Article

Size dimorphism in six juliform millipedes

Mark Cooper
School of Animal, Plant & Environmental Sciences University of the Witwatersrand, Johannesburg 2050, South Africa
Email: cm.i@aol.com

Received 25 January 2019; *Accepted 6 March 2019*; *Published 1 December 2019*

Abstract
Sexual Size Dimorphism (SSD) in the diplopod genera *Bicoxidens*, *Doratogonus*, *Harpagophora*, *Julomorpha* and *Orthoporoides* has length, width and rings as the main components of interspecific variation. Interspecific variation in size observed in *B. bricki* Schubart, 1966, *D. annulipes* Carl, 1917, *H. spirobolina* (Karsch, 1881), *J. hilaris* Attems, 1928, *J. panda* (Attems, 1928) and *O. tabulinus* (Attems, 1914) and the data sets were tested for normality. Male lengths differed from female lengths in all except *J. hilaris* which had different widths. Juliform millipedes appear to have decreased in size over evolutionary time and this study presents an interesting finding showing sexual dimorphism based on length in larger species and sexual dimorphism based on width in the smaller species. The reason for this has to do with the constraints imposed through a cylindrical body form which can be changed more powerfully through reducing width rather than length.

Keywords diplopod; horizontal; length; tergite.

Arthropods
ISSN 2224-4255
URL: http://www.iaees.org/publications/journals/arthropods/online-version.asp
RSS: http://www.iaees.org/publications/journals/arthropods/rss.xml
E-mail: arthropods@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

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 (Telford and Dangerfield, 1990; Hopkin and Read, 1992; Barnett and Telford, 1993; Barnett et al., 1993; Telford and Dangerfield, 1993; Barnett and Telford, 1994; Telford and Dangerfield, 1994; Barnett et al., 1995; Webb and Telford, 1995; Aarde et al., 1996; Barnett and Telford, 1996; Telford and Dangerfield, 1996; Telford and Webb, 1998; Cooper, 2014-2019). Diplopods resemble the majority of invertebrates in SSD is mostly reversed (Cooper, 2018). Larger females are thought to result from fecundity selection (Mauritz, 2011). In the present study, SSD in the superorder Juliformia was investigated in *B. bricki* Schubart, 1966, *D. annulipes* Carl, 1917, *H. spirobolina* (Karsch, 1881), *J. hilaris* Attems, 1928, *J. panda* (Attems, 1928) and *O. tabulinus* (Attems, 1914) and 2 factors determining a response in SSD (length and width) tested.

2 Materials and Methods

Two factors were obtained from *B. bricki*, *D. annulipes*, *H. spirobolina*, *J. hilaris, J. panda* and *O. tabulinus*: (1) body length (mm) (calibrated in mm); and (2) horizontal tergite width (mm). These basic descriptive figures were statistically tested for normality using a Kolmogorov-Smirnov Test Calculator. The D values of length and width was shown from extracted and published data for *B. bricki*, *D. annulipes*, *H. spirobolina*, *J. hilaris, J. panda* and *O. tabulinus* (Schubart, 1966). The factors were compared using a t-test for independent means or Mann-Whitney U-test depending on if the data was parametric or non-paramentric, respectively.

3 Results

In 6 tests of male and female widths and lengths the following were found:

B. brincki Schubart, 1966

Mean male length was 93.28571 mm (SD=10.111286) and was normal (D=0.28694; p=0.52037; n=7). Mean female length was 83.75 mm (SD=18.468119) and was normal (D=0.20156; p=0.84199; n=6). Mean male width was 5.92857 mm (SD=3.173551) and was normal (D=0.25091; p=0.29003; n=7). Mean female width was 5.9375 mm (SD=2.88603) and was normally distributed (D=0.14811; p=0.82514; n=7). Widths were not different (t=0.00807; p=0.496809; n=13). Lengths were significantly different (t=1.79492; p=0.04797; n=13).

D. annulipes Carl, 1917

Tests of male and female widths and lengths all were normal. Mean male length was 104.1667 mm (SD=14.972196) and was normal (D=0.19567; p=0.94162; n=6). Mean female length was 89.28571 mm (SD=26.367368) and was normal (D=0.21382; p=0.84574; n=7). Mean male width was 5.5 mm (SD=3.580249) and was normal (D=0.18377; p=0.74842; n=6). Mean female width was 5.92857 mm (SD=2.37403) and was normally distributed (D=0.16272; p=0.79716; n=7). Male length differed from female length (t=1.46963; *p*=0.084837; n=13). Male widths and female widths were not different (t=-0.32851; p=0.37686; n=13).

H. spirobolina (Karsch, 1881)

Tests of male and female widths and lengths all were normal. Mean male length was 71.66667 mm (SD=8.062258) and was normal (D=0.30483; p=0.53458; n=6). Mean female length was 79 mm (SD=9.617692) and was normal (D=0.15725; p=0.99764; n=5). Mean male width was 4.41667 mm (SD=2.712206) and was normal (D=0.25676; p=0.34669; n=6). Mean female width was 5,9 mm (SD=3.17805) and was normally distributed (D=0.24239; p=0.52305; n=5). Widths were not different (t=1.26653; p= 0.109937; n=11). Lengths were significantly different (t=-1.61942; p=0.069905; n=11).

J. hilaris Attems, 1928

Tests of male and female widths and lengths all were normal. Mean male length was 26.2 (SD=3.563706) and was normal (D=0.2834; p=0.72834; n=5). Mean female length was 27.8 mm (SD=5.215362) and was normal (D=0.21604; p=0.93275; n=5). Mean Male width was 2.4 mm (SD=1.349897) and was normal (D=0.32261; p=0.19988; n=5). Mean female width was 3.7 mm (SD=2.668749) and was normally distributed (D=0.30891; p=0.24086; n=5). Widths were different (t=-1.37457; p=0.093069; n=10). Lengths were not significantly different (t=-0.56639; p=0.29333; n=10).

J. panda (Attems, 1928)

Tests of male and female widths and lengths all were normal. Mean male length was 32 mm (SD=3.807887) and was normal (D=0.32147; p=0.57919; n=5). Mean female length was 37.8 mm (SD=2.280351) and was normal (D=0.25963; p=0.8136; n=5). Mean Male width was 4 mm (SD=2.905933) and was normal (D=0.26592; p=0.40748; n=5). Mean female width was 2.7 mm (SD=1.418136) and was normally distributed (D=0.28823; p=0.31349; n=5). Widths were not different (t=1.27136; p=0.109891). Lengths were significantly different (t=-2.922; p=0.009616; n=10).

O. tabulinus (Attems, 1914)

Tests of male and female widths and lengths all were normal. Mean male length was 63.4 375 mm (SD=16.124515) and was normal (D=0.21459; p=0.39631; n=16). Mean female length was 70.25 mm (SD=13.325381) and was normal (D=0.19271; p=0.39686; n=20). Mean male width was 5.09375 mm (SD=1.731719) and was normal (D=0.18187; p=0.21297; n=16). Mean female width was 4.95 mm (SD=2.489851) and was not normally distributed (D=0.2666; *p*=0.00529; n=20). Widths were not different (U=588; z=0.58362; p=0.28096). Lengths were significantly different (U=103; z=1.79872; p=0.03593).

4 Discussion

The normality of length and width of the two sexes in this species is a finding which successfully confirms the analysis of previous data sets and allows predictive power for the morphological data set in the 6 juliform genera. SSD was found based on length only. The finding does not entirely support studies which shows the size of Juliformia "has two main components: body diameter and number of" rings but includes length as a third component of Juliform size (Enghoff, 1992; Ilić et al., 2017). Other correlates of Juliform size include oxygen consumption, precipitation and temperature (Dwarakanath, 1971; Penteado et al., 1991; Echeverría et al., 2014). Size criteria are useful for determining species of Juliformia diplopods (Cooper, 2014-2019). The present research has illustrated what the minimum sizes of data sets need to be in order to be useful for determining sex of juliforms.

Acknowledgements

The author is grateful to the University of Stellenbosch for Interlibrary loans.

References

Aarde RJ van, Ferreira SM, Kritzinger JJ. 1996. Millipede communities in rehabilitating coastal dune forests in northern KwaZulu/Natal, South Africa. Journal of Zoology, 238(4): 703-712

Aarde RJ van, Ferreira SM, Kritzinger JJ. 1996. Successional changes in rehabilitating coastal dune communities in northern KwaZulu/Natal, South Africa. Landscape and Urban Planning, 34(3-4): 277-286

Aarde RJ van, Ferreira SM, Kritzinger JJ, Dyk PJ van, Vogt M, Wassenaar TD. 1996. An evaluation of habitat rehabilitation on coastal dune forests in northern KwaZulu-Natal, South Africa. Restoration Ecology, 4(4): 334-345

Barnett M, Telford SR. 1993. The functional morphology of gonopods as evidence for sperm competition in savannah millipedes. In: Abstracts, 9th International Congress of Myriapodology, Paris, France, 26-31.07.1993: 11

Barnett M, Telford SR. 1994. The timing of insemination and its implications for sperm competition in a millipede with prolonged copulation. Animal Behaviour, 48(2): 482-484

Barnett M, Telford SR. 1996. Sperm competition and the evolution of millipede genitalia. In: Acta Myriapodologica. Mémoires du Muséum national d'histoire naturelle (Geoffroy JJ, Mauriès JP, Nguyen DuyJacquemin M, eds), N. S. 169: 331-339

Barnett M, Telford SR, Tibbles BJ. 1995. Female mediation of sperm competition in the millipede *Alloporus uncinatus* (Diplopoda: Spirostreptidae). Behavioral Ecology and Sociobiology, 36(6): 413-419

Barnett M, Telford SR, Villiers CJ de. 1993. Sperm displacement in a millipede? An investigation into the genital morphology of the southern African spirostreptid millipede *Orthoporus pyrhocephalus*. Journal of Zoology, 231(3): 511-522

Cooper MI. 2014. Sex ratios, mating frequencies and relative abundance of sympatric millipedes in the genus *Centrobolus* Cook. Arthropods, 3(4): 174-176

Cooper MI. 2014. Sexual size dimorphism and corroboration of Rensch's rule in *Chersastus* millipedes (Diplopoda: Trigoniulidae). Journal of Entomology and Zoology Studies, 2(6): 264-266

Cooper MI. 2015. Competition affected by re-mating interval in a myriapod. Journal of Entomology and Zoology Studies, 3(4): 77-78

Cooper MI. 2015. Elaborate gonopods in the myriapod genus *Chersastus.* Journal of Entomology and Zoology Studies, 3(4): 235-238

Cooper M. 2016. Post-insemination associations between males and females in Diplopoda. Journal of Entomology and Zoology Studies, 4(2): 283-285

Cooper MI. 2016. Confirmation of four species of *Centrobolus* Cook based on gonopod ultrastructure. International Journal of Entomology Research, 1(3): 7-9

Cooper MI. 2016. Confirmation of four species of *Centrobolus* Cook based on gonopod ultrastructure. Journal of Entomology and Zoology Studies, 4(4): 389-391

Cooper MI. 2016. Do females control the duration of copulation in the aposematic millipede *Centrobolus inscriptus*? Journal of Entomology and Zoology Studies, 4(6): 623-625

Cooper MI. 2016. Fire millipedes obey the female sooner norm in cross mating *Centrobolus* Cook. Journal of Entomology and Zoology Studies, 4(1): 173-174

Cooper MI. 2016. Gonopod mechanics in *Centrobolus* Cook. Journal of Entomology and Zoology Studies, 4(2): 152-154

Cooper MI. 2016. Heavier-shorter-wider females in the millipede *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(2): 509-510

Cooper MI. 2016. Instantaneous insemination in the millipede *Centrobolus inscriptus* (Attems) determined by artificially terminated mating. Journal of Entomology and Zoology Studies, 4(1): 487-490

Cooper MI. 2016. Sexual bimaturism in the millipede *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(3): 86-87

Cooper MI. 2016. Sexual conflict over the duration of copulation in *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(6): 852-854

Cooper MI. 2016. Sperm dumping in *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(4): 394-395

Cooper MI. 2016. Sperm storage in *Centrobolus* Cook and observational evidence for egg simulation. Journal of Entomology and Zoology Studies, 4(1): 127-129

Cooper MI. 2016. Sperm storage in *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(4): 392-393

Cooper MI. 2016. Symmetry in ejaculate volumes of *Centrobolus inscriptus* (Attems). International Journal of Entomology Research, 1(2): 14-15

Cooper MI. 2016. Symmetry in ejaculate volumes of *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(1): 386-387

Cooper MI. 2016. Syncopulatory mate-guarding affected by predation in the aposematic millipede *Centrobolus inscriptus* in a swamp forest. Journal of Entomology and Zoology Studies, 4(6): 483-484

Cooper MI. 2016. Tarsal pads of *Centrobolus* Cook. Journal of Entomology and Zoology Studies, 4(3): 385-386

Cooper MI. 2016. The influence of male body mass on copulation duration in *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 4(6): 804-805

Cooper MI. 2016. The relative sexual size dimorphism of *Centrobolus inscriptus* compared to 18 congenerics. Journal of Entomology and Zoology Studies, 4(6): 504-505

Cooper MI. 2017. The effect of female body width on copulation duration in *Centrobolus inscriptus* (Attems). Journal of Entomology and Zoology Studies, 5(1): 732-733

Cooper MI. 2017. Size matters in myriapod copulation. Journal of Entomology and Zoology Studies, 5(2): 207-208

Cooper MI. 2017. Relative sexual size dimorphism in *Centrobolus digrammus* (Pocock) compared to 18 congenerics. Journal of Entomology and Zoology Studies, 5(2): 1558-1560

Cooper MI. 2017. Relative sexual size dimorphism in *Centrobolus fulgidus* (Lawrence) compared to 18 congenerics. Journal of Entomology and Zoology Studies, 5(3): 77-79

Cooper MI. 2017. Relative sexual size dimorphism *Centrobolus ruber* (Attems) compared to 18 congenerics. Journal of Entomology and Zoology Studies, 5(3): 180-182

Cooper MI. 2017. Allometry of copulation in worm-like millipedes. Journal of Entomology and Zoology Studies, 5(3): 1720-1722

Cooper MI. 2017. Copulation and sexual size dimorphism in worm-like millipedes. Journal of Entomology and Zoology Studies, 5(3): 1264-1266

Cooper M. 2017. Re-assessment of rensch's rule in *Centrobolus.* Journal of Entomology and Zoology Studies, 5(6): 2408-2410

Cooper MI. 2018. Allometry for sexual dimorphism in millipedes (Diplopoda). Journal of Entomology and Zoology Studies, 6(1): 91-96

Cooper MI. 2018. Sexual dimorphism in pill millipedes (Diplopoda). Journal of Entomology and Zoology Studies, 6(1): 613-616

Cooper MI. 2018. Sexual size dimorphism and the rejection of Rensch's rule in Diplopoda (Arthropoda). Journal of Entomology and Zoology Studies, 6(1): 1582-1587

Cooper M. 2018. Trigoniulid size dimorphism breaks Rensch. Journal of Entomology and Zoology Studies, 6(3): 1232-1234

Cooper M. 2018. A review of studies on the fire millipede genus *Centrobolus* (Diplopoda: Trigoniulidae). Journal of Entomology and Zoology Studies, 6(4): 126-129

Cooper MI. 2018. Volumes of *Centrobolus albitarsus* (Lawrence, 1967). International Journal of Entomology Research, 3(4): 20-21

Cooper M. 2018. *Centrobolus anulatus* reversed sexual size dimorphism. Journal of Entomology and Zoology Studies, 6(4): 1569-1572

Cooper M. 2018. *Centrobolus* size dimorphism breaks Rensch's rule. Arthropods, 7(3): 48-52

Cooper M. 2018. *Centrobolus dubius* (Schubart, 1966) monomorphism. International Journal of Research Studies in Zoology, 4(3): 17-21

Cooper M. 2018. *Centrobolus lawrencei* (Schubart, 1966) monomorphism. Arthropods, 7(4): 82-86

Cooper M. 2018. *Centrobolus sagatinus* sexual size dimorphism based on differences in horizontal tergite width. Journal of Entomology and Zoology Studies, 6(6): 275-277

Cooper M. 2018. Allometry in *Centrobolus.* Journal of Entomology and Zoology Studies, 6(6): 284-286

Cooper M. 2018. *Centrobolus silvanus* dimorphism based on tergite width. Global Journal of Zoology, 3(1): 003005

Cooper M. 2019. A review on studies of behavioural ecology of *Centrobolus* (Diplopoda, Spirobolida, Pachybolidae) in southern Africa. Arthropods, 8(1): 38-44

Cooper MI, Telford SR. 2000. Copulatory sequences and sexual struggles in millipedes. Journal of Insect

Behavior, 13(2): 217-230

David J-F. 1995. Size criteria for the distinction between *Cylindroiulus londinensis* (Leach) and *Cylindroiulus caeruleocinctus* (Wood) (Diplopoda: Julidae). Journal of Natural History, 29(4): 983-991

Dwarakanath SK. 1971. The influence of body size and temperature upon the oxygen consumption in the millipede, *Spirostreptus asthenes* (Pocock). Comparative Biochemistry and Physiology Part A: Physiology, 38(2): 351-358

Echeverría KS, Ignacio C, Bueno-Villegas J. 2014. Relationship between millipede body size (Polydesmida: Xystodemidae: Rhysodesmus) and altitude, latitude, precipitation and temperature. 16th International Conference of Myriapodology

Enghoff H. 1992. The Size of a Millipede. Berichte der naturhistorisch-medizinischen Vereins Innsbruck, Supplement, 10

Hopkin SP, Read HJ. 1992. The Biology of Millipedes. Oxford University Press, Oxford, UK

Ilić B, Mitić B, Makarov S. 2017. Sexual dimorphism in *Apfelbeckia insculpta* (L. Koch, 1867) (Myriapoda: Diplopoda: Callipodida). Archives of Biological Sciences, 69(1): 23-3

Mauritz B. 2011. Ecology of the Namaqua Dwarf Adder, *Bitis schneideri*. Dissertation. University of the Witwatersrand, South Africa

Penteado CHS, Hebling-Beraldo MJA, Mendes EG. 1991. Oxygen consumption related to size and sex in the tropical millipede *Pseudonannolene tricolor* (Diplopoda, Spirostreptida), Comparative Biochemistry and Physiology Part A: Physiology, 98(2): 265-269

Schubart O. 1966. Diplopoda III. In: South African Animal Life, 12: 1-227

Telford SR, Dangerfield JM. 1990. Manipulation of the sex ratio and duration of copulation in the tropical millipede Alloporus uncinatus: a test of the copulatory guarding hypothesis. Animal Behaviour, 40(5): 984-986

Telford SR, Dangerfield JM. 1990. Sex in millipedes: Laboratory studies on sexual selection. Journal of Biological Education, 24: 233-238

Telford SR, Dangerfield JM. 1993. Mating behaviour and mate choice experiments in some tropical millipedes (Diplopoda: Spirostreptidae). South African Journal of Zoology, 28(3): 155-160

Telford SR, Dangerfield JM. 1993. Mating tactics in the tropical millipede *Alloporus uncinatus* (Diplopoda: Spirostreptidae). Behaviour, 124(1-2): 45-56

Telford SR, Dangerfield JM. 1993. Millipedes mating systems. In: Abstracts, 9th International Congress of Myriapodology, Paris, France, 26-31.07.1993: 82

Telford SR, Dangerfield JM. 1994. Males control the duration of copulation in the tropical millipede *Alloporus uncinatus* (Diplopoda: Julida). South African Journal of Zoology, 29(4): 266-268

Telford SR, Dangerfield JM. 1996. Sexual selection in savanna millipedes: products, patterns and processes. In: Acta Myriapodologica - Mémoires du Muséum national d'histoire naturelle (Geoffroy JJ, Mauriès JP, Nguyen DuyJacquemin M, eds), N. S. 169: 565-576

Telford SR, Webb PI. 1998. The energetic cost of copulation in a polygynandrous millipede. Journal of Experimental Biology, 201(11): 1847-1849

Webb PI, Telford SR. 1995. Energy and water balance in the large sub-tropical millipede *Alloporus bilobatus* (Diplopoda: Spirostreptidae). Journal of Insect Physiology, 41(5): 389-393