Population dynamics of *Acentrogobius viridipunctatus* (Actinopteri: Gobiidae) in the Vietnamese Mekong Delta

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1. Introduction

Spotted green goby *Acentrogobius viridipunctatus* is one of the commercial gobies living from brackish to freshwater globally, including the Southwest of Viet Nam, but there is no data on population biological traits used for assessing status of stock. Consequently, the research aimed to provide life history parameters of this fish like asymptotic length (*L*∞), growth coefficient indicator (*K*), exploitation rate (*E*), length at first capture (*L*0), the maximum age (tmax), growth coefficient (θ'), and mortalities. A total 960 individuals (528 males and 432 females) were caught using trawls at two ecoregions, including Tra Vinh-Soc Trang (TVST) and Bac Lieu-Ca Mau (BLCM), from January to December 2020. Results showed that average fish length was 8.0–11.0 cm, and *L*∞ was 14.70 cm at TVST and BLCM. The von Bertalanffy growth curve was *L*∞ = 14.70 (1 – *e* –0.730 (t–0.27)) at TVST and *L*∞ = 14.70 (1 – *e* –0.84 (t–0.23)) at BLCM, respectively. The θ' at BLCM (2.26) was higher than that at TVST (2.20), but tmax at BLCM (3.57 yrs) was lower than that at TVST (4.11 yrs). The total mortality (Z), fishing mortality (F), and natural mortality (M) at TVST were 2.09 yr–1, 0.29 yr–1, and 1.80 yr–1, respectively. These parameters at BLCM were larger than those at TVST, with values of 3.47 yr–1, 0.34 yr–1, and 3.14 yr–1, respectively. The fishing status at TVST and BLCM was not subjected to overfishing as *E* in these regions (0.14 and 0.10) were lower than *E*<sub>0.1</sub> (0.76 and 0.72). Local authorities should ask fishermen to increase fishing mesh size for sustainable exploitation.

This fish is a multi-spawn, reproducing mainly in the wet season [13, 14]. However, the studies mentioned above focus primarily on growth or nutritional and reproductive characteristics without considering their population biology, which will be helpful for assessing status of stock.

According to Al-Husaini et al. [15], population biology plays a vital role in determining the stock status of fish populations. Length-frequency data are input data for population biological parameters analysis [16]. The basic principle of the length-frequency method is the frequency distribution of the lengths of fish in a given age group. The length frequency describes the growth and abundance of the population at different times [17]. Some parameters, such as growth rate and mortality, are determined by the population biology of the fish [18]. Population variability in replacing generations continuously over time, reproduction, growth, and mortality are related to changes in environmental factors during the year [17]. However, there is little information on the population parameters of the *A. viridipunctatus* population at VMD. Therefore, this study aims to contribute information on the population parameters of this species, i.e., length at first capture, longevity, growth...
coefficient indicator, exploitation rates, and mortalities. The variation of these parameters between the northern and southern parts of the Hau River mouth was also quantified. The findings will help provide information that may help in the sustainable harvest of this fish in the VMD.

2. Materials and methods

2.1. Study sites and fish collection

The four sites selected for sampling were located near estuaries in the provinces of Tra Vinh (9°41’18.6”N 106°30’35.8”E), Soc Trang (9°29’26.8”N 106°11’58.5”E), Bac Lieu (9°06’03.2”N 105°29’49.1”E), and Ca Mau (8°58’17.5”N 105°22’51.8”E) belonging to the region VMD. These sites were divided into two different ecoregions, and the Hau River was used as the boundary to separate these two areas. The first ecoregion included Tra Vinh and Soc Trang (TVST), located in the North of the Hau River. The second ecoregion was the remaining two sites, Bac Lieu and Ca Mau (BLCM), located south of the Hau River (Figure 1).

These two ecoregions were different in pH and salinity, e.g., at TVST, a range of pH was from 7.85 ± 0.02 to 7.96 ± 0.06, and salinity from 12.33 ± 2.51 to 14.00 ± 2.06‰, whereas at BLCM, pH was lower from 7.63 ± 0.05 to 7.81 ± 0.03, and salinity was from 23.17 ± 1.21 to 23.50 ± 1.48‰ [20]. Fish samples were collected continuously for 12 months at these two ecoregions, from January to December 2020. The trawl net was used in this study to collect fish samples with a codend mesh size of 2a = 1.5 cm. In each region, a canoe with a length of about 5.5 m was used as a means in order to set the trawl net during the highest tide, and fish samples were collected at the lowest tide. This activity was performed continuously for two days at each site to ensure the sample size. The external morphology documented by Tran et al. [1] was used to identify A. viridipunctatus. Fish was then anesthetized with MS222 before being transferred to the laboratory. Before measuring fish total length (TL) to the nearest 0.1 cm, fish sex at the laboratory was distinguished using the genital spines (e.g., oval in females and triangle in males) as described by Dinh and Le [21]. Fish total length was measured from the snout to the end of the caudal. The use of fish in the research was approved by the Scientific Committee of the School of Education, Can Tho University (No. Q2020-01/KSP).

2.2. Data analysis

According to Pauly [22], fish length-frequency data were used to determine population parameters using the von Bertalanffy Eq. (1):

\[ L_t = L_\infty (1 - e^{-K(t-t_0)}) \]  

in there, \( L_\infty \): the asymptotic fish length, \( K \): growth coefficient indicator, \( t \): fish age at \( t \)-period, \( t_0 \): the theoretical age at which the fish length was 0.
Length-frequency data were put into the FISAT II software to determine the $L_m$ and $K$ of the population using the ELEFAN 1 [23]. Powell-Wetherall routine [24] given by the linear regression Eq. (2) was estimated as the initial $L_m$:

$$L_m - L = a + bL$$  (2)

where $L$' the cut-off length; $L_m$ the mean length of all fish ($L_m = (L_{\infty} + L')/(1 + (Z/K))$; $L'$, the slope; $a$: the intercept; $L_{\infty} = -(1 + b)/b$.

The $L_0$ was determined by Eq. (3) of Pauly [25]:

$$\log_{10}(L_0 - L_0) = -0.3922 - 0.2752 \times \log_{10} L_{\infty} - 1.038 \times \log_{10} K$$  (3)

The growth coefficient ($\Phi$) of fish was estimated from Eq. (4) of Pauly and Munro [26]. This coefficient was species-specific and was used to quantify the variation of fish population growth concerning sex, species, and site, as recommended by Tran et al. [27] and Dinh et al. [28]:

$$\Phi' = \log K + 2 \times \log L_{\infty}$$  (4)

The fish longevity ($t_{\text{max}}$) was determined by Eq. (5) of [29, 30]:

$$t_{\text{max}} = 3/K$$  (5)

Total mortality ($Z$) was determined by a yield curve converted from length-frequency data [31]. The natural mortality ($M$) was determined from Eq. (6) as [30]:

$$\log M = -0.0066 - 0.279 \times \log L_{\infty} + 0.6543 \times \log K + 0.463 \times \log T$$  (6)

Fishing mortality ($F$) and exploitation rate ($E$) were determined from the formula of Ricker [32]: $F = Z - M$ and $E = F/Z$, respectively. The fish length at first capture ($L_C$ or $L_{50}$) (e.g., the length at which 50% of the fish was caught) was determined by the converted yield curve procedure described by Pauly [22]. The model of Beverton and Holt [33] was used to analyze the yield-to-addition ($Y/R$) and biomass-to-addition ($B/R$) models as the basis for determining $E_{\text{max}}$ (maximum yield exploitation rate), $E_{0.1}$ (optimal exploitation rate), and $E_{50}$ (exploitation rate of 50% stock reduction). According to Pauly and Soriano [34], the $L_C/L_{\infty}$ and $E$ were combined to determine the exploitation status of $A. \text{viridipunctatus}$ population.

3. Results

After scenes of sampling, 960 $A. \text{viridipunctatus}$ were collected from two ecoregions (528 males and 432 females; please see the Raw data $Acentrogobius \text{viridipunctatus}$ file), with 499 samples at TVST and 461 samples at BLCM. Fish size was divided into ten length groups, with a maximum length of 17.2 cm TL. At TVST, the typical length was 7.0–8.0 cm (82 individuals), 8.0–9.0 cm (102 individuals), 9.0–10.0 cm (113 individuals), and 10.0–11.0 cm (85 individuals). Meanwhile, the common length in BLCM only focused on three groups, including 8.0–9.0 cm (87 individuals), 9.0–10.0 cm (105 individuals), and 10.0–11.0 cm (78 individuals) (Table 1).

The length-frequency data converted to growth curves at two ecor-egions were presented in Figure 2a (at TVST) and Figure 2b (at BLCM), and $L_m$ obtained from Powell-Wetherall at these regions shared a similar value of 14.7 cm. The $Z/K$ estimated by Powell-Wetherall at TVST and BLCM was 2.32 (Figure 3a) and 1.32 (Figure 3b), respectively. In TVST, the von Bertalanffy parameters were $L_m = 14.70$ cm, $K = 0.73/yr$, and $L_0 = -0.27$, respectively, whereas these parameters at BLCM were $L_m = 14.7$ cm, $K = 0.84/yr$, and $L_0 = -0.23$, respectively. The von Bertalanffy growth curve equation of $A. \text{viridipunctatus}$ was $L_t = 14.70$ (1 $- e^{-0.73(1/0.73)})$ at TVST and $L_t = 14.7 (1 - e^{-0.84 (1/0.84)})$ at BLCM.

The yield curve converted analysis showed that $A. \text{viridipunctatus}$ at TVST exhibited $Z, M, F$, and $E$ of 2.09 yr$^{-1}$, 1.80 yr$^{-1}$, 0.29 yr$^{-1}$, and 0.14, respectively (Figure 4a). These parameters at BLCM was 3.47 yr$^{-1}$, 3.14 yr$^{-1}$, 0.34 yr$^{-1}$, and 0.10, respectively (Figure 4b). The $L_{50}$ of the fish population at TVST and BLCM was 7.7 cm (Figure 5a) and 7.9 cm (Figure 5b), respectively.

The Yield per recruit and Biomass per recruit analysis showed that $E_{\text{max}}, E_{0.1}$, and $E_{0.5}$ of 0.926, 0.755, and 0.378, respectively, in the TVST population displayed (Figure 6a). The $\Phi$ and $t_{\text{max}}$ of the TVST population were 2.20 and 4.11 yr. The BLCM population exhibited $E_{\text{max}}, E_{0.1}, E_{0.5}, \Phi'$, and $t_{\text{max}}$ of 0.836, 0.719, 0.377, 2.26, and 3.57, respectively (Figure 6b). The isopleth ratio ($L_{m}/L_{\infty}$) of $A. \text{viridipunctatus}$ was 0.52 at TVST (Figure 7a) and 0.54 at BLCM (Figure 7b).

4. Discussion

As $L_m$ of $A. \text{viridipunctatus}$ showed similar results of 14.7 cm, indicating that this value did not relate to the salinity variation in VMD. However, according to Le and Tong [11], this fish population in Thu Thien Hue (a province in Central Vietnam) showed an $L_m$ of 18.9 cm. Meanwhile, this species population in Japan showed an $L_m$ of 16.5 cm [10], implicating that $L_m$ changed in different environments. $Acentrogobius \text{pflaumii}$, a species of the genus $Acentrogobius$, showed a significantly smaller $L_m$ of 6.9 cm [35]. Compared with some other gobies in VMD, $A. \text{viridipunctatus}$ displayed a higher $L_m$ than $\text{Stigmatogobius pleurostigma}$ (8.6 cm) [36], but lower than $\text{Glossogobius giuris}$ (20.5 cm) [37], $\text{Butis butis}$ (24.0 cm) [38], $\text{G. aureus}$ (28.0 cm) [39], and $\text{G. sparsipapillus}$ (15.9 cm) [40].

The $\Phi'$ of $A. \text{viridipunctatus}$ at BLCM (2.26) was higher at TVST (2.20), implicating that BLCM could be a better place for this species. This could be because fish thrived in environments with higher salinity. Likewise.

Table 1. Length frequency of $Acentrogobius \text{viridipunctatus}$ in TVST (a) and BLCM (b).

| Months       | Length groups | >6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | 12-13 | 13-14 | >14 |
|--------------|---------------|----|-----|-----|-----|------|-------|-------|-------|-------|-----|
| January      | a             | b  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| February     | a             | b  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| March        | a             | b  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| April        | a             | a  | b   | a   | a   | b    | a     | b     | a     | b     | a   |
| May          | a             | b  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| June         | a             | b  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| July         | a             | b  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| August       | a             | b  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| September    | a             | b  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| October      | a             | a  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| November     | a             | a  | a   | a   | a   | b    | a     | b     | a     | b     | a   |
| December     | a             | a  | a   | a   | a   | b    | a     | b     | a     | b     | a   |

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Figure 2. Length frequency distribution of *Acentrogobius viridipunctatus* in TVST (a, n = 499) and BLCM (b, n = 461). The curves showed the increase of fish length over time.

Figure 3. Powell-Wetherall plots of *Acentrogobius viridipunctatus* in TVST (a, $L - L' = 8.5; L_0 = 1.92$) and BLCM (b, $L - L' = 7.50; L_0 = 2.91$). $L'$: Cut off length in cm; $L$: Mean length of fish $\geq L'$; Yellow data points: not used; Dark data points: used.
G. sparsipapillus displayed a better $\Phi$ at the brackish regions as this value increased from 2.19 at the lower salinity to 2.32 at the higher salinity [40]. Compared to some gobies living in VMD, the $\Phi$ of A. viridipunctatus was higher than that of S. pleurostigma (1.79) [36] and B. koilomatodon (1.97) [41], but lower than that of B. butis (2.55) [38] and G. aureus (2.75) [39]. This showed that in VMD, the $\Phi$ varied with species and region.

The growth rate of A. viridipunctatus at BLCM (2.26) was higher than at TVST (2.20). Whereas the reverse case was found in $t_{\text{max}}$, with 4.11 yrs at TVST and 3.58 yrs BLCM. Compared to the previous study at the centre of Viet Nam by Le and Tong [11], this goby could reach the $t_{\text{max}}$ of 18.75 yrs, suggesting that this species’ longevity significantly varied with habitat. By contrast, A. viridipunctatus exhibited a higher $t_{\text{max}}$ than its congener in Swan-Canning Estuary, Australia, A. pflaumii (1.09 yrs) [35].
Figure 7. The relative yield-per-recruit isopleth diagram of Acentrogobius viridipunctatus in TVST (a, Lc/L∞ = 0.52, Lc = 7.66 cm, L∞ = 14.7 cm, E = 0.14) and BLCM (b, Lc/L∞ = 0.54, Lc = 7.88 cm, L∞ = 14.7 cm, E = 0.10).

and other gobies in VMD like B. koilomadon (3.19 yrs) [41] and G. sparsipapillus (3.61 yrs) [40]. The A. viridipunctatus longevity was lower than that of G. giuris (5.36 yrs) [37], B. butis (4.92 yrs) [38], and G. aureus (4.16 yrs) [39] living in VMD. The variation of tmax between A. viridipunctatus and its congener and other gobies living in and out of VMD indicated that this value exhibited a strong relation with environmental conditions and species.

The Z and M were higher at BLCM than at TVST, confirming that in BLCM, this population was threatened by environmental conditions. The M of A. viridipunctatus (3.14 yr⁻¹) was higher than that of G. giuris (1.40 yr⁻¹) [37], B. butis (1.42 yr⁻¹) [38], B. koilomadon (2.37 yr⁻¹) [41], G. aureus (1.52 yr⁻¹) [39], and G. sparsipapillus (1.68 yr⁻¹) [40] living in VMD. This showed that BLCM tended to be an unfavourable environment for fish growth, and A. viridipunctatus tended to be more sensitively affected by environmental conditions than other gobies in VMD.

The TVST and BLCM populations were not subjected to overexploit as E of these ecoregions were <Ea1, suggesting that these fish resources in these regions still met the fishing demand. However, with high natural mortality, this species is in danger of decreasing the number of individuals at BLCM. Similar to A. viridipunctatus, some gobies in VMD did not overfish, e.g., Boleophthalmus boddiart [42] and Periophthalmodon septemradiatus [43]. Some gobid populations, on the other hand, were overexploited, e.g., G. aureus [39] and P. schlatter [44].

The Lc/L∞ ratio of A. viridipunctatus was 0.52 at TVST and 0.54 at BLCM, indicating that all fish specimens were sampled at the adult stage and that the fish resources were reasonably exploited. Compared to other gobies in VMD, this goby tended to be caught at a smaller size than Parapocryptes petersiana (0.63) [28], B. boddiart (0.77) [42] and Trypauchen vagina (0.57) [45], but larger size than G. aureus (0.24) [39]. It could be seen that the isopleth was species-specific.

These results showed that the current fishing length in A. viridipunctatus species was consistent with the growth of fish populations. However, fishing methods were relatively primitive and led to high mortality in this fish. Therefore, local authorities in these areas need to take measures in order to improve fishing methods more suitable, limiting the use of highly destructive fishing equipment (using electricity and chemicals).

5. Conclusion

Acentrogobius viridipunctatus was sampled at the common length of 8.0–11.0 cm and its population biological parameters showed a spatial variation. The species population at the two ecoregions was still exploited reasonably, and this goby displayed a potential candidate for artificial aquaculture and reproductive study due to its high tmax. For sustainable exploitation purposes, the mesh size should be increased.

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.

Ton Huu Duc Nguyen: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ngon Trong Truong; Tien Thi Kieu Nguyen: Conceived and designed 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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