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Does sexual size dimorphism vary with hours of sunshine throughout the year in forest millipedes *Centrobolus* Cook, 1897?

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Abstract

Sexual size dimorphism (SSD) and body size vary with abiotic factors in millipedes. Seasonality was associated with body size and SSD in the forest millipede genus *Centrobolus* to test for seasonality and a correlation between SSD and daylight hours throughout the year. There was a significant negative correlation between SSD and daylight hours throughout the year ($r=0.46$, Z score= 2.17 , $n=22$, $p=0.02$). *C. albitarsus* has the highest SSD (2.89 female-biased) and occurs in the month with low hours of sunlight throughout the year (2690.72 hours) whereas SSD was second-lowest in *C. promontorius* (0.69 male-biased) which occurred in very high (3087.04 hours) hours of sunlight throughout the year. SSD correlated with year-round sunlight hours differently to year-round sunlight hours with the highest sunlight hours per month ($z=0.75$, $p<0.01$). In these polygynandrous reproductive systems, larger females with a higher SSD occur with lower hours of sunlight throughout the year which differs from SSD covariance with the highest number of hours of sunlight per month. This study emphasizes the seasonality of these millipedes.

Keywords: Dimorphic, eco-geography, gradient, size, species, sunlight.

Introduction

The forest genus of millipedes of the Order Spirobolida diplopod found along the east coast of southern Africa was the subject of this study. The millipede genus *Centrobolus* is located in the temperate region of South Africa, with its northern boundary on the east coast of southern Africa at about 17° latitude South^[13]. Sexual size dimorphism is related to latitude, longitude, and temperature^[4-6]. SSD is tested for an association with seasonality. In particular hours of sunlight throughout the year were used as a proxy to determine if SSD correlated with seasonality in the pachybolid millipede genus *Centrobolus* Cook, 1897^[4-6]. The null hypothesis is that there are correlations between SSD or body size and (1) daylight hours throughout the year occurs. Furthermore, I test for relationships between hours of sunshine throughout the year and (1) latitude, (2) longitude, (3) temperature, (4) precipitation, (5) the month with the highest number of rainy days, and (6) the highest total hours of sunshine in a month.

2. Materials and Methods

Thirty-nine active species have been identified as part of the genus *Centrobolus* Cook, 1897^[9]. Their collection localities, SSD, latitude, longitude, hours of sunshine throughout the year, and highest total hours of sunshine in a month were calculated (Table 1). GPS coordinates (latitude and longitude) for collected localities were calculated (<https://www.google.co.za/maps/place>). Total hours of sunlight per month, mean annual rainfall, temperature, and month with the highest number of rainy days were sourced at <https://en.climate-data.org/search/?Q=>. Body size was calculated as the volume (of a cylinder) using the length and width of the organisms. The SSD was calculated as the average volume for females divided by the average volume for males of each species. Annual sunlight hours, SSD, latitude, longitude, rainfall, the maximum number of hours of sunlight per month, the month with the highest number of rainy days, and temperature were compared to one another using a Pearson Correlation Coefficient Calculator. The associated correlation coefficients between SSD and daylight hours throughout the year and SSD with latitude, length, rainfall, the maximum number of hours of

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Sunlight per month, the month with the highest number of rainy days, and average temperature were also compared with the package MedCalc. Data were tested for deviation from a normal distribution with Kolmogorov-Smirnov tests.

3. Results

There was a significant negative correlation between SSD and the hours of sunshine throughout the year (Fig. 1: $r=-0.45931187$, Z score= -2.16392666 , $n=22$, $p=0.01523493$). There was no difference between the correlation coefficients of SSD with hours of sunshine throughout the year and hours of sunshine throughout the year with latitude ($z=0.3611$, $p=0.7180$), SSD with the hours of sunshine throughout the year, and the hours of sunshine throughout the year with longitude ($z=1.2681$, $p=0.2048$), SSD with the hours of sunshine throughout the year and the hours of sunshine throughout the year with precipitation ($z=1.4833$, $p=0.1380$), SSD with the hours of sunshine throughout the year and the hours of sunshine throughout the year with temperature ($z=-0.0560$, $p=0.9553$), SSD with the hours of sunshine throughout the year and the hours of sunshine throughout the year with the month with the highest number

of rainy days ($z=0.0976$, $p=0.9223$). There was a difference between the correlation coefficients of SSD with the hours of sunshine throughout the year and the hours of sunshine throughout the year with the highest total hours of sunshine in a month ($z=0.74546448$, $p<0.0001$) and between the correlation coefficients of SSD with the hours of sunshine throughout the year and hours of sunshine throughout the year with temperature ($z=-2.6161$, $p=0.0089$). The hours of sunshine throughout the year correlated with precipitation (Fig. 2: $r=-0.75205618$, Z score= -4.26157162 , $n=22$, $p=0.00001016$), latitude (Fig. 3: $r=-0.36209403$, Z score= -1.65330343 , $n=22$, $p=0.04913454$), longitude (Fig. 4: $r=-0.72010029$, Z score= -3.95724057 , $n=22$, $p=0.00003793$), temperature (Fig. 5: $r=-0.44485773$, Z score= -2.08473431 , $n=22$, $p=0.01854665$), the month with the highest number of rainy days (Fig. 6: $r=-0.48392680$, Z score= -2.30193124 , $n=22$, $p=0.01066950$) and the highest total hours of sunshine in a month (Fig. 7: $r=0.74546448$, Z score= 4.19617158 , $n=22$, $p=0.00001358$). The data for the hours of sunshine throughout the year was normally distributed ($D=0.20237$, $n=22$, $p=0.28783$). SSD was normally distributed ($D=0.15168$, $n=22$, $p=0.20477$).

Table 1: Species in the millipede genus *Centrobolus* Cook, 1897, with SSD, type or collected localities GPS latitude and longitude points, hours of sunshine throughout the year, and highest total hours of sunshine in a month.

Species	SSD	Location	Latitude (°S)	Longitude (°E)	Hours of sunshine throughout the year (h)	Highest total hours of sunshine (hrs)
<i>C. albitarsis</i>	2.89	Lochiel	-26.150174	30.786	2690.72	259.73 (Aug.)
<i>C. angelicus</i>		Makhanda	-33.318134			
<i>C. anulatus</i>	1.19	Umhlanga Rocks	-29.746190	31.084	2709.47	248.89 (July)
<i>C. atrophus</i>		Signal Hill	-33.917273			
<i>C. bifidus</i>		Nkhandla	-28.728019			
<i>C. coriaceus</i>		caffraria	-	-		
<i>C. decoratus</i>	0.63	Ngome Forest	-27.840258	31.400	2740.74	256.6 (Aug.)
<i>C. digrammus</i>	1.01	Hout Bay	-34.047685	18.357	3145.74	342.21 (Dec.)
<i>C. dubius</i>	1.35	Gans bay	-34.584895	19.350	2846.04	293.68 (Dec.)
<i>C. formosus</i>		caffraria	-	-		
<i>C. fulgidus</i>	1.65	Richards Bay	-28.778417	32.049	2815.76	209.2 (Jan.)
<i>C. immaculatus</i>	2.72	Gorongosa	-18.686597	34.394	2703.13	247.85 (Sep.)
<i>C. inscriptus</i>	1.21	Scottburgh	-30.280460	30.754	2699.92	250.86 (July)
<i>C. inyanganus</i>	1.44	Inyanga village	-29.707964	30.666	2709.47	248.89 (July)
<i>C. lawrencei</i>	1.57	Pietermaritzburg	-29.630118	30.393	2583.18	247.77 (July)
<i>C. litoralis</i>		Algoa Bay	-33.967135			
<i>C. luctuosus</i>		Inhambambane	-23.900071			
<i>C. lugubris</i>	2.18	Glenconnor	-33.932215	25.173	2864.06	250.72 (Nov.)
<i>C. miniatomaculatus</i>		Tsitsikamma	-32.220918			
<i>C. pococki</i>		Cape Peninsula	-34.244295			
<i>C. promontorius</i>	0.69	Little Lions Head	-34.016370	18.348	3087.04	336.32 (Jan.)
<i>C. pusillus</i>	2.08	Qolora River mouth	-32.571689	28.433	2646.85	247.65 (Aug.)
<i>C. richardii</i>	0.95	Richards Bay	-28.778417	32.078	2815.76	209.2 (Jan.)
<i>C. ruber</i>	1.62	Port Shepstone	-30.715740	30.456	2654.59	251.38 (July)
<i>C. rubricollis</i>		Karkloof waterfall	-29.399869			
<i>C. rugulosus</i>	1.97	Hluhluwe	-28.024622	31.952	2702.09	195.55 (Jan.)
<i>C. sagittarius</i>	1.27	Between Uitenhage and Addo	-33.636710	25.396	2864.06	250.72 (Nov.)
<i>C. sanguine marginatus</i>		Bain's Kloof	-33.613179		3087.04	336.32 (Jan.)
<i>C. sanguinipes</i>		Qolora River mouth	-32.571689			
<i>C. saussurii</i>		caffraria	-	-		
<i>C. silvanus</i>	1.13	Kentani	-32.506398	28.317	2682.25	250.72 (Nov.)
<i>C. splendidus</i>		Masiene near Chai Chai	-25.615527			
<i>C. strigosus</i>		caffraria	-	-		
<i>C. striolatus</i>		Port St Johns	-31.633372			
<i>C. titanophilus</i>	1.15	DeHoop vlei	-34.414179	20.383	3126.58	312.99 (Jan.)
<i>C. transvaalicus</i>	1.26	Mariepskop	-24.539147	30.867	2841.89	258.55 (Aug.)
<i>C. tricolor</i>	1.10	Champaigne Castle	-29.093869	29.418	3070.45	274.85 (Dec.)
<i>C. validus</i>		Haroni River	-19.817644			
<i>C. vastus</i>	1.81	Port St Johns	-31.633371	30.451	2564.32	188.32 (Jan.)

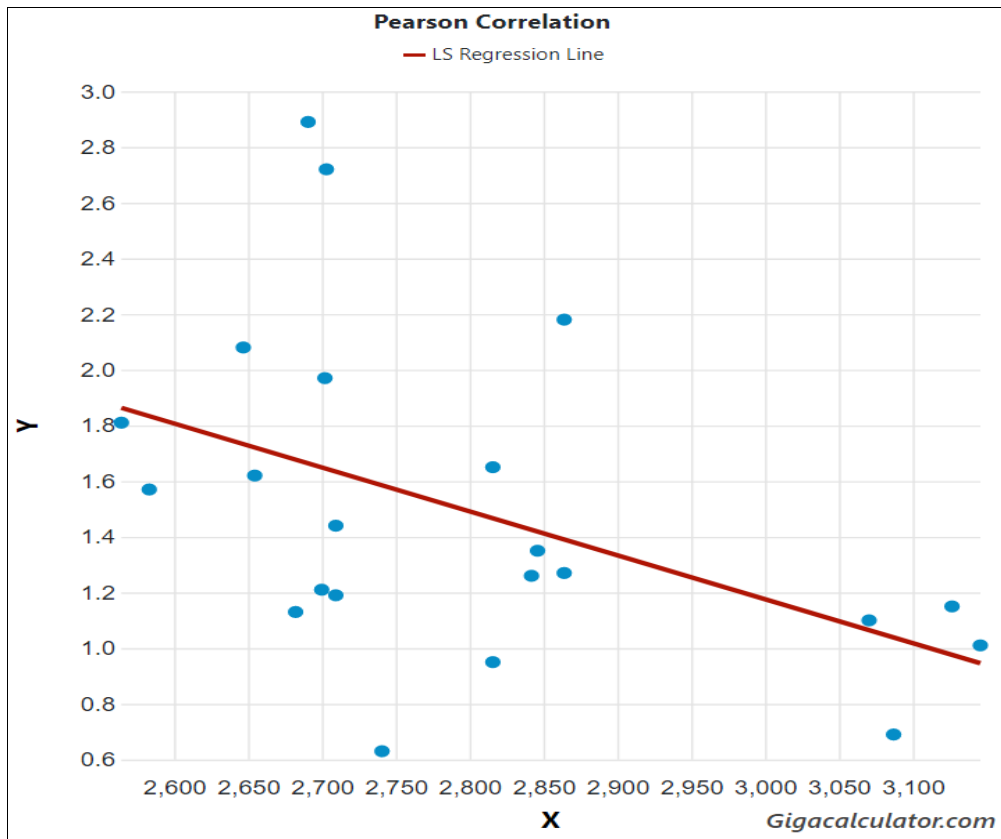


Fig 1: Relationship between Sexual Size Dimorphism (y-axis) and hours of sunshine throughout the year (x-axis) in *Centrobolus* Cook, 1897.

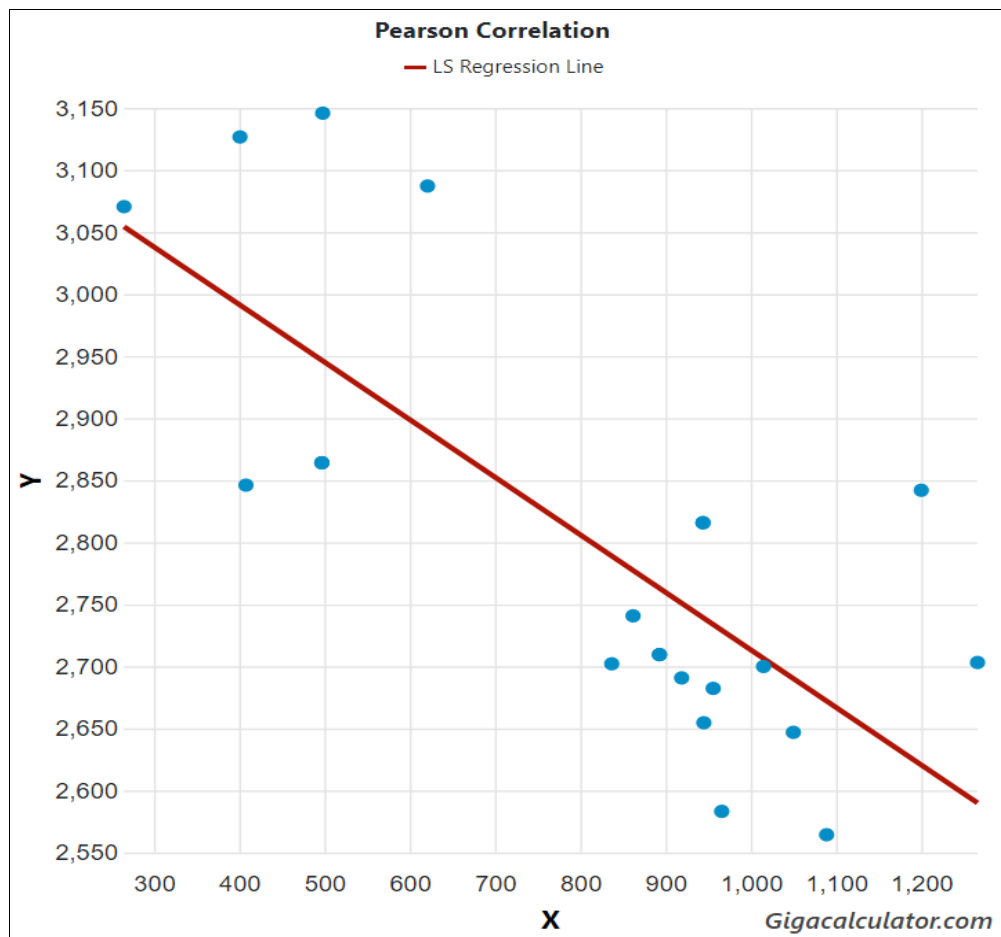


Fig 2: Relationship between hours of sunshine throughout the year (x) and precipitation (y: millimeters) in *Centrobolus* Cook, 1897.

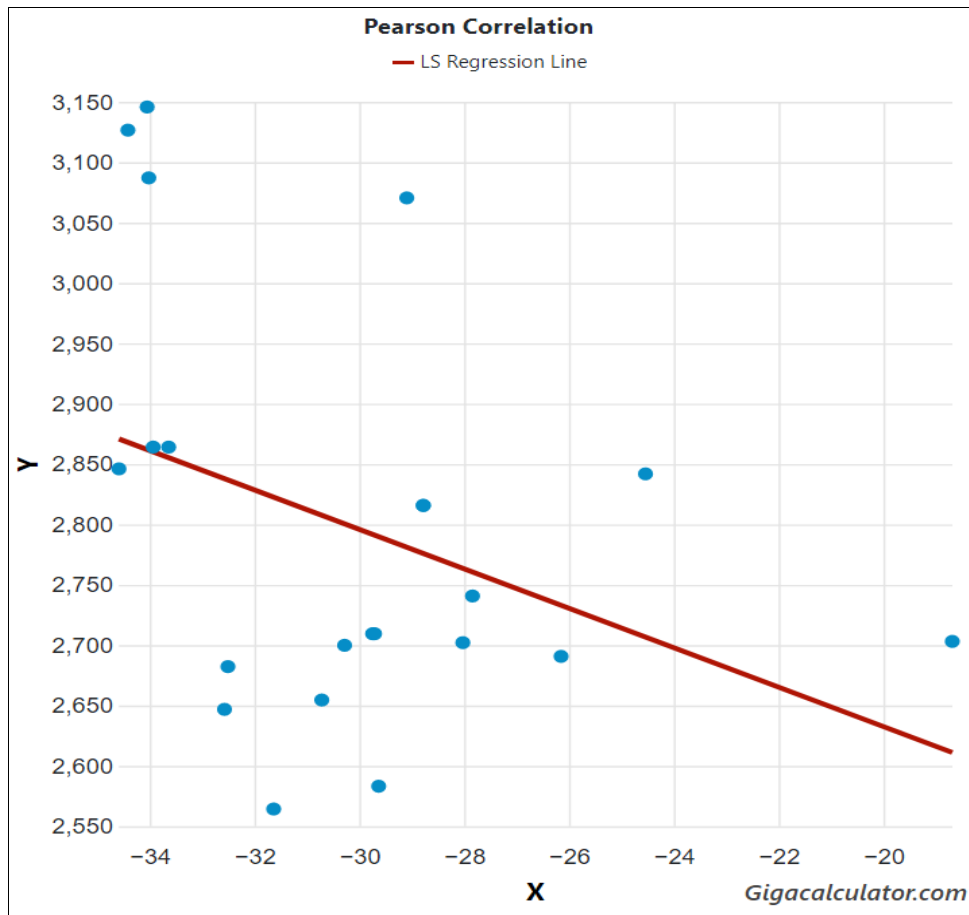


Fig 3: Relationship between total hours of sunshine throughout the year (y) and latitude (x: °South) in *Centrobolus* Cook, 1897.

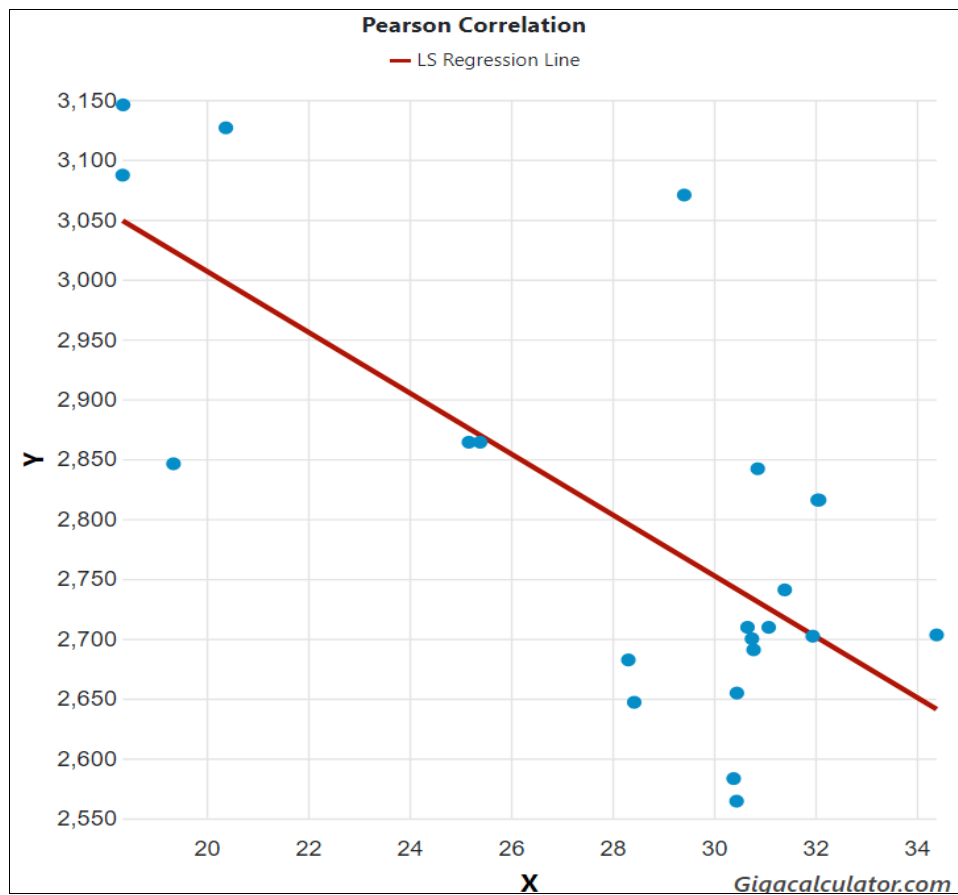


Fig 4: Relationship between a month with hours of sunshine throughout the year (y) and longitude (x: °East) in *Centrobolus* Cook, 1897.

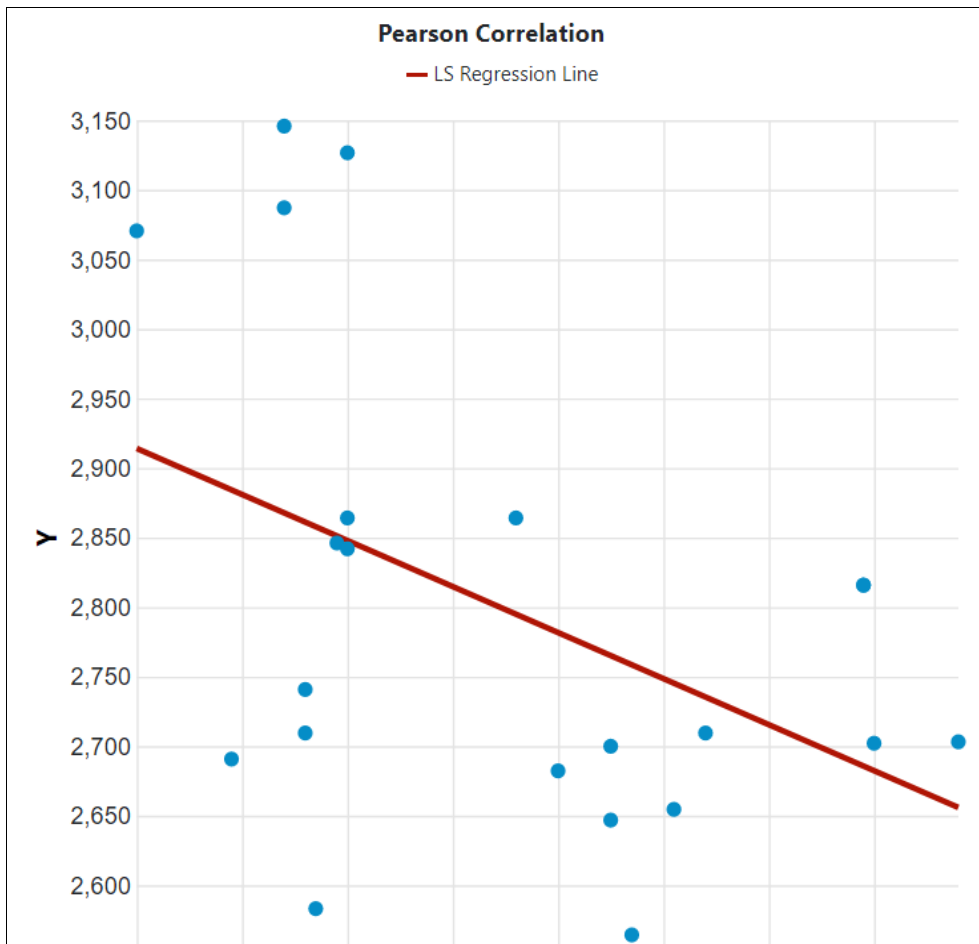


Fig 5: Relationship between hours of sunshine throughout the year (y) and temperature (x: °C) in *Centrobolus* Cook, 1897.

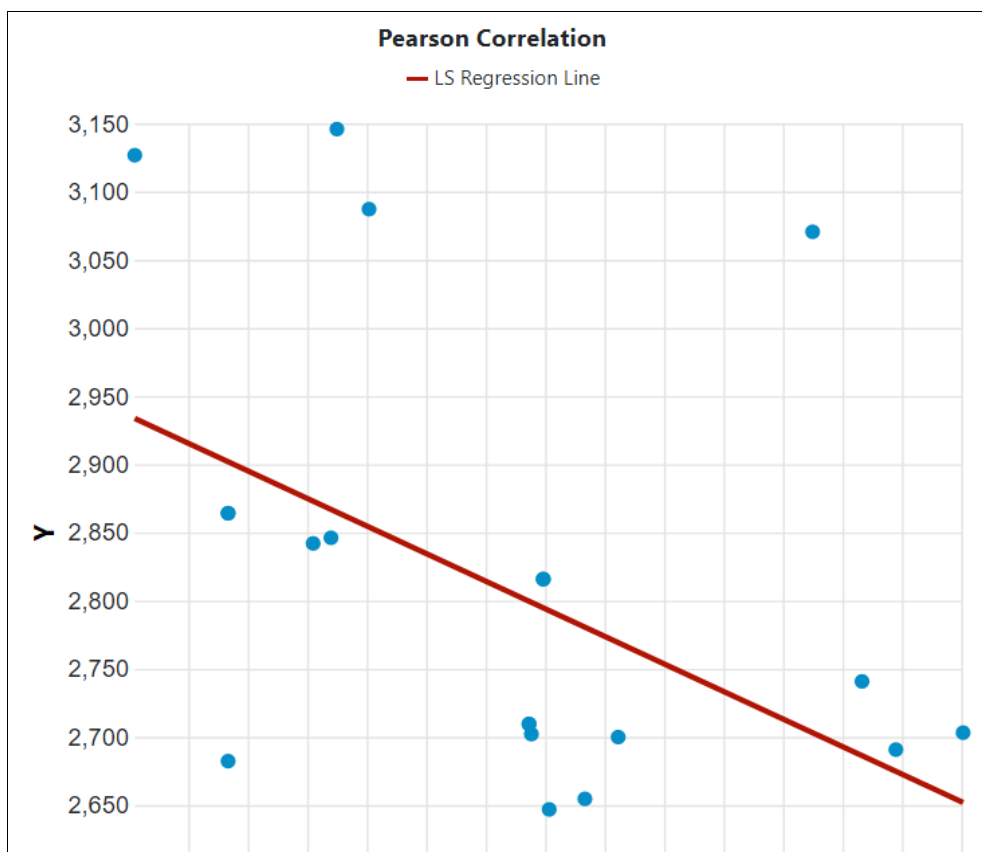


Fig 6: Relationship between hours of sunshine throughout the year (y) and month with the highest number of rainy days (x) in *Centrobolus* Cook, 1897.

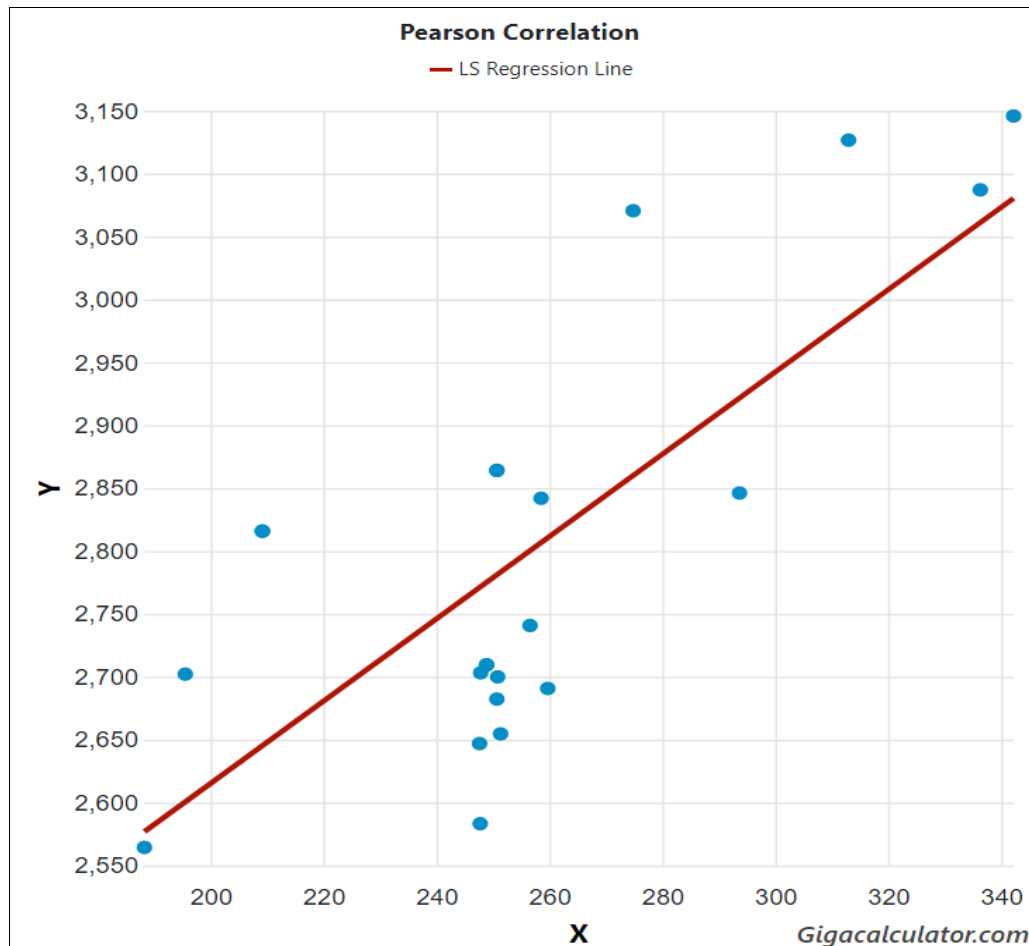


Fig 7: Relationship between hours of sunshine throughout the year (y) and highest total hours of sunshine in a month (x) in *Centrobolus* Cook, 1897.

4. Discussion

Six negative correlations between sunlight hours throughout the year were found with SSD, latitude, longitude, rainfall, temperature, and month with the highest number of rainy days as expected confirming all of the null hypotheses. Hours of sunlight throughout the year were closely related to the highest number of hours of sunlight per month. *C. albitarsus* has the highest SSD (2.89 female-biased) and occurs in the month with low hours of sunlight throughout the year (2690.72 hours). SSD was second lowest in *C. promontorius* (0.69 male-biased) which occurs in very high (3087.04 hours) hours of sunlight throughout the year. This study supports year-round daylight hours between latitude, length, rainfall, temperature, and the number of rainy days as SSD predictors in *Centrobolus*.

Size-assortative mating based on the width and height of individuals determines the variation of millipede polygynandrous mating systems throughout the hours of sunlight in a month gradient with a high SSD occurring at low hours of sunlight throughout the year. SSD decline with hours of sunlight throughout the year is evident in millipede seasonal activity patterns [1, 7, 8, 11, 12]. Future studies can expect to find variation in the patterns of daily activity rhythms in these millipedes which are known to occur in *Arthrosphaera*, *Ommatoiulus moreletii*, and other millipedes in the twilight zone [2, 10, 14]. Sexual dimorphism of the length of the hindlimb at the extremities of the desert is associated with habitat openness [15]. The negative correlation between year-round sunlight and SSD in

Centrobolus millipedes may be even more closely related to habitat openness across latitudes, longitudes, and temperatures [1-3], as well as month with the highest number of rainy days, the highest number of hours of sunlight per month and precipitation.

5. Conclusion

SSD is systematically decreased during daylight hours throughout the year in *Centrobolus*. Differences in polygynandrous reproductive systems occur when larger females with a higher SSD occur with lower hours of sunlight throughout the year different from (1) SSD covariance with the highest hours of sunlight per month and (2) SSD and temperature.

Competing interests

The author has declared that no competing interests exist.

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