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The Life Cycle and Secondary Production of *Nemoura gemma* Ham and Lee (1998) in a High Mountain Stream in Korea

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Life cycle and secondary production of Nymphs of *Nemoura gemma* Ham and Lee were estimated by using specimens collected from a stream in Mt. Jumbong in the central Korean peninsula. *N. gemma* in the study stream was univoltine. Youngest nymphs were collected in April. They appeared to grow continuously until the emergence in early spring next year. The cohort production interval for the species was estimated as 399 days. The annual secondary production (ash free dry weight) estimated by removal-summation and the size-frequency methods were 582 and 786 mg m^{-2} yr^{-1}, respectively. Gut content analysis showed that *N. gemma* was a shredder.

Key words : *Nemoura gemma*, life cycle, secondary production, Mt. Jumbong

INTRODUCTION

Nemoura gemma Ham and Lee (Plecoptera: Nemouridae) was reported as a new species in 1998 (Ham and Lee, 1998). The adult specimens of this species were collected from several mountain areas in both southern and northern parts of Korea (Ham and Lee, 1998), which strongly suggested that this species could be widespread in Korea. However, their biological information such as life cycle and feeding ecology are lacking.

In the previous study on the macroinvertebrate fauna in a small stream at Mt. Jumbong (Chung, 2005a), *Nemoura* sp. was the second most abundant taxa, representing 21.8% (2.4~29.9%) of the all macroinvertebrate density. They were not identified to the species level due to the difficulty in the identification of nymphs. Yoon (1995) was the then available keys to *Nemoura* nymphs, and it included only one species, *Nemoura tau*. However, there had been five recognized species (Zwick, 1973; Ham and Lee, 1998, 1999; Kim *et al.*, 1998) and some more species to be described (see Ham, 2000). By 2009, one new species, *Nemoura phasianusa* (Ham, 2009) was added to the Korean *Nemoura* fauna. Therefore, giving *Nemoura* nymphs a correct species name was practically impossible at that time.

The *Nemoura* sp. of Chung (2005a) was retrospectively identified by using both adults collected at the site and those reared and emerged in the laboratory. They were composed of two species, *N. gemma* and the other species yet to be identified.

In this paper, I present the growth pattern, food preferences and the secondary production of a population *N. gemma* which was a part of *Nemoura* sp. in Chung (2005a).

MATERIALS AND METHODS

1. Study site

The first order stream where nymphs of *N. gemma* were collected drained a part of the south eastern slope of Mt. Jumbong (38° 03′N, 128° 25′E). The length of the stream was about 600 m and

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flew into a third order stream at 800 m above sea level. Samples were collected from the first 10~300 m upstream section from the confluent. The width and depth of the stream water measured during the baseflow condition in 1997 were < 2.7 m and 5~10 cm, respectively. Daily mean water temperature recorded with submerged thermistors (Hobo®temp) at 2 hour interval ranged 0~14°C, with the annual mean water temperature of 6.3°C for the study period (Chung, 2005b). The annual degree days (> 0°C) estimated from data collected during May 1995~August 1996 and February 1998~April 1999 was 2,300~2,600. During 1998, the daily mean water temperature in early March rose up to 3~5°C, about a month earlier than in other years. In early April, stream water temperature became 10°C, similar to summer water temperature in an ordinary year. Consequently, the annual degree day of the study year was about 2,600. Electronic conductivity and pH measured with hand held meters at the sampling site ranged 15~25 $\mu S\ cm^{-1}$ and 5.1~6.9, respectively (Chung, 2005b). Dominant leaf litter species on stream substrata were *Carpinus cordata*, *Quercus mongolica*, *Acer* sp. and *Kalopanax pictus* (Chung, 2005a).

The study stream received large amount of organic matters such as leaf litter, bark, and woody debris (about 500 $g\ m^{-2}\ yr^{-1}$ in ash free dry mass) from the forest through year-round direct fall from stream-side trees and lateral movement from stream banks (Lee *et al.*, 1997). Leaf litter represented about 90% of annual organic inputs (unpublished data).

2. Data collection

Nymphs of *N. gemma* were collected with other macroinvertebrates by using a pipe-type sampler (ø20 × 40 cm, stainless steel) at 4~6 week intervals from November 1997 through October 1998. Five samples were collected at every sampling date.

Macroinvertebrates with debris and inorganic sediments were put in plastic bags and treated with 3~5% formalin solution on site. They were brought and stored in the laboratory. Later, samples were washed with tap-water and passed through nested 1 mm and 0.25 mm sieves. All specimens retained on the 1 mm sieve were handpicked. For those attained on 0.25 mm sieve, a sample splitter (Waters, 1969) was used and a part of the sample (1/32~1/4) was examined for macroinvertebrates depending on the amount of substrates.

Nymphs of *Nemoura* were sorted, identified and counted under a dissecting microscope. Body length (1 mm interval), from the anterior margin of head to the posterior end of the abdomen, and the head width, from left to right outer margins of compound eyes, were measured with a graduated stage (mm) and an ocular micrometer (to the nearest 0.01 mm), respectively. Body length data were used to estimate biomasses of nymphs, while data of head capsule width (grouped at 0.05 mm interval in Fig. 1 to improve visibility) were used to separate *N. gemma* from the other congenial species.

For biomass (mg of ash free dry mass: AFDM) determination, the equation below was used:

$$\text{AFDM} = 0.00751 \cdot (\text{Body Length in mm})^{2.949}$$

(Chung, 2008)

Secondary production was calculated by the removal-summation method and the size-frequency method (Benke, 1984). To determine cohort production interval (CPI), the time of hatching was estimated as the median date between the sampling date of the first appearance of young nymphs and that just prior to it. The end time of nymphal growth was estimated similarly between the date of last catch of mature nymphs and the subsequent sampling date. Since the study was conducted only for a year, all cohorts were assumed to have the same life history traits.

Gut contents were examined for October samples (6 individuals) and February and March samples (8 individuals). Small individuals were avoided in the analysis, due to operational difficulties. October samples were composed of relatively young nymphs (body length: 2.5~3.5 mm) while those of February~March were composed of mature nymphs (body length: 4.2~6.5 mm). Guts were removed from the body of the sampled insects with fine forceps under a dissecting microscope and were placed in a drop of water on the slide. Gut contents were extracted by gently pressing guts with forceps or teasing guts with insect pins. At this stage, much of the gut contents was spreaded over the preparation. After removing the gut wall materials, gut contents were further spread with fine forceps if needed. A cover glass was then placed, and gut contents were examined under a phase-contrast microscope (× 100 ~ 400).

The ingestion rate of each food type was estimated using equations described in Benke and Wallace (1980). Assimilation efficiency for leaf tissue and amorphous detritus (10%) was taken from Benke and Wallace (1980). Net production efficiency was assumed to be 0.5 (Benke and Wallace, 1980).

RESULTS

Nemoura gemma appeared to grow continuously from the hatching in spring and summer to the emergence in spring next year (Fig. 1). The largest head capsule width (1.48 mm) of full grown nymphs was attained by February. The largest head capsule width maintained similarly in March. Thereafter, it decreased to 1.35 mm. Based on the change in the head width, *N. gemma* appeared to emerge during the period from March 10 to May 13. The youngest nymphs (head width of 0.16 mm) of next generation began to be collected on April 26. Thus, the first day of hatching was estimated as April 9. Hatch seemed to continue until June 10. Therefore, the latest nymphs of a generation co-occurred with the newly hatched individuals of the next generation, making two consecutive generations overlapped for about a month. The cohort development interval estimated by using two consecutive generation appeared to be 399 days (from April 9 to May 13 next year). However, it took about 11 months for individual nymph to complete their growth.

The growth of early hatched individuals was rather slow for the first several months, then they grew rapidly until winter (Fig. 1). But thereafter until the emergence, the growth became slow down again. The change in body length measured at mm-interval (Fig. 2), however, did not provide such a detailed growth pattern.

Annual average density of *N. gemma* was 3,200 ±7,355 m^{-2} (Mean ± 1 S.D., n=55), with the monthly maximum of 15,643 ± 10,309 m^{-2} (Mean ± 1 S.D., n=5) in June and the monthly minimum of 344 ± 348 m^{-2} (Mean ± 1 S.D., n=5) in March. The value of the coefficient of variation for each sampling occasion ranged from 17% in July to 165% in August, with 7 out of 11 occasions with values equal to or less than 100%.

Annual mean biomass (in AFDM) was 138.5 mg m^{-2}, and mean biomass (in AFDM) for cohort production interval was 117.2 mg m^{-2}. The secondary production (in AFDM) of *N. gemma* estimated by removal-summation method was 582 mg m^{-2} yr^{-1}, while that estimated by size-frequency method was 786 mg m^{-2} yr^{-1}. Consequently, annual production/biomass ratio (P/$\overline{B}$) ranged from 4.2 to 5.7, and cohort P/$\overline{B}$ ranged from 5.0 to 6.7, depending on the production estimation methods.

N. gemma had in their guts exclusively amorphous organic matters and vascular tissues of plants. Intermediate-sized individuals collected

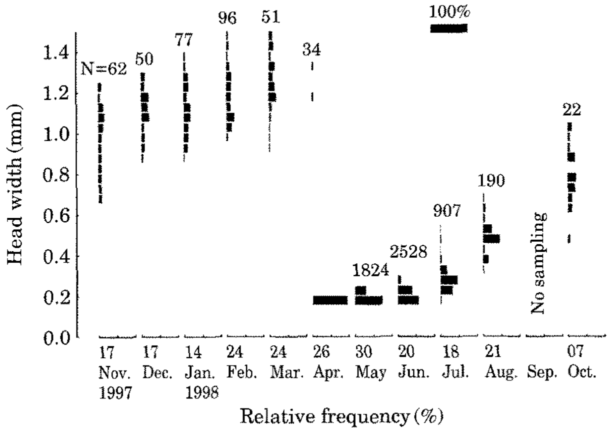

Fig. 1. Size frequency of head width measured from outer margins of left and right compound eyes of *Nemoura gemma*. Data were grouped at 0.05 mm interval to improve visibility. The smallest head width for April, May, June, and July were 0.16, 0.17, 0.16, and 0.20 mm, respectively.

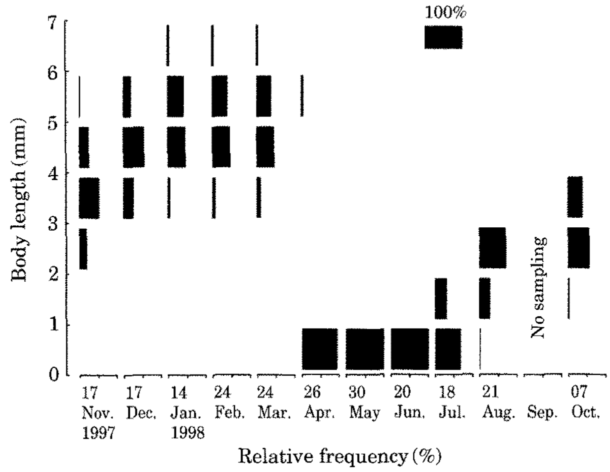

Fig. 2. Size frequency of body length measured from anterior margin of head to the tip of the last abdominal segment of *Nemoura gemma*.

in October 7 1988, had amorphous organic matter with few of vascular plant tissues. Full grown nymphs collected in February and March 1998 had vascular plant tissues in their guts, often covered with amorphous organic matters.

The amount of plant tissues (AFDM) consumed by the *N. gemma* was estimated as 11.7 or 15.7 g m^{-2} yr^{-1}, depending on secondary production estimation methods.

DISCUSSION

N. gemma in the study stream exhibited a univoltine, slow seasonal life cycle (*sensu* Hynes, 1970), apparently without delayed hatching or other developmental arrestment. The early advent of spring should have accelerated growth and caused an earlier emergence (see Brittain, 1983; Gregory *et al.*, 2000). Such a small change in the water temperature would not have any significant effect on the life cycle in Plecoptera (Harper, 1973). In addition, this species is largely restricted to small mountain streams with closed canopy (personal observation) which share similar characteristics such as cold and well aerated stream water and autumnal litter inputs from riparian vegetation (Ward, 1992). Therefore, the univoltinism, although it was concluded from one year study of a single population, seems to be applicable to other populations of *N. gemma* in Korea. Although some nemourids in Europe have been known to have flexible life cycles, their distribution ranges cover large geographical areas and their life cycle flexibility has been thought as one of reasons that enable them to spread over a wide range of habitats (Brittain, 1978). For example, *Nemoura cinerea* in southern Norway was univoltine under tree line, but populations above tree line was semivoltine (Brittain, 1974). *Nemurella pictetii*, another extremely widespread european Nemouridae species, exhibited plurivoltinism (Wolf and Zwick, 1989) and cohort splitting in Germany (Nesterovitch and Zwick, 2003).

Production estimates of *N. gemma* in dry mass, obtained by applying ash rate of 0.115 (Chung, 2008) to production estimated in AFDM, lied within the median range of production reported for shredders ($0.1 \sim 1.0$ g m^{-2} yr^{-1} in dry mass, Benke, 1993). The $P/\bar{B}$ ratios were largely in accord with the range ($4 \sim 6$) that was most frequently observed in univoltine stream insects (Waters, 1977; Benke, 1993).

The near-random distribution of *N. gemma* in the study stream seemed to reflect the facts that *N. gemma* was a shredder and organic matters were distributed rather evenly in the stream. Although further studies might need to confirm, such distribution pattern of organic matter was largely because the study stream was narrow and shallow such that effective litter trapping structures such as partly buried cobbles and twigs were common on the stream bottom. Leaf litter trapped by them would tend to stay there until occasional spates after heavy rainfall flushed them away to downstream sites.

N. gemma may be collected in almost any time of year at most of small streams in forests. However, since multiple species may occur simultaneously in a stream, one should be cautious in identifying nymphs of *Nemoura* species.

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LITERATURE CITED

Benke, A. 1984. Secondary production of aquatic insects. p. 289-322. *In*: The Ecology of Aquatic Insects (Resh, V.H. and D.M. Rosenberg, eds.). Praeger Publisher, New York.

Benke, A. and J.B. Wallace. 1980. Trophic basis of production among net-spinning caddisflies in a southern Appalachian stream. *Ecology* **61**: 108-118.

Benke, A.C. 1993. Edgardo Baldi Memorial Lecture. Concepts and patterns of invertebrate production in running waters. *Verh. Internat. Verein. Limnol.* **25**: 15-38.

Brittain, J.E. 1974. Studies on the lentic Ephemeroptera and Plecoptera of Southern Norway. *Norsk ent. Tidsskr.* **21**: 135-154.

Brittain, J.E. 1978. Semivoltinism in mountain populations of *Nemurella pictetii* (Plecoptera). *Oikos* **30**: 1-6.

Brittain, J.E. 1983. The influence of temperature on the nymphal growth rates in mountain stoneflies (Plecoptera). *Ecology* **64**: 440-446.

Chung, K. 2005a. Abundance and biomass of macroinvertebrate association in a first order stream at Mt. Jumbong, Kangwon-do. *Korean Journal of*

Limnology **38**: 1-10.

Chung, K. 2005b. The life cycle and secondary production of *Cincticostella levanidovae* (Tshernova) collected from a headwater stream in Mt. Jumbong, Korea. *J. Asia-Pacif. Entomol.* **8**: 367-374.

Chung, K. 2008. Body length-mass relationships of aquatic insect of mountain streams in central Korean peninsula. *Korean Journal of Limnology* **41**: 320-330.

Gregory, J.S., S.S. Beesley and R.W. Van Kirk. 2000. Effects of springtime water temperature on the time of emergence and size of *Pteronarcys californica* in the Henry's fork catchment, Idaho, U.S.A. *Freshwat. Biol.* **45**: 75-83.

Ham, S.A. 2000. Systematics of the Nemouridae (Plecoptera, Insecta) in Korea. Ph. D. Thesis. Chonnam National University, Gwangju.

Ham, S.A. 2009. *Nemoura phasianusa*, a new species of Nemouridae (Insecta: Plecoptera) from Korea. *Korean J. Syst. Zool.* **25**: 95-98.

Ham, S.A. and J.B. Lee. 1998. *Nemoura gemma*, a new species of the Nemouridae (Insecta: Plecoptera) from Korea. *Korean J. Syst. Zool.* **14**: 357-360.

Ham, S.A. and J.B. Lee. 1999. Four new species of Nemouridae (Plecoptera: Insecta) from Korea. *Korean. J. Biol. Sci.* **3**: 119-125.

Harper, P.P. 1973. Life histories of Nemouridae and Leuctridae in Southern Ontario (Plecoptera). *Hydrobiologia* **41**: 309-356.

Hynes, H.B.N. 1970. The Ecology of Running Water. University of Torento Press. Toronto.

Iversen, T.M. 1988. Secondary production and trophic relationships in a spring invertebrate community. *Limnol. Oceanogr.* **33**: 582-592.

Kim, J.S., Y.J. Bae and L.A. Zhiltzova. 1998. Biblographic review, systematic status, and biogeographic notes on Korean and Far East Russian stoneflies (Insecta: Plecoptera) with their new Korean records. *Korean J. Biol. Sci.* **2**: 419-425.

Lee, D.W., D.S. Cho, J.H. Lee and J.H. Park. 1997. Analysis of ecological structure and function of natural forest reserve in Mt. Jumbong for conservation of biodiversity. Report to Korea Science and Engineering Foundation.

Nesterovitch, A. and P. Zwick. 2003. The development of *Nemurella pictetii* Klapa'lek (Plecoptera: Nemouridae) in two springstreams in central Europe. *Limnologica* **33**: 231-243.

Ward, J.V. 1992. Aquatic Insect Ecology 1. Biology and Habitat. John Wiley & Sons, Inc., New York.

Waters, T.F. 1969. Subsampling for dividing large samples of stream invertebrate drift. *Limnol. Oceanogr.* **14**: 813-815.

Waters, T.F. 1977. Secondary production in inland waters. *Adv. Ecol. Res.* **10**: 91-164.

Wolf, B. and P. Zwick. 1989. Plurimodal emergence and plurivoltinism of Central European populations of *Nemurella pictetii* (Plecoptera: Nemouridae). *Oecologia* **79**: 431-438.

Yoon, I.B. 1995. Aquatic Insects of Korea. Junghaengsa, Seoul.

Zwick, P. 1973. On the stoneflies from Korea (Insecta, Plecoptera). *Fragmenta Faunistica* **19**: 149-156.

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