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Is mass correlated with width among red millipedes *Centrobolus* Cook, 1897?

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Abstract
Body mass variation was correlated with male and female width in the red millipede genus *Centrobolus*. Mass and width (r=0.91, Z score=3.46, n=8, *p*<0.01) in males (r=0.91, Z score=2.13, n=5, p=0.02) and females (r=0.995, Z score=4.27, n=5, *p*<0.01) were correlated. *C. inscriptus* females have the largest width (7.02 mm) and the highest mass (2.61 g) while *C. digrammus* has the lowest width (4.00 mm) and the lightest mass (0.68 g).

Keywords: Dimorphic, female, mass, morphology, ratio, width

1. Introduction
Red millipedes are found in the southern African subregion with northern limits on the east coast being about -17° latitude S and southern limits being -35° latitude S. They are well represented in the littoral forests of the eastern half of the subcontinent [28]. It consists of taxonomically important species with 12 species considered threatened and includes nine vulnerable and three endangered species [30]. It occurs in all the forests of the coastal belt from the Cape Peninsula to Beira in Mocambique [29]. In an analysis of four morphometric factors (male and female length and width), four positive correlations were found in the 22 species of *Centrobolus* [25]. These worm-like millipedes have female-biased sexual size dimorphism [7-25]. Here, body mass is correlated with body width in *Centrobolus* Cook, 1897 [6, 29, 30]. One hypothesis is body width correlates with body mass. The aim of the study is to determine the exact relationship between mass and width through correlation analysis with different species.

2. Materials and Methods
C. digrammus, *C. fulgidus*, *C. inscriptus*, *C. ruber* were identified as belonging to the genus *Centrobolus* Cook, 1897 from field collections at Admirals Waterfall, Richard's Bay, Mtunzini, and Anerley; all in South Africa (Table 1). Millipede collection localities were made in the rainy season [7]. Weight in millipedes was calculated with a (Mettler AC 100) Autobalance. Body width was calculated as the horizontal body width using a pair of vernier calipers calibrated in millimeters accurate to three significant figures. Horizontal tergite width and mean body mass were correlated with a Pearson Correlation Coefficient calculator available at https://www.gigacalculator.com/calculators/correlation-coefficient-calculator.php.

3. Results
Mass and width (Fig. 1: r=0.93468004, Z score=4.48243126, n=10, p=0.00000369) in males (Fig. 2: r=0.90615676, Z score=2.12925309, n=5, p=0.01661660) and females (Fig. 3: r=0.99521810, Z score=4.26644915, n=5, p=0.00000994) were related. Body width was normally distributed (D=0.18655, n=10, p=0.81643). Body mass was normally distributed (D=0.23289, n=10, p=0.57311). Female width was normally distributed (D=26643, n=5, p=0.79033). Female mass was normally distributed (D=0.29699, n=5, p=0.67584). Male width was normally distributed (D=21396, n=5, p=0.93695).

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Table 1: Species in the millipede genus *Centrobolus* Cook, 1897, with body width and body mass. Male followed by female body masses are given with sample sizes in parentheses. Two sets of measurements are included for *C. inscriptus*

Species	width	Location	Body mass (g)
C. fulgidus	5.4 (11), 6.2 (11)	Richards Bay	1.29 (11), 1.97 (11)
C. inscriptus	5.9 (88), 5.98 (56), 6.7 (88), 7.02 (41)	Mtunzini	2.48 (88), 2.00 (56); 2.27 (88), 2.61 (41)
C. ruber	5.0 (18), 6.1 (18)	Port Shepstone	1.28 (18), 2.00 (18)
C. digrammus	4.0 (6), 4.8 (6)	Admirals Waterfall	0.68 (6), 1.02 (6)

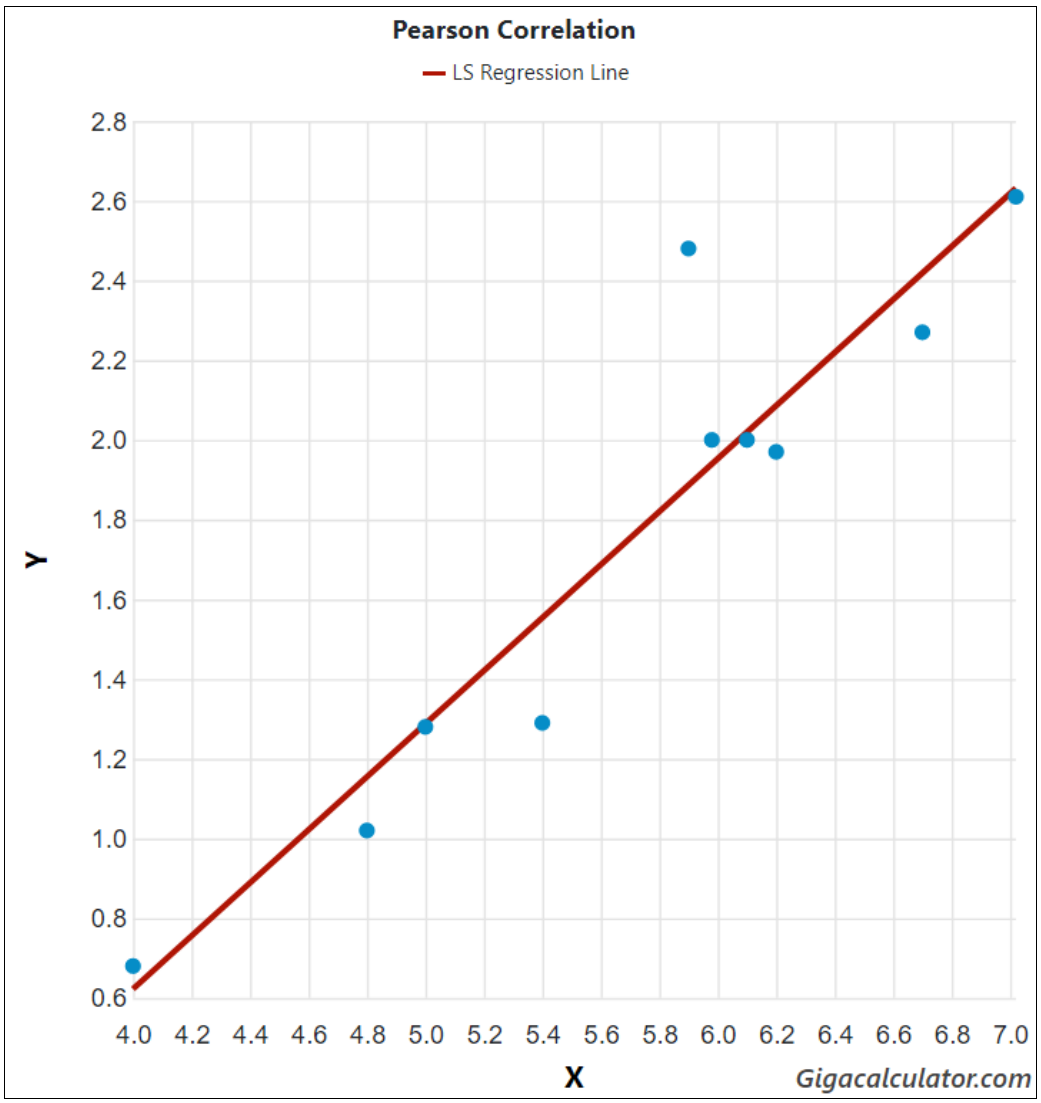

Fig 1: Relationship between body width (x-axis) and body mass (y-axis) in *Centrobolus* Cook, 1897

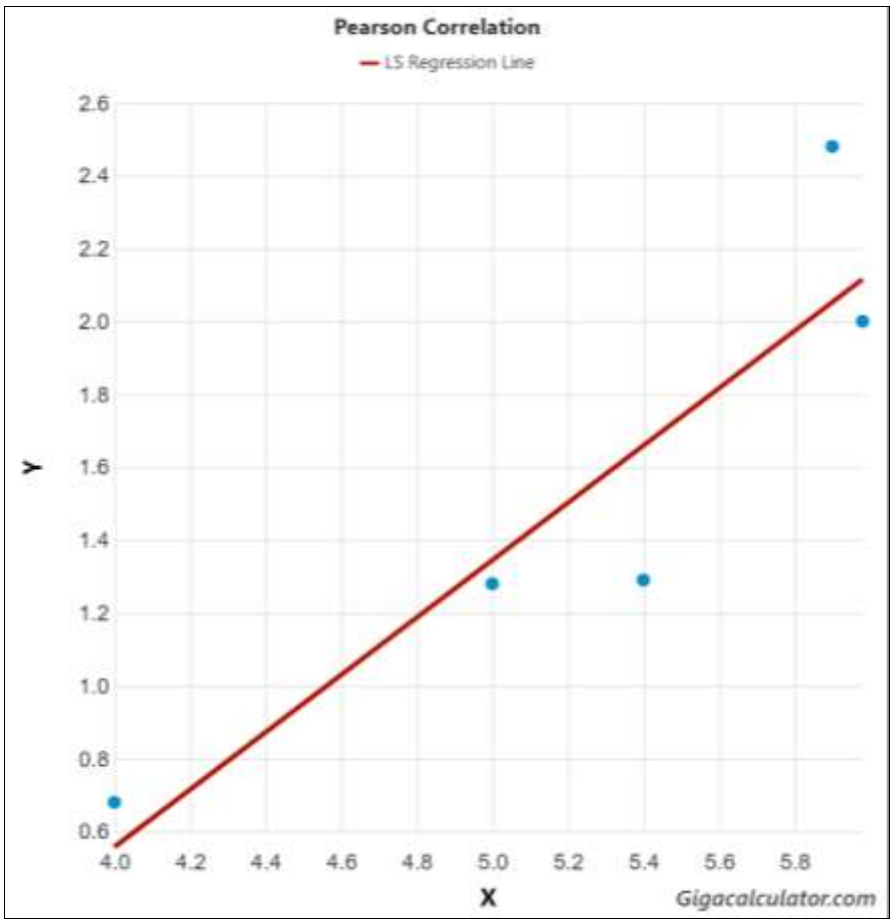

Fig 2: Relationship between male body width (x-axis) and male body mass (y-axis) in *Centrobolus* Cook, 1897

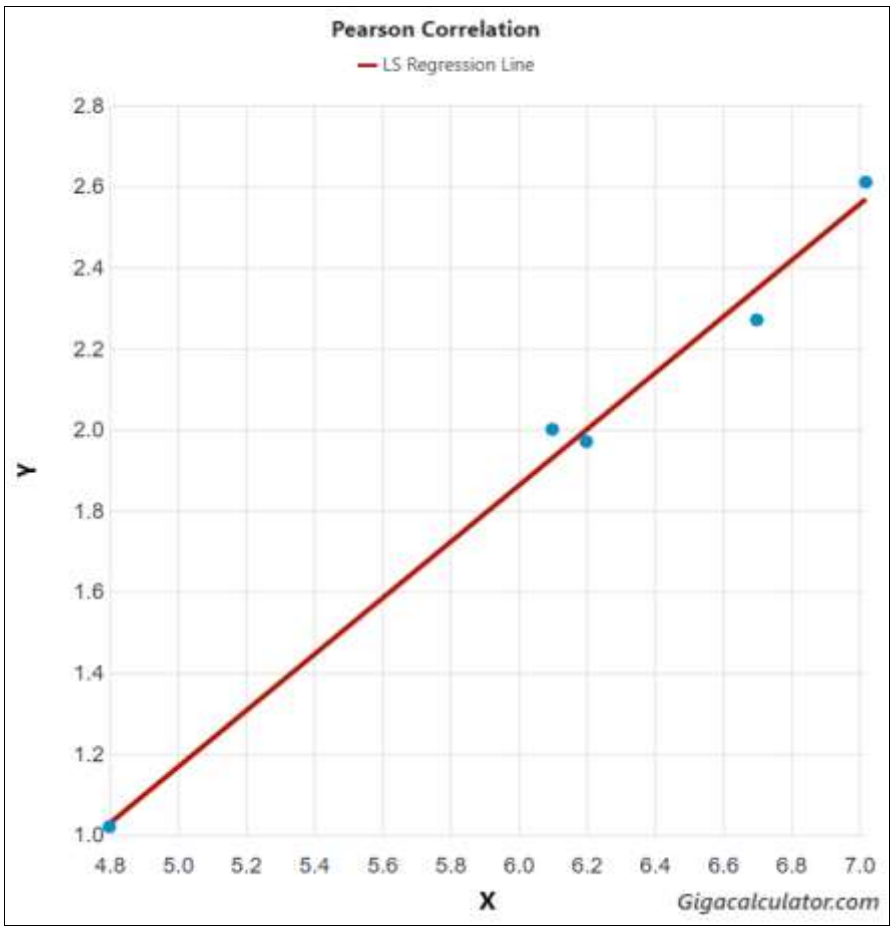

Fig 3: Relationship between female body width (x-axis) and female body mass (y-axis) in *Centrobolus* Cook, 1897

4. Discussion

Significant positive relationships between mass and length and width are given. *C. inscriptus* females have the largest width (7.02 mm) and the highest mass (2.61 g) while *C. digrammus* has the lowest width (4.00 mm) and the lightest mass (0.68 g). This study supports body mass and body width as predictable in *Centrobolus*.

Size-assortative mating based on body mass and body width determined through the variance in millipede polygynandrous mating systems across a size gradient with lower body width occurring in lighter individuals is shown. Body width increases with heavier body mass which is explained by a combination of copulatory guarding and fecundity selection.

In Danish red foxes *Vulpes vulpes* SSD varies with body mass at different population densities [31]. In the wandering albatross *Diomedea exulans* SSD varies with body mass with different adult survival, breeding probability, breeding success, chick mass, and juvenile survival [26]. In microtines mass rather than length is used to measure SSD [5]. In five species of *Drosphila*, the degree of dimorphism in development time was significantly correlated with dry weight and fecundity, with lighter species tending to be more dimorphic for development time as well as more fecund, both in absolute terms and terms of fecundity per unit weight [2]. In Red-Eared Sliders *Trachemys scripta elegans* sexual dimorphism of size in favor of females is maintained for variables related to mass and size [27]. Millipedes resemble the patterns of mass and sexual dimorphism in adult dragonflies [1]. Sexual dimorphism in mass and protein content of the forelimb muscles is known in the northern leopard frog *Rana pipiens* [3]. The influence of mass and mating systems has been documented in the most dimorphic mammals [32]. Morphological variance in the polygynandrous reproductive system of male and female millipedes means lighter individuals have lower body width or heavier individuals have greater body width pointing toward the evolution of condition-dependent SSD [4].

5. Conclusion

The width varied systematically with mass in *Centrobolus*. Morphological variance in the polygynandrous reproductive systems of *Centrobolus* has lighter individuals with a narrower width, or conversely heavier individuals have greater body width. Mass and width impact the moments of inertia.

6. Competing interests

The author has declared that no competing interests exist.

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