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Do copulation duration and sexual size dimorphism vary with relative abundance in red millipedes *Centrobolus* Cook, 1897?

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Abstract
Copulation duration, Sexual Size Dimorphism (SSD), and relative abundance (evenness) were checked for correlations in the red millipede genus *Centrobolus*. There was no significant relationship between SSD and relative abundance among the two species (r=0.47, Z score=1.13, n=8, p=0.13). There was a significant relationship between relative abundance in the trees pooled with an early and late relative abundance and SSD (r=0.84, Z score=2.10, n=6, p=0.02). Greater SSD was related to the higher abundance of one species (*C. inscriptus*) recorded in the trees but there was no absolute difference (T-score=1.29, n=4, 4, p=0.12) or relative difference (T-score=1.29, n=4, 4, p=0.12) in relative abundances of the two species (*C. anulatus* and *C. inscriptus*). There was a relative difference in relative abundances on the ground (0.50) and the trees (17) (T-score=-429.749622, d.f.=10, p=0). There was no relative difference between relative abundances early (17) and late (17) in the season (T-score=0, d.f.=10, p=0.50). Copulation duration was positively related to relative abundance (r=0.97, Z score=4.80, n=8, $p< 0.01$).

Keywords: Dimorphic, eco-geography, gradient, relative abundance, size, species

1. Introduction
The millipede genus *Centrobolus* is found in the temperate South African subregion, its northern limits on the east coast of southern Africa being about -17° latitude South (S) and its southern limits being about -35° latitude S. It consists of taxonomically important species with 12 species considered threatened and includes nine vulnerable and three endangered species [23]. It occurs in all the forests of the coastal belt from the Cape Peninsula to Beira in Mocambique [22]. Common with worm-like millipedes is the relative abundance which is known to differ in several populations of the genus [6]. Relative abundance is seasonal and determines the sex ratio which in turn determines the copulation durations for individuals of each species at any one time [13, 15-16].
Copulation duration and sexual size dimorphism (SSD) is correlated with relative abundance during the breeding season in the pachybolid millipede genus *Centrobolus* Cook, 1897 [4, 17, 22]. These are worm-like millipedes that have female-biased SSD [7-12]. The aim is to determine if there is body size and copulation duration variance with the relative abundance across species.

2. Materials and Methods
Two species were identified as belonging to the genus *Centrobolus* Cook, 1897 [4]. The relative abundance during the breeding season was obtained for *C. anulatus* and *C. inscriptus* [6]. 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) [5]. SSD was calculated as the ratio of female volume to male volume [5]. SSD and relative abundance 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). Copulation duration and relative abundance during early and late in the breeding season were checked for correlations using the same Pearson Correlation Coefficient calculator. Diversity was calculated online (https://bpmsg.com/tools/div-calc.php).

3. Results

C. anulatus has a lower relative abundance (0.09602649) and *C. inscriptus* has a higher relative abundance (0.90397351). There was no relationship between SSD and relative abundance (r=0.46683637, Z score=1.13148936, n=8, p=0.12892464). There was no significant relationship between relative abundance on the ground and in the trees pooled with those from early in the season and SSD (r=0.50180517, Z score=0.95560005, n=6, p=0.16963716). There was no significant relationship between relative abundance on the ground and in the trees pooled with those from late in the season and SSD (r=0.74091015, n=6, p=0.04949514). There was a significant relationship between relative abundance in the trees pooled with early and late sex ratios and SSD (Fig. 1: r=0.83748076, Z score=2.10041848, n=6, p=0.01784596). There was no absolute difference in relative abundances of the two species (T-score=1.293062, n=4, 4, p=0.121771). There was no relative difference in relative abundances of the two species (T-score=1.292021, n=4, 4, p=0.121940). There was no absolute difference in relative abundances on the ground (0.50) and the trees (17) (T-score=V, d. f.=10, p=0.171858). There was a relative difference in relative abundances on the ground and the trees (T-score=-429.749622, d.f.=10, p=0). There was no absolute difference between relative abundances early (17) and late (17) (T-score=0, d.f.=10, p=0.50). There was no relative difference between relative abundances early (17) and late (17) (T-score=0, d.f.=10, p=0.50). SSD was normally distributed (D=0.15168, n=22, p=0.20477). Relative abundances were normally distributed (D=0.43219, n=8, p=0.07114). Copulation duration was positively related to relative abundance (Fig. 2: r=0.97310307, Z score=4.80234775, n=8, p=0.00000079). Copulation duration was normally distributed (D=0.3298, n=4, p=0.1293).

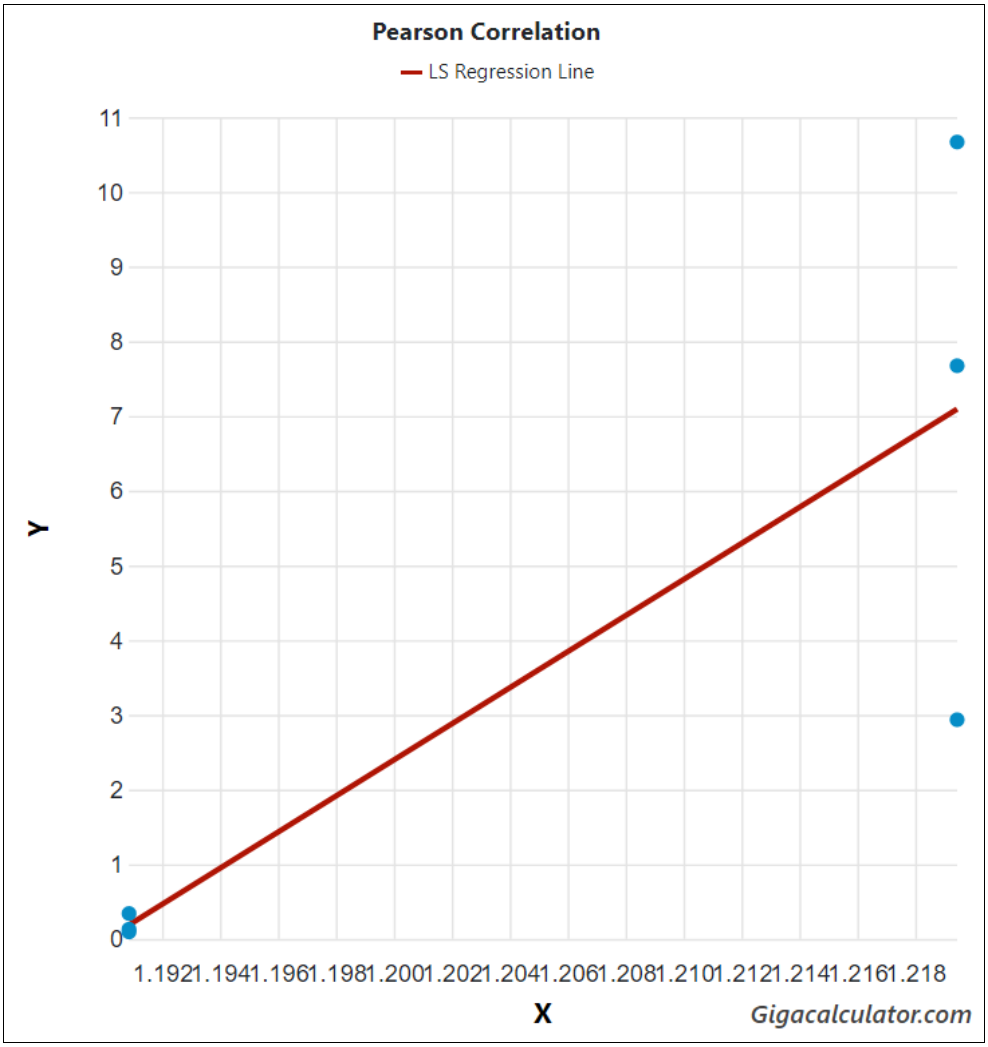

Fig 1: Correlation between SSD (x) and relative abundance early and late in the breeding season together pooled within the trees in *Centrobolus*

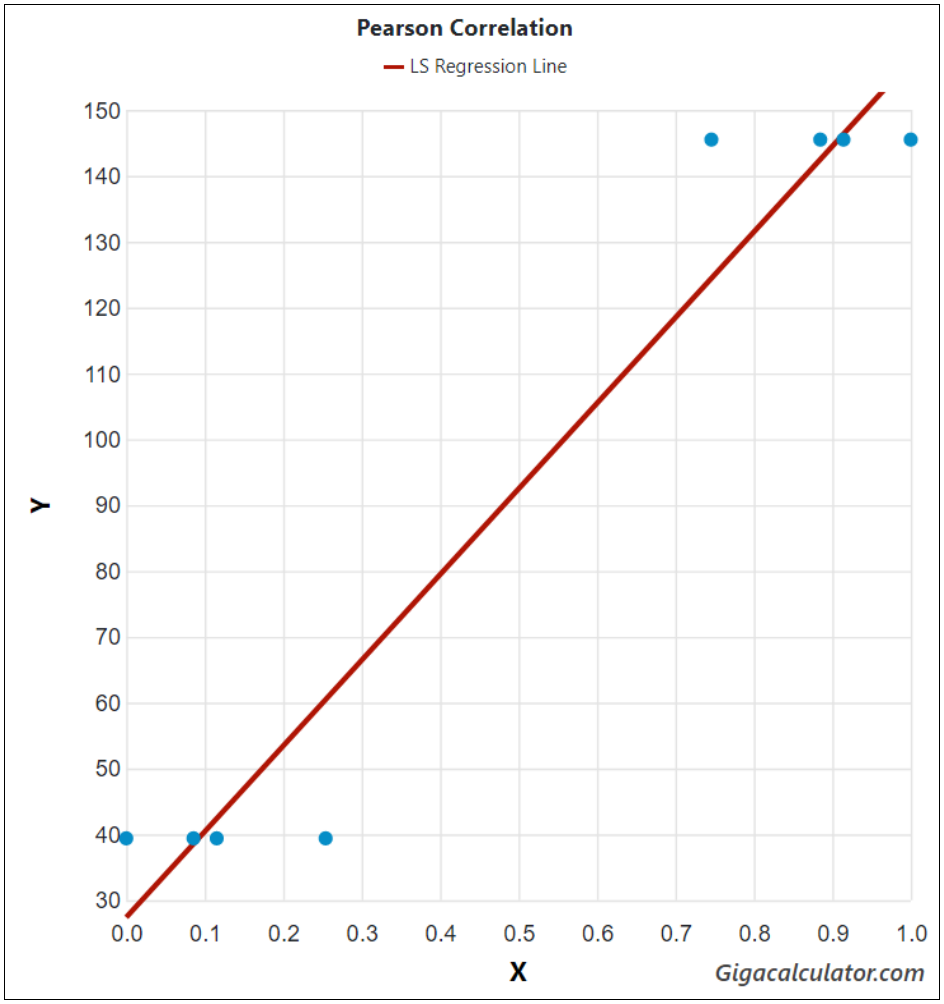

Fig 2: Correlation between the relative abundance (x) and copulation duration (y) in two species of *Centrobolus*

Table 1: Diversity indices (left column) and values (right column) for *Centrobolus* at Twin Streams, Mtunzini

Number of Classes *N*	**2**
Richness *R*	2
Berger Parker Index p_{imax}	90.4%
Shannon Entropy[1)] *H* (nat)	0.3163
Shannon Entropy[1)] *H* (bit)	0.4563
Number Eq. ^{1}D (True Diversity)	1.4
Shannon Equitability *H*/ln*N*	45.6%
Simpson Dominance *SD*	82.6%
SD (unbiased - finite samples)	n/a
True Diversity ^{2}D (Order 2)	1.2
Gini-Simpson Index 1-*SD*	17.4%
Gini-Simpson Equitability	34.7%

1) Sometimes referred to as Shannon-Weaver or Shannon-Wiener Index

4. Discussion

A non-overlapping relationship was found between relative abundance in the trees and SSD in sympatric *Centrobolus*. *C. anulatus* has the lower SSD (1.19086177) and occurred at a lower relative abundance in the trees (0.130337079). *C. inscriptus* has the higher SSD (1.2194459) and occurred in a higher relative abundance in the trees (7.67241379). This study found relative abundance recorded in the trees in *C. anulatus* and *C. inscriptus* were positively related to SSD. This study supports using relative abundance as a correlate of SSD in *Centrobolus* in the trees. There is an absence of an absolute and relative difference in relative abundances of the two species except in the tree substratum.

Examples of sexually dimorphic traits varying with relative abundance sex ratio are rare [29]. SSD variation with the relative abundance occurs during seasonal activity patterns in species showing SSD [1, 13, 16, 20]; and daily activity patterns [2, 25]. Relative abundance can bias the sex ratio and covary with SSD depending on the time and space in the season. Spatial changes in habitat preference are known in *C. fulgidus* and *C. richardii* [17]. These differences are likely due to the effects of SSD differences (65%) between the latter two species. Sex ratios may be usefully investigated and compared with this study.

The example presented in this paper is similar to sexual dimorphism divergence between sister species associated with a switch in habitat use and mating system in thorny devil stick insects (*Eurycantha calcarata* and *E. horrida*) [3]. Consequently, this has affected the species' life histories and reproductive strategies relationships differently [25]. The greater degree of SSD in *C. inscriptus* is associated with higher levels of scramble competition polygynandry between relatively smaller males and lower male contests compared with *C. anulatus* [26]. Overall sexual dimorphism was better expressed in larger *C. inscriptus* and the morphospace occupied by males and females overlap differently in *C. anulatus* compared with *C. inscriptus*, indicating that ecological niches of both sexes are differently separated in each species [17].

The two species studied here appear to have different life histories and reproductive strategies [26]. There was a positive relationship between copulation duration and relative abundance. Short copulations (*C. anulatus*) were

associated with low relative abundance while long copulations (*C. inscriptus*) were associated with high relative abundance. This suggests the pattern of mate-guarding is positively associated with a relative abundance and the intensity of intra-male competition [27]. The probability of a female remating is a function of male density [28].

5. Conclusion

Copulation duration and SSD varied systematically with the relative abundance in two *Centrobolus* species depending on the substrate. Variance in the polygynandrous reproductive systems occurs if larger females, higher SSD, and longer copulation durations correlate with higher relative abundance above ground.

6. References

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