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The Relationship Between Egg Incubation Period and Temperature in Several Species of Plecoptera

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Egg incubation periods of 14 species of plecoptera were examined at 10°~11°C, 15°~16°C, 20°C, and 23°C under dark conditions. The total effective temperature (TET) was calculated by multiplying mean egg incubation days and water temperature of incubation periods. The relation between the TET and the incubation temperature was used to compare the life cycle of respective species. Perlodid species had higher TET values with a positive relation to incubation temperature than those of other species. Perlid species had low TET values in the 14 species with negative to variable relation, and Chloroperlid species showed variable to positive relations to incubation temperature. These results suggest that the relation between the TET and the water temperature reflected on their habitat of respective species.

Key words : egg incubation period, habitat, Plecoptera, total effective temperature (TET)

INTRODUCTION

The effect of temperature on egg development of aquatic insects is well known. Eggs of aquatic insects such as caddisfly, mayfly and stonefly can develop generally in a shorter time period at higher water temperatures (Brinck, 1949; Hynes, 1974; Zwick, 1980; Ward and Stanford, 1982; Jop and Szczytko, 1984; Brittain *et al*., 1984; Marten, 1990). A coefficient of the regression line relating the egg incubation period and water temperature has been used to compare the characteristics of egg development process of respective species. Brittain (1990) reported that the coefficient explained the necessary condition of temperature for development of the eggs. However, the regression line does not suitably reflect egg periods at higher water temperatures. Using the coefficient is not always useful for considering the life cycle of aquatic insects. Other indicator is needed in order to consider the life cycle of aquatic insects. In this report, the total effective temperatures (TET) of 14 species in stonefly were calculated by multiplying the mean egg incubation days and the water temperature in the incubation period. From the results of optimal water temperature for the egg development in respective species, author tries to discuss their habitat.

MATERIALS AND METHODS

Adult females of *Oyamia lugubris*, *Oyamia seminigra*, *Kamimuria tibialis*, and *Kamimuria uenoi* were collected during the oviposition season in 1996; adult females of *Sweltsa* sp. 2, *Isoperla nipponica*, *Stavsolus* sp., *Ostrovus* sp., and *Amphinemura* sp. were collected in 1997, and those of *Sweltsa* sp. 1, *Sweltsa* sp. 3, *Stavsolus japonicus*, and *Kiotina pictetii* were collected in 1998. The females of all the species, except for *Isoperla aizuana*, were observed flying for oviposition at three stations: Aritoshi (34°23′N,

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136° 00′E), Omata (34° 22′N, 136° 03′E), and the upper reaches of Omata (34° 21′N, 136° 05′E) along the Shigo River in Nara Prefecture. Individuals of respective species were collected, brought to the laboratory, and housed separately in plastic vials (ø3 × 6.5 cm). Newly emerged adults of *Isoperla aizuana* were collected at Kizu in Kyoto Prefecture (34° 44′N, 135° 49′E) in 1998 and brought to the laboratory; they were paired in the vials and allowed to mate naturally. The insects were fed diluted honey with water (1 : 10) soaked into cotton almost every day.

Table 1. Averaged mean egg incubation period and averaged hatching success of 14 species.

	Temperature (°C)	Mean egg incubation period (Days)	Hatching success (%)	Number of examined egg masses
Chloroperlidae				
Sweltsa sp. 1	23	31.9	17.98	8
	20	27.8	67.72	8
	16	35.6	55.75	8
	11	54.3	54.46	7
Sweltsa sp. 2	20	39.0	10.58	1
Sweltsa sp. 3	23	41.0	10.60	1
	20	41.0	23.63	4
	16	56.8	16.02	5
	11	89.0	9.65	1
Perlodidae				
Isoperla aizuana	23	–	0.00	3
	20	164.0	85.71	2
	16	175.5	43.68	2
	11	189.0	21.88	1
Isoperla nipponica	15	138.0	44.84	5
	10	134.0	37.48	2
Stavsolus japonicus	23	123.0	41.96	6
	20	141.3	63.10	7
	16	118.1	97.86	7
	11	147.0	85.10	7
Stavsolus sp.	20	96.0	28.95	1
Ostrovus sp.	20	129.0	71.79	1
	15	116.0	77.39	1
Perlidae				
Kiotina pictetii	23	25.0	79.40	1
	20	25.0	100.00	1
	16	33.5	92.22	2
Oyamia lugubris	23	34.0	40.08	2
	20	35.0	68.69	2
	15	45.5	37.25	2
Oyamia seminigra	23	22.5	64.25	2
	20	29.5	74.15	2
	15	49.0	66.80	1
Kamimuria tibialis	23	17.5	59.78	4
	20	20.8	78.08	5
	15	35.0	70.00	4
Kamimuria uenoi	23	20.8	46.35	6
	20	24.5	41.15	2
	15	35.3	28.60	4
Nemouridae				
Amphinemura sp.	23	–	0.00	4
	20	12.0	24.59	2
	15	16.2	33.64	5
	10	20.0	38.69	2

Egg masses deposited at the bottoms of the vials were collected and put into a 3 or 5 cm diameter Petri dish filled with water. These eggs were incubated at 10～11°C, 15～16°C, 20°C, and 23°C under dark conditions. The temperature treatments for each egg mass were determined randomly. The egg masses of most of the species were incubated at three or four different temperatures. The *Sweltsa* sp. 2, *Isoperla nipponica*, *Stavsolus* sp., and *Ostrovus* sp. egg masses were incubated under one or two temperature conditions owing to the small number of egg masses available for examination. Newly hatched nymphs were counted every two days and removed.

The incubation of eggs was terminated in eight months after the oviposition date if new nymphs were not found in the petri dish. The day at which half the nymphs had hatched was estimated, and the period between the hatching and the oviposition date was used as the mean egg incubation period. The egg hatching rate was calculated as the total number of hatched nymphs divided by the number of total eggs per mass.

The total effective temperature (TET) was calculated by multiplying the mean egg incubation days and the incubation water temperature. The relations between TET and incubation temperature were categorized into three classes: positive, variable, and negative. When the TET value increased with water temperature, it was categorized as a positive. The TET value decreased with temperature categorized as a negative. A variable relation was defined as the TET value was unchanged with temperature (range: 50 days °C).

The *Sweltsa* sp. 1 investigated in the present study is the same as the *Sweltsa* sp. recorded by Hayashi *et al.* (1997). *Stavsolus* sp. 1 and *Stavsolus* sp. 2 were defined by habitat and by head and abdomen patterns according to Inada (1996). *Ostrovus* sp. was identified by the pattern of the head and abdomen according to Inada (1996). *Sweltsa* sp. 2 and *Sweltsa* sp. 3 were defined by the pattern of the prothorax and parietalia of the head according to Hayashi (1996).

RESULTS

The mean egg incubation period of perlodid species was longer than 100 days regardless of water temperature, except for *Stavsolus* sp. at 20°C, and the period of *Amphinemura* sp. (Nemouridae) was shorter than 20 days (Table 1). There were no intra−specific differences in the period at the same water temperature conditions in the 14 species. The period tended to decrease with temperature increased between 10°C and

Table 2. The value of TET at each water temperature and relations of fourteen species in this study.

	Total effective temperature (days °C)				Relations
Chloroperlidae					
Sweltsa sp. 1	538 (11)	534 (16)	538 (20)	711 (23)	Variable
Sweltsa sp. 2			780 (20)		
Sweltsa sp. 3	979 (11)	909 (16)	820 (20)	943 (23)	Variable
Perlodidae					
Isoperla aizuana	2079 (11)	2808 (16)	3280 (20)		Positive
Isoperla nipponica	1340 (10)	2070 (15)			Positive
Stavsolus japonicus	1617 (11)	1888 (16)	2820 (20)	2829 (23)	Positive
Stavsolus sp.			1920 (20)		
Ostrovus sp.		1740 (15)	2580 (20)		Positive
Perlidae					
Kiotina pictetii		536 (16)	500 (20)	575 (23)	Variable
Oyamia lugubris		683 (15)	700 (20)	690 (23)	Variable
Oyamia seminigra		735 (15)	590 (20)	518 (23)	Negative
Kamimuria tibialis		525 (15)	416 (20)	403 (23)	Negative
Kamimuria uenoi		530 (15)	490 (20)	479 (23)	Variable
Nemouridae					
Amphinemura sp.	200 (10)	243 (15)	240 (20)		Variable

Total Effective Temperature: TET, calculated by multiplying the mean egg incubation days times the incubation water temperature, Relations: the relations between TET and water temperature, (Number): the water temperature that each egg mass were incubated.

23°C. This decreasing trend was clearly observed in Perlidae; however, *Sweltsa* sp. 1, *Sweltsa* sp. 3, perlodid species, and *Kiotina pictetii* did not show a decrease in the period at higher water temperatures. Hatching success differed depending on water temperature (Table 1). The hatching success of chloroperlid and perlid species was highest at 20°C. In *Isoperla aizuana*, no eggs hatched at 23°C, and the success was highest at 20°C. In *Stavsolus japonicus*, the success was highest at 16°C.

The total effective temperature (TET) showed that perlodid species had higher values with a positive relation to water temperature (Table 2). Perlid species had lower TET values of the 14 species and showed a negative relation in *Oyamia seminigra* and *Kamimuria tibialis* and a variable relation in *Kamimuria uenoi* and *Oyamia lugubris*. Chloroperlid species showed variable relations; when the water temperature was higher than 20°C, the value of TET increased immediately. In *Amphinemura* sp., the TET value was low, and the relation between temperature and TET was variable.

DISCUSSION

Perlodid species had higher hatching success at lower water temperature, whereas Perlid species had it at higher water temperature. This result suggests that perlid species can inhabit warmer areas than perlodid species. In fact, only perlid species inhabit tropical areas (Illies, 1964; Zwick, 1996). In Japan, perlodid species are abundant in the northern areas and at higher altitudes, while perlid and chloroperlid species can be seen throughout Japan (Kawai, 1985; Uchida, 1987). The eggs of *Isoperla aizuana* did not hatch at 23°C, also suggesting that their habitats are in relatively cold areas. Besides, *Stavsolus japonicus* and *Isoperla aizuana* showed positive relations between TET and water temperature. So, it would indicate that the habitats of these species with a positive relation are in a relatively colder area.

Oyamia seminigra and *Kamimuria tibialis* exhibited a negative relation between TET and water temperature, while *Oyamia lugubris* and *Kamimuria uenoi* displayed a variable relation. In the field, *Oyamia seminigra* and *Kamimuria tibialis* inhabit warmer areas than *Oyamia lugubris* and *Kamimuria uenoi* (Uchida, 1987). Therefore, it appears that species with a negative relation are found in relatively warmer habitats than are species those with a variable relation. The higher TET values of *Kamimuria uenoi* and *Oyamia lugubris*, as compared with those of *Oyamia seminigra* and *Kamimuria tibialis*, would also indicate that their habitats have lower water temperatures.

The TET values calculated from the data of European species in Saltvait & Lillehammer (1984) also provide habitat information. *Isoperla difformis* shows a negative relation between 8°C and 20°C; thus, the optimal temperature would be higher than 20°C. *Isoperla grammatica* shows a variable to positive relation between 12°C and 20°C, and the optimal temperature would be between 12 and 20°C. *Isoperla obscura* shows a positive relation between 4°C and 12°C and has the highest TET value among the three species, making the optimal temperature lower than 4°C. The actual habitats of these three species are consistent with the predicted habitat temperatures. In the field, *Isoperla difformis* does not live above 700 m, whereas *Isoperla obscura* inhabits only higher altitudes. *Isoperla grammatica* inhabits areas midway between the two (Saltvait and Lillehammer, 1984).

In this study, the relations between TET and incubation temperature of *Oyamia seminigra* and *Kamimuria tibialis* were negative, so that their optimal water temperature would be warmer than the examined water temperatures. The relations of perlodid species were positive, and thus these species are considered to inhabit areas with colder water temperatures than those examined. Chloroperlid species, *Amphinemura* sp. and other perlid species exhibited variable relations, indicating that the examined water temperatures would be optimal for these species. I think that the value of TET helps us discern the species differences in optimal temperature and their habitat.

LITERATURE CITED

Brinck, P. 1949. Studies on Swedish stoneflies (Plecoptera). *Opuscula Entmologica, Supplement* **11**: 1–250.

Brittain, B.J., A. Lillehammer and S.J. Saltvei. 1984. The effect of temperature on intraspecific variation in egg biology and nymphal size in the stonefly, *Capnia atra* (Plecoptera). *Journal of Animal Ecology* **53**: 161–169.

Brittain, J.E. 1990. Life history strategy in Ephemeroptera and Plecoptera. In: Campbell (ed) *Mayflies and Stoneflies*. Kluwer. Academic Publishers, Dordrecht, pp. 1–12.

Hayashi, Y. 1996. Diel periodicity of emergence and its environmental factors in *Sweltsa* sp. *Master thesis*, Graduate School of Nara Women's University.

Hayashi, Y., Y. Isobe and T. Oishi. 1997. Diel periodicity of emergence of *Sweltsa* sp. (Plecoptera; Chloroperlidae). In: Landolt & Sartori (eds) *Ephemeroptera & Plecoptera: Biology–Ecology–Systematics*. MTL, Fribourg, pp. 52–59.

Hynes, H.B.N. 1974. Observation on the adults and eggs of Australian Plecoptera. *Australian Journal of Zoological Supplement* **29**: 37–52.

Illies, J. 1964. Phylogeny and zoogeography of the Plecoptera. *Annual Review of Entomology* **57**: 117–140.

Inada, K. 1996. Illustrated stonefly adults (Insecta, Plecoptera) of Hyogo Prefecture, Honshu, Japan, Part 1, Peltoperlidae and Perlolidae. *Biology of Inland Water* **11**: 45–74.

Jop, K. and S.W. Szczytko. 1984. Life cycle and production of *Isoperla Signata* (Banks) in a central Wisconsin trout stream. *Aquatic Insects* **6**: 81–100.

Kawai, T. 1985. Plecoptera. In: Kawai T. (ed) *An illustrated book of aquatic insects of Japan*. Tokai University, pp. 125–148.

Marten, M. 1990. Interspecific variation in temperature dependence of egg development of five congeneric stonefly species (*Protonemura Kempny*, 1898, Nemouridae, Plecoptera). *Hydrobiologia* **199**: 157–171.

Saltveit, S.J. and A. Lillehammer. 1984. Studies on egg development in the Fennoscandian *Isoperla* species (Plecoptera). *Annls. Limnol.* **20**: 91–94.

Uchida, S. 1987. Plecopteran distribution in the Tamagawa River system. In: Ishikawa T., Yamashita T., Kojima J. and S. Uchida. (eds) *Analytic studies on the distribution of some insectgroups in the Tamagawa River system and its upper reaches*. Tokyu Foundation for Better Environment. pp. 23–78.

Ward, J.V. and J.A. Stanford. 1982. Thermal responses in the evolutionary ecology of aquatic insects. *Annual Review of Entomology* **27**: 97–117.

Zwick, P. 1980. Plecoptera (Steinfliegen). In *Handbuch der Zoologie* 26. Walter de Gruyter, Berlin. pp. 1–115.

Zwick, P. 1996. Variable egg development of *Dinocras* spp. (Plecoptera, Perlidae) and the stonefly seed bank theory. *Freshwater Biology* **35**: 81–100.

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