International Journal of Recent Research in Thesis and Dissertation (IJRRTD)
Vol. 3, Issue 1, pp: (91-112), Month: January - June 2022, Available at: www.paperpublications.org

The inverse latitudinal gradients in species richness of Southern African millipedes

Mark I. Cooper

[1]University of Johannesburg, Auckland Park 2006, Gauteng, South Africa.

DOI: https://doi.org/10.5281/zenodo.6613064

Published Date: 04-June-2022

Abstract: **The Tropical Conservativism Hypothesis and Biogeographical Conservativism Hypothesis were tested in Southern African millipedes. Latitudinal diversity gradient (LDG) was measured in the Centrobolinae Hoffman, 1980, Chilognatha Latreille, 1802, Colobognatha Brandt, 1834, Dalodesmidea Hoffman, 1980, Diplopoda Gervais, 1844, Eugnatha Attems, 1898, Harpagophoridae Attems, 1909, Harpagophoridae *nomum nudem*, Helminthomorpha Pocock, 1887, Juliformia Attems, 1926, Julomorphidae Verhoeff, 1924, Merocheta Cook, 1895, Oniscomorpha Pocock, 1887, Polydesmida Leach, 1815, Polyzoniida Gervais, 1844, Sphaerotheriida Brandt, 1833, Sphaerotheriinae Brandt, 1833, *Spinitarsus* Attems, 1909*a*, Spirobolida Bollman, Spiroboloidea Sylvestri, 1896, Spirostreptida Brandt, 1833 and Trigoniulidea Brölemann, 1913 to distinguish between the two hypotheses. There was a significant correlation between the number of species and latitudinal degrees away from the equator in Centrobolinae (r=-0.91, r^2=0.83, n=35, p<0.01), Chilognatha (r=-0.87, Z score=-3.25, n=9, p<0.01), Colobognatha (r=-0.86, Z score=-2.92, n=8, p<0.01), Dalodesmidae (r=-0.78, Z score=-2.11, n=121, p=0.02), Diplopoda (r=-0.87, Z score=-3.24, n=9, p<0.01), Eugnatha (r=-0.85, Z score=-3.10, n=9, p<0.01), Harpagophoridae (r=-0.86, Z score=-2.90, n=8, p<0.01) (r=-0.68, Z score=-1.85, n=8, p=0.03), Helminthomorpha (r=-0.85, Z score=-3.09, n=9, p<0.01), Juliformia (r=-0.94, Z score=-3.99, n=8, p<0.01), Julomorphidae (r=-0.89, Z score=-2.02, n=8, p=0.02), Merocheta (r=-0.83, Z score=-2.68, n=8, p<0.01), Oniscomorpha (r=-0.86, r^2=0.75, n=47, p<0.01), Polydesmida (r=-0.83, Z score=-2.68, n=8, p<0.01), Polyzoniida (r=-0.87, Z score=-2.97, n=8, p<0.01), Sphaerothriida (r=-0.86, r^2=0.75, n=47, p<0.01), Sphaerotheriinae (r=-0.87, r^2=0.76, n=46, p<0.01), Sphaerotheriini (r=-0.87, r^2=0.76, n=46, p<0.01), *Spinotarsus* (r=-0.61, Z score=-1.41, n=8, p=0.08), Spirobolida (r=-0.82, r^2=0.68, n=38, p<0.01), Spiroboloidea (r=-0.82, r^2=0.68, n=38, p<0.01), and Spirostrepstida (r=-0.93, Z score=-3.78, n=8, p<0.01). An evolutionary preference for temperate environments appearing to have led to climatic constraints on dispersal based on precipitation seasonality gradients and predation was questioned.**

Keywords: **diversity, gradient, latitude, richness, species.**

1. INTRODUCTION

Species richness is the number of different species represented in an ecological community, landscape, or region [2-5]. Species richness and biodiversity increase from the poles to the tropics for a wide variety of terrestrial and marine organisms and is referred to as a latitudinal diversity gradient (LDG) [11, 21]. Inverse LDG in invertebrates is hypothesized and explained as the result of predation which plays an important "keystone" role in structuring the community [22]. Theory predicts as the abundance of the top predator, decreases, a greater number of taxa in lower trophic levels can persist.

The diplopods belonging to 22 taxonomic groups, Centrobolinae Hoffman, 1980, Chilognatha Latreille, 1802, Colobognatha Brandt, 1834, Dalodesmidea Hoffman, 1980, Diplopoda Gervais, 1844, Eugnatha Attems, 1898, Harpagophoridae Attems, 1909, Harpagophoridae *nomum nudem*, Helminthomorpha Pocock, 1887, Juliformia Attems, 1926, Julomorphidae Verhoeff, 1924, Merocheta Cook, 1895, Oniscomorpha Pocock, 1887, Polydesmida Leach, 1815, Polyzoniida Gervais, 1844, Sphaerotheriida Brandt, 1833, Sphaerotheriinae Brandt, 1833, Sphaerotheriini Brandt, 1833, *Spinitarsus* Attems, 1909*a*, Spirobolida Bollman, 1893, Spiroboloidea Sylvestri, 1896, Spirostreptida Brandt, 1833, and Trigoniulidea Brölemann, 1913 found in southern Africa was the subject of this study [10].

The LDG is measured and tested in all 22 groups. The null hypothesis is the Tropical Conservativism Hypothesis which suggests processes of speciation, extinction, and dispersal result in higher species richness in the tropics and decline away from the equator [19]. The alternative is the Biogeographical Conservativism Hypothesis which suggests the processes invoked are not intrinsic to the tropics but are dependent on historical biogeography to determine the distribution of species richness [23]. I tested for interactions with latitude in the detritivores by measuring and comparing their LDG's. The biotic hypothesis claims ecological species interactions, here avian competition on millipede prey, is stronger in the tropics and these interactions promote species coexistence and specialization of species.

2. MATERIALS AND METHODS

Thirty-nine valid species were identified as belonging to the subfamily Centrobolinae Hoffman, 1980 [1, 10]. Sixteen valid species were identified as belonging to the subfamily Centrobolinae Hoffman, 1980 [1, 10]. This was based on the list given in https://fr.wikipedia.org/wiki/Centrobolus and https://www.biolib.cz/en/taxon/id692900/. 12 millipede type localities were obtained from Hamer [10]. 455 valid species were identified as belonging to the Subclass Chilgnatha in southern Africa [10]. 213 valid species were identified as belonging to the Subterclass Colobognatha in southern Africa [10]. 121 valid species were identified as belonging to the families Dalodesmidae and Vaalogonopodidae [10]. 461 valid species were identified as belonging to the Class Diplopoda in southern Africa [10]. 408 valid species were identified as belonging to the Subterclass Eugnatha [10]. 179 valid species were identified as belonging to the Family Harpagophoridae in southern Africa [10]. 129 valid species were identified as belonging to the Family Harpagophoridae *nomen nudem* in southern Africa [10]. 416 valid species were identified as belonging to the Infraclass Helminthomorpha in southern Africa [10]. 243 valid species were identified as belonging to the superorder Juliformia [10]. 28 valid localities were obtained for the Family Julomorphidae in southern Africa [10]. 165 valid species were identified as belonging to the Superorder Merocheta in southern Africa [10]. 165 valid species were identified as belonging to the Order Polydesmida in southern Africa [10]. 211 valid species were identified as belonging to the Order Polyzoniida in southern Africa [10]. 49 valid species were identified as belonging to the genus *Sphaeotherium* [3] and one to the monospecific genus *Kylindotherium* [2, 12]. The locality for *Kylindotherium leve* [2] was Wellington (Latitude: -33.643055 degrees South). Localities were given in a checklist of Southern African millipedes [12]. 91 valid species were identified as belonging to the Genus *Spinotarsus* in southern Africa [10]. 42 valid species were identified as belonging to the order Spirobolida [10]. 205 valid species were identified as belonging to the Order Spirostreptida in southern Africa [10]. 41 valid species were identified as belonging to the suborder Trigoniulidea Brölemann, 1913 [1, 2, 11]. Type localities were obtained from a checklist of Southern African millipedes [10]. These were tabulated and known type localities also listed in Microsoft Word online (https://office.live.com/start/Word.aspx). GPS coordinates were obtained from internet sources for known type localities using google (https://www.google.co.za/maps/place). The Easy Histogram Maker (https://www.socscistatistics.com/descriptive/histograms/default.aspx) was used to plot latitudinal localities across the genus. The number of species and latitude were checked for a correlation using the Pearson Correlation Coefficient Calculator (https://www.socscistatistics.com/tests/pearson/default.aspx). This was plotted using https://www.gigacalculator.com/calculators/correlation-coefficient-calculator.php.

3. RESULTS

Centrobolinae

17 species of *Centrobolus* were found between -31.4 and -35, 12 species between -27.8 and -31.4 degrees latitude south, three species were found between -24.2 and -27.8, and one species between -20.6 and -24.2 degrees S, and two species between -17.0 and -20.6. There was a marginally significant correlation between the number of millipede species and latitudinal degrees away from the equator in Centrobolinae ($r=-0.9114$, $r^2=0.8306$, $n=35$, $p=0.00001$). 5 species of *Centrobolus* were found between -25 to -30 and 5 species between -30 and -35 degrees latitude south. 1 species was found between -15 and -20 and 1 species between -20 and -25 degrees S (Figure 1). There was a marginally significant correlation between the number of millipede species and latitudinal degrees away from the equator (Figure 2: $r=0.89442719$, Z score=1.44363548, $n=4$ pairs, $p=0.07442081$).

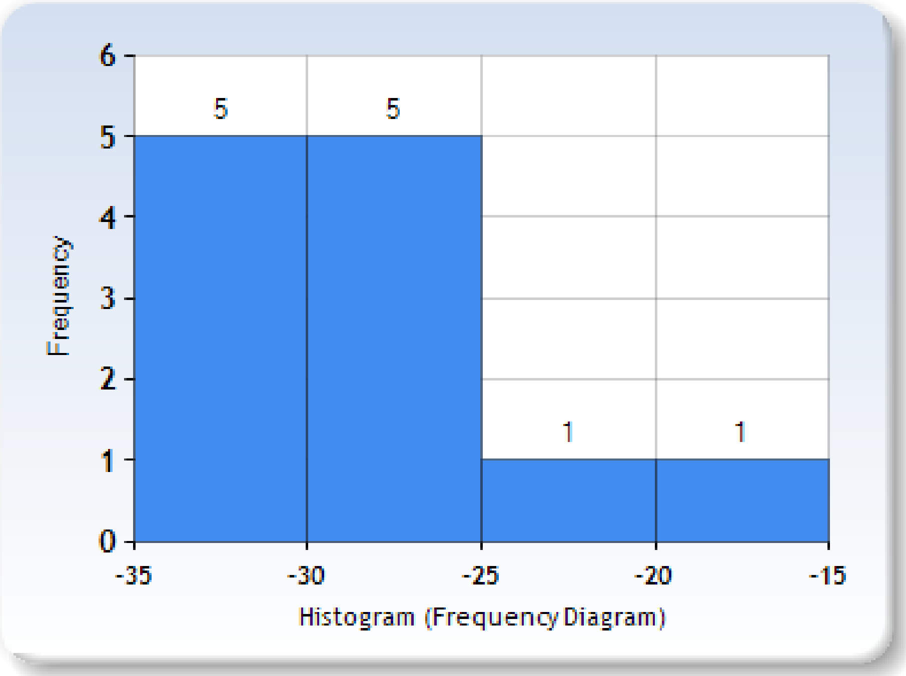

Figure 1: Latitudinal distribution of species in the subfamily Centrobolinae between latitudes -18.6865976 and -18.6865976 South (S).

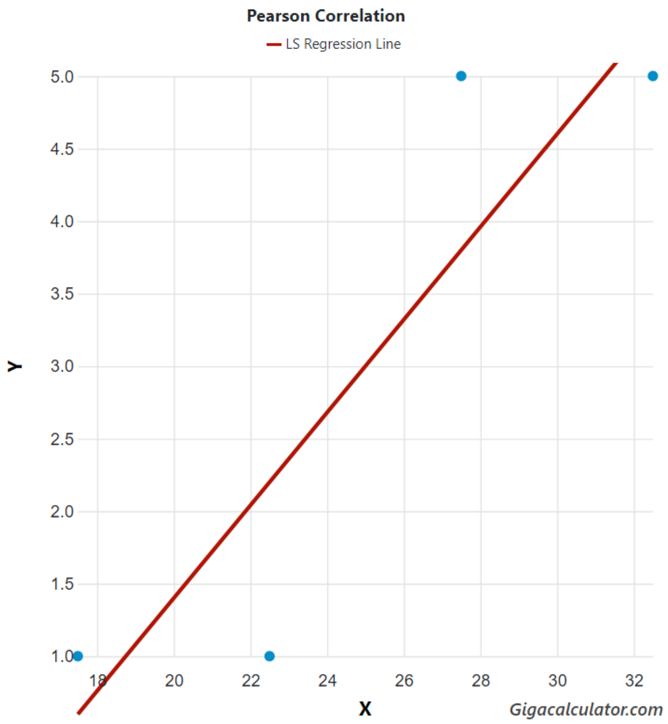

Figure 2: Correlation between species richness (y) and latitude south (x) in Centrobolinae.

<u>Chilognatha</u>

130 species were found between –31.4 and -35 degrees South, 174 species between -27.8 and –31.4 degrees South, 66 species between –24.2 degrees South and –27.8 degrees South, 33 species between –20.6 and –24.2 degrees South, 44 species between –17 and –20.6 degrees South, three between -13.4 and 17 degrees South, four between -9.8. and -13.4 degrees South, no species between -6.2 and -9.8 degrees South, and one species between -2.6 and -6.2 (Figure 3). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 4: r=-0.86879817, Z score=-3.25330698, n=9, p=0.00057041).

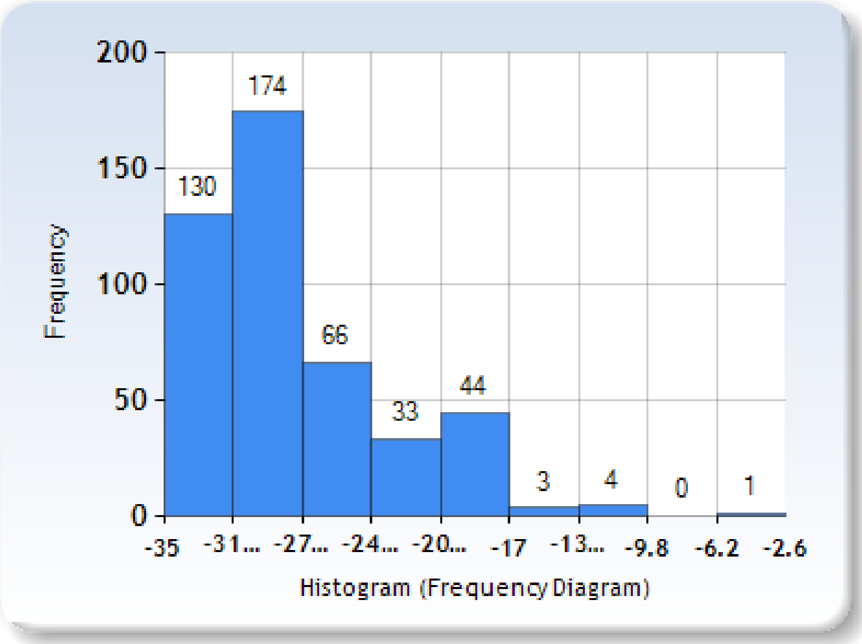

Figure 3: Histogram showing the distribution of species numbers in South African Chilognatha across latitude.

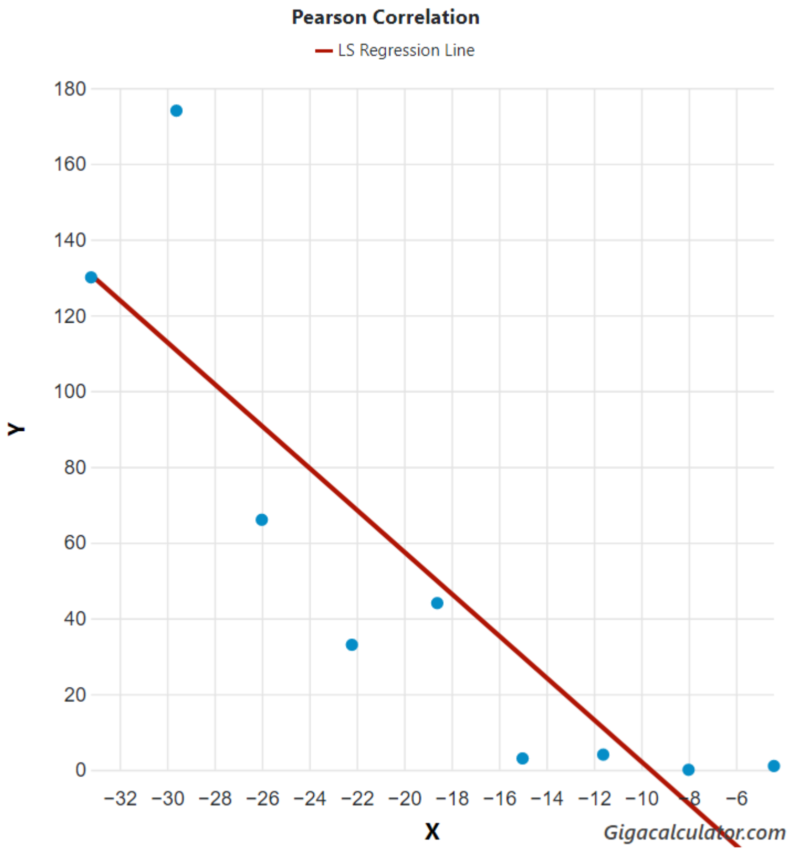

Figure 4: Correlation between species richness (y) and latitude in southern African Chilognatha.

<u>Colobognatha</u>

56 species were found between –32 and -35 degrees South, 79 species between -29 and –32 degrees South, 36 species between –26 degrees South and –29 degrees South, 20 species between –23 and –26 degrees South, three species between –20 and –23 degrees South, 15 between -17 and -20 degrees South, one between -14 and -17, three between -11 and -14 degrees South (Figure 5). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 6: r=-0.86352661, Z score=-2.92264858, n=8, p=0.00173541).

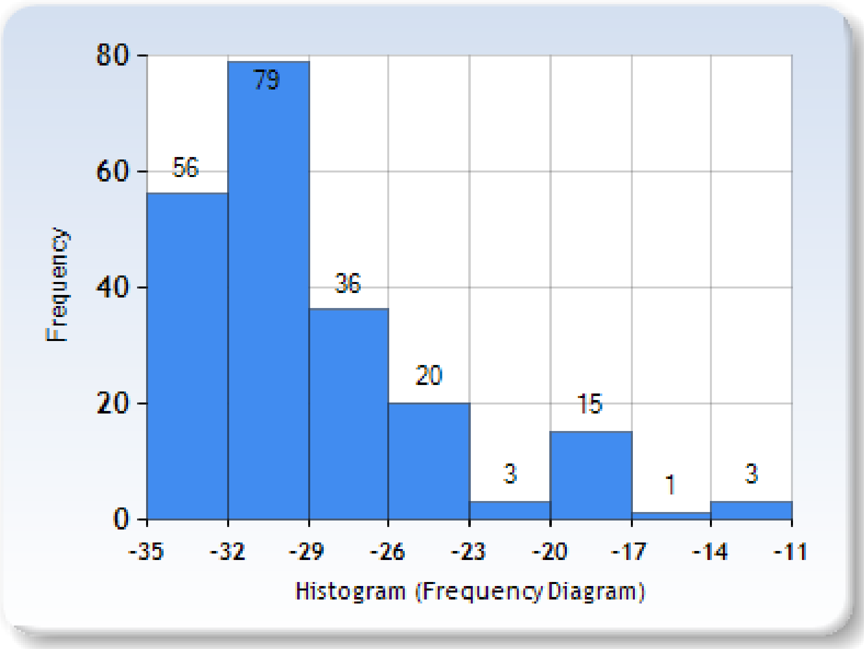

Figure 5: Histogram showing the distribution of species numbers in South African Colobognatha across latitude.

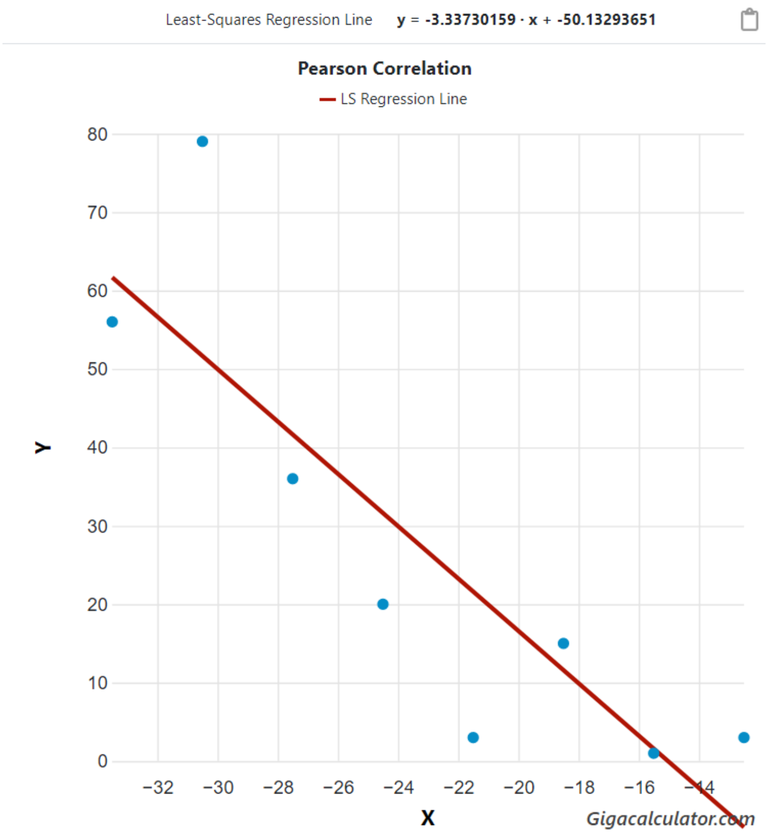

Figure 6: Correlation between species richness (y) and latitude in southern African Colobogntha.

<u>Dalodesmidae</u>

36 species were found between -31.5 and -35 degrees south, 63 species were found between -28 and -31.5 degrees south, 13 species between -24.5 and -28 degrees south, and 7 species between -21 and -24.5 degrees south, and 2 species between -10.5 and -14 degrees south (Figure 7). There was a significant correlation between the number of species of Dalodesmidae and Vallogopodidae and latitudinal degrees away from the equator (Figure. 8: R=-0.78393266, Z score=-2.11098544, n=121, p=0.01738672).

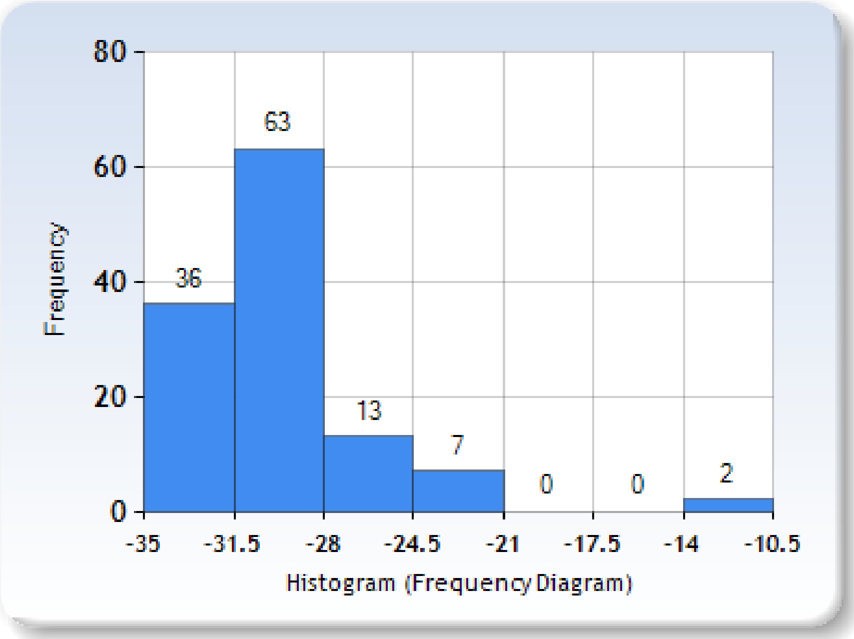

Figure 7: Histogram showing the distribution of species in the millipede Suborder Dalodesmidea Hoffman, 1980 across latitude.

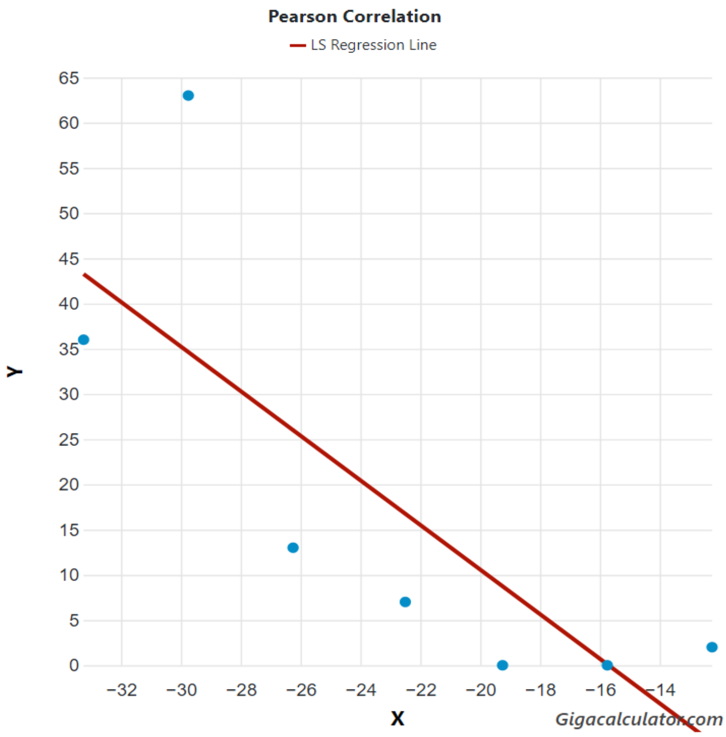

Figure 8: Correlation showing the inverse latitudinal diversity gradient of species richness (y) across latitude (x) in the millipede Suborder Dalodesmidea Hoffman, 1980.

<u>Diplopoda</u>

132 species were found between –31.4 and -35 degrees South, 177 species between -27.8 and –31.4 degrees South, 67 species between –24.2 degrees South and –27.8 degrees South, 33 species between –20.6 and –24.2 degrees South, 44 species between –17 and –20.6 degrees South, three between -13.4 and 17 degrees South, four between -9.8. and -13.4 degrees South, no species between -6.2 and -9.8 degrees South, and one species between -2.6 and -6.2 (Figure 9). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 10: r=-0.86770747, Z score=-3.24245256, n=9, p=0.00059259).

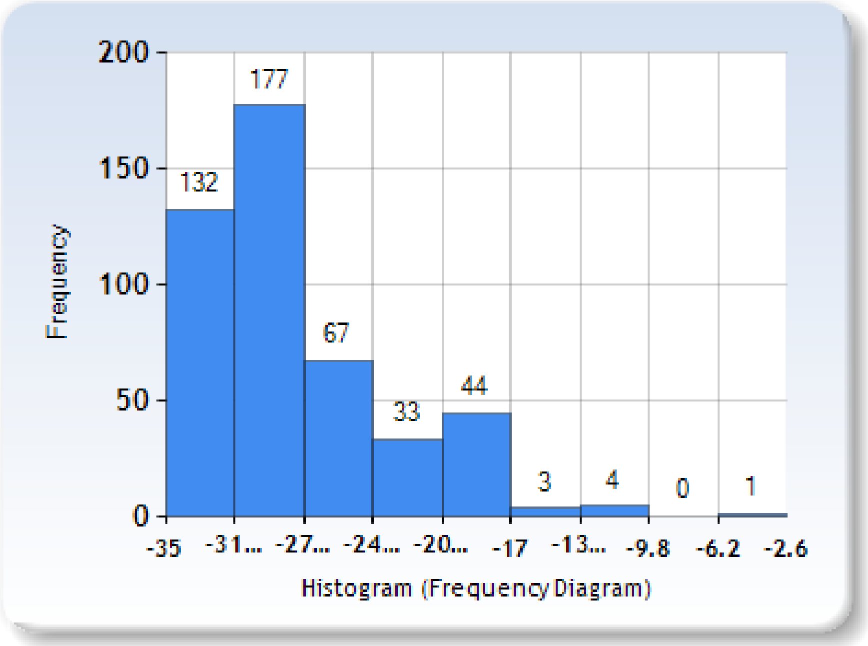

Figure 9: Histogram showing the distribution of species numbers in South African Diplopoda across latitude.

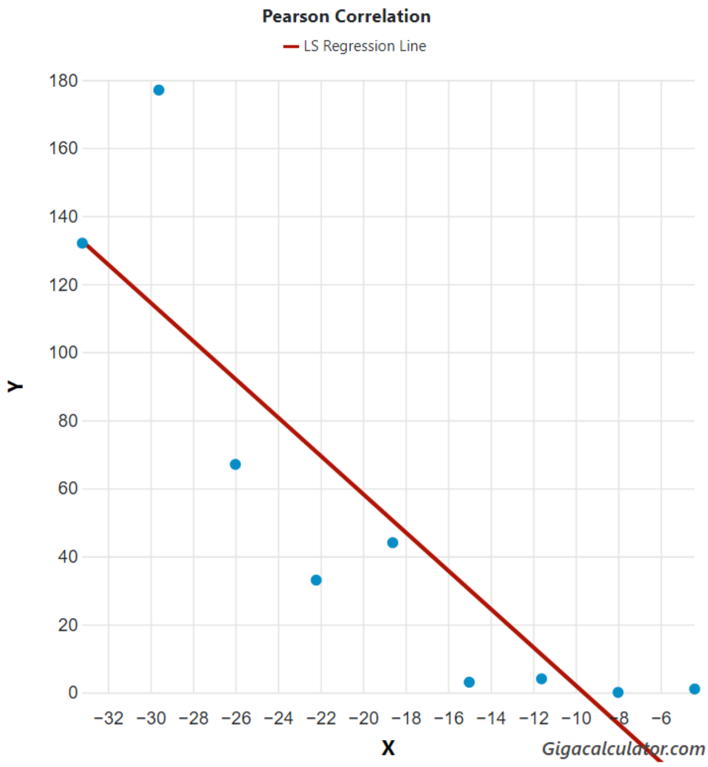

Figure 10: Correlation between species richness (y) and latitude in southern African Diplopoda.

<u>Eugnatha</u>

106 species were found between –31.4 and 35 degrees South, 161 species between -27.8 and –31.4 degrees South, 61 species between –24.2 degrees South and –27.8 degrees South, 32 species between –20.6 and –24.2 degrees South, 42 species between –17 and –20.6 degrees South, two species between -13.4 and -17 degrees South, three species between -9.8 and -13.4 degrees South, 0 between -6.2 and -9.8 degrees South, and one between -2.6 and -6.2 degrees South (Figure 11). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 12: r=-0.85220401, Z score=-3.09652085, n=9, p=0.00097910).

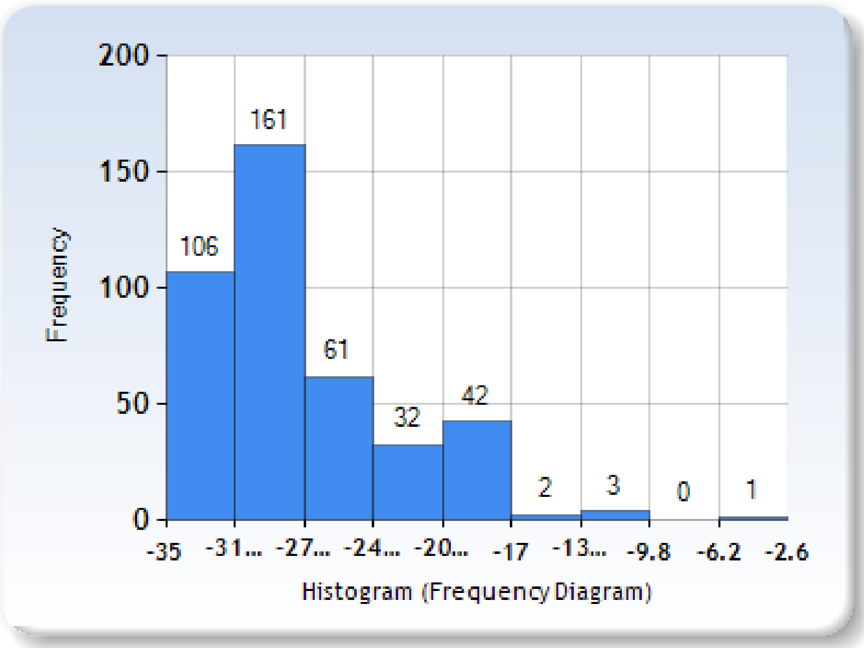

Figure 11: Histogram showing the distribution of species numbers in South African Eugnatha across latitude.

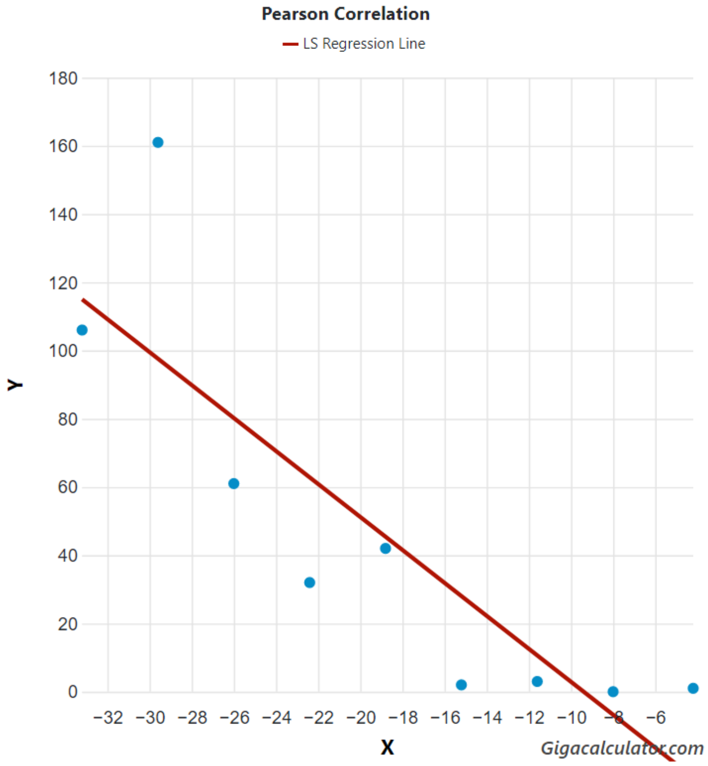

Figure 12: Correlation between species richness (y) and latitude in southern African Eugnatha.

<u>Harpagophoridae</u>

36 species were found between –31 and 35 degrees South, 65 species between -27 and –31 degrees South, 44 species between –23 degrees South and –27 degrees South, 19 species between –19 and –23 degrees South, 14 species between –15 and –19 degrees South, and one species between -3 and -7 degrees South (Figure 13). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 14: r=-0.86138907, Z score=-2.90398969, n=8, p=0.00184227).

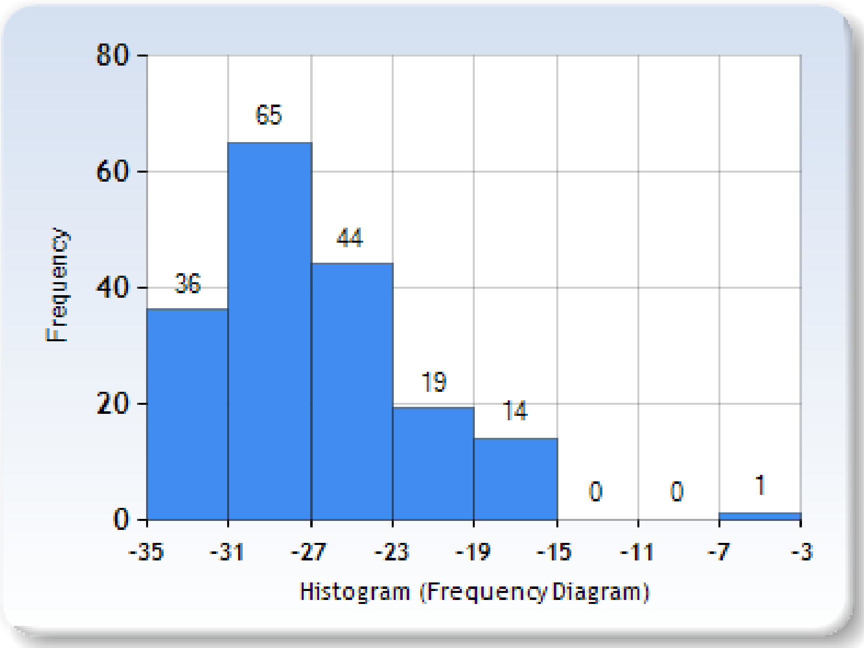

Figure 13: Histogram showing the distribution of species numbers in South African Harpagophoridae across latitude.

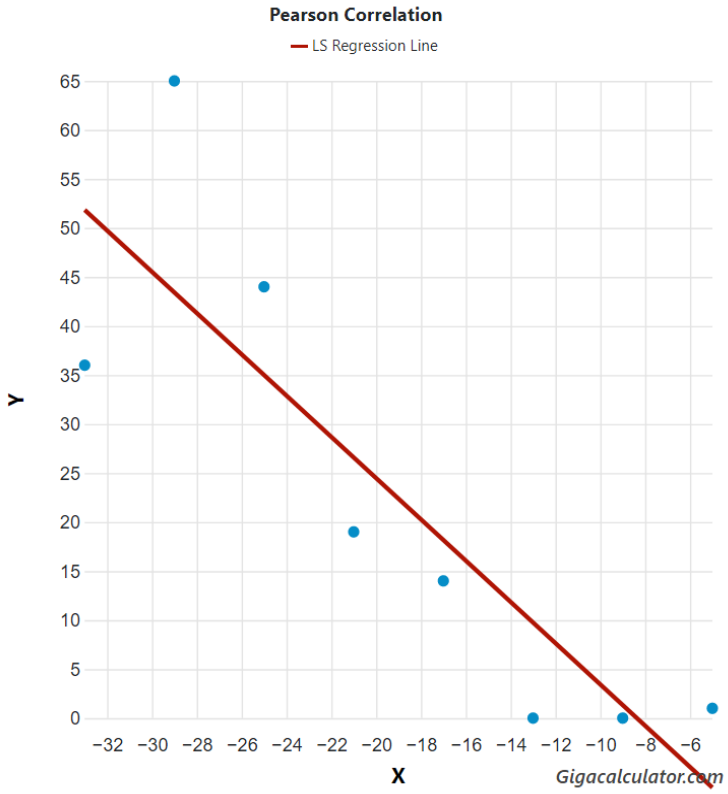

Figure 14: Correlation between species richness (y) and latitude in southern African Harpagophoridae.

16 species were found between –32.4 and 35 degrees South, 22 species between -29.8 and –32.4 degrees South, 40 species between –27.2 degrees South and –29.8 degrees South, 24 species between –24.6 and –27.2 degrees South, 11 species between –22 and –24.6 degrees South, seven species between -19.4 and -22 degrees South, and nine species between -16.8 and -19.4 degrees South (Figure 15). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 16: r=-0.67818936, Z score=-1.84644143, n=8, p=0.03241401).

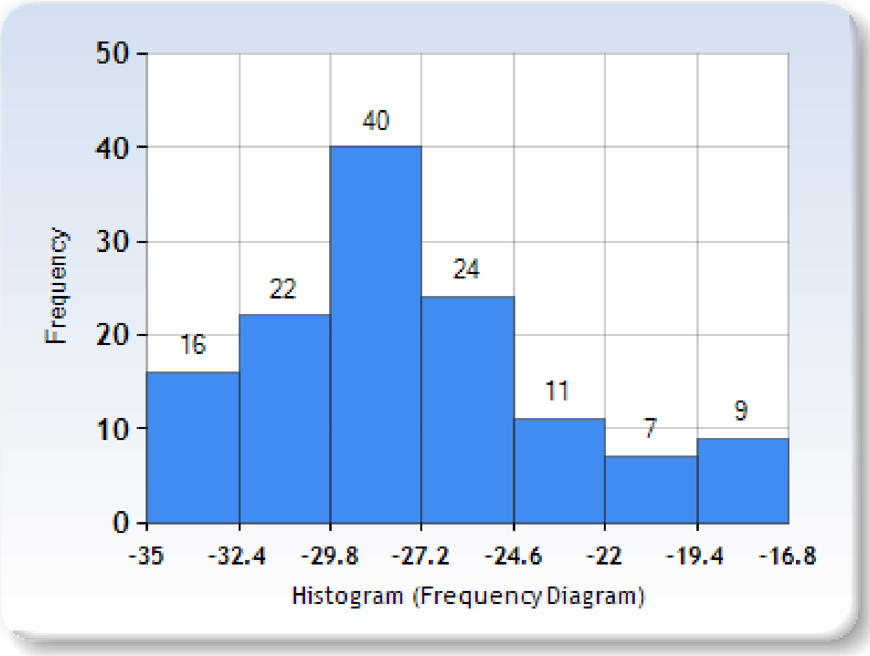

Figure 15: Histogram showing the distribution of species numbers in South African Harpagophoridae across latitude.

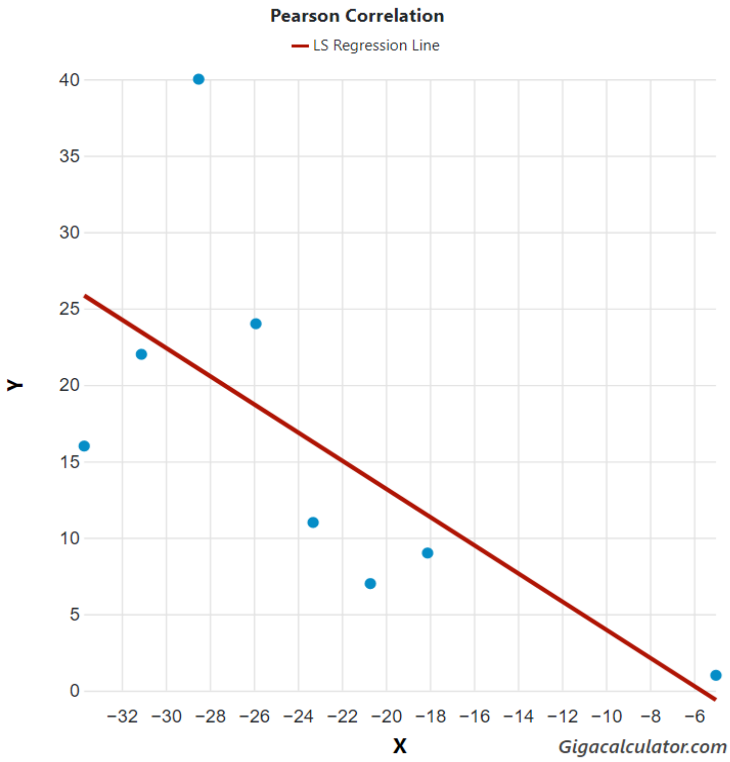

Figure 16: Correlation between species richness (y) and latitude in southern African Harpagophoridae.

Helminthomorpha

110 species were found between –31.2 and -35 degrees South, 165 species between -27.6 and –31.2 degrees South, 61 species between –24.0 degrees South and –27.6 degrees South, 32 species between –20.6 and –24.0 degrees South, 41 species between –17.0 and –20.6 degrees South, three between -13.4 and -17.0 degrees South, three between -9.8 and -13.4, 0 between -6.2 and -9.8 degrees South, and one species between -2.6 and -6.2 degrees South (Figure 17). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 18: r=-0.85104554, Z score=-3.08619211, n=9, p=0.00101376).

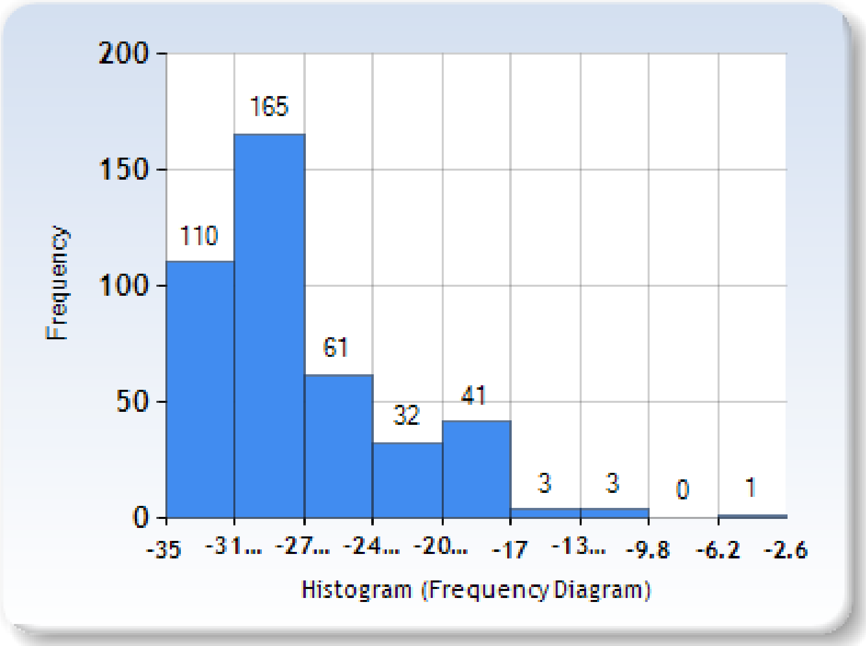

Figure 17: Histogram showing the distribution of species numbers in South African Helminthomorpha across latitude.

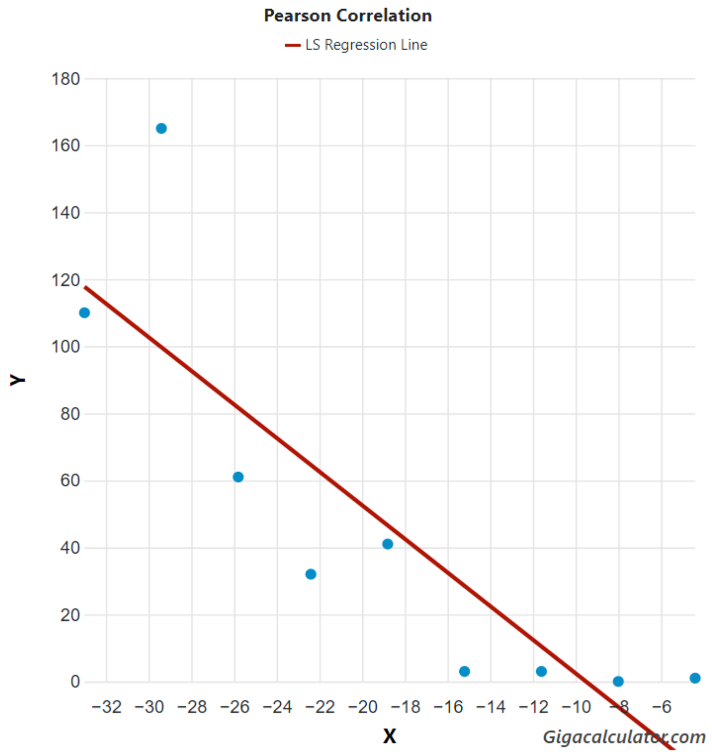

Figure 18: Correlation between species richness (y) and latitude in southern African Helminthomorpha.

<u>Juliformia</u>

70 species were found between –31 and 35 degrees South, 78 species between -27 and –31 degrees South, 49 species between –23 degrees South and –27 degrees South, 27 species between –19 and –23 degrees South, 18 species between –15 and –19 degrees South, and one species between -3 and -7 degrees South (Figure 19). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 20: r=-0.94498247, Z score=-3.98618964, n=8, p=0.00003359).

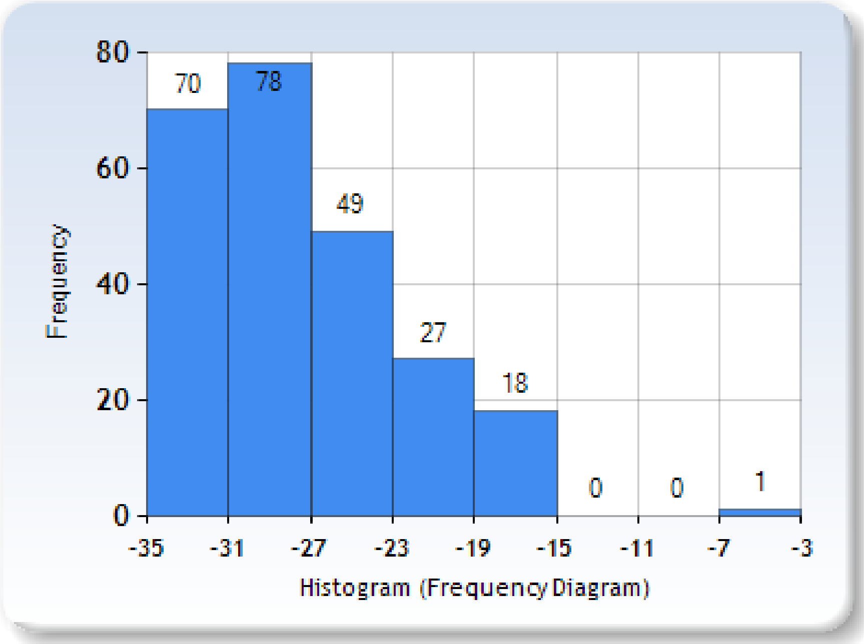

Figure 19: Histogram showing the distribution of species numbers in South African Juliformia across latitude.

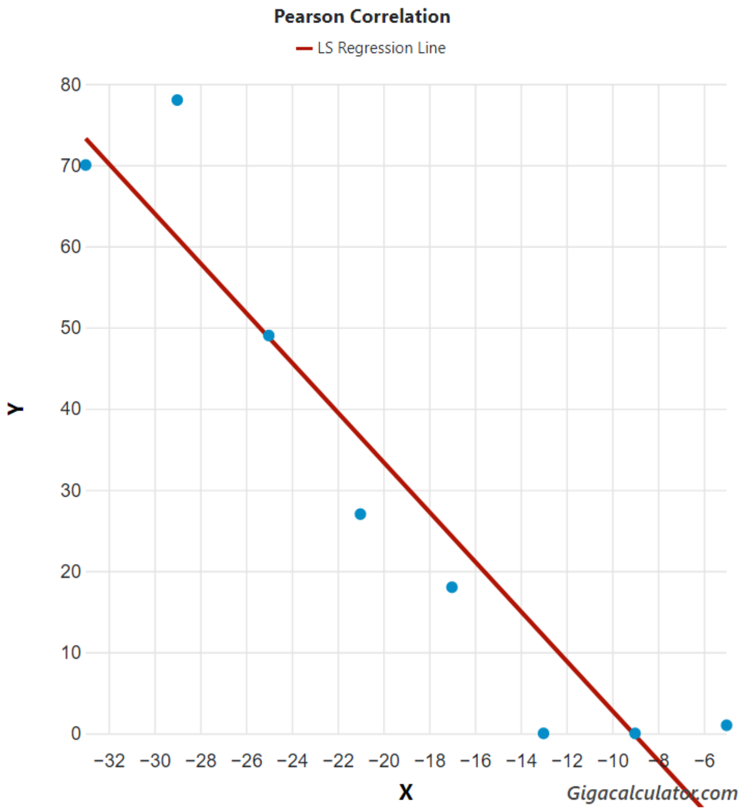

Figure 20: Correlation between species richness (y) and latitude in southern African Juliformia.

<u>Julomorphidae</u>

14 species were found between –31.4 and 35 degrees South, 11 species between -27.8 and –31.4 degrees South, one species between –24.2 degrees South and –27.8 degrees South, one species between –20.6 and –24.2 degrees South, and one species between –17 and –20.6 degrees South (Figure 21). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 22: r=-0.89113279, Z score=-2.01865013, n=8, p=0.02176173).

International Journal of Recent Research in Thesis and Dissertation (IJRRTD)
Vol. 3, Issue 1, pp: (91-112), Month: January - June 2022, Available at: www.paperpublications.org

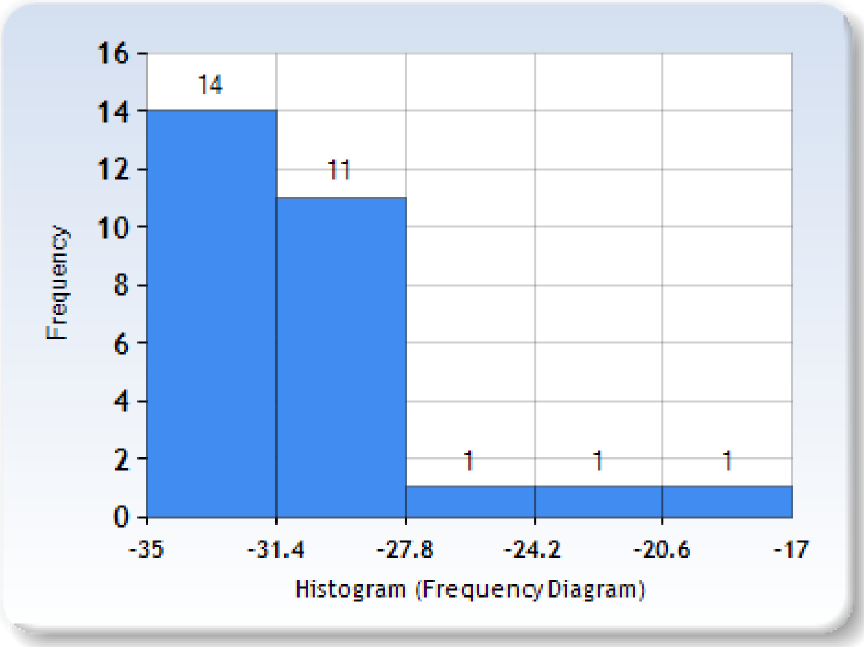

Figure 21: Histogram showing the distribution of species numbers in South African Julomorphidae across latitude.

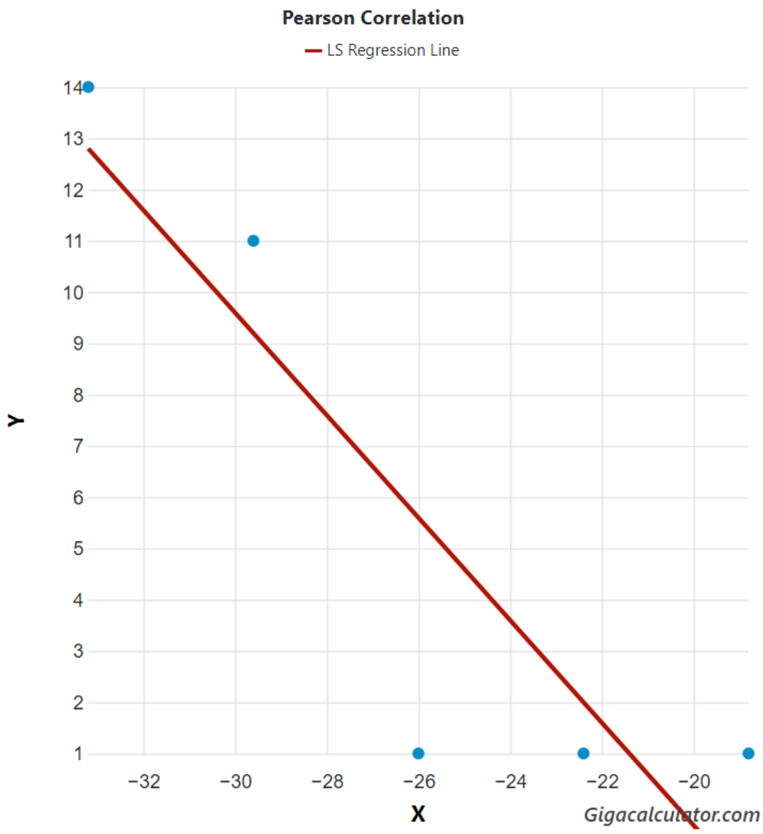

Figure 22: Correlation between species richness (y) and latitude in southern African Julomorphidae.

<u>Merocheta</u>

37 species were found between –32 and -35 degrees South, 64 species between -29 and –32 degrees South, 30 species between –26 degrees South and –29 degrees South, 17 species between –23 and –26 degrees South, three species between –20 and –23 degrees South, 11 between -17 and -20 degrees South, 0 between -14 and -17, and three between -11 and -14 degrees South (Figure 23). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 24: r=-0.83349723, Z score=-2.68212838, n=8, p=0.00365782).

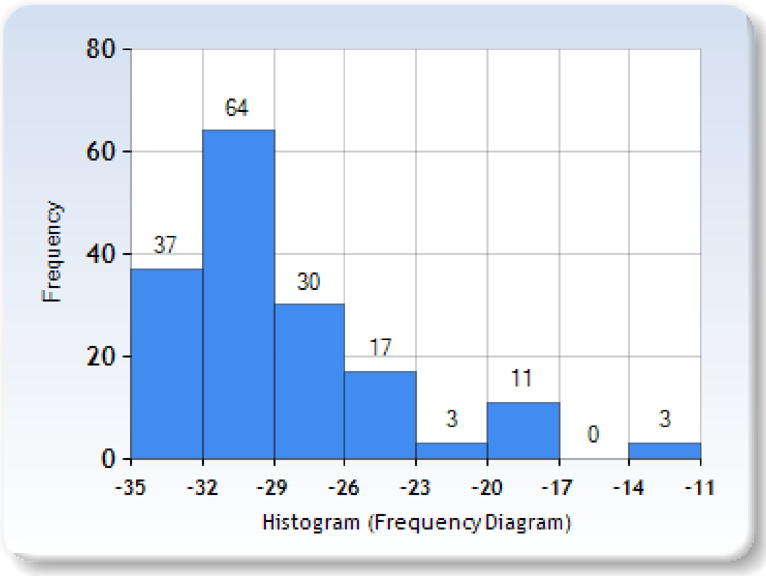

Figure 23: Histogram showing the distribution of species numbers in South African Merocheta across latitude.

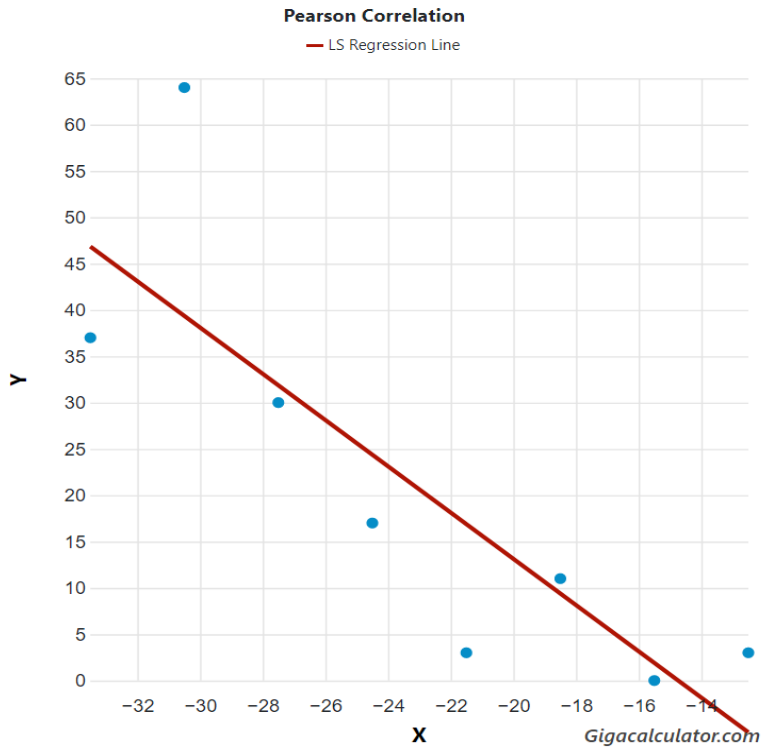

Figure 24: Correlation between species richness (y) and latitude in southern African Merocheta.

<u>Oniscomorpha</u>

25 *Sphaerotherium* species and *Kylindotherium leve* were found between -31- and -35-degrees latitude, 9 species between -27- and -31- degrees latitude, 7 species between -23- and -27-degrees latitude, 3 species between -19- and -23-degrees latitude, 1 species between -15- and -19-degrees latitude and 1 species between -11- and -15-degrees latitude South. There was a significant correlation between the number of species and latitudinal degrees away from the equator in Oniscomorpha and Sphaerotheriida (r=-0.8632, r2=0.74551, n=47, p<0.00001).

<u>Polydesmida</u>

37 species were found between –32 and -35 degrees South, 64 species between -29 and –32 degrees South, 30 species between –26 degrees South and –29 degrees South, 17 species between –23 and –26 degrees South, three species between –20 and –23 degrees South, 11 between -17 and -20 degrees South, 0 between -14 and -17, and three between -11 and -14

degrees South (Figure 25). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 26: r=-0.83349723, Z score=-2.68212838, n=8, p=0.00365782).

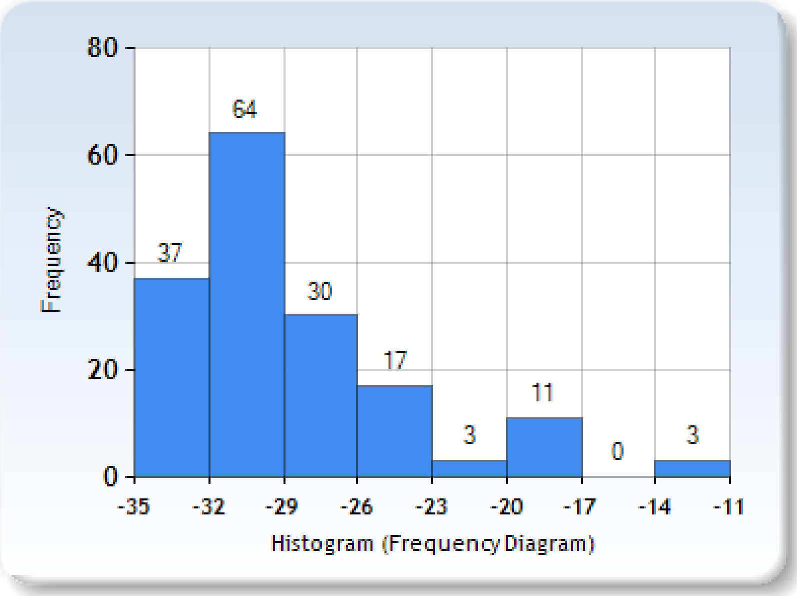

Figure 25: Histogram showing the distribution of species numbers in South African Polydesmida across latitude.

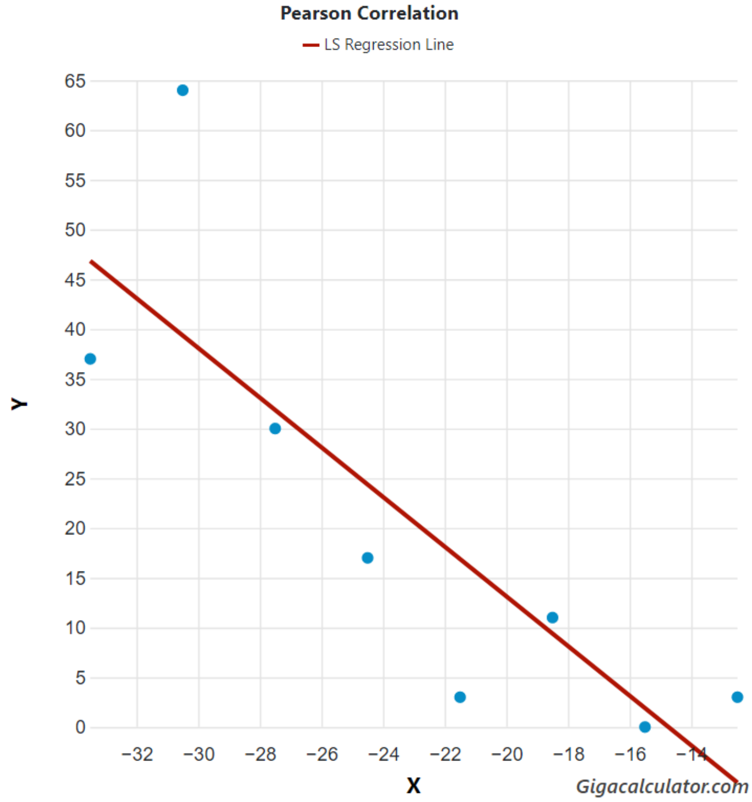

Figure 26: Correlation between species richness (y) and latitude in southern African Polydesmida.

Polyzoniida

56 species were found between –32 and -35 degrees South, 77 species between -29 and –32 degrees South, 36 species between –26 degrees South and –29 degrees South, 20 species between –23 and –26 degrees South, three species between –20 and –23 degrees South, 15 between -17 and -20 degrees South, one between -14 and -17, three between -11 and -14 degrees South (Figure 27). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 28: r=-0.86926446, Z score=-2.97410879, n=8, p=0.00146927).

International Journal of Recent Research in Thesis and Dissertation (IJRRTD)
Vol. 3, Issue 1, pp: (91-112), Month: January - June 2022, Available at: www.paperpublications.org

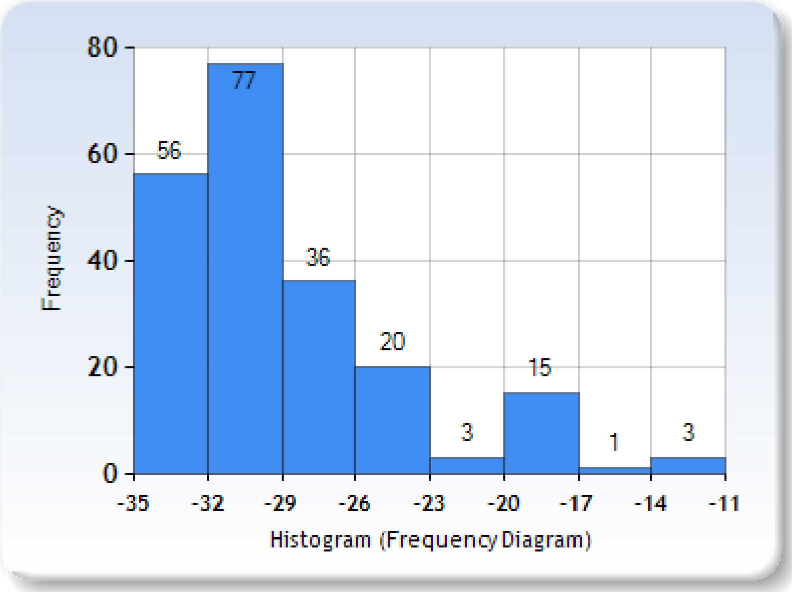

Figure 27: Histogram showing the distribution of species numbers in South African Polyzoniida across latitude.

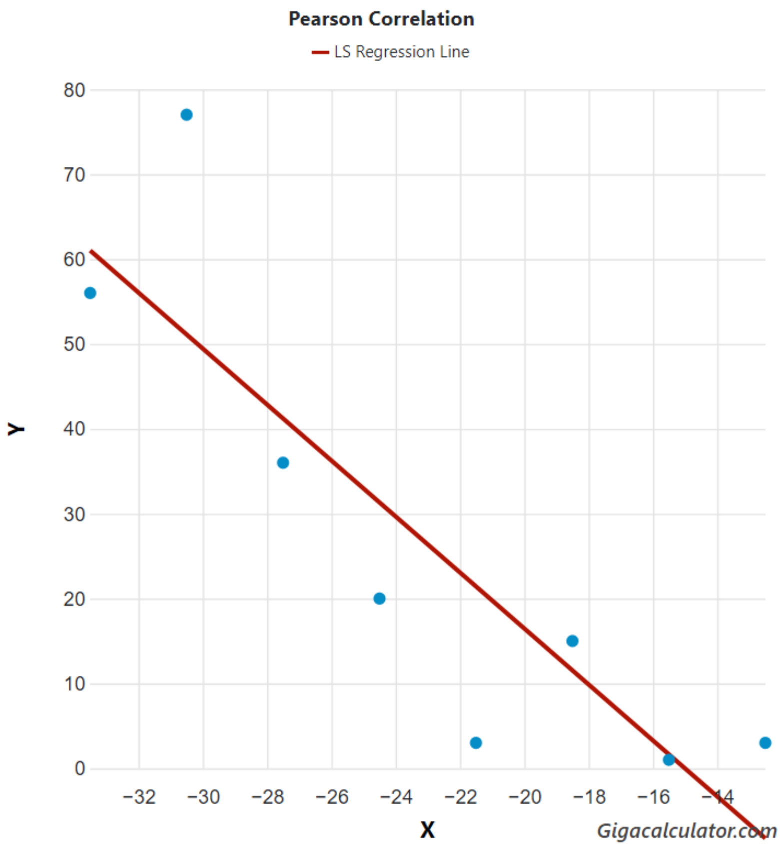

Figure 28: Correlation between species richness (y) and latitude in southern African Polyzoniida.

<u>Sphaerotheriidae</u>

25 *Sphaerotherium* species and *Kylindotherium leve* were found between -31- and -35-degrees latitude, 9 species between -27- and -31- degrees latitude, 7 species between -23- and -27-degrees latitude, 3 species between -19- and -23-degrees latitude, 1 species between -15- and -19-degrees latitude and 1 species between -11- and -15-degrees latitude South. There was a significant correlation between the number of species and latitudinal degrees away from the equator in Sphaerotheriida ($r=-0.8632$, $r2=0.74551$, $n=47$, $p<0.00001$). Figure available at https://www.entomoljournal.com/archives/2022/vol10issue1/PartA/9-6-47-966.pdf.

Sphaerotheriinae and Sphaerotheriini

25 *Sphaerotherium* species and *Kylindotherium leve* were found between -31- and -35-degrees latitude, 9 species between -27- and -31- degrees latitude, 7 species between -23- and -27-degrees latitude, 3 species between -19- and -23-degrees latitude, 1 species between -15- and -19-degrees latitude and 1 species between -11- and -15-degrees latitude South. There was a significant correlation between the number of species and latitudinal degrees away from the equator in Sphaerotheriinae and Sphaerotheriini ($r=-0.8701$, $r^2=0.7571$, $n=46$, $p<0.00001$). Figure available at https://www. entomoljournal.com/archives/2022/vol10issue1/PartA/9-6-47-966.pdf.

Spinotarsus

14 species were found between –32.4 and 35 degrees South, 15 species between -29.8 and –32.4 degrees South, 33 species between –27.2 degrees South and –29.8 degrees South, 18 species between –24.6 and –27.2 degrees South, three species between –22 and –24.6 degrees South, five species between -19.4 and -22 degrees South, and two species between -16.8 and -19.4 degrees South (Figure 27). There was a marginally significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 28: r=-0.60786873, Z score=-1.41106816, n=8, p=0.07911231).

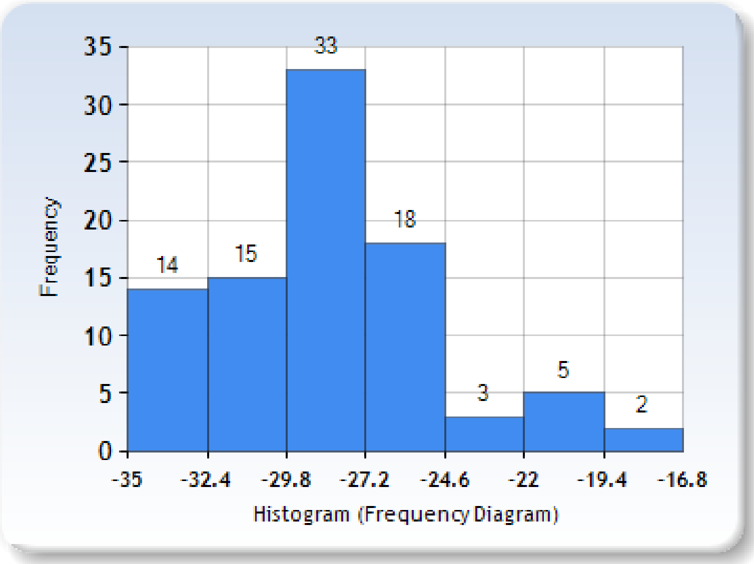

Figure 29: Histogram showing the distribution of species numbers in South African *Spinotarsus* across latitude.

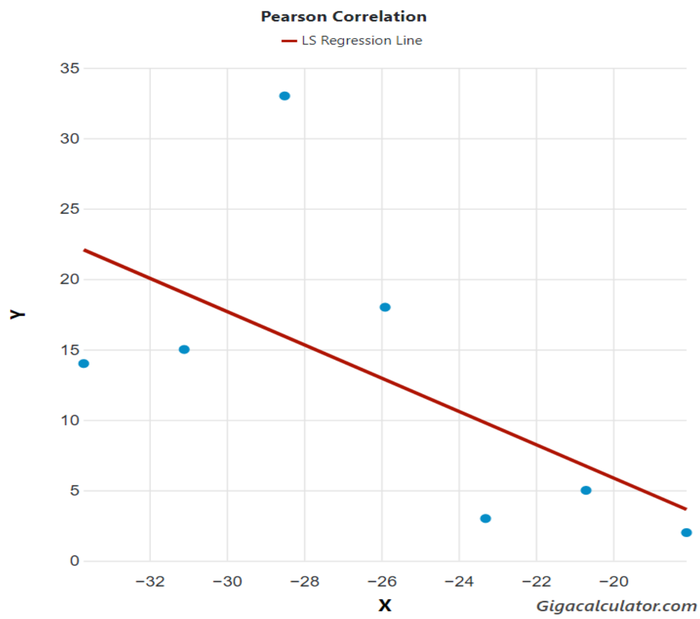

Figure 30: Correlation between species richness (y) and latitude in southern African *Spinotarsus*.

Spirobolida

15 species of Spirobolida were found between –33 and 35 degrees South, 9 species between -29 and –32 degrees South, 6 species between –26 degrees South and –29 degrees South, 3 species between –23 and –26 degrees South, and 5 species between –17 and –20 degrees South. There was a significant negative correlation between the number of species and latitudinal degrees away from the equator in Spirobolida (r=-0.8219, r2=0.6755, n=38, p=0.00001). Figure available at https://www.entomoljournal.com/archives/2022/vol10issue1/PartA/9-6-49-286.pdf.

Spirostreptida

53 species were found between –31 and 35 degrees South, 66 species between -27 and –31 degrees South, 45 species between –23 degrees South and –27 degrees South, 23 species between –19 and –23 degrees South, 17 species between –15 and –19 degrees South, and one species between -3 and -7 degrees South (Figure 29). There was a significant negative correlation between the number of species and latitudinal degrees away from the equator (Figure 30: r=-0.934150, Z score=-3.77900389, n=8, p=0.00007875).

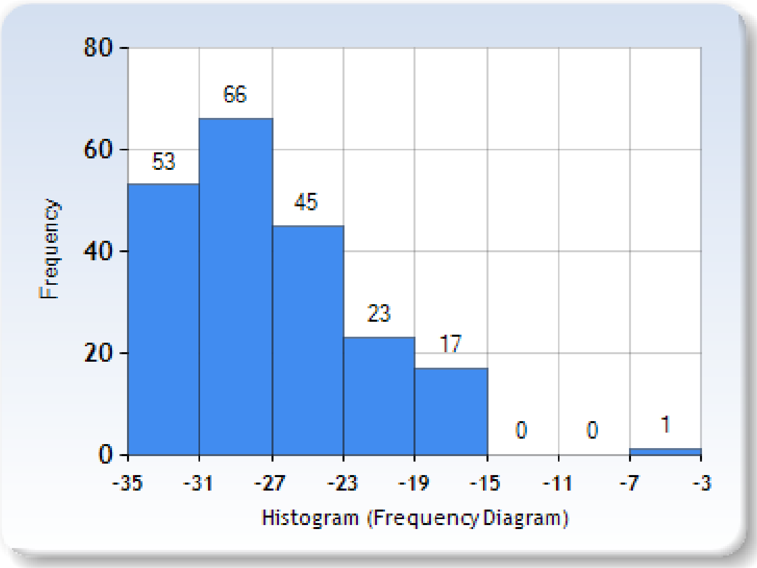

Figure 31: Histogram showing the distribution of species numbers in South African Spirostreptida across latitude.

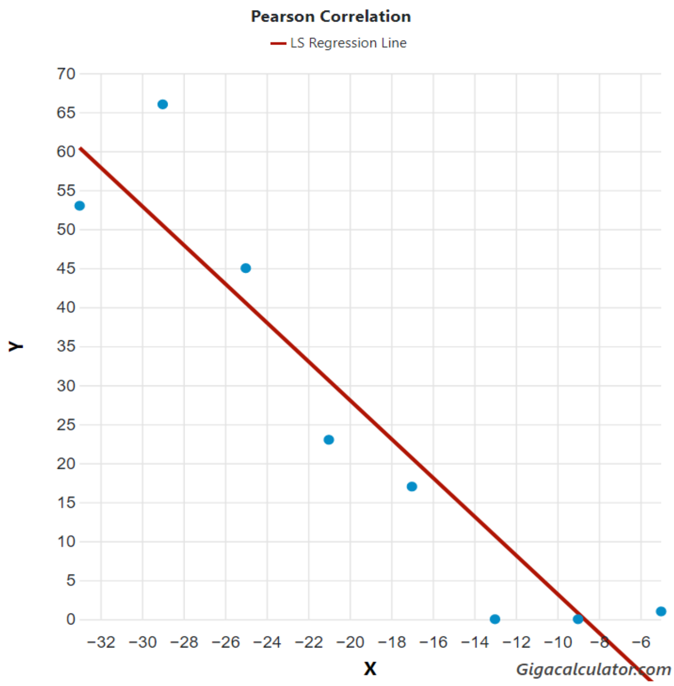

Figure 32: Correlation between species richness (y) and latitude in southern African Spirostreptida.

Trigoniulidea

17 species of *Centrobolus* were found between -31.4 and -35, 12 species between -27.8 and -31.4 degrees latitude south, three species were found between -24.2 and -27.8, and one species between -20.6 and -24.2 degrees S, and two species between -17.0 and -20.6. There was a marginally significant correlation between the number of millipede species and latitudinal degrees away from the equator in Trigoniulidea (r=-0.9114, r^2=0.8306, n=35, p=0.00001; see Figure 1 and Figure 2).

4. DISCUSSION

Southern Africa's Centrobolinae range in latitudinal distribution from *C. immaculatus* at Gorongosa (-18.6865976°S) to *C. dubius* at Gans bay, Chilognatha range in latitudinal distribution from -3.9613364 South throughout to the South Western Cape of the Republic of South Africa (-34.5849°S), Colobognatha range in latitudinal distribution from -11.6305075 South throughout to the South Western Cape of the Republic of South Africa (-34.5849°S), Diplopoda range in latitudinal distribution from -3.9613364 South throughout to the South Western Cape of the Republic of South Africa (-34.5849°S), Eugnatha range in latitudinal distribution from -11.6305075°S to *C. dubius* at Gans Bay (-34.584895°S), Harpagophoridae range in latitudinal distribution from -17.9338469 South throughout to the South Western Cape of the Republic of South Africa (-34.2777818°S), Helminthomorpha range in latitudinal distribution from -11.6305075 South throughout to the South Western Cape of the Republic of South Africa (-34.2777818°S), Juliformia range in latitudinal distribution from near Zambia (-16.1349062°S) to *C. dubius* at Gans Bay (-34.584895°S), Julomorphidae range in latitudinal distribution from -18.6865976 South throughout to the South Western Cape of the Republic of South Africa (-34.5848950°S), Merocheta range in latitudinal distribution from -11.6305075 South throughout to the South Western Cape of the Republic of South Africa (-34.3567°S), Polydesmida range in latitudinal distribution from -11.6305075 South throughout to the South Western Cape of the Republic of South Africa (-34.3567°S), Polyzoniida range in latitudinal distribution from -11.6305075 South throughout to the South Western Cape of the Republic of South Africa (-34.5849°S), *Spinotarsus* range in latitudinal distribution from -17.7858414° South throughout to the South Western Cape of the Republic of South Africa (-17.7858414°S), and Spirostreptida range in latitudinal distribution from near Zambia (-16.1349062°S) throughout to the South Western Cape of the Republic of South Africa (-34.2777818°S).

There are significant negative correlations between the number of species and latitudinal degrees away from the equator indicating inverse LDG in all 22 groups supporting the Biogeographical Conservativism Hypothesis [23]. Other groups showing an inverse LDG include aphids, Chinese litter-dwelling thrips, diving beetle subfamily Colymbetinae, European bryophytes, freshwater zooplankton, Holarctic tree frogs, ichneumonids, marine benthic algae, marine bivalves Anomalodesmata, New World snake tribe Lampropeltini, North American breeding birds, penguins, peracarid crustaceans, pitcher plant mosquito, pond turtles, Shallow-water mollusks, shorebirds, southeastern United States trees, subarctic forests, and tropical leaf-litter ant communities [14-16, 17, 18, 20, 23, 24, 26-28].

Two general explanations for the inverse trends in LDG include precipitation and predation which may be pertinent to Southern African millipedes [8]. Predation affects millipedes as many species have some form and degree of conglobation [7]. This behavior is also an adaptive response to conserving moisture [8]. I questioned the moisture conservation hypothesis in favor of predation. There is a higher predation risk for insect prey at lower latitudes [25].

Density-dependent mortality in the millipedes is supported by differences in relative abundance, mating frequencies, and sex ratios of sympatric species. There may be an evolutionary preference for temperate environments appearing to have led to climatic constraints on dispersal based primarily on precipitation or temperature seasonality gradients [13, 23]. LDG depends on proximate factors affecting processes of speciation, extinction, immigration, and emigration, and in millipedes, these factors are dependent on size which were investigated in millipedes based on temperature, precipitation, and latitude. LDG relates to body size in millipedes which do not agree with the trends in other taxa such as birds and fishes [29]. The trend of a small body size associated with the inverse LDG is similar to the weak tendency found in mammals however there was no significant association between body mass and species-richness [9]. In millipedes, size may be significantly related to latitude.

5. CONCLUSION

There was a significant negative correlation between the number of species and latitudinal degrees away from the equator indicating an inverse LDG in southern African millipedes supporting the Biogeographical Conservativism Hypothesis. An evolutionary preference for temperate environments appears to have led to climatic constraints on dispersal based on precipitation seasonality gradients.

Appendix.

Systematic list of GPS latitudinal co-ordinates for southern African Diplopoda.

-33.9465292, -33.2461502, -29.0938694, -24.969720, -28.9681053, -29.6301178, -30.2786, -25.9537, -25.7313, -33.9573, -34.0490, -30.9906, -34.2051, -33.9923, -25.9537, -33.9820, -29.6180, -34.2708, -18.9707, -25.3584, -28.6883, -11.8525, -22.4491, -19.8000, -34.4187, -28.6773, -33.9091, -34.0490, -30.0500, -32.5667, -30.4000, -20.4333, -33.9738, -25.3583, -33.7667, -32.9500, -32.1000, -34.0490, -34.0490, -28.6773, -34.2467, -33.9640, -33.9738, -33.9481, -28.0070, -29.8590, -29.0766, -34.4169, -34.0391, -34.1008, -33.9690, -34.0999, -29.0089, -33.9686, -31.6334, -34.0092, -33.8012, -17.8575, -17.8165, -12.9633, -18.9797, -34.2795, -11.6305, -18.0200, -29.6301, -29.7412, -28.7784, -29.6301, -29.6301, -23.1176, -28.7308, -29.6426, -26.5153, -28.0246, -23.9884, -29.6301, -30.8440, -29.7562, -29.6301, -28.0246, -29.8683, -28.9681, -29.3999, -31.0257, -25.1666, -23.8466, -27.32303, -28.9681, -30.7157, -29.7991, -29.0483, -28.3141, -29.5403, -25.1770, -17.8165, -23.5613, -17.9316, -18.4212, -23.9001, -17.8575, -22.4880, -32.1961, -34.2136, -34.0504, -33.9465, -19.1235, -28.9681, -18.8090, -25.1625, -18.3009, -20.1112, -31.0257, -23.8812, -29.8689, -23.4667, -29.0030, -29.3233, -30.9694, -29.3151, -33.9091, -23.0500, -29.8034, -29.3550, -30.6670, -29.7723, -33.7746, -33.3100, -28.7167, -33.3100, -33.8166, -29.6180, -31.4667, -27.8667, -22.6954, -29.0030, -29.6180, -29.0002, -28.7167, -29.4500, -29.7723, -32.5167, -29.0538, -27.1343, -28.7549, -29.0030, -33.9797, -34.1832, -27.1343, -30.5475, -29.0030, -33.2319, -29.6180, -34.0299, -30.5485, -29.4064, -29.0030, -34.0357, -24.9613, -29.4773, -31.6205, -11.8525, -24.9044, -29.7242, -26.3257, -26.5625, -32.6345, -27.2593, -27.8667, -25.7822, -23.0383, -30.9892, -30.9892, -29.0474, -29.0538, -26.1528, -28.8428, -31.6334, -28.0246, -29.8967, -28.9681, -30.5378, -31.1499, -33.6477, -33.9668, -28.6772, -34.2056, -34.0460, -33.6477, -34.0999, -33.9668, -33.9020, -34.0477, -34.0196, -34.2340, -29.0766, -30.6159, -28.7591, -28.6772, -30.1127, -33.9598, -28.9681, -29.6301, -30.4863, -29.0939, -29.6301, -29.6301, -29.4192, -33.8012, -33.9147, -34.0610, -34.3567, -25.1769, -28.9681, -29.0483, -28.7308, -29.6301, -34.0391, -25.7750, -26.1502, -33.3181, -29.7462, -33.9173, -28.7280, -27.8403, -34.0477, -34.5849, -28.7784, -18.6860, -30.2805, -29.7080, -29.6301, -33.9671, -23.9001, -33.9322, -32.2209, -34.2443, -31.0164, -32.5717, -28.7784, -30.7157, -29.3999, -28.0246, -33.6367, -33.6132, -32.5717, -32.5064, -25.6155, -31.6334, -34.4142, -24.5391, -29.0939, -19.8176, -31.6334, -19.7767, -15.0377, -18.9371, -33.9594, -34.2136, -34.2339, -33.9660, -33.9686, -34.2443, -33.9627, -34.1186, -34.2443, -29.2872, -34.1405, -34.0254, -33.6443, -33.3977, -32.5929, -33.9489, -33.9489, -32.5929, -26.1272, -16.1349, -22.9198, -18.9796, -19.9643, -18.9018, -22.4408, -20.3139, -33.8257, -29.8177, -32.7207, -25.8263, -29.8571, -28.7666, -31.7833, -30.6950, -33.7041, -24.9964, -26.0961, -25.1666, -33.8007, -27.8332, -25.6155, -25.9550, -28.7308, -26.0976, -27.3229, -18.9507, -21.9813, -29.8683, -18.5730, -26.8855, -22.9458, -19.2422, -31.6333, -22.8933, -17.7807, -25.7750, -27.0087, -29.5478, -28.1460, -26.9671, -31.3486, -29.5836, -34.4168, -29.3126, -18.9796, -22.0875, -24.1913, -24.8365, -26.0976, -22.9540, -16.1349, -23.5138, -26.9474, -18.5730, -34.2778, -3.9613, -22.3715, -26.1714, -26.0728, -25.3584, -28.5655, -25.6155, -20.5166, -29.8683, -23.0166, -22.0026, -18.2176, -19.5789, -18.3036, -19.2443, -17.9338, -31.3069, -24.3930, -28.5655, -30.7248, -18.4212, -23.9001, -18.3038, -29.6301, -28.9681, -25.7750, -29.0766, -29.7578, -34.0032, -23.8466, -31.0595, -30.7157, -24.1000, -29.8967, -29.0192, -26.9610, -31.3642, -22.9959, -18.3969, -33.8159, -28.0246, -29.8590, -29.0483, -31.6334, -26.9367, -30.1430, -29.7520, -25.6155, -21.8602, -23.9884, -30.8439, -33.3058, -29.4823, -29.4945, -26.0976, -31.6334, -29.6301, -29.5727, -29.7578, -29.8683, -28.0245, -28.3779, -33.9146, -25.7578, -29.5776, -28.9681, -29.6301, -26.0236, -22.4206, -28.0245, -29.0483, -27.8955, -27.1342, -31.6334, -32.5064, -28.9681, -29.6301, -25.3584, -19.8036, -31.6333, -26.9479, -32.7051, -29.5352, -28.3738, -32.9547, -25.4807, -32.8038, -29.6301, -25.6155, -20.1302, -29.0496, -27.8402, -25.6155, -31.6334, -24.6370, -17.7858, -18.8292, -31.6334, -30.7157, -32.7747, -32.6369, -34.2778, -19.8874, -25.6155, -30.0369, -27.3229, -24.9923, -25.5333, -29.9172, -32.7051, -29.6301, -22.3715, -32.4611, -29.2938, -28.3779, -29.7520, -28.3779, -24.7864, -28.8489, -28.9681, -29.7141, -31.4647, -31.0257, -33.3180, -33.4166, -20.1936, -24.8785, -28.5923, -25.4420, -34.2778.

REFERENCES

[1] C. Attems, "The Myriopoda of South Africa." Annals of the South African Museum, vol. 26, pp. 305, 1928.

[2] R. K. Colwell, "Biodiversity: Concepts, Patterns and Measurement" in The Princeton Guide to Ecology (Levin SA, ed). Princeton, Princeton University Press, USA, pp. 257-263, 2009.

[3] R. K. Colwell, and G. C. Hurtt, "Nonbiological gradients in species richness and a spurious Rapoport effect." American Naturalist, vol. 144, pp. 570-595, 1994.

[4] R. K. Colwell, and D. C. Lees, "The mid-domain effect: geometric constraints on the geography of species richness." Trends in Ecology and Evolution, vol. 15, pp. 70-76, 2000.

[5] R. K. Colwell, C. Rahbek, and N. J. Gotelli, "The mid-domain effect and species richness patterns: what have we learned so far?" American Naturalist, vol. 163, pp. E1-E23, 2004.

[6] O. F. Cook, "Introductory note on the families of Diplopoda, in The Craspedosomatidae of North America." Annals of the New York Academy of Sciences, vol. 9, pp. 1-9, 1895.

[7] M. I. Cooper, "Syncopulatory mate-guarding affected by predation in the aposematic millipede Centrobolus inscriptus in a swamp forest." Journal of Entomology and Zoology Studies, vol. 4, no. 6, pp. 483-484, 2016.

[8] S. H. Ferguson, "Does Predation or Moisture explain distance to Edge Distribution of Soil Arthropods?" The American Midland Naturalist, vol. 152, no. 1, pp. 75-87, 2004.

[9] J. L. Gittleman, and A. Purvis, "Body size and species-richness in carnivores and primates." Proceedings of the Royal Society B: Biological Sciences, vol. 265, no. 1391, pp. 113-119, 1998.

[10] M. L. Hamer, "Checklist of Southern African millipedes." Annals of the Natal Museum, vol. 39, no. 1, pp. 39-43, 1998.

[11] H. Hillebrand, "On the Generality of the Latitudinal Diversity Gradient." The American Naturalist, vol. 163, no. 2, pp. 192-211, 2004.

[12] S. P. Hopkin, and H. J. Read, "Taxonomy, evolution, and zoogeography." in The Biology of millipedes. Oxford University Press, UK, 1992.

[13] B. S. Kadamannaya, K. R. Sridhar, and S. Sahadevan, "Seasonal Periodicity of Pill Millipedes (Arthrosphaera) and Earthworms of the Western Ghats, India." World Journal of Zoology, vol. 4, no. 2, pp. 63-69, 2009.

[14] P. Kindlmann, A. F. G. Dixon, and I. Traxmandlová-Schödelbauerová, "Inverse latitudinal gradients in species diversity." in Scaling Biodiversity (Storch D, Marquet PA, ed). Cambridge University Press, Cambridge, UK, 2007.

[15] A. Z. Krug, D. Jablonski, and J. W. Valentine, "Contrarian clade confirms the ubiquity of spatial origination patterns in the production of latitudinal diversity gradients." Proceedings of the National Academy of Sciences of USA, vol. 104, no. 46, pp. 18129-18134, 2007.

[16] Y. Kwon, T. Lee, A. Lang, and D. Burnette, "Assessment on latitudinal tree species richness using environmental factors in the Southeastern United States." Peer J, vol. 7, pp. e6781, 2019.

[17] K. E. Marshall, and J. L. Baltzer, "Decreased competitive interactions drive a reverse species richness latitudinal gradient in subarctic forests." Ecology, vol. 96, no. 2, pp. 461-470, 2015.

[18] R. Mateo, O. Broennimann, S. Normand, B. Petitpierre, M. B. Ara Oyújo, and J-C. Svenning et al., "The mossy north: An inverse latitudinal diversity gradient in European bryophytes." Scientific Reports, vol. 6, pp. 25546, 2016.

[19] G. C. Mittelbach, G. W. Schemske, H. V. Cornell, A. P. Allen, J. M. Brown, and M. B. Bush, et al., "Evolution and the latitudinal diversity gradient: speciation, extinction and biogeography." Ecology Letters, vol. 10, pp. 315-331, 2007.

[20] J. Morinière, M. H. Van Dam, O. Hawlitschek, J. Bergsten, M. C. Michat, and L. Hendrich et al., "Phylogenetic niche conservatism explains an inverse latitudinal diversity gradient in freshwater arthropods." Scientific Reports, vol. 6, pp. 26340, 2016.

[21] E. R. Pianka, "Latitudinal Gradients in Species Diversity." Trends in Ecology and Evolution, vol. 4, no. 6, pp. 223, 1989.

[22] M. E. Power, D. Tilman, J. A. Estes, B. A. Menge, W. J. Bond, and L. S.Mills et al., "Challenges in the Quest for Keystones." Wildlife Biology Faculty Publications, vol. 1, 1996.

[23] R. A. Pyron, and F. T. Burbrink, "Can the Tropical Conservatism Hypothesis explain temperate species richness patterns? An inverse latitudinal biodiversity gradient in the New World snake tribe Lampropeltini." Global Ecology and Biogeography, vol. 18, pp. 406-415, 2009.

[24] M. M. Rivadeneira, M. Thiel, E. R. Gonzalez, and P. A. Haye, "An inverse latitudinal gradient of diversity of peracarid crustaceans along the Pacific Coast of South America: Out of the deep south." Global Ecology and Biogeography, vol. 20, no. 3, pp. 437-448, 2011.

[25] T. Roslin, B. Hardwick, V. Novotny, W. K. Petry, N. R. Andrew, A. Asmus, and I. C. Barrio et al., "Higher predation risk for insect prey at low latitudes and elevations." Science, vol. 356, no. 6339, pp. 742-744, 2017.

[26] R. R. Silva, and C. R. F. Brandão, "Ecosystem-wide morphological structure of leaf-litter ant communities along a tropical latitudinal gradient." PLoS ONE, vol. 9, no. 3, pp. e93049, 2014.

[27] K. R. Sime, and A. V. Z. Brower, "Explaining the latitudinal gradient anomaly in ichneumonid species richness: evidence from butterflies." Journal of Animal Ecology, vol. 67, pp. 387-399, 1998.

[28] J. Wang, X. Tong, and W. Donghui, "The effect of latitudinal gradient on the species diversity of Chinese litterdwelling thrips." Zookeys, no. 417, pp. 9-20, 2014.

[29] J. D. L. Yen, J. R. Thomson, J. Keith, D. M. Paganin, E. Fleishman, and A. F. Bennett et al., "Linking species richness and size diversity in birds and fishes." Ecography, vol. 41, no. 12, pp. 1979-1991, 2018.