Ent Rev Jpn 57 (2002): 119-122.

This is the author's version of the work. The original publication is available at the website of the Coleopterological Society of Japan: http://kochugakkai.sakura.ne.jp/archive/esj/jcs-erj.html

The Influence of Temperature on Flash Interval in the Genji-firefly *Luciola cruciata* (Coleoptera: Lampyridae)

Yutaka Iguchi
(E-mail: bio.iguchi@gmail.com)

Laboratory of Biology
Yamashita-cho 1-10-6, Okaya City, Nagano Prefecture, 394-0005, Japan

(Received February 16, 2002; Accepted May 3, 2002)

Abstract Flash intervals of *Luciola cruciata* were measured at various air temperatures at two sites for two years. The results revealed that flash intervals were negatively correlated with air temperatures. The regressions differed significantly between the sites, but not significantly between the years. In the previous studies, the flash types of this species were recognized on the basis of flash interval only. However, the present study suggests that the flash types of this species should be re-examined on the basis of relationships between flash interval and air temperature.

Introduction

The luminescence of the fireflies has the function as a signal for communication between the sexes, and is species-specific for the flash pattern (e.g. LLOYD, 1973; OHBA, 1983). Though the flash pattern is influenced by the various factors such as Temperature, quality and intensity of light, wind velocity, and rainfall, a few studies have been made on their correlation up to the present. As far as I know, LLOYD (1973) was the first to show the negative correlations between the flash interval and the air temperature in several species of fireflies. The same correlation was tested on Japanese species *Hotaria parvula* by OHOBA (1983), which did not show any correlation, but SASAI (1999) obtained the similar result as LLOYD (1973) in *Luciola cruciata*. These observations were, however, made on the same population for each species, and no comparison was made among the plural populations.

The present study is aimed to clarify the influence of temperature in two populations of *Luciola cruciata* on the light pattern. Because this firefly is well known for the synchronous rhythmic flashing in the male and has been divided into three ecological types of the allopatric distribution by their flash patterns of the male, namely, the fast-flash type (flash interval < 3 s), the intermediate-flash type (flash interval = 3–4 s), and the slow-flash type (flash interval > 4 s) (OHBA, 1988; MITSUISHI, 1991), but no consideration has been taken on the influence of temperature.

Materials and Methods

In the present study, flash intervals of the male *L. cruciata* were observed at two sites for two years under the falling temperature at night.

One of the study sites is located along a brook near the Tenryu River in Komazawa, Okaya City, Nagano Prefecture, Japan. Observations were conducted between 20:00 and 21:00 on 9 nights in 1994 and on 8 nights in 1995. While fireflies were flying and flashing synchronously, a flash interval was measured with a stopwatch as the time between the beginning of a flash to the succeeding one. In this way, 30 flash intervals were recorded and the average was calculated. After 15 flash intervals were recorded, air temperature was also measured at a height of ca. 3 m above the water.

The other site was located along a small river near the Tenryu River in Matsuo-kyo, Tatsuno-machi, Kamiina-gun, Nagano Prefecture, Japan. Observations were conducted between 21:00 and 22:00 on 13 nights in 1994 and on 12 nights in 1995. Flash intervals and air temperatures were also measured as mentioned above.

Results

As a result of my present observations, the correlation between the flash interval and air temperature is shown in Fig. 1. In both Okaya and Tatsuno, the regressions in both 1994 and 1995 showed significantly negative slopes (Okaya: $t = 10.72$, df = 7 in 1994, $t = 4.79$, df = 6 in 1995; Tatsuno: $t = 19.47$, df = 11 in 1994, $t = 4.46$, df = 10 in 1995; $P < 0.01$ for all). In Okaya, the regression slopes did not differ significantly ($t = 1.07$, df = 13, $P > 0.3$) and it was concluded that the two regression lines coincided (analysis of covariance, $t = 0.97$, df = 14, $P > 0.3$). Similarly, in Tatsuno, the regression slopes did not differ significantly ($t = 0.35$, df = 21, $P > 0.7$) and it was concluded that the two regression lines coincided (analysis of covariance, $t = 0.98$, df = 22, $P > 0.3$). Consequently, the data for 1994 and 1995 were pooled to compare the males in Okaya and Tatsuno. The result was that the regression slopes for the pooled Okaya and Tatsuno males did not differ significantly ($t = 1.49$, df = 38, $P > 0.1$) and it was concluded that the two regression lines were parallel (analysis of covariance, $t = 15.97$, df = 39, $P < 0.001$).

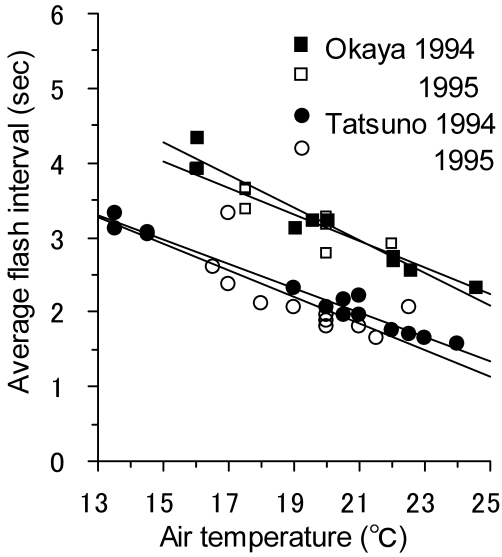

Fig. 1. Relationships between air temperature and average flash interval in male *Luciola cruciata* in Okaya and Tatsuno, Nagano Prefecture in 1994 and 1995. Each symbol indicates the average of 30 flash intervals measured during one night. The regression lines are as follows: Okaya, $y = -0.22x + 7.6$ in 1994, $y = -0.18x + 6.6$ in 1995; Tatsuno, $y = -0.16x + 5.4$ in 1994, $y = -0.18x + 5.6$ in 1995.

In the present observations, the average flash interval took a range between 2.6 and 4.4 s in Okaya and between 1.6 and 3.3 s in Tatsuno, and apparently overlapped the criteria of the flash intervals separating the ecological types as already mentioned above. As mentioned in the Introduction, flash patterns of *L. cruciata* have been traditionally divided into 3 ecological types; the fast type (flash interval < 3), the intermediate type (flash interval = 3–4), and the slow type (flash interval ≥ 4). Consequently, the Okaya males showed flashes of the fast, intermediate, and slow types, and the Tatsuno males showed flashes of the fast and intermediate types.

Discussion

The present results indicated that the flash interval of *L. cruciata* was strongly influenced by air temperature. That is, as air temperature fell, flash interval increased. This was consistent with the observation of SASAI (1999) on this firefly. Moreover, the regressions of flash interval on air temperature differed significantly between the sites, but not significantly between the years.

In previous studies, the 3 flash types of this firefly were identified on the basis of the flash interval only (e.g. OHBA, 1988; MITSUISHI, 1991). However, the present study indicates that this criteria are not always correct, because flash interval varies with air temperature. The present results suggest that the flash types and their geographical distribution should be reviewed on taking into account the influence of temperature. Previous studies based on flash interval showed that the Itoigawa-Shizuoka tectonic line separates two major flash types, the fast and slow types (e.g. OHBA, 1988; MITSUISHI, 1991). However, my recent reports based on the regression of flash interval on air temperature pointed out that the separation by the Itoigawa-Shizuoka tectonic line is unclear, and that the Kanto Mountains separate the two flash types, the intermediate and slow types (IGUCHI, 2001a, b). This was consistent with the results of recent molecular studies (SUZUKI et al., 2000; TAKEBE et al., 2000; SUZUKI, 2001; YOSHIKAWA et al., 2001).

As mentioned above, no attention has been paid to the influence of air temperature on the flash patterns in *L. cruciata*. Therefore, in future, it must be necessary to re-examine geographical variation in flash patterns of this firefly incorporated with the data on air temperature.

要　　約

井口豊：ゲンジボタルの明滅周期に与える気温の影響．　――― 長野県岡谷市駒沢と辰野町松尾峡で，ゲンジボタルの明滅周期と気温の関係を２年間調べた．その結果，明滅周期と気温は明瞭な負の相関を示した．この関係には，年による顕著な差はないが地域間の顕著な差は存在することがわかった．従来の研究では，明滅周期に基づいて，ゲンジボタルは短周期型（周期３秒未満），中間型（周期３－４秒），長周期型（周期４秒以上）の３タイプに分けられてきた．しかしながら，本研究の結果，ゲンジボタルの明滅周期は気温に強く影響されることが判明した．ゲンジボタルの発光タイプを分類し，その地理的変異を論ずるためには，単に明滅周期だけではなく，明滅周期と気温の関係を調べる必要があるだろう．

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