Hubbard Brook Experimental Forest
Student Activities

HBEF Activity 1
Introduction to the Hubbard Brook Experimental Forest

Introduction

During a raging snowstorm in late March, a frozen water droplet falls on a New Hampshire forest in the form of a snowflake. It stays in the meter-deep snowpack until the arrival of warm weather and snowmelt a month later. When the droplet warms and melts, its water molecules slowly seep into the forest soil, where the roots of a yellow birch tree quickly take them up. The tree transports the water molecules up to its leaves, where they evaporate back into the atmosphere in a process known as transpiration.

What else could happen to the water droplet as it warms and leaves the snowpack? Perhaps a trout lily – a small, short-lived plant common in New Hampshire forests – could take up its water molecules. When the trout lily dies, it would return the molecules to the forest floor, where microorganisms that decompose plant material would absorb them. Or maybe the molecules could move through the soil, bypassing plants and seeping directly into a small stream. The stream would flow into larger and larger streams and rivers, and the molecules would eventually make it to the ocean. In fact, there are dozens of possibilities.

Nutrient cycle: Pathway of a nutrient through an ecosystem from assimilation (transformation into living tissue) by organisms to release by decomposition.

Now, consider what might be *in* the water droplet when it falls on the forest as precipitation. This droplet contains pure water molecules, as well as different types of elements (like carbon and nitrogen) and compounds (for example, nitrate or sulfate) What happens to these compounds when they enter a forest ecosystem: do they quickly leave by flowing out in streams, or are they used by plants or animals that live in the forest? How do they *cycle*, or move through, the ecosystem? Could some compounds even have negative effects on the forest?

Scientists at the Hubbard Brook Experimental Forest (HBEF) in New Hampshire have been asking these and other questions for more than forty years. Their research is part of the Hubbard Brook Ecosystem Study (HBES), and is the focus of the activities in this manual.

Most of these scientists are *ecologists*. In your science classes you have probably learned about many different types of scientists. You may have learned about chemists who study how elements and other chemicals react with one another, and you may have had a chance to read about geologists who study different types of rocks and minerals. These types of scientists study physical, non-living things. And you have probably learned about scientists who study the behavior of different animals, or about scientists who study photosynthesis and other aspects of plant growth. Scientists like these study biological, living things.

Ecology: The study of the interactions of living organisms with one another and with their nonliving environment.

While the scientists who conduct research in the HBEF are interested in many different topics, most of them are studying how the biological components of an ecosystem interact with the physical features. An ecosystem is a community of different species interacting with one another and with their nonliving environment. An ecosystem can be small (for example, a pond), or very large (for example, a river valley). The branch of science that looks at the interactions in ecosystems is known as *ecology*.

Ecosystem: A community of different species interacting with one another and with the chemical and physical factors making up the nonliving environment.

Answering questions about ecosystems is neither quick nor easy for several reasons. First, the interactions between physical and biological factors can be very complicated. In the HBEF, the physical factors include a large number of environmental variables (for example, wind, temperature, and precipitation) and the biological factors include many different types of organisms (for example, trees, smaller plants, birds, invertebrates, and microorganisms). The potential interactions between these factors are numerous and complex.

Second, many ecosystem processes happen slowly or occur only once in a great while. For example, it can take tens or even hundreds of years for a fallen tree to decay and for the nutrients in that tree to cycle back to the soil. It may take hundreds or thousands of years for small amounts of bedrock to erode. A forest may experience only small changes for several decades, but in the span of a few hours or days can be drastically altered by a large storm. For example, in 1998 a tremendous two-day ice storm ripped through the HBEF, coating everything with ice and causing massive damage to limbs, branches, and entire trees. Scientists might miss these types of large, infrequent events if they only conduct two- or three-year studies.

Third, ecological processes also occur across areas of different sizes. For example, some HBEF scientists are interested in how microorganisms interact with nutrients and very small tree roots. Others want to know how these interactions affect the growth rate of trees in the entire Hubbard Brook valley. Similarly, some avian ecologists (ecologists who study birds) look at interactions between male black-throated blue warblers in a small patch of forest. Others study how these migratory birds transfer nutrients from the food they eat in the tropics (winter grounds) to their summer habitat (HBEF).

Monitor: To *systematically keep track* in order to collect information.
Experiment: *To alter or change something* in order to gain experience or learn new information.

When studying complex interactions over long time periods and large areas, it is difficult to find all the answers in laboratory studies. Thus, ecologists often conduct long-term research outside in the ecosystems they are studying. Scientists use a variety of methods, including *monitoring* changes in plant and animal populations or in atmospheric conditions. For example, bird watchers may monitor the date of first arrival of spring migrant birds and meteorologists record the high and low temperatures over many years. Field *experiments* are another kind of long-term research. As opposed to monitoring, where scientists observe changes occurring naturally, in field experiments scientists actually change something in nature and then compare the area they have altered to an area that is left intact.

In the HBEF, many long-term field experiments have been conducted on small *watersheds*. A watershed is the drainage area for a stream, river, or other body of water. A small stream generally has a small watershed, while a large river (like the Merrimack River) drains very large areas. The Merrimack River's watershed includes much of Massachusetts and New

Hampshire. Scientists have identified and marked out nine small watersheds in the HBEF, each of which contains a stream that drains a small, forested area. Each of these watersheds has similar characteristics like slope (steepness) and vegetation, and they vary in size from 10 to 70 hectares (about 25-175 acres).

Watershed: The drainage area of a stream, river, or other body of water; an area used for experiments and monitoring at the HBEF.

Scientists first monitor the amount of water, nutrients and other chemicals (compounds) that *enter* watersheds in precipitation or dry deposition. Dry deposition consists of small particles that fall on the forest, similar to the dust in your house. Next, they measure the water and compounds *leaving* each watershed in streamwater, through evapotranspiration (transpiration from plants and evaporation from soil), or as different gases. Finally, they study what happens *in* each watershed (for example, how quickly trees grow). Studying all components of an entire watershed is known as the, "Small Watershed Concept." Why do you think studying entire watersheds might be interesting or important?

Some of the most fascinating research at Hubbard Brook has examined how watersheds change after an experimental treatment. For example, in a study conducted in Watershed 2, scientists wanted to know how a major disturbance like deforestation (cutting down all the trees) would affect the forest and its water yield (how much water leaves the forest). One of their hypotheses was that because trees take up large amounts of water from the soil, if they were cut down more water would drain from soils and eventually leave the forest. This was particularly important at the time, because there was widespread concern about drought and low reservoir levels. By cutting down the trees in the forest, scientists reasoned, more water would leave the forest and eventually accumulate in reservoirs. As you will learn later in this manual, streamflow increased substantially in the first few years following the cut.

HBEF Research: From 1963 to 2001 HBEF scientists have published 6 books and more than *1000 scientific papers*. In addition, 535 abstracts were published, and over 160 theses were completed.

HBEF scientists are also interested in other types of research. For example, the United States Geological Survey is learning more about how water moves underground, and limnologists (scientists who study lakes and streams) are examining nearby Mirror Lake. Other scientists are monitoring acid precipitation and its effects on organisms and ecosystems, while forest ecologists are carefully measuring the growth of trees and forests.

In the activities in this manual you will read about some of these projects, will examine data generated from them, and will get a chance to measure different components of your schoolyard or community using the same basic protocols that HBEF scientists use. Finally, we hope you may take what you have learned and explore some basic research questions either individually or with your class.

A Quick Site Description

The HBEF is located near Thornton, New Hampshire, and is within the boundaries of the White Mountain National Forest. It is about 15 minutes north of Plymouth, and an hour north of

Concord, the state capital. The HBEF has hilly terrain, ranging from 222 to 1,015 meters in altitude, and it generally covered by an unbroken forest of northern hardwood trees. The northern hardwood forest biome consists primarily of American beech, yellow birch, and sugar maple. Red spruce and balsam fir are frequently found at higher elevations.

The HBEF officially became an experimental forest in 1955, when the US Forest Service established it as a major center for hydrologic (water) research in New England. Then, in the early 1960s, Yale professor F. Herbert Bormann and others decided to study entire watersheds to learn more about how nitrogen, carbon, and other elements cycle through ecosystems. In 1963, Bormann, Gene Likens, Noye Johnson, and Robert Pierce proposed using this Small Watershed Concept to study how water and nutrient cycles interact. They were also interested in how natural and human disturbances – such as air pollution, insect population fluctuations, climate changes, and more – affected these cycles. Why do you think the Small Watershed Concept would be a useful study design for this type of research?

> **Small Watershed Concept**: At the HBEF, scientists use the Small Watershed Concept to study how *all* the plants, animals, soil, and water interact in a single unit – a watershed.

Between 1955 and 1963, the Forest Service set the stage for long-term research: They built a number of precipitation, weather and stream measurement stations, and they started studying soil and vegetation throughout the forest. At first, they were interested in learning how to manage forests to control water quality and floods. But as the Ecosystem Study was initiated and more scientists started working in the HBEF, the research program expanded tremendously. Today over 100 scientists, graduate students, and technicians conduct research in the HBEF, and contribute to the longest dataset of this type in the entire country. In fact, if you decide to do environmental or ecological research in college, you may be able to get a summer job at the HBEF.

Virtual Tour

To help you learn more, you will now take an online tour of the HBEF. The tour begins with a brief description of the Hubbard Brook Experimental Forest, and then shows the forest, the history of the valley, the current facilities, short- and long-term research, and the people who make it all happen. When you are taking the tour, think about questions you would ask if you were an ecologist. Would you study trees and how they interact with soil, or would you be more likely to examine insects that live in streams? Are you curious about how nutrients move around in a lake, or would you rather study how winter snow levels affect forest growth? Or are you more interested in songbird reproduction or other types of animal behavior? Are there other questions you have asked when walking through forests near your home or school?

Protocol 1
Taking the HBEF online virtual tour

1) Go to the Hubbard Brook Ecosystem Study's website: http://www.hubbardbrook.org/.
2) Click on the "Educational Resources " link and then go to the "Student's Homepage."
3) Click on the button labeled, "Virtual Tour." Take some time to view the tour, following the links that are interesting to you. Then, answer the questions on the handout your teacher has given you. Most of the answers can be found in the tour.

Suggestions for further study

If you are interested in learning more about the HBEF after you have completed the tour, there are several online resources available to you.

- View other sections of the HBEF website. This site contains real data, in-depth explanations of research projects not covered in the Virtual Tour, contact information on HBEF scientists, and more.
- Visit the Long Term Ecological Research (LTER) network's website (www.lternet.edu). This website contains information about and links to the 24 LTER sites.
- For more information on the HBEF, you may be interested in reading all or sections of the following books:
    - Bormann, F. H. and G. E. Likens. 1979. *Pattern and Process in a Forested Ecosystem*. Springer-Verlag New York, Inc. 253 pp.
    - Likens, G. E. and F. H. Bormann. 1995. *Biogeochemistry of a Forested Ecosystem.* Springer-Verlag New York, Inc. 159 pp.

HBEF Activity 2
Watershed Experiments

This activity was adapted from Activity 3 of the Long Term Ecological Research: Teacher's Manual of Classroom Activities.*

Introduction

When research at the Hubbard Brook Experimental Forest began about 50 years ago, the northeastern states were experiencing a drought and many communities were suffering from water shortages. Knowing that plants (especially trees) take up large volumes of water from the soil, scientists wondered whether it might be a good idea to cut down the trees around drinking water reservoirs. They came up with a hypothesis that could be tested through long-term research: if trees were cut down and therefore not taking up water, more water would flow into the reservoirs.

As you may have learned in the virtual tour in Activity 1, the Hubbard Brook flows through New Hampshire's White Mountain National Forest and drains a range of small mountains. The tributaries of Hubbard Brook form a set of discrete watersheds, separated by mountain ridges. Because these watersheds share many characteristics in common (for example, similar size and vegetation), they provide an ideal setting for conducting ecosystem experiments.

> **Control**: A treatment that reproduces all aspects of an experiment except the variable of interest. Controls and treatments are the same before an experiment.

In laboratory experiments, scientists use *controls* to determine whether the treatments they impose cause any changes. For example, a scientist studying the effect of salt on plants would expose treatment plants to salt and compare their growth to control plants growing without salt. Similarly, scientists at Hubbard Brook devised experimental treatments for three watersheds to see whether different ways of cutting trees would affect the amount of water reaching the stream. When scientists manipulate the world outside of the laboratory, they are conducting a field experiment.

In one watershed, researchers cut all the trees in the middle of winter and left them lying on the snow so that the soil was not disturbed. In another watershed, all the trees were cut and entirely removed. In a third watershed, researchers divided the forest into 25-meter-wide strips. In the first year, they cut and removed all the "merchantable" materials (leaving branches and tree tops) in every third strip. In subsequent years, they returned and cut the adjacent strips. This treatment was designed to look at less damaging ways of cutting a watershed. And finally, the last watershed was left intact, similar to a control. However, unlike laboratory studies, the ecosystem experiments did not have true controls. Although the different watersheds were similar in size and vegetation, they were not exact replicates. (It is virtually impossible to have true replicates or controls in nature because of variations in soil, plants, etc.) Thus, the watershed that was left intact is referred to as the "*reference*" rather than the control watershed.

> **Reference**: Similar to control, referring to a treatment that reproduces *many* of the aspects of an experimental design, while excluding the variable of interest. A reference and a treatment are designed to be as *similar as possible*, but may have several differences.

Table 1. Hubbard Brook Watershed Treatments.

Watershed	Size (hectares)	Treatment
2	15.6	Clearcut in winter 1965-66. Trees left on the ground. Herbicides applied in 1966, 1967, 1968.
3	42.4	Reference (no treatment).
4	36.1	Strip-cut in 3 phases, in 1970, 1972, 1974. Trees removed from watershed.
5	21.9	Whole-tree harvested during the dormant season of 1983-1984.

To measure the changes in water flowing out of the different watersheds, scientists installed special gauges on forest streams, called "weirs." Weirs are permanent concrete structures consisting of a large basin with a v-notch cut on the side of the downstream end. The stream flows directly into the basin where it slows down and becomes less turbulent, and then flows out over the v-notch. By constantly measuring how high the stream is at is passes over this v-notch, and entering this height into a known formula, researchers can determine streamflow volume. A picture of a weir in the HBEF is below.

In this activity, you will be looking at some of the original streamflow data collected at Hubbard Brook to determine the short-term and long-term results of a forest tree-cutting experiment. You will be examining data from Watersheds 2 and 3. Watershed 2 is the treatment (cut) watershed and Watershed 3 is the reference watershed. All trees in Watershed 2 were cut in December 1965 and left on top of the snow. In the summers of 1966, 1967, and 1968 an herbicide was applied to the entire watershed to prevent the regrowth of any vegetation. Watershed 3 was not disturbed. This field experiment was the first study to examine how forest cutting might influence streamflow and subsequent reservoir levels.

Protocol 1

Examine the spreadsheet on the computer or the hard copy handed out by your teacher. This spreadsheet includes the streamflow and precipitation data collected from Watersheds 2 and 3 at the Hubbard Brook Experimental Forest over a 30-year period. Notice the headings at the top of the columns. The first column is labeled “year.” Data from 1958-1988 are presented. Streamflow data from the different watersheds (columns B and C) are presented as annual streamflow in mm per standard area per year. These values have been adjusted to account for the difference in size between the watersheds.

For each watershed, mean annual precipitation values are also provided (columns D and E). As you can imagine, the amount of rain usually varies from year to year, and the amount of rain that falls on the watershed obviously influences how much water comes out in streamflow. Initially, you will be graphing the streamflow data in Watersheds 2 and 3 for the years before the clearcutting treatment (1958-1965). Scientists refer to this as “baseline” data. You will then graph streamflow data in both watersheds for the five years following the treatment (1966-1970) and will assess the streamflow response of Watershed 2. Lastly, you will graph the remaining data (1971-1988) from both watersheds.

You (and your partner, if you are working in pairs) should examine the data. What is the best way to graph them? What will you use as your x-axis? Y-axis? You are interested in determining the watershed baseline and then the response following the clearcutting treatment. Your teacher may lead a classroom discussion about the best way to graph these data.

1) Graph streamflow in Watershed 2 (the treatment watershed) from 1958 – 1965. These are the baseline data.

2) Do the same with Watershed 3. Decide if you want to graph the two watersheds together or on separate pages.

3) Do you see any trends in annual streamflow in the watersheds? How do the watersheds compare to each other (e.g., does one watershed always have higher streamflow values, or is there variability between years and watersheds)? What do these baseline (before cutting) data tell you about the watersheds’ streamflow? When doing field experiments, scientists try to have an understanding of how the ecosystem is working before the treatment. In interpreting the results of the field experiment, it is essential to compare the watershed streamflow *after* the treatment (clearcut) to the streamflow *before* the experiment, for both watersheds. (What mistakes might you make if you did not have data from before the clearcutting?) Think about why it is important to monitor the reference watershed (Watershed 3) as well as the treatment watershed (Watershed 2) both before and after the treatment.

4) Continuing on the same graph(s), you should now include data from the next five years (1966-1970). Do you see any changes in watershed streamflow? By about how much did streamflow change? Are these changes in one or both watersheds? How do the two watersheds compare to each other in the five years following the treatment? If there is a

change, what year marks the change? The original hypothesis of this experiment was that if we clearcut and applied herbicide to a watershed, more water would flow out of it. Did this happen? Can you make any conclusions?

5) Now put the remaining data on the same graphs (1971-1988). What do you see now? What has happened to the streamflow in both watersheds, and how do they compare to each other? Do you see any differences between the short-term data (1966-1970) and the long-term data (1966-1988)? Does this information change your interpretation of the results? Do the reference and treatment graphs follow the same pattern? How do you explain what is happening?

6) Graph average annual precipitation in Watershed 2 and Watershed 3. Your teacher may ask you to transfer the graph to a transparency and superimpose it on the graph from step 5, and if you made separate graphs, step 6. Does the precipitation information change your interpretation of the results?

7) Using a graph, what is another way you might compare these two watersheds' annual streamflow? Consider graphing the difference between the two watersheds (i.e., Watershed 2 annual streamflow – Watershed 3 annual streamflow). What can you learn from this graph?

8) You have probably noticed that there are differences between the short-term and long-term WS2 streamflow data. Why might this have happened? Your teacher may lead the class in a discussion of possible reasons.

Given all of the streamflow data you have seen, what can you say about the original hypothesis? Does cutting all the trees in a watershed increase streamflow? Think about short- and long-term response. What does this experiment say about the need for long-term research? If the research had stopped five years after the clearcut, do you think your (and other people's) perceptions of clearcutting effects on streamflow would be different than they are now? If communities are trying to increase reservoir levels, is clearcutting nearby forests a good way to do it?

Suggestions for Further Study

Other Watersheds

You could do the same graphing steps using the data for Watershed 4, where trees were strip cut over the course of a four-year period. Visit the HBEF website, where you should be able to find the Watershed 4 streamflow information by clicking on the "data" button and following links to "stream." Getting data off of the HBEF website can be difficult: the data need to be downloaded and reformatted for database software. You may need to ask your teacher for help, or click on the "email" link of the HBEF website to ask the HBEF data manager for assistance.

Given the results you saw when an entire watershed was clearcut, how much of an increase in streamflow would you expect to see in Watershed 4 after one-third of the trees had been cut? After 2/3 of the trees had been cut? After ALL of the trees had been cut?

Compare your predictions to the actual results. How are they different from your prediction? What could explain this difference?

Societal Influences on Research

Consider the following question: Why did clearcutting and herbiciding a forest to get more water for human use seem like a great idea in 1955? How would society react to clearcutting and herbiciding a forest to increase water supply today? How have changing societal values influenced the research being conducted at Hubbard Brook and elsewhere? How does current research at Hubbard Brook differ from the research that was conducted in the 1950s and 1960s?

Acid Rain

Hubbard Brook is very famous because it was here that scientists first discovered acid rain. The knowledge gained from Hubbard Brook acid rain research was instrumental in the development of the federal Clean Air Act and subsequent amendments. The Clean Air Act and its amendments called for a reduction in acid rain-causing emissions from coal-fired power plants and other pollution sources. Because Hubbard Brook is a long-term ecological research site, scientists have had the opportunity to continue studying the effects of acid rain on northeastern forests after the passage of the Clean Air Act. And, unfortunately, while research shows that precipitation is generally becoming slightly less acidic, current studies indicate that acid rain and its effects are still a big problem.

In March 2001, Hubbard Brook scientists issued a news release urging the public to continue to work to reduce acid rain. "The science on this issue is clear," says Dr. Gene Likens, director of the Institute of Ecosystem Studies in Millbrook, New York, and one of the scientists who discovered acid rain at Hubbard Brook. "Current emission control policies are not sufficient to recover sensitive watersheds in New England. The deeper the emissions cuts, and the sooner they are achieved, the greater the extent and rate of ecological recovery from acid deposition." Dr. Likens' work is a powerful example of how scientists can influence policy at the national level. You may want to visit recent HBEF acid rain publications, located at: http://www.hbrook.sr.unh.edu/hbfound/hbfound.htm.

You may want to do more research on the Clean Air Act and acid rain using internet sources, including the Hubbard Brook website. Check out the Environmental Protection Agency's (EPA) acid rain website at http://www.epa.gov/airmarkets/arp/, or the National Atmospheric Deposition Program (NADP) at http://nadp.sws.uiuc.edu/. The National Science Teachers Association is another good source for acid rain materials, at http://www.nsta.org/.

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.

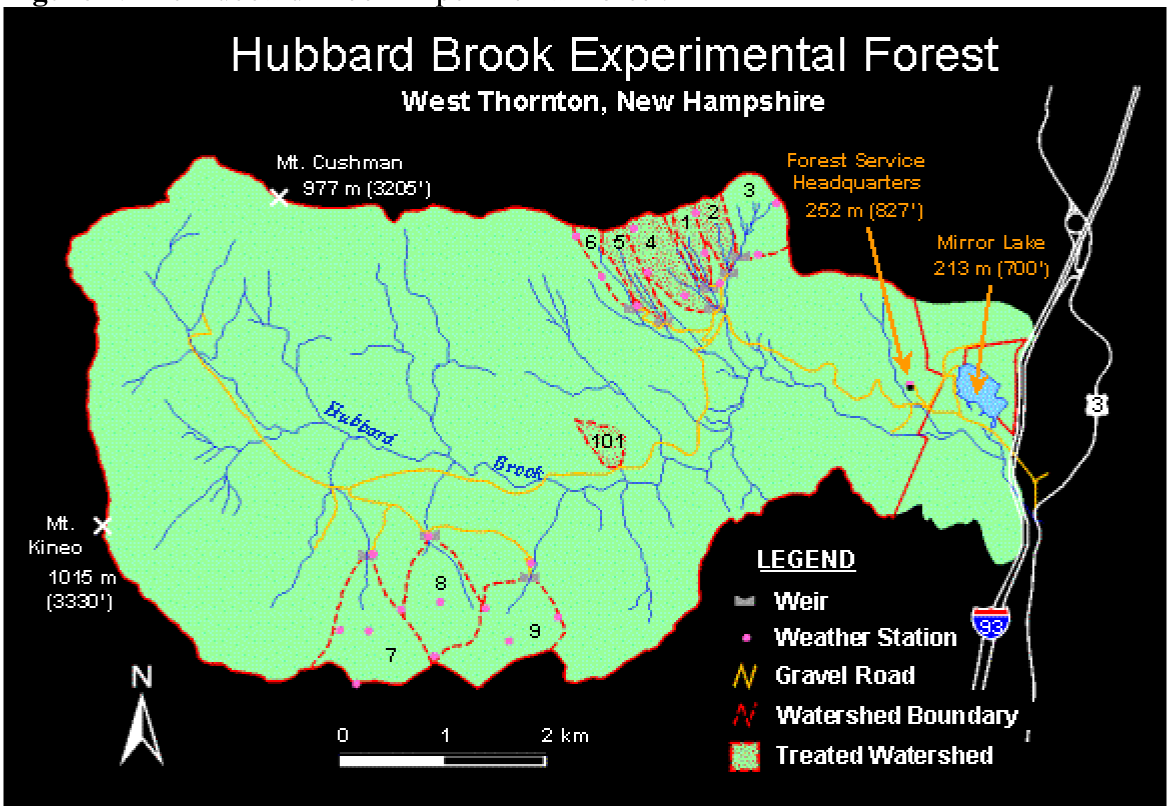
Watershed 6 has an area of 13 hectares (~33 acres), and ranges in elevation from 550 m to 800 m (1800 to 2600 feet). The forest is dominated by sugar maple, yellow birch and American beech, with balsam fir, red spruce, and paper birch more common in the upper section (Figure 2).

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*.

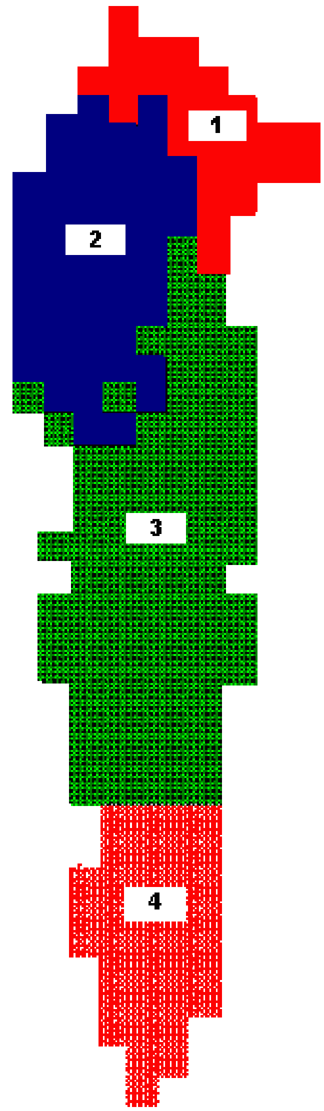
Species composition and density of species

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.

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						

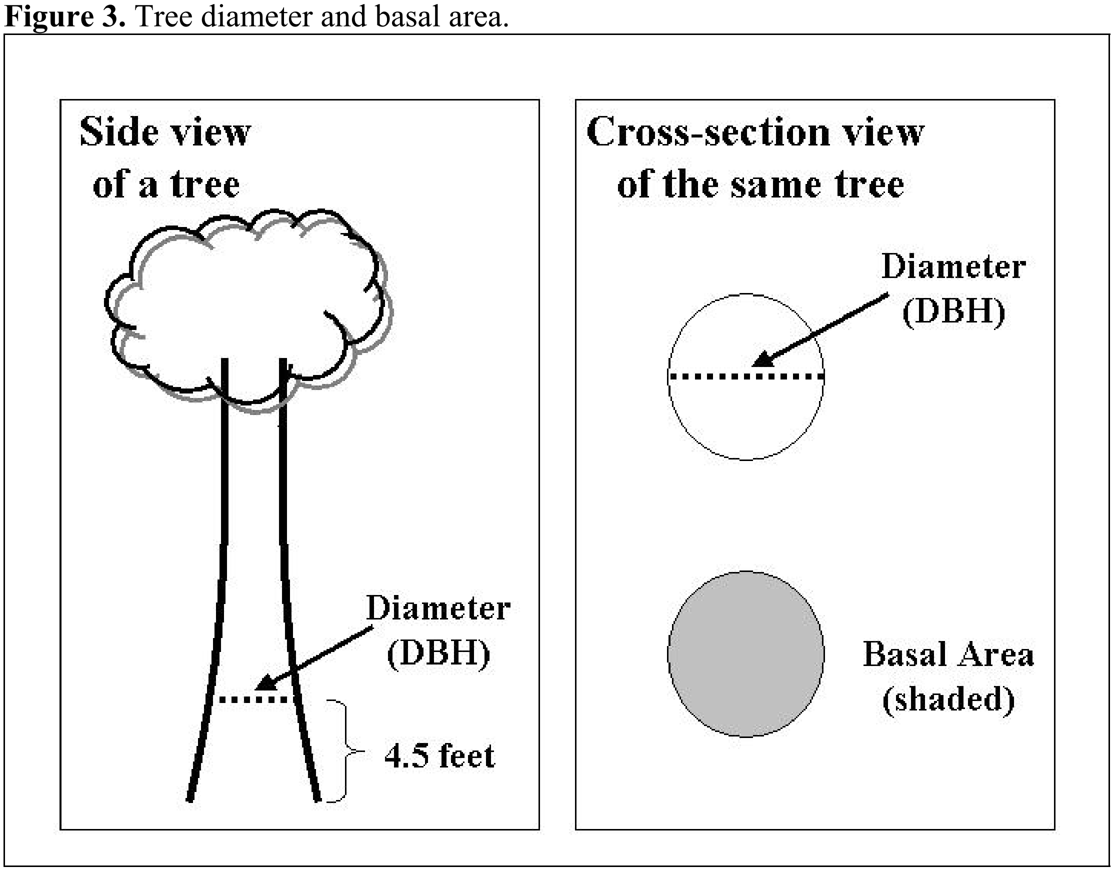
Measuring the forest
Part 2

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.

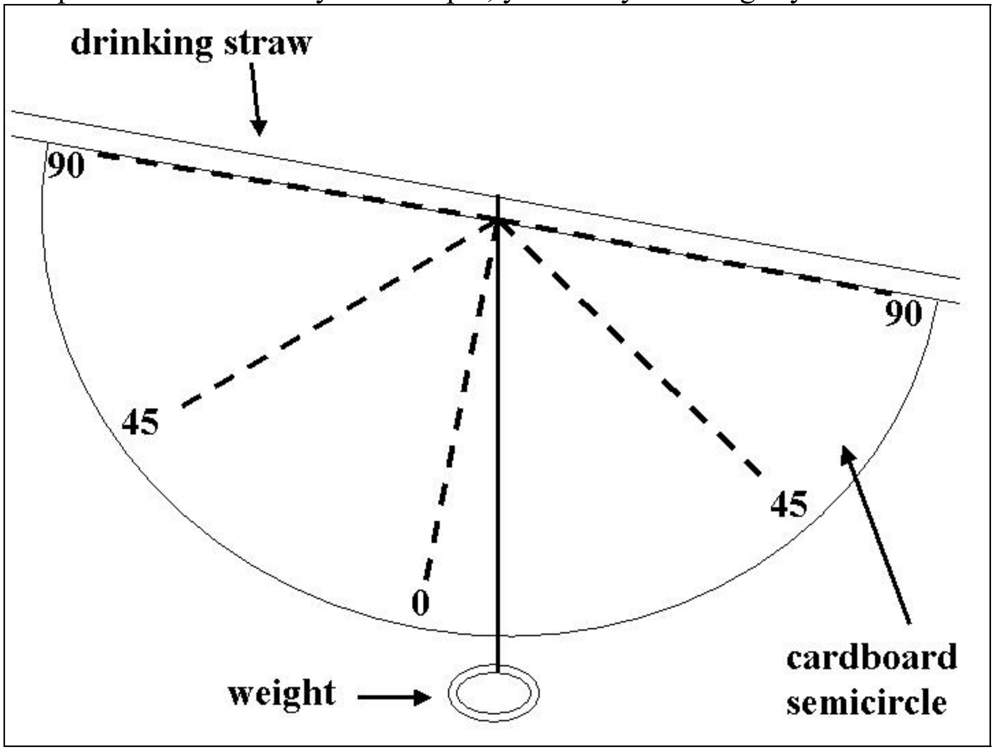
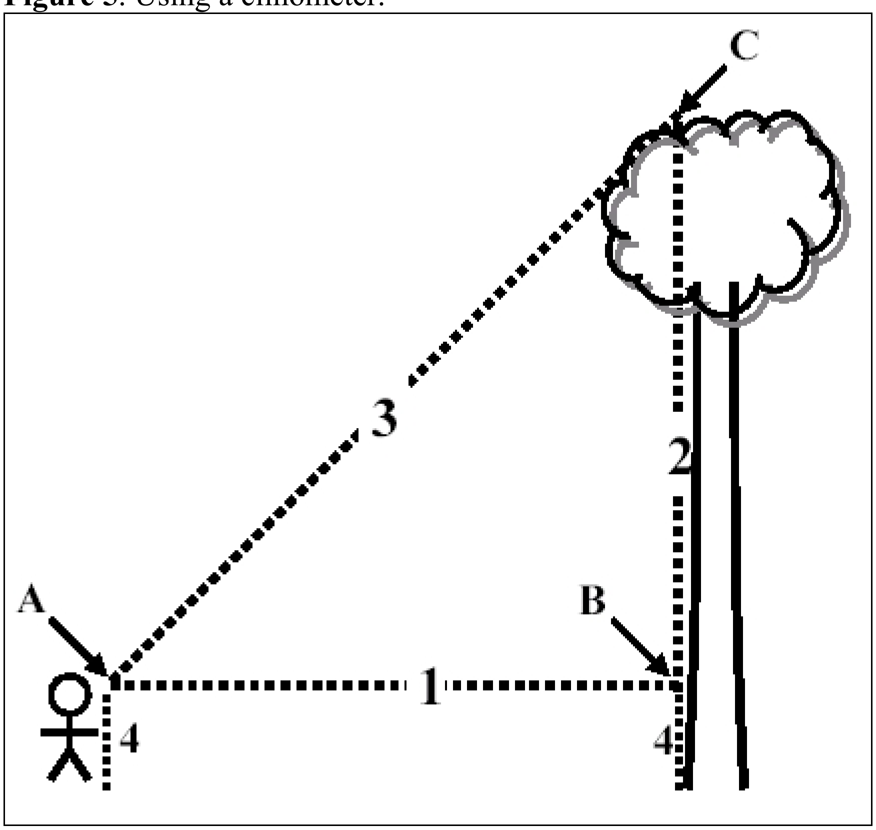


Figure 5. Using a clinometer.



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?

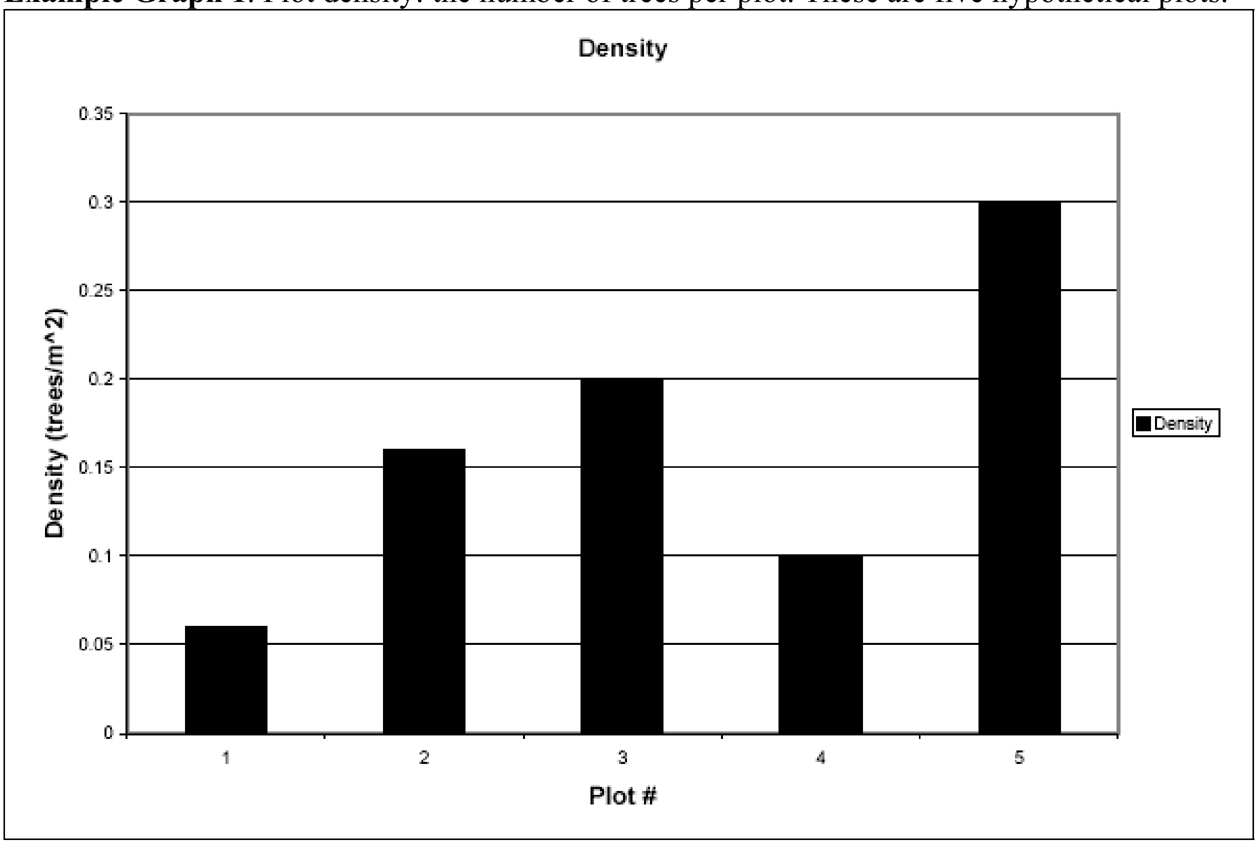
- How do the eleven plots differ in terms of the species composition, tree density, or basal area? Do elevation or plot slope seem to affect these relationships? What other factors could be influencing the patterns you see?
- At what elevation are you more likely to find balsam fir? Red spruce? Other 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

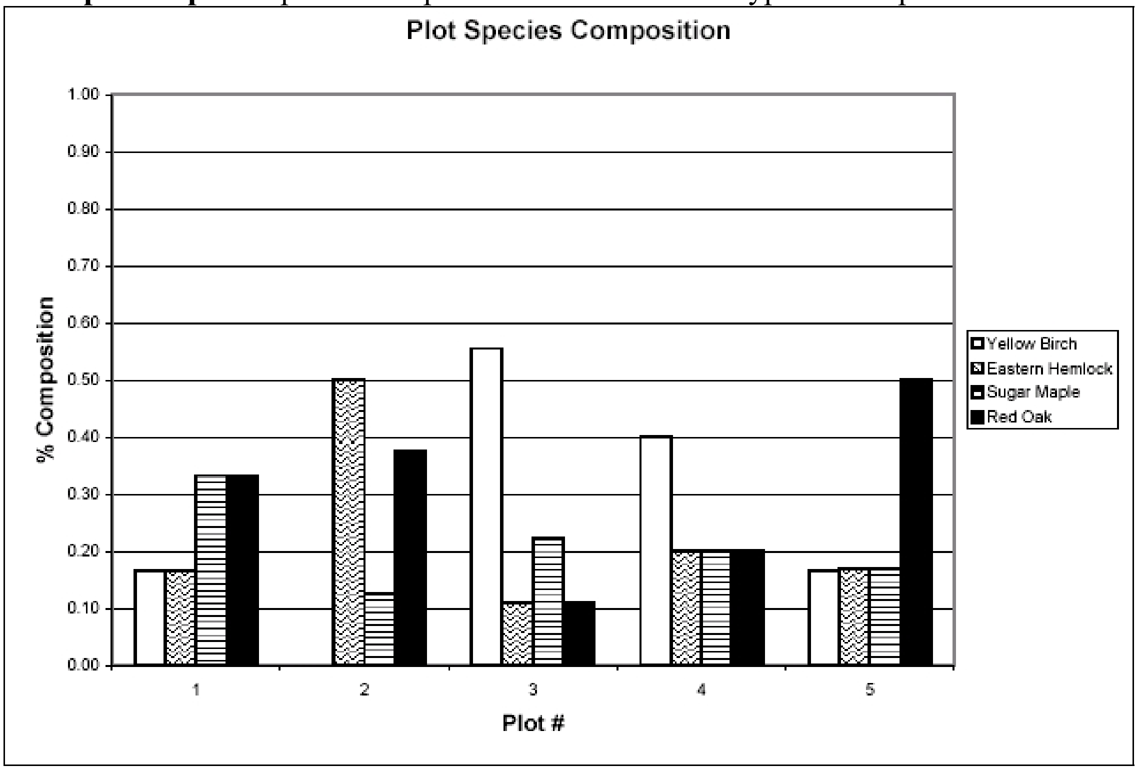
- You may be interested in visiting the HBEF and checking out Watershed 6. You can find contact information for the Forest Service on the HBEF website.
- Compare Watershed 6 data to your study area results. To make accurate comparisons, you would need to learn more about the environmental variables present 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

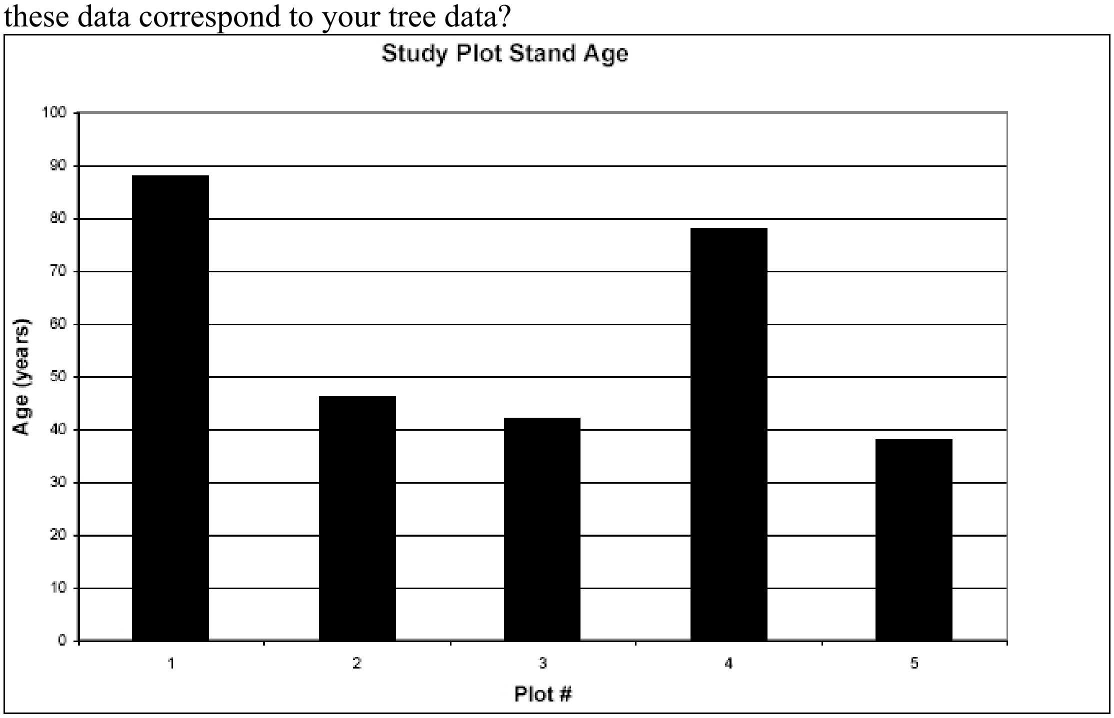
Example Graph 1. Plot density: the number of trees per plot. These are five hypothetical plots.



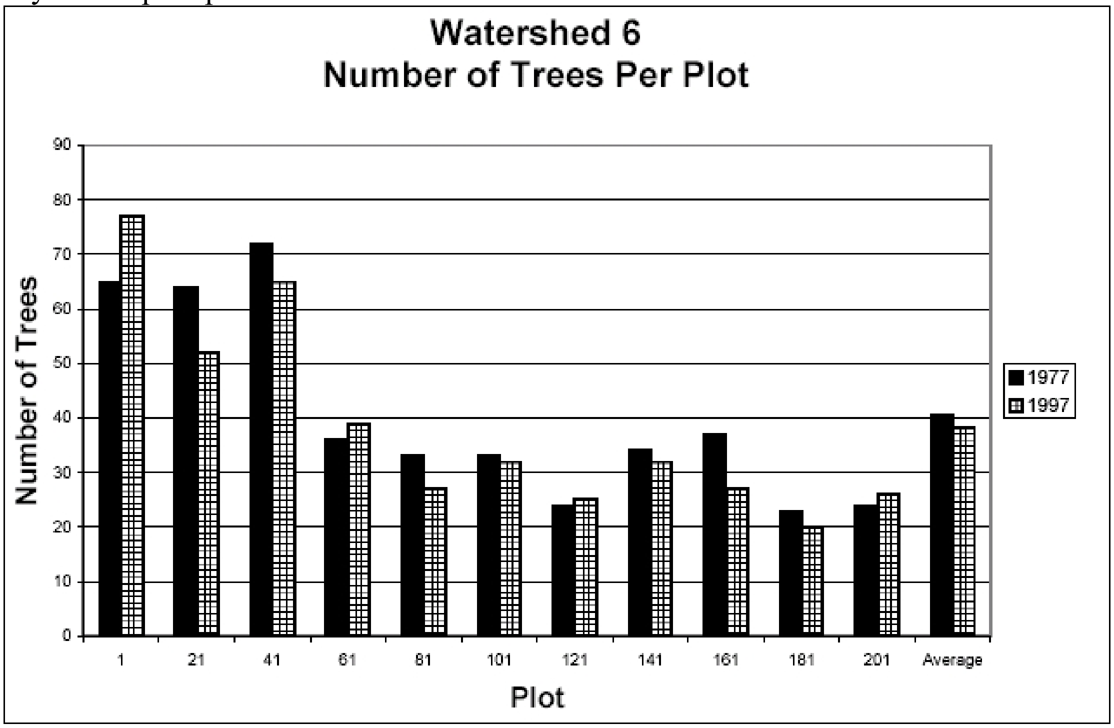
Example Graph 2. Species composition. These are five hypothetical plots.



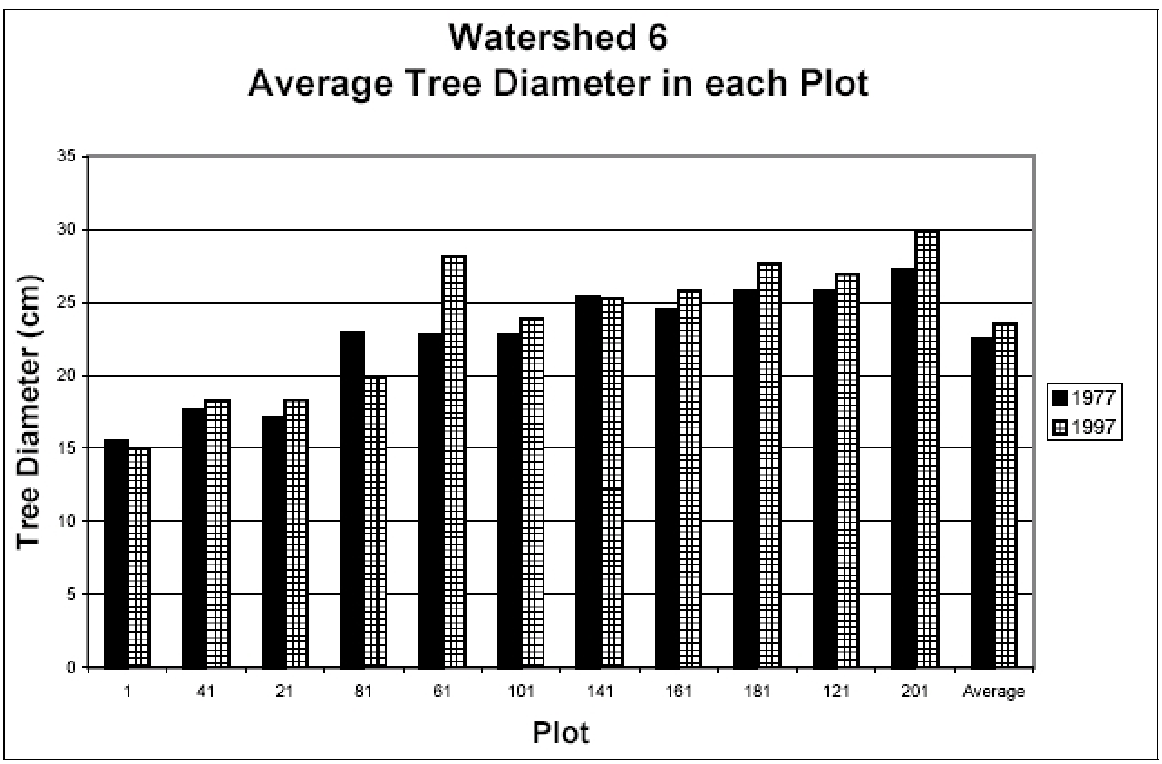
Example Graph 3. The stand age of 5 different hypothetical plots. "Stand age" refers to the age of plot trees, and often corresponds with when the area was last cut or otherwise disturbed. Trees were planted in these plots at year 0, so the oldest trees in plot 5 are 38 years old. How would these data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

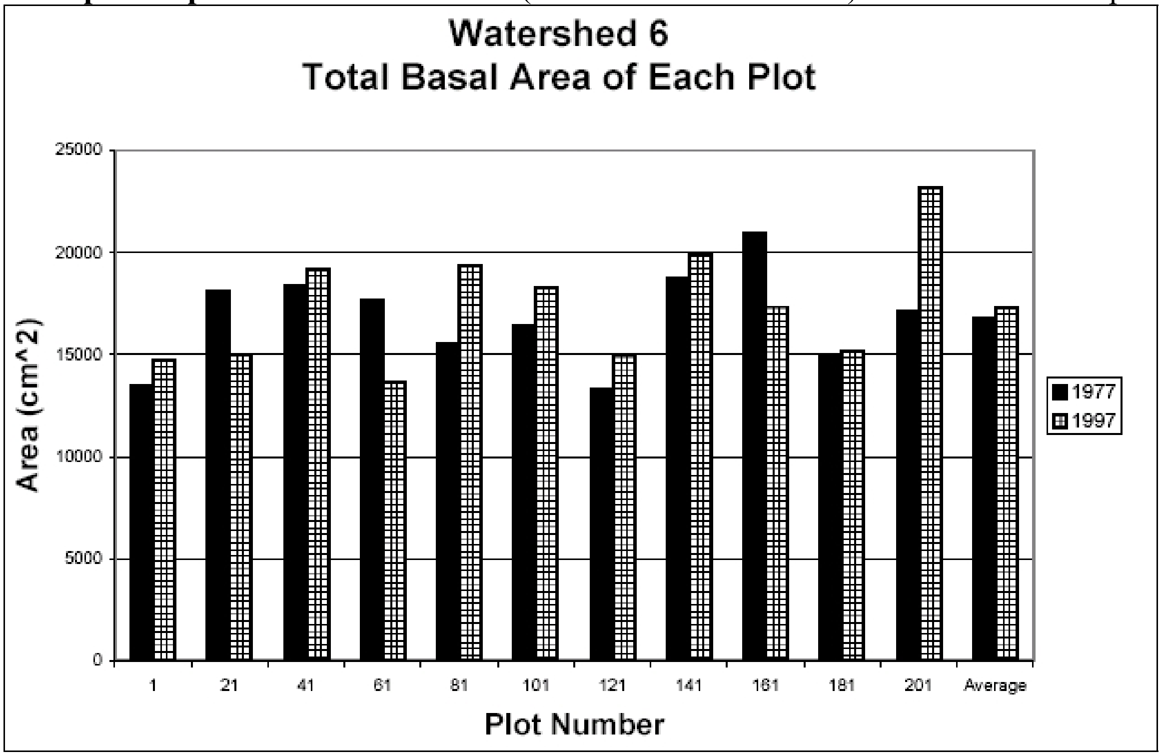
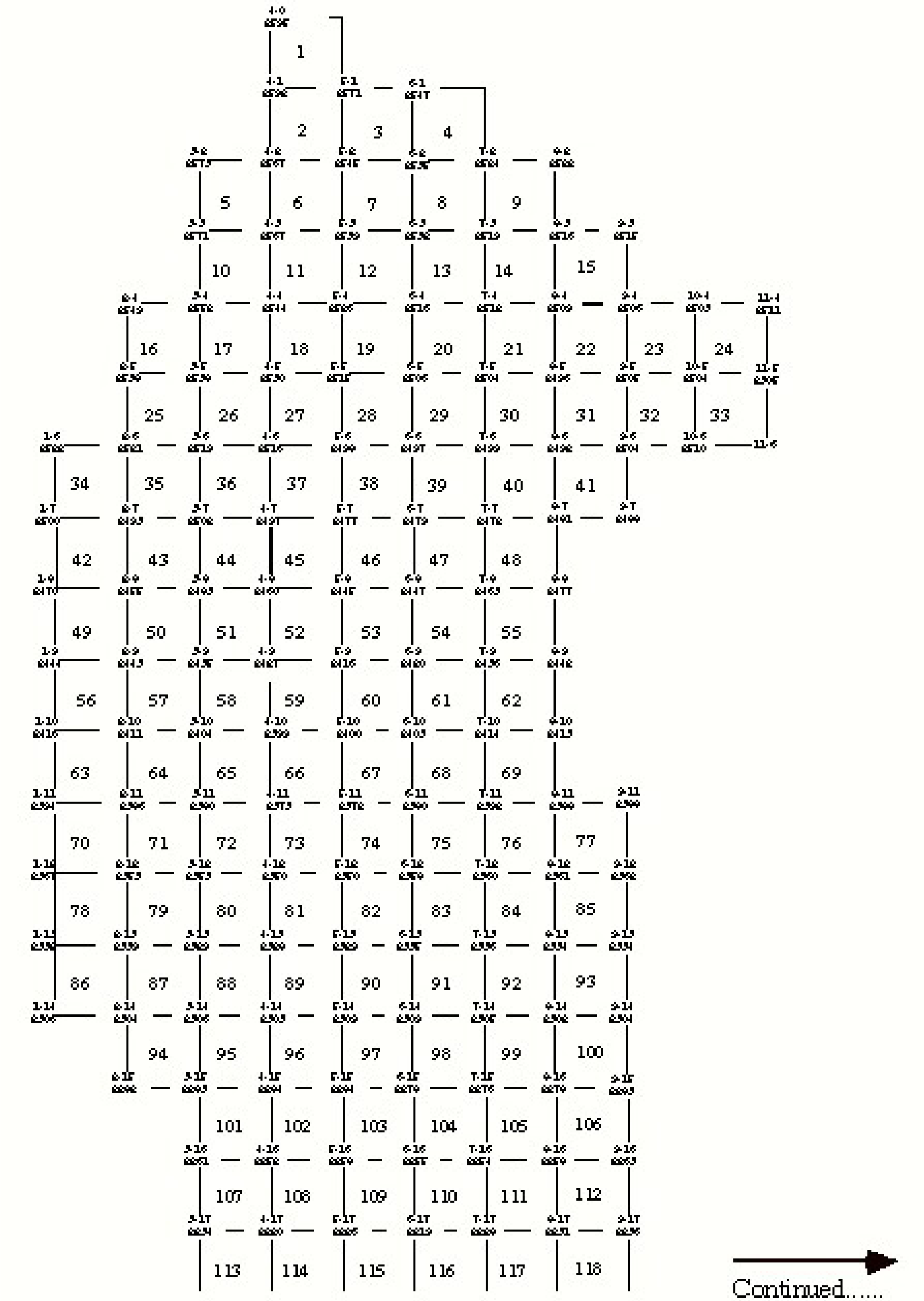


Figure 6. The plot system in Watershed 6. Each plots, shown by a number in the center of a box, is 25 meters by 25 meters. Plot number 1 is located at the top of the watershed.



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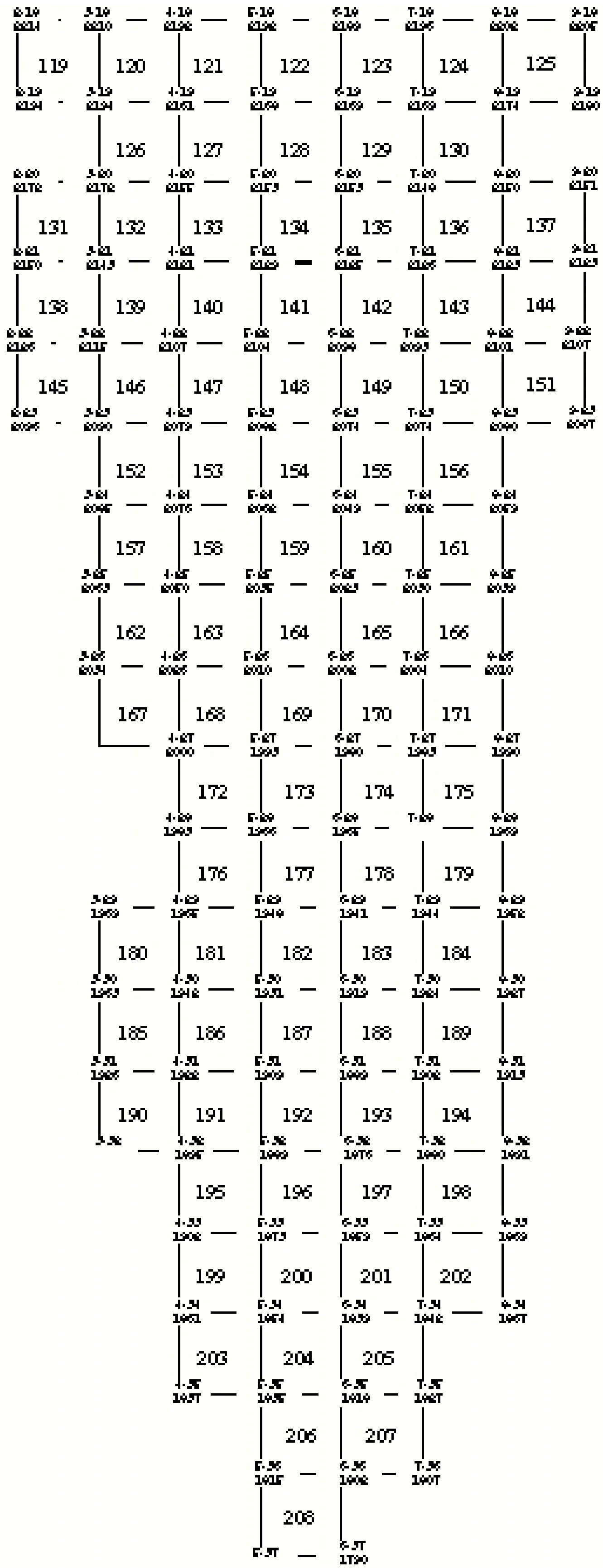
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Acknowledgements

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.

Thanks to Kate Macneale, Amey Bailey, Ellen Denny, and Tom Siccama for reviewing the activities and providing helpful comments. Additional thanks go to the US Forest Service for providing the data used in Activity 2 and to Tom Siccama and Yale University for providing the data used in Activity 3.

* 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