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Field study on capturing midges, *Propsilocerus akamusi* (Diptera: Chironomidae), by artificial wingbeat sounds in a hyper-eutrophic lake

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Abstract: This study was conducted to develop a new method to control adult midges *Propsilocerus akamusi* (Tokunaga) (Diptera: Chironomidae) using their acoustic responses to sound traps in the field. Trials were conducted from October 26 to November 3, 1999, near the hyper-eutrophic Lake Suwa in central Japan. The swarm of *P. akamusi* formed at 1 m to over 10 m above ground and was observed from 15 : 10–17 : 20. More than 93% of *P. akamusi* caught from the swarm were males. In cylindrical sound traps, optimal trapping of swarming males occurred at frequencies of 150–180 Hz at 13.8±3.1℃.

INTRODUCTION

Numerous studies have reported that many kinds of insects use sound as a means of communication with the opposite sex (reviewed by Belton, 1986; Downes, 1969). Many studies on the mating behaviour of mosquitoes have accumulated a wealth of information on acoustic behaviour, auditory sense and attraction (reviewed by Roth, 1948). Roth (1948) reported that males of *Aedes aegypti* (L.) are attracted to the female flight sound, and Wishart and Riordan (1959) reported that males of this species are attracted to an artificial sinusoidal wave of the same frequency as the female wingbeat. In contrast, such reports concerning chironomid midges are rare. Ogawa (1992), and Ogawa and Sato (1993) reported that great numbers of swarming males of chironomid midges, *Rheotanytarsus kyotoensis* (Tokunaga) and *Chironomus yoshimatsui* Martin et Sublette, near a river of an urban area were caught by traps emitting artificial wingbeat sounds.

In the area of Lake Suwa in Central Japan, massive swarms of adult midges *C. plumosus* (L.) and *Propsilocerus akamusi* (Tokunaga) have repeatedly caused problems for local residents. According to Hirabayashi (1991b), more than 10% of residents (about half of whom live within 500 m of the lakeshore) said that they can no longer tolerate such swarms of chironomid midges. Additionally, more than 30% of tourists in this area felt such swarms to be a significant nuisance (Hirabayashi and Okino, 1998). In the Lake Suwa area, the incidence of bronchial asthma has been proved to be induced by chironomid midges (Hirabayashi *et al.*, 1997).

Until now, lights have been used as the customary countermeasure against chironomid midges wherever they occur, e.g., around natural lakes (Ali *et al.*, 1986, Hirabayashi *et al.*, 1993a, 1993b, 1998). Recently, Hirabayashi and Ogawa (1999) reported that the combination of a black light and wingbeat sounds attracted large numbers of male *C. plumosus*. Thus, utilization of this method for midge control appeared to be quite feasible. On the other hand, in the case of *P. akamusi* which is regard as more problematic than *C. plumosus*, there are, however, no reports on the use of wingbeat sounds as a countermeasure against this species. The present study was carried out to trap adult midges by audio-frequency sounds in the field for the purpose of developing a new control method against adult *P. akamusi* using their acoustic response.

Materials and Methods

1. *Study site*

Lake Suwa is a tectonic lake in the central highlands of Honshu, Japan, 759 m above sea level (36°03′ N, 138°05′ E). The surface area of the lake is 13.3 km^2 and its maximum depth is 6.5 m. A single outlet, the Tenryu River, flows south into the Pacific Ocean. Lake Suwa is a hypereutrophic lake surrounded by municipalities, namely, Okaya City, Shimosuwa Town and Suwa City, with a total population of 140,000. Many resort hotels and businesses have been severely affected by the dense swarms of adult chironomids emerging from the lake. The biomass of larvae at the lake bottom is high, e.g., *C. plumosus*, about 440 mg dry weight and *P. akamusi*, about 1418 mg dry weight per m^2 in the profundal region (Nakazato *et al.*, 1998). In recent years, midge control attempts have been made by using artificial light (Hirabayashi, 1991c; Hirabayashi *et al.*, 1993a, 1993b, 1998).

2. *Adult midge collecting*

The field studies were conducted from October 26 to November 3, 1999, along the east shore of the lake (on land at ca. 20 m from the shore and 2 m above water level).

1) Net sweeping. Adult chironomids were collected by random sweeping ca. 2.5 m above ground along the shore with an insect net during their swarming time (from 15:10 to 17:20). The numbers of male and female *P. akamusi* were counted in the laboratory to determine the sex ratio in the swarm population. Six sweeps were made on different nights (October 26, 29, and 31).

2) Sound trapping. The trap was the cylindrical type used by Ogawa (1992) as follows: A speaker (9 cm diam.; 0.7 W, 8Ω) connected to a cassette tape recorder was placed in the center of a cylinder of transparent polyethylene (ca. 9 cm diam. and ca. 66 cm long). Glue (Kinryu®, Maruzen-kakou K. K., Tokyo) was sprayed on the inside wall of the cylinder. The sticky area was about 900 cm^2. Two cylindrical traps, one emitting sound and the other not, were set in parallel to each other about 30 cm apart. The traps were placed nearby or close by the swarm (ca. 2.5 m above ground). Sinusoidal sounds at various frequencies (150–510 Hz at intervals of 30 Hz) recorded from a sound generator were emitted at intervals of 10-s on/5-s off for 1 min (total: 4 times emitted) from a cassette tape recorder. The sound intensity was kept at 90 dB sound pressure level at the cylinder edge. The captured midges were identified and counted in the laboratory. The recorded number of *P. akamusi* caught by the sound trap was expressed as the catch difference between the sound trap and the no-sound trap. The air temperature and light intensity were measured about 1 m above the ground just after each trapping. At least three replicate captures on different nights were checked for each sound frequency. All collected data were analyzed using analysis of variance (ANOVA) and a multiple comparison test (Tukey's test).

Results

1. Swarm

The midges of *P. akamusi* appeared from the end of October to early November. The peak took place from October 26 to November 3. Almost all swarms were observed at 1 m to over 10 m above terrain that had more conspicuous color than the surrounding area, such as a light-colored jogging road, at the margin of the lake. A large swarm, consisting of more than a thousand males, formed before sunset and lasted for 30 min. Sunset was around 16:55 during the investigation periods. In this study, 752 midges (725 males and 27 females) were caught from 6 sweep samples. The mean±SD percentage of males in the swarm population was 96.7±1.6%, with a range of 93.6 to 98.4% (Table 1). The swarms began to form

Table 1. Number of male and female of *Propsilocerus akamusi* caught by net sweeping in the swarms.

Swarm No.	Number caught Male	 Female	Total	Male rate
1	116	4	120	96.7
2	123	2	125	98.4
3	137	6	143	95.8
4	146	10	156	93.6
5	95	3	98	96.9
6	108	2	110	98.2
Total	725	27	752	Average±SD 96.4±1.7

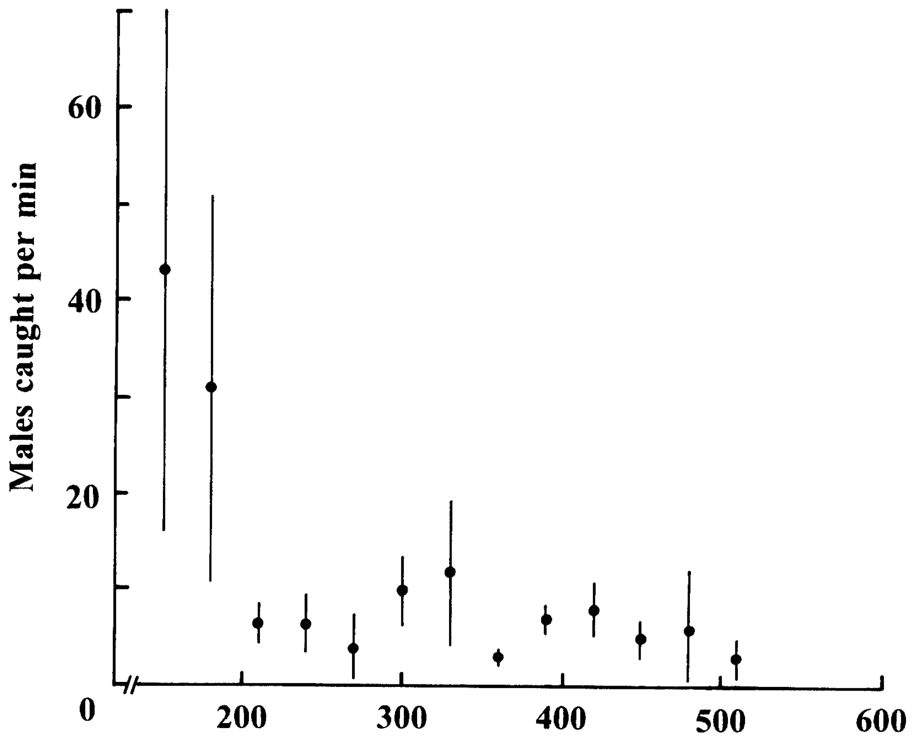

Fig. 1. Mean number of male *Propsilocerus akamusi* caught by a sound trap when sinusoidal sounds between 150 and 510 Hz (90 dB sound pressure level) at intervals of 10-s on/5-s off for 1 min were emitted (n=43) from October 26 to November 3 (8 nights, excluding October 30), 1999. Vertical lines indicate standard deviations.

around 15:10 (19.2±2.9℃, 1010±67 lx) and subsequently increased in density and numbers. The swarms then became more compact as illumination decreased (around 17:20, 12.2±0.6℃, 17±15 lx). During the experimental periods, the wind condition from 15:00 to 18:00 was very calm, except on October 30. The swarm of *P. akamusi* did not form on October 30 due to the winds (wind velocity was 5 m/s at 15:00) and low air temperature (15:10; 12.8℃ 1080 lx and 17:00; 7.6℃ 120 lx) during swarming time.

2. Sound trapping of males

The sound traps caught a large number of males at frequencies of 150 (43±30/min, mean males±SD, n=4) and 180 Hz (31±22, n=4) at 13.8±3.1℃ of the air temperature (Fig. 1). There was a significant difference in the number of midges captured by a sound trap depending on the frequency of sinusoidal sounds emitted ($F_{12,27}=3.60$, $P=0.0028$ in ANOVA). On the other hand, less than 7±3 mean males per 1 min were caught at sound frequencies between 210 and 510 Hz. A 150 Hz sound trap caught the highest number of males, i.e., a mean of 81 per min at 12.4℃. Although there was no significant difference between catches at 150 and 180 Hz, they were significantly different from the catches using other sound frequencies ($P<0.05$, Tukey's test).

Discussion

1. Swarms

Swarming times and sites have been confirmed for several chironomid species. According to Ogawa and Sato (1993), swarms of *C. yoshimatsui* formed close to a tree serving as a swarm marker above ground and was observed toward the evening in autumn to early winter or at dusk in summer. In the case of *C. plumosus,* the swarm formed above ground at the margin of the lake and was observed at dusk (Hirabayashi and Ogawa, 1999). Ogawa (1992) reported that a swarm of *R. kyotoensis* formed above the water surface of a river between noon and sunset. It has also been reported by Sasa (1978) that huge swarms of *P. akamusi* formed prior to sunset at Lake Kasumigaura. In addition, Kon *et al.* (1986) observed at Lake Biwa that a number of males of *P. akamusi* were hovering in the morning 10 to 40 cm above a resting place (a small swarm), and a large swarm formed before sunset and lasted for 30 min to one hour. In the present study, however, the swarm of *P. akamusi* formed above ground and was observed only in the afternoon (between 15:10–17:20), agreeing with the observations of Sasa (1978) of the Lake Kasumigaura population. Midges seem to come to a swarming site by being visually attracted by a species-specific swarm marker. The results of these observations indicate that the swarm-forming times are different both among species and local populations of *P. akamusi.*

The swarm-forming conditions of *P. akamusi* seemed to depend on the air temperature and wind condition. The midges seemed unable to swarm at temperatures below 10℃. Winds inhibited swarm-forming activity. We observed that swarms were swept down toward the ground by winds with a velocity greater than 5 m/s.

2. Response of P. akamusi *to artificial wingbeat sounds*

Some chironomid midges are known to respond to female wingbeat sounds (reviewed by Ikeshoji, 1982; Armitage, 1995). In this study, most swarming males of *P. akamusi* were caught by cylindrical sound traps emitting sound frequencies of 150–180 Hz at 13.8±3.1℃, i.e., they responded to a fairly narrow range of sound frequency (Fig. 1). However, during this time we could not measure frequencies less than 150 Hz. Therefore, it could not be ascertained whether or not the most attractive frequencies were at their peak from 150–180 Hz. To clarify this, further follow-up studies should be conducted.

Ogawa and Sato (1993) reported that, in the case of *C. yoshimatsui* and *R. kyotoensis,* there was a significant correlation between the air temperature and the wingbeat frequency. They suggested that the most attractive frequency changed among different seasonal generations (intraspecific) according to the ambient air temperature. The emergence of *C. yoshimatsui* and *R. kyotoensis* was observed from June to December when the range of air temperature was very wide and from October to December when the range of air temperature was also very wide, respectively (Ogawa 1992, Ogawa and Sato 1993). Therefore, Ogawa and Sato (1993) suggested that swarming males of both species have the hearing acuity to accurately detect the wingbeat frequency of conspecific females which varies with the ambient air temperature. In the case of *P. akamusi* at Lake Suwa, the emergence period was observed from end of October to early November during which the range of air temperature was very narrow (Yamagishi and Fukuhara, 1971; Hirabayashi, 1991a). Therefore, adult midges *P. akamusi* responded to a fairly narrow range of sound frequencies compared to *C. yoshimatsui* and *R. kyotoensis.* Further follow-up field studies should be conducted for different chironomid species to clarify the relationship between ambient air temperature and wingbeat sounds.

3. Possibility of control method against P. akamusi *midges using their acoustic responses*

Various midge control methods have been developed in the past several decades (reviewed by Ali, 1991, 1995). Studies in this area have focused on chemical control (Tabaru *et al.,* 1987; Ali, 1995). In a small area such as a stream, a sewage disposal plant, an eel pond, etc., chemical control is very useful (Edwards *et al.,* 1964; Yasuno *et al.,* 1982). However, in natural lakes covering a large area, chemical control of the midges is not economically feasible because of the large volume of water to be treated as well as the undesirable impact on other organisms. Therefore, the development of physical and biological control strategies is urgently needed. Based on midge biology, physical control of midges may be possible by manipulating adult behaviour. Ali *et al.* (1984, 1986) reported that light intensity was a more important factor in attracting midges than the wavelength of light in the visible spectrum. Hirabayashi *et al.* (1998) also reported that the flying behaviour of adult midges *P. akamusi* was greatly influenced by lamps with strong light intensity. In addition, according to Hirabayashi *et al.* (1993a), *C. plumosus* and *P. akamusi* were attracted by wavelengths of 300–390 nm in the near-ultraviolet region. Hirabayashi *et al.* (1993b) also tried to capture *P. akamusi* midges in the field using lethal electric insect traps with black light lamps emitting ultraviolet rays to which huge numbers of adult midges were attracted. These studies indicate that there may be species-specific preferences for wavelength or intensity that needed to be determined on an individual basis, and that clarification of appropriate light wavelengths is important for the development of an overall integrated strategy to control chironomid midges. On the other hand, wingbeat sounds to control some insect pests have been attempted (e. g., Khan and Offenhauser Jr., 1949; Ikeshoji, 1985, 1986; Ikeshoji and Yap, 1987; Ikeshoji and Ogawa, 1988; Ogawa, 1988). In the case of chironomid midges, there have been few reports on the behaviour and ecology of adult midges (reviewed by Armitage, 1995). Ogawa (1992) and Ogawa and Sato (1993) reported that the swarming males of *C. yoshimatsui* and *R. kyotoensis* responded to fairly narrow-ranged and species-specific sound frequencies at ambient air temperature. However, Ogawa (1992) also pointed out that sound traps were the only efficient capture method when the midges were swarming. Therefore, he suggested that joint use with other attractive devices and swarm markers is necessary.

Recently, Hirabayashi and Ogawa (1999) reported on a method combining light and wingbeat sounds to capture adult *C. plumosus* midges. As a result, many males of *C. plumosus* were attracted and eventually captured in sound traps equipped with a black light lamp emitting ultraviolet rays. In this study, the sound traps caught a large number of males of *P. akamusi* when sound frequencies of 150 and 180 Hz were emitted at 13.8±3.1℃. The effective sounds to the males lay within a fairly narrow range of sound frequencies (Fig. 1). Consequently, this acoustic sensitivity in a fairly narrow range of males of *P. akamusi* is quite similar to that of males of *C. plumosus* (Hirabayashi and Ogawa, 1999). In conclusion, the attraction of light and the application of the audio-frequency sounds for the control of *P. akamusi* midge seem to be quite feasible, assuming that a suitable collecting device is available. Further laboratory and field investigations are necessary to develop these methods to large-scale practical applications.

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摘　要

過栄養湖におけるアカムシユスリカ成虫の人工羽音による野外での捕獲実験

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諏訪湖から毎年秋期に大発生するアカムシユスリカについて，群飛間近に音響トラップを設置して，成虫を捕獲する野外実験を行った．調査は 1999 年 10 月 26 日から 11 月 3 日までの成虫発生最盛期に，諏訪湖東岸の湖畔において行った．群飛は 15:10 から 17:20 にかけて形成され，93% 以上が雄成虫で構成されていた．音響トラップには 13.8±3.1℃の時に 150 から 180 Hz の音響に雄が数多く誘引・捕獲された．