Relationship between male acoustic response and female wingbeat frequency in a chironomid midge, *Chironomus yoshimatsui* (Diptera: Chironomidae)*

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Abstract: The features of acoustic response and wingbeat frequency of a chironomid midge, *Chironomus yoshimatsui* were studied. The swarms observed were formed above the ground close by cherry trees. The swarming males were mainly caught by cylindrical sound traps emitting sound frequencies of 180–270 Hz at between 9 and 15°C and of 300–390 Hz at between 20 and 28°C during the experimental period in a field. However, the swarming male responded to a fairly narrow range of sound frequency at an ambient air temperature. Accordingly, there was a good correlation between the air temperature and the sound frequency of the highest male catch. The sound frequency of the highest male catch changed at the rate of 10 Hz/°C. The mean wingbeat frequencies of both sexes were almost at constant levels from the first day of emergence to the 4-day-old after emergence. The male wingbeat frequency was always higher than that of the female at the same air temperature. There was a good correlation between the air temperature and the wingbeat frequency of each adult day in both sexes. The wingbeat frequencies of male and female changed at the rate of 18–21 and 10–12 Hz/°C, respectively. When the regression line of the female wingbeat frequency on the air temperature of each adult day is compared with that of the sound frequency of the highest male catch on the air temperature, the former is consistent with the latter statistically. This indicates that swarming male has the hearing faculty to be accurately tuned to the wingbeat frequency of conspecific female which is variable with the ambient air temperature.

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INTRODUCTION

In general, males of chironomid species are known to respond and orient to female wingbeat sound (Ikeshoji, 1982). Recently, Ogawa (1992) first reported that the swarm-

ing males of *Rheotanytarsus kyotoensis* which broke out in large quantities in an urban area of Tokyo were caught by sound traps emitting artificial sounds. On the other hand, some chironomid species have become nuisances and potent inhalant allergens causing bronchial asthma (Freeman, 1950; Gad El Rab, 1980; Ito *et al.*, 1986; Igarashi *et al.*, 1987; Kino *et al.*, 1987). Especially, *Chironomus yoshimatsui* is one of the most common nuisances and allergens because of its outbreak in urban areas (Murakami *et al.*, 1986).

For the purpose of developing a new control method of the chironomid adults using their acoustic responses, the present study was carried out to trap adult midges of *C. yoshimatsui* by sounds in a field and measure the wingbeat frequencies of both sexes under various air temperatures and their adult ages.

MATERIALS AND METHODS

Study area. The bank of the River Nikaryoyosui (*ca.* 5 m wide) which runs through the town and commercial district of Shukugawara, Kawasaki City was selected as a study area. *C. yoshimatsui* mainly swarmed close by the trunks or under the branches of cherry trees on the bank.

Adult midge trapping by sounds. The trap used was the cylindrical form used by Ogawa (1992); a speaker (9 cm diam.; 1 W, 0.7 Ω) 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®, SDS Biotech K.K., Tokyo) was sprayed on the inside wall of the cylinder. The sticky area was about 900 cm². Two cylindrical traps, one emitting sound and the other emitting no sound, were set in parallel *ca.* 30 cm apart. This sound trap system was placed nearby the swarm during the swarming time before and after dusk during the experimental period from June to December in 1990, 1991 and 1992. Sinusoidal sound of various frequencies recorded from a sound generator on a cassette tape was emitted at intervals 10-sec on/5-sec off for 5 min by a cassette

tape recorder. The net number of *C. yoshimatsui* caught by the sound traps was expressed as the catch difference between the sound trap and the without-sound trap. The air temperature was measured just after each trapping *ca.* 1 m above the ground in the shade of a cherry tree.

Adult midge sweeping with insect net. Swarming chironomids were collected by random sweeping with a 42-cm diam. insect net during the swarming time and the number of male and female *C. yoshimatsui* caught was counted to study the sex ratio of the swarm population.

Measurement of wingbeat frequency. The larvae of *C. yoshimatsui* collected from the study area in 1992 were reared on ground mouse food at 25°C, and adults emerged were used in the experiment. The wingbeat frequencies of male and female *C. yoshimatsui* were measured from the first day of emergence to 4-day-old after emergence at 10, 15, 20 and 25°C by the method of Ogawa (1988); adults were mounted at the ventral side of the abdomen on the tip of a small piece of cardboard with nail polish as adhesive under ether-anesthesia. Flight sounds were recorded with a cassette tape recorder at *ca.* 1 cm distance from a microphone when the adult midges started beating their wings. The recorded flight sound was then displayed on an oscilloscope by connecting the earphone outlet to the input of the amplifier and the displayed wave was photographed with a Polaroid® Camera. The wingbeat frequencies of 9 to 17 midges were determined by measuring the wavelengths on the photogram or the oscilloscope directly, and averaged for each experiment.

RESULTS

1. Swarm

Almost all swarms observed were formed from 0.5 to over 5 m above the ground close by the trunks or under the branches of cherry trees. The swarm was formed in the dusk just after sunset in summer and toward evening in autumn to early winter.

In the present study, 88.6 to 100% (98.0%

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

Swarm No.	Number caught			Male rate (%)
	Male	Female	Total	
1	31	4	35	88.6
2	39	0	39	100
3	40	0	40	100
4	66	1	67	98.5
5	69	2	71	97.2
6	78	0	78	100
7	112	2	114	98.2
Total	435	9	444	Average 98.0

Fig. 1 Number of male *C. yoshimatsui* caught by a sound trap when sinusoidal sounds of various frequencies were emitted at between 20 and 28°C of air temperature ($n=52$). Fig. 2 Number of male *C. yoshimatsui* caught by a sound trap when sinusoidal sounds of various frequencies were emitted at between 9.4 and 15.0°C of air temperature ($n=66$).

in average) of midges caught by net sweeping in the swarm were males (Table 1). Occasionally, a few females were mixed in the swarms.

2. Sound trapping of males

The sound traps caught a large number of males when sound frequencies between 180 to 390 Hz were emitted (Figs. 1 and 2). Specifically, most of the traps caught a lot of males with sound frequencies of 300–390 Hz at between 20 and 28°C of air temperature (Fig. 1). On the other hand, the traps caught few males with the same sound frequencies and above 390 Hz at between 9 and 15°C of air temperature, but most of the traps

caught a lot of males with sound frequencies of 180–270 Hz (Fig. 2). Furthermore, the sound frequency of the highest male catch changed each day according to the air temperature; a 360-Hz sound trap caught the highest number of 577 males at 23.1°C on June 14 in 1990, a 270-Hz sound trap caught 127 males at 20.0°C on June 6 in 1990 and a 240-Hz sound trap caught 93 males at 12.2°C on December 5 in 1991 (Fig. 3). Accordingly, the sound frequencies and the air temperature of the days when the highest male catches were made are plotted in Fig. 4. The air temperatures varied between 10.2°C on November 27, 1991 and 27.0°C on September 5, 1991. Figure 4 shows a positive correlation between the sound frequency of the highest male catch and the air tem-

Fig. 3 Patterns of male catches in various sound frequencies each experimental day.

○, June 6, 1990; ●, June 14, 1990; □, December 5, 1991. Temperature: see text.

Fig. 4 Relationship between the sound frequency and the air temperature when the male catches were the highest each experimental day.

perature.

3. Wingbeat frequency

The wingbeat frequencies of male and female were measured in relation to both adult development after emergence and air temperature, and the results are shown in Figs. 5 and 6. The wingbeat frequencies of both sexes were almost at constant levels during the experimental period except the male wingbeat frequencies tended to be low on the first day of emergence at 20 and 25°C (Fig. 5). The mean wingbeat frequencies of male ranged from 293.4 to 318.1 Hz at 10°C, 382.1 to 405.3 Hz at 15°C, 460.6 to 543.2 Hz at 20°C and 566.7 to 614.9 Hz at 25°C. On the other hand, the mean wingbeat frequencies of female ranged from 212.9 to 240.0 Hz at 10°C, 274.0 to 293.6 Hz at 15°C, 318.3 to 358.8 Hz at 20°C and 371.0 to 382.9 Hz at 25°C. When the mean frequencies of both

Fig. 5 Changes in wingbeat frequency of *C. yoshimatsui* after emergence at various air temperatures.

Vertical lines indicate standard deviations.

■, 10°C; ●, 15°C; □, 20°C; ○, 25°C.

sexes were compared at the same age, the ratio of male to female ranged from 1.27:1 to 1.44:1 at 10°C, 1.31:1 to 1.47:1 at 15°C, 1.41:1 to 1.60:1 at 20°C and 1.48:1 to 1.68:1 at 25°C. Moreover, there was a good positive correlation between the air temperature and the wingbeat frequency of each adult day in both sexes (Fig. 6).

DISCUSSION

Ogawa (1992) reported that a swarm of a chironomid midge, *Rheotanytarsus kyotoensis* was formed above the water surface of a river and was observed about noon to sunset. In the present study, however, the swarm of *Chironomus yoshimatsui* was formed close by the cherry tree as a swarm marker above the ground and toward evening or later, in the same study area. These results of observation indicate that the swarm-forming conditions of *C. yoshimatsui* are different from those of *R. kyotoensis*. Moreover, the swarm of *C. yoshimatsui* consisted largely or entirely of males. This swarm feature is common to both the chironomid and the mosquito swarms (Downes, 1969; Marchand, 1984; Ikeshoji *et al.*, 1985; Peloquin and Olson, 1985; Ogawa, 1992).

The swarming males were mainly caught by sound traps emitting sound frequencies between 180 and 390 Hz, which are much

Fig. 6 Relationship between the wingbeat frequency and the air temperature each adult day after emergence.

Vertical lines indicate standard deviations. A0, the first day of emergence; A1, 1-day-old after emergence; A2, 2-day-old after emergence; A3, 3-day-old after emergence; A4, 4-day-old after emergence. ●, male; ○, female; -----, regression line of male acoustic response $Y = 10.01X + 109.86$ (see Fig. 4).

the same frequencies as the female wingbeat frequencies, during the experimental period (ref. Fig. 5). However, the sound frequency of the highest male catch changed at the rate of 10 Hz/°C which the regression line shows under the influence of ambient air temperature (Figs. 3 and 4). Moreover, the number of males caught decreased with a difference of only 30 Hz in frequency (Fig. 3). These results indicate that the swarming males respond to a fairly narrow range of sound frequency at an ambient air temperature. These acoustic responses of male *C. yoshimatsui* are quite similar to those of male *R. kyotoensis* (Ogawa, 1992).

The wingbeat frequencies of both sexes are almost independent of the adult age (Fig. 5). However, the wingbeat frequencies of both sexes are dependent on the ambient air temperature, and they rise linearly with

rising air temperature (Fig. 6). The male wingbeat frequency was always higher than that of the female at the same air temperature each adult day (ref. Fig. 6). The ratio of the mean wingbeat frequency of male to female increased with rising air temperature. As shown in Fig. 6, the wingbeat frequencies change to *ca.* 20 Hz/°C in male and *ca.* 10 Hz/°C in female, respectively, any adult day. These results indicate that increases in ambient air temperature produce more increases in the wingbeat frequency of male than that of female.

When the regression line of the female wingbeat frequency on the air temperature of each adult day is compared with that of the sound frequency of the highest male catch on the air temperature, there is no significant difference between the two regression lines in both regression coefficient and intercept at a 5% level (*t*-test) (ref. Fig. 6). Moreover, the swarming males respond and orient to the sound trap emitting a sound frequency of 180–390 Hz which is much the same frequency as the wingbeat sound of conspecific female as mentioned above (ref. Fig. 5). Furthermore, swarming males of *C. yoshimatsui* remarkably respond to the sound frequency of 30–40 Hz higher than those of *R. kyotoensis* under the same ambient air temperature (Ogawa, 1992; Fig. 4). These facts indicate that swarming male of *C. yoshimatsui* has the hearing faculty to be accurately tuned to the wingbeat frequency of conspecific female which is variable with the ambient air temperature, and is able to respond and orient to the female. On the other hand, Ogawa (1992) reported on the acoustic response of male *R. kyotoensis* that swarming males were mainly caught by sound traps emitting sound frequencies between 180 and 300 Hz and the most attractive frequency changed to *ca.* 11 Hz/°C. Moreover, the swarming male of *R. kyotoensis* responded to a narrow range of sound frequency at an ambient air temperature. These results of acoustic response of male *R. kyotoensis* closely resemble those of male *C. yoshimatsui*. Therefore, it is inferred from this fact that male *R. kyotoensis* has the same hearing

faculty as the male *C. yoshimatsui*.

In future, it is necessary to elucidate further the acoustic physiology and behaviour of adult of *C. yoshimatsui* for developing a new control method using acoustic response.

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摘 要

セスジユスリカ *Chironomus yoshimatsui* における雄の音響応答と雌の 羽音周波数との関係

群飛しているセスジユスリカの雄の音響応答を音響トラップを用いて野外で調べるとともに、雌雄の羽音周波数を羽化当日から羽化後4日目まで毎日、10°C、15°C、20°C および 25°C の各温度条件下で測定した。群飛は成虫の発生源の河川際の桜の木の幹横および枝下に、地上 0.5 m から 5 m 以上の高さに形成された。群飛は平均 98.0% が雄で構成されていた。雄は主に周波数 180 Hz から 390 Hz の音響に対して応答し、トラップに誘引・捕獲された。しかし、一定の気温条件下では、雄が顕著に応答する音響周波数の範囲がかなり狭いことも明らかとなった。この雄の音響応答において、捕獲に最適な音響周波数と気温との間にきわめて高い正の相関が認められ、音響周波数の変動は 10 Hz/°C であった。雌雄の羽音周波数は同一気温条件下で、羽化当日から羽化後4日目までほぼ一定であった。雄の羽音周波数は同日齢の雌より常に高く、1.27 倍から 1.68 倍であった。いずれの日齢においても、羽音周波数と気温との間にきわめて高い正の相関が雌雄ともに認められた。その羽音周波数の変動は雄で 18~21 Hz/°C、雌で 10~12 Hz/°C であった。さらに、気温に対する雄の音響応答の回帰直線と気温に対する雌の羽音周波数の回帰直線はいずれの日齢においても一致した。これらのことから、セスジユスリカの雄は気温の影響を受けて変動する雌の羽音周波数に的確に同調し、応答できる聴覚能力を有していることが明らかとなった。