Aquatic Insects
Vol. 31, Supplement 1, 2009, 333–341

Taylor & Francis
Taylor & Francis Group

Life history and secondary production of *Ephemera orientalis* (Ephemeroptera: Ephemeridae) from the Han River in Seoul, Korea

Jeong Mi Hwang[a], Tae Joong Yoon[b], Sung Jin Lee[b] and Yeon Jae Bae[a,b,c]*

[a]*School of Life Sciences and Biotechnology, Korea University, Seoul, Korea;* [b]*Korean Entomological Institute, Korea University, Seoul, Korea;* [c]*College of Life Sciences and Biotechnology, Korea University, Seoul, Korea*

(*Received 28 October 2008; final version received 13 June 2009*)

In this study, we investigated the life history of *Ephemera orientalis*, a common lowland burrowing mayfly which resides in temperate East Asia and often causes a serious nuisance to people due to mass emergence from the Han River in Seoul, Korea. Larvae were sampled monthly (every two weeks during the emergence period) from April 2006 to June 2007 using a Surber sampler (50 × 50 cm, mesh 0.25 mm, two replicates). The mean density of *E. orientalis* was found to be 105.88 ± 42.14 indiv/m^2 during the study period. On the basis of the larval body size distribution and emergence time, we concluded that *E. orientalis* has a univoltine life cycle with two distinct cohort groups, S1-group emerging in May–June and S2-group in August–September. The estimated annual production of the larvae was 1350.84 mg DW/m^2; the mean biomass was 325.17 mg DW/m^2; the annual production to mean biomass ratio (P/B) was 4.15. Mean water temperature during the study period was 15.02 ± 6.84°C. The accumulated degree days for the S1- and S2-groups were 2565.07 and 2,621.69 degree days, respectively. This study shows that the Han River population of *E. orientalis* lacks the fast growing cohort (F-group) in May–August, and demonstrates a relatively higher secondary production than that of other stream mayflies (e.g. Gapyeong stream population of *E. orientalis*).

Keywords: *Ephemera orientalis*; life history; secondary production; large river; Korea

Introduction

Ephemera orientalis McLachlan, 1875 is a common burrowing mayfly which is found distributed throughout temperate East Asia including northeastern China, Mongolia, the Russian Far East, the Korean Peninsula, and the Japanese Islands (Hwang et al. 2008). The larvae occur abundantly in the lower reaches of streams, rivers, and lentic areas such as lakes and reservoirs, and are becoming more important in the biomonitoring of freshwater environments. The mass emergence and light attraction behaviour of this species during the late spring and summer seasons, however, frequently caused serious nuisance to people residing in towns

*Corresponding author. Email: yjbae@korea.ac.kr

ISSN 0165-0424 print/ISSN 1744-4152 online

DOI: 10.1080/01650420903116078
http://www.informaworld.com

and cities near streams and rivers. This species is particularly abundant in the Han River that runs across the city of Seoul, Korea, and the frequency and intensity of its mass emergence has evidenced an increase in recent years.

The life history aspects of *E. orientalis* have been studied in streams in Japan and Korea. Kuroda et al. (1984) previously showed that *E. orientalis* has three generations in a year, whereas Watanabe (1992) demonstrated that the species is bivoltine with spring and autumn cohorts in Japanese streams. Lee et al. (2008) studied the life history of *E. orientalis* in the Gapyeong stream in the central Korean Peninsula, and showed that it underwent three generations within two years, with an alternation of a fast developmental cohort (F-group) and two slow developmental cohorts (S1- and S2-groups). The life history phenomena of *E. orientalis*, which inhabits diverse habitats from streams to large rivers and often causes serious nuisance to people due to mass emergence, has yet to be elucidated in detail.

The purpose of this study is to investigate the life history phenomena of *E. orientalis* for the population that inhabits the Han River, a large river in Seoul, via comprehensive field sampling and analyses of voltinism, secondary production, and accumulated degree days.

Materials and methods

Study area and temperature monitoring

This study was conducted in the downstream reach of the Han River at the Godeok-dong riverside preservation area in Seoul, Korea (37°57′16.24″N, 127°15′71.35″E; Figure 1a), between April 2006 and June 2007. The Han River (total length 514 km) consists of two large rivers, the Namhan (South Han) and Bukhan (North Han) Rivers, and the two rivers meet approximately 30 km above Seoul city. The average width is approximately 1000 m and the average depth is 5–10 m in the river section of the Seoul city area. The river bed is primarily comprised of sandy and muddy substrates, but that of the study site principally consisted of sand and gravel with abundant organic detritus with embedded cobble and boulder-sized stones. *E. orientalis* larvae (Figure 1d) were found within the 1–2 cm surface layer of the bottom.

The water temperature data at the sampling area were collated from data that were monitored every hour using an automatic temperature recorder (Sensortechnik Meinsberg GmbH, Model: MS2550, Germany) by the Amsa Water Purification Office of Seoul Metropolitan Government.

Water temperature was converted to degree days via the rectangle (Lee et al. 1999) method, as is shown in the following equation (1):

$$\text{Rectangle DD} = \frac{(T_{\max} + T_{\min})}{2} - T_{\mathrm{b}} \tag{1}$$

where DD is degree days, $T_{\max}$ is the daily maximum temperature, $T_{\min}$ is the daily minimum temperature, and T_{b} is the base temperature of the thermal threshold for egg development. A T_{b} value of 8.51°C, which was derived from a laboratory experiment on egg development (Lee et al., unpublished), was utilised for *E. orientalis* in this study.

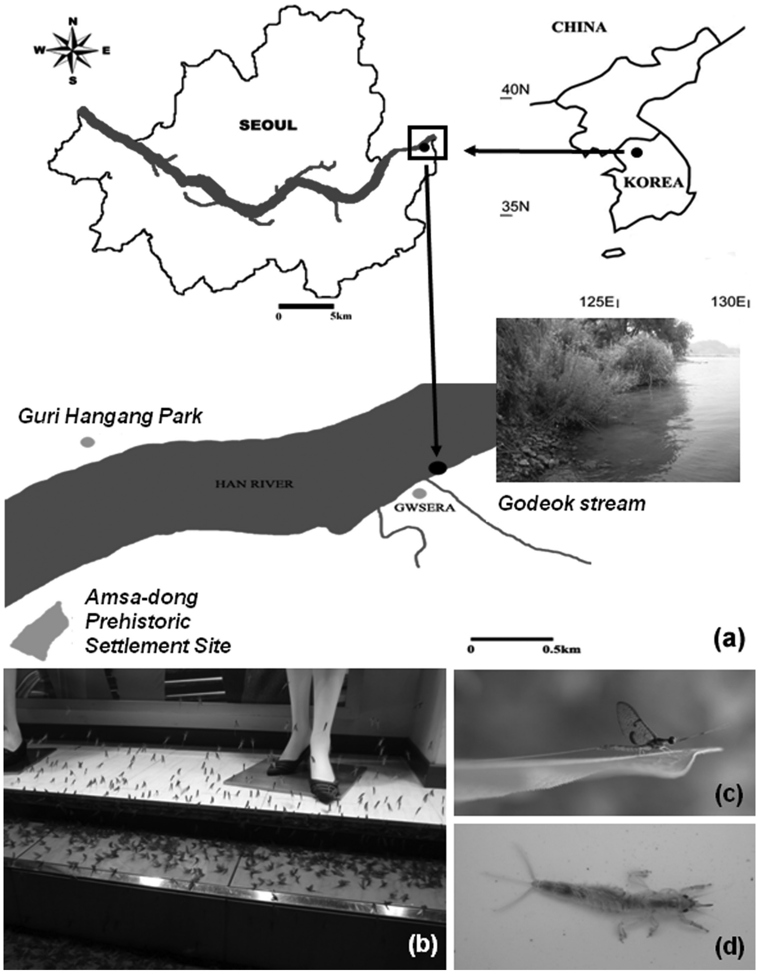

Figure 1. (a) The study area in the Han River, Seoul, Korea; (b) light attraction behaviour of *E. orientalis* near Han River; (c) male adult of *E. orientalis*; (d) larva of *E. orientalis*.

Sampling and laboratory procedure

E. orientalis larvae were sampled every month during the normal season between April 2006 and June 2007, but were sampled every two weeks during the emergence period from May to June of those years. Two quantitative samples were obtained during each sampling, using a Surber sampler (50 × 50 cm, mesh 0.25 mm). Sampling points were selected from the side of the river at a depth of 20–30 cm. All of the organic material, including larvae, within a 10 cm depth of the substrate, was sampled. The *E. orientalis* larvae were then sorted and preserved in 80% ethyl alcohol. *E. orientalis* adults (Figure 1c) were sampled using a sweeping net from the riparian vegetation around the sampling site. When available, the adult emergence was evaluated through observations of the swarming dance, car lights, street lights or light from windows around the sampling site (Figure 1b). Wingpad darkening of mature larvae was also evaluated in order to determine the time of emergence.

The adult and larval body lengths were measured with a Zeiss stereoscopic microscope (Zeiss Stemi 2000-C). All measurements were conducted with computer images captured under an image analyser using the AxioVision Rel. 4.5 program. The lengths of the adults and larvae (Figure 1c, d) were determined from the tip of the head to the last abdominal segment. Larval body size classes were categorised in 1 mm intervals of body length and were employed to analyse the larval development of *E. orientalis* (Lee et al. 1999, 2008). Using Cassie's probability paper method (Cassie 1954), cohorts of *E. orientalis* were identified from body length. All of the statistical analyses in this study were accomplished using SAS for Windows (SAS Institute Inc. 2004).

Estimation of secondary production and life cycle

Larval biomass was calculated indirectly from the body length (BL). Dudgeon (1996) previously demonstrated that log dry weight (DW) and ash-free dry weight (AFDW) are correlated strongly with BL in the case of *Ephemera spilosa*. Therefore, we randomly selected *E. orientalis* larvae ($n = 142$) and measured them, with DW from 1.0 to 13.0 mg and lengths between 2.59 mm and 22.61 mm. The linear regression curve derived from the log-transformed data evidenced a correlation coefficient of $r = 0.85$. From this regression, the following equation (2) was derived (Figure 2):

$$\text{In}\, Y = -11.53 + 2.28 \ln X \tag{2}$$

where $Y =$ dry weight (mg) and $X =$ body length (mm). This equation was employed to determine the biomass values of the *E. orientalis* larvae, for an estimation of secondary production. The biomass was determined from the dry weight (DW) of the larvae, which were dried using a dry oven (OHAUS Explorer Pro. Balance, Model: EPG213C, USA) at 60°C for 48 h with a precision of 0.1 mg.

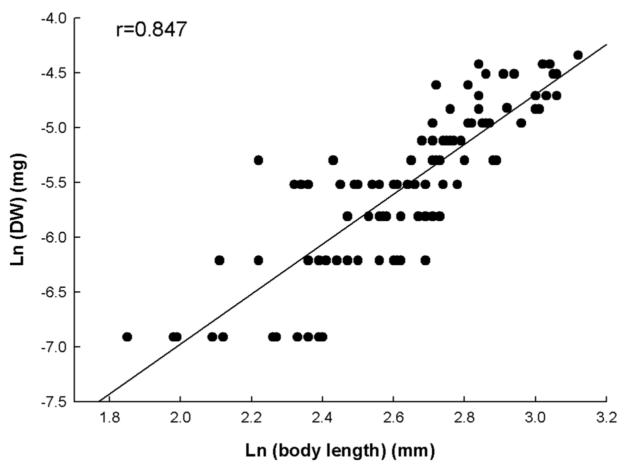

Figure 2. Linear regression of the log-transformed data (ln) of the length and dry weight of the larval *E. orientalis*.

The secondary production of *E. orientalis* larvae was estimated via the size–frequency method (Benke 1984, 1993). According to the size–frequency method, annual production estimation requires a calibration predicted on the cohort production interval (CPI: mean length of the aquatic stage relative to a full year); a calibration is necessary when CPI is significantly greater or less than one year. For the whole population including all the developmental groups, however, the CPI value of 12 was used as the larvae were observed throughout the study year (Lee et al. 2008).

The life cycle of *E. orientalis* was estimated via analysis of size–frequency distributions (in 13 size classes). The size classes varied between 2 mm and 28 mm, with an interval of 2 mm for each size class.

Results

Water temperature and temperature monitoring

The mean water temperature from the beginning of April 2006 to the end of June 2007 was 15.02 ± 6.84°C. The highest water temperature recorded was 25.22°C (September 4, 2006) and the lowest was 3.11°C (February 3, 2007) (Figure 3a). The precipitation of that period was 1998 mm.

Population size and life cycle

Total quantitative sampling of the larvae of *E. orientalis* resulted in a mean density (mean ± SD) of 105.88 ± 42.14 indiv/m^2. The collected number per quantitative sampling (5000 cm^2) was the largest on May 1, 2006 ($n = 104$) and the smallest on June 11, 2007 ($n = 28$) (Figure 4). While the number of sampled larvae of the spring cohort of 2007 was smaller than that of 2006, the mean larval body size was larger in 2007 (Figures 4 and 5).

The life cycle of *E. orientalis* in the Han River was analysed using 847 larvae collected during the sampling period. *E. orientalis* evidences a univoltine life cycle with two distinct cohorts (S1- and S2-groups) (Figure 5).

Figure 4 shows the frequency distribution of the body lengths of the *E. orientalis* larvae collected during each sampling occasion at the study site. The body lengths of the larvae ranged between 2.55 mm and 26.28 mm. The mass emergence of the S1-group was observed from mid-May to early June (Figure 5). The mean body length of the S1-group larvae reached 15.92 ± 3.57 mm in December, whereas that of the S2-group reached 5.71 ± 1.25 mm in December. A substantial increase in body length was observed during the winter (December 2006 to February 2007). The body length of the S-1 group adults was larger than that of the S2-group (male: $t_{22} = 8.08$, $p < 0.001$; female: $t_{39} = 15.85$, $p < 0.001$) (Table 1).

Based on the assumption of the life cycle pattern shown in Figure 5, the total accumulated degree days for the larval development of the S1- and S2-groups during the developmental period were 2565.07 and 2621.69, respectively (Figure 3b).

Secondary production

To determine the annual production of *E. orientalis*, we utilised the CPI 12, estimated for study area. Table 2 shows the estimate of the secondary production of *E. orientalis* in the study area during the study period. A total annual production

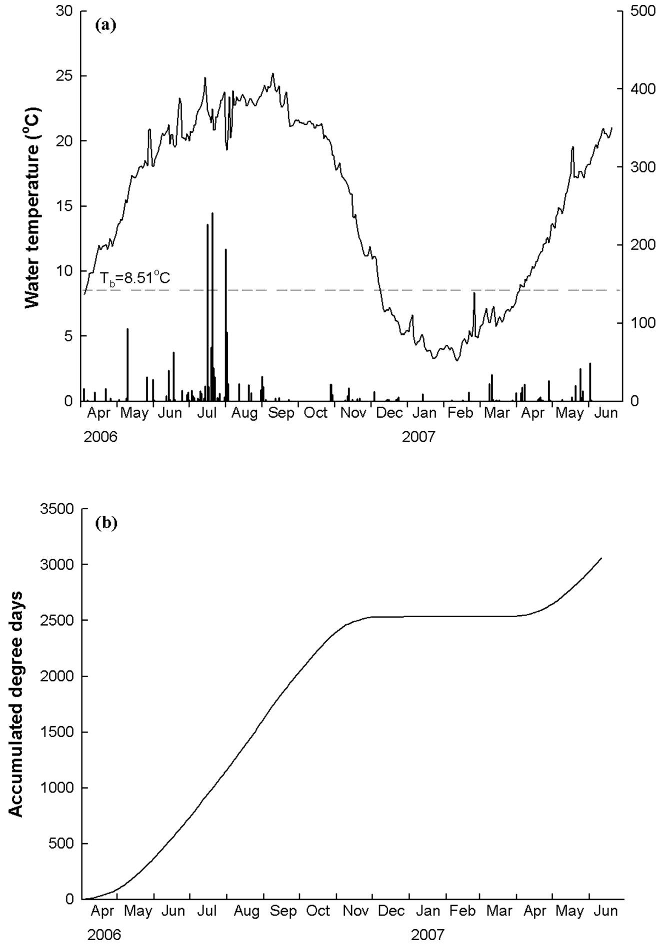

Figure 3. Water temperature and precipitation from the study area during study periods. (a) Water temperature and precipitation profile; (b) accumulated degree days (ADD) for larval development. T_b: base temperature of the thermal threshold for egg development.

Table 1. Two different adult body size groups of *E. orientalis* sampled from the study area.

Collecting time (cohorts)	Mean body length ± SD (mm) (no. of examined)	
	Male	Female
May–June (S1-group)	16.82 ± 1.32 (n = 19)	18.74 ± 1.43 (n = 17)
August (S2-group)	11.79 ± 0.76 (n = 5)	12.83 ± 0.96 (n = 24)

rate of 1350.84 mg DW/m^2/y, mean biomass of 325.17 mg DW/m^2, and P/B ratio of 4.15 were estimated. The mean biomass, cohort production, annual production, and cohort and annual P/B of larvae were greater in the S1-group than in the S2-group.

Table 2. Secondary production information for the cohorts of *E. orientalis* in this study.

Cohorts	CPI	D	B	CP	AP	P/B	
						Cohort	Annual
S1-group	11	52.50	233.36	815.83	889.99	3.50	3.81
S2-group	11	53.38	97.77	442.05	482.23	4.52	4.93
Whole population	12	105.88	325.17	1238.27	1350.84	–	4.15

Data were obtained by size–frequency method using the material collected between April 2006 and June 2007. CPI = cohort production interval; D = mean density (n/m^2); B = mean biomass (mg DW/m^2); CP = cohort production (mg DW/m^2); AP = annual production (mg DW/m^2/y); P/B = annual production to mean biomass ratio.

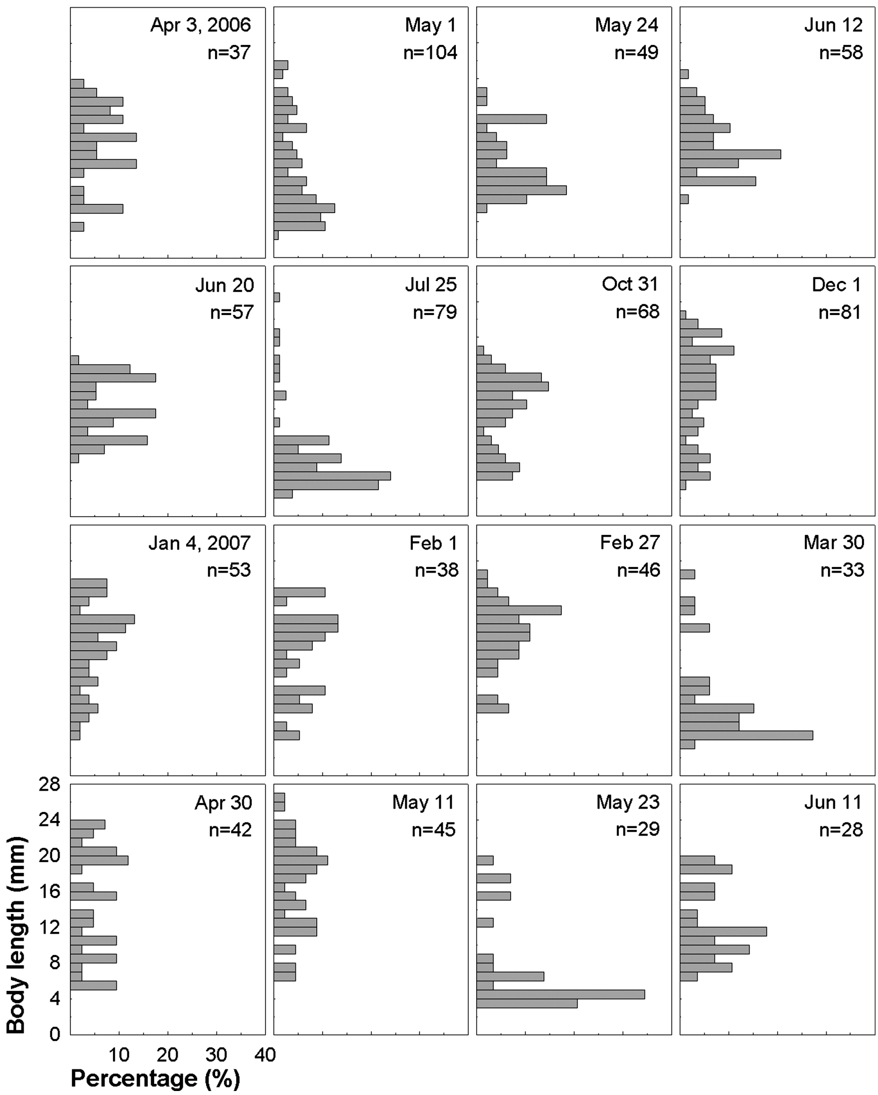

Figure 4. Size frequency histogram for *E. orientalis* larvae from the study area (n = sampled larvae per quantitative sampling (5000 cm^2)).

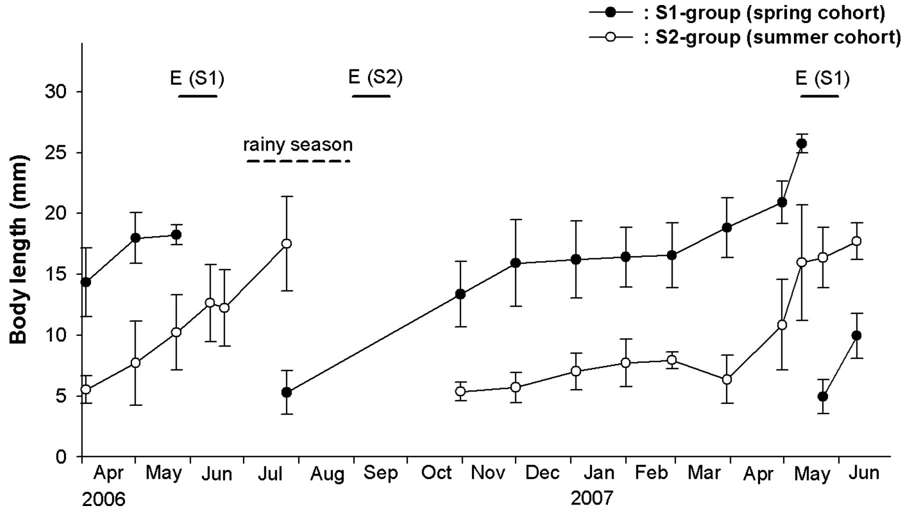

Figure 5. Life history pattern of *E. orientalis* from the study area.

Discussion

In this study, *E. orientalis* exhibited a univoltine life cycle with two distinct cohorts (S1- and S2-groups). Previous studies regarding the life history of *E. orientalis* demonstrated that the life cycles are flexible, depending on the habitat and location in which the populations inhabit. In the Japanese *E. orientalis*, Watanabe (1992) evidenced a bivoltine life cycle, and Kuroda et al. (1984) recognised three different cohorts in a year. Lee et al. (2008) demonstrated that the Korean *E. orientalis* has three generations within a two-year period in a Korean stream, in which the temperature is lower than that in this study. González et al. (2001) showed that the life cycles of two local populations of a caeniid mayfly in a stream reach differ depending on the prevailing spatial environmental conditions.

The emergence took place during two separate time periods from mid-May to early June, and in August. When the life cycle of the Han River population of *E. orientalis* was compared with that of the Gapyeong stream population, the life cycle of which consists of two slow-growing cohorts (S1- and S2-groups) and one fast growing cohort (F-group) (Lee et al. 2008), the former was found to lack the F-group. This can be explained in association with the precipitation pattern. As shown in Figure 2, we noted a localised heavy rain in Seoul and the Han River area in July 2006. The daily average precipitation in the Han River area in July 2006 was 32.71 ± 66.12 mm, whereas that of the Gapyeong stream in July 1998 was 7.58 ± 14.87 mm. The localised heavy rain reduced the water temperature and the newly hatched larvae of the S1-group were probably unable to develop into a fast growing cohort (F-group). The absence of small larvae in May and June of 2006 could also be affected by the water temperature. The daily mean water temperature from April 1 to June 11 in 2006 was 15.32 ± 3.83°C and that in 2007 was 15.76 ± 3.65°C. The occurrence of the small larvae (<6 mm) and the status of wingpad darkening of mature larvae could possibly separate the larval cohorts in May and June of 2007.

Our quantitative sampling of the larvae of the riverine *E. orientalis* in the Han River resulted in the annual production of 1350.84 mg DW/m^2, which is relatively higher than that of other stream mayflies. Lee et al. (2008) reported an annual production of 53.61 mg DW/m^2 in *E. orientalis* in the Gapyeong stream in Korea. Gose (1970) reported the value of 850 mg DW/m^2 for *E. strigata* in a Japanese stream. Dudgeon (1996) reported the value of 37.28 mg DW/m^2 for *E. spilosa* in the Tai Po Kau forest stream in Hong Kong. The P/B ratios were also higher than the values reported in the above studies, except that Lee et al. (2008) reported a P/B ratio of 6.36 for *E. orientalis* from the Gapyeong stream. The value for Han River *E. orientalis* was 4.15 in this study, 2.4 for *E. strigata* in a Japanese stream (Gose 1970), and 3.67 for *E. spilosa* from a Hong Kong stream (Dudgeon 1996). This may explain why the *E. orientalis* populations in the Han River evidenced richer nutrient contents and why the density of *E. orientalis* is higher than in other habitats.

Acknowledgements

This research was supported by a grant from the Ministry of Environment of Korean Government as ''Korea National Long Term Ecological Research Project (2006–2010)''.

References

Benke, A.C. (1984), 'Secondary production of aquatic insects', in *The Ecology of Aquatic Insects*, eds. V.H. Resh and D.M. Rosenberg, New York: Praeger, pp. 289–322.

Benke, A.C. (1993), 'Concepts and patterns of invertebrate production in running waters', *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie*, 25, 15–38.

Cassie, R.M. (1954), 'Some use of probability paper in the analysis of size frequency distributions', *Australian Journal of Marine and Freshwater Research*, 5, 513–522.

Dudgeon, D. (1996), 'The life history, secondary production and microdistribution of *Ephemera* spp. (Ephemeroptera: Ephemeridae) in a tropical forest stream', *Archiv für Hydrobiologie*, 135, 473–483.

González, J.M., Basaguren, A., and Pozo, J. (2001), 'Life history and production of *Caenis luctuosa* (Burmeister) (Ephemeroptera, Caenidae) in two nearby reaches along a small stream', *Hydrobiologia*, 452, 209–215.

Gose, K. (1970), 'Life history and production rate of *Ephemera strigata* (Ephemeroptera)', *Japanese Journal of Limnology*, 31, 21–26.

Hwang, J.M., Bae, Y.J., and McCafferty, W.P. (2008), 'A checklist of the Ephemeridae (Ephemeroptera)', in *Proceedings of the 11th International Conference on Ephemeroptera and 15th International Symposium on Plecoptera*, eds. F.R. Hauer and J.A. Stanford, Berkeley, CA: University of California Press, pp. 159–172.

Kuroda, T., Fujimoto, T., and Watanabe, N.C. (1984), 'Longitudinal distribution and life cycle of the three species of *Ephemera* in the Kazuradani River, Kagawa Prefecture', *Kagawa Seibutsu*, 12, 15–21.

Lee, S.J., Bae, Y.J., Yoon, I.B., and Watanabe, N.C. (1999), 'Comparisons of temperature-related life histories in two ephemerid mayflies (*Ephemera separigata* and *E. strigata*: Ephemeridae, Ephemeroptera, Insecta) from a mountain stream in Korea', *Korean Journal of Limnology*, 32, 253–260.

Lee, S.J., Hwang, J.M., and Bae, Y.J. (2008), 'Life history of a lowland burrowing mayfly, *Ephemera orientalis* (Ephemeroptera: Ephemeridae), in a Korean stream', *Hydrobiologia*, 596, 279–288.

SAS Institute Inc. (2004), SAS User's Guide. Version 9 (2nd ed.), Cary, SAS Institute Inc.

Watanabe, N.C. (1992), 'The life cycle of *Ephemera orientalis* (Ephemeroptera: Ephemeridae) in Kazuradani River, Kagawa Prefecture', *Kagawa Seibutsu*, 19, 105–109.