Comparison of Physical Characteristics, Avian Clutch Size, and Mating Tactics

https://github.com/jcf55/Fahrenholz_Costes_ENV872_EDA_FinalProject

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1 Rationale and Research Questions

According to the study from which this data was extracted, avian body size and the evolution of birds over time is a subject matter that has generated much debate. Generally, there is agreement around the idea that body size of bird species relates to other characteristics, but the role of evolution continues to be disputed. This project intends to explore the correlation between tail length and other characteristics in our data.

First, we ask the question if female tail length predicts clutch size. Tail length has a significant impact on control and agility (Evans 1999). Longer tails increase crash risk as well as reduce the ability to maneuver (Evans 1999). We believe that tail length may have an overall negative impact on clutch size, as birds with longer tail lengths may be less efficient at collecting food for their young.

Second, we will explore interactions between male tail length and methods of display, mating system, and resource sharing systems. As stated above, tail length likely has a negative impact on navigation and collecting food, but male tail length has a positive impact on sexual display for many species. Physical characteristics of males are evaluated by females in search of a mate, but the importance of tail length may vary greatly by species.

2 Dataset Information

Our dataset consists of ornithological data that was collected starting in 2005 and was last updated in January of 2007. Data for this collection come from regions that include:

- Western Palearctic
- Neararctic
- Africa
- Australia
- New Zealand
- Antarctica

The complete dataset (represented by the object `birds`) includes 41 variables and represents 125 families. According to the metadata, the majority of this information was gathered from ornithological handbooks, with some data obtained from personal communications with authors who published information on species bird groups. More information on the sources used can be found at: https://esapubs.org/archive/ecol/E088/096/metadata.htm (also in /Data/Raw in the .tex file)

Figure 1: A male Great Argus (*Argusianus argus*)

3 Exploration of Raw Data

View dimensions, column names, variable type, and head of each column:

```
## 'data.frame':    3769 obs. of  41 variables:
##  $ ï..Family       : int  115 101 116 116 116 116 116 116 116 116 ...
##  $ Species_number  : int  5351 3964 5402 5398 5400 5401 5396 5405 5404 5397 ...
##  $ Species_name    : chr  "Acanthagenys rufogularis" "Acanthisitta chloris" "Acanthiz
##  $ English_name    : chr  "Spiny-cheeked Honeyeater" "Rifleman" "Yellow-rumped Thornb
##  $ Subspecies      : chr  "-999" "-999" "leighi" "ewingii" ...
##  $ M_mass          : num  47.1 5.6 9.4 7.2 7.2 5.8 6.8 7.6 6.5 7.4 ...
##  $ M_mass_N        : int  4 33 25 16 43 16 10 25 27 37 ...
##  $ F_mass          : num  41.4 7 9.8 6.7 6.9 5.7 6.7 7.4 6.3 6.5 ...
##  $ F_mass_N        : int  5 20 16 19 76 12 7 27 23 20 ...
##  $ unsexed_mass    : num  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ unsexed_mass_N  : int  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ M_wing          : num  113.1 47.8 57.8 52.7 48.9 ...
##  $ M_wing_N        : int  25 10 25 21 28 29 11 36 25 52 ...
##  $ F_wing          : num  107.5 51.4 57.6 51 47 ...
##  $ F_wing_N        : num  21 10 26 22 26 25 7 26 29 30 ...
##  $ Unsexed_wing    : num  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ Unsexed_wing_N  : int  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ M_tarsus        : num  26.2 19.1 17.7 21.3 18 18.4 18.5 17.5 17.4 20.3 ...
##  $ M_tarsus_N      : int  10 10 23 21 28 29 11 36 25 51 ...
##  $ F_tarsus        : num  25.7 19.7 17.4 21.7 17.8 17.6 18.4 17.5 17.3 19.3 ...
##  $ F_tarsus_N      : int  5 7 24 23 25 25 7 25 27 29 ...
##  $ Unsexed_tarsus  : num  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ Unsexed_tarsus_N: int  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ M_bill          : num  26.8 13.2 11.9 11 11.3 9.7 11.6 10.2 10 11 ...
##  $ M_bill_N        : int  8 6 24 21 27 28 11 26 24 51 ...
##  $ F_bill          : num  25.5 14.4 11.7 10.9 11.4 9.6 11.2 9.9 10 10.5 ...
##  $ F_bill_N        : num  10 7 26 23 25 24 7 26 28 29 ...
##  $ Unsexed_bill    : num  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ Unsexed_bill_N  : int  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ M_tail          : num  113.4 23.3 40.8 47.8 36.3 ...
##  $ M_tail_N        : int  25 10 28 21 34 28 11 36 14 51 ...
##  $ F_tail          : num  106.4 22.1 39.3 46.8 35.4 ...
##  $ F_tail_N        : int  21 7 26 23 55 25 6 26 10 30 ...
##  $ Unsexed_tail    : num  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ Unsexed_tail_N  : int  -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 ...
##  $ Clutch_size     : num  2.2 4 3.5 3.5 3 3 2.5 3 3 3 ...
##  $ Egg_mass        : num  5.45 1.34 1.44 1.46 1.35 0.93 -999 1.32 1.34 1.4 ...
##  $ Mating_System   : int  2 2 2 2 2 -999 -999 2 2 2 ...
##  $ Display         : int  3 1 1 1 -999 1 -999 2 -999 1 ...
##  $ Resource        : int  2 2 1 0 1 1 -999 0 -999 2 ...
```

```
##  $ References      : chr  "1, 21" "21" "1, 22, 31 " "22, 31" ...
```

4 Data Wrangling

After the raw dataset had been explored, it was wrangled to better suit our analyses. Unavailable datapoints were recoded from "-999" to "NA", to be recognized by R as unavailable. Other variables were re-coded as needed. A genus column was added, and the dataset was modified to include only the following variables:

- Family
- Genus
- Species Name
- Mass (both female and male)
- Tail Length (both female and male)
- Clutch Size
- Mating System
- Display System
- Resource Sharing

This dataset was saved as **"birds.subset"** and used for subsequent analyses. Finally, a second exploratory dataset was created to summarize the variables of interest by family. If further time allowed, the authors would have liked to group by higher taxonomic level, but this information was not readily accessible.

5 Exploration of Processed Data

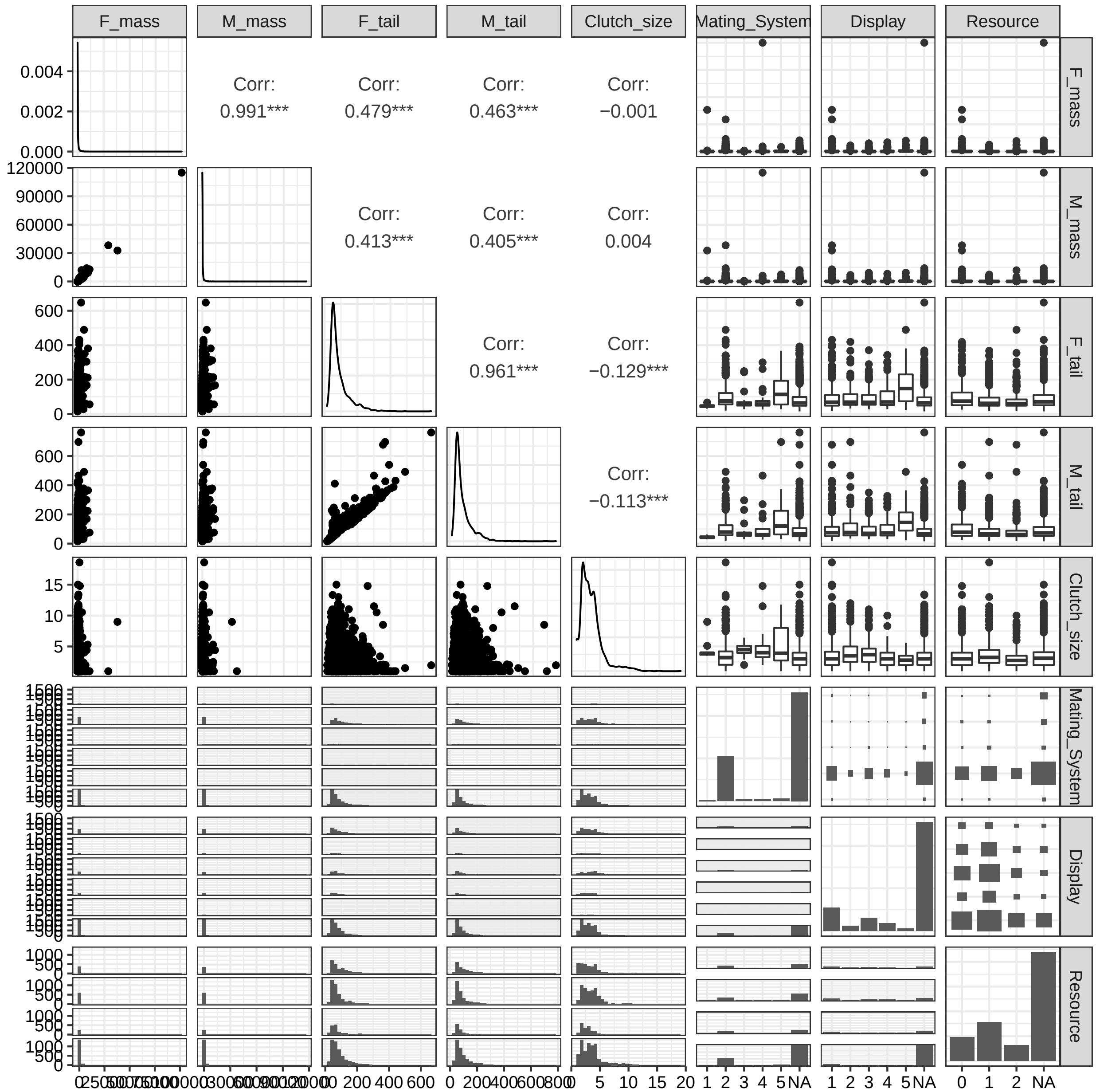


Table 1: Summary Statistics for Continuous Variables

	vars	n	mean	sd	min	max	range	se
F_mass	1	2706	411.472616	2320.49997	1.8	100000.0	99998.2	44.6085053
M_mass	2	2822	436.692275	2585.46747	2.0	115000.0	114998.0	48.6699134
F_tail	3	2352	88.340901	59.91081	15.4	647.5	632.1	1.2353402
M_tail	4	2390	92.410126	64.27592	15.8	762.0	746.2	1.3147688
Clutch_size	5	2392	3.448037	1.88880	1.0	18.6	17.6	0.0386194

Table 2: Summary Statistics for Mating System

Mating_System	freq	pct_valid	pct_tot
1	23	1.888341	0.6102414
2	1057	86.781609	28.0445742
3	36	2.955665	0.9551605
4	46	3.776683	1.2204829
5	56	4.597701	1.4858053
	2551	NA	67.6837357

Table 3: Summary Statistics for Display System

Display	freq	pct_valid	pct_tot
1	549	45.073892	14.566198
2	118	9.688013	3.130804
3	311	25.533662	8.251526
4	186	15.270936	4.934996
5	54	4.433497	1.432741
	2551	NA	67.683736

Table 4: Summary Statistics for Resource System

Resource	freq	pct_valid	pct_tot
0	480	30.49555	12.735474
1	780	49.55527	20.695145
2	314	19.94917	8.331122
	2195	NA	58.238259

5.0.1 Female versus Male Tail Length

As part of our exploration, we ran a regression to assess how correlated male and female tail lengths are.

```
##
## Call:
## lm(formula = M_tail ~ F_tail, data = birds.subset)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -46.84  -3.21  -1.27   0.85 345.40
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.226565   0.652716   1.879   0.0603 .
## F_tail      1.033250   0.006115 168.974   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 17.76 on 2348 degrees of freedom
##   (1419 observations deleted due to missingness)
## Multiple R-squared:  0.924,  Adjusted R-squared:  0.924
## F-statistic: 2.855e+04 on 1 and 2348 DF,  p-value: < 2.2e-16
```

The answer is yes, they are correlated ($p < 0.001$, Adjusted R^2 = 0.924).

Below, although male and female tail lengths are highly correlated, some male tail lengths are unusually longer in comparison with female tail lengths. These species may be ones where males have adapted longer tails via sexual selection.

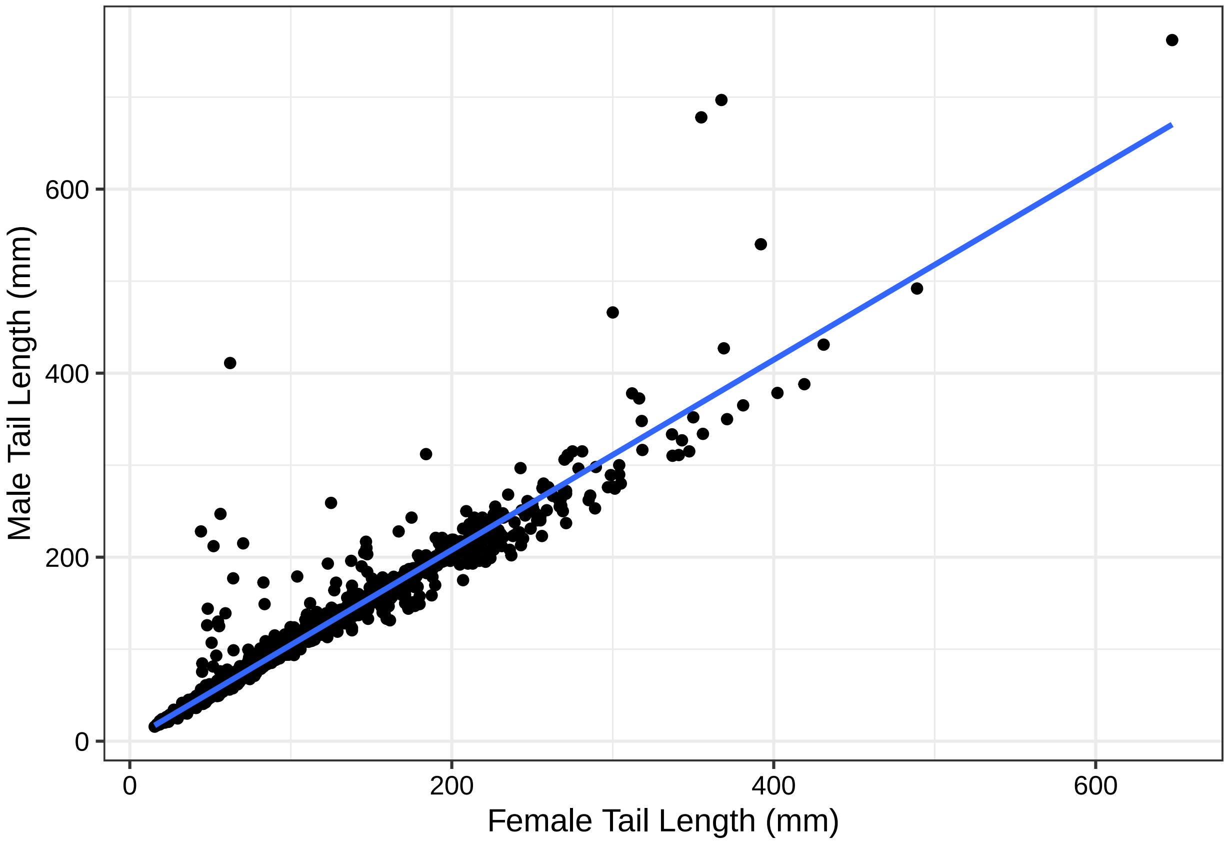


Figure 2: The Relationship between Female and Male Tail Length

To visualize the relationship between male and female tail length another way, here are the distributions of tail length sorted by family and divided by sex.

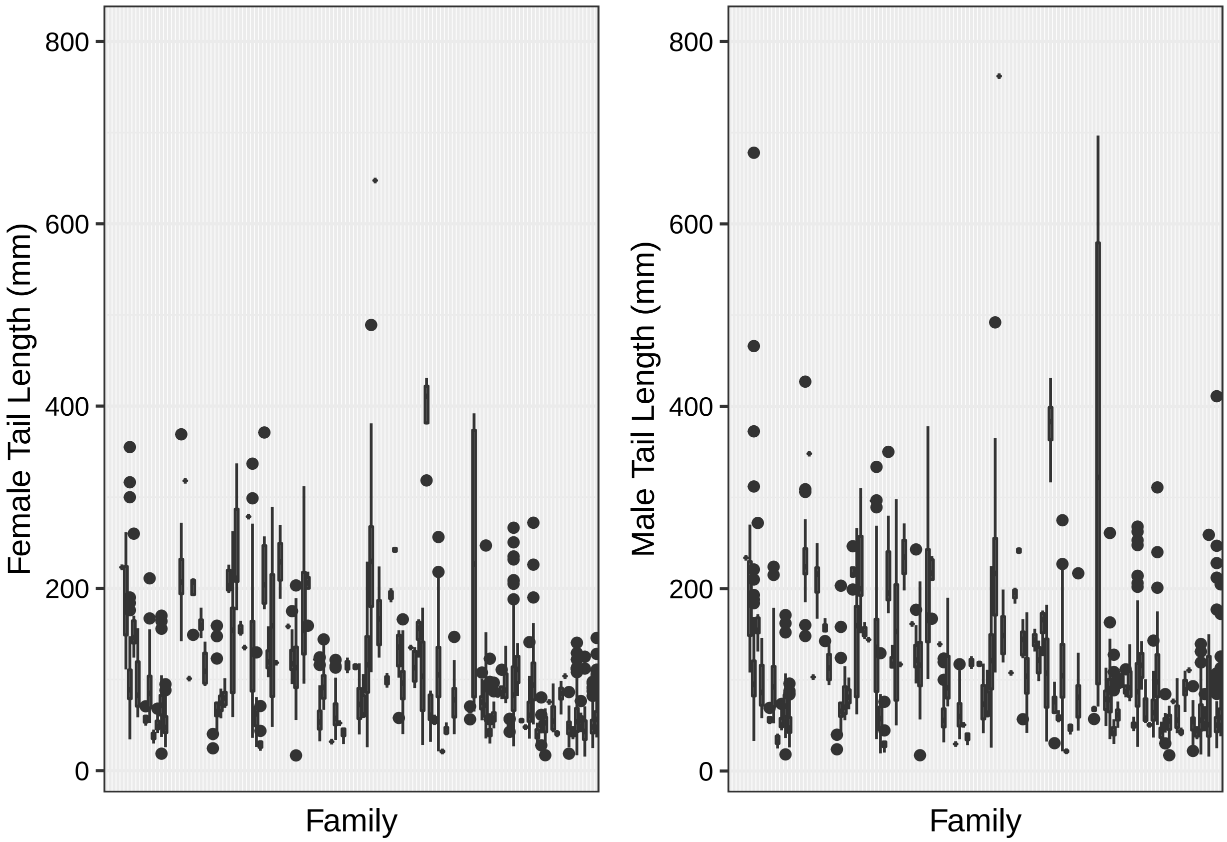


Figure 3: Exploratory Plots of Tail Length by Sex and Family

5.0.2 Exploratory Plots for Part 2

In preparation for the second part of our analysis, the following plots show the distribution of male tail length according to each behavioral variable: mating system, display system, and resource system.

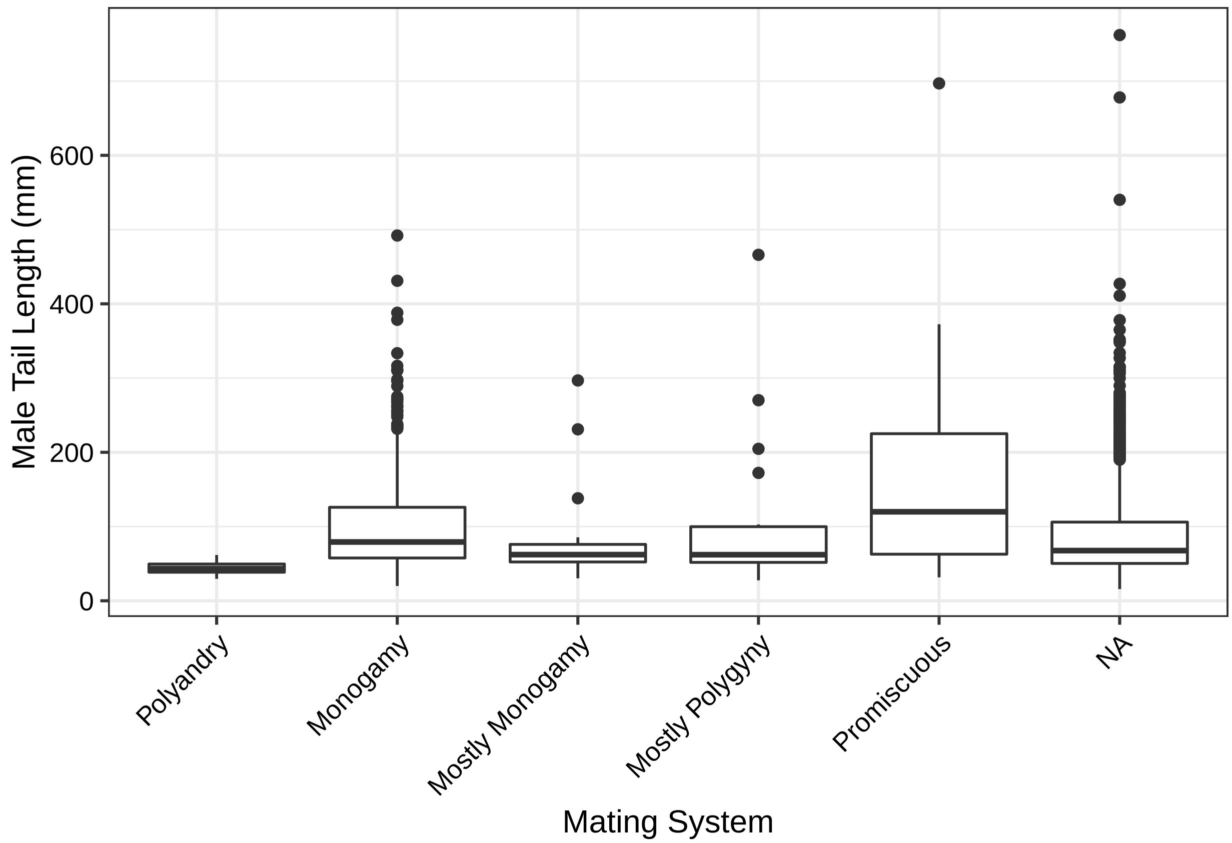


Figure 4: Male Tail Length by Mating System

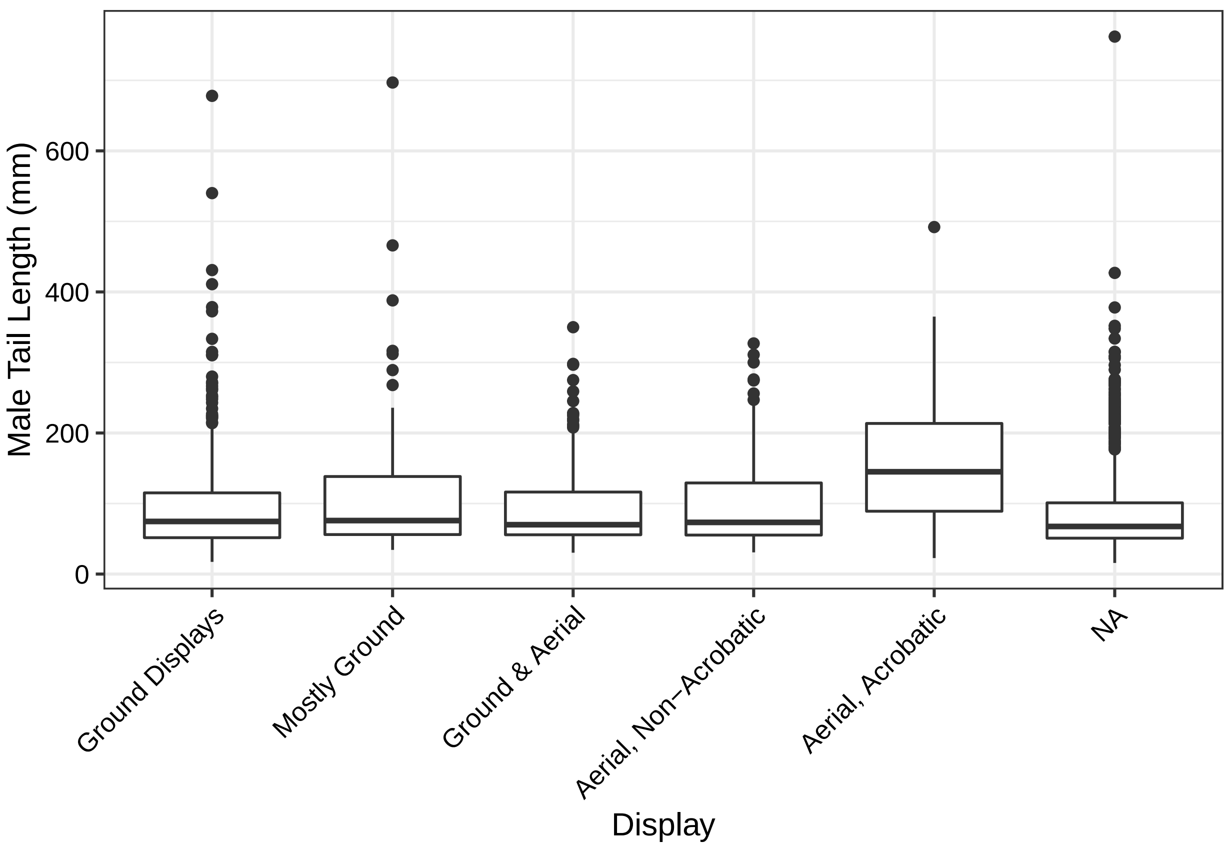


Figure 5: Male Tail Length by Display System

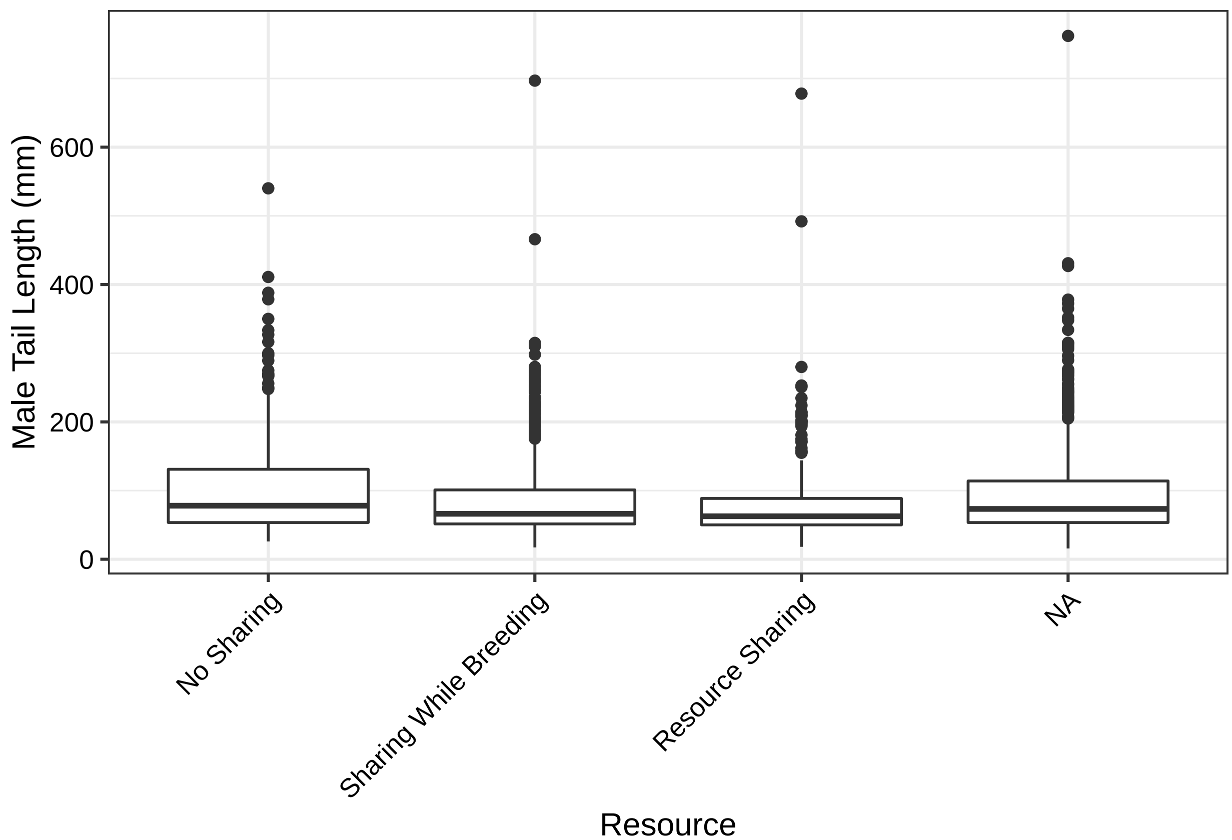


Figure 6: Male Tail Length by Resource System

6 Analysis

To test our hypotheses using our subset data `birds.subset`, we will conduct a linear regression and an analysis of variance (ANOVA). Our first research question will be answered using a linear regression, while our second will be addressed with an ANOVA. Results will be stated in words and supplemented using graphing visualizations.

6.1 Question 1: Does female tail length predict clutch size?

H_0 : There is no significant difference between female tail length and clutch size.

H_A : There is a significant difference between female tail length and clutch size.

Prior to conducting this analysis, it was identified that there is a strong correlation between female mass and female tail length. This makes sense: in general, bigger birds will have longer tails. We therefore included the mass variable in our model, in order to measure the effect of tail on clutch size while controlling for the effect of mass.

6.1.1 Model

```
##
## Call:
## lm(formula = Clutch_size ~ F_tail * F_mass)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.9660 -1.2529 -0.2852  0.7347 11.9351
##
## Coefficients:
##                    Estimate    Std. Error t value  Pr(>|t|)
## (Intercept)    3.8970630035  0.0920673618  42.328   < 2e-16 ***
## F_tail        -0.0038295564  0.0009331300  -4.104 0.0000426 ***
## F_mass         0.0002587737  0.0000979394   2.642   0.00832 **
## F_tail:F_mass -0.0000010753  0.0000004436  -2.424   0.01546 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.891 on 1642 degrees of freedom
##   (2123 observations deleted due to missingness)
## Multiple R-squared:  0.02398,    Adjusted R-squared:  0.02219
## F-statistic: 13.45 on 3 and 1642 DF,  p-value: 0.00000001141
```

Yes, both mass and tail and their interaction are significant ($p < 0.001$). We can reject the null hypothesis and conclude that mass and tail predict clutch size.

6.1.2 Assumptions

Check for multicollinearity. A VIF score below 5 indicates an acceptable level of multi-collinearity:

```
##        F_tail        F_mass F_tail:F_mass
##      1.564475      4.086442      4.876822
```

6.1.3 Residuals

Next, view residual plots:

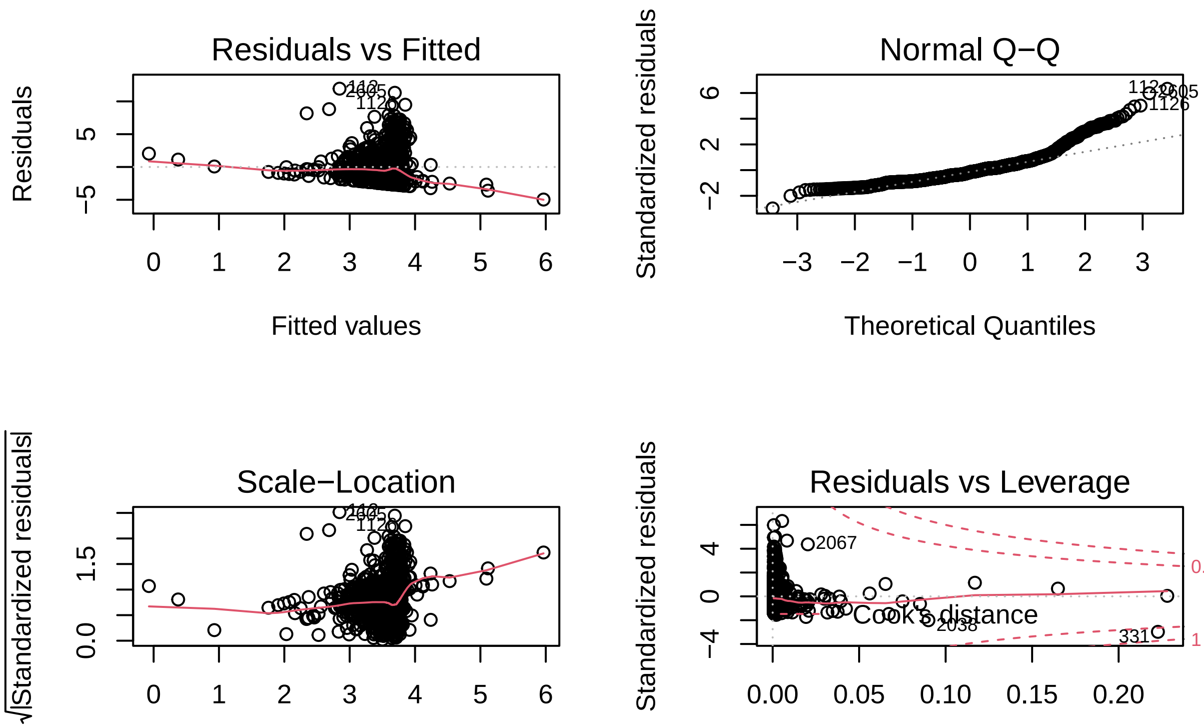


Figure 7: Residual Plots for Question 1

6.1.4 Clutch Size by Tail Length

Below: clutch size declines with increasing female tail length.

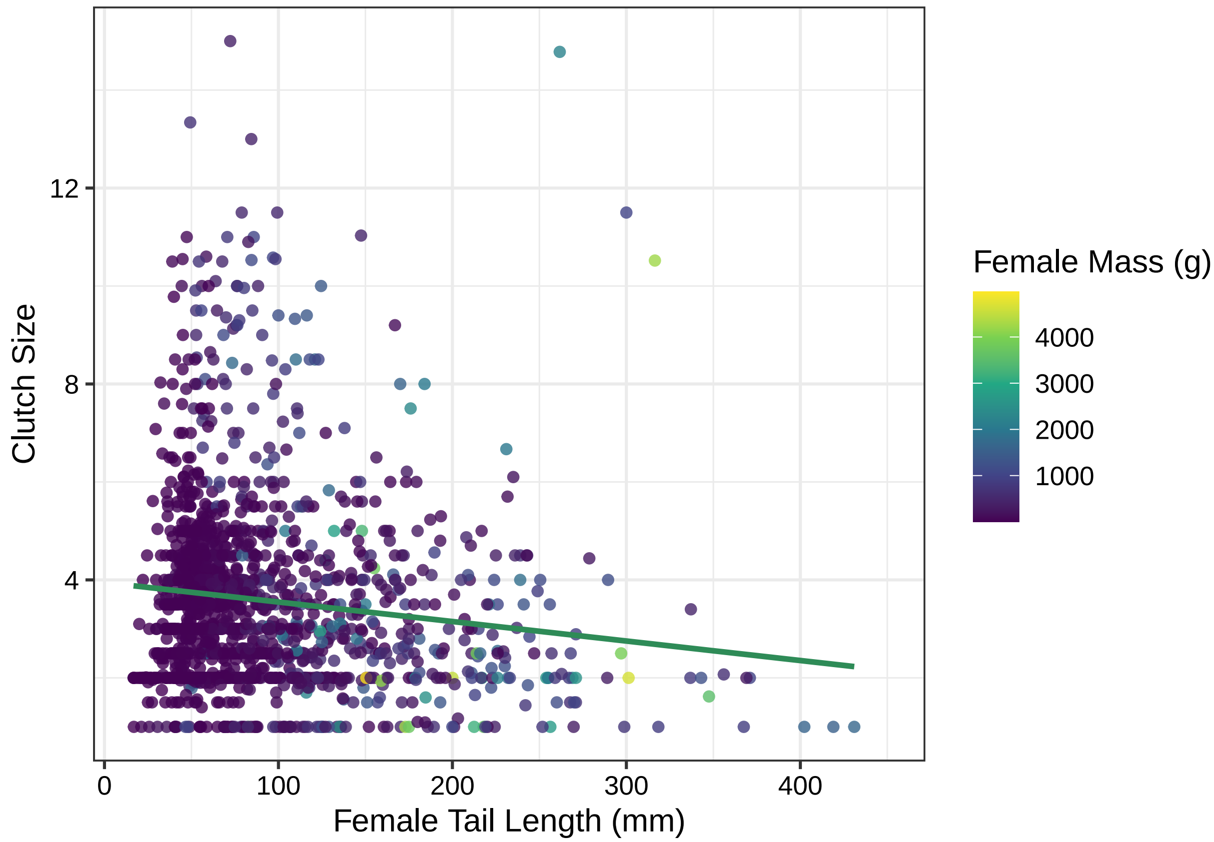


Figure 8: Female Tail Length vs Clutch Size

6.2 Question 2: Does male tail length relate to mating approaches?

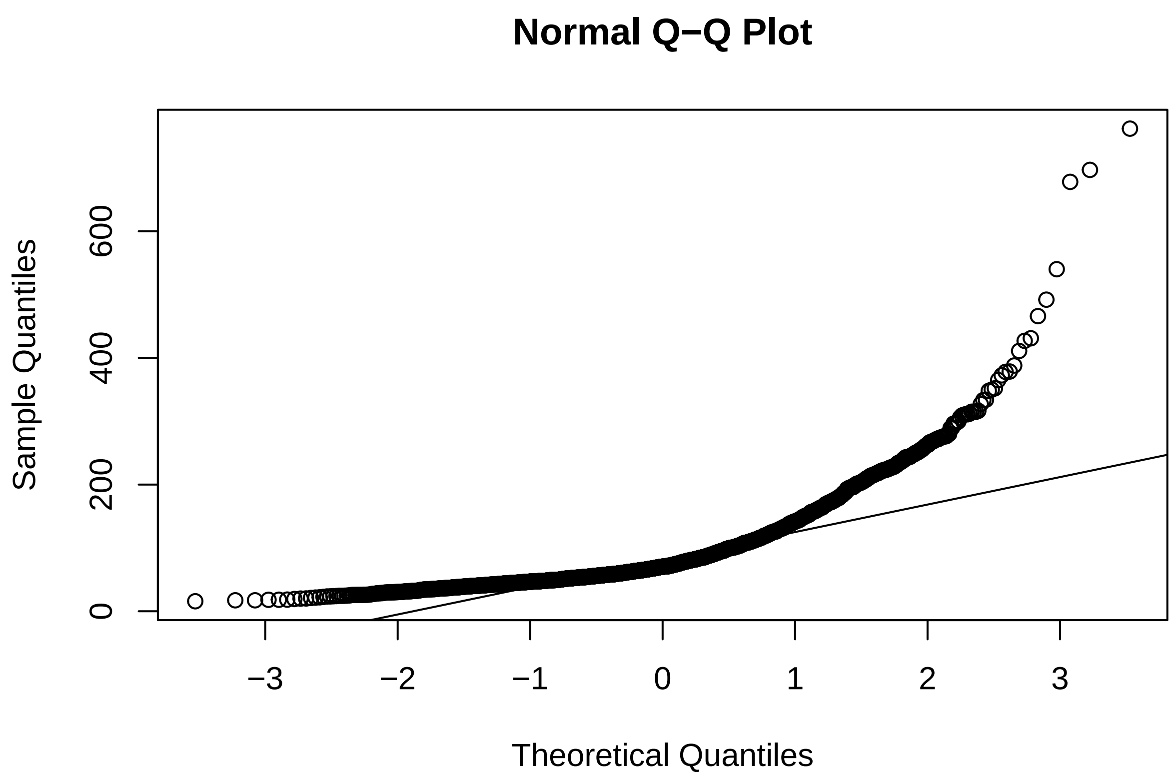
H_0 : Mating system and display behavior do not predict tail size.

H_A : Mating system and/or display behavior do predict tail size.

6.2.1 Assumptions

First, test for normality and equal variance:

```
##
##  Shapiro-Wilk normality test
##
## data:  birds.subset$M_tail
## W = 0.75655, p-value < 2.2e-16
```




```
##
##  Bartlett test of homogeneity of variances
##
## data:  M_tail by Mating_System
## Bartlett's K-squared = 102.13, df = 4, p-value < 2.2e-16
```

```
##
##  Bartlett test of homogeneity of variances
```

```
##
## data:  M_tail by Display
## Bartlett's K-squared = 71.043, df = 4, p-value = 0.00000000000001367
```

A p-value below the 0.05 threshold from the Bartlett Test indicates that the variances differ significantly for both Mating System and Display System.

6.2.2 Model Reduction

Next, run the model:

```
mating.anova <- aov(data = birds.subset, M_tail ~ Mating_System * Display * Resource)
summary(mating.anova)
```

```
##                                  Df  Sum Sq Mean Sq F value            Pr(>F)
## Mating_System                     4   59317   14829   3.548           0.00737
## Display                           4  164931   41233   9.865 0.000000129331941
## Resource                          2   18622    9311   2.228           0.10914
## Mating_System:Display            11  377637   34331   8.214 0.000000000000544
## Mating_System:Resource            3   13812    4604   1.102           0.34832
## Display:Resource                  8   35663    4458   1.067           0.38570
## Mating_System:Display:Resource    4   12473    3118   0.746           0.56109
## Residuals                       393 1642577    4180
##
## Mating_System                   **
## Display                         ***
## Resource
## Mating_System:Display           ***
## Mating_System:Resource
## Display:Resource
## Mating_System:Display:Resource
## Residuals
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 3339 observations deleted due to missingness
```

Because not everything was significant, we used a nested model approach to reduce the model until all components were significant.

Here is the final model:

```
mating.anova.final <- aov(data = birds.subset, M_tail ~ Mating_System * Display)
summary(mating.anova.final)
```

```
##                         Df  Sum Sq Mean Sq F value     Pr(>F)
## Mating_System            4  135625   33906   7.198 0.00001259 ***
## Display                  4  148286   37071   7.870 0.00000386 ***
## Mating_System:Display   12  229022   19085   4.052 0.00000526 ***
## Residuals              455 2143223    4710
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 3293 observations deleted due to missingness
```

The interaction between mating system and display system is significant ($p < 0.001$). We can reject the null hypothesis and accept that mating system and display system predict male tail length.

6.2.3 Residuals

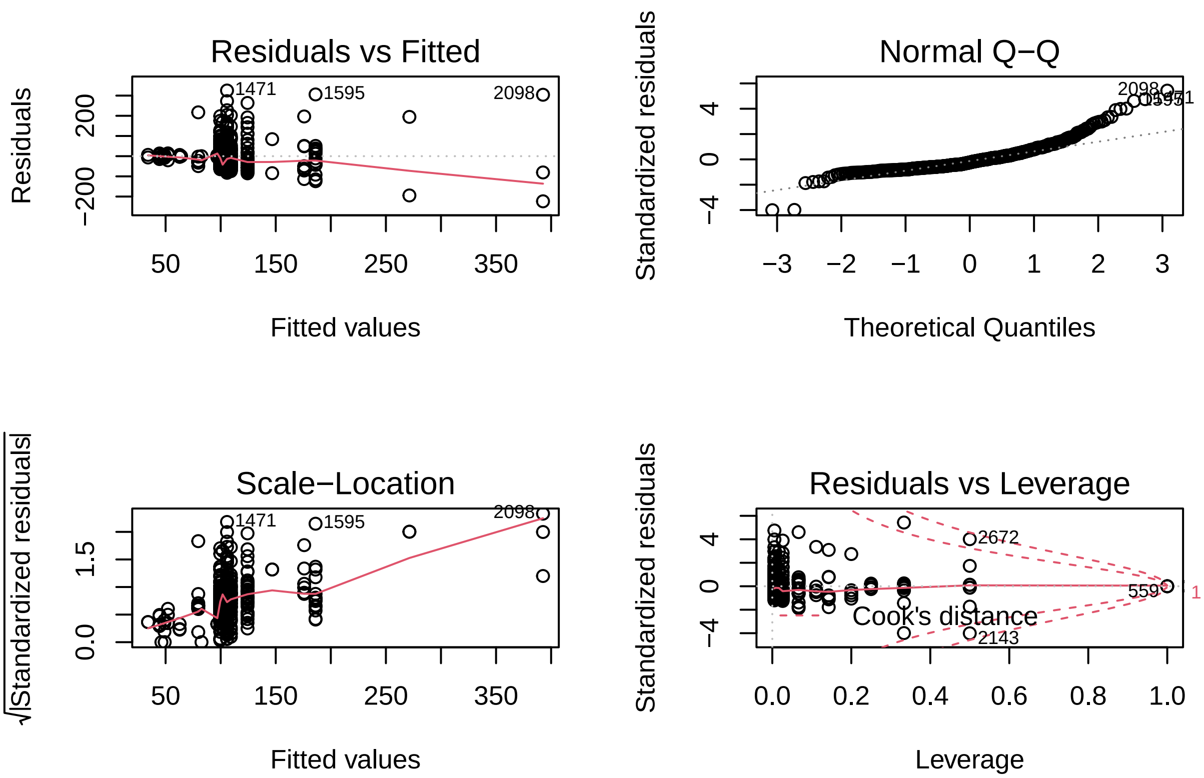


Figure 9: Residual Plots for Question 2

6.2.4 Tail Length by Mating and Display Systems

Below, average male tail length by mating system and display system.

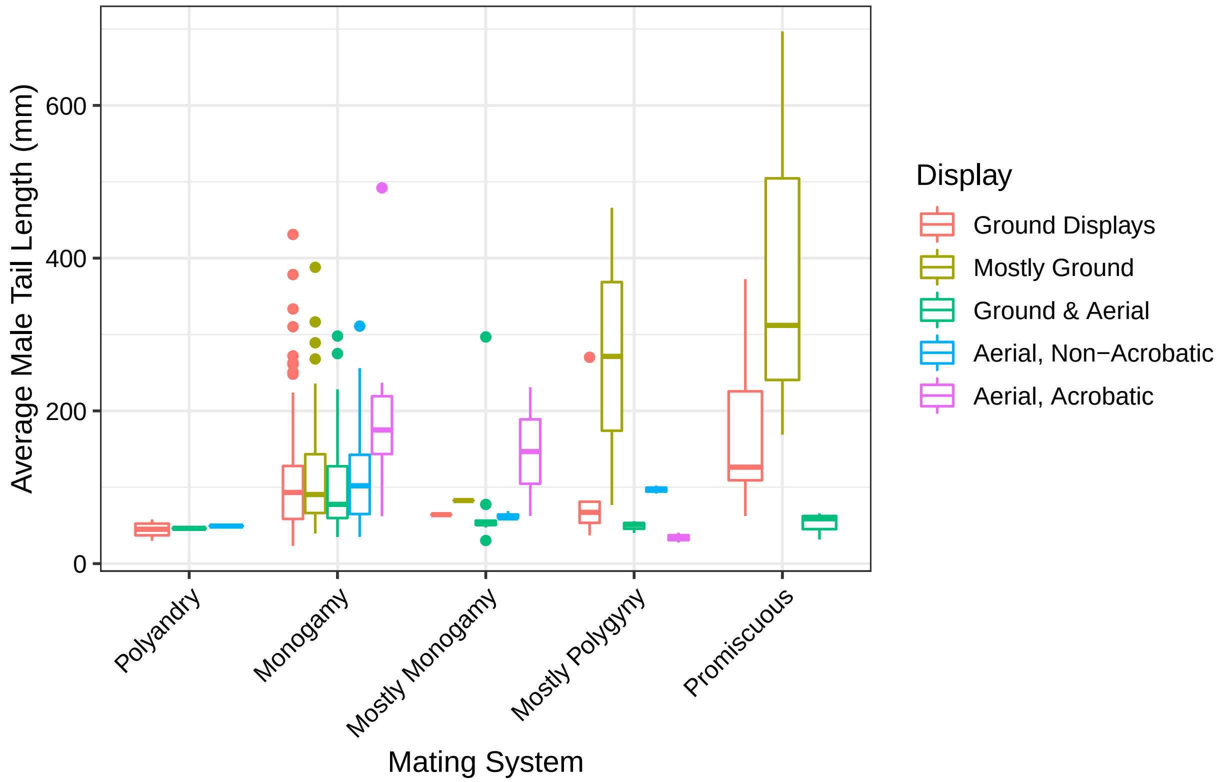
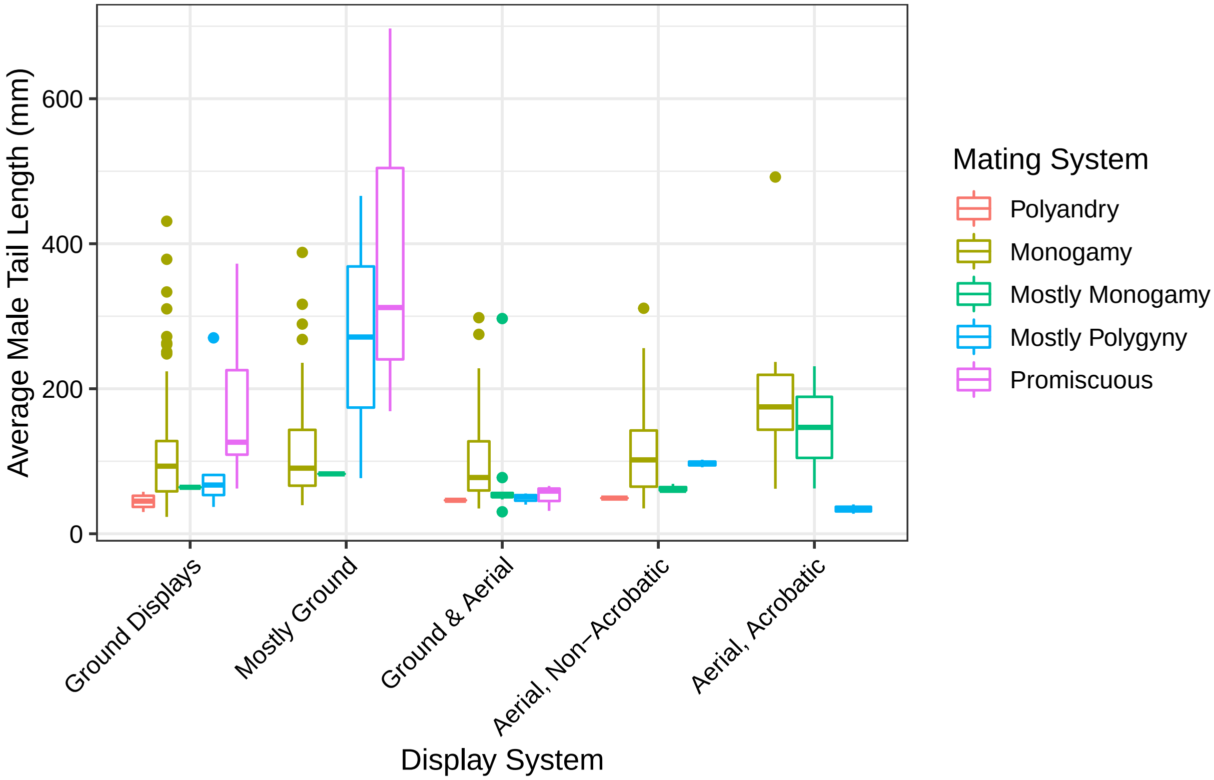


Figure 10: Male Tail Length vs Mating Tactics

Below, the same results as the previous page but with the mating system and display system



swapped.

7 Summary and Conclusions

7.1 Part 1

The interaction between female mass and tail size predicts clutch size ($p < 0.001$, $n = 1642$, $R^2 = 0.022$). In general, clutch size appears to decrease with increasing tail length, but this effect is mediated by overall body size as expressed by mass.

However, it is important to note the limitations of our model. Our model does not explain much of the variance, as seen from our low R^2 value. We can also see that the residual plots are quite clumped together in each plot at a different location. More explanatory variables should be used to determine the impact of female mass and tail size on clutch size.

Our finding supports the hypothesis that birds with longer tails may expend more resources collecting food because of their reduced agility. Therefore, they may have adapted to produce fewer eggs because they cannot care for as many chicks as more agile birds. More research is needed to substantiate this hypothesis as well as to better understand how overall body size mediates the effect.

Figure 11: A Short-tailed Babbler (*Pellorneum malaccense*)

7.2 Part 2

Mating system and display system interact to predict tail length ($n = 476$, $p < 0.001$), supporting our hypothesis. In general, mostly polygynous and promiscuous birds with mostly ground displays appear to have the longest tails. Among monogamous and mostly monogamous birds, those with aerial displays have the longest tails.

This said, it should be noted that tail length is not normally distributed, and could be transformed in future analysis to meet the normality assumption. Groups in this analysis also do not have equal variance. For example, in Mating System, most birds are identified as monogamous (2), leading to a skew in the data, not because of lack of samples but rather lack of diversity in this category. Similarly to part one, we find clumps of data points in the residual plots, but in this case they seem to reflect the unequal grouping of variables used within this analysis. There are vertical groups that are distinguishable across all plots, which is something that should be explored in the future, as an attempt to correct this or eliminate its overall impact on the data.

Our result indicates that birds vary in tail length according to both their mating system and their display system. This finding is not surprising considering that male birds with particularly long tails are known to use them in courtship displays, so species of birds have developed varied tail lengths alongside specific mating behaviors. We chose not to control for overall mass in this model because increasingly complex statistical analyses are outside of the scope covered in this course, but the lack of control is a definitive limitation of this finding: some patterns of mating system and display predicting tail length may be a result of overall size rather than tail length specifically. More research and analyses are needed.

Figure 12: A Male Ribbon-tailed Astrapia (*Astrapia mayeri*)

8 References

- Chotjuckdikul, N. 2017. Short-tailed Babbler: *Pellorneum malaccense.* eBird. https://ebird.org/species/shtbab1
- Evans, M.R. 1999. The consequences of flight for the evolution of tail ornaments in birds. In: Adams, N.J. & Slotow, R.H. (eds) *Proc. 22 Int. Ornithol. Congr.,* Durban: 1823-1843. Johannesburg: BirdLife South Africa.
- Jearwattanakanok, A. 2019. Great Argus: *Argusianus argus.* eBird. https://ebird.org/species/grearg1
- Lislevand, T., Figuerola, J., and Székely, T. 2007. Avian body sizes in relation to fecundity, mating system, display behavior, and resource sharing. *Ecology* 88:1605.
- Lorenz, S. 2019. Ribbon-tailed Astrapia: *Astrapia mayeri.* eBird. https://ebird.org/species/ritast1