Spatiotemporal variations in length-weight relationship, growth pattern and condition factor of *Periophthalmus variabilis* Eggert, 1935 in Vietnamese Mekong Delta

Quang Minh Dinh[1], Ton Huu Duc Nguyen[1], Tien Thi Kieu Nguyen[2], Giang Van Tran[3] and Ngon Trong Truong[4]

[1] Department of Biology, School of Education, Can Tho University, Xuan Khanh Ward, Ninh Kieu District, Can Tho, Vietnam
[2] Department of Biology, An Khanh High School, Ninh Kieu District, Can Tho, Vietnam
[3] Department of Zoology, Faculty of Biology, Hue University of Education, Hue City, Vietnam
[4] Department of Molecular Biology, Biotechnology Research and Development Institute, Can Tho University, Xuan Khanh Ward, Ninh Kieu District, Can Tho, Vietnam

Corresponding author
Quang Minh Dinh,
dmquang@ctu.edu.vn

ABSTRACT

Length-weight relationship (*LWR*), growth pattern and condition factor (*CF*) play a vital role in fish resource evaluation and management but data on this is limited for *Periophthalmus variabilis*. This is an amphibious fish that lives in the mudflats of the mangrove forests in the Western Pacific regions, including the Vietnamese Mekong Delta (VMD). This paper contributes to the understanding of the *LWR*, growth pattern and *CF* of *P. variabilis*. Fish specimens were collected by hand at four sites in the VMD from April 2020 to March 2021. The analysis of 495 individual fish (259 females and 236 males) showed that fish weight could be estimated from a given fish length due to high determination values ($r^2 = 0.70 - 0.97$). Dusky-gilled mudskippers of the VMD exhibited positive allometry, as indicated by their larger than 3 *b* value ($b = 3.094 \pm 0.045$, $p = 0.04$). However, the growth pattern of the mudskipper between the sex and maturation stage (immature versus mature) showed isometry. These fish displayed positive allometry in the dry season ($b = 3.138 \pm 0.065$) (>3, $p = 0.04$) but isometry in the wet season ($b = 3.058 \pm 0.061$) (≈ 3, $p = 0.34$). Fish growth ranged from isometry to positive allometry and varied by site ($b = 2.850 \pm 0.103 – 3.370 \pm 0.114$) and month ($b = 2.668 \pm 0.184 – 3.588 \pm 0.299$) based on the b value. The *CF* of *P. variabilis* was not affected by sex ($p = 0.29$), body size ($p = 0.64$) or season ($p = 0.43$), but was affected by site ($p = 0.01$) and month ($p = 0.01$). The *CF* of this species (1.05 ± 0.02) was higher than 1 ($p < 0.001$), indicating that the fish adapted well to their habitat.

INTRODUCTION

The length-weight relationship (*LWR*) plays an essential role in both evaluating the growth and biomass of a fish population (*Khaironizam & Norma-Rashid, 2002*; *Mahmood*

et al., 2012; *Jin et al., 2015*; *Dinh, 2016a*; *Lam & Dinh, 2021*) and in assessing fishery management (*Froese, 1998*; *Froese & Pauly, 2000*; *Gonzalez Acosta, De La Cruz Agüero & De La Cruz Agüero, 2004*; *Jin et al., 2015*; *Phan et al., 2021*). In addition, the growth pattern and the *CF* play a vital role in understanding the ecological adaptations of fish (*Abdoli et al., 2009*; *Dinh et al., 2016*). The growth pattern and the *CF* of some fish, including gobies, are affected by sexual, intraspecific and spatiotemporal variables (*Froese, 2006*; *Abdoli et al., 2009*; *Lam & Dinh, 2021*; *Phan et al., 2021*; *Truong et al., 2021*). However, this data is limited for mudskippers, one of the gobiid fish groups in the Vietnamese Mekong Delta (VMD).

The mudflats and mangroves are habitats for a number of animal species including fish (*Sanders et al., 2010*; *Sasmito et al., 2020*). The mudskipper is a unique fish group that lives mainly in these habitats (*Murdy, 1989*) and can obtain oxygen directly from the air using their skin and gills (*Jaafar, Perrig & Ming Chou, 2009*). *Periophthalmus* is one of the largest genera of mudskippers with 19 described species found throughout the world (*Murdy & Jaafar, 2017*). *Periophthalmus* of the VMD is comprised of three species: *P. chrysospilos*, *P. gracilis* and *P. variabilis* (*Tran et al., 2013*). Of these three species, *P. variabilis* is found quite frequently in mudflat and mangrove regions (*Murdy, 1989*; *Kottelat et al., 1993*; *Jaafar & Hou, 2012*; *Tran et al., 2013*; *Tran et al., 2020*; *Tran & Dinh, 2021*; *Tran et al., 2021a*) and can move flexibly in and out of the water to catch prey (*Wicaksono et al., 2020*). In the VMD, our observations show that the number of individual *P. variabilis* has decreased over time. However, there is no data on its biology and ecology. This study was conducted to document fish LWR, growth pattern and *CF* to further understand the ecological adaptations of the *P. variabilis* population.

MATERIALS AND METHODS

Study site and fish analysis

The present research was carried out in four locations along the estuarine and coastal regions in the VMD, including Duyen Hai–Tra Vinh (DHTV, 9°40′29.5″N 106°34′49.5″E); Tran De–Soc Trang (TDST, 9°26′19.7″N 105°10′48.1″E); Dong Hai–Bac lieu (DHBL, 9°05′50.5″N 105°29′54.7″E) and Dam Doi–Ca Mau (DDCM, 8°58′10.4″N 105°22′58.9″E) (Fig. 1). There are two seasons at these sites: the dry season from January to May and the wet season from June to December (*Le et al., 2006*). The dominant plants in DHTV, TDST and DHBL are *Sonneratia caseolaris*, *Avicennia marina* and *Bruguiera gymnorrhiza*, respectively. In DDCM, *A. marna* and *B. gymnorrhiza* are equally dominant (*Dinh et al., 2021a*). The pH ranged from 7.6–8.0, and the salinity varied widely from 12.3 to 23.5%. The pH varied with the site but not with the season, whereas the salinity varied with the season but not the site (*Dinh et al., 2021a*).

Fish samples were collected monthly by hand for 4-hours at a time in an area of 120 m^2 (6-m width × 20-m length) from April 2020 to March 2021. Fish specimens were easily distinguished from congeners using their external features (*Murdy & Jaafar, 2017*). *Periophthalmus variabilis* are covered by many irregular blackish dots, whereas *P. chrysospilos* and *P. gracilis* are covered by small orange spots and are greyish brown with
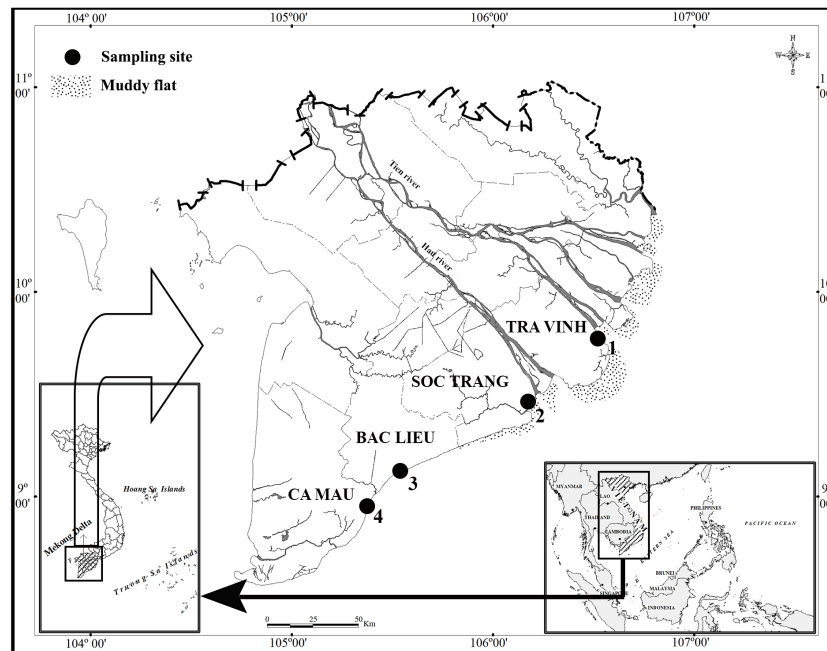
Figure 1 Distribution map of sampling points. ●: Sampling site; 1: Duyen Hai–Tra Vinh; 2:Tran De–Soc Trang; 3: Dong Hai–Bac Lieu; 4: Dam Doi–Ca Mau.

several irregular narrow white bars, respectively. The roughly triangular first dorsal fin is found on *P. variabilis* and *P. chrysospilos*, but not on *P. gracilis*. Filamentous spines are found in the first dorsal fin of *P. chrysospilos* but are not found in *P. variabilis*. MS222 was used to anaesthetize fish specimens before being preserved in a 5% formalin buffer and shipped to the laboratory. In the laboratory, fish sex was differentiated using genital papilla, *e.g.*, a triangle shape in males and an oval shape in females. Fish total length (*TL*) was measured to the nearest 0.1 cm using a ruler, and fish weight (*W*) was recorded to the nearest 0.01 g using an electric scale.

Data analysis

The *LWR* was determined using the formula $W = a \times TL^b$ (*W*: fish weight, *a*: intercept parameter, *TL*: fish total length, and *b*: slope parameter) (*Ricker, 1973*). The condition factor (*CF*) was calculated as suggested by *Le Cren (1951)* using the formula $CF = W/(a \times TL^b)$.

The quality of *LWR* s was determined by using the determination coefficient (r^2) (*Metin et al., 2011*). The *t*-test was performed to verify if the *b* value obtained from the *LWR* s was close to a cubic value. Species displayed positive allometry ($b > 3$), negative allometry ($b < 3$) and isometry ($b = 3$) (*Martin, 1949*). The *t*-test was applied to confirm whether the *CF* varied by sex, size and season, while one-way ANOVA was used to assess any variations in th *CF* between months and sites (*Mahmood et al., 2012*). The *t*-test was used to verify if the *CF* was significantly different from the threshold of 1. A General Linear Model was used to confirm if the interactions of sex × season, sex × site and season × site affected the *CF*

(*Dinh, 2016a*). The length at first maturity (L_m) was used to divide fish into the immature group if $TL < L_m$ and into the mature group if $TL \geq L_m$ (*e.g.*, L_m values of females and males were 5.0 cm and 5.7 cm in DHTV; 4.6 cm and 5.8 cm in TDST; 4.9 cm and 5.2 cm in DHBL; and 6.2 cm and 5.9 cm in DDCM, unpublished data). SPSS v.21 was used for data analysis and all tests were set at $p < 0.05$. The Benjamini–Hochberg procedure was used to decrease the Type I error of all tests (*Benjamini & Hochberg, 1995*; *McDonald, 2014*).

RESULTS

Length-weight relationship and growth pattern

A total of 495 individuals (TL: 3.7–8.5 cm; W: 0.31–7.09 g) were collected from the four sites, as shown in Table 1. The fish weight of males and females in different sizes, seasons, months and sites could be estimated from fish length due to high determination values ($r^2 = 0.70$–0.97, Table 2). The *LWR* of *P. variabilis* (female, male and both sexes) was presented in Table 2 as $W = aTL^b$. As the slope parameters (b) obtained from the *LWR* of males (3.123 ± 0.068, $n = 236$) and females (3.014 ± 0.064, $n = 259$) were not significantly different from the threshold of 3 ($df_{male} = 231$, $t_{male} = 1.81$, $p_{male} = 0.07$; $df_{female} = 257$, $t_{female} = 0.22$, $p_{female} = 0.83$, Table 2), both males and females displayed an isometric growth pattern. Similarly, the growth pattern of the fish was not affected by its developmental stages since the immature and mature fish both exhibited isometry with b values (2.964 ± 0.071, $n = 404$) close to 3 ($df_{immature} = 89$, $t_{immature} = 1.40$, $p_{immature} = 0.17$; $df_{mature} = 402$, $t_{mature} = 0.51$, $p_{mature} = 0.61$, Table 2). In contrast, the mudskipper displayed isometry in the wet season as b (3.058 ± 0.061, $n = 283$) was ≈ 3 ($df = 281$, $t = 0.95$, $p = 0.34$) but had positive allometry in the dry season since b (3.138 ± 0.065, $n = 212$) was >3 ($df = 210$, $t = 2.21$, $p = 0.03$). In the northern region of the Hau river mouth, *P. variabilis* exhibited isometry since the b value was ≈ 3 ($b_{DHTV} = 3.007 \pm 0.061$, $n_{DHTV} = 194$, $df_{DHTV} = 192$, $t_{DHTV} = 0.12$, $p_{DHTV} = 0.91$; $b_{TDST} = 2.850 \pm 0.103$, $n_{TDST} = 119$, $df_{TDST} = 117$, $t_{TDST} = -1.46$, $p_{TDST} = 0.15$, Table 2), but had positive allometry in the southern region because b was > 3 ($b_{DHBL} = 3.370 \pm 0.114$, $n_{DHBL} = 89$, $df_{DHBL} = 87$, $t_{DHBL} = 3.25$, $p_{DHBL} < 0.001$; $b_{DDCM} = 3.232 \pm 0.101$, $n_{DDCM} = 93$, $df_{DDCM} = 91$, $t_{DDCM} = 2.30$, $p_{DDCM} = 0.02$, Table 2). The species displayed isometry in April and again from August through December as the b value (2.668 ± 0.184 - 3.001 ± 0.105) was close to 3 (t-test, $p > 0.05$ for all cases, Table 3), but displayed positive allometry for the remaining months since the b value (3.215 ± 0.086–3.771 ± 0.325) was significantly higher than 3 ($p < 0.05$ for all cases, Table 3). Overall, the Dusky-gilled mudskipper displayed positive allometry as the b value (3.094 ± 0.045) was >3 ($n = 495$, $df = 493$, $t = 2.09$, $p = 0.04$).

Condition factor

The *CF* of *P. variabilis* varied by site and month but not by sex, size or season. The *CF* of males (1.04 ± 0.01, $n = 236$) was not significantly different from that of females (1.06 ± 0.01, $n = 259$) (t-test, $t = -1.05$, $n = 495$, $df = 493$, $p = 0.29$, $CI_{95\%} = (-0.01)$–(0.05)). The *CF* of the immature group (1.06 ± 0.03, $n = 91$) was similar to that of the mature group (1.05 ± 0.01, $n = 404$) ($t = -0.47$, $n = 495$, $df = 493$, $p = 0.64$, $CI_{95\%} = (-0.05)$–(0.08)). The *CF* in the dry season (1.06 ± 0.01, $n = 212$) was not significantly higher than in

Table 1 Number of samples by sex, site and month.

Months	Duyen Hai–Tra Vinh		Tran De–Soc Trang		Dong Hai–Bac Lieu		Dam Doi–Ca Mau	
	Male	Female	Male	Female	Male	Female	Male	Female
Apr-20	12	6	4	5	1	4	1	2
May-20	6	8	5	3	5	1	2	3
Jun-20	12	15	5	5	4	1	6	1
Jul-20	9	5	4	4	6	3	1	5
Aug-20	6	6	6	8	5	5	2	4
Sep-20	6	8	3	6	4	3	5	6
Oct-20	4	9	6	6	2	4	5	3
Nov-20	6	6	5	3	3	4	2	6
Dec-20	8	3	1	10	4	3	8	3
Jan-21	4	22	3	7	3	6	3	8
Feb-21	8	7	4	6	8	2	3	6
Mar-21	9	9	5	5	5	3	6	2
Total	90	104	51	68	50	39	44	49

Table 2 Variations of growth pattern of *P. variabilis* by sex, season, size and site (TL, total length; W, body weight; n, number of individuals, b, slope parameter; a, intercept parameter; r^2, determination parameter; df, freedom degree).

Fish groups		TL	W	n	b ± SE	a ± SE	r^2	t-value	df	p-value	Growth type
Gender	Female	3.7–8.5	0.31–7.09	259	3.014 ± 0.064	0.010 ± 0.001	0.90	0.83	257	0.22	Isometry
	Male	4.0–7.9	0.44–4.86	236	3.123 ± 0.068	0.008 ± 0.001	0.90	0.07	234	1.81	Isometry
Season	Dry	3.7–8.5	0.31–7.09	212	3.138 ± 0.065	0.008 ± 0.001	0.92	0.03	210	2.12	Positive allometry
	Wet	3.8–8.3	0.41–6.79	283	3.058 ± 0.061	0.009 ± 0.001	0.90	0.34	281	0.95	Isometry
Fish size	Immatury	3.7–5.7	0.31–2.68	91	3.327 ± 0.234	0.006 ± 0.002	0.70	0.17	89	1.40	Isometry
	Matury	5.2–8.5	1.20–7.09	404	2.964 ± 0.071	0.011 ± 0.001	0.81	0.61	402	−0.51	Isometry
Study site	Duyen Hai, Tra Vinh	3.8–7.8	0.41–4.76	194	3.007 ± 0.061	0.010 ± 0.001	0.93	0.91	192	0.12	Isometry
	Tran De, Soc Trang	4.1–7.9	0.44–4.86	119	2.850 ± 0.103	0.013 ± 0.003	0.87	0.15	117	−1.46	Isometry
	Dong Hai, Bac Lieu	3.7–7.5	0.31–4.86	89	3.370 ± 0.114	0.005 ± 0.001	0.91	0.00	87	3.25	Positive allometry
	Dam Doi, Ca Mau	7.1–8.5	0.78–7.09	93	3.232 ± 0.101	0.006 ± 0.001	0.92	0.02	91	2.30	Positive allometry
Total		3.7–8.5	0.31–7.09	495	3.094 ± 0.045	0.008 ± 0.001	0.91	2.09	493	0.04	Positive allometry

the wet season (1.05 ± 0.01, $n = 283$) ($t = -0.79$, $n = 495$, $df = 493$, $p = 0.43$, $CI_{95\%} = (-0.02)–(0.04)$). However, the *CF* in the DDCM was significantly lower in general than the remaining sites (One-way ANOVA, $n = 495$, $F_{2,3} = 3.82$, $p = 0.01$, Tukey Post Hoc comparison analysis) (Fig. 2). The *CF* all the sites in general also fluctuated from 0.93 ± 0.02 to 1.21 ± 0.02 ($n = 495$, $df = 493$, $F_{2,11} = 7.69$, $p < 0.001$) (Fig. 3) depending on the month. The *CF* of this species also varied by sex × site (General Linear Model, $n = 495$, $n = 495$, $F_{2,3} = 4.67$, $p = 0.003$, Fig. 4), but not by sex × season ($F_{2,1} = 1.30$, $p = 0.26$, Fig. 5), season × site ($n = 495$, $F_{2,3} = 0.41$, $p = 6.19$, Fig. 6) or sex × season × site ($n = 495$, $df = 1$, $F_{2,3} = 1.40$, $p = 0.24$). Overall, the *CF* value of the mudskipper (1.05 ± 0.02, $n = 495$) was significantly higher than an ideal threshold value of 1 ($t = 6.43$, $n = 495$, $df = 494$, $p < 0.001$, $CI95\% = 0.04–0.07$).

Table 3 Variations of growth pattern of *P. variabilis* by months (*TL*, total length; *W*, body weight; *n*, number of individuals; *b*, slope parameter; *a*, intercept parameter; r^2, determination parameter; *df*, freedom degree).

Months	TL	W	n	b ± SE	a ± SE	r^2	t-value	p	df	Growth type
Apr-20	5.6-7.3	1.00-4.66	35	3.588 ± 0.299	0.003 ± 0.002	0.81	2.57	0.01	33	Positive allometry
May-20	5.6-7.3	1.00-4.86	33	3.771 ± 0.325	0.002 ± 0.001	0.81	2.37	0.02	31	Positive allometry
Jun-20	3.9-7.7	0.44-4.76	49	3.390 ± 0.091	0.005 ± 0.001	0.97	4.29	0.00	47	Positive allometry
Jul-20	3.8-7.7	0.41-4.86	37	3.354 ± 0.143	0.005 ± 0.001	0.94	2.48	0.02	35	Positive allometry
Aug-20	4.8-8.3	1.30-6.89	42	2.887 ± 0.198	0.013 ± 0.005	0.84	−0.57	0.57	40	Isometry
Sep-20	4.5-7.8	1.02-4.40	41	2.767 ± 0.234	0.015 ± 0.006	0.78	−1.00	0.33	39	Isometry
Oct-20	4.3-7.8	0.82-4.71	39	2.668 ± 0.184	0.018 ± 0.006	0.85	−1.80	0.08	37	Isometry
Nov-20	4.7-8.2	1.22-6.79	35	2.772 ± 0.210	0.016 ± 0.006	0.84	−1.09	0.29	33	Isometry
Dec-20	4.10-7.7	0.62-4.41	40	3.001 ± 0.105	0.009 ± 0.002	0.96	0.01	0.99	38	Isometry
Jan-21	4.1-8.5	0.50-7.09	56	3.215 ± 0.086	0.006 ± 0.001	0.96	2.50	0.02	54	Positive allometry
Feb-21	3.7-7.9	0.31-4.61	44	3.418 ± 0.086	0.004 ± 0.001	0.97	4.86	0.00	42	Positive allometry
Mar-21	3.9-7.3	0.57-4.38	44	3.229 ± 0.090	0.008 ± 0.001	0.97	2.54	0.01	42	Positive allometry
Total	3.7-8.5	0.31-7.09	495	3.094 ± 0.045	0.008 ± 0.001	0.91	2.09	0.04	493	Positive allometry
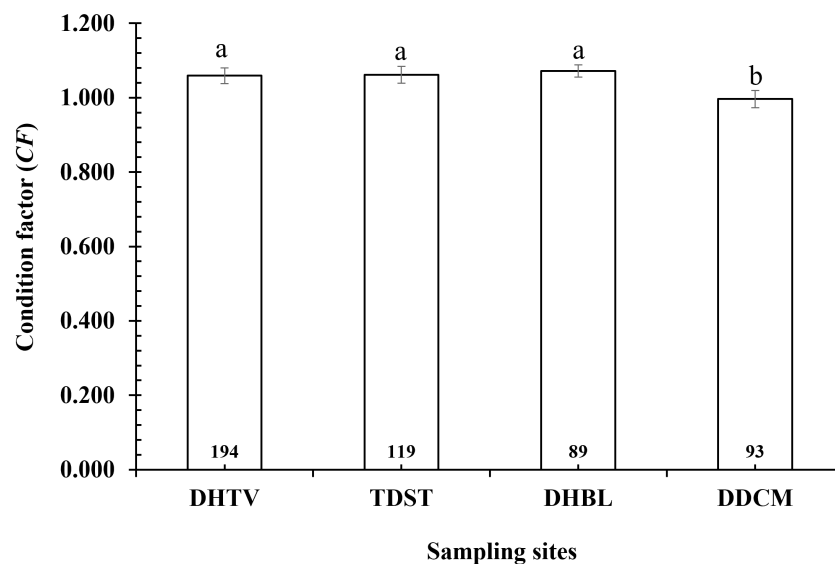
Figure 2 Variations of condition factor of *P. variabilis* by site. DHTV, Duyen Hai–TraVinh; TDST, Tran De–Soc Trang; DHBL, Dong Hai–Bac Lieu; DDCM, Dam Doi–Ca Mau; vertical bar is standard error of mean; a and b represent the significant difference; number in each column is number of samples.

DISCUSSION

The positive relationship between weight and length was found in male, female, immature and mature *P. variabilis* due to the high values of the determination coefficients (r^2) of the *LWRs*, suggesting that fish weight could be obtained from fish length regardless of the developmental stage of the fish. As high r^2 values were shown in Tables 1 and 2 over a year long study, fish weight and length could be extrapolated using the data from such a large
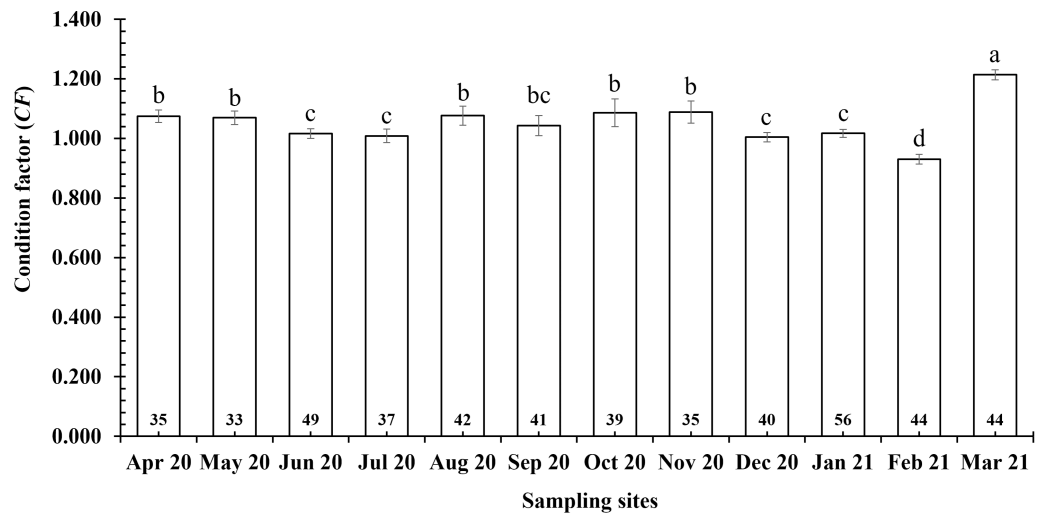
Figure 3 **Variations of condition factor of *P. variabilis* by month.** Letters a and b represent the significant difference; number in each column is number of samples.
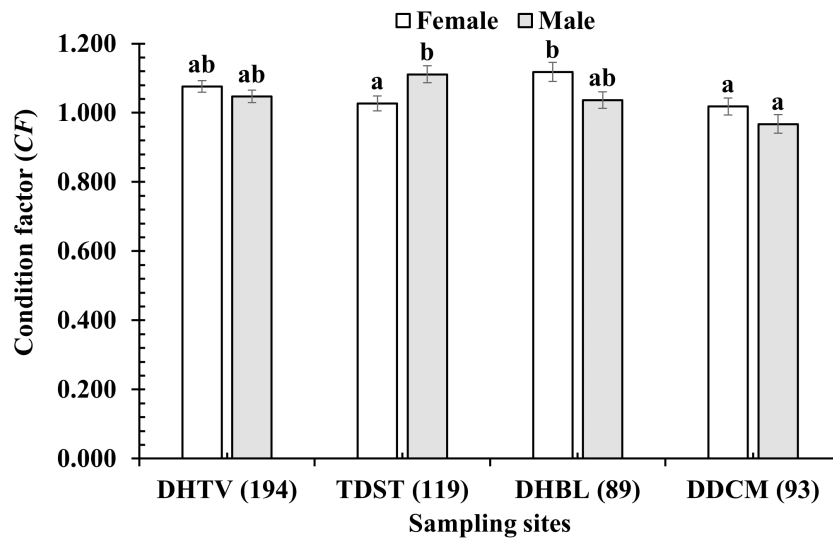
Figure 4 **Variations of condition factor of *P. variabilis* by sex and site.** DHTV, Duyen Hai–TraVinh; TDST, Tran De–Soc Trang; DHBL, Dong Hai–Bac Lieu; DDCM, Dam Doi–Ca Mau; vertical bar is standard error of mean; a and b represent the significant difference; number in parentheses is number of samples.

sample size and range. Similarly, a positive relationship between *TL* and *W* was found in *Periophthalmus* spp. living outside of the VMD (*Chukwu & Deekae, 2011*; *Panicker, Katchi & Gore, 2013*; *Tran, Nguyen & Ha, 2021b*). A positive *LWR* was also found in some other co-occurring gobies, *e.g.*, *Pseudapocryptes elongatus* (*Tran, 2008*), *Boleophthalmus boddarti* (*Dinh, 2014b*), *Glossogobius sparsipapillus* (*Dinh, 2015*), *P. serperaster* (*Dinh et al., 2016*), *Trypauchen vagina* (*Dinh, 2016c*), *Periophthalmodon schlosseri* (*Dinh, 2016b*), *Oxyeleotris*
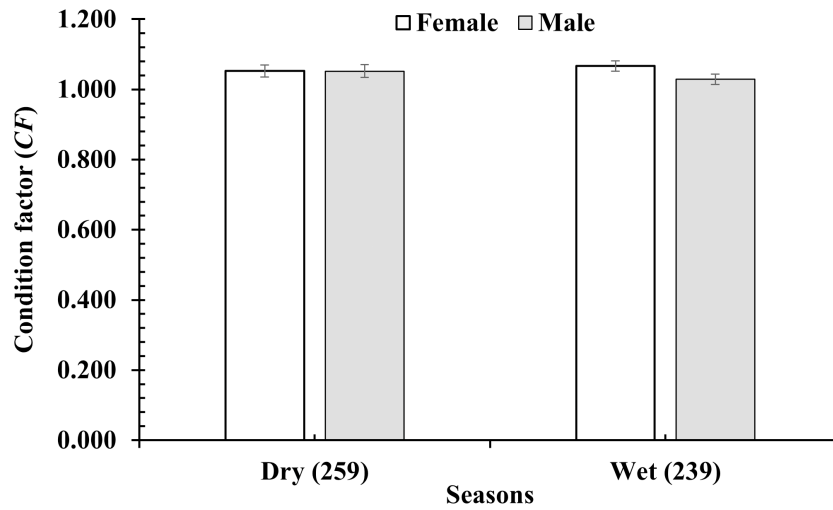
Figure 5 **Variations of condition factor of *P. variabilis* by sex and season.** Vertical bar is standard error of mean; number in parentheses is number of samples.
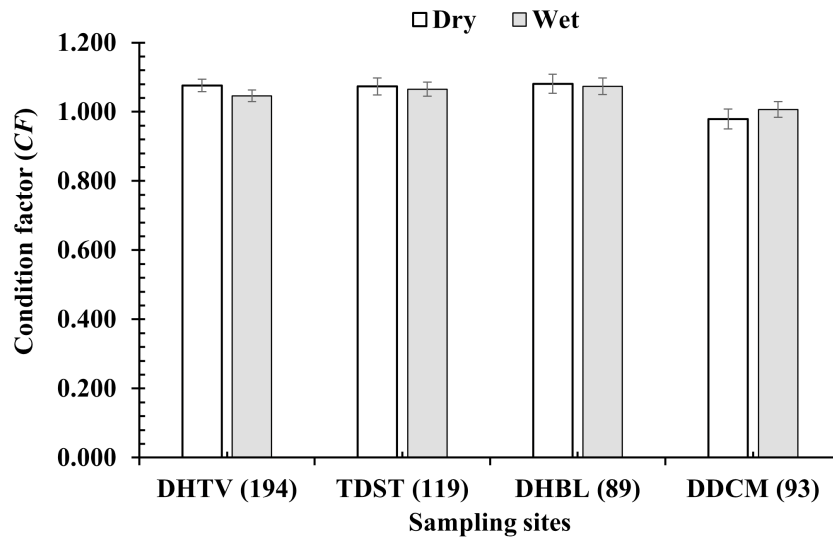
Figure 6 **Variations of condition factor of *P. variabilis* by season and site.** DHTV, Duyen Hai–TraVinh; TDST, Tran De–Soc Trang; DHBL, Dong Hai–Bac Lieu; DDCM: Dam Doi–Ca Mau; vertical bar is standard error of mean; number in parentheses is number of samples.

urophthalmus (*Dinh, 2016a*), *Butis butis* (*Dinh, 2017b*), *B. koilomatodon* (*Lam & Dinh, 2021*) and *G. giuris* (*Dinh & Ly, 2014*; *Phan et al., 2021*).

 P. variabilis displayed positive allometry ($b > 3$) and the fish specimens collected were mostly adults, indicating that the fish population in this region was not overfished. By contrast, its congener, *e.g.*, *P. barbarus* in Nigeria, displayed negative allometry ($b = 2.73$), indicating that most *P. barbarus* were caught during the juvenile stage (*King & Udo, 1998*). Another study on the genus *Periophthalmus* in Indonesia showed that both *P. argentilineatus*

and *P. gracilis* had negative allometry ($b < 3$) (*Taniwel & Leiwakabessy, 2020*). Negative allometry was also observed in some gobies living in the VMD, *e.g.*, *G. aureus* ($b = 2.71$) (*Dinh, 2014a*; *Phan et al., 2021*), *B. koilomatodon* ($b = 2.66$) (*Lam & Dinh, 2021*) and *G. sparsipapillus* ($b = 2.68$) (*Truong et al., 2021*). Meanwhile, other gobies living in the VMD exhibited isometric growth, *e.g.*, *B. boddarti* (*Dinh, 2014b*), *P. serperaster* (*Dinh et al., 2016*), *T. vagina* (*Dinh, 2016c*), *P. schlosseri* (*Dinh, 2016b*) and *G. giuris* (*Dinh & Ly, 2014*; *Phan et al., 2021*) with a *b* value of ≈ 3. Another congener of *P. variabilis*, *e.g.*, *P. modestus* found in the Red River Delta in northern Vietnam (VRD), showed positive allometry ($b > 3$) (*Tran, Nguyen & Ha, 2021b*). Positive allometry was also found in *P. chrysospilos* occurring in Malaysia (*Abdullah & Zain, 2019*) and *P. kalolo* and *P. malaccensis* in Indonesia (*Taniwel & Leiwakabessy, 2020*). Some other fish species living in the VMD, *e.g.*, *S. pleurostigma* displayed positive allometry as well ($b > 3$) (*Dinh, 2017a*). The similarities and differences in the growth pattern of *P. variabilis* and other gobies obtained from the *b* value of the *LWRs* suggest that fish growth type is species specific and regulated by the environment.

The growth pattern of *P. variabilis* did not change based on sex as both males and females showed isometry, suggesting that the different ovarian and testicular weights did not regulate fish growth type. A similar growth pattern in the two sexes was found in *P. barbarus* in Nigeria (*King & Udo, 1998*) but not in *P. modestus* in the VRD (*Tran, Nguyen & Ha, 2021b*). The growth pattern of *P. variabilis* was not impacted by size as evidenced by immature and mature groups both exhibiting isometry. This was also observed in *P. barbarus* in Nigeria (*King & Udo, 1998*) but not in *P. modestus* in the VRD (*Tran, Nguyen & Ha, 2021b*). Like its congener, *P. modestus* in the VRD (*Tran, Nguyen & Ha, 2021b*), the growth pattern of *P. variabilis* in the dry season was different from in the wet season, indicating that the difference in precipitation between these two seasons affected fish growth type. The various vegetation among the four sites could have an impact on *P. variabilis*' growth patterns as well. The impact of environmental conditions on fish growth patterns was also found in *P. waltoni* in Nigeria (*Sarafraz et al., 2012*) and *P. modestus* in the VRD (*Tran, Nguyen & Ha, 2021b*). Like *P. variabilis*, some gobies living in and out of the VMD, *e.g.*, *P. barbarus* (*King & Udo, 1998*), *P. waltoni* (*Sarafraz et al., 2012*), *G. giuris* (*Dinh & Ly, 2014*; *Phan et al., 2021*), *B. boddarti* (*Dinh, 2014b*), *P. serperaster* (*Dinh et al., 2016*), *T. vagina* (*Dinh, 2016c*), *P. schlosseri* (*Dinh, 2016b*) and *P. modestus* (*Tran, Nguyen & Ha, 2021b*) showed variations in their growth patterns that fluctuated based on the month.

Like *B. koilomatodon* in the VMD (*Lam & Dinh, 2021*), the *CF* of *P. variabilis* was not affected by its developmental stage as its *CF* did not change with sex and size. Likewise, the *CF* of *P. variabilis*'s congener, *P. barbarus*, in Nigeria did not indicate changes in the *CF* based on sex differences (*King & Udo, 1998*; *Chukwu & Deekae, 2011*). By contrast, *P. modestus*, another congener in the VRD, showed a change in its *CF* due to sex as this value was high in females towards the end of gonadal maturation. Like *P. variabilis*, the *CF* of some gobies in the VMD, *e.g.*, *Parapocryptes serperaster* (*Dinh et al., 2016*), *P. schlosseri* (*Dinh, 2016b*), *T. vagina* (*Dinh, 2016c*) and *G. giuris* (*Phan et al., 2021*) did not vary with size. *P. variabilis* could adapt well to environmental conditions as its *CF* showed a similar pattern in the dry and wet seasons. In contrast, the dry season was preferable

for *P. modestus* in the VRD as its *CF* value in the dry season was higher than it was in the wet season (*Tran, Nguyen & Ha, 2021b*). Like *P. variabilis*, a similar *CF* value was found between the dry and wet seasons in co-occurring gobiid species such as *P. elongatus* (*Tran, 2008*), *P. serperaster* (*Dinh et al., 2016*), *T. vagina* (*Dinh, 2016c*), *G. giuris* (*Phan et al., 2021*) and *B. koilomatodon* (*Lam & Dinh, 2021*). The difference in abiotic and biotic factors among sites (*Dinh et al., 2021a*) could be impacting the *CF* of *P. variabilis* as it showed a spatial variation in its *CF*. This same spatial variation in the CF was also found in the co-occurring goby species *B. koilomatodon* (*Lam & Dinh, 2021*) but was not found in the *P. modestus* species in the VRD (*Tran, Nguyen & Ha, 2021b*). Although *P. variabilis* showed spatiotemporal variations in its *CF*, overall its *CF* was higher than the threshold of 1 which could indicate that the study site had favourable environmental conditions. Congeners living outside of the VMD *e.g.*, *P. barbarus* (*King & Udo, 1998*), *P. chrysospilos* (*Abdullah & Zain, 2019*) and *P. modestus* (*Tran, Nguyen & Ha, 2021b*) were also well adapted to their habitats as evidenced by higher *CFs*. This was also observed in some other fish species in the VMD, *e.g.*, *P. elongatus* (*Tran, 2008*), *P. serperaster* (*Dinh et al., 2016*), *T. vagina* (*Dinh, 2016c*), *P. schlosseri* (*Dinh, 2016b*), *G. aureus* (*Dinh, 2019*), *P. chrysospilos* (*Dinh et al., in press*) and *G. giuris* (*Phan et al., 2021*).

CONCLUSIONS

Due to high determination values fish weight can be estimated using a given fish length. As the slope value obtained from its *LWRs* was higher than the cubic value, *P. variabilis* displayed positive allometry. The growth pattern of this species was not affected by sexual and intraspecific factors since male, female, immature and mature fish displayed isometric growth as indicated by a *b* value ≈3. The *CF* was not affected by sex, size or season, but did vary by site and month. The *CF* of this species was higher than 1, showing it adapted well to the environment. These results can play a vital role in the assessment and management of the *P. variabilis* population in the VMD.

Funding

This work is funded by the Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 106.05-2019.306. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Grant Disclosures

The following grant information was disclosed by the authors:
Vietnam National Foundation for Science and Technology Development (NAFOSTED): 106.05-2019.306.

Competing Interests

The authors declare there are no competing interests.
Author Contributions

- Quang Minh Dinh and Ton Huu Duc Nguyen conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Tien Thi Kieu Nguyen, Giang Van Tran and Ngon Trong Truong conceived and designed the experiments, authored or reviewed drafts of the paper, and approved the final draft.

Animal Ethics

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

The Council for Science and Education, School of Education, Can Tho University approved the study (BQ2020-03/KSP).

Data Availability

The raw data are available in the Supplementary File.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.12798#supplemental-information.

REFERENCES

Abdoli L, Kamrani E, Abdoli A, Kiabi B. 2009. Length-weight relationships for three species of mudskippers (Gobiidae: Oxudercinae) in the coastal areas of the Persian Gulf, Iran. *Journal of Applied Ichthyology* **25(2)**:236–237 DOI 10.1111/j.1439-0426.2009.01232.x.

Abdullah MIC, Zain KM. 2019. Length-weight relationships, condition factor and growth parameters of *Periophthalmus chrysospilos* (Bleeker, 1852) (Gobiiformes: Gobiidae) in Bayan Bay, Penang, Malaysia. *Sains Malaysiana* **48(2)**:271–279 DOI 10.17576/jsm-2019-4802-02.

Benjamini Y, Hochberg Y. 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the royal statistical society Series B (Methodological)* **57(1)**:289–300.

Chukwu K, Deekae S. 2011. Length-weight relationship, condition factor and size composition of *Periophthalmus barbarus* (Linneaus 1766) in New Calabar River, Nigeria. *Agriculture and Biology Journal of North America* **2(7)**:1069–1071 DOI 10.5251/abjna.2011.2.7.1069.1071.

Dinh QM. 2014a. Length-weight relationship of golden tank goby *Glossogobius aureus* Akihito & Meguro, 1975 in Con Tron River, Soc Trang Province. In: *The 2nd national scientific conference on marine biology and sustainable development*. Hai Phong, Vietnam: Natural Science and Technology Publisher, 467–472.

Dinh QM. 2014b. A preliminary study on length-weight relationship of the mudskipper *Boleophthalmus boddarti* in Soc Trang. *Tap Chi Sinh Hoc* **36(1)**:88–92.

Dinh QM. 2015. A preliminary study on length - weight relationship of the Linecheek tank goby. *Hanoi Pedagogical University 2 Journal of Science* **37**:52–57.

Dinh QM. 2016a. Length-weigth relationship of the goby *Oxyeleotris urophthlamus* in Soc Trang. In: *The 2nd national scientific conference on biological research and teaching in Vietnam, Da Nang.* Vietnamese National University Publisher, 637–641.

Dinh QM. 2016b. Growth and body condition variation of the giant mudskipper *Periophthalmodon schlosseri* in dry and wet seasons. *Tap Chi Sinh Hoc* **38**(3):352–358 DOI 10.15625/0866-7160/v38n3.7425.

Dinh QM. 2016c. Growth pattern and body condition of *Trypauchen vagina* in the Mekong Delta, Vietnam. *The Journal of Animal and Plant Sciences* **26**(2):523–531.

Dinh QM. 2017a. Morphometrics and condition factor dynamics of the goby *Stigmatogobius pleurostigma* (Bleeker 1849) during dry and wet seasons in the Mekong Delta, Vietnam. *Asian Fisheries Sciences* **30**(1):17–25 DOI 10.33997/j.afs.2017.30.1.002.

Dinh QM. 2017b. The length-weight relationship of the duckbill sleeper *Butis butis* (Hamilton, 1822). *Journal of Science and Technology, the University of Danang* **112**(2):47–49.

Dinh QM. 2019. The variation of growth pattern and condition factor of *Glossogobius aureus* at different fish sizes during dry and wet seasons. In: *Proceeding of the first national conference on ichthyology in Vietnam.* Ha Noi: Publishing House of Natural Sciences and Technology, 174–181.

Dinh QM, Lam TTH, Nguyen THD, Nguyen TM, Nguyen TTK, Nguyen NT. 2021a. First reference on reproductive biology of *Butis koilomatodon* in Mekong Delta, Vietnam. *BMC Zoology* **6**(1):1–14 DOI 10.1186/s40850-021-00072-y.

Dinh QM, Ly TV. 2014. Preliminary study result of length –weight of tank goby, Glossogobius giuris, distributing in Soc Trang. *Can Tho University Journal of Science* **2014**(2):220–225.

Dinh QM, Nguyen THD, Truong NT, Tran LT, Nguyen TTK. 2021b. Morphometrics, growth pattern and condition factor of *Periophthalmus chrysospilos* Bleeker, 1853 (Gobiiformes: Oxudercidae) living in the Mekong Delta. *The Egyptian Journal of Aquatic Research* 1–5 In Press DOI 10.1016/j.ejar.2021.10.009.

Dinh QM, Qin JG, Dittmann S, Tran DD. 2016. Morphometric variation of *Parapocryptes serperaster* (Gobiidae) in dry and wet seasons in the Mekong Delta, Vietnam. *Ichthyological Research* **63**(2):267–274 DOI 10.1007/s10228-015-0497-0.

Froese R. 1998. Length-weight relationships for 18 less-studied fish species. *Journal of Applied Ichthyology* **14**(1-2):117–118 DOI 10.1111/j.1439-0426.1998.tb00626.x.

Froese R. 2006. Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations. *Journal of Applied Ichthyology* **22**(4):241–253 DOI 10.1111/j.1439-0426.2006.00805.x.

Froese R, Pauly D. 2000. *FishBase 2000: concepts, design and data sources.* Philippines: ICLARM.

Gonzalez Acosta A, De La Cruz Agüero G, De La Cruz Agüero J. 2004. Length-weight relationships of fish species caught in a mangrove swamp in the Gulf of California

(Mexico). *Journal of Applied Ichthyology* **20(2)**:154–155
DOI 10.1046/j.1439-0426.2003.00518.x.

Jaafar Z, Hou Z. 2012. Partner choice in gobiid fish *Myersina macrostoma* living in association with the alpheid shrimp *Alpheus rapax*. *Symbiosis* **56(3)**:121–127 DOI 10.1007/s13199-012-0166-2.

Jaafar Z, Perrig M, Ming Chou L. 2009. Periophthalmus variabilis (Teleostei: Gobiidae: Oxudercinae), a valid species of mudskipper, and a re-diagnosis of *Periophthalmus novemradiatus*. *Zoological Science* **26(4)**:309–314 DOI 10.2108/zsj.26.309.

Jin S, Yan X, Zhang H, Fan W. 2015. Weight–length relationships and Fulton's condition factors of skipjack tuna (*Katsuwonus pelamis*) in the western and central Pacific Ocean. *PeerJ* **3**:e758 DOI 10.7717/peerj.758.

Khaironizam MZ, Norma-Rashid Y. 2002. Length-weight relationship of mudskippers (Gobiidae: Oxudercinae) in the coastal areas of Selangor, Malaysia. *Naga* **25(3–4)**:20–22.

King RP, Udo MT. 1998. Dynamics in the length-weight parameters of the mudskipper *Periophthalmus brabarus* (Gobiidae), in Imo River estuary, Nigeria. *Helgoländer Meeresuntersuchungen* **52(2)**:179–186 DOI 10.1007/BF02908746.

Kottelat M, Whitten T, Kartikasari SN, Wirjoatmodjo S. 1993. Freshwater fishes of western Indonesia and Sulawesi, Jakarta, Indonesia, Periplus Edition..

Lam TTH, Dinh QM. 2021. Factors affecting growth pattern and condition of *Butis koilomatodon* (Bleeker, 1849) (Gobiiformes: Eleotridae) from the Mekong Delta, Vietnam. *Acta Zoologica Bulgarica* **73(1)**:99–106.

Le T, Nguyen MT, Nguyen VP, Nguyen DC, Pham XH, Nguyen TS, Hoang VC, Hoang PL, Le H, Dao NC. 2006. Provinces and City in the Mekong Delta. In: Le T, ed. *Geography of provinces and cities in Vietnam, VI.* Ha Noi: Education Publishing House, 49–94.

Le Cren E. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *Journal of Animal Ecology* **20(2)**:201–219 DOI 10.2307/1540.

Mahmood K, Ayub Z, Moazzam M, Siddiqui G. 2012. Length-weight relationship and condition factor of *Ilisha melastoma* (Clupeiformes: Pristigasteridae) off Pakistan. *Pakistan Journal of Zoology* **44(1)**:71–77.

Martin WR. 1949. *The mechanics of environmental control of body form in fishes, 58.* Canada: University of Toronto Press.

McDonald H. 2014. Multiple comparisons in handbook of biological statistics. *Available at http://www.biostathandbook.com/multiplecomparisons.html* (accessed on 01 August 2021).

Metin G, Ilkyaz AT, Soykan O, Kinacigil HT. 2011. Age, growth and reproduction of four-spotted goby, Deltentosteus quadrimaculatus (Valenciennes, 1837), in İzmir Bay (central Aegean Sea). *Turkish Journal of Zoology* **35(5)**:711–716.

Murdy EO. 1989. A taxonomic revision and cladistic analysis of the oxudercine gobies (Gobiidae, Oxudercinae). *Australian Museum Journal* **11**:1–93 DOI 10.3853/j.0812-7387.11.1989.93.

Murdy EO, Jaafar Z. 2017. Taxonomy and systematics review. In: Jaafar Z, Murdy EO, eds. *Fishes out of water: biology and ecology of mudskippers.* Boca Raton: CRC Press, 1–36.

Panicker B, Katchi V, Gore B. 2013. Morphometry and length-weight relationship of goby, Parachaeturichthys ocellatus (Day 1873) from Malad creek, Mumbai. *International Journal of Engineering and Science Invention* **2(7)**:86–91.

Phan GH, Le LTT, Dinh QM, Truong NT, Nguyen THD. 2021. Length-weight relationship, growth pattern and condition factor of *Glossogobius giuris* caught from coastal areas in the Mekong Delta. *AACL Bioflux* **14(3)**:1478–1485.

Ricker WE. 1973. Linear regressions in fishery research. *Journal of the Fisheries Research Board of Canada* **30(3)**:409–434 DOI 10.1139/f73-072.

Sanders CJ, Smoak JM, Naidu AS, Sanders LM, Patchineelam SR. 2010. Organic carbon burial in a mangrove forest, margin and intertidal mud flat. *Estuarine, Coastal and Shelf Science* **90(3)**:168–172 DOI 10.1016/j.ecss.2010.08.013.

Sarafraz J, Abdoli A, Hassanzadeh B, Kamrani E, Akbarian MA. 2012. Determination of age and growth of the mudskipper *Periophthalmus waltoni* Koumans, 1955 (Actinopterygii: Perciformes) on the mudflats of Qeshm Island and Bandar-Abbas, Iran. *Progress in Biological Sciences* **1(1)**:25–54.

Sasmito SD, Kuzyakov Y, Lubis AA, Murdiyarso D, Hutley LB, Bachri S, Friess DA, Martius C, Borchard N. 2020. Organic carbon burial and sources in soils of coastal mudflat and mangrove ecosystems. *Catena* **187**:1–11 DOI 10.1016/j.catena.2019.104414.

Taniwel D, Leiwakabessy F. 2020. Density and length-weight relationship of mudskipper (*Periophthalmu* s spp.) in the mangrove area of Kairatu Beach, Maluku, Indonesia. *Biodiversitas Journal of Biological Diversity* **21(11)**:5465–5473 DOI 10.13057/biodiv/d211155.

Tran DD. 2008. Some aspects of biology and population dynamics of the goby *Pseudapocryptes elongatus* (Cuvier, 1816) in the Mekong Delta. PhD thesis, Malaysia, Universiti Malaysia Terengganu.

Tran CC, Dinh QM. 2021. Gastrointestinal tract morphology and Clark index of Dusky gilled mudskipper *Periophthalmus variabilis* caught in coastal regions from Tra Vinh to Soc Trang, Bac Lieu and Ca Mau provinces. *Science and Technology Journal of Agriculture & Rural Development* **10**:179–184.

Tran DD, Le BP, Dinh QM, Duong NV, Nguyen TT. 2021a. Fish species composition variability in Cu Lao Dung, Soc Trang, Vietnam. *AACL Bioflux* **14(4)**:1865–1876.

Tran DD, Nguyen VT, To HTM, Nguyen TT, Dinh QM. 2020. Species composition and biodiversity index of gobiid assemblage in estuarine areas of the Mekong Delta, Vietnam. *Egyptian Journal of Aquatic Biology and Fisheries* **24(7)**:931–941 DOI 10.21608/ejabf.2020.131385.

Tran HD, Nguyen HH, Ha LM. 2021b. Length–weight relationship and condition factor of the mudskipper (*Periophthalmus modestus*) in the Red River Delta. *Regional Studies in Marine Science* **46**:1–8.

Tran D, Shibukawa K, Nguyen T, Ha P, Tran X, Mai V, Utsugi K. 2013. *Fishes of Mekong Delta, Vietnam*. Can Tho: Can Tho University Publisher.

Truong NT, Phan GH, Dinh QM, Nguyen THD, Nguyen TTK. 2021. Growth and condition factor of the commercial goby *Glossogobius sparsipapillus* living along Bassac River, Vietnam. *AACL Bioflux* **14(3)**:1695–1701.

Wicaksono A, Hidayat S, Retnoaji B, Alam P. 2020. The water-hopping kinematics of the tree-climbing fish, *Periophthalmus variabilis*. *Zoology* **139**:1–15 DOI 10.1016/j.zool.2020.125750.