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Population and Age Structure of the Goby *Parapocryptes serperaster* (Richardson, 1864; Gobiidae: Oxudercinae) in the Mekong Delta

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Abstract

The goby *Parapocryptes serperaster* lives on the mud flats in estuaries and has been increasingly exploited as food fish in Mekong Delta, Vietnam, but little is known on its population, age structure and growth. This study aims to understand some basic parameters of its population biology and age used for fishery management and size-selective fishing. Based on monthly samples over a year, a total of 3002 fish were used for population structure analysis. Fish length distribution and otoliths were used for fish aging. The sex ratio of *P. serperaster* was near 1:1 and fish size at first entry to fishery was 14.6 cm. The longevity of this goby was 4.05 yr, but fishing mortality (1.57 yr^{-1}) and natural mortality (1.51 yr^{-1}) accounted for 51% and 49% of the total mortality (3.07 yr^{-1}), respectively.Relative yield-per-recruit and biomass-per-recruit analyses revealed the levels of maximum exploitation yield (E_{max} = 0.83), maximum economic yield ($E_{0.1}$ = 0.71) and the yield at 50% reduction of exploitation ($E_{0.5}$ = 0.37). Readable otoliths from female (*n*=164) and male (*n*=196) gobies with proper otolith morphometry were used for age identification. The mean age estimated by reading otolith annual rings matched the age estimate from length frequency distribution. The otolith morphometry is a reliable method to age this goby and possibly also applicable for other tropical gobies. The fishery analysis indicates that this goby stock is not overexploited and shows high population recruitment in the Mekong Delta.

Keywords: *Parapocryptes serperaster*, mortality, growth, exploitation, otolith, Vietnam.

Introduction

Growth and mortality rates are important population parameters to understand the population dynamics and recruitment pattern for a fish cohort (Al-Husaini *et al.*, 2001). Moreover, fish age determination using length-frequency distribution and otolith analysis (Tran, 2008; Pilling *et al.*, 2003; Cardinale and Arrhenius, 2004; Devries and Frie, 1996) is a fundamental step for fishery management and stock assessment as fish age is an important estimate for fish growth, recruitment, sexual maturation and population structure (Beatriz, 1992; Cardinale *et al.*, 2000).

Most fish species in the family Gobiidae live on mud flats and contribute significantly to fishery catch in Indo-Pacific regions (Hajisamae *et al.*, 2006; Matics, 2000). *Parapocryptes* is one of 10 genera of Gobiidae and consists of two species such as *P. rictuosus* (Valenciennes, 1837) and *P. serperaster* (Richardson, 1846) living in soft-bottomed tidal areas and estuaries (Murdy, 2011; Murdy, 1989). The goby *Parapocryptes serperaster* has an elongated and round body (Khaironizam and Norma-Rashid, 2000), and distributes in the Indo–West Pacific Region including the Mekong Delta, Vietnam (Froese and Pauly, 2014). *P. serperaster* is a species living in costal muddy areas and dwelling in burrows situated in estuarine mud flats (Dinh *et al.*, 2014), and is a commercially important food species in Taiwan, Vietnam and other Asian countries (Ip *et al.*, 1990). The use of versatile fishing gears including hook, gill net, deep net, even hand catching has significantly reduced the goby resource and may affect future sustainable exploitation (Dinh *et al.*, 2014). Understanding the effects of heavy floods on the population and age structure of *P. serperaster* in the Mekong Delta is limited (Le *et al.*, 2007). Therefore, this study aims to understand the population and age structure of this goby using length-frequency distribution and test if otolith morphometry is related to fish growth and aging. The result will contribute to our knowledge on population and age structure for this goby species and other burrow dwelling tropical fishes.

Materials and Methods

Study Site

This study was carried out in the Kinh Ba River, Cu Lao Dung district, SocTrang Province, Mekong Delta, Vietnam (9°26'3" N, 106°13'28" E), from March 2013 to February 2014 (Figure 1). SocTrang is a typical region in the Mekong Delta with a long coastline connected with mangroves and large areas of mudflats with semi-diurnal tides and a spring tidal range from 0.7 to 1 m. This region has a dry (January to May) and wet (June to December) seasonal cycle. The average annual temperature is 26.5–29 °C and the monthly precipitation in the wet season is about 400 mm, which represents a typical natural condition in the Mekong Delta (Soc Trang Statistical Office, 2012).

Fish Collection

Fish were collected monthly from a commercial fishery site using three gill nets with 1.5 cm mesh size in the cod end, 2.5 cm mesh size in mouth and 5 m in length for a year-round cycle. Each gill net was set at the highest tide (stagnant) and retrieved after 2-3 hours during the ebb tide. Three gill nets were set behind each other with 0.5 km apart. In the field, after sex determination using external morphology of genital papilla shape (oval shape for female and roughly triangle sharp for male), all fish were measured to the nearest 0.1 cm in total length and weighed to the nearest 0.01 g. Among 3002 individuals, 476 individuals were chosen over a period 12 months, from March 2013 to February 2014, and were immediately anesthetised using benzocaine and were stored in a plastic jar in 5% formalin before transport to the laboratory or fish age and population analysis (Table 1). The rest of fish specimens were released to the river. Thermometer (Model: HI98127, ±0.5°C) and refractometer (Model: #950.0100 PPT-ATC, ±1‰) were used to measure monthly the environmental parameters including surface water temperature and salinity at the study site, respectively. These parameters were used to test the influence of environmental factors on the sex ratio of *P. serperaster*.

In the laboratory, the otoliths from each side of all specimens were extracted by cutting the head along the mid-sagittal plane and removing the otoliths from the brain cavity. The otoliths were subsequently cleaned in water to remove any attached tissues, dipped in 75% ethanol and stored dry on plastic culture plates (David and John, 1992). Otoliths were measured in maximum length and width (Figure 2a) using the Motic Image ProPlus software v2.0 and

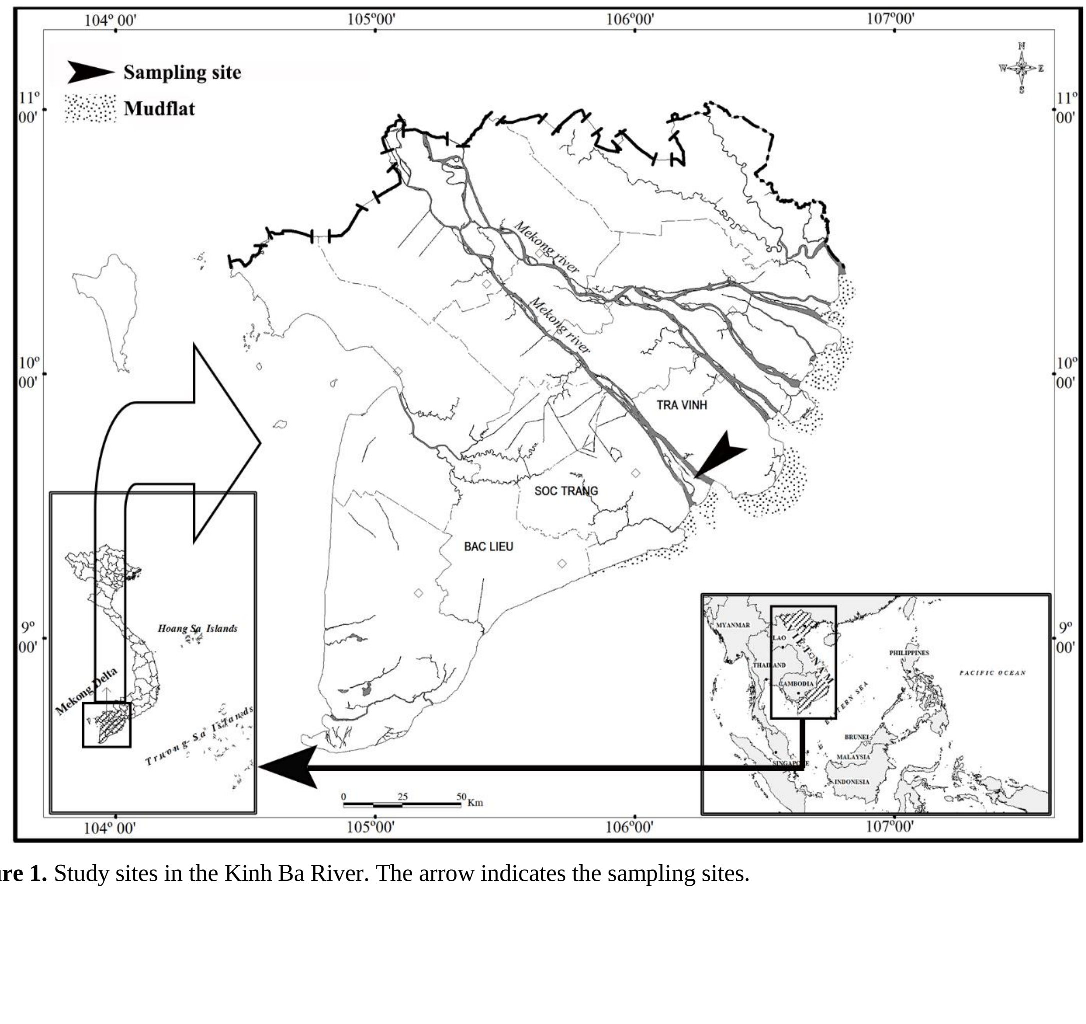

Figure 1. Study sites in the Kinh Ba River. The arrow indicates the sampling sites.

weighedto the nearest 0.1 mg.

Population Structure

Monthly data of length measurements of the goby *Parapocryptes serperaster* were used to estimate population parameters using the FiSAT II software (Gayanilo *et al.*, 2005).The difference in sex ratio was analysed by Chi-square test. After the Powell-Wetherall procedure was used to obtain the initial asymptotic length (L_∞) (Pauly, 1986; Powell, 1979; Wetherall, 1986), the Beverton and Holt length-based Z-equation was obtained and expressed as a linear regression equation:

$$\bar{L} - L' = a + bL'$$

where, *L'* is the cut off length (e.g., the length threshold larger than the smallest fish length in the capture samples); $\bar{L}$ is the mean length of all fish ($\geq L'$) and was calculated as

$$\bar{L} = \frac{L_\infty + L'}{1 + Z/K}$$

Table 1. Monthly sex ratio of *Parapocryptes serperaster* from March 2013 to February 2014 in the study area tested by χ^2 analysis (P<0.05)

Month	Population analysis					Aging analysis			
	Juveniles	Female	Male	Sex ratio	*P*-value	Female	Male	Sex ratio	*P*-value
Mar-13	65	85	89	1 : 0.96	0.762	15	13	1 : 1.15	0.705
Apr-13	65	76	84	1 : 0.90	0.527	19	24	1 : 0.79	0.446
May-13	106	162	161	1 : 1.01	0.956	18	13	1 : 1.38	0.369
Jun-13	32	108	101	1 : 1.07	0.628	21	19	1 : 1.11	0.752
Jul-13	8	75	79	1 : 0.95	0.747	22	17	1 : 1.29	0.423
Aug-13	8	109	101	1 : 1.08	0.581	15	19	1 : 0.79	0.493
Sep-13	3	135	121	1 : 1.12	0.382	25	20	1 : 1.25	0.456
Oct-13		96	77	1 : 1.25	0.149	19	16	1 : 1.19	0.612
Nov-13		109	127	1 : 0.86	0.241	17	21	1 : 0.81	0.516
Dec-13	6	96	82	1 : 1.17	0.294	27	28	1 : 0.96	0.893
Jan-14	77	121	105	1 : 1.15	0.287	23	18	1 : 1.27	0.435
Feb-14	126	107	100	1 : 1.07	0.627	25	22	1 : 1.24	0.662
Dry	439	551	539	1 : 1.02	0.761	100	90	1 : 1.11	0.468
Wet	57	728	688	1 : 1.06	0.288	146	140	1 : 1.04	0.723
Total	496	1279	1227	1 : 1.04	0.299	246	230	1 : 1.07	0.463

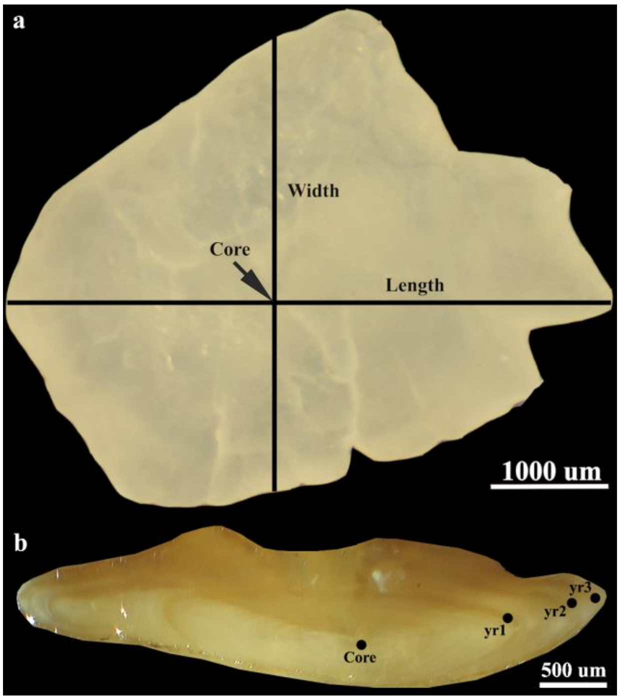

Figure 2. The otolith of a three-year old *Parapocryptesserperaster*. (a) left external morphology, (b) annuli at core, year 1, year 2 and year 3.

From the linear regression, the asymptotic length L_∞ was calculated as a/b and Z/K was defined as –(1+b)/b, where a is the regression intercept and b is the regression slope. The initial L_∞ was used in the ELEFAN I procedure (Pauly, 1982; Pauly, 1987; Pauly and David, 1981)to optimize the asymptotic length (L_∞) and the growth parameter (K). The L_∞ and K were used to obtain the $t_0$from this equation (Pauly, 1979):

$$\log(-t_0) = -0.392 - 0.275 \times \log L_\infty - 1.038 \times \log K$$

where, the initial L_∞ was set at 22.9 cm and Z/K was 2.757. The initial L_∞ was then used to determine the optimised growth parameters, i.e., L_∞ = 25.2 cm, K = 0.74 yr^{-1}. The value of t_0 was estimated as –0.22 yr^{-1} from the above equation.

Mortality rate (Z) was computed from the length-converted capture curve (Beverton and Holt, 1957; Ricker, 1975). The natural mortality rate (M) was estimated by the following empirical model (Pauly, 1980):

$$\text{Log} M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.463 \log T$$

where L_∞ and K were estimated from the ELEFAN I procedure and T was the average monthly water temperature (ºC) in the study area. The attainment of reasonable estimates of Z and M was used to estimate fishing mortality (F) based on the equation $F = Z – M$. The exploitation ratio (E) was then defined as $E = F/Z$ (Ricker, 1975). The probability of capture for each size class was analysed using the length-converted catch curve (Pauly, 1987). The seasonal recruitment pattern of the goby *P. serperaster* was reconstructed using the whole length-frequency dataset. By plotting the cumulative probability of capture against the class mid-length, a resultant curve was obtained to determine the fish length at first capture (L_c), which was then taken as the cumulative probability of capture at 50% (Pauly, 1987).

The yield-per-recruit model of Beverton and Holt (1957) was used to describe the stock and yield of fish when all fish are vulnerable to catch after recruitment (Sparre and Venema, 1992). The yield-per-recruit (Y'/R) of the goby *P. serperaster* was calculated using the equation of Beverton and Holt (1966):

$$Y'/R = EU^{M/K}\left(1 - \frac{3U}{1+m} - \frac{3U^2}{1+2m} - \frac{U^3}{1+3m}\right)$$

where, U = 1- (L_c/L_∞)is the fraction of growth to be completed by this species after entering the exploitation phase:

$$m = \frac{1-E}{M/K} = \frac{K}{Z}$$

The biomass-per-recruit relation (B'/R) of this species was computed from the equation

$$B'/R = \frac{Y'/R}{F}$$

The exploitation rate (E) of *P. serperaster*, obtained by dividing fishing (F) and total mortality (Z) rates, was compared to the anticipated values of E_{max} (the maximum yield exploitation rate), $E_{0.1}$ (the maximum economic exploitation rate at which the marginal increase of Y'/R is 10% of its value at E = 0), and $E_{0.5}$ (the exploitation rate with the reduction of stock to 50% of its unexploited biomass). The ratio of natural mortality (M) to growth parameter (K), and the ratio of the length at first capture (L_c) to the asymptotic length (L_∞) were used to estimate the values of E_{max}, $E_{0.1}$ and $E_{0.5}$ based on knife-edge selection described byBeverton and Holt (1966).The effect on yield derived by the change of exploitation rate and the fraction of length at first catch and asymptotic length (L_c/L_∞) was estimated by the yield isopleth diagram. This diagram was used to determine the fishing status of *P. serperaster* based on four quadrants of the yield contour described by Pauly and Soriano (1986).

For comparison of the von Bertalanffy growth parameters of *P. serperaster* and other goby fishesdwelling in the same habitat, the index of overall growth performance (Φ') was calculated from the following equation (Pauly and Munro, 1984):

$$\Phi' = \log K + 2\log L_\infty$$

where, K and L_∞ were parameters obtained from the von Bertalanffy curve. The longevity (t_{max}) of *P. serperaster* was calculated from the following equation (Taylor, 1958; Pauly, 1980):

$$t_{max} = \frac{3}{K}$$

where, K was the growth parameter and t_0 was the age when the egg was fertilised.

Fish Age Determination using Otolith

The otolith burning method for fish age determination was first described by Møller Christensen (1964), and has been used by many researchers for fish aging. Each otolith was randomly selected and cut through the core of the otolith and perpendicular with the sulcus by a pair of scissors before placing the otolith on the flame of an alcohol burner. The broken otolith was removed from the flame when its colour became ash grey. The otolith fragments were then fixed on a microscope slide using crystal-ball glue. The fractured otolith surface was facing upward under the digital microscope equipped with a camera (Motic model: 143-FBGG-

C). The otolith surface was gently brushed with vegetable oil before capturing the image under reflected light against a dark background using this microscope. With this method, the hyaline rings appeared as brown on a yellow background. The otolith photo was also used to determine the fish age because it was easier than reading on a digital microscope.

For fish otolith without obvious annuli, the fish age was determined based by the number of daily rings on the otolith. The otoliths were embedded in clear polyester resin mixed with hardener (ratio: 49 resins and 1 hardener). The mounted otoliths were grinded by using the 600-grit and 1000-grit silicon carbide papers until the core of otolith appeared. The otoliths were polished lightly on a polishing disc with diamond compound. During grinding, the otoliths were regularly checked for the ring structure ona microscope. If some rings appeared, the polishing was stopped and then the otoliths were washed with soap water (David and John, 1992). Otolith aging was undertaken with a transmitted light microscope, and the number of daily rings on the otolith was counted from the centre to the edge.

Each otolith was read at three independent times with a 3-week break between readings, and the result would be used only if the two of three readings agreed (Steven, 1992). The percent error between three readings on annual rings was quantified using the index of average percent errors (*IAPE*):

$$IAPE = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{\left|X_{ij}-X_{j}\right|}{X_{j}}\right]$$

where, N was the number of fish aged; Xj was the ith age calculated for the jth fish; Xij was the ith age determination of the jth fish (Beamish and Fournier, 1981).The result of age determination was accepted when the value of *IAPE* between three readings was less than 5%.

Fish age Determination Using Length-Frequency Distribution

The age of this *P. serperaster* was estimated using the following equation (Pauly, 1987):

$$L_t = L_\infty\left(1-e^{-K(t-t_0)}\right)$$

where, L_t is the length of fish at t age; L_∞ is asymptotic length;K is the growth parameter; and $t_0$is the age at which eggis fertilised. This method was successfully used by Tran (2008) to determine the fish age of *Pseudapocryptes elongatus*, and by Mazlan and Rohaya (2008) to determine the age of the mudskipper *Periophthalmodon schlosseri*.

The fish age estimated from otolith and that from length-frequency distribution was compared by *t*-test. Differences in percentage of male and female *P. serperaster* within months and seasons, and between dry and wet seasons were tested using the χ^2 test. All data were analysed using SPSS software v.21 and the level of significant differences for all tests was set at P<0.05.

Results

Sex Ratio and Environmental Factors

A total of 3002 fish (8-24 cm TL) including 496 juveniles, 1279 females and 1227 males were used for population analysis. The proportion of female and male *P. serperaster* was not significantly different within the month and the season or between dry and wet seasons based on χ^2 tests, and the sex ratio of *P. serperaster* was near 1:1 (Table 1). Among 3002 individuals, 476 individuals (246 male and 230 female) were randomly selected for otolith analysis on age determination, and the sex ratio was also close to 1:1 (Table 1).

In the study region, water temperature (29.07±1.32ºC) in the dry season was not significantly different from that in the wet season (28.33±1.05ºC, t-test, t = 1.78, P>0.05). However, the water in the study site was brackish in the dry season (8.86±3.75‰) and significantly higher than in the wet season (2.68±2.28‰, t-test, t = 16.67, P<0.001).

Population Structure

The length frequency analysis of 3002 fish were used to estimate the population parameters such as asymptotic length, growth rate, longevity, mortality, recruitment, exploitation indices and yield-per-recruit. The growth curves of *P. serperaster* from the length-frequency data showed that most of fish size in this study was greater than the length at first capture (L_{50}) in the spawning season from August to October (Figure 3). Moreover, there were four fish size groups, i.e., four growth curves represented by four dark lines (Figure 3) in the population of *P. serperaster* in this study area, and the slight slope in the bigger fish compared to smaller fish leading to large fish grew more slowly than small ones.

The total mortality (Z) of *P. serperaster* was 3.07 yr^{-1}(intercept: a = 11.372, slope: b = - 2.306, r = 0.967, n = 9, confidence interval: 2.4- 3.8 yr^{-1}), which was estimated from the length-converted catch curve (Figure 4a). The natural mortality (M), fishing mortality (F) and exploitation (E) rates of the goby *P. serperaster* were 1.57 yr^{-1}, 1.51 yr^{-1}, and 0.49, respectively (Figure 4a). Recruitment pattern showed that the variation in fishery recruitment over time, and the two recruitment peaks occurred in March and September with different magnitudes. The means of the two peaks were separated by a time interval of 6 months (Figure 4b). The analysis of capture probability indicated that the fish length at first capture ($L_c$or L_{50}) was 14.6 cm (Figure 4c).

The yield-per-recruit and biomass-per-recruit of this *P. serperaster* were analysed using the knife-edge selection. The maximum sustainable yield (E_{max}), the optimum yield ($E_{0.1}$) and the yield at stock reduction of 50% ($E_{0.5}$) were 0.83, 0.71 and 0.368, respectively (Figure 5a). The yield isopleths were used to predict the response of relative yield-per-recruit of the fish to the changes in L_c and E. The stock of *P. serperaster* was under-fishing as the yield isopleths with L_c/L_∞ being 0.57 and E being 0.49 (Figure 5b) failed to fit into quadrant A, one of four quadrants of the yield contour. The relative index of growth rate and the asymptotic length, e.g., growth performance (Φ') was calculated with the equation $\Phi' = \log K + 2\log L_\infty$, whereas the longevity (t_{max}) was estimated from the equation $t_{\max} = \frac{3}{K}$. The growth performance value of *P. serperaster* was 2.67, and longevity was 4.05 yr.

Otolith Morphometric Analysis

Among 476 individuals, only 360 individuals were successfully aged including 164 females and 196 males as otolith was broken down after removing from fish specimens. Fish length was 10.7-23 cm for the female and 12.1-23.1 cm for the male (Figure 6). The left otolith morphometric measurements (e.g., length, width and weight) of male and female fish were used to examine the potential use of otolith to age this goby by regression analysis. The result showed that the otolith was able to use for fish age determination as the fish length (TL) of two genders had positive relationships with the otolith length (OL_{female}=309.5+222.02 TL, n=164, R^2=0.683, F=283.56, P<0.001; OL_{male}=313.02+218.72 TL, n=196, F=500.16, R^2=0.721, P<0.001, Figure 7a); $OWidth_{female}$= -890.47+256.75 TL, n=164, F=356.07, R^2=0.838, P<0.001; $OWidth_{male}$=-515.21+232.96 TL, n=196, R^2=0.791, F=451.94, P<0.001, Figure 7b);and weight ($LogOW_{female}$=0.3426+0.0441 TL, n=164, R^2=0.780, F=575.15, P<0.001; $LogOW_{male}$= 0.1727+0.0536TL, n=196, R^2=0.862, F=1214.39, P<0.001, Figure 7c).

Age Determination using Fish-Length Distribution and Otoliths

The length frequency analysis showed that L_∞ was 25.2 cm, K = 0.74yr^{-1} and t_0= -0.22yr^{-1}; and fish length could reach 15 cm at age 0$^+$, 20.4cm at age 1$^+$, 22.9 cm at age 2$^+$, and 23.1 cm at age 3$^+$ (Figure 8a). The analysis of otolith annual rings (Figure 2b) showed that fish could reach 15.2 cm at age 0$^+$, 20 cm at age 1$^+$, 21.7 cm at age 2$^+$, and 23.1 cm at age 3$^+$ (Figure 8b). The index of average percent error of three readings was 4.65%. There were significant relationships between fish age and otolith length (Otolith length = 2767.1+680.04 Age, n=360, F = 381.55, P<0.001), width (Otolith width = 2158.2+658.56 Age, n = 360, F = 332.67, P<0.001) and weight (LogOW = 2.7566+5.2386 Age, n = 360, F = 701.62, P<0.001) in both male and female based on the regression analysis (Figure 9). The result of fish age determination by using length frequency analysis and reading annual ring on the otoliths was not significantly different (ANOVA, F=2.08, P>0.05).

Discussion

Sex Ratio

In the present study, the sex ratio of *P. serperaster* was not significantly different from the 1:1 female to male ratio. Similarly, Tran *et al.* (2007) reported that the male to female ratio of another goby (*P. elongatus*) living in Mekong Delta was also near 1:1. Moreover, the number of male and female of other gobiid species *Boleophthalmus boddarti* occupying the same habitat is also close to 1:1 (Dinh, 2014). The environmental temperature and salinity in the study of Tran *et al.* (2007) and Dinh (2014) are similar to this study, which may contribute to the relatively similar male to female ratio in the *P. serperaster*, *P. elongates* and *B. Boddarti* populations. The goby *Periophthalmodon schlosseri* in the Malaysia water also shares the same sex ratio (Mazlan and Rohaya, 2008), and the 1:1 male to female ratio is

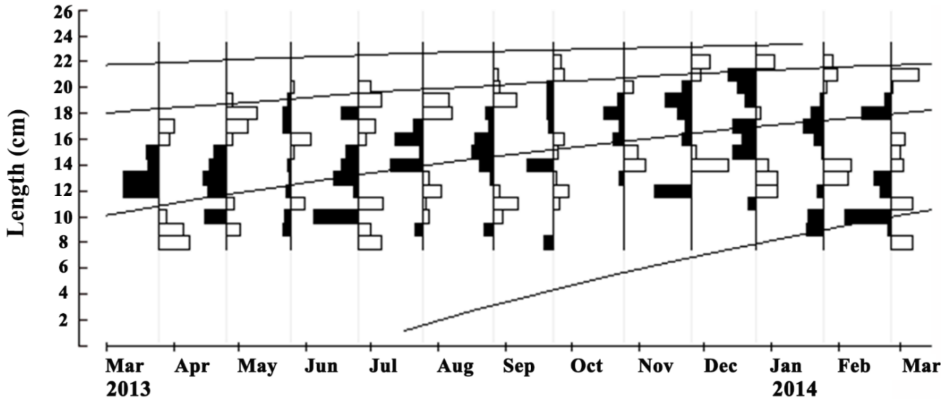

Figure 3. The von Bertalanffy fish growth curve. Black and white bars represent positive and negative deviation from the weighted average of the length classes; and curves represent fish length over time.

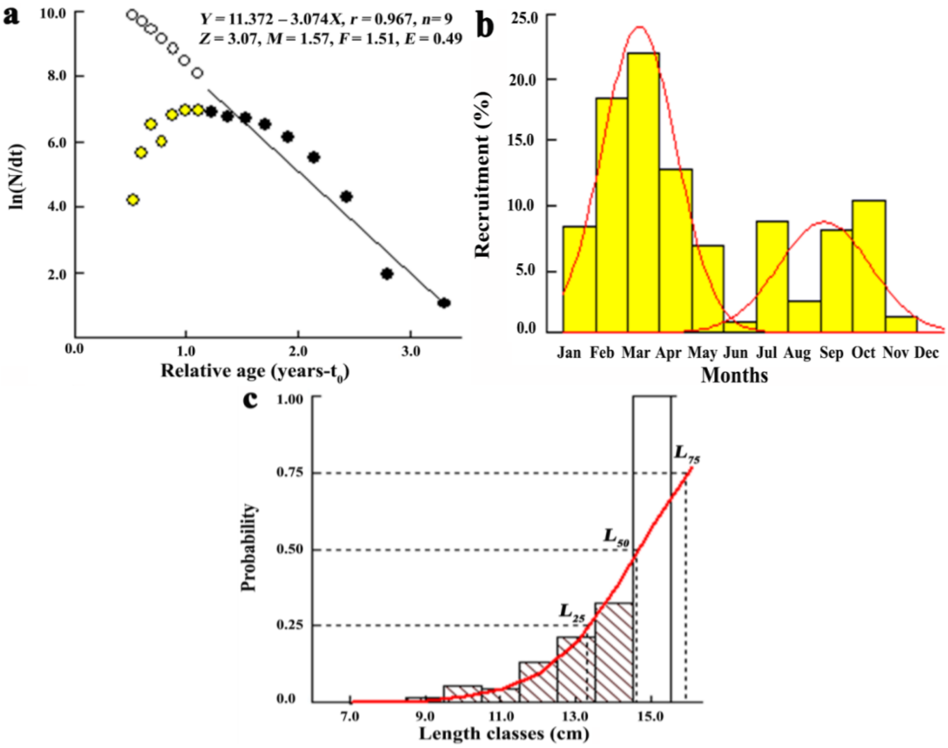

Figure 4. (a) The fish length converted catch curve(dark points: data for calculating least square linear regression; yellow points: data excluded from regression analysis; and open points: data for fish age expectation); **(b)** Recruitment pattern estimated from length frequency data; and **(c)** The probability of capture of each length class (L_{25} = 13.3, L_{50} = 14.6 and L_{75} = 15.9 cm, estimated from the logistic transform curve).

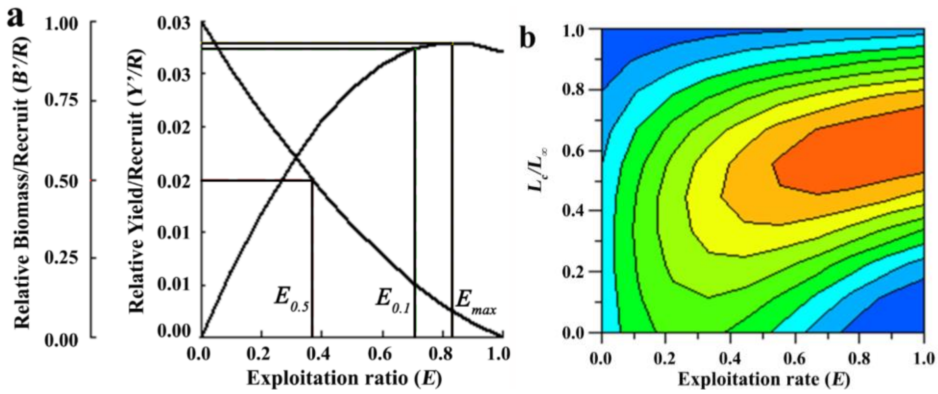

Figure 5. (a) The relative yield-per-recruit and relative biomass-per-recruit using the knife-edge procedure (E_{max} = 0.83, $E_{0.1}$ = 0.71 and $E_{0.5}$ = 0.37); and **(b)** the yield isopleths.

found in four-spotted goby *Deltentosteus quadrimaculatus* collected from İzmir Bay, central Aegean Sea (Metin *et al.*, 2011). It seems that the temperature and salinity could not regulate the sex ratio of gobiid species, corroborating the observations on most other fish species (Nikolsky, 1963).

Population Structure

Pauly (1987) suggested that the analysis on the structure of a fish population requires at least 1500 fish specimens collected over six months, and the length frequency distribution should display distinct peaks over time. The present study adopted this sampling criterion by collecting 3002 fish specimens during 12 months, and the sequentially arranged monthly abundance histograms displayed two distinct peaks in population abundance. Thus, it is reasonable to believe that that the results from such a large population size would provide a reliable dataset for the analysis of population parameters. The results from the length–frequency analysis in the present study showed the migration of two main cohort juveniles from the sea to the estuary and then to the Kinh Ba River for foraging, which is concomitant to the two spawning migration events from July to

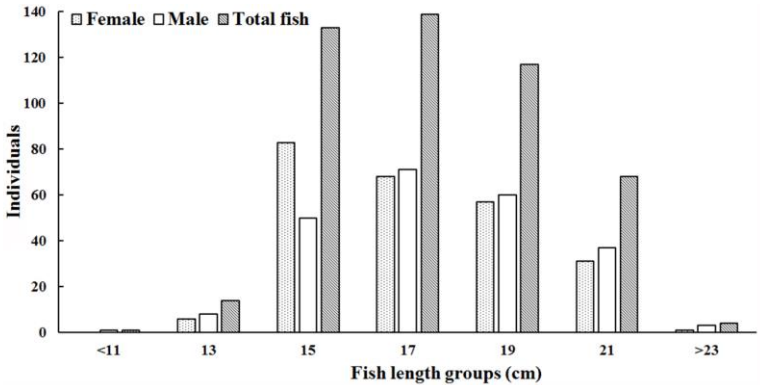

Figure 6. Length distribution of male, female and total number of fish used for aging (n = 476).

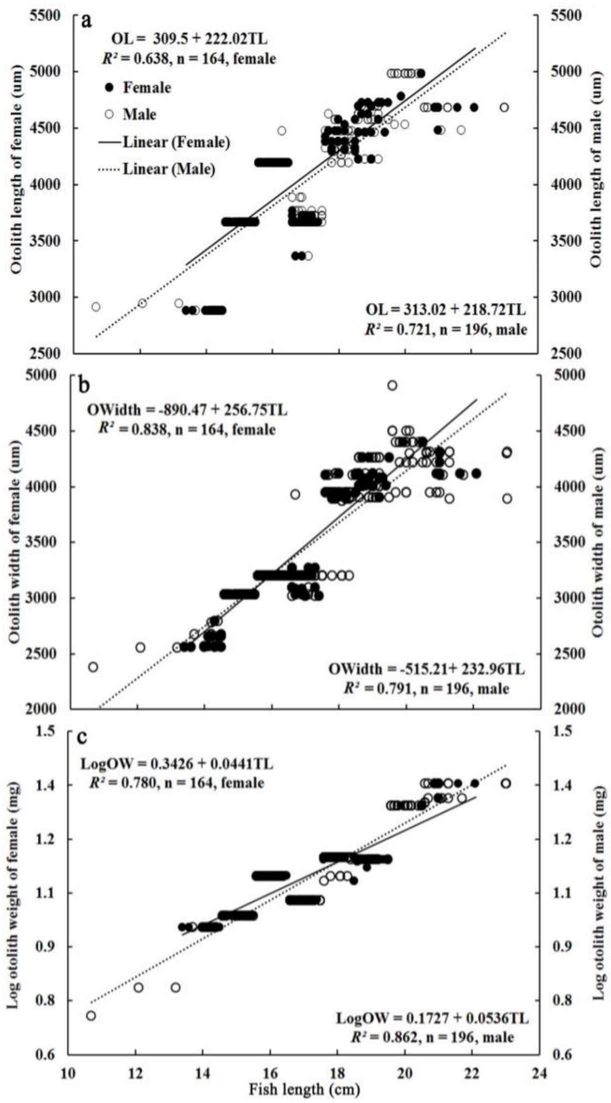

Figure 7. Relationships between total length of male and female fish from (a)otolith length (OL), (b) otolith width (OW), and (c) otolith weight (LogOW).

October during wet seasons (personal observation). Similarly, Tran (2008) also reported that *P. elongatus* juveniles move from the marine to brackish habitats for feeding, indicating that estuaries are the main nursery ground for gobies and other fish larvae.

Direct comparisons on von Bertalanffy growth parameters may not make precise biological sense as the fish growth curves are not linear and the growth rate varies with fish length and age. Therefore, the growth comparison should be made from a

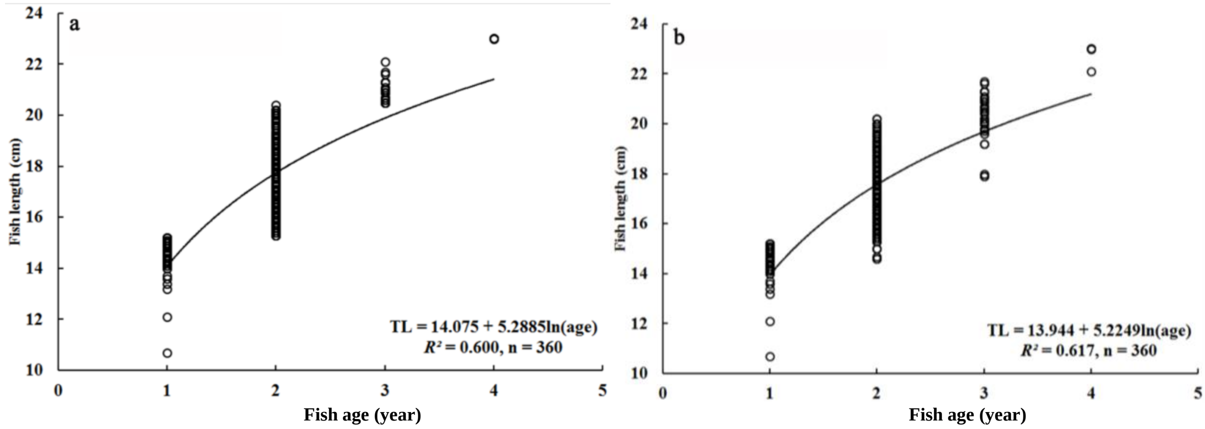

Figure 8. Relationships between fish total length and fish age obtainedfrom (a)the length-frequency analysis and (b) otolith annual ring readings.

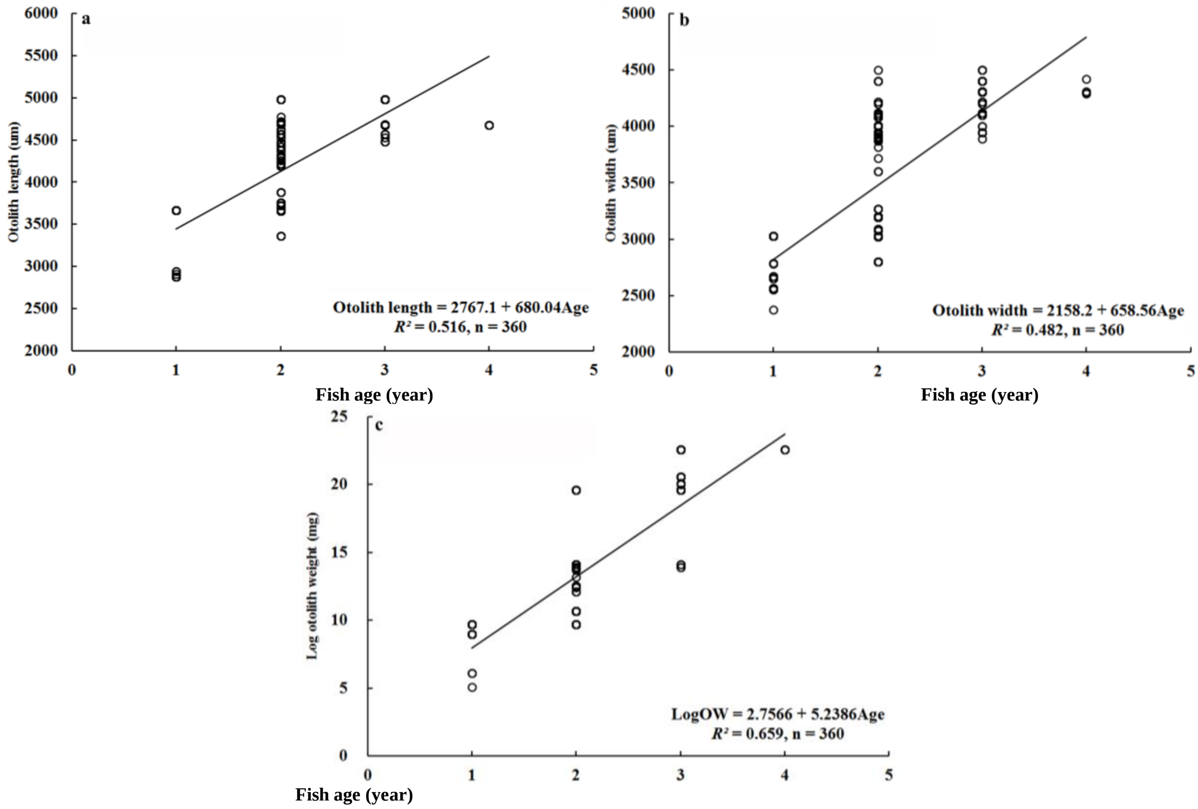

Figure 9. Relationships between fish age and (a)otolith length, (b) otolith width, and(c) otolithweight (*Log*OW).

multivariate perspective so that both fish asymptotic length (L_∞) and growth parameters (K) are considered, and growth performance index (*Φ'*)is used for growth comparison between fish species (Pauly and Munro, 1984; Tran *et al.*, 2007; Etim *et al.*, 2002). Besides, when comparing growth parameters between different tilapia populations, Moreau *et al.* (1986) used another growth index $\omega = KL_\infty$ for growth comparison, but found that the growth performance index (*Φ'*)is the best growth index as it exhibits the least degree of variation. The growth parameter *Φ'* is species-specific, i.e., its values are usually similar within the related taxa and have narrow normal distributions (Tran *et al.*, 2007).The *Φ'* value of *P. serperaster* was higher than its neighbour species *Pseudapocryptes elongatus* and other gobiid species, except for *P. schlosseri* (Table 2). The differences in L_∞ and K indices between these species could lead to the variation of *Φ'*, and it seems that a longer fish may lead to a greater value of the growth index.

The fishing mortality (F) of *P. serperaster* was slightly lower than that of the natural mortality (M), suggesting that its population has been under exploited. However, the mortalities including total mortality (Z) of this goby are slightly higher (Z = 3.07 yr^{-1}, M = 1.57 yr^{-1} and F= 1.51 yr^{-1}) than the

Pseudapocryptes elongates goby in the same area (Z=2.91 yr^{-1}, M = 1.44 yr^{-1} and F= 1.47 yr^{-1}) as the commercial fishing activity for *P. serperaster* has been recently increased. The two annual recruitment peaks of the *P. Serperaster* population indicate that this goby can spawn more than once per year, matching the two recruitment peaks of the goby *Pseudapocryptes elongates* (Tran *et al.*, 2007). However, the length at first capture (L_c = 14.60 cm) in *P. serperaster* was greater than that in *P. elongates* (12.85 cm), implying that the *P. serperaster* is less exploited than *P. elongatus*. The *P. serperaster* stock has not been subjected to overfishing as the exploitation rate of this goby (E= 0.49) is less than the maximum exploitation rate (E_{max}=0.83). Furthermore, fish were fully exploited below the length at first maturation in both sexes (15.63 cm for male and 15.9 for female, unpublished PhD thesis data).

Pauly and Soriano (1986) used four-quadrant models to describe fish yield related to fish size. Quadrant A represents under fishing where the ratio of fish length at first capture (L_c) to the asymptotic length (L_∞)is 0.5-1, and the exploitation rate(E)is 0-0.5. Quadrant B represents eumetric fishing where L_c/L_∞= 0-0.5 and E = 0-0.5. Quadrant C represents developed fishery where L_c/L_∞= 0.5-1, and E = 0.5-1. Quadrant D represents overfishing where L_c/L_∞= 0-0.5, and E = 0-0.5. In comparison, the fish yield isopleths of this goby belong to quadrant A as the ratios between the length at first capture (L_c) and the asymptotic length (L_∞) was 0.57 and the exploitation rate (E) was 0.49. Therefore, the population of this goby has not been overexploited and the current use of fishing gears is suitable to sustain the population growth of this goby species. Although the fish stock of *Pseudapocryptes elongatus* has not reached the point of overexploitation, more small fish were caught in the study of Tran *et al.* (2007)as the yield isopleths L_c/L_∞ (0.45) and E (0.51) belong to the quadrant D.

The longevity of *P. serperaster* in this study was quite high (4.05yr) and the age at first maturity was one year old. Comparing to other gobies, the maximum life span of *P. serperaster* is slightly shorter than that of *P. elongates* (4.55 yr) (Tran *et al.*, 2007), but is longer than *P. schlosseri* (2.14 yr) (Mazlan and Rohaya, 2008) and *Gobius vittatus* (2.94 yr) (Kovačić, 2007). The variation of longevity among gobies could be due to geographic latitude, predation and fishing activities.

Otolith Dimensional Morphometry and Age Determination

In the present study, the left otolith was used to determine fish age. The positive relationships between fish total length (TL), otolith length (OL), width (OW) and weight ($\log_{10}$ of otolith weight, LogOW) suggest that the otolith can be used to determine the age of tropical fish such as *P. serperaster*. Similarly, Matic-Skoko *et al.* (2011) and Pilling *et al.* (2003) also found that the above three variables for otolith dimensional measurements in both *Phycisphycis* (Gadidae) and *Lethrinus mahsena* showed positively close relationships with fish length. Moreover, the utilization of otolith dimensional measurements has been successfully used on other fish species such as *Melanogrammus aeglefinus* (Cardinale and Arrhenius, 2004), *Gadusmorhua* and *Pleuronectes platessa* (Cardinale *et al.*, 2000). Therefore, the growth rings on the otolith can be used as a quick, easy and reliable method for age determination on tropical fishes.

The ages of *P. serperaster* derived from the length-frequency distribution and otolith annual ring readings were similar, indicating that length frequency analysis can be used as an alternative for fish age determination on this goby, though length distribution was not recommended for age determination on older and slow growing fishes (Campana, 2001). Similarly, length-frequency distribution is also successfully used to determine the age of *Pseudapocryptes elongates* (Tran, 2008) possibly due to the short life span of fish and fast growth. In the present study, the method of using annual rings on the otolith for age determination was applied successfully for *P. serperaster*, a tropical goby fish. Likewise, this method was applicable for the age determination on *P. elongates*, another tropical fish living in the same habitat as *P. serperaster* (Tran, 2008). However, when a large number of specimen are available, the method of length frequency should be first considered for age determination as it does not require tedious preparation and treatment of otoliths for small and short life goby species.

In the use of otolith for age determination, the index of average percent errors (*IAPE*) was 4.65% in this study, which is less than the threshold value (5%) recommended by Beamish and Fournier (1981), suggesting that the result of three readings on the growth rings on the otolith is reliable. This index

Table 2. The von Bertalanffy growth parameters and growth-performance index for various gobiid species

Species	Φ'	L_∞ (cm)	K (yr^{-1})	Source
Periophthalmodon schlosseri	3.01	29	1.44	Mazlan and Rohaya (2008)
Periophthulmus papilio	2.28	19.39	0.51	Etim *et al.* (1996)
Periophthalmus barbarus	2.41	21.6	0.55	Etim *et al.* (2002)
Pseudapocryptes elongatus	2.64	26	0.65	Tran *et al.* (2007)
Parapocryptes serperaster	2.67	25.2	0.74	This study

(*IAPE*) was used as the principal index for comparing the results of otolith annual ring determination within a reader or between readers. For example, Matic-Skoko *et al.* (2011) apply this index for comparing the reliability between two readers and two reading times for age determination on *Phycisphycis* (Gadidae); Newman *et al.* (2000) used the *IAPE* to test the precision of age estimates for *Lutjanus erythropterus*, *L. malabaricus* and *L. sebae*; and this index is also used by Tran (2008) to examine the age precision on the goby *P.elongatus*.

In addition, the results of aging on this goby with the length-frequency method and reading annual rings on the otoliths were similar, suggesting that the length-frequency can also be used for age determination on tropical fish species. This study shows that despite a similar annual temperature condition in the growing area of this *P. serperaster*, growth rings can still be used for fish age determination. The development of a reliable tool to measure the age and length relationships is useful for fishery management and future aquaculture planning of this goby species.

In conclusion, the sex ratio of *P. serperaster* was close to 1:1 and its stock was high in population recruitment and was not over exploited in the Mekong Delta. Otolith measurements can be used for age determination for both male and female gobies. The use of length-frequency distribution of a large sample size validated the result of age determination using otolith. The age and growth relationships can be used to determine the proper size of fish at catch and manage the sustainable fishery in trophic areas.

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