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Geographic Differences in Allometric Patterns of Males of the Japanese Firefly *Luciola parvula*

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Abstract

It has been well known for many years that males of *Luciola parvula* (Coleoptera, Lampyridae) have two morphs, namely small and large morphs in Japan. This article performed a statistical reanalysis of their morphological measurements based on previously published data and compared them. As a result, the two morphs were found to have different allometric patterns in the Hakone and Nagano areas, Japan. In Hakone, the relationships between their pronotum width and length were expressed by a common allometric line and a shift in location along the line. However, in Nagano, the relationships between their pronotum width and body length were expressed by two parallel allometric lines (a common slope and different intercepts). The allometric pattern of males of this species may vary among different parts of the body or among different areas. Therefore, this article recommends future studies to measure the same parts of the body as previous studies to clarify geographic variation in allometric relationships.

Keywords

Body Size, Male Dimorphism, Allometric Pattern, Hakone, Nagano

1. Introduction

Luciola parvula (Coleoptera, Lampyridae) is a terrestrial firefly species widely distributed in Japan and one of the most popular insects, which is called Himebotaru, or Princess-firefly [1]. Therefore, many studies have been performed on various aspects such as life history [2], morphology [3] [4] [5], behavior [6] [7] [8], molecular phylogeny [9] [10] [11] [12], and biochemistry [13].

One of the interesting topics on this species is the presence of two male morphs, namely large and small male morphs [4] [5]. Male dimorphism in fireflies has been scarcely reported except for *Abscondita cerata* (previously named

Luciola cerata) in Taiwan [14]. Recently the present author reanalyzed previously published morphological data on this species and found the two male morphs to show a discontinuous allometric relationship [15]. However, the reanalysis data sources were restricted to specimens collected in Nagano Prefecture.

As mentioned above, this species is widely distributed in Japan and has been studied on various aspects for more than forty years. Some reports say that the small male morph is relatively abundant below 800 m altitude in western Japan [4] [7], whereas others say that both morphs are found above 1000 m altitude [16] [17] [18] [19]. It is not yet clear on geographical variation in the two male morphs. One of the reasons is the lack of sufficient statistical analysis of morphological measurements of this species [15]. Therefore, it is important to reanalyze previously published data on specimens collected in various areas and examine the presence of the two morphs before proceeding to further studies on this species.

In order to contribute to the topic of the two male morphs on this species, the present author decided to reanalyze the data in a pioneer study on this topic by the late Dr Nobuyoshi Ohba [3]. He collected male adults around Mt. Hakone, central Japan and then classified them into the large morph above 700 m altitude and the small morph below this altitude. He showed a scatter plot of pronotum width and length, but did not conduct any further statistical analysis.

As far as the present author knows, there have been no detailed statistical studies on morphological data collected around Mt. Hakone so far. Nevertheless, based on Ohba's classification [3], genetic differences were evaluated between the two male morphs [9]. Therefore, the detailed reanalysis of Ohba's data [3] will help researchers plan future studies not only on morphological characteristics but also on molecular genetic characteristics.

2. Materials and Methods

The data analyzed here were obtained from Figure 2.3 of the literature [3] (p. 24) shown as a scatter plot of pronotum width and length in *L. parvula* around Mt. Hakone, Kanagawa Prefecture, Japan. The data consisted of 29 specimens of males of this species collected from 100 to 1200 m altitude, but the raw measurement data were not shown there. Therefore, in the present article, those scatter plot data were first digitized using the GSYS 2.4 software developed by Nuclear Reaction Data Centre, Hokkaido University, Japan [20].

As mentioned above, the 29 specimens were classified into the large morph above 700 m altitude and the small morph below this altitude [3]. Therefore, in the present article as well as in the author's previous article [15], allometric equations were applied to the two morphs using standardized major axis regression with the smatr package in the R software [21]. The data were $\log_{10}$-transformed into the log-log relationship between pronotum width (x) and pronotum length (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.

3. Results

As shown in Figure 1, the two allometric lines representing the two morphs did not differ significantly in either slope ($\chi^2 = 0.878$, df = 1, $p = 0.349$) or elevation (y-intercept) ($\chi^2 = 0.00135$, df = 1, $p = 0.971$), but showed a significant shift along the common slope ($\chi^2 = 76.94$, df = 1, $p < 0.001$). The common slope ($b = 1.251$) was not significantly different from 1 ($\chi^2 = 2.342$, df = 2, $p = 0.310$), which indicated an isometric relationship between pronotum width and length.

4. Discussion

The allometric analysis of the literature [3] showed that the two male morphs of *L. parvula* around Mt. Hakone shared a common allometric line and shifted in location along the line. This allometric pattern was different from that in Nagano Prefecture found by the author's previous study [15], where the data of the literatures [16] [17] [18] [19] were reanalyzed (Figure 2).

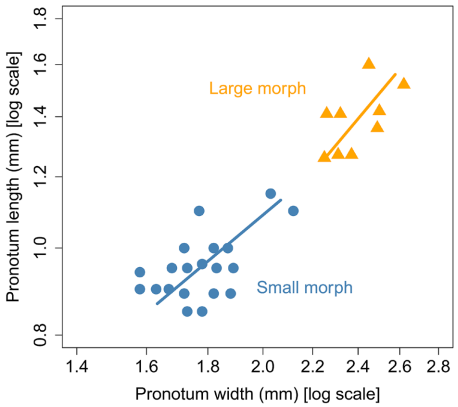

Figure 1. Allometric relationship between pronotum width and length in the two male morphs of *L. parvula* fireflies around Mt. Hakone. The data were obtained from Figure 2.3 of the literature [3] (p. 24), where the 29 specimens were classified into the large morph above 700 m altitude and the small morph below this altitude. The standardized major axis regression lines were separately fitted to each group.

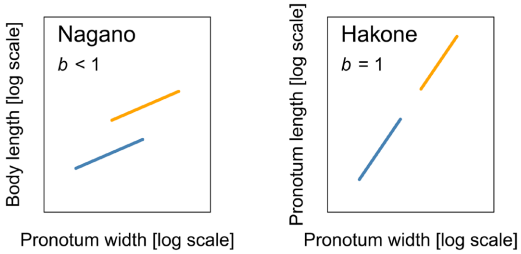

Figure 2. Different allometric relationships in the two male morphs of *L. parvula* fireflies in the Nagano and Hakone areas. The relationship in Nagano was analyzed in [15] and that in Hakone was analyzed in this article. The parameter b represents the allometric coefficient.

This difference may be because [3] and [16] [17] [18] [19] measured different parts of the body, namely pronotum width and pronotum length [3], and pronotum width and body length [16] [17] [18] [19]. Allometric relationships can vary geographically because of larval nutrition [22] [23] [24] [25], but they can also vary between different body parts for the same species [22]. Therefore, future studies on the male dimorphism of *L. parvula* will be recommended to compare geographical variations in allometric relationships between the same parts of the body.

Regarding genetic differences in the two male morphs of this species, [9] used allozyme loci and reported that they have genetic distance at the subspecies level. On the other hand, [11] used COI gene sequences and considered that this firefly may be pseudocryptic species with genetic divergence but not with appreciable morphological differences, except for body size. However, [15] revealed that the two male morphs of this species show different allometric relationships as well as different body sizes. Neither [9] nor [11] considered allometric relationships in this species. However, the results shown in the present article suggest that allometric analysis is very important in genetic studies to clarify the dimorphism of this species.

As mentioned above, there are two factors expected to cause the two different allometric patterns in the Nagano and Hakone areas. One is larval nutrition, and the other is gene expression. However, there is no evidence that these factors cause the two different allometric patterns in this species. Therefore, further ecological and genetic investigations are required to find the cause of the two different allometric patterns in this species.

5. Conclusion

Male size dimorphism is rarely observed in firefly species. However, the present study revealed that the large and small male morphs in *L. parvula* exhibit two different allometric patterns in two different areas, Nagano and Hakone, Japan. Further ecological and genetic studies will clarify the cause of the two different allometric patterns.

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Conflicts of Interest

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

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