Data Activity: Educator Materials

Title

Is bigger always better? An investigation on the effect of drought on different sizes of trees.

Overview

In this activity, students begin by first watching a video by Howard Hughes Medical Institute (HHMI) BioInteractive called Scientists at Work "Liz Hadley Tracks the Impact of Climate Change in Yellowstone". This video provides an example of the long-reaching effects of biotic interactions and how climate change can affect these interactions. Students then work with authentic data from Bennett et al. (2015) to statistically analyze the effect of drought, one consequence of climate change, on tree mortality and diameter growth, and assess how these variables are further exacerbated by bark beetle infestations. Tree mortality and growth are separated by the size category of tree, allowing students to conclude that larger trees are more negatively impacted by drought than smaller trees and mortality is drastically increased in the presence of beetle infestation. By first observing scientists in the field through the video, and then working with a real dataset, students are able to gain a broader perspective of the work scientists perform and gain experience analyzing and interpreting data. Students also reflect on the cascading effect of this one abiotic factor on a large interdependent ecosystem.

Key Concepts

- A forest ecosystem is structurally diverse, composed of many interconnected species with some species having a greater influence than others. Larger tree species can have a greater impact on other forest species and are, therefore, considered keystone individuals.
- Climate change continues to have varied effects on the global climate. An increase in temperature and precipitation redistribution are two specific global consequences of climate change. Drought is often associated with increased temperatures. Drought conditions are also predicted to increase in both frequency and severity for many locations worldwide as a result of precipitation redistribution.
- Warmer temperatures resulting from climate change can also impact biotic interactions. In particular, less cold temperatures are altering insect distributions, including those of damaging pest species.
- Abiotic variables, like temperature and precipitation, directly affect the species that will inhabit an area. For sessile species like plants, species will either shift distributions or die out, thereby changing the forest structure and influencing the animal species that depend on particular forest communities, further demonstrating the interconnectedness of an ecosystem.

Student Learning Targets

- Describe the complexity of an ecosystem regarding the interactions between abiotic and biotic components
- Explain the relationship between structural complexity and species diversity in a forest
- Create testable predictions as they relate to measuring the effects of climate change
- Calculate and interpret standard deviation and standard error
- Interpret the results of an Analysis of Variance (ANOVA) based on significance and biological relevance

Prior Knowledge

Students should:

- be able to list and describe general effects of climate change, particularly its effect on temperature and precipitation
- be able to define ecological niches
- be able to explain the difference between abiotic and biotic factors
- be able to construct and interpret 2-axes graphs
- have basic experience with Microsoft Excel or other spreadsheet software

Background

Students will first watch the HHMI's Scientists at Work video following Liz Hadley, a scientist who has been studying biodiversity in Yellowstone National Park for 30 years. In just these few decades, she has observed significant changes to the abiotic and biotic environment as a result of climate change. Increased temperature has resulted in prolonged dry periods allowing for some ponds to shrink or disappear, thereby having a huge negative impact on amphibian diversity and abundance. Additionally, increased temperatures are allowing for expansion of the Mountain Pine Beetle's distribution and preventing annual winter die-off, allowing for higher rates of beetle infestation in the area. Increased temperature and drought are not isolated to the National Park, but are pervasive problems throughout the western United States.

In the following activity, students will examine the effect of drought on the structural diversity of forests, which describes the three-dimensional variation in a forest. Structural diversity increases the number of niches and therefore leads to greater biodiversity. As larger trees in a forest have a larger effect than their density would suggest, they are considered keystone individuals. To explore these effects of drought on forest structure, students will analyze data from the Bennett et al. (2015) meta-analysis. Bennett et al. (2015) compiled worldwide data from various drought events and their subsequent tree mortality and diameter growth rate. These data were compressed into tree size categories based on their diameter at breast height (DBH; Figure 1), a common measurement of tree size. Also included are data on the presence or absence of bark beetles to explore any role these pests may play in tree survival and growth. After data exploration and analysis, students then reflect on the question: if the larger trees experience higher mortality then what does this mean for the local biodiversity?

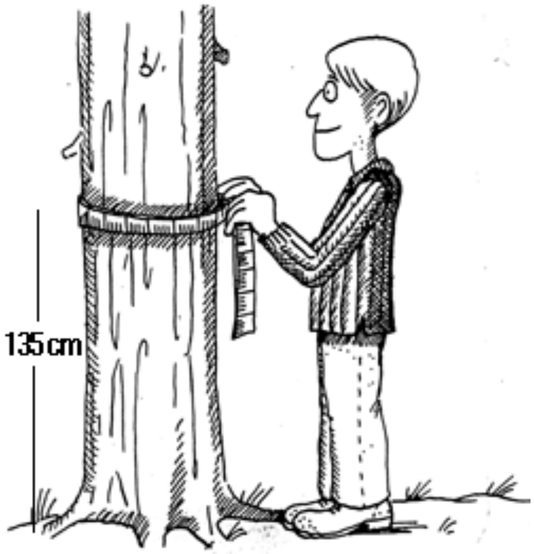


Figure 1. Demonstration of the diameter at breast height (DBH) measurement. The circumference of the tree is measured approximately 4.5 feet from the ground and then converted to a diameter (source: archive.epa.gov)

Teaching Tips

- Students should watch the Scientist at Work video, and answer the pre-activity questions, prior to the data analysis activity.
- Keystone species is a common ecological term but lesser known is the concept of keystone individuals. The concept of some individuals of the same species having a greater impact than others should be reviewed.
- The data set is compiled from a published meta-analysis data set. It could be useful to include a discussion of what a meta-analysis is and the benefits and limitations of this type of data set.
- Students are asked to label the data as either continuous or discrete, terms that may need to be defined if unfamiliar to them. Discrete variables are fixed values (2 or 3 people but never 2.5) while continuous variables assume an infinite number of values based on increased precision (for example, time is continuous).
- Data precision and accuracy are utilized in this activity. Students should be familiar with these terms.
- Students can use any spreadsheet software (e.g. Microsoft Excel, Google Sheets) to perform this activity. If students are using Microsoft Excel, they can analyze their data by downloading the free data analysis add-in. Directions in the activity are written for Microsoft Excel.
- Data analysis is suggested to be performed in student pairs.
- After student pairs finish analysis and answer the questions, the conclusion questions would create a great classroom discussion and review of the material.

Answer Key

Pre-Activity Assignment

Video: Liz Hadley tracks the impact of climate change in Yellowstone

After watching the video, answer the following questions:

1. Dr. Liz Hadley has been studying biodiversity in Yellowstone for 30 years. What is a benefit to a long-term study such as this?
   Long-term studies can show effects of climate change, which takes longer to observe since climate is a long-term measurement.

2. Why is the whitebark pine important to the grizzly bear?
   Grizzly bears eat whitebark pine seeds. It is a vital food source prior to hibernation and is correlated with overwinter survival of the bears.

3. How do grizzly bears access the seeds of the whitebark pine?
   The seeds are often too high up on the tree for grizzly bears to access. Red squirrels will store excess seeds in ground middens and these are found and eaten by the bears.

4. Describe what the mountain pine beetle does and why the species is of concern.
   They attack whitebark pine trees and can kill them within a day or two. This is a concern because grizzly bears rely heavily on this food item.

5. How has climate change affected the survival of the mountain pine beetle?
   Warmer temperatures are allowing beetles to expand their distribution to areas of higher elevation and the beetles are surviving longer. Because of this, beetles can kill more whitebark pine.

6. Describe the effect of drying ponds on wildlife. What species are most affected?
   Amphibians are the most affected. There has been a decline in species diversity and there are fewer populations for each species.

7. Write a brief paragraph on the importance of national parks at both the local level and the global level.
   Students' answers will vary but should focus on the role parks play in the protection of both abiotic and biotic factors to maintain the integrity and functionality of an ecosystem.

Activity Assignment

Using authentic data, you will analyze the mortality rate by tree size, mortality rate by bark beetle presence, and growth rate by tree size. You will first visualize the data by creating graphs and calculating standard deviation and standard error, and then analyze the data to determine if there is a statistically significant difference between the tree size categories.

1. Using the information from the video, formulate a hypothesis to describe mortality rate based on tree size.

   Students might tend to hypothesize that larger trees will have a reduced mortality rate compared to smaller trees because smaller trees may be seen as more fragile and susceptible to environmental conditions. Conversely, students may hypothesize that larger trees will have a higher mortality rate if they correlate size with age. Either hypothesis is acceptable for testing.

2. Based on your hypothesis above, draw a graph of what you predict to see in the data.

   Students should use a bar graph to depict a graph based on their hypothesis from Question 1. It should be a generalization and will likely either show a positive or negative association between size class and mortality.

3. Using Microsoft Excel, import the data and review it. From the File menu, select Import for a CSV file. The data is delimited by comma. You should have five columns of data.

   How many variables are there? Are the variables continuous or discrete? What units are used? Make sure you understand what was measured.

   Location = categorical variable
   Tree size category = categorical variable, measured in centimeters
   Mortality = continuous variable, measured in percent

Growth = continuous variable, measured in millimeters
Bark beetle = categorical variable

4. Once you view and understand the data, you can start to condense and visualize it. Before making a graph, however, you need to sort your data by size category. I recommend using the “Sort” option under the Data tab, then copying the data for each size class into separate columns (see example below).

Example of sorted data:

1	10	20	30	40	50
3.19	3.35	3.7	3.28	6.9	56.79
4.14	9.71	10.7	44.36	19.3	19.54
10.57	4.54	5.5	6.54	5.4	12.48
13.85	8.88	10.69	5.25	10.51	2.96
2.6	1.84	3.36	1.8	3.94	3.6
2.18	2.33	43.95	80.1	12.74	3.07
18.92	27.45	6.11	15.79	7.03	3.09
25.26	2.8	3.21	3.16	15.26	1.38
1.7	2.15	2.1	26.32	4.21	2.8
2.19	2.98	73.91	50	14.29	15.2
0.81	1.81	81.45	27.15	40	14.96

Using the Insert - Chart function in Microsoft Excel, create a graph of the mortality rate for each size class of tree. Don’t forget to add labels to your X- and Y-axes! You can do this in Excel using “Add Chart Element” under the “Chart Design” tab.

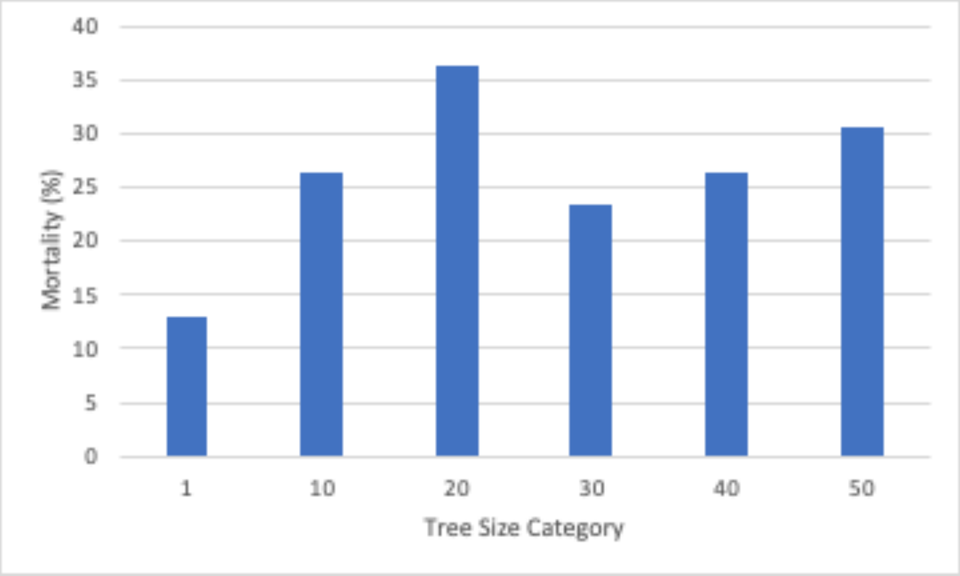
Which type of graph (bar/line graph) is best for this visualization? _bar__*Note: in Excel the best option to choose is “column” instead of “bar”______

Which variable is the dependent variable? __mortality rate________

Which variable is the independent variable? __size category__________

Describe any pattern or trends you see in the graph.

The graph shows variation in mortality based on tree size. There is no clear cut pattern but the smallest trees have the lowest mortality rate.



5. Now we want to examine the *variation* in the data, or the spread of the data around the mean. Standard deviation provides this measurement. If the data is variable, then there is low precision. Calculate and record the standard deviation for each size category (if you need additional help please see pages 8-11 in Data and Error Analysis in Science).

   Size category: 1 = _20.57_, 10 = _30.54_, 20 = _35.81_, 30 = _23.03_, 40 = _25.34_, 50 = _37.21_

   Does there appear to be low or high variability in the data? Explain.

   There is high variability in the data given the high standard deviation values.

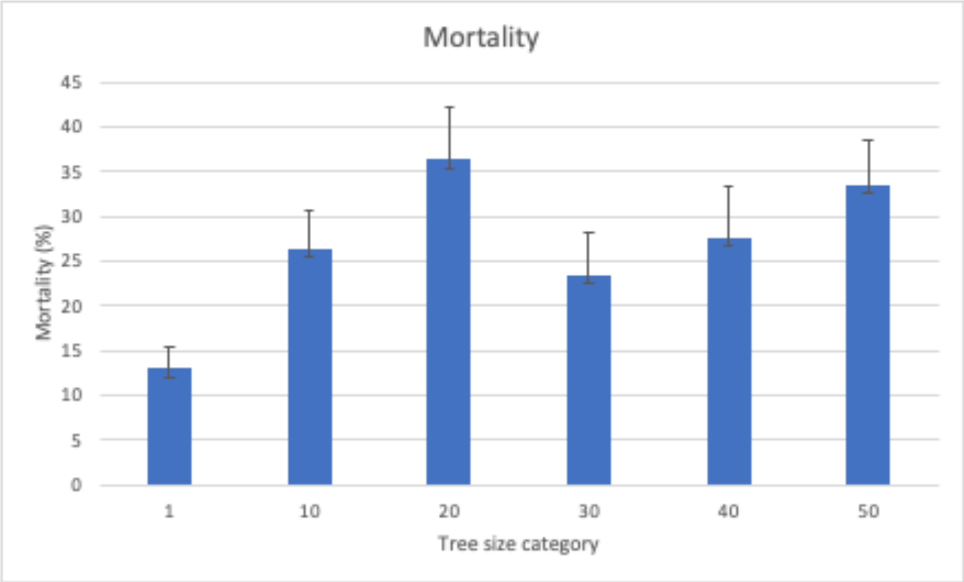
6. Another common data measurement is standard error. This calculation provides an estimate of how close your sample mean is to the actual mean, or in other words, the accuracy of your data (for further description see page 12 in Data and Error Analysis in Science). Calculate and record the standard error for each size category.

   Size category: 1 = _2.57_, 10 = _4.36_, 20 = _5.89_, 30 = _4.80_, 40 = _5.81_, 50 = _4.76_

   Does the data appear to be accurate? What could a scientist do to reduce the amount of standard error in a data set?

   Because of the high variability in the data, it is difficult to have high confidence that the sample mean is close to the actual mean.
   To reduce standard error and increase confidence in the data, a scientist should increase the sample size.

7. Let's visualize *standard error* on your graph. In Excel, go to "Add Chart Element" under the "Chart Design" tab. In the Error Bars tab, select "more options" in order to choose your Custom standard errors that you calculated.



8. Visualizing the data can provide an idea of what groups might be different but a statistical test is the only way to determine *significant* differences. *Data significance* means that the differences between groups is not due to chance and could be biologically relevant. One challenge of analyzing data is to choose the correct statistical test. In this case, the data is comparing mortality among multiple groups (tree sizes). Because we are comparing multiple groups, a common test to use is an Analysis of Variance (ANOVA).

   [*optional:* have a classroom discussion on how to choose the best statistical test to use]

   In the Data Analysis add-on for Excel, choose ANOVA: Single Factor test. Your input range is the data that you organized into columns for each size category (from Question 4). Make sure the Columns option is selected to describe how the data is grouped. Keep the Alpha value at 0.05, as is standard in biology. The alpha value is also called the significance level, and represents the probability of rejecting the null hypothesis when it is true.

   Fill in the values below with the results of your ANOVA.

   Df = _5____, F-value = _2.25_____, p-value = _0.0010_____

   Based on the results of your ANOVA, what can you conclude based on your hypothesis? Is there a statistically significant difference in mortality among the tree size categories?

The groups represent the different size categories from smallest (column 1) to the largest (column 6)

Anova: Single Factor

SUMMARY

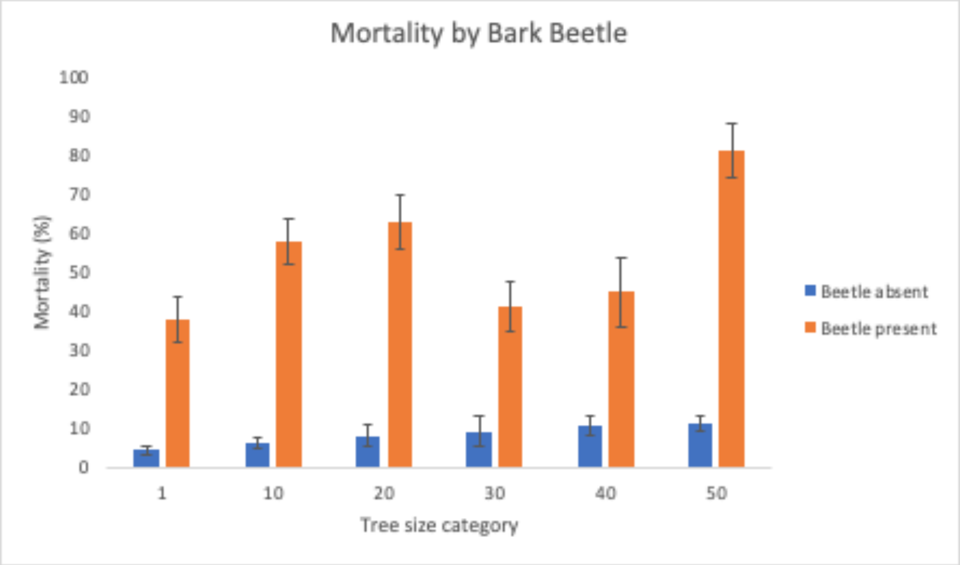
Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	68	886.99	13.0439706	401.007332
Column 2	49	1292.21	26.3716327	932.809447
Column 3	37	1346.73	36.3981081	1282.59852
Column 4	23	538.33	23.4056522	530.278389
Column 5	19	524.8	27.6210526	641.909254
Column 6	59	1980.49	33.5676271	1408.31905

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18990.8958	5	3798.17916	4.24636914	0.001008	2.25028021
Within Groups	222718.887	249	894.453363			
Total	241709.783	254				

9. Now you will examine tree mortality with the additional variable of bark beetle presence. As you saw in the Liz Hadley video, bark beetle infestation can have a considerable effect on the health of the trees in an ecosystem. Using Excel, create one graph that separates mortality rate by tree size category between those locations with bark beetles present and those locations where they are absent. Make sure to calculate the standard error for each average and add them to the graph.

   Note: It is important that they make one graph instead of two. Students may need assistance in creating two separate bars for the presence/absence of beetles.



10. Explain the mortality pattern you see in the graph between trees with bark beetles and trees without bark beetles. Do you think bark beetles play a significant role in tree mortality?

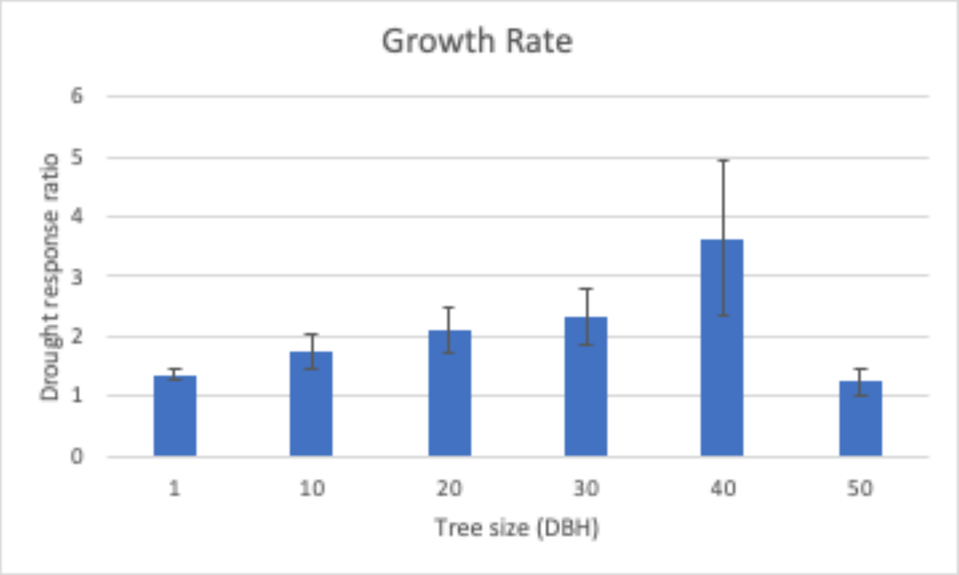
    Those trees infested with bark beetles experience higher mortality rates on average. There was also higher variability in mortality with beetles present. From looking at the graph, bark beetle presence plays a substantial role in tree mortality.

[OPTIONAL]

Mortality is an obvious negative consequence to environmental change. However, if the drought is not so severe as to cause mortality, a tree can be impacted in other way such as in their growth or reproduction. Slower growth is predicted during environmentally stressful conditions, of which drought can be considered as a stressful condition. In this section, you will examine the impact of drought on tree growth rate and determine if there is a difference based on the size of the tree.

11. Using the same data set but focusing on the **Growth** rate values instead of the Mortality values, sort the data based on tree size category as you did in Question 4. Create a graph of the average growth rate per size category and describe any patterns you see.

    Overall growth rate is low with a gradual increase with larger tree size but is lowest for the largest tree category.



12. Now, calculate standard error and add the error bars to your graph. Does your data appear to be reliable?

    See above graph.

13. List the sample size for each size category.

    Size category: 1 = _36_, 10 = _21_, 20 = _12_, 30 = _9_, 40 = _4_, 50 = _21_

14. If the low sample sizes were increased, predict what the graph may look like instead.

    One could predict that the difference seen in the 40 DBH size category would disappear and the graph would look more uniform.

Conclusions

Using your knowledge on the importance of a structurally diverse forest, what can you infer from your analysis regarding the future of the forest structure with respect to prolonged drought? In your answer, consider tree size and beetle presence. What impact could this have on the forest animals?

Using your local habitat, design an experiment that would allow you to more directly measure the effect of long-term drought on forest health.

Create a conservation management plan to protect large trees in light of impending climate change.

Extension activities

Examine mortality and growth based on sampling location to determine if there is a connection between tree response and location.

Collect global temperature/precipitation data (for example, NOAA has online climate data: https://www.ncdc.noaa.gov/cdo-web/) and/or local data from your region and examine the data trends. Make predictions of tree longevity of the forests in your area.

Search for data on bark beetle distribution and spread, or other forest damage agent (for example, the USDA has distribution maps for many different forest damage agents (https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/damage-agent-range-maps.shtml), and overlay that data with temperature/precipitation data within the same area.

Create a conservation management plan for sensitive forest areas to address a forest damage agent as explored above.

References

Bennett, A.C., McDowell, N.G., Allen, C.D., Anderson-Teixeira, K.J. 2015. Larger trees suffer most during drought in forests worldwide. *Nature Plants.*

Bennett AC, McDowell NG, Allen CD, Anderson-Teixeira KJ Data from: Larger trees suffer most during drought in forests worldwide. Dryad Digital Repository. http://dx.doi.org/10.5061/dryad.2v8p8

Figure 1. United States Environmental Protection Agency. Virtual Field Reference Database. https://archive.epa.gov/esd/land-sci/lcb/nrb/VFRDB/web/html/glossary.html

Liz Hadly tracks the impact of climate change in Yellowstone. HHMI BioInteractive Scientists at Work. https://www.biointeractive.org/classroom-resources/liz-hadly-tracks-impact-climate-change-yellowstone

Credits

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