ACTIVITY

6 Mapping Seed Sources

Students use growth data from loblolly pine forests to identify genetically different populations and project where trees with certain characteristics are likely to thrive in changing climatic conditions.

Subjects
Agriculture, Biology, Environmental Science

Skills
Analyzing Data, Determining Cause and Effect, Identifying Relationships and Patterns, Interpreting

Materials
Student pages, answer keys, and presentations (see Activity Webpage link below); graph paper; access to Microsoft Excel® (optional)

Time Considerations
One to three 50-minute class periods

Related Activities
This activity applies concepts of heredity to forests. Students may appreciate an introduction to forests and climate (Activities 1 and 3). It can be followed with additional strategies that forest landowners can use to create resilient forests (Activities 4 and 5).

Research Connection
By studying genetic traits, scientists can develop tree-breeding programs to identify parent trees that will produce seedlings that are better able to thrive in future climate conditions.

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section2/activity6

Objectives

By the end of this activity, students will be able to

- state two reasons for variation in growth of loblolly pine across its range, and
- explain the value of maintaining genetic diversity within a population as climate becomes more uncertain and variable.

Assessment

- Assess responses on student pages for identification of population source of each genetically related family and for responses to the writing prompt.
- Ask students to write a short essay explaining why the natural population of loblolly pine contains two relatively distinct populations, how the eastern and western populations differ, and how these differences might benefit the species' survival.

Background

Additional background information can be found in the **Section 2 Overview**.

How a tree grows is a function of its environment and genetic makeup. Whether a tree gets full sun or too much shade, a lot of rainfall or not enough, or is exposed to a horde of tree-eating insects is a function of its environment. But ***genes*** can predispose a tree to function a certain way in a variable environment. Traits such as growth potential, form, ability to tolerate drought, and disease resistance are controlled by many genes. These genes are not located on a single ***chromosome*** like the gene that controlled flower color in Mendel's famous peas. Because many genes on different chromosomes are involved in a trait such as tree growth, it is difficult to identify which genes control the trait. One way to better understand the genetic variation is to test different individuals and ***families*** of trees in multiple environmental conditions in order to determine which trees perform well in specific environments. These tests have been used extensively to rank the growth performance of individuals and families that were collected from different environments across the natural range of loblolly pine (*Pinus taeda*). A family consists of individuals that share one or both parents. It may be helpful to think of individuals in a family as siblings, similar to human brothers and sisters. Parents whose offspring (***progeny***) have outstanding individual traits, or ***phenotypes***, are then used to provide seeds for planting and are bred together to create genetically improved populations or families. Eventually, when technology improves to the point that important genes can be identified, researchers will breed individuals with suites of genes to create new seedlings with the desired combinations of characteristics.

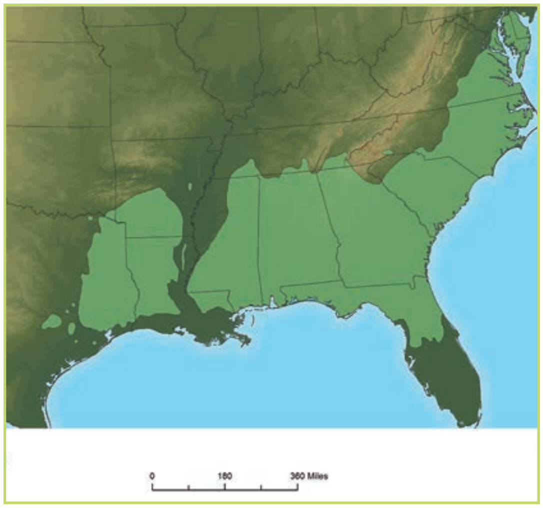
Loblolly pine is a native tree ***species*** whose natural range in the southeastern United States is separated by the Mississippi River valley into two populations. The genetic makeup of these two populations is significantly different, though there is some blending at

JOHN SEILER, VIRGINIA TECH

How a tree, such as this young loblolly pine, grows is a function of the environment in which it grows and its genetic makeup.

the edges of the river valley where pollen from the west fertilizes cones on the edge of the eastern zone. This genetic difference began thousands of years ago during the most recent Ice Age when glaciers covered northern North America and pushed native plants and animals south. The eastern loblolly pines survived by moving into Florida and the Caribbean Islands. Other loblolly pine trees in the west migrated into Mexico and Central America. While the trees were separated geographically, their genetic makeups diverged through natural selection, which allowed individuals with the highest ***genetic fitness*** in each ***climate*** to reproduce more often than those with a less appropriate set of ***alleles,*** which reproduced less effectively or died. After thousands of years, the glaciers receded, and loblolly pines slowly returned to their current natural range in the southeastern U.S., with the western population moving up from Mexico and the eastern population from the Caribbean and South Florida (Schmidtling et al., 2000).

In the western population, the trees tolerate drought significantly better than those in the eastern range. Compared with the western population, the eastern trees grow taller and faster with adequate rain. Forest researchers are looking for genes across both populations and testing which trees will tolerate the conditions that a future climate may bring to the region. They are also breeding trees with these superior characteristics to develop seedlings that will tolerate drought and still grow quickly (Lambeth et al., 2005). Since these traits are controlled by many different genes, the offspring from one parent from the western population and one from the eastern population are expected to produce offspring that exhibit a range of possible ***phenotypes***. Just like some brown-eyed parents could produce blue-eyed children (if the parents are ***heterozygous***—meaning the individuals have different alleles for the particular trait), the ***genotypes*** in the tree offspring will exhibit the full complement of traits. For example, some may be drought-susceptible and fast-growing; others may be more drought-tolerant and fast-growing. Breeders select the best parents and cross them to produce offspring for the next generation with the goal of growing at least some trees with an improved set of characteristics for future forests.



WADE ROSS, UNIVERSITY OF FLORIDA

Ranges of eastern and western populations of loblolly pine trees.

In this activity, students use tree height data from six families planted at three test locations across the entire range. By relating tree size and survival with average rainfall, they discover patterns of drought tolerance and growth and identify two distinct populations.

Teaching This Content

This activity provides a real and practical application of concepts and information related to genetics. It is a great follow-up to a basic genetics unit. In addition, this activity engages students in creating and interpreting column graphs. Students and teachers may need a quick refresher to be reminded of graphing skills. On the Activity 6 webpage, you will find a short video and a presentation with teacher notes to help you provide a brief overview of creating column graphs.

Getting Ready

The Activity 6 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section2/activity6).

You may want to provide an overview of forests and forests management by using Introduction to Southeastern Forests presentation on the Activity 6 webpage.

TEACHERS SAY ...

This activity provides a great opportunity to have my semi-urban students understand more about forestry in the Southeast.

—Agriscience/Horticulture Teacher, Florida

Systems Thinking Connection

IN THIS ACTIVITY students learn about the importance of maintaining a genetically diverse population. Systems thinkers explain this importance in terms of a concept called ***resilience***—the ability of a ***system*** to tolerate disturbances without changing into a completely different system, such as a forest eventually becoming a field if all the trees fail to reproduce. It is common to manage ***plantation*** forests for maximum ***timber*** production by planting progeny from specific parents that grow fast and are best suited to tolerate environmental conditions at the forest location. One potential concern with this approach is that we cannot exactly predict future conditions. If unexpected changes occur, the planted trees may no longer grow as well at that location.

In situations involving high levels of uncertainty, many forest managers take steps to minimize risk. By maintaining some ***genetic diversity,*** a forest manager accepts the fact that some trees are going to grow slower than others under the current conditions. However, if environmental conditions change (e.g., become drier), trees that were not growing as well before may become the most productive in the plantation. Managers have developed multiple strategies for hedging their bets in the face of climatic uncertainty (Millar et al., 2007). Instructors may want to emphasize that managers and landowners must balance the goal of forest ***productivity*** today with the goal of decreasing the risks associated with changing future conditions.

TEACHERS SAY ...

I went over graphing basics, assigned this activity as homework, and we discussed it the next day. Students were able to extrapolate the data needed and to interpret their graphs.

— Biology Teacher, Kentucky

Make copies of the student pages for each student.

Set up Microsoft Excel® in the computer lab or obtain graph paper for students. You may want to use the Creating Column Graphs in Excel presentation on the Activity 6 webpage if your students are unfamiliar with using this program.

Note: This exercise is somewhat simplified to help students understand the role of genetic research in forestry. The patterns observed in this exercise illustrate a general rule for the performance of two distinct seed sources. Pine trees are extremely variable, making it possible to identify outstanding trees from almost any seed source. Forest geneticists and tree improvement practitioners use selection and progeny testing to make these identifications and to refine their plans to distribute viable seeds.

Doing the Activity

1. If students are not familiar with southern pine trees and forest management in the Southeast, you can provide a brief overview of this topic using the Introduction to Southeastern Forests presentation, available on the Activity 6 webpage.

2. Provide an introduction or refresher to how genetic variation and natural selection affect populations of plants and animals. If students have studied genetics, ask them to recall some traits that are controlled by one gene with several alleles (eye color in people and flower color in sweet peas). Explain that other traits, such as body type or height in humans, are governed by a host of genes as well as environmental conditions. Even when the environment is controlled and people eat exactly the same thing, some people will grow differently than other people because of their genetic makeup. Trees are like that too.

3. Explain to students that the yield of wood from an acre of land is related to the number of trees that survive to harvest and the size of the trees. For example, 150 tons of wood from one acre can come from 300 trees that have an average diameter of 25 centimeters (cm) or 200 trees that have an average diameter of 30 cm, even if they are all the same age.

4. Ask students what they already know about the traits that might be important in trees, such as loblolly pine, that are grown for paper and lumber. This pine species is grown in plantations across its range from Virginia to Texas and also is found in naturally regenerated forests. You might find these discussion questions helpful:

- What traits are important to landowners who sell trees?
  Fast growth, straight growth, few branches, survival under stressful conditions, quick response to fertilizer, resistance to fire and disease, and wood density are important qualities.

- How can people obtain these traits for their trees?
  If forest managers save the seeds from trees that have an excellent form, they can grow seedlings in a nursery and make those particular traits available to more forest landowners.

5. Use the information in the activity background to explain to students that there is genetic variation across the population of loblolly pine—some trees have the potential to grow quickly while other trees tolerate drought better. These differences are due to natural selection. Natural selection favors trees that are more reproductively successful, i.e., trees that reach sexual maturity earlier and that survive the longest. Foresters favor trees with economically important characteristics, i.e., fast growth and straight stems. Most traits are not mutually exclusive and many traits are favored by both natural selection and by foresters. For example, disease resistance and adaptability help trees survive to reproduce and provide an economic value favored by humans.

Another example is that natural selection favors trees with greater drought tolerance in more drought-prone regions, which means on average that trees from these regions will survive better and reproduce more. In this way nature selects for trees adapted to thrive with less rainfall. Researchers study how well trees grow in many different areas of the Southeast and look for the trees with the optimal combination of adaptive and economically important traits. Forest researchers spend a lot of time in the woods measuring trees. They apply different types and rates of fertilizer and note which trees grow the most quickly. Since they return to the same trees each year, they establish permanent plots in the forest, similar to those students learn about in **Activity 8: Counting Carbon**. Since the plots are of a known size, the researchers can measure the sample of trees and then estimate the growth of similar trees in a larger area under similar climatic conditions. In the following example data, trees from west of the Mississippi River will tolerate drought better than trees east of the river.

6. Ask students to work in groups or individually based on how well your students can accomplish these tasks. As you distribute the student page, explain that these numbers are from researchers who are conducting a study where they have planted trees from six families (and each family is genetically related, with the individuals sharing one or both parents) at three different research stations. The first column identifies the location and average annual rainfall. The second column identifies the family. The remaining two columns provide the average survival as a percentage of the original number of trees planted and the average height of surviving trees after ten years of growth in the field. Each row provides these data for each family. Researchers collect data just like these and then look for patterns and relationships to understand more about the trees and conditions in which they grow best. However, one key piece of information is missing from this data set—information about which population is the original source of the genotypes (eastern or western). That is what students will be able to predict after graphing these data and examining patterns.

7. Ask students to make three double-column graphs, one for each site, with the families on the *x*-axis and both survival percent and height on the *y*-axis. It may help to keep survival and height in two different colors. Ask them to look at the patterns and determine which families are responding similarly to rainfall and are probably related. Ask students to predict which families came from the western population and which from the eastern population. Completed graphs are in the answer key, which can be found on the Activity 6 webpage.

Students should notice that at the site with an average of 130 cm of rainfall per year all families have high survival rate and families A, C, and E are slightly taller than families B, D, and F. At the drier site with an average of 100 cm of rainfall per year the survival rate of families A, C, and E is poor while families B, D, and F do much better. The trees in families B, D, and E are slightly taller compared with A, C, and E during drought conditions.

8. Ask students the following questions:

- Why do you think all families have high survival and the best growth at an average of 130 cm per year of rainfall?
  This amount of rain is not a limiting factor; all families will do well with adequate rainfall.
- Which families are likely to be from the western loblolly population and which ones from the east? Why?
  Western: B, D, and F. Eastern: A, C, and E. The site with 100 cm of rainfall shows a clear difference in survival when water is limited (B, D, F do well and are also taller). The site with 130 cm of rainfall demonstrates greater height for families A, C, and E.
- If you were a forest landowner today in Texas, would you plant trees from families

The **Introducing Column Graphs** video on the Activity 6 webpage explains how to create column graphs from data tables.

TEACHERS SAY ...

Some students had difficulty interpreting the data, but that's what I loved. This is a great assignment to work on students' data-analysis skills.

— AP Environmental Science Teacher, Florida

from the eastern or western populations?
Western.

- If you were a forest landowner in Georgia, would you plant trees from families from the eastern or western populations?
  Eastern.
- In areas where less rainfall is likely in the future, based on climate change models, which families would be better able to survive?
  Western.
- What are the disadvantages of planting a forest of only one family or genotype?
  If they are susceptible to a disease, they could all die. Therefore, planting only one family increases risk of catastrophic loss. Genetic diversity, even within a species, can help to decrease this risk.
- In areas where more rainfall is likely, which families should be planted?
  Eastern.
- What are the disadvantages of this strategy?
  If there is a prolonged drought, there may be a higher risk of losing a substantial number of trees.
- If you could pollinate eastern cones with western pollen, what types of trees would result?
  All potential variations and combinations would result. Some trees will thrive in drought, some will grow well in wetter conditions, some will grow tall quickly, and some will not.
- Which ones would be ideal in an uncertain climate?
  Those that tolerate drought, grow quickly in all conditions, and tolerate diseases.

9. Ask students to complete the writing assignment at the end of the student page, either in class or as homework. An ideal answer will suggest that because the landowner grew eastern and western trees in the same forest, they produced seeds that exhibited all of the traits of both populations, and a percentage (not all of them) of these offspring thrived better than either parent.

10. Systems Reflection: How can systems thinking skills help us maintain a system's resilience and avoid potential catastrophe?
By considering the variables within a system and the direct and indirect connections between variables, we can see how different actions or occurrences may affect the system. Causal loop diagrams are particularly helpful for exploring the relationships between variables (see Activity 5). These diagrams can help identify reinforcing feedback loops that might cause the system to behave in undesirable ways. They can also be used to identify how the forest management strategies can influence the system.

11. Summarize this activity by emphasizing that trees have certain genetic traits that make them more or less likely to survive and grow in future environmental conditions. For many years, scientists have been breeding trees to select for fast growth, high yields, and disease resistance. Given climate projections, scientists have more recently started exploring traits that might help trees survive under different climate scenarios. Can you think of other products where this type of research is very important (e.g., other crops we depend upon)? A video on the Activity 6 webpage enables your students to listen to a graduate student explain his research project focused on pine tree genetics.

Modifications

Students who have not learned about genetics in previous courses and/or those who are not familiar with how to create graphs will need additional instruction.

You can find a short video on the Activity 6 webpage that explains how to create column graphs from data tables. You may want to spread the activity over two or three days, so you can provide adequate background and examples.

Students can complete the graphing portion of the activity in groups, with each group completing one graph or a portion of the graph and then presenting it to the class.

Enrichment

Advanced students should be able to graph survival on the *y*-axis and height on the *x*-axis for each population. They can assess the strength of the linear association between survival and height by determining the coefficient of determination (R^2). The coefficient of determination provides the proportion of variation in one variable that is explained by another variable and can be shown as a percentage between 0 and 100 or as a decimal between 0 and 1.00. The Calculating Coefficient of Determination presentation on the Activity 6 webpage provides a quick "how-to-guide" for calculating the coefficient of determination using Microsoft Excel®. A coefficient of determination greater than 0.5 suggests that there is an association between survival and height, while a correlation coefficient of less than 0.5 is weaker, suggesting that variation in survival is not well explained by height; surviving trees may be shorter or taller. Which trees would a tree farmer prefer to plant? See the answer key on the Activity 6 webpage.

Ask students to go to the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) website (http://www.sgcp.ncsu.edu:8090) and explore the projected climate for your region. This is a site that enables foresters to assess the possible climate futures and make forest management projections. Would genes from eastern or western families of loblolly pine be useful to help trees thrive in your area?

STEVE MCKEAND, NORTH CAROLINA STATE UNIVERSITY

Tree measurements are taken on 4-year-old loblolly pines at a test site near Oliver, Georgia.

Additional Resources

A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States
Anantha Prasad, Louis Iverson, Stephen Matthews, and Matthew Peters; U.S. Forest Service
http://www.nrs.fs.fed.us/atlas/tree
This searchable database provides information on 134 common trees in the eastern U.S. The key feature is the presentation of data for each species describing both the current distribution of that species and future suitable habitat based on climate change models. This website is featured in **Activity 3: Atlas of Change.**

SHELBY KRANTZ, UNIVERSITY OF FLORIDA

In the **PINEMAP Focus on Research** video on the Activity 6 webpage, a graduate student shares information about a forest genetics research study.

Learn Genetics
Genetic Science Learning Center, University of Utah
http://learn.genetics.utah.edu
This interactive website provides an overview of genetics, heredity, traits, and other genetics-related topics. Teaching materials are also provided.

Southern Pine Seed Sources, General Technical Report SRS-44
Ronald Schmidtling, U.S. Forest Service, 2001
www.srs.fs.usda.gov/pubs/2797
This report provides guidance on selection of seed sources for six species of southern pine trees.

Template for Assessing Climate Change Impacts and Management Options (TACCIMO)
U.S. Forest Service
www.sgcp.ncsu.edu:8090
This web-based tool, intended for use by land managers, provides the most current climate change projections and research in an effort to link science to forest management and planning. Features include a geospatial mapping application, a searchable listing of peer-reviewed literature, and guides explaining how to use TACCIMO.

Trees Grow throughout Southeast with Help of UF
University of Florida
http://www.ufl.edu/spotlights/archives/trees-grow-throughout-southeast-with-help-of-uf.html
This short video introduces the work of the Cooperative Forest Genetics Research Program at the University of Florida, where researchers study tree breeding to improve tree growth and disease resistance in order to meet increasing demands for wood products.

References Cited

Lambeth, C., Mckeand, S., Rousseau, R., & Schmidtling, R. (2005). Planting nonlocal seed sources of loblolly pine: Managing benefits and risks. *Southern Journal of Applied Forestry, 29*(2), 96–104. Retrieved from http://www.srs.fs.usda.gov/pubs/21292#sthash.98ERjOJx.dpuf

Millar, C. I., Stephenson, N. L., & Stephens, S. L. (2007). Climate change and forests of the future: managing in the face of uncertainty. *Ecological applications*, 17(8), 2145–2151.

Schmidtling, R., Hipkins, V., & Carroll, E. (2000). Pleistocene refugia for longleaf and loblolly pines. *Journal of Sustainable Forestry, 10*(3–4), 349–354. Retrieved from http://www.srs.fs.usda.gov/pubs/2122#sthash.iAGObfNS.dpuf

Forest Growth and Rainfall Data (1 of 2)

NAME DATE

Imagine that forest researchers at three research stations in the Southeast planted loblolly pine trees 10 years ago. At each location, they planted six different families of loblolly pine trees. The families are groups of individuals that are genetically related because they share one or both parents. Some of these families originated from western populations of loblolly pine forests and some families originated from eastern populations. For 10 years, forest scientists collected data for the families at each site including rainfall, tree survival, and tree height.

The table below summarizes the results for survival and height for families at the three locations.

- Column A provides the site number and average annual rainfall at each location for years 1 to 10.
- Column B identifies the family.
- Column C is the average percent of the trees planted that are still alive after 10 years.
- Column D is the average height of surviving trees after ten years of growth.

A: Location and Average Rainfall (centimeters, cm)	B: Family	C: Percent Survival at Year 10	D: Average Height at Year 10 (meters, m)
Site 1: 100 cm per year	A	40	6
	B	80	9
	C	20	5
	D	75	10
	E	10	8
	F	60	9
Site 2: 115 cm per year	A	80	13
	B	90	9
	C	75	12
	D	86	11
	E	40	14
	F	75	11
Site 3: 130 cm per year	A	90	15
	B	90	11
	C	88	14
	D	88	12
	E	92	15
	F	92	12

Forest Growth and Rainfall Data (2 of 2)

1. Use the data table to make three graphs, one for each site. Column graphs with two y-axes will be easiest to interpret. For each graph, place the families on the x-axis, percent survival on the left y-axis, and height on the right y-axis. You will have two columns for each family (one for percent survival and one for average height). Include a key to indicate which column is percent survival and which column is height and label the units and axes.

2. The data table is missing important information! We don't know which families came from the western population of loblolly pine trees and which came from the eastern population. Use your graphs and what you know about the average annual rainfall at each site to predict which families came from the western population and which families came from the eastern population. Remember that families that came from the western population can survive with less rainfall, while families from eastern populations grow faster with adequate rainfall.

   For each family, write the original source of the genotype (eastern or western population).

   A: ______________________ B: ______________________ C: ______________________

   D: ______________________ E: ______________________ F: ______________________

3. Given what you know about the different growth patterns of eastern and western populations of loblolly pine, respond to the following writing prompt:

   It is 2050. You've been invited to an awards ceremony honoring an elderly forest landowner who is regionally known for his wood production. Many of his trees survive changes in climate, and a large number of them are taller than everyone else's. Unfortunately, the landowner is unable to attend the ceremony and you have been asked to substitute for him. The organizers would like you to explain why he was able to grow trees better than anyone else. You happen to know that this landowner has a brother in Texas and another in South Carolina who both grow loblolly pine trees. About 50 years ago he planted trees from both brothers on his property. You agree to explain to the audience what this landowner did that enabled his trees to thrive two generations later.