



# Variation in the Allometry of Morphometric Characteristics, Growth, and Condition Factors of Wild *Bostrychus sinensis* (Butidae) in Northern Vietnam

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## ABSTRACT

The four-eyed sleeper (*Bostrychus sinensis*), found in the Indo-Pacific, is a commercial goby in Vietnam. Knowledge of the allometric growth patterns of morphometric characters, the length-weight relationship, and the conditions for assessing and managing the fish populations is unknown. The present study tested the intersex differences in growth of morphometric characters, sexual and seasonal change in length-weight relationship, and growth conditions for this species based on a year-round (2018–2019) wild specimen collection in northern Vietnam. Four morphometric characteristics (standard length, pre-dorsal-fin length, body depth, body width) showed higher growth rates in males than in females, suggesting a morphometric sexual dimorphism. The growth pattern of males and females were similarly higher than the isometric value of three, showing positive allometric growth in favorable environmental conditions. The slope values were higher in the dry season than in the wet season, but this was only significant in females. The higher intra-seasonal variability in the slope values was evaluated, showing females undergoing gonad depletion of the two sexes during their spawning season. The condition factors of both sexes were higher in the wet season when water temperature and food availability are higher. Female fish seemed to be more sensitive to environmental changes. The high value of the condition factors was shown for fish 9.9–12.8 cm in total length (slightly larger than the optimum size of 11.48). Based on these findings, for a sustainable exploitation plan, we suggest fishing *B. sinensis* from December to March, with a catch size of 9.9–12.8 cm in total length.

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NTN and TTT contributed to designing the research, writing the original draft. LMH performed the statistical analysis, prepared the figures. ANT and HPN contributed to the field investigation, data collection. NHC contributed to the field investigation, data collection, and funding acquisition. HDT designed the method, supervised and funding acquisition. All authors contributed to the revision of the manuscript.

## Key words

Length-weight relationship, Allometric growth, Morphometry, Sexual dimorphism, Four-eyed sleeper goby

## INTRODUCTION

The four-eyed sleeper (*Bostrychus sinensis* Lacepède, 1801), distributed over the intertidal zone of the Indo-Pacific, is a commercially important fish in China

(Hong and Zhang, 2003) and in Vietnam (Ha and Pham, 2014). It has been listed as a threatened species in the Vietnam Red Data Book (Ministry of Science and Technology, 2007). *B. sinensis* is a carnivorous species (Wu et al., 2009). Males and females inhabit individually in a burrow during the non-breeding season, but in the breeding season, they pair in the same burrow to spawn, where they exhibit egg-guarding behavior after spawning (Zhong and Li, 2002). While this fish is widely cultured in Vietnam (Nguyen et al., 2019), information its behavior, population dynamics, and body conditions in the wild remain unknown.

The length-weight relationship (LWR) is an important tool for fishery management used to quantify measure of

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biomass while assessing the impact of the environment on fish (Tesch, 1968; Froese, 2006). By using the slope value of LWR regression, the growth patterns and dynamics of fish populations can be estimated (Anderson and Gutreuter, 1983). The body condition, which reflects the relative wellness of fish populations, can also be predicted from the LWR. This is assuming that fish living in better environmental conditions have a heavier weight at a given length (Le Cren, 1951; Froese, 2006). Condition factors are also an indicator of growth, feeding intensity, seasonal variation of food availability, and physiological fitness (Le Cren, 1951). The condition factors change by fish size and seasons (Froese, 2006), and the rate of change in females has been shown to be greater than in males due to differences in reproductive investment (Mahmood *et al.*, 2012). Taking together information regarding condition factors with spawning season and optimum fish size may be integrated into a sustainable exploitation strategy for commercial fisheries management (Beverton, 1992; Myers and Mertz, 1998; Froese, 2006).

In *B. sinensis* aquaculture, the procurement of fry still depends on parent collection from the wild. The quality of fry will be enhanced by a good quality of fish and an adequate sex ratio in the broodstock (Khalfalla *et al.*, 2008; Siddiqui and Al-Harbi, 1997). Distinguishing male and female fish in the process of *B. sinensis* broodstock selection is one of the major obstacles due to a lack of distinguishing external features in this species. Many fish species exhibit sexual dimorphism in growth patterns, in which one sex is larger than the other sex over the same period of time (Scott and Crossman, 1973). By using the allometric growth patterns of morphometric characteristics, the present study aimed to find any sexual dimorphism useful to distinguish sexes.

Thus, we estimated the variation of growth patterns, condition factors, and allometric growth patterns of morphometric characteristics among sexes, seasons, and fish size of *B. sinensis*. This information will be indispensable toward the basic requirements for sustainable management of the fish populations in commercial aquaculture.

## MATERIALS AND METHODS

### Study site

This study was conducted at Xuan Thuy National Park (20°13'28"N, 106°34'06"E), which is the first Ramsar site in Southeast Asia and considered a hotspot of biodiversity conservation in the North of Vietnam (Hoang *et al.*, 2013). The study site has the tropical monsoon region climate characteristics at which the rainy and dry seasons last from May to October, and from November to April, respectively (Dao *et al.*, 2008; Ngo *et al.*, 2013).

### Fish collection

A year-round fish collection was conducted in Xuan Thuy National Park (Fig. 1) with fishing net traps (mesh size 2 cm) from March 2018 to February 2019 (collections in the months of April and June were missed due to bad weather). Fish were anesthetized by an overdose of 2-phenoxyethanol and then stored with an 8-10% formalin solution immediately after collection. For each individual, total length and seventeen morphometric dimensions were measured to the nearest 0.01 cm using a caliper, and fish weight was recorded using an Analytical Balance SC4010 ( $\pm 0.1$  g).

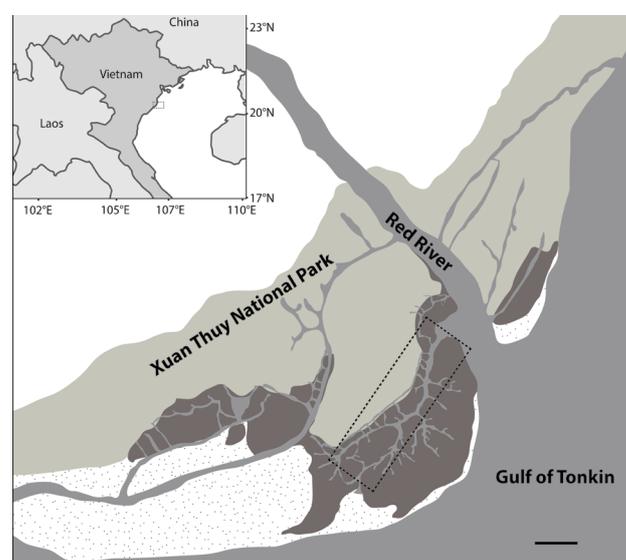


Fig. 1. A map showing sampling sites where surveys were carried out in the Ba Lat estuary of the Red River, northern Vietnam. Dash rectangles indicate where *B. sinensis* specimens were collected.

### Sex identification

The sex of *B. sinensis* was identified based on the shape of the genital papilla (which are reddish in females while opalescent in males) but should be taken into consideration for fish out of the spawning season (Pandian, 2011; Nguyen *et al.*, 2019). After measuring, the fish were dissected to remove the gonads from abdomens, the sex then confirmed based on the gonadal morphology.

### Data analysis

A Chi-square statistical test was used to examine the difference in the sex ratio. The data of morphometric measurements and weight were log-transformed then applied for regression analysis. The allometric growth of each morphometric dimension relative to the total length was calculated by the equation  $Y = aTL^b$  with  $Y$  being

the morphometric dimension,  $TL$  is total length,  $a$  is the intercept, and  $b$  is the slope of regression (Minos *et al.*, 1995). The growth patterns of morphometric variables were determined by comparing the slopes and isometric value of one using t-tests. The morphometric variable was categorized into positive allometry (+A) if the slope was significantly higher than 1, negative allometry (-A) if the slope significantly lower than 1, and isometry (I) if the slope was equal to 1.

LWR regression was determined using equation  $W = aTL^b$  (Riker, 1973), where  $W$  represents the bodyweight of fish (g),  $TL$  is the total length (cm),  $a$  and  $b$  are the intercept and slope of the regression, respectively. The log of weight ( $W$ ) and log of total length ( $TL$ ) were subjected to analysis of covariance (ANCOVA) to obtain values from the linear models (determination coefficient  $r^2$ , intercept and slope). The slope was then compared among fish groups (male and female, dry and wet seasons). The slopes were also compared to the isometric value of three ( $b = 3$ ) for growth type determination. Fish were divided into isometric growth types if the slope value was equal to three, positive allometric growth type if the slope was higher than three, and negative allometric growth if the slope was lower than three (Le Cren, 1951; Froese, 2006).

The condition factors ( $K$ ) of fish were estimated following Le Cren (1951) using the equation  $K = W/aTL^b$ , where  $W$  represents the fish weight (g),  $TL$  is the total length (cm)  $a$  and  $b$  are the regression coefficients. The  $K$  value of each fish group (divided by sexes, months, and seasons) was compared with the ideal value of one ( $K = 1$ ) by t-tests and then compared among fish groups by the ANOVA test. The comparisons for  $K$  values of fish size-classes with one and among size-classes were performed by the Wilcoxon test and Kruskal–Wallis test, respectively, due to small and unequal sample sizes among groups. The equation  $L_{max} - L_{min} / \log_{10} n$  was used to divide fish size into five classes (Wand, 1997). The equation to calculate the optimum size was:  $L_{opt} = 10^{1.0421 * \log L_{inf} - 0.274}$ , where  $L_{inf} = 10^{0.044 + 0.9841 \log L_{max}}$ , and  $L_{max}$  were obtained by using an average of the three largest specimens (Froese and Binohlan, 2000). The R software version 3.6.3 was used for statistical analyses (R Core Team, 2020) with the FSA package to perform regression analyses (Ogle *et al.*, 2020) and the ggplot2 package to produce the figures (Wickham, 2016). The level of significant difference for all statistical tests was set at  $p < 0.05$ .

## RESULTS

A total of 442 *B. sinensis* individuals were examined. The sex ratios calculated for combined specimens, in the dry and wet seasons were not significantly different from a 1:1 ratio (chi-squared test,  $p > 0.05$  for all cases). The

fish length and fish weight ranged from 7.00–21.40 cm and 3.00–114.40 g, respectively. The ranges of length and weight for fish in each month, season, and sex are shown in Table II.

### Morphometric characters in relation to the total length

The coefficient values of the correlation line between each morphometric measurement with the total length of fish in two sexes are shown in Table I. Most of the examined characteristics strongly correlated to the total length with high r-square value ( $r^2 > 0.8$ ) in both sexes, except for snout length, pelvic-fin length, pectoral-fin length in males, and snout length, upper jaw length, orbit diameter, and pelvic-fin length in females ( $r^2 < 0.8$ ).

The results of comparisons between regression slopes and an isometric value of 1 showed that in males, two dimensions (orbit diameter, pre-dorsal-fin length) had the regression slopes  $> 1$  (+A, t-test,  $P < 0.05$ , Table I). Six dimensions, including snout length, pelvic-fin length, dorsal-fin base, caudal peduncle depth, body depth, and body width, showed slopes  $< 1$  (-A, t-test,  $p < 0.05$ , Table I). Moreover, the nine remaining dimensions had slopes equal to the isometric value of 1 (I, t-test,  $p > 0.05$ , Table I). Meanwhile, in females, eleven dimensions (standard length, snout length, upper jaw length, inter-orbital length, pelvic-fin length, dorsal-fin base, caudal peduncle depth, pre-dorsal-fin length, pre-anal-fin length, body depth, and body width) had regression slopes  $< 1$  (-A, t-test,  $p < 0.05$ , Table I). The slopes of regression between total length and the six remaining dimensions, including head length, orbit diameter, post-orbital length, pectoral-fin length, anal-fin base, and caudal peduncle length were equal to 1 (I, t-test,  $p > 0.05$ ).

The comparisons of regression slopes between the two sexes showed that four morphometric characteristics (standard length, pre-dorsal-fin length, body depth, body width) had higher growth rates in males than in females (t-test,  $p < 0.01$  for all cases, Table II).

### Length-weight relationship

The weight of the fish was highly correlated with the total length in both sexes based on high regression coefficients ( $\text{Log}W = 0.006 + 3.240 * \text{Log}TL$ ,  $r^2 = 0.985$ ,  $F(1, 215) = 13950$ ,  $p < 0.001$  for males,  $\text{Log}W = 0.006 + 3.233 * \text{Log}TL$ ,  $r^2 = 0.979$ ,  $F(1, 223) = 10260$ ,  $p < 0.001$  for females), the slopes ( $b$ ) were similar between males and females ( $p > 0.05$ ). Slope values of fish in the dry season ( $b = 3.274 \pm 0.020$  SE) was not significantly different from that of fish in the wet season ( $b = 3.202 \pm 0.037$  SE,  $p > 0.05$ ). A significant interaction between seasons and sexes on slope values was detected for only female fish ( $F(1, 221) = 6.633$ ,  $p < 0.05$ , Fig. 2).

**Table I. Morphometric variables vs. total length (TL) (all measurements were transformed to logarithmic scale before computation) of wild female and male *B. sinensis*. The values given are from the equation  $Y = aTL^b$ ;  $a$  is intercept and  $b$  is slope value of regression;  $SE_b$ , standard error of  $b$ ;  $SE_e$ , standard error of estimation;  $R^2$ , coefficient of determination;  $G$ , growth type of morphometric demention; I, -A and +A indicating isometric, negative and positive allometric growth type, respectively.**

Dimension	Male						Female						P
	a	b	R <sup>2</sup>	SE <sub>b</sub>	SE <sub>e</sub>	G	a	b	R <sup>2</sup>	SE <sub>b</sub>	SE <sub>e</sub>	G	
SL	0.089	0.995	0.999	0.007	0.003	I	0.182	0.949	0.996	0.011	0.005	-A	0.002
SnL	1.671	0.510	0.457	0.135	0.067	-A	1.649	0.585	0.568	0.095	0.047	-A	0.638
UJL	1.138	0.887	0.865	0.085	0.034	I	1.356	0.690	0.643	0.096	0.043	-A	0.149
HL	0.585	1.025	0.961	0.050	0.018	I	0.589	1.027	0.893	0.066	0.024	I	0.976
OD	1.225	1.318	0.869	0.124	0.033	+A	1.497	0.936	0.648	0.129	0.043	I	0.050
IOD	1.212	0.874	0.920	0.062	0.026	I	1.252	0.839	0.820	0.073	0.031	-A	0.723
PrOL	0.801	1.012	0.993	0.020	0.008	I	0.864	0.964	0.949	0.042	0.016	I	0.353
PL	1.202	0.704	0.729	0.104	0.048	-A	1.166	0.750	0.682	0.095	0.041	-A	0.740
PLL	1.139	0.761	0.527	0.175	0.063	I	0.934	0.927	0.760	0.097	0.035	I	0.375
DFB	0.617	0.898	0.988	0.024	0.010	-A	0.594	0.912	0.980	0.024	0.010	-A	0.668
AFB	1.022	0.917	0.965	0.043	0.017	I	1.086	0.868	0.858	0.066	0.027	I	0.561
CPL	0.546	1.140	0.938	0.071	0.023	I	0.757	0.979	0.937	0.047	0.018	I	0.052
CPD	1.052	0.873	0.929	0.058	0.024	-A	1.213	0.737	0.849	0.058	0.028	-A	0.114
PrDL	0.355	1.088	0.985	0.032	0.011	+A	0.713	0.866	0.913	0.040	0.021	-A	0.002
PrAL	0.316	0.976	0.992	0.021	0.008	I	0.435	0.909	0.980	0.024	0.010	-A	0.051
BD	1.003	0.857	0.920	0.061	0.026	-A	1.244	0.660	0.864	0.049	0.027	-A	0.016
BW	1.009	0.879	0.969	0.038	0.016	-A	1.220	0.704	0.911	0.041	0.022	-A	0.005

SL, standard length; SnL, snout length; UJL, upper-jaw length; HL, head length; OD, orbit diameter; IOD, interorbital length; PrOL, postorbital length; PL, pelvic-fin length; PLL, pectoral-fin length; DFB, dorsal-fin base; AFB, anal-fin base; CPL, caudal peduncle length; CPD, caudal peduncle depth; PrDL, predorsal length; PrAL, preanal length; BD, body depth; BW, body width.

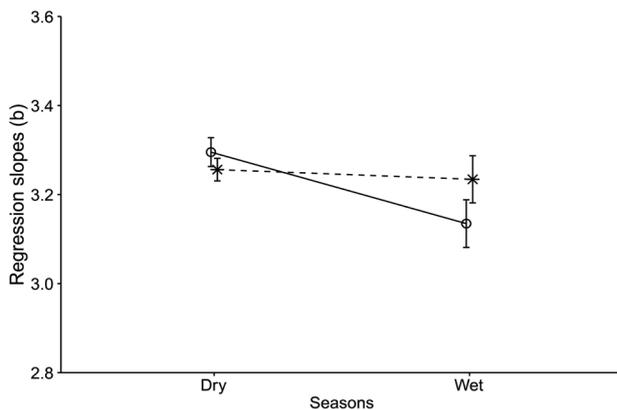


Fig. 2. Regression slope values ( $b$ ) of wild female and male *B. sinensis* in the dry and wet seasons.

The coefficients of regressions were also quantified for males and females in every month. No significant differences of slope values were found between the two

sexes in every month, but this value for the two sexes combined was significantly higher in three months (December, January, and February) than those of the other months ( $p < 0.05$ , Table II).

The results of one-sample t-tests revealed that the slope values of regression lines (for all fish, males and females, and fish in the dry and wet seasons) were significantly higher than the isometric value (the cubic value of three) with  $p < 0.05$  for all cases. The slopes for the LWR of fish were not significantly different from the isometric values in October for males, and in May, August, or October for females ( $p > 0.05$ , Table II). The regression slopes were significantly higher than the isometric values in the remaining months in both male and female fish ( $p < 0.05$ , Table II).

*Condition factors (K) and optimum size*

The mean  $K$  values were equal to 1 when calculated for all specimens, both male and female ( $p > 0.05$ ). In female fish, the condition factors were significantly higher

in the wet season than in the dry season ( $p < 0.001$ , Fig. 3). In male fish, the condition factors were slightly higher in the wet season than in the dry season though not significant ( $p > 0.05$ , Fig. 3). No significant difference was found between the two sexes in both the dry and wet seasons ( $p > 0.05$ , Fig. 3).

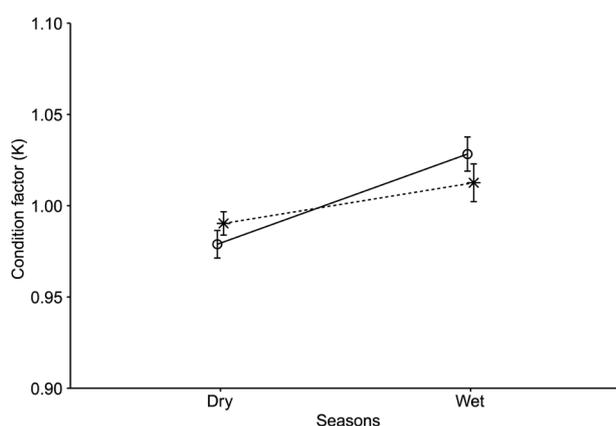


Fig. 3. Condition factors ( $K$ ) of wild female and male *B. sinensis* in the dry and wet seasons.

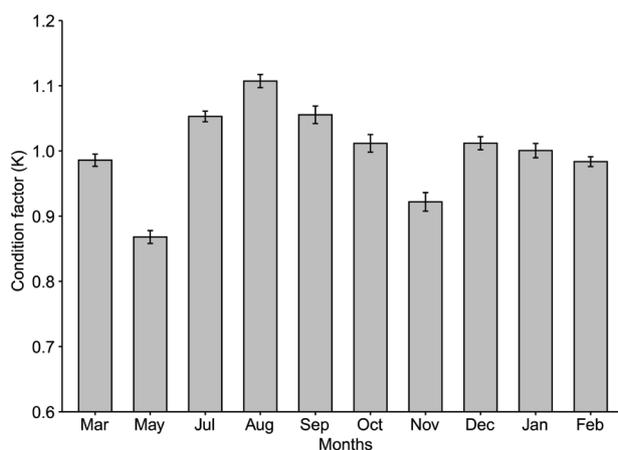


Fig. 4. Monthly changes in condition factors of wild *B. sinensis*, vertical bars showing standard error.

The  $K$  values were higher than the isometric value of 1 in the three months of July, August, and September ( $p < 0.05$ , Fig. 4). In the two months of May and November, the  $K$  values were significantly lower than the other months and were  $< 1$  ( $p < 0.05$ , Fig. 4). A significant difference was found among the five size classes ( $p < 0.01$ , Fig. 5), and the size class of 9.9–12.8 cm in total length had a  $K$  value  $> 1$  ( $p < 0.001$ ) compared to the other size classes. The estimated optimum size for specimens was 11.48 cm in total length.

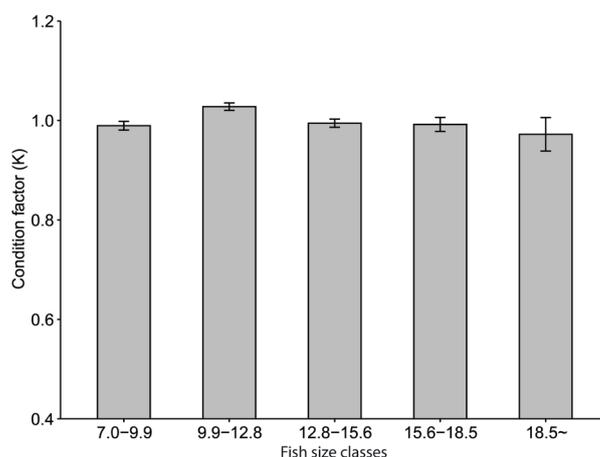


Fig. 5. Variation of condition factors ( $K$ ) among body size classes of wild *B. sinensis*, vertical bars are showing standard error.

## DISCUSSION

### Sex ratio

The difference in the behavior of males and females fish in different seasons, especially in spawning season, may result in an unequal number of fish caught in each sex (Silva and Gordo, 1997). In this study, the sex ratios of *B. sinensis* were not significantly different between the two seasons and they were equal to the 1:1 ratio, suggesting males and females do not live separately through the year. Similar to this study, the 1:1 sex ratio is widely observed in gobiid species collected from southern Vietnam, such as *Boleophthalmus boddarti* (Dinh, 2014), *Parapocryptes serperaster* (Dinh et al., 2016), and *Periophthalmodon schlosseri* (Dinh, 2016a).

### Sexual dimorphism in growth patterns of morphometric characteristics

Sexual dimorphism is common in fish and is expressed through differences between males and females in many features such as the genital papilla, fin shape, body-color, and breeding tubercles (Andersson, 1994). The dimorphism in body size composed of morphometric dimensions occurs in many species and is the most discernible sexual difference (Andersson, 1994). Investigating more sexual dimorphism characteristics in fish can help understand the nature of species, social function of sexes, or adaptive significance of characteristics (Kim et al., 2008).

The rate of increase of morphometric characteristics in relation to body length of fish is well expressed by the regression slope value ( $b$ ) and is both species-specific and sex-specific (Minos et al., 1995, 2008). The morphometric analysis showed considerable intersex differences in terms

**Table II.** Length, weight range and regression coefficient of wild *B. sinensis* over the sampling period. The values given are from the equation  $W = aTL^b$ ; *N*, number of sample; *TL*, total length; *W*, weight; *a* is intercept and *b* is slope value of regression;  $R^2$ , coefficient of determination; I and +A indicate isometric and positive allometric growth type, respectively.

Time	N	Range of TL and W				Intercept (a)		Slope (b)				R <sup>2</sup>		Compare sexes			
		Male		Female		Male	Fe- male	Male	Gro- wth	Female	Gro- wth	Male	Fe- male	t	df	P	
		TL	W	TL	W												
Mar	32	24	7.0-21.4	3.0-114.4	7.51-16.5	4.0-53.1	0.007	0.006	3.16	+A	3.23033	+A	0.99	0.99	-0.831	3/52	0.41
May	23	21	7.6-17.7	3.5-58.1	9.8-18.0	7.7-62.1	0.005	0.006	3.26	+A	3.1687	I	0.9978	0.9731	0.868	3/40	0.391
Jul	33	38	7.5-13.1	4.2-25.2	7.7-14.3	4.3-34.2	0.005	0.006	3.31	+A	3.27637	+A	0.9856	0.9817	0.32	3/67	0.75
Aug	18	26	8.2-15.0	5.7-40.5	8.3-16.9	6.1-61.9	0.007	0.008	3.19	+A	3.15007	I	0.9918	0.9864	0.459	3/40	0.648
Sep	14	19	7.8-16.6	4.7-57.9	8.2-17.8	5.9-85.2	0.007	0.006	3.22	+A	3.28999	+A	0.993	0.9857	-0.578	3/29	0.567
Oct	25	25	8.6-14.9	6.7-37.3	8.5-15.7	5.3-43.6	0.010	0.008	3.02	I	3.0991	I	0.9491	0.9545	-0.369	3/46	0.714
Nov	13	14	9.7-17.3	8.5-70.9	9.5-17.1	7.1-57.7	0.003	0.006	3.45	+A	3.2107	+A	0.9885	0.9804	1.395	3/23	0.176
Dec	19	27	8.2-16.8	5.3-58.1	7.2-17.2	3.5-6.4	0.004	0.005	3.39	+A	3.33819	+A	0.9968	0.9947	0.799	3/42	0.429
Jan	17	12	10.5-17.4	10.5-64.6	9.1-18.2	7.6-75.5	0.004	0.004	3.38	+A	3.37248	+A	0.9859	0.9962	0.096	3/25	0.924
Feb	23	19	7.7-18.1	4.1-69.9	8.7-17.8	6.2-70.7	0.005	0.004	3.31	+A	3.4148	+A	0.9973	0.9974	-1.788	3/38	0.081
Wet	113	129	7.5-17.7	3.5-58.1	7.7-18.0	4.3-85.2	0.006	0.008	3.23	+A	3.13476	+A	0.9712	0.9643	1.321	3/238	0.188
Dry	104	96	7.0-21.4	3.0-114.4	7.2-18.2	3.5-75.5	0.006	0.005	3.25	+A	3.29532	+A	0.9939	0.991	-0.965	3/196	0.336
All	217	225	7.0-21.4	3.0-114.4	7.2-18.2	3.5-85.2	0.006	0.006	3.24	+A	3.23309	+A	0.9848	0.9787	0.173	3/438	0.863

of growth patterns and the rate of change of some continuous variables in *B. sinensis*. Male fish showed isometric ( $b = 1$ ) and positive allometric ( $b > 1$ ) growth patterns for standard length and pre-dorsal-fin length, respectively. In contrast, female fish showed negative allometric ( $b < 1$ ) growth patterns for these two dimensions. The rates of change expressed through the slopes of regression lines for body depth and body width were significantly faster in males than in females. Therefore, the standard length, pre-dorsal-fin length, body depth, and body width were larger in males than in females of the same total length fish and can help to distinguish two sexes.

Such differences are consistent with previous studies that used morphometric analysis for sex determination in fishes (Oladosu *et al.*, 2007; Kim *et al.*, 2008). Mashiko and Yamane (1993) also demonstrated sexual dimorphism in morphometric characteristics for a goby named *Tridentiger kuroiwaie brevispinis*, using a similar method to the one presented here. In that study, the head width, mouth width, length of the third spine of the first dorsal fin, and anal fin length were relatively greater in males than in females (Mashiko and Yamane, 1993). The males of *Oxyeleotris marmorata*, another species in the same Family (Butidae) as our target species, were distinguished from females by shorter urogenital length and longer caudal fin, as well as caudal peduncle length (Idris *et al.*, 2012). For species that sex-related external characteristics are not as apparent as

*B. sinensis*, this kind of morphometric analysis may be helpful for sex determination. However, the morphometric differences identified in this investigation are not easily observed and require measurements that may lead to some difficulties in field identifications.

Many inductions were suggested for dimorphic morphometric characteristics, such as male-male competition, environmental factors, social role, and reproductive behaviors (Minos *et al.*, 2008; Shine, 1989). In this discussion, however, we did not discuss the cause of sex differences in the morphometric characteristics of *B. sinensis* due to the lack of sufficient ecological information. Further studies related to ecological differences and fish behavior are needed in order to produce any reliable conclusions.

#### Length-weight relationship

The high values of the coefficients of determinations ( $r^2$ ) were found in this study for fish of both sexes, in two seasons, in all months, and in combined fish, indicating that fish length can be used to estimate fish weight with ideal accuracy. The independent effects of season or sexes on LWR were not significant in this study. Furthermore, the regression slopes calculated for separated sexes, seasons, and combined specimens were all significantly higher than the isometric value ( $b=3$ ), indicating that the environmental conditions were favorable for this fish

to grow at the study area. As a consequence of positive allometric growth, larger specimens tended to have plumper bodies than smaller specimens (Froese, 2006). The  $b$  growth parameters of fish species commonly fell in a range of 2.5 to 3.5. This appears to be species-specific though it can be affected by environmental conditions (Ricker, 1973; Froese, 2006). The positive allometric growth pattern has been reported for some goby species, for example, *Periophthalmus argentilineatus* with  $b = 3.34$ , *Periophthalmus spiloptus* with  $b = 3.50$  (Khaironizam and Norma-Rashid, 2002), rock goby *Gobius paganellus* in Portugal with  $b = 3.16$  (Azevedo and Simas, 2000), and gudgeon *Gobio gobio* in northern Spain with  $b = 3.33$  (Oscoz *et al.*, 2005; Metin *et al.*, 2011). Each of these species has been reported positive allometric growth for both sexes, as well as the four-spotted goby *Deltentosteus quadrimaculatus* with  $b = 3.52$ , 3.29, and 3.45 for females, males, and all fish, respectively. From the Mekong Delta of southern Vietnam, isometric or positive allometric growth pattern were reported in several gobies such as *B. boddarti* with  $b = 3.13$  (Dinh, 2014), *Trypauchen vagina* with  $b = 3.44$  (Dinh, 2016b), *P. schlosseri* with  $b = 2.96$  (Dinh, 2016a). Accordingly, the Mekong Delta area provides suitable environmental conditions for fishes to grow (Dinh, 2014, 2016a, 2016b). However, in the same area, some species were reported to grow relatively negative allometric such as *P. serperaster* with  $b = 2.79$  (Dinh, 2015) and *Butis butis* with  $b = 2.74$  (Dinh, 2017). These differences suggest that the species-specific character may also play an important role in fishes' growth patterns.

We found that the physical conditions of the environment were different between the wet and dry seasons (Ta *et al.*, 2020). The heavy rain and strong wind during the wet season brought nutrients from inland areas to the estuarine and coastal waters resulting in higher primary production in the wet season over the dry season within the study area (Dinh *et al.*, 2016; Mahmood *et al.*, 2012; Twilley, 1988). It was therefore hypothesized that differences in climatic conditions and water quality dynamics might affect the LWR slopes as fish grow in weight slower in the dry season than in the wet season. However, the regression slopes for sex-combined specimens were similar between the two seasons, implying the variations in environmental conditions were still in the optimal range, and food availabilities in the environment were sufficient for this fish to develop in equally in both seasons. Similarly, the effects of the season on the growth patterns were not significant in *Parapocryptes serperaster* in the Mekong Delta of Vietnam (Dinh *et al.*, 2016).

Interestingly, the interactions of seasons and sex had a significant impact on the change of regression coefficient in females but not in males. Therefore, it is suggested that

the rates of change in growth trajectories were different between males and females. The parameter of the LWR may also be affected by reproductive investment and depletion during the spawning season (King and Udo, 1998; Froese, 2006). The lower slope value of LWR in the wet season than in dry season (even both higher than the cubic value) indicated that female fish get fleshy slower in the wet season. The higher intraseasonal variability in the slope values of females rather than males of *B. sinensis* might be attributed to a larger volume of gonad depletion in females than in males during the spawning season (peaked in the wet season). This phenomenon also suggested that the reproductive investment of females was higher than that of male *B. sinensis*.

In the present study, the heightened slope values over the three months of the pre-spawning season (December, January, and February) (Nguyen *et al.*, 2019) suggest a significant effect in gonad development on the LWR of this species. The increase of gonad size in the spawning season has been reported to induce an increase in the slope value of LWR in fish (Kalaycı *et al.*, 2007). Especially in some gobies, females' slope values are higher than that of males due to the increase of body weight in females during the spawning season, such as *B. boddarti* (Dinh, 2014) and *T. vagina* (Dinh, 2016b).

#### Condition factors

It is well known that the condition of fish is correlated with seasonal changes in environmental conditions (Froese, 2006). The condition factors tend to decrease during the times when water temperature and food availability are low; and increase in the times that fish prepare for spawning, then sharply decrease again after spawning and quickly increase if the environmental conditions are good. This process is manifest clearly in females (Le Cren, 1951; Froese, 2006). In the present study, the condition factors were higher in the wet season than in the dry season for both sexes (though only significant in females), indicating a seasonal variation for condition factors in *B. sinensis*. The inverse phenomenon was found in the goby *T. vagina* collected in the Mekong Delta area, where the condition factor is higher in the dry season than in the wet season (Dinh, 2016b). Differently, the condition factor stays stable over the year in *P. schlosseri* (Dinh, 2016a). Again in the present study, the seasonal variability in the condition factors in females being higher than males could be because females are more sensitive to environmental changes.

The monthly change of condition factors showed that reproductive investment has a significant impact on the condition factors of fish. The highest condition factor value was found in August. It then gradually decreased to

the lowest level in November, suggesting that most of the fish during these times were in the post-spawning phase. This finding also proposes that the peak of the spawning season of *B. sinensis* is approximately in late August and early September. This finding is in agreement with our gonadosomatic index data (authors' unpublished data). Similarly, the spawning season of *B. sinensis* in Vietnam has been reported to take place from April to August for cultured fish (Nguyen *et al.*, 2019). The low value of *K* in May and a gradual decrease from September to November might be induced by the burrowing and egg guarding behavior as has been reported in other species (Järvi-Laturi *et al.*, 2008; Lissåker and Kvarnemo, 2006).

Since this fish is still exploited commercially in the study area, a sustainable catch strategy with the least impact on the population is needed. Catching fish at an optimum size in good condition may be a solution to both achieve the fishing efficiency while at the same time minimizing the impact on population recruitment (Froese and Binohlan, 2000; Froese, 2006). The optimum size for our specimens was calculated, yielding a value of 11.48 cm *TL*, which is slightly larger than the first maturity size of ~9–10 cm *TL* (Nguyen *et al.*, 2019). The result of the condition factors calculated for each class size showed the best conditions for a range of 9.9–12.8 cm *TL*. Combining these results with the monthly changes of condition factors and suggesting the spawning season above, catching fish at a size of ~9.9–12.8 cm *TL* from December to March would allow fish to have an opportunity to spawn and bring forward high-quality individuals with minimum impact on population recruitment.

## CONCLUSIONS

The higher growth rates of four morphometric characteristics (standard length, pre-dorsal-fin length, body depth, body width) observed in males over females suggested morphometric sexual dimorphism in *B. sinensis*. The values of regression slopes (calculated for both sexes, both seasons, and in combined specimens) were higher than the isometric value of the three, suggesting that this species is living in favorable environmental conditions. Female fish showed higher intraseasonal variability in the slope values than males. This is most likely due to the difference in gonad depletion between the two sexes during their spawning season. The condition factors of both sexes were higher in the wet season when water temperature and food availability are higher. Female fish seemed to be more sensitive to environmental changes than males. Based on these results, we propose that fishing *B. sinensis* from December to March (non-spawning season) at a size range of 9.9–12.8 cm *TL* is optimum for this species.

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### Statement of conflict of interest

The authors have declared no conflict of interest.

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