Using Data to Investigate Elephant Evolution

Activity
Educator Materials

OVERVIEW

In this activity, students work with authentic research data to explore the impact of poaching on African elephants. The data set was collected from elephant populations that have suffered historically heavy poaching and shows changes in certain traits, such as tusk size, over time. Through a series of data exploration exercises that develop their quantitative literacy skills, students examine evidence of evolution in these elephant populations.

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

- In **“Version 1,”** students explore the data and generate their own research question, hypothesis, and plot. They then investigate changes in the population by building and analyzing bar graphs. An answer key (click the link to jump directly to this section) is provided below.
- **“Version 2”** has a similar structure, but it contains less scaffolding for graphing and more statistics. Students select a statistical analysis to explore their research question. They also determine statistical significance using error bars (95% confidence intervals) and the *t* test. An answer key (click the link to jump directly to this section) is provided below.

This activity supports the data set “Elephant populations under poaching” in *Data Explorer*. Additional information related to pedagogy and implementation can be found on this resource’s webpage, including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

- Evolution by selection occurs when individuals with an advantageous, heritable trait produce a greater number of viable offspring than those without the trait over generations.
- The advantages and disadvantages of certain traits may vary across different environments or conditions.
- Human activities can influence the evolution of other species.
- Graphing and statistics can be used to summarize and examine patterns in data.

STUDENT LEARNING TARGETS

- Use authentic research data to examine evidence of evolution through quantitative analysis and reasoning.
- Make predictions about the evolution of a population under certain selective pressures.
- Generate graphical representations to explore data and draw conclusions.

For **“Version 2”** only:

- Conduct statistical analyses to explore data and draw conclusions.
- Determine whether the difference in the means of two groups is statistically significant (e.g., by using error bars representing 95% CIs or Student’s *t* test).

PRIOR KNOWLEDGE

Students should have a basic understanding of:

- evolution (population genetics definition) and the forces that can drive evolution in a population
- using a data visualization and analysis tool (*Data Explorer*, Google Sheets, Microsoft Excel, etc.)
- constructing and interpreting bar graphs

For **"Version 2"** only, students should also understand:

- statistical significance and interpreting *P* values
- plotting and interpreting error bars representing 95% CIs
- some common statistical analyses (e.g., Student's *t* test)

BACKGROUND

Humans can, often unintentionally, drive evolution in other species. Evolution by selection in wild populations as a result of specific human activities has been called **human-induced evolution**. Some types of human-induced evolution are due to hunting or **poaching** (illegal harvesting of wildlife), which selectively removes animals from wild populations. When hunters or poachers preferentially kill animals that have "desirable" phenotypes (large size, big antlers, specific pelt/fur color, etc.), they may select against phenotypes that are advantageous in a natural environment. Thus, this type of selection is sometimes called **unnatural selection** (Allendorf and Hard 2009).

In this activity, students evaluate evidence of unnatural selection in African elephants (*Loxodonta africana*). Elephant populations have suffered massive declines due to hunting, habitat loss, and increased isolation between populations. The African elephant population, once estimated to be over 20 million historically, is now estimated to be approximately 370,000 (Chase et al. 2016). Scientists are investigating how individuals in these populations may differ physically or behaviorally over generations, particularly as a result of selection driven by poaching. Elephant poaching is extremely lucrative because elephant tusks are made of **ivory**: a valuable material used to produce jewelry, ornaments, and more. (Tusks are actually teeth composed of hard, dense bone covered in enamel, much like human teeth.)

Because poachers usually kill the elephants with the largest tusks in order to harvest them for ivory, they have triggered evolutionary changes in the tusk morphology of certain elephant populations. The data set for this activity, which comes from Chiyo et al. (2015), focuses on elephant populations along the Kenya-Tanzania border. Severe poaching of these populations occurred in the late 1970s and early 1980s. The data were collected in the 1960s and the 2000s and show changes in tusk size over this time period.

MATERIALS

- the elephant 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)

TEACHING TIPS

Working with the Data

- Students will need a tool that supports graphing (and statistical analyses if you are using the "Version 2" handout). 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 elephant data set by going to "Choose data to explore" and clicking on the "Elephant populations under poaching" 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.

Running the Activity

Both versions of the activity have four parts with similar structures. Completing all four parts is *not* necessary; you may want to focus on or modify certain parts depending on your class's background and needs.

- **Part 1** provides background on the data and has students start exploring the data set.
- **Part 2** is an open-ended, inquiry-based investigation in which students generate their own research question and hypothesis, create a plot, and (in "Version 2" only) run a statistical analysis.
  - It may be helpful to give students additional support for selecting and interpreting plots and statistical analyses. There are two handouts on the *Data Explorer* webpage that can be used as supporting resources.
    - The **"Plot Selection Guide"** summarizes some different plot types. For each plot type, the guide describes the purpose, the types of variables that can be used, and several examples.
    - The **"Statistical Analysis Selection Guide"** summarizes some different statistical analyses. For each analysis, the guide describes the purpose, the types of variables that can be used, and assumptions.
  - If students struggle to generate their own research questions, consider providing an example to help them get started. The two guides mentioned above could also be used as starting points.
    - You could also give more direction for the investigation if needed. For example, you could ask students to explore the relationship between two continuous variables (of their choice) using a scatterplot and linear correlation analysis.
  - Consider having students share their investigations with their peers. They can discuss how their investigations were similar or different, what they've learned from each other, and what they would like to investigate further.
- **Part 3** guides students through using the data to compare mean tusk size characteristics of elephant populations before and after poaching.
  - The introduction to Part 3 uses an example involving foxes (Allendorf and Hard 2009) to demonstrate the evolutionary impacts of hunting on wild populations. Consider supplementing or substituting this example with one more relevant or familiar to your students.
    - Other examples include the evolution of smaller body sizes in fish due to intensive fishing and the evolution of smaller horns in bighorn sheep due to trophy hunting.
  - Students will be asked to plan a plot that compares means of two groups (Question 12 in "Version 1" and Question 10a in "Version 2"). You may want to provide more support to make sure students choose an appropriate plot type (e.g., bar graph).
  - A few questions in "Version 2" require prior knowledge in statistics. For students without a statistics background, you will either want to remove/modify these questions or provide additional scaffolding and support. In particular:
    - Question 11 requires understanding of statistical significance.
    - Question 12 requires understanding of error bars and 95% confidence intervals.
    - Question 13 requires knowledge of a statistical analysis (e.g., *t* test) that can compare the means of two groups.
  - "Version 2" asks students to do plots and analyses for two traits: tusk length and tusk circumference. If you are short on time, you can just focus on tusk length.
    - Alternatively, you can do the plots/analyses for one trait as an example in class, then have students do the second trait on their own.

- **Part 4** has students consider whether their results provide evidence of evolution in the elephant population. Depending on students' backgrounds, you may wish to provide additional scaffolding for constructing explanations about evolution.
  - The activity "Developing an Explanation for Tuskless Elephants" provides some examples for a slightly different phenomenon and could be adapted for this activity.

Caveats and Clarifications

- The type of selection shown in this activity is known as "unnatural selection" (Allendorf and Hard 2009). Unnatural selection can be distinguished from natural selection and artificial selection as follows:
  - **Natural selection** occurs "naturally" without human intervention. The frequency of phenotypes that are advantageous in a particular environment increases over time.
  - **Artificial selection** is driven by humans selecting *for* phenotypes they consider "desirable" — i.e., by selectively breeding organisms with desirable phenotypes. The frequency of desirable phenotypes *increases* over time.
  - **Unnatural selection** is driven by humans selecting *against* phenotypes they consider "desirable" — e.g., by removing organisms with desirable phenotypes through hunting, fishing, or harvesting. These desirable phenotypes (e.g., large tusks for elephants) may also be advantageous in the natural environment. The frequency of desirable phenotypes *decreases* over time.

Supplements and Extensions

- Have students come up with examples of other populations (ideally ones relevant to their local contexts or interests) in which evolution may be affected by humans. Students could propose which types of data to collect, or which analyses to perform, in order to investigate their chosen populations.
- Have students delve deeper into the elephant data through additional plots or statistical analyses. Students could explore more evidence of the populations changing over time with respect to other characteristics in the data set.
  - The data set used in the activity is an abbreviated version of the data published by Chiyo et al. (2015). The full data set is freely available from the Dryad Data Repository through this link if your students would like to explore further.
  - Students could also find and explore more recent data on African elephants, to see what may have changed since the end of the Chiyo et al. (2015) study.
- Use the Scientists at Work video *Selection for Tuskless Elephants* to support continued discussions of elephants, poaching, and evolution. This video shows how poaching affected a different elephant population and, in this case, led to an increased proportion of female elephants without tusks.
  - If you would like students to explore the video's content in more depth, consider using the accompanying activities "Developing an Explanation for Tuskless Elephants" and "Analyzing Data on Tuskless Elephants."
  - The video *The Genetics of Tusklessness in Elephants* shows how scientists are determining which genes are involved in the development of tusks (or lack thereof).

ANSWER KEY: VERSION 1

PART 1: Exploring the Data Set

1. Based on the information so far, what kind of data are you expecting to see in this data set? For example, what types of measurements or observations do you think were included?
   Student answers will vary. They may give examples of individual traits (size, age, physical features, etc.) or of population-level characteristics (population size, growth rate, etc.)

2. Give a reason why collecting these types of data on elephants could be useful. For example, what do you think these data could help us learn or do? If you want, you can pick a specific part of the data to focus on.
   There are many possible answers. Students may suggest ways in which the data could be used to help the elephant populations; for example, data on the elephants' ages, sexes, etc., could be used to inform breeding programs and other conservation efforts. They could also suggest using the data to study the impacts of environmental changes over the same time period, or to just learn more about population ecology in general.

3. The data set shows different **variables** (characteristics that differ among individuals) in different columns. There are two types of variables: numerical variables and categorical variables.
   a. How can you tell if a variable is numerical or categorical?
      A numerical variable is for quantitative observations with numeric meanings. Its values are always numbers. A categorical variable is for qualitative observations without numeric meanings. Its values are usually names or labels. (You may need to clarify with students that categorical variables can also have values that are numbers representing categories, like ZIP codes or ID numbers.)

   b. Name one *numerical* variable from this data set.
      Possible answers are estimated age, shoulder height, tusk length, and tusk circumference.

   c. Name one *categorical* variable from this data set.
      Possible answers are years of sample collection, ID, and sex.

4. Sort the data set as needed to answer the following questions.
   a. What is the ID of the elephant with the longest tusks? When was this elephant measured?***This ID is 605 and was measured in 1966–68.***

   b. Find the group of elephants with the top 10 longest tusks. Are there more males or females in this group?
      There are more males. (In fact, they are all males.)

   c. What is the age of the youngest elephant, and how many elephants share this age? Why do you think there are no tusk lengths or tusk circumferences listed for these elephants?
      The youngest age is 0.08 years (about one month), and six elephants share this age. Student answers for why there are no tusk measurements may vary; be open to a range of reasonable responses. (The canonical answer is that elephants typically don't grow tusks until they are older.)

   d. What are the IDs of the two oldest elephants? Note that no tusk lengths are listed for these elephants. Why might data on these elephants have been included in the data set even though some information is missing?
      The two oldest elephants (55 years old) have IDs 470 and 471. Student answers for why the elephants were included may vary; be open to a range of reasonable responses. For example, students may suggest that these elephants can still be used to study other traits for which they do have information (height, tusk circumference, etc.).

PART 2: Visualizing the Data

Student answers throughout Part 2 vary. This part is intentionally open-ended in order to give students the freedom to explore and engage in inquiry. Be open to a range of reasonable responses and provide students with additional support as needed.

5. Come up with a research question that is interesting to you *and* could be answered by visualizing these data.
   There are many possible questions. For example, students could ask if there are differences in certain

elephant traits (e.g., age, height, tusk length, etc.) between different groups (e.g., sex, years of sample collection). They could also ask if there are relationships between certain traits (e.g., height and tusk length).

6. Write a hypothesis (your expected answer or result) for your research question.
Students' hypotheses will vary but should be consistent with the research questions they proposed. For example, if their question was "Is tusk length related to elephant height?" their hypothesis might be "Tusk length increases with height."

7. Plan a plot (graph) that could help you test your hypothesis. Feel free to explore several types of plots before choosing the one best suited to your purpose.
Responses will vary depending on the research question. Some example responses for the question "Is elephant height related to tusk length?" are shown below.

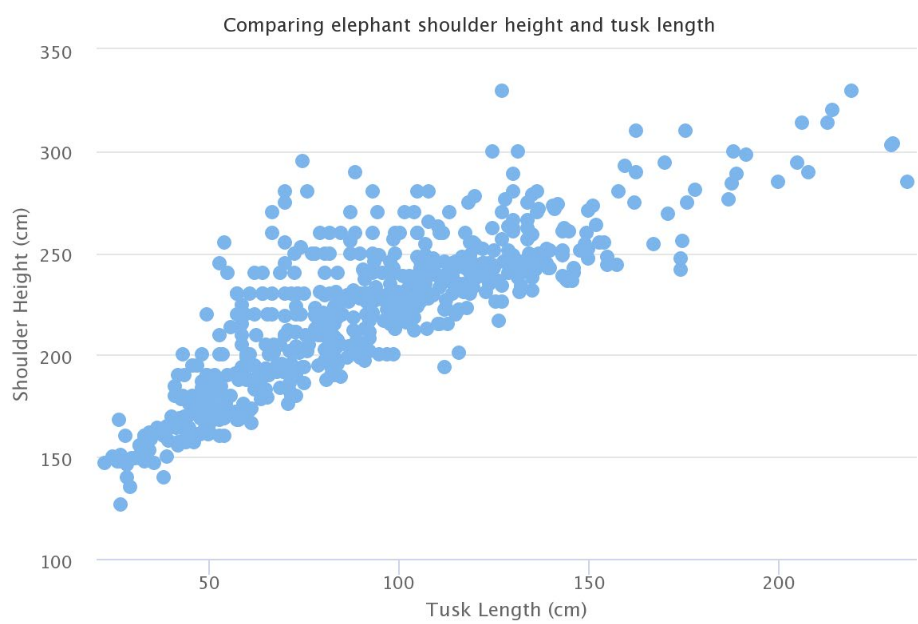
   a. Which variables from the data set will your plot show? Are they categorical or numerical variables?
   My variables are shoulder height and tusk length, both of which are numerical variables.

   b. What type of plot are you going to make? Why did you choose that plot type? (*Hint*: Think about the types of variables you chose. Some plots are better for showing certain types of variables than others.)
   I will make a scatterplot, because it is a type of plot that uses two numerical variables.

   c. What will be on the *x*-axis?
   Tusk length

   d. What will be on the *y*-axis?
   Shoulder height

8. Create your plot in *Data Explorer* (under the **"Visualize"** tab at the top) or another program, as directed by your instructor. <u>Make sure to include the plot when submitting this handout</u>.
A plot for the example above made in* Data Explorer *is shown below.



9. Summarize what you observe from your plot, including any patterns or trends. Does the plot support the hypothesis you made earlier? Why or why not?
A response for the example above could be as follows:
My plot shows that, in general, taller elephants have longer tusks, and shorter elephants have shorter tusks. This supports my hypothesis that tusk length increases with height.

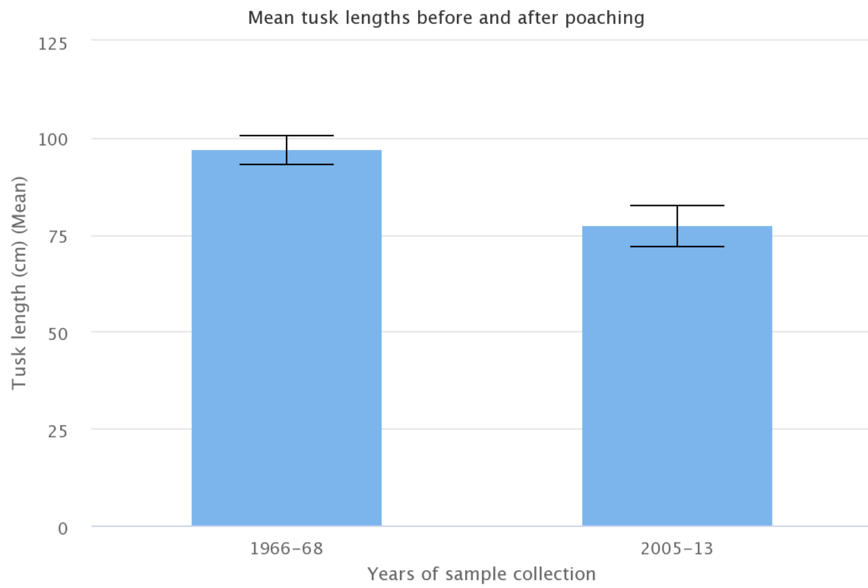
PART 3: Investigating the Impacts of Poaching

10. Based on what you learned about the fox population, which traits do you think were affected by poaching in the elephant populations? How might the elephant populations have changed over time as a result?
    Student answers may vary but should follow logically from the fox example. In the fox example, hunters killed foxes for their fur. They preferentially killed foxes with silver fur, since silver fur was more valuable. This made foxes with silver fur less common in the population over time.
    In the elephant example, poachers killed elephants for their tusks. They preferentially killed elephants with larger tusks, since larger tusks have more ivory and would be more valuable. As a result, one might expect traits related to tusk size (e.g., tusk length) to be the most affected by poaching, with traits associated with larger tusks becoming less common in the population over time.

11. Would you expect the elephants from the two different time periods to have different tusk lengths? Why or why not?
    Students' predictions may vary depending on their assumptions and prior knowledge. They will learn more by visualizing the data in the subsequent questions.
    Since poachers preferentially killed elephants with larger tusks, students might expect traits associated with larger tusks to be less common in the population after poaching. If so, the tusk lengths of elephants after poaching would probably be shorter than those of elephants before poaching.

12. Plan a plot that will compare the *mean* tusk length for elephants from 1966–1968 (before poaching) to that of elephants from 2005–2013 (after poaching).
    a. What type of plot are you going to make? (*Hint*: What type of plot can you use to compare mean values?)
       Bar graph (This is the most typical type of plot for comparing mean values. If students come up with other ideas, make sure that they are able to compare mean values as well.)
    b. What will be on the *x*-axis?
       Years of sample collection (1966–68 and 2005–13)
    c. What will be on the *y*-axis?
       Mean tusk length

13. Create your plot in *Data Explorer* (under the **"Visualize"** tab at the top) or another program, as directed by your instructor. <u>Make sure to include the plot when submitting this handout</u>.
    An example plot made in* Data Explorer *is shown below. The error bars are not required.



14. Summarize what you observed from this plot, including any patterns or trends. How do these results compare with your expectations in Question 11?
Student answers will vary depending on their predictions in Question 11. They will likely note that the elephants before poaching had a greater mean tusk length than the elephants after poaching. (Students with some statistics background may also recognize that this difference is statistically significant. Version 2 of this handout has more information on how to determine statistical significance using 95% confidence interval error bars and the* t *test.)

PART 4: Elephant Evolution

15. Consider the following conditions required for evolution. Describe how you think each condition applies to the elephant populations under poaching. Provide evidence based on the data set, your plots, and/or information you learned in this activity.

Condition	**Description**	**Evidence in the elephant population**
Variation	There is variation in the trait of interest (e.g., tusk size) in the population.	***The data set shows that different elephants have different tusk lengths.***
Inheritance	The trait of interest is at least partially inherited.	***Many elephant traits, including tusk length, are likely to be at least partially inherited.***
Differential survival and reproduction	Individuals with a certain version of the trait are more likely to survive and reproduce than individuals with a different version of the trait.	***Elephants are killed for their tusks by poachers. Since elephants with smaller tusks are less valuable to poachers, they aren't killed as often and are more likely to survive and reproduce.***
Adaptation	The version of the trait that helps individuals survive and reproduce becomes more common in the population over multiple generations. (The	***From the 1960s to the 2000s (about two elephant generations), the mean tusk length decreased. This indicates that elephants with smaller tusks became more common in the population.***

	average generation time for African elephants is 25 years.)	

16. Poaching has decreased a lot since the 1980s. Why might poaching still affect mean tusk length in 2005–2013? (*Hint*: The average generation time for African elephants is 25 years.)
Since the average generation time for African elephants is 25 years, even if poaching decreased in the 1980s, many of the elephants that were affected by poaching (and/or their offspring, which likely inherited similar traits) were probably still around in 2005–2013. These elephants have smaller tusks on average, so the mean tusk length is still smaller than it was before poaching.

17. If there is no more poaching in the future, how might the mean length in 100 years differ from the mean tusk length in 2005–2013? (*Hint*: African elephants use their tusks to strip bark off trees for food and to dig up water from the ground. Larger tusks are useful for these tasks.)
Without poaching, elephants with smaller tusks don't have a clear advantage over elephants with larger tusks. In fact, elephants with larger tusks might have an advantage because tusks are useful for getting food and water. So, assuming there are no other environmental changes that favor small tusks, the mean tusk length in 100 years would probably be greater than the mean tusk length in 2005–2013.

18. In addition to changes in tusk length, how else might elephant populations change due to poaching?
Student answers will vary. They may suggest that the elephants could evolve to no longer have tusks at all. (Tuskless elephants are, in fact, a real phenomenon; see the extension resources in the "Teaching Tips" section above for more information.) Students could also suggest changes in other physical characteristics that may be affected by poaching. For example, if smaller elephants are better at escaping poachers, the mean height and weight could decrease over time.
Students could also suggest behavioral changes that would help elephants avoid poaching (e.g., changes in where they live or migrate, when or what they eat) or changes in population-level characteristics (e.g., changes in population size or demographics).

ANSWER KEY: VERSION 2

PART 1: Exploring the Data Set

1. Give a reason why collecting these types of data on elephants could be useful. For example, what do you think these data could help us learn or do? If you want, you can pick a specific part of the data to focus on.
There are many possible answers. Students may suggest ways in which the data could be used to help the elephant populations; for example, data on the elephants' ages, sexes, etc., could be used to inform breeding programs and other conservation efforts. They could also suggest using the data to study the impacts of environmental changes over the same time period, or to just learn more about population ecology in general.

2. The data set shows different variables in different columns. There are two types of variables: numerical and categorical. In general, what is the difference between numerical and categorical variables?
Numerical variables are for quantitative observations with numeric meanings. Their values are always numbers. Categorical variables are for qualitative observations without numeric meanings. Their values are usually names or labels. (You may need to clarify with students that categorical variables can also have values that are numbers representing categories, like ZIP codes or ID numbers.)

3. Find one elephant that is missing data for one or more variables. What data is missing, and why might it be missing?
There are many possible answers. For example, the elephant with ID 470 is missing tusk length, and the elephant with ID 1 is missing tusk length and tusk circumference. Student ideas for why

certain measurements are missing will vary; be open to a range of reasonable responses. For example, students could suggest that some tusks were broken or hadn't grown yet for younger elephants.

PART 2: Investigating a Research Question

Student answers throughout Part 2 vary. This part is intentionally open-ended in order to give students the freedom to explore and engage in inquiry. Be open to a range of reasonable responses and provide students with additional support as needed.

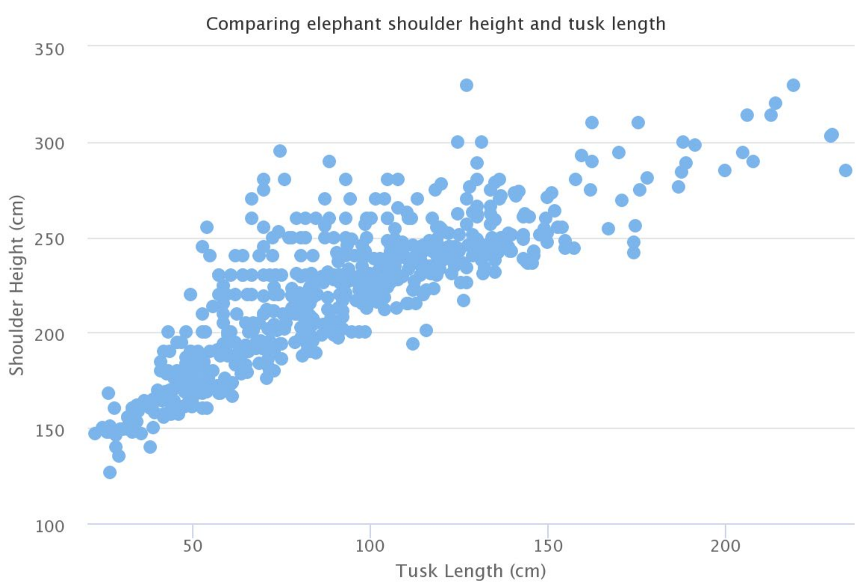
4. Come up with a research question that is interesting to you *and* that you think you could answer with a plot or statistical analysis.
   There are many possible questions. For example, students could ask if there are differences in certain elephant traits (e.g., age, height, tusk length, etc.) between different groups (e.g., sex, years of sample collection). They could also ask if there are relationships between certain traits (e.g., height and tusk length).

5. Write a hypothesis for your research question.
   Students' hypotheses will vary but should be consistent with the research questions they proposed. For example, if their question was "Is tusk length related to elephant height?" their hypothesis might be "Tusk length increases with height."

6. Plan a plot (graph) that could help you test your hypothesis. Feel free to explore several types of plots before choosing the one best suited to your purpose.
   Responses will vary depending on the research question and hypothesis. Some example responses for the question "Is elephant height related to tusk length?" are shown below.

   a. What type of plot are you going to make? Why did you choose that plot type?
      I picked a scatterplot because it shows two numerical variables, and my question is about the relationship between two numerical variables (elephant height and tusk length).

   b. Create your plot in *Data Explorer* (under the **"Visualize"** tab at the top) or another program, as directed by your instructor. Make sure to include the plot when submitting this handout.
      An example plot made in* Data Explorer *is shown below.



   c. Summarize what you observe from your plot, including any patterns or relationships. Does the plot support the hypothesis you made earlier? Why or why not?

My plot shows that, in general, taller elephants have longer tusks, and shorter elephants have shorter tusks. This supports my hypothesis that tusk length increases with height.

7. Plan a statistical analysis that could help you test your hypothesis or learn more about the patterns or relationships you observed from your plot.
Again, responses will vary depending on the research question and hypothesis. Some example responses for the question "Is elephant height related to tusk length?" are shown below.
   a. What type of analysis are you going to do? Why did you choose that analysis?
   I will do a linear correlation analysis. I chose this analysis because it determines the strength of a relationship between two numerical variables, and my research question is about the relationship between elephant height and tusk length.
   b. Do your analysis in *Data Explorer* (under the "**Analyze"** tab at the top) or another program, as directed by your instructor, then summarize your results. Does the analysis support the hypothesis you made earlier? Why or why not?
   The results of my linear correlation analysis were $r = 0.83$ ***and*** $P < 0.0001$***. Since*** r ***is positive and relatively close to 1, it indicates a reasonably strong positive correlation between elephant height and tusk length. Since the*** P ***value is very small, this correlation is likely to be significant. These results support my hypothesis that tusk length increases with height.***

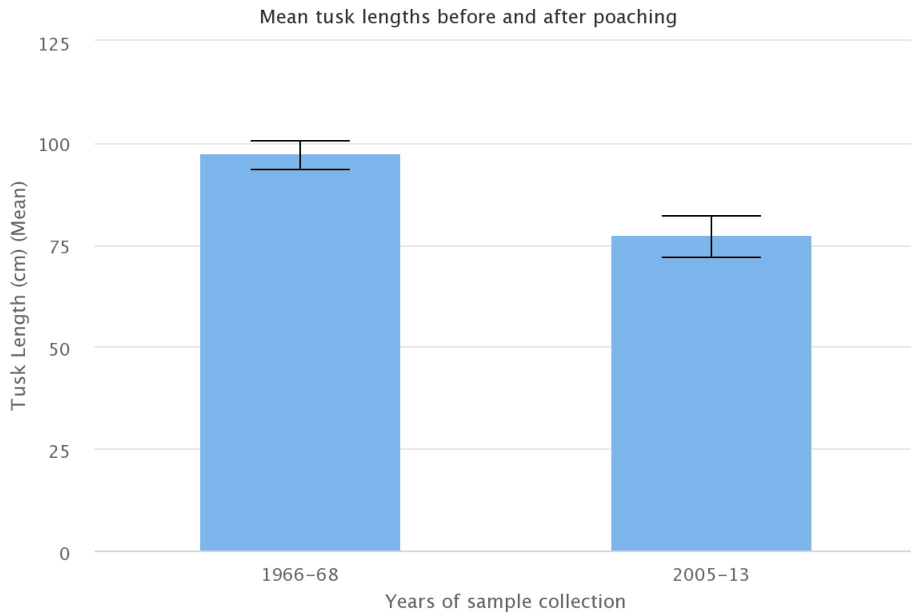
PART 3: Investigating the Impacts of Poaching

8. Based on what you learned about the fox population, which traits do you think were affected by poaching in the elephant populations? How might the elephant populations have changed over time as a result?
Student answers may vary but should follow logically from the fox example. In the fox example, hunters killed foxes for their fur. They preferentially killed foxes with silver fur, since silver fur was more valuable. This made foxes with silver fur less common in the population over time.
In the elephant example, poachers killed elephants for their tusks. They preferentially killed elephants with larger tusks, since larger tusks have more ivory and would be more valuable. As a result, one might expect traits related to tusk size (e.g., tusk length) to be the most affected by poaching, with traits associated with larger tusks becoming less common in the population over time.

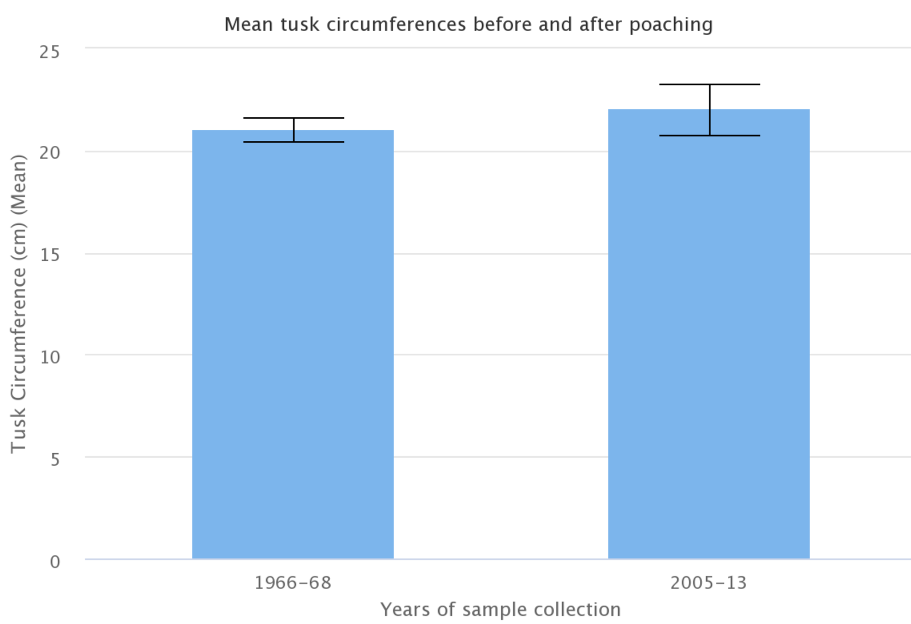
9. Would you expect the elephants from the two different time periods to have different tusk lengths or circumferences? Why or why not?
Students' predictions may vary depending on their assumptions and prior knowledge. They will learn more by analyzing the data in the subsequent questions.
Since poachers preferentially killed elephants with larger tusks, students might expect traits associated with larger tusks to be less common in the population after poaching. If so, the tusk lengths and circumferences of elephants from the later time period might be smaller than those of elephants from the earlier time period.

10. To see if the data support your expectations, you'll now create plots to compare mean tusk lengths and circumferences for the elephants from the two different time periods. You can make the plots in *Data Explorer* or another program, as directed by your instructor. <u>Make sure to include the plots when submitting this handout</u>.
   a. Which type of plot would you use to compare the means of two groups?
   Bar graph (This is the most typical type of plot for comparing mean values. If students come up with other ideas, make sure that they are able to compare mean values as well.)

b. Create a plot to compare the **mean tusk lengths** of the elephants from the two periods: **1966–1968** (before poaching) and **2005–2013** (after poaching).
An example plot made in* Data Explorer *is shown below. The error bars are not required for this question.



c. Create a plot to compare the **mean tusk circumferences** of the elephants from the two periods: **1966–1968** (before poaching) and **2005–2013** (after poaching).
An example plot made in* Data Explorer *is shown below. The error bars are not required for this question.



d. Summarize what you observed from these two plots, including any patterns or trends. How do these results compare with your expectations in Question 9?
Students may note that the elephants before poaching had a greater mean tusk length and a slightly smaller mean tusk circumference compared to the elephants after poaching. However, the difference between the two time periods for mean tusk circumference is small compared to the difference for the mean tusk length.

11. You may have observed some differences in the mean tusk lengths and circumferences of the elephants before and after poaching. But even if the mean values differ, these differences may or may not be **statistically significant**.
Student answers will vary depending on their prior knowledge. You may need to provide additional scaffolding or support if your students are not familiar with statistical significance.

    a. What does it mean for a difference to be "statistically significant"?
    A difference is statistically significant if it's likely to be caused by an actual difference between the groups rather than just happening by chance.

    b. Why would it be useful to know whether differences between the elephants before and after poaching are statistically significant?
    This would help us determine whether there are "real" differences between the elephants before and after poaching. If these differences exist, they could have been caused by poaching.

12. One way to determine whether a difference in means is statistically significant is by using **95% confidence intervals**, which can be shown on a graph as error bars.
Student answers will vary depending on their prior knowledge. You may need to provide additional scaffolding or support if your students are not familiar with error bars and confidence intervals.

    a. What is a 95% confidence interval (also written as 95% CI)?
    The 95% CI is a range around the mean of a sample within which the mean of the entire population is likely to be found. (Specifically, there is a 95% chance that the 95% CI contains the mean of the entire population.)

    b. When do error bars for 95% CIs suggest that a difference in means is statistically significant?
    When 95% CI error bars do not overlap, it suggests there is a statistically significant difference between the means ($P < 0.05$). 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.)

    c. Add error bars for 95% CIs to your plots of mean tusk length and mean circumference. <u>Make sure to include the plots with error bars when submitting this handout</u>.
    See the example graphs in Question 10b above.

    d. Based on these error bars, is there a statistically significant difference in the *mean tusk length* for the elephants before and after poaching? Or can you not tell?
    The 95% CI error bars do not overlap, suggesting that there is a statistically significant difference in these mean tusk lengths.

    e. Based on these error bars, is there a statistically significant difference in the *mean tusk circumference* for the elephants before and after poaching? Or can you not tell?
    You can't tell because the 95% CI error bars overlap, which doesn't suggest anything about whether the difference is statistically significant or not.

13. Another way to determine whether a difference in means is statistically significant is by doing a statistical analysis.
Student answers will vary depending on their prior knowledge. You may need to provide additional scaffolding or support if your students are not familiar with the relevant statistical analyses and hypothesis testing.

a. Which statistical analysis would you use to compare the means of two groups?
There are multiple analyses that can do this. Student's* t *test is a common choice. Welch's* t *test and one-way ANOVA with two samples could also be used.

b. Use the analysis to compare the *mean tusk length* for elephants before and after poaching. Summarize your results and whether they indicate that the difference in means is statistically significant.
Answers will vary depending on the chosen analysis. For Student's* t *test, for example,* P *< 0.0001. Since this* P *value is very small (i.e., less than the typical significance level of 0.05), the difference in mean tusk lengths is statistically significant.

c. Use the analysis to compare the *mean tusk circumference* for elephants before and after poaching. Summarize your results and whether they indicate that the difference in means is statistically significant.
Answers will vary depending on the chosen analysis. For Student's* t *test, for example,* P *= 0.1999. Since this* P *value is rather large (i.e., greater than the typical significance level of 0.05), the difference in mean tusk circumference is not statistically significant.

d. Did you discover anything new from your statistical analysis that you didn't already learn from the error bars? If so, what?
As discussed in Question 12e, the error bars are inconclusive as to whether the difference in mean tusk circumference is statistically significant. The statistical analysis was able to show that this difference is not statistically significant.

14. Summarize what you learned from your plots and analyses. How do the results compare to what you expected in Question 9? Why do you think the results are the way they are?
The mean tusk length was significantly smaller in the elephants after poaching compared to the elephants before poaching. The mean tusk circumference, on the other hand, was not significantly different before and after poaching. Students may be surprised that tusk length changed but tusk circumference did not. Student answers for why the results are the way they are may vary; be open to a range of reasonable responses. Students may suggest that poachers preferentially killed elephants with longer tusks, rather than tusks with greater circumferences, or that tusks with greater circumferences had other advantages to counteract disadvantages from poaching. Students with more background in statistics could also suggest that the result for tusk circumference was a false negative (Type II error). This is likely when the statistical power is low — which can happen when the sample size is small, the effect being studied is small, or both.

PART 4: Elephant Evolution

15. Consider the following conditions required for evolution. Describe how you think each condition applies to the elephant populations under poaching. Provide evidence based on the data set, your plots and statistical analyses, and/or information you learned in this activity.

Condition	Description	Evidence in the elephant population
Variation	There is variation in the trait of interest (e.g., tusk size) in the population.	***The data set shows that different elephants have different tusk lengths and tusk circumferences.***
Inheritance	The trait of interest is at least partially inherited.	***Many elephant traits, including tusk length and tusk circumference, are likely to be at least partially inherited.***

Differential survival and reproduction	Individuals with a certain version of the trait are more likely to survive and reproduce than individuals with a different version of the trait.	***Elephants are killed for their tusks by poachers. Since elephants with smaller tusks are less valuable to poachers, they aren't killed as often and are more likely to survive and reproduce.***
Adaptation	The version of the trait that helps individuals survive and reproduce becomes more common in the population over multiple generations. (The average generation time for African elephants is 25 years.)	***From the 1960s to the 2000s (about two elephant generations), the mean tusk length significantly decreased. This indicates that elephants with shorter tusks became more common in the population.***

16. Poaching has decreased a lot since the 1980s. Why might poaching still affect mean tusk size in 2005–2013? (*Hint*: The average generation time for African elephants is 25 years.)
    Since the average generation time for African elephants is 25 years, even if poaching decreased in the 1980s, many of the elephants that were affected by poaching (and/or their offspring, which likely inherited similar traits) were probably still around in 2005–2013. These elephants have smaller tusks on average, so the mean tusk size is still smaller than it was before poaching.
17. If there is no more poaching in the future, how might the mean tusk size in 100 years differ from the mean tusk size in 2005–2013? (*Hint: African* elephants use their tusks to strip bark off trees for food and to dig up water from the ground. Larger tusks are useful for these tasks.)
    Without poaching, elephants with smaller tusks don't have a clear advantage over elephants with larger tusks. In fact, elephants with larger tusks might have an advantage because tusks are useful for getting food and water. So, assuming there are no other environmental changes that favor small tusks, we'd expect the mean tusk size in 100 years to be greater than the mean tusk size in 2005–2013.
18. In addition to changes in tusk size, how else might elephant populations change due to poaching?
    Student answers will vary. They may suggest that the elephants could evolve to no longer have tusks at all. (Tuskless elephants are, in fact, a real phenomenon; see the extension resources in the "Teaching Tips" section above for more information.) Students could also suggest changes in other physical characteristics that may be affected by poaching. For example, if smaller elephants are better at escaping poachers, the mean height and weight could decrease over time.
    Students could also suggest behavioral changes that would help elephants avoid poaching (e.g., changes in where they live or migrate, when or what they eat) or changes in population-level characteristics (e.g., changes in population size or demographics).

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