BRAUERIA (Lunz am See, Austria) 37:7-12 (2010)

# Relationship between water temperature and developmental rate of *Himalopsyche japonica* (MORTON) (Trichoptera: Rhyacophilidae)

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**Abstract.** To examine the relationship between water temperature and developmental rate of *Himalopsyche japonica* (MORTON) (Trichoptera: Rhyacophilidae), egg masses were reared to fifth instar larval, prepupal and pupal stages, at several constant water temperatures ranging between 5-24 °C in the laboratory, during 1998-2002. The duration of all four stages (egg, larva, prepupa and pupa) decreased with an increase in temperature. The estimated values for developmental zero and thermal constant, from egg to adult, were 0.9 °C and 1882.6 °C days, respectively (egg: 2.1 °C, 239.5 °C days, larva: 1.4 °C, 811.1 °C days, prepupa: 0.0 °C, 356.1 °C days, pupa: 1.5 °C, 292.7°C days).

**Key words**: water temperature, development, Trichoptera, *Himalopsyche*, developmental zero, thermal constant

## Introduction

Water temperature is one of the most important environmental factors influencing the lives and life cycles of aquatic insects (LEHMKUHL, 1974; SWEENEY, 1984). It plays a major role in regulating growth rate, developmental rate, metabolic rate, and timing and length of emergence, together with nutritional factors and photoperiod (DANKS & OLIVER, 1972; BRITTAIN, 1976, 1983; HUMPESCH, 1980; ELLIOTT & HUMPESCH, 1980; MCCAFFERTY & PEREIRA, 1984; SWEENEY & VANNOTE, 1986; OEMKE, 1987; WAGNER, 1990). Flexible voltinism occurs in some aquatic insects, normally in response to thermal differences in habitats at different latitudes or altitudes (GOSE, 1970; MACKAY, 1984; RUTHERFORD & MACKAY, 1986; LAVANDIER & CEREGHINO, 1995; TSURUISHI, 2006).

As a general rule, for insects, developmental zero (the minimum threshold temperature for development, which refers theoretically to a specific cold temperature at which the rate of development is at or near zero) (DZ) (°C), and thermal constant (i.e. degree-days) (TC) are two of the most useful factors in determining the correspondence between water temperature and developmental period, voltinism, and lifecycle (DAJOZ, 1977; HUGHES et al., 1984; KUNO, 1986).

Therefore, the precise DZ of various aquatic species, mainly for the egg stage, which is easy to rear, have been reported (BAR-ZEEV, 1958; BRUST, 1967; DANKS & OLIVER, 1972; ELLIOTT, 1972, 1978; MACKEY, 1977; HUMPESCH, 1980; HUMPESCH & ELLIOTT, 1980; MCCAFFERTY & PEREIRA, 1984; TAKEMON, 1990). However, few DZ in trichopteran species, especially for the larval stage which is difficult to rear, have been studied experimentally (SHIBATA, 1975; WAGNER, 1986; AURICH, 1992). Some studies only roughly estimated DZ, based on the developmental data and water temperatures of inhabited sites (GOSE, 1970; CUDNEY & WALLACE, 1980; NAGAYASU & Ito, 1997).

In the present study, all immature stages (egg masses, larvae, prepupae and pupae) of the predatory caddisfly, *Himalopsyche japonica*, were reared at several constant water temperatures ranging between 5-24 °C in the laboratory, during the period 1998-2002. This case study provides data on the DZ and TC of each developmental stage in a trichopteran species.

## Materials

To estimate the DZ and TC of *H. japonica*, it is considered most appropriate to examine the relationship between water temperature and developmental rate for individuals in a single local population in order to minimize variance between different local populations. However, because of the difficulty of collecting large numbers of specimens of this species from a single population, since it is a predatory larva that inhabits cascades in low population densities, *H. japonica* were used from the same regional population. The sample thus consisted of 4 local populations gathered from 4 different mountain streams within a roughly circular area (radius 22 km) in central Nagano Prefecture, Japan, i.e., Oizumi Stream (35°54'05N, 137°54'36E; elevation 1,030m), Oguro Stream (35°50'01N, 137°54'04E; elevation 850m), Takinoyu Stream (36°04'08N, 138°17'10E; elevation 1,480m), and Yana Stream (35°58'50N, 138°18'33E; elevation 1,490m).

Thirty-seven $1^{st}$-to-$5^{th}$ instar larvae and 8 pre-pupae, collected in the 4 streams from 8 August 1999 to 24 October 2001, were reared in the laboratory between 1999-2002. Three egg masses (oviposited in the laboratory from 27 June 1999 to 14 July 2002), and 33 $1^{st}$ instar larvae (5 larvae hatched in the laboratory on 27 July 1999, 26 larvae on 7 December 1999 and 2 on 2 December 2001), were also used for the experiments during the period.

## Rearing method

Larvae and pupae were reared individually in caged aquaria, using the method of TSURUISHI (2003). *Stenopsyche marmorata* larvae were cut into pieces and supplied daily to each *H. japonica* larva with a tweezers, as the larval ration. The photoperiod was set at 16 hours for all treatments. Water temperature was controlled by cooler (Cool Pipe 150L, TAITEC, Kanagawa, Japan) and heater (Thermo minder Jr-80, TAIYO, Tokyo, Japan). The temperature was maintained at 5, 10, 15, 18, 21, and 24 °C, and the range of variance controlled within 0.5 °C. During the experiments, all individuals were checked daily. The days when the larvae moulted into the next instar stage were recorded, similarly for the days when the $5^{th}$ instar larvae started to build pupal cases, the days when pupation was completed, and the days of adult emergence and hatching from eggs.

## Experimental water temperature

The number of *H. japonica* used in the experiments differed for the different water temperatures because of the difficulties of obtaining plentiful numbers of developmental stages for particular experiment periods, when a given constant water temperature was maintained in the aquaria. Each of 3 egg masses was divided into 3 parts and reared at 5, 10, and 18 °C (Table 1). Two $1^{st}$ instar larvae were reared at 5 °C and 25 at 18 °C; 4 $2^{nd}$ instar larvae at 5 °C and 25 at 18 °C; and 4 $3^{rd}$ instar larvae at 5 °C and 31 at 18 °C. Twelve $4^{th}$ instar larvae were reared at 5 °C, 27 at 18 °C, 6 at 21 °C, and 4 at 24 °C. Six $5^{th}$ instar larvae were reared at 5 °C, 17 at 10 °C, and 4 at 18°C. Five prepupae were reared at 5 °C, 23 at 10 °C, and 4 at 15 °C. Four male and 3 female pupae were reared at 5 °C, 9 male and 13 female at 10 °C, and 2 male and 1 female at 15 °C.

## Analysis

Instar duration indicates the time until the next moulting (for $5^{th}$ instar, the period before the larvae begin to build a pupal case), and prepupal duration includes the period of pupal-case building. The reciprocals of duration ($Duration^{-1}$) for each egg mass, instar larva, prepupa, and pupa, were calculated individually, and the values were averaged at each temperature. These represented the developmental rates at each temperature for each developmental stage. Developmental rates of the entire larval stage at 5 °C and 18 °C were, respectively, were calculated by summing up the mean duration for each instar larva. Similarly, developmental rates from egg to adult at 5 °C and 18 °C were calculated by summing up the mean durations of egg, larva, prepupa, and pupa. At 18 °C, however, it was not possible to obtain the duration for prepupa and pupa, so these values were substituted with those at 15 °C.

### Results

The duration of each developmental stage--egg, larva, prepupa, and pupa--decreased with an increase in water temperature, except for the $4^{th}$ instar larvae reared at 21 °C and 24 °C (Table 1). At 21 °C and 24 °C, the duration increased with the increase in temperature and 4 of 6 specimens at 21 °C, and 3 of 4 specimens at 24 °C, died at the $4^{th}$ instar stage. The egg mass duration was about 75 days at 5 °C, 30 at 10 °C, and 15 at 18 °C (Table 1). The $1^{st}$-to-$4^{th}$ instar larval duration was around 30-40 days at 5 °C, and 6-9 days at 18 °C. The $5^{th}$ instar duration was about 90 days at 5 °C, 40 at 10 °C, and 20 at 18 °C. The prepupal duration was about 60 days at 5 °C, 40 at 10 °C, and 20 at 15 °C. The pupal duration was about 90 days at 5 °C, 35 at 10 °C, and 20 at 15 °C.

The developmental rates of egg, larval, prepupal, and pupal stages, showed a significant linear correlation with the rearing water temperature (Figs. 1, 2). From the equation for the linear regression line, the DZ and TC values of the eggs were calculated as 2.1 °C and 239.5 °C days, respectively; larvae 1.4 °C and 811.1 °C days; prepupae 0.0 °C and 356.1 °C days; and pupae 1.5 °C and 292.7 °C days (Table 2, Figs. 1, 2). The estimated DZ for the full developmental period, from egg to pupa, was 0.9 °C, and TC 1882.6 °C days (Table 2).

### Discussion

Since the developmental rates measured in the present study were influenced by water temperature, collection days and populations, the experimental methods used here were not fully appropriate for estimating DZ and TC. Nevertheless, the results of regression analysis for developmental rate and water temperature revealed that the developmental rates of *H. japonica* could be almost fully explained by water temperature, which was a covariate factor in all experiments. It was thus considered that the other mentioned covariates did not cause significant error in the estimation of DZ or TC.

The developmental periods of aquatic insects usually decrease with increase in temperature, regardless of taxonomical order (BRUST, 1967; ELLIOTT, 1972, 1978; BECKER, 1973; PAJUNEN & SUNDBÄCK, 1973; PAJUNEN, 1975; SHIBATA, 1975; BRITTAIN, 1977; HUMPESCH, 1980; HUMPESCH & ELLIOTT, 1980; WAGNER, 1990). In this study, the duration of *H. japonica* egg mass, larval instar stages, and pupal stage, also decreased with increase in water temperature (Table 1).

In some species of aquatic insects, the TC needed to complete egg or larval development are regarded as constant (BAR-ZEEV, 1958; WRIGHT et al., 1982; ELLIOTT, 1978; SHIBATA, 1975; NOZAKI & SHIMADA, 1996). When the TC is constant, the developmental rate ($duration^{-1}$) shows a linear correlation with water temperature: Developmental rate = $TC^{-1}$ (WT − DZ). In some species, however, TC is not constant (BECKER, 1973; SWEENEY & SCHNACK, 1977), and the relationship between developmental time and temperature is well described by a power law (HUMPESCH, 1980; HUMPESCH & ELLIOTT, 1980; WARINGER & HUMPESCH, 1984; ELLIOTT & HUMPESCH, 1980). Although, the developmental rate of *H. japonica* appears to possess a linear correlation with water temperature (Figs. 1, 2), more precise data are required for a clearer discussion of this topic.

A summary of DZ values for aquatic insects from a previous study is shown in Table 3. In the figure, the DZ of *H. japonica* (except for the egg stage) are lower than for other aquatic insects. In addition, *H. japonica* larvae could feed and develop at 5 °C, while the feeding activities of some net-spinning caddis-fly larvae are curtailed or cease at the same temperature (GOSE, 1970; CUDNEY & WALLACE, 1980). No *Chaetopteryx villosa* caddis-fly larvae pupated successfully at a constant 6 °C in laboratory experiments; all died during the $5^{th}$ instar stage (WAGNER, 1990). In contrast, *H. japonica* larval development was suggested to be hindered at around 20 °C (Fig. 1), while the larval period of *Hydropsyche orientalis* was shortest at 22 °C; their development was not hindered until the water temperature exceeded 24 °C (SHIBATA, 1975). *H. japonica* inhabits high mountain streams with cool running water (TSURUISHI 2003b); so, it is reasonable to suggest that *H. japonica* has adapted successfully to developing in cool water habitats.

### Acknowledgments

The author is grateful to Prof. Toshio Yoshida for advice enabling the successful completion of this research. Thanks to Mr Paul Adams (Mahidol University) for correcting the English. Toshiko Tsuruishi, Hirohide Kojima, Masayuki Yagyu, Yasuko Ryu, Satoko Hosoya, Shin Matsumoto, and the students of the Forest Animals Laboratory, Shinshu University, kindly provided field samples and assisted with rearing experiments.

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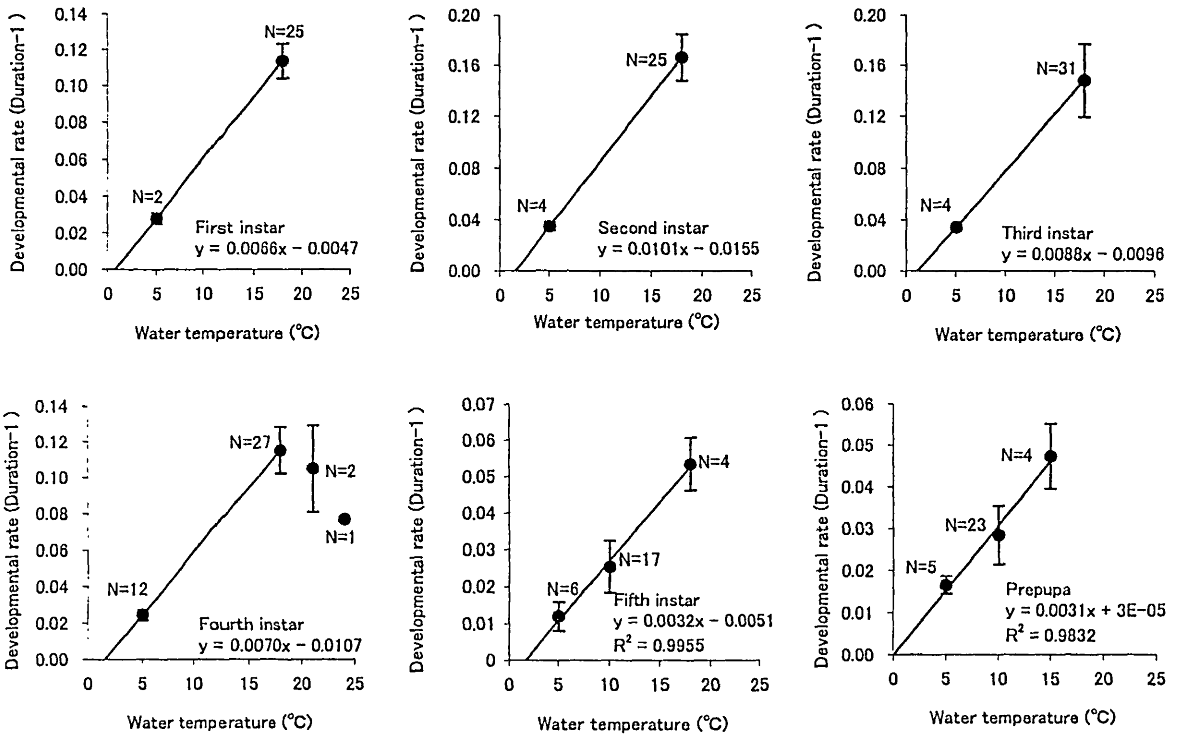


Fig. 1 Relationship between water temperature and larval developmental rate (mean value with standard deviation) from first instar to prepupae. Numbers of tested individuals are shown beside the plots. The vertical bars designate standard deviations.

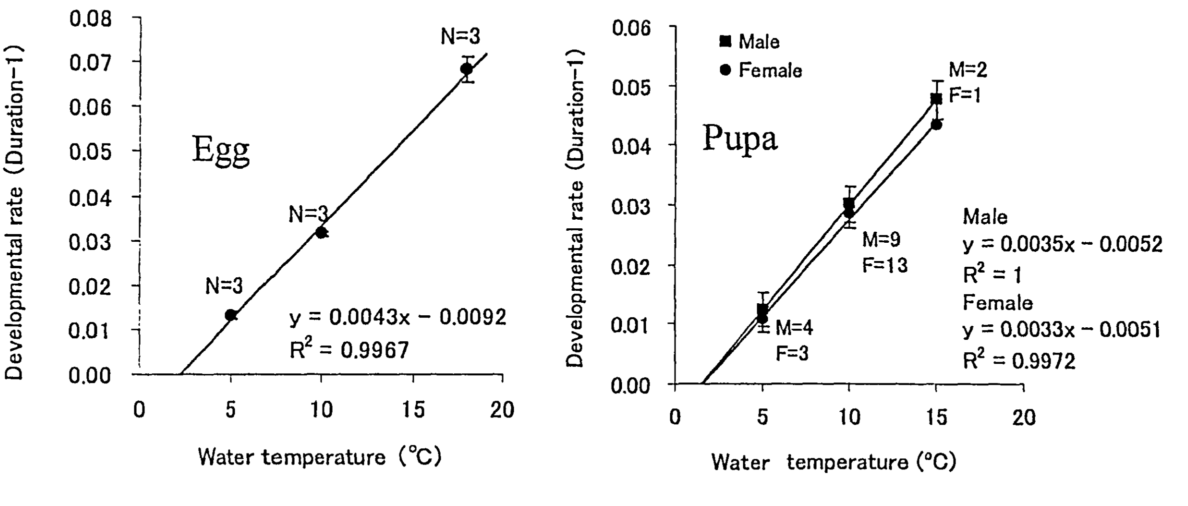


Fig. 2 Developmental rates of eggs and pupae at 5, 10, and 18 °C. Numbers of tested individuals are shown beside the plots.

Table 1. Instar durations (mean ± SD) of *Himalopsyche japonica* at different temperatures.

| | | | | | |
|---|---|---|---|---|---|
| Egg | WT (. ) | 5.0 | 10.0 | 18.0 | |
| | D (days) | 75.7±4.9 (3) | 31.7±0.6 (3) | 14.7±0.6 (3) | |
| 1st instar | WT (. ) | 5.0 | 18.0 | | |
| | D (days) | 35.5±3.5 (2) | 8.8±0.8 (25) | | |
| 2nd instar | WT (. ) | 5.0 | 18.0 | | |
| | D (days) | 28.5±2.6 (4) | 6.0±0.6 (25) | | |
| 3rd instar | WT (. ) | 5.0 | 18.0 | | |
| | D (days) | 29.3±1.9 (4) | 6.7±1.2 (31) | | |
| 4th instar | WT (. ) | 5.0 | 18.0 | 21.0 | 24.0 |
| | D (days) | 41.4±4.4 (12) | 8.7±1.0 (27) | 9.5±2.1 (2) | 13.0 (1) |
| 5th instar | WT (. ) | 5.0 | 10.0 | 18.0 | |
| | D (days) | 90.3±24.8 (6) | 42.8±13.4 (17) | 19.0±2.8 (4) | |
| Prepupa | WT (. ) | 5.0 | 10.0 | 15.0 | |
| | D (days) | 61.2±8.8 (5) | 37.2±9.6 (23) | 21.5±3.1 (4) | |
| Pupa | WT (. ) | 5.0 | 10.0 | 15.0 | |
| (Male) | D (days) | 83.3±16.5 (4) | 33.4±3.6 (9) | 21.0±1.4 (2) | |
| Pupa | WT (. ) | 5.0 | 10.0 | 15.0 | |
| (Female) | D (days) | 96.0±21.9 (3) | 35.2±2.9 (13) | 23.0±0.0 (1) | |

WT: Water temperature, D: Duration. Number of individuals for which data were obtained shown in parentheses.

Table 2. Developmental zero temperature and thermal constant for each stage of *Himalopsyche japonica.*

| Stage | Regression equation | Developmental Zero (. ) | Thermal constant (. days) |
|---|---|---|---|
| **Egg** | Y=0.0043X-0.0092 | **2.1□** | **239.5□ days** |
| **Larva** | | | |
| 1st | Y=0.0066X-0.0047 | 0.7 | 149.1 |
| 2nd | Y=0.0101X-0.0155 | 1.5 | 107.5 |
| 3rd | Y=0.0088X-0.0096 | 1.1 | 105.9 |
| 4th | Y=0.0070X-0.0107 | 1.5 | 146.7 |
| 5th | Y=0.0032X-0.0051 | 1.6 | 331.0 |
| | | **1.4□** | **Total 811.1□ days** |
| **Prepupa** | Y=0.0031X+0.0000 | **0.0□** | **356.1□ days** |
| **Pupa** | | | |
| Male pupa | Y=0.0035X-0.0050 | 1.4 | 283.7 |
| Female pupa | Y=0.0033X-0.0051 | 1.5 | 301.7 |
| | | **Average 1.5□** | **Average 292.7□ days** |
| **Egg to Adult** | | **0.9□** | **Total 1882.6□ days** |

Table 3. Summary of developmental zero temperatures (°C) of aquatic insects.

| | | E | L | P | W | References |
|---|---|---|---|---|---|---|
| Trichoptera | Himalopsyche japonica | 2.1 | 1.4 | 1.5 | 0.9 | Present Study |
| | Nothopsyche babai | -1 | | | | Aoya and Nozaki 2001 |
| | Nothopsyche ruficollis | -0.2 | | | | Nozaki and Shimada 1996 |
| | Apatania fimbriata | -0.255 | | | | Aurich 1992 |
| | Chaetopteryx villosa | 0.77 | 6 | | | Wagner 1986 |
| | Chaetopteryx villosa | | 6 | | | Wagner 1990 |
| | Hydolopsyche orientalis | 7.8 | 9.4 | 9.4 | | Shibata 1975 |
| Ephemeroptera | Ephemera strigata | | | 8.9 | | Takemon 1990 |
| | Ephemerella ignita | 3.6 | | | | Elliott 1978 |
| | Baetis rhodani | 0 | | | | . .... .. 1972 |
| | Rhithrogena cf. hybrida | 0 | | | | Humpesch & Elliott 1980 |
| | Rhithrogena semicolorata | 0 | | | | Humpesch & Elliott 1980 |
| | Rhithrogena loyolaea | 0 | | | | Humpesch & Elliott 1980 |
| | Ecdyonurus picteti | 0 | | | | Humpesch 1980 |
| | Ecdyonurus venosus | 0 | | | | Humpesch 1980 |
| | Ecdyonurus dispar | 0 | | | | Humpesch 1980 |
| | Ecdyonurus torrentis | 0 | | | | Humpesch 1980 |
| | Ecdyonurus insignis | 0 | | | | Humpesch 1980 |
| | Stenacron interpunctatum | | 4 | 18 | | McCafferty & Pereira 1984 |
| | Hexagenia bilineata | 10.0 | | | 10.1 | Wright et al 1982 |
| Diptera | Ablabesmyia monilis L. | | | | 11.7 | Mackey 1977 |
| | Synorthocladius semivirens (K.) | | | | 3.5 | Mackey 1977 |
| | Cricotopus bicinctus (Meig.) | | | | 3.8 | Mackey 1977 |
| | Cricotopus sylvestris (Fabr.) | | | | 3.8 | Mackey 1977 |
| | Microcricotopus bicolor (Zett.) | | | | 4.6 | Mackey 1977 |
| | Metriocnemus hirticollis (Staeg.) | | | | 4.3 | Mackey 1977 |
| | Limnochironomus pulsus Walk. | | | | 4.3 | Mackey 1977 |
| | Parachironomus biannulatus (Staeg.) | | | | 4.2 | Mackey 1977 |
| | Polypedilum convictum (Walk.) | | | | 4.2 | Mackey 1977 |
| | Phaenopsectra flavipes K. | | | | 2.4 | Mackey 1977 |
| | Cladotanytarsus atridorsum (K.) | | | | 4.4 | Mackey 1977 |
| | Rheotanytarsus photophilus G. | | | | 4.6 | Mackey 1977 |
| | Aëdes aegypti | | | | 13.3 | Bar-Zeev 1958 |
| | Aedes vexans | | | | 9.0 | Brust 1967 |
| | Aedes nigromaculis | | | | 11.0 | Brust 1967 |
| | Culiseta inornata | | | | 6.0 | Brust 1967 |
| | Anopheles quadrimaculatus | | 7 | | | Huffaker 1944 |
| Odonata | Coenagrion puella | 10 | 10 | 10 | 10 | Waringer &Humpesch 1984 |
| Plecoptera | Taeniopteryx nebulosa | -0.1 | | | | Mutch & Pritchard 1986 |
| | | -0.8 | | | | Mutch & Pritchard 1986 |
| | | -1.3 | | | | Mutch & Pritchard 1986 |
| | | -0.4 | | | | Mutch & Pritchard 1986 |
| | | 1.8 | | | | Mutch & Pritchard 1986 |
| | | -5.1 | | | | Mutch & Pritchard 1986 |
| | | 0.7 | | | | Mutch & Pritchard 1986 |
| | | -1.0 | | | | Mutch & Pritchard 1986 |
| | | 1.6 | | | | Mutch & Pritchard 1986 |

E: egg stage L: larval stage P: pupal stage W: all stages from egg to adult