EVOLUTION IN ACTION: STATISTICAL ANALYSIS

INTRODUCTION

In 1973, Princeton University evolutionary biologists Peter and Rosemary Grant began studying the finches of the Galápagos archipelago, a group of islands about 600 miles off the coast of Ecuador. They collected thousands of measurements every year to track changes in the physical characteristics of finch populations over time. One of their major goals was to collect enough data to identify associations between environmental and evolutionary changes in finch populations.

For their study, the Grants focused on the medium ground finch (*Geospiza fortis*), a seed-eating species of finch on the island of Daphne Major. Every year the Grants measured physical characteristics like wing length, body mass, tarsus length (the section of leg between the ankle and knee), and beak size for hundreds of individual medium ground finches. Small changes in these structures can be important for survival in different environments. In addition, these traits tend to vary widely within populations.

In early 1977 a drought began on Daphne Major. The drought lasted for 18 months and caused the type and abundance of food available to the finches to change rapidly. Medium ground finches prefer to eat the small, soft seeds of the bushy plant chamaesyce (*Chamaesyce amplexicaulis*), but the supply of chamaesyce seeds was extremely limited as a result of the drought. As the drought progressed and the hungry finches quickly ate the small, soft chamaesyce seeds, one of the only remaining food sources for the medium ground finch became the seeds of a plant called caltrop (*Tribulus cistoides*). Caltrop seeds are much larger and harder than those of the chamaesyce and are covered with pointy spines. More than 80% of the 1,200 medium ground finches on the island did not survive the drought of 1977.

The Grants were interested in determining whether there were any differences between the finches that survived the drought and the finches that did not—and in particular, whether any physical characteristics were key to survival. To answer this question they compared the average value of different characteristics in the finches that survived the drought to the average values of the same characteristics in those that did not survive. They then applied statistical methods to determine whether the differences they found between the two groups were likely to be real or merely occurred by chance.

You now have the opportunity to statistically analyze data collected by the Grants.

Table 1 (on the next page) shows body measurements from 100 medium ground finches living on Daphne Major in 1976. Fifty of those birds did not survive the 1977 drought (nonsurvivors) and 50 did (survivors). These data are also provided in an Excel spreadsheet; **use either the data in Table 1 or in the Excel spreadsheet to construct several graphs as outlined in the following pages**.

Table 1. Morphological measurements (wing length, body mass, tarsus length, and beak size) taken from a subsample of 100 medium ground finches (*Geospiza fortis*) before the drought began on the island of Daphne Major in 1977. Half of the birds in the sample (*n* = 50) did not survive the drought (Nonsurvivors) and half (*n* = 50) did (Survivors).

Nonsurvivors					Survivors				
Band #	Body Mass (g)	Wing Length (mm)	Tarsus Length (mm)	Beak Depth (mm)	Band #	Body Mass (g)	Wing Length (mm)	Tarsus Length (mm)	Beak Depth (mm)
9	14.50	67.00	18.00	8.30	309	18.00	71.00	20.20	9.80
12	13.50	66.00	18.30	7.50	560	14.00	67.00	19.10	8.50
276	16.44	64.19	18.47	8.00	572	18.00	70.00	20.20	10.30
278	18.54	67.19	19.27	10.60	618	17.50	68.00	20.70	9.90
283	17.44	70.19	19.27	11.20	623	15.00	67.00	19.00	8.80
288	16.34	71.19	20.27	9.10	673	18.00	72.00	19.00	10.10
293	15.74	67.19	17.57	9.50	685	14.50	67.00	18.00	8.20
294	16.84	68.19	18.17	10.50	891	15.00	65.00	18.60	8.00
298	15.54	68.19	18.57	8.40	931	14.50	65.00	19.60	8.90
307	17.50	70.00	20.00	8.60	943	15.00	66.00	19.30	9.10
311	15.00	67.00	18.40	9.20	1452	16.24	68.19	18.47	9.80
315	17.00	70.00	19.90	8.80	1477	17.34	70.19	20.57	10.10
321	15.00	66.00	19.10	8.50	1528	17.09	68.19	19.32	8.55
342	15.00	66.00	18.40	8.00	1587	17.64	72.19	20.57	9.30
343	15.00	67.00	18.00	9.70	1592	17.24	71.19	18.87	10.00
345	16.50	67.00	20.10	8.40	1599	18.04	72.19	19.77	10.70
346	13.00	64.00	17.60	7.90	1635	15.84	68.19	20.07	9.10
347	16.00	71.00	19.60	9.30	1643	15.24	65.19	20.17	8.80
352	13.50	65.00	18.40	7.70	1850	16.14	66.19	19.07	10.40
356	16.00	69.00	18.50	8.50	1861	20.19	72.69	19.32	10.70
413	14.00	65.00	17.90	8.20	1884	16.24	67.69	17.97	9.15
420	15.00	65.00	19.80	9.70	1919	21.24	72.19	19.47	11.20
422	19.00	70.00	19.40	10.30	2206	17.44	72.19	20.07	10.50
428	17.00	72.00	20.10	10.20	2211	16.94	70.19	19.27	9.70
452	15.00	68.00	20.00	8.90	2226	14.74	65.19	18.27	8.90
456	16.50	68.90	18.50	9.60	2887	17.34	69.19	19.07	10.10
457	14.75	64.20	17.05	7.85	8136	15.54	68.19	18.07	8.90
458	16.00	73.00	19.60	9.60	616	19.00	70.00	20.00	9.60
461	17.00	68.00	20.00	9.80	1248	15.40	66.00	19.50	8.50
462	15.00	68.00	19.60	8.80	2210	16.34	68.01	18.96	10.08
468	16.00	68.00	19.00	9.00	2242	15.41	72.94	18.26	9.45
503	14.50	65.00	18.90	9.10	2939	15.37	67.95	19.41	8.31
506	17.00	69.00	18.60	9.20	354	17.50	67.00	20.30	9.80
507	16.00	70.00	19.00	8.80	678	16.50	71.00	18.20	9.70
509	17.00	70.00	20.00	9.20	1418	17.94	71.01	18.76	10.38
511	14.50	66.00	19.10	8.80	1426	21.22	71.45	21.01	10.61
512	15.50	67.00	20.30	9.40	1527	17.04	68.01	18.46	8.38
519	14.50	67.00	19.10	8.30	1659	17.74	71.01	19.16	10.78
522	15.50	66.00	18.20	8.40	2244	18.87	71.95	20.16	11.01
561	16.50	70.00	20.00	10.20	2249	18.44	74.01	20.06	10.68
564	14.00	66.00	18.80	9.30	2940	15.14	70.01	17.86	8.78
605	15.50	71.00	19.90	10.20	3642	17.84	71.01	19.16	10.28
609	16.50	69.00	19.60	10.50	8191	19.63	70.41	20.81	10.86
610	14.00	66.00	18.80	9.00	1019	20.82	70.45	19.86	11.21
611	16.00	66.00	18.90	9.80	1372	16.64	69.01	18.16	9.48
619	14.00	65.00	18.00	9.30	1797	16.67	69.45	19.21	9.31
621	15.50	67.00	18.50	7.60	2378	18.07	70.95	21.06	9.86
674	18.50	70.00	20.50	10.50	8190	15.60	69.47	18.36	9.28
676	17.00	72.00	20.00	9.70	316	17.55	67.50	19.55	9.85
687	14.00	66.00	18.90	8.60	710	15.00	69.00	19.00	10.00
Mean					**Mean**				
Var (s^2)	**1.842**	**5.181**	**0.701**	**0.775**	**Var (s^2)**	**3.087**	**5.448**	**0.735**	**0.709**

Part A: Calculating Descriptive Statistics

As you complete steps 1-3 below, enter your calculations in Table 2 for the mean, standard deviation, standard error of the mean, and/or 95% confidence interval as assigned by your instructor.

Table 2. Descriptive statistics for morphological measurements taken from 100 medium ground finches (*Geospiza fortis*). The data are presented in two groups: birds that did not survive the 1977 drought (Nonsurvivors) and birds that survived the drought (Survivors).

	Nonsurvivors				Survivors			
Descriptive Statistics	Body Mass (g)	Wing Length (mm)	Tarsus Length (mm)	Beak Depth (mm)	Body Mass (g)	Wing Length (mm)	Tarsus Length (mm)	Beak Depth (mm)
Mean								
Variance (s^2)	1.842	5.181	0.701	0.775	3.087	5.448	0.735	0.709
Standard Deviation								
Standard Error of the Mean								
95% Confidence Interval								

1. For the data in Table 1, **calculate** the mean for each physical characteristic in the nonsurvivor and survivor group.

2. Calculate the standard deviation for each set of data. The standard deviation measures the mean difference between each individual measurement and the mean of the entire population. Standard deviation is a way to quantify how spread out a set of measurements is compared to the mean.

(Note: To calculate the standard deviation for a sample, simply calculate the square root of the variance (s^2) for that sample. In Table 2, the variance has already been calculated.)

3. Calculate the standard error of the mean for each set of data.
Because you are analyzing random samples of 50 birds taken from the entire medium ground finch population living on Daphne Major, it is not possible to know for certain that the mean you have calculated for each sample is the same as the mean of the entire medium ground finch population. One way to show how close the sample mean is to the population mean is to calculate the standard error of the mean (SEM). If you take many random samples, the SEM is the standard deviation of the different sample means. About 68% of sample means would be within one standard error of the population mean.

Use the formula below to calculate the SEM:

$$\text{SEM} = \frac{s}{\sqrt{n}}$$

4. Calculate the 95% confidence interval for each set of data.
Confidence limits serve the same purpose as SEM. The 95% CI provides a range of values within which the mean of the entire population is likely to be found.
As an approximation, use the simplified formula below to calculate the 95% confidence interval (95% CI), which is roughly twice the SEM:

$$95\%\ \text{CI} = \frac{2(s)}{\sqrt{n}}$$

Part B: Graphing the Data

5. On a separate sheet of graph paper or on your computer, **construct four bar graphs** that compare the means of nonsurvivors and survivors for each physical characteristic (wing length, body mass, tarsus length, and beak size). Label both axes of each graph and show either the SEM or 95% CI as error bars depending on your instructor's directions. An example of a well-constructed bar graph is shown below (Figure 1).

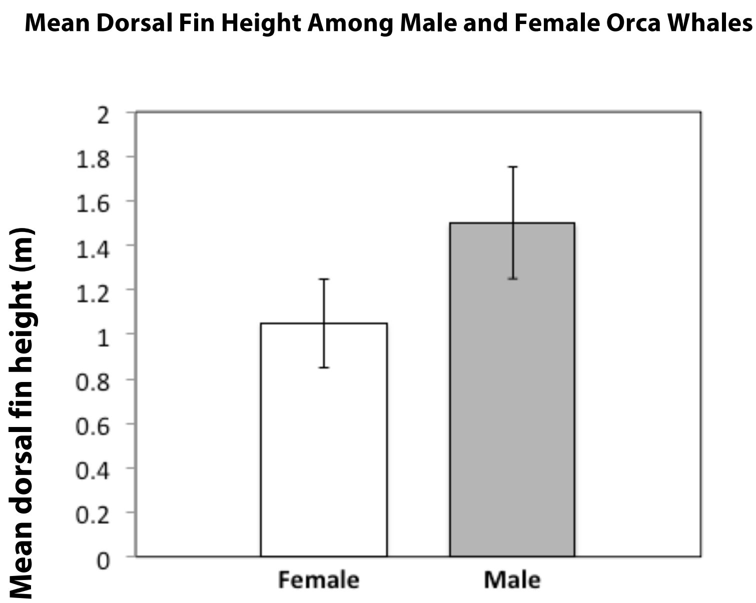

Figure 1. An example of a well-constructed bar graph: Mean dorsal fin height in meters (m) for 36 female and 36 male orca whales (*Orcinus orca*). In this case, error bars indicate 95% confidence intervals.

6. Once you complete your four bar graphs, **describe** in the space below any differences between nonsurvivors and survivors you observe in each graph.

Part C: Calculating *t*-Test Statistics

In Figure 1, the means are different and the error bars do not overlap, suggesting that there might be a difference between the two mean fin heights. But a statistical test is required to confirm that the difference is significant. The appropriate statistical test for comparing two means is the Student's *t*-Test for independent samples (the *t*-Test). The *t*-Test can assess whether any observed differences between the means of two samples (i.e., nonsurvivors and survivors) simply occurred by chance, by determining the probability (p) of obtaining a more different result if the null hypothesis is correct.

You will calculate the t statistic called "observed t" (t_{obs}) and then compare it to the critical t statistic (t_{crit}). This critical *t*-value is a cutoff value that determines whether you can reject the null hypothesis that the mean of the population from which the first sample came is equal to the mean of the population from which the second sample came, or $\mu_1 = \mu_2$. If your observed t value (t_{obs}) is less than the critical value (t_{crit}), then you cannot reject the null hypothesis. If the calculated statistic is larger than the critical value, then we have enough evidence to reject the null hypothesis and support the alternative hypothesis that the means are significantly different, or $\mu_1 \neq \mu_2$.

The t_{crit} for your sample size of 50 is 1.98. This is the t value that could occur 5% of the time for a sample size of 50 if the null hypothesis is true.

7. Calculate t_{obs} to **compare** the mean values of each physical characteristic between survivors and nonsurvivors.

a. Use a graphing calculator, a spreadsheet program (e.g., Excel: function "T.TEST"), or an online *t*-Test calculator (many are available) to calculate t_{obs}.

Mean body mass: t_{obs} =
Mean wing length: t_{obs} =
Mean beak depth: t_{obs} =
Mean tarsus length: t_{obs} =

b. How do your t_{obs} for each pair of measurements compare to the critical *t*-value (t_{crit}) of 1.98?

Mean body mass:
Mean wing length:
Mean beak depth:
Mean tarsus length:

8. Analyze your four bar graphs, their associated error bars, and the results of your t statistic calculations. For each characteristic, make a claim about the differences you observe between survivors and nonsurvivors. Support your claim with evidence from the graphs and statistics.

Mean body mass:

Mean wing length:

Mean beak depth:

Mean tarsus length:

9. Based on what you saw in the film, **identify** the adaptive trait that is most important to survival under the environmental conditions presented by the drought and **suggest** a reason for the differences between the measurements taken from the birds that died during the 1977 drought and the birds that survived.

Extension Activity: Evaluating Associated Variables

1. Using the data in Table 1, **construct** and **label** a scatter plot using a computer program or hand-graphing that illustrates the association between beak depth and wing length for the birds that survived the drought of 1977.
2. **Draw** a trend line either by hand on your graphing paper or automatically by right-clicking on your data plot in Excel and choosing "add trendline." If you are doing this exercise in Excel, a window will pop up after you choose "add trendline."
3. **Calculate** thecoefficient of determination, or r^2, using your calculator or spreadsheet program. This value represents the proportion of the variation in the y variable that is explained by the variation in the x variable. Values vary from 0 to 1; values near 0 mean there is little relationship between x and y. For example, if r^2 is 0.90, the x variable "explains" 90% of the variation in the y variable.

4. Based on these results, **comment** on the presence or absence of a relationship between beak depth and wing length in this population of medium ground finches.

5. **Suggest** a reason for the presence or absence of a relationship between beak depth and wing length in this population.

6. Based on your observations regarding beak depth and wing length, **predict** what might happen to body mass in the medium ground finch population over a few generations if small, soft seeds returned in abundance after the end of the drought in 1978, and explain your answer.

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