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Male Morphological Dimorphism in the Genji Firefly *Nipponoluciola cruciata* in Central Japan

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Abstract

The Japanese Genji firefly *Nipponoluciola cruciata* is famous for geographic variation in flash pattern. Such geographic variation has also been well studied in terms of ecology and molecular phylogeny. However, there are very few studies on geographic variation in morphology of this species. This study focused on morphological characteristics of males of this species in Yamanashi and Gunma Prefectures separated by the Kanto Mountains in central Japan. Previous studies have shown that this species in the two prefectures exhibits different genetic features as well as different flash patterns. This study aimed to explore morphological characteristics of males of this species and performed multivariate analysis using measurements previously published in the literature. As a result, allometric analysis between body length and elytra width suggested that this species exhibits different allometric patterns between the two prefectures. Moreover, cluster analysis of measurements of genitalia suggested that this species is completely separated into two different groups between the two prefectures. These results suggest the importance of further morphological studies to clarify the divergence of this species.

Keywords

Male Dimorphism, Allometriy, Cluster, Gunma, Yamanashi

1. Introduction

The aquatic firefly *Nipponoluciola cruciata* (formerly named *Luciola cruciata*, Coleoptera, Lampyridae) is commonly called Genji-botaru and is one of the most popular insects in Japan [1]. Interestingly, this species shows geographic variation in interflash intervals, which vary from about 2s in western Japan to about 4s in eastern Japan [2]-[4]. Molecular phylogenetic studies have also found genetic differentiation between the 4-s and 2-s flash types [5]-[8]. Howev-

er, there are very few studies on geographic differences in morphological characteristics of this species. Ohba [9] examined several morphological measurements of this firefly such as body length, body width, pronotum length, and pronotum width throughout Japan. However, he found no significant geographic differences in mean values of measurements. He also showed geographic differences in regression of pronotum length on pronotum width but did not further multivariate analysis to compare regression lines. Imasaka [10] [11] also examined several morphological measurements of this species throughout Japan but did not perform a detailed statistical analysis.

Fortunately, the present author found that Imasaka [10] [11] documented morphological measurements of this species in detail. Therefore, in this article, the author aims to reanalyze his data and statistically clarify characteristics of this species varying geographically.

This article focuses on morphological characteristics of this species in Gunma and Yamanashi Prefectures, central Japan (**Figure 1**). According to previous studies [4] [12] [13], this species in Gunma belongs to the 4-s flash type and in Yamanashi belongs to the 3-s flash type. In terms of geographic characteristics, the Kanto Mountains exist between the two prefectures. Previous studies [4] [12]-[14] inferred that the divergence of *N. cruciata* in central Japan occurred between the 4-s flash type and the common ancestor of the 2-s and 3-s flash types about 11 Ma in the Miocene in relation to the uplifting of the Kanto Mountains. Therefore, the present author hypothesized that statistical differences would be also observed in the measurements of Imasaka [10] [11] between the two prefectures.

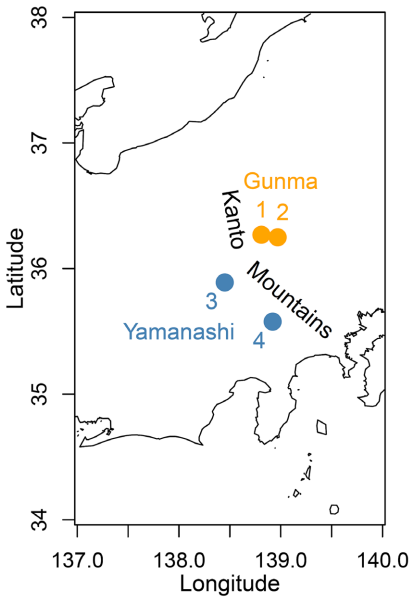

Figure 1. Map of the study area in Gunma and Yamanashi Prefectures, central Japan. Numbers denote the following localities for specimens used in this study: 1. Tomioka, Gunma; 2. Yoshii, Gunma; 3. Takane, Yamanashi; 4. Tsuru, Yamanashi.

2. Materials and Methods

The data used in this study were morphological measurements of male *N. cruciata* collected at two sites in Gunma Prefecture and two sites in Yamanashi Prefecture, central Japan as shown in **Figure 1**. They were obtained from Table 2 of Imasaka [10] and Table 2 of Imasaka [11].

The measurements used in this study are as follows: body length, elytra width (width of the basal part), and lengths of six parts of genitalia. The statistical analysis was performed using two multivariate analysis methods: allometric analysis between body length and elytra width and cluster analysis of lengths of six parts of genitalia. The data on genitalia contain missing values. Specimens with missing values were excluded from cluster analysis. The specimen B82 shows an extremely small value of the part j of genitalia (Table 2 of Imasaka [11]). This was assumed to be a misprint and therefore this specimen was excluded from cluster analysis.

According to previous studies on the firefly *Luciola parvula* [15] [16], allometric equations were applied to the data of body length and elytra width using standardized major axis regression with the smatr package in the R software [17]. The data were $\log_{10}$-transformed into the log-log relationship between body length (x) and elytra width (y). Consequently, the $\log_{10}$-transformed allometric equation was expressed as:

$$\log_{10} y = \log_{10} a + b \log_{10} x \quad (1)$$

where a and b are constants. The constant b is the slope of the line, also known as the allometric coefficient.

The hierarchical cluster analysis of lengths of six parts of genitalia was performed with the function hclust of the R software [17] using Ward's method with Euclidean distance.

3. Results

As shown in **Figure 2**, the two allometric lines did not differ significantly in slope (χ^2 = 2.07, df = 1, p = 0.150) but did differ significantly in elevation (y-intercept) (χ^2 = 8.31, df = 1, p = 0.004). The common slope (b = 1.40) was significantly different from 1 (χ^2 = 9.00, df = 2, p = 0.011), which indicated a positive allometry between body length and elytra width.

As shown in **Figure 3**, the results of cluster analysis showed that Gunma and Yamanashi specimens were completely classified into two major clusters.

4. Discussion

The results of allometric analysis showed that the allometry of *N. cruciata* in Gunma and Yamanashi Prefectures is represented by two parallel lines. In other words, the results showed that males of this species have a wider body shape in Yamanashi Prefecture than in Gunma Prefecture. These findings are similar to the allometric patterns of the Japanese terrestrial firefly *Luciola parvula* observed in Nagano Prefecture, central Japan [15]. However, as shown in **Figure 2**, there

remains a possibility that *N. cruciata* in Gunma and Yamanashi Prefectures may show different allomeric slopes. Further studies are required with larger sample size to determine the allometric patterns of *N. cruciata* in central Japan.

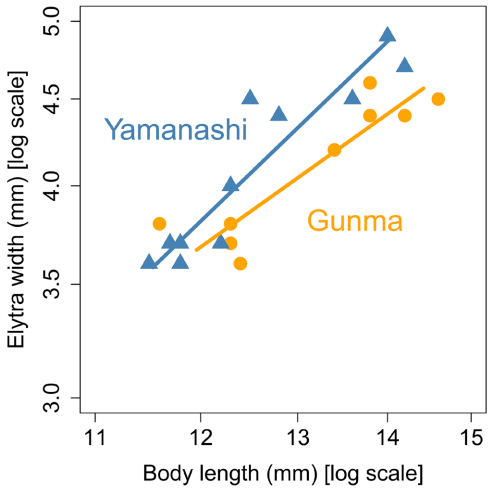

Figure 2. Allometric relationship between body length and elytra width in *N. cruciata* in Gunma and Yamanashi Prefectures, central Japan. The standardized major axis regression lines were separately fitted to each prefecture.

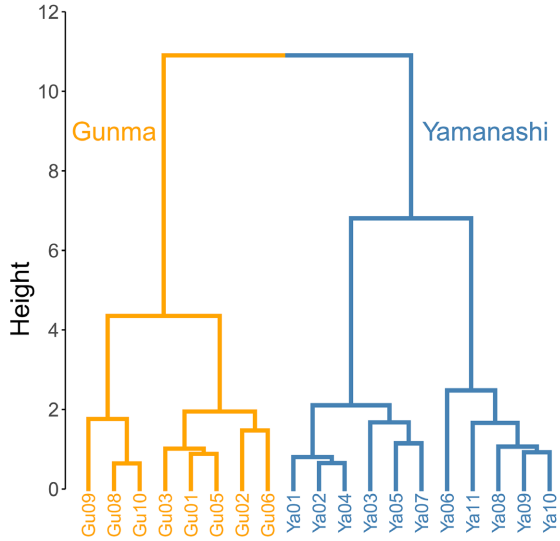

Figure 3. Dendrogram of cluster analysis of measurements of genitalia in male *N. cruciata* in Gunma and Yamanashi Prefectures, central Japan. The specimens collected in Gunma and Yamanashi Prefectures are represented by Gu and Ya, respectively, in the x-axis label.

The results of cluster analysis revealed that *N. cruciata* shows different shapes of male genitalia between Gunma and Yamanashi Prefectures. As mentioned above, this species in Gunma belongs to the 4-s flash type and in Yamanashi be-

longs to the 3-s flash type [4] [12] [13]. Therefore, this species of different flash types may exhibit different shapes of male genitalia in other areas. However, few studies have explored the relationship between morphology and flash types in this species. Ohba [18] mentioned that the 4-s type occasionally lacks a black marking in the pronotum but did not refer to differences in internal organs such as genitalia.

Ohba [9] suggested that variations in the size of external structures in *N. cruciata* are larger within populations than among populations. However, the results of this study showed that multivariate analysis can be useful to detect size variations in both external and internal structures. The male morphological dimorphism of this species observed in this study may be associated with topography in this area.

The 2s-fash type is distributed in western Japan, whereas the 4s-flash type is distributed in eastern Japan [3]. The 2s-fash type shows clearer synchronization of flashing than the 4s-flash type [9]. Iguchi [4] [19] statistically revealed that any flash type of this species shows faster flashing as air temperature rises. Therefore, the divergence among flash types may have occurred in relation to geographic variation in air temperature.

Previous studies reported that females of the 2s-fash type aggregate at one site for oviposition, but that those of the 4s-fash type oviposit individually [5] [7] [8]. However, there are no studies investigating geographic differences in reproductive capacity or maturity period of this species. Further morphological and ecological studies are required to clarify the divergence of this species especially in mountainous areas of central Japan.

5. Conclusion

This article explored differences in morphological characteristics of the Japanese Genji firefly *Nipponoluciola cruciata* between Yamanashi and Gunma Prefectures separated by the Kanto Mountains in central Japan. Two multivariate analysis methods were performed using measurements previously published in the literature. First, allometric analysis between body length and elytra width suggested that this species exhibits different allometric patterns between the two prefectures. Second, cluster analysis of measurements of genitalia suggested that this species in the two prefectures is completely classified into different groups. These results suggest the importance of further morphological studies to clarify the divergence of this species.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Takada, K. (2011) Popularity of Different Lampyrid Species in Japanese Culture as Measured by Google Search Volume. *Insects*, **2**, 336-342. https://doi.org/10.3390/insects2030336

[2] Kanda, S. (1935) Fireflies (Hotaru). Nippon Hakko Seibutsu Kenkyu Kai.

[3] Ohba, N. (1988) Genji Botaru (The Genji firefly). Bun-ichi Sogo Press.

[4] Iguchi, Y. (2010) Temperature-Dependent Geographic Variation in the Flashes of the Firefly *Luciola cruciata* (Coleoptera: Lampyridae). *Journal of Natural History*, **44**, 861-867.https://doi.org/10.1080/00222930903528206

[5] Suzuki, H., Sato, Y., Fujiyama, S. and Ohba, N. (1996) Allozymic Differentiation between Two Ecological Types of Flashing Behavior in the Japanese Firefly, *Luciola cruciata*. *Japanese Journal of Entomology*, **64**, 682-691.

[6] Yoshikawa, T., Ide, K., Kubota, Y., Nakamura, Y., Takebe, H. and Kusaoke, H. (2001) Intraspecific Genetic Variation and Molecular Phylogeny of *Luciola cruciata* (Coleoptera: Lampyridae) Inferred from the Mitochondrial ND5 Gene Sequences. *Japanese Journal of Entomology*, **4**, 117-127.

[7] Suzuki, H., Sato, Y. and Ohba, N. (2002) Gene Diversity and Geographic Differentiation in Mitochondrial DNA of the Genji Firefly, *Luciola cruciata* (Coleoptera: Lampyridae). *Molecular Phylogenetics and Evolution*, **22**, 193-205. https://doi.org/10.1006/mpev.2001.1046

[8] Kato, D., Suzuki, H., Tsuruta, A., Maeda, J., Hayashi, Y., Arima, K., Ito, Y., and Nagano, Y. (2020) Evaluation of the Population Structure and Phylogeography of the Japanese Genji Firefly, *Luciola cruciata*, at the Nuclear DNA Level Using RAD-Seq Analysis. *Scientific Reports*, **10**, Article No. 1533. https://doi.org/10.1038/s41598-020-58324-9

[9] Ohba, N. (2001) Geographical Variation, Morphology, and Flash Pattern of the Firefly, *Luciola cruciata* (Coleoptera: Lampyridae). *Science Report of the Yokosuka City Museum*, **48**, 45-89.

[10] Imasaka, S. (2010) Geographic Variation in *Luciola cruciata*: 1st Report on Measurement Data from Central and Western Japan. *Monthly Bulletin of Rikusei Hotaru Seitai Kenkyukai*, **24**, 1-18.

[11] Imasaka, S. (2012) Geographic Variation in *Luciola cruciata*: 2nd Report on Measurement Data from Central and Western Japan. *Monthly Bulletin of Rikusei Hotaru Seitai Kenkyukai*, **39**, 1-16.

[12] Iguchi, Y. (2001) Pattern and Process of Geographical Diversification of Flashes in The Firefly *Luciola cruciata* in the Northern Part of Yamanashi Prefecture. *Proceedings of the Japan Association for Fireflies Research* (*Zenkoku Hotaru Kenkyukai-shi*), **34**, 10-12.

[13] Iguchi, Y. (2008) The Interflash Interval of the Genji-Firefly *Luciola cruciata* in the Central Part of Japan. *Proceedings of the Japan Association for Fireflies Research (Zenkoku Hotaru Kenkyukai-shi*), **41**, 43-45.

[14] Iguchi, Y. (2024) Katsuyama Famous for Its Dinosaurs and Fireflies in Relation to Alien Fireflies in Tatsuno and Kamikochi Tourism. Report of Laboratory of Biology.

[15] Iguchi, Y. (2023) Allometric Approach to the Two Male Morphs in the Japanese Firefly *Luciola parvula*. *Frontiers in Insect Science*, **3**, Article 1230363. https://doi.org/10.3389/finsc.2023.1230363

[16] Iguchi, Y. (2024) Geographic Differences in Allometric Patterns of Males of the Japanese Firefly *Luciola parvula*. *Advances in Entomology*, **12**, 18-23. https://doi.org/10.4236/ae.2024.121002

[17] R Core Team (2023) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. https://www.r-project.org/

[18] Ohba, N. (2004) Flash Communication Systems of Japanese Fireflies. *Integrative and Comparative Biology*, **44**, 225-233.https://doi.org/10.1093/icb/44.3.225

[19] Iguchi, Y. (2002) The Influence of Temperature on Flash Interval in the Genji-Firefly *Luciola cruciata* (Coleoptera: Lampyridae). *Entomological Review of Japan*, **57**, 119-122.