Article

Centrobolus size dimorphism breaks Rensch's rule

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Abstract

This present research aims to study the relative sexual size dimorphism of *Centrobolus* (Cook) in 18 congenerics. Millipedes illustrated reversed sexual size dimorphism (SSD) where females were larger than males; and broke Rensch's rule as this dimorphism increased with body size. SSD was calculated in 18 species of the genus *Centrobolus* and illustrated was regressions; male *versus* female SSD and SSD *vs* body size. An allometric equation for *Centrobolus* was (1) $\hat{y}=0.00051x-0.01071$. SSD ranged from 0.63–2.89 (1.55±0.63; n≥18) and was not negatively correlated (R=0.70485; P=0.00109; n=18 spp.) with volume ranging from 284–2683 mm^3 (1097.89±638.06; 18). The rejection of the rule appears consistent among arthropods.

Keywords dimorphism; millipede; SSD; size.

1 Introduction

Sexual size dimorphism is prevalent in arthropods and females are usually larger than males. Behavioural patterns such as provisioning *versus* non-provisioning relate to SSD. Millipedes illustrate reversed sexual size dimorphism (SSD) and females are larger than males (Lawrence, 1967; Schubart, 1996; Cooper, 2014, 2016a, c). Forest millipede SSD has successfully been understood as volumetric measurements using *Centrobolus* to reject Rensch's rule (Cooper, 2014, 2016a, c). This rule maintains there should be a negative relationship between body size and SSD when females are larger, which is often not the case in Invertebrates (Webb and Freckleton, 2007). Based on the equal developmental rates in males and females, the proximate cause for Rensch's rule is sexual bimaturism (Webb and Freckleton, 2007; Cooper, 2016b). The trend of SSD has been calculated for *Centrobolus* and bimaturism shown (Cooper, 2014, 2016b).

The present study was aimed to illustrate the trend of SSD for the genus *Centrobolus* in 18 congenerics in order to highlight how males and females disobey the trend of Rensch's rule.

2 Material and Methods

Two factors were measured from *Centrobolus* species (1) body length (mm) by placing individuals collected in South Africa (1998-2018) alongside a plastic rule (calibrated in mm); and (2) width (mm) with Vernier calipers was measured in South Africa (1998-2018). So millipede SSD was calculated in the genus *Centrobolus* (Cooper, 2014, 2016c). A regression of male volume on female volume was used to show the position of 18 species and the volumetric measurements inserted into a Microsoft (MS) Excel spreadsheet and converted using the logarithmic (mathematical) equation. The chart for SSD in 18 species was captured, copied and exported using the snapshot function in the programme Soda Portable Document File (PDF) Desktop. It was pasted into this MS Word file.

The basic descriptive figures were statistically compared using Statistica 13. Body length: width ratios were compared on arcsine transformed data. The mean values of length and width was extracted from published data for 18 species intersexual comparisons performed using Wilcoxon matched pairs tests.

Size was perceived as body volume and calculated based on the formula for a cylinder ($l.\pi.r^2$) where l is body length and r half of the width. SSD was estimated as the mean female volume divided by mean male volume and converted into a SSD index by subtracting 1. Allometry for SSD was based on a general allometric model where male size = α (female) $^{\beta}$.

3 Results

The quantitative resolution of Rensch's rule for 18 species of *Centrobolus* is shown in Fig. 1. The positive relationship between SSD and body size is show in Fig. 2. The allometric equation for *Centrobolus* was (1) $\hat{y}$=0.00051x-0.01071. SSD ranged from 0.63–2.89 (1.55±0.63; n≥18) and was not negatively correlated (R=0.70485; P=0.00109; n=18 spp.) with volume ranging from 284–2683 mm^3 (1097.89±638.06; 18).
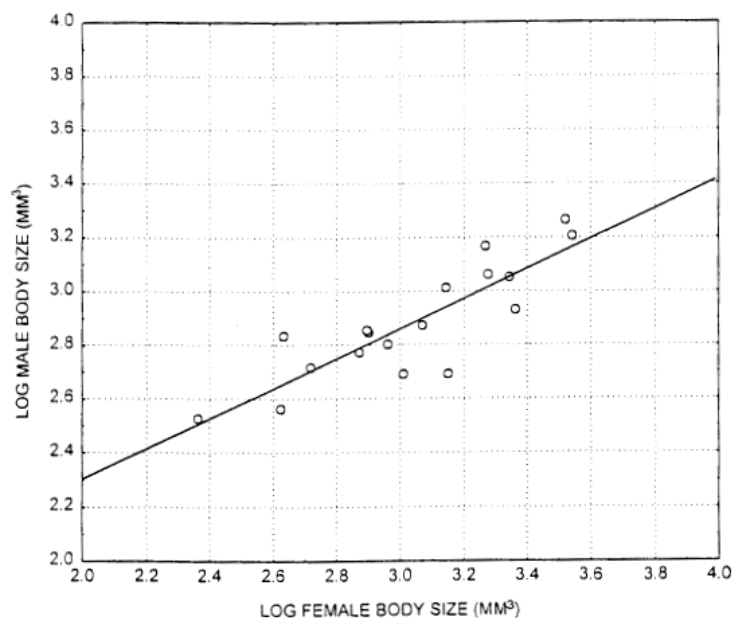

Fig. 1 Quantitative resolution of Rensch's rule for 18 species of millipedes of genus *Centrobolus*. Allometry for sexual size dimorphism (SSD) is based on the model: male size = α (female size) $^{\beta}$ (Leutenegger, 1978), correlation coefficient, r= 0.85. The regression of log (female size) on log (male size) would generate an identical relationship with $\beta < 1$.
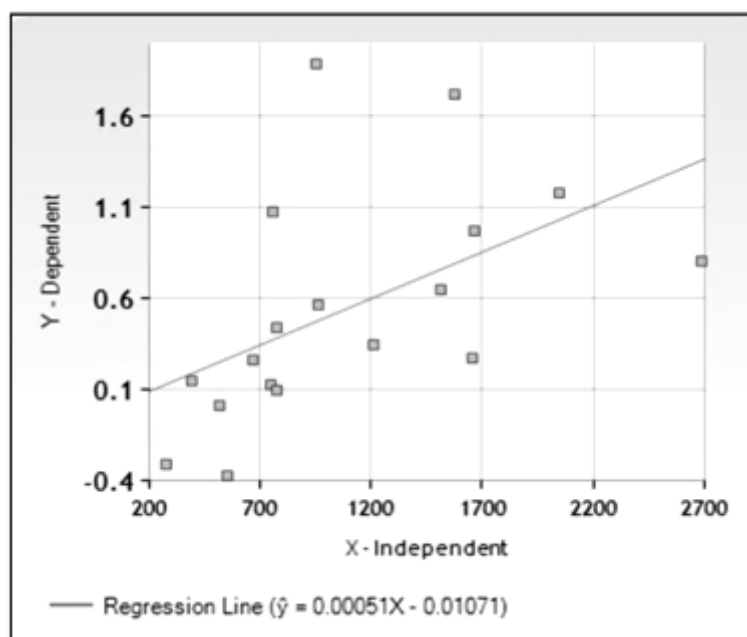
Fig. 2 Regression showing the relationship between *Centrobolus* sexual size dimorphism and body size.

4 Discussion

The results consistently reject Rensch's rule. Fig. 1 shows the finding for *Centrobolus* where mean volume ratios ranged from 0.63-2.72 with the regression of log male volume on log female volume was highly significant with a positive slope less than 1 showing females get larger than males with an increase in body size (Lawrence, 1967; Cooper, 2014, 2016*c*). The mean volume ratio of above 1.0 was a trend for the genus.

This study was in agreement with numerous studies which are finding animal taxa having female biased SSD mostly disobey Rensch's rule including corvids, and pinnipeds (Monnet and Cherry, 2002; Tubaro and Bertelli, 2003; Rutherford, 2004; Sutter et al. 2008; Stuart-fox, 2009; Herczeg et al., 2010; Remeš and Székely, 2010; Minton and Wang, 2011; Liao and Chen, 2012; Bidau et al., 2013; De Lisle and Rowe, 2013; Liao et al., 2013; Liao, 2013; Colleoni et al., 2014; Guillermo-Ferreira et al., 2014; Husak and McGuire, 2014; Lu et al., 2014; Liao et al., 2015; Martin et al., 2017; Cooper, 2018a, b, c).

5 Conclusion

Centrobolus males and females break Rensch's rule as was the case in arthropods.

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