International Journal of Engineering Science Invention Research & Development; Vol. 11, Issue 5, November 2024
www.ijesird.com, E-ISSN: 2349-6185

MODEL OF MANTLE IRIDOSOME DIAMETER (VARIATION), BODY MASS, TERRITORY SIZES AND (FEMALE-BIASED) SEX RATIOS IN GREEN AND VIOLET WOODHOOPOES (CORACIFORMES: PHOENICULIDAE)

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Abstract. **A model was tested between group and territory size as well as sex ratio and microscopic size in green and violet woodhoopoe mantle iridosome diameters (and variation) of mantle feathers when controlling for body mass. Differences between outer iridophore diameters from Green Woodhoopoe *P. p. purpureus* barbules (0.22± 0.03 µm, n = 244) recorded at Morgan Bay were marginally smaller (relatively) than those from violet barbules (0.28 ± 0.04 µm, n = 248) recorded in Namibia (Z test: P-value=0.054511, Z score=-1.602605, n= 2, 2). Variation in outer iridophore diameters from *P. p. purpureus* barbules were relatively smaller than those from violet barbules (Z-test: P-value=0.018736, Z score=-2.080577). Sex ratio was related to outer iridosome diameter (Pearson's r=-0.65328501, Z score=-1.74638743, n=8, p=0.04037178) and variation of outer iridosome diameter (Pearson's r=0.77431978, Z score=2.30544574, n=8, p=0.01057078). Results of the multiple linear regression indicated that there was an effect between the sex ratio, territory size, and outer iridosome diameter variation, (F(1, 6) = 8.98, p = 0.024, R^2 = 0.6, R^2adj = 0.53) and indicated that there was an effect between the outer iridosome diameter variation, outer iridosome diameter, and sex ratio, (F(2, 9) = 138.48, p < 0.001, R^2 = 0.97, R^2adj = 0.96). Outer iridosome diameter variation (t = 11.154, p < 0.001) and iridosome diameter (t = -9.661, p < 0.001) were significant predictors in the model. There was a very strong collective significant effect between the sex ratio, outer iridosome variation divided by male body mass, and outer iridosome size divided by male body mass, (F(1, 2) = 3.709058206e+28, p < 0.001, R^2 = 1, R^2adj = 1) and sex ratio, outer iridosome variation divided by female body mass, and outer iridosome size divided by female body mass, (F(1, 2) = 4.094448214e+27, p < 0.001, R^2 = 1, R^2adj = 1). There was an effect between the sex ratio, territory size, and male body mass, (F(1, 2) = 48.12, p = 0.020, R^2 = 0.96, R^2adj = 0.94). There was an effect between the iridosome outer diameter, territory size, and sex ratio, (F(1, 2) = 48.12, p = 0.020, R^2 = 0.96, R^2adj = 0.94), and between the iridosome diameter variation, territory size, and sex ratio, (F(1, 2) = 48.12, p = 0.020, R^2 = 0.96, R^2adj = 0.94) independent of body mass. The effect between the body mass, outer iridosome variation, and outer iridosome size is possibly due to allometry.**

Keywords: **allometry, mass, ratio, sex, territory, *Phoeniculus*, woodhoopoe.**

I. INTRODUCTION

The Namibian Violet Woodhoopoe *Phoeniculus damarensis damarensis* is an arid near endemic with a partially resolved taxonomic status [1, 2, 3]. It is closely related to the Green Woodhoopoe *Phoeniculus purpureus* yet differs in mass and mantle feather colouration [1, 3]. Differences between outer iridophore diameters from Green Woodhoopoe *P. p. purpureus* barbules recorded at Morgan Bay were thought to be smaller (relatively) than those from violet barbules recorded in Namibia but their variation has not been properly studied [3]. Here I provide some resolution to the status of the Violet Woodhoopoe *P. damarensis* in comparison with the Green Woodhoopoe *P. purpureus*, using microscopic details of mantle feathers across territory and group sizes as well as sex ratio.

II. MATERIALS AND METHODS

Mantle feathers were sampled from netted live Violet (Namibia: Hobatere and Omaruru; n = 9) and a dead Green Woodhoopoe (Morgan Bay; n = 1) in 1999. Mantle feathers were soaked for 30 minin 0.25M NaOH, followed by 2 hours in formic acid: EtOH (2:3 v/v) and 3 days in 15% (v/v) Spurr's resin in propylene oxide. They were then embedded in Spurr's resin. Both transverse and longitudinal sections of the barbules were cut, revealing that the iridophores of both species were hollow prolate cylinders. Iridophore cylinder widths were measured and correlated with group and territory sizes as well as sex ratios using Correlation Coefficient Calculators (https://www.gigacalculator.com/calculators/correlation-coefficient-calculator.php).
Measurements of the outer iridosome diameter of Green feathers from the Morgan Bay bird were compared with those from a Hobatere bird and an Omaruru bird. Next I controlled for

species and produced a correlation of mean outer iridosome diameters divided by body mass with group size and territory size as well as sex ratio. Territory sizes, group sizes (and there variations) and sex ratios were given in [10]. The P-value calculator was used to confirm differences in outer iridosome diameter variation between green and violet woodhoopoes when controlling for body mass at https://www.gigacalculator.com/calculators/p-value-significance-calculator.php. I controlled for group size and body mass. (Appendix 1-10). Multivariate Statistical Ananlysis (Multiple Linear Regressions) were used to confirm the results at https://www.statskingdom.com/410multi_linear_regression.html. Live mass from *P. purpureus* adult males (84.8±8.45g; n=139) and adult females (72.9±11.0g, n=128) and *P. damarensis* adult males (91.3±8.84g, n=5) and adult females (77.6±11.2g, n=6) were previously calculated [1].

III. RESULTS

Variation in iridosome outer diameter

Variation in outer iridophore diameters from Green Woodhoopoe *P. p. purpureus* barbules (0.22± 0.03 µm, n = 244) recorded at Morgan Bay were relatively smaller than those from violet barbules (0.28 ± 0.04 µm, n = 248) recorded in Namibia (Z-test: P-value=0.018736, Z score=-2.080577).

Territory size (variation)

Mantle feathers and iridophores from Namibian Violet Woodhoopoe *P. damarensis* and Green Woodhoopoe *P. p. purpureus* vary according to territory size (Figure 1). Birds identified as *P. d. damarensis* had predominantly violet mantles. The difference between woodhoopoe species is a marginal correlation between outer diameter and territory size (Pearson's r=-0.61558701, Z score=-1.55910986, n=8, p=0.05948520), when the outer diameters were divided by body mass. Outer diameters did correlate with mean body mass (r=0.40824829, Z score=20000, n=4, p=0). Territory sizes appear different between violet (Mean=12.3ha, n=1) and green (Mean=36.533333ha) (Z-test: P-value=0.001182, Z score=3.040244, n=2, 3). Standard deviations of territory size were marginally related to outer iridosome diameters (Spearman r=-0.61558701, Z score=-1.55910986, n=8, p=0.05948520). Territory sizes were marginally correlated with standard deviations in outer iridosome diameter (Spearman's r=-0.61558701, Z score=-1.55910986, n=8, p=0.05948520). Standard deviations in territory sizes were marginally related to standard deviations in outer iridosome diameter (Spearman's r=-0.61558701, Z score=-1.55910986, n=8, p=0.05948520).

Group size (variation)

Mean group size was related to standard deviation in outer iridosome diameter (Kendall's τ=0.23640271, Z score=130000, n=12, p=0) and outer iridosome diameter (Kendall's τ=0.23640271, Z score=130000, n=12, p=0). Mean group size was not relatively different between violet (Mean=4.266667) and green (Mean=3.966667) woodhoopoes (Z-test: P-value=0.292675, Z score=-0.545587, n=3, 3). Mean group size variation was related to outer iridosome diameter (Kendall's τ=0.14547859, Z score=80000, n=12, p=0) (Pearson's r=-0.44960117, Z score=-1.45260088, n=12, p=0.07316734). Mean group size variation was related to standard deviation in outer iridosome diameter (Kendall's τ=-0.14547859, Z score=-80000, n=12, p=0) (Pearson's r=0.49327678, Z score=1.62114483, n=12, p=0.05). Group size variation was relatively diffferent between violet (Mean=2.333333) and green woodhoopoes (Mean=1.566667) (Z-test: P-value=0.047677, Z score=-1.667806, n=3, 3).

Sex ratio

Sex ratio was related to outer iridosome diameter (Pearson's r=-0.65328501, Z score=-1.74638743, n=8, p=0.04037178) and variation thereof (Pearson's r=0.77431978, Z score=2.30544574, n=8, p=0.01057078). Sex ratios were different between violet (Mean=1.13, n=2); 1.26 (n=1) plus an equal sex ratio variable

(1.0, n=1) compared to green (Mean=0.826667, n=3) (Z-test: P-value=0.045722, Z score=-1.687832, n=2, 3). P-value absolute differences were found between variation in green and violet woodhoopoe outer iridosome diameters when controlling for body mass (Z-test: P-value=0.025554, Z score=-1.950563, n= 2, 2). P-value relative differences were found between variation in green and violet woodhoopoe outer iridosome diameters when controlling for body mass (Z-test: P-value=0.018736, Z score=-2.080577, n= 2, 2). Sex ratio was related to variation in group size [10] (Pearson's r=0.57617593, Z score=1.97015767, n=12, p=0.02441008) when the Namibian violet woodhoopoe sex ratio was controlled.

Multivariate Statistical Analysis

Results of the multiple linear regression indicated that there was a strong collective significant effect between the sex ratio, territory size, and outer iridosome diameter variation, ($F(1, 6) = 8.98$, $p = 0.024$, $R^2 = 0.6$, $R^2adj = 0.53$) and indicated that there was a strong collective significant effect between the outer iridosome diameter variation, outer iridosome diameter, and sex ratio, ($F(2, 9) = 138.48$, $p < 0.001$, $R^2 = 0.97$, $R^2adj = 0.96$). The individual predictors were examined further and indicated that outer iridosome diameter variation ($t = 11.154$, $p < 0.001$) and iridosome diameter ($t = -9.661$, $p < 0.001$) were significant predictors in the model. Results of the multiple linear regression indicated that there was a very strong collective significant effect between the sex ratio, outer iridosome variation divided by male body mass, and outer iridosome size divided by male body mass, ($F(1, 2) = 3.709058206e+28$, $p < 0.001$, $R^2 = 1$, $R^2adj = 1$) and sex ratio, outer iridosome variation divided by female body mass, and outer iridosome size divided by female body mass, ($F(1, 2) = 4.094448214e+27$, $p < 0.001$, $R^2 = 1$, $R^2adj = 1$).

Differences in iridosome outer diameters

Differences between outer iridophore diameters from Green Woodhoopoe *P. p. purpureus* barbules (0.22± 0.03 µm, n = 244) recorded at Morgan Bay were marginally smaller (relatively) than those from violet barbules (0.28 ± 0.04 µm, n = 248) recorded in Namibia (Z test: P-value=0.054511, Z score=-1.602605, n= 2, 2). There were no male-female differences between iridosome outer diameters (Z test: P-value=0.453735, Z score=0.116229, n= 2, 2). There were no male-female differences between iridosome outer diameters variation (Z test: P-value=0.452185, Z score=0.120143, n= 2, 2).

Body mass

Results of the multiple linear regression indicated that there was a very strong collective significant effect between the sex ratio, territory size, and male body mass, ($F(1, 2) = 48.12$, $p = .020$, $R^2 = 0.96$, $R^2adj = 0.94$). Results of the multiple linear regression indicated that there was a very strong collective significant effect between the body mass, outer iridosome variation, and outer iridosome size, ($F(1, 2) = 2.076918743e+28$, $p < 0.001$, $R^2 = 1$, $R^2adj = 1$).

Body mass variation

Results of the multiple linear regression indicated that there was a very strong collective significant effect between the body mass variation, territory size, and territory size variation, ($F(1, 6) = 29.41$, $p = 0.002$, $R^2 = 0.83$, $R^2adj = 0.8$). Results of the multiple linear regression indicated that there was a moderate collective significant effect between the body mass variation, group size, and group size variation, ($F(1, 10) = 5.55$, $p = .040$, $R2 = 0.36$, $R2adj = 0.29$). Results of the multiple linear regression indicated that there was a very strong collective significant effect between the body mass variation, body mass, and sex ratio, ($F(2, 5) = 30.96$, $p = .002$, $R2 = 0.93$, $R2adj = 0.9$). The individual predictors were examined further and indicated that body mass variation ($t = 7.305$, $p < .001$) and body mass ($t = 7.826$, $p < .001$) were significant predictors in the model.

Differences independent of mass

Results of the multiple linear regression indicated that there was a very strong collective significant effect between the iridosome outer diameter, territory size, and sex ratio, (F(1, 2) =

48.12, $p = 0.020$, $R^2 = 0.96$, $R^2adj = 0.94$), and between the iridosome diameter variation, territory size, and sex ratio, ($F(1, 2) = 48.12$, $p = 0.020$, $R^2 = 0.96$, $R^2adj = 0.94$).

Sex-ratio bias

Results of the multiple linear regression indicated that there was a weak collective non significant effect between the iridosome outer diameter, territory size, and male-biased sex ratios, ($F(1, 2) = 0.29$, $p = 0.647$, $R^2 = 0.12$, $R^2adj = -0.31$) and between the iridosome outer diameter variation, territory size, and male-biased sex ratios, ($F(1, 2) = 0.29$, $p = 0.647$, $R^2 = 0.12$, $R^2adj = -0.31$).

IV. DISCUSSION

Larger iridosome outer diameters were associated with smaller territory sizes, and female-biased sex ratios, which is important because there are significant differences in outer iridosome diameters between Namibian and South African birds. The converse could be true and smaller iridosome outer diameters may be associated with larger territory sizes, and male-biased sex ratios. Hence, examination of mantle feathers from woodhoopoes suggests a marginal negative correlation between outer iridosome diameter variation and territory size [3]. A model of latitudinal and longitudinal gradients can account for differences between iridophore diameters [4-6, 8], differences that may be enough to distinguish green from violet woodhoopoes. This study reveals woodhoopoes mantles have consequences for energy expenditure [9]. Closer examination of rainfall and temperature and a comparison among woodhoopoes from different latitudes have assisted in reconciliation of the differences in outer iridosome diameter variation with group and territory sizes as well as (female-biased) sex ratio [5, 7]. Larger iridosome outer diameters were associated with smaller territory sizes, and female-biased sex ratios, and larger iridosome outer diameter variation was also associated with smaller territory sizes, and perhaps male-biased sex ratios. The effect between the iridosome outer diameter, territory size, and female-biased sex ratio, and between the iridosome diameter variation, territory size, and female-biased sex ratio, independent of body mass is significant as is the effect between the female-biased sex ratio, territory size, and male body mass [11].

V. CONCLUSION

Examination of mantle feathers from woodhoopoes suggests territorial and (female-biased) sex ratio gradients with the outer iridosome diameter (variation).

ACKNOWLEDGEMENTS

Trevor Sewell provided comments on the manuscript.

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Appendix 1. Territory size (ha) versus outer iridosome diameter (µm) / body mass (male then female) in *Phoeniculus damarensis* (first two) and *P. purpureus* (last six).
12.3, 0.00306681271
12.3, 0.00360824742
51.0, 0.00301783265
51.0, 0.00259433962
35.1, 0.00301783265
35.1, 0.00259433962
23.5, 0.00301783265
23.5, 0.00259433962.

Appendix 2. Variation in territory size (ha) versus outer iridosome diameter (µm) / body mass (male then female) in *Phoeniculus damarensis* (first two) and *P. purpureus* (last six).
3.0, 0.00306681271
3.0, 0.00360824742
28.1, 0.00301783265
28.1, 0.00259433962
8.0, 0.00301783265
8.0, 0.00259433962
4.2, 0.00301783265
4.2, 0.00259433962.

Appendix 3. Territory size versus variation (ha) in outer iridosome diameter (µm) / body mass (male then female) in *Phoeniculus damarensis* (first two) and *P. purpureus* (last six).
12.3, 0.000438116101
12.3, 0.000515463918
51.0, 0.000411522634
51.0, 0.000353773585
35.1, 0.000411522634
35.1, 0.000353773585
23.5, 0.000411522634
23.5, 0.000353773585.

Appendix 4. Variation in territory size (ha) versus variation in outer iridosome diameter (µm) / body mass (male then female) in *Phoeniculus damarensis* (first two) and *P. purpureus* (last six).
3.0, 0.000438116101
3.0, 0.000515463918
28.1, 0.000411522634
28.1, 0.000353773585
8.0, 0.000411522634
8.0, 0.000353773585
4.2, 0.000411522634
4.2, 0.000353773585.

Appendix 5. Mean group size versus outer iridosome diameter (µm) / body mass (male then female) in *Phoeniculus damarensis* (first six) and *P. purpureus* (second six).
4.3, 0.00306681271
4.3, 0.00360824742
4.3, 0.00306681271
4.3, 0.00360824742
4.2, 0.00306681271
4.2, 0.00360824742
4.9, 0.00259433962
4.9, 0.00301783265
4.0, 0.00259433962
4.0, 0.00301783265
3.0, 0.00259433962
3.0, 0.00301783265.

Appendix 6. Mean group size versus variation in outer iridosome diameter (µm) / body mass

(male then female) in *Phoeniculus damarensis* (first six) and *P. purpureus* (second six).
4.3, 0.000438116101
4.3, 0.000515463918
4.3, 0.000438116101
4.3, 0.000515463918
4.2, 0.000438116101
4.2, 0.000515463918
4.9, 0.000353773585
4.9, 0.000411522634
4.0, 0.000353773585
4.0, 0.000411522634
3.0, 0.000353773585
3.0, 0.000411522634.

Appendix 7. Group size variation verus outer iridosome diameter (µm) / body mass (male then female) in *Phoeniculus damarensis* (first six) and *P. purpureus* (second six).
1.6, 0.00259433962
1.6, 0.00301783265
3.0, 0.00259433962
3.0, 0.00301783265
2.4, 0.00259433962
2.4, 0.00301783265
2.1, 0.00306681271
2.1, 0.00360824742
1.5, 0.00306681271
1.5, 0.00360824742
1.1, 0.00306681271
1.1, 0.00360824742.

Appendix 8. Group size variation verus outer iridosome diameter variation (µm) / body mass (male then female) in *Phoeniculus damarensis* (first six) and *P. purpureus* (second six).
1.6, 0.000438116101
1.6, 0.000515463918
3.0, 0.000438116101
3.0, 0.000515463918
2.4, 0.000438116101
2.4, 0.000515463918
2.1, 0.000353773585
2.1, 0.000411522634
1.5, 0.000353773585
1.5, 0.000411522634
1.1, 0.000353773585
1.1, 0.000411522634.

Appendix 9. Female-biased sex ratio versus outer iridosome diameter (µm) / body mass (male then female) in *Phoeniculus damarensis* (first two) and *P. purpureus* (last six).
1.26, 0.00259433962
1.26, 0.00301783265
0.67, 0.00306681271
0.67, 0.00360824742
0.80, 0.00306681271
0.80, 0.00360824742
0.71, 0.00306681271
0.71, 0.00360824742.

Appendix 10. Female-biased sex ratio versus outer iridosome diameter variation (µm) / body mass (male then female) in *Phoeniculus damarensis* (first two) and *P. purpureus* (last six).
1.26, 0.000438116101
1.26, 0.000515463918
0.67, 0.000353773585
0.67, 0.000411522634
0.80, 0.000353773585
0.80, 0.000411522634
0.71, 0.000353773585
0.71, 0.000411522634.