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FLIGHT BEHAVIOR OF *LIMNOPHYES NATALENSIS* (DIPTERA: CHIRONOMIDAE) WITHIN A FOOD INDUSTRY

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Abstract We investigated the seasonal abundance and flight activity of adult *Limnophyes natalensis* within a food industry. A total of 43,163 insects were automatically counted with a special light trap during the study period. The automatically counted numbers reflected the abundance of *L. natalensis,* because other insect abundance was negligible. The daily total *L. natalensis* abundance showed the highest peak in mid June (716 individuals/day), some adults were collected during winter. Daily abundance of *L. natalensis* showed a significant positive correlation with daily mean room air temperature. The diel flight activity of *L. natalensis* showed two peaks (morning and evening) from spring to autumn, with one peak in winter. Adult *L. natalensis* were collected on days when mean air temperature was higher than 7.4°C. Results suggest that thermal conditions influence daily abundance and diel flight activity.
Key words Chironomid midges, control, diel flight activity, light trap, seasonal abundance

INTRODUCTION

The Chironomidae -non-biting midges- are one of the largest groups of the order Diptera, containing over 10,000 species and having a worldwide distribution (Langton and Pinder, 2007). The immature majority of the species live in aquatic habitats, although some species of Orthocladiinae are semi-aquatic or terrestrial (Pinder, 1995). Massive chironomid swarms have been observed near their habitats. The swarms often limit human activities and lead to severe nuisances. In addition, the adults may cause economic problems, such as contaminating the final products of food processing industries. Nearly 100 nuisance species have been reported to emerge in massive swarms (Ali, 1995). As Chironomidae is not listed as a household pest (Ito, 1982), places indoors are generally invaded by adults from outdoor habitats (Matsuzaki and Buei, 1993; Hattori and Moriya, 1996).

Recently, the abundance of *Limnophyes natalensis* (Kieffer) indoors has been reported (Tanikawa et al., 2009). Kimura et al. (2010) also reported emerging and swarming of *L. natalensis* within a food industry by species such as *Limnophyes* sp. (Kimura, unpublished). *Limnophyes natalensis* is not listed as a nuisance species (Ali, 1995). Methods for controlling *L. natalensis* have not been established, because the species' biological and ecological characteristics are poorly understood (Sæther, 1990). However, chemical control has a tendency to be avoided, and biological control is not realistic in indoor environments. In this study, we investigated the seasonal abundance and flight activity of adult *L. natalensis* within a food industry in order to establish an ecological basis for the physical control of *L. natalensis*.

MATERIALS AND METHODS

Study site

A certain food industry is located in Chiba City, Chiba Prefecture, Japan. The industry usually operates from 8:00 to 18:00. Lights-out is from 18:00 to 8:00.

Collection of *L. natalensis*

Limnophyes natalensis were collected by a light trap (Figure 1, OptCounterFIS-003, IKARI Corp.) in the industry. The light trap, equipped with a 20-W black fluorescent lamp and a sticky sheet, was hung on the wall 1.8 m above the floor. The most important feature of the light trap is its automatic counting and collecting of insects more than 0.7 mm in length with photoelectric sensors. The seasonal abundance of *L. natalensis* was monitored from February 1, 2010 to January 31, 2011. A black fluorescent lamp and a sticky sheet were usually replaced every three months and every month, respectively. All insects except *L. natalensis* that were collected by the sticky sheets were identified as several other taxa and counted separately under a binocular dissecting microscope.

Environmental Condition

Room air temperature was measured every hour with a thermo-recorder (Ondotori TR-72U, T and D Corp.) during the study periods. In addition, outside air temperature during the study period was measured at the nearest public observatory, Chiba Station (Japan Meteorological Agency, 2010, 2011), and used for the environmental data. Sunrise and sunset were obtained from the database of the Ephemeris Computation Office Public Relations Center (National Astronomical Observatory of Japan, 2010). In the present study, morning and evening flight periods were defined as 4:00 to 9:00 and 16:00 to 21:00, respectively. Flight periods included the sunrise or sunset regardless of the season.

Data Analysis

Statistical tests were performed in SPSS version 11.5.1.J for Windows (SPSS Japan Inc.).

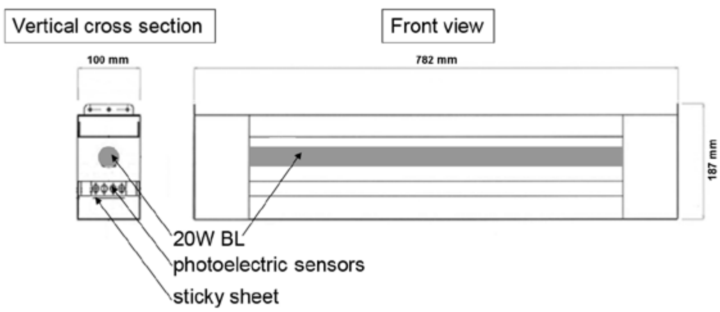

Figure 1. Structure of automatic counting light trap.

RESULTS

Daily Abundance

The daily mean room air temperature ranged from 11.1°C (January 16) to 22.2°C (August 17), averaging 17.1 ± 2.5°C during the study period (Figure 2). On the other hand, the daily mean outside air temperature ranged from 2.1°C (February 13) to 30.9°C (August 17), averaging 16.6 ± 8.4°C during the study period. The monthly value of daily mean room air temperature was significantly higher than the monthly value of daily mean outside air temperature ($p < 0.001$, Wilcoxon signed-rank test), except for May ($p = 0.192$, Wilcoxon signed-rank test) and October ($p = 0.432$, Wilcoxon signed-rank test). A total of 43,163 insects were automatically counted in the study period. The sticky sheet collected *L. natalensis* and other insects, such as Psychodidae (481 individuals), Diptera excluding Psychodidae (471 individuals) and other insects except for Diptera (70 individuals). In particular, only two individuals of the dipteran species other than *L. natalensis* were collected in January and February. The automatically counted numbers reflected the abundance of *L. natalensis*, because other insects were in the minority (1022 individuals, 2.4%) and their abundance was negligible. The daily number of adults evidenced a repeated short-term fluctuation. The daily abundance of adults reached a maximum on June 14 (714 individuals/day; room temperature 18.1°C; outside temperature 18.8°C) and minimum on January 28 (3 individuals/day; room temp. 12.0°C; outside temperature 4.2°C), averaging 118.3 ± 101.8 individuals/day during the study period. There was no day in the year when an adult was not collected. Daily abundance of *L. natalensis* showed a significant positive correlation with daily mean room air temperature ($r = 0.530$, $p < 0.001$, Pearson's correlation coefficient).

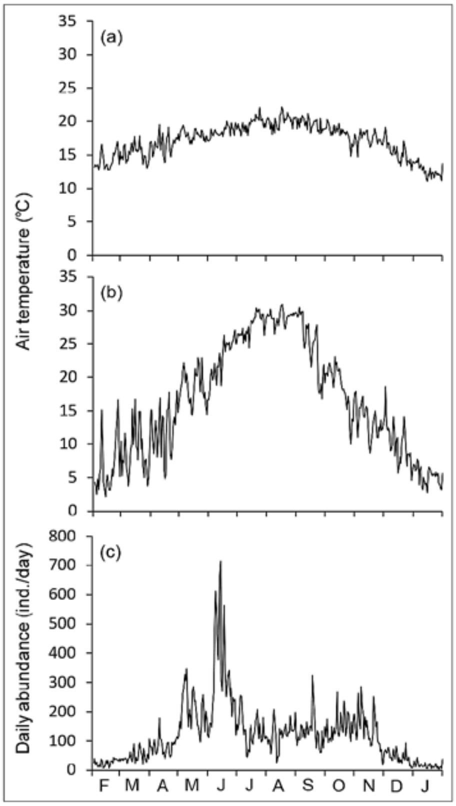

Figure 2. Thermal condition and daily abundance of Limnophyes natalensis in a food industry; showing (a) daily mean room air temperature, (b) daily mean outside air temperature (Japan Meteorological Agency, 2010, 2011), and (c) daily abundance of Limnophyes natalensis.

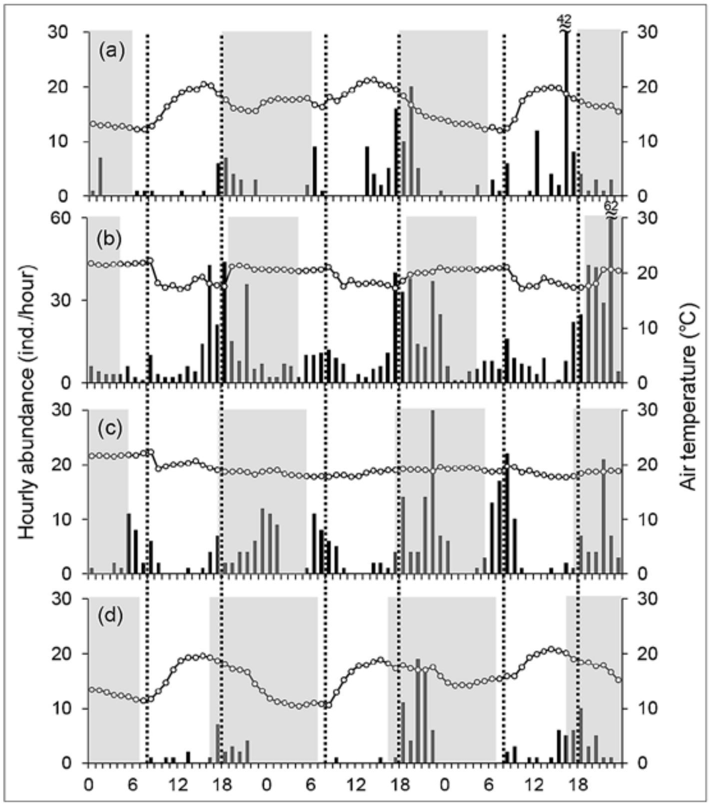

Figure 3. Diel activity of Limnophyes natalensis (black bars) and thermal condition (open circles) in a food industry; (a) spring (March 20-22, 2010), (b) summer (June 20-22, 2010), (c) autumn (September 22-24, 2010), and (d) winter (December 20-22, 2010). Shaded area and dashed line indicate nighttime and lighting (8:00) and lights-out (18:00), respectively.

Diel Activity

Figure 3 shows a typical diel flight pattern of *L. natalensis* in each season. The number of adults was large at morning and evening, but small in the day and at midnight from spring to autumn. Adults were collected only at dusk in winter. The room air temperature changed with the industry's operation. The air temperature of the evening flight period did not change between seasons, but the air temperature at the morning flight period was affected by outside temperature. The morning abundance of *L. natalensis* showed a significant positive correlation with mean room air temperature ($r = 0.640$, $p < 0.001$, Pearson's correlation coefficient). *L. natalensis* were collected in the morning when the mean air temperature was higher than 7.4°C.

DISCUSSION

A total of 28 species from Japan are recognized in the genus *Limnophyes* (Yamamoto, 2004; Nihon Yusurika Kenkyu-kai, 2010). However, *L. natalensis* are not included in this list of Japanese *Limnophyes*. The first record of *L. natalensis* in Japan was made in an indoor drain pit (Tanikawa et al., 2009). In addition, *L. natalensis* was collected on the outdoors of the western and southern parts of Japan (Kawai et al., 2011). As *L. natalensis* is very rare in Japan, their biological and ecological characteristics have scarcely been studied. In addition, Sæther (1990) indicated that all previous world records of *L. natalensis* need to be reexamined due to misidentification.

A large number of adult *L. natalensis* were collected throughout a year indoors. The automatically counting light trap is useful for capturing simple fauna. Genus *Limnophyes* is eurytopic (Wiederholm, 1983; 1989), and *L. natalensis* have been reared from rivers and streams (Sæther, 1990). Organic (materials of products) residue from drains and machines in a certain food industry contained *L. natalensis* larva (Kimura, unpublished). Although larva *L. natalensis* may only be able to distribute in water, they also have lentic and/or semiterrestrial habitats. Thermal conditions determine the flying activity, larval development, emergence period and number of generations per year, all of which govern the seasonality of insects (Gullan and Cranston, 1994). Except for some Orthocladiinae species, nuisance midges are not collected by light trap outside of winter (e.g., Sasa and Nishino, 1995; Tanaka et al., 2003), much less throughout a year in Japan. On the other hand, room temperature was fixed during the operation of this food industry by air conditioning. It is known that household pests are able to emerge at fixed temperatures caused by air conditioning throughout the year (Matsuzaki and Buei, 1993; Hattori and Moriya, 1996). Our results suggest that there was enough warm air temperature in this industry in winter for the emergence of *L. natalensis*.

The diel flight activity of *L. natalensis* showed two peaks (morning and evening). Flight activity was from spring to autumn, with one peak in winter. Morning room air temperature in winter limited the flight of *L. natalensis*. Environmental cues for the timing of emergence have been attributed to changes in light intensity (Armitage, 1995). Diel flight activity is affected not only by light intensity but also air temperature. *L. minimus*, the most abundant species of genus *Limnophyes* in Japan (Yamamoto, 2004), was collected from midnight to dawn in summer (Kawai et al., 2002). The diel flight activity of *Limnophyes* may differ from species to species, but that is unclear because Kawai et al. (2002) studied only one night.

Physical and cultural control methods for chironomidae are divided broadly into three categories: mechanical control, habitat management and ecological manipulation, and behavioral manipulations of adult midges (Ali, 1995). In this study, adult *L. natalensis* were collected on days when mean air temperature was higher than 7.4°C. Therefore, keeping daily mean room air temperatures below 7.4°C may serve to reduce the contamination of the final industrial products by the flight of *L. natalensis*. In addition, daytime production also reduces the contamination of *L. natalensis*. Further research on the flight behavior of this species should be undertaken for us to better understand how to control the species in the food processing industries. Increased knowledge of population dynamics in ecosystems outdoors would also assist in preventing the invasion and colonization indoors coming from the outside.

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