

Evolution in Action: Data Analysis

OVERVIEW

In this activity, students analyze and graph data taken from a population of Galápagos finches before and after a major drought. These data track the morphological traits of 100 medium ground finches (*Geospiza fortis*) living on the island of Daphne Major.

There are two versions of the “Student Handout” for this activity, which can be customized based on your needs:

- In **“Version 1,”** students analyze the data by interpreting histograms, calculating means and standard deviations, and constructing bar graphs to develop explanations about natural selection. An [answer key](#) (click the link to jump directly to this section) is provided below.
- In **“Version 2,”** students analyze the data by calculating descriptive statistics (mean, standard deviation, standard error of the mean, 95% confidence interval), constructing bar graphs with error bars, using a *t* test to form conclusions about natural selection, and optionally using linear regression to investigate an association between traits. An [answer key](#) (click the link to jump directly to this section) is provided below.

This activity supports the data set “Finches in the Galápagos” in [Data Explorer](#) and concepts covered in the short film [The Origin of Species: The Beak of the Finch](#). Additional information related to pedagogy and implementation can be found on [this resource’s webpage](#), including suggested audience, estimated time, and curriculum connections. The webpage also provides a download for the data set.

KEY CONCEPTS

- Individuals in a population have different variations of heritable traits.
- In a given environment, individuals with one variation of a trait may be more likely to survive and reproduce than individuals without that variation.
- The frequency of advantageous, heritable variations will increase in the population over successive generations. This is known as evolution by natural selection.
- Graphing and statistics can be used to summarize data, examine variability in data, and more readily identify patterns in data.

STUDENT LEARNING TARGETS

For **both versions** of the “Student Handout”:

- Calculate and interpret the mean and standard deviation of a data set.
- Construct graphs with appropriate labels, including a title, axes, and units.
- Evaluate the evidence provided by data sets in relation to a particular scientific question.
- Construct biological hypotheses and explanations based on an understanding of natural selection.

For **“Version 1”** only:

- Analyze histograms to describe patterns in distributions of data.

For **“Version 2”** only:

- Calculate and interpret the 95% confidence interval and standard error of the mean of a data set.
- Use error bars to represent the reliability of an estimate of the mean and to determine whether means of two groups are significantly different.
- Use Student’s *t* test to determine whether means of two groups are significantly different.
- (extension only) Use linear regression to examine an association between two variables.

PRIOR KNOWLEDGE

For **both versions** of the “Student Handout,” students should have a basic understanding of:

- general genetic and evolutionary theory, including natural selection
- making and justifying claims using data, including using samples to make inferences about a population
- mean (including how to calculate the mean of a data set) and standard deviation
- constructing bar graphs

For **“Version 2”** only, students should also have a basic understanding of:

- standard error of the mean (SEM) and 95% confidence intervals (CI)
- plotting and interpreting error bars for 95% CI, including the meaning of error bars that do or do not overlap
- Student’s *t* test
- (extension only) constructing scatterplots and linear regression lines (“trendlines”)

MATERIALS

- the finch data set (in [Data Explorer](#) or as a spreadsheet downloaded from [this resource’s webpage](#))
- a data visualization and analysis application (such as *Data Explorer*) or a spreadsheet program (such as Microsoft Excel or Google Sheets)
- (optional) calculator and graphing materials (colored pencils, ruler, graph paper, etc.)

TEACHING TIPS**Working with the Data**

- Students will need a tool that supports graphing and statistical tests. Use the tool that works best for your classroom; options include [Data Explorer](#), Google Sheets, Microsoft Excel, R, or jamovi.
 - If students are using *Data Explorer*, they can select the finch data set by going to “Choose data to explore” and clicking on the “Finches in the Galápagos” option. The data set will load automatically, and students will also be able to access information about the data from the “Background” tab.
 - If students are not using *Data Explorer*, they will need to load the data set themselves. The data set can be downloaded from [this activity’s webpage](#) as a CSV file.
- Make sure students are familiar with the tool they will use. *Data Explorer* includes tooltips and a “Help” section. BioInteractive also provides a [series of spreadsheet tutorials](#) for how to use Excel and Google Sheets.
- Consider having students explore and ask questions about the data set before they do the activity. You could introduce the data set through a class discussion that includes the following questions:
 - Identify some of the trends and patterns you see in the data. Are all the birds of similar size? What measurements seem to vary the most from individual to individual? Why do you think the sample only includes adult birds?
 - Do you see any differences between the group of finches that only lived until 1977 (nonsurvivors) and the finches that lived to 1978 and beyond (survivors)?
 - This data set is a sample of only 100 birds. Scientists typically collect data from samples rather than the entire population. Why do you think that is? What are some advantages and disadvantages of using samples in research?

Running the Activity

- You can use either version of the “Student Handout” depending on your class’s needs and students’ backgrounds. The [“Student Learning Targets”](#) section above describes each handout’s contents.

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- Both handouts are designed to be modular. You could choose to use only certain parts or combine parts. For example, you could have students do some of the “Version 1” handout as an introduction to data analysis before doing the more advanced statistical calculations in the “Version 2” handout.
- You may wish to have students work in pairs or small groups.
- Students view the film [The Origin of Species: The Beak of the Finch](#) at the start of the “Version 1” handout. Consider having students watch the film in class or as homework before class. The “Version 2” handout does not require the film, but it may be helpful for students to watch the film for more information at the end.

Clarifications and Caveats

- The data set for this activity is a small random sample of the data collected by biologists Peter and Rosemary Grant. It contains morphological measurements of 100 medium ground finches born between 1973 and 1976 on the island of Daphne Major in the Galápagos.
- The data set includes data on males, females, and birds of undetermined sex. The third category was included because young male finches often look like females and may not have typical male plumage for a year or more.
- In Part 4 of the “Version 2” handout, students calculate t test statistics. Different types of t tests are appropriate for different types of data. The t test used in this activity (Student’s t test, which is the t test most often used in high school biology classes) assumes that the observations in each sample are independent and randomly selected. The variable being observed is also assumed to be normally distributed with equal variance among populations.
 - Observations are independent if they 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.
 - The t_{crit} in Part 4 was determined using a calculation for the degrees of freedom (df) of $n_1 + n_2 - 2 = 98$.
- In the “Extension” of the “Version 2” handout, students examine the association between beak depth and wing length. You may want to discuss with students that association (correlation) does not necessarily imply causation. For example, larger beaks are not causing birds to have longer wings.

Supplements and Extensions

- If you are showing the film *The Beak of the Finch*, consider supplementing it with the accompanying [film activity](#). The “Educator Materials” for the film activity include recommended pause points and questions, as well as additional background information on the Grants’ work.
- Consider providing more ways for students to engage with the data set. For example:
 - If you’d like to give students additional practice with graphing, have them construct the graphs provided in Part 2 of the “Version 1” handout themselves.
 - Students could also calculate the means and standard deviations provided in Parts 2 and 4 of the “Version 1” handout.
- For more information on interpreting the results of statistical tests, please refer to the “Answer Key” sections below or BioInteractive’s [“Mathematics and Statistics in Biology”](#) guide.

ANSWER KEY: VERSION 1**PART 1: Introducing the Study**

1. Describe the major environmental change on Daphne Major that took place in 1977.
A drought killed much of the island’s vegetation, resulting in the finches having to switch from mainly eating small seeds to eating large, hard seeds.

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2. What types of medium ground finches were more likely to survive the environmental change you described?
Finches with bigger beaks were more likely to survive, because they were better able to crack open the large, hard seeds for food.

PART 2: Analyzing Data with Histograms

3. Observe the shapes of the graphs. It may help to draw a line connecting the tops of the black bars.
 - a. Describe the overall shape of each graph.
The graphs are shaped like hills that are taller in the middle and lower on the sides. (Some students may know that this is a normal distribution, or “bell curve.”)
 - b. What do the shapes of the graphs indicate about the distribution of beak depths in these two groups of birds?
The shapes of the graphs show that there is variation in beak depth among the birds. In each group, most of the birds have beak depths that are close to the mean.
4. Compare and contrast the distributions of beak depths for the survivors and nonsurvivors. For each distribution, include the range of the data and the most common measurements.
The shapes of the survivor and nonsurvivor distributions are similar, but the nonsurvivor distribution is “shifted” to the left. For the nonsurvivors, beak depths ranged from 7.25 to 11.25 mm, and the most common beak depths were 8.5 mm and 9 mm. For the survivors, beak depths ranged from 8.0 to 11.25 mm, and the most common beak depth was 10 mm.
5. Propose a biological hypothesis to explain the differences in the distribution of beak depths for the survivors and nonsurvivors. (Hint: It may help to review your answers for Part 1.)
During the drought in 1977, the finches’ main food source changed from small, soft seeds to large, hard seeds. Finches with bigger beaks were more likely to survive the drought because they were better able to use these large, hard seeds as food. This is why the survivors tend to have larger beak depths than the nonsurvivors do.
6. Take a look at the means and standard deviations of beak depth in each group.
 - a. How do these means and standard deviations compare between the groups?
The mean beak depth for the nonsurvivors (9.11 mm) was somewhat smaller than the mean beak depth for the survivors (9.67 mm). The standard deviations for the two groups were about the same: 0.88 mm for the nonsurvivors and 0.84 for the survivors.
 - b. If the standard deviations of the two groups were very different, what would you conclude about the groups?
Standard deviation is a measure of how “spread out” the data are. If the standard deviations of two groups are different, the measurements in the group with the larger standard deviation are more spread out from the mean, meaning that there is more variability compared to the mean in that group.

PART 3: Examining the Importance of Sample Size

7. For each sample, calculate the mean beak depth and standard deviation (s). Record your answers in Table 1.

Nonsurvivors				Survivors			
5-bird sample		15-bird sample		5-bird sample		15-bird sample	
Mean	8.78	Mean	9.11	Mean	9.78	Mean	9.56
s	1.15	s	0.98	s	1.06	s	0.90

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8. Record the means and standard deviations for each sample of survivors and nonsurvivors (the 50-bird samples in Figure 3, then the 15-bird and 5-bird samples in Table 1) in Table 2.

	Mean			Standard deviation		
	50-bird sample	15-bird sample	5-bird sample	50-bird sample	15-bird sample	5-bird sample
Nonsurvivors	9.11	9.11	8.78	0.88	0.98	1.15
Survivors	9.67	9.56	9.78	0.84	0.90	1.06

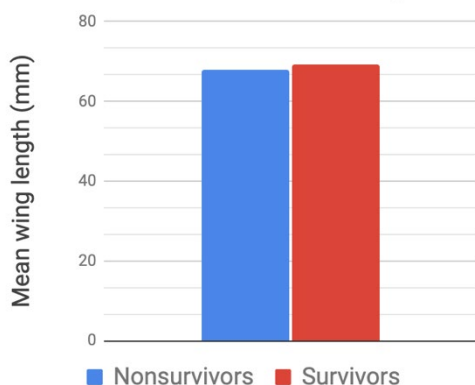
9. Compare the means and standard deviations for the samples in Table 2.
- Are the means in smaller samples different from the means in larger samples? Explain why you think that is.
Yes, in general, the means in the smaller (5-bird or 15-bird) samples are different from the means in the larger (50-bird) samples. (There is one exception for the nonsurvivors, where the mean of the 15-bird sample matches the mean of the 50-bird sample.)
The reason these means are different could be due to sampling. All the samples were taken randomly from a population with variation in beak depth. The means of each sample will depend on which birds were randomly selected for that sample. As a result, it's unlikely for the means of all the samples to match.
 - Are the standard deviations in smaller samples different from the standard deviations in larger samples? Explain why you think that is.
Yes, in this example, the smaller samples have larger standard deviations. (You may want to clarify with students that this is not always the case; standard deviation can increase or decrease with a smaller sample size. Standard error/SE, on the other hand, does tend to increase with a smaller sample size.)
The reason the standard deviations are different could be due to sampling, with an explanation similar to the one for means above.
10. Which results (from 5, 15, or 50 birds) do you think are closest to the means and standard deviations of the entire population of medium ground finches on the island? Explain your answer.
We would expect the largest samples (50 birds) to have the means and standard deviations closest to those of the entire population. This is because larger samples are more likely to better represent or capture the variety in a population. (If students are curious about how large samples must be in order to "accurately" represent a population, consider introducing the concepts of standard error/SE and confidence intervals.)
11. What is one advantage and one disadvantage of calculating the mean from a sample of a population rather than the entire population?
Advantages may include lower cost and less time; it is usually not feasible to collect data on an entire population if the population is large and spread out. One disadvantage is that the data obtained from a sample may not be representative of the population as a whole, especially if the sample size is small.

PART 4: Adaptive Traits and Constructing Bar Graphs

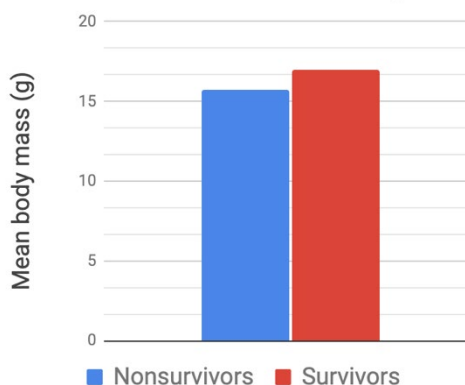
12. Construct two bar graphs, one comparing the means of *wing length* for the two groups and another comparing the means of *body mass*.

Example graphs made in Google Sheets are shown below.

Mean wing length for finches that did vs. did not survive the 1977 drought



Mean body mass for finches that did vs. did not survive the 1977 drought



13. Based on your graphs, how does the mean wing length compare between survivors and nonsurvivors? What about the mean body mass?

Both mean wing length and mean body mass were slightly larger for the survivors than the nonsurvivors.

14. What do your graphs suggest about the effects of the drought on birds with particular wing lengths and body masses?

These results could suggest that the drought selected for longer wings and larger body masses. In other words, it was advantageous for finches to have long wings or a large body during the drought, in that finches with these traits were more likely to survive. (Based on the questions below, students may also suggest that the drought actually selected for larger beaks, and that longer wings and larger body masses just happen to be associated with larger beaks since they are all features of larger birds.)

15. The film in Part 1 claimed that beak depth is the trait that made the greatest difference in survival for the birds during the drought. Do the data you examined support this claim? Explain your answer.

The data show that, on average, beak depth was larger for survivors than nonsurvivors. This is consistent with the claim that beak depth was important for survival. But the data also show that, on average, body mass and wing length were larger for survivors than nonsurvivors too. So, without more information, we cannot tell which trait was the most important for survival.

16. Based on what you learned from the film, why might beak depth play a more important role in survival during the drought than either wing length or body mass? (Hint: According to the film, what was the main impact of the drought on the finches?)

The film suggests that the main impact of the drought on the finches was a change in food source: a switch from small seeds to large, hard seeds. Out of all these traits, beak depth seems like it would play the most important role in helping finches survive this change. Finches with bigger beaks (larger beak depths) can open the large, hard seeds for food more easily, making them more likely to survive the drought. It's not as clear, at least from the film, how either wing length or body mass would have helped finches survive the drought.

17. How might variation in key traits within a population, such as beak depth in medium ground finches, make that population more likely to survive environmental changes?

Variation in a key trait makes it more likely that at least one form of the trait will help individuals in the population survive an environmental change. For example, variation in beak depth within the finch population meant that there were finches with beaks large enough to get food during the drought.

ANSWER KEY: VERSION 2**PART 1: Learning about the Study**

- Describe the major environmental change on Daphne Major that took place in 1977.
As a result of a drought, finches had to switch from small seeds as their primary food source to large, hard seeds.
- Based on what you know so far, what differences (if any) do you think there were between the finches that survived this major environmental change and the finches that did not?
Students' initial ideas may vary. They will explore these ideas during the rest of the activity.

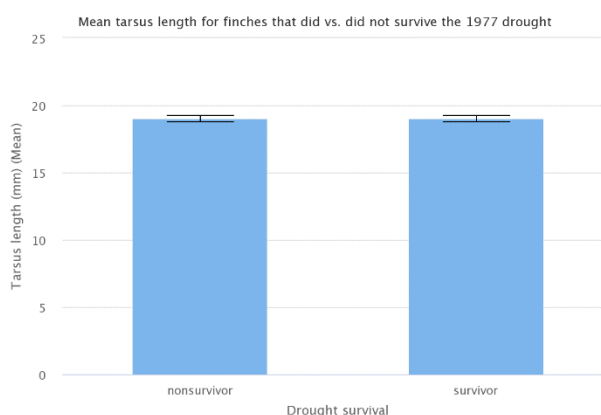
PART 2: Calculating Descriptive Statistics

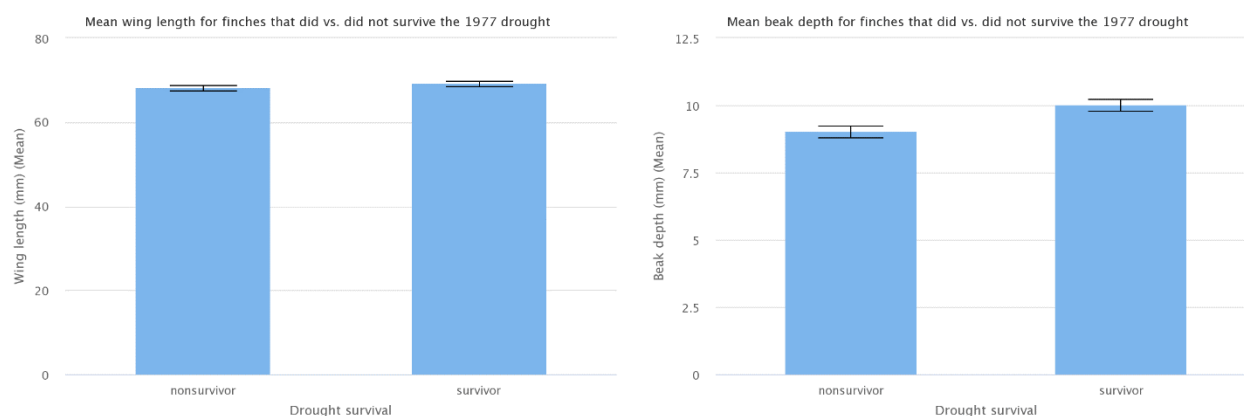
Answers for Questions 3–6 are shown in the completed version of Table 2 below.

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 (s^2)	1.842	5.181	0.701	0.775	3.087	5.448	0.735	0.709
Standard deviation (s)	1.36	2.28	0.84	0.88	1.76	2.33	0.86	0.84
Standard error of the mean (SEM)	0.19	0.32	0.12	0.12	0.25	0.33	0.12	0.12
95% confidence interval (CI)	0.38	0.64	0.24	0.25	0.50	0.66	0.24	0.24

PART 3: Graphing the Data

- Construct four bar graphs that compare the means of each physical characteristic (body mass, wing length, tarsus length, and beak depth) for survivors and nonsurvivors.
Example graphs made in Data Explorer are shown below.





4. In some cases, whether or not your error bars overlap can suggest whether the difference between the means is **statistically significant** — that is, due to actual differences between nonsurvivors and survivors instead of just happening by chance.
 - a. You created error bars that represent 95% CIs. What does it suggest if these error bars do *not* overlap? What does it suggest if these error bars *do* overlap?
If 95% CI error bars do not overlap, it suggests that there is a statistically significant difference between the means. But if 95% CI error bars do overlap, it doesn't suggest anything about whether the difference is statistically significant or not.
(As an extension, you may want to let students know that error bars can also represent other quantities, such as the standard error of the mean/SEM or standard deviation/SD. In these cases, the meaning of error bars that do or do not overlap is different.)
 - b. For which of the four physical characteristics did your error bars *not* overlap?
The 95% CI error bars did not overlap for body mass, wing length, or beak depth.
5. Summarize the differences between nonsurvivors and survivors that you observed from your graphs. Make sure to consider each of the four physical characteristics and the error bars from the previous question.
For all four characteristics, the means for the survivors are greater than those of the nonsurvivors. For all the characteristics except for tarsus length, the 95% CIs did not overlap, suggesting that the difference in the survivor vs. nonsurvivor means was statistically significant.

PART 4: Calculating t Test Statistics

6. Calculate t_{obs} to compare the means of each physical characteristic between survivors and nonsurvivors.
 - a. Record your results for $|t_{\text{obs}}|$ (the absolute value of t_{obs}) in the following table.

Characteristic	$ t_{\text{obs}} $
Body mass	4.08
Wing length	3.27
Tarsus length	1.82
Beak depth	3.27

- b. For each characteristic, how does $|t_{\text{obs}}|$ compare to the t_{crit} of 1.98?
The $|t_{\text{obs}}|$ for body mass, wing length, and beak depth all exceed the t_{crit} of 1.98, but the $|t_{\text{obs}}|$ for tarsus length does not.
- c. For each characteristic, make a claim about whether the means of the survivors and nonsurvivors are significantly different. Support your claim with evidence from the t test.
Since $|t_{\text{obs}}|$ for body mass, wing length, and beak depth all exceed the t_{crit} of 1.98, the differences

between the means of nonsurvivors and survivors for these traits are statistically significant. (In other words, there is a 5% or less chance that these differences occurred by chance. Students may indicate that this allows you to reject the null hypothesis.)

On the other hand, $|t_{\text{obs}}|$ for tarsus length ($t_{\text{obs}} = 1.82$) does not exceed the t_{crit} of 1.98, which means that the difference between the means of nonsurvivors and survivors for tarsus length is not statistically significant. (In other words, there is a greater than 5% chance that this difference occurred by chance. Students may indicate that you cannot reject the null hypothesis in this case.)

7. Answer the following questions about the finches based on your analysis of the data.

- d. Which of the four physical characteristics do you think were important for the finches' survival during the drought? Explain your reasoning.

The t test indicates that there were significant differences between nonsurvivors and survivors in the means of three characteristics: body mass, wing length, and beak depth. Since they differed significantly between finches that survived the drought compared to finches that did not, these characteristics may have been important for survival during the drought. (Students could also suggest that some or all of these characteristics did not contribute directly to survival, but were instead associated with other characteristics that did.)

- e. Based only on these data, can you determine which characteristic was the most important for survival during the drought? If yes, explain how you know. If no, describe what other information you might need.

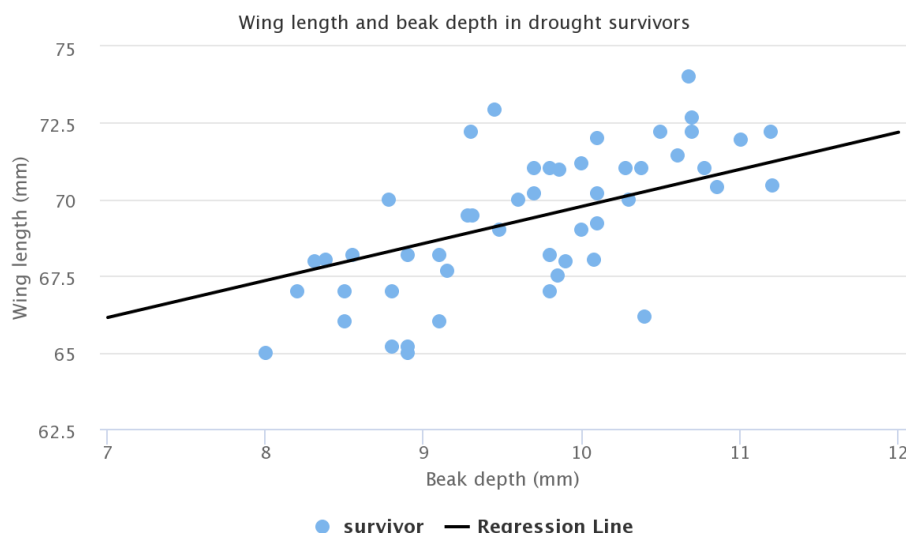
No, you cannot determine this based on just these data. You can see which characteristics were significantly different for finches that did vs. did not survive, but that does not tell you which characteristic was the most important for survival. Other information you might need includes how finches used these characteristics to survive during the drought (e.g., which characteristics helped them get food, save energy, etc.) and whether certain characteristics are associated with others.

- f. Suggest a biological reason for the differences you found between the nonsurvivors and survivors. *Student answers will vary depending on their prior knowledge. Consider showing the short film [The Beak of the Finch](#) to help students learn more about the finches and the characteristics that were most advantageous during the drought. Using knowledge from the film, an example answer could be as follows:*

During the drought, the finches' main food source shifted to large, hard seeds. Finches with bigger beaks could open the large, hard seeds for food more easily, making them more likely to survive the drought. This is why, on average, the drought survivors had bigger beaks (and thus larger beak depths) compared to the nonsurvivors. The birds with bigger beaks were probably bigger in general. This could explain why the survivors also had a larger mean wing length and larger mean body mass compared to the nonsurvivors. (Students could also suggest other reasons for why greater wing length and body mass may have been advantageous during the drought.) Tarsus length, which didn't differ as much between the survivors and nonsurvivors, may not be as strongly associated with changes in body size as the other characteristics.

EXTENSION: Evaluating Associations Between Variables

1. Construct a scatterplot showing the beak depths and wing lengths of the survivors in the finch data set. *An example scatterplot made in Data Explorer is shown below.*



Regression equation: Wing length (mm) = 51.04674 + 1.88652 * Beak depth (mm)
 r^2 : 0.4634

- Add a linear regression line, also known as a “trendline,” to your graph in the program you are using.
See the example graph above.
- Calculate the **coefficient of determination (r^2)** for beak depth and wing length in the program you are using.
 $r^2 = 0.46$

- Based on your results, is there an association between beak depth and wing length in this group of finches? Why or why not?

Based on the scatterplot and linear regression line, there appears to be a positive association between beak depth and wing length in the survivors. In general, the birds with larger beaks tend to also have longer wings. (Depending on their statistics background, students may or may not also discuss the r^2 value. Interpreting regression statistics, such as r^2 , is often not required at the high school level. You may want to focus more on using the linear regression line to model the relationship between the variables.)

- Suggest a biological reason for the presence or absence of an association between beak depth and wing length in this group of finches.

Finches with larger beaks or larger wings are likely to be larger in general. Larger birds probably have larger versions of many body parts, which could explain the positive association between beak depth and wing length.

- Imagine that the abundance of small, soft seeds resumed after the drought ended in 1978. Predict what would happen to **body mass** in this finch population over later generations. Explain your answer. (Hint: Think about whether and how body mass could be associated with beak depth and wing length. You can make another graph or do additional calculations to check your expectations.)

Student answers will vary depending on their prior knowledge. Consider showing the short film [The Beak of the Finch](#) to help students learn more about the finches and their characteristics. Using knowledge from the film, an example answer could be as follows:

Small, soft seeds can be eaten by finches with smaller beaks. So, if these seeds became abundant again, finches with smaller beaks would no longer be at a disadvantage compared to finches with bigger beaks. Small-beaked finches could even be at an advantage if the smaller seeds are harder for big-beaked finches to handle and eat. If this is the case, we would expect finches with small beaks to become more common in the population.

Finches with smaller beaks tend to have lower body mass. (Students may suggest that this is because they are smaller in general. Students could also show the association between beak depth and body mass using another scatterplot/linear regression.) So, as small beaks become more common, lower body masses will probably also become more common in the population.

CREDITS

Data set from Rosemary B. Grant and Peter R. Grant, used under CC BY-NC-SA 4.0

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