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Latitudinal-size trend in eight species of *Centrobolus*

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Abstract
Bergmann's eco-geographical rule maintained within a taxonomic clade, populations and species of larger size were found in colder environments, and species of smaller size were found in warmer regions. It was tested in the millipede genus *Centrobolus* with reversed sexual size dimorphism (SSD). Two factors were measured from eight *Centrobolus* species, body lengths (mm) and widths (mm). *Centrobolus* male lengths were positively related to latitude (r=0.643, r^2=0.4134, n=8, p=0.085467). The short species, *C. digrammus* occurred at the southern tips of South Africa (-34.19°S) while longer species, *C. inscriptus* and *C. anulatus* were found north (-28.98°S). In-between these two latitudes all the medium sized species ranged.

Keywords: Bergmann's, clade, cline, dimorphism, ecology, size

1. Introduction
Bergmann's rule is an ecogeographical rule which states that within a broadly distributed taxonomic clade, populations and species of larger size are found in colder environments, and species of smaller size are found in warmer regions and was originally formulated in terms of species within a genus [15]. Evidence for and against Bergmann's rule follows an even distribution in arthropods [17].
Millipedes are important environmental indicators and under-represented in analyses of invertebrate Sexual Size Dimorphism (SSD) which is the phenotypic condition where the two sexes of the same species exhibit different characteristics beyond the differences in their sexual organs [96]. Common sexual differences are thought to occur in body mass, length, width and leg dimensions of over half the taxa studied [1-3, 9-13, 21-74, 85]. Diplopods resemble invertebrates in SSD is reversed [25].
The forest clade *Centrobolus* of pachybolid millipedes belonging to the Order Spirobolida is distributed along the eastern coast of southern Africa [37, 105]. They consist of brightly coloured (aposematic) species with concentrations around coastal bush or forests [37]. Their terrestrial habits make them ideal organisms for testing Bergmann's rule. In the present study, SSD in the forest genus *Centrobolus* was investigated in eight species and 2 factors determining a response in SSD (length and width) recorded, data checked for a correlation with latitude.

2. Materials and Methods
Two factors were obtained from eight *Centrobolus* species: (1) body length (mm) in placing individuals collected in South Africa alongside a plastic rule (calibrated in mm); and (2) horizontal tergite width (mm) with Vernier calipers. The basic descriptive statistics; mean, standard deviation (SD) and CV of length and width were checked for Pearson's correlations with latitudinal, available at https://www.socscistatistics.com/tests/pearson/default.aspx. All estimates were standardized as length per degree latitude (Table 1). A linear regression was performed, available at https://www.socscistatistics.com/tests/regression/default.aspx.

3. Results
Across *Centrobolus* male lengths were positively correlated to latitude (r=0.643, r^2=0.4134, n=8, p=0.085467). The shortest species, *C. digrammus* occurred at the southern tip of South Africa found at Admirals Waterfall, Simon's Town (-34.19S; 18.433E). The longer species, *C. inscriptus* and *C. anulatus* were found at Twin Streams farm, Mtunzini (-28.98S; 31.716E). Between these two extremes all the medium-sized species ranged. The regression equation for length (*Y*) is: $\hat{y} = 2.55897X + 134.44599$.

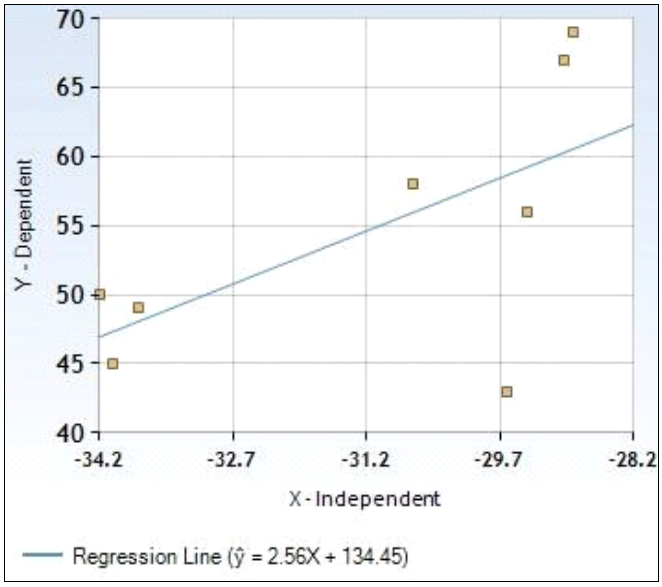

Fig 1: Linear regression of male length across latitude, $\hat{y} = 2.55897X + 134.44599$

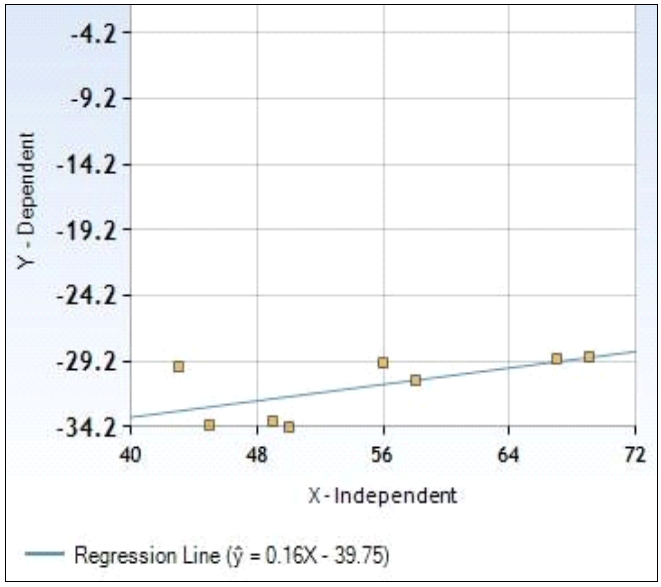

Fig 2: Linear regression of latitude across length, $\hat{y} = 0.15662X - 39.74793$

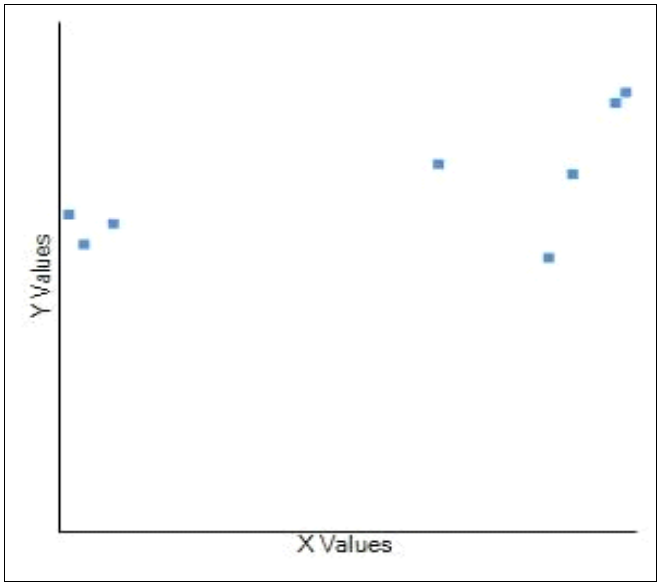

Fig 3: Moderate positive correlation between male length and latitude in *Centrobolus.*

4. Discussion

The data presented here for *Centrobolus* agree with Bergmann's rule as they demonstrate a moderate positive correlation between size and latitude (Figure 1-3). This result may not change the distribution of evidence from an even distribution in arthropods [5-8, 14, 17, 19, 20, 78, 82, 83, 90, 91, 94, 95, 98, 100-102, 110-112]. It may suggest "Direct evidence for the adaptive nature of Bergmann clines which requires that the fitness optimum lies at smaller body sizes at warm temperatures (or in warm habitats), typically involving demonstration of temperature dependent trade-offs. Such demonstrations are rare. The best, but by no means conclusive evidence to date in this regard has been presented in McCabe and Partridge (1997) [103] and Reeve *et al.* (2000)." The evidence in support for this was found in showing longer-lighter male millipedes occurred at higher temperatures and lower latitudes, providing support for directional selection on male size in 126 arthropod species from 16 taxonomic orders [75, 87].

The evidence for the rule is supported on a global scale and suggests directional selection on male length is somehow an effect of the correlation between male length and latitude [82]. Because males and females differ in volumes and it can be reduced to sexual selection for male length and fecundity selection for female width [75, 76]. Male length is correlated with the order of mating in the millipede *C. inscriptus* [37]. This finding differs from the geophilomorph chilopod where a clear'converse-Bergmann' pattern which was hypothesized to be a temperature dependence [84].

This study is in agreement with the prediction for northern hemisphere European millipedes and provides supporting evidence from the southern hemisphere. "[T]he general trend for terrestrial invertebrates to be larger in the tropics also holds for millipedes. Among Juliformia, the huge species of Spirostreptidae, Harpagophoridae, Rhinocricidae, and Pachybolidae, all occur at low latitudes. In Europe, the largest julids (Pachyiulus spp., up to 10 cm long) only occur in the south. Central and northern European species seldom exceed 3 cm. The northernmost European juliformian is the minute blaniulid *Protemiulus fuscus*" [81]. Size increases across latitude however SSD doesn't correlate with latitude; the trend is in agreement with the Moreau-Lack rule which hypothesized that fecundity increases with increasing latitude

[92, 97]. The latitudinal trend with size in *Centrobolus* suggests it is matched with increasing terrestrial temperature [86]. This is an aspect of Arthropods life history [18]. And for this reason the latitudinal trends may correlate with the abundance and length of the breeding season [109].

Table 1: Male (m) and female (f) length and width's means (μ), standard deviation (SD) and coefficients of variation (CV) in *Centrobolus* spp. Original data based on descriptions of Cooper [25], Lawrence [93] and Schubart [107].

Species	Male	Female	Male	Female	Lat., Lon.	N
	Length μ±SD CV	Length μ±SD CV	Width μ±SD CV	Width μ±SD CV	S,E	m,f
Anulatus	69±5.069517 7.34712609	63±7.761599 10.1724758	5.35333±0.46176 8.62565917	5.86167±0.68115 11.6204085	-28.88 30.81	5, 12
Digrammus	49.9±2.1, 4.20841683	54.5±5.4, 9.90825688	4.0±0.1, 2.5	4.8±0.3, 6.25	- 18.433	6, 6
Fulgidus	56.2±2.5 4.44839858	63.5±5.2 8.18897638	5.4±0.2 3.7037037	6.2±0.4 6.4516129	32.100	11, 1
Inscriptus	67.4±2.9, 4.30267062	63.0±3.6 5.71428571	5.9±0.2, 3.38983051	6.7±0.3, 4.47761194	-28.98 31.716	88, 88
Lawrence	43.125±2.64237 6.12723478	43±0 2.3255814	4.6875±0.2031 4.3328	5.9±0 16.9491525	-29.618	8, 1
Rubber	57.8±2.6, 4.4982699	62.3±6.3, 10.1123596	5.0±0.24	6.1±0.4, 6.55730 7705	30.513	18, 18
Sagatinus	48.5±1.73205 3.57123711	47±4.63681 9.86555319	6.225±0.17078 2.74345382	6.98±0.249 3.56733524	33.767 25.396	4, 5
Silvanus	45.2±2.04939 4.53404867	43.8±6.76018 15.4342009	4.42±0.13038 2.94977376	4.8±0.6442 13.4208333	-34.049 23.047	5, 5

5. Conclusion

The data presented here show *Centrobolus* agree with Bergmann's rule based on a significant correlation and regression of male length across latitude. SSD also increases with latitude in agreement with the Moreau-Lack Rule.

6. References

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