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PAIR-WISE COMPARISON OF SEXUAL SHAPE DIMORPHISM AMONG FIFTEEN FACTORS IN FOREST MILLIPEDES *CENTROBOLUS* COOK, 1897

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Abstract

The objectives of this study were to determine what happened when Bergmann's Rule met Rensch's Rule if Sexual Shape Dimorphism (SShD) varied with 15 factors. Body size, latitude, longitude, precipitation, temperature, the highest total hours of sunshine in a month, the hours of sunshine throughout the year, the month with the highest number of rainy days, female length, female width, female volume, male mass, body mass, moments of inertia and male moments of inertia were correlated with SShD in the forest millipede genus Centrobolus. Correlation coefficients were compared using MedCalc. Forty-one significant differences were found among the 78 pair-wise comparisons. Eight highly significant differences in pair-wise comparisons of correlations in SSD were found among (1) body size and the highest total hours of sunshine in a month, (2) body size and latitude, and (3) body size and sunshine throughout the year, (4) latitude and female width, (5) hours of sunshine throughout the year and female width, (6) the hours of sunshine throughout the year and female volume, (7) body mass and female width, and (8) body size and body mass.

Keywords: *Abiotic; biotic; dimorphic; mass; size; width.*

INTRODUCTION

A forest genus of diplopods belonging to the Order Spirobolida found along the eastern coast of southern Africa was the subject of this study. 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 S. It occurs in all the forests of the coastal belt from the Cape Peninsula to Beira in Mocambique. While the coastal forests of the South-West and Eastern Cape are mist belt temperate forests, those of the Transkei, Natal, Zululand and Mocambique are somewhat different, being better 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 of them. There is a summer rainfall of 76.2-101.6 cm, a uniform temperature, and an absence of frost; the component trees of the coastal bush with their abundant creepers and lianas, while not usually reaching a height of more than 11 meters, provide a dense covering with abundant shade and humidity at ground level. As essentially shade-loving Diplopoda, the members of the genus are especially well represented in these litoral forests of the eastern half of the subcontinent [4].

Sexual shape dimorphism (SShD) is correlated with 15 factors: body size, latitude, longitude, precipitation, temperature, the highest total hours of sunshine in a month, the hours of sunshine throughout the year, the month with the highest number of rainy days, female length, female width, female volume, male mass, body mass, moments of inertia, and male moments of inertia in the pachybolid millipede genus *Centrobolus* Cook, 1897 [1, 2, 4]. The null hypothesis is that all 15 factors

are somewhat important in relative body size correlation comparisons.

MATERIALS AND METHODS

Twenty-two of 39 valid species were identified as belonging to the genus *Centrobolus* Cook, 1897. Millipede-type localities were obtained from a checklist of southern African millipedes [2]. These were tabulated and known type localities also listed in Microsoft Word online (https://office.live.com/start/Word.aspx). GPS coordinates were obtained from internet sources for known type localities using google (https://www.google.co.za/maps/place). The highest total hours of sunshine in a month, hours of sunshine throughout the year, mean annual precipitation, temperature, and the month 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). SShD was calculated as the ratio of female volume to male volume. Mean body mass and male body mass were obtained through registering the weight with a Mettler AC 100 Autobalance. SShD, body size, latitude, longitude, precipitation, the highest total hours of sunshine in a month, hours of sunshine throughout the year, the month with the highest number of rainy days, temperature, female length, female width, female volume, and male mass were checked for correlations using the Pearson Correlation Coefficient calculator (https://www.gigacalculator.com/calculators/correlation-coefficient-calculator.php). Pairwise comparisons between correlation coefficients of SShD and the eleven factors were made at https://www.medcalc.org/calc/comparison_of_correlations.php. Sample sizes for 10 factors were 22. Body size (n=18), male mass (n=4), male moments of inertia (n=4), body mass (n=5, 5), and moments of inertia (n=10) had smaller samples.

RESULTS

The results of the 105 possible pair-wise comparisons between correlations with SShD were as follows: latitude and temperature (z=2.5341, p=0.0113), latitude and longitude (z=2.6548, p=0.0079), latitude and precipitation (z=-2.3560, p=0.0185), longitude and temperature (z=0.1206, p=0.9040), longitude and precipitation (z=0.2988, p=0.7651), precipitation and temperature (z=0.1782, p=0.8586), the month with the highest number of rainy days and latitude (z=2.6591, p=0.0078), the month with the highest number of rainy days and longitude (z=0.0044, p=0.9965), the month with the highest number of rainy days and precipitation (z=0.3032, p=0.7618), the month with the highest number of rainy days and temperature (z=0.1250, 0.9005), highest total hours of sunshine in a month and latitude (z=0.2150, p=0.8297), highest total hours of sunshine in a month and longitude (z=-2.4398, p=0.0147), highest total hours of sunshine in a month and precipitation (z=-2.1409, p=0.0323), highest total hours of sunshine in a month and temperature (z=-2.3191, p=0.0204), highest total hours of sunshine in a month and month with the highest number of rainy days (z=2.4441, p=0.0145), body size and latitude (z=3.8991, p=0.0001), body size and longitude (z=1.4054, p=0.1599), body size and precipitation (z=1.6861, p=0.0918), body size and temperature (z=1.5187, p=0.1288), body size and the month with the highest number of rainy days (z=1.4013, p=0.1611), body size and the highest total hours of sunshine in a month (z=3.6971, p=0.0002), sunshine throughout the year and latitude (z=-0.43808630, p=0.9347), sunshine throughout the year and longitude (z=-2.7367, p=0.0062), sunshine throughout the year and precipitation (z=0.28628078, p=0.0148), sunshine throughout the year and temperature (z=-2.6161, p=0.0089), sunshine throughout the year and highest total hours of sunshine in a month

(z=-0.2969, p=0.7665), sunshine throughout the year and highest number of rainy days (z=0.37383618, p=0.0061), sunshine throughout the year and body size (z=-3.9761, p=0.001), body size and female length (z=-1.1743, p=0.2403), latitude and female length (z=2.9008, p=0.0037), longitude and female length (z=0.2460, p=0.8056), temperature and female length (z=0.3667, p=0.7138), precipitation and female length (z=0.3972, p=0.6912), the highest total hours of sunshine in a month and female length (z=2.6858, p=0.0072), the hours of sunshine throughout the year and female length (z=2.9827, p=0.0029), the month with the highest number of rainy days and female length (z=0.2417, p=0.8090), body size and female width (z=-0.3614, p=0.7178), latitude and female width (z=3.7662, p=0.0002), longitude and female width (z=1.1114, p=0.2664), temperature and female width (z=1.2320, p=0.2179), precipitation and female width (z=1.2626, p=0.2067), the highest total hours of sunshine in a month and female width (z=3.5511, p=0.0004), the hours of sunshine throughout the year and female width (z=3.8481, p=0.0001), the month with the highest number of rainy days and female width (z=1.1070, p=0.2683), body size and female volume (z=-0.7078, p=0.4790), latitude and female volume (z=3.3974, p=0.0007), longitude and female volume (z=0.7426, p=0.4577), temperature and female volume (z=0.8633, p=0.3880), precipitation and female volume (z=0.8938, p=0.3714), the highest total hours of sunshine in a month and female volume (z=3.1824, p=0.0015), the hours of sunshine throughout the year and female volume (z=3.4793, p=0.0005), the month with the highest number of rainy days and female volume (z=0.7382, p=0.4604), female length and female width (z=-0.8653, p=0.3869), female length and female volume (z=-0.4966, p=0.6195), female width and female volume (z=0.3688, p=0.7123), male mass and latitude (z=1.6574, p=0.0974), male mass and longitude (z=2.4970, p=0.0125), male mass and precipitation (z=2.4025, p=0.0163), male mass and temperature (z=2.4588, p=0.0139), male mass and the highest total hours of sunshine in a month (z=1.7254, p=0.0844), male mass and the month with the highest number of rainy days (z=2.4983, p=0.0125), male mass and body size (z=2.9505, p=0.0032), male mass and sunshine throughout the year (z=1.6315, p=0.0128), male mass and female length (z=-2.1600, p=0.0308), male mass and female width (z=0.63636246, p=0.0149), and male mass and female volume (z=-2.3171, p=0.0205), body mass and latitude (z=0.6111, p=0.5411), body mass and longitude (z=2.5592, p=0.0105), body mass and precipitation (z=2.4482, p=0.0144), body mass and temperature (z=2.4707, p=0.0135), body mass and the highest total hours of sunshine in a month (z=0.7689, p=0.4420), body mass and hours of sunshine throughout the year (z=0.5510, p=0.5816), body mass and the month with the highest number of rainy days (z=2.5624, p=0.0104), body mas and female length (z=2.7397, p=0.0061), body mass and female width (z=3.3747, p=0.0007), body mass and female volume (z=3.1041, p=0.0019), body mass and male mass (z=-0.9399, p=0.3473), body size and body mass (z=3.5325, p=0.0004), moments of inertia and latitude (z=-0.3648, p=0.7153), male moments of inertia and latitude (z=-1.3962, p=0.1627), moments of inertia and longitude (z=-2.3128, p=0.0207), male moments of inertia and longitude (z=-2.5548, p=0.0106), moments of inertia and precipitation (z=-2.2019, p=0.0277), male moments of inertia and precipitation (z=-2.4888, p=0.0128), moments of inertia and temperature (z=-2.2243, p=0.0261), male moments of inertia and temperature (z=-2.5022, p=0.0123), moments of inertia and the highest total hours of sunshine in a month (z=-0.5225, p=0.6013), male moments of inertia and the highest total hours of sunshine in a month (z=-1.4900, p=0.1362), moments of inertia and the hours of sunshine throughout the year (z=-2.5503, p=0.0108), male moments of inertia and the hours of sunshine throughout the year (z=-2.6960, p=0.0070), moments of inertia and the month with the highest number of rainy days (z=-2.3160, p=0.0206), male moments of inertia and the month with the highest number of

rainy days (z=-2.5567, p=0.0106), moments of inertia and female length (z=-2.4934, p=0.0127), male moments of inertia and female length (z=-2.6622, p=0.0078), moments of inertia and female width (z=-3.1284, p=0.0018), male moments of inertia and female length (z=-3.0399, p=0.0024), moments of inertia and female volume (z=-2.8578, p=0.0043), male moments of inertia and female volume (z=-2.878, p=0.0040), moments of inertia and body size (z=-3.2945, p=0.0010), male moments of inertia and body size (z=-3.1678, p=0.0015), moments of inertia and mass (z=0.2038,p=0.8385), male moments of inertia and mass (z=-0.9575, p=0.3383), male moments of inertia and male mass (z=0.1936,p=0.8465), moments of inertia and male mass (z=1.0418, p=0.2975), and moments of inertia and male moments of inertia (z=1.0934, p=0.2742). Fifty-nine significant differences were found among the 105 pair-wise comparisons. The data for all factors were normally distributed. The distribution of body size was normal (D=0.15999, n=22, p=0.57201). SShD was normally distributed (D=0.15168, n=22, p=0.20477).

DISCUSSION

Fifty-nine significant differences were found among the 105 comparisons of 15 factors. These occurred between correlation coefficients of SShD with latitude and temperature, latitude and longitude, latitude and precipitation, the month with the highest number of rainy days and latitude, highest total hours of sunshine in a month and longitude, highest total hours of sunshine in a month and precipitation, highest total hours of sunshine in a month and temperature, highest total hours of sunshine in a month and month with the highest number of rainy days, body size and latitude, body size and the highest total hours of sunshine in a month, sunshine throughout the year and longitude, sunshine throughout the year and precipitation, sunshine throughout the year and temperature, sunshine throughout the year and highest number of rainy days, sunshine throughout the year and body size, latitude and female length, the highest total hours of sunshine in a month and female length, the hours of sunshine throughout the year and female length, latitude and female width, the highest total hours of sunshine in a month and female width, the hours of sunshine throughout the year and female width, latitude and female volume, the highest total hours of sunshine in a month and female volume, the hours of sunshine throughout the year and female volume, the month with the highest number of rainy days and female volume, male mass and longitude, male mass and precipitation, male mass and temperature, male mass and the month with the highest number of rainy days, male mass and body size, male mass and sunshine throughout the year, male mass and female length, male mass and female width, male mass and female volume, body mass and longitude, body mass and precipitation, body mass and temperature, body mass and the month with the highest number of rainy days, body mass and female length, body mass and female width, body size and body mass, moments of inertia and longitude, male moments of inertia and longitude, moments of inertia and precipitation, male moments of inertia and precipitation, moments of inertia and temperature, male moments of inertia and temperature, moments of inertia and the hours of sunshine throughout the year, male moments of inertia and the hours of sunshine throughout the year, moments of inertia and the month with the highest number of rainy days, male moments of inertia and the month with the highest number of rainy days, moments of inertia and female length, male moments of inertia and female length, moments of inertia and female width, male moments of inertia and female length, moments of inertia and female volume, male moments of inertia and female volume, moments of inertia and body size, and male moments of inertia and body size.

Eight highly significant differences in pair-wise comparisons of correlations with SShD were found between (1) body size and the highest total hours of sunshine in a month, (2) body size and latitude, and (3) body size and sunshine throughout the year, (4) latitude and female width, (5) hours of sunshine throughout the year and female width, (6) the hours of sunshine throughout the year and female volume, (7) body mass and female width, and (8) body mass and body size. All covary with female width [5-6]. This highlights the importance of female width as the single most important factor of SShD. Selection for female width and volume is responsible for the variance in the millipede polygynandrous mating systems across the latitude, longitude, male mass, precipitation, temperature, the highest total hours of sunshine in a month, hours of sunshine throughout the year and the month with the highest number of rainy days gradients thought to be consistent with fecundity maxima. This study highlights the minute differences required in scaling to result in functionally significant differences in shape [3].

Among the examples where fecundity is related to body width in relatives of diplopods are decapods [7-12]. Blue crabs *Callinectes sapidus* are seasonal and carapace width is positively correlated with fecundity [7]. Fecundity and female carapace width also increases in snow crabs *Chionoecetes opilio* [8, 9]. Fecundity and carapace width are related in the decapod crab species *Cancer pagurus* [10]. The fecundity of the mangrove crab *Ucides cordatus* is related to carapace width [11]. The number of eggs (fecundity) at maturity in the fiddler crab *Uca vocans* is related to carapace width [12].

CONCLUSION

SShD varies systematically with body size, latitude, longitude, precipitation, temperature, the highest total hours of sunshine in a month, the month with the highest number of rainy days, female length, female width, female volume, male mass, body mass, moments of inertia and male moments of inertia. The eight highly significant differences in pair-wise comparisons of correlations in SShD were found among (1) body size and the highest total hours of sunshine in a month, (2) body size and latitude, (3) body size and sunshine throughout the year, (4) latitude and female width, (5) hours of sunshine throughout the year and female width, (6) the hours of sunshine throughout the year and female volume, (7) body mass and female width, and (8) body size and body mass. All covary with female width.

COMPETING INTERESTS

The author has declared that no competing interests exist.

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