Zoological and Entomological Letters

E-ISSN: 2788-8428
P-ISSN: 2788-8436
IJZEL 2022; 2(1): 66-68
Received: 15-10-2021
Accepted: 31-11-2021

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Does sexual size dimorphism vary with sex ratio in red millipedes *Centrobolus* Cook, 1897?

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Abstract
Sexual Size Dimorphism (SSD) and sex ratio were checked for correlations in the red millipede genus *Centrobolus*. There was no significant relationship between SSD and sex ratios in general among the two species (r=0.49, Z score=1.21, n=4, 4, p=0.11). There was no significant relationship between sex ratios on the ground and in the trees pooled with those from early in the season and SSD (r=0.29, Z score=0.52400671, n=3, 3, p=0.30). There was a significant relationship between sex ratios on the ground and in the trees pooled with those from late in the season and SSD (r=0.74, Z score=1.64976836, n=3, 3, $p < 0.05$). Greater female-biased SSD was related to male-biased sex ratios among two species (*C. anulatus* and *C. inscriptus*) recorded later in the season.

Keywords: Dimorphic, eco-geography, gradient, sex ratio, size, species

1. Introduction

The red millipede genus *Centrobolus* is well known for studies on sexual size dimorphism (SSD) and displays sex ratios that are seasonal and determine optimal copulation durations for individuals of each species at any one time [8-10]. *Centrobolus* is distributed in temperate southern Africa with northern limits on the east coast of southern Africa at -17° latitude South (S) and southern limits at -35° latitude S. It consists of taxonomically important species with 12 species considered threatened and includes nine vulnerable and three endangered species [20]. It occurs in all the forests of the coastal belt from the Cape Peninsula to Beira in Mocambique [19]. Common with worm-like millipedes (Juliformia) is the sex ratio biases which are known to occur in several populations of the genus *Centrobolus* [7].

SSD is correlated with sex ratio during the breeding season in the pachybolid millipede genus *Centrobolus* Cook, 1897 [5, 12, 19]. The objective here is to determine if there is a body size correlation and particularly SSD variation with the sex ratio across two sympatric species recorded across substrates at different times (early and late) in the breeding season.

2. Materials and Methods

Two species were identified as belonging to the genus *Centrobolus* Cook, 1897 [5]. The sex ratio during the breeding season was obtained for *C. anulatus* and *C. inscriptus* [7]. Body size was obtained by calculating the volumes (cylindrical) using the lengths and widths of species which were inputted into the formula for a cylinder's volume (https://byjus.com/volume-of-a-cylinder-calculator) [6]. SSD was calculated as the ratio of female volume to male volume [6]. SSD and sex ratios during early and late in the breeding season were checked for correlations using the Pearson Correlation Coefficient calculator (https://www.gigacalculator.com/calculators/correlation-coefficient-calculator.php).

3. Results

The SSD and the pooled (arboreal and terrestrial) sex ratio in the pair of species were positively related (r=1.00, n=2). There was no relationship between SSD and sex ratios in general (r=0.49434648, Z score=1.21149333, n=8, p=0.11285326). There was no significant relationship between sex ratios on the ground and in the trees pooled with those from early in the season and SSD (r=0.29363115, Z score=0.52400671, n=6, p=0.30013692). There was a significant relationship between sex ratios on the ground and in the trees pooled with those from late in the season and SSD (Fig. 1: r=0.74091015, Z score=1.64976836, n=6, p=0.04949514). SSD and arboreal sex ratios were related in the pair of species (r=1. 00, n=2). SSD was normally distributed (D=0.15168, n=22, p=0.20477). Sex ratios were normally distributed (D=0.34986, n=8, p=0.22192).

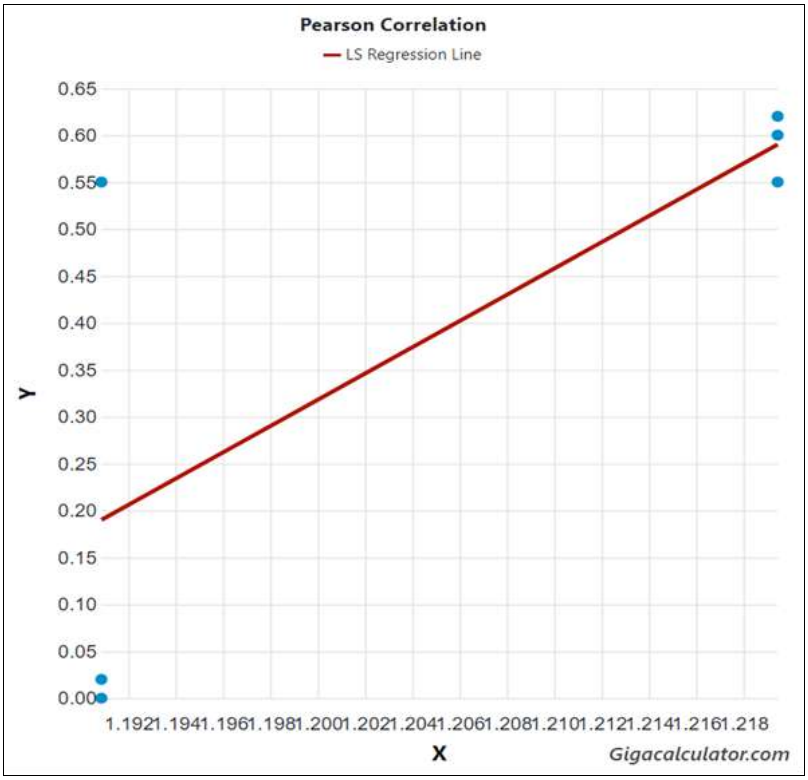

Fig 1: Correlation between SSD (x) and sex ratios late in the season in *Centrobolus*

4. Discussion

Relationships were found between sex ratio and SSD in *Centrobolus*. *C. anulatus* has the lower SSD (1.19086177) and occurred in a neutral sex ratio (55%). *C. inscriptus* has the higher SSD (1.2194459) and occurred in a male-biased sex ratio (65%). This study found sex ratios recorded late in the season in *C. anulatus* (2%) and *C. inscriptus* (60%) were positively related to SSD. So the sex ratio became more male-biased in the species with the greater female-biased SSD later in the season. This study supports using sex ratio as a correlate of SSD in *Centrobolus* late in the breeding season.

Examples of sexually dimorphic traits varying with sex ratio are known in several cases. In arthropod ectoparasites, *Anas* and quail, bethylid wasps, dytiscid beetle *Hyphydrus ovatus*, lice, estuarine snapping shrimp *Alpheus colombiensis*, Madagascan Proscimians, *Nycteris thebaica*, the Terrestrial Girdled Lizard *Cordylus macropholis*, primates, red-winged blackbirds, spiders, and wild birds [4, 11, 13, 15, 22-28]. Disparate sex ratios and sexual dimorphism are related in the genus *Anas* as they are in quail [4]. In 19 species of bethylid Wasps male size correlated with sex ratio [13]. In the dytiscid beetle *Hyphydrus ovatus* male-biased SSD is associated with male-biased sex ratios [15]. In primates increased SSD is thought to be due to male-biased sex ratios [22]. In the estuarine snapping shrimp *Alpheus colombiensis* female-biased sex ratios are assiated with male-biased dimorphism [2]. In the bat *Nycteris thebaica* female-biased SSD is associated with female-biased sex ratios [23]. In *C. macropholis* female-biased SSD is associated with female-biased sex ratios [24]. In *Philopterus fingillae* size is positively correlated with the sex ratio [25]. In fleas and gamasid mites similar sexual size dimorphism-sex ratio relationships in infrapopulations are found [26]. In wild birds, intrasexual competition over food and sexual dimorphism are sometimes responsible for sex ratio biases [28]. The present study does not agree that sex ratio, size, and SSD be considered independent traits [13].

SSD variation with the sex ratio occurs during seasonal activity patterns in species showing SSD [1, 8, 9, 15, 16]; and daily activity patterns [3, 15, 20]. Sex ratio biases can go towards males and covary with SSD depending on the time in the season. Time to maturity is a similar factor as early (or even late) maturity can buffer biases in the sex ratio as has been demonstrated in spiders [26]. Seasonal changes in habitat preference are known in *C. fulgidus* and *C. richardii* [10]. These differences are likely due to the effects of SSD differences (65%) between the latter two species. Similarly, sex ratios may be usefully investigated and compared with this study.

5. Conclusion

SSD varied systematically with the sex ratio during the latter part of the breeding season in two *Centrobolus* species. Variance in the polygynandrous reproductive systems occurs if larger females and higher SSD correlate with biased sex ratios late in the season.

6. References

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