International Journal of Recent Research in Thesis and Dissertation (IJRRTD)
Vol. 3, Issue 1, pp: (6-11), Month: January - June 2022, Available at: www.paperpublications.org

Does sexual size dimorphism vary with latitude 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 meets Rensch's Rule if Sexual Size Dimorphism (SSD) and body size changed with a geographical factor. Latitude was correlated with body size and SSD in the forest millipede genus *Centrobolus*. There were significant positive correlations between SSD and latitude (r=-0.44, Z score=2.05, n=22, p=0.02), temperature and latitude (r=0.364, Z score=1.66, n=22, p= 0.05), longitude and latitude (r=0.75, Z score=4.28, n=22, p<0.01), and precipitation and latitude (r=0.62, Z score= 3.079, n=22, p<0.01). Geographical variance in the polygynandrous reproductive systems occurs with larger females and higher SSD occurring in northern habitats.**

Keywords: **Dimorphic; geography; gradient; latitude; size; species.**

I. 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 762-1016mm, a uniform temperature, and an absence of frost; the component trees of the coastal bush with their abundant creepers and lianes, 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 [1].

Sexual size dimorphism (SSD) is correlated with latitude in the pachybolid millipede genus *Centrobolus* Cook, 1897 [1-3]. The null hypothesis is that there is no body size correlation with latitude.

II. MATERIALS AND METHODS

39 valid species were identified as belonging to the genus *Centrobolus* Cook, 1897 [2]. Millipede-type localities were obtained from a checklist of southern African millipedes [3]. These were tabulated and known type localities also listed in Microsoft Word online (https://office.live.com/start/Word.aspx) (Table 1). Global Positioning System coordinates were obtained from internet sources for known type localities using google (https://www.google.co.za/maps/place). Mean annual precipitation and temperature values were obtained from https://en.climate-data.org/search/?q= and internet sources for known type localities using google (https://www.google.co.za). 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 and latitude were checked for correlations using the Pearson Correlation Coefficient calculator (https://www.gigacalculator.com/calculators/correlation-coefficient-calculator.php).

III. RESULTS

There was a significant correlation between SSD and latitude (Fig. 1: r=-0.43808630, Z score=2.04807286, n=22, p=0.02027636). There was no difference between the correlation coefficients of SSD with precipitation and SSD with temperature (z=-0.1782, p=0.8586), SSD with latitude and SSD with longitude (z=-0.2383, n=22, 22, p=0.8117), SSD with precipitation and SSD with latitude (z=0.7919, p=0.4284), SSD with precipitation and SSD with longitude (z=1.0302, p=0.3029), SSD with temperature and SSD with latitude (z=0.3589, p=0.7197), or SSD with temperature and SSD with longitude (z=0.1206, p=0.9040). Precipitation was correlated with latitude (Fig. 2: r=0.62042640, Z score= 3.07887606, n=22, p=0.00103898). Temperature correlated with latitude (Fig. 3: r=0.36420866, Z score=1.66392111, n=22, p= 0.04806408). Latitude was correlated with longitude (Fig. 4: r=0.75356591, Z score=4.27676003, n=22, p=0.00000949). Latitude was normally distributed (D=0.13031, n=22, p=0.80345). SSD was normally distributed (D=0.15168, n=22, p=0.63788).

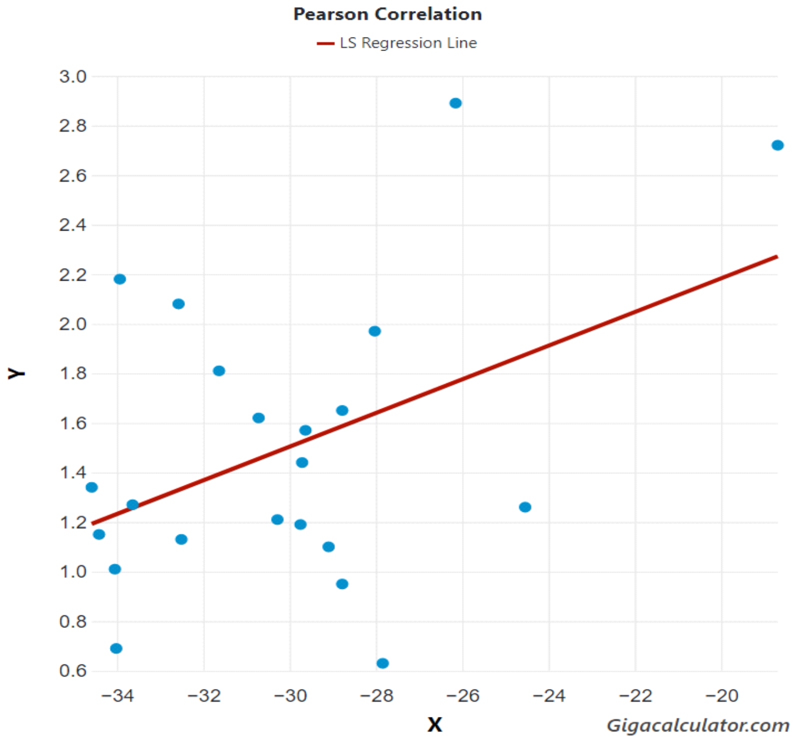

Fig. 1: Relationship between Sexual Size Dimorphism (y-axis) and latitude (x-axis: °S) in *Centrobolus* Cook, 1897.

Table 1: Species in the millipede genus *Centrobolus* Cook, 1897, with SSD, type or collected localities GPS latitude and longitude points, temperature, and precipitation.

Species	SSD	Location	Latitude (°S)	Longitude (°E)	Temp. (°C)	Precipitation (mm)
C. albitarsis	2.89	Lochiel	-26.150174	30.786	15.9	919
C. angelicus		Makhanda	-33.318134			
C. anulatus	1.19	Umhlanga Rocks	-29.746190	31.084	20.4	893
C. atrophus		Signal Hill	-33.917273			
C. bifidus		Nkhandla	-28.728019			
C. coriaceus		caffraria	-	-		
C. decoratus	0.63	Ngome Forest	-27.840258	31.400	16.6	962
C. digrammus	1.01	Hout bay	-34.047685	18.357	16.4	498
C. dubius	1.35	Gans bay	-34.584895	19.350	16.9	408
C. formosus		caffraria	-	-		
C. fulgidus	1.65	Richards Bay	-28.778417	32.049	21.9	944
C. immaculuatus	2.72	Gorongosa	-18.686597	34.394	22.8	1266
C. inscriptus	1.21	Scottburgh	-30.280460	30.754	19.5	1015
C. inyanganus	1.44	Inyanga village	-29.707964	30.666	16.6	893
C. lawrencei	1.57	Pietermaritzburg	-29.630118	30.393	16.7	966

C. litoralis		Algoa Bay	-33.967135			
C. luctuosus		Inhambambane	-23.900071			
C. lugubris	2.18	Glenconnor	-33.932215	25.173	17.0	497
C. miniatomaculatus		Tsitsikamma	-32.220918			
C. pococki		Cape Peninsula	-34.244295			
C. promontorius	0.69	Little Lions Head	-34.016370	18.348	16.4	621
C. pusillus	2.08	Qolora River mouth	-32.571689	28.433	19.5	1050
C. richardii	0.95	Richards Bay	-28.778417	32.078	21.9	944
C. ruber	1.62	Port Shepstone	-30.715740	30.456	20.1	945
C. rubricollis		Karkloof waterfall	-29.399869			
C. rugulosus	1.97	Hluhluwe	-28.024622	31.952	22.0	837
C. sagatinus	1.27	Between Uitenhage and Addo	-33.636710	25.396	18.6	497
C. sanguineomarginatus		Bain's Kloof	-33.613179			
C. sanguinipes		Qolora River mouth	-32.571689			
C. saussurii		caffraria	-	-		
C. silvanus	1.13	Kentani	-32.506398	28.317	19.0	956
C. splendidus		Masiene near Chai Chai	-25.615527			
C. strigosus		caffraria	-	-		
C. striolatus		Port St Johns	-31.633372			
C. titanophilus	1.15	DeHoop vlei	-34.414179	20.383	17.0	401
C. transvaalicus	1.26	Mariepskop	-24.539147	30.867	17.0	1200
C. tricolor	1.10	Champaigne Castle	-29.093869	29.418	15.0	265
C. validus		Haroni River	-19.817644			
C. vastus	1.81	Port St Johns	-31.633371	30.451	19.7	1089

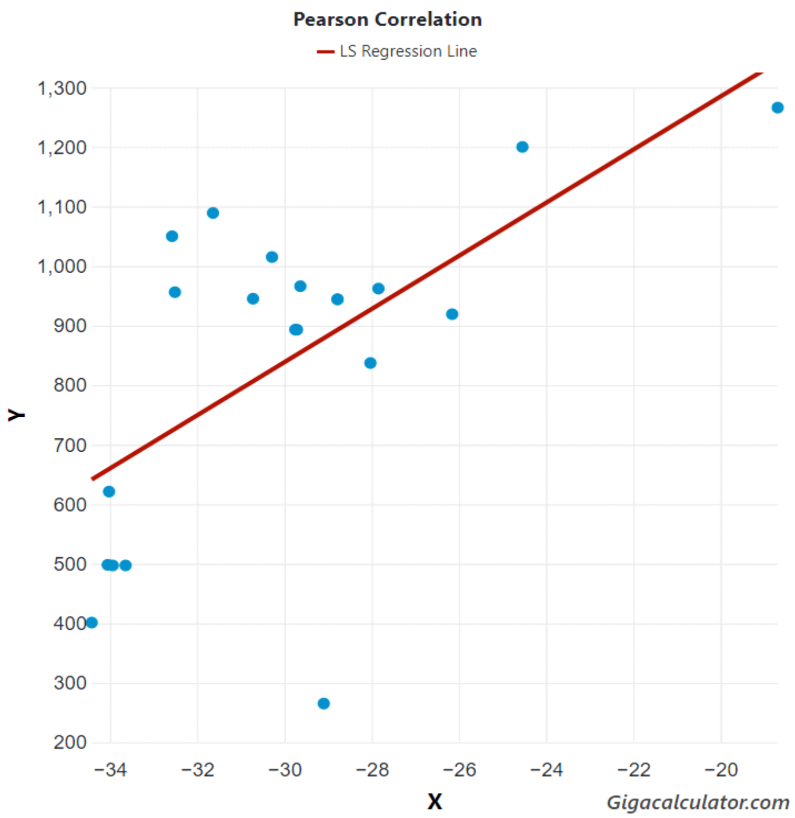

Fig. 2: Relationship between precipitation (y: millimeters) and latitude (x: °South) in *Centrobolus* Cook, 1897.

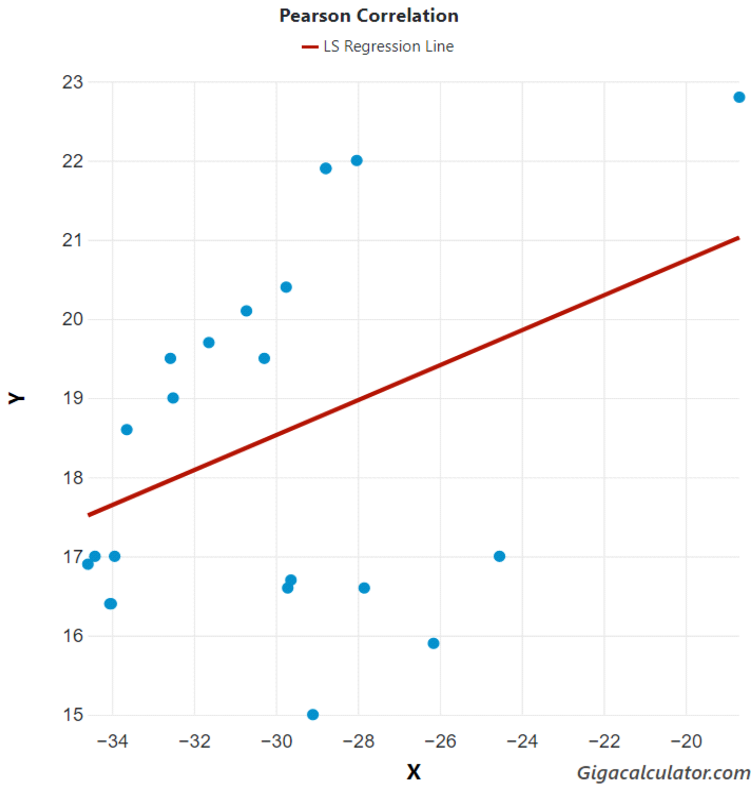

Fig. 3: Relationship between temperature (y: °C) and latitude (x: °East) in *Centrobolus* Cook, 1897.

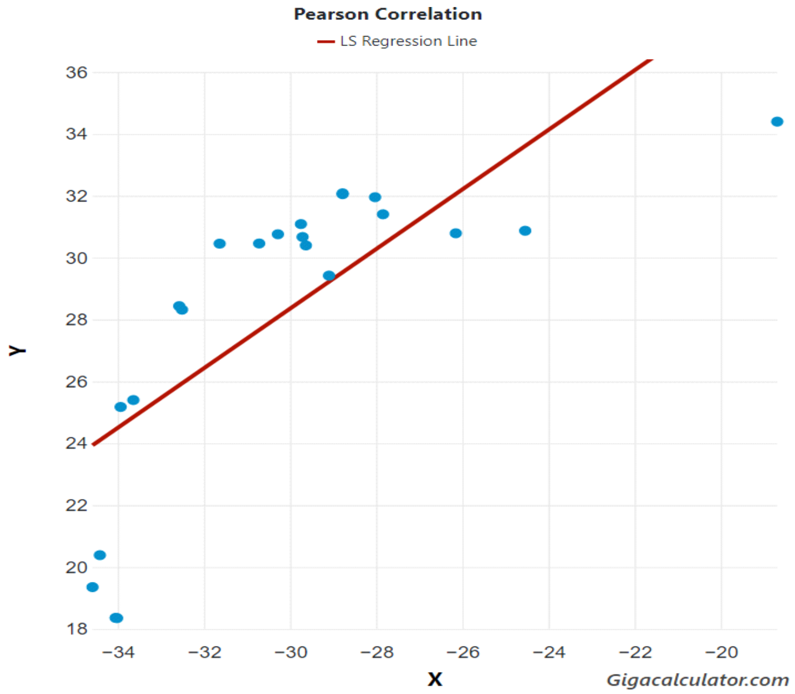

Fig. 4: Relationship between latitude (x: °S) and longitude (y: °East) in *Centrobolus* Cook, 1897.

IV. DISCUSSION

Although most relationships between body size and latitude were absent with weak negative correlations between female, male, and species body sizes and latitude, there was an important significant negative relationship between SSD and latitude. *C. immaculatus* has the highest SSD (2.72) and is most northern (-18.686597°S). SSD of southern species includes *C. titanophilus* (1.15) and *C. dubius* (1.35). This study supports body size as a determiner of the latitudinal gradient [6]. Positive-assortative mating based on width and length also determines the variance in polygynandrous mating systems across latitudes with smaller females and less SSD occurring at higher latitudes.

Latitudinal variation in SSD was first documented in sea-run masu salmon (*Oncorhynchus masou*) [8]. It is also known in a Seed-feeding beetle (*Stator limbatus*) [7], Cuban Treefrog (*Osteopilus septentrionalis*) [9], Pacific blue-eye (*Pseudomugil signifer*) [10], Marine Fish (*Bathygobius soporator*) [11], Ground Beetles (*Pterostichus melanarius*) [12, 18], Cis-Andean South American Howler Monkey (*Alouatta* sp.) [19], common musk turtles (*Sternotherus odoratus*) [20], and the damselfly (*Lestes sponsa*) [21]. Latitude, life history, and sexual size dimorphism correlate with reproductive seasonality similar to rodents [10]. The evidence is for a sexual selection regime shifting from favoring larger males in the south, to favoring smaller males in the north [5] because SSD decreased systematically with latitude and increased with body size [4] due to sexual bimaturism, fertility selection and intra-male competition [13, 14, 15-17, 22].

In the treefrog *Scinax fuscovarius* body size is negatively related to precipitation and varies with longitude and less with latitude [6]. Size-assortative mating based on width and male length determines the variance in *Centrobolus* millipede polygynandrous mating systems across a latitudinal gradient with higher SSD occurring northwards.

V. CONCLUSION

SSD decreased systematically with latitude in *Centrobolus*. SSD increased with body size in this genus. Geographical variance in the polygynandrous reproductive systems occurs if larger individuals and higher SSD occur in northern habitats.

COMPETING INTERESTS

The author has declared that no competing interests exist.

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