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Population Biology of the Goby *Pseudapocryptes elongatus* (Cuvier, 1816) in the Coastal Mud Flat Areas of the Mekong Delta, Vietnam

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Abstract

The goby, *Pseudapocryptes elongatus*, is an amphibious fish and common in the coastal mud flat areas of the Mekong Delta, Vietnam. The fish population was examined to obtain the information required for sustainable use and aquaculture development. Length frequency data of the fish ranging from 9.0 to 24.0 cm total length were analyzed using the FiSAT II software. The parameters of von Bertalanffy growth function fit to the length frequency data were L_∞ = 26 cm, K = 0.65 yr^{-1}, and t_o = - 0.26 yr^{-1}. The longevity (t_{max}) was 4.35 yrs. There were two recruitment peaks with very different magnitudes and the means of the two peaks were separated by an interval of 5 months. Length at first capture (L_c) was 11.75 cm. The fishing mortality (F = 1.47 yr^{-1}) and natural mortality (M = 1.44 yr^{-1}) accounted for 51 and 59% of the total mortality (Z = 2.91 yr^{-1}), respectively. Relative yield-per-recruit and biomass-per-recruit analyses gave E_{max} = 0.74, $E_{0.1}$ = 0.61 and $E_{0.5}$ = 0.35. The breeding season was extended during the rainy season, with the spawning peaks in July and October. Length at first maturity (L_m) was estimated at 15.4

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and 16.3 cm for females and males, respectively. The batch fecundity estimates ranged from 2,652 to 29,406 hydrated oocytes per ovary in the fish specimens ranging from 12.8 to 22.4 cm total length. Results show that the fish stock is subjected to growth overexploitation.

Introduction

The goby, *Pseudapocryptes elongatus* (Cuvier 1816, Gobiidae), is distributed in the Indo-Pacific region and is common in the Mekong Delta, Vietnam (Weber and De Beaufort 1953; Mohsin and Ambak 1996; Rainboth 1996; Froese and Pauly 2006). This gobiid species resides in muddy localities and also in burrows situated in mud flats of the estuarine areas (Murdy 1989; David 1993). In the Mekong Delta, the highest number of gobiid species is found in the estuarine areas (Matics 2000). The goby *P. elongatus* is a commercially important species for food, especially in Japan, Taiwan and Vietnam (Ip et al. 1990; Dinh et al. 2004). Thus, this species is presently cultured in semi-intensive and intensive farming systems in the Mekong Delta. However, the seeds are collected only from the wild and not enough for aquaculture because of the rapid development of aquaculture and depletion of the fish stocks.

The Gobiidae consists mainly of small, benthic fishes that occupy estuarine habitats in tropical and subtropical waters (Chotkowski et al. 1999). The estuarine habitats are ecologically dynamic and productive areas used by many estuarine-dependent species for reproduction (Blaber et al. 1995). Most of the fishes in tropical estuaries spawn and complete their life cycle within the estuarine environment (Blaber 2000). Nearly all gobies produce demersal eggs and a highly variable number of spawning per season (Miller 1984). Despite the fact that the gobies are the largest family of fishes, almost nothing is known of the reproduction of most species (Blaber 2000).

The goby *P. elongatus* has been studied on the ecology (Das 1933 & 1934; Cees et al. 1995), food habits and feeding apparatus (Sarker et al. 1980; Cees et al. 1995), morphology (Amrendra and Singh 1989) and length-weight relationship (Khaironizam and Rashid 2002). However, there is no published work on the fish population dynamics of this species, especially in the Mekong Delta where this fish is common. In addition, only one study on the reproductive biology of this species in the Gangetic Delta is reported by Hora (1936), but the author did not give enough evidence concerning their statements (cited by Charles and Donn 1966).

Therefore, this study was carried out to determine the population parameters and reproductive biological characteristics of the goby *P. elongatus* in the coastal mud flat areas of the Mekong Delta.

Materials and Methods

Between January 2004 and June 2005, length frequency data of the goby were collected monthly in the coastal mud flat areas of the Mekong Delta, South of Vietnam (Fig. 1). The fish species was caught using the fixed-bag nets with a codend of 15 mm mesh size. The length frequency data were analyzed using FiSAT II software for the estimation of the fish population parameters (Gayanilo et al. 1996 & 2006). The Beverton and Holt length-based Z-equation is expressed as the linear regression equation

$$\overline{L} = L'a + bL$$

where, L' is cut off length, i.e. a length not smaller than the smallest length of fish fully represented in catch samples, $\overline{L}$ is mean of all fish $\geq L'$, and $\overline{L} = (L_\infty + L') / [(1+ (Z/K)]$. From the linear regression equation, the preliminary asymptotic length (L_∞) was calculated as (a/b) and Z/K as $-(1 + b)/b$ (Powell 1979; Wetherall 1986; Pauly and Soriano 1986). The ELEFAN procedure contained in the FiSAT II was used to arrange and restructure length frequency data. Then, they were fitted to the von Bertalanffy growth function (Pauly and Gaschutz 1979):

$$L_t = L_\infty\{1 - \exp[-K(t - t_o)]\}$$

where, L_t is a mean length at age t (year), L_∞ is asymptotic length, K is growth coefficient, and t_o is the hypothetical starting time at zero length. The age at length zero (t_0) was obtained using the empirical equation by Pauly (1979):

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

For comparison of the von Bertalanffy growth parameters, the index of overall growth performance was calculated from the formula given by Pauly and Munro (1984) as $\Phi' = \log K + 2 \times \log L_\infty$. Longevity ($t_{max}$) was calculated from the relationship: $t_{max} = \dfrac{2.997}{K} + t_o$ (Taylor, 1958).

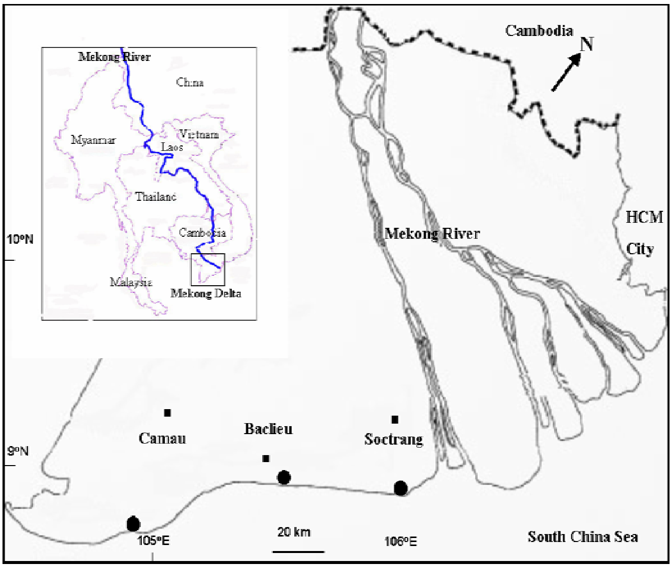

Fig. 1. Map showing three sampling sites (●) along the southeast coast of the Mekong Delta, South of Vietnam

Total mortality rate (Z) was determined using the length-converted catch curve (Pauly 1990; Pauly et al. 1995). The natural mortality rate (M) was estimated using the empirical model of Pauly (1980):

$$\log M = -0.0066 - 0.279 \times \log L_\infty + 0.6543 \times \log K + 0.463 \times \log T \ ;$$

where, L_∞ is expressed in cm (*TL*) and T is the mean annual surface water temperature (in ^{o}C) which was measured monthly using a mercury thermometer. The temperature fluctuated from 28.5 to 31.5 ^{o}C (29.8 ^{o}C ± 0.86). The attainment of reasonable estimates of Z and M could lead to an accurate estimate of fishing mortality (F) based on the equation $F = Z - M$. The exploitation ratio (E) was then defined as $E = F/Z$ (Ricker 1975). The method of Pauly (1987) was used to analyze the probability of capture for each size class using length-converted catch curve. The seasonal recruitment pattern of the fish species was reconstructed using the entire restructured length-frequency data set. This involved projecting backward, along a trajectory described by the computed von Bertalanffy growth function. Then using the maximum likelihood approach, the Gaussian distribution was fitted to the back-projected data through NORMSEP procedure (Hasselblad 1966).

The yield per recruit model (Beverton and Holt 1957) is a principal steady state model that describes the state of the stock and the yield in a situation when fishing pattern has been the same for a long time so that all fish are vulnerable to capture after recruitment (Sparre et al. 1989). The model, as modified by Pauly and Soriano (1986), was used to predict the relative yield-per-recruit (Y'/R) and biomass-per-recruit (B'/R) of the goby to the fishery as follows:

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

and

$$B'/R = (Y'/R)/F\ ;$$

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

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

The exploitation ratio (*E*) was compared with: i) the exploitation ratio which produces maximum yield (E_{max}), ii) the exploitation ratio at which the marginal increase of *Y'/R* is 10% ($E_{0.1}$), and iii) the exploitation ratio at which the stock is reduced to 50% ($E_{0.5}$). The yield isopleths diagram was used to assess the impact on yield created by changes of exploitation ratio (*E*) and the ratio of length at first capture to asymptotic length (L_c / L_∞).

On the other work, the fish specimens were also monthly sampled to determine the reproductive biological characteristics. A total of 886 *P. elongatus* specimens ranged from 9.6 to 23.1 cm *TL* were measured to the nearest mm for total length (*TL*), and 0.01 g for body (*BW*), visceral (*VW*) and gonad weight (*GW*). The ovarian development was classified into five stages according to the scale of maturity proposed by Vesey and Langford (1985) for *Gobius niger*. Gonadosomatic index (*GSI*) was determined as [*GW*/(*BW*–*VW*)]*100. Based on the fraction of mature specimens per length class, the maturity curve was estimated adjusting the simple logistic model (Zar 1999) expressed by

$$P = \frac{1}{1+\exp[-(\beta_0+\beta_1 L)]}$$

where, *P* is the proportion of mature specimens at length class *L*, β_0 and β_1 are model parameters. Then, the length of fish at which 50% of fish attain sexual maturity (*P* = 0.5) was determined to be $L_m = -\beta_0/\beta_1$ for both sexes. The dimensionless L_m/L_∞ ratio, which is expressed as the proportion of the potential growth span of the fish before maturation, was determined for both male and female (Beverton 1992). Length at maximum possible yield per recruit (L_{opt}) was determined using the empirical equation revealed by Froese and Binohlan (2000):

$$\log L_{opt} = 1.053 \times \log L_m - 0.0565 .$$

The whole mature ovary was placed in Gilson's fluid and periodically shaken to release oocytes from the ovarian tissue. The batch fecundity (F) was estimated as a number of hydrated oocytes in each ovary using the volumetric subsampling method (Bagenal and Braum 1978):

$$F = (V/V')\, n$$

where, V is a volume of sample, V' is a volume of sub-sample, and n is a number of hydrated oocytes in sub-sample. The relationship between the batch fecundity (F) and total length (TL) was described using simple standard regression. A power model was fitted to the relationship of F and TL.

Results

The length frequency data of 9,435 fish specimens ranged from 9 to 24 cm total length were analyzed using the Powell-Wetherall procedure and gave an initial L_∞ of 24.99 cm and Z/K of 3.356. The initial L_∞ was fitted into ELEFAN I to determine the optimized von Bertalanffy growth curve. Results show that the von Bertalanffy growth curve was obtained with the following parameters: L_∞ = 26 cm, K = 0.65 yr^{-1}, and t_0 = - 0.26 yr. The growth curves superimposed over the length frequency data are presented in figure 2. The index of growth performance was calculated to be Φ'= 2.64. Longevity was also estimated to be 4.35 yr.

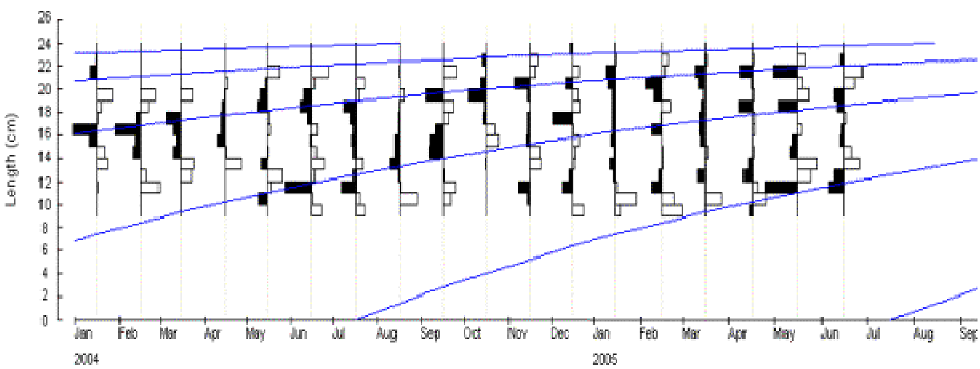

Fig. 2. The von Bertalanffy growth curve of *Pseudapocryptes elongatus* superimposed over reconstructed length frequency data (n = 9,435) collected in the Mekong Delta

Total mortality based on the length converted catch curve (Fig. 3) gave a value of Z = 2.91 yr^{-1} (intercept: a = 13.63, slope: b = -2.906, r = 0.994, n = 5, confidence interval of Z: 2.5–3.31 yr^{-1}). The natural mortality and fishing mortality rates were determined to be M = 1.44 yr^{-1} and F = 1.47 yr^{-1}, respectively; thus, the exploitation ratio was E = 0.51. Recruitment pattern was demonstrated with a graph that displays variation in intensity of recruitment with time. The result shows that there were two recruitment peaks with very different magnitudes, but the recruitment was continuous between these peaks (Fig. 4). The means of the two pulses were separated by an interval of 5 months. The analysis of probability of capture indicated that the length at first capture (L_c or L_{50}) was 11.75 cm (Fig. 5).

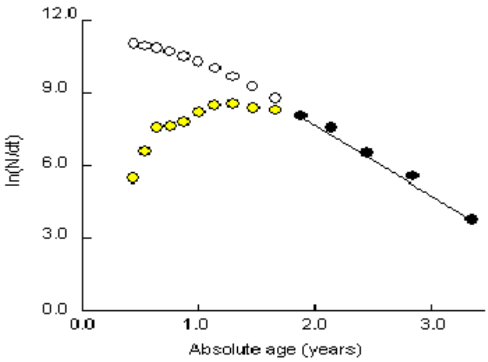

Fig. 3: The length converted catch curve for *Pseudapocryptes elongatus*. Regression equation: Y = 13.63 – 2.906X, r = 0.99, n = 5 (●: Points used; ○: Points not used).

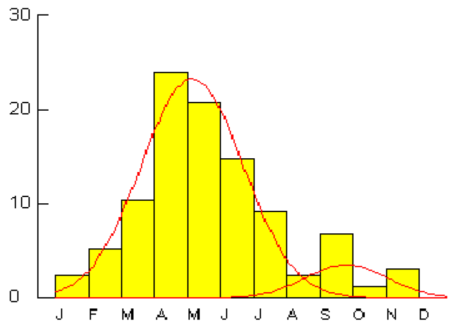

Fig. 4. Recruitment pattern of *Pseudapocryptes elongatus* in the coastal mud flat areas of the Mekong Delta estimated from length frequency data obtained from January 2004 to June 2005

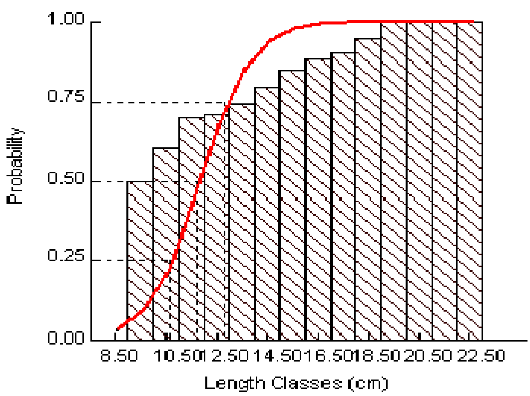

Fig. 5. The probability of capture of each length class of *Pseudapocryptes elongatus* (L_{25} = 10.65, L_{50} = 11.75, L_{75} = 12.85 cm) by using fixed-bag net with codend of 15 cm mesh size.

In the present study, the analyses of yield-per-recruit and biomass-per-recruit with the assumptions of knife-edge selection, that only fish of lengths $\geq L_c$ are recruited by the gear, gave the summary statistics as follows: $E_{max} = 0.74$, $E_{0.1} = 0.61$ and $E_{0.5} = 0.35$ (Fig. 6). The yield isopleths were used to predict the response of relative yield-per-recruit of the fish species to changes in L_c and E (Fig. 7). The yield contours usually consist of four quadrants (Pauly and Soriano 1986); in the present study, yield isopleths with $L_c / L_\infty = 0.45$ and $E = 0.51$ belong to quadrant D, which implies that small fish species were caught at high effort level.

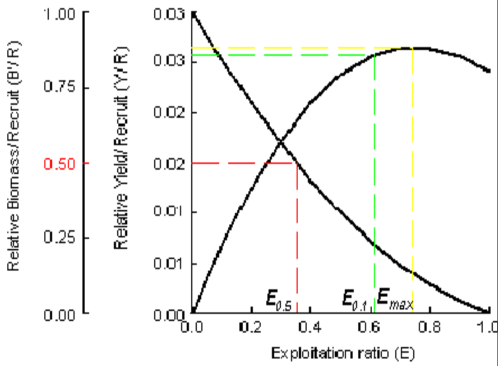

Fig. 6. The relative yield-per-recruit and relative biomass-per-recruit for *Pseudapocryptes elongatus* using the knife-edge procedure ($E_{0.5}$ = 0.351, $E_{0.1}$ = 0.613, E_{max} = 0.741)

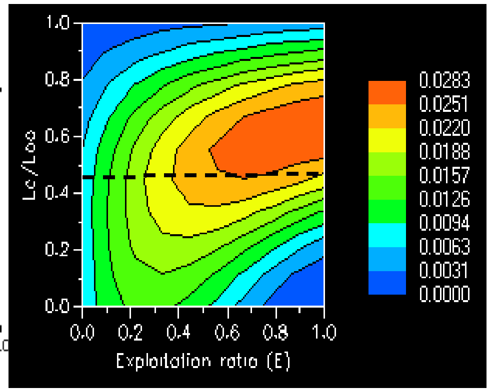

Fig. 7. The yield isopleths for *Pseudapocryptes elongatus.* The yield contours predict the response of relative yield-per-recruit of fish to changes in L_c and E. The dotted link is the actual computed critical ratio L_c / L_∞=0.45

The highest *GSI* values were recorded between July and October for females, and between July and November for males (Fig. 8). Results showed that the *GSI* values of females were higher than those of males. The result indicated that the breeding season may occur during June-November with two spawning peaks in July and October.

In determining length at first maturity (L_m), the proportions of maturity for 379 female and 445 male specimens were obtained. Thus, the model parameters estimated were β_0 = -125.35, β_1 = 8.14 ($p < 0.01$) for females; and β_0 = -130.05, β_1 = 7.96 ($p < 0.01$) for males. Therefore, the length at first maturity (L_m) was determined at 15.4 cm and 16.3 cm for females and males, respectively (Fig. 9). The dimensionless L_m/L_∞ ratio was also obtained to be 0.59 and 0.63 for females and males, respectively. Furthermore, the length at maximum possible yield per recruit (L_{opt}) was determined to be 15.6 for females and 16.6 cm for males.

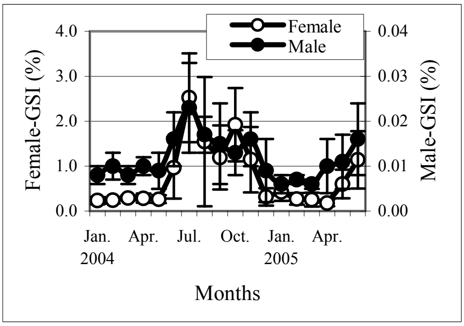

Fig. 8. Seasonal variations in gonadal-somatic index (GSI) of female and male *Pseudapocryptes elongatus* in the Mekong Delta

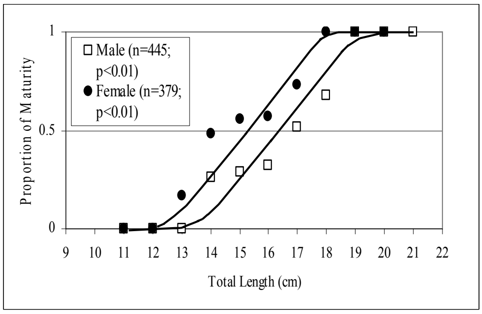

Fig. 9. Proportion of mature *Pseudapocryptes elongatus* by 1 cm total length intervals, fitted to a logistic function, L_m = 15.4 cm (n = 379; p < 0.01) for females and L_m = 16.3 cm (n = 445; p < 0.01) for males.

The batch fecundity estimates ranged from 2,652 to 29,406 hydrated oocytes per ovary in the fish specimens ranging from 12.8 to 22.4 cm *TL*. The mean fecundity was 15,608 (S.E. = 2,478) hydrated oocytes per ovary and the mean total length was 17.9 cm. The relationship between total length (*TL*) and batch fecundity (*F*) was $F = 0.1517 \times L^{3.9757}$ (R^2 = 0.727; n = 48) (Fig. 10), in which L is total length in cm.

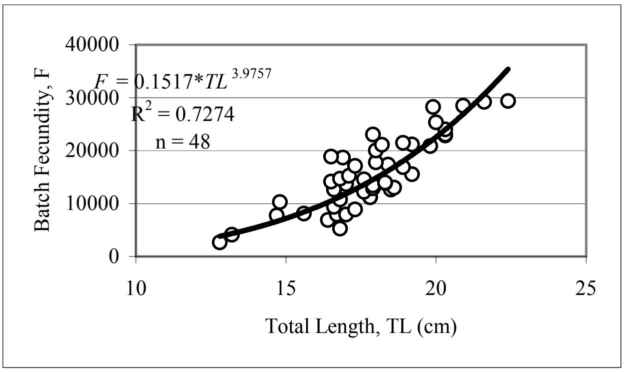

Fig. 10. The relationship between total length (*TL*) and batch fecundity (*F*) of *Pseudapocryptes elongatus* in the Mekong Delta

Discussion

Mekong River is one of the largest rivers in the Southeast Asia; great volumes of sediment are carried towards the coastal areas of the Mekong Delta during the rainy season. Therefore, the estuarine ecosystem provides a habitat for a variety of wildlife species, as well as spawning grounds for fish (Nedeco 1993). In the present study, the high *GSI* values of the goby were determined from June to November in both sexes. Therefore, these results show that the breeding season of the goby occurs from June to November, nearly during the rainy season (April - November) in the Mekong Delta, with two spawning peaks in July and October. This result also agreed with the recruitment pattern which showed two recruitment peaks with an interval of about 5 months.

In the present study, the *GSI* values of female were higher than those of male, which probably contributes towards the heavier mature females when compared to mature males. This result agrees with that of Kader et al. (1988) study on reproductive biology of *Gobioides rubicundus*. The authors showed that the *GSI* values of females in mature stages ranged from 1.031 to 2.8879 which were also higher than those of males (ranged from 0.01 to 0.0482). The spawning periods of the male was extended from late January to early February and from late June to early October while those of the female extended from late January to early February and from late August to early September. Those results also indicated that *Gobioides rubicundus* spawns two times per year.

In the Gangetic Delta, *P. elongatus* breeds just before the beginning of the southwest monsoon during the rainy season, i.e. from July to September (Hora 1936 as cited by Charles and Donn 1966). Miller (1984) and Blaber (2000) also stated that nearly all gobies are multiple-spawners; they breed throughout or most of the year, often a wet season. In goby *Aphia minuta*, the breeding season is quite long and that spawning takes place at least twice during its short lifespan (Caputo et al. 2003). *Acentrogobius masago* (Tomiyama) spawn on sandy mud bottoms near Kyushu from May to September; meanwhile, *Acentrogobius reichei* (Bleeker) spawns before the monsoon season, in October and November (Charles and Donn 1966). During the breeding season, *Gobius minutus* can spawn at least three batches of eggs (Healey 1971). The fecundity of gobiids varies widely among and within species, ranging from less than 100 eggs in *Eviota lacrimae* to over 500,000 eggs in *Awaous guamensis* (Ha and Kinzie 1996).

The length at first maturity (L_m) is an important management parameter used to monitor whether there is enough juveniles in an exploited stock (Ault et al. 1998). The length at first maturity (L_m) is also related closely to the asymptotic length (L_∞) and would be very interesting to assess the proportion of the growth span of a species before maturation by using the dimensionless L_m/L_∞ ratio (Pauly 1984; Beverton 1992; Froese and Binohlan 2000). Beverton (1992) stated that the L_m/L_∞ ratio range from 0.4 to 0.88 and the sex differences in the L_m/L_∞ ratios are much less pronounced and are probably insignificant. In the present study, the L_m/L_∞ ratio of female and male was not significantly different and fell within the range suggested by Beverton (1992). The length at maximum possible yield per recruit (L_{opt}) was also slightly higher than the length at first maturity (L_m) in both sexes. In addition, Beverton (1992) stated that the small and short-lived fishes with high mortality rates, the starting maturity at maximum biomass ($L_m \approx L_{opt}$) would maximize egg production at the first spawning season.

According to Pauly (1987), in order to obtain true estimates of growth and other fisheries parameters, the reliability of length frequency data must be ascertained. Firstly, a minimum sample size of 1,500 fish specimens collected over a period of at least six months is adequate. Secondly, the sequentially arranged length frequency data should display distinct peaks with an apparent shift in modal length over time. In the present study, a total of 9,435 fish specimens were collected over a period of 18 consecutive months, and the sequentially arranged monthly histograms displayed distinct peaks. Therefore, the length frequency data in the present study met both prescribed criteria; and the data were analyzed using FiSAT II software to determine the fish population parameters.

The growth curves of fish are not linear, thus direct comparison of growth parameters is not biologically possible. Therefore, growth comparison must be approached from a multivariate perspective in which both L_∞ and K are taken into consideration. A comparison of growth performance of the goby *P. elongatus* with other gobiid species is given in table 1. The growth performance index (Φ') is a species-specific parameter, i.e. its values are usually similar within the related taxa and have narrow normal distributions. Moreau et al. (1986) stated that the gross dissimilarity of Φ' for a number of stocks of the same species or related species is an indication of unreliability in the accuracy of estimated growth parameters. The coefficient of variation of 9.35% together with other measures of dispersion (range = 0.59, variance = 0.05, standard deviation = 0.22 and mean = 2.3) for Φ' values in table 1 is low. However, the Φ' in this study is higher than in the other studies. This may be because of the long caudal fin of the goby as compared with that of the other gobiid species. Cees et al. (1995) also reported that this species has the longest caudal fin in relation to its total length (20 % *TL*).

Table 1. The von Bertalanffy growth parameters (L_∞ and K) and growth-performance index (Φ') for various gobiid species

Species	Φ'	L_∞ (cm)	K (yr^{-1})	Source
Gobius niger (male)	2.1	11.7	0.91	Vesey and Langford (1985)
Gobius niger (female)	2.32	15.1	0.91	Vesey and Langford (1985)
Gobio gobio	2.05	10.6	0.99	Bowker, (1996)
Periophthulmus papilio	2.28	19.39	0.51	Etim et al. (1996)
Perriophthalmus barbarus	2.41	21.6	0.55	Etim et al. (2002)
Pseudapoctyptes elongatus	2.64	26	0.65	This study

The current exploitation ratio (E) of the fish stock is less than the maximum exploitation ratio (E_{max}). Results show that the fish stock is not overexploitation. However, the yield isopleths with L_c /L_∞ = 0.45 and E = 0.51 belong to quadrant D, which implies that small fish species were caught at high effort level (Pauly and Soriano 1986). Furthermore, the fish was fully exploited below the length at first maturation in both sexes. Therefore, these results indicated that although the fish stock is not over-exploited, the growth of this species is over-exploited. The results suggested that the codend of 15 mm mesh size of the fixed-bag nets should be increased and the fishing efforts in the fishery should also be managed.

The research areas are managed under traditional ownership by an adjacent community group and the fish stock is regarded as a common resource. Therefore, increase in mesh size of the fishing gear and reduction in fishing effort may be difficult to implement, and can probably only be considered if management of the fishery is devolved to the local communities. Furthermore, the difficulties involved in managing a fisheries resource are also related to the number and types of user groups (Jentoft 1989). Hence, the community-based co-management approach should be applied to the fishery for sustainable development of the habitats and fish stock; because this approach focuses not only on resource management, but also on community and economic development (Pomeroy and Viswannathan 2003).

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