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Reproduction and growth of the freshwater prawn, *Palaemon paucidens* (Decapoda: Palaemonidae) in a lake of Korea

Jong Chun Kim[1], Chae Woo Ma*[1], Chul Woong Oh[2] and Sang Gyu Paik[3]

[1]Department of Marine Biotechnology, Soonchunhyang University, Asan, Chungnam - 336 745, Korea
[2]Department of Marine Biology, Pukyung National University, Busan - 336 745, Korea
[3]Marine Ecosystem and Environment Research Division, Korea Ocean Research and Development Institute, Ansan P.O. Box 29, 425 600, Korea

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Abstract: *This study analyzed the reproduction and growth of freshwater prawn, Palaemon paucidens De Haan 1844 from Suk-dang lake(Korea). The analysis of the sex ratio showed a higher proportion of males than that of females. The average size of the eggs was 6.12 (± 0.55) mm^3 in the non-eyed stage (stage A) and 7.20(±0.86)mm^3 in the eyed stage (stage B). The reproductive output (RO) calculated with the dried-body weight of an incubating female and the weight of the eggs in dried condition was 26.97% (n = 17) of the average females weight. Incubating prawn appeared in April, and the gonadosomatic indices(GSI) showed the highest value during three months from January to March. Based on the month when there was a high proportion of incubating females with a high GSI, the estimated spawning season of P. paucidens was April. The maturity of the female was evaluated by the development of the ovaries and the existence of eggs. The average body length when 50% of the females in the group reached maturity was 8.55 (±2.74) mm. The analysis of the length-frequency distribution showed that the life span of P. paucidens ranged from 12 to 13 months. Females mature faster than males.*

Key words: *Palaemon paucidens, Growth, Sex ratio, GSI, Fecundity, Reproduction intensity*
PDF of full length paper is available with author ***(*cwooma@sch.ac.kr)***

Introduction

Palaemon paucidens De Haan 1844 is a species of freshwater prawn of the Palaemonidae family. Palaemonid shrimp live in a wide range of environments from freshwater estuaries to the ocean. There are 13 known species in Korea (NFRDI, 2001). They eat a mixed diet which includes seaweed, aquatic insects, small crustaceans and epifauna and are an important part of the food chain as food for fish, birds and other predators. Freshwater palaemonid shrimp particularly, have commercial value as fishing bait and food. *P. paucidens* hides under or between stones and aquatic plants during the day and comes out at night searching for food.

Several studies have been performed on the reproduction, physiology and ecology of palaemonid shrimp. The tolerance limit against environmental factors, such as, water temperate and salinity was reported for *Palaemon affinis* (Kirkpatrick and Jones, 1985) and the energy index of the life cycle for *Palaemon macrodactylus* (Chin *et al*., 1992). Comprehensive research of palaemonids includes studies on the differences in habitation, ecology and reproduction between *Palaemon adspersus* and *Palaemon squilla* (Berglund, 1980, 1981, 1982, 1984, 1985).

Also, several research have been performed on *P. paucidens* on the survival and production rate of the young population and larva which didn't receive food (Mashiko, 1985) and research on the relationship between the embryonic period and egg size of different populations of *P. paucidens* and *Macrobrachium nipponenses* from different areas (Mashiko, 1987). Other studies include researches on the growth and physiology of the *P. paucidens* population in the east lake of Hiroshima (Ogawa and Kakuda, 1988); the egg yolk size using immune and structural techniques (Tsumura and Nakagawa, 1989); on the comparison of the requirements for larva and adults from reservoirs, lakes, rivers and estuaries (Fidhiany *et al*., 1991). However, there hasn't been any research on the population dynamics and reproduction of *P. paucidens* in Korea.

In this paper, we investigate the sex ratio, length-frequency distribution of population, and monthly gonadosomatic index (GSI) of female, the proportion of spawning females, and the size and weight of eggs in palaemonid shrimps. Our research provides biological information, such as, reproduction period, spawning frequency and population maturity in palaemonid shrimp. Our research also helps to understand ecology and population dynamics of palaemonid shrimp in a lake in Asan. Our study further suggests the possibility of commercial culture for palaemonid shrimp and provides information for future management of plaemonid population.

Materials and Methods

Sampling: Monthly samples of *P. paucidens* were collected between October 2001 and September 2002. Prawns were caught with hand nets (1mm mesh size) in Suk-dang Lake, Korea (Fig. 1). Samples were fixed in 4% neutralized formalin during 24 hr and then transferred and stored in 70% alcohol.

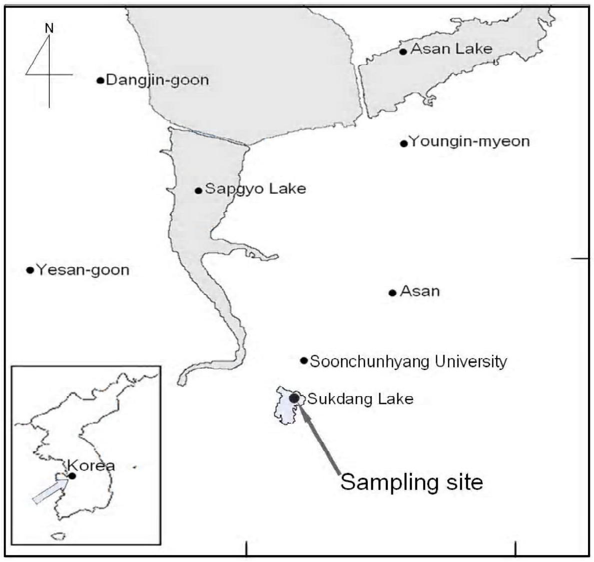

Fig. 1: Map showing the location of a sampling site (●) in Suk-dang lake, Korea

Sample analysis: The sex was determined using morphological examination (the shape of the endopod of the second pleopod and the presence or absence of an appendix masculina), or observation of reproductive organs under a stereo- microscope where the former was obscure. Carapace length (CL), the shortest distance between the posterior margin of the orbit and the mid-dorsal posterior edge of the carapace, was measured using a microscope with micrometer.

Fecundity and reproductive output (RO): Egg stage was recorded as non-eyed stage (A) and eyed stage (B). Eggs were carefully stripped from pleopods using fine forceps and any setal material or extraneous material was removed. All eggs were counted directly. For fecundity-carapace length relationship and reproductive output (RO) estimation only females with non-eyed eggs were used. Female and egg dry weights were determined after drying at 60°C during 48 h and weighing to the nearest 0.0001g using an electronic digital balance. Reproductive output (RO) was estimated using dry weight by applying the formula:

$$RO = \text{total mass of egg batch/mass of female} \quad .....(1)$$

Ovary examination: Ovarian stage was determined using a microscope equipped with a calibrated ocular micrometer. Ovaries were divided into three arbitrary stages according to the following criteria: Stage I developing: thin, pale orange, filling one-third of cephalothorax volume, oocytes <0.3 mm diameter (spent ovaries could not be discriminated and therefore are included in this category); Stage II, mature: orange, filling two-thirds of the cephalothorax III volume, oocyte generally 0.3 to 0.5 mm diameter; Stage III, ripe or almost ripe: deep orange, filling almost all the cephalothorax, oocytes generally >0.5 mm diameter. Ovary dry weight was determined by drying as described above. The gonadsomatic index (GSI) was determined as follows:

$$GSI = (\text{Ovary dry weight/Female somatic body dry weight}) \times 100 \quad ....(2)$$

Growth: Length frequency distributions (LFD) were performed using 1-mm length intervals of carapace length. Growth was described using the modified von Bertalanffy growth function (VBGF) (Pauly and Gaschutz, 1979):

$$L_t = L_\infty [(1 - \exp(-K(t - t_0) - (CK/2\pi)\sin(2\pi(t - ts)] \quad .....(3)$$

where L_∞ is the asymptotic length, K is the intrinsic growth rate, t_0 is the age which the length of animals is 0, C is the amplitude of seasonal growth oscillation, ts is the age at the beginning of growth oscillation, and WP (= ts + 0.5) the time of year when growth is slowest. The growth parameter was estimated separately for each sex.

Growth curve presumed the length frequency data using Non-parametric method of ELEFAN of FiSAT program (Gayanilo *et al*., 1995). To compare growth between both sexes, we calculated Growth performances Index(Φ') according to the method of Pauly and Munro (1984) using L_∞ and K-value.

$$\Phi = \log10K + 2\log10L_\infty \quad ......(4)$$

This growth performance index is preferred for growth comparison, rather than using L_∞ and K individually, because these two parameters are correlated. The growth performance index is more robust than either L_∞ or K individually, as it takes into account the negative correlation between the two parameters, and fulfils the requirement for a simple single parameter for comparison of growth.

The recruitment pattern of *P. paucidens* was established by projecting the corrected length frequency data backward on the time axis to zero length, using the estimated growth parameters (Pauly, 1982).

Statistical analysis: Chi square was employed to test for differences in sex ratio. Differences in some reproductive variables between months and between embryonic stages were tested by ANOVA, with prior testing of assumptions by Bartlett's test. Where necessary, the data were log-transformed to produce acceptable homogeneity of variances and distribution of residuals. When ANOVA was significant, differences in means of the variables were tested by the a posteriori Tukey-HSD method (*T*-method) (Sokal and Rohlf, 1995), performed with SYSTAT Version 9.0. The linear regressions of reproductive traits (number of eggs, egg dry weight, and ovarian dry weight) on the body measurements (carapace length and body dry weight) were analysed with log-transformed data. ANOVA was used to compare the slopes and elevations of these regressions (Zar, 1984) in SYSTAT Version 10.0. When individual slopes were not significantly different, a common slope (b_c) was computed, and the recalculated elevations tested.

Results and Discussion

Changes of environmental factors: Water temperature in centrigrade ranged from 4.2 to 25.0 and average reached 15.2. It was observed the lowest temperature 4.2 in January and the highest temperature, 25.0 in August (Fig. 2). Dissolved oxygen ranged from 5.18 to 7.06 mg l^{-1} with an average of 6.26 mg l^{-1}. It was seen the lowest dissolved oxygen 5.18 mg l^{-1} in December and the highest

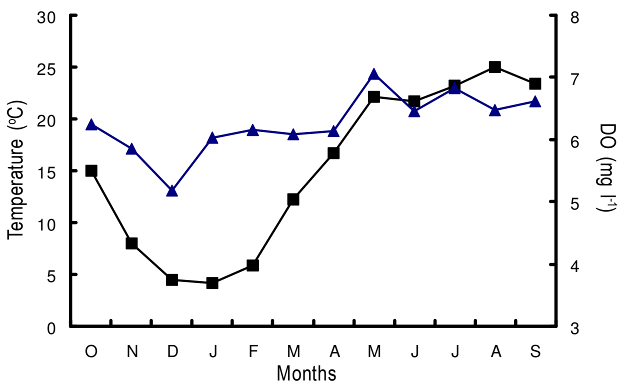

Fig. 2: Monthly variation of water temperature (■) and dissolved oxygen (▲)

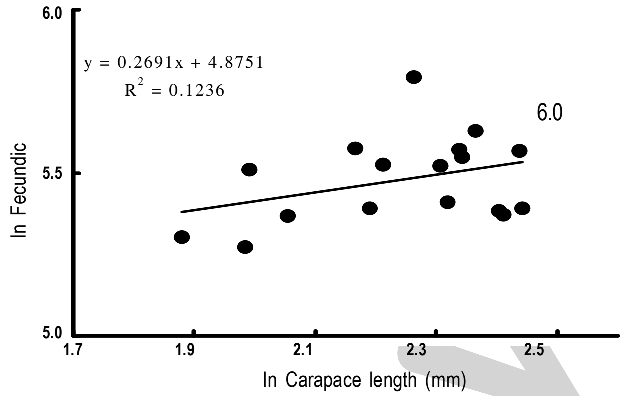

Fig. 5: Relationship between carapace length (CL) and number of egg (EN) of *Palaemon paucidens*

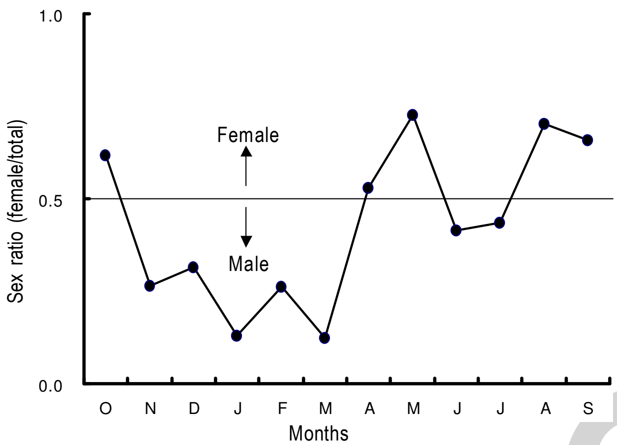

Fig. 3: *Palaemon paucidens*. Monthly fluctuations in the sex ratio (female/total)

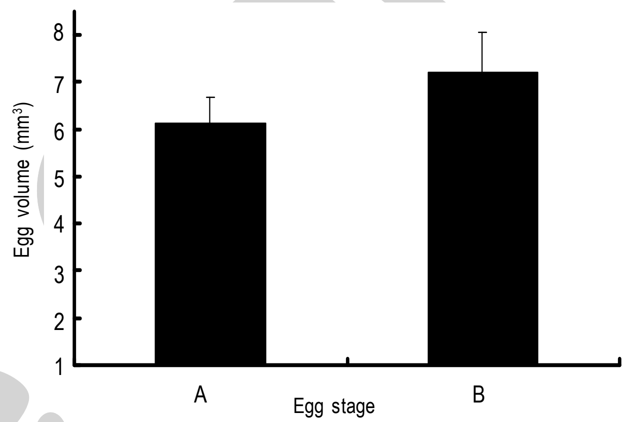

Fig. 6: Mean egg volume (mm^3) in the two embryonic stages of *Palaemon paucidens*. The vertical bar indicates standard deviation

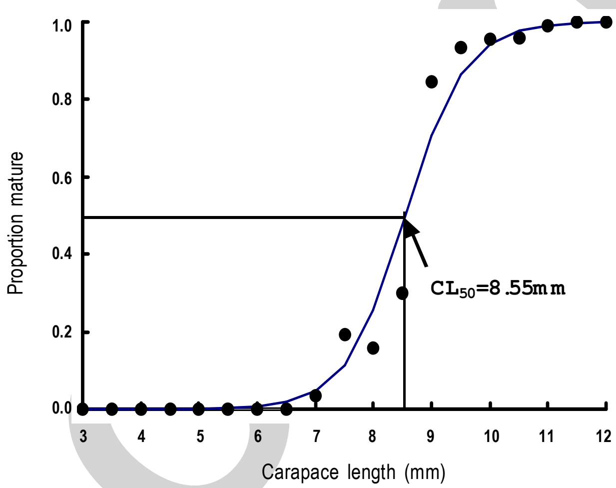

Fig. 4: A logistic function fitting of mature female *Palaemon paucidens* to carapace length. CL_m (8.55 mm), which corresponds to a proportion of 0.5 (50% of females are mature), is indicated

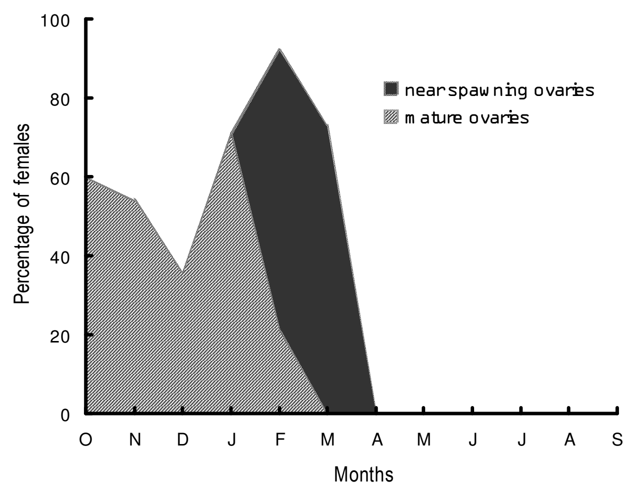

Fig. 7: Percentage of female *Palaemon paucidens* with mature, fully mature during the study period

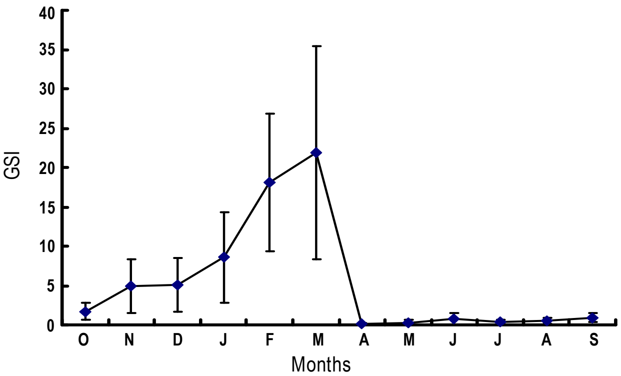

Fig. 8: Monthly values for female gonadosomatic indices (GSI) of *Palaemon paucidens*. The vertical bar indicates standard deviation

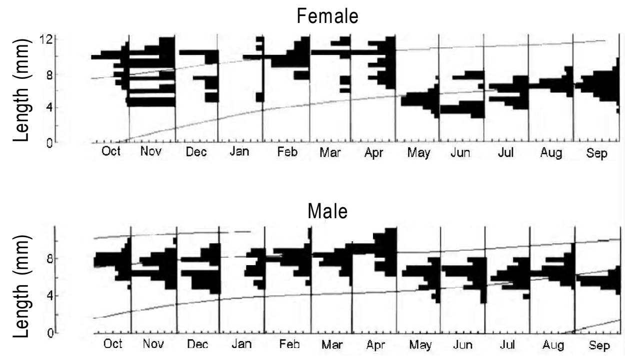

Fig. 9: Length-frequency distribution, expressed as percentage, of females and males of *Palaemon paucidens* during a year in suck-dang reservoir and estimated growth curves for each population

dissolved oxygen 7.06 mg l^{-1} in May (Fig. 2). Dissolved oxygen was relatively steady monthly, against the water temperature.

Sex ratio: 1,195 specimens were collected from October, 2001 to September, 2002. Of these, females were 590 specimens (49%) and males were 605 specimens (51%). The result of Chi-square test indicated that ratio of males are higher. (χ^2 = 216.49, *d.f.* = 11, *p* < 0.001). Monthly changes of *P. paucidens* sex ratio appeared; females are dominant in May, August and September and males during November, December, January, February and March (Fig. 3).

Size at sexual maturity: A total of 590 female *P. paucidens,* used in the analysis, ranged 2.5-11.7 mm CL. The relationship between CL and the proportion of ovigerous females was calculated by fitting a logistic function to the size- specific data:

$$P = 1/ [1\exp\{-(16.667 - 1.9491CL)\}]$$

$$(r^2 = 0.94, p<0.001)$$

From this, the estimated size at 50% sexual maturity (±95% Wald confidence interval) for females was 8.55 (±0.38) mm CL (Fig. 4).

Fecundity and reproductive output (RO): The number of eggs per brood ranged 195-328 for females ranging 7.26-11.50 mm CL. and the mean number of eggs indicated 241±33. The relationships between the number of eggs per brood (EN) and carapace length (CL) were significant (Fig. 5).

$$\ln EN = 0.2691 \ln CL + 4.8751 \ (n = 16, r^2 = 0.1236, p\ 0.16).$$

Reproductive output (RO) of *P. paucidens* occupied average 26.97% (n = 17) of female dry weight. The mean volume of eggs by embryonic stages ranged 6.12 (±0.55) - 7.20 (±0.86) mm^3 (Fig .6).

Breeding pattern: Ovigerous females occurred February- April (Fig. 7). They first were observed in February, reached a peak during April, and then disappeared. In total, 590 females were examined for ovary condition and gonadosomatic index (GSI). Mean oocyte diameter was 0.16mm in Stage II ovaries, 0.45 mm in Stage V, and 0.68 mm in Stage V: a significant difference between ovary stages(ANOVA, $F_{2,407}$= 9.274, p<0.001). Subsequent a posteriori multiple comparison tests showed significant differences between all ovary stages (Tukey HSD, p< 0.001), indicating a steady increase in oocyte diameter with maturation.

Monthly variation of GSI indicated high value from January to March and decreased rapidly from April and indicated similar aspect from May to September. After that, it began to increase again from October to December. GSI value was highest in March (21.86) while it was lowest in April (0.12). During January to March, GSI value (16.19±6.84) was higher than mean value (5.27±7.20).

Growth: Modal progressions of 1-mm size classes over a year, as used in the ELEFAN program are given in Fig. 9. The length-frequency distribution showed that the populations had two modal size groups per year, displaying similar pattern in both male and females. There was apparent shift in modal length of cohorts with time. In both sexes the sample in February showed a clear cohort. It could be followed through to April. By May the new recruits to the population formed another new cohort, clearly distinguishable from the older individuals in the population. The best fits to the length-frequency identified a distinct new cohort, which became apparent in May. The newly recruited cohort increased rapidly, and a few older individuals occurred until April, when they disappeared. This cohort could be traced through to April of next year. The maximum life span was estimated to be one year, from May to July being considered the main spawning period.

Females had faster growth rates than males (Fig. 10), as is also indicated by the growth performance indices(Φ') of 2.06 for males and 2.25 for females (Table 1). The growth curve showed a seasonal oscillation in growth(C) of 51% for females, and 65% for males.

In carideans(Corey and Reid, 1991), female body size was the principal determinant of number of eggs per brood. In palaemonid shrimp, the number of eggs per brood is closely related with female body size (Berglund, 1981).

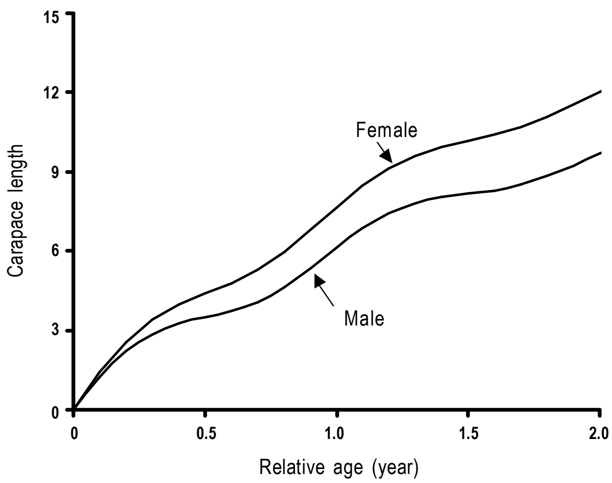

Fig. 10: Growth curves for male and female data of *Palaeom paucidens* based on length-frequency distribution during the sampling period

Table - 1: Von Bertalanffy growth parameter estimated by the ELEFAN analysis of length frequency data for males, females data: L_∞ = asymptotic length (mm), *K* = growth coefficient, *C* = amplitude of growth oscillation, *WP* = wintering point, Φ = growth performance index, *Rn* = score function.

Species	Parameter	Present study	
		Males	Females
P. paucidens	L_∞	14.51	17.75
	K (year^{-1})	0.55	0.57
	C	0.65	0.51
	WP	0.20	0.41
	Φ	2.06	2.25
	Rn	236	215

Table - 2: Comparison of reproductive output(RO) for a variety of Palaemonidae

Species	RO	Source
Palaemon northropi (Rankin)	0.14	Anger and Moreira (1998)
P. pandaliformis (Stimpson)	0.19	Anger and Moreira (1998)
Macrobrachium olfersii (Wiegmann)	0.22	Anger and Moreira (1998)
M. acanthurus (Wiegmann)	0.19	Anger and Moreira (1998)
Palaemon gravieri (Yu)	0.12	Oh and Park (2000)
Exopalaemon modestus (Heller)	0.17	Oh *et al.* (2002)
Palaemon paucidens	0.27	**This study**

Sex ratio in the population may be related with the growth and longevity of shrimp populations. In this study *P. paucidens* had prominent sexual dimorphism in growth. The growth rate of females was much higher than that of males. Reduced male energy investment in growth may decrease their risk of predation (Berglund, 1981). Variation in sex ratio may also be explained as differential mortality or pattern between sexes.

P. paucidens brood weight averaged 27% of female body weight. This is different from other Palaemonid shrimp which ranged from 12 to 22% (Table 2). Brood weight in brachyuran crabs is generally proportioned to 10% of the female body weight (Hines,1982, 1991, 1992, 1998). This study shows RO was higher than other caridians. In Korean waters, the freshwater *P. paucidens* (27%) showed higher RO than *Exopalaemon modestus* (17%)(Oh *et al.,* 2002). This coincided with Anger and Moreira (1998) findings that the marine species *Palaemon northropi* had a significantly lower RO than all freshwater shrimps studied. The pattern could imply the rule of the reproductive ecology of palaemonids. Higher RO in freshwater shrimp environments may be adaptive to increase the survival rate of offspring.

The breeding period of *P. paucidens* was from January to April, with a peak in April. Other temperate atyids, such as *Paratya compressa* (Kamita, 1958) and *Paratya australiensis* (Williams, 1977) breed in the summer. In Korean waters, *Neocaridina denticulata denticulata* (Oh *et al*., 2003) breeds in summer. Such variations in breeding periods along the latitude have always been considered as an indication of environmental stimuli triggering and maintaining gametogenesis and other reproductive characteristics in freshwater invertebrates (Adiyodi and Subramoniam, 1983).

The Von Bertalanffy model fitted the data of *P. paucidens* well indicated by the relatively high score function (Rn). The K value (0.57 year^{-1} for females and 0.55 year^{-1} for males) corresponded to L_∞ (17.75mm CL for females and 14.51 mm CL for males). The growth performance index(Φ') is preferred for growth comparison between sexes of a species, and between species rather than comparison of L_∞ and K, as these two parameters are inherently negatively correlated (Pauly and Munro, 1984). There was some difference in the growth performance index between two sexes, indicating that females grew faster and reached a larger size at age than males. There are numerous records in the literature of sexual differences in growth for freshwater and marine decapods. Silva and Silva (1989) reported that female *Caridina fernandoi* in Lake Kandy, Sri Lanka, grew faster than males. Similar patterns of growth were recorded by Bergstrom (1992) and Baelde (1994) on marine shrimps.

Our study demonstrates that the growth patterns of *P. paucidens,* in which males grow faster than females, is different from the general growth pattern of other crustaceans, which females grow faster than males. In *P. paucidens,* females may invest more energy to ovarian maturation than growth.

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