Unit 9: Forestry

Biology in a Box

A science education outreach program brought to you by a partnership between The University of Tennessee and the National Institute for Mathematical and Biological Synthesis

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Unit 9 : Forestry
Materials List

Exercise 1

- Tree Parts poster
- Trunk Parts poster
- Set of "Missing Parts" cards
  - 7 question cards
  - 5 answer cards
- Tree trunk puzzle
- Tape measure
- Tree cookies or tree cookie wedges from 2 species (A & B)
- Laminated leaves (labeled A-N)
- Sealed containers with seed cases (labeled 1-14)
- Clinometer

Exercise 2

- 12 wood chips labeled with species
- 12 mystery wood chips (labeled A-L)
- Wood density cubes (3 species)
  - Balsa
  - White birch
  - Lignum vitae
- 6" ruler
- Digital scale
- 100g calibration mass
- Magnifying glass
- Wood porosity samples (2)
  - Oak porosity sample
  - Pine porosity sample
- Magnifying glass

Exercise 3

- Container of wood products
  - Aspirin (replica for safety reasons)
  - Cellophane
  - Chewing gum
  - Clothespin
  - Cork
  - Crayon
  - Glue stick
  - Latex glove (not actually latex, for those with allergies)
  - Maple syrup
  - Oil
  - Paper product (cardboard, paper, etc.)
  - Photographic film
  - Plastic comb
  - Rayon fabric
  - Soap
  - Toothpaste
  - Toothpick

Exercise 4

- Forest habitat poster
- 15 Critter cards
- 15 Habitat cards

Exercise 5

- Succession game boards
  - Monotypic stand
  - Mixed stand
  - Blank land board
- Deck of 27 "External Forces" cards
- Container of paper clips

Exercise 6

- Sample of damage by Southern Pine Beetle (*Dendroctonus frontalis*)
- Game board depicting monotypic stand
- Game board depicting mixed stand
- Blank game board

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Unit 9: Forestry

Introduction

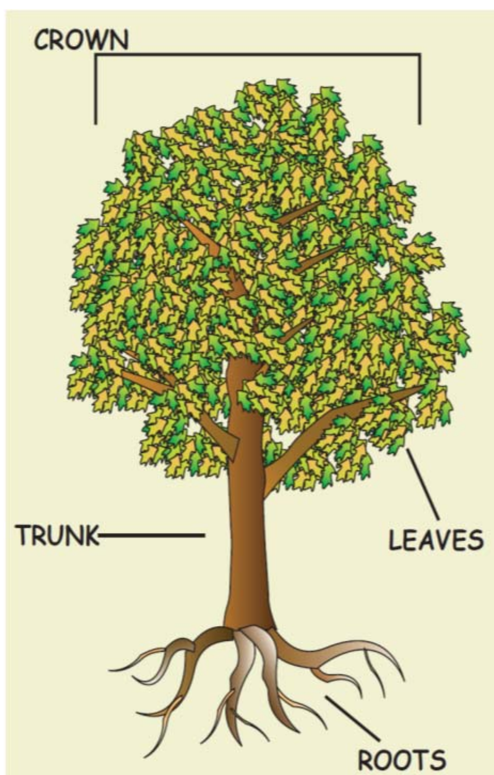
Forestry is the science and practice of studying and managing forests and their natural resources. Tennessee produces more hardwood flooring and pencils than any other state, and Tennessee is the second largest producer of hardwood lumber. In fact, wood is among Tennessee's five top agricultural crops, so forestry is important to us. We need to keep our forests healthy so that trees that are removed to make products such as pencils and lumber are replaced by new trees. This is called forest regeneration. To keep our forests healthy, we must understand the biology of trees and the ecology of forest systems. In this unit, students will learn about tree biology (**Exercise 1: Dendrology**), the value of tree resources (**Exercise 2: Wood Types** and **Exercise 3: Forest Products**), and about forest ecosystems (**Exercise 4: Who lives Here?**, **Exercise 5: Forest Succession**, **and Exercise 6: Forest Pests**).

*This unit was originally developed for *Biology in a Box* by Allison Mains and Dr. Scott E. Schlarbaum of the UT Forestry Department under the auspices of a grant from the Healing Stones Foundation. Modifications have been made by members of the *Biology in a Box* team (Dr. Susan E. Riechert, J.R. Jones) and math collaborators at NIMBioS (Dr. Suzanne Lenhart, Dr. Emily Moran, and Kelly Sturner).

Exercise 1: Dendrology: The Study of Trees

Just like humans, trees need several important things in order to help them grow and function. They need sunlight, water, and minerals that are contained in the soil, such as nitrogen, magnesium, calcium and potassium. Different parts of the tree help in providing for its growth. Starting as a seed, a tree pushes its roots into the soil as an anchor. The roots also collect minerals and water from the soil. As the tree grows, it reaches its leaves to the sky to collect energy from the sun. In a process called photosynthesis (**foto-sin-theh-sis**), tree leaves use energy from sunlight to turn water and carbon dioxide into food for the tree. The leaves release oxygen into the air in the process. (This is just the reverse of our exchange of gases. We breathe in oxygen and release carbon dioxide when we exhale.) The food is used to keep the growing tree healthy and strong.

Trees have three main sections: the **crown**, the **trunk**, and the **roots**. Examine the picture below that shows these sections. Each is made up of smaller parts that all serve important functions. A larger poster of this image is also provided in this box.



Exercise 1a: Tree Trunks

Exercise 1a.1: Parts of a Tree Trunk (*Grades K-12*)

In this activity you will learn the different parts of a tree trunk and their functions.

The **bark** protects the tree from harmful elements like fire, insects, disease, and lightning.

> **Fun Fact:** The cork oak (*Quercus suber*, which is native to southwest Europe and northwest Africa) has bark so thick and spongy it can be peeled off in one thick layer without killing the tree. This bark is used to make the corks that seal bottles, as well as bulletin boards, sandals, and other products.

The **phloem** (**flow-um**) forms the inner bark and contains tiny vessels that transport food (in the form of sugar) from the leaves to other parts of the tree all the way from the twigs to the roots.

> **Fun Fact:** Maple syrup is made by tapping a small tube into the phloem layer of a maple tree and collecting the sap that comes out. This doesn't harm the tree, because only a small part of the phloem is damaged. The sap contains a lot of water and a little bit of sugar, but once boiled to remove the water, thick sweet maple syrup is left behind!

The **cambium** (**cam-bee-um**) layer is a layer that produces new cells. These cells keep dividing, some becoming the **inner bark** or **phloem** (outwards from the cambium), and some becoming **sapwood** or **xylem** (inwards from the cambium).

The **xylem** (**zy-lum**) forms the **sapwood** and the **heartwood**. The sapwood contains tiny vessels that transport water from the roots all the way to the leaves. These vessels only work for a few years, so the tree must keep making new ones. The heartwood is the xylem layer of dead cells that used to be sapwood. This layer is very strong and gives the tree its main support.

The **pith** is found in the center of the trunk, inside the xylem. It stores sugars and also holds wastes. In older trees, the pith is crushed by the xylem's woody tissue, and wastes are simply deposited in the wood cells near the center of the trunk.

- Locate the "***Trunk Puzzle***" found in your box, and place the pieces so that they fit together as shown in Figure 1 below.
- Locate all of the parts of the tree trunk shown in the cross section or 'tree cookie' represented by the puzzle.
- Try to recall what job each part performs for the tree.
- You may also wish to examine the wedges of tree cookies cut from actual trees, and see if you can identify each of the parts that you identified on the puzzle.
- After you have learned the function of each part, test your memory.
  - Look through the "***Missing Parts***" question and picture cards.
  - For each question card, try to find a picture card that answers the question about what would happen if a tree were missing a particular part. Some picture cards may be used for more than one question.
  - Check your answers in the answer section for Exercise 1a at the end of this book.

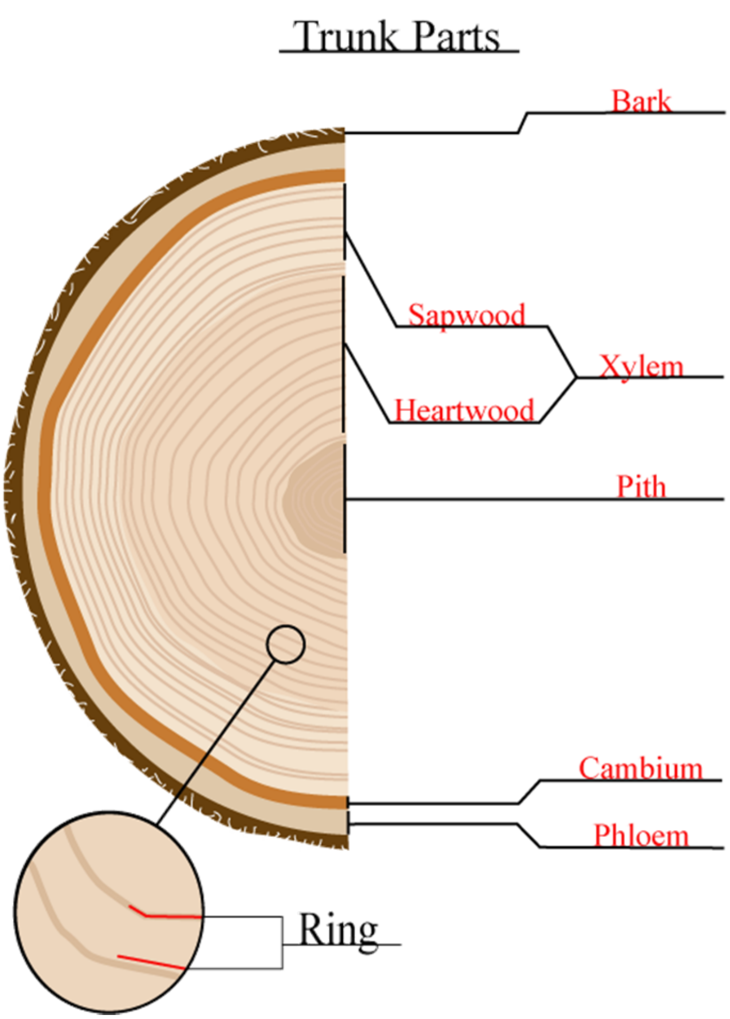


Figure 1: Cross section of a tree trunk or half of a 'tree cookie' showing parts described on previous page.

Exercise 1a.2: Trunks Tell Tales: Tree Rings and Tree Cookies (*Grades 3-12*)

Often you can tell a lot about a tree's history by looking at a slice or cross section of its trunk. As a tree grows, it lays down two tissue layers. The **early wood** forms during the wet spring season, which is when the tree grows most rapidly. In the drier period from summer to winter, the **late wood** forms. As a result, the colors and density of these two layers are different from each other. In the winter, the tree stops growing and becomes dormant, or inactive. Because of this growing process every year, the wood of a tree develops what looks like rings, two per year of growth. Look at the picture of the tree cookie shown in Figure 1 as an example. You can count the rings to see how old a tree is. Be sure to divide this number by two though! The tree rings can also inform you of past weather patterns and disturbances like fire.

<u>**Things to look for when examining tree rings:**</u>

- A **wide ring** means that the tree grew a lot during a given season (***fast growth).***
- A **narrow ring** means that the tree did not grow much that season ***(slow growth).***
- A **curled/wavy ring** means the ***tree was injured by something during that time period***. Perhaps it was hit by a car or struck by lightning.
- **Holes** in the tree cookie show that ***insects damaged the tree by boring into it at some point***.
- **Charcoal** on the tree cookie is a sign that ***a fire burned through the area where it was growing.***
- **Knots** on the tree cookie indicate ***presence of branches.***

Sometimes the information learned from tree rings provides insight into mysterious occurrences. For instance, from tree ring patterns, scientists found that there was a severe drought from 1587 to 1589 in Virginia, coinciding with the disappearance of people from what has been called the "Lost Colony". Scientists suggest that this severe drought caused crops to fail, leading to starvation and migration of the local population from the area. Tree rings from the area have become an important part of human history.

- Look at two tree cookies or tree cookie wedges supplied for you. Each tree cookie (or wedge) is marked with the species name of the tree from which it came, as well as the year that the tree fell.

- Find the smooth sides of each cookie and count the rings to determine what ages the trees were when they fell.

<u>Tips on counting tree rings:</u>

- You can use a paper clip to help you to keep your place as you count.
- Decide to count just the dark-colored rings or just the light-colored rings. Remember, a pair of dark and light rings represents the early wood and late wood laid down by the tree in a given year.
- Do not count the pith, and do not count the bark as a separate year.
- Now try to answer the following questions.
  1. What year did each tree start to grow?
  2. Identify rings that correspond to the same year on the respective trees. Does one tree species show greater growth (have wider rings) than the other in that or additional years that you compare their rates of growth in.
  3. At what time of year did each tree fall (early or late in the year)?
  4. Which years did the trees grow the most in? What do you think the environmental conditions were that year?
  5. When did the trees have slow growth? What could have happened those years to keep the trees from growing?
  6. Does either of the trees show wounds like holes or knots? What could cause these?
  7. What kind of growth did each tree have the year that you were born?
  8. What were the diameters of each of the trees the year that you were born?
  9. Think of an important year in your life, and then match that year on the tree cookies to see what happened in the lives of each of the trees in that year.

Discussion Question: The tree cookies in this box came from North American tree species. Many trees that grow in temperate climates (places where it is warm in the summer and cold in the winter) make paired annual tree rings like the ones you can see here. However, many trees that grow in tropical climates (places where it is warm all year) do *not* make annual rings. Why might this be?

Exercise 1b: Forest Measurements

Foresters regularly need to measure the trees they manage so that they know how well they are growing, what they might need to grow at a faster rate, and which ones should be harvested (cut for use or to make more room for other trees). The measurements the forester makes include such things as trunk diameter, tree height, crown size, and general tree health as indicated, for instance, by leaf color.

Exercise 1b.1: Measuring Individual Trees (*Grades 3-12*)

Let's talk about measuring width of a tree trunk. Since a tree's trunk is circular, foresters need to know a little about circles to do this. One can find out the width of a circle by measuring the length of a line that passes from one side of the circle through the center to the other side. We call this the circle's **diameter** (shown in Figure 2 below). However, it would be inaccurate, time-consuming and destructive to the tree to drill a hole through its trunk to take this measurement. Instead, foresters obtain an estimate of the tree's width by measuring the distance around the outside of the trunk referred to as its **circumference** (Fig.2).

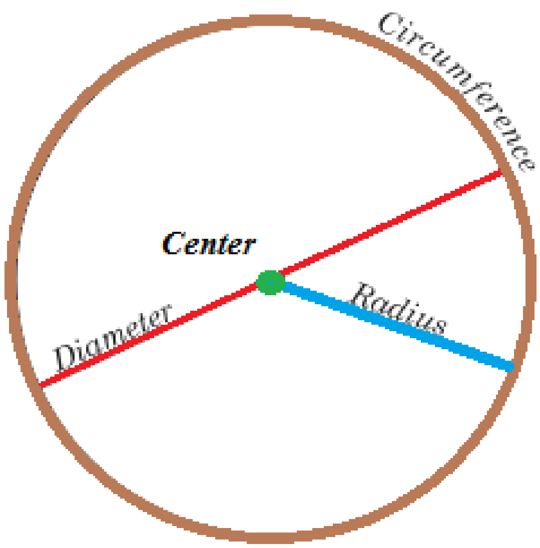


Figure 2. Parts of a circle

Exercise 1b.1.1: Measuring Circumference (*Grades 3-12*)

- Divide into teams of two-three students.
- Look around your classroom and find several circular objects of which you might measure the circumference using the tape measure your teacher provides to each team. Some examples could include jar lids, cups, circular manipulatives, a clock on the wall, etc.
- Each team should measure these items and record the values they obtain in a table that resembles the one shown below. You should measure your objects to the nearest *millimeter* (mm). It is important to be as careful as possible so that you get an accurate measurement. Measure to the nearest millimeter and record that length in the column labeled "*Circumference (C)*" in the table.

Item Measured	**Circumference in mm (C)**	**Diameter in mm (D)**

- Compare the circumference values between groups for each object the class chooses to measure. Did every group get the same circumference value?
- Discuss why variable results might have been obtained.

In order to account somewhat for inter-observer differences, scientists often have more than one person take the same measurement. They compute a **mean** or *average value* of these measurements. The mean value refers to central tendency. The formula for calculating the mean for the circumference of any object your teams might have measured is:

$$\boldsymbol{C_{mean} = \frac{\sum x}{n}}$$

In the previous equation, **Σ** indicates a sum, $\boldsymbol{x}$ = each of the measurements teams 1, 2, 3… have taken for that object, and $\boldsymbol{n}$ = the total number of measurements made (3teams measured the circumference of item $\boldsymbol{x}$ in this example).

If the three measurements of circumference of a clock were 19.5, 19.8 and 20.1cm respectively, $C_{mean} = (19.5 + 19.8 + 20.1)/3$ or $C_{mean} = 19.8$ cm for that clock.

- Compute the mean of your measurements for some of the circular objects in your room that more than one team has measured.

For all perfect circles, the relationship between circumference and diameter can be written as follows:

$$C = \pi D$$

The same equation may be written another way:

$$D = C/\pi$$

In these equations, C = Circumference, $\pi \approx 3.14$, and D = Diameter (See Figure 2 for the visual relationship between the circumference of a tree trunk and its diameter).

You may be familiar with a more common representation of the equation, $C=2\pi R$, where R is the **radius** of the circle (Fig. 2). The radius is the distance from the exact center of the circle to any edge, or half of the diameter ($D=2R$).

Q1. Using the above equations and a calculator, compute the missing circumference (C), diameter (D), or radius (R) in the examples below. Then check your work in the answer key under **Exercise 1a: *Measuring a tree trunk.***

a. $D = 2.5$, C = ?
b. $D = 6$, C = ?
c. $C = 9$, D = ?
d. $C = 0.32$, D = ?
e. $R = 3$, D = ?
f. $D = 8$, R = ?
g. $R = 5$, C = ?

To find the diameter of a tree trunk, foresters use a special kind of measuring tape called a DBH (or Diameter at Breast Height) tape. The DBH tape is specially calibrated to tell you the diameter of the tree trunk when placed around its circumference. Even though the DBH tape looks like a regular measuring tape, you wouldn't want to use it to measure things besides diameter, or your answers would come out all wrong! Also, foresters measure the trunk's diameter at "breast height" (based on the chest height of a 6 foot tall man), defined as 4.5 feet off the ground on the upslope side of the tree. The 4.5 foot height helps to reduce variation related to the swelling of a tree trunk at ground level and its thinning higher up associated with branching. If a slope is really steep, it may not be possible to measure circumference on the down slope side of a tree. Thus, by convention the upslope side is measured.

Even if you don't have a DBH tape you can still find the diameter using a regular measuring tape and the simple mathematical equation above. The measuring tape in your box is a regular measuring tape.

- Find several trees in your schoolyard and use the cloth tape measure included in the box to obtain the circumference of each tree trunk.
- Stretch the tape around the tree and read the number of inches where the two parts meet. This is the tree's circumference.
- Write this number down.
- To find each tree's trunk diameter use the equation presented above for D.

IMPORTANT NOTE: In measuring DBH, foresters use inches as their unit of measurement. While most scientists use the metric system (centimeters and meters), foresters use inches and feet (English units). Perhaps this is because they work so closely with the logging industry, which uses English units. However, knowing how to convert between these units is important, particularly for forest scientists that may need to communicate their results to forest scientists in other countries.

- Convert your measured tree diameters to metric units. (**HINT: 1 in = 2.54 cm**)
- Now answer the following questions:

Q2. Would it be practical to measure tree diameters in meters? (**HINT: 1 meter is equal to 100 cm**) Why or why not?

Q3. Would it be practical to measure tree heights in centimeters? Why or why not?

Alternate Indoor Activity:

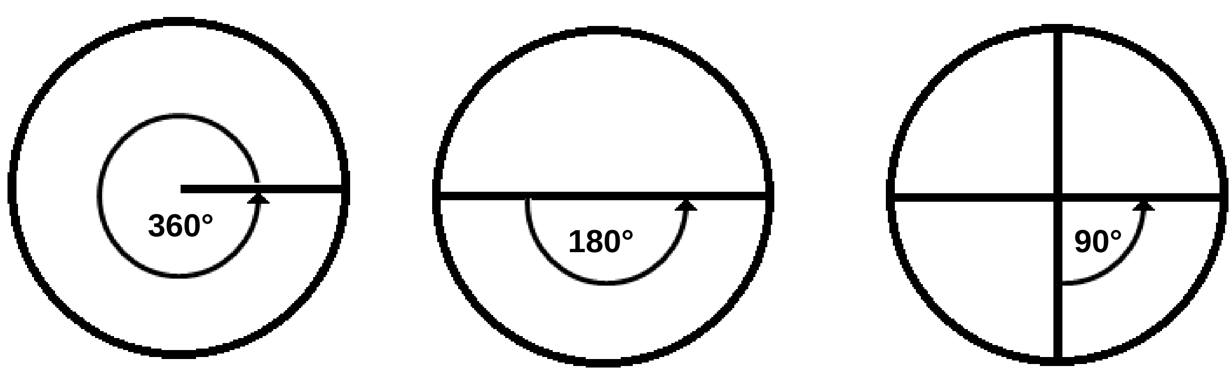
- Find the tree cookies (or tree cookie wedges) you examined in ***Exercise 1a2 & 1b1.1.*** Each "cookie" is a cross-section slice from a tree trunk. Non-circular tree cookie wedges are basically pieces of an entire tree cookie, much like a slice from a piece of pie.
    - Using a ruler, can you measure the tree's radius?

- Can you figure out the tree's diameter?
- How about its circumference?

- Using the information you obtained from the previous exercise, measure either the circumference or the diameter of one or both of the tree cookies provided in this unit. If you measure the tree cookie's diameter, use the equations above to calculate the circumference. If you measure the tree cookie's circumference, use the equations to calculate the diameter.

NOTE: In some copies of this unit, only half (or another portion) of a tree cookie may be provided, making measurement of the entire circumference of the tree cookie (and in some cases the entire diameter) impossible. However, you should still be able to measure the radius of the tree cookie (and estimate its diameter by multiplying this value by 2). You can estimate how large the circumference of the tree cookie would be if it were an entire cross section by figuring out what **proportion** of an entire circle that your tree cookie represents.
How can you determine what proportion of an entire circle your tree cookie (if not an entire cross section) represents?

One way to do this is to think about another property of circles. All perfect circles consist of 360 degrees. A half-circle, then, consists of 180 degrees. In other words, the straight edge of a half circle forms an angle of 180 degrees (a straight line), and a quarter circle (one fourth of a circle) has two straight edges that form a 90 degree angle. See the image below for an illustration:



By measuring the angle formed by the straight edges of your portion of a tree cookie (if you do not have an entire one), you can determine what **fraction** of a circle your tree cookie piece represents, and thus also what fraction of the circumference the curved edge of your tree cookie represents by using the equation on the following page.

$$\frac{(Angle\ formed\ by\ cut\ edges)^{\circ}}{360^{\circ}} = \frac{Distance\ around\ curved\ edge}{Circumference}$$

This relationship can be rearranged by cross multiplying:

$$(Angle\ formed\ by\ cut\ edges)^{\circ} \times Circumference = Distance\ around\ curved\ edge\ \times 360^{\circ}$$

You can then solve for an estimate of what the circumference of the entire tree cookie would be by dividing both sides by the number of degrees formed by the tree cookie portion's straight edges:

$$Estimated\ Circumference = \frac{Distance\ around\ curved\ edge \times 360^{\circ}}{(Angle\ formed\ by\ cut\ edges)^{\circ}}$$

- If you have a full tree cookie, take actual measurements of the diameter and circumference of it, and compare these values to your calculated value. If you only have a portion (wedge) of a tree cookie, calculate the circumference from your measured diameter (or radius), and compare this value to the "*Estimated Circumference*" value, as calculated above.

- Discuss the following questions with your classmates.
  - Were your actual measured values of diameter and/or circumference of your tree cookies close to your calculated values?
  - If there was a fairly substantial difference between the calculated and measured values, why do you think this might be the case?

Exercise 1b.1.2: Finding *pi* (π) (*Grades 3-12*)

There is a relationship between diameter and circumference that is very useful for us. In this exercise, you will examine several circular objects, and discover this relationship for yourself!

- Divide into teams of two-three students.
- Look around your classroom and find several circular objects of which you might measure the circumference using the tape measure your teacher provides to each team. Some examples could include jar lids, cups, circular manipulatives, a clock on the wall, etc.
- Each team should measure these items and record the values they obtain in a table that resembles the one shown on the following page.

Item Measured	Circumference in mm (C)	Diameter in mm (D)

- You should measure your objects to the nearest *millimeter* (mm). It is important to be as careful as possible so that you get an accurate measurement. Measure to the nearest millimeter and record that length in the column labeled "*Circumference (C)*" in the table.
- Revisit each item in your table that you measured the circumference of, and measure the distance across it from one edge to the other, being careful to position the tape over the center point of the *circular item*. This new distance represents the *diameter* (D) of the item (see Figure 2). Measure to the nearest millimeter, and record your number under the column labeled "***Diameter (D)***" in the row for that item.
- Now add some additional columns to your table as shown below:

Item Measured	Circumference in mm (C)	Diameter in mm (D)	C + D	C – D	C × D	C ÷ D

- Use the numbers you have recorded in the columns representing the circumference (C) and the diameter (D) of the items you measured to find the *sum* (+), *difference* (-), *product* (×), and *quotient* (÷) of those numbers. Record your answers in the appropriate columns.

- Compare the answers in each *column*. In what ways are they different? Are they similar in any way? Discuss these differences and similarities with your classmates.
- Your teacher will collect all the measurement data for the class and list each of the four calculation column findings for the collection of items. Do you see any patterns in the list of sums? What about the list of differences? Do you notice any patterns in products list, or in the quotients list? Describe and discuss any patterns you discover.

If your data have been collected properly, you should notice that the list of quotients of the circumferences divided by the diameters (C ÷ D) of the items produces a consistent outcome. Every one of the quotients will have resulted in a number very close to 3.14, which is the number used to represent *pi* or the Greek letter **π**. The quotient of the circumference of every circle divided by its diameter results in *pi* (π), or the number 3.1415926535897932... Since this value is a non-repeating, non-terminating decimal number (or ***irrational*** number), we often just use **π** ≈ **3.14** (≈ means *approximately*) when we need to use the value of *pi* in our work or activities. This relationship is true for every circle no matter if it is very small or very large.

By completing this activity, you have *discovered* **π**!

Exercise 1b.2: Measuring and Comparing Forests (*Grades 5-12*)

Just as trees can come in many different shapes and sizes, forests can also look very different. Look at the pictures of the two forests on the following page (Figures 3 & 4). How are they different? If you were a forester in charge of one of the forests depicted in the two figures, how would you measure how much wood is in your forest? How would you describe your forest to another forester using numbers? In this exercise, you will learn how foresters describe **stands** (groups of trees).

One of the measures foresters use to distinguish between a stand with many small trees close together and one that is more open, with fewer trees is referred to as **stand density**. **Stand density** is *the number of trees per unit area*. This is an important measure because when growing trees that are closely packed, they compete more intensely with one another for sun, water, and air, and therefore grow more slowly. They also tend to have thinner, more spindly stems, which are not as valuable. If a stand is too dense, a forester might choose to remove some of the smaller trees.

Density tells us how much of a particular thing exists in a specific space, or a comparison of the number of things within the space to the size of the space. For example, if you walk along a city block, you are not likely to see a lot of trees standing close together. However, if you drive through a National Forest, you are going to see many trees standing close together. The *density* of the trees in the forest is much greater than the *density* of the trees within a city block.
Density is expressed as a ratio. In the example above, we could write a ratio with the number of trees we find in the city block as the numerator and the area of the city block (acres) as the denominator (# of trees/#of acres). The ratio is then simplified so it results in a denominator of 1. We then have a unit rate to express the density of the trees in one unit (in this case the unit is *acre*) of space (# of trees/acre). Review the example below:

Example 1: 8 trees were found in a 2 acre city block. What is the stand density of that city block?

$$\frac{8\ trees}{2\ acres} = \frac{?\ trees}{1\ acre} \rightarrow 4\ trees\ per\ acre$$

The tree density (*stand density*) for this city block is 4 trees per acre. In other words, since there were 8 trees in 2 acres, we could expect to count 4 trees on one acre.

Example 2: 120 trees were found on a 4 acre parcel of vacant land. What is the stand density on this parcel of land?

$$\frac{120\ trees}{4\ acres} = \frac{?\ trees}{1\ acre} \rightarrow 30\ trees\ per\ acre$$

The tree density (*stand density*) for this land is 30 trees per acre. In other words, since there were 120 trees in 4 acres, we could probably expect to count 30 trees on one acre.

The stand density of the city block is far less than the stand density of the parcel of vacant land. The stand density of a National Forest would be even greater than those in the preceding examples. Just remember, stand density can be calculated as below:

$$\textbf{Stand Density} = \frac{\textbf{number of trees}}{\textbf{area of stand}}$$

Figure 3. Chequamegon National Forest, WI

Figure 4. Mendocino Pygmy Forest, Van Damme State Park, CA (*Photos courtesy of Jason Sturner*)

Basal areas are also used as a descriptor of stand structure. The **basal area** of a *single tree* is the cross-sectional area of its trunk. This is determined at breast height or, in other words, if you stand next to the tree, you will determine the basal area of the tree at a height that is adjacent to your chest. The diameter of the tree at breast height (DBH or 4.5feet) is used to find the basal area. If you lay your tree cookie flat on your desk and imagine the other half of the tree cookie is still intact, the *basal area* is the flat, cut surface of the tree where you see the rings.

How do we find the basal area of a tree? Since the cross-section of a tree is a circle, we use the formula for finding the area of a circle.

$$A = \pi R^2$$

Since we are using tree trunk diameter for our calculations, you will need to divide the DBH by two to find the radius (R) for finding the basal area of a single tree:

$$\textbf{Basal Area of Tree} = \pi R^2 = \pi \left(\frac{DBH}{2}\right)^2$$

The **basal area** of *a stand of trees* is the total or sum of the basal areas of *all* the trees in that stand. In other words, this is a measure of the amount of area in a stand of a particular area that is taken up by the tree trunks. Imagine if you were to ride over a forest in an airplane and could look *straight* down so that each tree looks like a circle on the ground, the basal area of that stand of trees is the total area of all those circles laying on the ground in that stand. This is useful because if two stands of the same area have the same number of trees, but one stand has a higher basal area, that means the trees in the stand with the higher basal area have thicker trunks and are probably more valuable timber trees.

Total basal area of a stand of trees is the sum of the basal areas of all the trees in the stand:

$$\boldsymbol{Basal\ Area\ of\ Stand\ with\ n\ trees} \\ = Basal\ area\ of\ tree\ 1 + Basal\ area\ of\ tree\ 2 + \cdots + Basal\ area\ of\ tree\ n$$

On the following pages, you will find DBH and height measurements for all trees in two hypothetical forest stands.

Comparing Stand A to Stand B

This is how we calculate **stand density** for Stand A:

- Count the number of trees in the stand. In our example, there are 12 trees in stand A.
- Find the area of the stand. Foresters usually use the **acre** as a unit of measurement of area for very large areas (see the information on large English and metric units of area often used in forestry below). In our example, the total area of stand A is 0.025 acres.
- Now simply divide the number of trees by the area of the stand:

$$\boldsymbol{Stand\ Density\ = \frac{12\ trees}{0.025\ acres} = 480\ trees/acre}$$

<u>Large English & Metric Units of Area & Useful Conversions</u>

English unit: 1 acre = 43,560 ft^2

Metric unit: 1 hectare = 10,000 m^2

English to metric conversion: 1 foot = 0.3048 m

Metric to English conversion: 1 meter = 3.28 feet

- Answer the following, and check your answers in the back of this book:

Q4. How many acres are in a hectare?

Q5. A particular forest stand has an area of 2.35 hectares. Convert this area to acres, ft^2, and m^2.

Q6. How long, in feet, would the sides of a perfectly square 1 acre plot of land be?

Q7. How long, in meters, would the sides of a perfectly square 1 hectare plot of land be?

Measurements from Two Forest Stands (Area of each stand = 0.025 acres)

Stand A

DBH (in)	Height (ft)	Basal Area (in^2)	Basal Area (ft^2)	Tree Volume (ft^3)
45	35	**See following pages**	**See following pages**	**See following pages**
27	30	573	3.98	29.85
37	37	1075	7.47	69.10
21	21	346	2.40	12.60
14	14	154	1.07	3.75
9	9	64	0.44	0.99
26	26	531	3.69	23.99
50	50	1963	13.63	170.38
36	36	1018	7.07	63.63
27	27	573	3.98	26.87
26	26	531	3.69	23.99
39	39	1195	8.30	80.93

Stand B

DBH (in)	Height (ft)	Basal Area (in^2)	Basal Area (ft^2)	Tree Volume (ft^3)
5	8			
11	16			
4	7			
8	14			
7	20			
9	14			
6	11			
4	8			
8	22			
6	12			
2	10			

Stand B, continued

DBH (in)	Height (ft)	Basal Area (in^2)	Basal Area (ft^2)	Tree Volume (ft^3)
4	14			
6	20			
3	15			
10	14			
5	16			
6	18			
1	10			
7	14			
9	19			
9	20			
6	7			
15	34			

Q8. What is the stand density for Stand B?

Now let's calculate the missing **basal area** of the first tree in stand A in in^2 (rounded to the nearest square inch):

- The first tree in stand A has a DBH of 45 inches.
- $Basal\ area\ of\ tree = \pi\left(\frac{45\ inches}{2}\right)^2$

Answer: 1590 in^2

Now let's calculate the **basal area of the stand** for stand A in ft^2:

- We'll need to add up the basal areas of every tree in stand A.
- Basal area of stand = 1590 in^2 + 573 in^2 + 1075 in^2 + 346 in^2 + 154 in^2 + 64 in^2 + 531 in^2 + 1963 in^2 + 1018 in^2 + 573 in^2 + 531 in^2 + 1195 in^2
- Basal area of stand A = 9613 in^2
- Let's convert the units to ft^2, since square feet are better to use for larger areas.
- Since there are 12 inches in 1 foot, there are 12^2 in^2 (144) in one ft^2. To convert from in^2 to ft^2, divide by 144. For the purposes of this exercise, express your answers rounded to two decimal places.

- Basal area of stand A $= 9613 \text{ in}^2 \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 66.76 \text{ ft}^2$

Answer: 66.76 ft^2

How does a forester know when it's time to harvest? When a forest stand is managed for timber, the goal is to harvest as much usable wood as possible. From just two measurements, the DBH and height, a forester can calculate the amount of usable wood in a tree. By taking into account the product of area and height, measurements in three dimensions, the forester is calculating **wood volume**.

Volume refers to the size of solid objects, or the amount of space a solid object occupies. Volume is expressed in cubic units. For instance, if a cereal box measures 9 inches × 3 inches × 12 inches (called a *rectangular prism* because all faces are rectangles), we can find the volume of a rectangular prism by multiplying the length (***l***) × width (***w***) × height (***h***):

Volume of rectangular prism = ***l*** × ***w*** × ***h***

For the cereal box example, we could then calculate its volume as follows:

$$\mathbf{V = 9 \times 3 \times 12 = 324}\ \boldsymbol{in^3}$$

The cereal box would have a volume of 324 *cubic inches*. Volume is expressed in cubic units because, if you have 324 cubes with edges 1-inch in length, you could fill the cereal box with all those cubes and there would be no gaps or overlaps. The box would contain 324 cubic inches of cereal if completely filled.

Volume is calculated using **formulas** that have been developed for specific shapes. A **formula** is a rule or mathematical statement that indicates general relationships. For instance, the above formula for finding volume of a rectangular prism uses the length, width, and height of the prism to indicate the relationship between those dimensions and how much the box will hold.

Refer to Figure 5 below, which shows some of the standard ways (**formulas**) to calculate volume of objects of different shapes, as well as how foresters calculate tree volume. If the tree were a perfect cylinder, the volume of the trunk would be the area of its circular base × height.

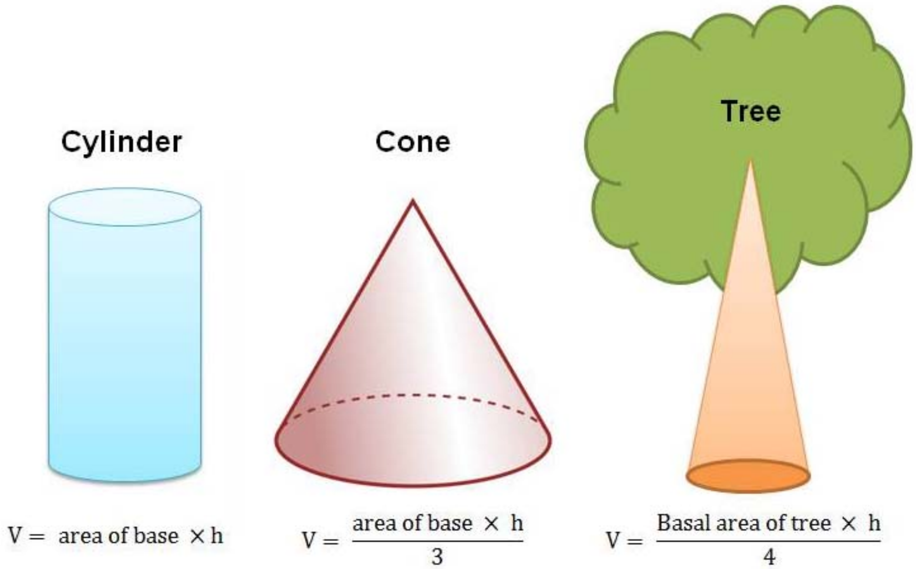


Figure 5. Volume equations for a cylinder, a cone, and for wood from a tree trunk.

However, tree trunks taper – they are thick at the base and very slender at the tip, more like a *cone*. We find the volume of a cone using the formula:

$$Volume = \frac{(area\ of\ circular\ base) \times height}{3}$$

But trees are not quite conical either, they are less perfect. Also, part of the tree trunk is the bark, which won't be used. To correct for both of these factors, foresters use the formula:

$$\text{Wood Volume} = \frac{\text{Basal area of tree } \times \text{ Height}}{4}$$

For this calculation to be done correctly, all of the units must agree (no mixing of inches and feet!). So, to find wood volume in ft^3, the basal area must be in ft^2 and the height must be in ft. Express your answers for volume rounded to two decimal places. Let's calculate the wood volume of the first tree in stand A.

- We'll need to start by converting its basal area (1590 in^2) into ft^2 as outlined on the following page.
- $\text{Basal area of tree} = 1590\ \text{in}^2 \times \frac{1\ \text{ft}^2}{144\ \text{in}^2} = 11.04\ \text{ft}^2$

- The height of this tree is given as 35 ft, therefore, we can calculate the volume as follows:

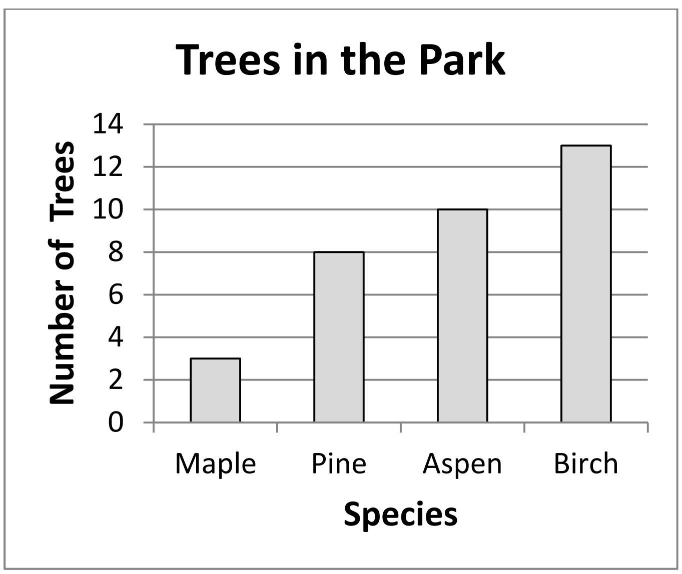
- $\text{Wood Volume} = \frac{\text{Basal area of tree} \times \text{Height}}{4} = \frac{11.04\ \text{ft}^2 \times 35\ \text{ft}}{4}$

Answer: 96.60 ft^3

Q9. Complete the data table for stand B, calculating basal area of each tree in in^2 and ft^2, as well as the volume of each tree.

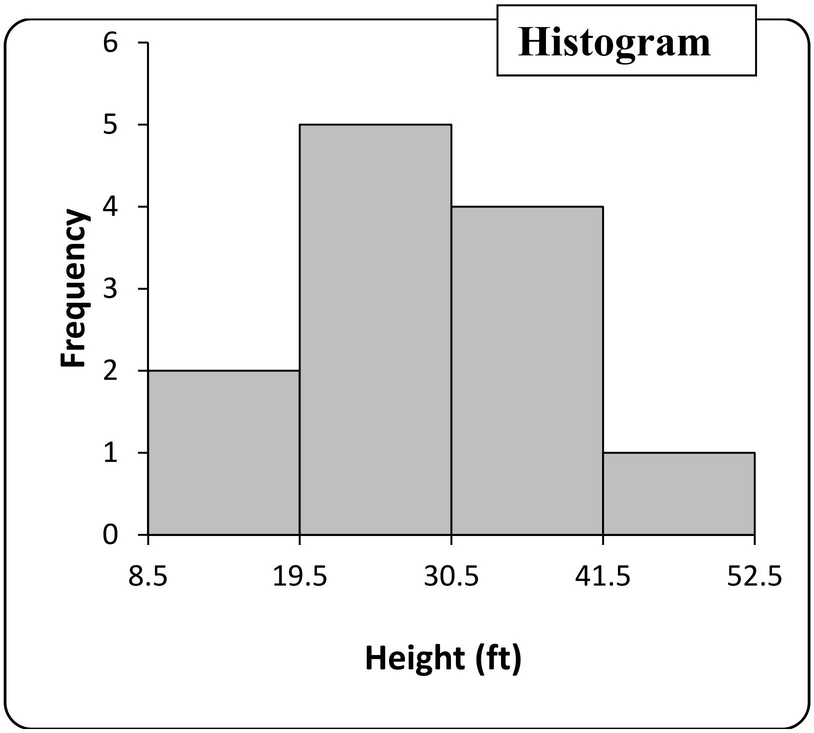
Exercise 1b.3: Visualizing Forests: Using Histograms to see Data Distributions (*Grades 5-12*)

There are many great ways to display data so that one may draw meaning and look for patterns. The trick is using the best one for the situation. You may be familiar with using bar charts to graph data. See the example below. A bar chart works well when your data is **categorical**, for example when each data point belongs to a discrete class (like tree species).



Tree Species	**Number of Trees**
Maple	3
Pine	8
Aspen	10
Birch	13

But what if the data are instead **quantitative**, meaning that you have taken measurements on them? The data from Stand A and Stand B shown on pages 18 and 19 consist of numbers because a forester went out into these forests and collected measurements from each tree. Data like this can be shown using a **histogram**, which displays information from a **frequency table**. See the histogram and frequency table for Stand A on the following page:



Frequency Table

Height in Feet	Number of Trees
8.5-19.5	2
19.5-30.5	5
30.5-41.5	4
41.5-52.5	1

Unlike a bar graph, notice that both the x-axis (horizontal) and y-axis (vertical) are represented using numerical scales (numbers) in the case of a histogram. Also, notice there are no gaps between the bars in the histogram. In this example, the x-axis represents the height of the trees, and the y-axis represents the number of data points (number of trees) falling within a particular height range.

How was the frequency table made? Four classes were used for the data, though one might have chosen to have more or fewer classes. Once you have decided how many classes you would like, you can use the highest data point and the lowest data point to calculate the width of each class. In Stand A the tallest tree was 52 feet, and the shortest was 9 feet.

$$\textit{Approximate width of class} = \frac{\textit{Highest Data} - \textit{Lowest Data}}{\textit{Desired Number of Classes}} = \frac{52 - 9}{4} = 10.75$$

To make our class width simpler, we prefer to use an integer, so round up to get the width of each class: 11

Our first class starts at 9, the second at 20, the third at 31 and the Fourth at 42. Since our collected data were positive integers, and we do not want a data point to fall on the boundary between classes, we used numbers to mark the boundaries between classes with decimal units 0.5. Thus the boundaries here are:

8.5, 19.5, 30.5, 41.5, 52.5

The number of data points in each class (the frequency) is on the vertical axis. See that there are 5 points in the second class. We can notice that the data are mostly in the second and third classes.

> **NOTE:** When constructing histograms, it is perfectly fine to have boundaries between classes that fall at nice round numbers. Just remember, when defining classes, though, we don't want any data points to fall exactly on the boundaries between classes. Also, it is okay if there are classes that are empty, as a particular class may not have any data points that fall within it!

Q10. Now make a frequency table and a histogram with four classes for the height data in stand B. Check the answer section at the end of the book to see if your histogram looks correct.

- Now compare your histogram constructed from the height data for Stand B to the previous one using the height data from Stand A, and answer the following questions:

Q11. What general comparison can you make about the two stands in terms of tree height?

Q12. Were the two histograms easy to compare? Why or why not?

Q13. Can you think of a way to make the two histograms easier to compare? If so, make new histograms of the height data for each stand.

Q14. Make a frequency table and a histogram with four classes for the DBH data in stand B.

- Imagine you went out to a forest and counted the different species of birds that you saw that morning. You counted and recorded the number of American Robins, American Goldfinches, Golden-rumped Warblers and Palm Warblers.
- Now answer the following questions:

Q15. Are the data you collected categorical or quantitative?

Q16. To visualize your data, would you want to make a bar chart or a histogram?

- Imagine you went out to a forest with a special instrument that measures the rate at which a leaf on a tree is photosynthesizing. You go to all of the trees and make measurements on random leaves. In the end, you have measurements ranging in value.
- Now answer the following questions:

Q17. Are the data you collected categorical or quantitative?

Q18. To visualize your data, would you want to make a bar chart or a histogram?

Exercise 1b.4: From Trees to Boards, From Boards to a House (*Grades 5-12*)

When a logging company is considering buying a forest stand, they prefer to use a measure of wood volume called **board feet** (Figure 6). One board foot is a piece of wood one foot long, one foot wide, and one inch thick. More than one board foot becomes board *feet*. Using board feet calculations, one can determine how many objects you can make that may be of use to you out of the wood you harvest.

Figure 6. Diagram of a board foot, a unit of wood volume.

A ranch-style house with three bedrooms (about 1000 square feet) requires about 3000 board feet to build. Let's calculate how many trees from forest A (on average) it might take to build this house. There are actually a few different ways to do this, but one way is outlined on the following page.

- First we'll add together all of the wood volumes in stand A to get the total wood volume of the stand.
- Total wood volume for stand A = 97 ft^3 + 30 ft^3 + 69 ft^3 + 13 ft^3 + 4 ft^3 + 1 ft^3 + 24 ft^3 + 170 ft^3 + 64 ft^3 + 27 ft^3 + 24 ft^3 + 81 ft^3 = 603 ft^3
- Now let's find the average wood volume for a tree in stand A.

$$\frac{\text{total wood volume stand A}}{\text{total number of trees}} = \frac{603 \text{ ft}^3}{12 \text{ trees}} = 50.3 \text{ ft}^3 \text{ per tree}$$

- Now convert the average wood volume in stand A to board feet: imagine how twelve of the boards in shown in Fig 6 stacked on top of each other would create a cube 1 foot by 1 foot by 1 foot. Therefore there are 12 board feet in a cubic foot. **Remember: 1 board foot is 1 foot × 1 foot × 1 inch.**

$$\frac{50.3\ ft^3}{1\ tree} \times \frac{12 \text{ board feet}}{1 \text{ ft}^3} = 603.6 \text{ board feet per tree}$$

- If it takes 3000 board feet to build a house, then:

$$\frac{3000\ board\ feet}{1\ house} \times \frac{1\ tree}{603.6\ board\ feet} = 5\ trees$$

Answer: It would take 5 trees from stand A to build one small house

Q19. Approximately how many trees, on average, from stand B it would take to build the same house?

Exercise 1b.5: Foresters for a Day (*Open-ended Exploration for Grades 3-12*)

- Identify one or more plots of forest habitat near your school or your home.
- Naturally, if the forest plot is rather large, you will not realistically be able to measure all the trees in the plot, unless you do this as a long-term project. Because of this, you could divide your class into teams of 3-4 students and each team would sample a plot (scientists call these plots ***quadrats***) of trees in the forest. You can use the ***random walk method*** to locate each plot.

To do so, you will use the random numbers table provided below.

First, one of the team members should close his/her eyes and place a finger on some point on the random numbers table. Open them and record the first five numbers that fall to the right of your finger on that line. Let's say, for example, the number string is 8 2 4 7 1.

- Starting at the edge of the forest, you will walk forward into it the number of paces (large steps) indicated by the first number (8 in this case). If the next number is an odd number (1,3,5,7, or 9), you will turn to the left for your next steps. If the number is even (2,4,6, or 8), you will turn to the right. Since our next number in the string is 2 in our example, you would turn to your right. The third number indicates how many paces you would take in this direction, 4 in our example.
- Repeat the process for the remaining two numbers: in our example a turn to the left and 1 pace. This is where team 1 will establish the plot they will sample.
- Team 2 will continue from this point using their unique set of numbers from the table below to establish their quadrat location and so on.

If the forest is quite large, we recommend that you add 10 paces to the prescribed distances. Thus for team 1 in our example above, the initial move into the woods would be 18 paces, right turn 14 paces, left turn 10 paces.

8 0 9 4	2 5 2 5	8 2 4 7	1 3 4 7	7 4 3 3	3 6 2 0
3 5 6 3	2 1 9 8	8 2 1 1	9 0 4 5	2 6 1 8	2 7 5 1
1 3 3 0	6 3 3 1	3 7 5 3	9 6 9 3	8 7 3 8	6 8 1 5
3 5 6 5	0 0 1 6	2 2 4 3	6 4 3 2	4 7 9 6	6 0 9 5
7 8 5 0	5 9 2 5	5 5 8 8	7 3 1 1	2 1 9 2	4 5 4 5
4 4 9 0	5 4 1 7	9 7 2 7	6 1 5 3	5 9 0 1	4 8 7 8
6 5 4 5	9 1 0 4	9 3 1 8	8 8 1 9	7 5 3 7	2 7 8 5
3 6 2 6	5 9 9 5	1 2 1 5	9 7 5 3	9 2 2 3	5 6 5 8
4 8 6 5	4 8 2 0	7 5 5 4	0 6 1 2	9 6 8 3	4 2 5 1
6 4 9 8	7 5 1 9	0 4 7 4	7 8 1 8	6 8 3 2	9 6 8 3
6 7 2 2	9 8 6 9	9 3 6 1	7 8 7 5	4 8 8 3	1 3 1 5
9 7 4 8	5 9 3 2	5 1 1 5	2 7 2 1	0 0 3 3	9 3 0 3
5 6 4 1	1 4 1 7	1 4 1 9	7 4 3 4	8 1 6 5	7 3 6 8
7 4 4 4	9 2 0 0	8 8 4 0	5 8 8 2	4 3 9 8	3 9 0 4
8 2 7 9	3 0 1 9	4 6 7 2	3 7 4 3	3 9 7 9	4 6 8 9
0 1 6 1	7 6 1 7	1 0 2 4	2 3 8 7	2 8 9 1	6 6 7 7
7 3 8 8	9 7 5 9	7 5 5 5	6 6 2 4	9 9 7 7	2 0 0 8
7 8 3 0	4 7 1 4	3 6 9 5	2 9 1 9	1 8 0 4	4 0 4 4
9 8 8 7	4 2 1 6	6 5 2 6	4 5 3 5	8 4 3 0	5 2 7 0
1 2 6 1	2 5 1 6	8 5 6 9	2 3 1 0	3 9 3 9	8 7 0 3

- Once each team has established their plot's location, use a measuring tape to determine the plot's boundary, which you can mark with pieces of cloth, paper plates etc.
- Scientists prefer that sample plots be circular for measuring trees. Also the plots should be quite large, say have a radius of at least 5 meters. Have a team member stand in the center of the plot and another student stretch out a string that is 5 meters long (or use a meter tape) to locate points along the circle's boundary to place markers.
- Next take some measurements (such as DBH and height, which can be measured using the provided clinometer and the information on the next page) of all of the trees in your sample plot. You should place a mark (e.g. a piece of tape or pin a piece of paper) on each tree sampled, so that you do not measure the same tree more than once.
- You may also use a field guide to identify the species of trees in your plot, so that the measurements might be compared among the different tree types.
- **Be sure to remove all plot and tree markers when you are finished and carry this trash out of the woods.**
- Back in your classroom, determine the basal stand area for your plot.
- Use the gathered data from your forest plot to determine how many trees it would take to build a 1000 square foot house.
- Compare the results among teams for class discussion, just as we have done for stand A and B above. If foresters cannot measure all trees in a forest, they always sample a number of quadrats to characterize it. This is because the number and sizes of trees may vary at different locations within the forest.
- Discuss potential factors that might create this variation in a forest.

Using a clinometer (and some trigonometry) to calculate the height of a tree

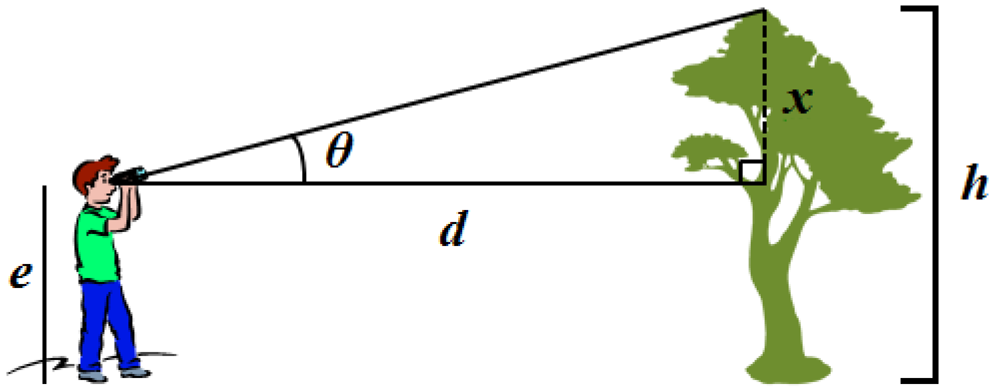


Figure 7a. Determining a tree's height with trigonometry.
To easily find the height of a tree when standing on ground level with its base, one can use a tool called a **clinometer.** This tool applies **trigonometry**, the branch of mathematics dealing with the relationships among the sides and angles of triangles. In the figure above, the unknown height of a tree is of interest. Also note that several quantities are illustrated. The quantity e represents the height of the observer's eye, which can easily be measured. The quantity d, which is the distance of the observer's eye from the tree, is also easily measurable. The angle, θ, from the observer's eye to the top of the tree, is measured by using a clinometer. From these values, the quantity x, representing the height of the tree that is *above* the observer's eye level, is calculated from a simple trigonometric relationship. Notice that since the observer is standing on level ground with the base of the tree, the angle formed by d and x is a right angle. Because of this, the relationship between d, x and θ is known from a trigonometric ratio known as the **tangent**. In a right triangle, the tangent is defined as *the value resulting from the division of the length of the side of a right triangle opposite the angle is divided by the length of the side of the triangle adjacent to the angle* (not the hypotenuse, which is the side opposite the right angle).

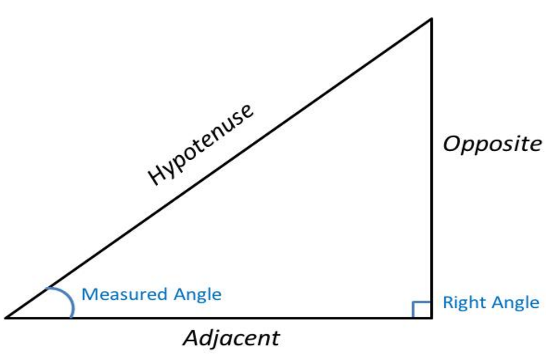


Figure 7b. Sides of a triangle for the measured angle as defined by right angle trigonometry.

Using the variables from the Figure **7a** above, this means that

$$\tan\boldsymbol{\theta} = \frac{\boldsymbol{x}}{\boldsymbol{d}}$$

From this equation, solve for the unknown ***x*** by multiplying both sides of the equation by ***d***:

$$\boldsymbol{x} = \boldsymbol{d}\tan\boldsymbol{\theta}$$

Thus by simply calculating the tangent of the observed angle, and multiplying the result by the distance between the observer's eye and the tree, one can find the value ***x***. However, keep in mind that the ***total*** height of the tree, ***h***, is the quantity of interest. Remember, ***x*** is the height of the tree ***above*** the observer's eye level, so the total height of the tree is the value of ***x*** added to the height of the observer's eye above ground level ***e***:

$$\boldsymbol{h} = \boldsymbol{e} + \boldsymbol{x}$$
$$\boldsymbol{h} = \boldsymbol{e} + \boldsymbol{d}\tan\boldsymbol{\theta}$$

It is important to remember when doing these calculations that tangents (and other trigonometric functions) represent simple ratios. Therefore, they have ***no units***. Remember, the tangent of an angle is calculated as follows:

$$\tan\theta = \frac{\boldsymbol{x}}{\boldsymbol{d}}$$

Because the numerator ***x*** and the denominator ***d*** **MUST** be expressed in the same length units, when calculated as ***x***/***d***, the units cancel out!

Before using the clinometer, try out these practice questions to make sure you're ready to use it. Check your answers in the back of the book.

Q1. Using a calculator, calculate tan (45º)

Q2. Using a calculator, calculate tan (10º)

Q3. If you are 10 feet from a tree, and using a clinometer you find the angle to the top of the tree is 31º, what else do you need to know to calculate the height of the tree? Explain how you would find this value.

Q4. How can you measure the distance from the tree to your eye most accurately? Explain.

Q5. If your measured **θ** angle is 60º, your distance from the tree 10 ft, and ***e*** is 3.8 feet, what is the height ***h*** of the tree?

Using the clinometer

In this unit, you have been provided with a simple clinometer. Foresters often use much more sophisticated clinometers with lenses and digital displays, but the one provided performs the exact same function: helping estimate tree height. There are several parts of the clinometer that you should note, which will help you understand the instructions on how to use it.

- First, look at both ends of the upper long edge of the clinometer. Note that this upper edge forms a tube through which you can sight the top of a tree whose height you wish to determine.
- Next, note the angular scale (which is in degrees) on both sides of the clinometer. You will also notice that there is a hole, through which a string, with weights on either end, passes.
- Finally, look at the lower rear corner of the clinometer, and you will notice a small Velcro strip. Examine the figure below, which also identifies these parts.

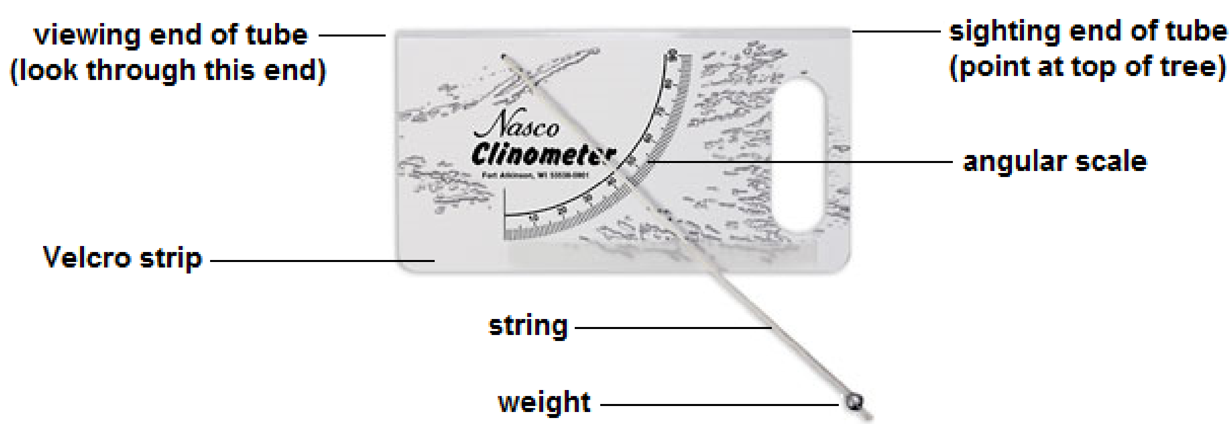


Figure 8. Parts of the clinometer provided with this unit.

Using the provided clinometer to determine the height of a tree is fairly simple, using the following steps:

- Find an observation point in an area that is on level ground even with the base of the tree. Conducting these measurements on a slope uphill or downhill of the tree will result in inaccurate calculation of the tree's height! **NOTE: You may wish to locate yourself less than 10m away from the tree for easier measurement.**
- Pull the string through the hole until the entire length of the string is on one side of the clinometer. You should pull the string to the side that will be away from your body (to the right side if you will be viewing through your right eye, or to the left side if you will be viewing through your left eye).
- Hold the string out and away from the clinometer to make sure it is not caught in the Velcro.
- Close one eye, and using the other eye, look through the viewing end of the tube at the clinometer's top edge, and sight the top of the tree of interest through the viewing tube.
- While keeping the top of the tree in sight through the viewing tube, release the string. While you still have the top of the tree in sight, and without pulling the string in any direction, press the string firmly into the Velcro strip to hold it in place. **NOTE: Make sure to mark your current observation position so you can accurately measure the distance between this spot and the tree. You may also wish to have a friend observe the angular position marked by the string when it is released, before you press it against the Velcro, just in case you accidentally move the string during this step!**
- Now look at the angular scale on the clinometer, and the position of the string. The place on the angular scale that the string intersects is the measurement of the angle θ (in degrees) between your eye and the top of the tree. Record this value.
- Using the provided 10m measuring tape, measure the distance d, along the ground, between your viewing position and the tree. Record this value, as well.

Now you can use the trigonometric relationship you learned earlier to determine the height h of the tree. Remember, your angle measurement allows you to calculate, based on the right triangle formed by your eye, the top of the tree, and the distance from your eye to the tree, the height of the portion of the tree *above your eye* level, x:

$$\tan\theta = \frac{x}{d} \quad \Rightarrow \quad x = d\tan\theta$$

- Using a calculator, find the tangent of the angle, θ, obtained from your measurement of the angle used to sight the top of the tree.
- Multiply $\tan\theta$ by the horizontal distance, d, between your position and the tree.
- The result, x, is the height of the portion of the tree above your eye level, in the same units you used to measure d.
- Now all you need to know to calculate the total height of the tree, h, is the height of your eye level, e. Measure this distance, making sure to use the same units you used for measuring the distance from your position to the tree.
- Remember, so far, you have only calculated the height of the *portion of the tree above your eye level* x. To get the total height of the tree, simply add the height of your eye level e to the calculated value of x:

$$h = e + x$$
$$h = e + d\tan\theta$$

Exercise 1c: Leaves and Seed Cases

Leaves

Everyone knows that trees produce leaves. In this part of the world, leaves change colors and fall to the ground each fall. Leaves are important to tree survival and growth, because they contain chloroplasts (**klor-oh-plasts**), which act like little factories to make the food the tree needs to grow and reproduce. Water and nutrients move from the roots through the xylem to the leaves. Meanwhile, the leaves collect carbon dioxide from the air and capture energy from the sun. Through a process called photosynthesis (**foto-sin-theh-sis**), chloroplasts convert the light energy, water, and carbon dioxide into sugars that can be utilized by the tree. These sugars are transported from the leaves through the phloem to the other parts of the tree.

Seeds and Seed Cases

A tree's seeds are important because they make new trees. The seed can travel by water, wind, or in an animal's fur or stomach to a new location. If the environment there is ideal, a new tree will grow. Trees produce special structures that surround their seeds to help with dispersal, so what you see is not the seed exactly since it is hidden inside (and there may be many hidden in there!). We call these fruits, cones, or pods, and they come in many varieties unique to each kind of tree. For this exercise we'll use a very general term for all of these: we'll call them **seed cases**.

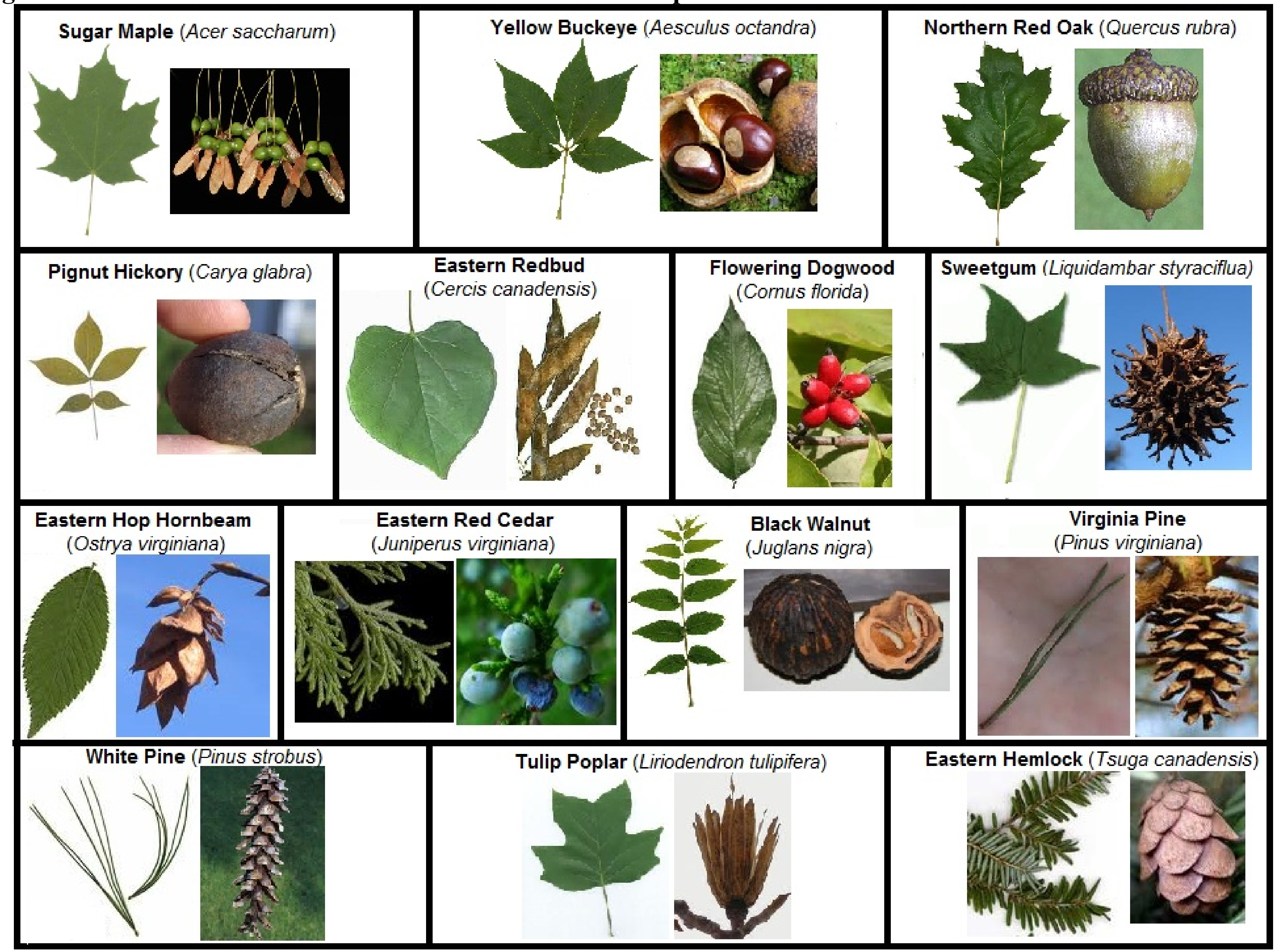
Both leaves and seed cases have special adaptations that help trees survive in the environments in which they live. For example, a tree species that typically lives in dry areas must have ways to conserve water, or it will not survive. For example, some trees have waxy leaves preventing some loss of water through evaporation. Also, seed cases may have also developed characteristics that allow them to be carried or dispersed by wind. On the other hand, a tree species that commonly lives near water often develops seed cases that can float, helping them disperse by water.

Exercise 1c.1: Leaf and Seed Case Match (*Grades K-5*)

In this and the following exercises, you are provided with samples of leaves and seed cases from 14 tree species. All of these specimens come from trees that are found in Tennessee. Perhaps you can find them in your own backyard or schoolyard. Follow the instructions on the next page to begin this exercise.

- Examine each of the provided leaves.
- Study their shapes and forms, and see if you can match each leaf with the pictures of leaves from the tree species in Figure 7 on the following page.
- Once you have figured out the tree species of each leaf, try to find the seed or seed case that goes with each leaf. Look at the picture of the seed next to each leaf to help you with this task.
- Since size is difficult to assess from the pictures, be sure to pay attention to the shape and texture of the seeds.
- Check your answers in the answer section at the end of this book.

Figure 7. Leaves & seed cases from various Tennessee tree species.



Exercise 1c.2: Sorting Seed Cases (*Grades 3-12*)

You have probably noticed that some of the seed case samples look similar to each other. Let's try to sort the seeds into categories so that we can learn a little about how each tree's type of seed case gives it special advantages. Below is a list of several types of seed cases seen in various plants (including trees). With the exception of the category "cone", all of the others are considered "fruits".

Cone – Many seeds are contained in these woody structures. When a cone dries, it opens up and releases the seeds. If it becomes moist again, it will close, even after the seeds are released. Some trees (not any of these) actually need the high heat of fire for their cones to open.

Samara – A fruit with "wings" that allows wind to carry seeds far from the parent tree.

Nut – A hard-shelled dry fruit containing the seed inside. It doesn't open to release the seed. These seeds may be round, so they can roll away from the parent tree. They may float, permitting them to migrate away from the parent tree by water. They may also be tasty and nutritious. This last characteristic attracts animals to gather and bury these nuts for later consumption. Because animals may forget where they bury some of the nuts, they inadvertently plant seeds for tree species such as oaks that produce acorns. A substance called tannin that is in acorns needs to break down over time before the acorn can be consumed. This substance favors the caching/burying of acorns for later use, a great tree strategy to ensure the production of new oak trees.

Capsule – Capsules are dry fruits that split open at maturity to release seeds.

Legume – A legume is a fruit in which the seeds are contained in a pod, like a bean. The pod can split open along its seams to release the seeds.

Drupe – The fruit is fleshy outer part, with a large seed in the center (a peach is a large example of this type of fruit).

- Now that you have learned a little about each of these types of fruits/seed cases, try to sort each of the seed cases provided in this unit into one of the categories above.
- **NOTE:** Some of the seed cases are hard to categorize without knowing a little more about them, so check out the hints on the following page.

- When you are finished, check your answers in the answer section at the end of this book.

  <u>Hints for sorting seed cases in this unit</u>
  - In the hop hornbeam, the seeds are hidden inside clusters that hang down like pendulums. However, if you were to open up the clusters further, you would see the seeds are in hard-shelled fruits that don't split open.
  - In the tulip poplar, the seed case may be cone-shaped, but when it is dry, it splits apart and the seeds are carried away in the wind on light wings.
  - In the red cedar, the seeds are hidden inside tiny woody structures that open when conditions are dry and close when conditions are moist. These woody structures produced by the cedars (and junipers) look very different than the structures produced by other conifers. In cedars and junipers, the individual scales that make up the seed case are fleshy, and fuse during development, giving them a berry-like appearance. They are not a berry, though!
  - The sample you have from a buckeye is actually a large seed that was released from a fruit that split open when it was mature.

Discussion question: Why would the trees producing cones prefer their seeds to be released when conditions are dry?

Exercise 1c.3: Using Dichotomous Keys (*Grades 6-12*)

People like to label and categorize things. This helps us to communicate with others. We do not need to describe the characteristics of something each time we mention it. Think how difficult it would be, for instance, if you could not use the name of a friend each time that person came up in conversation. Thus we have given common names to the organisms we frequently encounter in our environment. However, different regions (and different people) often have different common names for the same species of plant or animal. This too can cause communication problems, because the same big cat may be called a "puma" or a "cougar" or a "mountain lion", while three completely different trees may all be called "cedars". Thus, scientists give every particular species a name that is the same no matter where it is found or what language the scientists speak. We call this its **scientific name**. Each scientific name is made up of two parts: its genus designation (group of similar organisms to which it belongs) and its species designation (individuals that are capable of interbreeding with one another). For example, the four-legged barking mammal that commonly lives with humans has a common English name of "dog" and a Spanish name of "perro". Its scientific name is *Canis familiaris*. Some other members of the genus *Canis* are wolves, foxes, and coyotes. Although the different breeds of dogs may look very different, they are all capable of breeding with one another naturally. Thus they all belong to the same species.

If you were to encounter a particular plant or animal and did not know what its scientific name was, you could use what is called a dichotomous (**die-kot-oh-muss**) key to find that name. This key is a set of steps that gives you two choices at each step. Each choice at a step leads you to another set of two choices, which eventually leads you to the identity organism in question and its scientific name.

- Examine the 14 leaves (labeled with letters A-N) provided in this unit.
- Make a list of letters from A to N on a sheet of paper.
- Pick a leaf from the sample, and note its letter.
- Use Figure 8 and the dichotomous key on the following page to find the common and scientific name of the tree from which each came.
- Record these two names on your sheet of paper next to the letter that matches the one on the leaf.
- Go to the next leaf, and repeat the previous steps until you have identified each of the leaves.
- When you have keyed all of the leaves, check your answers in the answer section at the end of this book.

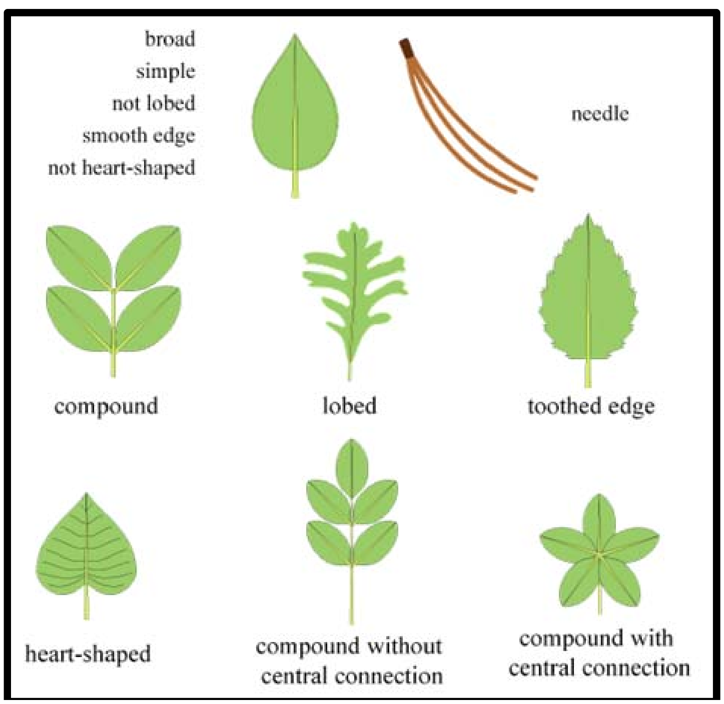


Figure 8. Terminology used to describe leaves

LEAF KEY

1a. Leaf is needle-shaped.. **Go to 2**
b. Leaf is broad and flat .... **Go to 5**

2a. Needles connect at a central point .... **Go to 3**
b. Needles connect along the length of stem .... **Go to 4**

3a. 2 needles.. **Virginia Pine (*Pinus virginiana*)**
b. 5 needles .... **White Pine (*Pinus strobus*)**

4a. Scale-like or three-sided needles .... **Eastern Red Cedar (*Juniperus virginiana*)**
b. Flat needles attached singly ....**Eastern Hemlock (*Tsuga canadensis*)**

5a. Leaf is simple .... **Go to 6**
b. Leaf is compound .... **Go to 12**

6a. Leaf is lobed.. **Go to 7**
b. Leaf is not lobed .... **Go to 10**

7a. Leaf edge is smooth .... **Go to 8**
b. Leaf edge is jagged or toothed like a saw... **Go to 9**

8a. Leaf has 4 lobes ....**Tulip Poplar (*Liriodendron tulipifera*)**
b. Leaf has more than 4 lobes .... **Northern Red Oak (*Quercus rubra*)**

9a. Leaf had 5 distinct lobes .... **Sweetgum (*Liquidambar styraciflua*)**
b. Leaf has 3-5 shallow lobes ....**Sugar Maple (*Acer saccharum*)**

10a. Leaf is heart-shaped ....**Redbud (*Cercis canadensis*)**
b. Leaf is not heart-shaped.. **Go to 11**

11a. Leaf edge is jagged or toothed............................**Eastern Hop Hornbeam (*Ostrya virginiana*)**
b. Leaf edge is smooth .... **Flowering Dogwood (*Cornus florida*)**

12a. Leaflets are from a central point .... **Yellow Buckeye (*Aesculus octandra*)**
b. Leaflets not from a central point... **Go to 13**

13a. More than 7 leaflets .... **Black Walnut (*Juglans nigra*)**
b. 7 or less leaflets ....**Pignut Hickory (*Carya glabra*)**

Exercise 1c.4: Developing a Dichotomous Key (*Open-ended Exploration for Grades 6-12*)

- Using the provided seed cases and the answer key of the trees that produced them, develop your own dichotomous key to help others identify the seed cases in this sample.

Exercise 2: Wood Types: What Wood Would You Use?

Take a few minutes to look around at all the different objects in your classroom. Note the types of materials used to make these objects. How many of these things are made of wood? Do you notice any differences in the types of wood used to make these items? Why do you suppose different things are made from different types of wood? For example, why would your desk be made from a different type of wood than a tooth pick or baseball bat?

Because there are many different species of trees, there are many different types of wood. Each unique wood type has its own combination of properties such as color, scent, strength, density, flexibility, and grain pattern. These factors make different types of wood better for making certain items we use in our daily lives.

Wood can be broadly classified in two main groups: softwoods and hardwoods. The structure of the cells, or wood fibers, is what determines the strength and flexibility of a particular type of wood. What kinds of objects do you think a heavy, hard wood would be used to make? What types of things do you think would be made from a soft flexible wood type? Think about the importance of color, grain pattern, and scent of different woods. Why would these properties be important in making something like furniture or other items found in your classroom or home?

Exercise 2a: What's That Wood? (*Grades 3-12*)

- Find the container filled with a large collection of wood chips.
- Sort the chips and set those with only a letter on them aside.
- Examine each wood chip labeled with the name of the tree species from which it was obtained.
- Write down its name and a list of its characteristics. Some examples of characteristics you should examine are listed on the following page.

    - Its color and pattern of grain (You can wet the wood to more easily observe its grain). **NOTE TO TEACHERS: If students wet any of the wood samples, let them dry completely before putting them back in the container of chips to be returned to the Box Keeper.**
    - Its density (Does it feel heavy or light?)
    - Its scent (If the wood does not seem to have a smell, scratch it lightly with your fingernail and try to smell it again. If a wood sample is varnished on one side, try the "scratch and sniff" method on the non-varnished side.)

- Read about the traits of wood produced by each species in the table on the next page.
- Now examine the "mystery" wood chips with a letter on each.
- On a sheet of paper, make a list of the letters A-L.
- Make the same observations of each mystery chip and see if you can match it to the correct species.
- When you have examined all of the mystery chips and assigned them to a species, check your answers in the answer section at the back of this book.
- For each wood type, there is a list of objects that might be made from that type of wood. List things you can find in your classroom or home that could be made from these types of wood.

WOOD CHARACTERISTICS AND USES

Type of wood	Characteristics	Uses
ASH	Tough & elastic	Bows & arrows, ribs of boats & chairs, baseball bats, tool handles, canoe paddles
BASSWOOD	Soft , consistent light color, lack of grain	Carving, wood boxes, window sashes & door frames, molding
BIRCH	Light and odorless	Wooden bowls, tongue depressors, toothpicks, kitchen cabinets
CEDAR	Durability, pleasant odor	Telephone poles, wood fences, patios & decks, pencils, roof shingles, boats & canoes chests, closet paneling; used in smoking food
CHERRY	Reddish in color, little grain, easy to sand and take finishes well, pleasant odor –smoking wood	Indoor projects-fine furniture, paneling, specialty items (e.g., pipes, musical instruments); used in smoking food
MAHOGANY	Beautiful reddish brown color, straight grain, resistance to rot	Pianos, acoustic guitars, drums, boats & furniture
MAPLE	Hard; often called "sound wood," as it resonates well	Necks of guitars & drums, bowling pins, bowling alleys & gym floors, butcher blocks, decorative furniture surfaces
OAK	Hard dense wood with distinct grain. Has tannic acid which turns black on exposure to water.	Railroad ties & pallets but mainly indoor use (furniture & flooring)
PECAN	Hard, strong, stiff, tough	Furniture, flooring, cabinets, used in smoking food
PINE	Strongest of soft woods (fast growing timber)	Construction lumber, plywood, pine plank flooring, outdoor furniture, pet litter
TULIP POPLAR	Large size and soft, easily worked wood	Cabinets and furniture, dugout canoes, barn siding
WALNUT	Beautiful dark color & stability to fracture, pungent Odor	Fine furniture, musical instruments, interior trim and decorative work, gun stocks

Exercise 2b: Wood Density (*Grades 5-12*)

As you have already observed, the woods of different tree species have different properties. One of these properties is density. **Density** is a **ratio that compares mass to a unit of volume.** If two objects, A and B, are the same size, but A weighs more than B on a scale, we say object A is more dense. Suppose you have an apple and a big ball of cotton the same size as the apple. The apple is heavier, so it is more dense. In this activity, you will compare the density of three types of wood. You will calculate the density and compare your results.

- Locate the container labeled "Wood Density Samples." You will see that there are three types of wood cubes in this container: white birch, balsa, and lignum vitae.
- Take out each of the wooden cubes and, without measuring them quantitatively in any way, see if you can get some idea of their relative densities (which is the least/most dense).
- From your observations, what sort of hypothesis would you make regarding their densities? In other words, how would you rank these woods in order from least to most dense based on your observations?
- Now you will actually measure the densities of each of these woods.
- Measure the mass (in grams) of each wood type on the scale and record your results. Make sure that your scale reads at zero when there is no wood being measured, otherwise it will require adjustment. **NOTE:** The terms **mass** and **weight** are often used interchangeably in everyday life. Though they *are* related concepts, these terms actually mean very specific things. **Weight** *is the measurement of the pull of gravity on an object, and this value for an object can change based on the location where it is measured* (things weigh less on the Moon, due to the smaller gravitational force there). **Mass**, however, *is a measure of the amount of matter an object contains.* The mass of an object does not change based on location. For example, a mass of 150g still has a mass of 150g whether it is measured on Earth, the Moon, or elsewhere.
- Next, use a ruler to measure the width, length, and height of each wood sample in millimeters. Record your results.
- Calculate the volume of each sample using the following formula. This formula should be familiar to you since it was used in a previous exercise. The formula for volume of a rectangular prism is:

Volume = length* x *width* x *height

- Convert the volume to cm^3 (cubic centimeters) by dividing by 1000. This is because densities are often reported in g/cm^3 (grams per cubic centimeter), and

$$1\ cm^3 = 1 cm \times 1\ cm \times 1\ cm = 10\ mm \times 10\ mm \times 10\ mm = 1000\ mm^3$$

- Now calculate and record the density of each sample with the following formula:

density = mass/volume

- Make a bar graph of the wood samples and their corresponding densities. **Make sure to clearly label your axes!**
- Now answer the following questions:

Q1. What values did you calculate for the density of each wood? Did your results of calculating the various woods' densities support your original hypothesis?

Q2. If your results agreed with your original observations, would you say that your results *prove* your hypothesis or *support* your hypothesis? What is the difference between the two?

Q3. In the same way, if you rejected your hypothesis, does this *prove* that your hypothesis was wrong?

Q4. What are some ways you could improve upon or add to your testing methods?

Q5. What is the disadvantage of having only one sample of each wood type?

Q6. What are some properties that would make a wood type heavy? See how many different properties you can think of.

Q7. Based on the densities that you calculated for each wood type, what type of behavior would you expect each wood to display if placed in water? (**HINT:** The density of pure water is close to 1 g/cm^3 at most temperatures.) After answering this question, test it out to see if you were right!

Q8. If any of the wood samples sank, can you think of some ways you could get a cube made out of that wood to float?

Q9. Based on your calculated densities of each of these woods, what types of uses do you think each might have? To help you think about this, you may wish to look over the properties of each of the other woods in the previous exercise, as well as see if you can find density values for them, and compare these to the woods in this exercise.

Q10. Based on your results, you should have learned that different species of tree differ in their wood densities. The growth habits and life histories of various species play important roles in the determination of the density of their wood. What aspects of the growth and life histories of the woods in this exercise might help explain these density differences?

Optional Exercise: If multiple groups are conducting this exercise, students may find that their answers differ a little bit compared to those of other students, even if they did their measurements and calculations carefully. To get the most accurate calculations of density, have your students share their answers and calculate the class's average value . The equaton for calculating an average is presented on p. 8 under **Exercise 1b1.1: Measuring Circumference**. Discuss with the class how it is possible to have different right answers.

Exercise 2c: Wood Porosity (*Grades 3-12*)

Many trees belong to a group called **angiosperms**. Angiosperms have true flowers (which can be showy like a magnolia or very small, like an oak or birch) and seeds contained in a fruit (which can by fleshy like a plum or dry and hard like a walnut), and they usually have broad, flat leaves. Other trees, including pines, junipers, and ginkos, are called **gymnosperms**, which means "naked seed" – they do not have flowers or fruits. Most modern gymnosperms have needle-like leaves, but the gingko has pretty fan-shaped leaves that turn yellow in the fall.

One way to tell gymnosperms from angiosperms is by looking at the **porosity** of their wood. Porosity is the measurement of empty spaces (or pores) in a material. Often it is calculated as a ratio of the fraction of pore space volume to the total volume of the material. Gymnosperms are an older group of plants, that is, they evolved on earth earlier than angiosperms. Gymnosperms were the first plants to develop true wood. They transport water to their leaves using a system of **tracheids**, or long tapered cells with pitted walls. Angiosperms, which emerged around the age of the dinosaurs, transport water through **vessels** – entirely hollow vertical pipes made of dead cells. When wood is cut crosswise, vessels look like round pores. Gymnosperm wood has no pores.

Water is more efficiently transported through vessels than tracheids, which may be a reason why angiosperms are so much more common and diverse than gymnosperms in our world today. Under dry conditions, however, vessels are prone to **cavitation** or the formation of air-bubbles that block water transport. This gives gymnosperms such as pines an advantage in areas where water is limited due to icy conditions under which water can be tied up in snow for much of the year (e.g. in northern latitudes and at the tops of high altitude mountains) or in sandy substrates where water quickly percolates down below the reach of roots (e.g., the western US and Florida).

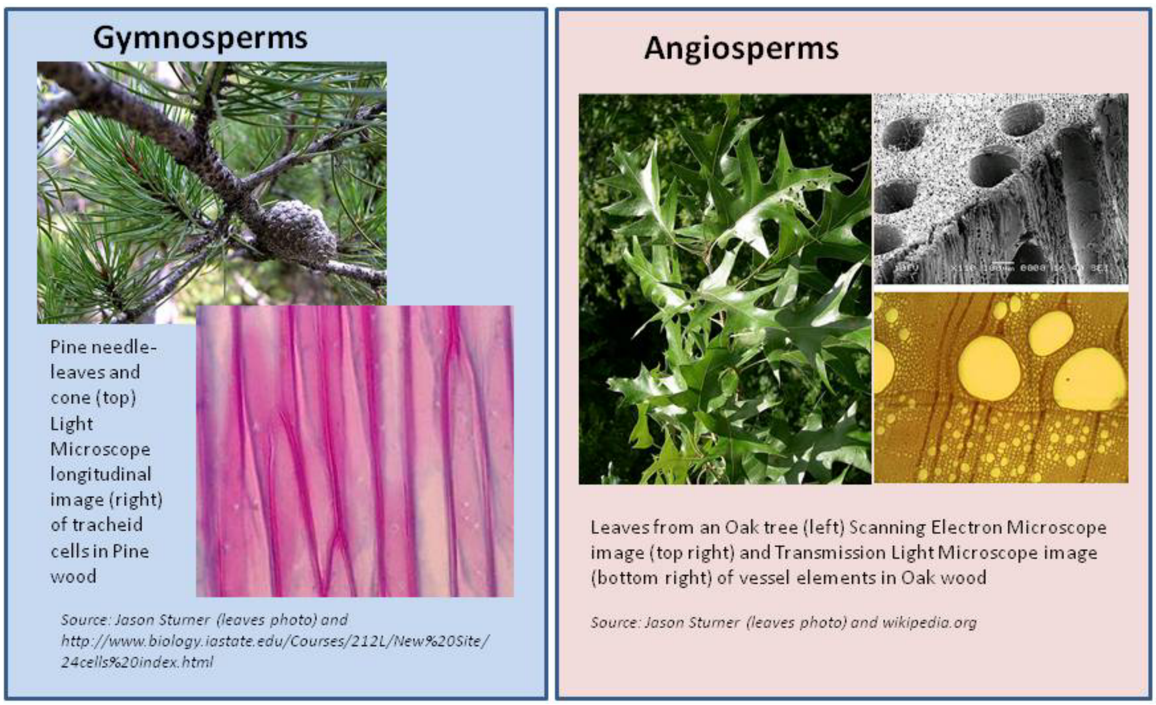
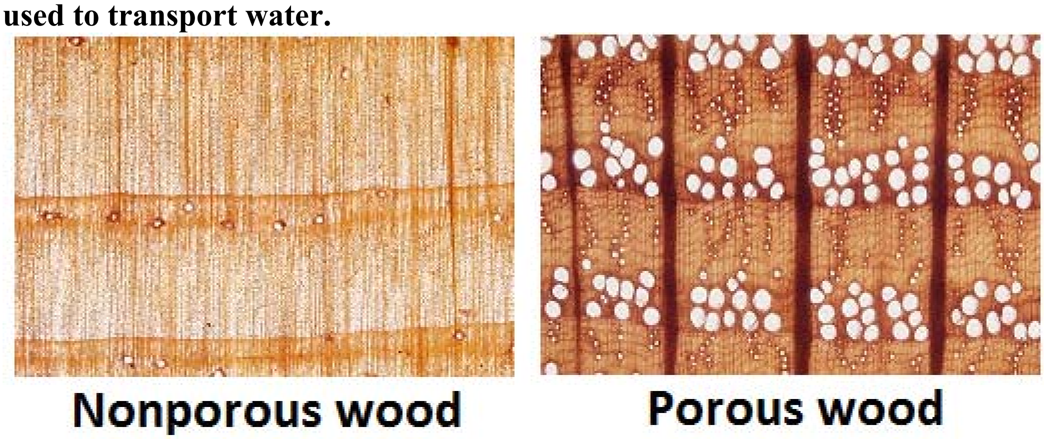


Figure 9. Example of gymnosperm and angiosperm woods and microscope images of cells used to transport water.



NOTE: In the image of nonporous wood above, don't confuse the circular structures (which are actually resin ducts) with vessels.

- Find the container labeled ***"Wood Porosity Samples".*** These may be either small pieces of wood, short sections of dowel of different wood types, or small tree cores of two different species (labeled A and B) mounted on wooden blocks.

NOTE: Tree cores are wood samples extracted from the tree trunk using a boring tool. You can also use cores to age a tree by its rings in the same way as you did with the tree cookies.

- Use the provided magnifying glass to examine the two tree cores.
- Now answer the following questions.

Q11. One of the samples comes from a species of pine, and one comes from a species of oak. Can you tell which is which?

Q12. If you were to dip chips of oak and pine in soapy water and then blow on one end, which one do you think would produce bubbles at the other end? Why would this happen?

Q13. What function do pores have for a tree?

Q14. Which wood sample would come from a tree that will *not* easily suffer from cavitation (air bubble formation that blocks water transport)?

Q15. Based on the definitions above, which wood sample comes from an angiosperm, and which is from a gymnosperm?

Q16. If you soaked these samples in water overnight, which one would absorb the most water? It turns out this is very important for choosing wood to build buildings with – why do you suppose this is so?

Exercise 2d: Tennessee's Trees and their Properties (*Open-ended Explorations for Grades 6-12*)

Below are some ideas to get you inspired to learn a little more about the diverse trees found in our home state. (If you are not in Tennessee, feel free to modify these to work with trees native to your area!)

- Using the information you learned about the properties of the various woods in the previous three exercises, do some additional research on a few of the tree species examined. See what else you can learn about these trees (such as in what types of habitat/environmental conditions they live, growth rates, potential threats to the species, etc.) Do you think that any of these aspects of the tree species' life histories are related to the qualities of the wood they produce?
- Try to find information regarding the density and degree of porosity of other Tennessee tree species.
- Do some additional research on the relative abundance of each of these tree species in Tennessee. You may also wish to examine whether they are more common in certain areas of the state, and if so, why.

Exercise 3: Forest Products: Trees are Good!

Trees play an extremely important role in many ecosystems. Not only do they provide homes for many different species of organisms, but they also play a role in improving water, air and soil quality, and in controlling erosion. Trees are also quite important in our everyday lives. There are many items on which we rely that are made from the bark, wood, sap, or fruits and nuts of many types of trees. Managing our lives without some of these products would prove to be quite difficult in some cases. For instance, paper products come from trees. What would we do for paper if trees disappeared? Perhaps you are unaware of all the ways you use paper products in one day. In fact, the amount of paper that you use in one year would be almost equal to a tree 100 feet tall and 18 inches around.

Trees are important and valuable for many reasons, but they are extremely important for us as a natural and renewable resource. A **renewable resource** is one that, if we are careful, is available to us indefinitely. This is one of the reasons that it is important that we are good stewards of the planet's forests by managing and preserving them for valuable resources and recreation.

In these exercises, you will learn about the wide range of products that are obtained from trees, as well as a little further information about how such products are produced.

Exercise 3a: That Came From a Tree?! (*Grades K-12*)

Several parts of trees are used to produce many products that are useful to us:

- **Bark** – the outer protective layer that guards a tree against insects and diseases
- **Leaves** – structures that allow a tree to produce its own food
- **Wood** – tissues that carry water and nutrients throughout a tree
- **Cellulose** – material that makes up cell walls of trees & other plants
- **Resin** – the sap, or liquid that is transported throughout a tree, which contains water, nutrients, wastes, and compounds produced by the tree

- On a sheet of paper, make separate columns labeled "**Bark**," "**Leaves**," "**Wood**," "**Cellulose**," and "**Resin**."
- Locate the container of objects labeled "***Forest Products***".
- Examine each of these items, and try to see if you can figure out from which part of a tree each product was made, listing each item under the column for the appropriate tree part.
- After you have listed all of the items from this container, see how many other products you can think of that may have come from these various parts of trees.
- When you are finished, check the answer section at the end of this book to see how many you got right!

Exercise 3b: Ask the Experts! (_Open-ended Exploration for Grades K-12_)

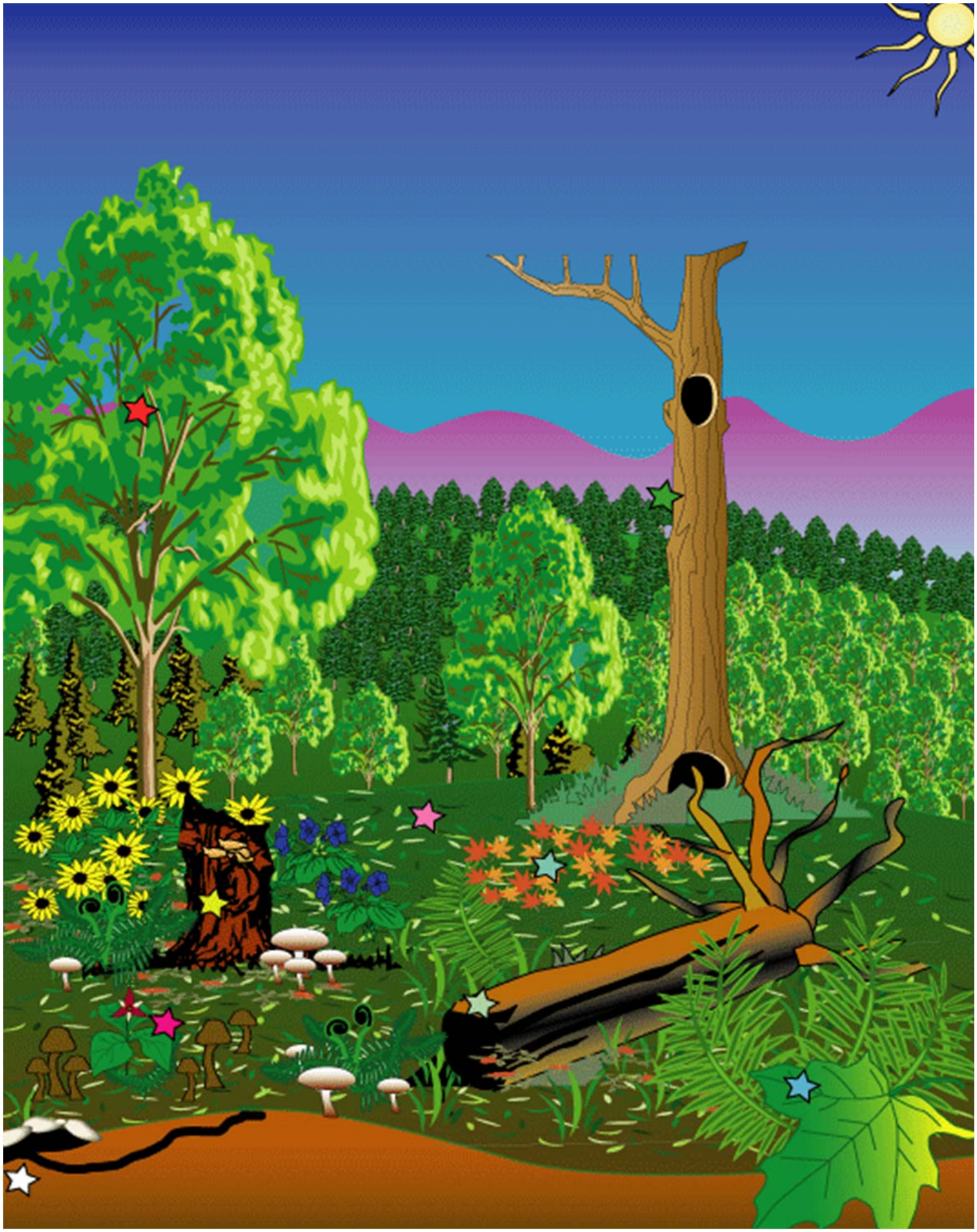
- If possible, see if you can arrange a visit to a business that produces or sells wood products, or even see if you can conduct an email interview. Some ideas include a lumber company, a sawmill, a paper mill, a logging company, a furniture manufacturer, or even something as simple as a home improvement store. Talk to people that work there to get even more firsthand information about wood products, such as how they are made, what types of wood are used, etc.

Exercise 4: Who Lives Here? (*Grades K-12*)

Forests are not just a place for trees! The forest is a home for many kinds of animals. While the trees themselves do create homes for animals, they also help create habitats in other ways. For example, a group of trees can promote the growth of other plants that provide food and shelter for forest animals. The nooks and crevices created by root systems also offer a safe haven to animals. Thus, while an animal species may not be directly dependent upon the trees, they may depend on another habitat that the trees create.

In part, trees provide so many animals homes because they extend the available habitat well above the forest floor. Animal homes are found at many different heights within the forest. Some live in the tree **canopy** at the top of the forest, others at various heights along the **trunk**, and still others within the **leaf litter** on the forest floor. Finally, animals vary in the space they require. Some may wander in search of food throughout the expanse of a woodlot, while others may live on a single leaf. In this exercise, you will learn about forest animals and how they use trees, as well as how animals themselves may influence forests.

- Look at the forest scene illustration on the next page. A larger poster of this image is also provided with this unit.
- Study all the areas and note any places where you think an animal might live. Pay special attention to the areas indicated with a star.
- Find the cards that illustrate forest habitats. The stars on the cards will show you where you are in the forest scene. Think about what you might find living there.
- Now locate the cards with animals on them, and see if you can match each animal card with the habitat card that is most likely where each animal can be found in the forest. Answers can be found at the end of this book.



- Now answer the following questions:

Q1. In what ways do these animals depend on the forest?

Q2. How might the forest help an animal that may not even use trees to live?

Q3. How do some of these animals change the forest, and what do they do to influence it?

- You may wish to discuss each of these questions in small groups, and/or as a class. Check your answers to these questions at the end of this book.

Exercise 5: Forest Succession: Stages of Forest Growth (*Grades 6-12*)

The forest is an ecosystem that is influenced by numerous factors. An external or internal influence, whether natural or human, can completely change the structure of a forest and the habitats within it. For instance, lightning may strike a large old tree, leading to a fire that spreads throughout the forest. In its wake, this fire may leave patches within the forest with no vegetation at all, and may also selectively kill those tree species that lack fire resistance. This allows the growth of a whole host of plants that were unable to grow in the dense shade of the large tree canopy, and may encourage a shift to pines and other tree species that are adapted to fires. These trees might have already been present in low numbers, kept in check by the more shade tolerant large canopy trees. The resulting vegetation shifts attract different animal species to the forest as well. This kind of effect is called a **cascade**. Something happens to a dominant species, and this affects other species, which affects other species and so on.

The observed change in forest composition, however, is not permanent. Over time, the dense forest canopy returns and shade-tolerant and fire-sensitive species come back. This process of recovery from a disturbed forest to a mature forest is called **succession**. Succession can take many decades, but some changes will be noticeable even within the first ten years after a disturbance.

Some ecosystems are maintained by disturbance. For instance, long-leaf pine savannahs are characterized by widely spaced large pines with many types of wildflowers and grasses growing underneath. Long-leaf pines are extremely fire-resistant, with deep roots and thick bark. When fires of moderate intensity happen on a regular basis, they kill off shrubs and most tree species, making space for the wildflowers and young pines – and the animals that depend on them. Long-leaf pine savannahs are now rare because people first cut many of the pines for timber and then suppressed the wildfires, allowing other species of plants to take over.

In order to maintain the health of a forest system, one must first understand it. Foresters work to understand the presence of influences and their subsequent effects on forest interactions. One thing is certain. The forest is always changing. In the following exercise, you will learn about the complexity of even a simple, single-species forest system, and the factors that influence change in its age structure. Your job will be to try to make it a stable mature system, but the deck may be stacked against you. (By the way, in real forest succession, tree species will depend on other associated tree species, plants and animals that live with it in a **community**, which would be even more complex to handle!)

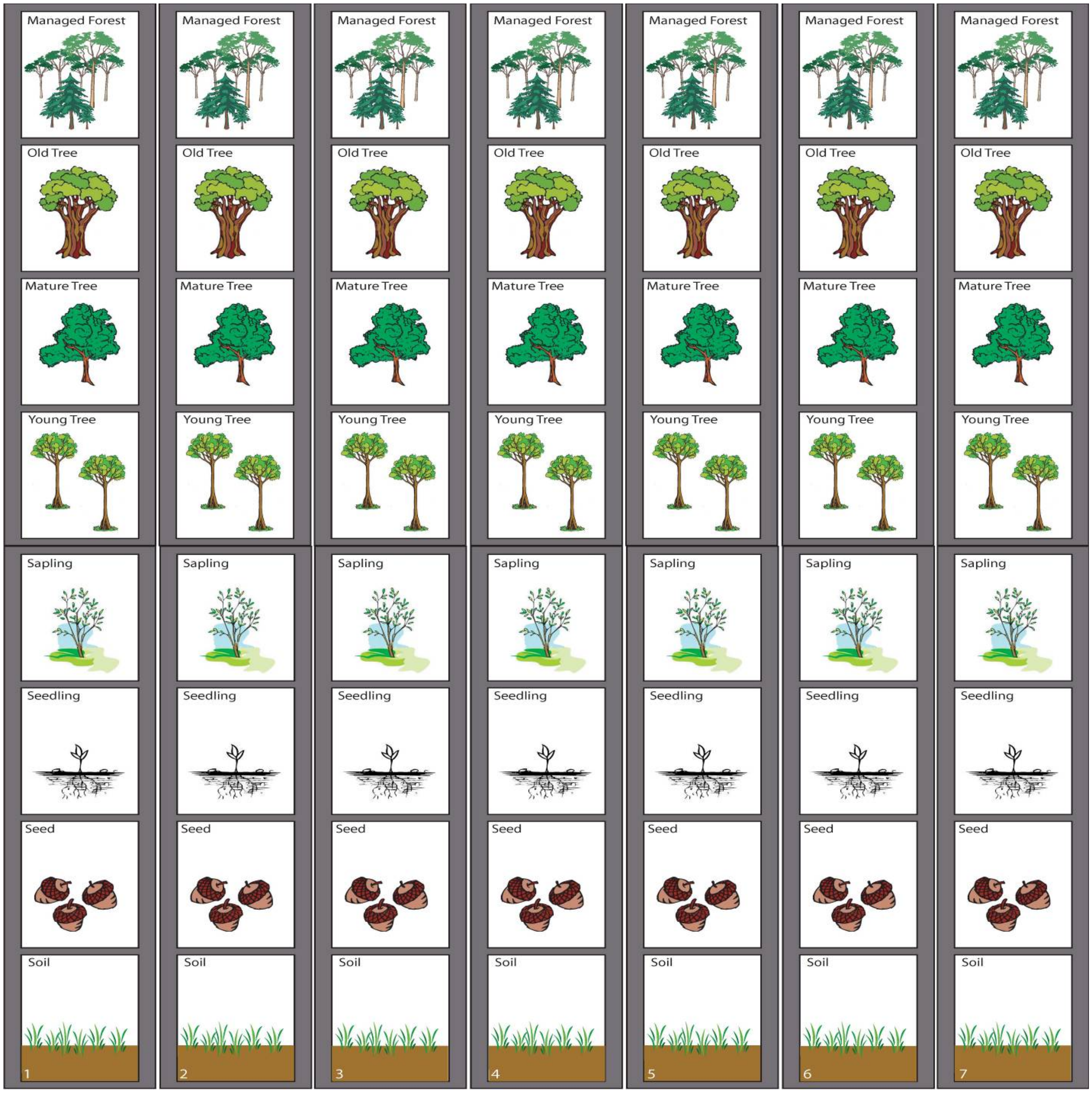
Exercise 5a: The Succession Game: External Forces in Action

The Situation

You have acquired a large tract of land planted with a hardwood tree species (in this example, black walnut, whose wood is valuable to the furniture trade). Across this property, there are different levels of tree growth, and in some areas, there is no tree growth at all. Think of your property as a mosaic of forest patches that are in different stages of succession from disturbed (bare soil) to mature (mature trees) and finally to **senescent** (old/dying trees). Any plot that has a mix of different ages we will call "managed forest".

- Study the succession game board on the next page (You are also provided with a larger version of this game board in this unit). Identify the following patches of different successional stages available: ***bare soil***, ***seed***, ***seedling***, ***sapling***, ***young tree***, ***mature tree***, ***old tree***, and ***managed forest***.

These patches are serially arranged as seven numbered columns. You will be moving paper clips on each of these columns from one stage to another during each round of the succession game. Each column represents a patch of trees. ***The position of the clips within each column will indicate the growth stage of each forest patch (representing 10 acres of trees/seeds/bare ground, etc., not just one tree).***



SUCCESSION GAME BOARD

- Now find the poster matching the picture on the previous page
- Locate the container of paper clips included with this unit, and take seven paper clips of a single color.
- Place one paper clip on the following squares in any order of columns ***with only one clip per column:***

Successional Stage	**Initial # of clips**
Soil	2
Seed	2
Seedling	1
Sapling	1
Young Tree	1
Mature Tree	0
Old Tree	0
Managed Forest	0

- Find seven paper clips of a different color. Keep these to the side.
- Use the worksheet to record the stages in patches 1-7 for the "start" row.
- In each round:
    1. Go through the set of rules described on the next page, which will prescribe whether or not each patch (column) moves up to the next successional stage. Place a clip of the opposite color on the new space to indicate its progress for the round. Once all patches of land have been changed, remove the colored paperclips from the previous round. The new clips indicate your new successional stages.
    2. Choose a card from the "External Forces" pile to see how the structure of your forest changes because of outside forces.
        - If there are no clips that can be moved as the external forces card directs, then start another round.
        - If the card asks you to move more clips than you have available for the round, then just move as many as you have.
    3. Record the stages for each of the seven patches. Note the numbering at the bottom of each column for guidance.
- Repeat steps 1-3 for 10 rounds.

Succession Game Sheet

	1	2	3	4	5	6	7
Start							
Round 1							
Round 2							
Round 3							
Round 4							
Round 5							
Round 6							
Round 7							
Round 8							
Round 9							
Round 10							

Rules for the start of each round of the Succession Game

- Look at each column and place a new colored clip at the next successional stage if any of the statements below are true for that column.
  - o Soil patch is next to a mature, old, or managed forest patch. (The bare soil needs a seed source from surrounding adult trees.)
  - o Seed, seed, seedling or sapling patch is next to a soil, seed, seedling, sapling, or young tree patch. (These seeds will germinate faster if there is no dense canopy above them to block the sunlight.)
  - o Young tree or mature tree patch is next to a soil, seed, seedling, sapling, or young tree patch. (These young trees will grow faster if there are no older trees to out-compete them.)
  - o Do not move old tree patches until an External Forces card instructs that you move it.
- If there are no clips that can be moved as the External Forces card directs, then start another round.
- If the card asks you to move more clips than you have available, just move as many as you have.
- Remember to check both columns surrounding the column in question and make your decision based on the position of the colored clips from the start of each round.
- Start from the left side of the board and move from one column to the next to make it easier to keep your place.

- Answer the following questions after you have finished:

Q1. Stability means "resistance to change." If a forest is stable, external forces will cause losses of trees but eventually the trees will grow back again. Were your forest patches able to grow back when external forces caused the loss of trees? If not, would they have come back in a few more rounds?

Q2. What factors helped the forest patches to advance in succession?

Q3. How could a manager use these trends to help manage a stable forest?

Q4. What factors caused you to lose trees?

Q5. What are some strategies you can use to help you reach your goal if your goal was to establish a forest of mature trees?

Q6. What could you do to help induce your bare patches to produce trees faster?

Q7. Which patch type seemed the least unlikely to change? Which patch type was the most likely to change?

Q8. If you started out with all of your patches in the mature tree stage, what do you expect would happen? Try it!

- Check your answers in the answer section at the end of this book.

Exercise 5b: Probability in the Succession Game

Games often use ***probability***, or the likelihood that something will occur, in order to make the game interesting. For example, when you play a coin toss game, you must guess whether the coin will fall on heads or tails. There is a chance your guess will be right, and a chance it will be wrong. We can determine probability by using a ratio:

$$Probability = \frac{Number\ of\ Desired\ Outcomes}{Number\ of\ Possible\ Outcomes}$$

In the case of the coin, there are two possible outcomes: heads and tails. There is one desired outcome: your guess (heads or tails). Therefore you can express the probability your guess is correct as:

$$Probability = \frac{Number\ of\ Desired\ Outcomes}{Number\ of\ Possible\ Outcomes} = \frac{1}{2} = 50\%$$

One would say there is a 50% chance you will guess correctly.

How does this work in practice? Let’s try a similar experiment. Pick out two paper clips of different colors, let’s say red and blue. Have a partner hide the two clips behind his or her back, one in each hand. Make sure your partner mixes them up! Guess which hand the red paper clip is in. Again we will have two possible outcomes, just like the coin toss. Guessing correctly is your one desired outcome, just like guessing heads or tails. Record whether or not you were right. Repeat this ten times. Below is an example of someone’s results:

Guess	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Right?	Yes	No	No	Yes	Yes	No	Yes	No	Yes	Yes

This person guessed correctly 6 of the 10 possible times. From this we can determine the probability of success. For the example, we would determine it like this:

$$Probability = \frac{Frequency\ of\ Desired\ Outcomes}{Number\ of\ Possible\ Outcomes} = \frac{6}{10} = 60\%$$

Just like in this example, the probability you determine from doing trials and the probability you expect from calculating in advance may not match, but if you continue to repeat the game you would expect these numbers to become more similar over time. It's this uncertainty that makes games fun!

Suppose you want to figure out how difficult the designers of this succession game made it to advance from a mature or old tree patch to a managed forest patch. The only way one may do this is to draw a favorable card.

First one would count the total number of cards (the total number of possible outcomes). There are 27. Then one would count the number of desired outcomes, or the number of cards that result in moving a clip from a mature or old patch to a managed forest. There are 9.

$$Probabilty = \frac{9\ Desired\ Outcomes}{27\ Possible\ Outcomes} = \frac{1}{3} = 33.3\%$$

Your probability is 33.3% that you will choose a card that would advance a mature or old patch to a managed forest patch.

- Take a moment to look through the External Forces cards, and use them to answer the following questions:

Q9. What is the probability that you will draw a card that causes insect damage?

Q10. What is the probability you will draw a card where you may have to move a patch back to bare soil?

Q11. What is the probability you will draw a card that causes damage from humans?

Q12. Let's say you wanted to change the game to make it easier to move from an old or mature patch to a managed one. How many cards that don't advance to managed forest would you need to remove from the deck in order to make the probability you will draw a desired card 50%?

Q13. Shuffle the cards. Draw five at random. From your results, calculate the probability of drawing a card which instructs you to move a mature or old patch to a managed patch. How does your answer compare to what was calculated in the example? How about when compared to others?

- Check your answers in the answers for Exercise 5 at the end of this book.

Exercise 6: Forest Pests: Curtailing the Critters (*Grades 6-12*)

Every forest includes a host of microorganisms, insects, and pathogens (disease-causing organisms) that cause damage to the trees within it. A certain level of damage is unavoidable, and can even be healthy for a forest ecosystem. The relationships between forest trees and their main pests have evolved over many years. Epidemics or catastrophes are normally rare. However, poor management techniques and the introduction of organisms from other countries can devastate a forest ecosystem. They can even eliminate a specific tree species from a region. Since humans can change the landscape in such a short period, we sometimes interrupt the natural defenses that evolved within the system we are changing. In the case of exotic pests, the forest has not evolved with these organisms, and may be defenseless against attack. Therefore, modern management techniques must include the consideration of protection against forest pests.

Various organisms, including viruses, bacteria, fungi, nematodes, parasites, and insects, cause diseases in forests. Damage may occur to the leaves, roots, or stem tissues, which severely reduces the tree's ability to function in a healthy manner. Foresters continuously work to try to stay ahead of any impending attacks. The southeastern forests have their share of challenges. The plight of the American chestnut gave biologists a look at what can happen if exotic organisms are left unchecked. The chestnut once dominated southeastern forests, but there was an accidental introduction of a fungus called chestnut blight that killed nearly all adult chestnut trees in the early 1900s. Now American chestnut trees exist in forests only as sprouts from stumps of long dead trees, though some people are attempting to breed a blight-resistant tree that can be re-introduced into the wild. Pests that are on their way or are already a problem in southern forests number in the hundreds, including dogwood anthracnose (another fungus) and hemlock woolly adelgid (an insect).

Landowners can have a variety of goals for their forests. They may want to manage for timber to sell, to manage the forest for recreation, hunting, aesthetics, or habitat quality, or they may simply want to maintain it for sentimental reasons. This activity presents a simplified exercise for one struggle that a plantation manager might face. It will help you to understand some of the factors that influence the level of damage within a forest. You will learn some simple methods of management that can help improve forest resistance to disease.

- Familiarize yourself with the life history of the Southern Pine Beetle and examine the bark sample showing Southern Pine Beetle tracks made inside the bark.

In the following exercise, you will play a game to learn strategies for management against this pest.

Figure 10. The Southern Pine Beetle (*Dendroctonus frontalis*)

The Southern Pine Beetle (*Dendroctonus frontalis*, see Figure 10) is a native forest pest of southern pines. It is considered the most destructive pest of pines in the southeastern region. Adult females bore into the trees and send out pheromones that, together with chemicals of the tree, can attract a large number of other beetles. These aggressive beetles can attack and kill large tracts of pine in one growing season. After killing their host tree, they will spread to neighboring trees. Outbreaks generally occur every 7-10 years. Most infestations are limited to small areas, but occasionally these infestations can sometimes kill thousands of acres of pines. Figure 11 shows a large infestation. The reddish- brown trees are dead pines.

Figure 11. Effects of a large-scale infestation by the Southern Pine Beetle. The reddish-brown trees are pines that died from beetle damage.

Figure 12. Inner bark of pine infested with Southern Pine Beetles. The winding S-shaped or serpentine galleries are typical of the damage caused by the pest.

Inside the inner bark of the pine tree, the beetles feed on the phloem tissues, forming serpentine galleries (Figure 12). Both the adults and larvae feed in this way, which essentially girdles the tree (cutting off the transport of sugars) and eventually kills it. One external sign that a tree is infected is the presence of white globs of resin that look similar to popcorn (Figure 13).

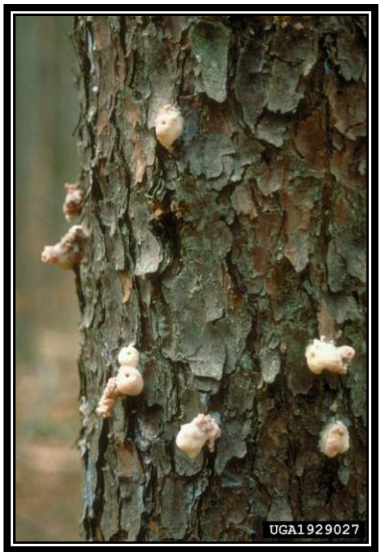


Figure 13. Exterior bark of a pine infested by Southern Pine Beetles. The popcorn-like blobs on the bark are known as pitch tubes, as they are formed when the pitch, or sap (which carries food and nutrients throughout the tree) leaks out through tunnels excavated by the beetles.

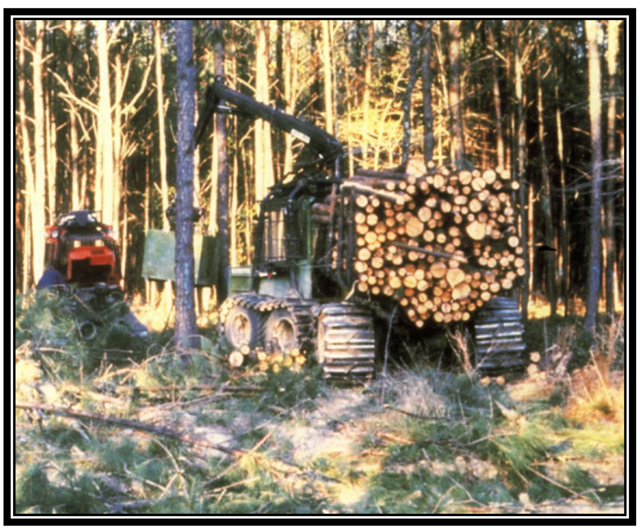


Figure 14. Foresters removing infected pines and a buffer zone of surrounding healthy trees in an attempt to curb the beetle invasion.

After an infestation of pine beetles, forest managers cut the infected trees and a buffer of surrounding healthy trees in attempt to stop the invasion (Figure 14). This can be challenging for managers as the adult beetles can fly up to around 2 miles.

One strategy to prevent massive tracts of trees from being infected is to plant zones of a different species of tree within a plantation. Many pests are specific to one host species, so alternating with another species can help stop a disease from potentially spreading widely, isolating it to one area where the infestation starts.

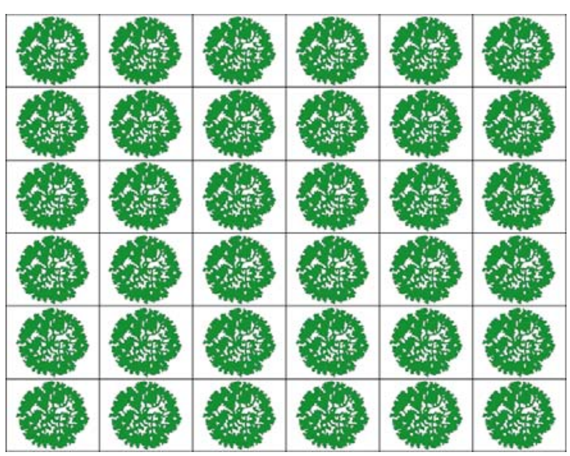
The Scenario: Imagine that you own a tract of land planted with pine. Your plan is to sell the pine to pulp and timber companies. Your challenge as a land manager is to maximize your profits while faced with possibility of beetle infestation. Beetles spread to surrounding trees with each generation. For simplicity's sake, we will assume that the beetles take one year to do so, but in reality they may spread even faster!

The trees are worth more every year you let them grow larger, but if they become infected with beetles they will be worth less. For example, in the first year, you could get $100 for each patch of pines, but if you let them grow for 4-6 years each patch will be worth $250. However, if they become infected in years 4-6, they will only be worth $70. See the table below.

Year	Price for uninfected pine patch	Price for infected pine patch
1	$100	$40
2	$150	$50
3	$200	$60
4-6	$250	$70

Exercise 6a: Infestation in a Monotypic Stand

- Find the game board covered only with light green tree crowns that looks like the one below. This represents your newly-purchased land, which has 36 plots of pines on it.



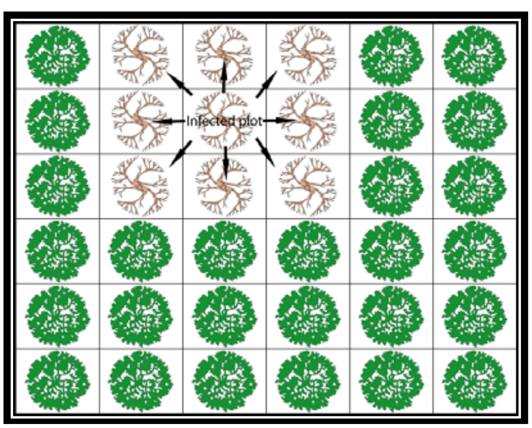
Unfortunately, there is an outbreak of Southern Pine Beetle in your plantation.

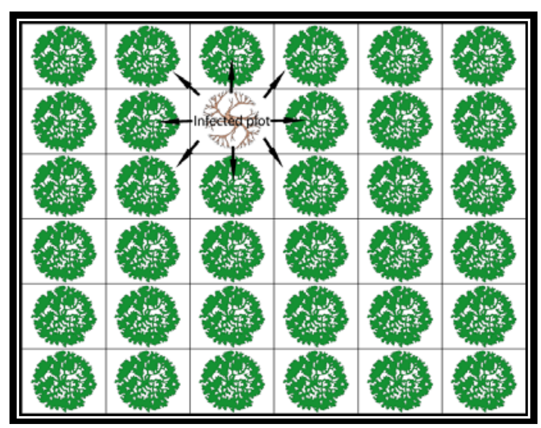
- Now choose any plot of pine on the plantation and place a paper clip on it. This represents a plot in which a beetle infestation begins.
- In the next generation of this infestation, each pine tree plot adjacent to your infected plot is now infected. (Any plots touching the infected plot, whether above, below, on either side, or even diagonal, are considered adjacent.) Place a paper clip on each of these plots.
- Make a table like the one below. We have already filled in data for generation 1 of the infestation.

Year	# Healthy	# Infected	Profit if Harvested
1	35	1	35 × \$100 + 1 × \$40 = \$3540
2			
3			
4			
5			

- Record the number of plots remaining free of beetles infestation and those infested for the second generation of beetles. Calculate your potential profits.
- Repeat the pattern of spread of beetle infestation for a total of 5 generations of the beetle, filling in the cells of the chart as you proceed.

Example of spread of infestation





- See how much of your forest remains after a total of five generations of beetle infestation.
- Now answer the following questions:

Q1. Describe what happened to the pine plantation.

Q2. What is the health of the plantation in year 5?

Q3. Given this infection, in what year should you harvest to maximize profits?

Q4. What is a disadvantage to having a monoculture, or a forest with only one tree species?

Q5. What are some possible solutions for keeping an infestation contained?

Q6. Where would you want the infestation to start in order to have the most healthy trees after five rounds?

On the following page is a plot of the number of trees infected over time in the example.

- Use the graph to answer the following questions:

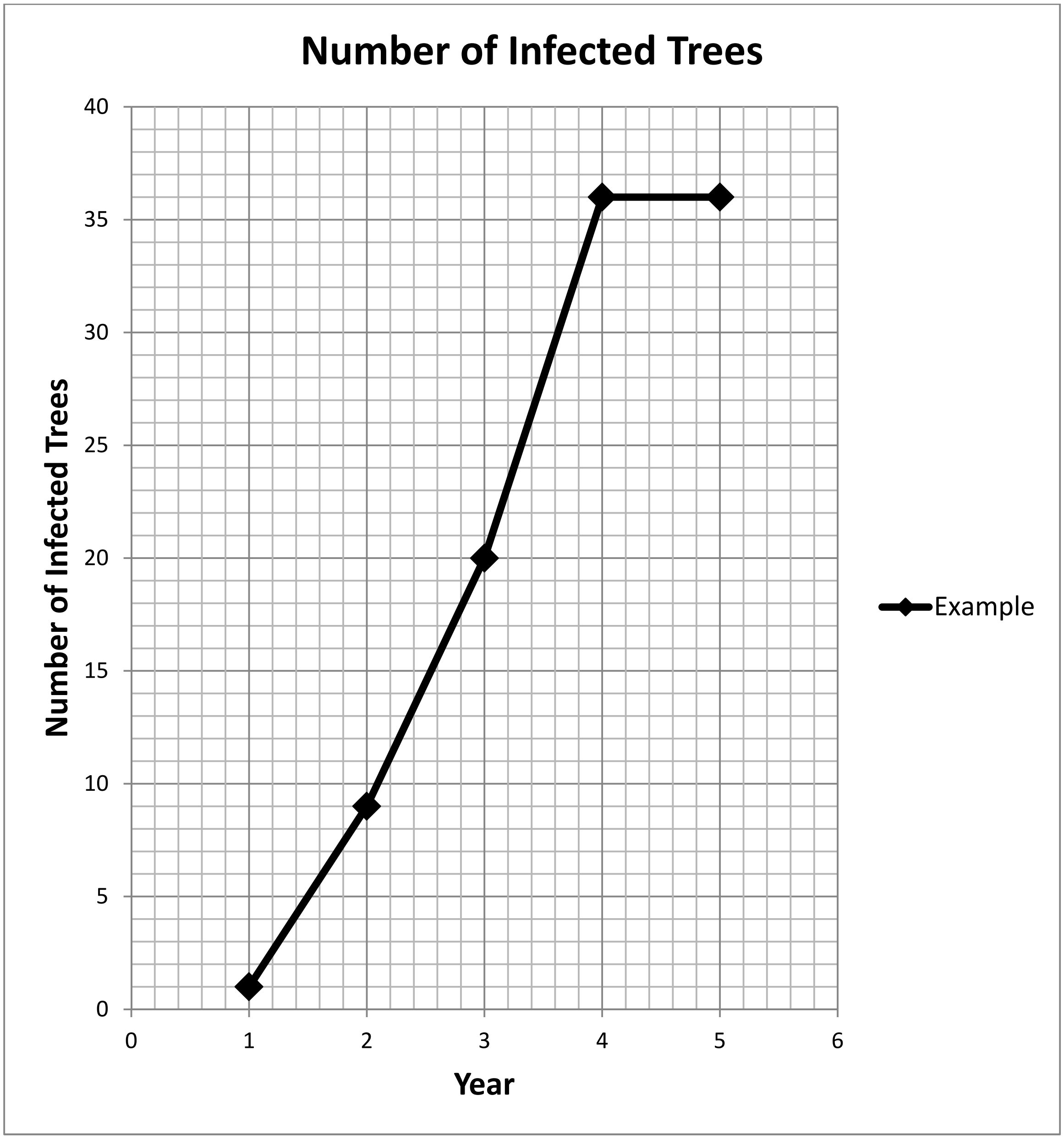
Q7. In what year does the infection begin to level off?

Q8. On a separate sheet of paper, copy and fill in the corresponding table, including calculating the profits by year. In what year should the plantation manager have harvested to maximize profits?

Q9. Looking at the game board, can you figure out where the infection may have started?

Q10. If your teacher provides you with a copy of the same graph, use it to plot the infected trees from your plantation on the same plot in order to compare the infection progress. Which one progressed more quickly? Were the results in year 5 different?

- Check your answers to these questions on the answer sheet for Exercise 6 at the end of this book before moving on to the next exercise.



Year	# Healthy	# Infected	Profit if Harvested
1	35	1	35 × $100 + 1 × $40 = $3540
2			
3			
4			
5			

Finding the Percent Infected

When a forester writes up a report of how healthy his or her forest is, often he or she will want to communicate the proportion of trees infected with a pest. A **proportion** is a fraction that ***compares part of a quantity to the whole quantity***. For example, if you took a test that had ten questions, and you got eight of them correct, you can then say you answered 8/10 questions correctly. You can reduce this down to 4/5.

However, usually teachers prefer to tell your grade in the form of a percent. A **percent** is a proportion that has a denominator of 100. You can remember this by thinking about the root of this word. Per means "for each" and cent is the Latin root for "hundred". (Think of *cent*ury, 100 years, or one *cent*, which is one hundredth of a dollar). Even the symbol for percent is a clue: %. Doesn't it look a little like the number 100, but rearranged?

So what is your test grade when converted to a percent?

$$\frac{\mathbf{8}\ \boldsymbol{questions\ right}}{\mathbf{10}\ \boldsymbol{total\ questions}} \times \frac{\mathbf{10}}{\mathbf{10}} = \frac{\mathbf{80}}{\mathbf{100}} = \mathbf{80}\%$$

We multiplied by a factor of 10/10 to increase the denominator to 100. This doesn't really change anything except the way that the proportion is expressed, since multiplying by 10/10 is the same thing as multiplying the original proportion by 1. We simply did this to get the denominator (100) we wanted in order to express the test grade as a percent (which, by definition, is a proportion with 100 as the denominator). Sometimes, however, it's not so easy to figure out what that factor should be, so here's a shortcut to the same answer:

$$\frac{\boldsymbol{Part}}{\boldsymbol{Whole}} \times \mathbf{100}\% = \ \%$$

$$\frac{\mathbf{8}}{\mathbf{10}} \times \mathbf{100}\% = \ \mathbf{80}\%$$

Foresters also prefer to use percents, because then it's easier to compare health between forests that may have different numbers of trees. Let's say that you have two forests: Forest A has 80 trees, of which 60 are infected. Forest B has 140 trees and 70 are infected. Which one has the greater percent infected? Let's calculate the percents that are infected.

Forest A:

$$\frac{\boldsymbol{Part}}{\boldsymbol{Whole}} \times \mathbf{100\%} = \frac{\mathbf{60}}{\mathbf{80}} \times \mathbf{100\%} = \mathbf{75\%}$$

Forest B:

$$\frac{\boldsymbol{Part}}{\boldsymbol{Whole}} \times \mathbf{100\%} = \frac{\mathbf{70}}{\mathbf{140}} \times \mathbf{100\%} = \mathbf{50\%}$$

Forest A has the greater percent infected. Even though Forest A has fewer trees infected overall (60 compared to 70), it's in worse shape because a higher percentage are infected.

- Try to answer the following questions (you may need a calculator):

Q11. In a forest of 200 trees, 15 are infected. What percent are infected?

Q12. In a forest of 900 trees, 800 are infected. What percent are infected?

Q13. Forest X has 210 trees, 100 are infected. Forest Y has 70 trees, 40 are infected. Which one has the greatest percent infected?

Q14. In a forest of 36 trees, one is infected. What percent are infected?

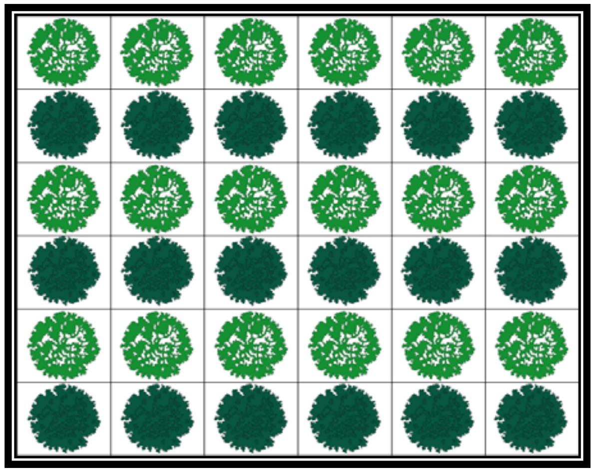
Q15. Bonus: In a forest of 36 trees, one is infected. What percent are *healthy*?

- Go back to the table generated in Round 1. Calculate what percent of trees are infected and what percent of trees are healthy in each year.

Q16. If you add up the percent of healthy trees and percent of infected trees in any given year, what do they add up to? Does that make sense? Why?

Exercise 6b: Infestation in a Mixed Stand

- Now find the game board that has alternate rows of dark green tree crowns and light green tree crowns like the image below:



The light green tree crowns are your pine plots (the cash crop). The dark green tree crowns represent plots of hickory trees that offer no cash reward (at least not for many more years than pine, because hickory is slow-growing). **However, note that hickory is not attacked by the Southern Pine Beetle.**

- Repeat the same invasion process you followed in Exercise 6a (using the monotypic stand): Choose a random pine tree plot as a point of beetle infestation and proceed through 5 generations of beetle damage. Record your infestation in a table like the one below.

Year	# Healthy Pines	# Infected Pines	Profit if Harvested	% Pines Infected
1				
2				
3				
4				
5				

- Calculate the percent of pines infected in each year in the table. Remember, this is for ***pines only*** and the game board has changed, so when calculating percentages, make sure you use the total number of pines only in your denominator.

- On a sheet of graph paper, make a plot that depicts the percentage of infected pine trees for each beetle generation based on the total initial number of pine trees.
- Now answer the following questions:

Q17. What differences are there after five generations of beetle damage as compared to your monoculture?

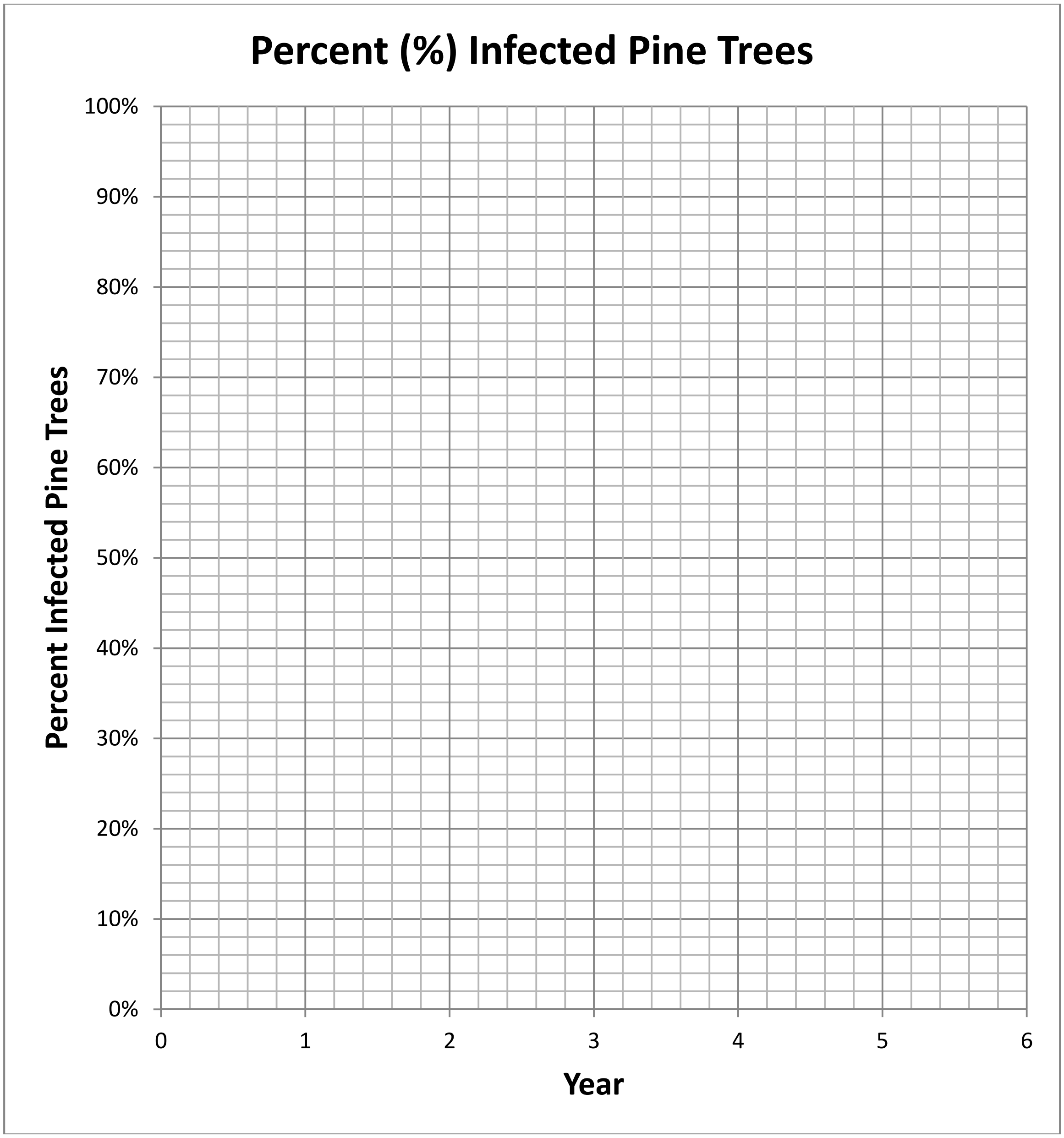
Q18. What did planting alternate rows of hardwoods trees do for your pine trees?

Q19. What are other management techniques that might result in the same outcome?

Q20. What happened to your pine tree profits in terms of selling harvested trees to timber and pulp companies?

Q21. What are you compromising in trying to manage against Southern Pine Beetle damage?

- Check your answers to these questions on the answer sheet for Exercise 6b at the end of this book.


Percent (%) Infected Pine Trees
Percent Infected Pine Trees
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
6
Year

Exercise 6c: Managing Your Own Mixed Stand

In this exercise, you will continue to play the role of a forest manager, but this time, imagine that you are planting your own plot of pines and hickories from scratch, with the same goal of eventually selling the pines for profit.

- Make a blank 36 plot grid on a piece of paper. Alternatively, your teacher may provide you with a copy of such a blank grid, which is given on page 63.
- Given a single initial point of infection, arrange 18 pine and 18 hickory plots such that no more than four plots have the potential to become infected. Draw your configuration.
- Using your blank grid, now arrange any number of pine tree plots and hickory plots in a way you think will reduce Southern Pine Beetle damage yet have the highest yield of timber and pulp.
- Make a table and a plot that depict the percentage of **LIVE** pine trees for each beetle generation based on the total initial number of pine trees.
- Do this after each trial to keep track of your results. In fact, you can even use the same graph paper for each trial for easy comparison.
- Now answer the following questions.

Q22. Which pattern did you find most effective?

Q23. What challenges did you have in making your decisions?

Q24. What challenges do you think land managers and foresters face in real life situations?

Q25. What other factors, not presented in this activity, may affect the outcome?

- Now imagine a pest species that cannot be managed by buffer zones such as you experienced in this activity. For instance, there are spore-producing fungi that affect butternut trees in Tennessee. These spores can be carried on air currents, birds, cars, people, and other far-reaching carriers.
- Now answer the following questions:

Q26. What special challenges does this pest present to managers?

Q27. What are some ways that a manager may use to keep the pest from spreading across forests?

Q28. Why would it be important to preserve genetic diversity in the population of butternut trees?

- Check your answers in the answer section for Exercise 6c in the back of this book.

Exercise 6d: Bugs? In Our Trees?! (*Open-ended Exploration*)

- Many trees can be threatened with extinction when faced with introduced or invasive species. Do some research on one of the forest pests or pathogens presented below, or try to find an example of another forest pest that is or could become problematic in Tennessee.
    - Hemlock wooly adelgid (*Adelges tsugae*)
    - Balsam wooly adelgid (*Adelges piceae*)
    - Ips beetles (*Ips sp.*)
    - Gypsy moth (*Lymantria dispar*)
    - Pales weevil (*Hylobius pales*)
    - Pitch-eating weevil(*Pachylobius picivorus*)
    - Nantucket pine tip moth (*Rhyacionia frustrana*)
    - Emerald ash borer (*Agrilus planipennis*)
    - Red oak borer (*Enaphalodes rufulus*)
    - Asian longhorned beetle (*Anoplophora glabripennis*)
    - Beech scale (*Cryptococcus fagisuga*)
    - Beech bark disease (*Neonectria galligena*)
    - Dutch elm disease(*Ophiostoma ulmi*)
    - Dogwood anthracnose (*Discula destructiva*)
    - Thousand cankers disease (*Geosmithia morbida*)
- Though this exercise focuses primarily on insect pests, and to a smaller degree, pathogens, you may also wish to consider introduced and/or invasive plants that can also affect forest systems!
- Prepare a brief report of your findings to share with your classmates.

Grid for Exercise 6c: Managing Your Own Mixed Stand

ANSWER SHEETS

<u>Answers for Exercise 1: Dendrology: The Study of Trees</u>

Answers for Exercise 1a: Tree Trunks

<u>Answers for "Missing Parts" card game</u>

If the bark is missing …the tree will get sick.
If the phloem vessels stopped working…the tree is hungry.
If the heartwood rotted…the tree will fall.
If the xylem stopped working…the tree is thirsty.
If it lost all of its leaves…the tree is hungry.
If the cambium is missing…the tree will not grow.
If the roots are cut…the tree is thirsty.

Answers for Exercise 1a.2: Tree Rings and Tree Cookies

Discussion Question: The tree cookies in this box came from North American tree species. Many trees that grow in temperate climates (places where it is warm in the summer and cold in the winter) make annual tree rings like the ones you can see here. However, many trees that grow in tropical climates (places where it is warm all year) do *not* make annual rings. Why might this be?

In temperate climates, trees do most of their growing in the spring and early summer when it is warm and wet. In the fall, as it gets colder and dryer, trees start to grow more slowly – many lose their leaves, too. In the winter, most trees (even pines that keep their needles all year) don't grow much at all. So, the wood temperate trees produce during different times of year looks a little bit different, creating the patterns we call rings. But in the tropics where it is warm all year, trees grow continuously – so they don't make rings. However, in some tropical climates with otherwise consistent year-round temperatures, there are distinct wet and dry seasons, which might result in trees producing visible growth rings that correspond to these periods.

Answers for Exercise 1b: Forest Measurements

Q1. Using the equation above and a calculator, compute the missing circumference, diameter, or radius for each example below.

a. $C = 7.9$
b. $C = 18.8$
c. $D = 2.9$

d. $\boldsymbol{D} = 0.10$
e. $\boldsymbol{D} = 6$
f. $\boldsymbol{R} = 4$
g. $\boldsymbol{C} = 31.4$

Q2. Would it be practical to measure tree diameters in meters? Why or why not?
No. Meters are very large units, approximately equal to 3.28 feet. In most forests, many trees would be likely to be under a meter in diameter. If using metric units to measure the trees' diameters, centimeters are a more practical unit.

Q3. Would it be practical to measure tree heights in centimeters?
No. In a mature forest, most trees would be thousands of centimeters tall. Meters (if measuring the trees using metric units) would be much more practical.

Q4. How many acres are in a hectare?

1 hectare = 2.47 acres

Q5. A particular forest stand has an area of 2.35 hectares. Convert this area to acres, ft^2, and m^2.

2.35 hectares = 5.81 acres = 252,951.90 ft^2 = 23,500 m^2

Q6. How long, in feet, would the sides of a perfectly square 1 acre plot of land be?
A square plot with an area of 1 acre would have sides 208.71 feet long.

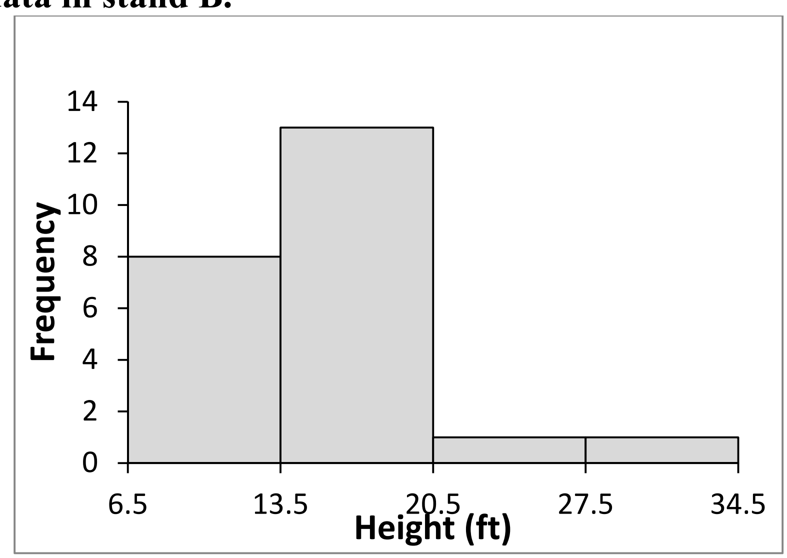
Q7. How long, in meters, would the sides of a perfectly square 1 hectare plot of land be?
A square plot of land with an area of 1 hectare would be 100 m on each side.

Q8. What is the stand density for Stand B?
Stand B has a density of 920 trees per acre.

Q9. Complete the data table for stand B, calculating basal area of each tree in in^2 and ft^2, as well as the volume of each tree.

DBH (in)	Height (ft)	Basal Area (in^2)	Basal Area (ft^2)	Tree Volume (ft^3)
5	8	20	0.14	0.28
11	16	95	0.66	2.64
4	7	13	0.09	0.16
8	14	50	0.35	1.23
7	20	38	0.26	1.30
9	14	64	0.44	1.54
6	11	28	0.19	0.52
8	22	50	0.35	1.93
6	12	28	0.19	0.57
2	10	3	0.02	0.05
4	8	13	0.09	0.18
4	14	13	0.09	0.32
6	20	28	0.19	0.95
3	15	7	0.05	0.19
10	14	79	0.55	1.93
5	16	20	0.14	0.56
6	18	28	0.19	0.86
1	10	1	0.01	0.03
7	14	38	0.26	0.91
9	19	64	0.44	2.09
9	20	64	0.44	2.20
6	7	28	0.19	0.33
15	34	177	1.23	10.46

Q10. Now make a frequency table and a histogram with four classes for the height data in stand B.



Q11. What general comparison can you make about the two stands in terms of tree height?

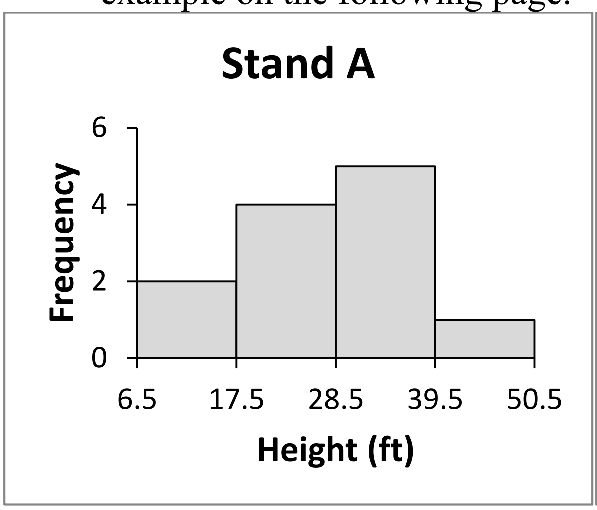
Stand A consists of trees that are taller on average than those in Stand B.

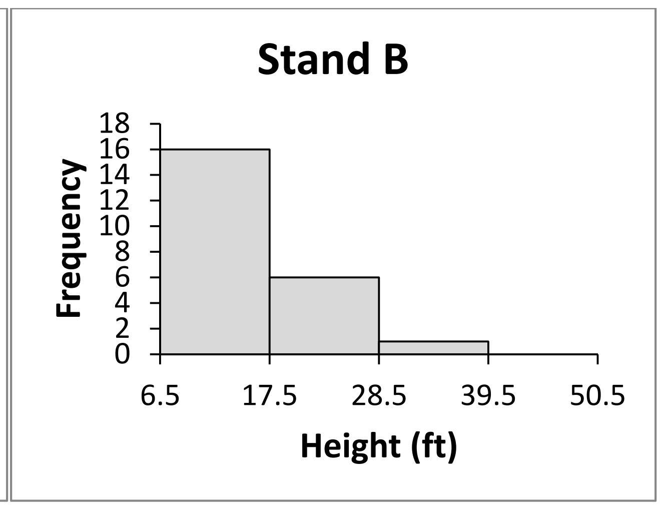
Q12. Were the two histograms easy to compare? Why or why not?

At first, one might think that these two histograms were relatively easy to compare. If you simply look at the class boundary points on each histogram, it is clear that the largest trees in Stand A are larger than those in Stand B. However, most of the trees in Stand A are in between 19.5 and 30.5 feet in height, and most of the trees in Stand B are between 13.5 and 20.5 feet tall. Because the above ranges of tree heights overlap somewhat, comparing Stands A and B might be slightly misleading.

Q13. Can you think of a way to make the two histograms easier to compare? If so, make new histograms of the height data for each stand.

One could make new histograms of each stand, using the same class widths and boundary points. In this case, you could calculate the class widths based on the overall minimum and maximum heights of all the trees. See the example on the following page.

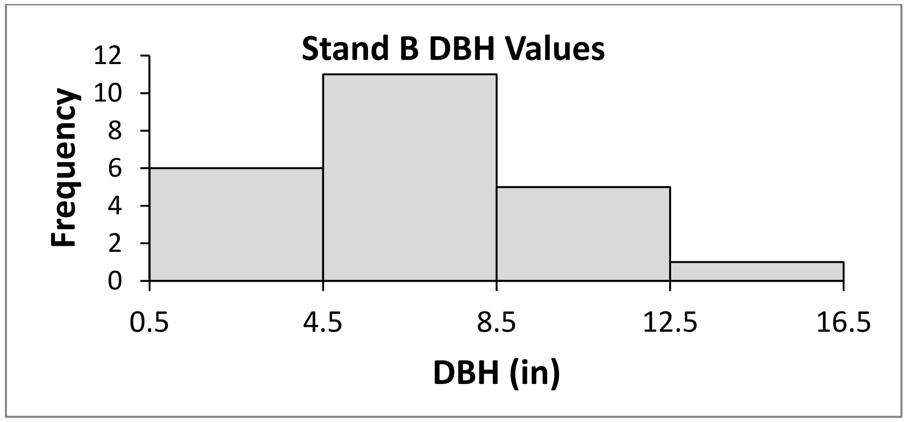




In the example histograms above, the equal class intervals and boundary points make it much clearer that the distribution of tree heights tends towards taller trees in Stand A.

Q14. Make a frequency table and a histogram with four classes for the DBH data in stand B.

DBH (in)	Frequency
0.5 – 4.5	6
4.5 – 8.5	11
8.5 – 12.5	5
12.5 – 16.5	1



Q15. Are the data you collected categorical or quantitative?
The data (types of birds) are categorical.

Q16. To visualize your data, would you want to make a bar chart or a histogram?
Since the data are categorical, you would make a bar chart to display them.

Q17. Are the data you collected categorical or quantitative?
The data (rates of photosynthesis) are quantitative.

Q18. To visualize your data, would you want to make a bar chart or a histogram?
Since the data are quantitative, you would make a histogram to display them.

Q19. Approximately how many trees, on average, from Stand B it would take to build the same house?
There is only a total of 31.23 cubic feet of volume in Stand B.

$$\frac{\text{total wood volume stand B}}{\text{total number of trees}} = \frac{31.23\ \text{ft}^3}{23\ \text{trees}} = 1.36\ \text{ft}^3\ \text{per tree}$$

- Now convert the average wood volume in stand A to board feet: imagine how twelve of the boards in Fig 6 stacked on top of each other would create a cube 1 foot by 1 foot by 1 foot. Therefore there are 12 board feet in a cubic foot.

$$1.36\ \text{ft}^3 \text{per tree} \times \frac{12\ \text{board feet}}{1\ \text{ft}^3} = 16.32\ \text{board feet per tree}$$

- If it takes 3000 board feet to build a house, then:

$$\frac{3000\ board\ feet}{one\ house} \times \frac{tree}{16.32\ board\ feet} \approx 184\ trees$$

You would need 184 average-sized trees from Stand B to build the house. Since there are only 23 trees in the stand, you'll have to find a bigger stand!

Answers for Exercise 1b.5: Foresters for a Day

Q1. Using a calculator, calculate tan (45º) = 1

Q2. Using a calculator, calculate tan (10º) = .18

Q3. If you are 10 feet from a tree, and using a clinometer you find the angle to the top of the tree is 31º, what else do you need to know to calculate the height of the tree? Explain how you would find this value.
You would still need to find ***e***, the distance between your eye and the ground. You could use a measuring tape to measure the height of your eye above the ground.

Q4. How can you measure the distance from the tree to your eye most accurately? Explain.
You can measure along the ground from your feet to the base of the tree. This distance would be the same since you and the tree are both standing at right angles to the ground. Measuring through the air might allow the tape measure to flop around.

Q5. If your measured θ angle is 60º, your distance from the tree 10 ft, and *e* is 3.8 feet, what is the height *h* of the tree?

$$\boldsymbol{h = e + x}$$
$$\boldsymbol{h = e + d \tan\theta}$$
$$\boldsymbol{h = 3.8 + 10\tan}(60^{\circ})$$
$$\boldsymbol{h = 3.8 + 17.32}$$
$$\boldsymbol{h = 21.12\ ft}$$

Answers for Exercise 1c: Leaves and Seed Cases

Below is a table showing the correct identities of each tree species' leaf and seed case specimens, as well as the type of seed case produced by each tree:

Common Name	Scientific Name	Leaf ID	Seed Case ID	Seed Case Type
Black Walnut	*Juglans nigra*	A	2	nut
Eastern Hemlock	*Tsuga canadensis*	F	13	cone
Eastern Hop Hornbeam	*Ostrya virginiana*	C	8	nut
Eastern Red Cedar	*Juniperus virginiana*	E	9	cone
Eastern Redbud	*Cercis canadensis*	H	11	legume
Flowering Dogwood	*Cornus florida*	D	5	drupe
Northern Red Oak	*Quercus rubra*	M	12	nut
Pignut Hickory	*Carya glabra*	G	14	nut
Sugar Maple	*Acer saccharum*	I	7	samara
Sweetgum	*Liquidambar styraciflua*	J	6	capsule
Tulip Poplar	*Liriodendron tulipifera*	K	1	samara
Virginia Pine	*Pinus virginiana*	L	3	cone
White Pine	*Pinus strobus*	N	10	cone
Yellow Buckeye	*Aesculus octandra*	B	4	capsule

Discussion question: Why would the trees producing cones prefer their seeds to be released when conditions are dry?

Since cones are dispersed by the wind, having them wait to open until a dry time ensures they will travel further, perhaps by rolling over dry land rather than being stuck in mud. Also, in some cases, the high heat of fire is required for cones to open – this ensures that the area around the seed will be relatively clear of competition.

Answers for Exercise 2: Wood Types

Answers for Exercise 2a: What's That Wood?

Wood Chip Answer Key

Letter	Type
A	MAPLE
B	PINE
C	BASSWOOD
D	ASH
E	BIRCH
F	OAK
G	WALNUT
H	CEDAR
I	TULIP POPLAR
J	CHERRY
K	MAHOGANY
L	PECAN

Answers for Exercise 2b: Wood Density

Q1. What values did you calculate for the density of each wood? Did your results of calculating the various woods' densities support your original hypothesis?

Student Answers for this question may vary, but many will likely find that their hypothesized rankings of density before measuring it are supported by the actual measurement of each wood's density. Below is a table showing typical range of densities for each wood type from this exercise.

Common Name	Scientific Name	Density (g/cm^3)
Balsa	*Ochroma pyramidale* or *O. lagopus*	0.10 – 0.17
White Birch	*Betula papyrifera* or *B. pubescens*	0.62 – 0.70
Lignum Vitae	*Guaiacum officinale* or *G. sanctum*	1.04 – 1.37

The values you calculated for the densities of these woods may differ from the values in the table. In addition to possible differences in moisture content, oils, etc., read the rest of the answers in this section for other possible reasons why your answers may fall outside of the ranges above.

Q2. If your results agreed with your original observations, would you say that your results *prove* your hypothesis or *support* your hypothesis? What is the difference between the two?

If measured densities of the woods corresponded to your hypothesized rankings of the density, the results ***support*** your hypothesis. They do not completely ***prove*** your hypothesis, as in science, nothing can ever be completely proven true. The only way you could ***prove*** your hypothesis to be correct would be to measure the density of ALL balsa, white birch, and lignum vitae wood on the entire planet, which would be impossible.

Q3. In the same way, if you rejected your hypothesis, does this *prove* that your hypothesis was wrong?

No. It merely does not support your hypothesis. Further testing of a larger sample might reveal results that actually support your hypothesis.

Q4. What are some ways you could improve upon or add to your testing methods?

Student answers for this question may vary.

Q5. What is the disadvantage of having only one sample of each wood type?

There may be something uncommonly different about that one sample. For example, a particular wood sample could have been taken from a part of a tree where the wood was formed during weather non-typical for the region of its origin. More tests will give more data and having more data will strengthen the reliability of your results.

Q6. What are some properties that would make a wood type heavy? See how many different properties you can think of.

Heavier woods may have more tightly packed tissue cells, and may contain chemicals that give the wood its color or scent.

Q7. Based on the densities that you calculated for each wood type, what type of behavior would you expect each wood to display if placed in water? (HINT: The density of pure water is close to 1 g/cm^3 at most temperatures.) After answering this question, test it out to see if you were right!

The balsa should have floated completely on the surface of the water, while the lignum vitae should have sunk to the bottom of the container of water. The birch should have also floated, similar to the balsa, but only partially above the water's surface. If an object is less dense than water, it will float. If it is more dense than water, it will sink. This is because when objects are placed into water, they displace an amount of water that is equal to their volume. The displaced water exerts an upward force on the object equal to the amount of water displaced. If the object has more mass than the water displaced, the downward force (due to the acceleration of gravity on the object) of the object is greater than the upward force of the displaced water, and the object will sink.

Q8. If any of the wood samples sank, can you think of some ways you could get a cube made out of that wood to float?

One easy way to do so without altering the cube in any way would be to simply increase the density of the water, such as by adding salt. A great example of this is that some objects that would sink in fresh water would float in the ocean. Seawater is denser than fresh water due to the presence of dissolved salts. Because of this, an equal volume of displaced seawater applies more upward force on an object than the force applied by fresh water.

Another way would be if you could somehow make a hollow cube of lignum vitae of the same size, but that had very thin walls. Even though this would still displace the same amount of water (since it would have the same volume), it would have less mass than the water that it displaced. This is exactly why a large boat made out of metal can float: because a lot of the volume occupied by such a boats is the air (which is less dense than water) that fills its cargo hold and/or hull, thus making the overall ***average density*** of the boat less than that of water. However, if you were to take the same amount of metal and crunch it into a solid ball (with no air), it would have much less volume, so would displace less water, which would provide less upward force to hold the metal up, and it would sink.

Q9. Based on your calculated densities of each of these woods, what types of uses do you think each might have? To help you think about this, you may wish to look over the properties of each of the other woods in the previous exercise, as well as see if you can find density values for them, and compare these to the woods in this exercise.

Balsa's low density makes it easy to work with for carving and crafts, though not very suitable for heavy-duty construction, as its soft wood doesn't hold nails very well. Balsa is often used for toys, such as model airplanes, but is also used in surgical splints. Its low density has often made it popular for building toy boats, but also floats and life belts or rafts. It also makes good insulation against heat and vibration.

Birch is often used in veneers and for making furniture and cabinets, and makes very sturdy plywood for indoor use. Its strength and resonance also make it popular in musical applications, such as speaker cabinets, drums, guitar bodies, and mallets for percussion.

Lignum vitae's high density and hardness makes it difficult to work, but good for heavy-duty purposes, such as pulleys, croquet mallets, and mortars and pestles. It is also the traditional wood used for British police truncheons (clubs). Lignum vitae also has a high content of oily resin, which gives it a self-lubricating property. This property, coupled with its durability, makes it ideal for underwater and at-sea uses, such as the propeller shafts and rigging for ships.

Q10. Based on your results, you should have learned that different species of tree differ in their wood densities. The growth habits and life histories of various species play important roles in the determination of the density of their wood. What aspects of the growth and life histories of the woods in this exercise might help explain these density differences?
Balsa and birch are fast growing pioneer, or weedy tree species. As they are among the first trees to invade a grassland or disturbed habitat, there is little competition for sunlight. In producing rapid growth in height, cell density is sacrificed. On the other hand, lignum vitae is a late succession tree species that grows slowly under the shade of a forest canopy. Rather than emphasizing height, these species put more energy into cell density. There is a greater energetic cost to producing high density wood, but there is greater stem longevity associated with higher cell densities.

Answers for Exercise 2c: Wood Porosity

Q10. One of the samples comes from a species of pine, and one comes from a species of oak. Can you tell which is which?
Tree core A, which does not display pores, comes from a pine. Tree core B, in which pores are present, comes from an oak.

Q11. If you were to dip chips of oak and pine in soapy water and then blow on one end, which one do you think would produce bubbles at the other end? Why would this happen?
Blowing on the oak chip would produce bubbles. Blowing on the pine chip would not. Oak is a porous wood with vessels (pores), while pine is a nonporous wood with tracheids. Vessels are hollow and tracheids are not.

However, there are some species of oaks that have pores, but their wood is not as porous as expected. This is because in species such as the white oak (*Quercus alba*) cells growing adjacent to the pores, fill them in.

Q12. What function do pores have for a tree?
Pores are part of the ***xylem*** tissue, which serves the important function of carrying water from the roots of a tree throughout the rest of the tree.

Q13. Which wood sample would come from a tree that will *not* easily suffer from cavitation?
The pine would not as easily suffer from cavitation, since the tracheids that carry water in gymnosperms like the pine are not hollow and narrow. They are thus less likely to allow the formation of air bubbles that may block water flow.

Q14. Based on the definitions above, which wood sample comes from an angiosperm, and which is from a gymnosperm?
The pine is a gymnosperm, and the oak is an angiosperm.

Q15. If you soaked these samples in water overnight, which one would absorb the most water? It turns out this is very important for choosing wood to build buildings with – why do you suppose this is so?
The oak would absorb the most water due to the presence of the large number of pores (vessels) in the wood. In fact, because they lack the vessels that make them more absorbent, conifers (gymnosperm cone bearing trees, like pine) are the most popular trees used in building log homes.

Answers for Exercise 3: Forest Products: Trees Are Good!

All of the products included in this exercise are, at least partly, made from some part of a tree. We harvest trees to make more than 5,000 products. Look at the guides to each of the provided items on the following pages to see from what parts of trees these items are made.

In addition to all of the products listed on the following pages, a few of the many other important uses of trees include oxygen, clean air, clean water, shade, foods and drinks, and recreation. As you can see, forests, and the products we obtain from them are very important!

BARK PRODUCTS

- **Aspirin:** Though it is now made synthetically, aspirin was originally obtained from extracts from the bark of willow trees (*Salix sp.*).
- **Cork:** Just about every tree has an outer layer of cork bark, but this layer in the tree called **cork oak** (*Quercus suber*) is extra thick. Cork oak grows in the Mediterranean region. Most of the cork products that are made come from the cork tree. The thick corky layer helps to protect the tree from harsh conditions, like droughts and fire, which occur frequently where the tree grows. The cork layer can be harvested from the cork oak about every 10 years. The tree can regenerate this cork layer and live for about 150 years.

Wax products, tannin, cork products, plastics, adhesives, flooring materials, soil conditioner, are among the many additional products made from tree bark.

LEAF PRODUCTS

- **Crayons:** The wax from the leaves of the **carnauba palm tree** (*Copernica cerifera*) is the ingredient that makes your crayons waxy.

Other uses for leaves include compost, essential oils, crafts, and more!

WOOD PRODUCTS

- **Clothespins:** Clothespins are manufactured from the wood of a tree.
- **Toothpicks:** Toothpicks are made from steamed birch logs. The logs are then peeled into a thin sheet. Flat toothpicks are stamped out of the sheets and round toothpicks are fed into a milling machine called a rounder, which shapes them.

CELLULOSE PRODUCTS

Cellulose is the material that makes up the cell walls in trees and other plants. To obtain cellulose from a tree, the bark is removed, and the underlying wood is chipped up, cooked, and chemically treated. The end product of this process is called **pulp**.

- **Cellophane:** To make cellophane, cellulose is further treated so that it forms this type of plastic that we use to wrap foods and other products, which keeps them fresh and safe from tampering.
- **Paper products**: Paper (toilet paper, notebook paper, magazines, newspapers, cardboard, etc.) is made from cellulose fibers that are strained, washed, and then bleached. Different kinds of pulp are then blended, drained, matted, dried, and compressed to make different types of paper. This may be one of the most important ways we are dependent on trees.
- **Photographic film:** Photo film is made with cellulose acetate, a chemical obtained from the processing of wood pulp. Cellulose acetate is clear, hard, and glossy compound which is also used in the coatings on playing cards.
- **Plastic combs:** Plastics made from cellulose fibers are also used to make combs and other items.
- **Rayon:** Rayon is also made from the plastic substance produced from treating cellulose fibers, just like cellophane.
- **Toothpaste:** Cellulose is also added to toothpaste to give it thickness and texture. (Also **terpene**, a wood derivative, is often added for the spearmint or peppermint flavors).

Other items made from tree cellulose include sponges, toilet seats, tool handles, helmets, electrical outlets, nail polish, solid rocket fuel, industrial explosives, eyeglass frames, steering wheels, hairbrush handles, and food thickeners in such yummy treats as milk shakes, ice cream, cake frosting, and pancake syrup!

RESIN PRODUCTS

Resin is the sticky stuff that a tree secretes to coat a wound. It helps to protect the tree from harmful microorganisms and insects. After making a shallow wound in a tree, the sap that is secreted from the wound is then collected in a tin that is strapped to the tree. This is called "**tapping**" a tree.

- **Gum:** Gum base is what makes some chewing gum chewy. A hard resin, called rosin in this case, is added to gum base to improve the texture.
- **Glue:** The stickiness of some gums makes them useful in the manufacture of glue and adhesives.
- **Latex:** Latex is a natural substance made from a milky, thick liquid, found in the **rubber tree** (*Hevea brasiliensis*). Experts can tap a tree to harvest the latex in such a way that the tree is not harmed, just as maple syrup is harvested each spring from sugar maple trees. After the latex has hardened it becomes the rubbery substance with which we are familiar. It was named rubber by the British chemist Joseph Priestly, who noticed that it could be used to rub away pencil marks.
- **Maple syrup:** This tasty resin product is obtained by tapping maple trees. This sap is boiled until only the sweet stuff you put on your pancakes remains.
- **Oils:** Some essential oils used in aromatherapy are derived from treating certain saps with alcohol.
- **Soap:** Some gums of certain trees have antiseptic qualities and are therefore used in making soap.

Other materials made from resin include paint, varnish, shoe polish, and turpentine. Musicians also use rosin on the bows of their stringed instruments to make the draw of the bow smoother, and baseball players (both pitchers and batters), gymnasts, and even bull riders also use rosin to improve their grip.

Answers for Exercise 4: Who Lives Here?

These answers are not *strictly* true. While all of these animals utilize different parts of the forest habitat, they can be found in a variety of places. These answers represent the BEST matches with the cards you have.

Critter card	Habitat card
Mole	Burrow
Mouse/Red Fox	Ground Den
Butterfly	Cocoon
Honey Bee/Hummingbird	Forest Flowers
Maple Leaf Miner	Maple Leaf
Fence Lizard/Cicada	Tree Trunk
Chipping Sparrow	Tree Nest
Ants/Millipede/Wolf Spider	Leaf Litter
Opossum/Hornet/Blue Jay	Tree Crowns
White-tailed Deer/Coyote	Forest Floor
Earthworms	Soil
Termites	Fallen Log
Green Treefrog/Snail	Moist Understory
Red-headed Woodpecker/Great Horned Owl	Tree Cavity
Chipmunk/Timber Rattlesnake	Hollow Tree

Q1. In what ways do these animals depend on the forest?

Many of these animals use forest habitats for shelter. Other animals may visit the forest to forage for food (such as nuts, berries, insects, etc.) that can only be found in a forest ecosystem. Others may use the clean waters of forest streams for activities such as drinking water or laying eggs.

Q2. How might the forest help an animal that may not even use trees to live?

The forest is a host to many plants and animals that are food for other animals. For instance, an animal that visits the forest may eat insects that primarily live in the forest.

Q3. How do some of these animals change the forest, and what do they do to influence it?

Some animals such as moles, mice, foxes, chipmunks, earthworms, termites, dig burrows that help aerate (provide oxygen to) the soil. This may influence the types of plants and animals that can live on (or in) the forest floor. Some organisms (lizards, frogs, snakes, spiders, birds, and sometimes mammals like mice, chipmunks and even foxes and coyotes) prey on insects (such as the maple leaf miner, termites, and cicada) and other invertebrates (such as the snail) that are herbivores that feed on and damage trees and other plants. Some mammals (such as the deer, mice, chipmunks, and sometimes even foxes and opossums), also eat plant material, including leaves, shoots, fruits, and seeds of trees and other plants. This is not always necessarily harmful, as these animals also often help disperse seeds to new locations, either in their fur, by dropping them, or passing them in their feces.

Some organisms, such as bees, hornets, and ants, and even birds like the hummingbird, act as pollinators that help many plants reproduce, and major predators, such as owls and coyotes, prey on a wide variety of other organisms. Scavengers like the opossum also help disperse seeds, but also help clean up dead organisms, reducing the spread of diseases in the forest. Organisms like millipedes eat and help break down the tough cellulose in fallen leaves, helping process them to eventually become soil.

Each of these processes can change the dynamics of the forest from its state before the animal interrupted that particular process. As you can see, forests are full of all sorts of interactions, each of which help shape the forest habitat in many ways!

Answers for Exercise 5: Forest Growth/Succession

Answers for Exercise 5a: The Succession Game: External Forces in Action

Q1. Were your forest patches able to grow back when external forces caused the loss of trees? If not, would they have come back in a few more rounds?

Your answers will vary, but in general, you should see that the forest is always changing, but that trees do grow back in time.

Q2. What factors helped the forest patches to advance in succession?

It was best when tree patches were next to patches that were either the same age or younger than them. This minimizes the effects of competition for sunlight. Also, soil patches near mature or old trees are beneficial, as they represent places for seeds to sprout and grow.

Q3. How could a manager use these trends to help manage a stable forest?

Managers could observe which stages benefited the most from being near other stages, then plan harvests to promote growth of nearby patches. Also, a manager might see that soil patches were in need of seed, and choose to seed them manually.

Q4. What factors caused you to lose trees?

As reflected in the External Forces cards, fire, pests, herbivory, weather, pollution, and other human activity, among many other factors, can all result in the loss of trees from forests.

Q5. What are some strategies you can use to help you reach your goal if your goal were a forest of mature trees?

Planting seeds in bare patches, thinning canopies to encourage understory tree growth, managing against pests, and managing to maintain wildlife that promote forest growth are just a few of many ways to reach the goal of a mature, healthy forest.

Q6. What could you do to help induce your bare patches to produce trees faster?

Plant seeds or seedlings.

Q7. Which patch type(s) seemed the least likely to change? Which patch type(s) was the most likely to change?

Managed forest and bare soil are the least likely to change. Seed, seedling, sapling, and young tree are the most likely to change. This should make sense in the context that management of forests is typically towards a particular stable goal, and that bare soil (perhaps representing a clearcut forest) takes a long time to become a mature forest. The fact that the younger tree stages are most likely to change reflects the fact that trees are at their most vulnerable at younger stages.

Q8. If you started out with all of your patches in the mature tree stage, what do you expect would happen? Try it!

You should find that you are unable to proceed in succession until external forces cause some of your patches to change. While this might seem like an ideal situation for a manager, a forest will not stay this way forever.

Answers for Exercise 5b: Probability in the Succession Game

Q9. What is the probability that you will draw a card that causes insect damage?

Two of the 27 cards cause insect damage. The theoretical probability is thus 2/27 = 7.4%

Q10. What is the probability you will draw a card where you may have to move a patch back to bare soil?

Nine of the 27 cards move patches to bare soil. The theoretical probability is thus 9/27 = 33.3%

Q11. What is the probability you will draw a card that causes damage from humans?

Four of the 27 cards involve damage from humans. The theoretical probability is thus 4/27 = 14.8%

Q12. Let's say you wanted to change the game to make it easier to move from an old or mature patch to a managed one. How many cards that don't advance to managed forest would you need to remove from the deck in order to make the probability you will draw a desired card 50%?

If you don't yet know algebra, you might use the "guess and check" method to get to the right answer. But if you know how, you can use algebra and proportions to solve this like so:

$$Probability = \frac{Desired\ Outcomes}{Possible\ Outcomes}$$

We would like the probability to be 50% or ½. In the existing deck there are 9 cards with the desired outcome. We want to solve for the denominator, possible outcomes, to see how many total cards we would need in our deck.

$$\frac{1}{2} = \frac{9}{x}$$

Through cross-multiplication: $2 \times 9 = 1 \times x$
Then simplify: $18 = x$

You will need 18 cards in your deck. Since the deck now has 27, you'll need to remove 27 – 18 = **9 cards** in order for your probability to be 50%.

Q13. Shuffle the cards. Draw five at random. From your results, calculate the probability of drawing a card which instructs you to move a mature or old patch to a managed patch. How does your answer compare to what was calculated in the example? How about when compared to others?
Your answers will vary, and that is the point to notice!

<u>Answers for Exercise 6: Forest Pests</u>

Answers for Exercise 6a: Infestation in a Monotypic Stand

Q1. Describe what happened to the pine plantation.
Answers will vary, but overall, most or all of the forest should have become infected by round 5.

Q2. What is the health of the plantation in year 5?
Not healthy at all!

Q3. Given this infection, in what year should you harvest to maximize profits?
This will vary depending on where you selected for the infestation to begin. Look for the highest value in the "Profit if Harvested" column. It may not be what you would expect!

Q4. What is a disadvantage to having a monoculture, or a forest with only one tree species?
A monoculture plantation is devastated if a pest attacks it. Since all of the trees are the same, all of the trees are likely to be affected.

Q5. What are some possible solutions for keeping an infestation contained?
Plant buffers of either trees that are resistant to pine beetles, or plant in a scheme using gaps that are larger than the dispersal ability of the female beetles.

Q6. Where would you want the infestation to start in order to have the most healthy trees after 5 rounds?
One of the four corners would be best. If you were incorrect, try this out to see for yourself.

Q7. In what year does the infection begin to level off?
The number of infected trees levels off at year 4.

Q8. On a separate sheet of paper, copy and fill in the corresponding table, including calculating the profits by year. In what year should the plantation manager have harvested to maximize profits?
The completed table can be found on the following page. The manager should have harvested in Year 2, when profits would have been at their highest, at $4500.

Year	# Healthy	# Infected	Profit if Harvested
1	35	1	35 × $100 + 1 × $40 = $3540
2	27	9	27 × $150 + 9 × $50 = $4500
3	16	20	16 × $200 + 20 × $60 = $4400
4	0	36	36 × $70 = $2520
5	0	36	36 × $70 = $2520

Q9. Looking at the game board, can you figure out where the infection may have started?
There are a few possibilities that would work, but one is row 2, column 3. Actually, it's just like in the "Example of spread of infestation" figure. Since the number of infected trees went from 1 to 9 in the second generation, you know the infestation had to start on one of the interior plots, since only those plots would have had enough neighbors to which the beetles could have spread in one generation.

Q10. If your teacher provides you with a copy of the same graph, use it to plot the infected trees from your plantation on the same plot in order to compare the infection progress. Which one progressed more quickly? Were the results in year 5 different?
Your answers will vary, based on your chosen initial starting point for the infection.

Q11. In a forest of 200 trees, 15 are infected. What percent are infected?

$$\frac{Part}{Whole} \times 100\% = \frac{15}{200} \times 100\% = 7.5\%$$

Q12. In a forest of 900 trees, 800 are infected. What percent are infected?

$$\frac{Part}{Whole} \times 100\% = \frac{800}{900} \times 100\% = 88.9\%$$

Q13. Forest X has 210 trees, 100 are infected. Forest Y has 70 trees, 40 are infected. Which one has the greatest percent infected?

Forest X:

$$\frac{Part}{Whole} \times 100\% = \frac{100}{210} \times 100\% = 47.6\%$$

Forest Y:

$$\frac{Part}{Whole} \times 100\% = \frac{40}{70} \times 100\% = 57.1\%$$

Since 57.1% > 47.6%, Forest Y has the greater percent infected.

Q14. In a forest of 36 trees, one is infected. What percent are infected?

$$\frac{Part}{Whole} \times 100\% = \frac{1}{36} \times 100\% = 2.8\%$$

Q15. In a forest of 36 trees, one is infected. What percent are *healthy*?

There are 2 potential ways to solve this:

(1)

- First find the number of healthy trees, 36-1 = 35
- Then solve using the equation

$$\frac{Part}{Whole} \times 100\% = \frac{35}{36} \times 100\% = 97.2\%$$

(2) Also, realize that since trees are either infected or healthy, and all trees together would equal 100%, you can use their answer from **Q14**:

100% - 2.8% = 97.2%

Q16. If you add up the percent of healthy trees and percent of infected trees in any given year, what do they add up to? Does that make sense? Why?
Together healthy and infected trees will add up to 100%. Since a tree can either be healthy or infected, this should make sense in that the parts (number of healthy trees and number of infected trees) must sum up to equal the whole (the total number of trees altogether).

Answers for Exercise 6b: Infestation in a Mixed Stand

Q17. What differences are there after 5 generations of beetle damage as compared to your monoculture?
A greater number of the trees are still undamaged.

Q18. What did planting alternate rows of hardwoods trees do for your pine trees?
It provided a buffer of trees that are resistant to the beetle. This kept the beetles from infecting all of the pines.

Q19. What are other management techniques that might result in the same outcome?
Managers can create gaps that are larger than the beetles' dispersal capabilities.

Q20. What happened to your pine tree profits in terms of selling harvested trees to timber and pulp companies?
In the short term, profits are lower because fewer of the trees can be harvested for profit. But in the long term if there is an infestation, profits are better if management techniques are used to guard against beetle attack. In this example, the maximum loss of trees to infestation would be 5, as opposed to all 36. More of the trees are able to grow to a higher value.

Q21. What are you compromising in trying to manage against Southern Pine Beetle damage?
It's a tradeoff between planting fewer pine trees and earning less money if there is no infestation or planting a monoculture of pine trees and losing more trees overall if there ***is*** an infestation.

Answers for Exercise 6c: Managing Your Own Mixed Stand

Q22. Which pattern did you find most effective?

Answers may vary, but below are some example configurations, where the positions of hickory plots are indicated by the letter “H”.

	H		H		
	H		H		
H	H	H	H	H	H
	H		H		
	H		H	H	H
	H		H		

		H			
		H			
		H			
		H			
		H			
		H			

			H		
			H		
			H		
		H	H		
		H			
		H			

The first configuration is an example of how one can arrange plots using the requirement of 18 hickory plots and 18 pine plots and lose no more than 4 pine plots to an infestation. In this configuration, a manager could make between $3780 and $4140 profit after 5 years, depending on the initial point of infestation.

The second and third configurations are two ways to plant a greater proportion of pines (thus increasing potential profits if there were no outbreak), while still protecting as many pines as possible if an infestation did occur. In the second, 40-60% of the trees could become infested, though you would still make a return (although smaller) on them. In this scenario, you could still make between $4260 and $5340 even if an infestation occurred. In the third, 48.2-51.7% of the trees could get infected, and you could make between $4550 and $4730. Though this is a smaller maximum profit, this scenario provides a greater minimum profit, and a smaller maximum percentage of trees infected (though a greater minimum percentage of trees infested). Either of these configurations could be considered the best possible solutions if an outbreak did occur, depending on your criteria. This should also be a good illustration of the difficulty of evaluating potential risks and profits in making management decisions, when considering such tradeoffs if an infestation does or does not occur. Did you find any configurations that came close to this example?

Q23. What challenges did you have in making your decisions?
Balancing the two requirements of maximizing profit while minimizing damages can be quite difficult. Each hickory patch planted results in zero profits in that patch, but hedges against possible infection and decreasing value of surrounding plots.

Q24. What challenges do you think land managers and foresters face in real life situations?
Finding the maximum yield, predicting possible outbreaks, and managing correctly are just a few of many challenges that land managers and foresters face.

Q25. What other factors, not presented in this activity, may affect the outcome?
Fire, pollution, market saturation of tree species, drought, and strains/genotypes of pines that differ in susceptibility to beetle damage are a few examples of other factors that could play important roles in similar situations.

Q26. What special challenges does this pest present to managers?
Since there are so many possible means of transmission of the pest/disease, it is practically impossible to manage each and every one of them. However, managers must consider the modes of transmission that are most likely to affect each plot in question, and manage those accordingly.

Q27. What are some ways that a manager may use to keep the pest from spreading across forests?
Various management practices might include application of chemicals that kill the pest (and/or insect vectors that may transport the pest), removal and destruction of infected individuals, taking care to thoroughly clean tools and clothing to avoid transporting the pest to other areas, culture and planting of individuals that are resistant to the pest, etc.

Q28. Why would it be important to preserve genetic diversity in the population of butternut trees?
If there is greater genetic diversity, then the possibility of resistance to the canker is greater.

SUGGESTED READING

Grades K-3

I See Animals Hiding - Jim Arnosky
The Tree of Time: A Story of a Special Sequoia - Kathy Baron
A Tree for All Seasons - Robin Bernard
Looking at Trees and Leaves (My First Field Guides) - Lara Rice Bergen & Tim Haggerty (Illustrator)
While a Tree Was Growing - Jane Bosveld & Daniel O'Leary (Illustrator)
One Small Place in a Tree - Barbara Brenner & Tom Leonard (Illustrator)
Deciduous Forests - Holly Cefrey
Grand Old Tree - Mary Newell Depalma
Forest - DK Publishing
Leaf Man - Lois Ehlert
Around One Log: Chipmunks, Spiders, and Creepy Insiders - Anthony D. Fredericks & Jennifer Dirubbio (Illustrator)
Trees - Linda Gamlin
In the Woods: Who's Been Here? - Lindsay Barrett George
Tell Me, Tree: All About Trees for Kids - Gail Gibbons
The Big Tree - Bruce Hiscock
Who Lives Here? Forest Animals - Deborah Hodge & Pat Stephens (Illustrator)
My Favorite Tree - Terrific Trees of North America - Diane Iverson
In the Forest - Gallimard Jeunesse & Pierre de Hugo
Flip, Float, Fly!: Seeds on the Move - JoAnn Early Macken & Pam Paparone (Illustrator)
The Mystery of the Tree Rings - Mark Meierhenry, David Volk, & Jason Folkert (Illustrator)
Are Trees Alive? - Debbie S. Miller & Stacey Schuett (Illustrator)
Oak Tree - Gordon Morrison
This is the Tree - Miriam Moss
Out of Thin Air: A Story of Big Trees - Nancy Muleady-Mecham, & Robert E. Muleady & Sandra Kim Muleady (Illustrators)
Counting on the Woods - George Ella Lyon & Ann W. Olson
The Forest - Claire A. Nivola
Old Elm Speaks: Tree Poems - Kristine O'Connell George & Kate Kiesler (Illustrator)
Who Will Plant a Tree? - Jerry Pallotta & Tom Leonard (Illustrator)
The Charcoal Forest: How Fire Helps Animals & Plants - Beth A. Peluso & Lynn Purl (Editor)
A Log's Life - Wendy Pfeffer & Robin Brickman (Illustrator)
In the Forest: A Nature Trail Book - Maurice Pledger
Rachel and Sammy Visit the Forest - Jannifer Powelson
Investigating Why Leaves Change Their Color - Ellen Rene
Seeds - Ken Robbins
A Whiff of Pine, a Hint of Skunk: A Forest of Poems - Deborah Ruddell & Joan Rankin (Illustrator)
Lost In the Woods - Carl R. Sams & Jean Stoick
Shelterwood - Susan Hand Shetterly & Rebecca Haley McCall (Illustrator)
One Small Square: Woods - Donald Silver & Patricia Wynne
Look What I Did with a Leaf! - Morteza E. Sohi
The Gift of the Tree - Alvin Tresselt & Henri Sorensen
Busy Tree - Jennifer Ward & Lisa Falkenstern (Illustrator)
Bear's New Friend - Karma Wilson & Jane Chapman (Illustrator)
Nature Hide & Seek: Woods & Forests - John Norris Wood & Maggie Silver (Illustrator)

Grades 4-6

Why Pi? – Johnny Ball
Trees of North America: A Field Guide to the Major Native and Introduced Species North of Mexico - C. Frank Brockman
Trees, Leaves, and Bark - Diane Burns & Linda Garrow

Grades 4-6 (continued)

Trees (National Audubon Society First Field Guide) - Brian Cassie
Julia Butterfly Hill - Dawn Fitzgerald
Life in a Forestry Community - Lizann Flatt
Forest Food Webs - Paul Fleisher
Why Do Leaves Change Color? - Terry Allan Hicks
Faces in the Forest - Ron Hirschi & Thomas D. Mangelsen
The Tree Book for Kids and Their Grown Ups - Gina Ingoglia
The Temperate Forest: A Web of Life - Philip Johansson
Take a Tree Walk - Jane Kirkland
Amazing Biome Projects You Can Build Yourself - Donna Latham & Farah Rizvi (Illustrator)
The Maple Syrup Book - Marilyn Linton & Lesley Fairfield (Illustrator)
Trees (Fantastic Facts) - Peter Mellett
Sir Cumference and the First Round Table – Cindy Neuschwander
Pharmacy in the Forest: How Medicines Are Found in the Natural World - Fred Powledge
Fire in the Forest: A Cycle of Growth and Renewal - Lawrence Pringle & Bob Marstall (Illustrator)
Longleaf - Roger Reid
Who on Earth is Aldo Leopold?: Father of Wildlife Ecology - Glenn Scherer & Marty Fletcher
Temperate Forests - John Woodward

Grades 7+

A&O Forestry (And Outdoor Enthusiast) Handbook - Thomas Anundson
Flames in Our Forest: Disaster or Renewal? - Stephen F. Arno & Steven Allison Bunnell
The Global Forest - Diana Beresford-Kroeger
Living in the Appalachian Forest: True Tales of Sustainable Forestry - Chris Bolgiano
Finding the Forest - Peter P. Bundy
Handmade Forests: The Treeplanter's Experience - Helene Cyr
Ecoforestry: The Art and Science of Sustainable Forest Use - Alan Drengson, Duncan Taylor, & Jerry Mander
American Chestnut: The Life, Death, and Rebirth of a Perfect Tree - Susan Freinkel
Elers Koch: Forty Years a Forester - Elers Koch
A Field Guide to Eastern Forests: North America (Peterson Field Guide) - John C. Kricher, Roger Tory Peterson (Editor), Gordon Morrison (Illustrator)
Forever Green: The History and Hope of the American Forest - Chuck Leavell
The Life of the Forest - Jack McCormick
Once Upon a Tree: Life from Treetop to Root Tips - James B. Nardi
Remarkable Trees of the World - Thomas Pakenham
The Hidden Forest - Sigurd F. Olson; Les Blacklock & Nadine Blacklock (Photographers)
The Urban Tree Book: An Uncommon Field Guide for City and Town - Arthur Plotnik & Mary H. Phelan (Illustrator)
The Tree Doctor: A Guide to Tree Care and Maintenance - Daniel Prendergast & Erin Prendergast
Forests (Diminishing Resources) - Allen Stenstrup
The Way of the Woods: Journeys Through American Forests - Linda Underhill
Forests: A Naturalist's Guide to Woodland Trees - Laurence C. Walker
Opportunities in Forestry Careers - Christopher Wille

All Ages

The Giving Tree – Shel Silverstein

Scientific Journal Publication (included on Teacher CD)

Stahle, D.W., M.K. Cleveland, D.B. Blanton, M.D. Herrell, & D.S. Gay. 1998. The Lost Colony and Jamestown Droughts. *Science* 280:564-567.

UT Extension Publications (all included on Teacher CD)

Bond, B. 2009. *Forest Products Measurements and Values*. Pub#PB1628, University of Tennessee Extension.
Bond, B. & P. Hamner. 2009. *Wood Identification for Hardwood and Softwood Species Native to Tennessee*. Pub#PB1692, University of Tennessee Extension.
Clark, C.D., L. Tankersley, G.F. Smith, & D. Starnes. 2009. *Farm and Forest Land Preservation with Conservation Elements*. Pub#SP646, University of Tennessee Extension.
Clatterbuck, W.K. 2009. *Changing Colors of Leaves*. Pub#SP529, University of Tennessee Extension.
Clatterbuck, W.K. 2009. *Dieback and Decline of Trees*. Pub#SP686, University of Tennessee Extension.
Clatterbuck, W.K. 2009. *Fast-Growing Trees*. Pub#SP616, University of Tennessee Extension.
Clatterbuck, W.K. 2009. *Growing Trees from Seed*. Pub#SP629, University of Tennessee Extension.
Clatterbuck, W.K. 2009. *Tree Wounds: Response of Trees and What You Can Do*. Pub#SP683, University of Tennessee Extension.
Clatterbuck, W.K. 2009. *Urban Trees for Wildlife*. Pub#SP530, University of Tennessee Extension.
Franklin, J. & D. Mercker. 2009. *Tree Growth Characteristics*. Pub#W227, University of Tennessee Extension.
Garton, S. & L. Tankersley. 2009. *What Are Those Plants Worth?*. Pub#SP614, University of Tennessee Extension.
Hale, F.A. & J.F. Grant. 2009. *Insect Defoliators of Ornamental Trees and Shrubs*. Pub#SP609, University of Tennessee Extension.
Hale, F.A. 2009. *Insects: The Hemlock Wooly Adelgid - A Threat to Hemlock in Tennessee*. Pub#SP503-G, University of Tennessee Extension.
Hale, F.A. & M.A. Halcomb. 2009. *Common Tree Borers in Tennessee*. Pub#SP547, University of Tennessee Extension.
Harper, C.A. 2009. *Growing and Managing Successful Food Plots for Wildlife in the Mid-South*. Pub#PB1743, University of Tennessee Extension.
Harper, C.A. 2009. *Improving Your Backyard Wildlife Habitat*. Pub#PB1633, University of Tennessee Extension.
Hennings, J.G. & D.C. Mercker. 2009. *Conducting a Simple Timber Inventory*. Pub#PB1780, University of Tennessee Extension.
Hooper, G.M., H. Applegate, G. Dale, & R. Winslow. 2009. *Forest Practice Guidelines for Tennessee*. Pub#PB1523, University of Tennessee Extension.
Jackson S.W. & W.K. Clatterbuck. 2009. *Identification and Control of Non-Native Invasive Forest Plants in Tennessee*. Pub#SP627, University of Tennessee Extension.
Johnson, J.E., G.A. Scheerer, G.M. Hopper, J.A. Parkhurst, M. King, J.C. Bliss, & K.M. Flynn. 2009. *Managed Forests for Healthy Ecosystems*. Pub#PB1574, University of Tennessee Extension.
Jones, D., D. Harper, & A. Taylor. 2009. *Wood Pellets - An Introduction to Their Production and Use*. Pub#W214, University of Tennessee Extension.
Kimbro, C.C. 2009. *Developing an Outdoor Classroom to Provide Education Naturally*. Pub#W113, University of Tennessee Extension.
Mercker, D. 2009. *Forest*A*Syst: Self Assessment to Prioritize Your Forest Uses*. Pub#PB1679, University of Tennessee Extension.
Mercker, D. 2010. *Marketing Timber in Tennessee*. Pub#PB1790, University of Tennessee Extension.
Mercker, D. 2009. *The Business of Carbon Credit Trading for Forest Landowners*. Pub#W217, University of Tennessee Extension.
Mercker, D. & G. Hopper. 2009. *Why Do Trees Die?*. Pub#SP615, University of Tennessee Extension.
Mercker, D., D. Buckley, & B. Ostby. 2009. *Identifying Oak Trees Native to Tennessee*. Pub#PB1731, University of Tennessee Extension.
Mercker, D., J. Franklin, & L. Tankersley. 2009. *How Do Acorns Develop?*. Pub#W126, University of Tennessee Extension.
Oswalt, C.M. & W.K. Clatterbuck. 2009. *Impacts of Air Pollution on Urban Forests*. Pub#SP657, University of Tennessee Extension.
Tankersley, L. 2009. *Native Trees for Tennessee*. Pub#SP515, University of Tennessee Extension.
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Taylor, A., V. Yadama, K.R. Englund, D. Harper, & J. Kim. 2009. *Wood Plastic Composites - A Primer*. Pub#PB1779, University of Tennessee Extension.
Williams, M.D. & W.K. Clatterbuck. 2009. *The All Season Pocket Guide to Identifying Common Tennessee Trees*. Pub#PB1756, University of Tennessee Extension.

LINKS

Exercise 1: Dendrology: The Study of Trees

Crossdating: Introduction – A cool site from The University of Arizona, Tucson's Laboratory of Tree Ring Research, which has an interactive exercise allowing students to cross date tree cores based on their rings. Probably most appropriate at the high school level, or perhaps for fairly advanced middle school students.
http://www.ltrr.arizona.edu/skeletonplot/introcrossdate.htm

Dendrochronology - A fairly advanced, yet succinct introduction to dendrochronology, including its history, principles, and utility.
http://sonic.net/bristlecone/dendro.html

Forests: What Are the Parts of A Tree? - This site from EcoKids gives a good very basic introduction to parts of a tree. Also contains links to other good introductory info on forests.
http://ecokids.ca/pub/eco_info/topics/forests/parts_of_a_tree.cfm

Label Tree Anatomy Printout - A great simple printout for younger students to color and label parts of a tree.
http://www.enchantedlearning.com/subjects/plants/label/labeltreesimple/

Measuring the Tree Trunk - A site from the Fenner School of Environment and Society (associated with the Australian National University) on taking measurements of tree trunks.
http://sres-associated.anu.edu.au/mensuration/BrackandWood1998/DBHOB.HTM

NASA - First-of-its-Kind Map Depicts Global Forest Heights - A super cool site from NASA that shows data on forest heights obtained from space!
http://www.nasa.gov/topics/earth/features/forest-height-map.html

NOVA Online | The Vikings | Build a Tree-Ring Timeline - A really neat page that includes an interactive exercise on dendrochronology.
http://www.pbs.org/wgbh/nova/vikings/treering.html

Real Trees 4 Kids – A great site sponsored by the National Christmas Tree Association with TONS of information on trees for kids, broken down into several pages based on grade level, as well as resources for teachers.
http://www.realtrees4kids.org

UT Knoxville | Forest Resources Research and Education Center - A great UT site with lots of tree facts, featured plants, videos, and other great links about the forests of Tennessee, and forests and forestry in general.
http://forestry.tennessee.edu

Exercise 2: Wood Types: What Wood Would You Use?

Amateur Woodworker: Wood Types - A site giving descriptions and uses of many different types of wood.
http://www.am-wood.com/wood/wood.html

Friends of the Earth: Different types of wood timber: Good Wood Guide - A great website with TONS of information on various wood types, with information on region of origin, as well as conservation status, to assist in making environmentally conscious decisions when buying/using wood.
http://www.foe.co.uk/campaigns/biodiversity/resource/good_wood_guide/wood_timber_types_a_to_g.html

NASA - What on Earth are "Moon Trees?" - A really cool site from NASA. Instead of spoiling the coolness for you, we suggest you just go check it out!
http://www.nasa.gov/centers/kennedy/news/moon_trees.html

The Space Place :: Sorting Out Trees in the Forest - Another awesome site from NASA describing how different tree species can even be identified from space with current technology!
http://spaceplace.nasa.gov/en/kids/eo1_1.shtml

Exercise 3: Forest Products: Trees Are Good!

Forest Products Extension at the University of Tennessee - "Forest and wood products are an important part of the environment, culture and economy of Tennessee. The Forest Products Extension Program at the University of Tennessee exists to assist the wood products industry and the citizens of Tennessee through information transfer and applied research." Contains maps of TN wood industry, as well as extension forest products publications.
http://web.utk.edu/~mtaylo29/default.html

UT Knoxville: Forest Products Center - Great UT website with lots of cool information about forest products, including forest product research going on right here in our home state of Tennessee! Lots of great links full of info to explore! http://wood.tennessee.edu/

Exercise 4: Who Lives Here?

Deciduous Forest Biome - A nifty overview of decidous forests, including information on locations of these forests on earth, climate, and details of several forest plants and animals.
http://www.blueplanetbiomes.org/deciduous_forest.htm

eNature: FieldGuides - Excellent online field guide that allows you to enter your ZIP code to access field guides to plants and animals in your area!
http://www.enature.com/fieldguides

Ijams Nature Center - Located in Knoxville, Ijams is a "275-acre wildlife sanctuary and environmental learning center, providing community-wide connections and experiences through education, conservation, recreation and responsible environmental stewardship for all people." A great place to visit and walk in the woods to see plenty of trees, other forest plants, and forest critters!
http://www.ijams.org

Special Habitats of Tennessee - Supported by the National Geographic Society Education Foundation, the Tennessee Geographic Alliance, and many other sponsors, this website focuses on, you guessed it, special habitats found in Tennessee. Teachers and students can register their schools to participate in collaborative projects to form a network of information about their own local special habitats and wildlife in Tennessee. Geared primarily towards grades 4-6.
http://specialhabitats.net

Tennessee Wildlife Resources Agency - State website with lots of great information about Tennessee's wildlife.
http://www.state.tn.us/twra

Temperate Deciduous Forest Animal Printouts - Information on temperate deciduous forests, along with pictures and information on forest animals from around the world (approximately at the 4th-5th grade level).
http://www.enchantedlearning.com/biomes/tempdecid/tempdecid.shtml

TLC Family Animal Crafts - Lots of cool animal-related activities and crafts for all ages.
http://tlc.howstuffworks.com/family/animal-crafts-guide.htm

What's It Like Where You Live? - Great website covering the many diverse biomes and ecosystems on earth. The link below goes to the main page for temperate deciduous forests, with lots of additional subtopics on temperate deciduous forests, and other cool links!
http://www.mbgnet.net/sets/temp/index.htm

Wildlife Extension - UT's Wildlife Extension site contains links to several publications on wildlife research in Tennessee.
http://fwf.ag.utk.edu/Extension/wildlife.htm

Exercise 5: Forest Succession

American Field Guide: Primary and Secondary Succession in America's Forests - A site from PBS with three grade 9-12 classroom activities for learning about forest succession.
http://www.pbs.org/americanfieldguide/teachers/forests/forests.pdf

Ecological Succession - Middle school level information on succession from Barry Hoffman, an 6th grade math & science teacher at Weber Middle School in Port Washington, New York.
http://hoffkids.com/Succession%20science%20homework.htm

Exploring Nature: Forest Succession - Good introductory information (including a video) from Exploring Nature.
http://www.exploringnature.org/db/detail.php?dbID=27&detID=1207

MI Watchable Wildlife: Ecology - Succession - Short interactive introductory lesson on succession from Michigan's Department of Natural Resources.
http://www.dnr.state.mi.us/publications/pdfs/wildlife/viewingguide/eco_succession_rollover.htm

Exercise 6: Forest Pests

BugGuide.Net – Do you have bugs on your trees or other plants, or maybe you just found a cool bug that you want to identify. This site is THE one-stop shop for insect (and other invertebrate) identification. Browse through the extensive photographic field guide, or even submit your own insect photos to be identified by experts!
http://bugguide.net

Forest Pests – Great site with tons of info on forest pests, including insects, diseases, and weeds, as well as other agents of forest damage. http://www.forestpests.org

Invasive.Org – From the Center for Invasive Species and Ecosystem Health, this site is a comprehensive source for information on invasive species. http://www.invasive.org

NASA Finds Trees and Insect Outbreaks Affect Carbon Dioxide Levels - Though a few years old (2004), this study by NASA is quite pertinent to the topics outlined in this exercise.

http://www.nasa.gov/vision/earth/environment/climate_bugs.html

Study Finds Hemlock Trees Dying Rapidly, Affecting Forest Carbon Cycle - Data from NASA that is extremely relevant to forests and forest pests in Tennessee.

http://earthobservatory.nasa.gov/Newsroom/view.php?id=37301

General Links

Arbor Day Foundation - A well-known 501(c) organization devoted to "inspiring people to plant, nurture, and celebrate trees."

http://www.arborday.org/

Forestry Extension - The University of Tennessee Knoxville's Forestry Extension site. Contains interesting links to departmental and extension research, other forestry organizations in Tennessee, and publications about Tennessee's forest treasures.

http://fwf.ag.utk.edu/Extension/forestry.htm

TDA - Forestry Division - The Tennessee Department of Agriculture's Forestry site, which contains lots of great info on management, urban forests, forest health, forest pests and diseases, state timber sales, and much more. Great overall link that has information tied to all exercises in this unit.

http://www.state.tn.us/agriculture/forestry

TDA - Tennessee's State Forests - Links to information on Tennessee's 15 beautiful state forests. This could provide good field trip ideas!

http://www.state.tn.us/agriculture/forestry/stateforests.htm