural distribution range of all populations of the species under study

(Tarkan *et al*., 2012), which is one of the most threatening factors along with habitat destructions for endemic species. Recent observations have confirmed that *C. sieboldii* has not been found despite its high abundance in early 2000s in Porsuk stream (pers. obser. Emiroğlu, Aksu and Başkurt) where *C. gibelio* invasion has taken place (Gaygusuz *et al*., 2013b).

For all these reasons, as it is the case in the present study, the use of standardized methods as relative weight or specific length equations to study fish populations is strongly recommended being easy and not cruel tools that can assist in comparing populations of the same species inhabiting different habitats or biotopes.

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