

MORPHOMETRICS AND BODY CONDITION OF *GLOSSOGOBIOUS OLIVACEUS* IN MANGROVE FORESTS OF NORTHERN VIETNAM

T. T. Ta¹, N.H. Chu², N. T. Nguyen², H. D. Tran², T. T. Tran^{3,4}, L. M. Ha⁵ and N. T. Nguyen^{3,4,6*}

¹Hanoi Metropolitan University, 98 Duong Quang Ham, Cau Giay, Hanoi, Vietnam

²Hanoi National University of Education, 136 Xuan Thuy, Cau Giay, Hanoi, Vietnam

³Faculty of Biology, VNU University of Science, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam

⁴Center of Life Science Research (CELIFE), VNU University of Science, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam

⁵Graduate School of Fisheries and Environmental Sciences, Nagasaki University, Nagasaki 852-8521, Japan

⁶Biological Museum, VNU University of Science, 19 Le Thanh Tong, Hoan Kiem, Hanoi, Vietnam

*Corresponding author: Nam Thanh Nguyen (N. T. Nguyen), nguyenthanhnam@hus.edu.vn

ABSTRACT

Little is known on growth and size relationships of *Glossogobius olivaceus*, a high-value commercial species in northern Vietnam. This study aimed to explore morphometric relationships, growth and condition factor of *G. olivaceus* from mangrove forests of the Ba Lat estuary, the Red River in northern Vietnam. Analysis of 679 *G. olivaceus* collected monthly from March 2018 to February 2019 showed a sex ratio of approximately 1:1. The mean total length and body weight were not significantly different between females and males. Length-weight relationships (LWR) for *G. olivaceus* showed high correlations that varied slightly by season. This species presented a positive allometric growth pattern as the slope b of the LWR which was significantly higher than the cubic value of 3. Estimates of condition factor (K) were not different from the value of 1, implying a favorable nutritional condition of specimens collected. Both the LWR (b slope) and condition factor (K) of *G. olivaceus* from our study varied by sex, and seasons indicated that *G. olivaceus* lives across variable environmental conditions. Furthermore, shifts in growth patterns between the breeding ($b \approx 3$) and non-breeding season ($b > 3$) potentially suggest that this species has an adaptation strategy to monthly/seasonal environmental variability.

Key words: *Glossogobius olivaceus*, length-weight relationship, growth pattern, condition factor, mangrove forests.

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INTRODUCTION

Length-weight relationship (LWR) is of great importance in fishery assessments as it can be utilized to assess the relative nutritional condition of a fish population (Bagenal and Tesch, 1978; Bolger and Connolly, 1989), and can be an indirect measurement of fish biomass (Froese, 1998) and size-selective exploitation (Froese and Pauly, 2000; Gonzalez Acosta *et al.*, 2004; Mahmood *et al.*, 2012). For a particular species and population, trends in fish growth can be forecasted using the slope value (b), an exponent of the arithmetic form of the LWR (Froese, 2006). The condition factor (K) can indirectly measure the nutritional condition of fish, which may reflect its environment, which may respond differently with sex, size, seasonality, and food availability (Le Cren, 1951; Froese, 2006).

Glossogobius olivaceus (Gobiiformes: Gobiidae) (Nelson *et al.*, 2016) occur in lower reaches of rivers, tidal estuaries and mangrove forests of the Western Pacific Ocean from Japan to northern Vietnam (Nguyen, 2005; Wu *et al.*, 2009; Nguyen *et al.*, 2012; Nguyen *et al.*, 2013, Tran & Ta, 2014; Xiong *et al.*, 2017;

Kimura *et al.*, 2018). In northern Vietnam, this species of goby is highly abundant in mangrove forests around the Ba Lat estuary of the Red River (Nguyen *et al.*, 2013; Ta *et al.*, 2020; Tran *et al.*, 2020), and as a result, it is of ecological and commercial significance to the region (Nguyen, 2005).

Prior to this study, little information on LWR and trends in condition factor of *G. olivaceus* are available (Xiong *et al.*, 2017; Froese and Pauly, 2019). Subsequently, the present study aimed to establish the first data on morphometrics, length-weight relationships, and condition factor of this species from northern Vietnam. This information is fundamental for stock assessments that can guide conservation and management of fish diversity and sustainable fisheries of Vietnam.

MATERIALS AND METHODS

Study site: This study was carried out in mangrove forests (Tien Hai Wetland Nature Reserve and Xuan Thuy National Park) within the Ba Lat estuary, the Red River in northern Vietnam (Fig. 1). Xuan Thuy National Park is the first Ramsar site in Southeast Asia, which is

considered the largest coastal wetland ecosystem and a hotspot of biodiversity and conservation efforts in the northern part of Vietnam (Hoang *et al.*, 2013).

The study site lies in the tropical monsoon region, which is driven by monsoon systems. The rainy season is from May to October, and the dry season is

from November to April (Dao *et al.*, 2008; Ngo *et al.*, 2013). Annual air temperatures range from 6.8 °C to 40.1 °C, with an average of 24 °C (Dao *et al.*, 2008), and average precipitation of 1,175 mm per year. The northeast monsoon dominates in the dry season (Dao *et al.*, 2008).

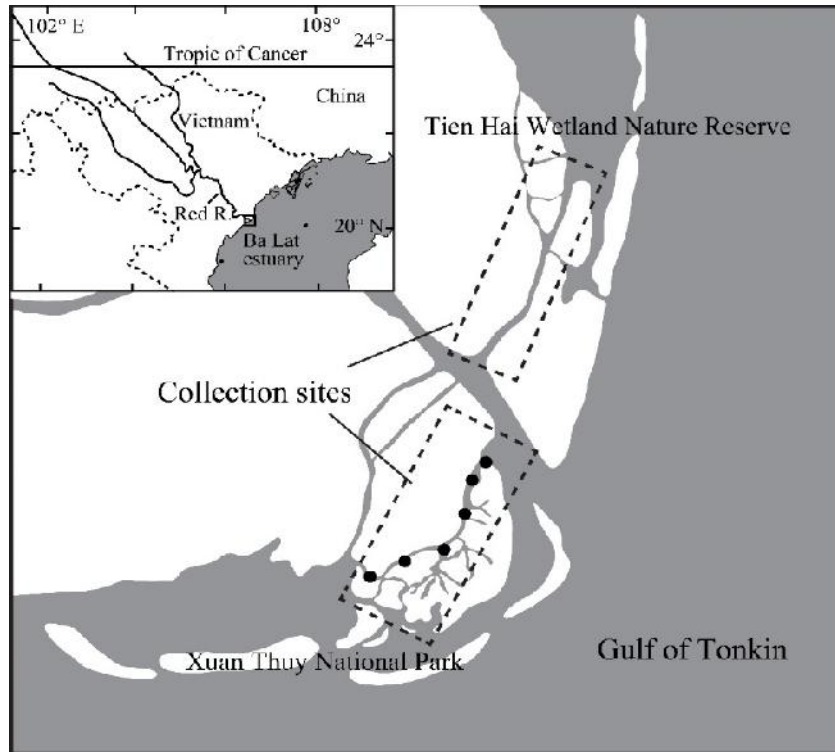


Fig 1. Chart showing stations where surveys were carried out in the Ba Lat estuary of the Red River, northern Vietnam. Dash rectangles indicate where *Glossogobius olivaceus* were collected; solid circles indicate where water quality parameters were measured.

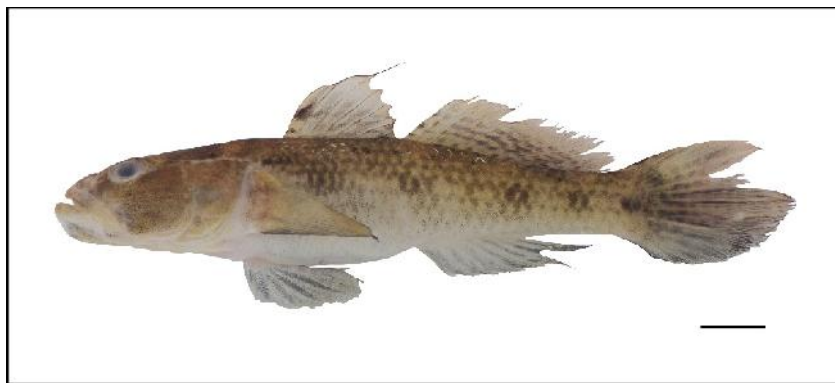


Fig 2. An individual of *Glossogobius olivaceus* collected from Xuan Thuy National Park; scale bar is 1 cm.

Fish collection and identification: Fish specimens were collected monthly by fishing net traps (mesh size 2 cm) with help from local fishers, from March 2018 to February 2019 in Xuan Thuy National Park, and in March, July and August 2019 in Tien Hai Wetland Nature Reserve (Fig. 1). After collection, specimens were

fixed with 8-10% formalin solution in a plastic jar and subsequently transferred into 75% ethanol in the laboratory. Identification was based on external morphology, with this species is characterized by having multiple black dots on the nape and occipital region (Fig. 2) (Kimura *et al.*, 2018; Ta *et al.*, 2020). Sexual

identification was performed based on the shape of the genital papilla (Padian, 2011). For each individual, total length was measured to the nearest 0.01 cm using a caliper, and total weight was measured using an Analytical Balance SC4010 to nearest 0.1 g. Water temperature (°C), salinity (Practical Salinity Units – PSU), and turbidity (Nephelometric – NTU) were measured monthly at six sampling stations along the main channel inside the mangroves where fish samples were collected (Fig. 1) using a Water Quality Checker (WQC-22A, TOA-DDK, Tokyo, Japan).

Data analysis: Differences in the sex ratio were examined by a Chi-square statistic test. The relationship between length and weight of fish was determined using the equation $W = a \times T^b$ (Riker, 1973) where W is the bodyweight of fish (g), TL is the total length (cm), a and b are intercept of the regression, and the regression coefficient (slope), respectively. Parameters a and b of the length-weight relationship were estimated by linear regression analysis based on natural logarithms: $\ln(W) = \ln a + b \ln L$. Analysis of covariance (ANCOVA) was performed to determine differences of obtained values from the linear models (intercept and slope) among fish groups (male and female, dry and rainy seasons or two sexes in each season). Additionally, 95% confidence limits of intercept a , slope b , and the statistical significance level of r^2 were also estimated (Santos et al., 2002). The determination coefficient (r^2) was used as an indicator of the quality of the linear regressions (Scherrer, 1984). The modeled relationship between length and weight will have $b = 3$ if the fish exhibit isometric growth. Therefore, the growth types of fish groups were tested by comparing the respective b value to the cubic value of 3 using Student t-tests. If $b > 3$, the fish grows faster in weight relative to length, then is considered to possess positive allometric growth. On the other hand, if $b < 3$, the fish grows more quickly in length than in weight and is categorized as negative allometric growth (Froese, 2006). Fish body condition factor was estimated following Le Cren's (1951) method: $K = W \times (a \times TL^b)^{-1}$, where W is the fish weight (g), TL is the total length (cm). The K value of each fish group was tested if it was equal to one by a Student t-test.

One-way ANOVA was performed to examine potential differences in length, weight, and body condition of fish among the fish groups (male and female, dry and rainy seasons) and collection times (months). All statistical analyses were performed using R software version 3.6.2 (R Core Team, 2020). The level of statistical significance for all tests was set at $p < 0.05$.

RESULTS AND DISCUSSION

Environmental factors and sex ratio: Water temperatures were lowest in January and highest in June, and it was generally warmer in the rainy season ($28.8 \pm$

0.28 °C) compared to the dry season (22.9 ± 0.32 °C) ($t(68) = 1.9954$, $P < 0.05$) (Table 1). Mean salinity of the study sites ranged from 0.6 psu in September to 18.2 psu in December, and this was also reflected in higher values in the dry season (12.3 ± 0.80 psu) relative to the rainy season (4.8 ± 0.65 psu) ($t(67) = 3.4417$, $P < 0.001$) (Table 1). Mean turbidity was significantly different between the two seasons ($t(62) = 3.4544$, $P < 0.05$), and fluctuated monthly (Table 1). Seasonal patterns in temperature and salinity revealed a reciprocal pattern (Table 1), which was likely driven by discharge from the Red River. This is different from the Kalong estuary, at the northward area, where the temperature is driven tidally (Tran et al., 2012).

The proportion of males to females of *G. olivaceus* in this study were not significantly different ($\chi^2(1, N = 679) = 1.99$, $P = 0.16$, Table 1), suggesting the sex ratio of this population was close to 1:1 over the year, which was also found in other gobies such as *Glossogobius giuris* from Pakistan (Achakzai et al., 2014), and *G. giuris* and *Boleophthalmus boddarti* from the Mekong Delta, Vietnam (Dinh and Ly, 2014; Dinh, 2015). However, the number of females was significantly higher than males from collections between June to August and October, primarily during the rainy season ($\chi^2(1, N = 276) = 6.09$, $P < 0.05$, Table 1) when water temperatures were highest (ca. 27 to 32°C), and salinities lowest (ca. 0.6 to 11.3 psu). The sex ratio is strongly regulated by temperature changes (Kvarnemo, 1996; Abucay et al., 1999; Baroiller and D'Cotta, 2001), which could also be observed from the present study as the sex ratio and water temperatures were significantly different between the two seasons (Table 1). In addition, differences in behavior and habitat selection or preference, including migration between sexes, may have contributed to females being more easily collected relative to males (Mahmood et al., 2011). Indeed, the spawning of *G. olivaceus* from the study site occurs in the rainy season (Tran, unpublished data) when more females collected seem to be related to breeding behavior, which warrants further investigation.

Morphometrics: The mean total length of females (8.93 ± 0.08 cm) was not significantly shorter than that of males (9.06 ± 0.09 cm) ($t(645.7) = -1.026$, $P = 0.3$, Table 2), and the mean body weight of females (7.31 ± 0.24 g) was statistically similar to males (7.69 ± 0.29 g) ($t(636.7) = -1.01$, $P = 0.31$, Table 2). This result suggests that with the assumption of equal growth rates, male and female *G. olivaceus* reach a marketable size at the same age. This trend was also found in some other gobies, such as *B. boddarti* (Dinh, 2014) and *Trypauchen vagina* (Dinh, 2016b). In August 2018 and February 2019, the mean length and weight *G. olivaceus* were significantly different between females and males (t-test, $P < 0.05$ for all cases, Table 2; Fig. 3). The mean length and weight of females, males, and both sexes combined were highest in

July and were significantly different between months ($F(11, 667) = 12.1, P < 0.001$, Table 3, Fig. 3).

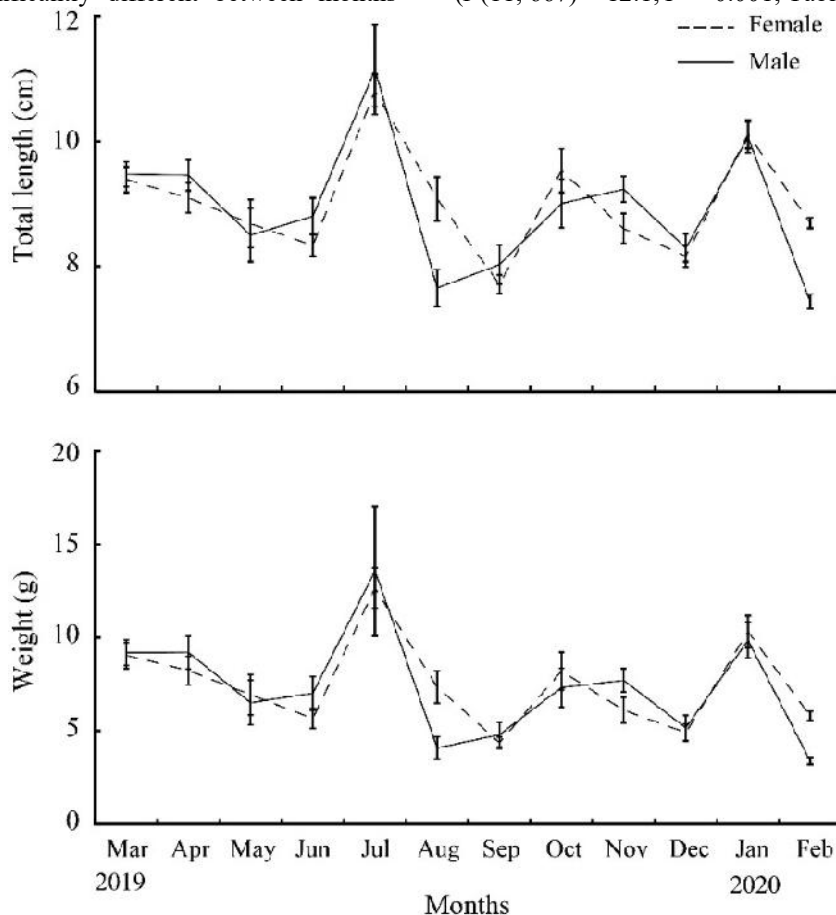


Fig 3. Line graph with error bar showing monthly variations in total length (cm) and weight (g) of male and female *Glossogobius olivaceus*; point symbols indicate monthly means; vertical bars indicate standard error of means.

Table 1. Sex ratio and water quality parameters from sites where *Glossogobius olivaceus* were collected.

Sampling time (individuals)	Sex ratio	P-value	Water temperature (°C)			Salinity (psu)			Turbidity (NTU)		
			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
March (n=107)	1.00:1.33	0.056	21.2	22.5	21.8	8.9	12.8	11.5	3	224	67.3
April (n=73)	1.00:0.97	1.000	22.1	25.0	24.3	5.6	9.2	7.8	30	96	51.5
May (n=44)	1.00:1.00	1.000	28.5	30.0	29.3	6.2	9.7	7.6	42	126	62.5
June (n=73)	1.00:0.66	0.020	30.0	33.1	31.5	2.2	4.6	3.4	23	117	51.8
July (n=16)	1.00:0.33	0.013	26.7	27.6	27.1	0.4	4.1	2.6	133	467	251
August (n=43)	1.00:0.48	0.002	28.6	29.4	29.0	0.2	3.8	2.6	51	286	121
September (n=57)	1.00:0.90	0.708	26.4	27.9	26.9	0.1	1.3	0.6	179	335	216
October (n=43)	1.00:1.68	0.031	29.0	29.8	29.4	8.8	16.1	11.3	20	445	120
November (n=48)	1.00:1.09	1.000	22.6	24.7	23.2	4.9	10.2	8.1	35	201	116
December (n=57)	1.00:0.68	0.061	23.8	25.3	24.2	16.5	20.8	18.2	85	474	175
January (n=88)	1.00:1.17	0.451	19.3	19.7	19.4	11.8	27.1	17.1	20	84	39.3
February (n=30)	1.00:1.73	0.071	23.9	24.5	24.2	9.7	13.3	11.1	25	165	77.5
Year (n=679)	1.00:0.97	0.266	21.2	22.5	21.8	8.9	12.8	11.5	3	224	67.3
Rainy season (153F:123M)	1:00:0.80	0.013	26.4	33.1	28.8*	0.1	16.1	4.8*	20	467	137.5
Dry season (192F:211M)	1:00:1.10	0.205	19.3	25.3	22.9*	4.9	27.1	12.3*	3	474	87.8

* indicates a significant difference between two seasons, $P < 0.001$

Table 2. Descriptive statistics and estimated parameters of the Length Weight Regression (LWR) between females and males for *Glossogobius olivaceus* from the study site.

Gender	Season	Total length (cm)			Weight (g)			Regression parameters		95% CI of a	95% CI of b	r ²	t _s	Growth type
		Min	Max	Mean ± SE	Min	Max	Mean ± SE	a	b					
Female	Rainy season	6.00	14.97	8.73 ± 0.13	1.6	27.1	6.78 ± 0.36	0.006	3.162	0.005–0.008	3.059–3.265	0.96	58.98	A+ ^{***}
	Dry season	6.44	13.10	9.12 ± 0.10	2.0	26.0	7.82 ± 0.33	0.004	3.413	0.003–0.005	3.286–3.541	0.93	52.76	A+ ^{***}
Male	Rainy season	6.00	14.30	8.56 ± 0.16	1.7	23.7	6.35 ± 0.43	0.006	3.203	0.005–0.007	3.089–3.317	0.96	57.49	A+ ^{***}
	Dry season	5.5	14.90	9.33 ± 0.11	1.5	34.6	8.40 ± 0.37	0.005	3.309	0.004–0.006	3.201–3.417	0.95	60.71	A+ ^{***}
Female		6.00	14.97	8.93 ± 0.08	1.6	26.0	7.31 ± 0.24	0.005	3.300	0.004–0.006	3.217–3.383	0.95	77.61	A+ ^{***}
Male		5.50	14.89	9.06 ± 0.09	1.5	34.6	7.69 ± 0.29	0.005	3.276	0.004–0.006	3.200–3.351	0.96	85.38	A+ ^{***}
All		5.50	14.97	9.00 ± 0.06	1.5	34.6	7.49 ± 0.19	0.005	3.285	0.004–0.005	3.229–3.341	0.95	115.10	A+ ^{***}

CI, confidence intervals; t_s, t values of coefficients; A +, positive allometric growth; A -, negative allometric growth; * indicates significant differences between slopes and cubic value of 3 (** = P < 0.01, *** = P < 0.001).

Table 3. Descriptive statistics and estimated parameters of the LWR between months and seasons for *Glossogobius olivaceus* from the study site.

Time	Total length (cm)			Weight (g)			Regression parameters		95% CI of a	95% CI of b	r ²	t _s	Growth type
	Min	Max	Mean ± SE	Min	Max	Mean ± SE	a	b					
Mar.	5.50	14.89	9.43 ± 0.14	1.5	34.6	9.13 ± 0.49	0.005	3.280	0.004–0.007	3.142–3.420	0.95	46.95	A+ ^{***}
Apr.	6.40	13.80	9.27 ± 0.17	2.2	30.6	8.72 ± 0.58	0.006	3.223	0.004–0.009	3.041–3.405	0.95	35.28	A+ [*]
May	6.00	14.64	8.59 ± 0.29	1.8	27.1	6.73 ± 0.80	0.007	3.148	0.005–0.009	2.993–3.302	0.98	41.08	I ^{ns}
Jun.	6.29	12.53	8.52 ± 0.16	2.1	22.2	6.21 ± 0.48	0.004	3.328	0.003–0.007	3.123–3.533	0.94	32.36	A+ ^{**}
Jul.	9.51	12.95	10.9 ± 0.26	7.8	23	12.9 ± 1.13	0.002	3.574	0.001–0.007	3.127–4.023	0.95	17.11	A+ [*]
Aug.	6.00	14.97	8.61 ± 0.27	1.6	24.3	6.29 ± 0.65	0.008	3.063	0.005–0.011	2.879–3.248	0.97	33.54	I ^{ns}
Sep.	6.01	11.99	7.86 ± 0.19	1.8	16.4	4.58 ± 0.35	0.006	3.185	0.004–0.009	2.958–3.411	0.94	28.17	I ^{ns}
Oct.	6.02	14.32	9.22 ± 0.27	1.9	23.7	7.70 ± 0.73	0.006	3.139	0.004–0.010	2.936–3.340	0.96	31.35	I ^{ns}
Nov.	6.82	11.43	8.93 ± 0.16	2.7	17.3	6.95 ± 0.47	0.003	3.582	0.001–0.004	3.318–3.846	0.94	27.29	A+ ^{***}
Dec.	6.64	11.96	8.21 ± 0.14	1.9	18.3	5.02 ± 0.38	0.004	3.366	0.002–0.007	3.099–3.633	0.92	25.31	A+ ^{**}
Jan.	6.59	14.20	10.10 ± 0.17	1.9	31	10.10 ± 0.65	0.003	3.473	0.002–0.004	3.303–3.642	0.95	40.83	A+ ^{***}
Feb.	6.82	9.36	8.23 ± 0.13	2.7	7.7	4.93 ± 0.27	0.004	3.384	0.001–0.010	2.901–3.842	0.89	14.68	I
Rainy season	6.00	14.97	8.66 ± 0.10	1.6	27.1	6.59 ± 0.27	0.006	3.193	0.005–0.007	3.117–3.270	0.96	81.96	A+ ^{***}
Dry season	5.50	14.89	9.22 ± 0.07	1.5	34.6	8.11 ± 0.25	0.004	3.349	0.004–0.005	3.267–3.431	0.92	80.10	A+ ^{***}

CI, confidence intervals; t_s, t values of coefficients; A+, positive allometric growth; A-, negative allometric growth; I, isometric growth; * indicates significant differences between slopes and cubic value of 3 (* = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = no significance).

The length and weight of fish in the dry season were higher than that observed from the rainy season ($t(544.04) = 4.51$ and $t(624.26) = 4.09$, respectively, with $P < 0.001$, Table 3). A similar case was observed in *Stigmatogobius pleurostigma* distributed in the Mekong Delta (Dinh, 2017). The mean length of females (9.12 ± 0.10 cm) in the dry season was significantly longer than those collected from the rainy season (8.73 ± 0.13 cm) ($t(311.32) = 2.65$, $P < 0.01$, Table 2, Fig. 3), and the length and weight of males in the dry season were significantly larger than those in the rainy season ($t(226.08) = 3.6$, $P < 0.001$ and $t(269.61) = 3.18$, $P < 0.01$, respectively Table 2, Fig. 3). Therefore, the length and weight of *G. olivaceus* from our study area may not be affected by sex but rather by environmental conditions. Indeed, fish collected in our study were below the maximum recorded standard length for the species (ca. 17 cm, Froese and Pauly, 2019; ca. 18 cm and 90 g from Zhanjiang mangrove of China (20°36'N; 110°54'E), Xiong *et al.*, 2018)). As previously shown, the water conditions in this mangrove system showed marked differences between seasons and months, which may influence development and growth. However, further study and collection of specimens across a broader area and across environmental gradients are needed to assess the main drivers of fish condition. Moreover, this information suggests the need to increase the mesh size for the collection of larger specimens in the study site.

Length-weight relationships: The LWR coefficients of *G. olivaceus* were highly significant ($P < 0.001$ for all of the months), with r^2 values being greater than 0.92 over most of the months, with the lowest value of 0.89 in February (Tables 2, 3). The strong length-weight relationship, therefore, allows for *G. olivaceus* weights to be estimated from length. Thus, the biomass estimated in this method can readily provide data for the management of the fishery. Strong positive length-weight relationships were also observed in other gobies, such as *Pseudapocryptes elongatus* (Tran *et al.*, 2007), *T. vagina* (Dinh, 2016b), and *G. giuris* (Dinh and Ly, 2014; Hossain and Sultana, 2014).

Overall, the LWR slope (b) value of *G. olivaceus* for all individuals from our study was 3.285 ± 0.029 , which was higher than the isometric value of 3 ($t(677) = 9.98$, $P < 0.001$, Tables 2, 3), indicating that this population exhibited a positive allometric growth. The positive allometric growth also suggests that smaller individuals may have a more elongated or thinned body form than larger individuals (Froese, 2006). The growth type of this species in the present study is different from that reported from a population in China, where the slope was 2.73, indicating negative allometric growth (Xiong *et al.*, 2018). In the same genus, *G. giuris* distributed in Bangladesh showed isometric growth (Hossain *et al.*, 2009; Hossain and Sultana, 2014). From the southern part

of Vietnam, Dinh (2016b) categorized the goby *T. vagina* in the “well-being” category, as this fish exhibited isometric growth with a b value of 2.88. Thus, we categorized *G. olivaceus* as being in a positive nutritional state from our research area and time of the study, where water conditions were likely suitable, and food resources might be sufficient for feeding and growth of this species.

Monthly, the b values from our regression models were significantly higher than the cubic value of 3 in most of the months ($t_s = 2.44$ – 5.56 , $P < 0.05$, Table 3), revealing positive allometric growth. Only in five months, mainly during the rainy season (only one month of the dry season), the growth pattern of *G. olivaceus* showed isometric growth as b values were not significantly different from 3 ($t_s = 0.697$ – 1.927 , $P > 0.05$, Table 3). As the author Kalaycı *et al.* (2007) reported that the b values of *G. niger* from the Black Sea, Egypt, and in the Mediterranean were 2.81, 2.89, and 3.85, respectively, this implied that the growth type is unique for this species, which may also be influenced by environmental conditions. Therefore, the positive allometric and isometric growth of *G. olivaceus* observed across months in the present study indicates that this species is highly adaptive to changing environmental conditions.

The ANCOVA revealed no significant difference ($F(3, 675) = 0.19$, $P = 0.67$) between the LWR slopes of males (3.276 ± 0.038) and females (3.300 ± 0.043) when models were fitted for all specimens (Table 2). Seasonally, the slope b in the dry season (3.349 ± 0.420) was higher than that from the rainy season (3.193 ± 0.039) with a 99% confidence level ($F(3, 675) = 8.02$, $P < 0.01$, Table 3). In both the rainy and dry seasons, b values were not different between sexes. In some gobies, slope b are regulated by gonadal development. For example, b values of *Parapocryptes serperaster*, *Gobius niger*, and *G. giuris* (Kalaycı *et al.*, 2007; Hossain and Sultana, 2014; Dinh *et al.*, 2016) were higher in females compared to males during the reproductive period. The different growth patterns observed between the two seasons from our study may be due to reproductive investment. The increased growth rate in body height, thickness, or width of a fish should be reduced following energy contributions to reproduction, and this has also been observed in some other gobies, namely *P. barbarus* and *Stigmatogobius pleurostigma* (King and Udo, 1998; Dinh, 2017).

Condition factor (K): The condition factor (K) was significantly different between females (1.02 ± 0.137) and males (0.10 ± 0.130 , $t(677) = -2.154$, $P < 0.05$, Fig. 4). The K values from the dry season (1.02 ± 0.145) were higher than those from the rainy season (0.10 ± 0.116 , $t(677)$, $P < 0.05$, Figs. 4, 5), suggesting that *G. olivaceus* from our study seemed better adapted in the dry season and that the gonadal development and maturation

influenced the variation in *K* of this species. In the spawning period (rainy season), the spent gonad of mature fish may have contributed to the lower mean *K* value. Furthermore, the higher *K* value of females (1.01 ± 0.109) to males (0.98 ± 0.123) in the rainy season ($t(274) = 2.687, P < 0.01$) (Figs. 4, 5) were related to the higher gonadal weight in females. These results were also observed in *T. vagina* (Dinh, 2016b) and *G. giuris* (Hossain and Sultana, 2014). Additionally, this suggests

that *K* values could be used to evaluate the sensitivities of fish to ambient factors or health conditions (Jin *et al.*, 2015). The condition factor (*K*) averaged 1.01, being not significantly different from the nutritional threshold of 1 ($t(678) = 1.647, P > 0.05$), and similar to other gobies, such as *P. elongatus* (Tran *et al.*, 2007), *T. vagina* (Dinh, 2016b) and *G. giuris* (Hossain and Sultana, 2014), which suggest the specimens were healthy and in a positive nutritional condition in the present study.

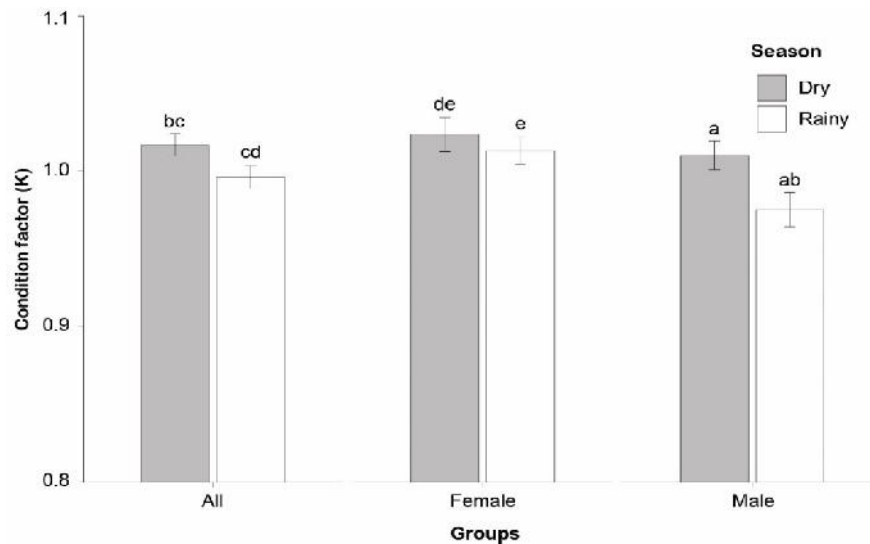


Fig 4. Bar graph showing the seasonal variation of condition factor (*K*) of *Glossogobius olivaceus* by sex and combined; vertical bars indicate standard errors of means; different letters indicate significant differences.

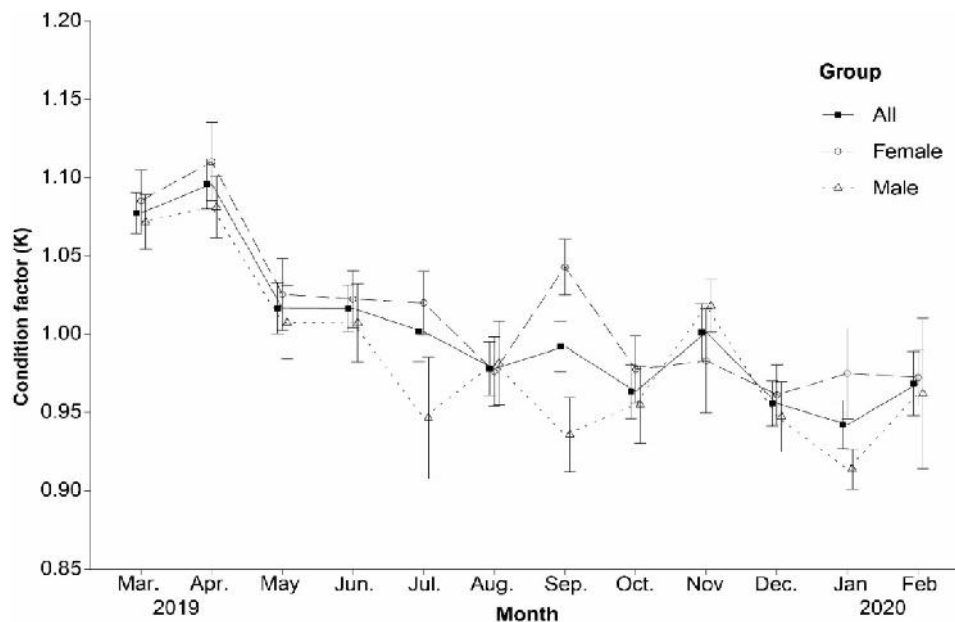


Fig 5. Line graph with error bar showing monthly variations of condition factor (*K*) for male and female *Glossogobius olivaceus* and all samples combined; point symbols indicate the means of each month; vertical bars indicate standard error of means.

The *G. olivaceus* from our study seems to have a survival strategy adapted toward unstable environmental conditions. Outside the spawning period, in the dry season, fish tend to grow faster, especially in terms of weight ($b > 3$, Tables 2, 3), and they maintain their positive nutritional condition as indicated from K values being significantly different from the well-being value of 1 (Fig. 5). This positive nutritional state is presumably due to *G. olivaceus* preparing energy reserves for reproductive activities. It is interesting to note that in their spawning periods, the lower slope b and higher body condition factor (K) in females relative to males may favor a strategy of growing isometrically to adapt to environmental conditions. Furthermore, in March and April, the K value is above the positive nutritional state of 1 (Fig. 5), which may be due to more favorable environmental conditions; thus, *G. olivaceus* seems to be nutritionally healthy in this area prior to the spawning period.

This research was the first attempt to examine morphometrics, growth patterns, and body condition of *G. olivaceus*. The growth patterns of fish are not only species-specific but also driven by environmental conditions. Different from some other gobies collected in the Mekong Delta, the b and K values of *G. olivaceus* are affected by sex and season, indicating that they live in less suitable environmental conditions compared to southern Vietnam, in which there are distinct rainy and dry seasons (Dinh, 2016a, 2016b, 2017). However, *G. olivaceus* seems to adapt well to their localized environments as they are the dominant goby species in the study site (Ta *et al.*, 2020; Tran *et al.*, 2020). The above parameters vary with respect to maturity, developmental change, gear selectivity, and even time of day (Hossain and Sultana, 2014). Hence further investigations should be conducted to better understand drivers of growth in this commercially and ecologically important species.

Conclusion: The sex ratio, lengths and weights, slope values, and condition factors of *G. olivaceus* from the mangrove forests of the Ba Lat estuary, the Red River, all varied between the rainy and dry seasons. *G. olivaceus* expressed allometric growth as the regression slope value was above 3. The slope values of this species of goby were significantly different between seasons. Likewise, the condition factors varied with season and sex, but overall they were close to 1. These findings suggest that *G. olivaceus* lives across variable environmental conditions, where water quality varies monthly and seasonally, but that *G. olivaceus* showed high adaptability to such environmental change. This paper provides baseline information for further conservation and fisheries management of gobies in mangrove forests from northern Vietnam.

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