Turkish Journal of Zoology
http://journals.tubitak.gov.tr/zoology/
Research Article
Turk J Zool
(2018) 42: 694-699
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doi:10.3906/zoo-1802-36

Standard weight equations of two sub-/tropic nonnative freshwater fish, *Clarias gariepinus* and *Oreochromis niloticus*, in the Sakarya River Basin (NW Turkey)

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Received: 23.02.2018 • **Accepted/Published Online:** 25.10.2018 • **Final Version:** 12.11.2018

Abstract: *Clarias gariepinus* and *Oreochromis niloticus* are two hot-water fish species of African origin that have been recently reported to occur unnaturally in hot-water resources and springs in the Sakarya River Basin (northwestern Turkey). Within effective planning strategies to maintain native biodiversity, monitoring fishes' well-being can be useful to evaluate the status of nonnative fish populations and their degree of adaptation to new environments. Relative weight (W_r) is a condition index widely used to estimate the well-being of fish by comparing the actual weight of a specimen with a standard weight (W_s) that is the ideal weight of that fish at that length. In this study, length and weight data of *C. gariepinus* and *O. niloticus*, collected throughout the Sakarya River Basin, were used to estimate W_s equations. The resulting W_s equations were $\log_{10}W_s = -3.668 + 1.885 \log_{10}TL + 0.2087 (\log_{10}TL)^2$ (TL range: 18–45 cm) for *C. gariepinus* and $\log_{10}W_s = -8.796 + 6.751 \log_{10}TL - 0.8479 (\log_{10}TL)^2$ (TL range: 8–28 cm) for *O. niloticus*. The use of these W_s equations to estimate the fishes' condition is suggested as a monitoring tool to assess the status and the best management actions of these two nonnative species populations throughout the Sakarya River Basin.

Key words: Condition index, nonnative species, translocated species, length-weight equation, relative weight

1. Introduction

In the last two centuries, a wide number of alien fish species have been introduced into freshwater ecosystems mainly for trading, aquaculture, and game fishing (Cox, 1998; Rahel, 2007). The worldwide deliberate and unintended spreading of nonnative species is now considered one of the main threats to biodiversity and the second leading cause of animal extinctions (Clavero and García-Berthou, 2005; Toussaint et al., 2016; Piria et al., 2018). In conjunction with introduction, translocations of species from native ranges to other basins within the same country are also common worldwide practices (Cox, 1998; Tarkan et al., 2015).

North African catfish *Clarias gariepinus* (Burchell, 1822) and Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758) are two hot-water (subtropic and tropic) fish species of African origin introduced worldwide for aquaculture purposes (Vitule et al., 2006). Both species are valuable for aquaculture due to their fast growth, resistance to diseases, and high stocking density (Lal et al., 2003). However, released specimens are able to quickly spread to nearby natural waters, escaping from aquaculture ponds or through river flooding (Vitule et al., 2006). Both *C. gariepinus* and *O. niloticus* are known to severely impact native biodiversity in their regions of introduction (Verreth et al., 1993; Lal et al., 2003; Amin et al., 2009; Khan and Panikkar, 2009; Booth et al., 2010). For all these reasons both species are currently assessed as potential pests worldwide (www.fishbase.org). With regard to Turkey, these species were assessed as having a "high risk" of being invasive by the Aquatic Species Invasiveness Screening Kit (AS-ISK) to assess the potential invasiveness for aquatic species (Tarkan et al., 2017).

C. gariepinus naturally occurs only in the southern part of Turkey from Manavgat to the Orontes River (Geldiay and Balık, 2007). Nevertheless, in the late 1970s the species was translocated to the Sakarya River from the Göksu River for scientific purposes (Erençin, 1978; Ergüven,

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1978). The peculiar environmental conditions of geothermal waters in the Sakarya River Basin give excellent potential for the acclimatization of the species and *C. gariepinus* has been stated as the most severe threat for endemic/native fish species in the upper Sakarya Basin (Emiroğlu, 2011). *C. gariepinus* was also reported to exacerbate habitat degradation and the spread of diseases and new parasites (Booth et al., 2010; Tepe et al., 2013).

O. niloticus was first introduced in south-central Turkey for scientific and aquaculture purposes (Tekelioğlu, 1991; Emiroğlu, 2011). Currently, several acclimatized populations are known from Çukurova, the Orontes River, Hirla Lake, and Köyceğiz Lake, where the species dominates the fish fauna and threats the native fish communities (Çelik and Gökçe, 2003; Başusta et al., 1996; Akin et al., 2005). *O. niloticus* is known to adversely impact self-recruiting native fish species because its high-density populations can strongly compete and dominate at spawning grounds (Perdikaris et al., 2000; Piria et al., 2018). In the Sakarya River Basin the species was introduced probably in the late 1990s and it is now present with large colonies throughout the region (Emiroğlu, 2011).

To be effective, any approach to preserve biodiversity involves an adequate knowledge of nonnative populations in order to evaluate their potential threats to native fauna. Monitoring of fishes' conditions can be useful to evaluate the status of fish populations and their degree of adaptation to new environments. Relative weight (W_r) (Wege and Anderson, 1978) is an index of condition estimated by comparing the actual weight of a specimen with a standard weight (W_s) that is the ideal weight of a fish of the same species and size in good physical condition estimated by species-specific W_s equations (Bister et al., 2000). While the methodology is currently commonly used in the United States (Blackwell et al., 2000), its use in other countries is still limited, probably because of the lack of specific W_s equations (Giannetto et al., 2015a). With regard to Turkey, specific W_s equations are currently available only for some endemic freshwater species (Giannetto et al., 2012c; Sülün et al., 2014; Giannetto et al., 2015b; 2019).

The main aim of this research was to propose specific W_s equations for *C. gariepinus* and *O. niloticus* from the Sakarya River Basin. A further aim was to provide the general models of length-length and length-weight for these species. Since both species' survival and distribution mainly dependent on hot-water resources across the basin, the results of the study should represent a useful tool for the management of these nonnative species in the Sakarya River Basin and to investigate the adaptability of the two species to new environments.

2. Materials and methods

Specimens of *C. gariepinus* and *O. niloticus* were collected by means of electrofishing (with a backpack - SAMUS 725G, from a boat - LANJING LJ-4085NP-24V IGBT NC Fish Shocker) across the Sakarya River Basin during different monitoring studies carried out to study the fish biodiversity of the basin (Figure 1). After capture, each fish was measured for lengths (total (TL) and standard (SL)) to the nearest mm and wet weight (W) to the nearest 0.1 g. Specific linear conversion models to convert SL to TL and a log-transformed TL-W regression for the two species were computed by means of the following equations:

Figure 1. Area of collection of the data (black rectangle = Sakarya River Basin; yellow dots = locations of the field stations within the Sakarya River Basin) (courtesy of Google Earth).

TL (mm) = *a* + *b* SL (mm)
and
$\log_{10}$W = $\log_{10}$ *a* + *b* $\log_{10}$ TL (mm),
where *a* is the intercept on the Y-axis of the regression curve and *b* is the regression coefficient (Ricker, 1975; Froese, 2006).

Then the total dataset was validated and screened according to the procedure recommended by Giannetto et al. (2012b). All the anomalous values (outliers) were removed from the regressions because they were almost certainly the consequence of incorrect measurements in the field (Bister et al., 2000). For each species, the total dataset was divided into "statistical populations" with every population consisting of data collected at the same sampling location (Sülün et al., 2014). The estimation of a W_s equation includes the preliminary determination of a proper range-length: a minimum and a maximum length of applicability. The minimum TL was estimated according to Willis et al. (1991) as the length at which the ratio variance/$\log_{10}$W mean was less than 0.01 (Murphy et al., 1991). The maximum TL was identified as the TL class in the dataset that was present in at least three different statistical populations (Gerow et al., 2005). All the specimens smaller or bigger than this proper length range were excluded from the dataset and not used in the subsequent analyses. For each statistical population of the two species a log-transformed TL-W regression was estimated separately to identify and remove the potential outliers (Bister et al., 2000). The resulting equations for all the populations were then screened to remove all the samples showing R^2 values less than 90% or a value of *b* outside the 2.5–3.5 range because, according to Carlander (1977), these anomalous values of *b* or R^2 could derive from statistical populations with narrow length range.

The empirical percentile (EmP) method proposed by Gerow et al. (2005) was used to estimate the W_s equation for the two species. According to the EmP method, for every 1-cm length class the mean empirical W was estimated by the logarithmic TL-W equation of the single statistical populations; after the 75th percentile of the estimated mean empirical *W* values were plotted against TL to estimate the EmP W_s equation by using a weighted quadratic model (Gerow et al., 2005).

The developed EmP W_s equations were then validated to investigate the potential influence of length-related bias (Gerow et al., 2004), applying two different methods: analysis of residuals' distribution versus fitted values of the W_s equation (Lorenzoni et al., 2012) and the empirical quartiles (EmpQ) method proposed by Gerow et al. (2004). Both methods were assessed by the Fisheries Stock Assessment package (FSA) (v 0.8.17) (https://cran.r-project.org/web/packages/FSA/index.html) with R software (R Development Core Team, 2016) to verify whether the slope of the plot between the 3rd quartile of mean W (standardized by W_s) and the 1-cm TL class was zero (Giannetto et al., 2016).

3. Results

During the study, a total of 521 specimens (261 *C. gariepinus* and 260 *O. niloticus*) were analyzed (Table).

The estimated SL-TL equations were:

TL = 6.7518 + 1.1301 SL (R^2 = 0.995; n = 261; TL range: 15–71.7 cm) for *C. gariepinus*
and
TL = 2.2918 + 1.2336 SL (R^2 = 0.994; n = 260, TL range: 8–28.9 cm) for *O. niloticus*.

The log-transformed TL-W equations were:

$\log_{10}$W = −4.9634+ 2.923 $\log_{10}$TL (mm) (R^2 = 0.973, n = 261) for *C. gariepinus*
and
$\log_{10}$W = −5.0447+ 3.159 $\log_{10}$TL (mm) (R^2 = 0.991, n = 260) for *O. niloticus*.

For both species, the total datasets were divided into statistical populations, and for all of them the value of R^2 was >0.95 and the *b* value resulted in the range of 2.5–3.5. Thus, no populations were removed.

For *C. gariepinus* the minimum TL was identified to be 18 cm and the maximum TL was 45 cm. For *O. niloticus* the applicable range was 8–28 cm.

The resulting W_s equations were:

$\log_{10}W_s = -3.668 + 1.885 \log_{10}TL + 0.2087 (\log_{10} TL)^2$ for *C. gariepinus* and

$\log_{10}W_s = -8.7961 + 6.751 \log_{10}TL - 0.8479 (\log_{10} TL)^2$ for *O. niloticus*.

For both species, the residuals distribution of the EmP W_s equations displayed a random distribution and did not exhibit evident patterns (Figure 2). From the EmpQ method no length-related bias emerged for either species (for *C. gariepinus* $p_{quadratic}$ = 0.325, p_{linear} = 0.537; for *O. niloticus* $p_{quadratic}$ = 0.147, p_{linear} = 0.394).

4. Discussion

The EmP W_s equations developed in this study were not affected by length bias and their use to estimate W_r for

Table. Descriptive statistics for the samples of *C. gariepinus* and *O. niloticus* collected from the Sakarya River Basin.

		N	Mean	Min	Max	SD
C. gariepinus	TL (mm)	261	320	150	717	76.17
	SL (mm)		277	130	645	67.03
	W (g)		276	24	3816	309.71
O. niloticus	TL (mm)	260	198	30	289	53.92
	SL (mm)		158	25	234	43.50
	W (g)		198	0.5	543	127.51

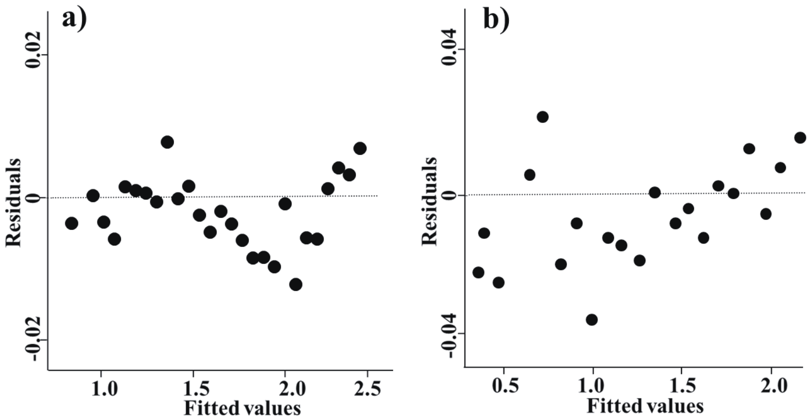

Figure 2. Distribution of the residuals used to investigate potential length-bias in the standard weight (W_s) equation for *C. gariepinus* (a) and *O. niloticus* (b) from the Sakarya River Basin (residuals = standardized residuals of the regression; fitted values = values obtained by the model fit).

C. gariepinus and *O. niloticus* across the Sakarya Basin is suggested. A further result of the study was the estimation of length-length and total length-weight equations for *C. gariepinus* and *O. niloticus* from the Sakarya River Basin.

Previous studies on length-weight for *C. gariepinus* from its native Turkish range are available in the literature: Yalçın et al. (2002) reported a value of *b* of 2.82 (length range: 12.0–82.6 cm) from the Orontes River, whereas Özcan (2008), examining samples collected from the Hatay commercial fish market, reported a *b* value of 2.967 (length range: 18.2–47.0 cm). In this study, the value of *b* for the length-weight relationship was estimated as 2.923 (length range: 15–71.7 cm) for the sample from the Sakarya River Basin. The differences may be due to the dissimilar length ranges and sample sizes, but it cannot be ruled out that differences in *b* values could illustrate different growth rates between native and translocated populations. In this regard, Turan et al. (2005) reported high morphologic differentiations among six populations of *C. gariepinus* from Turkey with the sample from Sakarya highly diverging from the other populations and they suggested that those differentiations may be related to different environmental conditions of the Sakarya River, though the species is widely tolerant to extreme environmental conditions.

For *O. niloticus* the *b* value of the TL-W in the Sakarya River Basin was 3.16 (length range: 8.0–28.9 cm). To the authors' knowledge, no previous data on *O. niloticus* from Turkey have been available in the literature. Comparing the value of *b* with the data reported on FishBase (www.fishbase.org) for populations of *O. niloticus* from other countries, it is possible to underline that all the samples with similar *b* values (and similar length ranges) refer to nonnative populations.

Due to the risks of new introduction, acclimation, and competition with native/endemic species, especially under the condition of climate change predicted for Turkey (Tarkan et al., 2017), the potential impacts of these two species are expected to be exacerbated. Therefore, it is essential to monitor and manage their spread throughout Turkey and investigate their impact on native fish communities. To this end, assessment of well-being could be a useful tool to investigate the general status of nonnative populations and the degree of adaptation to new environments. Indeed, body condition indices have already been successfully used to assess the impact of nonnative species on natural and endemic species (Giannetto et al., 2012a; Gaygusuz et al., 2013). The current findings might also be particularly important for future eradication practices by giving priority to the populations in relatively higher conditions.

Overall, further specific studies are encouraged to better investigate the characteristics of these species in the Sakarya River Basin and to collect data on other populations of the species from Turkey. Such information can contribute to the development of specific management plans aiming to minimize the impacts of these species on native fish communities and environments.

Acknowledgment
This study was produced through the support by the Çifteler Municipality and the Research Fund of Eskişehir Osmangazi University with the project entitled "Support the native fish populations through the suppression of invasive freshwater fish species, in the Sakarbaşı in Çifteler" and coded 2016-1099.

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