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Growth patterns and mortality rates of the short-necked clam *Paratapes undulatus* (Born, 1778) in Ba Lua Archipelago, An Giang Province, South-western Sea of Viet Nam

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Abstract

This study investigated the growth patterns, mortality rates, and exploitation rate of the short-necked clam *Paratapes undulatus* (Born, 1778) in Ba Lua Archipelago, An Giang Province, South-western Sea of Viet Nam, using biological data conducted between November 2022 to September 2023. A total of 1,140 individuals were randomly sampled from the clam dredge landings for biological analysis. The length–weight relationship revealed a negative allometric growth ($b < 3$), indicating that the shell length increased proportionally faster than the body weight. The estimated VBGF parameters were $L\infty = 53.6$ mm, $K = 0.91$ year^{-1}, $t_0 = -0.149$, $t_{max} = 4.2$ year and the growth performance index $\Phi' = 3.417$. The estimated mortality rates were $Z = 3.80$ year^{-1}, $M = 1.47$ year^{-1}, $F = 2.34$ year^{-1}. The exploitation rate ($E = 0.61$) indicates that the stock is currently fully exploited. These findings emphasize the need for management measures to ensure the sustainable exploitation of this commercially valuable species.

Keywords: length-weight relationships, VBGF, mortality rates, exploitation rate, short necked clam

The short-necked clam *Paratapes undulatus* (Born, 1778) with the original described as *Paphia undulata* (locally known as nghêu lụa or sò lụa), is a bivalve species of the family Veneridae. It is widely distributed across the tropical Indo–West Pacific region (Carpenter and Niem, 1998), typically inhabiting shallow sandy substrates in intertidal and shallow subtidal zones (Huber, 2015; Thu et al., 2023) to the depths of about 30m (Carpenter and Niem, 1998). In Viet Nam, they appear along the entire coastal zone (Tuyen et al., 2006; Tu et al., 2019; Thu et al., 2023), with its highest abundance in An Giang province.

The Ba Lua Archipelago (104°31′17.6″E; 10°09′04.8″N), located in Kien Luong Ward, An Giang Province (Figure 1), to the North-west of the Ecological Production Unit VI of Viet Nam (Bell et al., 2021), is one of the major fishing grounds for the clam fishery. The archipelago consists of 45 small islands forming a closely distributed cluster along the coastal waters. This site is affected by a tropical monsoon with two distinct seasons: wet season (April–October) and dry season (November–March) with strong seasonal variability (Dang et al., 2020). The wet season is affected by the high rainfall of 1,860mm on average (ranged between 1,439 mm to 2,247 mm). In dry

season, although the rainfall is lower (156 mm on average), but the coastal waters are heavily influenced by Mekong River discharge, which drives seasonal salinity fluctuations (Voss et al., 2014; Minh et al., 2022).

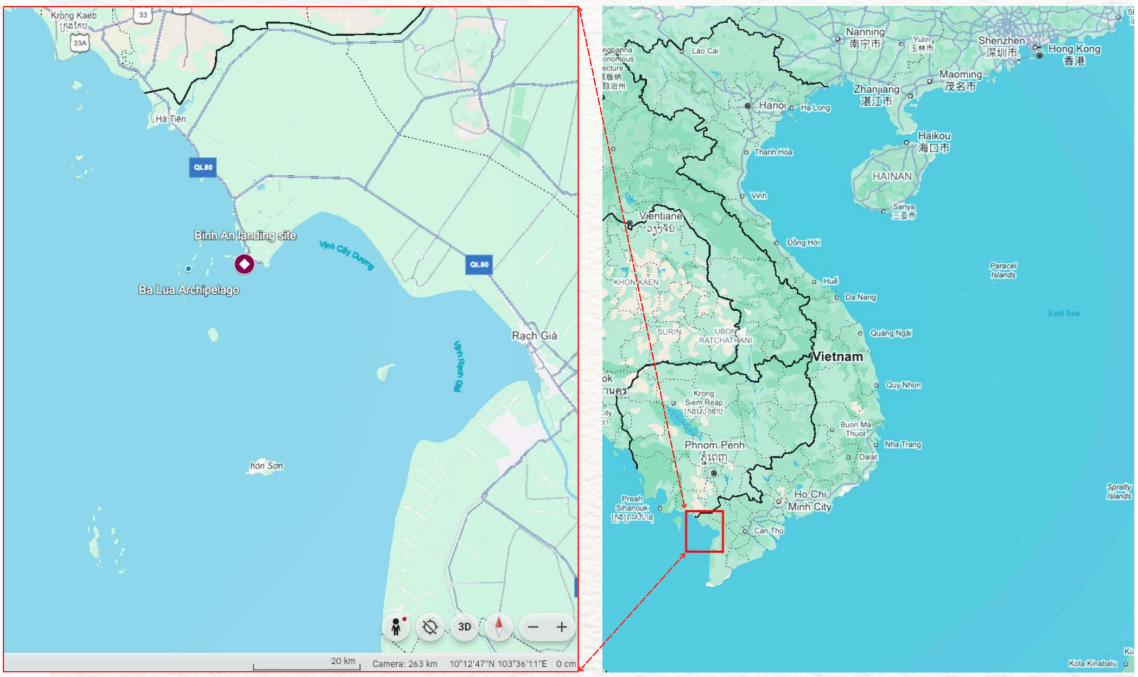

Figure 1. Location of the sampling site (diamond symbol) where short-necked clam samples were collected during the study. The map was generated using Google Maps

The short-necked clam resources play an important role in supporting small-scale fisheries and livelihoods, contributing substantially to local household income and food supply in coastal communities in An Giang. Fishermen use the small fishing boats equipped with dredges (locally known as "cào nghêu" or "cào lụa") to harvest clams at a depth of 6-12m (per.com.). The dredge is normally made of steel and has a frame dimension of approximately 3.20 m x 0.13 m x 0.40 m (width × height × depth), with a bar spacing of 1.5 cm.

In recent years, the clam dregde fishery has intensified due to increasing market demand. The dredge fishing fleet consist of about 300-400 fishing vessels catching 30-50 thousand tons annually (interviewed with fishermen), which has raised concerns about overfishing and depletion of the resources.

Despite the economic and commercial importance of this fishery in An Giang, studies on this species under nature conditions are limited and information required for fisheries management are either scarce or absent. Although, several studies on biology and population parameters have been conducted for Paphia species in other tropical regions (Vakily, 1992; Mohite and Mohite, 2009; Thomas and Nasser, 2009; Argente and Estacion, 2014; Nagvenkar et al., 2014). However, the application of parameters derived from distant populations may lead to biased assessments and inappropriate management strategies, as life-history traits are species- and region-specific (King, 2007) and may vary with fishing intensity. Therefore, region-specific study is required to provide baseline biological information to support sustainable exploitation and effective management of the short-necked clam in Viet Nam.

Biological data of the short-necked clam were collected monthly in Binh An landing site (Figure 1), where the fishing boats unloaded the harvested catches from Ba Lua Archipelago fishing grounds. Each month, at least 90 individuals were randomly sampled from the landings upon the return of the fishing boats to the port. Shell length (SL) was measured using a vernier caliper (±0.1 mm), and body weight (BW) was recorded with an electronic balance (±0.01 g).

The LWR of short-necked clam was calculated using the equation $BW = a*SL^b$ by logarithmically transforming into log(BW)= log(a) + b* log(SL), where *BW* is the total body weight (g), *SL* is the shell length (mm), *a* is the intercept of the regression curve and *b* is the regression coefficient. The growth of the clam is considered negative allometric if $b < 3$, positive allometric if $b > 3$ and isometric when $b = 3$ (Bayer, 1987). The relative condition factor (*Kn*) was used to assess the growth and it is calculated by $Kn = BW/(a \times SL^b)$ (Le Cren, 1951) . A higher *Kn* value indicates a faster increase in weight relative to the average weight of the species. Student's t-tests were performed to determine whether the monthly, seasonal, and annual *b* values obtained from the LWRs were significantly different from the cubic value *(b* = 3). Welch's t-test was used to compare the size of the clam and *Kn* values between the dry season and the wet season. All data were analyzed and plotted using R Studio (R Core Team, 2021), following the guidelines of Ogle (2016). Plots of Welch's t-test were conducted using the ggstatsplot package (Patil, 2021).

The growth patterns of short-necked clam were assumed to be described by the the von Bertalanffy Growth Function (VBGF) and be estimated using ELEFAN I routine (Pauly and Morgan, 1987) conducted in the FAO-ICLARM Stock Assessment Tools (FiSAT II) software (Gayanilo Jr and Pauly, 1997). Growth was modeled by fitting $SL_t = SL_\infty [1 - e^{-K(t - t_o)}]$, where SL_∞ is the asymptotic *SL, K* is the growth curvature parameter ($year^{-1}$), SL_t is the shell length at age *t*, t_0 is the theoretical size when SL_t is equal to zero, estimated by the formula: $\log(-t_o) = -0.3922 - 0.2752 \log(SL_\infty) - 1.038 \log(K)$. The growth performance index (Φ') was estimated by equation: $\Phi' = \log K + 2 \log L_\infty$ (Pauly and Munro, 1984) and longevity (t_{max}) was estimated by equation of Michaelson and Neves (1995) : $t_{max} = (\ln SL_\infty + K t_o)/K$.

The length-converted catch curve method in FiSAT II (Gayanilo Jr and Pauly, 1997; Gayanilo and Sparre, 2005) was used to estimate the total instantaneous mortality (*Z*) using the length data collected monthly between 2022 November to 2023 September, VBGF paramaters and mean annual bottom temperature of 29.6 °C. The fishing mortality *(F)* was derived from the difference between *Z* and *M* (F=Z - M). Mortality estimates (*F* and *Z*) were used to determine the exploitation rate $E = F/Z$.

A total of 1,140 specimens were collected from harvested catches in Binh An landing site (Table 1). The *SL* ranged between 30 - 52 mm (mean ± *SE*: 41.2 ± 0.10 mm) and the *BW* was 2.9 - 14.4 g (mean ± *SE*: 6.9 ± 0.05 g). The mean *SLs* fluctuated between 38.8 ± 0.25 mm (5.6 ± 0.11 g) in August 2023 and 45.5 ± 0.25 mm (8.7 ± 0.15 g) in April 2023. The length frequency distributions of the short-necked clam exhibited temporal variation from November 2022 to September 2023 (Figure S1, supplementary data). Most monthly distributions were unimodal, indicating relative synchronous size cohorts during the November 2022 – May 2023. Large size clams were dominant in February and April 2023, coinciding with the highest mean *SLs* recorded. In contrast, the *SL* distributions were left -skewed, with a higher proportion of the smaller clams. One-way ANOVA revealed significant differences in *SL* ($F = 84.88$, $p < 0.001$) and *BW* ($F = 71.12$, $p < 0.001$) among months, reflecting strong temporal variation in size of clams. The Welch's t-test indicated significant

differences in *SL* (p = 9.16×10^{-15}) and *BW* (p = 9.16×10^{-19}) between the dry and wet seasons (Figure S2). The mean *SL* and *BW* in dry season were smaller (40.4 ± 0.15 mm and 6.5 ± 0.07 g) compared with those in wet season (42.00 ± 0.14 mm and 7.4 ± 0.07 g).

Table 1. Number of specimens and descriptive statistics of shell length (SL) and body weight (BW) of the short-necked clam (Paratapes undulatus) collected from clam dredge fishing catches in An Giang Province, Viet Nam, from November 2022 to September 2023. N = sample size; SE = standard error,

Year/Month; Season	SL (mm)			BW (g)			N
	Range	Mean	SE	Range	Mean	SE	
2022 Nov.	36 - 49	41.0	0.25	4.1 - 10.8	6.7	0.13	149
2022 Dec.	30 - 42	36.7	0.22	2.9 - 7.5	5.2	0.09	120
2023 Jan.	32 - 49	40.6	0.35	3.4 - 13.1	7.3	0.18	90
2023 Feb.	37 - 48	43.2	0.29	4.5 - 11.5	7.8	0.16	91
2023 Mar.	35 - 47	41.3	0.22	3.3 - 9.6	6.0	0.10	120
2023 Apr.	39 - 52	45.5	0.25	5.1 - 14.4	8.7	0.15	90
2023 May	36 - 47	41.2	0.24	5.7 - 12.2	7.9	0.12	90
2023 Jun.	36 - 50	40.9	0.23	5.0 - 13.9	7.2	0.14	90
2023 Jul.	36 - 49	41.3	0.30	4.1 - 9.8	6.6	0.13	90
2023 Aug.	33 - 44	38.8	0.25	3.4 - 8.6	5.6	0.11	90
2023 Sep.	37 - 50	43.8	0.23	5.4 - 11.9	8.1	0.12	120
All Data	30 - 52	41.2	0.10	2.9 - 14.4	6.9	0.05	1,140
Dry season (November–March)	30 - 49	40.4	0.15	2.9 - 13.1	6.5	0.07	570
Wet season (April–October)	33 - 52	42.0	0.14	3.4 - 14.4	7.4	0.07	570

Monthly LWR parameters of the short-necked clam are presented in Table 2. The coefficients of determination (r^2) were in acceptable range, indicating a good fit of LWRs. Negative allometric growth (b < 3, Student's t-test p < 0.001) was observed with the b values ranging from 2.223 ± 0.135 in May 2023 to 2.913 ± 0.083 in December 2022, and a pooled estimate of b = 2.616 ± 0.037 (N=1,140; r^2 = 0.81). Seasonally, the b values were 2.560 ± 0.052 (N = 570; r^2 = 0.81) and 2.595 ± 0.056 (N = 570; r^2 = 0.79) for the dry and wet seasons, respectively (Figure S3, supplementary data).

Table 2. Parameters of the length–weight relationship (LWR) equation and relative condition factor (Kn) of the short-necked clam (Paratapes undulatus) in An Giang waters, South-western Sea of Viet Nam. N = sample size; a = intercept; b = slope; r^2 = coefficient of determination; SE(b) = standard error of b; CI(b) = 95% confidence interval of b; Kn = relative condition factor; SE(Kn) = standard error of Kn

Year/ Month; Season	**N**	**a**	**b**	**r²**	**CI (b)**	**SE (b)**	**Mean Kn**	**SE (Kn)**
2022 Nov.	149	0.00013	2.913	0.89	2.75 - 3.08	0.083	1.0026	0.006

2022 Dec.	120	0.00029	2.714	0.85	2.5 - 2.93	0.107	1.0030	0.007
2023 Jan.	90	0.00030	2.722	0.89	2.52 - 2.92	0.101	1.0030	0.008
2023 Feb.	91	0.00017	2.846	0.89	2.64 - 3.05	0.104	1.0020	0.007
2023 Mar.	120	0.00016	2.824	0.78	2.55 - 3.09	0.136	1.0036	0.008
2023 Apr.	90	0.00044	2.590	0.74	2.27 - 2.91	0.162	1.0035	0.009
2023 May	90	0.00201	2.223	0.75	1.95 - 2.49	0.135	1.0024	0.007
2023 Jun.	90	0.00022	2.801	0.79	2.49 - 3.11	0.156	1.0029	0.008
2023 Jul.	90	0.00062	2.490	0.85	2.27 - 2.71	0.112	1.0026	0.008
2023 Aug.	90	0.00014	2.900	0.86	2.66 - 3.15	0.124	1.0024	0.007
2023 Sep.	120	0.00047	2.579	0.81	2.35 - 2.81	0.117	1.0026	0.007
All Data	1,140	0.00040	2.616	0.81	2.54 - 2.69	0.037	1.0028	0.002
Dry season (November–March)	570	0.00049	2.560	0.81	2.45 - 2.66	0.052	1.0028	0.003
Wet season (April–October)	570	0.00045	2.595	0.79	2.49 - 2.70	0.056	1.0027	0.003

The growth of the short-necked clam in the Ba Lua Archipelago exhibited negative allometry, as the *b* values were consistently < 3, indicating that shell length increased faster than body weight. This finding contrasts with results reported for other Vietnamese populations of short-necked clam. For example, Tuyen et al. (2006) observed positive allometric growth ($b > 3$) in specimens from Binh Thuan Province in central Viet Nam. This difference suggests that growth patterns of *P. undulatus* may vary geographically and are likely influenced by local environmental conditions as well as fishing pressure.

In addition, those authors (Tuyen et al., 2006) recorded Fulton's condition factor values ranging between 0.89 and 1.13, suggesting that the physiological condition of individuals varied temporally and was occasionally affected by less favorable environmental conditions. In the present study, although the Ba Lua Archipelago is influenced by two distinct monsoon seasons, the growth pattern of the short-necked clam did not appear to be affected as the *Kn* values remained highly stable (≈ 1.0) across months and seasons, indicating that the short-necked clam population maintained consistently good physiological condition throughout the study period. The consistently stable Kn values observed in this study indicate that the population remained in good physiological condition, in contrast to several previous studies reporting seasonal fluctuations in condition factor

in other coastal regions**.** These results suggest that the environmental conditions in the Ba Lua Archipelago are favorable for sustaining this species.

The negative allometric growth pattern of the short-necked clam in Ba Lua Archipelago was dissimilar to other clam species in genus Paphia. Farghaly et al. (2022) studied on growth and population aspects of the carpet clam (*P. textile*) in Timsah Lake and Great Bitter Lake along the Suez Canal (Egypt) and concluded that the carpet clam is a positive allometry species with b = 3.284 and 3.250 for Timsah Lake and Great Bitter Lake, respectively.

Negative allometry has also been observed in genus Paphia. Nagvenkar et al. (2014) reported the b values of 2.44 for the length–wet weight relationship and 3.06 for the length–total weight relationship in *P. malabarica* from the estuarine region of Goa, on the west coast of India. Similar variability in growth patterns and exploitation parameters has been widely reported for other species within the family Veneridae across tropical regions, reflecting strong influences of local environmental conditions and fishing intensity (Vakily, 1992; Mohite and Mohite, 2009).

The *Kn* values were relatively stable (Table 2) with the mean values of 1.0028 ± 0.0022 for the pooled dataset, 1.0028 ± 0.0032 for the dry season and 1.0027 ± 0.0031 for the wet season. One-way ANOVA indicated no significant differences in *Kn* among months ($F = 0.004$, $p = 1.000$) and between seasons ($F = 0.001$, $p = 0.97$), revealing that the relative condition of clams was consistently maintained throughout the study period.

The von Bertalanffy growth parameters estimated for short-necked clam were as follows: asymptotic shell length (SL_∞) = 53.6 mm, growth coefficient (K) = 0.91 year^{-1}, the theoretical age at zero length (t_0) = -0.149 year^{-1} and the longevity (t_{max}) = 4.2 year. The growth performance index (Φ') was estimated at 3.417, indicating a relatively rapid growth. Restructured length frequency, the growth curves derived using the VBGF and length converted catch curve for the short-necked clam from the Ba Lua Archipelago, An Giang Province, South-Western Sea of Viet Nam is presented in Figure S4 (supplementary data).

The estimated population parameters of the short necked clam in this study were generally lower than those reported by Del Norte-Campos and Villarta (2010) for the same species in the Philippines (L_∞ = 79.0 mm; K = 1.00 year^{-1}; Φ' = 3.80). Similar trends were also observed when comparing the present estimates with those reported for *P. textile* and *P. malabarica* in several localities, where higher asymptotic lengths and growth performance indices were recorded (Mohite and Mohite, 2009; Thomas and Nasser, 2009; Argente and Estacion, 2014). These differences may be explained by the fact that growth patterns are species-specific when comparing different species within the genus. In contrast, the variability observed within species across study areas may be related to local environmental conditions (e.g., food availability, productivity, water temperature) and differing levels of fishing pressure.

The total mortality rate (Z) of the short-necked clam was estimated to be 3.80 year^{-1}, based on length-converted catch curve analysis, with a 95% confidence interval from 3.36 to 4.23 year^{-1}. The natural mortality rate (M) was estimated at 29.6°C is 1.47 year^{-1}, while the fishing mortality rate (F) was estimated at 2.34 year^{-1}. Consequently, the exploitation rate (E) was determined to be 0.61, substantially exceeding the threshold commonly associated with sustainable exploitation ($E \leq 0.5$). This high exploitation level suggests that the clam population is fully exploited and subjected to intense fishing pressure, which may lead to recruitment overfishing if not adequately managed.

The exploitation rate of the short-necked clam in Ba Lua Archipelago was relatively lower than

that reported for the same species in southern Negros Occidental, Philippines (E=0.75) (Del Norte Campos and Villarta, 2010) but slightly higher than that estimated for *P. malabarica* in Dharmadom, India (Thomas and Nasser, 2009). The present results indicate that the population of the short-necked clam in Ba Lua Archipelago is fully exploited ($E > 0.5$, $F > M$), and currently under considerable fishing pressure with a high risk of depletion. Nevertheless, an M/K value of approximately 1.62 suggests that this species exhibits a fast-growing, short-lived life-history strategy and thus a relatively high potential for population recovery if effective management measures are put in place. Comparisons with studies conducted in the Philippines (Del Norte Campos and Villarta, 2010) and India (Thomas and Nasser, 2009) indicate that the growth and exploitation parameters of *P. undulatus* in the Ba Lua Archipelago reflect relatively high fishing pressure, emphasizing the need for population-based management measures to ensure sustainable exploitation of this local resource.

In summary, the short-necked clam *P. undulatus* in the Ba Lua Archipelago (An Giang Province) exhibited a negative allometric growth pattern. Although seasonal variations in size were detected, no significant differences in growth dynamics were observed among months or between seasons. This species is characterized by rapid growth and a short life span. Nevertheless, the population is currently under intensive fishing pressure, with exploitation levels exceeding the sustainable limit. These findings highlight the urgent need for effective management interventions to secure the long-term viability of this valuable fishery resource.

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AUTHOR CONTRIBUTION

Vu Viet Ha: Conceptualization, Methodology, Project Administration, Funding Acquisition, Supervision, Formal Analysis, Writing, Review and Editing.
Tu Hoang Nhan: Investigation, Data curation, Writing.

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DATA AVAILABILITY STATEMENT

All data are available from the corresponding author upon reasonable request

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available via hyperlinks to the Zenodo service.

COMPETING INTERESTS

The authors declare that there are no conflicts of interest.

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