Longitudinal-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* female widths were positively related to longitude ($r=0.6474$, $r^2=0.4191$, $n=8$, $p=0.082656$). The squat species, *C. digrammus* occurred at the western tips of South Africa (18.433°E) while thinner species, *C. inscriptus* and *C. tanulatus* were found in east (31.716°E). In between these two longitudes all the medium sized species ranged. This agrees with Bergmann’s rule.

**Keywords:** Bergmann’s, Clade, Cline, Dimorphism, Ecology, Size

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**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 (Bergmann, 1847). Evidence for and against Bergmann’s rule follows an even distribution in arthropods (Blanckenhorn and Demont, 2004).

Diplopoda 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 (Maggenti *et al.*, 2008). Common sexual differences are known to occur in body mass, length, width and leg dimensions of over half the taxa studied (Hopkin and Read, 1992; Barnett...

The forest clade *Centrobolus* of pachybold millipedes belonging to the Order Spirobolida is distributed along the eastern coast of southern Africa (Cooper Mi., 1998; Pitz and Sierwald 2010). They consist of brightly coloured (aposematic) species with concentrations around coastal bush or forests (Cooper Mi., 1998). 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 were checked for a correlation with longitude.

**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 longitude (Table 1). A correlation was performed, available at https://www.socscistatistics.com/pvalues/pearsondistribution.aspx.

**Results**

Across *Centrobolus* male lengths not correlated to longitude but female widths (Fig. 1) were correlated ($r=0.6474$, $r^2=0.4191$, n=8, p=0.082656). The wider species, *C. digrammus* occurred at the western tip of South Africa found at Admirals Waterfall, Simon’s Town (-34.5; 18.433E). The thinner 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.

![Fig. 1: Correlation of female width across longitude](image)

**Discussion**

The data presented here for *Centrobolus* show a moderate positive correlation between female size and longitude. This result may not change the distribution of evidence from an even distribution in arthropods (Park, 1949; David and Bocquet, 1975; Londsday and Levinton, 1985; Cushman et al., 1993; Atkinson, 1994; Barlow, 1994; Van Voorhies, 1996; Mousseau, 1997; Partridge and Coyne, 1997; Karan et al., 1998; Arnett and Gotelli, 1999 a, b; van't Land et al., 1999; Loeschcke et al., 2000; Belk and Houston, 2002; Chown and
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 (2018), Lawrence (1967) and Schubart (1966).

<table>
<thead>
<tr>
<th>Species</th>
<th>Male</th>
<th>Female</th>
<th>Male</th>
<th>Female</th>
<th>Lat, Lon.</th>
<th>N</th>
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<tbody>
<tr>
<td></td>
<td>Length</td>
<td>Width</td>
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<td>Width</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>µ±SD</td>
<td>CV</td>
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<td>CV</td>
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<tr>
<td>asulatus</td>
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<td>5.35333±0.46176</td>
<td>5.86167±0.68115</td>
<td>-28.88</td>
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<td>11.6204085</td>
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<td>digrammus</td>
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<td>4.8±0.3</td>
<td>-34.19</td>
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<td></td>
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<td>6.25</td>
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<td>fulgicus</td>
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<td>inscriptus</td>
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<td>lawrencei</td>
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<td>sagatius</td>
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<td>3.56733524</td>
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<td>silvus</td>
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</table>

Klok, 2003; Johansson, 2003; Blanckenhorn and Demont, 2004; Nesrine and Enghoff, 2011; Hassall et al., 2013; Vinarski, 2013; Pallarés et al., 2018; Gérard et al., 2018). 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 by McCabe and Partridge (1997) 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 (Cooper M., 2019 a; Horne et al., 2019). The evidence for the rule is supported on a global scale and suggests fecundity selection on female width (Cooper M., 2016). Because males and females differ in volumes and it can be reduced to sexual selection for male length and fecundity selection for female width (Darwin, 1874; Cooper M., 2019 a).

The present study is in agreement with the prediction for northern hemisphere European millipedes and provides supporting evidence from the southern hemisphere.
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” (Enghoff, 1992). The trend is in agreement with the Moreau-Lack rule which hypothesized that fecundity increases with increasing latitude/longitude (Moreau, 1944; Lack, 1954). The longitudinal trend with size in Centrobolus suggests it is matched with increasing terrestrial temperature (Horne et al., 2015). This is an aspect of Arthropods life history (Chapin, 2017). And for this reason the longitudinal trends may correlate with the abundance and length of the breeding season (Supriya et al., 2019).

Conclusion

The data presented here show a significant correlation and regression of Centrobolus female width across longitude. This agrees with Bergmann’s rule.

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