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Life history of the river goby *Glossogobius callidus* (Teleostei: Gobiidae)

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Abstract

The river goby *Glossogobius callidus* is native to freshwater and estuarine habitats in South Africa. Individuals [21.1–144.4 mm total length (L_T)] were sampled from impoundments in the Sundays River Valley, Eastern Cape, from February 2014 to March 2015. The largest female was 137.2 mm L_T, and the largest male was 144.4 mm L_T. Length-at-50% maturity was 75.2 ± 2.1 mm L_T for males and 76.2 ± 2.0 mm L_T for females. Absolute fecundity was 1028.2 ± 131.7 oocytes per fish, and relative fecundity was 50.1 ± 18.1 oocytes per gram. The spawning season extended from October to December. Fish were aged using sectioned sagittal otoliths. The growth zone periodicity was validated using edge analysis. Longevity was more than 7 years for females and more than 6 years for males. Length-at-age was similar for the two sexes and was best described using the von Bertalanffy growth model as $L_t = 74.7(1 - e^{-1.0(t + 0.1)})$ mm L_T for the entire population. Using the population age structure, the mortality rate was estimated at 1.3 per year.

KEYWORDS

Age and growth, fresh water, *Glossogobius callidus*, length-at-50% maturity, life history

1 | INTRODUCTION

The family Gobiidae is one of the largest vertebrate groups and contains more than 2000 species that inhabit freshwater, estuarine and marine habitats (Thacker, 2003). The group has not been well studied from a life-history perspective, which constrains the understanding of their general ecology and hinders trait-based comparisons with other taxa (*e.g.*, Winemiller *et al*., 2015). Nonetheless, this group of fishes has recently received increased attention, as several species have invaded rivers and lakes in Australia, Europe and North America (Gertzen *et al*., 2016; MacInnis & Corkum, 2000). Globally, the main attributes for invasion successes appear to be their tolerance for a wide range of environmental conditions, a broad diet and aggressive behaviour (Charlebois *et al*., 2001; Hempel *et al*., 2019; Kotta *et al*., 2016).

Although only native gobies are known to occur in southern African freshwater ecosystems, the river goby *Glossogobius callidus* (Smith 1937) has been documented to rapidly colonise artificial impoundments (Woodford *et al*., 2013). This species occurs as two reproductively isolated populations along the subtropical and temperate

African east coast from northern Mozambique to the Cape region of South Africa (Maake *et al*., 2013). In the temperate Eastern Cape region of South Africa, *G. callidus* is particularly abundant in both estuarine and freshwater environments, where it often dominates fish communities (*e.g*., Wasserman *et al*., 2011; Woodford *et al*., 2013).

Current knowledge on the biology and ecology of the river goby is scant. What is known is that this moderately small goby is an invertivorous (Mofu *et al*., 2019; Wasserman, 2012), speleophil hole-nester that practices parental care with the male guarding and maintaining the egg mass until the larvae hatch (Wasserman *et al*., 2015). Sneaking, a spawning strategy whereby smaller males that are capable of reproduction but are less able to defend a territory or nest spawn in the nest of a guarding male when the opportunity arises, has been reported for some members of the family but not for *G. callidus* (see Immler *et al*., 2004; MacInnis & Corkum, 2000; Takegaki *et al*., 2012). There is, however, currently no information on other life-history traits of this species, including gonadal recrudescence, maturity, fecundity, growth and mortality. The objective of the current study was, therefore, to provide the first comprehensive description of the life history of a temperate population of *G. callidus* to compare its life history to that of other freshwater gobies.

2 | MATERIALS AND METHODS

This project was conducted with permission from the National Research Foundation – South African Institute for Aquatic Biodiversity Animal Ethics Committee (NRF-SAIAB reference number 2011/02), and specimens were collected with permission obtained from the Eastern Cape Department of Economic Development and Environmental Affairs (DEDEA permit number CRO 18-11CR and CRO 19-11CR).

Fish were randomly sampled monthly between August 2013 and March 2015, from 10 irrigation ponds located in the Sundays River Valley, on the eastern extremity of the Cape Fold Ecoregion (Abell *et al*., 2008) in South Africa (Figure 1) (see Supporting Information S1 for geographical coordinates). The climate in the region is warm temperate, with water temperatures ranging from a minimum of 10°C in winter to a maximum of 31°C in summer (Woodford *et al*., 2013). Fish were sampled using a 30 × 2 m seine net with 12 mm mesh (stretched) in the wings and an 8 mm stretched mesh codend. Seine hauls, typically two or three per pond, were conducted until a minimum of 100 *G. callidus* were collected. The fish were euthanised with an overdose (40 mg l^{-1}) of clove oil, and specimens were either kept on ice (if required for otolith extraction for ageing) or preserved in a 10% formalin solution (for reproductive assessment).

In the laboratory, all fish were then measured for total length L_T and standard length L_S to the nearest millimetre and total mass (M_T) to the nearest 0.1 g. Fish were subsequently dissected, and gonads were first visually assessed under a dissecting microscope to determine sex, before being categorised into one of the five macroscopic stages using the standard macroscopic criteria and terminology described by Brown-Peterson *et al*. (2011). The gonads were subsequently removed, patted dry and weighed (M_G nearest 0.1 g), and the eviscerated body mass of the fish was recorded (M_E nearest 0.1 g). To determine absolute fecundity (F_A), all mature, yolked and unovulated oocytes in the ovaries of a minimum of two spawning-capable females were used per site, and these were selected randomly across ponds and counted under a stereomicroscope. Relative fecundity (F_R) was then calculated as a proportion of M_T. Length-at-50% maturity (L_{M50}) was calculated by fitting a logistic function to the proportion of mature fish (macroscopically staged as developing, spawning capable and regressing) collected during the reproductive season that were grouped into 5 mm L_T size classes.

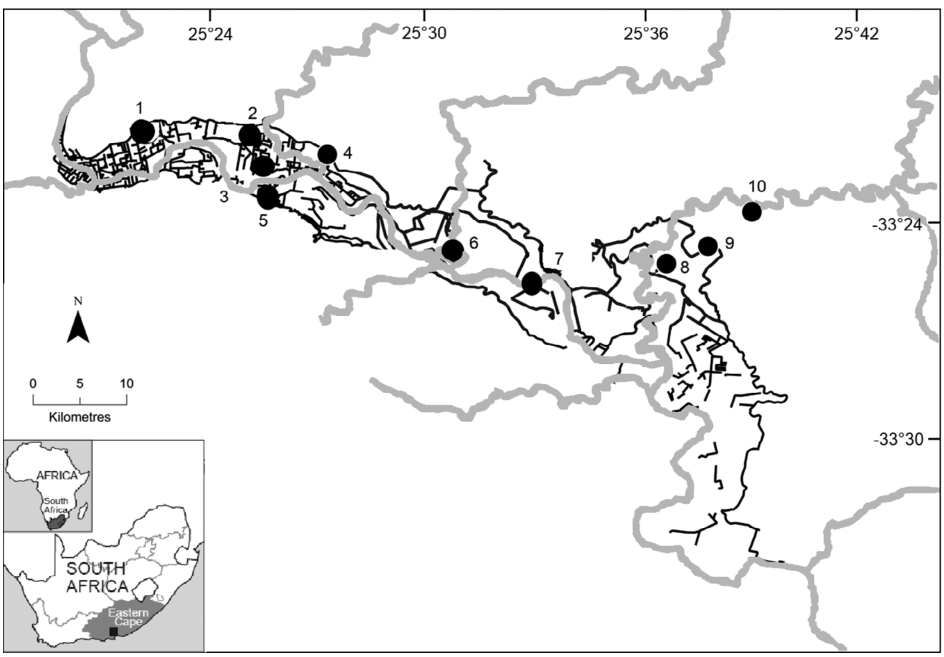

FIGURE 1 Sundays River Valley irrigation ponds in the Eastern Cape, South Africa, Pond 1; Pond 2; Pond 3; Pond 4; Pond 5; Pond 6; Pond 7; Pond 8; Pond 9; Pond 10 (●) Surveyed ponds, (—) Sundays River and tributaries, ( ) Sundays irrigation network (see Supporting Information S1 for geographical coordinated and pond names)

For ageing, a pilot study (n = 240 fish) demonstrated that unburnt sectioned sagittal otoliths provide the most appropriate structure for ageing as 95% of scales and 83% of burnt otolith sections were unreadable. Otoliths were set in clear polyester casting resin, sectioned transversely through the nucleus using a double-bladed diamond saw at a thickness of 0.4 mm and mounted onto microscope slides using di-*N*-butyle phthalate in xylene microscopy mountant (Merck Private Ltd., Darmstadt, Germany) (Figure 2). The sections were then examined under a binocular microscope using transmitted light at variable magnifications (×10–40) to count pairs of opaque and hyaline growth zones and to assess the appearance of the otolith margin. Precision was assessed by the average percent error (APE) and Coefficient of Variation (CV) calculated from the relative ages assigned by three separate readers as described by Beamish and Fournier (1981) and Chang (1982). The growth zone deposition rate was validated as annual using edge analysis (EA) whereby the optical appearance of the edge on the otoliths was noted as Bernoulli variables (1 = opaque zone present and 0 = absent) and plotted against time. Under the assumption that the frequency of edge zones follows a yearly sinusoidal cycle when plotted against time (Campana, 2001), a periodic logistic regression analysis was used to test a unimodal null hypothesis and bimodal alternate hypothesis (Beamish *et al*., 2005).

FIGURE 2 Unburnt otolith of a 86.1 mm L_T river goby *Glossogobius callidus*, showing five annuli (marked by black circles), sampled from the Sundays River Valley irrigation ponds in the Eastern Cape of South Africa

Growth was estimated using a sample of 153 fish collected between November 2014 and January 2015 that were sampled from across the 10 freshwater ponds (see Figure 1). This sampling period was selected to coincide with the period when, as indicated by the validation experiment, opaque zones become optically discernible on the edge of the otoliths of the highest proportion of fish. As this sampling period was also consistent with the peak of the spawning season, the length of the newly hatched fish was measured during the spawning experiment of Wasserman *et al*. (2015). These fish averaged 21.2 mm L_T and were included as age 0 fish for modelling age. The length-at-age was subsequently modelled using the von Bertalanffy growth (VBG) function, which is described as $L_t = L_\infty\left(1-e^{-K(t-t_0)}\right)$, where L_t is the length at time t, L_∞ is the theoretical asymptotic length, K is the Brody growth coefficient and t_0 is the age of a zero-

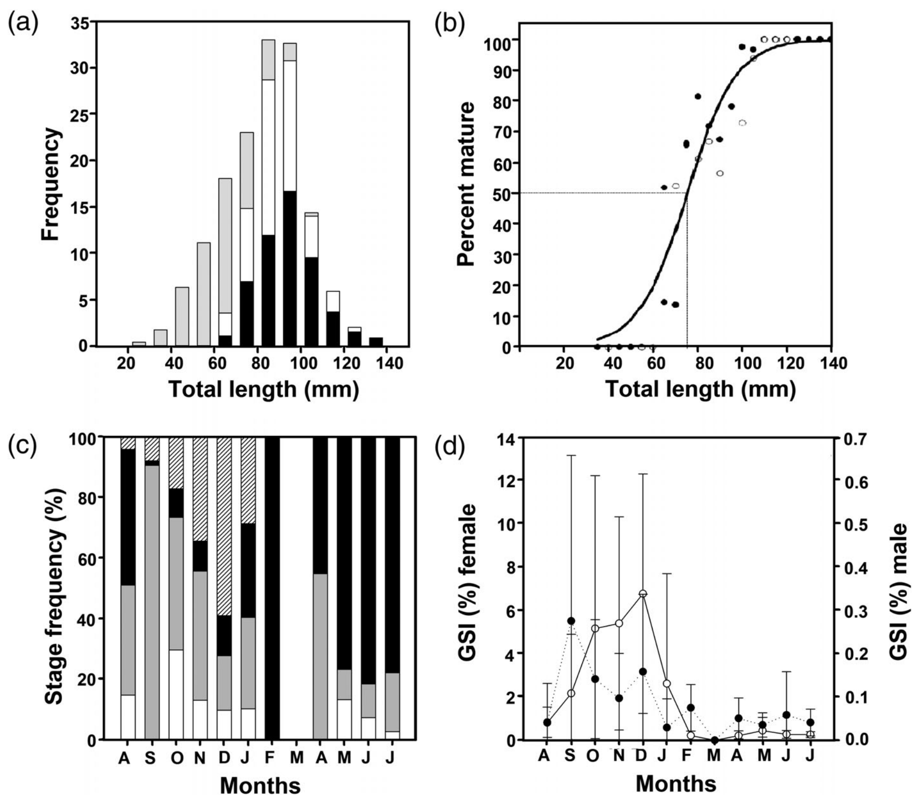

FIGURE 3 Monthly variation in (a) length–frequency distributions for (■) males, (□) females, (▭) and juveniles; (b) logistic ogive fitted to the percentage of sexually mature male (n = 13, black circles) and female (n = 15, white circle) river goby *Glossogobius callidus*; red line represents L_{M50} (total length at 50% maturity) (●) male, (○) female; (c) monthly maturity stages of female (n = 431) river goby *G. callidus* (□) Regressing, (▭) Resting, (■) Regenerating, (▨) Spawning capable; (d) mean (±S.D.) gonado-somatic index (GSI) for male (n = 595, white circles) and female (n = 659, black circles) river goby *G. callidus*, sampled from the irrigation ponds located in the Sundays River Valley, Eastern Cape, between August 2013 and March 2015 (–○–) Female, (···●···) Male

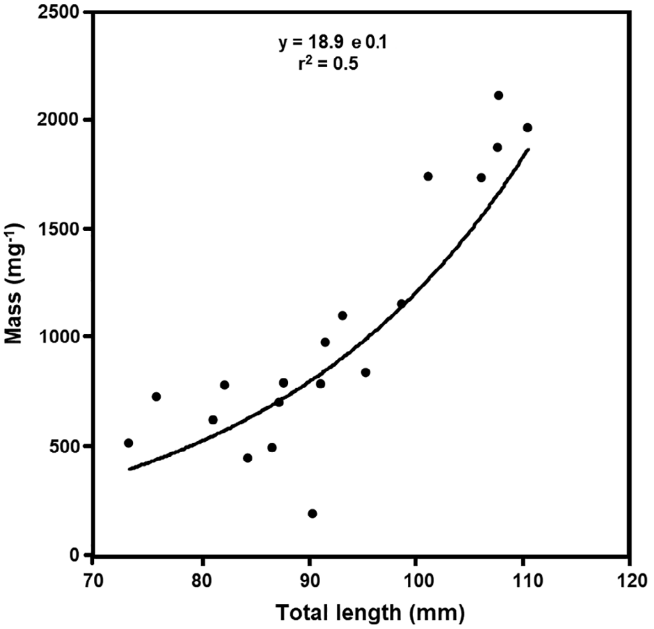

FIGURE 4 Total length (L_T)–mass (mg^{-1}) relationship for female (n = 19) river goby *Glossogobius callidus*, sampled from the Sundays River Valley irrigation ponds in the Eastern Cape, South Africa

length fish. The variance estimates were calculated using parametric bootstrap resampling with 1000 replicates drawn from a normal distribution (Efron, 1982), and standard errors and confidence intervals were constructed using the percentile method of Buckland (1984). Differences in growth parameter estimates between sexes were assessed using a likelihood ratio test (Cerrato, 1990).

The instantaneous rate of annual mortality (Z) was estimated by catch curve analysis (Ricker, 1975) whereby length–frequency data were converted to age–frequency data by means of an age–length key developed from the aged individuals. The annual mortality (Z) was estimated by the negative slope of the linear regression through the descending data points of the natural logarithm of frequency against age. As these populations are not exploited, Z was assumed to approximate natural mortality M.

3 | RESULTS

In total 1945 fish (579 female, 667 male, 699 juvenile) ranging from 21 to 144 mm L_T were examined (Figure 3a). The sex ratio did not differ from unity (χ^2 test, χ^2 = 0.02, df = 1, P > 0.05). The length-at-50% maturity was estimated at 75.1 ± 2.1 mm L_T for males and 76.2 ± 2.0 mm L_T for females. Length-at-50% maturity did not differ significantly between sexes and was calculated at 75.2 ± 2.1 mm L_T for the combined sexes (Figure 3b). Gonad development for fish exceeding L_{M50} followed a distinct seasonal pattern with only spawning-capable female fish recorded in the population from September (early spring) to January (mid-summer) (Figure 3c). The female gonado-somatic index followed a similar pattern observed with

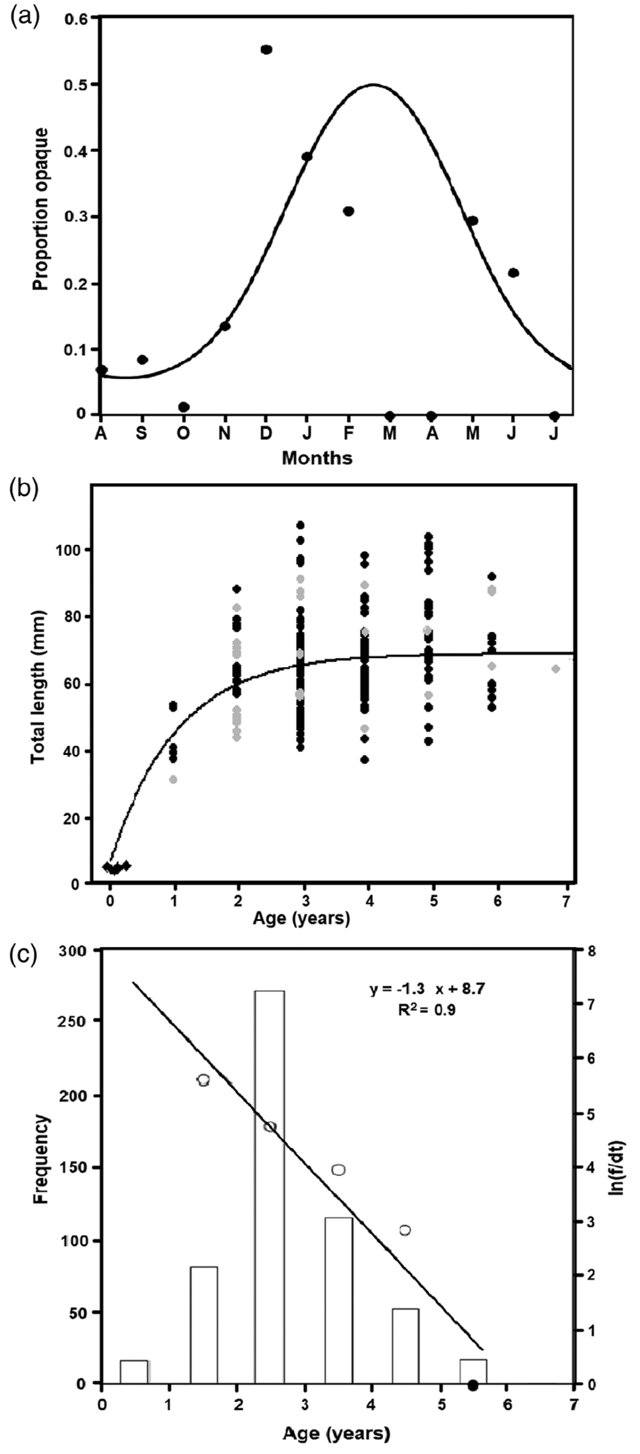

FIGURE 5 (a) Proportion of otoliths (n = 623) with an opaque zone on the margin, with a solid line representing the predicted unimodal annual cycle of opaque zone deposition using a full model periodic regression; (b) combined von Bertalanffy growth curve of total length-at-50% maturity (L_{M50}), juvenile (n = 6, black diamond), male (n = 84, black circles), female (n = 69, grey circles) (●) Female, (●) Male, (◆) Juvenile; (c) age–frequency histogram (n = 560) and resultant catch curves generated from length frequencies, and the instantaneous rate of mortality (Z) is the slope of the descending limb of the catch curve (closed circles). All graphs are for the river goby *Glossogobius callidus*, sampled from the Sundays River Valley irrigation ponds in the Eastern Cape, South Africa

TABLE 1 von Bertalanffy parameter and S.E. calculated using error methods (Cope & Punt, 2007) for the entire population of the river goby *Glossogobius callidus* (n = 153), from the Sundays River Valley in the Eastern Cape, South Africa

	L_∞ (mm)	S.E.	K (year^{-1})	S.E.	t_0 (year)	S.E.
Entire population	74.7	1.7	1.0	0.1	−0.1	0.1

TABLE 2 Life-history comparison of the river goby *Glossogobius callidus*, with other goby species using von Bertalanffy growth parameters

Species	Region	Sex	L_∞ (mm)	K (year^{-1})	t_0 (year)	Φ′(mm)	A_{max} (year)	A_{mat} (year)	A_{max}/ A_{mat}	Mortality rate (year^{-1})	Main reference
Glossogobius callidus	South Africa	P	74.7	1.0	−0.1	0.7	7.0	2.0	3.5	1.3	This study
Neogobius melanostomus	United States	M	215	0.4	−0.8	0.9	1	2	0.5	1.0	MacInnis and Corkum (2000)
	United States	F	237	0.2	−1.6	1.7	4	3	0.8	1.3	Apanasenko (1973) and Skora *et al*. (1999)
Gobius niger	Turkey	F	148	0.3	−1.5	1.9	9	2	4.5	0.7	Filiz and Toğulga (2009)
		M	167	0.3	−2.2	1.9	9	2	4.5	0.7	Filiz and Toğulga (2009)
Aphia minuta	Italy	M	740	1.4	−0.2	1.9	5	4	1.3	2.5	La Mesa (1999)
	Italy	F	660	1.6	−0.2	1.9	5	4	1.3	3.0	La Mesa (1999)
Neogobius fluviatilis	Ukraine	U	138	0.7	−0.3	2.1	4	1	4	1.3	Bilko (1971)
Pomatoschistus lozanoi	Europe	U	860	0.9	−0.2	1.8	3	1	3	1.5	Froese and Binohlan (2003)
Gobius paganellus	Isle of Man	U	116	0.4	−0.2	1.7	3	1	3	1.6	Pauly (1980)

Note: A_{mat}: age at maturity; A_{max}: maximum age; F: female; K: Brody growth coefficient; L_∞: asymptotic length; M: male; P: entire population surveyed from all sites used in this study; Φ' (phi prime: Pauly & Munro, 1984): growth performance; t_0: age at zero length; U: unknown; Z: mortality rate (see Materials and Methods).

macroscopic staging with an increase in October and December, whereas the male gonado-somatic index showed a marked increase in November (Figure 3d). Fecundity ranged from 100 to 2000 oocytes per fish. Oocyte diameter ranged from 107.1 to 299.1 μm with a mean (±S.D.) of 207.2 ± 7.9 μm. Absolute fecundity (F) is dependent on L_T whereby F = 18.9 L_T (mm)$^{0.1}$ (Figure 4).

For 1424 otoliths from the examined specimens of *G. callidus*, APE was 2.9% and CV was 3.9%. The periodic logistic regression analysis failed to reject the null hypothesis that one opaque zone was deposited annually (χ^2 = 0.4, df = 3, P > 0.05) but rejected the alternative hypothesis that growth zone deposition was bimodal (χ^2 = 25.7, df = 3, P < 0.05). Thus, the growth zone deposition rate was validated as annual (Figure 5a), and subsequent analyses were based on the direct interpretation that one opaque/hyaline growth zone pair is equivalent to 1 year of age. Power analysis was completed using G*Power version 3.1.9.4, and the sample size required for α = 0.05 and a power of 95% was 111.

The oldest female fish sampled was a more than 7 year old, 69 mm L_T female, and the oldest male was a more than 6 year old, 126 mm L_T fish. VBG models fitted to male and female data did not differ significantly between sexes (log-likelihood ratio test, χ^2 = 301.1, df = 1, P > 0.05), and the best fit for the entire population is L_t = 74.7 $(1 - e^{-1.0(t + 0.1)})$ mm L_T (Table 1; Figure 5b). The estimated total mortality Z is 1.3 per year$^-$(Figure 5c). As this species is not exploited, Z was taken to equal natural mortality M.

4 | DISCUSSION

Based on the findings of this study, *G. callidus* is best categorised as an opportunistic life-history strategist *sensu* Winemiller *et al.* (2015). The species is relatively fast growing, reaching adulthood at 2 years. Maturity is attained during the second year of life at lengths approximating 50% of maximum L_T. The species has a short spawning season from spring (October) to early summer (December). These life-history traits facilitate its prevalence in a wide range of habitats and explain why this species is able to rapidly colonise new environments (Woodford *et al*., 2013).

The life-history of *G. callidus* is not unusual for the Gobiidae (Table 2). The males mature slightly earlier, and at smaller sizes, than females, a trait often documented in this fish family (Kovačić, 2007; Sokołowska & Fey, 2011). To compare the growth performance, the parameter Φ′ takes into consideration the interaction and dependence between the VBG parameters (Pauly & Munro, 1984). The growth performance of *G. callidus* was lower than that of round goby *Neogobius melanostomus* (Pallas 1814), black goby *Gobius niger* (Linnaeus 1758), monkey goby *Neogobius fluviatilis* (Pallas 1814) and Lozano's goby, *Pomatoschistus lozanoi* (de Buen 1923) (Apanasenko, 1973; Bilko, 1971; Filiz & Toğulga, 2009; Froese & Binohlan, 2003; MacInnis & Corkum, 2000). In addition to slower growth, *G. callidus* is relatively long lived (7 years) when compared to gobies such as *N. melanostomus* which generally live for about 4 years (Grula *et al*., 2012), similar to that reported for *Gobius vittatus* where males attained ages of 7 years (Kovačić, 2006) but shorter lived than *G. niger* from Turkey (9 years) (Filiz & Toğulga, 2009). Overall, *G. callidus* had higher mortality rates compared with *G. niger* from Turkey (Filiz & Toğulga, 2009), and female *Neogobius caspius* (Eichwald 1831), however, had low mortality rates than male *N. caspius* (Aghajanpour *et al*., 2016) from the Caspian Sea and *Aphia minuta* (Risso 1810) from Italy (La Mesa, 1999). Furthermore, *N. melanostomus* had higher mortality rates than *G. callidus* (Kasapoğlu, 2016).

Although fecundity, maturity and spawning frequency are important components of understanding the life history, these need to be coupled with information regarding age and growth to allow for the interpretation of these data on the context of rates. Relatively fast growth and early maturity allow juveniles to reach maturity rapidly, a trait linked to successful colonisers of novel habitats (Corkum *et al*., 2004). This is similar to the traits exhibited by invasive *N. melanostomus* (Corkum *et al*., 2004). MacInnis and Corkum (2000) show that successful invaders are characterised by a short generation time, rapid growth and early maturity. Where present, these gobies have generally dominated benthic communities by highly competitive feeding strategies. A speleophil reproductive strategy, high fecundity (Corkum *et al*., 2004), rapid maturity (Kornis *et al*., 2017) and a generalist feeding strategy are traits linked to its success as an invader in the Great Lakes. Similarly, the ability of *G. callidus* to rapidly colonise the irrigation impoundments in the Sundays River system (Woodford *et al*., 2013) is most likely facilitated by its generalist diet (Mofu *et al*., 2019), wide environmental tolerance and similar reproductive strategy to invasive gobies. Such traits may thus represent indicators for the establishment of success in freshwater gobies introduced into novel environments.

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REFERENCES

Abell, R., Thieme, M. L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., … Bussing, W. (2008). Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. *Bioscience*, *58*, 403–414.

Aghajanpour, M., Haghparast, S., Raeisi, H., & Jabale, A. R. (2016). Growth parameters and mortality rate of *Neogobius caspius* (Eichwald, 1831) in the southern part of the Caspian Sea (Teleostei: Gobiidae). *Iranian Journal of Ichthyology*, *3*, 122–129.

Apanasenko, M. (1973). Age and size of round goby *Neogobius melanostomus* (Pallas) from different regions of the Azov and Black seas. *Biologia Moria*, *31*, 98–106.

Beamish, R. J., & Fournier, D. A. (1981). A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences*, *38*, 982–983.

Beamish, C. A., Booth, A. J., & Deacon, N. (2005). Age, growth and reproduction of largemouth bass, *Micropterus salmoides*, in Lake Manyame, Zimbabwe. *African Zoology*, *40*, 63–69.

Bilko, V. (1971). Comparative characteristics of the growth of Gobiidae and the Lee phenomenon. *Voprosy Ikhtjologii*, *11*, 650–663.

Brown-Peterson, N. J., Wyanski, D. M., Saborido-Rey, F., Macewicz, B. J., & Lowerre-Barbieri, S. K. (2011). A standardized terminology for describing reproductive development in fishes. *Marine and Coastal Fisheries*, *3*, 52–70.

Buckland, S. T. (1984). Monte-Carlo confidence intervals. *Biometrics*, *40*, 811–817.

Campana, S. E. (2001). Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology*, *59*, 197–242.

Cerrato, R. M. (1990). Interpretable statistical statistical tests for growth comparisons using parameters in the von Bertalanffy equation. *Canadian Journal of Fisheries and Aquatic Sciences*, *47*, 1416–1426.

Chang, W. Y. B. (1982). A statistical method for evaluating the reproducibility of age determination. *Canadian Journal of Fisheries and Aquatic Sciences*, *39*, 1208–1210.

Charlebois, P. M., Corkum, L. D., Jude, D. M., & Knight, C. (2001). The round goby (*Neogobius melanostomus*) invasion: current research and future needs. *Journal of Great Lakes Research*, *27*, 263–266.

Cope, J. M., & Punt, A. E. (2007). Admitting ageing error when fitting growth curves: an example using von Bertalanffy growth function with random effects. *Canadian Journal of Fisheries and Aquatic Science*, *64*, 205–218.

Corkum, L. D., Sapota, M. R., & Skora, K. E. (2004). The round goby *Neogobius melanostomus*, a fish invader on both sides of the Atlantic Ocean. *Biological Invasions*, *6*, 173–181.

Efron, B. (1982). The jacknife, the bootstrap and other resampling plans. *Society for Industrial and Applied Mathematics, Philadelphia*, 92.

Filiz, H., & Toğulga, M. (2009). Age and growth, reproduction and diet of the black goby (*Gobius Niger*) from Aegean Sea, Turkey. *Journal of Fisheries Sciences*, *3*, 243–265.

Froese, R., & Binohlan, C. (2003). Simple methods to obtain preliminary growth estimates for fishes. *Journal of Applied Ichthyology*, *19*, 376–379.

Gertzen, S., Fidler, A., Kreische, F., Kwabek, L., Schwamborn, V., & Borcherding, J. (2016). Reproductive strategies of three invasive Gobiidae co-occurring in the lower Rhine (Germany). *Limnologica*, *56*, 39–48.

Grula, D., Balazova, M., Copp, G. H., & Kovac, V. (2012). Age and growth of invasive round goby *Neogobius melanostomus* from middle Danube. *Central European Journal of Biology*, *7*, 448–459.

Hempel, M., Magath, V., Neukamm, R., & Thiel, R. (2019). Feeding ecology, growth and reproductive biology of round goby *Neogobius melanostomus* (Pallas, 1814) in the brackish Kiel Canal. *Marine Biodiversity*, *49*, 795–807.

Immler, S., Mazzoldi, C., & Rasotto, M. B. (2004). From sneaker to parental male: change of reproductive traits in the black goby, *Gobius Niger* (Teleostei, Gobiidae). *Journal of Experimental Zoology*, *301A*, 177–185.

Kasapoğlu, N. (2016). Age, growth and mortality rates of discard species (*Uranoscopus scaber*, *Neogobius melanostomus* and *Gobius niger*) in the Black Sea. *Journal of Fisheries and Aquatic Sciences*, *33*, 397–403.

Kornis, M. S., Weidel, B. C., & Vander Zanden, M. J. (2017). Divergent life histories of invasive round gobies (*Neogobius melanostomus*) in Lake Michigan and its tributaries. *Ecology of Freshwater Fish*, *26*, 563–574.

Kotta, J., Nurkse, K., Puntila, R., & Ojaveer, H. (2016). Shipping and natural environmental conditions determine the distribution of the invasive non-indigenous round goby *Neogobius melanostomus* in a regional sea. *Estuarine, Coastal and Shelf Science*, *169*, 15–24.

Kovačić, M. (2006). Age structure, growth and mortality of the striped goby, *Gobius vittatus* (Gobiidae) in the northern Adriatic Sea. *Scientia Marina*, *70*, 635–641.

Kovačić, M. (2007). Reproductive biology of the striped goby, *Gobius vittatus* (Gobiidae) in the northern Adriatic Sea. *Scientia Marina*, *71*, 145–151.

La Mesa, M. (1999). Age and growth of *Aphia minuta* (Pisces, Gobiide) from the Central Adriatic Sea. *Scientia Marina*, *63*, 147–155.

Maake, P. A., Mwale, M., Dippenaar, S. M., & Gon, O. (2013). Mitochondrial and nuclear DNA reveals a complete lineage sorting of *Glossogobius callidus* (Teleostei: Gobiidae) in southern Africa. *African Journal of Aquatic Sciences*, *38*, 15–29.

MacInnis, A. J., & Corkum, L. D. (2000). Fecundity and reproductive season of the round goby *Neogobius melanostomus* in the upper Detroit River. *Transactions of the American Fisheries Society*, *129*, 136–144.

Mofu, L., Woodford, D. J., Wasserman, R. J., Dalu, T., & Weyl, O. L. F. (2019). Diet of *Glossogobius callidus* (Teleostei: Gobiidae) in freshwater impoundments in the Sundays River Valley of the Eastern Cape, South Africa. *African Journal of Aquatic Science*, *44*, 415–420.

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *ICES Journal of Marine Science*, *39*, 175–192.

Pauly, D. & Munro, J. L. (1984). Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte*, *2*, 21.

Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish populations. *Canadian Fisheries Research Board Bulletin*, *191*, 1–38.

Skora, K., Olenin, S., & Gollasch, S. (1999). *Neogobius melanostomus* (Pallas, 1811). P 69-73. In Gollasch, S., Michin, D., Rosenthal, H., & Voight, M. (eds.) case histories on introduced species: their general biology and distribution, range expansion and impact. Logos Verlag Berlin.

Sokołowska, E., & Fey, D. P. (2011). Age and growth of the round goby *Neogobius melanostomus* in the Gulf of Gdansk several years after invasion. Is the Baltic Sea a new promised land? *Journal of Fish Biology*, *78*, 1993–2009.

Takegaki, T., Svensson, O., & Kvarnemo, C. (2012). Socially induced tactic change in 2 types of sand goby sneaker males. *Behavioral Ecology*, *23*, 742–750.

Thacker, C. E. (2003). Molecular phylogeny of the gobioid fishes (Teleostei: Perciformes: Gobioidei). *Molecular Phylogenetics and Evolution*, *26*, 354–368.

Wasserman, R. J. (2012). Feeding ecology of the early life-history stages of two dominant gobiid species in the headwaters of a warm-temperate estuary. *Estuarine, Coastal and Shelf Science*, *109*, 11–19.

Wasserman, R. J., Strydom, N. A., & Weyl, O. L. F. (2011). Diet of largemouth bass, *Micropterus salmoides* (Centrarchidae), an invasive alien in the lower reaches of an Eastern Cape river, South Africa. *African Zoology*, *46*, 378–386.

Wasserman, R. J., Vink, T. J., Woodford, D. J., & Froneman, P. W. (2015). Spawning and nest guarding of the river goby (*Glossogobius callidus*) from the Eastern Cape province of South Africa. *African Journal of Ecology*, *53*, 609–612.

Winemiller, K. O., Fitzgerald, D. B., Bower, L. M., & Pianka, E. R. (2015). Functional traits, convergent evolution, and periodic tables of niches. *Ecology Letters*, *18*, 737–751.

Woodford, D. J., Hui, C., Richardson, D. M., & Weyl, O. L. F. (2013). Propagule pressure drives establishment of introduced freshwater fish: quantitative evidence from an irrigation network. *Ecological Applications*, *23*, 1926–1937.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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