



Evolution in Action: Statistical Analysis

OVERVIEW

This activity serves as a supplement to the film [The Origin of Species: The Beak of the Finch](#) and provides students with the opportunity to analyze data collected by Princeton University evolutionary biologists Peter and Rosemary Grant. The Grants have provided a random sample of morphological measurements, including wing length, body mass, and beak depth, taken from a sample of 100 medium ground finches (*Geospiza fortis*) living on the island of Daphne Major in the Galápagos archipelago. The complete data set is available in the accompanying Excel spreadsheet.

This activity provides an example of how those data could be analyzed in class using statistical tests. In an extension activity, students are prompted to graph two of the morphological measurements against each other to investigate a possible association and propose an explanation for the association.

KEY CONCEPTS

- Evolution by means of natural selection can only occur if heritable traits vary among individuals in a population.
- In a given environment, individuals with one form of a trait may be able to better exploit some aspects of the environment than individuals with other forms of the trait can.
- Natural selection involves the differential survival and reproduction of individuals with different heritable traits.
- Evolution occurs when inherited traits in a population change over successive generations.
- Graphing allows scientists to more readily identify patterns and trends in data.
- Statistical tools provide a way to quantify variability in biological data and describe the degree of uncertainty in the results obtained using these data.

STUDENT LEARNING TARGETS

- Calculate descriptive statistics (mean, standard deviation, and 95% confidence interval) for multiple sets of data.
- Use trend lines to show correlations between two variables.
- Graph primary research data using both bar graphs and a scatter plot graph and appropriately label all graph components, including title, axes, units, and legend.
- Evaluate the evidence provided by data sets in relation to a particular scientific question.
- Determine the reliability of their sample mean with 95% confidence intervals.
- State that error bars are a graphical representation of the variability of data.
- Analyze the means between data sets with *t*-tests to determine the significance between data sets.
- Construct explanations using evidence about the role of natural selection on morphological traits based on the measurements.

CURRICULUM CONNECTIONS

Standards	Curriculum Connection
NGSS (2013)	HS-LS2-2, HS-LS4-3, HS-LS4-4
AP Bio (2015)	1.A.1, 1.A.4, SP1, SP2
IB Bio (2016)	5.2, C.1, C.5
AP Env Sci (2012)	II.A, II.C, III.A
IB Env Systems and Societies (2017)	1.2, 2.1
Common Core (2010)	ELA.RST.9-12.7, ELA.WHST.9-12.1; Math.N-CN.2, S-ID.1, S-IC.1, S-IC.3, MP1, MP2, MP5
Vision and Change (2009)	CC1, CC5, DP2

KEY TERMS

evolution, evolution of populations, natural selection, scientific process, speciation, statistics and math

TIME REQUIREMENTS

- Two 50-min classroom periods or one 90-min block period. Homework may be required.
- The extension on correlations will require an additional 50 min.
- Viewing the short film (15 min) prior to the activity is highly recommended and can be viewed at the beginning of class prior to starting the activity or assigned as homework.
- Time requirements may differ depending on computer/internet access.

SUGGESTED AUDIENCE

- High School: IB or AP Biology
- College: Introductory Biology, Ecology or Evolution course

PRIOR KNOWLEDGE

- How to construct bar and scatter plot graphs
- Basic understanding of descriptive statistics (mean, standard deviation, 95% confidence interval) and Student's *t*-test
- Basic understanding of making and justifying claims using experimental evidence
- General understanding of genetic and evolutionary theory, including concepts like adaptation, fitness, and natural selection.

MATERIALS

- Scientific calculator if not using a computer with a spreadsheet program like Excel or Google spreadsheet
- Graphing paper if not using a computer
- Colored pencils for graphing if not using a computer
- Ruler for graphing if not using a computer

TEACHING TIPS

- It is highly recommended for students to view the film *The Beak of the Finch* (<http://www.hhmi.org/biointeractive/origin-species-beak-finch>) before doing this activity. Students may watch the film in class or as homework the day before.
- You may choose to have students do the related activity “Evolution in Action: Graphing Activity” as an introduction to data analysis before performing the statistical calculations in this activity.
- For additional background information on the Grants’ work, consult the [In-Depth Film Guide](http://www.hhmi.org/biointeractive/) available at <http://www.hhmi.org/biointeractive/>.
- You may wish to have students work in pairs.
- If you are unfamiliar with interpreting the results of statistical tests, please refer to the Answer Key below for further explanation. You may also refer to the “Mathematics and Statistics in Biology” guide on the BioInteractive.org website.

ANSWER KEY

PART A: Calculating Descriptive Statistics

See Table 2 on the next page for numerical answers to steps 1-4 in the student document. Note: Depending on the course, students can calculate either standard error of the mean or 95% confidence interval or both.

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).

Descriptive Statistics	Nonsurvivors				Survivors			
	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	15.71	67.79	19.04	9.11	16.99	69.30	19.35	9.67
Variance	1.842	5.181	0.701	0.775	3.087	5.448	0.735	0.709
Standard Deviation	1.36	2.28	0.84	0.88	1.76	2.33	0.86	0.84
Standard Error of the Mean	0.19	0.32	0.12	0.12	0.25	0.33	0.12	0.12
95% Confidence Interval	0.38	0.64	0.24	0.25	0.50	0.66	0.24	0.24

PART B: Graphing the Data

- 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 (body mass, wing length, tarsus length, and beak depth). Label both axes of each graph and show either the SEM or 95% CI as error bars, depending on your instructor's directions.

Note: Based on the course you are teaching, you can choose to have your students include either 95% CI bars or standard error of the mean in the graphs. Alternatively, you could have half of your students graph the 95% CI bars and the other half the SEM bars.

Student graphs should look like the ones shown in Figure 1 below, including appropriate labels for each graph.

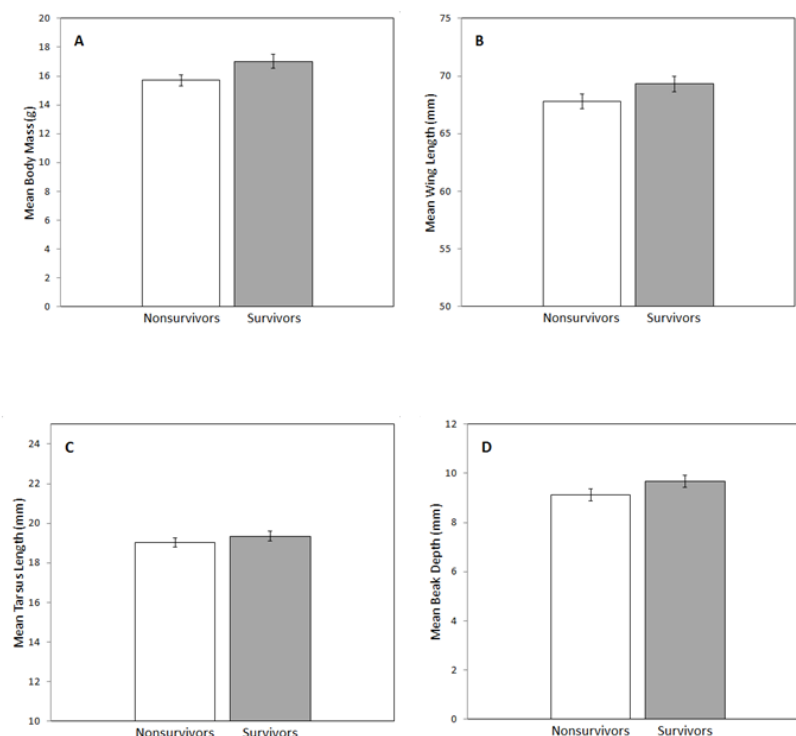


Figure 1. Mean body mass (A), mean wing length (B), mean tarsus length (C), and mean beak depth (D) calculated from 100 medium ground finches (*Geospiza fortis*) on the island of Daphne Major.

Bars labeled “Nonsurvivors” represent 50 birds that did not survive the 1977 drought on the island. Bars labeled “Survivors” represent 50 birds that survived the drought.

In these graphs, error bars are 95% confidence intervals. Students could draw the same graphs with error bars that are standard errors of the mean; they would be about half the size of these error bars.

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

Students should indicate that all four morphological measurements from the surviving birds are greater than the measurements for the nonsurviving birds. Some students may also indicate that the 95% confidence intervals for the nonsurvivors and survivors do not overlap for body mass, wing length, or beak depth, suggesting that the differences between the two groups may be real. However, the 95% confidence intervals for tarsus length do overlap for the two groups of birds. Determining whether the differences are statistically significant requires a statistical test, like the Student t-test.

PART C: Calculating t-Test Statistics

In this part of the activity, students are asked to calculate t -test statistics. Different types of t -tests are appropriate for different types of data. The one used in this activity, which is most often used in high school biology classes, is for independent samples and for data that are normally distributed. Samples are independent if the observations you make are not in any way linked to additional observations. For instance, measuring the wing length of 10 of the 50 survivors should not affect wing length measurements of the remaining 40 survivors.

7. Calculate t_{obs} to compare the mean values of each physical characteristic between survivors and nonsurvivors.
- Use a graphing calculator, a spreadsheet program, or an online t -test calculator (many are available) to calculate t_{obs} .
Mean body mass: $t_{\text{obs}} = 4.08$
Mean wing length: $t_{\text{obs}} = 3.27$
Mean beak depth: $t_{\text{obs}} = 3.27$
Mean tarsus length: $t_{\text{obs}} = 1.82$
 - How do your t_{obs} for each pair of measurements compare to the critical t -value (t_{crit}) of 1.98?
The mean body mass ($t_{\text{obs}} = 4.08$), mean wing length ($t_{\text{obs}} = 3.27$), and mean beak depth ($t_{\text{obs}} = 3.27$) all exceed the critical t -value of 1.98 for a sample size of 50. The mean tarsus length ($t_{\text{obs}} = 1.82$) does not exceed the critical t -value of 1.98 for a sample size of 50 (i.e., d.f. of 98).

Note: The t_{crit} was determined using a calculation for the degrees of freedom (d.f.) of $n_1 + n_2 - 2 = 98$.

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 claims with evidence from the graphs and statistics.
- The mean body mass ($t_{\text{obs}} = 4.08$), mean wing length ($t_{\text{obs}} = 3.27$), and mean beak depth ($t_{\text{obs}} = 3.27$) all exceed the critical t -value of 1.98 for a sample size of 50, which means that the differences between nonsurvivors and survivors for these traits are statistically significant. On the other hand, the mean tarsus length ($t_{\text{obs}} = 1.82$) does not exceed the critical t -value of 1.98 for a sample size of 50, which means that there is a greater than 0.05 probability that the t_{obs} of 1.82 occurred by chance.*

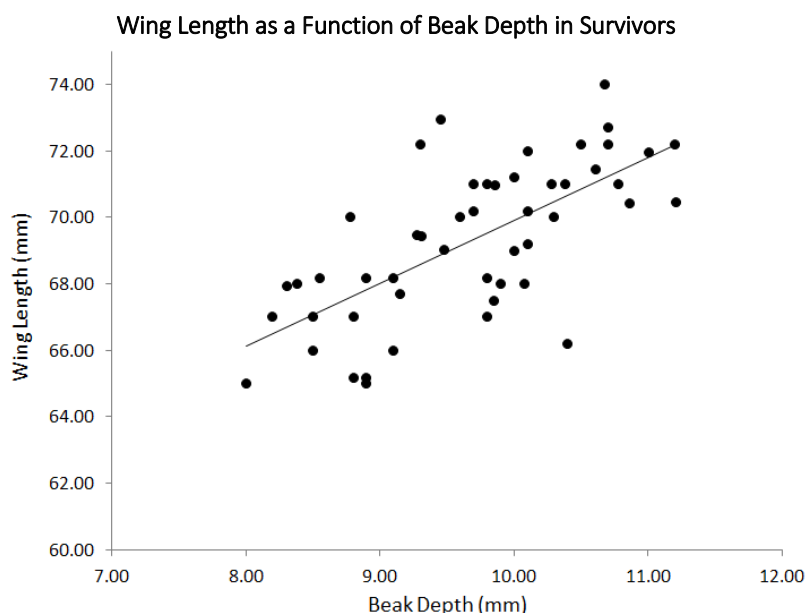
Note: If students have been instructed in statistical hypothesis testing, they may further explain that the large t_{obs} values for body mass, wing length, and beak depth allow them to reject the null statistical hypothesis (H_0) that the means are equal for each group of birds within each trait and that the small t_{obs} value for tarsus length does not allow them to reject the null hypothesis for that trait.

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 those from the birds that survived.

Beak depth was the trait under the most intense natural selection given the environmental change of a limited food amount and type, which made it the trait most important to survival for the finches. In the environment created by the drought, having a larger beak was an adaptive advantage and birds with larger beaks were more likely to survive. Large beaks are likely associated with larger birds; therefore, the difference in wing length and body mass between the nonsurviving birds and the surviving birds was significant. Tarsus length may not be as strongly associated with changes in body size as the other traits.

EXTENSION: 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. *The trend line is illustrated in the graph above.*
3. $r^2 = 0.46$
 $r = 0.68$
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.
- Students need only explain that there appears to be a positive relationship between beak depth and wing length in the surviving group of medium ground finches, and birds with larger beaks tend to also have longer wings.*

Note: Students may or may not provide the r^2 value. For the IB curriculum, students are not expected to know how to interpret regression statistics, but they are expected to be able to add trend lines to scatter-plot data to show uncertainty in the apparent relationship between the x and y variables.

5. **Suggest** a reason for the presence or absence of a relationship between beak depth and wing length in this population.
Large beaks are likely associated with larger birds in general; therefore, beak depth and wing length for the drought-surviving birds are related. Note: Discuss with students that association (correlation) does not necessarily imply causation. In other words, larger beaks are not causing birds to have longer wings.

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 became abundant again after the drought ended in 1978, and explain your answer.
If small, soft seeds become abundant again on Daphne Major, body mass will likely decrease over a few generations because smaller beaked birds will no longer be at a disadvantage to larger beaked birds and may even be at an advantage if most of the available food consists of small, soft seeds. The association between having a small beak and also being a small bird will likely drive the change in bird size toward smaller birds with less body mass.

AUTHOR

Paul Strode, PhD, Fairview High School, Boulder, Colorado

Edited by Laura Bonetta, PhD, and Sandra Blumenrath, PhD, HHMI, and Ann Brokaw, Rocky River High School, Ohio

Reviewed by Brad Williamson, University of Kansas; Peter Grant, PhD, and Rosemary Grant, PhD, Princeton University