〔Med. Entomol. Zool. Vol. 54 No. 1 p. 89–96 2003〕

Long-term investigation of *Propsilocerus akamusi* (Tokunaga) (Diptera, Chironomidae) from a shallow eutrophic lake, Suwa, in Central Japan —An attempt to forecast the massive emergence of adult midges

Kimio HIRABAYASHI[1], Takayuki HANAZATO[2], Makoto OGAWARA[2], Masataka SAKUMA[2] and Nobutada NAKAMOTO[1]

[1] *Department of Applied Biology, Faculty of Textile Science and Technology, Shinshu University, 3–15–1, Tokida, Ueda, Nagano, 386–8567 Japan*
[2] *Research and Education Center for Inlandwater Environment, Shinshu University, 5–2–4, Kogandori, Suwa, Nagano, 392–0027 Japan*

(Received: 23 August 2002; Accepted: 2 December 2002)

Abstract: The long-term population dynamics of chironomids were investigated in Lake Suwa, a shallow eutrophic lake in Central Japan, in order to clarify the temporal variations in the abundance of *Propsilocerus akamusi* (Tokunaga). The characteristics of the emergence of *P. akamusi* from the lake in recent years are (1) shorter emergence periods, (2) smaller number of midges collected, and (3) high ratio of females. These results clearly show that the number of *P. akamusi* in Lake Suwa has recently tended to decrease. There is significant relationship between the density of larvae in spring and the total number of midges trapped during the emergence period in fall. Thus, it is possible to estimate the focus of massive emergence of the midges from the larval density in the spring.

Key words: forecast, emergence, Lake Suwa, massive flight of midges, *Propsilocerus akamusi*

INTRODUCTION

In the profundal zone of hyper-eutrophic Lake Suwa in Central Japan, *Propsilocerus akamusi* (Tokunaga) and *Chironomus plumosus* (L.) are the most predominant species in the chironomid community (Nakazato et al., 1998; Yamagishi and Fukuhara, 1971b). These chironomid species have been observed in the lake since the late 1920s (Miyadi, 1931), and are well known as major foods for *Hypomesus transpacificus nipponensis*. Takeuchi and Okino (1982) reported that the rapid growth of *H. transpacificus nipponensis* in the fall depended on the larvae and pupae of *P. akamusi*, which is among the most ubiquitous chironomid species in Japanese eutrophic lakes, ponds and reservoirs (Iwakuma et al., 1988; Kondo et al., 2001).

In Lake Suwa, *P. akamusi* midges emerge once a year, i.e., from early October to mid-November (Yamagishi and Fukuhara, 1971b) and their high densities have been a severe nuisance to the local community and have caused economic problems (Hirabayashi, 1991b; Hirabayashi and Okino, 1998, 2000). However, starting in the late 1990s, massive flights of *P. akamusi* midges have not often been observed in the area surrounding Lake Suwa. Thus, it is suspected that the number of *P. akamusi* midges in Lake Suwa has been decreasing. The authors have investigated the long-term population dynamics of *P. akamusi* in this lake. The objective of the present study is to clarify the temporal variations in the abundance of *P. akamusi* midges collected with a light trap in 2000 and 2001. Moreover, we compared our results with those of previous reports, to forecast the massive flights of adult *P. akamusi* midges from Lake Suwa.

Materials and Methods

1) Study site

Lake Suwa is a tectonic lake located in the central highlands of Honshu, Japan, at an altitude of 759 m a.s.l. (36°03′N, 138°05′E), about 160 km W of Tokyo. The surface area of the lake is 13.3 km^2 and its maximum depth is 6.5 m and a mean depth of 4 m. The lake has inflowing water from 31 rivers and a single outlet, the River Tenryu-gawa, flows south into the Pacific Ocean. Lake Suwa is a hyper-eutrophic lake surrounded by the municipalities of Okaya City, Shimosuwa Town and Suwa City, with a total population of 140,000 (Fig. 1).

2) Estimation of *P. akamusi* midges emerging from the lake

The abundance of *P. akamusi* midges was monitored by daily catch using a light trap equipped with a 6-W black fluorescent lamp (Nozawa NH-5) set up at the Research and Education Center for Inland-water Environment, Shinshu University, located on the eastern shore of the lake (Fig. 1), during October-November 2000 and 2001. The insects that entered the cage were killed with insecticide spray every morning (about 10 a.m.). At the same time, the lake surface water temperature was recorded. After the midges of *P. akamusi* were sorted from the other insects, the numbers of males and females were counted separately in the laboratory. In the present study, the emergence period was regarded as the time between 1% and 99% of the cumulative capture dates.

3) Estimation of density of *P. akamusi* larvae in the lake

Sediment samples were taken with a standard Ekman-Birge grab (15×15 cm) in the central part of Lake Suwa (about 6 m depth) in March, when almost all larvae come close to the surface of the sediment (Iwakuma and Yasuno, 1981; Yamagishi and Fukuhara, 1972). Three replicate samples were taken and each sample was washed in situ with a Surber net (NGG 54; 0.344 mm aperture) and transported to the laboratory. The samples were kept cool and sorted immediately.

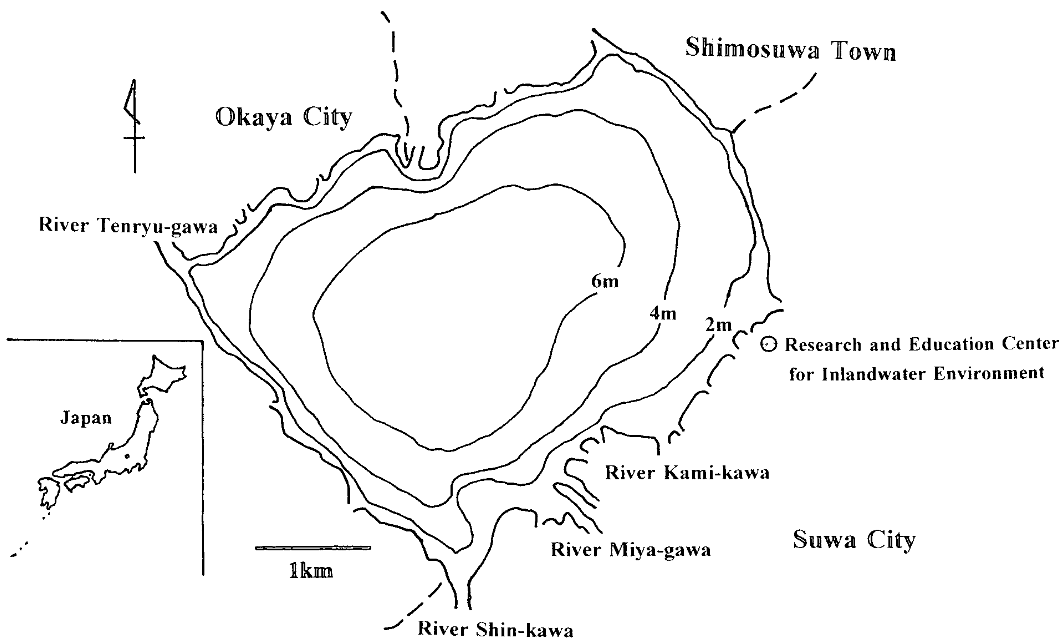

Fig. 1. Map of Lake Suwa.

4) Comparison with previous data

a) Changes in pattern and quantity of emergence

We compared our results with previous data from specimens collected by light trap in the same place in Lake Suwa (Hirabayashi, 1991c; Hiraide and Okino, 1983; Nakazato, 1992; Yamagishi and Fukuhara, 1969, 1970, 1971a). However, Yamagishi and Fukuhara (1969, 1970, 1971a) used a light trap equipped with a 10-W black fluorescent lamp, whereas Nakazato (1992) used a light trap with a 21-W black fluorescent lamp. Consequently, we needed to adjust these data to the same wattage, in order to make a quantitative comparison between the previous data and the present data. Assuming that the number of trapped midges was proportionate to the wattage of the black fluorescent lamp, we converted the data to show values for collection in a 6-W light trap. Moreover, in the comparisons we used the data on mean daily air temperature from the monthly weather report of Nagano Prefecture, since the measuring time and instruments were not the same in all the studies.

b) Relationship between the total number of trapped midges and the larval density in the mud in March

It is expected that the amount of *P. akamusi* midges to emerge from the lake relies on the larval density of the bottom mud. The larvae begin to burrow from the bottom surface layer to a deep layer (more than 50 cm depth) of the sediment in the end of May to early June in Lake Suwa (Yamagishi and Fukuhara, 1972). We analyzed the relationship between the preburrowing number of larvae in spring (March or April) and the total number of midges during the emergence period in fall (October to November). In spring, almost all larvae were the 4th instar larvae and their standing crop was very high compared with the rest of the year. The data on larval density of *P. akamusi* in spring are from Hirabayashi et al. (1991) and Nakazato (personal communications). All data on larval density were recorded at the lake center and each sample was washed with an open mesh Surber net of nearly the same size (0.25–0.40 mm aperture). In 1989, *P. akamusi* began to burrow from the surface layer to a deeper layer of the bottom sediment earlier than in other years. It is possible that the larval density for the spring of 1989 was underestimated because of this, so we excluded the 1989 data from the analysis.

Results

1) Abundance of *P. akamusi* midges collected with a light trap

Fig. 2 shows the records of daily catches of *P. akamusi* midges and the lake surface water temperature during emergence periods in 2000 and 2001. *P. akamusi* midges were trapped from 14 October until 17 November in 2000 and from 15 October until 20 November in 2001, with several peaks occurring in mid-October and early November. The maximum number of light-trapped midges was 610 per trap on 23 October, 2000 and 144 on 29 October,

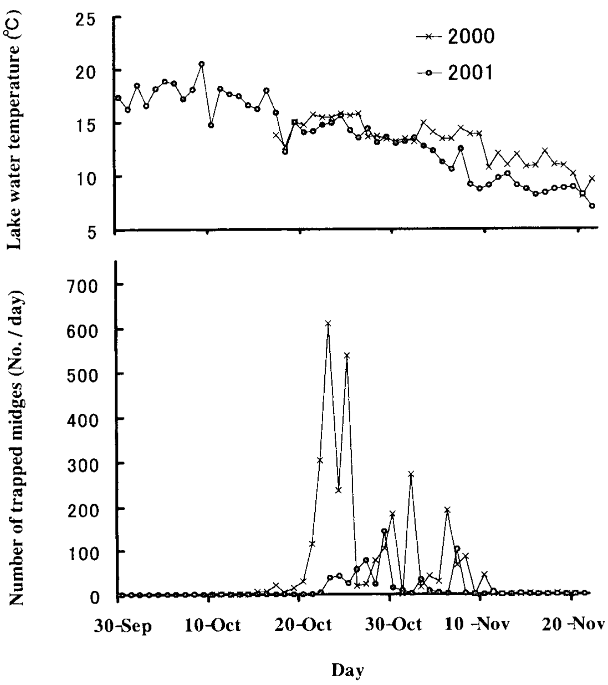

Fig. 2. Daily records of the catch of *Propsilocerus akamusi* midges by light trap, and lake water temperature at 10 a.m. in 2000 and 2001.

Table 1. Comparison of the emergence pattern of *Propsilocerus akamusi* midges with corresponding light-trap data and the larval densities in spring reported by others.

Authors	Yamagishi and Fukuhara (1969, 1970, 1971a)			Hiraide and Okino (1983)	Hirabayashi (1991a)	Nakazato (1992)		Present study	
Year	1968	1969	1970	1982	1989	1990	1991	2000	2001
Total number of trapped midges (Individual number)	23,641	58,028	1,856	54,872	77,064	6,059	15,461	2,987	594
Mean daily catch of midges (Individual number)	1,478	1,872	66	2,032	2,141	209	573	130	31
Maximum daily catch of midges (Individual number)	4,019	13,105	396	15,076	12,507	1,098	3,913	610	144
Emergence start date	Oct. 14	Oct. 3	Oct. 13	Oct. 5	Sep. 28	Oct. 11	Oct. 11	Oct. 17	Oct. 23
Emergence end date	Oct. 29	Nov. 2	Nov. 9	Oct. 31	Nov. 2	Nov. 8	Nov. 6	Nov. 8	Nov. 10
Duration of emergence period (Days)	16	31	28	27	36	29	27	23	19
Ratio of females (%)	9.2	6.9	16.2	10.4	32.5	19.6	15.9	53.7	32.7
Mean air temperature (±SD ℃)	9.2±1.3	11.1±2.5	9.5±3.3	11.4±2.7	12.3±2.7	11.7±2.0	11.2±2.7	12.0±2.1	9.8±2.1
Bottom water temperature (Emergence start date ℃)	15.2	14.7	15.1	14.5	17.2	16.1	15.9	15.1	14.9
Bottom water temperature (Emergence end date ℃)	11.8	11.0	10.6	11.1	13.2	10.5	10.9	12.4	9.7
Larval densities in spring (Individual number/m^2)	572	4,752	1,375	2,768	1,000	326	1,304	370	104

2001. The water temperature decreased day by day, and at water temperatures lower than about 10℃ only a few individuals flew into the light trap. The total number of trapped midges was 3,052 (male 1,439, female 1,613; during 35 days) in 2000 and 607 (male 408, female 199; during 37 days) in 2001. During the emergence period of *P. akamusi* midges, the total number was 2,987 in 23 days (17 October–8 November, mean water temperature 12.0±2.1℃) in 2000 and 594 in 19 days (23 October–10 November, 9.8±2.1℃) in 2001.

2) The density of *P. akamusi* larvae

The average density of *P. akamusi* larvae was 370.3±219.2 individuals per m^2 in March 2000 and 103.7±67.9 in March 2001, respectively.

3) Comparison with previous data

a) Changes in pattern and quantity of emergence

Table 1 shows the emergence start or end date, duration of the emergence period (days), total number of trapped midges, ratio of females among the total trapped midges, mean or maximum daily catch of midges, and mean air temperature and bottom water temperature (emergence start and end date) during the emergence periods of each year. The mean daily catch of midges was more than 1,800 individuals in 1969, 1982 and 1989, against less than 180 individuals in 1970, 2000 and 2001, i.e., it was about ten times greater in the former years than in the latter years (Table 1). The emergence period of *P. akamusi* occurs approximately from the end of September (the earliest emergence date was Sep. 28, 1989) to the beginning of November (the latest emergence date was Nov. 10, 2001) each year. The emergence periods ranged from 16 days (in 1968) to 36 days (in 1989), and mean values (±SD) were 26.2±5.7 days. The total number of trapped midges during the emergence period was positively correlated to the number of days of the emergence periods ($r=0.60$, $n=9$, $P<0.05$ in linear regression and correlation). The relationship between the total number of trapped midges and the emergence start or end date is clear, with the emergence starting earlier in large catch years (e.g., 1989, 1969 and 1968). There is a difference of 25 days between the earliest start date (Sep. 28, 1989) and the latest (October 23, 2001). On the other hand, in small catch years (e.g., 2001, 2000 and 1970), the emergence ended later. There is a difference of 12 days between the earliest end date (Oct. 29, 1989) and the latest (November 10, 2001).

b) Relationship between the total number of trapped midges and the larval density in the mud in March

There is a significant relationship between the number of larvae in spring and the total number of midges during the emergence period in fall ($r=0.88$, $n=8$: except in 1989, $P<0.01$ in linear regression and correlation).

Discussion

The chironomids of Lake Suwa have been studied by many researchers since the 1920s (reviewed by Hirabayashi et al., 1991). These reports have mainly focussed on the dominant species, the two large chironomids *P. akamusi* and *C. plumosus*, and have also investigated the ecology of these chironomids, i.e., population dynamics, larval production, distribution, and predation by fish (Hirabayashi, 1991a, 1991c, Hiraide and Okino, 1983; Iwakuma et al., 1989; Nakazato and Hirabayashi, 1998; Nakazato et al., 1998; Yamagishi and Fukuhara, 1971b). Many workers have used light traps to monitor the appearance of *P. akamusi* midges from the lake since the late 1960s, and have compared our present results with previous data (Hirabayashi, 1991c; Hiraide and Okino, 1983; Nakazato, 1992; Yamagishi and Fukuhara, 1969, 1970, 1971a). The characteristics of the emergence of *P. akamusi* midges from the lake in 2000 and 2001 were found to be as follows: (1) The emergence start dates (Oct. 17, 2000 and Oct. 23, 2001) were the latest to date. (2) The emergence period was very short (23 days in 2000 and 19 days in 2001). (3) The mean daily catch of midges in 2000 was the smallest after the 66 individuals caught in 1970, and that of 2001 was even smaller. (4) There was a high ratio of females in 2000 (53.7%) and 2001 (32.7%) (Table 1). According to Okino and Hanazato (1997), the bottom water temperature on the emergence start date was 14.5–17.2℃ (average: 15.4±0.8℃), and on the emergence end date was 9.7–13.2℃ (11.2±1.0℃). According to Iwakuma et al. (1989), emergence of *P. akamusi* took place within a range of decreasing bottom water temperatures of 18–10℃ in Lake Suwa. The results of the present study agree with those of Iwakuma et al. (1989), who also reported that a drop in bottom water temperature might have triggered the emergence of *P. akamusi*, and that a further drop below 10℃ might have terminated its pupation. These facts may explain why the total number of captured *P. akamusi* midges differs largely by year, and why the duration of the emergence period of *P. akamusi* depends on the bottom water temperature.

In the data examined, the ratio of females in each year was 6.9–19.6%, except in 1989, 2000 and 2001, so the trapped midges were mostly male (80.4–93.1%) (Table 1). A negative correlation was seen between the total number of trapped midges during the emergence period and the ratio of females ($r=-0.62$, $n=8$: except in 1989, $P<0.05$ in linear regression and correlation). Thus, it became clear that in small catch years (e.g., 2000 and 2001) the ratio of females was higher. The year 1989 was anomalous, but the reasons for this are unclear. According to Tokeshi (1996), adult *Chironomus anthracinus* Zetterstedt emerging offshore fly to inshore resting sites for physical/sexual maturation, before gathering at lake margins to form swarms. After copulation, females immediately return to open-water sites for oviposition. Protandry is evident and sex ratios are completely reversed in the near-shore swarming site and the off-shore oviposition site. In this study, when the behavioral pattern of *P. akamusi* midges was almost the same as *C. anthracinus*, the light trap was set up at a near-shore swarming site (male dominant); certainly, the ratio of males was higher in large catch years; however, the ratio of females was higher in recent years (2000 and 2001), and the number of midges has tended to decrease. It is probably difficult to form swarms around the lake when productivity of *P. akamusi* was low. Consequently, females would stay at lake margins for a long time until they could copulate, and females were easy to catch by light trap. This may be one of the causes of these phenomena.

There is a significant relationship between the number of larvae in spring and the total number of midges during the emergence period in fall. Thus, it is possible to estimate the focus of the massive flight of chironomid midges based on the larval density in the spring of the same year.

Acknowledgements

We would like to thank Mr. Y. Moriyama and colleagues at the Research and Education Center for Inlandwater Environment, Shinshu University, and Mr. M. Ando, Mr. T. Tukazaki and colleagues at the Department of Applied Biology, Faculty of Textile Science and Technology, Shinshu University, for their generous support. We are deeply indebted to Dr. R. Nakazato, Center for Water Environment Studies, Ibaraki University, for his valuable data on density of chironomid larvae in the bottom. This study was supported by a grant-in-aid for Scientific Research (No. 14570297 and No. 14208070) from the Ministry of Education, Science and Culture, Japan.

References

Hirabayashi, K. 1991a. Studies on massive flights of chironomid midges (Diptera: Chironomidae) as nuisance insects and plans for their control in the Lake Suwa area, central Japan: 1. Occurrence of massive flights of *Tokunagayusurika akamusi*. *Jpn. J. Hyg.*, 46: 652–661 (In Japanese with English abstract).

Hirabayashi, K. 1991b. Studies on massive flights of chironomid midges (Diptera: Chironomidae) as nuisance insects and plans for their control in the Lake Suwa area, central Japan: 2. Quantitative evaluations of the nuisance of chironomid midges. *Jpn. J. Hyg.*, 46: 662–675 (In Japanese with English abstract).

Hirabayashi, K. 1991c. Studies on massive flights of chironomid midges (Diptera: Chironomidae) as nuisance insects and plans for their control in the Lake Suwa area, central Japan: 3. Some experimental trials for control of nuisance midges and proposed counter plans. *Jpn. J. Hyg.*, 46: 676–687 (In Japanese with English abstract).

Hirabayashi, K., Nakazato, R., Nasu, Y., Okino, T. and Murayama, N. 1991. Study of chironomids (Diptera) in Lake Suwa, Japan: Review. *Ann. Environ. Sci. Shinshu Univ.*, 13: 5–20.

Hirabayashi, K. and Okino, T. 1998. Massive flights of chironomid midge nuisance insects around a hyper-eutrophic lake in Japan: A questionnaire survey of tourists. *J. Kansas Entomol. Soc.*, 71: 439–446.

Hirabayashi, K. and Okino, T. 2000. Massive flights of chironomid midges (Diptera) as nuisance insects and plans for their control in hyper-eutrophic Lake Suwa in Japan. *Verh. Int. Verein. Limnol.*, 27: 2378–2382.

Hiraide, T. and Okino, T. 1983. Influence of chironomidae on the organic matter balance of Lake Suwa. *Research reports of watershed ecosystem study of Lake Suwa*, 9: 31–44 (In Japanese).

Iwakuma, T., Sugaya, Y. and Yasuno, M. 1989. Dependence of the autumn emergence of *Tokunagayusurika akamusi* (Diptera: Chironomidae) on water temperature. *Jpn. J. Limnol.*, 50: 281–288.

Iwakuma, T. and Yasuno, M. 1981. Chironomid populations in highly eutrophic Lake Kasumigaura. *Verh. Int. Verein. Limnol.*, 21: 664–674.

Iwakuma, T., Yasuno, M., Sugaya, Y. and Sasa, M. 1988. Three large species of Chironomidae (Diptera) as biological indicators of lake eutrophication. *In*: Biological Monitoring of Environmental Pollution. (ed. Yasuno, M. and Whitton, B. A.), pp. 101–113. Tokai University Press, Tokyo.

Kondo, S., Hirabayashi, K., Iwakuma, T. and Ueno, R. 2001. The World of Chironomidae. 306 pp. Baifukan, Tokyo (In Japanese).

Miyadi, D. 1931. Studies on the bottom fauna of Japanese lakes: 1. Lakes of Shinano Province. *Jpn. J. Zool.*, 3: 201–257.

Nakazato, R. 1992. Population dynamics of Chironomidae in the littoral zone of Lake Suwa. *M. Sc. Thesis, Shinshu Univ.* 123 pp. (In Japanese).

Nakazato, R. and Hirabayashi, K. 1998. Effect of larvae density on temporal variation in life cycle patterns of *Chironomus plumosus* (L.) (Diptera: Chironomidae) in the profundal zone of eutrophic Lake Suwa during 1982–1995. *Jpn. J. Limnol.*, 59: 13–26.

Nakazato, R., Hirabayashi, K. and Okino, T. 1998. Abundance and seasonal trend of dominant chironomid adults and horizontal distribution of the larvae in eutrophic Lake Suwa, Japan. *Jpn. J. Limnol.*, 59: 443–455.

Okino, T. and Hanazato, T. 1997. A result of the 20-year-monitoring of water quality in Lake Suwa. *Rep. Suwa Hydrobiol. Sta.*, 10: 7–249 (In Japanese).

Takeuchi, K. and Okino, T. 1982. Growth and feeding habit of *Hypomesus transpacificus nipponensis* in Lake Suwa. *In*: Many Aspects of Environmental Science (ed. Mitsui, K.), pp. 17–22. Doboku kougakusha, Tokyo (In Japanese).

Tokeshi, M. 1996. Reproductive behavior in *Chironomus anthracinus* (Diptera: Chironomidae), with consideration of the evolution of swarming. *J. Zool., Lond.*, 240: 103–112.

Yamagishi, H. and Fukuhara, H. 1969. Studies on Chironomids in Lake Suwa. *JIBP-PF Suwako seibutugunshu seisanryoku kenkyu*. (*Studies on biological production in Lake Suwa*), 1: 45–56 (In Japanese).

Yamagishi, H. and Fukuhara, H. 1970. Studies on Chironomids in Lake Suwa II. *JIBP-PF Suwako seibutugunshu seisanryoku kenkyu*. (*Studies on biological production in Lake Suwa*), 2: 65–78 (In Japanese).

Yamagishi, H. and Fukuhara, H. 1971a. Studies on Chironomids in Lake Suwa III. *JIBP-PF Suwako seibutugunshu seisanryoku kenkyu*. (*Studies on biological production in Lake Suwa*), 3: 77–90 (In Japanese).

Yamagishi, H. and Fukuhara, H. 1971b. Ecological studies on Chironomids in Lake Suwa, 1. Population dynamics of two large Chironomids, *Chironomus plumosus* L. and *Spaniotoma akamusi* Tokunaga. *Oecologia*, 7: 309–327.

Yamagishi, H. and Fukuhara, H. 1972. Vertical migration of *Spaniotoma akamusi* larvae (Diptera: Chironomidae) through the bottom deposits of Lake Suwa. *Jpn. J. Ecol.*, 22: 226–227.