Variations in length-weight relationship, growth and body condition of the commercial mullet *Ellochelon vaigiensis* in the Vietnamese Mekong Delta

Quang Minh Dinh, Ngon Trong Truong, Ton Huu Duc Nguyen, Lam Thi Huyen Tran, Tien Thi Kieu Nguyen, Linh Hoang Phan

*Department of Biology, An Khanh High School, An Khanh Ward, Ninh Kieu District, Can Tho 900000, Vietnam*

Research article

The Squaretail mullet *Ellochelon vaigiensis* is widely found from marine to brackish and freshwater, including the Vietnamese Mekong Delta (VMD). Data on the length-weight relationships (LWRs), growth pattern, and condition factor (CF) play an essential role in fisheries assessment but are limited to *E. vaigiensis* – a commercial fish in VMD. To better understand the growth pattern of this fish, the study collected samples at four sites, including Thanh Phu, Ben Tre (BT); Duyen Hai, Tra Vinh (TV); Tran De, Soc Trang (ST); and Dong Hai, Bac Lieu (BL). Each month, fish samples were collected using bottom nets at each sampling site during high tide in both the dry season (January to May 2021) and the wet season (November to December 2020 and June to October 2021). This study qualified whether LWRs, growth pattern, and CF of *E. vaigiensis* vary with sexual, intraspecific, and spatiotemporal variables. The analysis results of 942 specimens showed that fish total length (TL = 17.86 ± 0.13 cm) and weight (W = 54.29 ± 1.05 g) changed with sex, season, month and site. The W could be appraised from a given TL due to high coefficients (r²) of LWRs that were regulated by fish size and season but not sex. The species showed negative allometry as its slope value of LWRs (b = 0.81 to 1.25/C6 0.01) was significantly higher than the one threshold, indicating that *E. vaigiensis* lived a favorable condition. Research results show that this fish species has a dominant growth pattern in terms of length (b < 3) and is well adapted to the environment (CF ≥ 1). These data have an important role in suggesting the future aquaculture of this fish.

1. Introduction

*Ellochelon vaigiensis* (Quoy & Gaimard, 1825) is a monotypic species in the genus *Ellochelon* (Mugiliformes: Mugilidae) and is distributed widely in marine, brackish, reef-associated, and even freshwater [1]. Up to now, a total of 78 species of mullet of 30 genera have been recorded and described in the world [1, 2]; however, only eight species, including *E. vaigiensis*, are known as commercial catches [3]. The juveniles are used as baifish, whereas the adults are marketed in the form of salted, fresh fish, boiled, canned, or frozen fish [4]. This fish can reach the maximum length of 63 cm in Indo-Pacific and Caribbean regions [5], but common fish caught at 35 cm in the Western Central Pacific [6]. *Ellochelon vaigiensis* is available throughout the year and is considered to be an essential food source in the VMD [7, 8, 9], where it is facing the loss of habitats and population degradation due to anthropogenic and natural threats, e.g., over-exploitation, environmental pollution, and climate change [10].

The length-weight relationships (LWRs) database provides critical information on the fish growth pattern [11, 12, 13, 14, 15] and fisheries management [12, 16, 17, 18, 19]. The slope parameter (b) of LWRs is used to determine the fish growth pattern [20], and the condition factor (CF) is essential to understand fish ecological adaptation [21, 22, 23, 24, 25]. Fish growth patterns and CF are affected by sexual, intraspecific, and
spatiotemporal variables [20, 21, 26, 27, 28, 29]. However, these data are limited for mullet—a commercial fish group in the VMD.

Some research on LWRs and CF have been reported for Mugil assamieri in Indonesia [30]; Liza macrolepis in India [31]; L. macrolepis in Taiwan [32]. Guino-o [33] documented the LWRs and CF of ten mullets in the Philippines. Nevertheless, no study has been published on LWRs, growth patterns, and CF of E. vaigiensis living mainly along the estuarine and coastal regions in VMD. Hence, the present study aims to provide these data to E. vaigiensis, and qualify if its LWRs, growth pattern, and CF change the sexual, intraspecific, and spatiotemporal variables. The findings will help us understand fish adaptation and resource management.

2. Materials and methods

2.1. Study site and fish collection

During 12 months from November 2020 to October 2021, monthly sampling was conducted at Thanh Phu, Ben Tre (BT, 9°57’01.3”N 106°31’43.1”E); Duyen Hai, Tra Vinh (TV, 9°40’29.5”N 106°34’49.5”E); Tran De, Soc Trang (ST, 9°26’19.7”N 105°10’48.1”E); and Dong Hai, Bac Lieu (BL, 9°05’50.5”N 105°29’54.7”E) (Figure 1). Fish sampling was purposefully done at four river mouths since mullets were reported to be present during the initial survey. The common feature of these sampling sites is that they have a mangrove ecosystem with an abundant food source, which is a suitable habitat for many fish species [34, 35]. Sampling times stood for the dry with infrequency rain and the wet season with total annual rainfall accounting for more than 99%. Predominant flora is Sonneratia caseolaris (L.) Engler, Avicennia marina (Forssk.) Vierh, and Bruguiera gymnorrhiza (L.) Lam; and salinity values in these sites range 7.6–8.0 and 12.3–23.5‰, respectively [36, 37].

The trawl nets (mesh size of 1.5 cm in the cod-end) were used to catch the squaretail mullet (Animal Welfare Assessment number: BQ2020-05/KSP). The trawl nets were used at tides and returned after 3 h at the lowest tide to collect fish specimens. Fish samples were anaesthetized with MS222 before being stored. The Council for Science and Education, School of Education, Can Tho University permitted fish to use in this study. At the laboratory, fish were classified based on the data of Tran et al. [38] (16 pectoral-fin rays; 25–29 longitudinal scales; 16 conjunctival scales; 4 hard dorsal fin rays, 9–10 dorsal-fin rays, 3 anal hard rays, 7–9 soft anal rays, pectoral fin black, caudal fin fairly flat) and determined total length (TL, cm) and weight (W, g) before dissecting for sex determination through gonadal characteristics.

2.2. Fish and data analysis

The growth pattern of E. vaigiensis was inferred from the length-weight relationships. The LWR was calculated as \( W = a \times T L^b \) (a is the regression intercept and b is the regression slope) [39]. The fish body condition factor (CF) was calculated as: \( CF = \frac{W}{LWL} \), where, W is fish body weight (g); TL is fish total length (cm); a is the regression intercept; and b is the slope [11]. The quality of the relationship between W and TL was determined via the determination coefficient \( r^2 \) [40]. The variations of LWRs between sexes, fish sizes, and seasons were qualified using ANCOVA [22]. The t-test was used to verify if b was approximate to 3, and fish growth patterns could be isometry (b = 3), positive allometry (b > 3), and negative allometry (b < 3) [41]. The CF variations by sex, fish size, and season were verified by t-test; meanwhile, one-way ANOVA with Tukey Post Hoc comparison analysis was used to test the differences in CF according to sampling months and sites [14]. The t-test was used to assess if CF was a well-being condition of 1 [42].

Figure 1. The sampling site in the Vietnamese Mekong Delta (●: Sampling area; 1: Thanh Phu, Ben Tre, 9°57’01.3”N 106°31’43.1”E; 2: Duyen Hai, Tra Vinh, 9°40’29.5”N 106°34’49.5”E; 3: Tran De, Soc Trang, 9°26’19.7”N 105°10’48.1”E; 4: Dong Hai, Bac Lieu, 9°05’50.5”N 105°29’54.7”E; modified from Dinh [51]).
### Results

Table 1. Number of specimens by sex, site, and month. TL: fish total length (cm); W: fish body weight (g).

| Months  | Month  | Site  | Male | Female | TL range | W range |
|---------|--------|-------|------|--------|----------|---------|
| Nov-20  | 12     | 12    | 10.8-17.9 | 43.65-102.47 |
| Dec-20  | 10     | 10    | 10.0-16.20 | 27.07-96.20 |
| Jan-21  | 7      | 7     | 15.0-28.27 | 20.70-95.20 |
| Feb-21  | 3      | 3     | 13.0-28.27 | 13.97-96.20 |
| Mar-21  | 5      | 5     | 17.2-22.11 | 24.74-87.92 |
| Apr-21  | 10     | 10    | 15.5-28.27 | 19.0-96.20 |
| May-21  | 15     | 15    | 13.0-28.27 | 19.18-87.92 |
| Jun-21  | 15     | 15    | 16.0-28.27 | 27.27-101.46 |
| Jul-21  | 10     | 10    | 15.4-28.27 | 27.27-101.46 |
| Aug-21  | 10     | 10    | 14.5-28.27 | 27.27-101.46 |
| Sep-21  | 15     | 15    | 14.0-28.27 | 27.27-101.46 |
| Oct-21  | 10     | 10    | 14.5-28.27 | 27.27-101.46 |
| Nov-21  | 10     | 10    | 16.0-28.27 | 27.27-101.46 |
| Total   | 120    | 120   | 16.0-28.27 | 27.27-101.46 |

The influence of sex *x* site *x* season on body weight was analyzed by general linear model. *p* < 0.05 was set for all tests.
Figure 3. The length-weight relationship of *E. vaigiensis* (942 individuals) between female (a) and male (b); immature (c) and mature (d); dry (e) and wet seasons (f).

Figure 4. The length-weight relationship of *E. vaigiensis* amongst sampling sites (a; b; c; and d represent Thanh Phu, Ben Tre; Duyen Hai, Tra Vinh; Tran De, Soc Trang; Dong Hai, Bac Lieu).
The species *E. vaigiensis* Ws were independent of the interaction: sex × season (General Linear Model, $F = 1.52$, $p = 0.22$), but depended on sex × site ($F = 8.66$, $p < 0.01$, Figure 2a), season × site ($F = 9.32$, $p < 0.01$, Figure 2b) and sex × season × site ($F = 2.62$, $p = 0.05$). The mullet TLs changed with interactions: season × site ($F = 18.94$, $p < 0.01$, Figure 2c) and sex × season × site ($F = 6.62$, $p < 0.01$) but not sex × season ($F = 1.293$, $p = 0.26$) and sex × site ($F = 1.57$, $p = 0.20$).

### 3.2. Length-weight relationship and growth pattern

The species *E. vaigiensis* exhibited positive relationships between TL and W because of a high determination coefficient ($r^2 > 0.80$). The LWRs did not vary according to fish sex ($t = 0.73$, $p = 0.47$, Figures 3a and 3b) but changed with fish size (ANOVA, $t = -4.32$, $p < 0.01$, Figures 3c and 3d) and season ($t = 5.61$, $p < 0.01$, Figures 3e and 3f). Although LWRs varied with fish size and season, this fish showed negative allometry as $b$ ranged from 2.13 to 2.68 and was $<3$ ($t$-test, $p < 0.01$ for all cases). Specifically, the $b$ value was 2.29 ± 0.04 in males ($n = 516$, $t = -16.05$, $p < 0.01$), 2.25 ± 0.05 in females ($n = 416$, $t = -15.73$, $p < 0.01$), 2.64 ± 0.05 in immature fish ($n = 363$, $t = -5.86$, $p < 0.01$), 2.27 ± 0.05 in mature fish ($n = 579$, $t = -14.00$, $p < 0.01$), 2.68 ± 0.04 in the dry season ($n = 366$, $t = -7.73$, $p < 0.01$) and 2.33 ± 0.04 in the wet season ($n = 576$, $t = -16.44$, $p < 0.01$). This value was 2.17 ± 0.09 at BT ($n = 213$, $t = -9.03$, $p < 0.01$), 2.53 ± 0.06 at TV ($n = 265$, $t = -7.48$, $p < 0.01$), 2.50 ± 0.06 at ST ($n = 209$, $t = -7.84$, $p = 0.01$) and 2.13 ± 0.05 at BL ($n = 255$, $t = -17.69$, $p < 0.01$). This showed that the variation of fish growth pattern was not regulated by sex, season, and site, and TLs tended to increase faster than fish width and height as fish grew.

The lowest $r^2$ value of 0.73 was recorded at BT (Figure 4a), while in the other three sampling sites, this value was greater than 0.80, for instance, TV ($r^2 = 0.81$, Figure 4b), ST ($r^2 = 0.80$, Figure 4c), BL ($r^2 = 0.82$, Figure 4d), showing that TLs could be used to infer the Ws because the two indexes were closely related. Likewise, LWRs expressed a positive relationship amongst sampling months due to $r^2 > 0.80$ (Fig 5a-b, d-l), excluding in January 2021 ($r^2 = 0.73$, Figure 5c). The fish growth pattern changed with month, ranging from negative allometry to isometry. Indeed, the isometry was found in December 2020 (0.31 ± 0.16, $n = 62$), May 2021 (3.05 ± 0.10, $n = 66$), and August–October 2021 (2.90 ± 0.07, $n = 88$; 2.91 ± 0.06, $n = 92$; and 2.87 ± 0.07, $n = 83$, respectively) since the $b$ value was equivalent to the cubic value (Table 2). Meanwhile, the negative allometric growth was recorded in the remaining months as $b$ values were $<3$ (Table 2).

### 3.3. The condition factor

The CF of squaretail mullet was 0.97–1.13 and closed to the well-being threshold of 1. The CF of males (1.08 ± 0.01, $n = 526$) was significantly higher ($t = 5.86$, $p < 0.01$) than females (0.99 ± 0.01, $n = 416$), showing that males tend to be adapted well to their environmental condition than females. The CF of this fish in the wet (0.97 ± 0.01, $n = 576$) was significantly different ($t = 11.27$, $p < 0.01$) from the dry season (1.13 ± 0.01, $n = 366$). The CF also varied with months (one-way ANOVA, $n = 492$, $F = 48.05$, $p < 0.01$), reaching the highest value in April 2021 (1.24 ± 0.03, $n = 80$) and December 2020 (1.25 ± 0.02, $n = 83$) but the lowest one in September 2021 (0.81 ± 0.01, $n = 92$). By
contrast, the CF of immature fish (1.04 ± 0.01, n = 363) was not significantly different (t = 1.31, p = 0.19) from mature fish (1.02 ± 0.01, n = 579), indicating that they shared a similar ability fish adapt to the environment. Likely, the CF of this species did not change with the sampling site (n = 492, F = 1.03; p = 0.38), displaying 1.04 ± 0.02 at BT (n = 213), 1.04 ± 0.02 at TV (n = 265), 1.01 ± 0.01 at ST (n = 209), and 1.03 ± 0.01 at BL (n = 255).

Similar to LWRs, the CF was also affected by the interactions: sex × season (General Linear Model, F = 4.61, p = 0.04), sex × site (F = 4.61, p < 0.01, Figure 6a), fish size × season (F = 7.61, p < 0.01), fish size × site (F = 7.72, p < 0.01), sex × fish size × season (F = 15.01, p < 0.01), and fish size × season × site (F = 15.01, p < 0.01). However, the CF did not vary with interactions sex × fish size (F = 3.03, p = 0.08), season × site (F = 2.20, p = 0.09, Figure 6b), sex × fish size × site (F = 1.61, p = 0.19), sex × season × site (F = 0.25, p = 0.09) and sex × fish size × season × site (F = 0.19, p = 0.91).

4. Discussion

The TLs and Ws of squaretail mullet showed a strong relationship because of high determination values (r²>0.8), indicating that Ws could be inferred from the TLs with ~80% of total variants. The positive relationship between TLs and Ws was also recorded in the other mullets; for instance, in Indonesia, the r² of LWRs of male and female L. macrolepis were 0.85 and 0.65, while this value of Moolgarda engeli were 0.90 and 0.94 for males and females [43]. In research documented by Guino-o [33], the r² of E. vaigiensis and the other nine mullets in the Philippines ranged from 0.88 to 0.98.

The TLs and Ws of mullets were generally affected by sex, season, and site. The highest values of TLs and W were reported at TV and from July to August. In the present study, the average TLs and Ws of squaretail mullet were smaller than E. vaigiensis in the Philippines, with a W of 96.1 ± 41.4 g [33]. This difference could be caused by sample size as the number of fish used in the present study was 942 individuals, while the sample in the Guino-o [33] study was only three individuals. Females were heavier and longer than males due to their different roles in reproduction. In the present study, the variation in TLs and Ws of E. vaigiensis could be caused by the rain being concentrated in the wet season, so the turbidity and source of nutrients were higher. Hence, the wet season could be the favourite environment for developing the number of squaretail mullets.

The typical growth pattern of E. vaigiensis was negative allometry since the b value was <3, showing that length increased faster than weight as fish grew. Nevertheless, in some months in the wet season (May, August–October, and December), the mullet exhibited the isometric growth pattern, which meant fish grew equally in weight and length. The opposite result was found in the study of Guino-o [33], as the growth pattern of E. vaigiensis was positive allometry (b = 3.36). The different habitat conditions between the Philippines and the VMD might cause different growth patterns in some mullet species. For example, in Indonesia, the growth pattern of L. macrolepis and M. engeli were negative allometry and positive allometry, respectively [43]. Three mullet species, Parachelon grandisquamis, Neochelon falcipinnis and M. cephalus, living in Nigeria exhibited negative growth patterns [44]. Muchlisin et al. [45] noted that fish behavior could affect the growth pattern besides the environmental factors, as the b value of active fish was lower than that of passive fish. Karakulak et al. [46] and Fontoura et al. [47] emphasized that the growth pattern could vary according to sex, seasons, physiological condition, habitats, food availability, and their interrelationship.

Table 2. Growth pattern and condition factor of fish in 12 months of study (N: negative allometry, I: Isometry).

| Months   | n  | r² | b   | SE  | a   | SE  | Growth pattern | t   | p   | CF  |
|----------|----|----|-----|-----|-----|-----|----------------|-----|-----|-----|
| Nov-20   | 77 | 0.96| 2.69| 0.06| 0.02| 0.00| N             | -4.80| 0.00| 1.06±0.01|
| Dec-20   | 62 | 0.87| 3.11| 0.16| 0.01| 0.00| I             | 0.71 | 0.48| 1.25±0.02|
| Jan-21   | 69 | 0.95| 2.66| 0.08| 0.03| 0.01| N             | -4.50| 0.00| 1.10±0.02|
| Feb-21   | 78 | 0.89| 2.67| 0.11| 0.03| 0.01| N             | -3.06| 0.00| 1.11±0.02|
| Mar-21   | 73 | 0.97| 2.79| 0.06| 0.02| 0.00| N             | -3.40| 0.00| 1.06±0.02|
| Apr-21   | 80 | 0.87| 2.39| 0.10| 0.06| 0.02| N             | -5.91| 0.00| 1.24±0.03|
| May-21   | 66 | 0.94| 3.05| 0.10| 0.01| 0.00| I             | 0.53 | 0.60| 1.14±0.02|
| Jun-21   | 91 | 0.80| 2.16| 0.12| 0.09| 0.03| N             | -7.28| 0.00| 0.94±0.03|
| Jul-21   | 83 | 0.93| 2.78| 0.08| 0.01| 0.00| N             | -2.71| 0.01| 0.87±0.01|
| Aug-21   | 88 | 0.96| 2.90| 0.07| 0.01| 0.00| I             | -1.49| 0.14| 0.87±0.02|
| Sep-21   | 92 | 0.97| 2.91| 0.06| 0.01| 0.00| I             | -1.65| 0.10| 0.81±0.01|
| Oct-21   | 83 | 0.95| 2.87| 0.07| 0.01| 0.00| I             | -1.85| 0.07| 1.09±0.02|
| Total    | 942| 0.85| 2.34| 0.03| 0.06| 0.01| N             | -20.56| 0.00| 1.03±0.01|

Figure 6. The influence of sex × site (a) and season × site (b) on the variation of fish condition factor (BT: Thanh Phu, Ben Tre; TV: Duyen Hai, Tra Vinh; ST: Tran De, Soc Trang; BL: Dong Hai, Bac Lieu; The vertical bar was the standard error of mean; * and ** showed a significant difference; Number in each column: Number of individual fish).
The differences in habitats and food availability could be attributed to the variations in CF values [48, 49]. As CF value was approximated or higher than one, fish live in good condition [50]. In the present research, males were better proposed to the environment than females, and in the dry season, the fish population was in good condition than in the wet season. Although the squailet mullet CF changed depending on sex, season, and temporal factors, its value was near the threshold of 1, suggesting that E. vaigiensis lived in good conditions. Similar outcomes were found in L. macrolepis and M. engeli [43] since their CF value was higher than 1. This result indicated that the surveyed living environment had provided a good food source for the growth of the squailet mullet.

5. Conclusion
The TLs and WSs of E. vaigiensis changed under sex, season, and spatiotemporal factors. The fish showed negative allometry in all cases, except in May, August–October, and December (isometry). The CF of E. vaigiensis were different by sex, season, and sampling month; however, they were >1, indicating the environmental condition of estuaries in VMD was favorable for this mullet. The results of this study have contributed to providing necessary information on the growth pattern and adaptation to the environment of this fish. This fish species is suitable for future aquaculture research and development.

Ethical statement
The fish used in this study was approved by the Council for Science and Education, School of Education, Can Tho University (Animal Welfare Assessment number: BQ2020-05/KSP).

Declarations
Author contribution statement
Quang Minh Dinh: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Ngon Truong Tran, Lam Thi Huyen Tran, Tien Thi Kieu Nguyen and Linh Hoang Phan: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Ton Huu Duc Nguyen: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement
Data will be made available on request.

Declaration of interest's statement
The authors declare no conflict of interest.

Additional information
No additional information is available for this paper.

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