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ORIGINAL PAPER

Growth of two invasive cichlids (Perciformes: *Cichlidae*) in a natural thermal water habitat of temperate Central Europe (Lake Hévíz, Hungary)

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Abstract

The outflow of the natural thermal Lake of Hévíz is habitat of several fish species, with conservation relevance. In the past few years, numerous thermophile (tropically originated) fishes were reported in this waterbody, from which two species *Parachromis managuensis* (Günther, 1867), *Vieja melanurus* (Günther, 1862) characterized with strong, self-sustaining population. The aim of our research was to provide basic population data and to study their individual growth. The standard length of jaguar cichlid ranged from 37 to 283 mm (mean $SL = 110.21 \pm 65.4$ mm), the redhead cichlid standard length varied between 30 and 203 mm (mean $SL = 93.91 \pm 40.0$ mm). Slightly positive allometry ($b > 3$) was found in the case of both species. The von Bertalanffy Growth Function can be described as the following $L_t = 343.6[1 - e^{-0.196(t+0.973)}]$ in jaguar cichlid and $L_t = 298.9[1 - e^{-0.113(t+0.997)}]$ in the case of redhead cichlid. The Bertalanffy growth equations show slow growth for both species. Fulton's condition factor (K) values varied between 1.376 and 2.11 (mean $K = 1.701 \pm 0.17$) in the case of jaguar cichlid, and between 1.391 and 3.033 (mean $K = 2.237 \pm 0.24$) for redhead cichlid. These baseline population biology data from the first known self-sustaining, temperate-zone populations of two tropical cichlids provide information e.g., for future ecological risk assessments or comparative growth analyzes.

Keywords *Vieja melanurus* · *Parachromis managuensis* · Non-indigenous · Thermal lake · Tropical fish · Pet-trade

Introduction

Decrease in freshwater biodiversity is a growing concern Europewide (e.g., Mueller et al. 2018; Irz et al. 2022). Introduction of non-indigenous species is among the most important components of this loss (Gherardi et al. 2009; Warren et al. 2022). According to studies from the last decade, a high proportion of introduced fish species are originated from the tropical climate zone, usually introduced for ornamental purposes (Kalous et al. 2015; Maciaszek and Sosnowski 2019). These non-indigenous fish species most commonly released illegally, by aquarists (Copp et al. 2005; Pandakov et al. 2021). The establishment and spreading of these species are generally linked to waterbodies affected by warmwater (e.g., thermal spa or industrial effluent) inlets (Yamada et al. 2017; Tuckett et al. 2021). The number of such freshwater habitats are significantly increasing as a result of recent development of recreational and industrial facilities (West et al. 2021). It is most commonly hypothesized, that introduced tropical

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fish species are only affecting novel ecosystems in the close proximity of warm water inlets, however their effects may be substantially extended during the summer and can also be further enhanced by climate change (Rubenson and Olden 2017; Togaki et al. 2022). There are also many examples of species showing exceptional ability to adapt to temperate conditions within a few generations (Martinez et al. 2016; Yankova 2016). The negative effects of these ornamental species on native fish assemblages may be widespread, such as predation pressure, competition for resources or hosting of diseases and parasites (Gozlan et al. 2010; Gkenas et al. 2019).

The outflow canal of Lake Hévíz, being the main outflow of the largest thermal lake of Europe, is an excellent model area to study population biology of several non-indigenous, thermophilous fish species. The outflow canal is a part of a unique wetland habitat system (Kis-Balaton), which provides habitat for a number of species of high conservation importance e.g., *Umbra krameri* (Walbaum, 1792)*, Triturus dobrogicus* (Kiritzescu, 1903). The wetland system is connected to Lake Balaton, the largest shallow lake of Central Europe, which is considered sensitive to biological invasions (Ferincz et al. 2016).

The two most abundant introduced ornamental fish taxa are redhead cichlid (*Vieja melanurus*) and jaguar cichlid (*P. managuensis*) (Fig. 1). They were first observed in the area in 2015 and since than have self-sustaining populations in the canal (Takács et al. 2017; Weiperth et al. 2022). Both species originate from the tropical climate zone of Central America. The jaguar cichlid is native to Honduras, Costa Rica, Guatemala, Panama and Nicaragua, while the redhead cichlid is common to Mexico and Guatemala (Froese and Pauly 2023), and is therefore known as a highly heat-demanding species. The water temperature in their native area is consistently above 24 °C (Bussing 2002). Both species inhabit lakes and slow running waterflows, preferring waterbodies, which show signs of eutrophication (Kullander 2003). Jaguar cichlid have been introduced to many countries around the globe and have typically shown signs of invasiveness in these areas (e.g., Agasen et al. 2006; Hamiyati et al. 2019; Kresnasari and Darajati 2020; Resende et al. 2020).

Some morphological characteristics may suggest that the cichlid individuals in the study area hybrids of closely related species (Takács et al. 2015). Given specimens of jaguar cichlid may show overlapping morphological features to *Parachromis dovii*. In the case of redhead cichlid, some characteristics could be confused with *Vieja fenestrata* and *Vieja bifasciatus*. Artificial and natural hybridization is a common phenomenon in closely related, aquarium utilized cichlid species. Their ecological function, population biology and behavior characteristics are similar to parent species in most of the cases, therefore the possible hydrid origin was neglected in this study (Duffy et al. 2013; Aqmal-Naser and Ahmad 2020).

Fish somatic growth corresponds well to environmental changes (Denechaud et al. 2020) furthermore, it is expected that the life history traits of fish undergoing invasion process will predictably change (Gutowsky and Fox 2012). Therefore the aim of this study was to assess the individual growth characteristics of the redhead and jaguar cichlids in a natural thermal water habitat in temperate Central Europe to provide a baseline for further (long-term) studies and provide new information for the ecological risk assessment of these globally invasive species. Life history trait data, derived from this study may further enhance the understanding of factors that influence the spread of alien species, as well as the effects of these species on native communities, since other life-history metrics (e.g., fecundity, broods per season, longevity) are all highly dependent on somatic growth (Top et al. 2018). Consequently, studying how the growth rates differ between invasive and native populations is an important knowledge to better understand the ecology of invasions in general (Hierro et al. 2013).

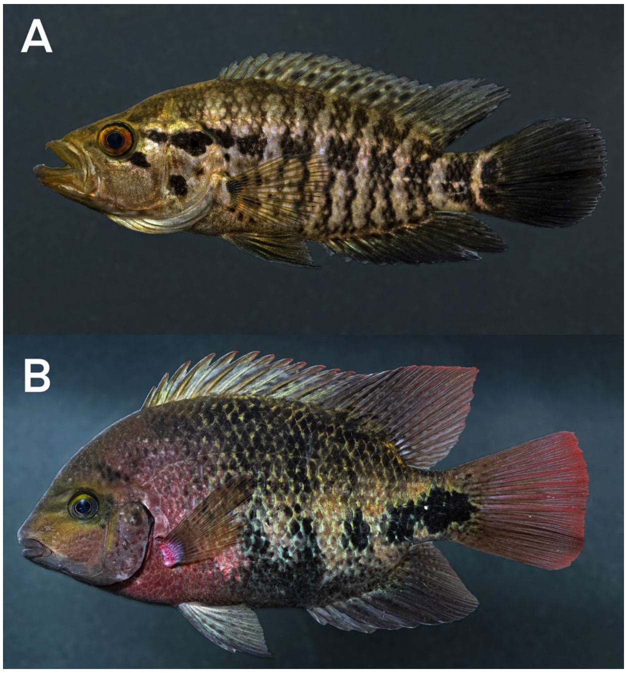

Fig. 1 Jaguar cichlid (*Parachromis managuensis*) (**A**) and Redhead cichlid (*Vieja melanurus*) from outflow canal of Lake Hévíz (**B**) (photo: Árpád Ferincz)

Materials and methods

The study area of our research was the uppermost section of the draining canal of Lake Hévíz (N46.7822, E17.1961) (Fig. 2). Lake Hévíz is the biggest natural bathable thermal lake of the World. The water of the lake originates from two crater springs with temperatures: 26 °C and 41 °C. The cumulative discharge of the springs is about 390 l/s

(Lőkkös et al. 2016). The average summer and winter temperatures of the lake are 33–35 °C and 24–28 °C respectively (Specziár 2004). The lake has two outlets, a larger one (Hévíz outflow canal) and a smaller one (Északi-árapasztó-canal). The two outlets are confluent and both of them discharge into the Kis-Balaton Water Protection System after app. 12 km. The sampling area was a 500 m long stretch, starting directly at the main outflow sluice, where redhead and jaguar cichlids are presented at the highest density (> 50% relative abundance). This section has been characterized by app. 6 m width and 1–1.5 m depth, water temperature reaches 32 °C in summer and around 24 °C in winter. The current velocity is low, the bottom is sandy or muddy, the lower part of the section is densely covered by submerse and emerse macrophytes, such as non-native (*Elodea* sp., *Vallisneria* sp). and protected native (*Nymphaea* alba) species (Lőkkös et al. 2016).

Fish were collected seasonally between February and October 2020 (21 February 2020; 26 May 2020; 18 August 2020; 30 October 2020). Sampling was carried out over a standard 500 m transect using a high performance, aggregator powered Hans-Grassl EL63II electrofisher. All non-native fish individuals were immediately euthanized with an overdose of clove oil. Standard (SL) and total body (TL) length measured to the nearest 0.1 cm and in wet body weight (TW) measured to the nearest 1.0 g. Captured specimens were placed in a Dometic CFX40 12 V powered portable refrigerator and kept on – 20 °C until further examination. Sex was determined after dissection, if it was possible.

For age determination, 8–10 scales were removed from each specimen, which were digitalized, using an Epson V850pro upper-lighting scanner in high resolution (2400dpi). Measurement of annual ring distances were carried out on 1 scale/specimen using the ImageJ ver.1.53 k software (Schneider et al. 2012). Measurements were carried out by the same expert throughout the study (Staszny et al. 2021). The von Bertalanffy Growth Function (VBGF) was used to model the growth of an average specimen. According to the model, the body length at any time (t) can be described by the following relation $L_t = L_{\mathrm{inf}}\,[1 - \mathrm{e}^{-\mathrm{K}(t - t0)}]$. In the equation, "$L_{\mathrm{t}}$ " is the body length of the fish (in our case, the standard body length) at age "t ", "L_{inf} " is the

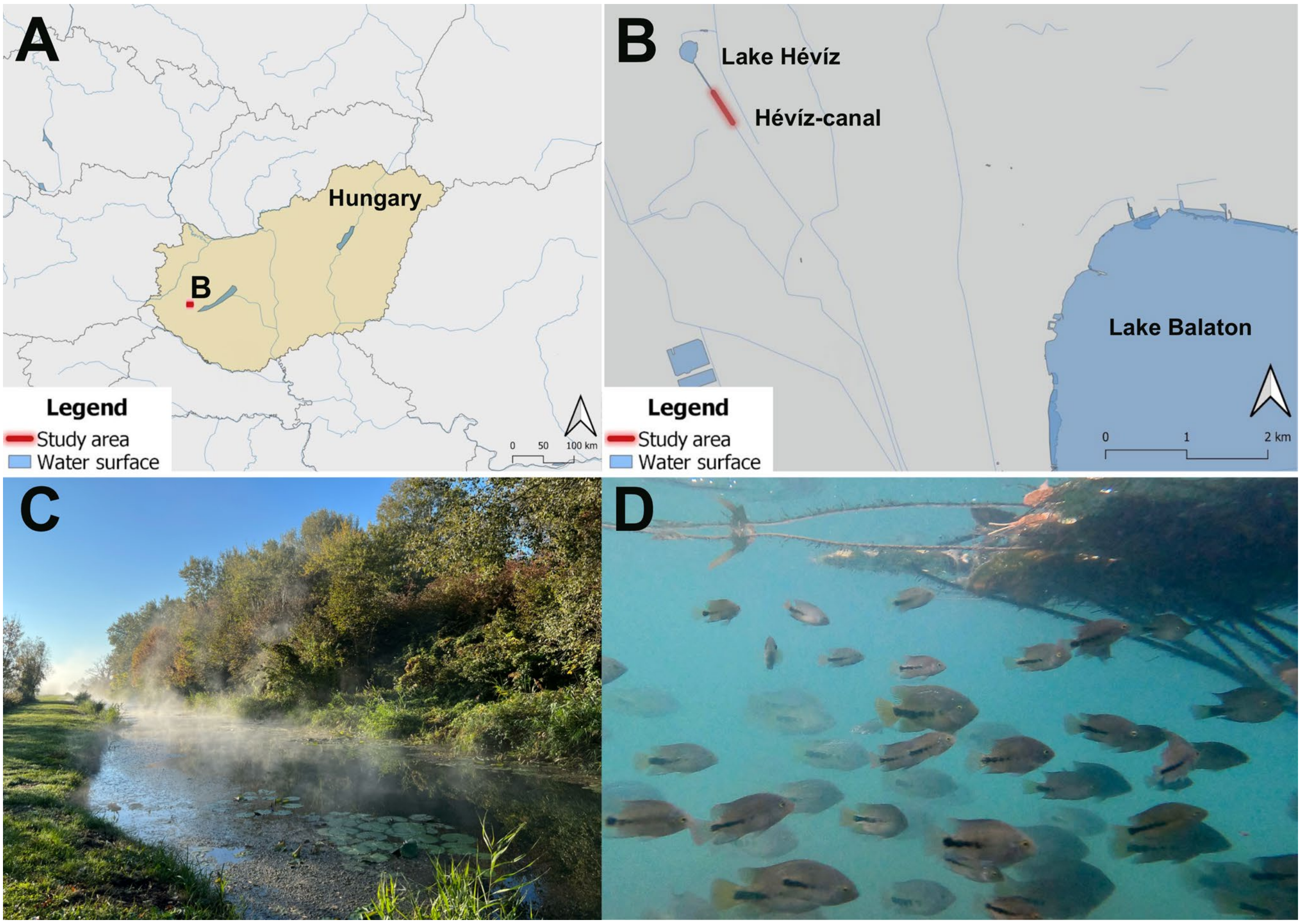

Fig. 2 **A**, **B**: Location of sampling site in Hungary. **D**, **C**: habitat photo of the study area (photo: Vera Lente)

asymptotic body length approximated by the body size of the fish, "K" is the growth rate constant, "t_0" is the hypothetical time at which the size of the fish is theoretically zero (practically, when scales are developed), and "e" is the base of the natural logarithm (Bagenal and Tesch 1978). Condition of individuals were also calculated using the formula of Fulton. $K = W \times 100/\mathrm{SL}^3$, where "$K$" is the Fulton condition factor, "W" is the weight of the fish in g, and "SL" is the standard body length in cm (Bagenal and Tesch 1978).

Differences in condition factors between age groups were tested with Welch ANOVA (normality was pre-checked using Shapiro–Wilks test; homogeneity of variances were tested using Levene-tests).

Results

In the present study, a total of 58 jaguar cichlid, and 159 readhead cichlid were analyzed. The standard length distribution of jaguar cichlid ranged from 37 to 283 mm (mean SL = 110.21 ± 65.4 mm). Length distribution indicated that app. 60% of the sample consisted of small fish, ranging from 37 to 100 mm (Fig. 3). The total wet weight of the fish varied between 1.7 and 738.8 g (mean $W = 107.91 \pm 189.6$ g). The weight distribution of the sample was similar to length distribution: more than 70.0% of the fish were under 100 g.

The standard lengths of redhead cichlid varied between 30 and 203 mm (mean SL = 93.91 ± 40.0 mm) and more than 65% of the specimens were smaller than 100 mm (Fig. 3). The total wet weights of fish specimens in the sample ranged between 1.1 and 353 g (mean $W = 59.175 \pm 74.3$ g). The weight distribution was unbalanced as well: 75% of the specimens weighed less than 100 g.

The fishes were not further grouped by sex, due to the low number of identified adults. The length–weight relationship of jaguar cichlid can be calculated as $W = 3\text{E-}05^{3.0431}$ ($R^2 = 0.9735$) (Fig. 3). Quite a similar relationship can be observed in case of redhead cichlid $W = 3\text{E-}05^{3.0897}$ ($R^2 = 0.9578$) (Fig. 3). Slightly positive allometry ($b > 3$) was found in the case of the fishes. Fulton's condition factor (K) values varied between 1.376 and 2.11 (mean $K = 1.701 \pm 0.17$) in the case of jaguar cichlid, and between 1.391 to 3.033 (mean $K = 2.237 \pm 0.24$) for redhead cichlid.

Age composition revealed that younger age groups have dominated for both taxa. In jaguar cichlid the age class 0+ accounted for 50% of the individuals (Fig. 4), while for

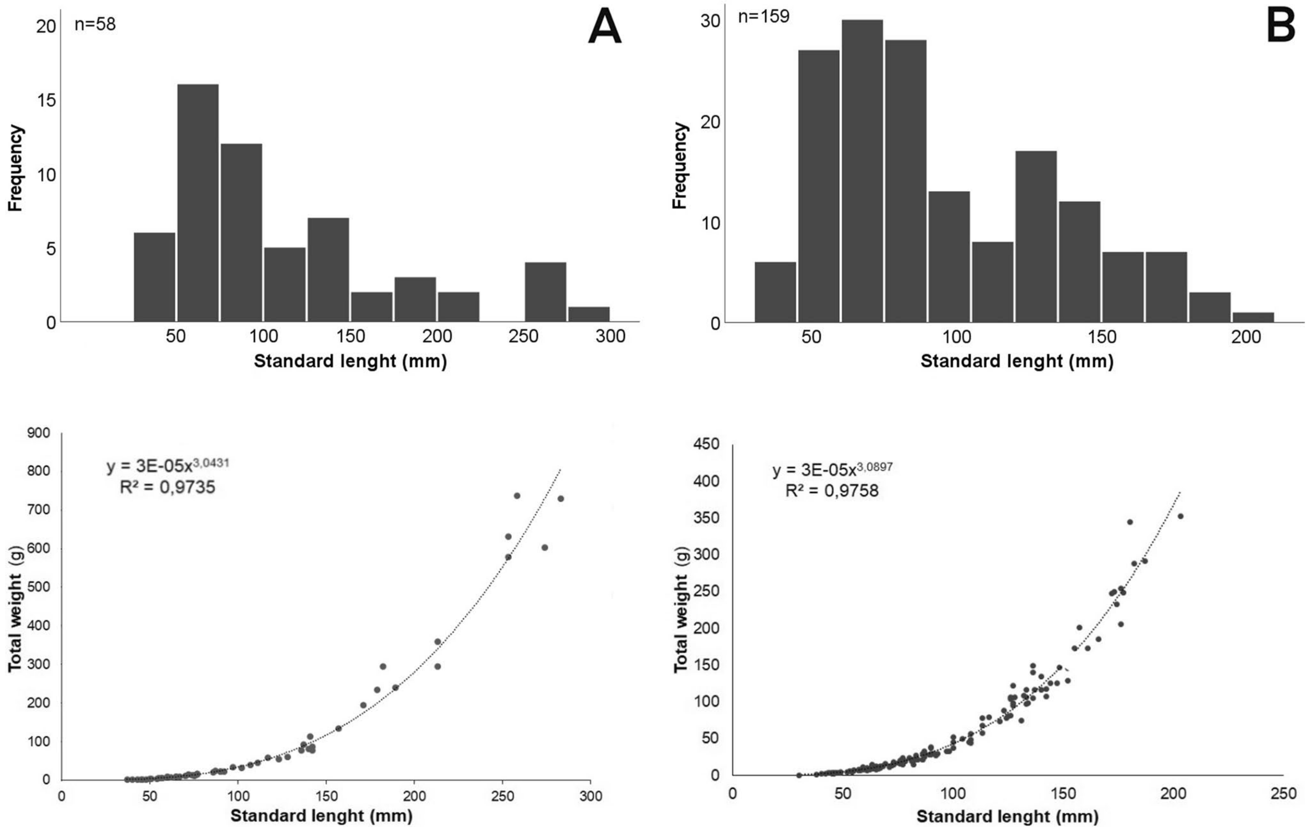

Fig. 3 Length frequency histograms and length–weight relationships of jaguar cichlid (*Parachromis managuensis*) (**A**) and redhead cichlid (*Vieja melanurus*) (**B**)

redhead cichlid the 0+ and 1+ age groups accounted for 55% (Fig. 4). The longest (SL) jaguar cichlid proved to be 7+ years old, according to the annual rings counted on the scales. In the case of redhead cichlid, the largest specimen was 6+ years old. The mean annual standard length increase for jaguar cichlid was 38.00 ± 14.6 mm; while for redhead cichlid it was 20.00 ± 7.6 mm.

The length of jaguar cichlid at a given age proved to be $L_t = 343.6[1 - e^{-0.196(t+0.973)}]$ and $L_t = 298.9[1 - e^{-0.113(t+0.997)}]$ for the redhead cichlid according to the VGBF (Fig. 4. respectively).

For the comparison of ages by condition factor (K), three age groups have been determined in the case of both species. Jaguar cichlids were grouped as following: 0+ age (TL = 77.97 ± 17.4), 1+ age (TL = 131.40 ± 21.3), 2+ < age (TL = 237.11 ± 74.3). No significant differences could be observed in the condition factors of different age groups (Welch ANOVA, $P = 0.139$). Tested age categories were the following in case of redhead cichlid: 0+ age (TL = 67.40 ± 11.8), 1+ age (T = 94.82 ± 11.9), 2+ < age (TL = 161.26 ± 36.9). Significant differences were revealed (oneway ANOVA: $F = 11.8$, $P < 0.01$, Tukey post hoc tests) between 2+ < and younger age groups: the condition of older specimens was higher (Table 1.).

Discussion

Non-indigenous, thermophilous species cause growing concerns in temperate climate zones along the increasing effects of climate change (Riccardi et al. 2021; Campbell et al. 2022). Self-sustaining, and dense populations of

Table 1 Fulton's condition factors (K) of the *Vieja* sp. in 3 age classes (0+, 1+, 2<)

Age group	Mean (K)	Std. deviation	Tukey post hoc
0+	2.15	0.20	a
1+	2.17	0.24	a
2<	2.33	0.24	b

Different letters identify significantly different groups. (Tukey $p = < 0.05$)

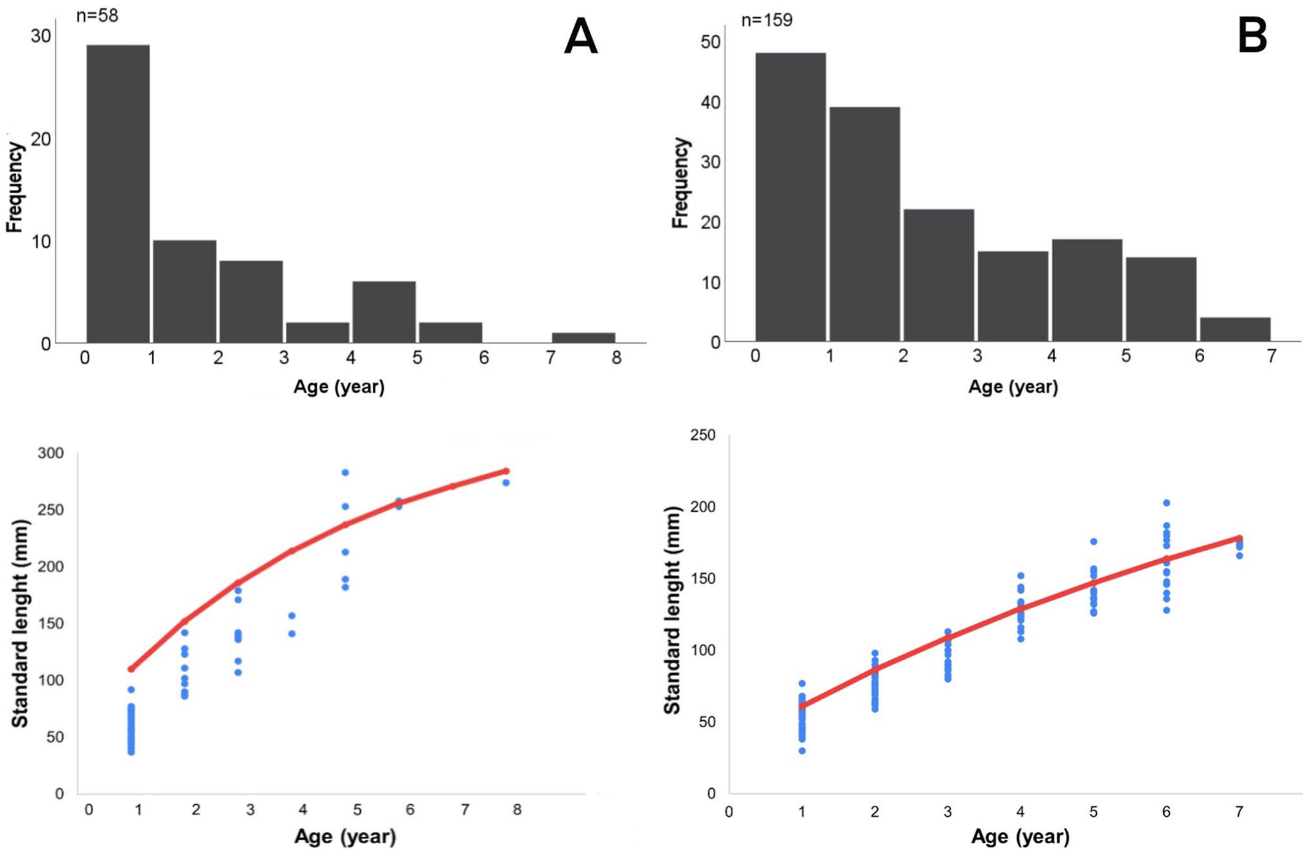

Fig. 4 Age-frequency distributions, observed (blue) and predicted lengths (red, VBGF: $L_t = 343.6[1 - e^{-0.196(t+0.973)}]$) at age for jaguar cichlid (*Parachromis managuensis*) (**A**); and **B**: redhead cichlid (*Vieja melanurus*) (VBGF: $L_t = 298.9[1 - e^{-0.113(t+0.997)}]$)

jaguar cichlids and redhead cichlids were studied in the outflow of Lake Hévíz, in temperate Central-Europe.

The individual growth characteristics of *P. managuensis* in its non-native range have previously been studied in subtropical or tropical territories of Java (Hamiyati et al. 2019; Kresnasari and Darajati 2020), and a tropical semiarid region in Brazil (Resende et al. 2020). Despite the limited sample size, the length range was wider (TL = 44–376 mm) than found in previous studies, most possibly due to the less selective sampling method (electrofishing). The jaguar cichlid population of the outflow canal of Lake Hévíz consisted of a higher proportion of smaller individuals, compared to the basin of River Pajeú (Brazil) (Resende et al. 2020).

In contrast to the results of Resende et al. (2020), the length–weight curve of jaguar cichlids of outflow canal of Lake Hévíz showed a near allometric growth ($b = 3.043$). The allometric exponent of the population inhabiting Penjalin-reservoir (Java) was similar (Kresnasari and Darajati 2020). This value indicates a balanced growth of individuals throughout their life cycle. A strongly positive allometry ($b = 3.378$) was found in a former study conducted also in the Penjalin reservoir (Java), indicating a more optimal weight gain of individuals (Hamiyati et al. 2019). Condition factor values proved to be slightly higher in our case than in River Pajeú and Penjalin-reservoir (Resende et al. 2020; Kresnasari and Darajati 2020 respectively). L_{inf} value derived from VBGF for the outflow canal of Lake Hévíz is similar to the Brazilian habitat (341.4 mm), however the rate of individual growth was slower in our case (Resende et al. 2020).

Individual growth of redhead cichlid has not been studied yet, however in Singapore and China it has been reported where self-sustaining stocks have been established (Wilkinson et al. 2021; Zhu et al. 2022). Standard lengths and weights measured in the cases of specimens caught from the tropical River Nandu (Hainan, China) ranged between 57–153 mm and 8.23–216.15 g, which is narrower than found in present study (Zhu et al. 2022).

Climatic and other possible covariates of the recipient environment should always be considered in case of fish growth rate assessments. Climatic conditions (mainly temperature) in recently invaded waters can differ significantly from those in the native range, this potentially leads to changes in growth rates as well (Rypel 2014). This is illustrated well in case of the invasive population of the Mayan cichlid (*Cichlasoma urophthalmus*) in the subtropical Everglades (Florida, US). Growth rate of the species was significantly slower than in its native range (tropical Central America), however the species' invasion potential was not affected negatively (Faunce et al. 2002). High incidence of young specimens of both species also may indicate the high invasive potential and ongoing expansion of a given fish population (Carol et al. 2009; Teixeira et al. 2020).

Although winter temperature can considered a significant barrier for cichlids at the Hévíz outflow, there are numerous cases where species have successfully established populations well beyond their preliminarily known temperature limitations (e.g., largemouth bass (*Micropterus salmonids*) in Kenya, common carp (*Cyprinus carpio*) in Canada and Wisconsin, and northern snakehead (*Channa argus*) in Arkansas) (Rypel 2014). Moreover, increased fishing (angling) pressure may also result such population structure alterations, since "catch and take" anglers targets larger specimens (e.g., Faunce et al. 2002; Evangelista et al. 2015). No exact data available regarding the fishing pressure on Hévíz-outflow, however the preference of jaguar and redhead cichlid by anglers cannot be excluded, due to their exotic nature.

Conclusions for future biology

This study provides the first individual growth data of jaguar cichlid from a thermal water affected habitat of temperate Central Europe (Hungary) and can be considered the first growth analysis in a natural habitat of redhead cichlid. The results suggest that the outflow canal of Lake Hévíz is a suitable habitat for the two non-indigenous cichlid species. Stock size changes and distribution patterns along the thermal gradient of the Hévíz-outflow should be also studied, to assess the potential ecological risk on native community. The presence and activity of these thermophilous species in this novel environment may also serve as model system for climate change related adaptation studies as well.

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Author contributions All authors have seen and approved the manuscript. Author contributions were the following: VL contributed to sample design and methodology, investigation, data collection, data analysis and interpretation, writing- original draft. ÁS contributed to sample design and methodology, investigation and data collection, data analysis and interpretation. AH contributed to investigation and data collection. AW contributed to sample design and methodology, investigation and data collection, review and editing. ZsMB contributed to investigation and data collection. BU contributed to ethics approval, funding provision. ÁF contributed to Corresponding author, research conceptualization, sample design and methodology, funding provision, data analysis and interpretation, writing—review & editing.

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Declarations

Conflict of interest We declare no conflicts of interest.

Ethical approval Vera Lente: Hungarian Ministry of Agriculture, Department of Fisheries. Contrywide license for fishing. Permit number: HaGF/172/2021. Árpád Ferincz: Hungarian Ministry of Agriculture, Department of Fisheries. Contrywide license for fishing. Permit number: HaGF/154/2021. Permission for enter and work in the protected areas Lake Balaton Catchment: PE/KTFO/1401–11/2022.

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