

Male Morphological Difference in the Genji Firefly *Nipponoluciola cruciata* between Eastern and Western Japan

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Abstract

The Genji firefly *Nipponoluciola cruciata* shows different flash patterns between eastern and western Japan. The geographic variation in flash patterns has also been supported by ecological and molecular phylogenetic studies. However, there are very few studies on morphological variation in this species. This study aims to explore morphological differences in males of this species and to perform allometric analysis using measurements previously published in the literature. The results indicate that males of this species exhibit different allometric patterns between eastern and western Japan. This species has been often used for tourism purposes and sometimes intentionally introduced into non-native areas. Therefore, the results demonstrate the importance of the conservation of morphological diversity as well as genetic and ecological diversity in this species.

Keywords

Genji Firefly, Morphological Diversity, Geographic Variation

1. Introduction

The aquatic firefly *Nipponoluciola cruciata* (formerly named *Luciola cruciata*, Coleoptera, Lampyridae) is widely distributed throughout Japan except in the Hokkaido region. This firefly is commonly called Genji-botaru in Japanese and is one of the most popular insects in Japan [1] [2]. Therefore, this firefly has been widely used for tourism purposes [3] [4] and sometimes intentionally introduced into non-native areas [5] [6]. This species has been well-known for its geographic variation in interflash intervals, which vary from about 2 s in western Japan to about 4 s in eastern Japan [7]-[9]. Molecular phylogenetic studies have also found

genetic differentiation between the 4-s and 2-s flash types [10]-[13]. However, there are very few studies on geographic differences in the morphological characteristics of this species. Ohba [14] 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 the mean values of measurements.

Recently, the present author [15] reanalyzed the measurements of this species recorded by Imasaka [16] [17] and found that the allometric equations of this species are different between the eastern and western regions of the Kanto Mountains (Figure 1). Fortunately, the present author found that Ohba [14] documented morphological measurements of this species in detail. Therefore, in this article, the author aims to reanalyze his data and statistically clarify the geographic variation in the morphological characteristics of this species.

As mentioned above, this firefly is very popular in Japan. People enjoy watching, touching, and sometimes collecting fireflies every summer. Previous studies have promoted the conservation of genetic and ecological diversity [10]-[12]. This study will help people to recognize and conserve morphological diversity as well as genetic and ecological diversity in this firefly.

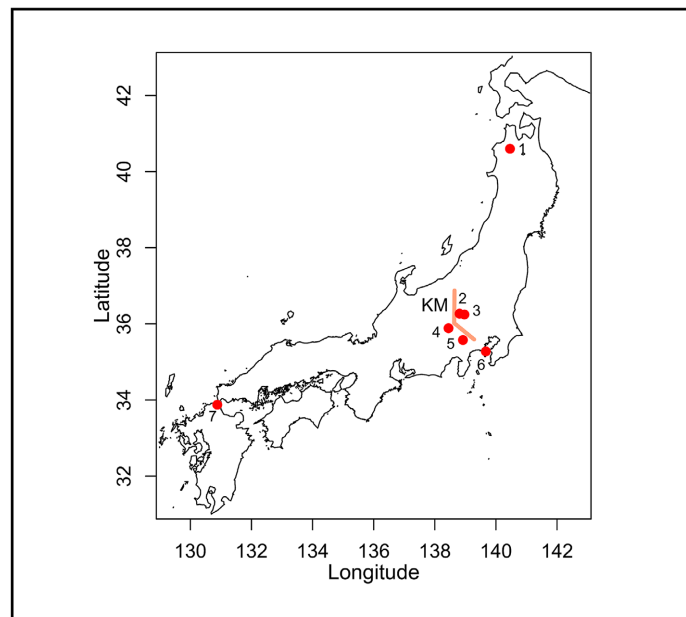


Figure 1. Map showing sample localities in Japan. Numbers denote the following localities: 1. Hirosaki, Aomori; 2. Tomioka, Gunma; 3. Yoshii, Gunma; 4. Takane, Yamanashi; 5. Tsuru, Yamanashi; 6. Yokosuka, Kanagawa; 7. Kitakyushu, Fukuoka. Localities 1, 6, and 7 were analyzed in this study, whereas localities 2 - 5 were analyzed in my previous study [15].

2. Materials and Methods

The data used in this study were morphological measurements of male *N. cruciata* collected at the following three localities with the collection date (year-month-day): Hirosaki (1985-06-11 and 1985-07-11), Yokosuka (1980-06-10, 1986-06-15,

1987-06-14, 1988-06-28, 1989-06-18, and 1995-06-15), and Kitakyushu (1978-06-day unknown) as shown in **Figure 1**. These data were obtained from Table 2 of the paper by Ohba [14], which is available at the repository of the Yokosuka City Museum:

https://www.museum.yokosuka.kanagawa.jp/wp/wp-content/uploads/2020/08/s48-6_Ohba_2001.pdf.

He described measurements from nine localities. However, the above-mentioned three localities with larger sample sizes ($n > 30$) were chosen in this study.

The measurements analyzed in this study were pronotum length and pronotum width. According to previous studies on Japanese fireflies [15] [18] [19], allometric equations were applied to the data of pronotum length and pronotum width using standardized major axis regression with the *smatr* package [20] in the R software. The data were \log_{10} -transformed into the log-log relationship between pronotum length (x) and pronotum width (y). Consequently, the \log_{10} -transformed allometric equation was expressed as:

$$\log_{10} y = \log_{10} a + b \log_{10} x$$

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

All calculations and graphic presentations were performed using the R software.

3. Results

Following the instructions of the *smatr* package [20], this study analyzed differences in the slope and elevation of the three allometric lines shown in **Figure 2**.

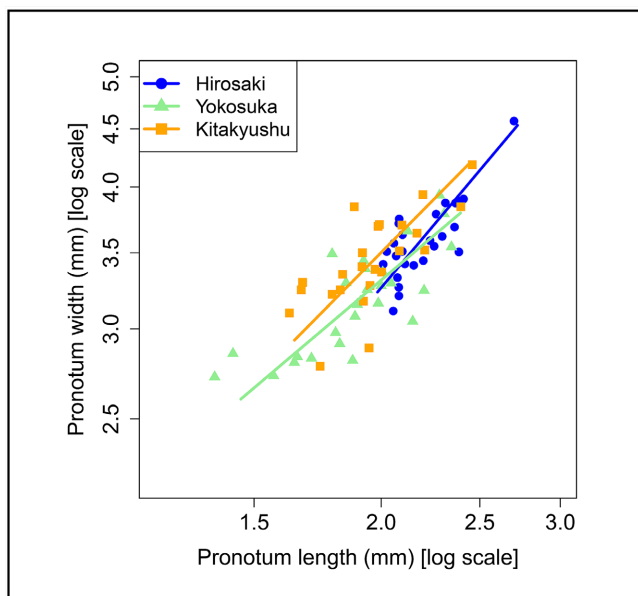


Figure 2. Allometric relationship between pronotum length and pronotum width in *N. cruciata* at Hirosaki, Yokosuka, and Kitakyushu in Japan. The standardized major axis regression lines were separately fitted to each locality.

The three allometric lines did not differ significantly in slope ($\chi^2 = 3.438$, $df = 2$, $p = 0.179$), but did differ significantly in elevation (y -intercept) ($\chi^2 = 9.130$, $df = 2$, $p = 0.010$). Therefore, pair-wise comparisons were made between localities for differences in elevation. The p values were adjusted using the Sidak correction. As a result, there was a significant difference in elevation between Kitakyushu and Hirosaki and between Kitakyushu and Yokosuka ($p < 0.01$ for both), but no significant difference between Hirosaki and Yokosuka ($p = 0.773$). These findings showed that the three allometric lines were classified into two parallel lines, that is, Kitakyushu vs. Hirosaki and Yokosuka.

4. Discussion

The results of the allometric analysis showed that the allometric lines of male *N. cruciata* in Japan are classified into two parallel lines. In other words, the results showed that males of this species have a wide pronotum shape in western Japan (Figure 3, W1) and a thin pronotum shape in eastern Japan (Figure 3, T1). My previous study [15] showed that males of this species have a wide body shape in the western part of the Kanto Mountains (Figure 3, W2) and a thin body shape in the eastern part (Figure 3, T2). Therefore, the present results are consistent with my previous study [15].

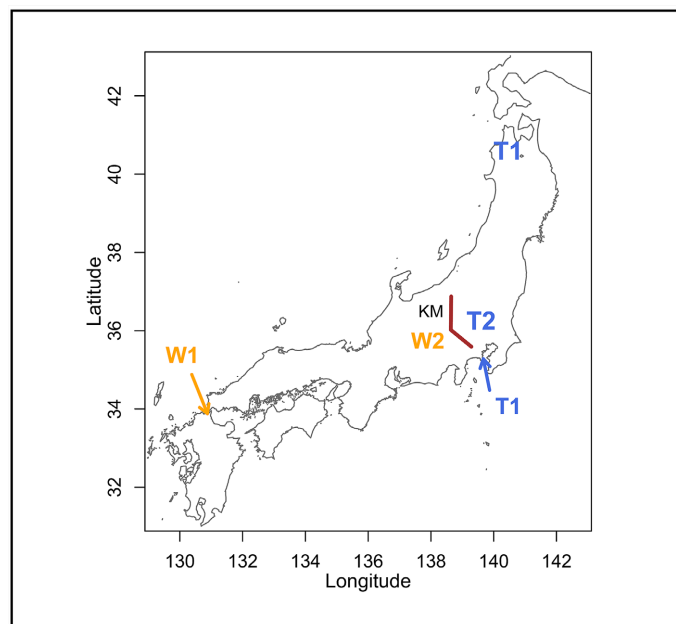


Figure 3. Geographic distribution of the two morphological types of *N. cruciata* in Japan. T1 and W1 denote the thin pronotum type and the wide pronotum type respectively in this study. T2 and W2 denote the thin body type and the wide body type respectively in my previous study [15]. KM denotes the Kanto Mountains.

Interestingly, a similar parallel allometric pattern is observed for the terrestrial firefly *Luciola parvula* in central Japan [18]. It is not yet clear what factor causes their morphological differences between eastern and western Japan. Nevertheless,

the central mountainous region of Japan seems to be a boundary region of the two morphological types in both *N. cruciata* and *L. parvula*.

A recent review article [21] suggests that due to the geological uplift of central Japan since the Miocene period, the formation of mountains has acted as a barrier to population mixing and dispersal of several insect taxa. My previous study [15] also made a similar suggestion for the diversification of *N. cruciata*.

Ohba [14] suggested that variations in the size of external structures in *N. cruciata* are larger within populations than among populations. However, he did not perform multivariate analysis. In the present study, allometric analysis was useful in detecting geographic variation in the body shape of this species. Nevertheless, the limitation of this study is that the data were collected regarding only the two morphological traits at a few localities. Further studies will be required for various morphological traits in more regions to clarify morphological diversity in this species.

5. Conclusion

This article explored morphological variation in the Japanese Genji firefly *Nipponoluciola cruciata* throughout Japan. Allometric analysis between pronotum length and pronotum width was performed using measurements previously published in the literature. The results suggested that this species exhibits different allometric patterns between eastern and western Japan. This study will help to recognize morphological diversity as well as genetic and ecological diversity in this species.

Conflicts of Interest

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

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