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Population Biology of Korean Pomfret *Pampus echinogaster* (Basilewsky, 1855) (Perciformes: Stromateidae) on the Western Coast of Korea, Yellow Sea

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Abstract: Investigations were made on population biology of *Pampus echinogaster* (Basilewsky, 1855) in the coastal areas of Korea, Yellow Sea, between August 2005 and July 2006. Population structure was not significantly different between male and females. Monthly variation of gonadosomatic index (GSI) of both sexes defined spawning period extending from March through July. A similar pattern was also observed in change at maturity stages. For males and females GSI was positively correlated with hepatosomatic index (HSI). Fecundity, ranging from 41,250 to 103,610 eggs, was related to body size, indicating that body size is the useful determinant of fecundity. The sexual maturity (L_{50}) was estimated as 14.98 cm TL for males and 19.32 cm TL for females. Parameters of growth estimated by the modified von Bertalanffy growth function model showed that the values of L_∞ and K for combined data were 39.12 cm TL and 0.65 yr^{-1}. The growth performance index of this study (2.75) was higher than that of the previous study (2.45). This difference could be attributed to sampling method. The recruitment patterns indicated one normally distributed group. Percentage of the recruitment was 51.04% in the spawning season and the highest in August (19.78%).

Key words: *Pampus echinogaster*, population biology, spawning period, sexual maturity, growth, recruitment pattern, Yellow Sea

INTRODUCTION

The Korean pomfret, *Pampus echinogaster* (Basilewsky, 1855) is common in the coastal waters of the Yellow Sea and East China Sea (Lee, 2004). As a specialized feeder eating mainly planktonic shrimps (*Acetes chinensis*

Hansen, 1919 and *Acetes japonicus* Kishinouye, 1905), copepods, hydromedusae, salps, S*agitta* and other fishes (Huh, 1989), it plays a key role in food chain of the pelagic ecosystem in the coastal waters. *P. echinogaster* has also been intensively exploited by Chinese, Korean and Japanese fishermen. Thus, increased fishing effort has resulted in almost all major stocks being fully fished by the mid-1970s and over-fished by the 1980s (Zhang and Kim, 1999). Similarly, in Korea an annual mean yield of the combined two stromateid fish, *Pampus argenteus* (Eupherasen, 1788) and *Pampus echinogaster* has dramatically declined from 106,615 t in 1980s (1981~1990) to 7,526 t in recent years (2001~2004) (NFRDI, 2005).

Despite its ecological and economic importance (Abe and Kosakai, 1964), little investigations have been carried out on biological and ecological aspects of *P. echinogaster*. Some studies described morphological characters (Abe and Kosakai, 1964; Kim and Han, 1989). Examinations on gonad maturation and spawning were made on the basis of gonadosomatic index (GSI) and ovarian development (Lee and Jin, 1989; Yamada et al., 2007). Growth was studied by increment of annual rings using the vertebral centrum (Kang et al., 1989) and otoliths (Yamada et al., 2007), and feeding habitats examined (Huh, 1989). However, most of these studies are based on the larger samples caught selectively by commercial vessels to meet market demand. This biased sampling could lead to inappropriate understanding on reproductive biology and lack of information on population dynamics, which impedes proper stock assessment and management of *P. echinogaster* in the Yellow Sea. Therefore, the purpose of the present study is to investigate the population dynamics and reproduction of *P. echinogaster* which is important for an adequate stock management and potential future commercial exploitation of this species.

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This study investigates size at sexual maturity, sex ratio, fecundity and reproductive aspects based on observations of gonadosomatic index (GSI), hepatosomatic index (HSI) and ovarian development. We also estimate growth from length-frequency data analysis (LFDA) and recruitment patterns.

MATERIALS AND METHODS

Specimens (total of 715 individuals; 367 females and 348 males) of the Korean pomfret were collected monthly on the south western coast of Korea, Yellow Sea located between latitude 34°30' and 35°10' N, and longitude 125° 50' and 126° 20'E, from the stow nets, with fine mesh size (33×33 mm), between August 2005 and July 2006. Stow nets, fixed to anchors, have rectangular mouth opening of 16 m wide and 16 m high, and a length of 120 m (NFRDI, 2002).

Total lengths (TL: snout to upper caudal fin) were measured to the nearest millimeter, using a measurement board. Total weight (TW) of fish body, gonad and liver were measured to the nearest 0.01g. The length-weight relationship was expressed by $TW = aTL^b$. The parameters a and b of the relationship were estimated by the least squares method. After recording developmental stages, gonads were extracted, weighed and then preserved in 5% buffered formalin. Maturity of ovary was determined within four categories, according to Lee and Jin (1989): Stage I, growing stage; Stage II, mature stage; Stage III, ripe and spent stage; Stage IV, recovery and resting. The gonadosomatic index (GSI) was determined as follows:

$$GSI = (\text{gonads weight/somatic body weight} - \text{gonads weight}) \times 100 \qquad (1)$$

Monthly change in the hepatosomatic index (HSI) was also analyzed as a clue of the energy budget during the reproductive cycle. HSI index was determined as follows:

$$HSI = (\text{liver weight/somatic body weight}) \times 100 \qquad (2)$$

The proportions of sexually mature males and females, based on the number of males and females past Stage II in the ovarian development were calculated for each size class. A logistic equation curve was fitted for the proportions of sexually mature males and females (P) by total length:

$$P = 1/[1 + \exp(a - bTL)] \qquad (3)$$

where P is the predicted mature proportion, a and b coefficients of the logistic equation and TL the total length. The analysis is limited to the spawning season. The parameters were estimated by a nonlinear regression analysis in SYSTAT Version 10.0. Size at sexual maturity (L_{50}) is the total length, which corresponds to a proportion of 0.5 of sexually mature males and females. It was calculated from the ratio between the constants a and b ($L_{50} = -(a/b)$).

Length-frequency distributions (LFD) were constructed for pooled data, using 1 cm intervals of TL. Growth was described using the modified von Bertalanffy growth function (VBGF) (Pauly and Gaschütz, 1979):

$$L_t = L_\infty[1 - \exp\{-K(t-t_0) - (CK/2\pi)\sin(2\pi(t-ts))\}] \qquad (4)$$

Where L_t is the length at age t (cm), L_∞ the asymptotic length (cm), K the intrinsic growth rate (year^{-1}), t the age (year), t_0 the age at which the length of animals is 0 (year), C the amplitude of seasonal growth oscillation, ts the age at the beginning of growth oscillation, and winter point (WP= $ts+0.5$) the time of year when growth is slowest.

Growth curves were estimated from the length-frequency distribution data using the ELEFAN in FiSAT (FAO ICLARM Stock Assessment Tools) program (Gayanilo et al., 1997). ELEFAN estimates the growth parameters (L_∞, K, C, and WP) without standard errors. The Rn value gives an estimator of the goodness of fit. The estimates of L_∞ and K were used for comparison of growth performance indices (ϕ') (Pauly and Munro, 1984):

$$\phi' = \log_{10} L_\infty + \log_{10} K \qquad (5)$$

Differences in the size-frequency distributions of population between two sexes were determined by the Kolmogorov-Smirnov two sample test (Sokal and Rohlf, 1995). Chi-square test was used to detect difference in the occurrence of males and females over the sampling period. One-way analysis of variance (ANOVA) was used to test difference in mean GSI and HSI between sexes. Prior to ANOVA, assumptions of ANOVA were examined using Bartlett's test. Where necessary, the data were transformed to meet acceptable homogeneity of variances and distribution of residuals. Multiple comparisons were made with Tukey's honestly significant difference (HSD) test. The relationships of fecundity on the body length were analyzed with log$_e$-transformed data. Statistical analyses were carried out using MINITAB Version 12.2 and SYSTAT Version 10.0.

RESULTS

Population structure
During the period between August 2005 and July 2006, a total of 715 individuals (348 males and 367 females) were examined. The total length of the individuals ranged from 11.1 cm to 34.0 cm for males and from 11.5 cm to 34.4 cm for females. Mean total length (SD) for male and females were 21.15 (±4.52) cm and 23.48 (±5.24) cm, respectively. No significant difference was found in mean total length between males and females for all sampling months (Mann-Whitney U-test: U=159.0, df=1, P>0.6) (Fig. 1). The size-frequency distribution showed that both males and
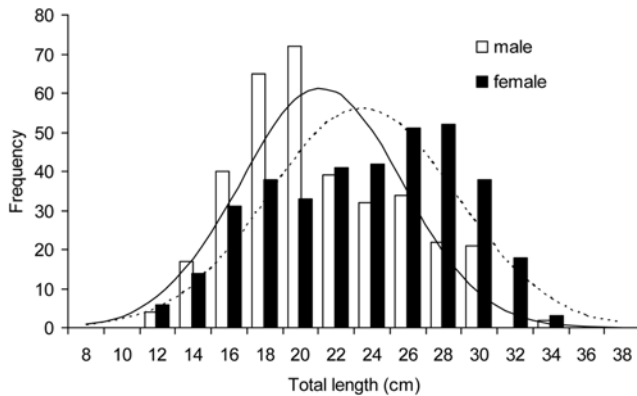
Fig. 1. Length- frequency distribution of male and females of *Pampus echinogaster* (Basilewsky, 1855). The solid lines indicate the normal distribution curve of male and the doted lines that of female.
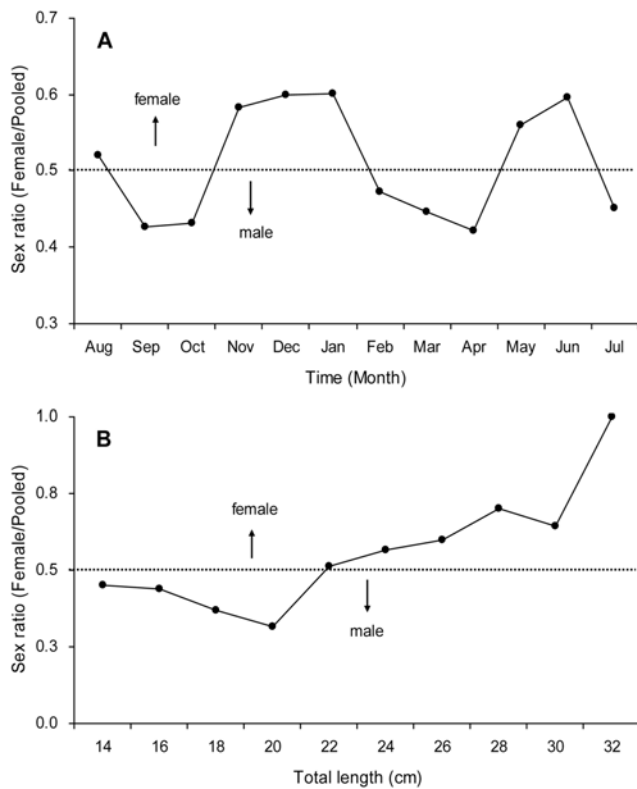

Fig. 2. Sex ratio of *Pampus echinogaster* (Basilewsky, 1855). (A) monthly variation in sex ratio and (B) sex ratio according to size intervals. The dotted line indicates a ratio of 1:1 (female : male).

Fig. 3. Seasonal changes in the maturity stage of males (A) and females (B) of *Pampus echinogaster* (Basilewsky, 1855).

females were normally distributed (Anderson-Darling normality test: P<0.001) (Fig. 1). There was no significant difference in size composition structure between males and females (Kolmogorov-Smirnov two-sample test; d_{max}= 0.167, P=0.985). The length-weight relationship was: TW =0.0091 TL$^{3.175}$ (r^2=0.97; n=715, P<0.001). For comparison with other studies, total length (TL) is converted into standard length (SL), using the regression: SL=0.73TL +0.77 (r^2=0.96, n=713, P<0.01).

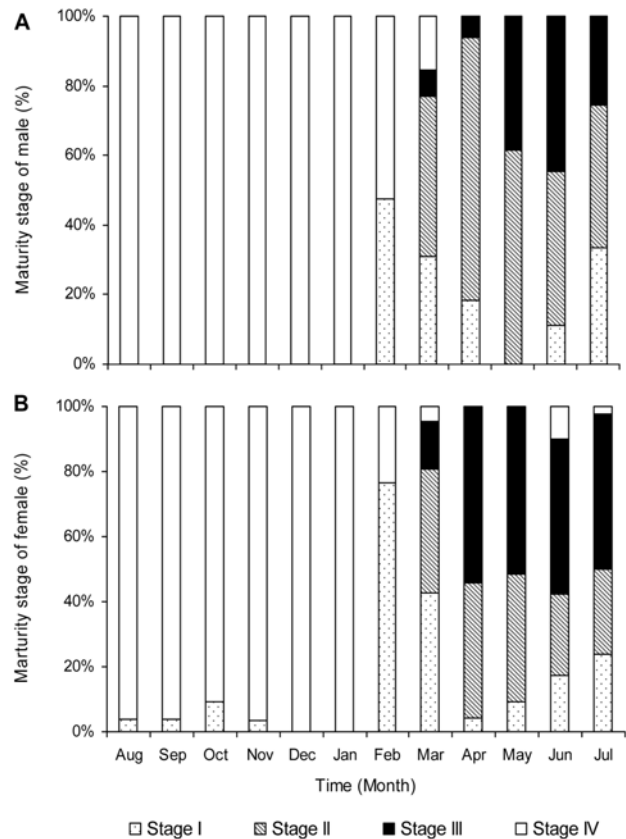## Sex ratio, reproduction pattern and fecundity

Proportions of males and females in samples taken monthly are shown in Fig. 2A. The monthly sex ratio (female/ pooled) ranged from 0.43 to 0.60. Males outnumber females in September and October 2005, and February, March, April and July 2006, whereas females do males during the other months. The number of females was not significantly greater than that of males in the samples throughout the sampling period (χ^2=15.58, df=11, P>0.05). Females outnumbered males at total lengths greater than 22 cm (Fig. 2B).

Maturing (stage II) testis of *P. echinogaster* appeared in March (Fig. 3A). Mature testes became dominant in samples of April and remained high until July. Males at ripe and spent stage took place mainly in May and June. Females were showed to be growing (stage I) in February. Females with maturing ovary (stage II) appeared in March and persisted until July. The first occurrence of ripe and spent females was observed in March and continued until July (peaking in April and May), after which a rapidly reduction in frequency of occurrence was observed until January (Fig. 3B).

Gonadosomatic index (GSI) and hepatosomatic index (HSI) were examined to determine the spawning period. In
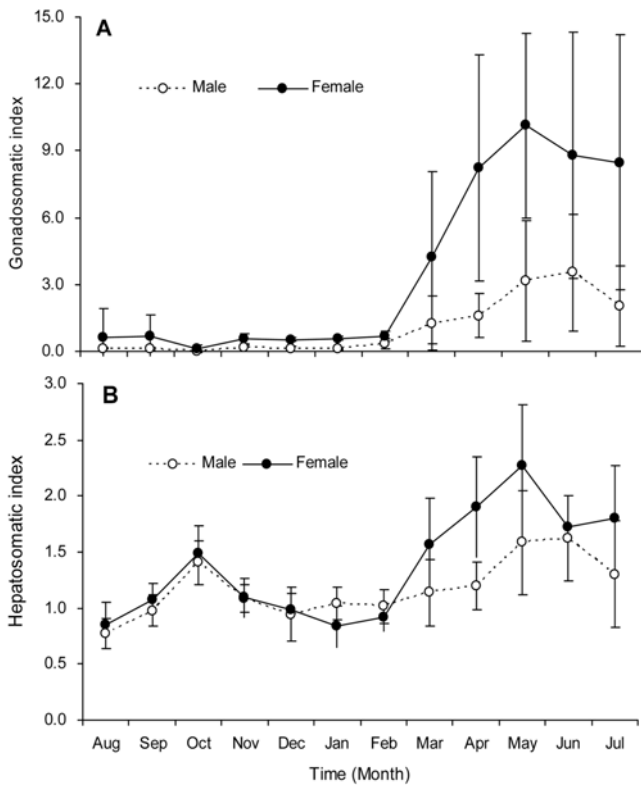
Fig. 4. (A) Variation of gonadosomatic index (GSI) and (B) hepatosomatic index (HSI) in males and females of *Pampus echinogaster* (Basilewsky, 1855). Solid and open circles indicate mean and vertical bars standard deviation.
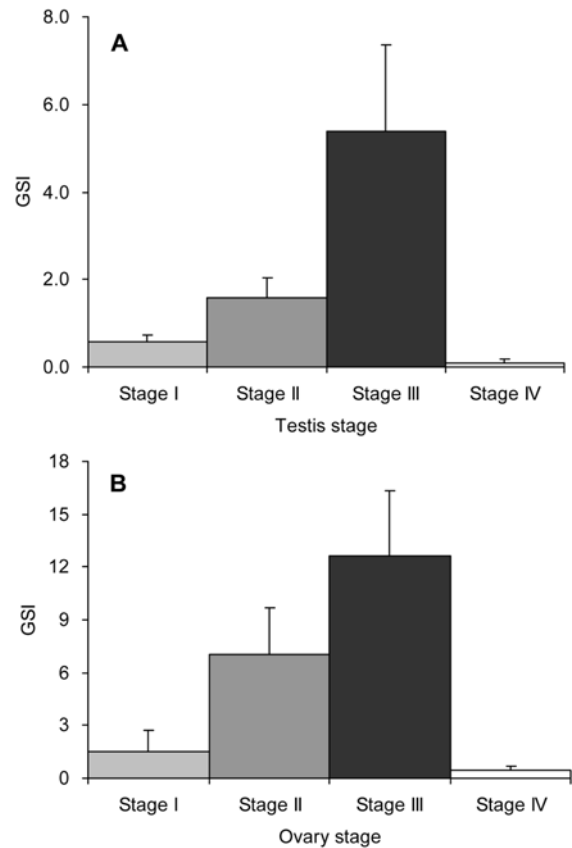

Fig. 5. Mean gonadosomatic index of maturity stage in male (A) and female (B) of *Pampus echinogaster* (Basilewsky, 1855). Vertical bars indicate standard deviation.

male, GSI showed its low value until February, increase in March and maximum in June, and sudden decrease after July. In female, GSI showed its low value until, increase in March and maximum in May, and gentle decrease after June (Fig. 4A). Therefore, spawning period was determined between March and July, and main spawning time May. An analysis of variance (ANOVA) showed a significant difference in the mean GSI of both sexes between months (Males: F=25.81, df=1, 11, P<0.001; Females: F=47.08, df=1, 11, P<0.001). A similar pattern was observed in monthly variation of HSI. In males, HSI increase until October, decrease after that, slightly increase until May and maximum in June. In females, HSI increase until October, gently decrease after that, sharply increase until April and maximum in May. ANOVA showed a significant difference in the mean HSI between months (Males: F=21.01, df=1, 11, P<0.001; Females: F=50.45, df=1, 11, P<0.001) (Fig. 4B). For both sexes the monthly variation of GSI was significantly correlated with that of HSI (r=0.813, P=0.001 for male and r=0.905, P=0.001 for female).

Mean GSI of males was 0.58±0.16 in the testis stage I, 1.57±0.46 in the testis stage II, 5.40±1.97 in the testis stage III and 0.10±0.09 in the testis stage IV: a significant

difference between testis stages was found (ANOVA, F= 633.64, df=3, 344, P<0.001). Subsequently a *posteriori* multiple comparison tests showed that there were significant differences between all testis stages (P<0.001) (Fig. 5A). Mean GSI of females was 1.53±1.19 in the ovarian stage I, 7.03±2.68 in the ovarian stage II, 12.61±3.73 in the ovarian stage III and 0.48±0.22 in the ovarian stage IV: a significant difference between ovary stage was detected (ANOVA, F=731.640, df=3,363, P<0.001). Subsequently a *posteriori* multiple comparison tests revealed a significant difference between all testis stages (P<0.005) (Fig. 5B).

The observed fecundity varied between 41,250 eggs at 22.2 cm total length and 103,610 eggs at 26.7 cm total length. Regression analysis on natural logarithm transformed data showed a significant relationship between ova number (F) and total length (TL) (Fig. 6): ln F=3.45 (±0.79) ln TL −0.70 (n=28, r^2=0.76, P<0.001). The relationship between ova number (F) and body weight (BW) was also significant: ln F=1.08 (±0.25) ln BW+4.47 (r^2=0.70, n=28, P<0.001) (Fig. 6). The slopes of the two regressions were just equal to 3.0 or 1.0 at a 95% confidence limit of slope, indicating a significant isometry.
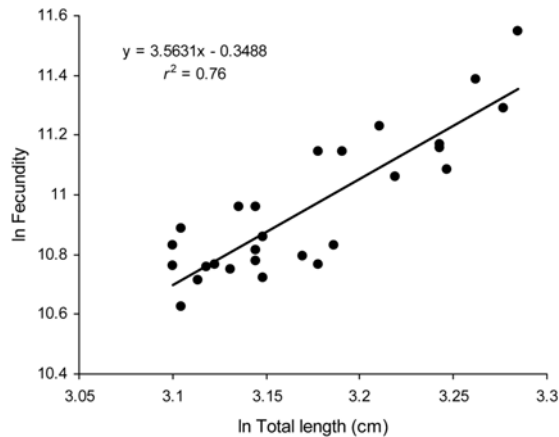
Fig. 6. Relationship between ln Fecundity and ln TL in *Pampus echinogaster* (Basilewsky, 1855).
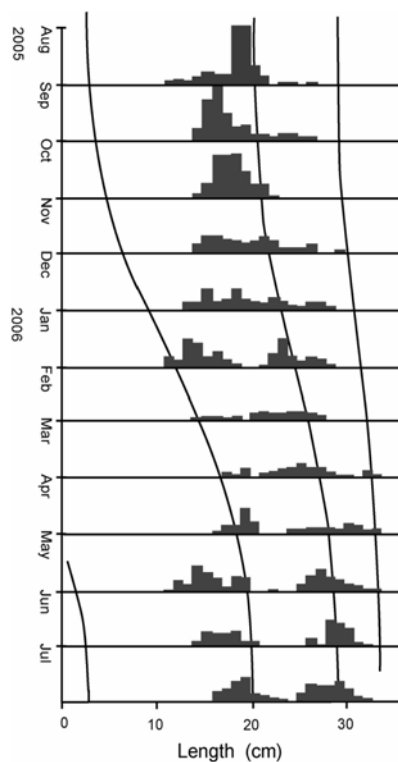

Fig. 7. Growth curves of *Pampus echinogaster* (Basilewsky, 1855) based on length-frequency distributions (LFD).

Size at sexual maturity

The 137 males of *P. echinogaster* used in the analysis ranged from 15.5–33.3 cm TL and 139 females ranged from 15.0–33.6 cm TL. The relationship between TL and the proportion of sexually mature males and females by 2 cm TL classes was calculated by fitting a logistic function to the sizespecific maturity data:

Male: $P=1/[1+\exp(2.71-0.18\text{ TL})]$ ($r^2=0.75$, $P<0.01$)
Female: $P=1/[1+\exp(20.15-1.04\text{ TL})]$ ($r^2=0.99$, $P<0.001$)

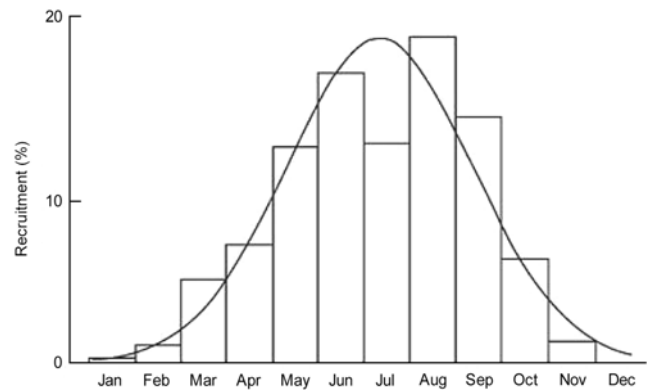The proportion of sexually mature males and females by

Fig. 8. Recruitment pattern of *Pampus echinogaster* (Basilewsky, 1855) as identified by ELEFAN in FiSAT program.

length class increased logistically with length. From this, the estimated size at 50% sexual maturity (L_{50}) for males and females was 14.98 cm TL and 19.32 cm TL, respectively. Males were mature at earlier than females.

Growth and recruitment pattern

Monthly specimens (total of 715 individuals) of *P. echinogaster* were examined to estimate growth parameters. Graphical presentation of VBGF curves are showed for pooled data because of no significant difference in the population structure between males and females (Fig. 7). The values of L_∞ and K estimated for combined data were 39.12 cm TL (29.29 cm SL) and 0.65 yr^{-1}, respectively. The growth performance indices (ϕ'), using standard length dimension, was 2.75. The growth curves showed a strong seasonal oscillation in growth (C) of 95% for the pooled data. The phase of slow growth (WP=0.62) occurred in July, when the spawning event of *P. echinogaster* took place.

The structure of the recruitment patterns obtained by the ELEFAN program indicated one normally distributed group (Fig. 8). Percentage of the recruitment was 51.04% in the spawning season and the highest in August (19.78%).

DISCUSSION

The Korean pomfret, *Pampus echinogaster* has distribution area restricted to the coastal waters of the Yellow Sea and East China Sea (Kim et al., 1989). One of the most commercial aspects was the striking success of *P. echinogaster* on the western coast of Korea, Yellow Sea. This area has relatively shallow waters with a maximum depth of little over 200m and one of the world's largest areas of continental shelf (Cho et al., 1989). Valuable nutrients flow from the Yangtze and Yellow river and combine with sunlight and shallow waters to create an area that teems with abundant marine life. *P. echinogaster* migrates to south-north according to the expansion and contraction of the Tsushima Warm

Current including the Yellow Sea Bottom Cold Water (Cho et al., 1989). Therefore, it migrates to the north of Yellow Sea in spring and summer (spawning migration) and to southern part of East China Sea in winter (wintering migration) (Cho et al., 1989; NFRDI, 2004).

This study showed that population structure was not different between sexes. This result is consistent with Kim et al. (1989) who found no significant difference in mean total length and population distribution between males and females collected for 9 years. Thus pooled data were used for estimation of growth and recruitment pattern. The von Bertalanffy growth models fitted the data of the examined *P. echinogaster*, as indicated from high score functions (Rn value is 250). The K value (0.65 yr^{-1}) corresponds to the best estimate of L_∞ (29.29 cm SL). The growth performance index (ϕ') is preferred for growth comparison within and between species rather than comparison of L_∞ and K, individually, as the two growth parameters are inherently negatively correlated (Pauly and Munro, 1984). For *P. echinogaster* investigated in the same area, the growth performance of this study (ϕ'=2.75) was higher than that (ϕ'=2.45) estimated by Kang et al. (1989). These differences could be found in the sampling method. This study collected the samples using stow nets and thus smaller-sized specimens are included in the catch, whereas Kang et al. (1989) collected larger-sized specimens at the public fishing market to analyze growth parameters. In this study, growth slowdown coincides with the maturation and spawning period, reflecting metabolic costs associated with reproductive activities.

Sex ratio in *P. echinogaster* population on the western coast of Korea was not significantly different in the samples throughout the sampling period. Changes in sex ratios revealed that the number of females was greater than that of males from >22 cm TL. Sex ratio may be related to growth, migration and behavior of *P. echinogaster* population. Although difference in growth between sexes was not investigated in this study, previous studies suggested that there was slightly faster growth in females (Kang et al., 1989; Yamada et al., 2007). Kang et al. (1989) reported that the growth performance indices (ϕ') of males and females was 2.40 and 2.43, respectively. As a recent study, Yamada et al. (2007) also showed that the growth performance indices (ϕ') was 2.35 for males and 2.39 for females. These differences result in higher mesh size selection for females, leading to the biased proportions toward females for samples larger than 22 cm TL.

The main spawning seasons (percentage of the combined both sexes with mature testes and ovary greater than 50%) was a prolonged spawning period lasting from April through July, with activity concentrated in May for females and June for males. This is consistent with the result of morphological and histological examination in the East China Sea (Lee and Jin, 1989; Yamada et al., 2007). In this study female and male GSI reached a peak in May and June, respectively, and then after spawning it began to decrease. This reproductive pattern suggests that this species has one peak of spawning activity. This reproductive pattern could agree with observations of Lee and Jin (1989) that the residual follicles and remaining ripe eggs degenerate after spawning.

Considering a little change of GSI during somewhat long reproductive periods (March-July), and inner spawning cycle of gonad development (for example, 15 days for *P. argentus* (Almatar et al., 2004)), *P. echinogaster* is likely to be a batch spawner. Based on histological examination of oocytes Lee and Jin (1989) also observed this spawning patttern. Their observation showed that size-frequency distribution of oocyte had two peaks of yolked oocytes in all the maturity stages except for the resting stage, thus suggesting that the Korean pomfret are indeterminate spawners capable of > two batches within a spawning season. Similar reproductive pattern was observed in *P. argentus* in Kuwait waters (Almatar et al., 2004) and the Yellow Sea (Lee and Jin, 1989). However, the number of batches produced in the same species seems to vary highly with factors such as ambient environments, food availability, and fish age. Thus because of an essential information in the estimation of spawning stock biomass as well as annual egg production of batch spawner, it should be known exactly along with the number of eggs in each batch.

There is a positive correlation of GSI and HSI. This can be found in some fishes such as *Scomber japonicus* (Houttuyn, 1782), *Onchorhynuchus nerka* (Walbaum, 1792), and *Microstomus achne* (Jordan et Starks, 1904) (Imura and Saito, 1969; Noguchi and Bito, 1953; Byun, 2002). On the contrary, some fishes, *Anguilla japonica* (Temminck et Schegel, 1846) and *Limanda yokohamae* (Günter, 1877) had a negative relationship (Sugimoto et al., 1976; Kang et al., 1985). This difference could be attributed to environmental factors, particularly water temperature, which subsequently can affect vitellogenesis (vitellogenin uptake from liver to oocyte) related to annual reproductive cycle (Lee and Jin, 1989).

The size at sexual maturity (L_{50}) was estimated at 11.7 cm standard length (SL) for males and 14.9 SL for females. In contrast, in the Yellow Sea it was estimated as 12.5 cm SL for males and 17.0-18.0 cm for females (Lee and Jin, 1989; Yamada et al., 2007). It is likely that these differences are primarily affected by sampling method. Sampling in this study was made by research vessel employed but in the previous studies samples were collected from sea food market. Such difference was also found between areas with different environmental factors for congeneric species, *Pampus argenteus*. In the Kuwait waters the size at sexual maturity was 12.5-14.4 cm SL for males and 20.5-22.4 cm

SL for females (Daize et al., 1998), and in the Bay of Bengal it was 15.0 cm SL for males and 17.0 cm SL for females (Pati, 1982).

In this study there was a significantly positive relationship between fecundity and fish length/weight (Yamada et al., 2007), as shown in *Pampus argenteus* (Euphrasen) (Dadzie et al., 2000). The high coefficient of determination for the two regressions indicates that fish length can be used as an index determining fecundity.

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