Article

Size dimorphism and directional selection in forest millipedes

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Abstract
Sexual Size Dimorphism (SSD) in the diplopod genus *Centrobolus* has a positive correlation with body size. Length, width and rings are the main components of interspecific variation in diplopod species. Interspecific variation in size was calculated in 6 species and data sets tested for normality. All data observed and tested were normal. Intersexual variation (coefficients of variation) in length and width was compared in 9 species using MEDCALC®. In *C. digrammus, C. inscriptus,* and *C. silvanus* there was significant directional selection for slender males.

Keywords diplopoda; horizontal; length; normal; tergite; width.

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1 Introduction

Diplopoda are important environmental indicators and under-represented in analyses of invertebrate Sexual Size Dimorphism (SSD) which is the condition where the two sexes of the same species exhibit different characteristics beyond the differences in their sexual organs, although common sexual differences are thought to occur in body mass, length, width and leg dimensions of over half the taxa studied (Aarde et al., 1996; Barnett and Telford, 1993, 1994, 1996; Barnett et al., 1995; Barnett et al., 1993; Cooper, 2014, 2015, 2016, 2017, 2018; Hopkin and Read, 1992; Telford and Dangerfield, 1990, 1993, 1994, 1996; Telford and Webb, 1998; Webb and Telford, 1995). Diplopods resemble the majority of invertebrates in SSD is reversed (Cooper, 2018).

The forest genus *Centrobolus* of millipedes belonging to the Order Spirobolida is distributed along the eastern coast of southern Africa (Cooper, 1998). They consist of brightly coloured (aposematic) species with concentrations around coastal bush or forests. Their terrestrial habits make them ideal organisms for laboratory studies because they are relatively easy to collect. In the present study, SSD in the forest genus *Centrobolus* was investigated in 9 species and 2 factors determining a response in SSD (length and width) recorded, data tested for normality and coefficients of variation (CV) calculated and compared to test for directional sexual selection (Burley, 1981; Ridley, 1993).

2 Materials and Methods

Two factors were obtained from 9 *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. These basic descriptive figures were statistically tested for normality using a Kolmogorov-Smirnov Test Calculator. The D values of length and width was shown (Table 1) from extracted and published data for 6 species (Schubart, 1966; Cooper, 2018). The basic descriptive statistics; mean, standard deviation (SD) and CV of length and width was shown from extracted and published data for the 9 species (Cooper, 2018; Schubart, 1966). CV's were statistically compared using MEDCALC ® (https://www.medcalc.org/ calc/comparison_of_coefficientsofvariation.php). F and P values were obtained from each positive test (Table 2).

3 Results

In 6 species tests (Table 1) of male and female widths and lengths all were normal. In 9 species male and female widths and lengths showed in 5 species (*C. digrammus*, *C. inscriptus*, *C. ruber*, *C. sagatinus*, C. *silvanus*) male's had lower CV's in length, 2 were untested due to low sample sizes (*C. fulgidus*, *C. lawrencei*) and 2 showed no difference (*C. anulatus*, *C. titanophilus*) (Table 1). In 4 species (*C. digrammus, C. inscriptus, C. silvanus*, *C. titanophilus*) male widths had lower CV's, 2 were untested (*C. fulgidus*, *C. lawrencei*) and 3 were no different (*C. anulatus, C. ruber, C. sagatinus*).

Table 1 Male and female length and widths tested for normality in *Centrobolus spp*. Values given are D and p-values. Original data based on descriptions of Schubart (1966) and Cooper (2018).

Species	Male		N	Female		N
	Length	**Width**		**Length**	**Width**	
anulatus	0.40436	0.20338	5	0.20657	0.26452	12
	0.29748	0.73122		0.61408	0.05689	
digrammus	0.26813	0.27101	5	0.24906	0.1802	7
	0.39745	0.38459		0.69292	0.76853	
lawrencei	0.14694	0.26806	8	-	-	1
	0.98441	0.16644				
sagatinus	-	-	4	0.25915	0.27978;	5
				0.81518	0.34712	
silvanus	0.30382	0.38122	5	0.17866	0.33136	5
	0.37493	0.14881		0.98844	0.17658	
titanophilus	0.22993	0.19725	7	0.15068	0.32022	5
	0.77967	0.58031		0.99872	0.20664	

Table 2 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) and Schubart (1966).

Species	Male Length µ±SD CV	Female Length µ±SD CV	Test F, P	Male Width µ±SD CV	Female Width µ±SD CV	Test F, P	N m, f
anulatus	69±5.069517 7.34712609	6.3±7.761599 10.1724758	1.90717 0.55951	5.35333±0.46176 8.62565917	5.86167±0.68115 11.6204085	1.80340 0.59966	5, 12
digrammus	49.9±2.1 4.20841683	54.5±5.4 9.90825688	5.50629 0.08456	4.0±0.1 2.5	4.8±0.3 6.25	6.23297 0.06610	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	-	11, 1
inscriptus	67.4±2.9 4.30267062	63.0±3.6 5.71428571	1.76134 0.00892	5.9±0.2 3.38983051	6.7±0.3 4.47761194	1.74329 0.01022	88, 88
lawrencei	43.125±2.64237 6.12723478	43±0 2.3255814	-	4.6875±0.2031 4.3328	5.9±0 16.9491525	-	8, 1
ruber	57.8±2.6 4.4982699	62.3±6.3 10.1123596	5.01498 0.00179	5.0±0.2 4	6.1±0.4 6.55737705	0.37305 1.00000	18, 18
sagatinus	48.5±1.73205 3.57123711	47±4.63681 9.86555319	7.57970 0.12779	6.225±0.17078 2.74345382	6.98±0.249 3.56733524	1.69004 0.69492	4, 5
silvanus	45.2±2.04939 4.53404867	43.8±6.76018 15.4342009	11.38967 0.03698	4.42±0.13038 2.94977376	4.8±0.6442 13.4208333	20.42069 0.01267	5, 5
titanophilus	28±4.71405 16.8358929	29±2.607681 8.99200345	0.28870 1.00000	4.1±0.57735 14.0817073	4.3±1.831955 42.6036047	8.05590 0.22820	3, 6

4 Discussion

The normality of length and width of the two sexes in the six species is a finding which successfully confirms the analysis of previous data sets and allows predictive power for small morphological data sets in the genus *Centrobolus*. The finding supports studies which shows the size of Juliformia "has two main components: body diameter and number of" rings (Enghoff, 1992). Other correlates of Spirobolida size include copulation duration, energetic expenditure of copulation, oxygen consumption, precipitation and temperature (Dwarakanath, 1971; Penteado et al., 1991; Telford and Webb, 1998; Echeverría et al., 2014; Cooper, 2017). Size criteria are useful for determining species of Spirobolida diplopods (Cooper, 2014, 2015, 2016, 2017, 2018).

The distribution of differences between CV's in length and width of the 2 sexes in the 9 species is a finding which successfully confirms the idea of directional selection for long slender males in 3 species of the genus *Centrobolus*. Width and length are size criteria which are correlates of sex in Spirobolida diplopods (Cooper, 2016, 2017, 2018). Length and width are interesting since their lower variance in males relative to females may indicate directional sexual selection (Burley, 1981; Ridley, 1993). The lower CV's of males with higher CV's of females indicates millipede size was maximised through an increase in the body length of the cylinder rather as well as decrease in width in males of the species where differences occur. In situations of size-assortative mating in millipedes there was preference for larger size (Telford and Dangerfield, 1993). This was supported by the finding in *C. inscriptus* where males have a greater body length and are slender and lighter than females and body mass is positively related to copulation duration (Cooper 2016). Male length was positively related to the duration of the first mating but negatively related to the duration of the second mating indicating size-assortative mating and directional sexual selection (Cooper, 1998). The absence of relationships between length and width supports this statement (Cooper, 1998).

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