Does sexual size dimorphism vary with maximum and minimum temperatures in red millipedes *Centrobolus* Cook, 1897?

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Abstract

Sexual Size Dimorphism (SSD) and body size variation with minimum and maximum temperature were correlated in the red millipede genus *Centrobolus*. There was a significant correlation between SSD and minimum temperature \((r=0.37, Z\text{ score}=1.70, n=22, p<0.05)\). There was a significant correlation between SSD and the maximum temperature during the month with the highest number of rainy days \((r=0.42, Z\text{ score}=1.97, n=22, p=0.02)\). Minimum temperature was strongly correlated with latitude \((r=0.52, Z\text{ score}=2.59, n=23, p=0.005)\). Maximum temperature was strongly correlated with latitude \((r=0.55, Z\text{ score}=2.78, n=23, p=0.003)\). Minimum temperature was strongly correlated with longitude \((r=0.54, Z\text{ score}=2.63, n=22, p=0.004)\). Maximum temperature was strongly correlated with longitude \((r=0.67, Z\text{ score}=3.55, n=22, p=0.0002)\). Variance in the polygynandrous reproductive systems occurs when larger females and higher SSD occur with higher minimum and maximum temperatures during the month with the highest number of rainy days which were strongly correlated with latitude and longitude.

Keywords: Dimorphic, eco-geography, gradient, size, species, temperature

1. Introduction

*Centrobolus* is a forest genus of millipede belonging to the Order Spirobolida which is distributed along the eastern coast of southern Africa. *Centrobolus* inhabits the temperate South African subregion with northern limits on the east coast of southern Africa is about -17° latitude S and southern limits being about -35°S. Its omnipresence in all the forests of the coastal belt from the Cape Peninsula to Beira in Mozambique makes it an ideal study organism. While the coastal forests of the South-West and Eastern Cape are mist belt temperate forests, those of the Transkei, Natal, Zululand, and Mozambique are different, being best described as East Coast Bush, they are developed almost entirely in a narrow strip of the litoral on a dune sand substratum, and are more tropical in aspect and composition than those to the west. A summer rainfall breeding season with uniform temperature, an absence of frost, and component trees known as a coastal bush with abundant creepers and lianas not usually reaching a height of more than 11 meters provide a dense covering with abundant shade and humidity at ground level. *Centrobolus* are essentially shade-loving Diplopoda and the 39 members of the genus are especially well represented in these litoral forests of the eastern half of the subcontinent \[15\].

Sexual size dimorphism (SSD) correlates with mean annual temperatures \[5\]. This instigated a study here where SSD is correlated with maximum and minimum temperatures during the month with the highest number of rainy days in *Centrobolus* \[4, 10, 15\]. A null hypothesis is there is no body size correlation with the maximum and minimum temperatures.

2. Materials and Methods

Twenty-two of 39 valid species belonging to the genus *Centrobolus* Cook, 1897 were the focus of this study \[4\]. Millipede type localities were tabulated according to the checklist of southern African millipedes \[10\] (Table 1). GPS coordinates (latitude and longitude points) were sourced for known type localities \[10\]. The minimum temperatures and maximum temperatures during the months with the highest number of rainy days were obtained from https://en.climate-data.org/search/?q=. 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). SSD was calculated as the ratio of female volume to male volume.
SSD, latitude, longitude, minimum and maximum temperatures during the month with the highest number of rainy days were correlated using the Pearson Correlation Coefficient calculator. Maximum and minimum temperatures were compared using a T-test for 2 independent means.

3. Results
There was a significant correlation between SSD and the minimum temperature during the month with the highest number of rainy days (Figure 1: r=0.37128137, Z score=1.69957187, n=22, p=0.0460571) (Table 1). There was a significant correlation between SSD and the maximum temperature during the month with the highest number of rainy days (Figure 2: r=0.42436179, Z score=1.97458074, n=22, p=0.02415780) (Table 1). There was no significant difference between the correlation coefficients of maximum and minimum temperatures with SSD (z=0.1945, n=22, 22, p=0.8458). Minimum temperature was strongly correlated with latitude (Figure 3: r=0.52155291, Z score=2.58699897, n=23, p=0.00484083). Maximum temperature was strongly correlated with latitude (Figure 4: r=0.55282911, Z score=2.78366528, n=23, p=0.00268748). Minimum temperature was strongly correlated with longitude (Figure 5: r=0.53889002, Z score=2.62662911, n=22, p=0.00431180). Maximum temperature was strongly correlated with longitude (Figure 6: r=0.67236526, Z score=3.55270935, n=22, p=0.00019068). The data for minimum temperature was normally distributed (D=0.16489; n=22, p=0.53407). The data for maximum temperature was not normally distributed (D=0.31202, n=22, p=0.02115). Latitude was normally distributed (D=0.12321, n=23, p=0.83467). Longitude was normally distributed (D=0.26876, n=22, p=0.06808). SSD was normally distributed (D=0.15168, n=22, p=0.20477). Mean minimum (16.48 °C) and mean maximum (24.44 °C) temperatures were significantly different (t-value=6.87313, n=22, 23, p < 0.0001).

Table 1: Species in the millipede genus Centrotulus Cook, 1897, with SSD, type or collected localities GPS latitude and longitude points, the highest number of rainy days, and maximum and minimum temperature

<table>
<thead>
<tr>
<th>Species</th>
<th>SSD</th>
<th>Location</th>
<th>Latitude (°S)</th>
<th>Longitude (°E)</th>
<th>The highest number of rainy days</th>
<th>Min. Temp. (°C)</th>
<th>Max. Temp. (°C)</th>
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<td>C. albitalis</td>
<td>2.89</td>
<td>Lochiel</td>
<td>-26.150174</td>
<td>30.786</td>
<td>19.90 (Dec.)</td>
<td>14.5</td>
<td>24.7</td>
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<td>C. anglicus</td>
<td></td>
<td>Makhanda</td>
<td>-33.318134</td>
<td>10.973</td>
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<td>C. anulatus</td>
<td>1.19</td>
<td>Umhlanga Rocks</td>
<td>-29.746190</td>
<td>31.084</td>
<td>13.73 (Dec.)</td>
<td>19</td>
<td>25.4</td>
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<td>C. atropus</td>
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<td>-33.917273</td>
<td>15.155</td>
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<td></td>
<td>Nkhandla</td>
<td>-28.728019</td>
<td>26.015</td>
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<td>-</td>
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<td>Ngome Forest</td>
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<td>31.400</td>
<td>19.33 (Dec.)</td>
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<td>Hout bay</td>
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<td>18.357</td>
<td>10.50 (June)</td>
<td>11.4</td>
<td>15.7</td>
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<td>Gans bay</td>
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<td>19.350</td>
<td>10.40 (June)</td>
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<td>16.6</td>
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<td>C. fulgidas</td>
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<td>Richards Bay</td>
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<td>32.049</td>
<td>13.97 (Nov.)</td>
<td>19.8</td>
<td>25.5</td>
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<td>C. immaculatus</td>
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<td>1.44</td>
<td>Inyanga village</td>
<td>-29.707964</td>
<td>30.666</td>
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<td>30.393</td>
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<td>-33.967135</td>
<td>18.543</td>
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<td>Inhambambane</td>
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<td>Glenconnor</td>
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<td>8.67 (Mar.)</td>
<td>17.7</td>
<td>24.8</td>
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<td>Tsisikamma</td>
<td>-32.220918</td>
<td>18.315</td>
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<td>-34.244295</td>
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<td>Little Lions Head</td>
<td>-34.016370</td>
<td>18.348</td>
<td>11.07 (June)</td>
<td>11.4</td>
<td>15.7</td>
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<td>C. pusillus</td>
<td>2.08</td>
<td>Qolora River mouth</td>
<td>-32.571689</td>
<td>28.433</td>
<td>14.07 (Jan.)</td>
<td>15.7</td>
<td>25.6</td>
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<td>C. richardi</td>
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<td>Richards Bay</td>
<td>-28.778417</td>
<td>32.078</td>
<td>13.97 (Nov.)</td>
<td>19.8</td>
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<td>19.7</td>
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<td>Karkloof waterfall</td>
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<td>29.018</td>
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<td>-28.024622</td>
<td>31.952</td>
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<td>1.27</td>
<td>Between Uitenhage and Addo</td>
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<td>18.348</td>
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<td>1.13</td>
<td>Kentani</td>
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<td>C. splendidus</td>
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<td>Masiene near Chai Chai</td>
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<td>caffiraria</td>
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<td>C. striolatus</td>
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<td>Port St Johns</td>
<td>-31.633372</td>
<td>25.396</td>
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<td>DeHoop vlei</td>
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<td>9.5</td>
<td>19.4</td>
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<td>-19.817644</td>
<td>25.958</td>
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<td>C. vastus</td>
<td>1.81</td>
<td>Port St Johns</td>
<td>-31.633371</td>
<td>30.451</td>
<td>16.97 (Dec.)</td>
<td>19.0</td>
<td>24.2</td>
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</table>
Fig 1: Relationship between Sexual Size Dimorphism (y-axis) and minimum temperature during the month with the highest number of rainy days (x-axis: °C) in *Centrobolus* Cook, 1897

Fig 2: Relationship between Sexual Size Dimorphism (y-axis) and maximum temperature during the month with the highest number of rainy days (x-axis: °C) in *Centrobolus* Cook, 1897
Fig 3: Relationship between minimum temperature (y: °C) and latitude (x: °South) in *Centrobolus* Cook, 1897

Fig 4: Relationship between maximum temperature (y) and latitude (x: °South) in *Centrobolus* Cook, 1897
Fig 5: Relationship between minimum temperature (y: °C) and longitude (x: °East) in *Centrobolus* Cook, 1897

Fig 6: Relationship between maximum temperature (y: °C) and longitude (x: °East) in *Centrobolus* Cook, 1897
4. Discussion
Relationships were found between minimum temperature and maximum temperatures during the month with the highest number of rainy days and SSD in *Centrobolus*. *C. albitarsus* has the highest SSD (2.89) and occurred at a minimum temperature of 14.5 °C and a maximum temperature of 24.7 °C. *C. promontorius* has low SSD (0.69) and occurs at a low minimum temperature (11.4 °C) and the lowest maximum temperature (15.7 °C). This study supports both minimum and maximum temperature as correlates of SSD in *Centrobolus*.

Examples of sexually dimorphic traits varying with temperature in the literature are known in the lion *Panthera leo* [10], ambush bug *Phymata americana* [17], green turtle *Chelonia mydas* [9], zebrafish *Danio rerio* [8], and frogs *Limnodynastes tasmaniensis* and *L. peronii* [18]. The maximum and minimum temperature may be an explanation for skewed sex ratios in species showing SSD, such as millipedes and mosquito fish [11]. In *Drosophila melanogaster* sexual dimorphism was shown to be triggered in developmental temperature [14].

SSD variation with the maximum and minimum temperatures may explain seasonal activity patterns in species showing SSD [1, 6, 7, 12, 13], and daily activity patterns [2, 11, 16]. The results of maximum and minimum temperatures appear consistent with SSD on mean annual temperature [10].

5. Conclusion
SSD increased systematically with the minimum and maximum temperatures during the month with the highest number of rainy days in *Centrobolus*. SSD increased with body size in this genus. Abiotic variance in the polygynandrous reproductive systems occurs if larger females and higher SSD occur with higher maximum and minimum temperatures.

6. References
8. Dimitriadi A, Beis D, Arvanitidis C, Adriaens D, Koumoundouros G. Developmental temperature has persistent, sexually dimorphic effects on zebrafish cardiac anatomy. Scientific Reports. 2018;8:8125.