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Original Artcle

Distribution of adult *Cheumatopsyche brevilineata* (Trichoptera : Hydropsychidae) along the shore of Lake Suwa, Japan

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Abstract

We collected adult *C. brevilineata* with light traps to clarify the in distribution along the shore of Lake Suwa. Light traps were located 0 m (St. 0), 1,375 m (St. 1), 2,700 m (St. 2), 3,650 m (St. 3), 4,600 m (St. 4) and 5,325 m (St. 5) from the outlet stream of the lake. A total of 105,874 adults were collected, and the sex ratio of the adults was biased to female throughout the study period except on July 23. The daily mean abundance of adults was highest at St. 0 (9,368.4 ± 8,569.1 ind. day^{-1}) and declined rapidly the further the distance from the outlet of the lake. The mean relative proportion of the daily abundance at St. 1-5 to that at St. 0 was less than 5%. In addition, there was a significant negative correlation between the daily abundance at a site and the distance from the lake outlet to the site. These results suggest that adult *C. brevilineata* can move at least 5,325 m, although most adults do not move so much.

Key words : Adult caddisfly, *Cheumatopsyche brevilineata*, Flight distance, Lake outlet, Lake Suwa, Light trap

Introduction

Outlet streams of lakes and reservoirs are noted for high densities of filter feeding invertebrates, e.g. net-spinning caddisflies (Trichoptera: Hydropsychidae, Stenopsychidae, etc) and blackflies (Diptera : Simuliidae) (Armitage, 1976 ; Harding, 1992, 1994 ; Hoffsten, 1999 ; Katagami *et al.*, 2004, Oswood, 1979 ; Sheldon and Oswood, 1977 ; Wotton, 1982, 1988, 1992). The large quantity and high quality of suspended solid (seston) from lakes and reservoirs provide food for filter feeders in outlet streams (Armitage, 1977 ; Cushing, 1963 ; Gibson and Galbraith, 1975 ; Malmqvist and Brönmark, 1984 ; Richardson, 1984 ; Wotton, 1988). The density of filter feeders decreases downstream as the quality and/or quantity of seston decreases (Armitage & Caper, 1976 ; Maciolek and Tunzi, 1968 ; Morin and Peters, 1988 ; Oswood, 1979). Therefore, the outlets of lakes and reservoirs are likely to provide a good habitat for filter feeders.

The Tenryu River flows from the Kamaguchi Floodgate as the sole outlet stream of Lake Suwa in the central part of Nagano Prefecture. Several species of filter feeders live in the Tenryu River at a high density (Katagami *et al.*, 2004; Komatsu, 1974 ; Kumakawa and Uchida, 2001) because Lake Suwa supplies a large quantity of seston to the upper reaches (Katagami *et al.*, 2004). Recently, a large number of adults of a caddisfly, *Cheumatopsyche brevilineata* (Iwata), has occurred at the outlet of Lake Suwa (Kimura *et al.*, 2006). *C. brevilineata* is a small-sized species that belongs to the Hydropsychidae, and widespread in the southern part of the Eastern Palearctic Region, including Japan and Russia (Tanida *et al.*, 2005). Trichoptera is sometimes the most abundant benthic macroinvertebrate of rivers (Tanida *et al.*, 2005 ; Wiggins, 1996), especially *C. brevilineata* in Japanese rivers (e.g., Adachi *et al.*, 1987 ; An *et al.*, 1993 ; Murakami *et al.*, 1987 ; Yagi and Sasakawa, 1992). Larvae of *C. brevilineata* distribute in the upper to middle reaches of the Tenryu River (Katagami *et al.*, 2004 ; Komatsu, 1974 ; Kumakawa and Uchida,

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2001 ; Tenryu River Upper Reaches Construction Work Office, 1996), however, they have never been recorded either in Lake Suwa or around the mouth of inflows (Chino, 1918 ; Uchida, 2005 ; Yoshida *et al.*, 1997 ; Yoshida, 1998). Therefore, the adult *C. brevilineata* distributed along the shore of Lake Suwa quite likely came from the Tenryu River, at the outlet of the lake.

In this study, we collected adult *C. brevilineata* with light traps placed along the shore to clarify the distribution of adults in Lake Suwa. In addition, we examined the relationship between the abundance of adults at a site and the distance from the outlet to the site to estimate the maximum flight distance of the adults.

Materials and Methods

Study Site

Lake Suwa is a eutrophic shallow lake located in the central highlands of Honshu, Japan, at the altitude of 759 m a.s.l (36° 03' N, 138° 05' E). The lake has a surface area of 13.3 km^2 and a mean depth of 4 m (maximum 6.5 m). Thirty-one rivers flow into Lake Suwa, but the Tenryu River is the sole outlet **(Fig. 1)**.

Collection of adult *C. brevilineata*

Adult *C. brevilineata* were collected along the shore of Lake Suwa using light traps from June 3 to 7 and July 22 to 29 in 2004, i.e. 11 days. Each trap was equipped with a 6-W black fluorescent lamp. The traps were placed along the north shore at the distance of 1,375 m (St. 1), 2,700 m (St. 2), 3,650 m (St. 3) and 4,600 m (St. 4), and the furthest 5,325 m (St. 5) from the outlet of Lake Suwa. In addition, we also set traps on the south shore of the lake 2,650 m (St. 6) and 3,700 m (St. 7) from the lake outlet. Trap was also set at the lake outlet (0 m: St. 0) to clarify the daily emergence of adult *C. brevilineata*. All traps were operated throughout the day, and the cages to capture adults were replaced every morning between 7:30 and 9:30. The numbers of males and females of adult *C. brevilineata* were counted under a binocular microscope and stored in 70% ethyl alcohol in the laboratory. The abundances were indicated as the sum of the numbers of males and females unless otherwise stated.

Environmental Data

Environmental conditions, e.g. air temperature, wind velocity and direction, cloud cover, relative humidity and moon age, may directly influence flight behavior of

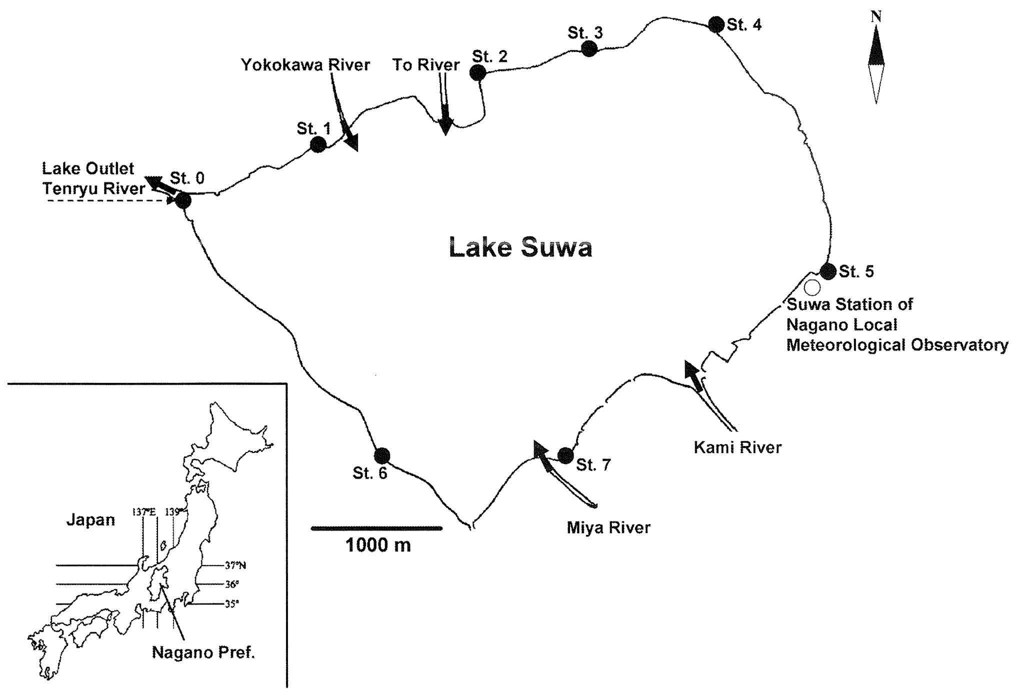

Fig. 1 Map of Lake Suwa, showing distance of sampling sites from lake outlet and Suwa Station of Nagano Local Meteorological Observatory.

insects. In this study, we focused on the air temperature, wind velocity and wind direction as environmental factors that affect dispersal behavior (Johnson, 1969). Daily mean wind velocity and wind direction between 17:00 and 22:00 were used. This may be the same as the swarming time of adult caddisflies (Mori and Matsutani, 1953 ; Katoh and Ohgushi, 1959) during the study period. Modal wind direction was used for the wind direction. All these environmental data were obtained from the Suwa Station of Nagano Local Meteorological Observatory (Japan Meteorological Agency, 2004).

Data Analysis

The significance of the differences in daily abundance of adults between males and females among the sites were tested using the Wilcoxon signed-rank test. The significance of the Pearson correlation coefficients between the daily total abundance of adult *C. brevilineata* and the environmental factors were tested. The significance of the differences in daily abundance of adults between St. 2 and St. 6, and St. 3 and St. 7 were also tested using the paired-sample t test or Wilcoxon signed-rank test. Moreover, the significance of the Spearman's rank correlation coefficient between the distance from the outlet to a site and the daily total abundance of adult *C. brevilineata* at the site was tested, and a linear regression model was fitted to these data. All the data analyses were conducted using the software SPSS version 11.5.1J (SPSS Japan Inc.).

Results

Environmental conditions

Mean air temperature during the swarming time of adults were 20.1 ± 2.7℃ (ranged from 18.2 ± 2.2℃ to 21.8 ± 2.9℃), and 25.5 ± 2.8℃ (ranged from 21.4 ± 0.2℃ to 27.4 ± 2.0℃) in June and July, respectively (**Table 1**). In addition, mean wind velocity during the swarming time averaged 3.1 ± 1.5 m s^{-1} (n = 11), and ranged from 1.7 ± 0.8 m s^{-1} (July 25) to 4.9 ± 2.3 m s^{-1} (July 22) (**Table 1**). The most frequent direction of the wind was southeast followed by south during the study period.

Abundance of adult *C. brevilineata*

A total of 110,511 adult *C. brevilineata* (21,014 males

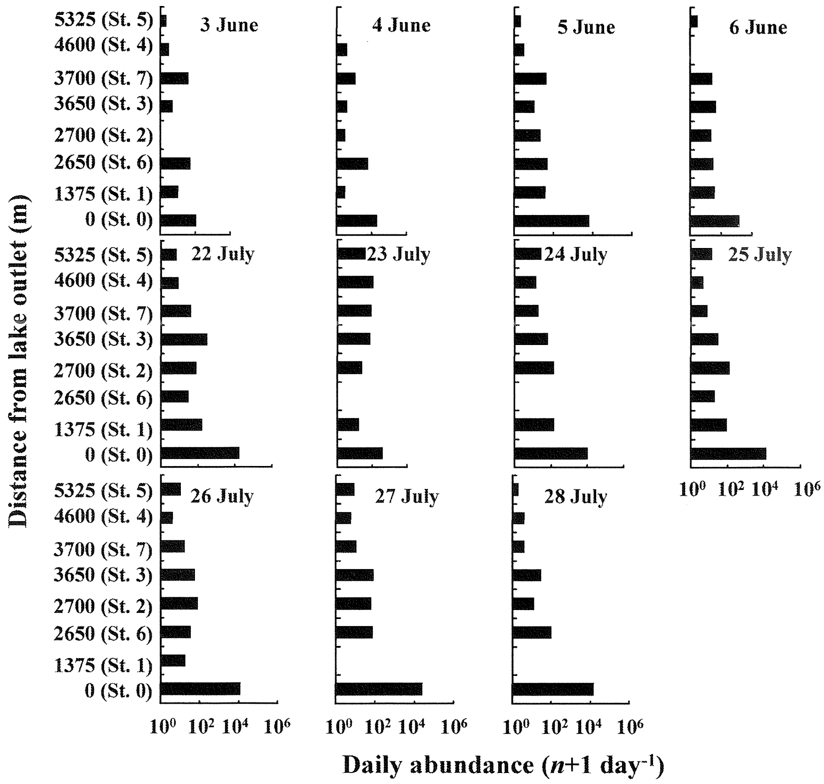

Fig. 2 Daily abundance of *C. brevilineata* at each distance from the lake outlet.

Table 1 Daily aboundanse of *C.brevilineata* and environmental conditions (mean air temperature, mean wind velocity, modal wind direction between 17:00 and 22:00) during the sampling periods. Data from Suwa Station of Nagano Local Meteorological Observatory were used during the investigation (Japan Meteorological Agency, 2004).

Date	n male / female	Mean air temperature (℃)	Mean wind velocity (m s^{-1})	Modal wind direction
2004 June 03	38 / 176	18.2 ± 2.2	3.7 ± 1.7	SE
2004 June 04	84 / 197	21.4 ± 3.2	3.6 ± 1.0	SE/ESE
2004 June 05	987 / 5655	21.8 ± 2.9	2.7 ± 1.0	SE
2004 June 06	231 / 1473	19.0 ± 0.3	2.0 ± 0.4	S/SSE
2004 July 22	5653 / 13062	26.1 ± 2.1	4.9 ± 2.3	WNW/W
2004 July 23	437 / 293	26.5 ± 2.2	3.7 ± 0.5	ESE
2004 July 24	2792 / 7817	26.9 ± 3.0	3.0 ± 1.4	S
2004 July 25	246 / 12846	21.4 ± 0.2	1.7 ± 0.8	S
2004 July 26	474 / 12122	23.1 ± 1.1	2.7 ± 0.5	SE
2004 July 27	5136 / 21523	27.1 ± 1.8	1.9 ± 0.6	E/SE
2004 July 28	4490 / 10146	27.4 ± 2.0	3.8 ± 2.1	NNE/ENE
Total	20564 / 85310			
Mean ± SD	1869.5 ± 2221.5 / 7755.5 ± 6949.6	23.5 ± 3.8	3.1 ± 1.5	

and 89,497 females) were collected over 11 days of the study period, and the sex ratio of the adult *C. brevilineata* was significantly biased to female ($p < 0.01$, Wilcoxon signed-rank test). Daily abundance of the adults did not show significant correlations either with the daily mean air temperature or wind velocity.

Distribution pattern of adult *C. brevilineata*

Figure 2 shows daily abundance of adult *C. brevilineata* in each station. The daily abundance of adult *C. brevilineata* at St. 0 was the highest among the stations throughout the study period. At St. 0, the maximum abundance was 26,417 ind. on July 27, and the minimum was 111 ind. on June 3. The daily abundance at St. 0 accounted for 86.3 ± 19.0% (n = 11) of the daily total abundance of all stations. The daily mean abundance was 52.3 ± 52.5 ind. day^{-1} at St. 2, located on the north shore of the lake, and 39.5 ± 29.2 ind. day^{-1} at St. 6 on the south shore. In addition, the daily mean abundance was 65.0 ± 89.3 ind. day^{-1} at St. 3 on the north shore, and 27.6 ± 24.6 ind. day^{-1} at St. 7 on the south shore. There was no significant difference in the daily abundance between St. 2 and St. 3, and St. 4 and St. 5, i.e. among stations with almost the same distance from the lake outlet. The daily mean abundance was 9,368.4 ± 8,569.1 ind. day^{-1} at St. 0, 48.0 ± 60.8 ind. day^{-1} at St. 1 (relative proportion to the daily abundance of adults at St. 0 : 1.8 ± 2.5%), 52.3 ± 52.5 ind. day^{-1} at St. 2 (1.2 ± 1.9%), 65.0 ± 89.3 ind. day^{-1} at St. 3 (2.8 ± 5.4%), 14.3 ± 33.0 ind. day^{-1} at St. 4 (3.1 ± 9.0%), and 9.9 ± 13.2 ind. day^{-1} at St. 5 (1.2 ± 3.4%). The daily abundance at St. 1 was much lower than at St. 0.

Figure 3 shows the relationship between the daily abundance of adults at a site and the distance from the lake outlet to the site. The daily abundance at a site declined with the distance from the lake outlet (r = -0.61, n = 66, $p < 0.01$, Spearman's rank correlation coefficient) (**Fig. 3**).

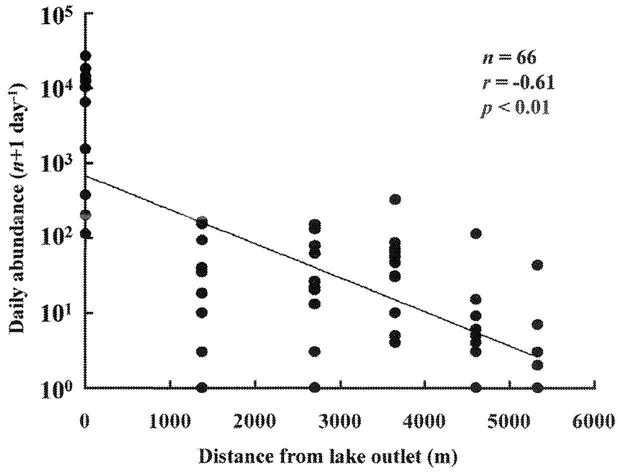

Fig. 3 Relationship between total abundance of *C. brevilineata* in light traps and distance from the lake outlet. Solid line corresponds to the regression equation ln (daily abundance + 1) = 6.42 − 0.001 × (distance).

Discussion

Movement of the aquatic insects enables them to avoid inbreeding, migrate to a new site with low-density occupation and few resource competitors, and escape from unfavorable conditions, e.g. limited resources, presence of predators, pathogens and parasites (Bilton *et al*., 2001). In particular, adult movement of aquatic insects has attracted a considerable interest combined with Muller's colonization cycle hypothesis that describes the sequence of downstream drift of larvae and supposed upstream flight for oviposition by females (Müller, 1954, 1982). However, only a few studies have so far reported how far adults of aquatic insect taxa move. Our study provided knowledge of the adult movement of *C. brevilineata* for the first time.

In the present study, we collected adult *C. brevilineata* with light traps. Light trap is one of the most useful methods to measure adult movement (Collier and Smith, 1998 ; Kovats *et al*., 1996 ; Svensson, 1974). Because the adults of this species show high positive phototaxis to artificial light (e.g., Kimura *et al*., 2006, Nozaki & Gyoutoku 1990, Sasaki *et al*., 1985), we can easily collect them with light traps. With the high air temperature, adult hydropsychid species, including *Cheumatopsyche*, are abundant in summer season when the air temperature is high (Kimura *et al*., 2008 ; Waringer, 1991). In the present study, we often collected more than 10,000 ind. day^{-1} in July. Moreover, the influence of environmental conditions, e.g. wind velocity less than 10 km h^{-1} (approximately 2.8 m s^{-1}), cloud cover, and precipitation, on adult caddisfly activity can be neglected (Kovats *et al*., 1996 ; Waringer, 1991). The daily abundance of adults was not directly influenced by wind velocity (range : 1.7 ± 0.8 m s^{-1} - 4.9 ± 2.3 m s^{-1}) during the study period.

In this study, daily abundance of adult *C. brevilineata* at a site decreased with distance from the lake outlet to the site. Moreover, there was no significant difference in the daily abundance of adults between St. 2 and St. 6, and St. 3 and St. 7, namely, between north and south shore sites, although the wind blew frequently from the southeast and south during the study period. Wind is one of the most important environmental factors that affect flight behavior (Johnson, 1969). However, the present study suggests that the influence of wind on the flight behavior of adult *C. brevilineata* can be neglected during the study period. In addition, larvae of *C. brevilineata* have never been recorded either in Lake Suwa or around the mouth of inflows (Chino, 1918 ; Uchida, 2005 ; Yoshida *et al*., 1997 ; Yoshida, 1998), although they were common in lake outlet and outflows (Katagami *et al*., 2004 ; Komatsu, 1974 ; Kumakawa and Uchida, 2001 ; Tenryu River Upper Reaches Construction Work Office, 1996). These facts indicate that the distance from the lake outlet directly determined the daily adult abundance at each sampling station.

Total abundance of other the two *Cheumatopsyche* species (*Cheumatopsyche campyla* Ross and *Cheumatopsyche speciosa* (Banks)) in traps also decreased with the distance from the shore (Kovats *et al*., 1996). The relative proportion of abundance of adults collected at a site to that at the shore was approximately 20% at the site 625 m from shore, and a few percent at sites located between 1250 and 5000 m from the shore (Kovats *et al*., 1996). On the other hand, *Hydropsyche* species exhibited inland maxima at 625 m from the shore, so the distribution pattern is different among the hydropsychid species (Kovats *et al*., 1996). In this study, we did not collect adult *C. brevilineata* at sites along the shore from the lake outlet for 1375 m. However, the distribution pattern at sites more than 1375 m from the outlet was fairly similar to that reported by Kovats *et al*. (1996). For the same reasons mentioned above, the abundance of adult *C. brevilineata* also decreased rapidly with the distance from the emergence source. We collected adult *C. brevilineata* at St. 5, which was furthest from the lake outlet among the stations. A wide dispersal range has been reported for Hydropsychidae, Limnephilidae, and Stenopsychidae, and these adults were collected more than 1,000 m away from their larval habitat (Johnson, 1969 ; Kovats *et al*., 1996 ; Svensson 1974 ; Sode and Wiberg-Larsen, 1993 ; Nishimura, 1967 ; Nishimura, 1981). In particular, *Hydropsyche pellucidula* (Curtis) female was collected 8,000 m from the nearest larval habitat (Sode and Wiberg-Larsen, 1993). Kovats *et al*. (1996) reported that two *Cheumatopsyche* species collected with traps 5,000 m from shore suggested the potential for long-distance (> 5,000 m) flight by adults. In this study, the distance for potential movement of adult *C. brevilineata* was estimated to be at least 5,325 m.

The density of filter feeding caddisflies at lake outlets often becomes high (Harding, 1992, 1994 ; Hoffsten, 1999 ; Oswood, 1979). Density of filter feeding caddisflies declined with distance from the outlet downstream (Maciolek and Tunzi, 1968; Oswood, 1979), however, the change in density with distance from the outlet upstream is not known. Daily abundance of adult *C. brevilineata* also decreased with distance from St. 0, suggesting that the density of filter feeding caddisflies decreases in both directions from the outlet of the lake. Several species of filter feeding caddisflies distribute in the upper to middle reaches of the Tenryu River (Katagami *et al.*, 2004; Komatsu, 1974; Kumakawa and Uchida, 2001; Tenryu River Upper Reaches Construction Work Office, 1996), however, most of them have never been recorded both in Lake Suwa and around the mouth of inflows (Chino, 1918; Uchida, 2005; Yoshida *et al.*, 1997; Yoshida, 1998). Flight distance of a caddisfly species increases with the wing length of a given species (Kovats *et al.*, 1996). Our future studies should clarify the relationship between flight distances and wing length of filter feeding caddisflies.

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諏訪湖沿岸部におけるコガタシマトビケラ成虫の分布

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コガタシマトビケラ成虫の移動・分散を明らかにするために，ライトトラップを用いて諏訪湖沿岸部における成虫の分布を調査した．トラップは湖の流出部から，直線距離で 0 m (St. 0)，1,375 m (St. 1)，2,700 m (St. 2)，3,650 m (St. 3)，4,600 m (St. 4)，5,325 m (St. 5) の湖岸に設置した．調査期間中，合計 105,874 個体のコガタシマトビケラ成虫が捕獲され，成虫の性比は雌に偏っていた．St. 0 における成虫の日平均捕獲数は 9,368.4 ± 8,569.1 個体／日であり，流出部から離れると急激に捕獲数が減少した．St. 0 の発生量に対する相対的な捕獲割合は，St. 1 から St. 5 の間で数パーセント程度であった．諏訪湖沿岸部におけるコガタシマトビケラ成虫の捕獲数は，流出部からの距離と有意な負の相関が認められた．本研究により，コガタシマトビケラ成虫は少なくとも 5,325 m は移動可能であることが示唆された．