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Male Horn Dimorphism in *Copris acutidens* (Coleoptera, Scarabaeoidea): Consistency of the Threshold Values in Head and Prothoracic Horns

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The coprophagous beetle, *Copris acutidens* Motschulsky (Coleoptera, Scarabaeoidea; Japanese name, Go-hon-daikoku-kogane, Fig. 1), distributed in Japan, Korea and China, is known to exhibit dimorphism in the male horn size morphology (Masumoto, 1967). The nest-staying behavior associated with the male horn dimorphism is reported by Akamine (2016 a). Allometric analyses in the species using the models of Eberhard and Gutiérrez (1991) revealed that both head horn length and prothoracic horn height (distance from the base of the head to the apex of the prothoracic horn) relative to body size follow a discontinuous pattern, but prothoracic horn length (distance from the posterior margin of the prothorax to the apex of the prothoracic horn) relative to body size follows linear pattern (Akamine, 2016 b). In the model, the estimated threshold or switch point values that can be classified as either a major or minor morph showed almost same value in the head horn length and prothoracic horn height. The fact suggests that the dimorphism in each horn may be formed by same developmental threshold mechanism (Eberhard, 1987; Akamine, 2016 b). However, only specimen from Nara City, central Japan, at one season in 2002 was analyzed by Akamine (2016 b). In this study, prothoracic width as an indicator of body size, head horn length and prothoracic horn height using specimens from Ôto Village, in Nara Prefecture, the locality about 50 km distant from Nara City, were measured under microscope with eyepiece micrometer. The threshold or switch point values in the head horn length and prothoracic horn height were estimated using the models of Eberhard and Gutiérrez (1991): The first model tests if the relationship between horn length and body size can be expressed as a simple allometric relationship:

$$\ln Y = \alpha_0 + \alpha_1 \ln X + \alpha_2 \ln X^2 + \varepsilon \qquad (1)$$

in which Y is horn length, X body size, α_i the regression coefficient and ε the random component with normal distribution and common variance. Values of α_2 that differ significantly from zero indicate a more complex relationship. A further analysis was conducted:

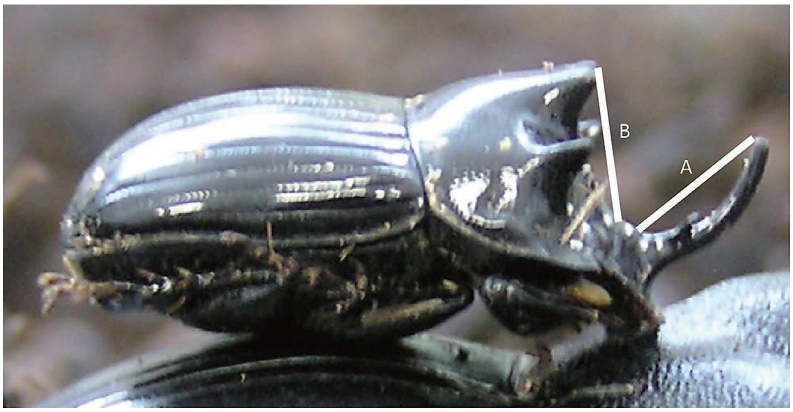

Fig. 1. Lateral view of male *Copris acutidens*. —— A, Head horn length; B, prothoracic horn height.

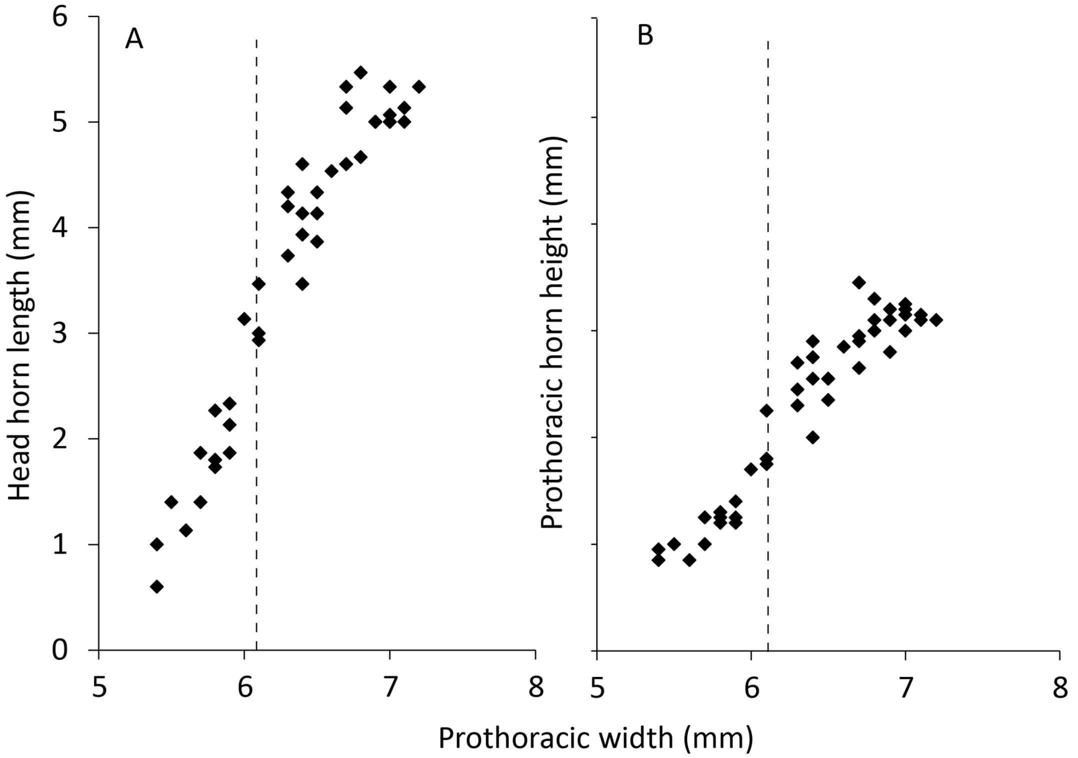

Fig. 2. Allometric scaling relationship between prothoracic width as indicator of body size and each horn. —— A, Head horn length; B, prothoracic horn height. Broken lines show switch point value of each horn.

$$Y = \beta_0 + \beta_1 X + \beta_2 (X - X_0)\, D + \beta_3\, D + \varepsilon \qquad (2)$$

in which X_0 is the threshold or switch point value; $D = 0$ if $X < X_0$ or otherwise $D = 1$, and β_i the regression coefficient. The optimal value of X_0 was identified to give the maximum value of adjusted R^2 calculated using SPSS Statistics version 19 (IBM, Japan). In Eq (2), if β_3 is significantly different from zero using the optimal switch point value, then the dimorphism is judged as discontinuous at X_0. If β_3 is not significantly different from zero, the slope parameter β_2 identifies a continuous dimorphic pattern if the value of β_2 is significantly different from zero. Based on results from Eq (2), males can be classified as either a major or minor morph based on the estimated threshold value of the dimorphic pattern. In Eq (1), the coefficient α_2 was found to differ significantly from zero (for head horn length, $\alpha 2 = -26.7$, $t = -9.3$, $P < 0.0001$; for prothoracic horn height, $\alpha_2 = -13.4$, $t = -4.8$, $P < 0.001$). The switch point with the best fit was estimated to be 6.2 mm in both head and prothoracic horn. In Eq (2), given each switch point value, the coefficient β_3 was significantly different from zero (for head horn length, $\beta_3 = 0.53$, t = 4.04, P < 0.001; for prothoracic horn height, $\beta_3 = 0.49$, t = 5.04, P < 0.001). Thus, the model analyses concluded that the allometry of respective horn sizes in male *C. acutidens* was discontinuous in both head horn length (Fig. 2A) and prothoracic horn height (Fig. 2B), and the switch point values with the best fit head horn length and prothoracic horn height are almost the same value in even the different locality from Nara City.

Specimens examined. 45 ♂♂; Ôto Village, Nara Pref., from 12 to 21.IX of an unknown year, the collector unknown.

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