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POPULATION DYNAMICS OF *BOLEOPHTHALMUS BODDARTI* IN THE MEKONG DELTA, VIETNAM

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ABSTRACT

Boleophthalmusboddarti has been increasingly being fished, but littleis knownabout its population dynamics. This study aims to providesome basic parameters of its population biology used for fishery management. A total of 1702 individualscollected by deep gill net along the mudflat in the Mekong Delta, Vietnam, from March 2013 to February 2014.Data analysis showed that the male to female *B. boddarti*ratio was nearly 1:1.The parameters of von Bertalanffy growth function fitting to the length frequency data were L_∞= 16.8 cm, K = 0.79 yr^{-1} and t_0 = –0.24 yr^{-1}. The longevity (t_{max}) and the growth performance (Φ') were 3.55 yrs and 2.35, respectively. The fishing mortality (F = 0.30 yr^{-1}) and natural mortality (M = 1.83 yr^{-1}) amounted for 14.1% and 85.9% of the total mortality (Z = 2.13 yr^{-1}), respectively. There were two recruitment peaks separated by an interval of 6 months and relative yield-per-recruit and biomass-per-recruit analyses gave E_{max} = 0.737, $E_{0.1}$ = 0.618 and $E_{0.5}$ = 0.348. This study reported that this mudskipper could be potential for future aquaculture due to high growth constant (K), and the local government should require fisherman to change the deep gill net mesh size for the future sustainable exploitation and development.

Keywords: mortality indices, longevity, growth performance, exploitation rate.

INTRODUCTION

The growth parameters of a fish population enable us to understand how individual fish grows over time, and the mortality indices(natural mortality and fishing mortality) can be used to estimate fish loss from the population (Amezcua *et al.* 2006).The natural mortalityis the loss ofindividuals due to natural events such as predation, disease, and aging, whereas fishing mortality comes from amateur and commercial catches(Simpfendorfer *et al.* 2005). The exploitation rate represents the fishing status of a fish stock, e.g., the number caught versus the total number of individuals died due to fishing and ecological reasons, and the yield-per-recruit analysis isa useful tool for fishery management (Al-Husaini *et al.* 2002). Moreover, the growth performanceanalysis can compare the growth parameter and asymptotic lengths between genders, sites of a fish species or between species as growth and asymptotic length havea close relationship (Pauly & Munro 1984). However, little is known about population dynamics inmostgobiid species, especially in the Mekong Delta.

The blue-spotted mudskipper [*Boleophthalmusboddarti* (Pallas, 1770), Gobiidae] is one ofthe amphibious fishes(Murdy 1989)and is a potential commercial fish in Southeast Asia (Ip *et al.* 1990) and Vietnam (Dinh 2014). This species can use the air surroundingthe surface of the mudflat for breathing and use burrows asa place of living, forging prey and refuge from predators (Clayton & Vaughan 1986; Dinh *et al.*2014). The *B.boddarti* displays isometric growth (Dinh 2014),feeds mainly on diatoms(Ravi 2013; Dinh 2015), and is a multi-spawner releasing egg in the main wet season from August to October (Dinh *et al.* 2015b). Some information on its geographic distribution, external morphology, environmental adaptation is presented byFroese & Pauly (2015). However, the status of the fish stock of *B. boddarti*hasnot been known, especially in the Mekong Delta where fish recruitment is severely affected by heavy floods (Le *et al.* 2007). Therefore, this study aims to understand population parameters including asymptotic length, growth constant, exploitation rates, mortalities, longevity, recruitment and yield-per-recruit of *B. boddarti*. The results will contribute to theknowledgeof the population dynamics of this species and how to improve its stock assessment and fishery management.

MATERIALS AND METHODS

Study site: The Mekong Delta wetlands created by seasonal or permanent floodingshave fundamental functions in the ecology and economy as they provide habitats for various wildlife species to spawn, shelter and feed(Keddy 2000).Mangrove forest distributed along the shoreline and their waterways provide organic matter and detritus as food sources for various fish species in the Mekong Delta (Kamaludin 1993).The mangrove ecosystem comprising intertidal flora and fauna of tropical and sub-tropical regions is a transitional forest between marine and terrestrial environments in this area(Nedeco 1993). However, deforestation for shrimp culture and intentional fire of forest lead to the depletion of mangrove forest (Thu & Populus 2007).

Soc Trang comprises a long coastline fringed by mangroves and a large number of mud flats withsemi-diurnal tide. There are two seasons in thisregionincluding the dry (January to May) and the wet (June to December) seasons with amean of the annual temperature of 27°C and 400 mm monthly precipitation in the wet season. It is representedfor the typical natural environment in Mekong Delta (Soc Trang Statistical Office 2012).

Fish collection: Fish specimens were collected monthly using deep gill nets with 1.5 cm mesh size along the mudflat and mangrove forest in Tran De District, Soc Trang Province, Vietnam (9°28'47.41"N, 106°12'25.96"E), from March 2013 to February 2014. Deepgill nets were set at the highest tide and retrieved after 2-3 hours during ebb tide along the margin of mangrove forest. After sexual differentiating based onthe external morphology of genital papilla shape (oval shape for female and roughly triangle sharp for male), fish specimens were stored in 5% formalin and transported to the laboratory. Inthe laboratory, specimens were measured to the nearest 0.1 cm in total length and weighed to the nearest 0.01 g. The water temperature and salinity at the study site were measured monthly using a thermometer (Model: HI98127, ±0.5 ºC) and a refractometer(Model: 950.0100 PPT-ATC, ±1‰)respectively to test if the environmental factors influence on the sex ratio.

Data analysis: The difference in thesex ratio of *B. boddarti* was analyzed by Chi-square test, whereas the FiSAT II (Gayanilo *et al.* 2005) was used to estimate the population parameters of this mudskipper based on monthly total length measurement data. The initial asymptotic length (L_∞) was calculated using the Powell-Wether all procedure (Powell 1979; Pauly 1986; Wetherall 1986). The Beverton and Holt length-based Z-equation was expressedas $\bar{L} - L' = a + bL'$, where,*L'* is the cutoff length; $\bar{L}$ is the mean lengthof all fish (≥*L'*) and was calculated as $\bar{L} = \frac{L_\infty + L'}{1 + Z/K}$.

The initial asymptotic length $L_\infty$was calculated as *a*/*b* and *Z*/*K*was definedas –(1+*b*)/*b*from the linear regression, where *a* is the regression intercept and *b* is the regression slope.The ELEFAN I procedure was performed to optimize the asymptotic length and the growth parameter (*K*) based on the initial L_∞(Pauly & David 1981; Pauly 1982;Pauly 1987). The L_∞ and *K* were then used to estimate the t_0 from the equation $\log(-t_0) = -0.392 - 0.275 \times \log L_\infty - 1.038 \times \log K$ (Pauly 1979).

The length-converted capture curve was used to compute the mortality rate (*Z*) (Beverton & Holt 1957; Ricker 1975), whereas the natural mortality rate (*M*) was estimated by the following empirical model $LogM = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.463 \log T$, where, L_∞ and *K* were two parameters obtained from the ELEFAN I, and *T* was the mean of monthly water temperature (ºC) in the study area (Pauly 1980).After obtaining the reasonable value of *Z* and *M*, the fishing mortality (*F*) was calculatedas$F = Z - M$, and the exploitation ratio (*E*) was estimated from the equation $E = F/Z$(Ricker 1975).

The length-converted catch curve and whole length-frequency dataset were used to compute the probability of capture for each size class and the seasonal recruitment pattern of the goby *B. boddarti*, respectively (Pauly 1987).The fish length at first capture (L_c) taken as the cumulative probability of capture at 50% was obtained by plotting the cumulative probability of capture against the class mid-length(Pauly 1987).

The stock and yield of fish were described using the yield-per-recruit model of Beverton & Holt (1957)(Sparre & Venema 1992). The yield-per-recruit (Y'/R) of the mudskipper*B. boddarti*was calculated using the equation $Y'/R = EU^{M/K}(1 - \frac{3U}{1+m} - \frac{3U^2}{1+2m} - \frac{U^3}{1+3m})$, where, U = 1- (L_c/L_∞) and $m = \frac{1-E}{M/K} = \frac{K}{Z}$ (Beverton & Holt 1966).

The biomass-per-recruit relation (B'/R) of this species was computed from the equation $B'/R = \frac{Y'/R}{F}$. After obtainingby dividing fishing (*F*) and total mortality (*Z*) rates, the exploitation rate (*E*) of *B. boddarti*was compared to the anticipated values of E_{max} (the maximum yield exploitation rate), $E_{0.1}$(the exploitation rate with the minimal increase of 10% of Y'/R when *E* close tozero), and $E_{0.5}$ (the exploitation rate in which the reduction of stock to 50% of the unexploited biomass).The knife-edge selection was used to estimate the values of E_{max}, $E_{0.1}$and$E_{0.5}$(Beverton & Holt 1966).The ratio of length at first catch and asymptotic length (L_c/L_∞) was determined using the yield isopleth diagram that was used to estimate the fishing status of *B. boddarti*based four quadrants of the yield contour (Pauly & Soriano 1986).

The growth performanceindex(ϕ') was calculated as $\phi' = \log K + 2\log L_\infty$,where, *K* and L_∞ were two parameters of the von Bertalanffy curve (Pauly & Munro 1984). This parameter was used to compare the von Bertalanffy growth parameters of *B. boddarti* and other goby fishes dwelling in the same habitat. The longevity (t_{max}) of *B. boddarti*was calculated from the following equation $t_{max} = \frac{2.997}{K} + t_0$, where, *K* and $t_0$were the growth parameter and the age when the egg was fertilized, respectively (Taylor 1958; Pauly 1980). The SPSS v.21 was used to analyze all data and the level of significant differences for all tests was set at the meaningful level of 5%.

RESULTS AND DISCUSSION

Sex ratio and environmental factors: The number of female *B. boddarti*(880) was not significantly different from males (822)withinand betweenmonths and seasons, and the sex ratio of *B. boddarti* was nearly 1:1 based on ¡^{2} tests (Table 1), which was similar to sex ratio of *Pseudapocryptes elongatus* in the same region reported by Tran *et al.* (2007).In the study region,the water temperature in the dry season (29.07±1.32ºC) was not significantly different from the wet season (28.33±1.05ºC, t-test, t = 1.78, $P > 0.05$). However, the water salinity in the study site was significantly higher in the dry season (8.86±3.75‰) than that in the wet season (2.68±2.28‰, t-test, t = 16.67, $P < 0.001$). The environmental temperature and salinity were not different from the study of Tran *et al.* (2007), suggesting that these environmental factors in this region did not affecttheabundance of male to female in the *B. boddarti* and *P. elongates* populations.

Population dynamics: The population parameters such as asymptotic length,growth rate, longevity, mortality, recruitment, exploitation indices and yield-per-recruit were estimated from the length frequency analysis of 1702 individuals (8 - 16 cm in TL). The initial L_∞ (16.27 cm) and Z/K (1.669) of *B. boddarti*obtained from the Powell-Wether all procedure were used to determine the optimized parameters, i.e., L_∞ = 16.8 cm, K = 0.79 yr^{-1}. The value of $t_0$estimated from the equation (3) was –0.24 yr^{-1}. Most of fish size in this study was greater than the L_{50}based on the growth curves of *B. boddarti* from the length-frequency data. Moreover, there were six fish size groups, i.e., six growth curves represented by four dark lines (Fig. 1) in the population of *B. boddarti* in this study area.Pauly (1987)reported that a fish population structure analysis requires at least 1500 fish of specimens, which show distinct peaks in length frequency distribution, are collected over six months. The fish samples (e.g., 1702 individuals collected during 12 months, and the sequentially arranged monthly histograms displayed distinct peaks) in the present study adopted this sampling criterion. Thus, it is reasonable that the results from such a large population size provide a reliable dataset for the analysis of population parameters.

The total mortality (Z) of *B. boddarti*was 2.13 yr^{-1}(intercept: a = 11.423, slope: b = –2.132, r = 0.99, n = 3, confidence interval: 0.90- 3.37 yr^{-1}), which was estimated from the length-converted catch curve (Fig. 2a). The natural mortality (M), fishing mortality (F) and exploitation (E) rates of the goby *B. boddarti*were 1.83 yr^{-1}, 0.30 yr^{-1}, and 0.14, respectively (Fig. 2a). Recruitment pattern showed that the variation in fishery recruitment overtime and the two recruitment peaks occurred in March and August with different magnitudes. The means of the two peaks were separated by a time interval of 6 months (Fig. 2b). The fish length at first capture of this fish ($L_c$orL_{50}) was 12.97 cm (Fig. 2c). The population of *B. boddarti* has been unexploited, and its survival rate depended on more environmental factors as the fishing mortality (F) of *B. boddarti* was lower than that of the natural mortality (M) in this study. The two annual recruitment peaks of the *B. boddarti*population indicated that this goby can spawn more than once per year that was also found in some co-occurring gobies such as *Pseudapocrypteselongatus*(Tran *et al.* 2007) and *Parapocryptesserperaster* (Dinh *et al.* 2015a). However, the length at first capture (L_c = 12.97 cm) in *B. boddarti* was slightly greater than that in *P. elongatus* (12.85 cm)(Tran *et al.* 2007), seeming that the *B. boddarti*was slightly less exploited than *P. elongatus*, but more than *P. serperaster* (14.6 cm) (Dinh *et al.* 2015a)

The yield-per-recruit and biomass-per-recruit of this *B. boddarti*were analyzed using the knife-edge selection. The maximum sustainable yield (E_{max}), the optimum yield($E_{0.1}$) and the yield at thestockreduction of 50% ($E_{0.5}$) were 0.737, 0.618 and 0.348, respectively(Fig. 3a). The stock of *B. boddarti*wasunder-fishing as the yield isopleths with L_c/L_∞ being 0.77 and E being 0.14 (Fig.3b) failedinto quadrant A, one of four quadrants of the yield contour.Itsexploitation rate (E = 0.14) is less than the maximum exploitation rate (E_{max} = 0.737), indicating that the *B. boddarti* stock has not been overfishing that was also found in *P. serperaster* (Dinh *et al.* 2015a).Pauly & Soriano (1986)used four-quadrant models to describe fish yield related to fish size. Quadrant A represents under fishing (L_c/L_∞ = 0.5-1.0 and E = 0-0.5). Quadrant B represents eumetric fishing (L_c/L_∞ = 0-0.5 and E = 0-0.5). Quadrant C represents developed fishery (L_c/L_∞ = 0.5-1, and E = 0.5-1). Quadrant D represents overfishing (L_c/L_∞ = 0-0.5, and E = 0-0.5). The fish yield isopleths of *B. boddarti* in this study closed to the quadrant A since the ratio ofL_c and L_∞ was 0.77,and the exploitation rate (E) was 0.14. It suggested that the *B. boddarti*population has not been overexploited, and the current use of fishing gears is suitable for sustain exploitation. Although the fish stock of neighbor goby*P. elongatus* has not reached the point of overexploitation, more small fish was caught in the study of Tran *et al.* (2007).

The growth performance (Φ’)of *B. boddarti*was 2.35and longevity (t_{max}) was 3.55yr. Growth performance index (Φ’) was used for growth comparison between fish species in this study as the fish growth curves were not linear and the growth rate varied with fish length and age. In addition, when comparing growth parameters between different tilapia populations, Moreau *et al.*

(1986)indicated that *Φ'* is the best growth index compared to another growth index ω = *KL*∞since*Φ'* exhibits the least degree of variation. The growth parameter *Φ'* is usually similar within the related taxaand have narrow normal distributions (Moreau *et al.* 1986; Tran *et al.* 2007). However, the *Φ'* value of *B. boddarti* was lower than its neighbor species such as *P.elongatus* and *P. serperaster* and higher than other gobiid species (Table 2).

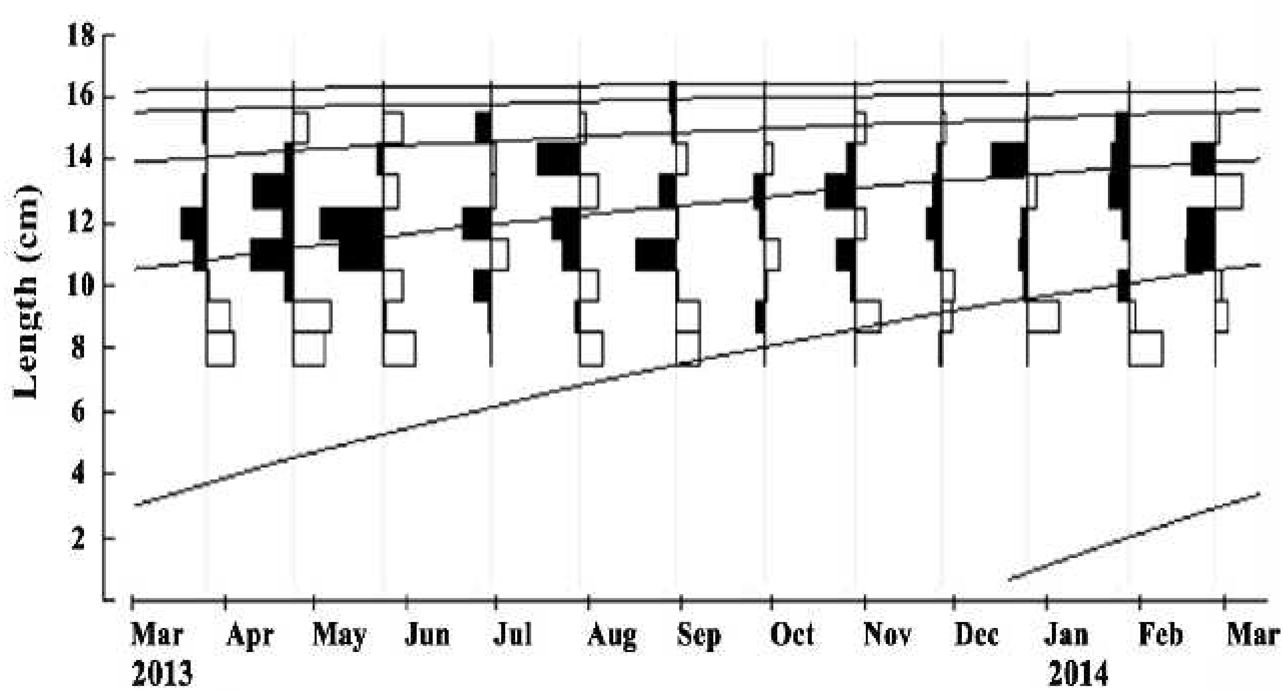

Fig.1.The von Bertalanffy growth curve of *Boleophthalmusboddarti* superimposed over the reconstructed length frequency data (*n* = 1702) in the Mekong Delta. The curves show the increase of fish length over time

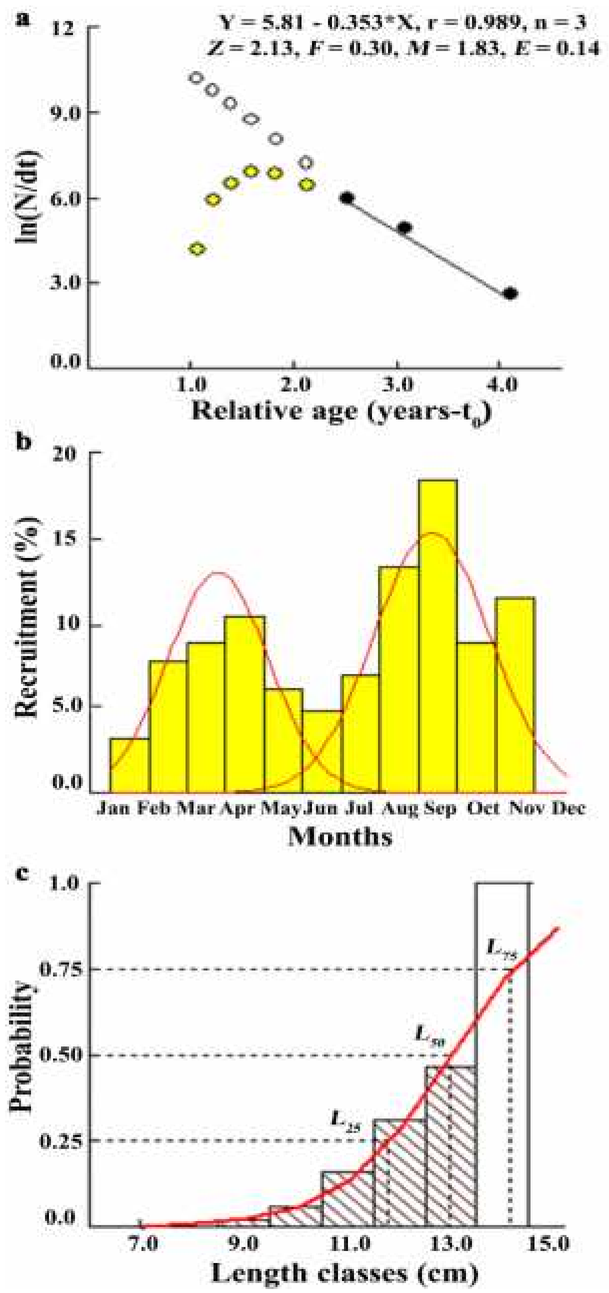

Fig.2.(a) The length converted catch curve of *Boleophthalmusboddarti*. The dark points were used to calculate the least square linear regression, while the yellow points were excluded from regression analysis. The open points represent the expected fish age. (b) Recruitment pattern of *B. boddarti* estimated from length frequency data (March 2013 - February 2014). (c) The probability of capture of each fish length class of*B. boddarti* (L_{25}= 11.78, L_{50} = 12.97 andL_{75} = 14.15 cm, estimated from the logistic transform curve, e.g., red line)

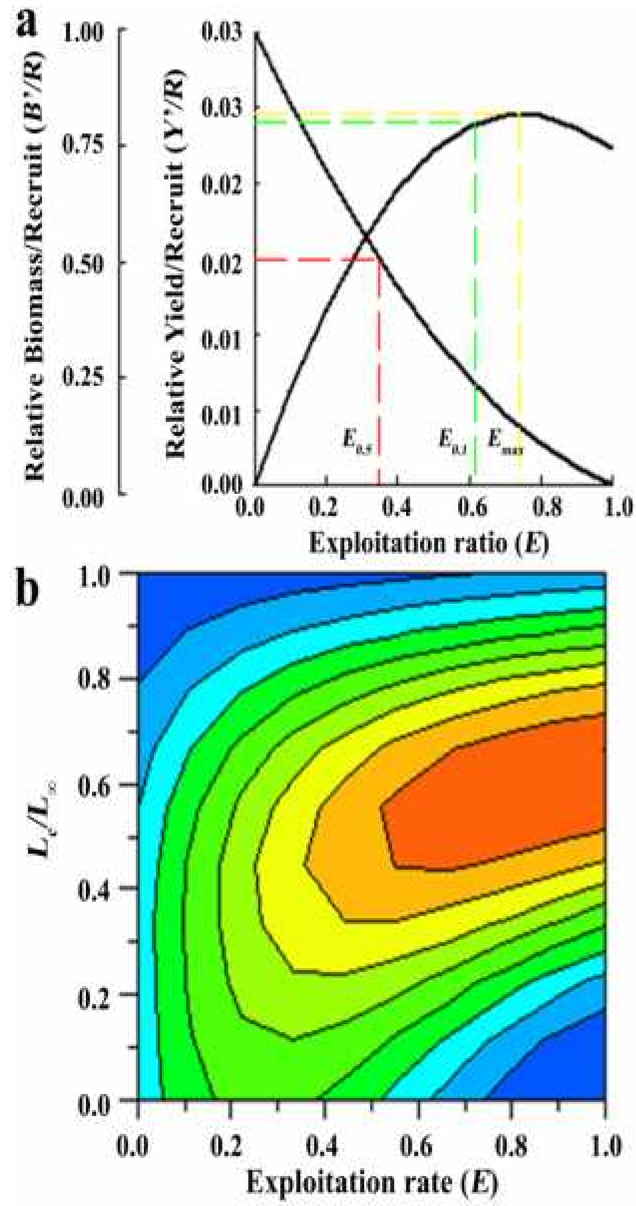

Fig.3.(a) The relative yield-per-recruit and relative biomass-per-recruit for *Boleophthalmusboddarti* using the knife-edge procedure (E_{max} = 0.737, $E_{0.1}$ = 0.618 and $E_{0.5}$ = 0.348). (b) The yield isopleths for*B. boddarti*

Table1.Monthly sex ratio of *Boleophthalmus boddarti* from March 2013 to February 2014 in the study area tested by ¡^{2} analysis (*P*< 0.05).

Months	Female	Male	Sex ratio	¡^{2}	*P*-value
Mar-13	59	50	1 : 1.18	0.743	0.389
Apr-13	67	49	1 : 1.37	2.793	0.095
May-13	46	55	1 : 0.84	0.801	0.371
Jun-13	52	58	1 : 0.90	0.327	0.567
Jul-13	65	56	1 : 1.16	0.669	0.413
Aug-13	59	45	1 : 1.31	1.885	0.170
Sep-13	65	57	1 : 1.14	0.525	0.469
Oct-13	81	69	1 : 1.17	0.960	0.327
Nov-13	98	85	1 : 1.15	0.923	0.337
Dec-13	88	90	1 : 0.98	0.022	0.881
Jan-14	105	94	1 : 1.12	0.608	0.436
Feb-14	101	108	1 : 0.94	0.234	0.628
Dry	378	356	1 : 1.06	0.659	0.417
Wet	508	460	1 : 1.10	2.380	0.123
Total	880	822	1 : 1.07	2.879	0.090

Table2. The von Bertalanffy and performance growth parameters of some gobiid species.

Species	*Φ'*	L_∞ (cm)	K(yr^{-1})	Source
Periophthalmuspapilio	2.28	19.39	0.51	Etim *et al.* (1996)
Periophthalmusbarbarus	2.41	21.6	0.55	Etim *et al.* (2002)
Pseudapocrypteselongatus	2.64	26	0.65	Tran *et al.* (2007)
Parapocryptesserperaster	2.67	25.2	0.74	Dinh *et al.* (2015a)
Boleophthalmusboddarti	2.35	16.8	0.79	This study

Conclusion: The sex ratio of *B. boddarti* was close to 1:1, and its fish stock was unexploited in the Mekong Delta. This species was high in population recruitment and could be potential for future aquaculture due to high growth constant (*K*). However, local government should require fisherman to change the deep gill net mesh size for future sustainable fishery managementthroughthe use of slightly small mesh size of current gear.

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