Article

Centrobolus lawrencei (Schubart, 1966) monomorphism

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Abstract
The present research aimed to study relative sexual size dimorphism of *Centrobolus lawrencei* compared to congenerics. Millipedes illustrated reversed sexual size dimorphism (SSD) as females were larger than males and broke the rule as this dimorphism increased with body size. SSD was calculated in 21 species of the genus *Centrobolus* and illustrated as a regression. The approximate relative position of *C. lawrencei* was shown from measurements taken in South Africa. The average size of *C. lawrencei* was 47.3333 × 4.82222 mm (n=9) and logged (x/y = 2.36132). Males were 47.875 × 4.6875 mm (n=8) and females 43 × 5.9 mm (n=1). The SSD index was 1.00201. Log volume measurements were (females/x = 2.36553 mm^3; males/y = 2.36079 mm^3). The difference between the correlation coefficients for the species and the genus were not highly significant (r_a = 0.867365, r_b = 0.7473; n_a = 9, n_b = 21; Z = 0.75; P (one-tailed) = 0.2266, P (two-tailed) = 0.4533). The mean volume ratio for *C. lawrencei* was 1.00201 which did not differ from 1 (*t*=1.82574; *p*-value=0.097855; *NS* at $p < 0.01$; n=8).

Keywords *Centrobolus*; dimorphism; *lawrencei*; millipede; SSD; size.

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1 Introduction

Sexual size dimorphism (SSD) 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 SSD and females are larger than males (Telford and Dangerfield, 1990; Hopkin and Read, 1992; Cooper and Telford, 2000; Cooper, 2016; Cooper, 2017a, e; Mori et al., 2017). Diplopoda are underrepresented in allometric analyses of SSD, although SSD is known in body mass, length, width and leg dimensions of over half the taxa studied (Hopkin and Read, 1992; Enghoff, 1992; Cooper, 2016a-e). Size differences correlate with factors such as color, sexes, species, urbanisation and water relations (Enghoff, 1992; David, 1995; Rowe, 2010; Mori et al., 2017). Diplopoda resemble the majority of invertebrates where SSD is as reversed (Cooper, 2017a-e; Cooper, 2018a-c). SSD has consequences for outcomes of sexual encounters in diplopod mating

(Telford and Dangerfield, 1990; Hopkin and Read, 1992; Enghoff, 1992; David, 1995; Rowe, 2010; Akkari and Enghoff, 2011; Cooper, 2016a,e; Cooper, 2017a,e; Mori et al., 2017). The allometry of SSD involves the detection of a relationship between body size and SSD and is known by Rensch's rule (Rensch, 1957, 1960). Rensch's rule may be explained by sexual selection and fecundity selection (Dale et al., 2007; Pincheira-Donoso and Hunt, 2015). The macro-evolutionary pattern is unresolved in Diplopoda. Here, Rensch's rulewas tested in predicting SSD was not negatively correlated with diplopod body size in African forest and savanna taxa. SSD in the forest genus *Centrobolus* was investigated.

SSD in forest millipedes have successfully been understood as volumetric measurements using *Centrobolus* to test Rensch's rule.The general trend of SSD has been calculated for *Centrobolus* and bimaturism shown (Cooper, 2016c).The present study was aimed to illustrate the trend of SSD for the genus *Centrobolus* and estimate the position of *C. lawrencei* relative to 21 congenerics in order to determine whether species follow the trend of Rensch's rule.

2 Materials and Methods

Two factors were measured from *Centrobolus lawrencei*: (1) body length (mm) of individuals collected in South Africa (Table 1) and (2) width (mm) with Vernier calipers. *C. lawrencei* (Schubart) were collected at Town bush, Pietermaritzburg, South Africa. Millipede SSD was also calculated in the genus *Centrobolus* (Cooper, 2014a-b, 2016a-e). A regression of male volume on female volume was used to show the position of 21 species and the size of *C. lawrencei* was taken as a volumetric measurement and inserted into a Microsoft (MS) Excel spreadsheet and converted using the log (mathematical) equation. The chart for SSD in 21 species was figured using the Pearson Correlation Coefficient Calculator function in the online Social Science Statistics (https://www.socscistatistics.com/tests/pearson/Default2.aspx).

The basic descriptive figures were statistically compared using Statistica. Body length: width ratios were inputted into the formula for a cylinder. The mean values of length and width was obtained for 9 individuals of *C. lawrencei*. Size was perceived as body volume and calculated based on the formula for a cylinder ($h.\pi.r^2$) where h 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. Allometry for SSD was based on a allometric model where male size = α (female)$^{\beta}$. A Spearman's Rho calculation was made in order to test the correlation between the male and female volumes at http://www.socscistatistics.com/tests/spearman/Default3.aspx. Correlation coefficients were compared at http://vassarstats.net/rdiff.html. SSD was compared against to 1 using a two-tailed t-test at http://www.socscistatistics.com/tests/studentttest/Default2.aspx.

3 Results

The quantitative resolution of Rensch's rule for 21 species of *Centrobolus* together with the relative estimated position of *C. lawrencei* is shown in Fig. 1. The average size of *C. lawrencei* was 47.3333 × 4.82222 mm (n=9) and logged (x/y = 2.36132). Males were 47.875 × 4.6875 mm (n=8) and females 43 × 5.9 mm (n=1). The SSD index was 1.00201. Log volume measurements were (females/x = 2.36553 mm^3; males/y = 2.36079 mm^3). SSD was absent. The difference between the correlation coefficients for the species and the genus were not highly significant (r_a = 0.867365, r_b = 0.7473; n_a = 9, n_b = 21; Z = 0.75; P (one-tailed) = 0.2266, P (two-tailed) = 0.4533). The mean volume ratio for *C. lawrencei* was 1.00201 which was somewhat different from 1 (t=1.82574; p=0.097855; p<0.10).

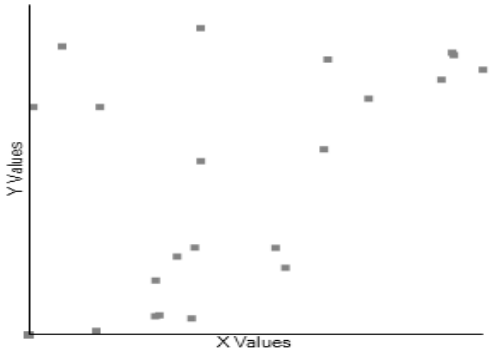

Fig. 1 Quantitative resolution of sexual size dimorphism for 21 species of millipedes of the genus *Centrobolus*. Allometry for sexual size dimorphism (SSD) is based on the allometric model (Leutenegger, 1978), male size = α (female size)$^{\beta}$; correlation coefficient, r = 0.7473. X Values log female volumes, Y Values log male volumes. The value of R^2, the coefficient of determination, is 0.5585.

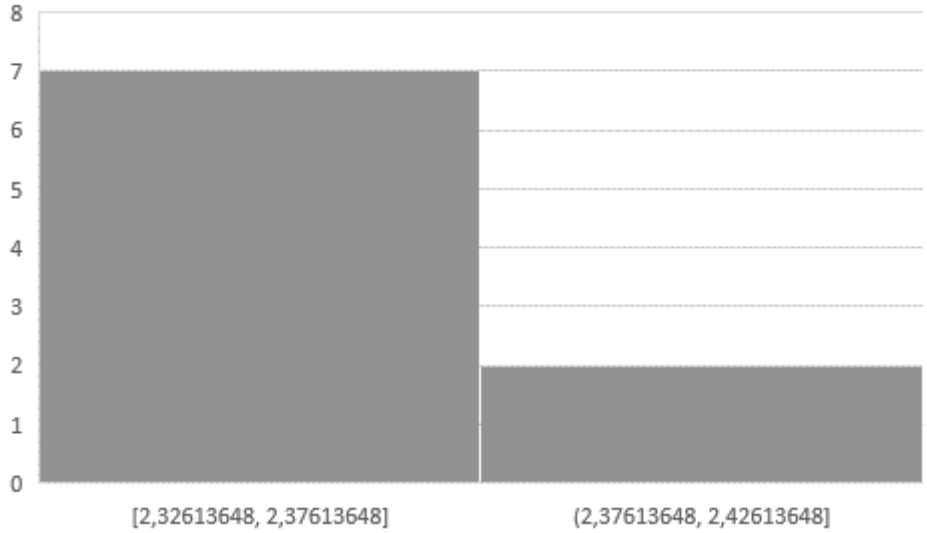

Fig. 2 Distribution frequency histogram for male and female volumes of *Centrobolus lawrencei*.

4 Discussion

Previous studies on SSD in invertebrates and these results consistently give a positive correlation and break the rule (Webb and Freckleton, 2007; Cooper, 2016a; Cooper, 2017b-d, f; Cooper, 2018a-j). The finding for *Centrobolus lawrencei* where the regression of log male volume on log female volume was highly significant with a positive slope of 0.867365; showing females get larger than males with an increase in body size (Cooper, 2014a, b, 2016c-d) shows SSD was not significant in this species. Mean volume ratio of 1.00201 for *C. lawrencei* was in line with the trend for the genus in Fig. 1. As causes for SSD in millipedes the evidence may suggest the sexual bimaturism hypothesis and intersexual competition (Cooper, 2016a, c). Evidence for sexual selection on monomorphism based on the relative size dimorphism in *C. lawrencei* implies size would not be important in determining the outcome of mating (Telford and Dangerfield, 1993; Tolley et al. 2011; Cooper, 2016e). In the millipede *Doratogonus uncinatus* female choice for mating partners is “size selective” (Telford and Dangerfield, 1993) but the cross-mating experiments in *Centrobolus* suggest a combination of size assortative mating without a size based preference operates (Cooper, 2016a). Studies of diplopod SSD

may include more taxa and make use of the length and width measurements to calculate volumes using the geometric morphometric approach shown here for finding causal relationships of dimorphism. O. Schubart's (1966) measurements for *C. lawrencei* show no SSD with similar males and females.

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References

Akkari N, Enghoff H. 2011. Copulatory-copulatory male succession and male slenderness in *Ommatoiulus sempervirilis* n. sp., a new insular millipede from Tunisia (Diplopoda: Julida: Julidae). Journal of Zoological Systematics and Evolutionary Research, 49(4): 285-291

Cooper MI. 2014a. Sex ratios, mating frequencies and relative abundance of sympatric millipedes in the genus *Centrobolus* Cook. Arthropods, 3(4): 174-176

Cooper MI. 2014b. Sexual size dimorphism and corroboration of Rensch's rule in *Chersastus* millipedes (Diplopoda: Trigoniulidae). Journal of Entomology and Zoology Studies, 2(6): 264-266

Cooper MI. 2016. Post-insemination associations between males and females in Diplopoda. Journal of Entomology and Zoology Studies, 4(2): 283-285

Cooper MI. 2016a. Fire millipedes obey the female sooner norm in cross mating *Centrobolus* Cook. Journal of Entomology and Zoology Studies, 4(1): 173-174

Cooper MI. 2016b. Heavier-shorter-wider females in the millipede *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(2): 509-510

Cooper MI. 2016c. Sexual bimaturism in the millipede *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(3): 86-87

Cooper MI. 2016d. The relative sexual size dimorphism of *Centrobolus inscriptus* compared to 18 congenerics. Journal of Entomology and Zoology Studies, 4(6): 504-505

Cooper MI. 2016e. Sexual conflict over the duration of copulation in *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(6): 852-854

Cooper M. 2017. Re-assessment of rensch's rule in *Centrobolus.* Journal of Entomology and Zoology Studies, 5(6):2408-2410

Cooper MI. 2017a. The effect of female body width on copulation duration in *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 5(1): 732-733

Cooper MI. 2017b. Relative sexual size dimorphism in *Centrobolus digrammus* (Pocock) compared to 18 congenerics. Journal of Entomology and Zoology Studies, 5(2): 1558-1560

Cooper MI. 2017c. Relative sexual size dimorphism in *Centrobolus fulgidus* (Lawrence) compared to 18 congenerics. Journal of Entomology and Zoology Studies, 5(3): 77-79

Cooper MI. 2017d. Relative sexual size dimorphism *Centrobolus ruber* (Attems) compared to 18 congenerics. Journal of Entomology and Zoology Studies, 5(3): 180-182

Cooper MI. 2017e. Size matters in myriapod copulation. Journal of Entomology and Zoology Studies, 5(2): 207-208

Cooper MI. 2018a. Allometry for sexual dimorphism in millipedes (Diplopoda). Journal of Entomology and Zoology Studies, 6(1): 91-96

Cooper MI. 2018b. Sexual dimorphism in pill millipedes (Diplopoda). Journal of Entomology and Zoology Studies, 6(1): 613-616

Cooper MI. 2018c. Sexual size dimorphism and the rejection of Rensch's rule in Diplopoda (Arthropoda).

Journal of Entomology and Zoology Studies, 6(1): 1582-1587

Cooper MI. 2018d. Trigoniulid size dimorphism breaks Rensch. Journal of Entomology and Zoology Studies, 6(3): 1232-1234

Cooper MI. 2018e. Volumes of *Centrobolus albitarsus* (Lawrence, 1967). International Journal of Entomology Research, 3(4): 20-21

Cooper M. 2018f. A review of studies on the fire millipede genus *Centrobolus* (Diplopoda: Trigoniulidae). Journal of Entomology and Zoology Studies, 6(4): 126-129

Cooper M. 2018g. *Centrobolus anulatus*reversed sexual size dimorphism. Journal of Entomology and Zoology Studies, 6(3): 1569-1572

Cooper MI. 2018h. *Centrobolus* size dimorphism breaks Rensch's rule. Arthropods, 7(3): 48-52

Cooper M. 2018i. *Centrobolus* size dimorphism breaks Rensch's rule. Scholars' Press, Mauritius

Cooper M. 2018j. *Centrobolus dubius* (Schubart, 1966) monomorphism. International Journal of Research Studies in Zoology, 4(3): 17-21

Cooper MI, Telford SR. 2000. Copulatory Sequences and Sexual Struggles in Millipedes. Journal of Insect Behaviour, 13: 217-230.

Dale J, Dunn PO, Figuerola J, Lislevand T, Székely T, Whittingham LA. 2007. Sexual selection explains Rensch's rule of allometry for sexual size dimorphism. Proceedings of the Royal Society B., 274: 2971-2979.

David JF. 1995. Size criteria for the distinction between *Cylindroiulus londinensis* (Leach) and *Cylindroiulus caeruleocinctus* (Wood) (Diplopoda: Julidae). Journal of Natural History, 29: 983-991.

Enghoff H. 1992. The size of a millipede. In: Advances in Myriapodology (Meyer E, Thaler K, Schedl W, eds). Berichte des naturwissenschaftlich-medizinischen Vereins in Innsbruck, Supplement, 10: 47-56

Hopkin SP, Read HJ. 1992). The Biology of Millipedes. Oxford University Press, UK

Leutenegger W. 1978. Scaling of sexual dimorphism in body size and breeding system in primates. Nature, 272: 610-611

Mori E, Mazza G, Lovari S. 2017. Sexual Dimorphism. In: Encyclopedia of Animal Cognition and Behavior (Vonk J, Shakelford T, eds). Springer International Publishing, Switzerland

Pincheira-Donoso D, Hunt J. 2015. Fecundity selection theory: concepts and evidence. Biological Reviews, 92: 341-356

Rensch B. 1947. Evolution above the Species Level. Columbia, New York, USA

Rensch B. 1950. Die Abhängigkeit der relativen Sexualdifferenz von der Körpergrösse. Bonn Zoological Bulletin, 1: 58-69.

Rowe M. 2010. Copulation, mating system and sexual dimorphism in an Australian millipede, *Cladethosoma clarum.* Australian Journal of Zoology, 58(2): 127-132

Telford SR, Dangerfield JM. 1990. Sex in millipedes: laboratory studies on sexual selection. Journal of Biological Education, 24: 233-238

Telford SR, Dangerfield JM. 1993. Mating Tactics in the Tropical Millipede *Alloporus uncinatus* (Diplopoda: Spirostreptidae). Behaviour, 124: 45-56

Tolley KA, Tilbury CR, Measey GJ, Menegon M, Branch WR, Matthee CA. 2011. Ancient forest fragmentation or recent radiation? Testing refugial speciation models in chameleons within an African biodiversity hotspot. Journal of Biogeography, 38(9): 1748-1760

Webb TJ, Freckleton RP. 2007 Only Half Right: Species with Female-Biased Sexual Size Dimorphism Consistently Break Rensch's Rule. PLoS ONE, 2(9): e897