Hubbard Brook Experimental Forest
Student Activities

HBEF Activity 3
Forest Ecology

Introduction

Imagine taking a short hike through the woods near your home or school. The parking area you start from is near a small stream, which the trail follows for some time. There are several types of trees growing near the trail, and you notice that most of them – especially the ones close to the stream – are eastern hemlocks. After a while, the trail leaves the stream and starts climbing steeply. You no longer notice any hemlocks, and as you climb higher and higher, you begin to see red spruce and balsam fir trees. Are these patterns random? Do eastern hemlock trees really grow near streams? Are spruce and fir trees only located at higher elevations?

Now think about forests that you have walked through in your lifetime. Are the same species and patterns present? Why? Have you noticed other things – like how fast trees grow, how large different species can get, or how the forest changes over time? What do you think controls these types of growth? Why do you think forests look the way they do?

Since the early 1960s, scientists at the Hubbard Brook Experimental Forest (HBEF) have been trying to answer these and other questions about the ecology of the northern hardwood forest biome. The HBEF, located in the White Mountains of New Hampshire, is part of this biome. (For more information on the HBEF, read the Introduction to Activity 1 in this manual.)

Northern hardwood forest: A biome in the northeastern U.S. that consists primarily of sugar maple, beech, and yellow birch trees

In this activity, you will read about forest ecology research at the HBEF, learn basic scientific methods for measuring trees and forests, explore data that scientists have gathered, and measure these characteristics on your school property or in your community. At the end of the activity (see "Analyzing Your Study Area Data") we provide ideas for what questions you might ask about your study areas and what data you should collect to answer them. Finally, we have also provided a few suggestions for further research.

The reference: Watershed 6

Ecology is the branch of science that examines how biological components (such as trees) interact with each other and with the physical components (such as precipitation) in an ecosystem. For almost fifty years, scientists at the HBEF have been measuring trees and other ecosystem components to help them learn about the *ecology of forests*. Much of this intensive long-term monitoring has occurred in an area known as Watershed 6. Why do you think ecologists might want to study an entire watershed?

If you have completed Activity 1 or taken the HBEF virtual tour, you know that scientists study watersheds to learn about complex ecosystem processes. A *watershed* is the drainage area of a stream, river, or other body of water. There are nine research watersheds in the HBEF, all of which drain small streams and share similar characteristics like size, elevation, and vegetation. In four *treatment* watersheds, scientists have conducted experiments to determine the effects of different forest disturbances (for example, deforestation and acid deposition). Two of the remaining watersheds serve as *references* for the treatments.

When scientists do research, the objects they manipulate are referred to as the experimental "treatments." Scientists compare the treatments to objects that have not been manipulated to learn about the effects of the experiment. The non-manipulated objects are referred to either as "controls" or "references."

If all the objects are the same before an experiment, then the non-manipulated objects are referred to as *controls*. For example, consider an experiment testing the effects of salt on tomato seedling growth. In this experiment, twenty seedlings are initially grown in the same type of soil and location, and are all treated identically. Then, salt is added to the soil of ten of the seedlings, creating ten treatments and leaving ten controls. The only difference between the two groups (*treatment* and *control*) is a single variable: salt.

> In many field experiments, the *reference* and *treatment* objects are very similar at the beginning of the experiment, but they are not identical.

In HBEF field research, the experimental subjects – watersheds – are unlike the tomato seedlings and have small differences even before the experiments are conducted. For example, the watersheds are not all exactly the same size, and have slightly different densities and types of trees. Therefore a non-manipulated watershed is not a true control, but is referred to as a *reference.*

At the HBEF, Watershed 6 is the primary reference area (Figure 1). This watershed has not been altered since it was logged in the early 1900s, and will never be manipulated by scientists. In fact, scientists have been intensively monitoring its precipitation, streams, soil, geology, animal life, and trees since the beginning of the Hubbard Brook Ecosystem Study in 1963. Scientists monitor Watershed 6 both because it serves as an experimental reference and an example of northern hardwood forest growth.

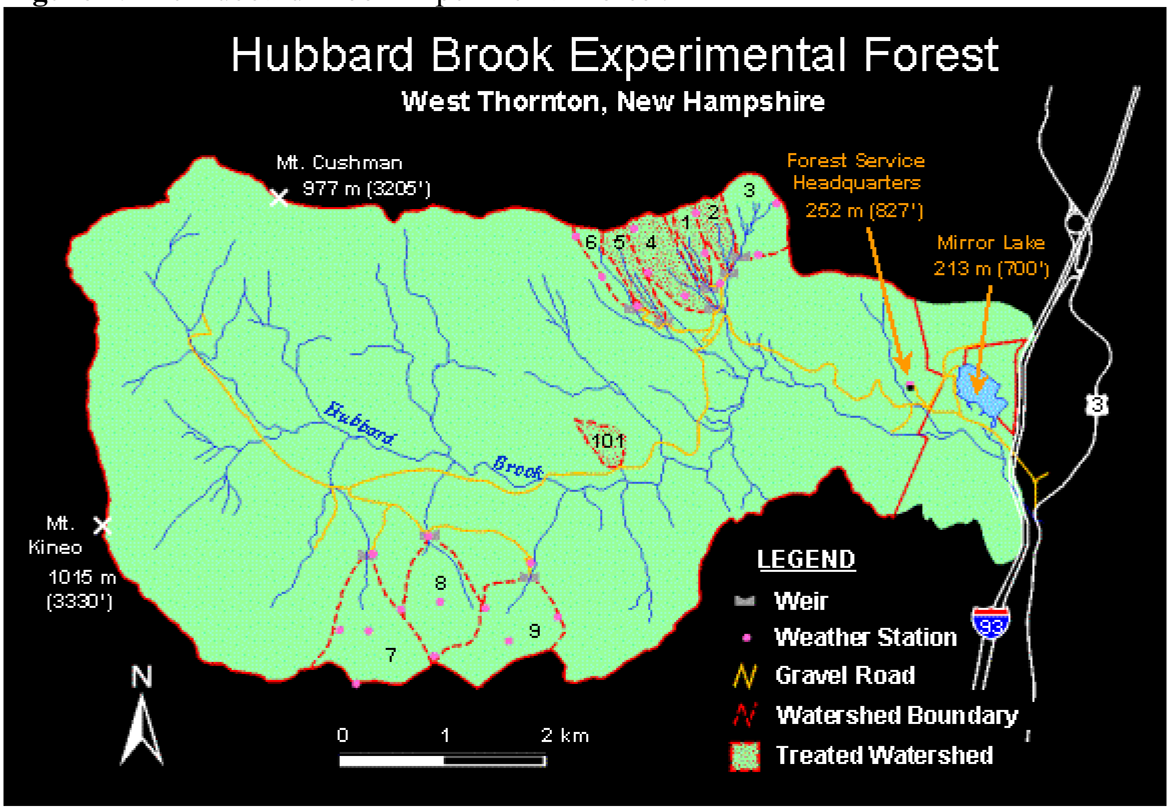
> **Watershed 6** has an area of 13 hectares (~33 acres), and ranges in elevation from 550 m to 800 m (1800 to 2600 feet). The forest is dominated by sugar maple, yellow birch and American beech, with balsam fir, red spruce, and paper birch more common in the upper section (Figure 2).

Study plots: How scientists study large areas

Imagine trying to measure every tree and record all the important environmental variables in Watershed 6. It would likely take many researchers several weeks, and could become quite confusing! At the end of each day, how would they know which trees had been counted, and which had not? How would they compare one area of the forest to another, if there were no way to separate the two?

To solve these and other problems, scientists organize large study areas like Watershed 6 into smaller sections known as study *plots*. Watershed 6 has been divided into 208 plots, each measuring 25 meters by 25 meters (Figure 6). In each of these plots, scientists measure variables such as elevation, slope, and soil depth. They also record the height, diameter, and species of each tree present in every plot. Scientists can use these data to keep track of which areas have been measured, and to make comparisons between different areas in the forest. In fact, scientists visit all the plots every five years so they can study how the forest grows over time.

Figure 1. The Hubbard Brook Experimental Forest.



Protocol 1
Arranging your study area into plots

Scientists use *protocols* to help them accurately and consistently measure things. This protocol helps you arrange a study area into smaller plots. But before you begin any of the protocols in this activity, you should develop questions about your study area. What can you learn by measuring the size and type of different trees in different areas? Before proceeding, read the section on, "Analyzing Your Study Area Data," located at the end of this activity.

1) Locate one or more study areas. You can use your school property, but because it has probably been landscaped (trees planted there in an orderly fashion) a nearby park or forest may work better. If you conduct research in your schoolyard, you will need to consider how humans have altered the area. *Please note: if you wish to use Protocol 5 to measure the height of trees, your plots must be located on flat ground; hillsides or sloping areas will not work with Protocol 5. Ask your teacher for more information.*
2) Explore your study area with your class. Be on the lookout for the size, type, and distribution of trees. What environmental variables might be affecting how and where trees are growing? Do you notice differences between species? What else do you notice about the size and locations of different types of trees? Decide which of these or your own questions you could answer by measuring the trees in your study area.
3) Discuss with your class how many plots you will use. If you have more plots you can make more comparisons; but fewer plots require less work.
4) Select your plots. They should be small enough to allow several plots to fit into your study area, but large enough to contain at least a few trees (if possible).
5) Mark the plots in a semi-permanent way. One idea is to use small PVC or wooden stakes with flagging around the tops. Be sure to obtain permission from your school to mark the plots.
6) Record where each plot is located, and record the dimensions. All the plots should be the same size.
7) Depending on what questions you would like to answer about your study area, record all relevant environmental variables about each of your plots. For example, you might want to record:
    - Elevation
    - Water. Is there running or standing water in your plot? How wet is the soil? Your teacher might be able to help you measure soil moisture in your plots
    - Precipitation. How much rain does the plot receive? You could measure this by placing a precipitation gauge in the plot and measuring it every week.
    - What other variables do you think might affect tree growth?

Measuring the forest

Part 1

Some Watershed 6 scientists study the size and type of trees in different parts of the forest. Others are interested in how elevation affects tree growth: are the same types of trees found at both the bottom and top of the watershed? And still others want to know if an area contains many small trees or only a few large ones. In fact, there are hundreds of other similar questions scientists are asking about the HBEF.

What do scientists measure to answer these types of questions? They can look at things like *species composition*, *density of species*, *tree diameter*, *height*, and *basal area*.

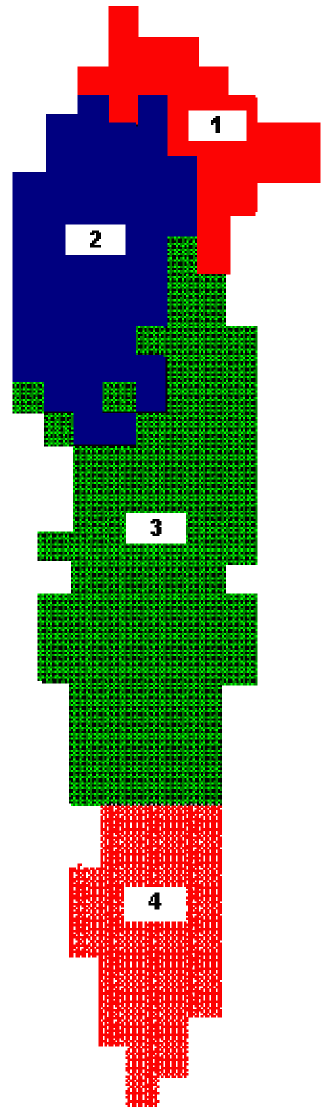
Species composition and density of species

Species composition refers to the *number* and *type* of one species in an area, compared to others in the same area (for example, a forest could contain 90% sugar maple). Density is a measure of how many objects (trees) are present in an area (for example, that same forest might contain 9 sugar maples per 100 m^2). Scientists can compare this information to environmental variables that may (or may not) correspond to the variability in species composition or density. In this section we focus on how scientists *quantify* species composition and density.

Scientists quantify things by using precise numbers, and *qualify* them by using descriptive terms. For example, if you hiked up Watershed 6, it would appear that balsam fir and red spruce are relatively more abundant at the top, while the bottom is dominated by American beech, yellow birch, and sugar maple (Figure 2). A qualitative description of this pattern would use words like, "it seems that balsam fir are more common at the top." But how can scientists be certain this pattern is real?

Scientists can be sure of the pattern by counting and identifying every tree in many or all of the 208 Watershed 6 plots. They could learn, for example, that the species composition of plots near the top of the watershed is 90% spruce and fir, while plots towards the bottom had a species composition of about 10% spruce and fir. Protocol 2 explains how scientists measure species composition in Watershed 6 plots.

Figure 2. The four regions in Watershed 6 are dominated by the following tree species: 1) balsam fir, red spruce and paper birch; 2) American beech, yellow birch, and sugar maple; 3) sugar maple and American beech; 4) American beech, yellow birch, and sugar maple (similar to 2, but at a lower elevation).



Protocol 2
Determining species composition in your study area

This protocol demonstrates how you can measure the species composition of the plots in your study area.

1) Obtain a local tree identification guide, and become familiar with trees in your study area.
2) Determine the minimum tree size for your study. Because scientists do not always want to measure very small seedlings in a plot, they may have a size limit. For example, they may only measure trees that have a diameter greater than 5 cm. If you want to use this type of limit, you will need to read "Measuring the Forest: Part 2," and Protocol 4 for more information.
3) Identify all the trees in each of your study plots. Your class may decide to semi-permanently mark each tree. One idea is to use plastic flagging and a permanent marker.
4) Record the data using a method that allows for easy comparison between plots. Some researchers use both descriptive names (such as the tree species) and a numerical code when identifying trees. For example, consider a plot containing six trees:

Plot #	Tree Number	Tree Species	Tree Code
1	1	sugar maple	3
1	2	eastern hemlock	2
1	3	red oak	4
1	4	red oak	4
1	5	yellow birch	1
1	6	sugar maple	3
Key: yellow birch = 1; eastern hemlock = 2; sugar maple = 3; red oak = 4			

5) Your class may be interested in mapping each of your plots and identifying where each tree is located. You may also want to add other columns for the percent composition of each species (for example, in this plot 2 out of 6, or 33% of the trees are red oak).

Protocol 3
Measuring tree density in your study area

In this protocol, you will determine the density of trees in each of your study area plots. *Density* is the number of objects (for example, trees) in a unit of measure (for example, an acre of land); in this protocol it refers to the number of trees in a study plot.

1) Add two columns to the table in which you recorded the number and identity of trees in each of your plots.
2) Record the total number of trees in each plot.
3) Calculate the area of your plots in meters. For example, perhaps the plot considered in Protocol 2 is 10 meters long and 10 meters wide, and had an area of 100 m^2.

$$\textbf{10 meters * 10 meters = 100 meters}^2$$

Therefore, there are 6 trees in 100 square meters, or .06 trees/meter^2. Here we have added another plot with an area of 50 m^2 to the example table. How did we arrive at 0.16 trees/m^2?

Plot #	Tree Number	Tree Species	Tree Code	Number of trees/plot	Area (m^2)	Density (trees/m^2)
1	1	sugar maple	3	6	100	0.06
1	2	eastern hemlock	2			
1	3	red oak	4			
1	4	red oak	4			
1	5	yellow birch	1			
1	6	sugar maple	3			
2	1	eastern hemlock	2	8	50	0.16
2	…	*continues…*				
Key: yellow birch = 1; eastern hemlock = 2; sugar maple = 3; red oak = 4						

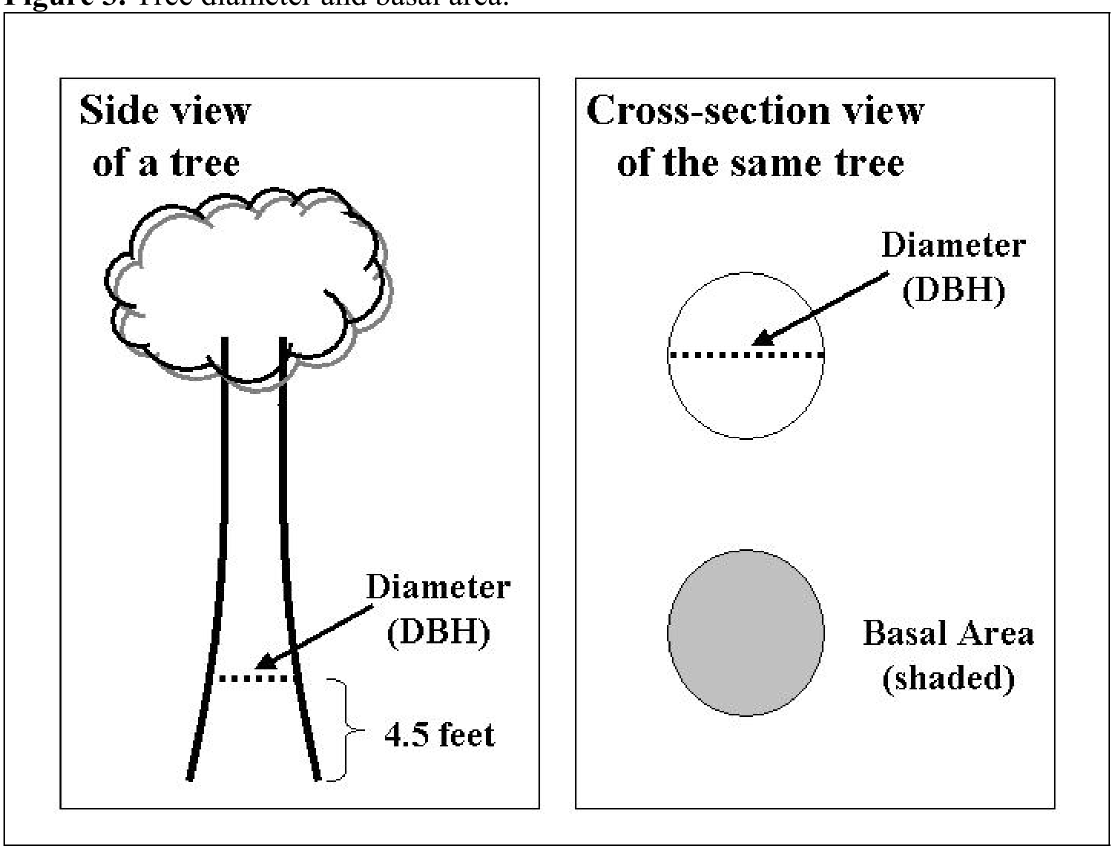
Measuring the forest
Part 2

Tree diameter, basal area, and height

The diameter of a tree is the widest distance from one side of the trunk to the other, at a specified height above the ground. The basal area is how much space the tree covers at that point, and is calculated by using the diameter (Figure 3). Scientists measure the diameter, basal area, and height of trees over long periods of time to help them learn more about how big they are, and how quickly they grow.

Why are scientists interested in these types of variables? Have you ever noticed that trees near the top of a tall mountain are often smaller than trees – of the same species – at the bottom? Do you know of any tree species that are usually larger than others, even if they are growing in the same area? Have you noticed that some grow faster than others? Scientists have also noticed these things, and conduct research to help them learn what causes these patterns. First, they measure the size of trees over long periods of time and large areas. Then they can examine and experiment with some of the reasons for the differences (for example, genetics or environmental factors). In Protocol 4 you will learn how to measure tree diameter and basal area.

Figure 3. Tree diameter and basal area.



Protocol 4
Measuring tree diameter and calculating basal area

In this protocol you will first measure the circumference and then calculate the diameter and basal area of each of the trees in your study plots. The circumference of a tree can be measured by using a tape measure to record the distance around the outside of the entire tree. It is easiest to determine the circumference by reaching around the tree from a standing position and measuring at the level of your chest. Because some people are taller than others, and a tree's diameter varies with its height, scientists have standardized this measurement. The standard height at which tree circumference is measured is known as the DBH ("diameter at breast height"), and is 4.5 feet (1.4 meters) above the ground.

1) Take out the table you used in previous protocols. Add columns as you need them.
2) Measure and record the circumference, approximately 4.5 feet above the ground, of all the trees in each of your plots.
3) Calculate the diameter of each of these trees using the following formula:

   Circumference/Pi = diameter

   For example, a tree with a circumference of 78.5 cm has a diameter of 25.0 cm.

   78.5 cm/ 3.14 = 25.0 cm

Plot #	Tree Number	Tree Species	Tree Code	Tree Circumference (cm)	Tree Diameter (cm)
1	1	sugar maple	3	78.5	25.0

Calculating basal area

After calculating the diameter of all the trees in a plot, you can then determine the area covered by each tree, by each species, or by all the trees in your study area.

1) Using the diameter data you gathered in the first part of this protocol, calculate the basal area of each tree using the following formula:

   Basal area = Pi * Radius ^{2} (Remember, the radius of a circle = 0.5 * diameter)

   For example, consider Tree #1 in the example table (above). First, calculate the radius. Then calculate the basal area.

   Radius = 0.5 * 25 cm = 12.5 cm

   Basal area = 3.14 * 12.5 ^{2} = 490.6 cm^2

Plot #	Tree Number	Tree Species	Tree Code	Tree Circumference (cm)	Tree Diameter (cm)	Basal Area (cm^2)
1	1	sugar maple	3	78.5	25.0	490.6

Protocol 5:
Building and using a clinometer to measure tree heights

In this protocol you will build a clinometer and use it to measure the height of trees in your study plots. A clinometer is a tool commonly used by foresters and scientists. Figure 4 (below) depicts an example of the type of clinometer you will be constructing. *Please note that this method only works for trees that are growing straight up on a flat surface*. Ask your teacher for help if your plot is sloping or a tree is tilted.

Materials

- Drinking straw
- Semicircle of cardboard
- Tape
- String
- Small weight (for example, a few washers)
- tape measure (at least 15-20 meters)

Building a clinometer

1) Use a protractor to accurately mark a semicircular piece of cardboard into degrees. Degree 0 should be at the base of the semicircle (Figure 4). You should mark the protractor at least every 10 degrees (more than shown in the figure).
2) Tie the weight to the end of the string.
3) Tie the string to the center of the drinking straw, and attach the straw to the top of the cardboard using the tape. Make sure the straw is attached to the cardboard in such a way that the string is exactly in the center of the cardboard and can move freely.
4) The clinometer is complete. Test to make sure that when you hold it level the string falls at the 0 degree mark.

Using the clinometer

1) Locate the tree you would like to measure (see Figure 5).
2) Hold the clinometer so that you can see the top of the tree (Point C) through the straw.
3) Continuing to hold the straw so you can see the top of the tree, move backwards or forwards until the string and weight are hanging at 45 degrees. You are now at Point A.
4) Measure the distance between you and the tree using a tape measure (Distance 1).
5) Have a classmate measure the distance from your eyes to the ground (Distance 4).
6) Because the clinometer reads 45 degrees, Distance 1 = Distance 2. If you cannot move such that your clinometer reads 45 degrees, you will need to use trigonometry to solve for Distance 2. Ask your teacher for help.
7) To calculate the total height of the tree, add Distance 4 to Distance 2.

   Distance 1 = Distance 2 (*for a 45 degree clinometer reading only*)
   Height of the tree = Distance 2 + Distance 4

Figure 4. A clinometer similar to the one you will be building in this protocol. This is only an example; yours may look slightly different.

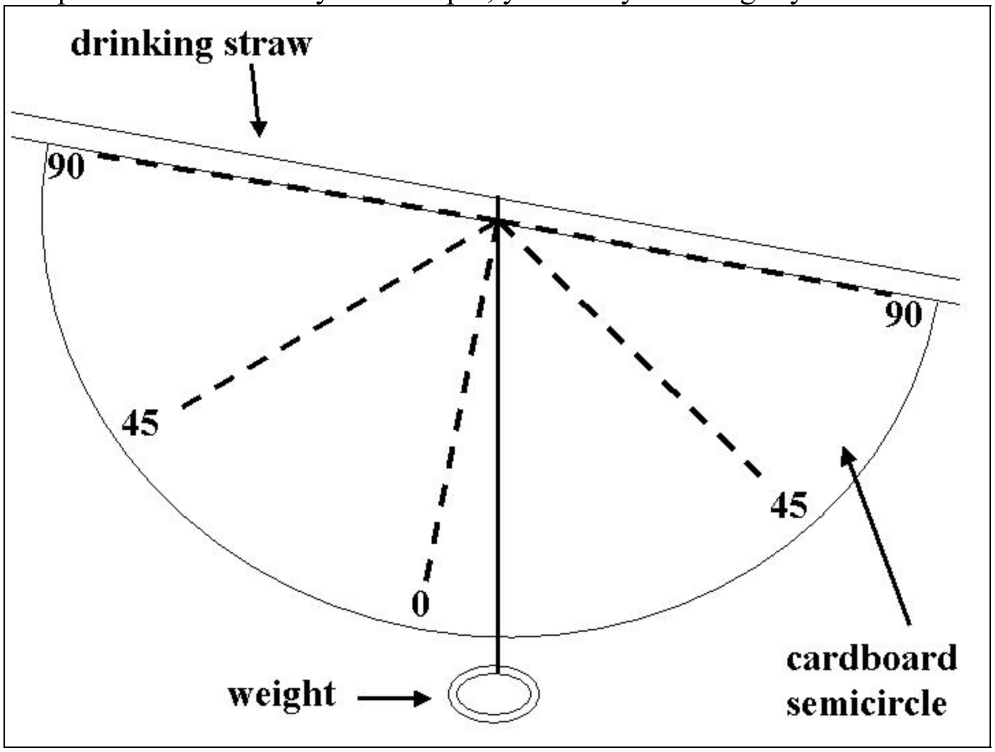
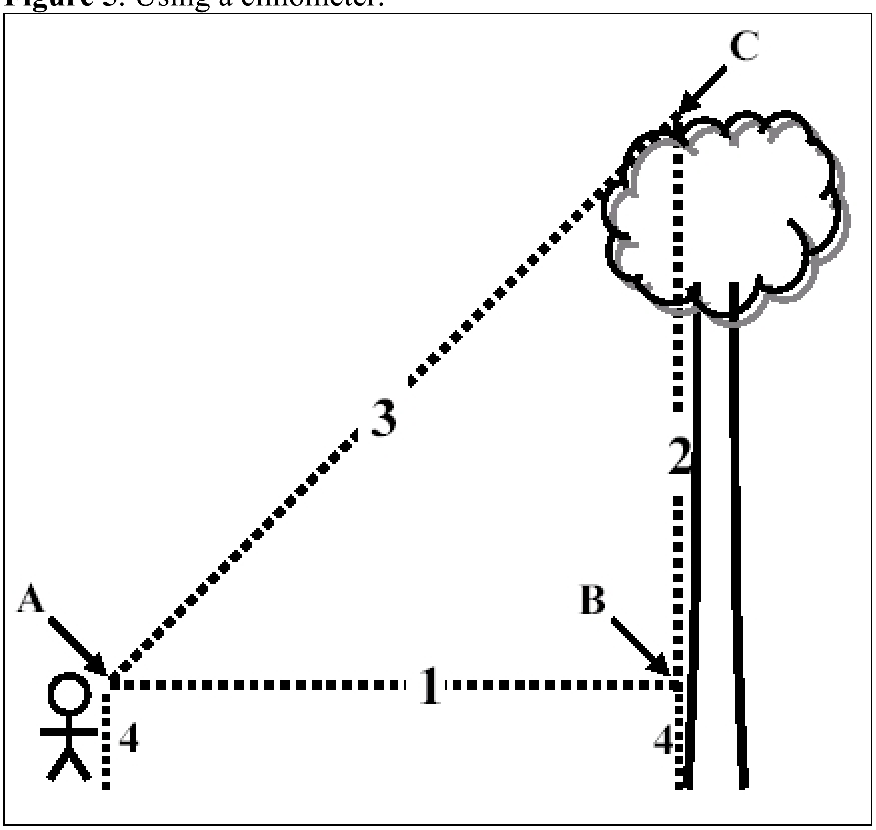


Figure 5. Using a clinometer.



Analyzing Your Study Area Data

Once you have completed some or all of the protocols above, you are ready to use your data! By now, you and your class have developed some questions regarding the trees in your study area (if you have not yet collected data, read through this section to help you develop questions). By analyzing your data you may be able to answer some of these questions.

In this section we provide suggestions for using your data – the rest is up to you, your classmates, and your teacher. Be creative! Think about what your measurements can tell you about the forest and trees you have studied, and read about how scientists, foresters, and others use similar types of information to help them. If you have access to a computer spreadsheet and graphing program such as MS Excel, you should first enter all of your data into it, as this will make comparing and graphing your data straightforward. Graphs can be especially useful for noticing differences between plots. At the end of this section we provide a variety of example graphs.

Plot data

As you have learned, scientists use plots to help them organize large study areas; and you should use your plots in the same way. Your plot data will be useful if you want to visually represent your study area, and will certainly be useful to help you explain the patterns you have found.

- If you create a poster, written report, or other way to present your results, draw a map of your study area(s). Include specific drawings of each of your plots.
- If you collected other variables (for example, land-use history, precipitation, the presence of water, or ground cover), show how they are different – or the same – in each of the plots. Be sure that you describe the exact method you used to collect these variables. See example graphs below.
- If you decide to collect more variables to help you compare plots, remember that data from different plots will only be comparable if you use standard protocols.

Species composition and tree density data

Species composition and density can tell you a lot about a study area. The types of trees present in a forest can indicate the age of a forest, how long since it was logged, how good – or bad – the growing conditions are, and what type of trees grow best in that type of forest. Consider some of the question below, and use your species composition and tree density to help answer them. You may decide to return to your plots to measure more variables to help explain these patterns.

- Do all of your plots contain the same species? Are the species compositions similar? Why might this be the case? What other environmental variables could you measure to help answer this? For example, is there a stream or other body of water that runs through one of your plots? Could water affect this or other plots?

- What might be responsible for these different densities in your plots? How would you determine what was responsible for these different densities? Consider what has happened to the plots in the past (land-use history). Have they been logged? Were the trees planted, or did they grow there naturally? What else could it be?
- Do some trees grow in denser groups than others? Why might this be the case? For example, in Watershed 6 at the Hubbard Brook Experimental Forest, many small beech saplings grow very close to one another in some areas of mature forest. What could be responsible for this? You may have to do more research on different tree species to answer this question.
- How do you think the species composition or tree density of your study area will change over time? Will new species replace what is currently growing in your plots? How would you test this?

Tree diameter, height, and basal area data

Foresters can use information about the size of trees in a forest – especially if they have measured data over a period of time – to tell them how their forests are growing, how much they can cut, what their forest is worth now and will be in the future, and more. Scientists use this information to learn about what controls and influences forest growth, how elements are cycling in a forest, and how forests respond to a disturbance and other ecosystem processes. As with species composition and tree density, you may want to use your data to answer basic questions or compare different plots or different study areas. We provide suggestions below.

- What is the total basal area of each species in each plot or study area? The total tree basal area of a species is calculated by adding up *all* the individual tree basal areas. For example, if the first tree in a plot has an area of 490 cm^2, and the second tree has an area of 400 cm^2, the combined, or total basal area of these two trees is 890 cm^2. You can calculate the total basal area of each species in each plot, or all the trees in each plot. Can you calculate the tree basal area of your study area?

- What is the total basal area of each species in your study area? What factors could influence this (use your plot data and other environmental variables)? How could this pattern change over time? How would you test this?

- What is the area covered by each species in different plots? Why would this vary?

- What trees are the tallest? Does it appear that some species are taller than others, or are other factors (age of trees) involved?

- Predict what will happen to the basal areas, diameters, or heights of trees in your plots over the next decade (or more). How would you test these predictions?

There are literally hundreds of other questions you may ask about your data. Use your imagination and work with your class and data to fully explore your results. In this activity, there are no correct or incorrect answers – there is only the potential for you to conduct good science to help explain some of the patterns you see in you study area. You may want to visit the HBEF website (http://www.hubbardbrook.org) to read about research that has used similar types of data.

Analyzing Hubbard Brook Data

In this section of Activity 3, you will examine actual HBEF data to see what patterns are present in Watershed 6. Your teacher has a copy of two datasets, each containing data from 11 plots. The first is from 1977, and the second was collected in 1997. All plots are 25 meters wide and 25 meters long, and are numbered as shown in Figure 6.

There are three worksheets in each file: **Plot Information**, **Plot Data**, and the **Key**. The **Key** contains information about the tree codes. The **Plot Information** contains the plot number and the plot elevation, in feet. The **Plot Data** worksheet contains the plot number, each tree (and its species) in the plot, and the diameter of each tree. We have not included any dead trees in this database; all the trees listed are alive.

You can use this information and the protocols above to calculate *species composition*, *tree density*, and *basal area*. Before you calculate any of these, consider which questions interest you and how these data may help you answer them.

Here we describe and give suggestions for how you may compare different plots from within one year, as well as plots from 1977 and 1997. We have also provided several example graphs below. What patterns do you notice in these graphs? Do you need more information to interpret these graphs? What could be responsible for the patterns? What other graphs could you create to help you visually depict these data?

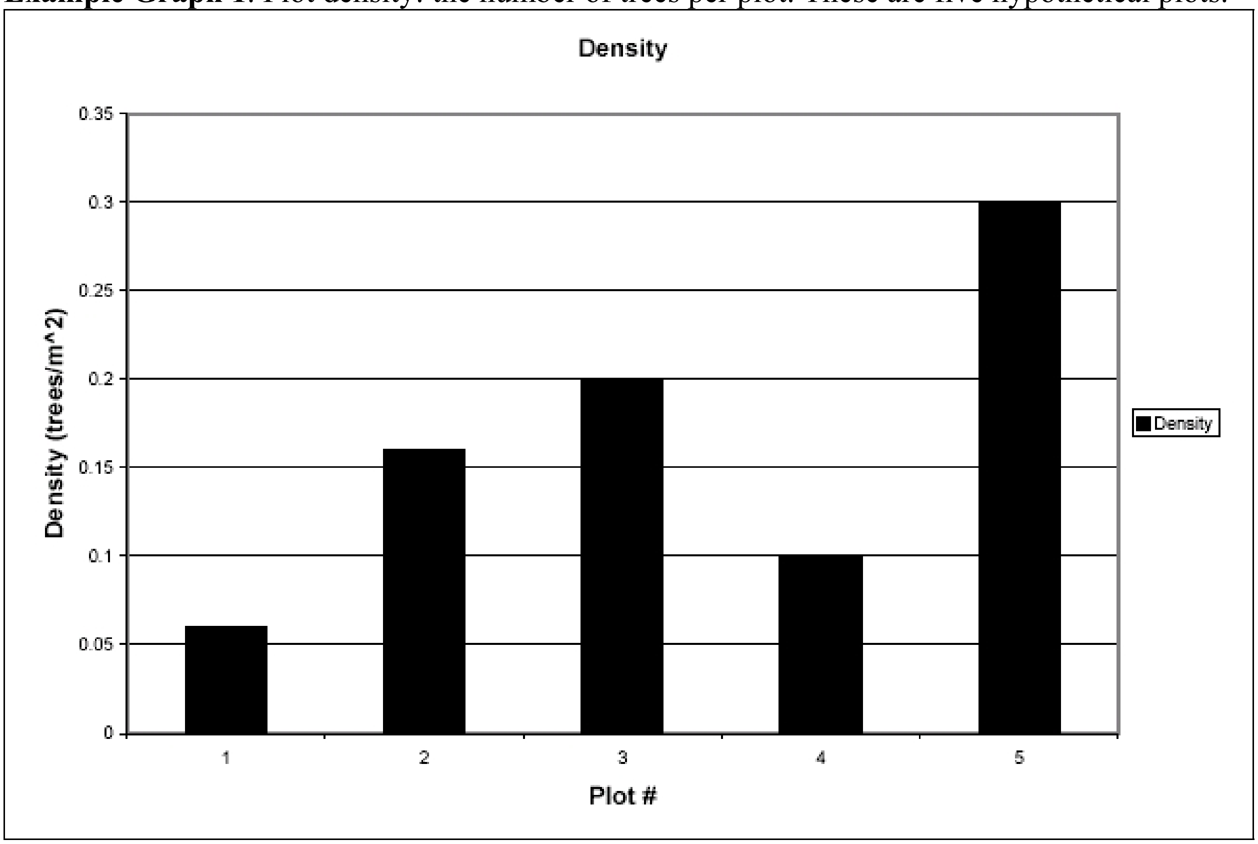
- How do the eleven plots differ in terms of the species composition, tree density, or basal area? Do elevation or plot slope seem to affect these relationships? What other factors could be influencing the patterns you see?
- At what elevation are you more likely to find balsam fir? Red spruce? Other trees? What factors could influence these patterns?
- Are trees more or less dense at different elevations? Is the tree density higher at the top of the watershed than it is at the bottom? In the middle?
- Does basal area vary between species? How does it vary with elevation?
- What are the differences between plots and between years? For example, how has Plot #1 changed between 1977 and 1997? Has the species composition varied between the two sampling dates? What about the other variables? What could be responsible for these changes?
- What differences can you notice in the entire watershed between the two sampling dates? You can explore this question by combining data from all the plots in the watershed for each of the two years. What does this show about how the watershed and the northern hardwood forest biome has been growing over the past two decades? What else can you learn from this information?

Suggestions for Further Study
Comparing HBEF and your data

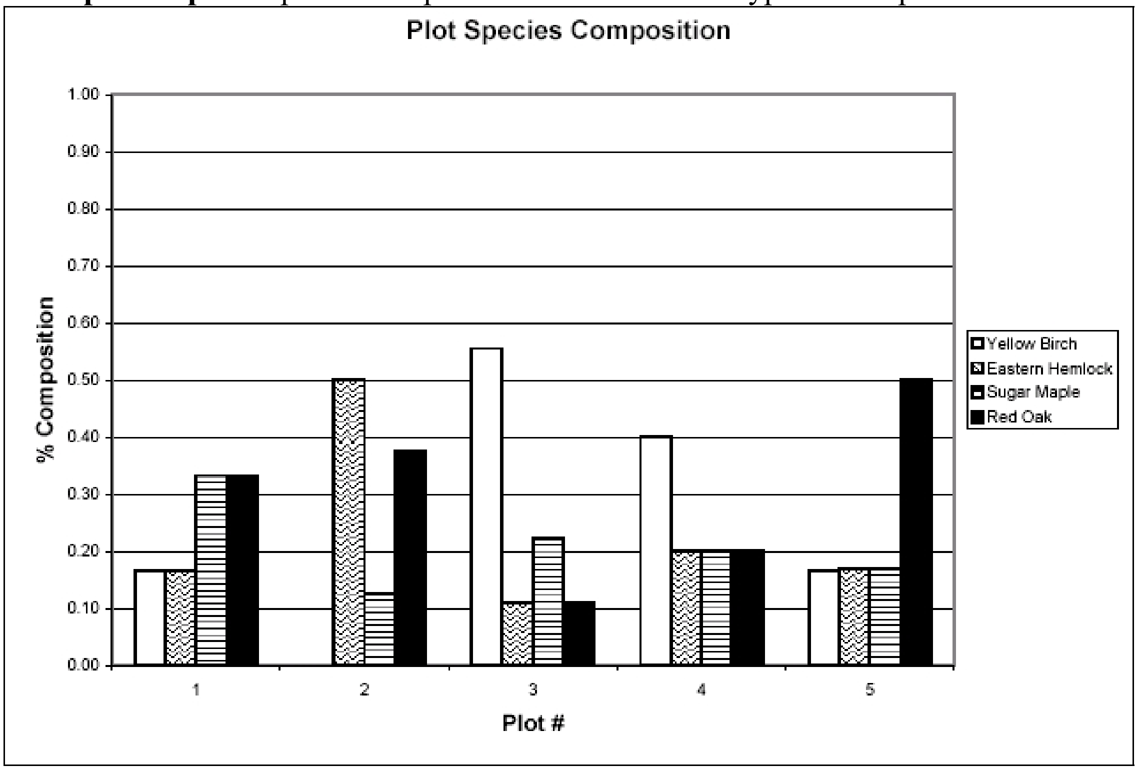
- You may be interested in visiting the HBEF and checking out Watershed 6. You can find contact information for the Forest Service on the HBEF website.
- Compare Watershed 6 data to your study area results. To make accurate comparisons, you would need to learn more about the environmental variables present in Watershed 6. You can locate more information on the HBEF website (see next suggestion).
- If you would like to gather more data, visit the HBEF website and locate the "data" button. You will be able to locate forest ecology and many other categories of data.
- Visit the website of another LTER site (http://www.lternet.edu), and see if this site has collected similar data. Compare these data to yours or those from the HBEF.

Example graphs

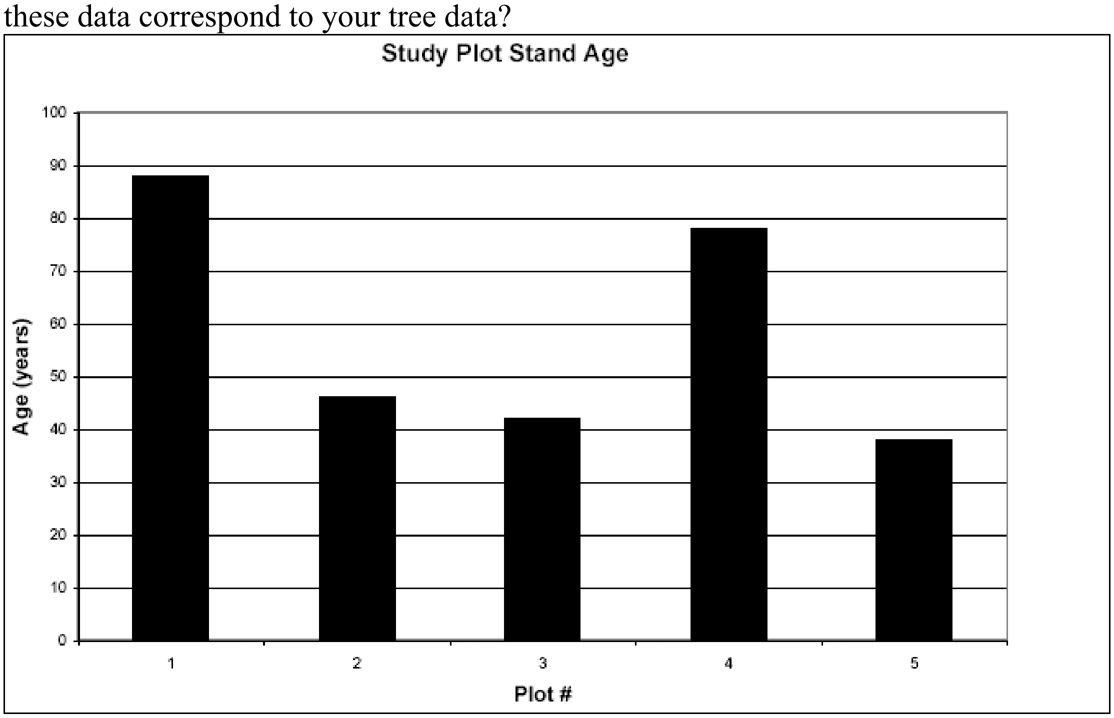
Example Graph 1. Plot density: the number of trees per plot. These are five hypothetical plots.



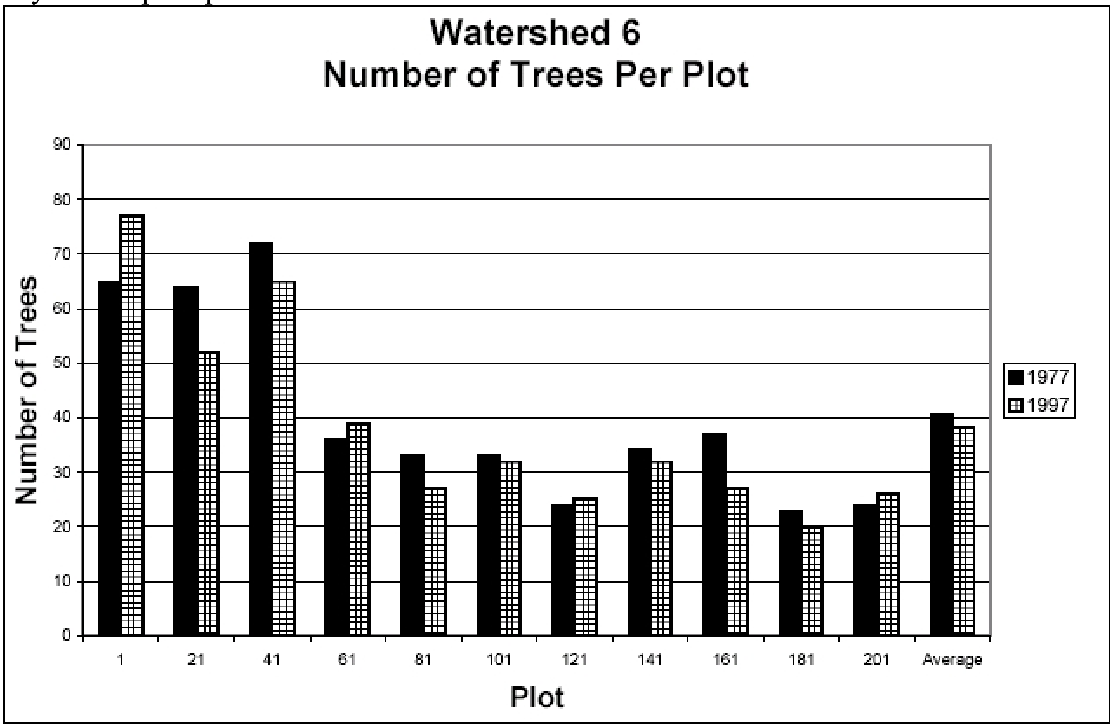
Example Graph 2. Species composition. These are five hypothetical plots.



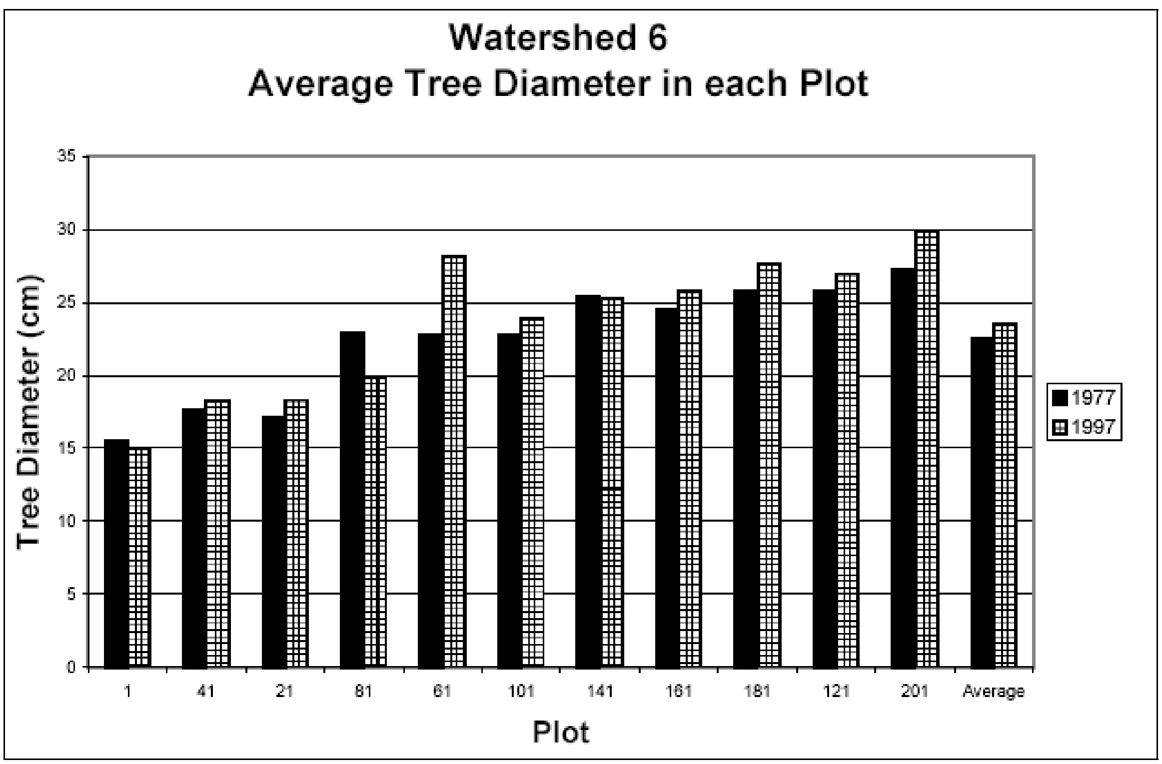
Example Graph 3. The stand age of 5 different hypothetical plots. "Stand age" refers to the age of plot trees, and often corresponds with when the area was last cut or otherwise disturbed. Trees were planted in these plots at year 0, so the oldest trees in plot 5 are 38 years old. How would these data correspond to your tree data?



Example Graph 4. The number of trees per plot in Watershed 6: 1977 and 1997. What happens if you compare plot elevation with these data?



Example Graph 5. The average tree diameter in each plot. How does this variable change with elevation? Between 1977 and 1997? What could be some reasons for these patterns?



Example Graph 6. The total basal area (all of the trees combined) of all Watershed 6 plots.

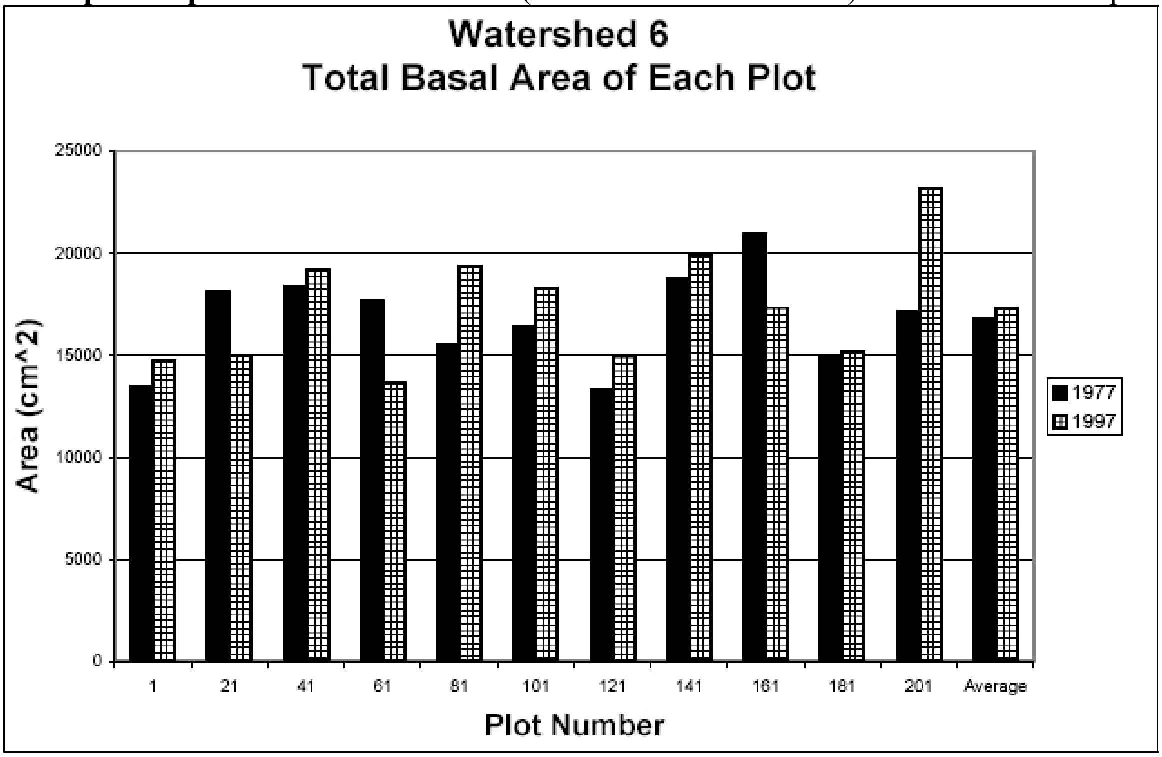
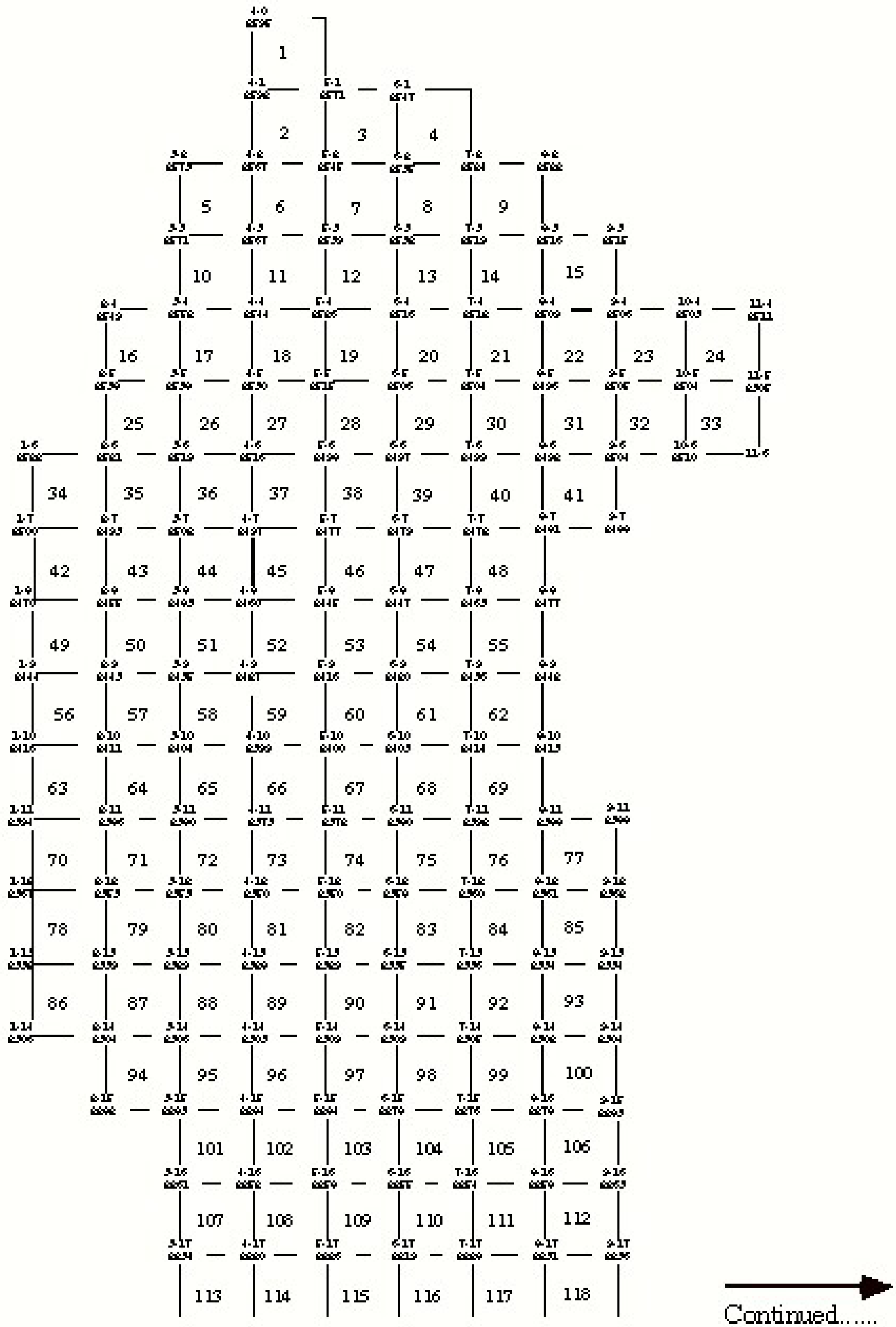
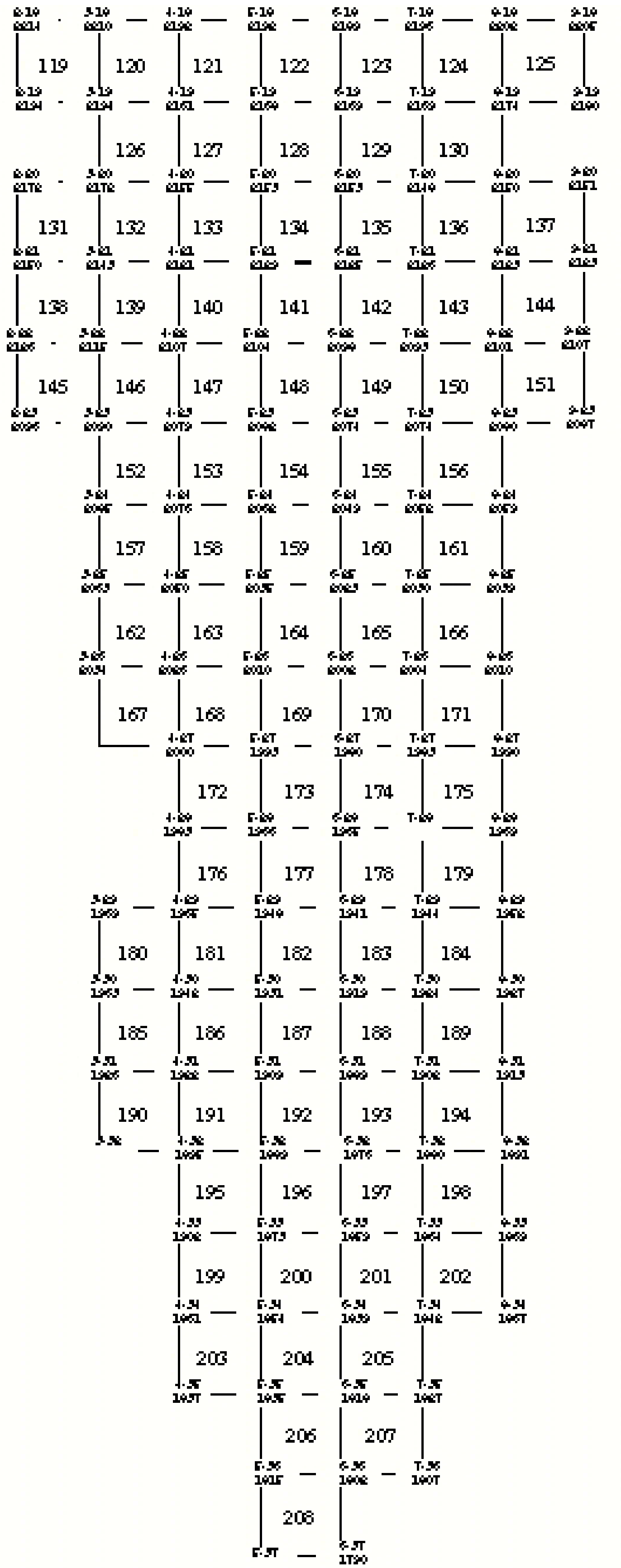


Figure 6. The plot system in Watershed 6. Each plots, shown by a number in the center of a box, is 25 meters by 25 meters. Plot number 1 is located at the top of the watershed.

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131 132 133 134 135 136 137
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Acknowledgements

Some of the material in the introduction was adapted from *Long Term Ecological Research: teacher's manual of classroom activities**. The activities in this manual introduce high school students to the National Science Foundation's Long Term Ecological Research (LTER) program and the variety of research being conducted at LTER sites. The activities also are designed to teach basic ecological principles and inquiry skills, and to make students aware of the value of long-term research as a basis for conservation management and regional planning decisions.

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* Krasny M, Berger C, and Welman TA. 2001. Long Term Ecological Research: teacher's manual of classroom activities. http://www.dnr.cornell.edu/ext/LTER/lter.asp