DOES SEXUAL SIZE DIMORPHISM VARY WITH SPECIES RICHNESS IN FOREST MILLIPEDES *CENTROBOLUS* COOK, 1897?

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Abstract

The objectives of this study were to determine Sexual Size Dimorphism (SSD) variation with species richness in the forest millipede genus Centrobolus*. Species richness and SSD correlations across -17°S to -15°S latitudes were compared. There was a significant difference between the correlation coefficients of SSD and species richness when latitude was controlled (z=-3.68, n=35, 22, p<0.01). Species richness was negatively related to SSD (r=-0.45, Z score=-2.13, n=22, p=0.02). There was no difference between the correlation coefficients of species richness with SSD and species richness with latitude (z=-0.0582, p=0.9536). There was a difference between the correlation coefficients of species richness with SSD and SSD with latitude (z=3.6150, p=0.0003). SSD (1.368421) with high species richness (12-17) was different from SSD (2.29) with low species (1-3) both absolutely (Z score=1.81, n_1=19, n_2=3, P-value (one-tailed)=0.04) and relatively (Z score=1.66, n_1=19, n_2=3, P-value (one-tailed)<0.05) implying a causal link between SSD and species richness..*

Keywords*: dimorphic; latitude; species.*

INTRODUCTION

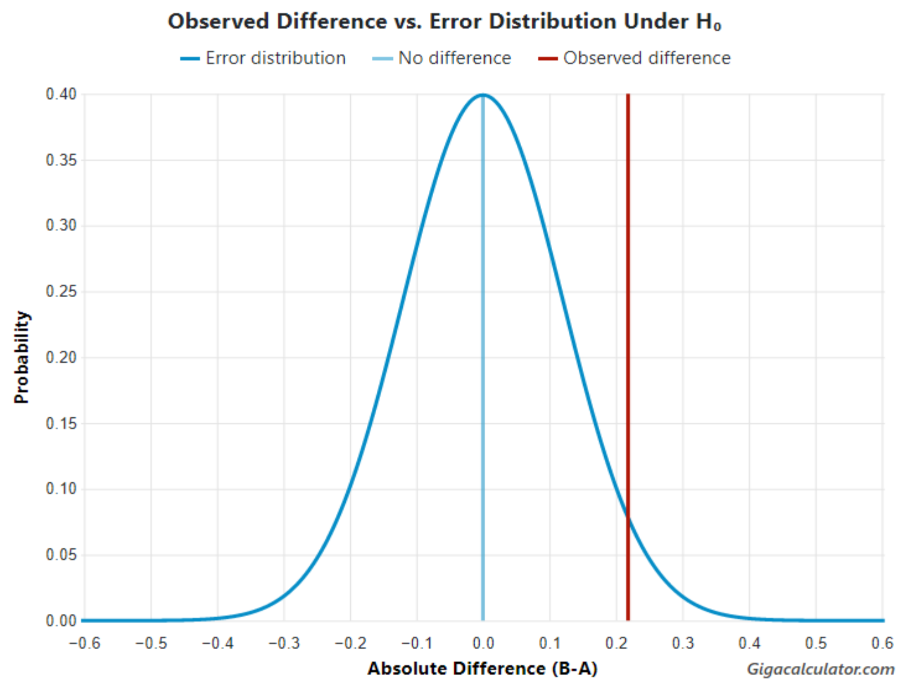
A forest genus of diplopods belonging to the Order Spirobolida found along the eastern coast of southern Africa was the subject of this study. The millipede genus *Centrobolus* has its northern limits on the east coast at about -17° South (S) and southern limits at about -35° S [5]. It occurs in all the forests of the coastal belt from the Cape Peninsula to Beira in Mocambique [14]. As essentially shade-loving Diplopoda, the members of the genus are especially well represented in these forests of the eastern half of the subcontinent with 39 species [14]. *Centrobolus* illustrates female-biased sexual size dimorphism (SSD) which is compared with species richness across latitude in this pachybolid millipede genus [3, 10, 15]. Few studies have shown a causal link between SSD and species richness [2, 14]. The null hypothesis here is that there is no difference and relationship between SSD and species richness. Alternatively, SSD with high species richness differs from SSD with low species richness.

MATERIALS AND METHODS

Thirty-nine valid species were identified as belonging to the genus *Centrobolus* Cook, 1897 (Table 1). Millipede localities were obtained from a checklist of southern African millipedes [10]. Correlation Coefficients between SSD and latitude and species richness and latitude were obtained from the literature [5, 6]. The correlation coefficients were compared at https://www.medcalc.org/calc/comparison_of_correlations.php. To test for a linear relationship between SSD and species richness a correlation was performed. SSD values were correlated against species richness within 3.6-degree classes from -17° S to -35° S. To model, this variation SSD with high species richness was compared to SSD with low species richness comparing SSD for species between -17° S to -27.8° S with SSD for species between -27.8° S to -35° S using a P-value calculator determining whether the difference between two proportions or means (independent groups) is statistically significant (http://www.gigacalculator.com/calculators/p-value-significance-calculator.php). To meet the assumptions for a t-test on 2 independent means the log SSD data were inputted at http://www.socscistatistics.com/tests/studentttest/default2.aspx. A Z-test on absolute and relative differences between logged data was also performed available at http://www.gigacalculator.com/calculators/p-value-significance-calculator.php. To test between divergent and convergent series a series integral test calculator was used (http://www.symbolab.com/solver/series-integral-test-calculator).

RESULTS

The was a significant difference between the (negative) correlation coefficients of SSD with latitude and species richness with latitude (z=-3.6802, n=35, 22, p=0.0002). Species richness was negatively related to SSD (r=-0.45321706, Z score=-2.13037512, n= 22, p=0.01657027). There was no difference between the correlation coefficients of species richness with SSD and species richness with latitude (z=-0.0582, p=0.9536). There was a difference between the correlation coefficients of species richness with SSD and SSD with latitude (z=3.6150, p=0.0003). SSD was normally distributed (D=0.15168, n=22, p=0.63788). Species richness was normally distributed (D=0.33543, n=5, p=0.52476). SSD (1.368421) with high species richness (12-17) was different to SSD (2.29) with low species (1-3) (T-score=-2.101932, degrees of freedom=20, p=0.024215). Log SSD with high species richness was different to log SSD with low species richness (t=-2.2821, n_1=19, n_2=3, p=0.016784).



This was confirmed with a Z-test on absolute differences (Figure 1: Z score=1.806332, n_1=19, n_2=3, P-value (X; H0: B ≤ A) = 0.035433, P-value (X; B ≤ A ∪ B ≥ A) = 0.070866) and relative differences (Figure 2: Z score=1.664796, n_1=19, n_2=3, P-value (X; H0: B ≤ A) =0.047977, P-value (X; H0: B ≤ A ∪ B ≥ A) = 0.095954). Both series diverged based on the integral ratio test. All SSD pairs, and triplets with low species and high species diverged. All SSD quartets, quintets, and sextets within high species diverged (Table1).

Figure 1. Absolute differences (0.218377) between log SSD with low species richness and log SSD with high species richness in *Centrobolus.* SEM =0.120896.

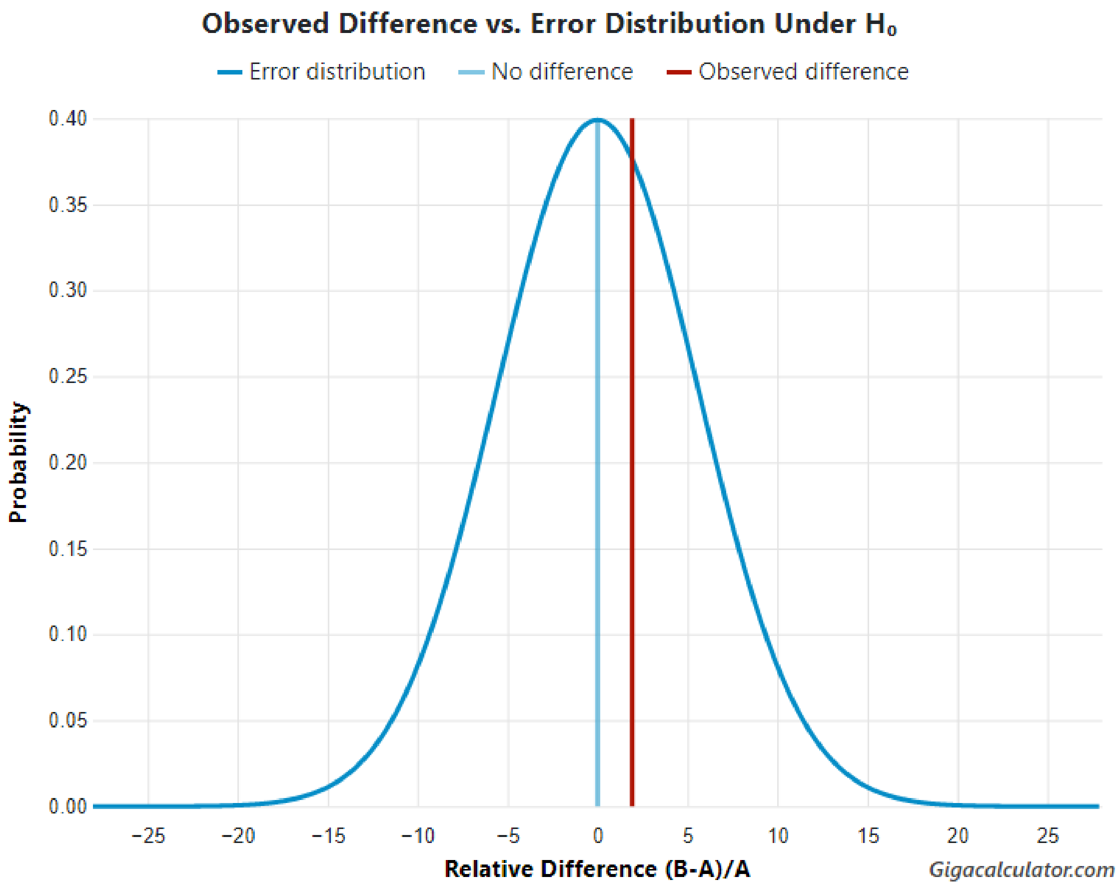


Figure 2. Relative differences (1.922871) between log SSD with low species richness and log SSD with high species richness in *Centrobolus.* Pooled SEM = 5.609857.

Table 1. Raw log SSD data was used to compare species richness.

Log SSD with high species richness (-27.8° S to -35° S)	Log SSD with low species richness (-17° S to -27.8°)
0.0755469614	0.460897843
-0.200659451	0.434568904
0.00432137378	0.100370545
0.130333768	
0.217483944	
0.0827853703	
0.158362492	
0.195899652	
0.338456494	
-0.161150909	

0.318063335	
-0.0222763947	
0.209515015	
0.294466226	
0.103803721	
0.0530784435	
0.0606978404	
0.0413926852	
0.257678575	
Sum=2.157799	Sum=0.995837292

Global extreme point = 3.15363.

DISCUSSION

The results of the comparison of correlations show a decrease in sexual size dimorphism with latitude which is less than the decrease in species richness with latitude. I found an inverse relationship between SSD and species richness. A linear relationship in the correlation between species richness and SSD validates this. SSD (1.368421) with high species richness (12-17) were relatively different to SSD (2.29) with low species (1-3) in *Centrobolus* implying a causal link between SSD and species richness. Female-biased SSD is evident among members of the genus and is suggested to be a cause of lower species richness. This satisfies the assumption "if sexual dimorphism and interspecific divergence are alternative means of ecological diversification, then the degree of sexual dimorphism may be negatively related to the extent of adaptive radiation."[2] This study supports sexual dimorphism predicting species richness and adaptive radiation across *Centrobolus* [14]. To satisfy causality between SSD and species richness – SSD with lower species richness arises before SSD with higher species richness, the observed relationship between SSD and species richness didn't happen by chance alone, and there is nothing else that accounts for the SSD and species richness relationship. We know SSD with lower species richness and SSD with higher species richness are divergent series (Table 1).

Sexual dimorphism and speciation are two axes of ecological variation which readily cooccur [4]. "On the other hand, Fujimoto et al. (2015) [9] proposed that latitudinal clines in reproductive seasonality will lead to latitudinal clines in the operational sex ratio (OSR), which is an important determinant of the strength of sexual selection pressures; biased OSRs cause strong sexual selection, because the more abundant sex, usually males, will compete for available partners (Emlen & Oring, 1977 [8]; Ims, 1988 [11]; Janicke & Morrow, 2018 [13]). In high-latitude temperate environments, where reproduction is restricted to a favorable season (e.g. Awaji & Hanyu, 1987 [1]; Egami et al., 1988 [7]; Isaac, 2005 [12]), many mature males and females are expected to appear in synchrony during a short period. Such temporal overlaps in the appearance of mature females will cause OSRs that are more equal, leading to weaker sexual selection pressures. In the tropics, in contrast, a lack of seasonality prolongs reproductive seasons, which will stochastically reduce temporal overlap in the appearance of mature females, while males will tend to mature throughout the year, leading to male-biased OSRs." [16] This study supports the view that sexual selection pressure is stronger in the tropics than in temperate regions, which explains why tropical animals are characterized by showy ornaments and conspicuous body colour [16].

CONCLUSION

SSD varied inversely with species richness in *Centrobolus* which is validated with a correlation. SSD (1.368421) with high species richness (12-17) was different from SSD (2.29) with low species (1-3) implying a causal link between SSD and adaptive radiation as species richness.

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