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

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**Abstract**

Sexual Size Dimorphism (SSD), copulation duration, and absolute abundance were checked for correlations in the red millipede genus *Centrobolus*. There was a significant relationship between SSD and absolute abundance ( $r=0.63$ ,  $Z$  score= $1.66$ ,  $n=8$ ,  $p<0.05$ ). Greater SSD was related to a higher absolute abundance of *C. inscriptus* over *C. anulatus*. There was an absolute difference (326) ( $T$ -score= $1.99$ , d. f. = 6,  $p<0.05$ ) and a relative difference (7.27) in absolute abundances between species ( $T$ -score= $3.60$ , d. f. =6,  $p<0.01$ ). Absolute abundances were higher in the trees ( $Z$  score= $2.46$ , d. f. =10,  $p<0.01$ ). Absolute densities were higher late in the season ( $Z$  score= $-124$ ,  $n=6$ ,  $p=0$ ). Copulation duration increased with absolute abundance ( $r=0.63$ ,  $Z$  score= $1.66$ ,  $n=8$ ,  $p=0.049$ ).

**Keywords:** Dimorphic, eco-geography, gradient, absolute abundance, size, species

**1. Introduction**

The millipede genus *Centrobolus* Cook, 1897 is found in the temperate South African subregion, its northern limits on the east coast of southern Africa being about  $-17^\circ$  latitude South (S) and its southern limits being about  $-35^\circ$  latitude S [3, 9, 13]. It consists of taxonomically important species with 12 species considered threatened and includes nine vulnerable and three endangered species [14]. It occurs in all the forests of the coastal belt from the Cape Peninsula to Beira in Mocambique [13]. Common with worm-like millipedes is the absolute abundance which is known to differ in several populations of the genus [5]. Absolute abundance is seasonal and determines the sex ratio which in turn determines the copulation durations for pairs of individuals of each species at any one time [6-8].

Sexual size dimorphism (SSD) and copulation duration are tested for a correlation with absolute abundance during the breeding season in the pachybolid millipede genus *Centrobolus*. The aim is to determine if there is a correlation between absolute abundance and SSD as well as a correlation between absolute abundance and copulation duration across species.

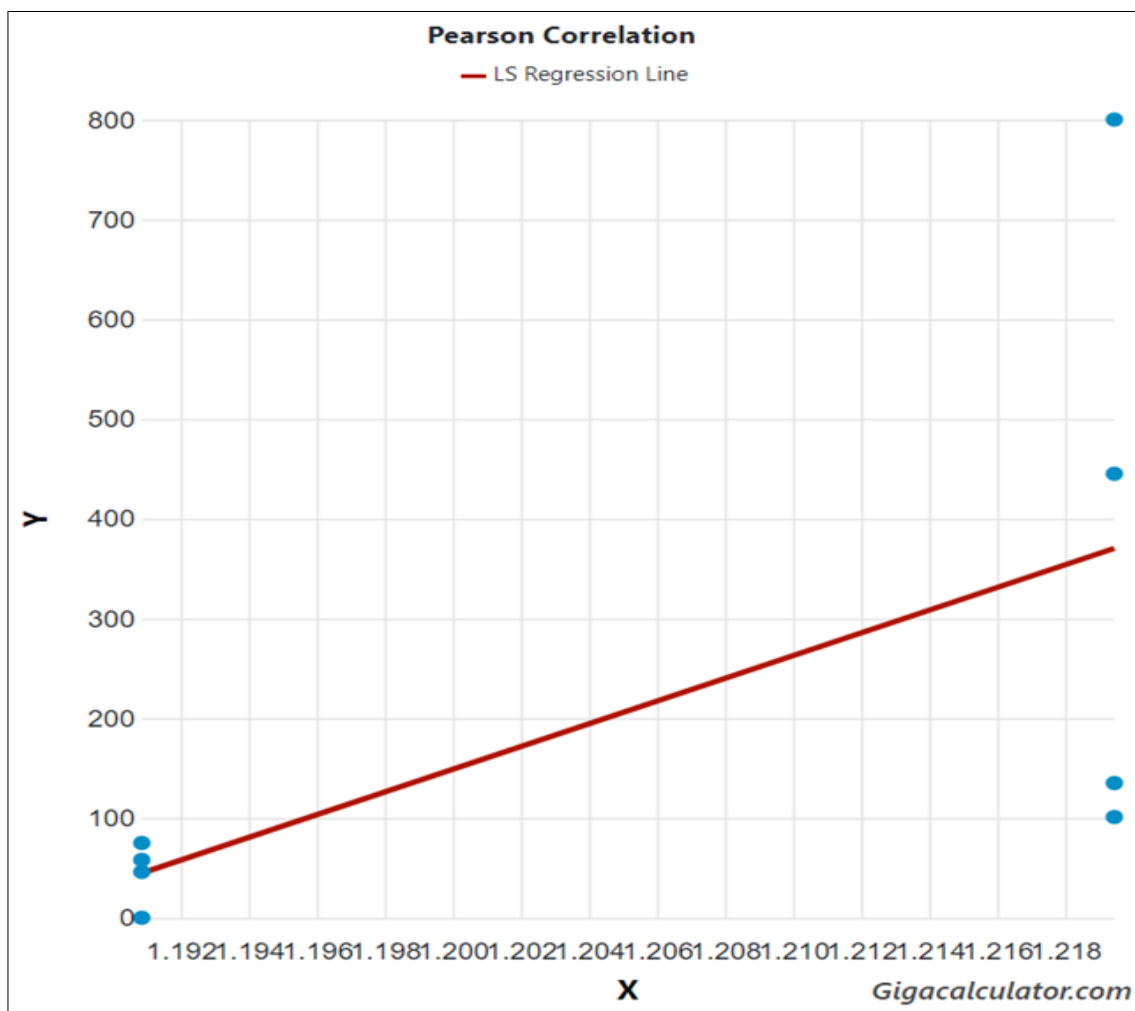
**2. Materials and Methods**

Two species were identified as belonging to the genus *Centrobolus* Cook, 1897 [3]. The absolute abundance during the breeding season was obtained for *C. anulatus* and *C. inscriptus* [5]. The number of individual millipedes was hand collected, counted, and sexed *in situ* from the Mick's Park Conservation area in Twin Streams farm (Mtunzini) over a period of up to 3 days early and late in a season. 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>) [4]. SSD was calculated as the ratio of female volume to male volume [4]. SSD and absolute 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>). Tests for normality were conducted. Differences between absolute abundances were compared across time (early and late) and space (ground or trees) using the P-value calculator (<https://www.gigacalculator.com/calculators/p-value-significance-calculator.php>).

### 3. Results

The mean absolute abundance for *C. anulatus* was 44.75 and for *C. inscriptus* was 370.25. There was a relationship between SSD and absolute abundance (Fig. 1:  $r=0.63046242$ ,  $Z$  score= $1.65957221$ ,  $n=8$ ,  $p=0.04850025$ ). There was a marginally significant relationship between absolute abundance on the ground and in the trees pooled with those from early in the season and SSD ( $r=0.70553681$ ,  $Z$  score= $1.52115733$ ,  $n=6$ ,  $p=0.06411020$ ). There was a marginally significant relationship between absolute abundance on the ground and in the trees pooled with those from late in the season and SSD ( $r=0.65527536$ ,  $Z$  score= $1.35877368$ ,  $n=6$ ,  $p=0.08710922$ ). There was a marginally significant relationship between absolute abundance in the trees pooled with early and late sex ratios and SSD ( $r=0.72113613$ ,  $Z$  score= $1.57618023$ ,  $n=6$ ,  $p=0.05749214$ ). There was no relationship between absolute abundance on the ground pooled with early and late absolute abundances and SSD ( $r=0.55496829$ ,  $Z$  score= $1.08345398$ ,  $n=6$ ,  $p=0.13930352$ ). There was an absolute difference

(325.50) between the species in absolute abundance ( $T$ -score= $1.989528$ ,  $d. f. = 6$ ,  $p=0.046889$ ). There was a relative difference (7.273743) in absolute abundances between the species ( $T$ -score= $3.596695$ ,  $d. f. = 6$ ,  $p=0.005706$ ). There was no absolute difference between absolute abundances on the ground (192.833333) compared to the trees (259.833333) ( $Z$  score= $0.383571$ ,  $d. f. = 10$ ,  $p=0.350648$ ). There was a relative difference between absolute abundances on the ground compared in the trees ( $Z$  score= $2.462243$ ,  $d. f. = 10$ ,  $p=0.006904$ ). There was no absolute difference between absolute densities early (130.833333) and late (246.50) in the season ( $Z$  score= $-0.803377$ ,  $n=6$ ,  $p=0.210878$ ). There was a relative difference between absolute densities early and late in the season ( $Z$  score= $-124.425395$ ,  $n=6$ ,  $p=0$ ). Copulation duration was related to absolute abundance (Fig. 2:  $r=0.63046242$ ,  $Z$  score= $1.65957221$ ,  $n=8$ ,  $p=0.04850025$ ). SSD was normally distributed ( $D=0.15168$ ,  $n=22$ ,  $p=0.20477$ ). Absolute abundances were normally distributed ( $D=0.36059$ ,  $n=8$ ,  $p=0.19432$ ).



**Fig 1:** Correlation between SSD (x) and absolute abundance in *Centrobolus*.

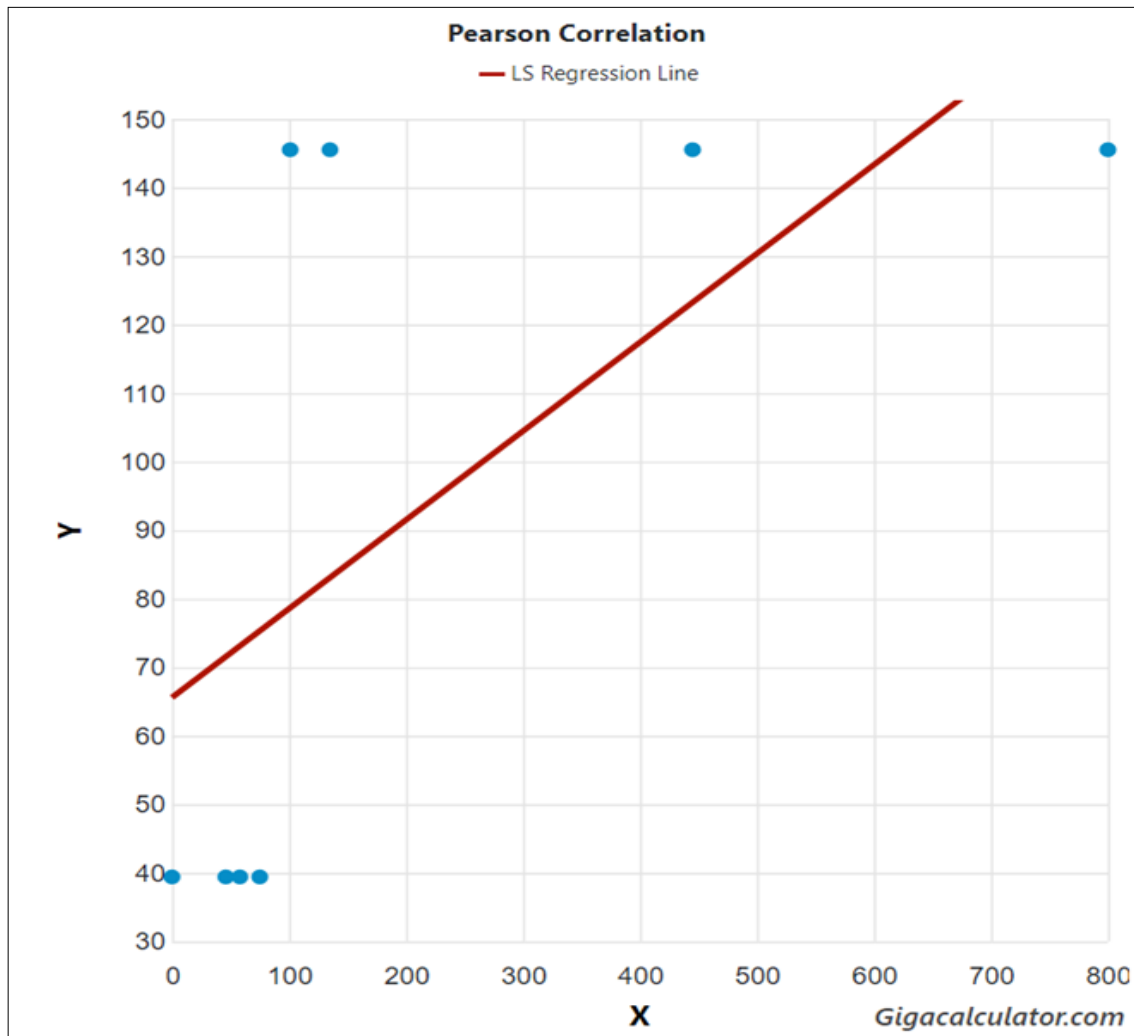


Fig 2: Correlation between absolute abundance (x) and copulation duration (y) across two species of *Centrobolus*.

#### 4. Discussion

A non-overlapping relationship was found between absolute abundance and SSD in sympatric *Centrobolus*. *C. anulatus* has the lower SSD (1.19086177) and occurred in a lower absolute abundance (0-75). *C. inscriptus* has the higher SSD (1.2194459) and occurred in higher absolute abundances (101-800). This study found absolute abundance recorded in *C. anulatus* and *C. inscriptus* were positively related to SSD. So the absolute abundance probably determined sex ratio bias in these species with the greater female-biased sexually size dimorphic species being in the trees. This study supports using absolute abundance as a correlate of SSD across *Centrobolus*.

Examples of sexually dimorphic traits varying with absolute abundance are lacking [18]. SSD variation with the absolute abundance occurs during seasonal activity patterns in species showing SSD [1, 6, 7, 10]; and daily activity patterns [2, 15]. Absolute abundance can bias the sex ratio and covary with SSD depending on the time and place in the season. Spatial changes in habitat preference are known in *C. fulgidus* and *C. richardii* [8]. These differences are linked to the effects of SSD differences (65%) between the latter two species. Similarly, sex ratios may be usefully investigated and compared with this study.

Copulation duration was positively related to absolute abundances across *Centrobolus*. Short copulations (*C. anulatus*) were associated with low absolute abundances and long copulations (*C. inscriptus*) were associated with high

absolute abundances. This suggests the pattern of mate-guarding is positively associated with absolute abundance and the intensity of intra-male competition [16]. This implies the probability of a female remating is a function of male density [17].

#### 5. Conclusion

SSD varied systematically with the absolute abundance in two *Centrobolus* species. Increase in the copulation duration occurs when larger females and higher SSD correlate with higher absolute abundance.

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