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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 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 score=1.97, n=22, p=0.02). Minimum temperature was strongly correlated with latitude (r=0.52, Z score=2.59, n=23, p=0.005). Maximum temperature was strongly correlated with latitude (r=0.55, Z score=2.78, n=23, p=0.003). Minimum temperature was strongly correlated with longitude (r=0.54, Z score=2.63, n=22, p=0.004). Maximum temperature was strongly correlated with longitude (r=0.67, Z 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 Mocambique 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 Mocambique 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 lianes 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=0.04460571) (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 temeprature 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, $p < 0.00001$).

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

Species	SSD	Location	Latitude (°S)	Longitude (°E)	The highest number of rainy days	Min. Temp. (°C)	Max. Temp. (°C)
C. albitarsis	2.89	Lochiel	-26.150174	30.786	19.90 (Dec.)	14.5	24.7
C. angelicus		Makhanda	-33.318134				
C. anulatus	1.19	Umhlanga Rocks	-29.746190	31.084	13.73 (Dec.)	19.9	25.4
C. atrophus		Signal Hill	-33.917273				
C. bifidus		Nkhandla	-28.728019				
C. coriaceus		caffraria	-	-			
C. decoratus	0.63	Ngome Forest	-27.840258	31.400	19.33 (Dec.)	14.8	25.6
C. digrammus	1.01	Hout bay	-34.047685	18.357	10.50 (June)	11.4	15.7
C. dubius	1.35	Gans bay	-34.584895	19.350	10.40 (June)	11.5	16.6
C. formosus		caffraria	-	-			
C. fulgidus	1.65	Richards Bay	-28.778417	32.049	13.97 (Nov.)	19.8	25.5
C. immaculuatus	2.72	Gorongosa	-18.686597	34.394	21.03 (Jan.)	21.6	29.0
C. inscriptus	1.21	Scottburgh	-30.280460	30.754	15.23 (Dec.)	18.7	25.0
C. inyanganus	1.44	Inyanga village	-29.707964	30.666	13.73 (Dec.)	20.5	25.5
C. lawrencei	1.57	Pietermaritzburg	-29.630118	30.393	19.27 (Dec.)	15.3	24.8
C. litoralis		Algoa Bay	-33.967135				
C. luctuosus		Inhambambane	-23.900071				
C. lugubris	2.18	Glenconnor	-33.932215	25.173	8.67 (Mar.)	17.7	24.8
C. miniatomaculatus		Tsitsikamma	-32.220918				
C. pococki		Cape Peninsula	-34.244295				
C. promontorius	0.69	Little Lions Head	-34.016370	18.348	11.07 (June)	11.4	15.7
C. pusillus	2.08	Qolora River mouth	-32.571689	28.433	14.07 (Jan.)	15.7	25.6
C. richardii	0.95	Richards Bay	-28.778417	32.078	13.97 (Nov.)	19.8	25.5
C. ruber	1.62	Port Shepstone	-30.715740	30.456	14.67 (Dec.)	19.7	24.6
C. rubricollis		Karkloof waterfall	-29.399869				
C. rugulosus	1.97	Hluhluwe	-28.024622	31.952	13.77 (Jan.)	22.2	27.9
C. sagatinus	1.27	Between Uitenhage and Addo	-33.636710	25.396	8.67 (Mar.)	16.6	26.1
C. sanguineomarginatus		Bain's Kloof	-33.613179		11.07 (June)	11.4	15.7
C. sanguinipes		Qolora River mouth	-32.571689				
C. saussurii		caffraria	-	-			
C. silvanus	1.13	Kentani	-32.506398	28.317	8.67 (Mar.)	13.6	24.8
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	7.10 (Mar.)	15.0	28.3
C. transvaalicus	1.26	Mariepskop	-24.539147	30.867	10.10 (Dec.)	19.4	29.5
C. tricolor	1.10	Champaigne Castle	-29.093869	29.418	18.50 (Dec.)	9.5	19.4
C. validus		Haroni River	-19.817644				
C. vastus	1.81	Port St Johns	-31.633371	30.451	16.97 (Dec.)	19.0	24.2

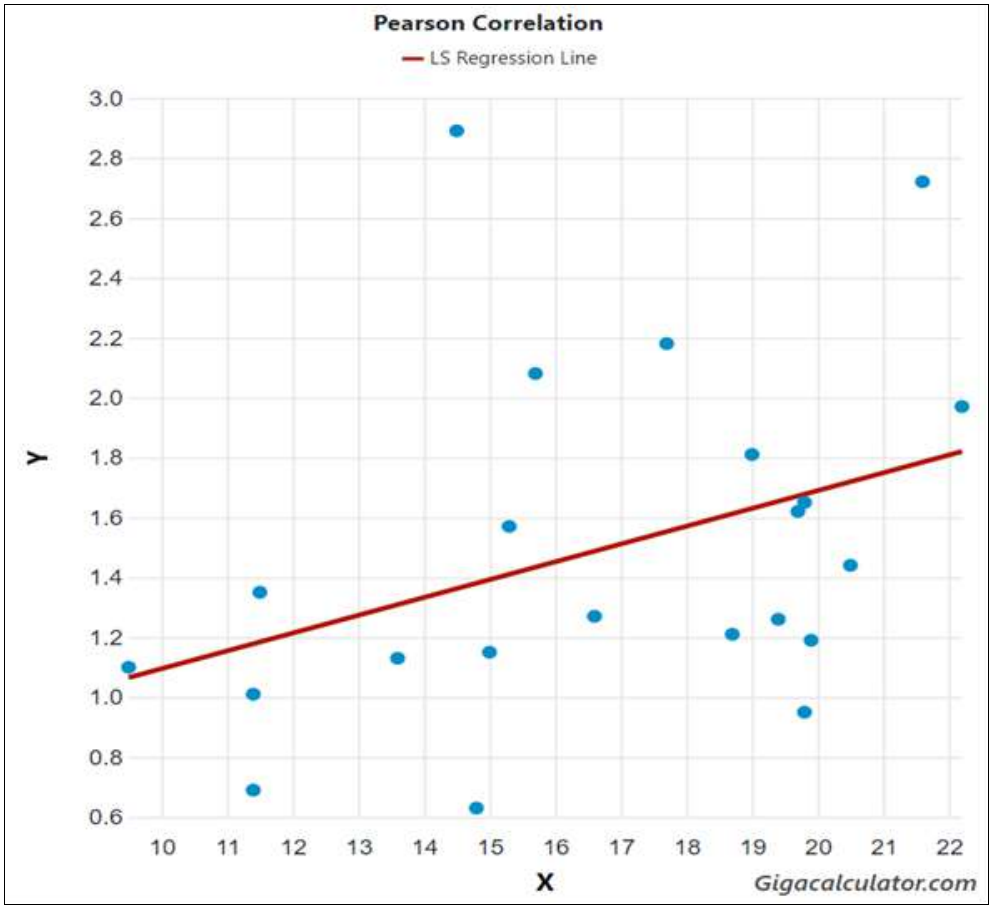

Fig 1: Relationship between Sexual Size Dimorphism (y-axis) and minimum temperature during the month with the highest number of rainy days (x-axis: °C) in *Centrobolus* Cook, 1897

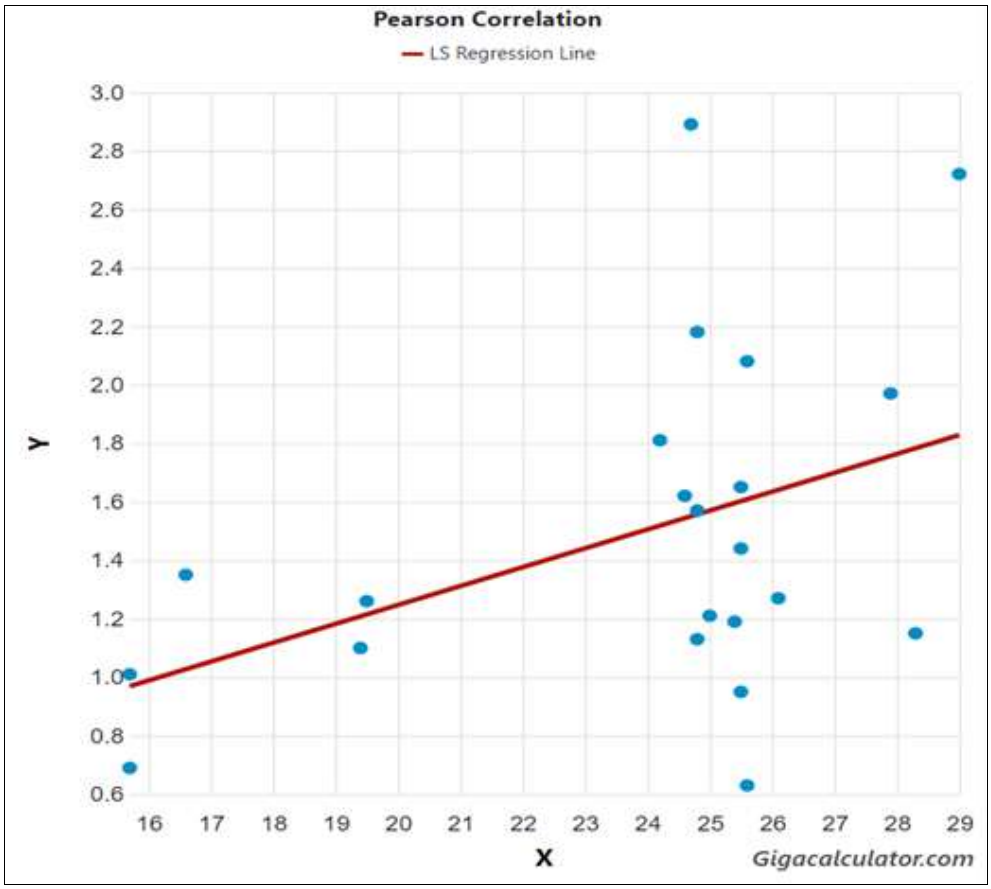

Fig 2: Relationship between Sexual Size Dimorphism (y-axis) and maximum temperature during the month with the highest number of rainy days (x-axis: °C) in *Centrobolus* Cook, 1897

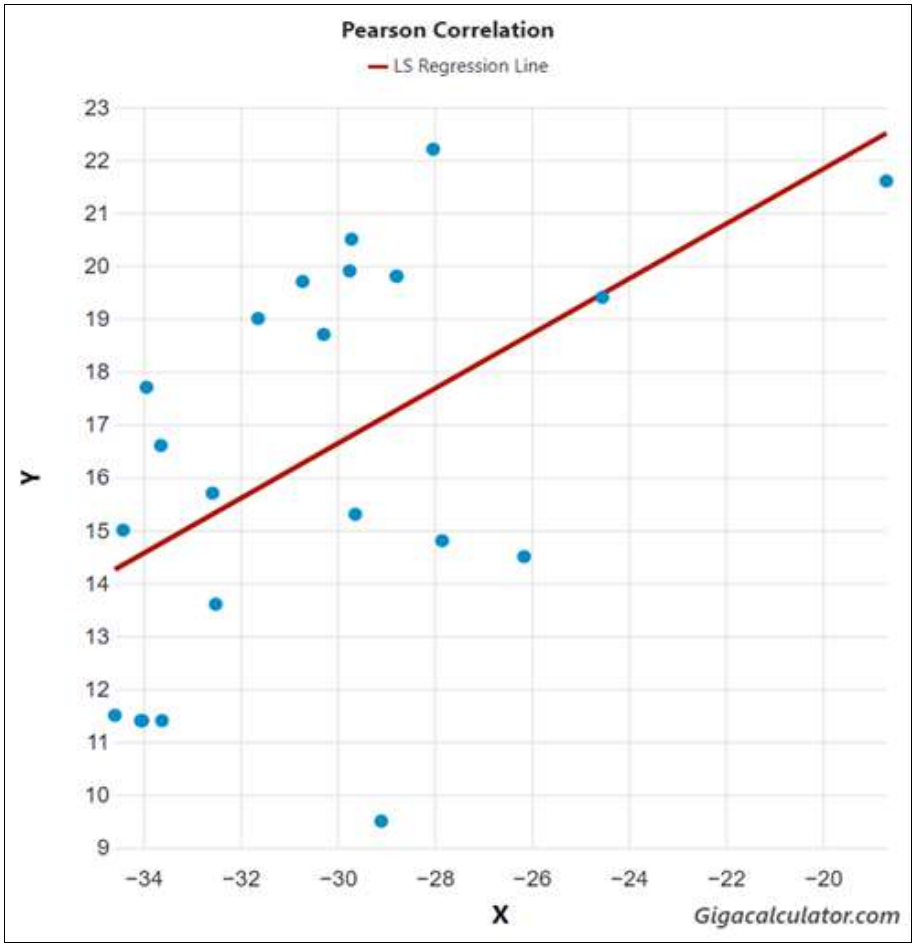

Fig 3: Relationship between minimum temperature (y: °C) and latitude (x: °South) in *Centrobolus* Cook, 1897

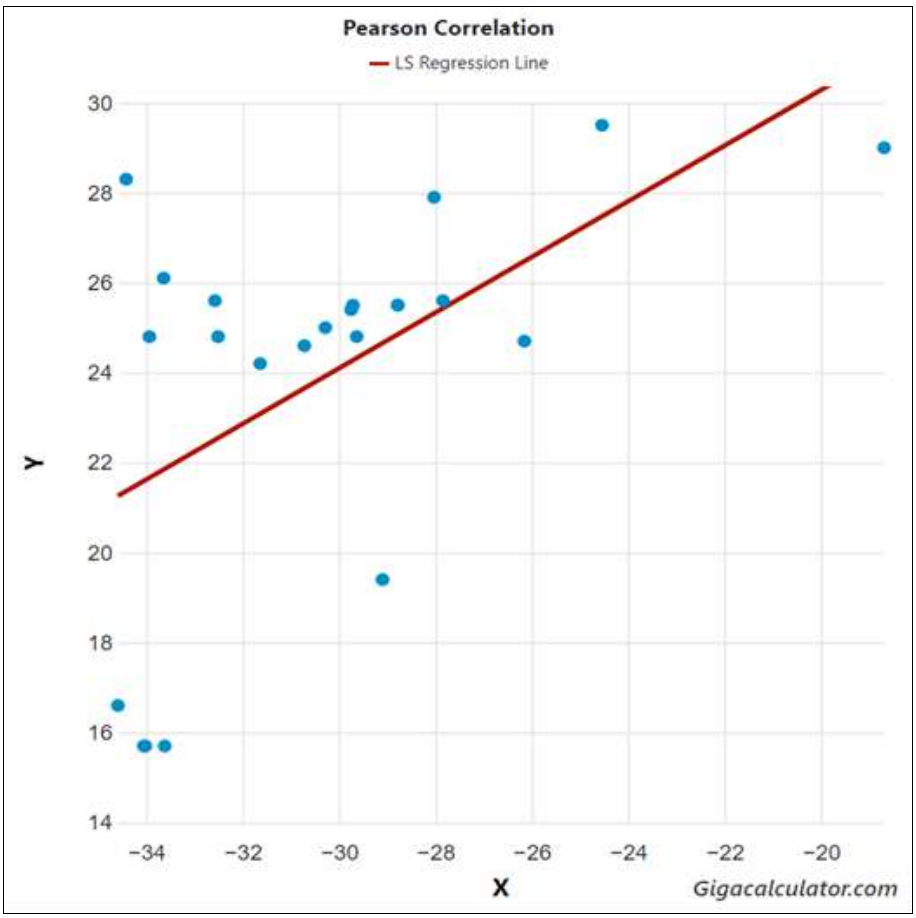

Fig 4: Relationship between maximum temperature (y) and latitude (x: °South) in *Centrobolus* Cook, 1897

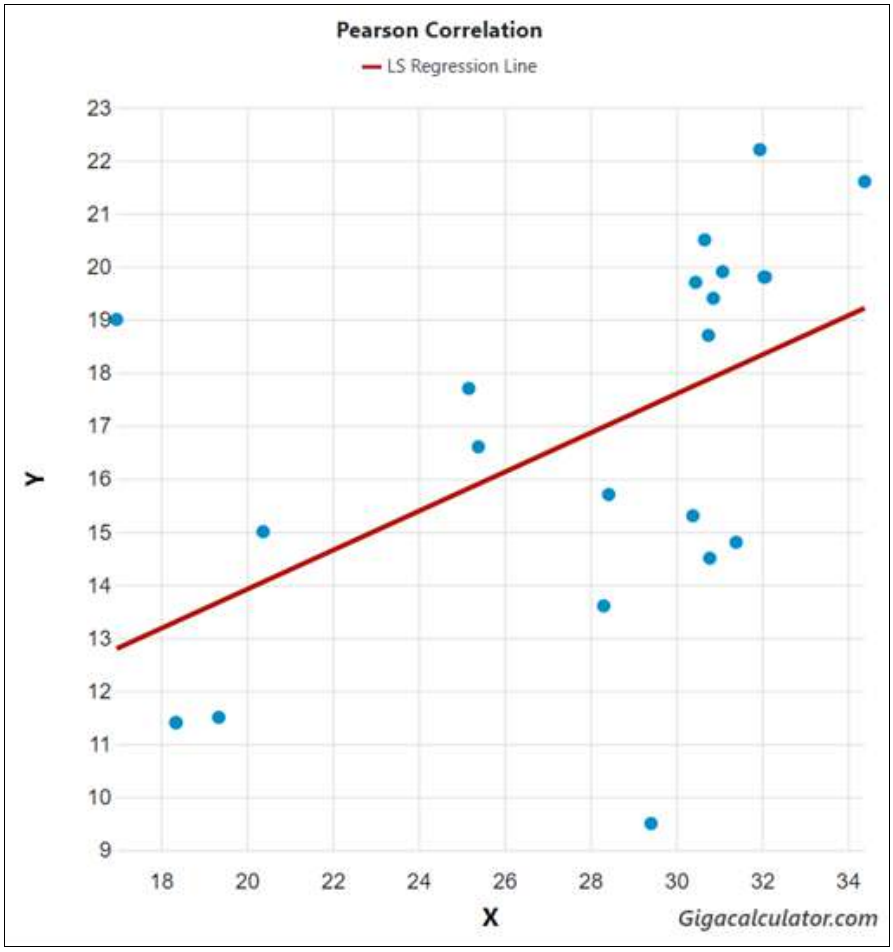

Fig 5: Relationship between minimum temperature (y: °C) and longitude (x: °East) in *Centrobolus* Cook, 1897

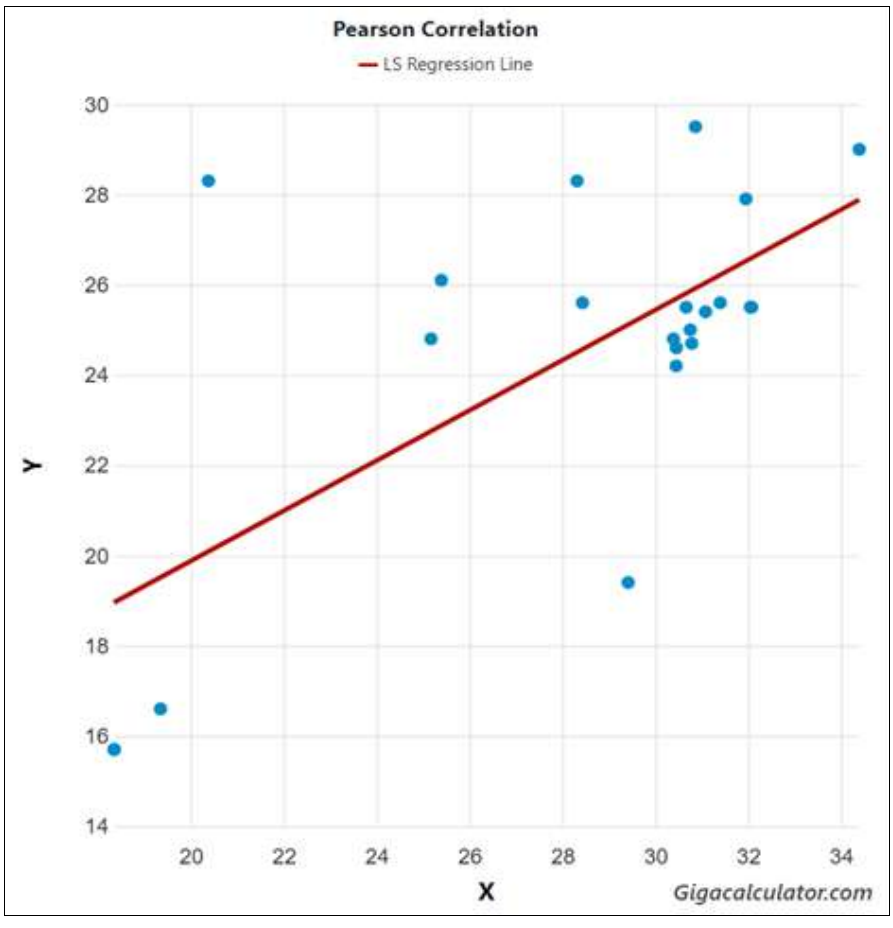

Fig 6: Relationship between maximum temperature (y: °C) and longitude (x: °East) in *Centrobolus* Cook, 1897

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 maximum and minimum 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* [19], 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 mosquitofish [3]. 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 [5].

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.

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