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Length-Weight Relationships of *Pseudorasbora parva* (Temminck and Schlegel, 1842) Around the World

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Key words
***Pseudorasbora parva*, Length-weight relationship, Indigenous and non-indigenous populations, Invasive fish, Condition and fitness of population**

ABSTRACT

Pseudorasbora parva (Temminck and Schlegel, 1842) has a significant potential to spread outside of its current locations and regions, all-continents-spanning invasive range. The invasion of *P. parva* has threatened the existence of native species. Therefore, evaluation of the condition and fitness of the invasive *P. parva* population in different regions is necessary. However, no systematic reports of the *P. parva* length-weight relationships (LWRs) around the world has been documented, especially comparing indigenous and non-indigenous populations. Thus, the goal of the current study was to offer a systematic report of *P. parva* LWRs worldwide and a comparison of *P. parva* LWRs in native and non-native regions. In the present results, *P. parva* showed positive-allometric growth, it became more rounded as the length increases, and both native and invasive populations showed similar growth patterns and form factor. Considering its invasive potential, the harmful effects of this alien species cannot be ignored. The present research will also focus on eliminating or mitigating the adverse effects caused by the further expansion of the species through a series of prevention and management strategies proposed.

INTRODUCTION

Over the past two centuries, the number of invasive species has quickly expanded, posing a serious threat to biodiversity (Xiong *et al*., 2015; Seebens *et al*., 2017; Cuthbert *et al*., 2021). Among these invasive species, *Pseudorasbora parva* (Temminck and Schlegel, 1842), one notorious small freshwater Cyprinid species with a pan-continental invasion, is of special concern and an iconic example that could be used for explaining this detrimental impact (Carosi *et al*., 2016). This species is native to Japan, China, the Korean peninsula, and Russia (Gozlan, 2002). Due to the importation of Chinese silver and grass carps for aquaculture in the 1960s, *P. parva* was unintentionally introduced to Romania, Hungary, and other nations bordering the Black Sea (BĂNĂRescu, 1964; Gozlan *et al*., 2010). Later, the species spread throughout the Danube basin in a westward direction (Gozlan *et al*., 2010). The species currently has a pan-European invasion with distributions in more than half of the European countries (Froese and Pauly, 2022). It is therefore regarded as the most invasive fish on the continent (Gozlan *et al*., 2005). Additionally, it has established successful wild invasive populations in more than 40 nations in Asia, Europe, and Africa (Fig. 1) (Kottelat and Freyhof, 2007;

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Gozlan *et al*., 2010; Froese and Pauly, 2022). Even worse, this fish has a significant potential to spread to locations and regions outside of its current, all-continents-spanning invasive range (Fletcher *et al*., 2016).

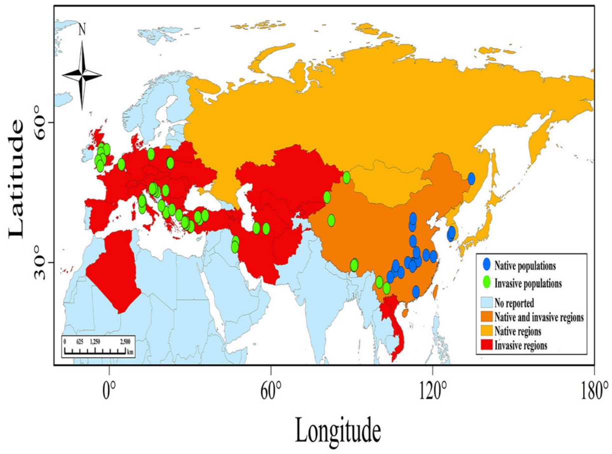

Fig. 1. As a result of the distribution study in the Fishbase, *Pseudorasbora parva* (Temminck and Schlegel, 1842) was found in 43 countries (Froese and Pauly, 2022). In spite of the fact that China is classified as the source of this fish in Fishbase, vast swaths of western China have been invaded by this species and have caused great harm (Jia *et al*., 2019). In accordance with this, China was categorized as both a native and an invasive region (dark yellow range), whilst the Korean peninsula, Japan, Russia, and Mongolia were categorized as native regions (light yellow ranges) and others as invasive regions (red ranges). There have been reports of both native (blue solid circles) and invasive (green solid circles) length-weight relationships (LWRs) for this species in 12 different countries.

The invasion of *P. parva* has threatened the existence of native species through predation, competition for resources (such as food and habitat), hybridization, and disease transmission (Gozlan *et al*., 2005, 2010), putting the local biodiversity and ecosystems at risk (Gozlan *et al*., 2010). The greater the fitness of the invasive fish population in a region, the greater threat to the existence of native species. Therefore, evaluation of the condition and fitness of the invasive *P. parva* population in different regions is necessary.

There were several parameters used to evaluate the condition and fitness of fish population in a region, such as the length-weight relationship (LWR), lipid accumulation and population structure (Arts and Wainman, 1999; Schiemer, 2000; Verreycken *et al*., 2011). Among these indices, LWR, as one of the most effective and convenient tools for evaluating the condition and fitness of the fish population, has been widely used in fisheries management (Froese, 2006). And the LWR for this species of fish has been documented in some publications (Fei, 2012; Tang *et al*., 2013). However, the majority of these *P. parva* LWRs results came from research in a single area (Supplementary Table I) (Liu *et al*., 2016; Arslan and Özeren, 2019; Benzer and Benzer, 2020a). No systematic reports of the *P. parva* LWRs around the world has been documented, especially comparing indigenous and non-indigenous populations.

As a result, the goal of the current study was to offer a systematic report of *P. parva* LWRs worldwide and a comparison of *P. parva* LWRs in native and non-native regions. The present research sought to answer the following question: Whether a significant difference in *P. parva* LWRs between indigenous and non-indigenous populations or not?

MATERIALS AND METHODS

Data collection and sampling

Data on LWRs of *P. parva* were gathered from all available published literature sources, including peer-reviewed papers, dissertations, conference minutes, reports, and our field investigation (Supplementary Table I). Since the majority of LWRs reported in the literature were from invasive regions, we also estimated a LWR of *P. parva* that was sampled from one native region in Jiangjin Town (29°17′ N, 106°15′ E) in Chongqing Municipality, the upper reaches of the Yangtze River (Fig. 1). Fish were caught using hooks, drift gill nets (mesh: 1.0 cm × 2.0 cm × 3.0 cm), and electrofishing (depth: 30–60 cm; near the beach) between December 2011 and September 2012. Individual fish was measured for total length (nearest to 1 mm) and body weight (nearest to 0.1 g).

In total, data about LWRs of *P. parva* (98 sexed: 78 combined sexes, 10 males and 10 females) were obtained from literature and our investigation which were published or conducted between 1990 and 2021 in twelve countries (Supplementary Table I). Those records that were considered in this study have a correlation coefficient greater than 0.8, and the records were not marked as questionable because of potential misidentifications or other factors (Froese, 2006). Due to 5 records (invasive populations in Supplementary Table I) with coefficient of determination below 0.8, these populations were excluded from subsequent analyses that were used in the remaining 93 populations studied, of which sixty-seven LWRs were from invasive regions and other twenty-six from native regions (Supplementary Table I).

Length-weight relationship and form factor

The estimated parameters for the equation $W = aL^b$, where W is the wet body weight (g); L is the total length

(TL, cm); a is the intercept; and b is the slope (Froese, 2006). Parameter a was obtained by the anti-logarithmic transformation (log is the logarithm to the base 10) when the LWR was only expressed in the logarithmic form (e.g. $\log W = \log a + b\log L$) and depended on the units chosen and the value of the exponent (Froese, 2006). Since most LWRs measured length in cm and expressed it as TL conversion factors $a_{cm} = a_{mm}10^b$ and $a_{TL} = a_{LS}$ (TL / LS)$^{-b}$ (where LS is length type in the original study by fork length (FL) or standard length (SL); TL/ FL= 1.10, TL/SL= 1.22, as estimated from FishBase) were used for all those studies reporting length in mm and/or LS (Supplementary Table I) (Froese, 2006). The exponent, b, is independent of the system of units chosen and has a straightforward physical meaning that an ideal fish has a "b" value of 3 (Fig. 2), indicating isometric growth by the one-sample t-test, which is widely used as a scale in the study of LWRs (Froese, 2006).

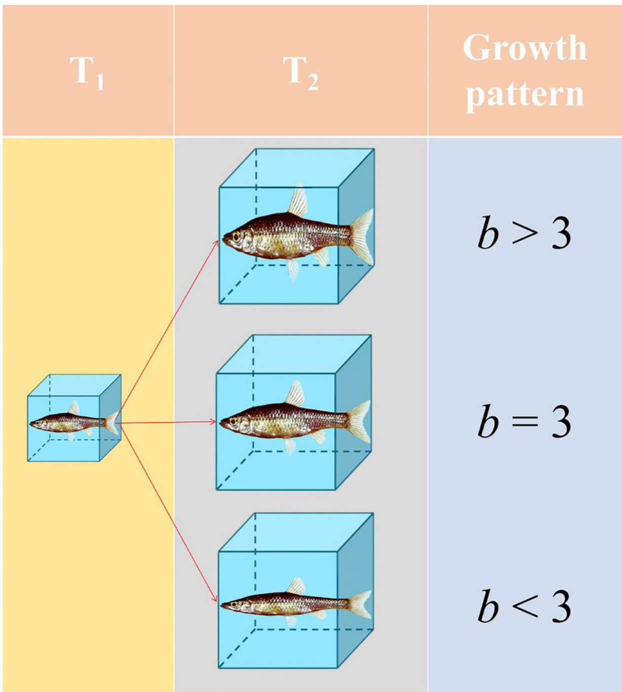

Fig. 2. A simple diagram of three growth patterns. When a small fish (T_1) grows to the assumed length of the large fish (T_2). If $b = 3$, then this species is isometric growth, that is, T_1 has the same form and condition as T_2. If $b > 3$, then this species is positive-allometric growth, that is, T_2 increases in relative body thickness or plumpness more than T_1. If $b < 3$, then this species is negative-allometric growth, that is, body shapes of T_2 are changed to become more elongated.

We used the plot of log (a') vs b in the data of *P. parva*. This method led to the detection of outliers, where the respective point deviated by more than two standard deviations from the regression line (Froese and Pauly, 2000). Then, the plot of log (a') vs b identified five outliers (Fig. 3), including the populations from Nanwan Lake (combined genders, females and males, 2014), the populations from Sava River Medsave (combined sexes; 2004), and the female populations from Süreyyabey Reservoir (females, 2016). These LWRs were marked as questionable in Supplementary Table I and eliminated in subsequent analysis. Due to their outliers, these populations were excluded from subsequent analyses that were used in the remaining 88 populations studied, of which sixty-five LWRs were from invasive regions and other twenty-three from native regions (Supplementary Table I).

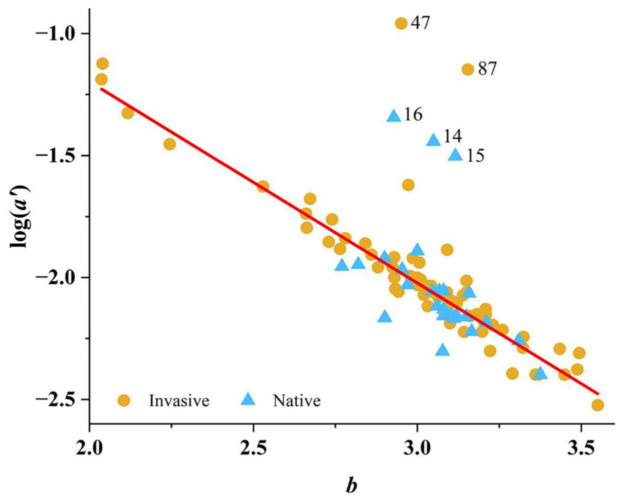

Fig. 3. Plots of log (a') vs b for 93 LWRs of *P. parva*. Five outliers were marked by row number of Supplementary Table I in the graphs, and eliminated in subsequent analysis. Regression line: $\log(a') = 0.45 - 0.83b$, n = 88, $R^2 = 0.84$, $P < 0.05$.

By comparing the form factor with other populations and species, one can determine whether the body shape of one is significantly different from another. If $b = 3$, the slopes of log (a') vs b can be used to estimate the value of coefficient a' for a given LWR. This value ($a'_{3.0}$) can be regarded as the form factor of the population (Froese, 2006). The equation $a'_{3.0}$= 10^(log(a')-S(b-3)), where a and b are regression parameters of LWR and S= - 0.83 is the slope of the regression of log(a') vs b (Froese, 2006). Then calculate the summary statistics for parameters a', $a'_{3.0}$, and b. Finally, differences in b and the form factor $a'_{3.0}$ between native populations and invasive populations were tested by the Kruskal-Wallis Test with IBM SPSS Statistics 23. All statistical analyses were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

The values of *b* in the present study ranged from 2.04 in Lugoj (Turkey) to 3.55 in the Strymon River (Greece). The Kolmogorov-Smirnov test refused to regard this distribution as normal, although it seemed to be close to normal (Fig. 4). As shown in Figure 4, by comparing frequencies with the normal distribution line, the frequencies of *b* values were higher than predicted by a normal distribution, except at 2.20-2.40 and 2.80-3.00. The median value of *b* was 3.07 (*SE* = 0.02) for all LWRs. 90% of the values ranged from 2.55 to 3.43, thus confirming the suggestion of Carlander (1969) that *b* normally falls between 2.50 and 3.50. This was shown in Figure 4, in which the vast majority of *b* (n = 61; accounting for 69.32% of the total) was located on the right side of the isometric line (*b* > 3.00), while only one population located in the *b* > 3.50 on the graph. A variety of factors, such as gonadal maturity and nutritional status, could have significant differences in the length-weight relationship, however, these factors were not considered in our report. Furthermore, there was no significant differences in the median value of *b* between native (*b* = 3.08, *SE* = 0.02) and invasive (*b* = 3.09, *SE* = 0.03) regions (*P* > 0.05) (Supplementary Table II). The median's 95% confidence intervals did not include 3.00, indicating that *P. parva* exhibited overall positive allometric growth (Supplementary Table II). This indicated a tendency for this species to increase in thickness as they grew. There were no significant differences in the form factor for this species sampled from native regions and invasive regions (*P* > 0.05) (Supplementary Table III). This indicated that the body shape of this species in the two regions were similar.

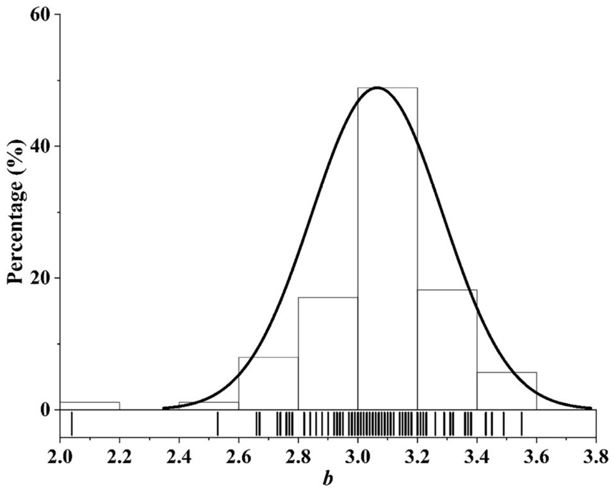

Fig. 4. Frequency distribution of mean exponent *b* based on 88 records for *P. parva*, with 5th percentile = 2.70 and 95th percentile= 3.44. Gaussian distribution line was overlaid.

In the present results, *P. parva* grew at positive-allometric growth, it became more rounded as the length increases, and both native and invasive populations showed similar growth patterns and form factor (Froese, 2006). This showed that this species was in a dominant position in the trophic niches and competition with the native species in invasive ecosystems, which would threaten the existence of native species and subsequently the biodiversity (Gozlan *et al.*, 2010). Considering its invasive potential, the harmful effects of this alien species cannot be ignored.

And, several measures should be taken to inhibit or mitigate its further invasion: (1) international standards should be followed for inspections, quarantine, and treatment of imported cargo and ship ballast water; (2) surveillance and monitoring through government and public participation is necessary to inform early-warning and rapid-response efforts; (3) if prevention methods fail, invasive species should be controlled mechanically or physically, chemically, or biologically (Fletcher *et al.*, 2016; Dong *et al.*, 2020; Pysek *et al.*, 2020).

DECLARATIONS

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Ethical statement

The authors declare that the fish sampling in the present study was performed under the guidelines of Ethics Committee of Hubei University.

Supplementary material

There are supplementary materials associated with this article which can be accessed at https://dx.doi.org/10.17582/journal.pjz/20221012141044

Statement of conflict of interest

The authors have declared no conflict of interest.

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