

## Length-weight Relationship and Condition Factor of Amur Goby *Rhinogobius similis* Gill, 1859 (Actinopteri: Gobiidae) from Different Areas in Vietnam

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**Abstract:** *Rhinogobius similis* is a common freshwater goby, widely distributed from temperate to tropical regions. Information about the length-weight relationship (LWR) and condition factor (K) of this species, which is important for assessing and managing fish resources, is still limited. This study aimed to examine the variation of the LWR and K among seasons, localities and habitats of this species based on 2508 specimens collected in 2020–2021 from the Red River system in the north and a lake in the central highland of Vietnam. The standard length of the collected fish ranged 2.30–8.27 cm ( $4.65 \pm 0.84$  cm) and the weight ranged 0.1–5.8 g ( $1.03 \pm 0.61$  g). Fish weights could be predicted based on fish length with high accuracy, as the  $r^2$  value of LWR was high ( $r^2 > 0.83$ ). The  $b$  values ranged 2.804–3.462, being higher than those in temperate and subtropical populations in China. This species generally showed positive allometric growth with a  $b$  value generally larger than 3, meaning smaller individuals having more elongated body shape than older individuals. The estimated  $K$  value for all individuals was lower than the nutritional threshold of 1, thus suggesting that *R. similis* lived in unfavourable environmental conditions at the time of sampling. The growth pattern and  $K$  varied with season, locality and habitat. In the riverine habitat of the Red River, this species expressed a positive allometric growth during the rainy season but isometric during the dry season. The  $K$  values were higher than 1 in some cases and were higher during the rainy season as compared to the dry season, higher in the riverine habitat of the Red River and in the lacustrine habitat of the south than in other habitats. These latitudinal variances in the growth pattern and  $K$  across various regions affirm the adaptive ability of this species in various habitats. The obtained data will be useful for controlling this fish while managing ecosystems since it is abundant in tropical regions and has potential ecological impacts on native species.

**Key words:** *Rhinogobius similis*, positive allometric growth, biodiversity, temperate goby fish, lacustrine and riverine habitats

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## Introduction

The length-weight relationship (LWR) indicates growth patterns and dynamics of fish populations. The slope  $b$  calculated from the LWR is used to understand how fish react to the ambient environment, as it is different depending on season and locality (LE CREN 1951). Furthermore, the body condition factor ( $K$ ) is an important tool for assessing environmental impacts on fish and is indicative for the relative health of fish populations (TESCH 1968, FROESE 2006). In addition, the LWR and  $K$  vary between sexes and they are species-specific (Le CREN 1951, FROESE 2006). Hence, information on the two parameters will be worthy in examining the capability of the species to adapt to various environmental conditions.

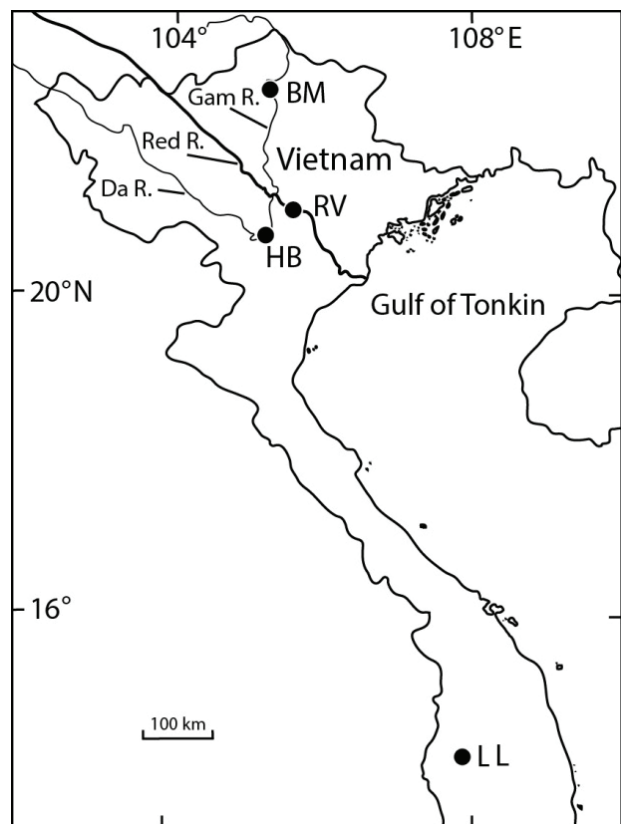
*Rhinogobius similis* Gill, 1859 (Gobiidae) is a common freshwater goby widely distributed from temperate to tropical climate regions. This species is found in Japan, Korea, Russia, Mongolia, China, Taiwan and Vietnam (LARSON & KIM 2005, NGUYEN 2005, TRAN & TA 2014, SUZUKI et al. 2016, TRAN et al. 2018, NGUYEN et al. 2019) and is introduced to Iran, Malaysia and Singapore (CHONG et al. 2010, SUZUKI et al. 2016, EAGDERI et al. 2017), being well-adapted to different climate zones. *Rhinogobius similis* lives in shallow waters over sandy bottoms, including canals, streams, drains, ponds and reservoirs (LIM & NG 1990, SEROV et al. 2006). This goby is considered an invasive species and is a serious threat to native and endemic fish (LARSON & KIM 2005, LARSON et al. 2008, EAGDERI et al. 2017). It is a euryhaline species that can adapt to a wide range of salinity, from freshwater to marine environments. Its food sources are animals and plants (MASUDA et al. 1984). However, information on its growth and development is still limited. The LWR of *R. similis*, also known as *R. giurinus*, has been mainly reported from China in subtropical and temperate climates (LEI et al. 2015, XIONG et al. 2015).

Based on collections of *R. similis* in the north and central highlands of Vietnam, the present study attempted to address three goals. The first goal was to provide LWR and  $K$  data for this species for the first time in the tropical region. Despite having a wide distribution range, the LWR and  $K$  parameters of this species are available only for the subtropical and temperate regions. Thus, the current data are valuable for understanding the diversity of this species relative to its morphometrics, ecology and biology across different climate zones. The second goal was to determine whether the LWR and  $K$  of *R. similis* in Vietnam varied among seasons, sampling

localities and habitats. The third goal was to provide basic information that can be used to explain the abundance of this temperate species in tropical regions, including ecosystems where it is invasive species.

## Materials and Methods

**Study area.** The study was conducted in two habitat types from north to central Vietnam: riverine (Red River) and lacustrine habitats (Bacme Reservoir in Ha Giang Province, Hoabinh Reservoir in Hoa Binh Province and Lak Lake in Dak Lak Province) (Table 1, Fig. 1). The Red River is the longest river in northern Vietnam facing the Gulf of Tonkin. The sampling site of the Red River is in Hanoi, which is located at the middle reach of the river. Bacme and Hoabinh Reservoirs are situated in the Gam and Da Rivers, respectively, which are large tributaries and flow into the Red River at the upper reach. The southernmost locality of the present study is in Lak Lake of Dak Lak Province, this is the largest natural freshwater lake of Vietnam (VU 2006).



**Fig. 1.** Chart showing the stations where the *Rhinogobius similis* were collected in Bac Me Reservoir in Ha Giang Province (BM), Red River in Hanoi (RV), Hoa Binh reservoir in Hoa Binh Province (HB) and Lak Lake in Dak Lak Province (LL), Vietnam.

**Table 1.** Collection data of *Rhinogobius similis* from the north and central highlands of Vietnam used in the present study.

Location	Coordinates	Sampling time	Sampling frequency	Sampling method	No of individuals
Bacme Reservoir Ha Giang Province	22°40'59.90"N 105°15'27.20"E	December 2019	1	Net traps, hand net	195
Red River in Hanoi	21° 8'55.48"N 105°38'59.90"E	May to December 2020, March, April 2021	10	Net traps	1326
Hoabinh Reservoir Hoa Binh Province	20°47'41.10"N 105°17'53.00"E	May to June 2020	1	Net traps	349
	20°47'0.50"N 105°13'49.60"E		1	Net traps	
Lak Lake Dak Lak Province	12°25'45.77"N 108°11'14.52"E	Rainy (August) 2020 Dry (December) 2020	2	Net traps	638

**Fish collection.** In total, 2508 specimens of *R. similis* were collected during the study. Seasonal samples were collected in the Bacme Reservoir of Ha Giang Province (dry season), Hoabinh Reservoir of Hoa Binh Province (rainy season) and Lak Lake of Dak Lak Province (both dry and rainy seasons) from December 2019 to December 2020 (Table 1). To test the monthly changes in LWR and condition factor of the Amur goby, samples were collected from the Red River from May 2020 to April 2021, excluding the period January – February 2021. Fish were collected using net traps (2–5 mm mesh size) at all stations and hand net (2 mm mesh size) in the Bacme Reservoir. After collection, specimens were fixed and were deposited in an 8–10 % formalin solution. For each individual, the total length was measured to the nearest 0.01 cm using a calliper. The total weight was measured using a SC4010 analytical balance ( $\pm 0.1$  g).

**Fish identification.** Following SUZUKI et al. (2016), the collected specimens were identified as *R. similis* based on the following characters (Fig. 2): predorsal squamation composed of large ctenoid scales, reaching anteriorly the near posterior margin of eye; dark brownish-grey reticulation or reddish oblique lines on head except for its ventral surface; black spot, as large as the pupil, at upper end of pectoral-fin base; longitudinal series of alternating large and small black blotches on mid-lateral body; two to four irregular longitudinal rows of small sky-blue spots on mid-lateral body when alive.

**Data analysis.** Fish growth was assessed by analysing the relationship between total length (TL) and weight (W) of fish using the formula  $W = a \times TL^b$  (LE CREN 1951), where  $a$  and  $b$  were the intercept and slope value of the LWR, respectively. The coefficient of determination  $r^2$  and parameters  $a$  and  $b$  of the LWR were estimated using linear regression analysis based on natural logarithms:  $\ln(W) = \ln a$

+  $b \ln TL$ . Possible types of growth of fish include theoretical growth of body height, body length and body width ( $b = 3$ ; isometric growth, symbol I) and growth that prioritises body width and body height ( $b > 3$ ; positive allometric, +A) or prioritises length ( $b < 3$ ; negative allometric, –A) (FROESE 2006). The parameter  $r^2$  is used as an indicator of the quality of linear regression. A one-sample t-test was used to examine whether the  $b$  value obtained from a linear regression was significantly different from the isometric value ( $b = 3$ ). Analysis of covariance (ANCOVA) was used to evaluate the similarity between regressions.

The  $K$  of the fish was estimated following LE CREN (1951) and using the equation  $K = \frac{W}{aTL^b}$ . The  $K$  value of each fish group (divided by season, location and habitat) was compared with the ideal value of one ( $K = 1$ ) using a one-sample t-test, and values were compared among fish groups by t-test, Wilcoxon test or Kruskal-Wallis test depending on the distribution of data and equality of sample sizes among groups. R software (version 4.0.5) was used for statistical analyses (R CORE TEAM 2021). The FSA package was used to perform regression analyses (OGLE et al. 2020) and the ggplot2 package was applied to produce the figures (WICKHAM 2016). The level of significant difference for all statistical tests was set at  $p < 0.05$ .

## Results

### Length-weight relationship

As seasonal and monthly sampling was conducted only at the Red River in Hanoi and the Lak Lake, the seasonal variation of LWR is available only for these two locations. In general, the body weight of *R. similis* could be predicted with high accuracy based on body length since we obtained high val-



**Fig. 2.** *Rhinogobius similis* collected from several regions in Vietnam: A. Bac Me Reservoir, 5.79 cm SL; B. Hoa Binh Reservoir, 4.50 cm SL; C. Red River, 4.90 cm SL; D. Lak Lake, 4.95 mm SL.

ues of regression determination from all models ( $r^2$  ranged from 0.826 to 0.972,  $p < 0.001$  for all models). The coefficients of LWRs of *R. similis* varied among locations, sampling months and seasons (Tables 2, 3, 4). Remarkably, for fish collected from the Red River, the slope values ( $b$ ) of the regressions varied monthly, with the highest values in July ( $b = 3.396$ ) and the lowest in June ( $b = 2.936$ ) (Table 2). The  $b$  values also differed significantly between the dry and rainy seasons for these samples ( $b = 3.204$  in the rainy season;  $b = 3.079$  in the dry season,  $p < 0.05$ ; Table 2). The  $b$  values were not significantly different between the two seasons for fish collected from the Lak Lake ( $b = 2.804$  in the rainy season;  $b = 2.998$  in the dry season,  $p > 0.05$ ; Table 2). Generally, the growth pattern of this species in Lak Lake

and most of the time in the Red River were isometric ( $b = 3$ ,  $p > 0.05$ ; Table 2) but being positive allometric during July, December and the rainy season for the later locality ( $b > 3$ ,  $p < 0.001$ ; Table 2).

The LWR estimated for all specimens showed a positive allometric growth with a relatively high  $b$  value (3.305, significantly larger than 3 at  $p < 0.001$ ; Table 3). For different locations, the slope values ( $b$ ) of this species was lowest in fish collected in Lak Lake ( $b = 3.025$ ) and highest in Hoa Binh Reservoir ( $b = 3.330$ ). Fish in the Red River and the two reservoirs exhibited positive allometric growth ( $b > 3$ ,  $p < 0.001$ ) and fish in the Lak Lake exhibited isometric growth ( $b = 3$ ,  $p > 0.05$ ; Table 3). Fish LWRs differed significantly among the habitat types ( $p < 0.001$ ; Table 4). The  $b$  value was higher in fish

**Table 2.** Length-weight range and regression coefficient of *Rhinogobius similis* over the sampling period; *N*, number of samples; *TL*, total length; *W*, weight; *a* is intercept and *b* is slope value of regression; *R*<sup>2</sup>, coefficient of determination; *I*, isometric; +*A*, positive allometric.

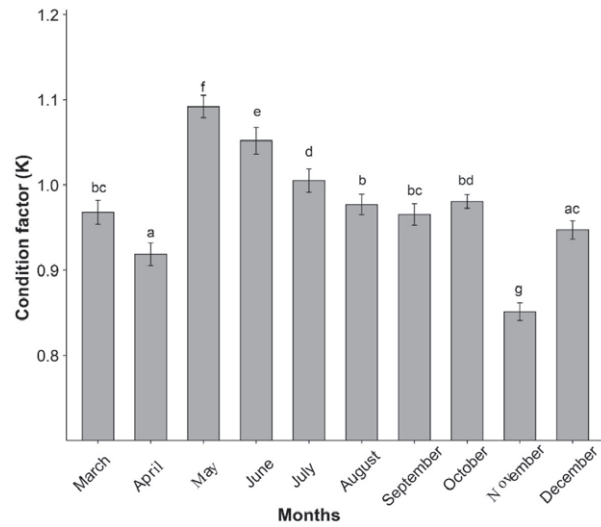
Location	Time	N	Range		Intercept (a)			Slope (b)			R <sup>2</sup>	p of regression	Compare to 3			Growth
			TL (cm)	W (gr)	a	2.5%	97.5%	b	2.5%	97.5%			t	df	p	
Red River in Hanoi	May	71	3.39-7.9	0.5-5.8	0.009	0.007	0.011	3.116	2.990	3.242	0.972	<0.001	1.833	69	0.071	I
	Jun	150	2.79-7.07	0.2-4.2	0.011	0.008	0.014	2.936	2.782	3.089	0.906	<0.001	-0.829	148	0.408	I
	Jul	174	2.3-8.27	0.1-5.3	0.005	0.004	0.006	3.396	3.294	3.498	0.962	<0.001	7.693	172	<0.001	+A
	Aug	220	2.63-7.04	0.2-2.8	0.009	0.007	0.011	2.999	2.857	3.140	0.888	<0.001	-0.021	218	0.984	I
	Sep	149	2.91-6.82	0.3-2.9	0.007	0.005	0.010	3.136	2.942	3.331	0.874	<0.001	1.385	147	0.168	I
	Oct	107	3.9-6.03	0.4-2.0	0.008	0.006	0.010	3.085	2.929	3.240	0.936	<0.001	1.077	105	0.284	I
	Nov	123	4.00-6.77	0.4-2.9	0.006	0.004	0.009	3.144	2.934	3.354	0.879	<0.001	1.358	121	0.177	I
	Dec	132	2.88-7.03	0.2-3.4	0.006	0.005	0.007	3.273	3.146	3.399	0.953	<0.001	4.266	130	<0.001	+A
	March	111	3.20-6.55	0.3-2.7	0.010	0.007	0.013	2.963	2.756	3.170	0.881	<0.001	-0.359	109	0.721	I
	April	89	3.30-6.3	0.2-2.5	0.008	0.006	0.011	3.074	2.867	3.281	0.909	<0.001	0.714	87	0.477	I
	Rainy	871	2.30-8.27	0.1-5.8	0.007	0.006	0.007	3.204	3.146	3.261	0.932	<0.001	6.941	869	<0.001	+A
	Dry	457	2.88-7.03	0.2-3.4	0.008	0.007	0.009	3.079	2.985	3.172	0.902	<0.001	1.654	455	0.099	I
Total	1326	2.30-8.27	0.1-5.8	0.007	0.007	0.008	3.131	3.081	3.180	0.921	<0.001	5.188	1324	<0.001	+A	
Lak Lake	Rainy	63	2.93-6.31	0.4-3.2	0.016	0.011	0.023	2.804	2.565	3.043	0.900	<0.001	-1.642	61	0.106	I
	Dry	575	2.73-6.29	0.2-3.1	0.010	0.009	0.011	2.998	2.924	3.072	0.918	<0.001	-0.051	573	0.959	I
	Total	638	2.73-6.31	0.2-3.2	0.010	0.009	0.011	3.025	2.953	3.098	0.913	<0.001	0.683	636	0.495	I

**Table 3.** Variation of length-weight relationships of *Rhinogobius similis* among sampling locations; *N*, number of samples; *TL*, total length; *W*, weight; *a* is intercept and *b* is slope value of regression; *R*<sup>2</sup>, coefficient of determination; *I*, isometric; +*A*, positive allometric.

Location	N	Range		Intercept (a)			Slope (b)			R <sup>2</sup>	p of regression	Compare to 3			Growth
		TL (cm)	W (gr)	a	2.5%	97.5%	b	2.5%	97.5%			t	df	p	
Red River in Ha Noi	1326	2.30-8.27	0.1-5.8	0.007	0.007	0.008	3.131	3.081	3.180	0.921	<0.001	5.188	1324	<0.001	+A
Baomh Reservoir	195	2.55-7.17	0.1-3.2	0.005	0.004	0.007	3.257	3.063	3.450	0.826	<0.001	2.620	193	0.009	+A
Hoabinh Reservoir	349	2.40-6.25	0.1-1.6	0.005	0.004	0.006	3.330	3.187	3.473	0.858	<0.001	4.537	347	<0.001	+A
Lak Lake	638	2.73-6.31	0.2-3.2	0.010	0.009	0.011	3.025	2.953	3.098	0.913	<0.001	0.683	636	0.495	I

**Table 4.** Variation of length-weight relationships of *Rhinogobius similis* among living habitats; *N*, number of samples; *TL*, total length; *W*, weight; *a* is intercept and *b* is slope value of regression; *R*<sup>2</sup>, coefficient of determination; *I*, isometric; +*A*, positive allometric.

Habitats	N	Range of TL and W		Intercept (a)			Slope (b)			R <sup>2</sup>	p of regression	Compare to 3			Growth
		TL (cm)	W (gr)	a	2.5%	97.5%	b	2.5%	97.5%			t	df	p	
Riverine	1326	2.30–8.27	0.1–5.8	0.007	0.007	0.008	3.131	3.081	3.180	0.921	<0.001	5.188	1324	<0.001	+A
Lacustrine	1128	2.40–7.17	0.1–3.2	0.004	0.004	0.005	3.462	3.384	3.521	0.894	<0.001	13.350	1180	<0.001	+A
Lacustrine in the north	544	2.40–7.17	0.1–3.2	0.006	0.005	0.007	3.127	3.037	3.218	0.895	<0.001	2.767	542	0.005	+A
Lacustrine in high-land	638	2.73–6.31	0.2–3.2	0.010	0.009	0.011	3.025	2.953	3.098	0.913	<0.001	0.683	636	0.495	I



**Fig. 3.** Monthly variation of condition factor of *Rhinogobius similis* collected from Red River, Hanoi, Vietnam; error bars indicate standard errors; different letters indicate significant difference at *p* < 0.05; the months sharing the letter are not significantly different in fish condition factor.

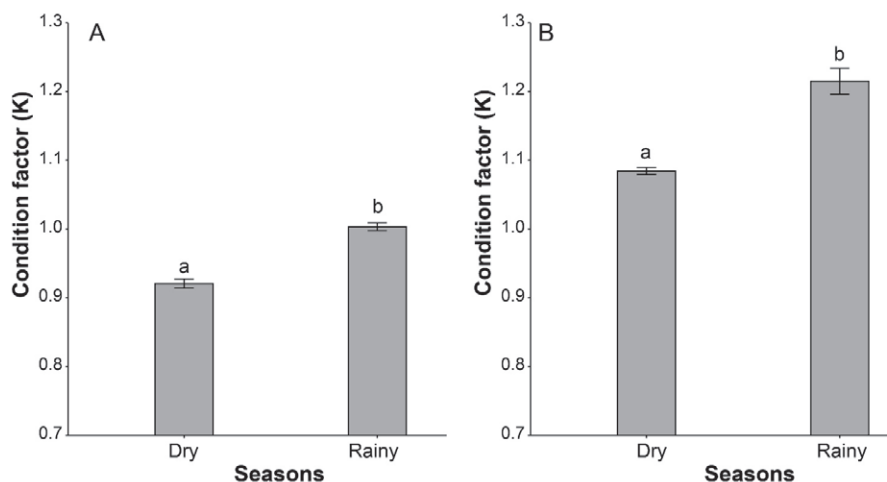
collected from lacustrine habitats, including Bacme and Hoabinh Reservoirs and the Lak Lake (*b* = 3.462) than those from riverine habitat, e.g., Red River (*b* = 3.131, *p* < 0.001; Table 4) but fish in both riverine and lacustrine habitats showed positive allometric growth (*b* > 3, *p* < 0.001; Table 4). The *b* values of LWRs calculated for fish from lacustrine of the north were higher than those from highlands, with *b* = 3.127 and *b* = 3.025, respectively, showing positive allometric growth (*b* > 3, *p* < 0.001; Table 4) and isometric growth (*b* = 3, *p* > 0.05; Table 4).

**The condition factor (K)**

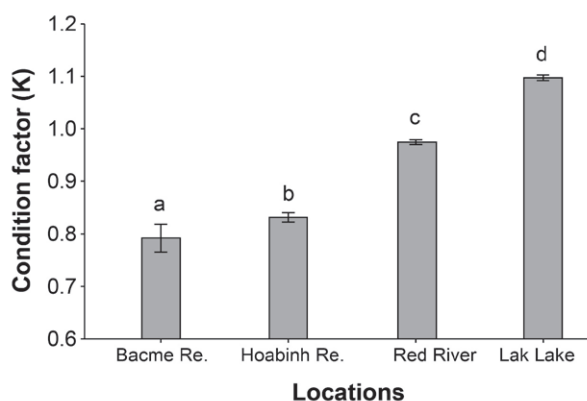
The monthly variation in the *K* value of fish collected from the Red River is presented in Fig. 3. For most of the months, *K* values were close to 1, demonstrating that fish have body conditions equal to the value estimated for all specimens based on the means of LWR coefficients. The *K* value was highest in May (*K* = 1.09 ± 0.11), followed by June (*K* = 1.05 ± 0.19), while the lowest value was found in November (*K* = 0.85 ± 0.12).

The condition factor of this species showed significant seasonal variation. For both Red River and Lak Lake populations, the t-tests revealed that fish specimens possessed significantly higher *K* value during the rainy season (1.00±0.17 for the Red River and 1.21±0.15 for the Lak Lake) compared to the dry season (0.92±0.14 for the former and 1.08±1.22 for the latter) (*p* < 0.001 for both cases; Fig. 4).

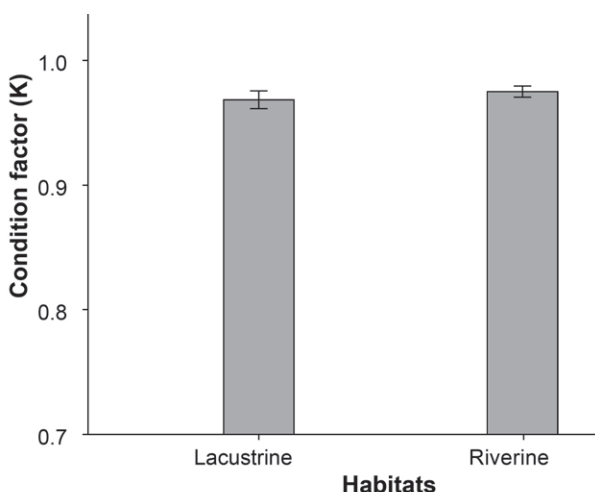
Comparing *K* values among locations showed a significant variation and a latitudinal tendency in-



**Fig. 4.** Seasonal variation in condition factor of *Rhinogobius similis* collected from Red River in Hanoi (A) and Lak Lake (B) in Vietnam; error bars indicate standard errors; different letters indicate significant difference at  $p < 0.05$ .



**Fig. 5.** Variation of condition factor of *Rhinogobius similis* among locations in Vietnam; error bars indicate standard errors; different letters indicate significant difference at  $p < 0.05$ .



**Fig. 6.** Variation of condition factor among different habitats of *Rhinogobius similis* in Vietnam; error bars indicate standard errors.

creasing from north to south. Fish specimens had the lowest  $K$  value in the northernmost location, Bacme Reservoir ( $0.79 \pm 0.37$ ), followed by fish in Hoabinh Reservoir ( $0.83 \pm 0.17$ ) and the Red River ( $0.97 \pm 0.16$ ) and the highest in the Lak Lake ( $1.09 \pm 0.13$ ) (Kruskal-Wallis test,  $\chi^2(3) = 8.53.87$ ,  $p < 0.001$ ; Fig. 5).

The comparison of  $K$  values between two types of habitats, lacustrine and riverine, revealed no significant differences between the two types ( $K = 0.97 \pm 0.16$  for riverine habitat;  $0.97 \pm 0.24$  for lacustrine habitat; Wilcoxon test,  $W = 786426$ ,  $p = 0.88$ ) (Fig. 6). However, within the lacustrine habitat, a significant difference in  $K$  values of fish collected from the north ( $0.81 \pm 0.26$ ) and those collected in the highlands ( $1.09 \pm 0.13$ ) was detected (Wilcoxon test,  $W = 321891$ ,  $p < 0.001$ , Fig. 5).

## Discussion

These are the first LWR data for *R. similis* from a tropical region. The  $r^2$  values of *R. similis* for all cases analysed in this study were high (primarily  $> 0.88$ ) (Table 2), suggesting that the fish's weight could be estimated from length. Similar data were observed for the same species distributed in subtropical and temperate regions in China (YE et al. 2007, LEI et al. 2015, XIONG et al. 2015, HEIDARI et al. 2018). The slope  $b$  ranged from 2.804 to 3.462 (Tables 2–4), almost within the standard range of 2.7 to 3.4 reported for 90 % of fish examined (FROESE 2006). Overall, the LWR regression slope ( $b$ ) value of *R. similis* for all individuals from the present study was 3.305, higher than the isometric value of 3 (Table 3), indicating that this goby species had a positive allometric growth. This implies that smaller individuals of *R. similis* tend to be more elongated,

with a thinned body, while bigger individuals tend to be plumper in shape (FROESE 2006). The positive allometric growth could be found in seven goby species in the same river basin (TRAN et al. 2021b).

The parameter of LWR could be a species-specific characteristic that is affected by environmental conditions (RICHER 1973, FROESE 2006). Of the five surveyed sites in the present study, the specimens of *R. similis* from the Red River and two reservoirs had positive allometric growth. The positive growth pattern (with  $b = 3.38$ ) has also been reported for this species (reported as *R. giurinus*) in the Xiangjiang River, a tributary of the middle Yangtze River, Southern China (24°31'–29°52' N, 110°31' E) (LEI et al. 2015). On the other hand, an isometric growth was observed in specimens from the Lak Lake (*highland*), which was similar to the specimens collected in a shallow macrophytic Yangtze Lake in China (30°16'–22' N, 114°27'–38' E) (YE et al. 2007) and in *R. cf. similis* from the southern Caspian Sea basin (37°28'13"N, 49°20'33"E) (HEIDARI et al. 2018). In addition, negative allometric growth was obtained for *R. similis* from a wetland lake in central Yangtze River (30°31'0–30°36'0 N; 114°21'0–114°28'0 E) (XIONG et al. 2015). These differences in growth patterns support that the growth patterns of this species may vary depending on environmental factors.

Since the change of the  $b$  value can be affected by the changes in environmental conditions, the seasonal variations in the growth pattern of *R. similis* between the Red River and the Lak Lake (Table 2) could be explained by the difference in the hydrology of the river and the lake. Seasonal change of hydrologic conditions, e.g. velocity, turbidity and water discharge in the Red River, was more pronounced than in the Lak Lake and could influence the growth of the fish, making the fish growing differently during the two seasons in the river but similarly in the lake. This result implies that *R. similis* has high plasticity in growth patterns and is likely adapted to variable (unstable) environmental conditions. Similarly, the seasonal difference in growth pattern has also been reported for *Periophthamus modestus* from the estuary of the Red River, in which fish also have significantly higher growth in the rainy season than in the dry season as suggested by their  $b$  coefficients (TRAN et al. 2021a). Differently, other species from the Red River, i.e. *Glossogobius olivaceus* (TA et al. 2022) and *Bostrychus sinensis* (NGUYEN et al. 2022), have similar growth patterns between seasons. The  $b$  value is regulated by the specific gonadal developmental stage and reproductive investment (FROESE 2006), and the spawning season of *R. similis* is in

rainy season months in Taiwan (CHANG et al. 2008). Therefore, the higher  $b$  value in rainy season in this study might partly be a consequence of increasing of gonad volume in the pre-spawning period.

The present results reveal that fish in the lacustrine habitat generally has higher  $b$  values than those in the riverine habitat (Table 4). This suggest that fish in the lacustrine habitat (particularly in the reservoir) tends to increase in thickness as they grow. Thus, the larger specimen have a plumper body shape than the smaller ones. Contrary to the present study, the fish collected in China grow in weight better in the riverine habitat (as the  $b$  values were higher) than in the lacustrine habitat (YE et al. 2007, LEI et al. 2015, XIONG et al. 2015, HEIDARI et al. 2018). As seen from Fig. 2, a difference in morphology and pigmentation could be found in fish collected from different study areas. The above information demonstrates the diversity of the growth pattern of this temperate goby species, which leads to its adaptation to different habitats.

The present study contributes the first data of condition factor for this species with relations to changes of environmental conditions and fish health (FROESE 2006). The estimated  $K$  value for all individuals averaged 0.97, which was significantly lower than the ideal threshold value of 1 ( $t(2507) = -7.606$ ,  $p < 0.001$ ). This suggested that, in general, the fish were not in healthy conditions at the time of sampling. Given that the condition factor can be regulated by the seasonal change in environmental conditions (FROESE 2006), in more cases in the present study (Bacme and Hoabinh Reservoirs), fishes showed a low condition factor; they were collected during the winter month in the north of Vietnam when the water temperature was low and food resource might be limited. The seasonal variation in  $K$  of collected fish from the Red River and the Lak Lake confirmed the significant effect of season on condition factor in this species. Fish were in a better condition during the rainy season than during the dry season (Fig. 4), contradicting the results for *P. modestus* inhabiting the lowland area of the Red River (TRAN et al. 2021a). The higher  $K$  value in the riverine habitat within the Red River suggests that the fish are more adaptable to this type of habitat, where environmental conditions exhibited seasonal variations. The condition factor of fish in the present study seemed to follow a latitudinal tendency, increasing from north to south. E.g., in the same type of habitat (stillness waters), the fish collected from more southern locations were healthier than those from the north (Fig. 5), suggesting this fish having the potential to adapt to different environments in

the southern distribution range. Originally, this species was distributed in cold waters (SUZUKI et al. 2016). The high  $K$  value in the more southern area (highland) and during the hotter period (the rainy season) may support the speculation that *R. similis* is tolerant to higher temperature, which leads to its expansion to tropical regions (SEROV et al. 2006, TRAN & TA 2014, SUZUKI et al. 2016, TRAN et al. 2018). This species develops well after introduction (SUZUKI et al. 2016, EAGDERI et al. 2017). Factors such as maturity, reproduction, feeding habits and availability of food resources should be further concerned to provide insights into the growth of this species.

Introduced species could have an inverse effect and eventually cause the extinction of native species through acting as predators or competitors as well as by changing habitat (WORKMAN & MERZ 2007, STRAYER 2010). It has been reported that *R. similis* may be responsible for the disappearance of *Pseudogobiopsis* species in Singapore (LARSON & KIM 2005, LARSON et al. 2008) and the recorded adverse ecological impacts (EAGDERI et al. 2017). The difference in growth parameters of *R. similis* between the present study and previous reports firmly supports that the environmental conditions in the tropics are suitable for this temperate species. Furthermore, the higher  $K$  in the more southern population within Vietnam suggests that this goby adapts well to the higher temperature. In addition, the present study also reports the high variation in growth patterns and the condition factor. This species is an amphidromous fish that utilises estuarine habitats during a certain period of its life history; however, some studies indicate that it can remain in reservoirs (LIM & NG 1990, TRAN et al. 2018). Hence, these facts suggest that this goby may have an impact on native species and become a threat for the local biodiversity.

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**Compliance to ethical standards:** We confirm that the use of fish specimens in the present study was performed in compliance with current laws and ethical requirements for using animals for research.

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