Carbon Cycle
Field Measurements

How do Scientists Measure Trees?

Biomass Units

Allometry: Not A Llama Tree

Conducting Field Work

GLOBE Carbon Cycle

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Any opinions, findings, conclusions or recommendations expressed in this material are those of the developers and do not necessarily reflect the views of the National Science Foundation.

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Field Engagement Activities

To make field data collection meaningful, it is important to understand why data is being collected and how it will be used later. Before going outside, consider the essential question -

How much carbon is being stored in the forest ecosystem near my school?

To learn how scientists answer this question, perform field engagement activities, which are designed to progress through the basic concepts of tree measurement and carbon storage calculation.
The concept flow chart (Figure 1) shows the progression of concepts covered in the engagement activities, *How to Measure Trees, Biomass Units* and *Allometry, Not a Llama Tree*.

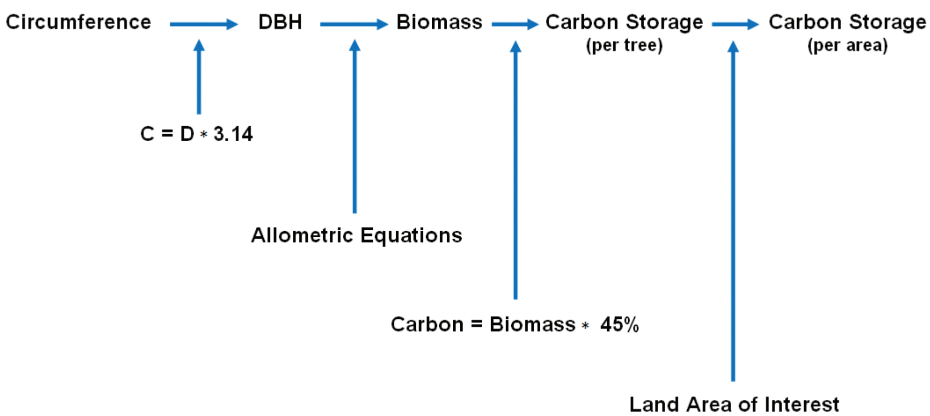

Figure 1, Flow chart displaying progression of concepts

Each part of the concept flow chart can be broken down by section and is covered by a specific engagement activity (Figures 2, 3 and 4).

How Do Scientisits Measure Trees?

Scientists use a standard method to measure the size of trees, diameter-at-breast height (DBH), to ensure consistency over time, across plots and between data collectors. DBH means the diameter of each tree is measured at "breast height", defined as 1.35 meters up from the highest point of ground at the tree's base (See *How do Scientists Measure Trees? Figure 1, Tree Circumference Guide*, for some pictorial examples). DBH measurements can be used to estimate the volume, biomass, and carbon storage of trees - to learn more about the relationship between DBH and biomass refer to the activity, *Allometry: Not a Llama Tree*. Keep in mind that circumference and DBH are the first two steps in the process of understanding biomass and carbon storage in local ecosystems.

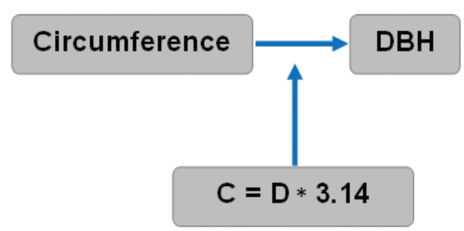

Figure 2, Concepts of Measuring Trees activity

From geometry class, we know that diameter is a line that passes through the center of a circle, with the endpoints of the line located on the edge of the circle. How then can foresters and scientists measure tree diameter without cutting down the tree and measuring its cross section? Scientists measure the circumference of a tree and calculate the diameter using Equation 1 (below). Scientists sometimes use tape measures that are calibrated or adjusted for diameter based on this equation. These tapes are referred to as DBH tapes. During the GLOBE Carbon Cycle field data collection, tree circumference is measured rather than diameter (due to tool restrictions); therefore it is important to understand how they are related.

Circumference = π × diameter (where π = 3.14) or Diameter = Circumference ÷ π [equation 1]

Biomass Units

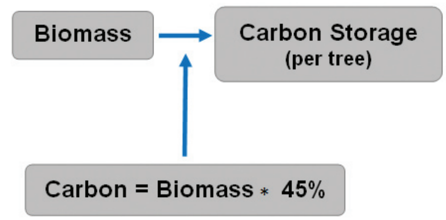

Figure 3, Concepts of Biomass activity

Biomass is the total mass of living material measured over a particular area. Because all living things contain water (fresh weight) and the percentage of water can vary widely from species to species, biomass is calculated as a dry weight. Dry weight is the mass of life that is left after all the water is removed, much like squeezing out a sponge. For plants, scientists use an oven to remove all the water from the plant material before weighing it to determine its biomass. **Total biomass** is found by summing the dry weight biomass of all individuals in a given land area and then reported by naming the area of concern, e.g. biomass per plot, ecosystem, biome, classroom. To be able to compare biomass in different locations, scientists standardize biomass per unit of area. Typical units of biomass are grams per meter squared (g/m^2), although you will also see kg/m^2, lb/ft^2, etc.

[Biomass = dry weight/area]

While knowing an ecosystem's biomass is useful for many applications such as farming, logging, and wildlife management, another helpful unit of measure in an ecosystem is how much carbon is stored.

Understanding how terrestrial ecosystems store and transfer carbon to and from the atmosphere is essential to understanding climate change, so biomass is often converted to carbon storage (For more information on the role of carbon in climate, see the *Carbon Cycle Introduction Activities* - think photosynthesis, the global carbon cycle and the greenhouse effect). But how do scientists know how much carbon is being stored? All life (biomass) is composed of carbon molecules, and as it turns out plant matter is actually 45% carbon by dry weight. This means once biomass has been calculated, it can be multiplied by 0.45 to achieve approximate carbon content.

Allometry: Not a Llama Tree

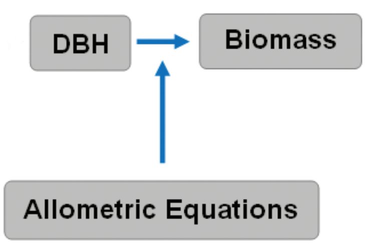

Figure 4, Concepts of Allometry activity

If biomass is a key unit of measurement for understanding ecosystems, it is essential that we have a way to measure it. Logically, it makes no sense to measure the mass of trees by cutting down and weighing them on a scale every time. This would ultimately mean destroying the ecosystem we are trying to understand. Because this is the case, over time, scientists have cut down many trees of different sizes and species to look for relationships between parts of the tree that can be measured easily, such as DBH or height and the whole tree's biomass. The study of this kind of relationship is known as **allometry**.

Allometry is the study of an organism's growth, as is used to describe the relationship between an organism's size and the size of any of its parts. Allometric relationships can be studied during the growth of a particular organism, as a comparison between organisms of the same species or between organisms of different species. Allometric relationships are best shown on a graph where body size is depicted on the y-axis and body part size is depicted on the x-axis (Figure 5). As individual measurements are added to the graph, a scatter is produced. The average through that scatter (a regression line) determines the allometric equation.

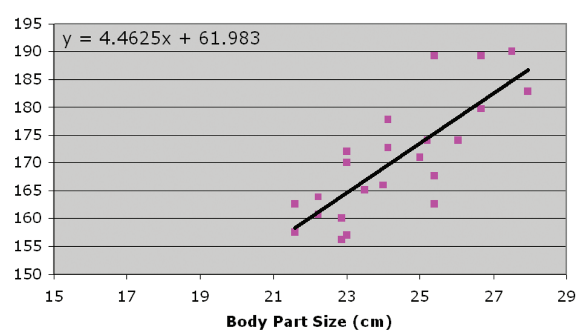

Figure 5, Allometric equation depicted in a graph

Allometric equations often take the form of:
$y = mx + b$ (line equation)
where y = body size, x = body part size, m = slope, and b = y-intercept value of a straight line.

Not all allometric relationships are linear, such as the relationship between tree DBH and tree biomass. When this is the case, a nonlinear equation, such as log or natural log might be used. Log equations and their transformations can be confusing. For clarification see the Log Calculations Example in the appendix and/or talk to a math teacher.

$\ln(y) = a + b[\ln(x)]$
where y = body size, a and b are coefficients and x = body part size

A log transformation will allow you to solve for y.
$y = e^{(a + b[\ln(x)])}$

The exact form of equations students will see in the Plot Biomass Analysis is:
biomass = Exp(B0 + B1 ln dbh), where ln = log base e (or 2.718282).
If your students participate in the field data collection and analysis, they will need to understand the basics of tree allometry. During *Sample Site Biomass Analysis* students will be able to view their circumference field data in the spreadsheet calculator and a version of the above equation, which is used to calculate biomass. Although a similar equation exists for all trees, they will differ slightly for different tree species groups. These equation differences between species groups largely exist due to differences in tree wood density.

The Allometry activity addresses the connection between the two previous concept activities, DBH and biomass. By the end of the activity students should understand why they are collecting tree circumference data and how real data are used to create valuable equations.

How do Scientists Measure Trees?

Purpose

- Students will develop an understanding of tree size and how scientists measure trees. Students will observe and measure tree cookies and explore the relationship between tree circumference and diameter.
- Students will compare the estimates of diameter made from circumference measurements (and vice versa).

Overview

Students will observe and explore the relationship between circumference and diameter using tree cookies (cross sections from real trees).

Essential Question

How do scientists measure trees?

Sub-Questions

What is the relationship between circumference and diameter?

What is diameter-at-breast-height (DBH)?

Student Outcomes

- Students will observe the physical characteristics of and suggest ways to measure tree cookies (e.g., cross sections of real trees).
- Students will work with a partner to measure the circumference and diameter of one tree cookie.
- Students will work with a partner to calculate circumference or diameter of the tree cookie based on the equation of a circle. Students will compare and contrast the calculated circumference and diameter values to the actual measurements.

Science Concepts

Change, constancy, measurement

Abilities necessary to do scientific inquiry

Time

60 - 90 minutes

Level

Secondary (Middle & High School)

Materials and Tools

- Several different sized tree cookies (1 per student pair)
- Flexible measuring tape (metric) (1 per student pair)
- Calculator (1 per student pair)
- Notebook and pencil (1 per student)
- Items for circumference height tool (Optional)
  - Sticks and permanent marker OR Strings and scissors (see part 2)

Preparation

Write the main essential question on the board. Gather all materials for the activity.

Prerequisites

Basic skills in calculating average (mean) numbers.

Background

Scientists use a standard method to measure the size of trees diameter-at-breast height (DBH), to ensure consistency over time, across plots and between data collectors. DBH means the diameter of each tree is measured at “breast height”, defined as 1.35 meters up from the highest point of ground at the tree’s base. Appendix A, *Tree Circumference Guide* provides some pictorial examples. DBH measurements can be used to estimate the volume, biomass and carbon storage of trees (To learn more about the relationship between DBH and biomass refer to the activity, *Understanding Allometry*). Figure 1 shows the progression of concepts students need to understand the amount of carbon being stored in forested ecosystems. The concepts addressed in this activity are highlighted in gray. Notice that circumference and DBH are the first two steps in the process of understanding biomass and carbon storage in local ecosystems.

From geometry class, we know that diameter is a line that passes through the center of a circle, with the endpoints of the line located on the edge of the circle. How then can foresters and scientists measure tree diameter without cutting down the tree and measuring the cross section? Scientists measure the circumference of a tree and calculate the diameter using equation 1 shown below. Scientists sometimes use tape measures that are calibrated (or adjusted) for diameter based on this equation. These tapes are referred to as DBH tapes. During the GLOBE Carbon Cycle field data collection, however, students will measure tree circumference rather than diameter (due to tool restrictions); therefore it is important for them to know how circumference and diameter are related.

Circumference = π × diameter (where π = 3.14) or Diameter = Circumference ÷ π [equation 1]

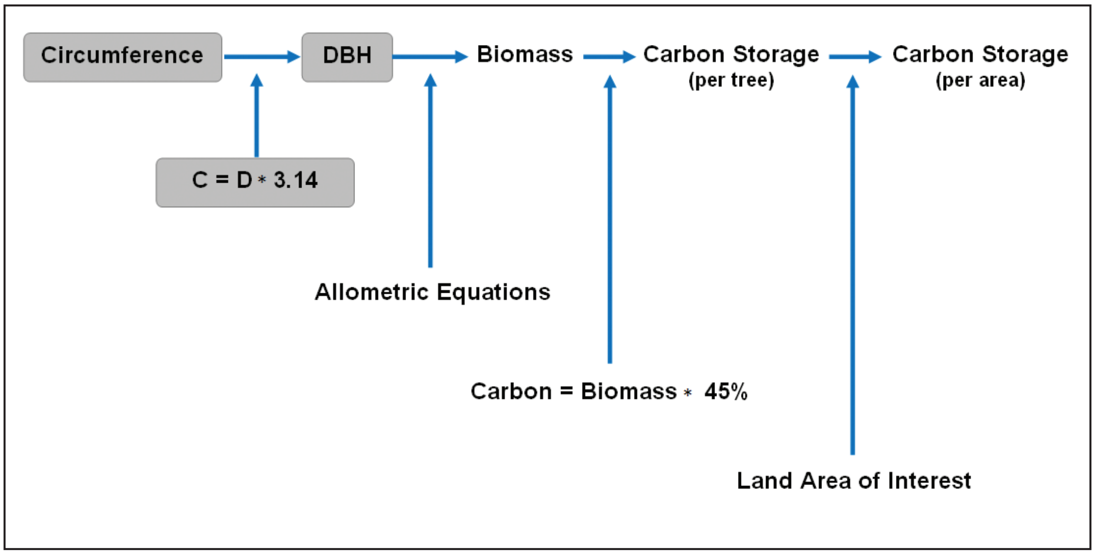

Figure 1, Field Concepts for " How do Scientists Measure Trees?"

What To Do and How To Do It

	Student Grouping	Time
	Student Grouping: Partners (Part 1)	**Time: 5 minutes**

ENGAGE	• In groups of two, students select a tree cookie and complete Part 1a of the Student Directions.
	• Class discussion of student's observations and suggestions for tree cookie measurement.
	• Introduce the essential question, equation 1, and set the expectations for Part 2.
	  ◦ Demonstrate to measure the circumference and diameter of a tree cookie.
	  ◦ Remind students how to calculate an average if necessary.	

	Student Grouping: Partners (Part 2)	**Time: 20 minutes**
EXPLORE	• Students conduct measurements and calculations as directed on the student sheet. This is a proof of concept exercise to show students how diameter and circumference are related.	
	Student Grouping: Entire Class	**Time: 15 minutes**
EXPLAIN	• Interpret the measurements and discuss answers student questions #5a-c. • Use question 5c as a lead in to the next part of the activity: How might scientists (and you) use the circumference/diameter relationship to study live trees? • Discuss the standard height at which circumference (diameter) is measured, 1.35m, called diameter-at-breast-height (DBH). • Students create a tool for measuring that height in the field. ◦ Ahead of time you should select the method students should use. • This is a good point to have a discussion about accuracy and precision. You may want to brainstorm some ideas about what those terms mean before students read about them in Student Directions: Part 3	
	Student Grouping: Partners (Part 3)	**Time: 30 minutes**

ELABORATE/ INVESTIGATE	• Students determine the height of 1.35m against their own body.
	• Students follow teacher directions to create a height measurement tool. [Optional]
	  ◦ Use a measuring tape or meter stick, measure out 1.35m:
	    • on a stick and mark with a permanent marker
	    OR
	    • on a string and cut the string so it is exactly 1.35m tall
	• Students perform activities to investigate accuracy and precision	

	Student Grouping: Whole Class	**Time: 10 minutes**
EVALUATE/ WRAP-UP	• Introduce the Field Concepts Diagram and highlight the first step, which this activity supports. **See activity example in HowToMeasureTrees_example.xls	

Assessment

- Students should answer the essential question individually and explain the connection between this activity and the upcoming field work.

Name: ________________________________ **Date:** _______________________

Student Directions: How do scientists measure trees? What is DBH?

Part 1: Tree Cookie Observations

1. Record the physical traits of your selected tree cookie. Draw and/or describe.

2. Suggest some ways that your tree cookie could be measured to learn about its size.

Essential Question: How do scientists measure trees?

Part 2. Circumference versus Diameter

1. Measure 1 tree cookie per group
   ◦ Pull the measuring tape tightly around the tree cookie and record its circumference in the data table below. Repeat the circumference measurement 2 more times on the same tree cookie.
   ◦ Measure the tree cookie's diameter and record in the data table. Repeat the diameter measurement 2 more times. Note: Measure the diameter in several directions across the surface of the tree cookie, as they will not be perfectly round and you want to make sure your measurements represent the overall shape of the tree cookie

2. Calculate an average (mean) circumference and average (mean) diameter for the tree cookie.
   ◦ Finding the average of both circumference and diameter measurements: Sum all of the values of each type then divide by the # of values.

3. Use equation 1 and the appropriate calculated averages (of circumference and diameter) to find a calculated circumference and diameter

Circumference = π × diameter (where π = 3.14) or Diameter = Circumference ÷ π [equation 1]

4. Compare calculations to your averages.

	Measured (1)	**Measured (2)**	**Measured (3)**	**average (1 + 2 + 3) ÷ 3**	**Calculated (using Equation 1)**	**Notes**
Circumerence						
Diameter						

Answer the following questions:

◦ How similar are your measured circumference values? How similar are your measured diameter values?

◦ Why might calculated values be different from measured average values?

◦ How might scientists (and you) use the circumference/diameter relationship to study live trees?

Welcome Introduction Learning Activity Protocols Appendix

Part 3. Prepare to measure tree circumference in the field

1. How high is 1.35 meters
   - Measure 1.35 meters (m) from the ground and determine where this falls on your body (nose/neck/shoulder/etc.) as a basic reference. This reference point will be used when making field measurements. By standing near a tree, and using this reference point, you will not have to measure from the ground at each tree to determine the correct height. (Question to consider: How long until this measurement reference will no longer be correct?)
   - Follow your teacher's instructions for creating a height measurement tool.

2. Measuring trees greater than 15 centimeters (cm) circumference.
   - When measuring trees in the field you will only record information for trees greater than or equal to 15 cm circumference. While this value may seem arbitrary it is equal to 2 inches diameter, a cutoff used by scientists in many other forest inventory programs. A cutoff value is used for several reasons:
     - It is not practical to measure every small sapling on a sample site,
     - In a forest, saplings do not contribute a significant amount of biomass,
     - Many saplings smaller than 15 cm die off due to lack of available light.

   In some forest inventories saplings are counted separately on a sub-plot, however, since we are only trying to assess basic carbon storage we will not include saplings in our study

How much is 2 inches diameter? 1 inch = 2.54 cm. What equation can you use to find the answer?

3. Two key concepts scientists must consider when they measure trees in the field, are accuracy and precision.
   - <u>Accuracy:</u> Accuracy is the degree to which a measured or calculated value matches the true value. In the case of circumference measurements this can be influenced by:
     - Placement of the measuring tape: Is the measurement 1.35 m from the ground? Was the tape perpendicular to the main axis of the tree? Was the tape twisted?
     - Reading and recording data: Was the correct number read from the tape? Was this number correctly entered on the datasheet?

   By closely following the rules in the Tree Circumference Guide, and carefully recording data, one will be able to make accurate circumference measurements. Accuracy becomes particularly important if trees are measured in future years and compared to previous measurements.

   - <u>Precision:</u> Precision is the degree to which repeated measurements of the same tree are in agreement. You can determine how precise circumference can be measured by making repeated measurements of the same tree – either by one person, or by several people.

     - With your group, examine your tree cookie circumference results from Part 1. How close were your measurements? Did one person make all the measurements?

     - Join with another group and trade tree cookies.
     - Measure the circumference of your new tree cookie. Make sure each person in your group gets a chance to measure the cookie. Record your results below.

     - Compare your circumference measurements between group members and then with measurements taken by other groups. Discuss your results.

     - How close are all of the circumference measurements?

     - Why might they be different? How tight did you pull the tape to read the measurement? What decimal place did they record to? Was the measuring tape flat or twisted as it was pulled around cookie?

Biomass Units

Purpose

- Introduce the concept of biomass, including definition and standard units.
- Relate biomass to carbon storage in living things.
- Explore differences in plant biomass and carbon storage between global biomes, as a foundation for collecting field data in their own biome, comparing student collected data from other biomes, and using the NPP-Biomass Model to investigate biomass and carbon storage now and under future conditions.

Overview

Students will calculate the biomass of their classroom using an estimate of the total dry weight of students in the class as well as the classroom area. Students calculate current carbon storage in the classroom. Students consider vegetation biomass across global biomes.

Content Questions

What is biomass and how is it measured?
How does biomass relate to carbon?
How does biomass compare across biomes?

Student Outcomes

- Students will determine the biomass of the classroom by calculating the total students' dry weight within the classroom area.
- Students will calculate differences in classroom biomass when the classroom area or students' dry weight changes.
- Students will investigate and discuss connections between basic biomass concepts (mass/area) and the amount of biomass in natural systems (biomes).

Science Concepts

Change, constancy, measurement
Form and function
Abilities necessary to do scientific inquiry

Time

45 - 60 minutes (Part 1- Classroom Biomass)
45 minutes (Part 2 – Biome Biomass)

Level

Secondary (Middle & High School)

Materials and Tools

- 50 meter tape measure OR meter stick (one per group)
- Student Directions sheet (one per student)
- Calculator (one per student)
- Notebook and pencil (one per student)
- Global Biome Table
- Global Biome Map (separate)
- Access to internet or other research sources
- Optional: Satellite imagery of global biome

Preparation

Write the content questions on the board. Organize all materials for the activity. Make copies of the Student Directions.

Prerequisites

None

Background

Biomass is the total mass of living material measured over a particular area. Because all living things contain water (fresh weight) and the percentage of water can vary widely from species to species, biomass is calculated as a dry weight. Dry weight is the mass of life that is left after all the water is removed, much like squeezing out a sponge. For plants, scientists use an oven to remove all the water from the plant material before weighing it to determine its biomass. **Total biomass** is found by summing the dry weight biomass of all individuals in a given land area and then reported by naming the area of concern, e.g. biomass per plot, ecosystem, biome, classroom. To be able to compare biomass in different locations, scientists standardize biomass per unit of area. Typical units of biomass are grams per meter squared (g/m^2), although you will also see kg/m^2, lb/ft^2, etc.

While knowing an ecosystem's biomass is useful for many applications such as farming, logging, and wildlife management, another helpful unit of measure in an ecosystem is how much carbon is stored. Understanding how terrestrial ecosystems store and transfer carbon to and from the atmosphere is essential to understanding climate change, so biomass is often converted to carbon storage (For more information on the role of carbon in climate, see the Carbon Cycle Introduction Activities). But how do scientists know how much carbon is being stored? All life (biomass) is composed of carbon molecules, and as it turns out is approximately 50% carbon by dry weight. This means once biomass has been calculated, it can be multiplied by 0.50 to achieve approximate carbon content. (This value has been agreed upon by IPCC scientists and used to estimate carbon storage globally.)

Figure 1 shows the progression of concepts students need to understand the amount of carbon being stored in forested ecosystems. The concepts addressed in this activity are highlighted in gray.

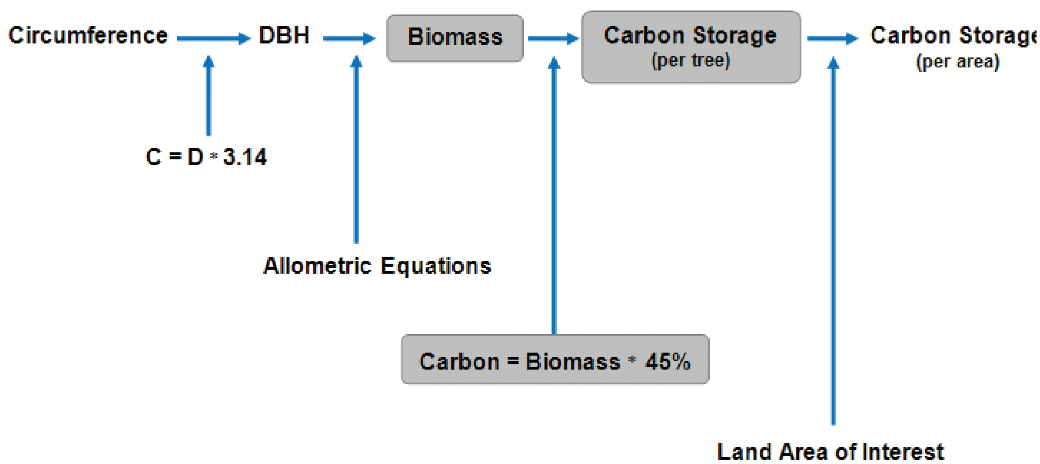

Figure 1, Field Concepts of "Biomass Units"

What To Do and How To Do It

	Student Grouping: Entire Class	Time: 5 minutes
ENGAGE	• Generate a class list of ideas: How much does a tree weigh? How do scientists measure the amount of living matter in a given habitat? • Define biomass. • Identify the variables needed to calculate classroom biomass. Including classroom area and students' dry weight. • To build students' inquiry skills, ask students to develop at least part of the method for calculating classroom biomass before handing out the Student Direction sheet	
	Student Grouping: Individual	**Time: 15 minutes**
EXPLORE	• Students calculate and record the total class fresh weight and the biomass of the classroom in **Part 1** of the Student Worksheet. • Students initially calculate their weight in grams. Each student's weight will need to be summed to get a total wet or fresh weight for the classroom. In order to protect students' anonymity, you may have students record their weight on a slip of paper and drop it into a box at the front of the room. You can now sum individual weights and report only a total classroom fresh weight to the class. You may also choose to have students write down an average human weight if you foresee a problem with using individual student weights. • **Note:** Approximately 60% of the total weight of humans is water. (Although % water can vary slightly between men & women and will depend on each individual's make up.) Students must account for this because biomass is always calculated as a dry weight. Students are instructed here to use 60%. • Students measure and record the classroom dimensions for use in classroom area calculations	
	Student Grouping: Entire Class	**Time: 15 minutes**
EXPLAIN	• Students discuss: What is the calculated classroom biomass? Are there any ways in which biomass could be different than what we calculated? • Discuss the importance of understanding biomass as a means of determining carbon storage. ◦ How does measuring biomass of the classroom relate to measuring biomass in a forest or grassland? ◦ Why is understanding biomass important? What can it tell us about an ecosystem? ◦ It tells us something about: carbon storage, the amount of timber available, and forest health. • Calculate carbon storage in the classroom. (Multiply biomass by 50%)	
	Student Grouping: Individual	**Time: 30 minutes**
ELABORATE/ INVESTIGATE	• Review the concept of biomes. • Now that students understand how biomass can be very different depending on the mass of the living matter (which is based on size, density and water content) and the area that a particular group is located in, have them consider the biomass of global ecosystems. • Students rank global biomes listed in **Part 2** of the Student Directions using prior knowledge, satellite images (e.g. Google Earth), and the *Global Biome Table.*	

	Student Grouping: Entire Class	Time: 15 minutes
EVALUATE/ WRAP-UP	• Discuss what students noticed about the patterns of biomass (per unit area) across biomes. ◦ How would this be different if you considered total biome area (use Global Biome Map) • Generate a list of student's ideas about how scientists measure biomass for biomes. **See activity example with sample calculations and answers in BiomassUnits_example.xls.	

ASSESSMENT

- Option1 - Changing Biomass: Do students understand the two components of biomass, mass and area?
    - Each individual/group calculates how biomass would change if the area of the room changed or if the number/composition of students in the room changed. Below are a few possible ideas:
        - Area: football field, gym, maintenance closet
        - Mass: the whole grade, a group of first graders, a group of athletes (football/hockey players)
    - Students answer the following questions, including all calculations and present in small groups or to the class.
        - What new scenario did you choose? Indicate which component of biomass you changed in your scenario (area or mass).
        - What is your new biomass? Show all of your calculations.
    - Students compare the new biomass values.
    - * Bring the class to a maintenance closet or football field to make the activity visual.
- Option 2 - Estimate carbon storage: Do students understand biomes, biomass and carbon storage?
    - Students use their knowledge of biomass, biomes, and their local area to make a hypothesis about the carbon storage of the vegetation in their schoolyard.
        - Think about the area around your school. What type of vegetation is present? How much vegetation covers the ground area? Using the Global Biomass Table and your basic knowledge, estimate the amount of carbon storage in g C/m2 for the vegetated area around your school. Record your estimate and your reasoning.
    - Assess student's estimate and reasoning of carbon storage in the area around the school.

REFERENCES

Intergovernmental Panel on Climate Change (IPCC). 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Land Use Change and Forestry.

Name: ______________________________ Date: ______________________

Student Directions: Classroom Biomass

Content Question: What is biomass and how does it relate to carbon?

Background

Biomass is the mass of living material measured over a particular area. Biomass can be calculated for all organisms present or for a particular group (vegetation, bacteria) or species (eastern white pine). Because all living things contain water, and the percentage of water can vary widely from species to species, biomass is often calculated as a dry weight. Dry weight is the mass of life that is left after all the water is removed, much like squeezing out a sponge. For plants, scientists use an oven to remove all the water from the plant material before weighing it to determine its biomass. Total biomass is found by summing the dry weight biomass of all individuals in a given land area and then reported by naming the area of concern, e.g. biomass per plot, ecosystem, biome, classroom. To be able to compare biomass in different locations, scientists standardize biomass per unit of area. Typical units of biomass are grams per meter squared (g/m^2), although you will also see kg/hectare, lb/ft^2, etc.

Conversions:

1 pound = 454 grams

1 kilogram = 1000 grams

While knowing an ecosystem's biomass is useful for many applications such as logging, forest health and wildlife management, another helpful unit of measure in an ecosystem is how much carbon is stored. Understanding how terrestrial ecosystems store and transfer carbon to and from the atmosphere is essential to understanding climate change (think photosynthesis, global carbon cycle and the greenhouse effect), so biomass is often converted to carbon storage. But how do scientists know how much carbon is being stored? All life (biomass) is composed of carbon molecules, and as it turns out is approximately 50% carbon by dry weight. This means once biomass has been calculated it can be multiplied by 0.50 to achieve approximate carbon content.

Part 1a: Calculate Classroom Biomass

Individual

1. Calculate your weight in grams (see conversions above). Follow your teacher's instructions about what to do with this information. Your mass will be used by the teacher to determine total classroom fresh weight.

2. Your teacher will announce the total classroom fresh weight. Record this value below.

   - To calculate dry weight you must assume what percent of the human body is comprised of water. According to literature humans, on average are 60% water by weight. Multiply total classroom fresh weight by percent water to get the water weight.
     For example: 1,207,640g (class fresh weight) x 0.60 = 724,584g (water weight)

   - Calculate your classroom dry weight in grams by subtracting the water weight from total fresh weight.
     For example: 1,207,640g – 724,584g = 483,056g

3. As a class, measure the classroom dimensions using a tape measure or meter stick. Calculate the total area in square meters.
   - Area of a rectangle: Area = length * width

4. Divide classroom dry weight in grams by classroom area in square meters to find the biomass of your classroom in g/m^2.

5. How would biomass change if one of the biomass components, either area of the room or the number/composition of students in the room changed? For each scenario state whether there would be an increase or a decrease in biomass.
   - Football field
   - Elementary school students
   - Maintenance closet
   - All the students in the school
   - Professional hockey players

Whole Class (record class data from board)

6. Calculate the current carbon storage of the classroom in g C/m2. Assume that humans are 50% carbon.

<u>Part 2: Biome Biomass</u>
Individual

1. Rank the following **14** terrestrial (land) biomes (Table 1) from greatest to least plant biomass. *Remember that we are considering biomass as living dry mass per unit area.
   a. Initially, draw diagrams to help you conceptualize.
      Where is biomass stored in vegetation? Think about plant components (leaves, branches, stem and roots).
      How does a forest look from the side view? From a top view? How about a grassland?
      How large is 1 square meter?
   b. Optional: Check your rankings using satellite imagery (e.g. Google Earth) - How does vegetation look from the air? Use the *Global Biome Map* to locate different biomes you would like to view.
   c. Confirm rankings using the *Global Biomass Table* (Table 2).

		Biomass Ranking		
	Ecosystem Type	**Initial**	**Satellite Image**	**Global Biomass Table**
1	Boreal forest			
2	Cultivated land			
3	Desert scrub			
4	Lake and stream			
5	Rock, ice and sand			
6	Savanna			
7	Swamp and marsh			
8	Temperate deciduous forest			
9	Temperate evergreen forest			
10	Temperate grassland			
11	Tropical rain forest			
12	Tropical seasonal forest			
13	Tundra and alpine meadow			
14	Woodland and shrubland			

Table 1, Biomes arranged from greatest to least plant biomass storage

2. Were the actual biomass rankings different than you expected? Why do you think this was the case?

3. Biomass can vary widely between biomes, what do you think is driving that difference?

4. How is biomass related to carbon? Why is our knowledge of carbon storage in biomes important?

Ecosystem Type	Area ($10^6 km = 10^{12} m^2$)	Total Plant Carbon (10^9 metric tons C)	Mean Plant Biomass (g/m^2)	Mean Plant Carbon Storage (gC/m^2)
Rock, ice and sand	24	0.2	20	10
Lake and stream	2.5	0.02	20	10
Tundra and alpine meadow	8	2.4	600	300
Desert scrub	18	5.4	600	300
Cultivated land	14	7	1000	500
Temperate grassland	9	6.3	1400	700
Savanna	15	27	3600	1800
Woodland and shrubland	8	22	5400	2700
Swamp and marsh	2	13.6	13600	6800
Boreal forest	12	108	18000	9000
Temperate deciduous forest	7	95	27000	13500
Tropical seasonal forest	7.5	120	32000	16000
Temperate evergreen forest	5	80	32000	16000
Tropical rain forest	17	340	40000	20000
Total Continental	**149**	**827**	**11100**	**5550**
Open ocean	332	0.46	3	1.4
Continental shelf	26.6	0.13	10	5
Upwelling zones	0.4	0.004	20	10
Estuaries	1.4	0.63	900	450
Algal bed and reef	0.6	0.54	1800	900
Total Marine	**361**	**1.76**	**10**	**4.9**

Table 2, Global Biome Map; the Carbon Component of Primary Production and Biomass for the Biosphere (adapted from Whittaker and Likens 1973)

Allometry: Not A Llama Tree

Purpose

- To introduce the concept of allometry, a method for calculating tree biomass, using a simple measurement, circumference or diameter.

Overview

In this activity students will measure the height, foot length and arm span of other students in the class and graph them in relation to one another to recognize how allometry can be used to estimate the size of one part of a living thing if another part size is known. Students will then apply their understanding of allometry to the study of biomass and carbon storage in trees.

Content Questions

How is allometry used to calculate forest biomass?

Sub-Questions

How are allometric equations developed?

Student Outcomes

- Students will develop an allometric equation for human height by measuring each other for height, foot length and arm span.
- Students will validate the human allometric equation(s) by determining the heights of individuals not used in the equation development.
- Students will relate human allometry to tree allometry.
- Students will understand why allometric equations are different for different groups of tree species

Science Concepts

Change, constancy, measurement
Form and function
Abilities necessary to do scientific inquiry
Diversity and adaptation of organisms

Time

60 - 90 minutes

Level

Secondary (Middle & High School)

Materials and Tools

- 50 meter tape measure OR meter stick OR flexible measuring tape (metric)
- Calculator
- Notebook and pencil
- Graph paper OR computers with a spreadsheet application
- National-Scale Biomass Estimators for United States Tree Species, Jenkins et al. [Optional]
- Species Groups List adapted from Jenkins et al. paper
- Predicted Biomass Graph adapted from Jenkins et al. paper
- Tree Identification Guide

Preparation

- Review Species Group List and Predicted Biomass Graph to be able to answer student questions.
- UnderstandingAllometry_example.xls
- Copy student directions sheets (1 per student)
- Copy Species Group List and Predicted Biomass Graph (1 per group of 3).

Prerequisites

Knowledge of DBH and Biomass (See: *How do Scientists Measure Trees?* and *Biomass Units*)

Background

If biomass is a key unit of measurement for understanding ecosystems, it is essential that we have a way to measure it. Logically, it makes no sense to measure the mass of trees by cutting down and weighing them on a scale every time. This would ultimately mean destroying the ecosystem we are trying to understand. Because this is the case, over time, scientists have cut down many trees of different sizes and species to look for relationships between parts of the tree that can be measured easily, such as DBH or height and the whole tree's biomass. The study of this kind of relationship is known as **allometry**.

Allometry is the study of an organism's growth as is used to describe the relationship between an organism's size and the size of any of its parts.

Allometric relationships can be studied during the growth of a particular organism, as a comparison between organisms of the same species or between organisms of different species. Allometric relationships are best shown on a graph where body size is depicted on the y-axis and body part size is depicted on the x-axis (Figure 1). As individual measurements are added to the graph, a scatter is produced. The average through that scatter (a regression line) determines the allometric equation.

Allometric equations often take the form of:

$y = mx + b$ (line equation)

where y = body size, x = body part size, m = slope, and b = y-intercept value of a straight line.

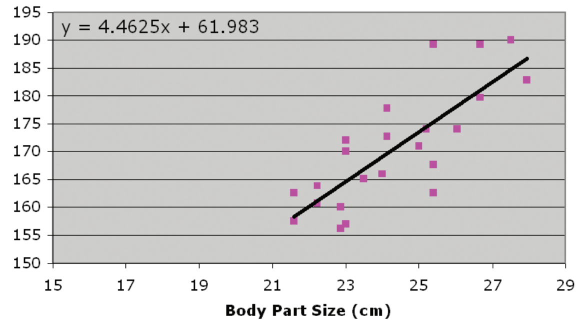

Figure 1, Allometric equation depicted in a graph

Not all allometric relationships are linear, such as the relationship between tree DBH and tree biomass. When this is the case, a nonlinear equation, such as log or natural log might be used. Log equations and their transformations can be confusing. For clarification see the Log Calculations Example in the appendix and/or talk to a math teacher.

$\ln(y) = a + b[\ln(x)]$

where y = body size, a and b are coefficients and x = body part size

A log transformation will allow you to solve for y:

$y = e^{(a + b[\ln(x)])}$

The exact form of equations students will see in the Plot Biomass Analysis is:
biomass = Exp(B0 + B1 ln dbh), where ln = log base e (or 2.718282).

If your students participate in the field data collection and analysis, they will need to understand the basics of tree allometry. During Sample Site Biomass Analysis students will be able to view their circumference field data in the spreadsheet calculator and a version of the above equation, which is used to calculate biomass. Although a similar equation exists for all trees, they will differ slightly for different tree species groups. These equation differences between species groups largely exist due to differences in tree wood density (see Extensions). For additional information see the National-Scale Biomass Estimators for United States Tree Species (Jenkins et al. 2003) paper; of particular interest in this paper are Figure 1 (Predicted Biomass Graph) and Appendix A (Species Groups List).

The Understanding Allometry activity addresses the connection between the two previous concept activities, *How Do Scientists Measure Trees?* and *Biomass Units*. By the end of the activity students should understand why they are collecting tree circumference data and how real data are used to create valuable equations (Figure 2).

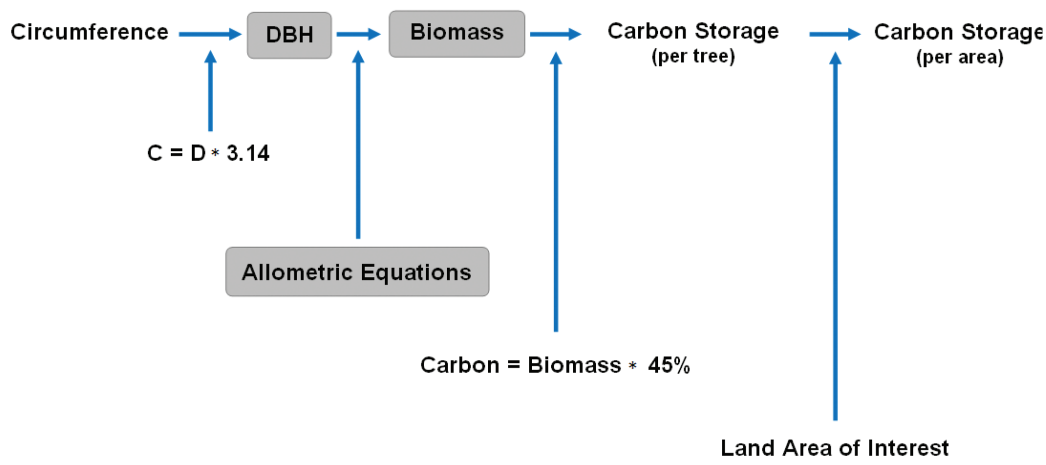

Figure 2, Field Concepts of " Allometry: Not A Llama Tree"

What To Do and How To Do It

<table>
<tr><th></th><th>Student Grouping: Entire Class</th><th>Time: 10 minutes</th></tr>
<tr><td>ENGAGE</td><td colspan="2">

Students share ideas about how vegetative biomass is measured/calculated.
Discuss the implications of weighing trees in order to calculate biomass. Discuss that allometric equations allow scientists to calculate tree biomass without having to cut down trees.
Do humans have allometric relationships? Can you think of any examples?

</td></tr>
<tr><th></th><th>Student Grouping: Small Groups</th><th>Time: 20 minutes</th></tr>
<tr><td>EXPLORE</td><td colspan="2">

Students follow the Student Directions procedure in Part 1a for measuring and recording the height, arm span and foot length of each group member.
Note: Middle school students are still growing so there may not be a very clear relationship between height and the other variables. You may choose to have students ask other teachers to participate in their study.
Compile student measurements. Measurements can be tallied on the board or in the AllometryNotALlamaTree_example.xls spreadsheet template.
This may be a good opportunity to have students practice using spreadsheets for data entry and graph creation.
Graph class data (can be done individually or as a class).
Data can be graphed on graph paper or in the spreadsheet file.
Students should graph height versus arm span AND height versus foot length.
Students use the data to answer thought questions in Part 1b of their student directions.

</td></tr>
<tr><th></th><th>Student Grouping: Entire Class</th><th>Time: 15 minutes</th></tr>
<tr><td>EXPLAIN</td><td colspan="2">

Examine data and graphs as a class. Discuss answers to questions 1-3.
If your students have studied line equations (y = mx + b) show them how their data just helped to create a line equation that can be used to predict the height of people that have not yet been measured. To emphasize this point see the Extension section.
Discuss how this activity is related to the calculation of biomass using DBH.
Students share answers to question 4: How does this activity relate to measuring trees? Also refer back to discussions from the Engage section.
Because there are differences between trees (wood density), there have been many equations developed, just like the equation developed for class. To make forest biomass assessments a little easier, Jenkins and others have grouped all United States trees into 10 species groups, and each species group has a slightly different equation.
Share the Predicted Biomass Graph adapted from the Jenkins et al. 2003 paper.

</td></tr>
<tr><th></th><th>Student Grouping: Individual</th><th>Time: 20 minutes</th></tr>
<tr><td>ELABORATE/ INVESTIGATE</td><td colspan="2">

Students examine the Predicted Biomass Graph and Species Groups List in greater detail using questions in Part 2 of the student directions to ensure understanding of the species groups and differences in predicted biomass between groups.
Students will also need access to the Internet or a tree identification guide for this section.

</td></tr>
</table>

	Student Grouping: Entire Class	Time: 10 minutes
EVALUATE/ WRAP-UP	• Discuss the answers to questions in Part 2.. **See activity example with sample calculations and answers in *AllometryNotALlamaTree_ example.xls*.	

Extension

- Analyze class data (height vs. arm span and height vs. foot length) to find an actual regression line (y = mx + b). Measure other students and/or teachers to see if your line equation makes accurate predictions of body measurements other than those used to make the original equation. (You may choose to have these data available ahead of time, e.g. from the sample data in UnderstandingAllometry_example.xls, from other teachers at your school, or from previous years or other classes.)
- Wood Density. After students have seen that tree species are divided into groups based on their DBH-Biomass relationships, they may have questions about why one equation cannot be used for all trees or why particular trees are grouped with other trees. The answer to these questions is wood density. To examine wood density, buy or make blocks of wood of different species. First have students mass each block. Then measure the length, width, and height of each block to find volume. Divide mass by volume to find the density of each wood species.

Assessment

- How would you use DBH and species/species groups to calculate the carbon storage for one tree? Draw, diagram or describe.

Name: ______________________________ **Date:** ______________________

Student Directions: Allometry, Not A Llama Tree

Content Question: What is biomass and how does it relate to carbon?

Essential Question: How is allometry used to calculate forest biomass?

Part 1a: Measuring Human Allometry - Procedure

1. Form groups of three.

2. Measure (in centimeters) the height, arm span and foot length of each student in the group (hint – use a wall to help you).
   a. Height: Student removes shoes. Partners measure from the floor to the top of the head
   b. Arm span: Student extends arms straight out to the side. Partners extend the measuring tape across their back measuring from finger tip to finger tip.
   c. Foot length: Place the measuring tape on the floor. Student stands with the back of their heel on 0cm and reads the value at the front of their big toe.

3. Record your data.

Height (cm)	Arm Span (cm)	Foot Length (cm)

4. Enter your group's data into the class data table.

Part 1b: Measuring Human Allometry – Questions

Use the class data to create graphs that help you understand the relationship between your measured variables, height, arm span, and foot length. Use your graphs to answer the following questions.

1. What do you notice about the relationship between height and arm span?

2. What do you notice about the relationship between height and foot length?

3. Can you draw an "average" line through your data?
   a) Is this line meaningful or is there a lot of scatter in the data?
   b) Why might there be a lot of data scatter?

4. How might scientists, such as yourself, use a similar approach to determine tree biomass?

Part 2: Tree Allometry

Use the Species Groups List and Predicted Biomass Graph adapted from the National Scale Biomass Estimators Paper. Explore the follow questions and discuss answers with your peers. Record your answers in your science journal.

1. Review the Species Groups List.
   a. What are the 10 species groups?
   b. How many of them are broadleaf? How many are conifers?
   c. Which species groups are you most likely to find in your region?
   d. Examine some of the species that fall into each group, can you picture what any of these trees look like? Use the Species Groups List and a tree ID guide to find out a little more about 3 trees you are likely to find during a field investigation of your schoolyard. Describe or draw some of their primary characteristics.

2. Examine the Predicted Biomass Graph.
   a. Which species group has the highest predicted biomass for a DBH of 30cm?
   b. For a predicted biomass of 1000kg what is approximate DBH of the spruce group?
   c. Do you notice any patterns between species groups?
   d. The graph represents the predicted biomass at a given DBH for the whole tree. How do you think the percentage of biomass for individual tree components (stem, branches, leaves) might change as the same tree gets bigger? Explain your answer.

TEACHER ANSWERS

Student Directions: Allometry, Not A Llama Tree

Essential Question: How is allometry used to calculate forest biomass?

Part 1a: Measuring Human Allometry - Procedure

1. Form groups of three.

2. Measure (in centimeters) the height, arm span and foot length of one student (hint – use a wall to help you).

   a. Height: Student removes shoes. Partners measure from the floor to the top of the head
   b. Arm span: Student extends arms straight out to the side. Partners extend the measuring tape across their back measuring from finger tip to finger tip.
   c. Foot length: Place the measuring tape on the floor. Student stands with the back of their heel on 0cm and reads the value at the front of their big toe.

3. Record your personal data.

Height (cm)	Arm Span (cm)	Foot Length (cm)

4. Repeat the measurement and recording process for all group members.

*See sample class data in Understanding Allometry_example.xls

Part 1b: Measuring Human Allometry – Questions

Use the class data to create graphs that help you understand the relationship between your measured variables, height, arm span, and foot length. Use your graphs to answer the following questions.

1. What do you notice about the relationship between height and arm span?

   Arm span and height have a strong linear relationship, close to 1:1. As arm span increases, height increases by the same amount.

2. What do you notice about the relationship between height and foot length?

   Foot length is also linearly related to height. As foot length increases, height increases.

3. Can you draw an "average" line through your data?

   a. Is this line meaningful or is there a lot of scatter in the data?
   b. Why might there be a lot of data scatter?

   There is not a great amount of scatter in the sample data because all the measured participants are adults. Because students are still growing the relationships between foot length vs. height and arm span vs. height will likely be more scattered.

4. How might scientists, such as yourself, use a similar approach to determine tree biomass?

   Thought question. Students should use their knowledge from the WhatisDBH? and BiomassUnits to make a good guess. Measuring DBH can help us estimate biomass if there are established equations.

Part 2: Tree Allometry

Use the Species Groups List and Predicted Biomass Graph adapted from the National Scale Biomass Estimators Paper. Explore the follow questions and discuss answers with your peers. Record your answers in your science journal.

1. Review the Species Groups List.

   a. What are the 10 species groups?

   AspenAlder, CedarLarch, DougFir, FirHemlock, MapleOak, MixedHardwood, Pine, SoftMapleBirch, Spruce, Woodland

   b. How many of them are broadleaf? How many are conifers?

   4 broadleaf, 4 conifer, woodland has both

   c. Which species groups are you most likely to find in your region?

   This will depend on your location.

   d. Examine some of the species that fall into each group, can you picture what any of these trees look like? Use the Species Groups List and a tree ID guide to find out a little more about 3 trees you are likely to find during a field investigation of your schoolyard. Describe or draw some of their primary characteristics.

2. Examine the Predicted Biomass Graph.

   a. Which species group has the highest predicted biomass for a DBH of 30cm?

   MapleOak (maple/oak/hickory/beech)

   b. For a predicted biomass of 1000kg what is approximate DBH of the spruce group?

   47cm

   c. Do you notice any patterns between species groups?

   MapleOak biomass increases more quickly with small changes in DBH.
   The Woodland group has a very different relationship between biomass and DBH than all the other groups.
   On the whole the relationship between biomass and DBH is very similar between all groups (except Woodland).
   **Students may see a variety of other patterns.*

   d. The graph represents the predicted biomass at a given DBH for the whole tree. How do you think the percentage of biomass for individual tree components (stem, branches, leaves) might change as the same tree gets bigger? Explain your answer.

   This is a thought question with no right or wrong answer. View the Jenkins paper, figures 5 and 6, which show the change in biomass components with an increase in DBH. Students will revisit this concept during their field data analysis.

CARBON CYCLE FIELD UNIT

Field activities allow students to collect and analyze data about their local environment to facilitate a greater understanding of the role that ecosystems play in the global carbon cycle.

The field section of the Carbon Cycle project begins in the classroom with a set of engagement activities (What is DBH?, Biomass Units, Not A Llama Tree) where students perform basic exercises that enable them to answer fundamental science content questions, including how is vegetation measured, what is vegetation biomass and how is it calculated, and how does biomass relate to carbon storage? It is important that these activities be performed or that students have a concrete understanding of the topics prior to heading to the field, to be sure that students know why they are collecting data.

Students use their knowledge during an inquiry activity to develop a basic procedure for collecting data to answer the essential question: How much carbon is stored in the forested area of our schoolyard? Students evaluate their own procedure by comparing it to the procedure developed by carbon cycle scientists.

Students then set up, map and collect data on a designated Carbon Cycle Sample Site.

After entering field data in the computer and making an assessment of schoolyard area, the data analysis component guides students to consider what their data mean and how the information they gain is relevant to the study of the carbon cycle.

Results from the field data analysis can be compared to results obtained during modeling activities. In the following Field Unit Flow Chart individual activities are represented by bubbles and are boxed into like categories.

Conducting Field Work - Trees

Purpose

- To set up a Carbon Cycle Sample Site, identify and map all trees greater than 15cm circumference, and collect tree circumference data. Students will use scientific field methods including, azimuth, distance in meters, breast height at 1.35m, species ID using a scientific key, and tree circumference.

Overview

Students will re-examine the unit essential question, ***How much carbon is being stored in the forest ecosystem near my school?*** Using the knowledge they gained during the in-class field engagement activities (***How To Measure Trees***, ***Biomass Units***, ***Allometry: Not a Llama Tree***) students will discuss potential methods for assessing carbon storage in their schoolyard. After developing a basic procedure students will review the scientific procedure they will be asked to follow and have the opportunity to ask questions. Student will then work in small groups and use scientific field methods to set up, map and measure trees on the Carbon Cycle Sample Site. Students will also calculate how much of their schoolyard area is forested, which will be used later to scale from plot level carbon estimates to schoolyard carbon estimates..

Content Questions

How much carbon is being stored in the trees near my school?

Student Outcomes

- Students will gain a hands-on understanding of field work concepts learned during Field Engagement activities.

Science Concepts

Time

X minutes

Level

Secondary (Middle & High School)

Materials and Tools

- 50 meter tape measure OR meter stick OR flexible measuring tape (metric)
- Calculator
- Notebook and pencil
- Graph paper OR computers with a spreadsheet application
- National-Scale Biomass Estimators for United States Tree Species, Jenkins et al. [Optional]
- Species Groups List adapted from Jenkins et al. paper
- Predicted Biomass Graph adapted from Jenkins et al. paper
- Tree Identification Guide

Preparation

- See individual components.

Prerequisites

Concepts:
For students to get the most out of the field experience they should have an understanding of the following concepts: how carbon is stored in trees, primary factors that limit tree growth and carbon uptake, why and how circumference/DBH is measured, the units of biomass, and how biomass is calculated from DBH using allometry (see ***Field Engagement Activities***).

Skills:
Students should be able to accurately read and record values from a meter tape, and know the fundamentals of species keys and how to use one to ID species to at least the genus level or common species group, e.g. pine, spruce, birch.

Background

Students can now put basic concepts learned during engagement activities into practice. Figure 1 outlines the following concepts. Carbon dioxide is taken up by trees during photosynthesis and is stored as carbon in the roots, bark, branches, stem and leaves. Carbon, the building block of life, accounts for approximately 45-50% of the mass of all living things after the water has been removed. While perhaps the best way to find the exact mass of each tree under consideration is to cut it down, oven dry it and weigh it, this is neither practical nor logical. To this end scientists, including ecologists and foresters, have cut down many trees of varying sizes and varieties to come up with size based relationships, called allometry. One relationship that has proved especially consistent is between diameter at breast height and tree biomass. Such a consistent relationship led to the development of allometric equations that allow scientists, and now students, to measure circumference (or DBH) to estimate the biomass of whole trees as well as their individual components including leaves, branches, bark, stem and roots. With a good estimate of biomass, carbon storage of each tree and its components can also be calculated. While carbon storage estimates of individual tree components are great for understanding ecosystem dynamics such as how the ratio of carbon in roots versus stem changes with a change in environmental conditions it can also be interesting to look at carbon storage at larger scales including a specific sample site, schoolyard, town or region. This type of scaling allows us to look at the bigger picture of carbon storage and provides a reference point to consider when making management decisions in the light of climate change. Should these trees be logged? Should more trees be planted? If the biomass of the same trees is then monitored over several years you can begin to look at growth, carbon uptake over time, another important component in the global carbon cycle equation. Carbon uptake from the atmosphere is particularly interesting because it is the opposite of carbon emissions to the atmosphere, typically calculated through a carbon footprint assessment.

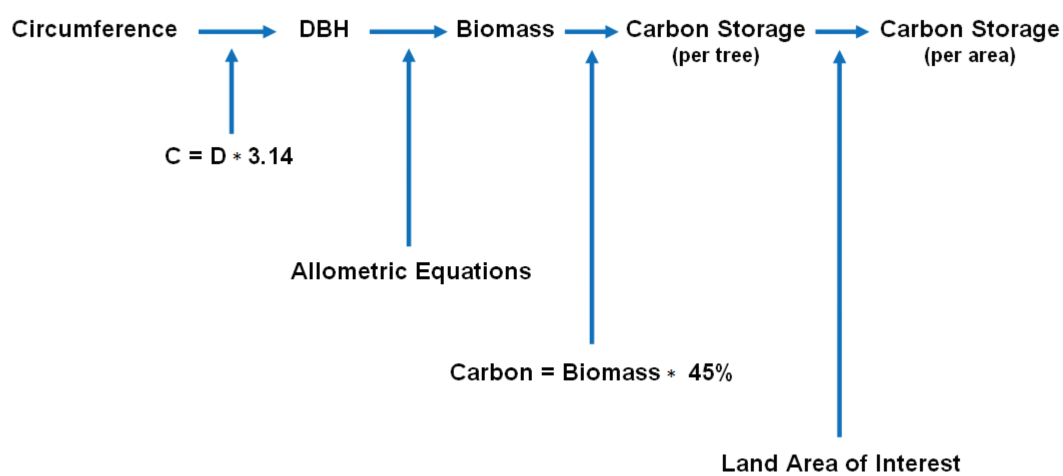

Figure 2, Field Concepts of "Conducting Field Work"

Assessment

Inquiry: Formal or informal presentation of field methods
Carbon Cycle Sample Site Set Up: Participation
Tree Mapping: Tree Data Collection Challenge (see rubric)
Tree Circumference: Tree Data Collection Challenge (if performed with or instead of Tree Mapping) ***or*** a completed Field Data Sheet.

Adaptations

Younger students are capable of completing all parts of the fieldwork, but may need additional time and teacher direction. For students ages 10 - 13 it may be helpful to have additional adults at the field site to help answer questions and keep students on task.

If you have students with physical disabilities you may consider placing your sample site next to a more accessible trail or close to the school building. Once in the sample site these students could act as the data recorder for their group.

Resources/References

Using a Compass - http://www.dnr.state.wi.us/org/caer/ce/eek/cool/orienteering.htm
Going Outside - Project Learning Tree's Resource Guide for Conducting a Forest Field Day

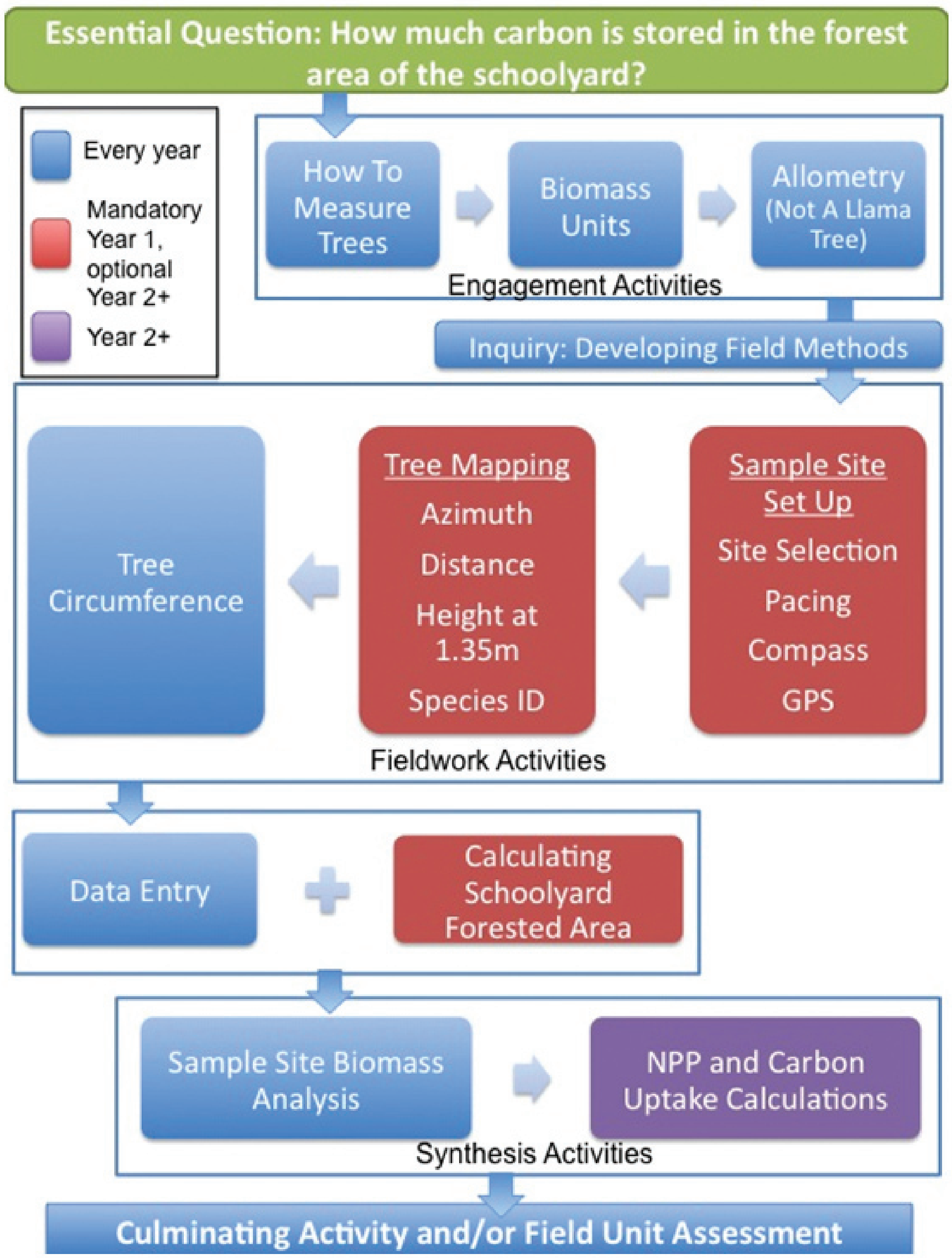

Figure 3, Following the Essential Question diagram

Tree Mapping

Purpose

- To prepare the Carbon Cycle Sample Site for tree circumference measurements by identifying and mapping all trees greater than 15 cm circumference. Students will use scientific field methods including, azimuth, distance to trees from plot center, breast height at 1.35 m, and species ID using a scientific key.

Overview

Using skills they gained during Carbon Cycle Sample Site Set Up and class field engagement activities (***How to Measure Trees***, ***Biomass Units***, ***Allometry: Not a Llama Tree***) students will work in small groups and use scientific field methods to map and identify trees on the Carbon Cycle Sample Site.

Essential Questions

How much carbon is being stored in the trees near my school?

Student Outcomes

What data/measurements are required to make a carbon assessment on a sample site over time (from year to year)?

- Students will work as a team to delegate and complete field tasks.
- Students will use their knowledge about accuracy and precision to carry out scientific measurements (azimuth, distance, CBH) on all trees greater than 15cm circumference in the Carbon Cycle Sample Site.
- Students will use tree identification keys and guides to ID trees to at least the genus level or common species group, e.g. pine, spruce, birch.

Science Concepts

Climate Literacy 3E, 4G, 5B
Earth Science Literacy 1.3, 3.2, 6.8

Time

75 minutes (Travel time not included.) Only needs to be completed once for each sample site

Level

Secondary (Middle & High School)

Materials and Tools

Note: Materials and tools numbers are listed for each of 4 quadrant groups (North, South, East, West).

- Clipboard (1)
- Pencil (2)
- *Tree Data Sheet* (1)
- *Tree Mapping Packet (graphics, azimuth, distance, height at 1.35 m, species ID)*
- Compass (1-2)
- Flexible measuring tape (150-300 cm) (3)
- Flexible measuring tape (30-50 m) (1)
- Height indicator for 1.35 m (e.g. string or stick with permanent mark) (1)
- Paint Stick/Tree Crayon (2)
- Tree identification guide/species keys (2)
- *Tree Circumference Measurement Guide* (2)

Preparation

1. Divide the class into 4 quadrant groups of approximately 6 students each. You may want to consider only 2 groups if you have a small class (thus the field process will take longer than suggested).
2. Review and make copies of the *Tree Data Sheet*, *Tree Mapping Packet*, *Tree Circumference Measurement Guide,* and *Species Groups List* for each quadrant group.
3. If you are new to student field excursions read *Going Outside*, which discusses considerations to make before heading to the field, including: weather, appropriate clothing, dangers such as ticks, etc.

Prerequisites

1. Inquiry Activity: Methods for Assessing Total Schoolyard Carbon
2. A Carbon Cycle Sample Site should already be set up.

What To Do and How To Do It

Prepare to go outside (15min).

1. Review expected student behavior while in the field.
2. Divide into Quadrant Teams.
3. Students gather field materials and tools.
4. Students review the *Tree Mapping Packet* and *Tree Data Sheet* and ask questions.

Perform Mapping field tasks (60min). Students should follow the procedures for each task in their packet.

NOTES:

- You may choose to tag or number your trees to eliminate student confusion. If you follow this route be sure to check with school administrators about potential future use of the forested area, as tags can cause a problem if trees are harvested. Please be aware that tagging and painted numbers can call attention to the site, which may result in vandalism.
- In subsequent years, after the initial site set up you will need to occasionally map trees that have grown to 15 cm or greater. The mapping procedures should be followed for each "new" tree. This can be done when students go out to perform *Tree Circumference*.
- If you choose not to have students perform *Tree Mapping* after the initial year it is suggested that students view and discuss the sample site before performing *Tree Circumference*. Use the Discussion Points for Site Visit as a guide.

Assessment

Tree Data Collection Challenge (Rubric)

Quadrant Teams compete against each other to complete their field tasks. To win the challenge students will be graded on a number of factors – see rubric.

NOTES:

1. The precision, accuracy, and completeness of collected data.
   a. Either you or a student pair from another team can randomly select 2-4 trees and check all of its measurements.
   b. Example. Tree Tag # N24. Azimuth 30 degrees, distance 6.1 meters, breast height 1.35 from the highest point of ground.
2. How quickly all tasks are completed may be different for quadrants if there are significantly more trees in one area of the sample site.

Tree Tagging and Mapping – Team Instructions

Quadrant Team ______________________________

Names ____

____

Task

Work as a team to tag and map trees greater than 15 cm circumference on your Carbon Cycle Sample Site.

Materials

Clipboard (1)
Pencil (2)
Tree Data Sheet (1)
Tree Mapping Packet (azimuth, species ID, distance, height at 1.35 m)
Compass (1-2)
Flexible measuring tape (150-300 cm) (3)
Flexible measuring tape (30-50 m) (1)
Height indicator for 1.35 m (e.g. string or stick with permanent mark) (1)
Paint Stick/Tree Crayon (2)
Tree identification guide/local species keys (2)
Tree Circumference Measurement Guide (2)
Species Groups List (2)

Procedure

1. Your quadrant team (North, East, South, West) is written at the top of the page. All of the following field procedures are to help you tag and map your quadrant.

2. Read the attached field instruction guides. Determine how many people should work on each task. View the tree mapping diagrams and *Tree Data Sheet*. Write down anything that is unclear and discuss it with your team and the teacher.

3. Select a team data recorder. This person should be able to write clearly and record data quickly and accurately. The data recorder will need the *Tree Data Sheet*, a clipboard and one pencil.

4. Divide remaining team members between the Azimuth, Species ID, Distance and Height at 1.35 m groups. The Azimuth group should help orient all other team members to the quadrant (following their initial field guide instructions).

5. When azimuth, species ID, distance and height at 1.35 m are complete, your team is ready to make tree circumference measurements.

Field Guide Instructions - Azimuth

Azimuth Group (2 people)

Names ____

Task

Find the azimuth from plot center to the center of all trees greater than 15 cm circumference on your Carbon Cycle Sample Site.

Materials

Compass

Procedure (See Figure 1 for comapss references)

1. Stand at the center of the plot and face north.
   - Hold the compass in front of you with the ***direction of travel arrow*** pointed away from you.
   - Turn your compass housing so that N (the ***North Sign***) is lined up with the ***direction of travel arrow***.
   - Turn your body (the compass in front of you) until the red ***magnetic needle*** is in the ***orienting arrow*** (*red is in the shed*).

2. Show your Quadrant Team where the cardinal directions are (N, E, S, W) and specifically where the boundaries of your quadrant are located.

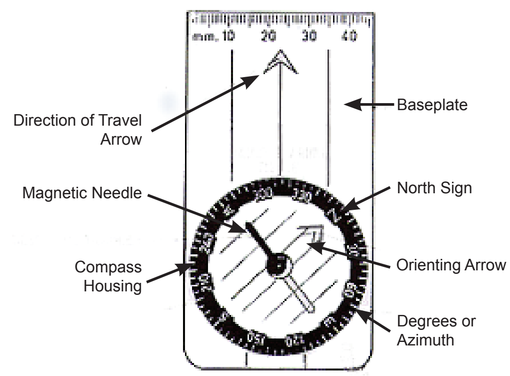

Figure 1, Parts of the compass (Adapted from Wisconsin Dept. of Natural Resources: www.dnr.state.wi.us/org/caer/ce/eek/cool/orienteering.htm)

3. To find the ***azimuth*** to the first tree in your quadrant, turn your ***compass housing*** to the direction indicated by your quadrant name, as you did for North. Then turn your body until you are facing that direction and *red is in the shed*.

4. Now turn your body clockwise until you are facing the first tree in your quadrant. (Keep in mind it may be far away {15-20 m}.)

5. Turn your ***compass housing*** until *red is in the shed*.

6. Read the number on the ***compass housing*** that is lined up with the ***direction of travel arrow***. This is the ***azimuth*** from the center of the plot to the tree you are looking at.

7. Have the second azimuth group member check the ***azimuth***.

8. When you both agree, record the ***azimuth*** on the *Tree Data Sheet*.

9. Repeat this process for each tree on the plot.

Field Guide Instructions – Species ID

Tree Species Group (2-4 people)

Names ____

Task

Identify species (or general species group, e.g. pine, oak) for all trees greater than 15 cm circumference on your Carbon Cycle Sample Site.

Materials

Clipboard
Pencil
Tree Data Sheet
Flexible measuring tape (best if 150-300 cm)
Tree identification guide/local species keys
Species Groups List adapted from Jenkins et al. paper

Procedure

1. Start with the first tree in your quadrant and work around the plot clockwise, following the azimuth team.

2. Using a species identification key or guide identify the species (or general species group, e.g. pine, oak) of each tree.

3. Report species information to the team data recorder to be recorded on the *Tree Data Sheet*.

4. Repeat this process for all trees in your quadrant.

5. After completing species identification, use the *Species Groups List* (or similar classification system) to assign all recorded species into species group categories. [This step can also be done during data entry into the computer.]

Field Guide Instructions - Distance

Distance Group (2 people)

Names ____

Task

Measure the distance from plot center to the center of all trees greater than 15 cm circumference on your Carbon Cycle Sample Site.

Materials

Flexible measuring tape (50m)

Procedure

1. Person one: Stand at plot center facing the direction of your quadrant name (N,E,S,W) and hold the measuring tape case (or one end of the measuring tape).

2. Person two: Pull the end of the tape away from the case out to the first tree clockwise from the direction you are facing.
   - Be careful to make as straight of a line as possible between the center of the plot and the tree.
   - If there is an obstacle between the plot center and the tree measure the distance from the plot center to the obstacle, walk to the obstacle and measure the distance from the obstacle to the desired tree, remember to add the 2 measurements together to get the total distance from the plot center to the tree.

3. Record the distance in meters to the nearest tenth (e.g. 13.2 m).

4. Have the data recorder repeat the distance back to you after they have recorded it to ensure that it was recorded correctly.

5. Repeat the process until the distance to all tagged trees in the quadrant is measured.

Field Guide Instructions - Tree Circumference

Tree Circumference Group - 2 - 4 people (1 - 2 groups per quadrant)

Task

Make measurements of circumference at breast height (CBH) (1.35m) for all tagged trees greater than 15 cm circumference on your Carbon Cycle Sample Site.

Materials (1 per group)

- Clipboard
- Pencil
- *Tree Data Sheet*
- Height indicator for 1.35 m (e.g. string or stick with permanent mark)
- Flexible measuring tape (best if 150-300 cm)
- *Tree Circumference Measurement Guide*

Procedure

1. Review the *Tree Circumference Measurement Guide* for guidelines about marking circumference at breast height.

2. Stand at plot center facing north, east, south or west (according to your quadrant team name).

   a. NOTE: **If 2 groups are measuring 1 quadrant**- Divide the total number of trees in your quadrant between the two tree circumference groups, for example: north to north-east (0°-45°), north-east to east (45°-90°)

3. Turn your body clockwise until you are facing the tree closest to that direction.

4. Check to make sure the tree is alive. If it has died, do not measure it.

5. Using a pre-measured height indicator or flexible tape measure, measure from the ground at the base of the tree to a height of 1.35 m.

6. Using the marked height, measure CBH to the nearest tenth centimeter, e.g. 16.6cm.

7. Report this value to the data recorder. The recorder should repeat the value out loud as they write it next to the appropriate tree on the Tree Data Sheet. (This will ensure accurate circumference values.)

8. Repeat this process for all trees in your designated section.

Field Guide Instructions - Tree Circumference

Tree Circumference (2 people)

Names ____

Task

Measure and mark at 1.35 m (known as breast height by foresters and field biologists) on all trees greater than 15 cm circumference on your Carbon Cycle Sample Site.

Materials

Height indicator for 1.35 m (e.g. string or stick with permanent mark)
Flexible measuring tape (best if 150-300 cm)
Paint Stick/Tree Crayon
Tree Circumference Measurement Guide

Procedure

1. Review the *Tree Circumference Measurement Guide* for guidelines about marking circumference at breast height.

2. Stand at plot center facing north, east, south or west (according to your quadrant team name).

3. Turn your body clockwise until you are facing the tree closest to that direction.

4. Using a pre-measured height indicator or flexible tape measure, measure from the ground at the base of the tree to a height of 1.35 m.

5. Using a tree crayon, draw a straight line on the tree at 1.35 m. This will ensure that future measurements are made at the exact same height.
   - The line does not need to extend around the whole tree, but should be long enough to be clearly visible when being measured.

6. Repeat breast height measurements on all trees in your quadrant.

Notes:

- If there is a bulge, split, or other kind of deformity at 1.35 m follow the examples shown in the *Tree Circumference Measurement Guide* to determine at what height you should mark the tree for circumference measurements. Be sure to record the actual height you marked in the "Notes" section of your Data Sheet.

- Keep in mind you only need to report non-standard height measurements to the data recorder.

Appendix A - Species Groups List (adapted from Jenkins et al. 2003, Appendix A)

Species Group	Common Name	Genus	Species
AspenAlder	Balsam poplar	Populus	balsamifera
AspenAlder	Bigtooth aspen	Populus	grandidentata
AspenAlder	Black cottonwood	Populus	trichocarpa
AspenAlder	Black willow	Salix	nigra
AspenAlder	Cottonwood (general)	Populus	spp.
AspenAlder	Diamond willow	Salix	eriocephala
AspenAlder	Eastern cottonwood	Populus	deltoides
AspenAlder	Fremont cottonwood	Populus	fremontii
AspenAlder	Narrowleaf cottonwood	Populus	angustifolia
AspenAlder	Peachleaf willow	Salix	amygdaloides
AspenAlder	Plains cottonwood	Populus	sargentii
AspenAlder	Quaking aspen	Populus	tremuloides
AspenAlder	Red alder	Alnus	rubra
AspenAlder	Silver poplar	Populus	alba
AspenAlder	Speckled alder	Alnus	rugosa
AspenAlder	Swamp cottonwood	Populus	heterophylla
AspenAlder	White alder	Alnus	rhombifolia
AspenAlder	Willow (general)	Salix	spp.
CedarLarch	Alaska-cedar	Chamaecyparis	nootkatensis
CedarLarch	Atlantic white-cedar	Chamaecyparis	thyoides
CedarLarch	Baldcypress	Taxodium	distichum
CedarLarch	Eastern redcedar	Juniperus	virginiana
CedarLarch	Giant sequoia	Sequoiadendron	giganteum
CedarLarch	Incense-cedar	Calocedrus	decurrens
CedarLarch	Larch (general)	Larix	spp.
CedarLarch	Pondcypress	Taxodium	distichum var. nutans
CedarLarch	Port-Orford-cedar	Chamaecyparis	lawsoniana
CedarLarch	Redwood	Sequoia	sempervirens
CedarLarch	Softwoods (general)	Softwood	spp.
CedarLarch	Southern redcedar	Juniperus	silicicola
CedarLarch	Subalpine larch	Larix	lyallii
CedarLarch	Tamarack (native)	Larix	laricina
CedarLarch	Western larch	Larix	occidentalis
CedarLarch	Western redcedar	Thuja	plicata
CedarLarch	White-cedar	Thuja	occidentalis
DougFir	Bigcone Douglas-fir	Pseudotsuga	macrocarpa
DougFir	Douglas-fir	Pseudotsuga	menziesii
FirHemlock	Balsam fir	Abies	balsamea
FirHemlock	Bristlecone fir	Abies	bracteata
FirHemlock	California nutmeg	Torreya	californica

Species Group	Common Name	Genus	Species
FirHemlock	California red fir	Abies	magnifica
FirHemlock	Carolina hemlock	Tsuga	caroliniana
FirHemlock	Corkbark fir	Abies	lasiocarpa var. arizonica
FirHemlock	Eastern hemlock	Tsuga	canadensis
FirHemlock	Fir (general)	Abies	spp.
FirHemlock	Fraser fir	Abies	fraseri
FirHemlock	Grand fir	Abies	grandis
FirHemlock	Hemlock (general)	Tsuga	spp.
FirHemlock	Mountain hemlock	Tsuga	mertensiana
FirHemlock	Noble fir	Abies	procera
FirHemlock	Pacific silver fir	Abies	amabilis
FirHemlock	Pacific yew	Taxus	brevifolia
FirHemlock	Shasta red fir	Abies	magnifica var. shastensis
FirHemlock	Subalpine fir	Abies	lasiocarpa
FirHemlock	Western hemlock	Tsuga	heterophylla
FirHemlock	White fir	Abies	concolor
MapleOak	American beech	Fagus	grandifolia
MapleOak	Bear oak, scrub oak	Quercus	ilicifolia
MapleOak	Bitternut hickory	Carya	cordiformis
MapleOak	Black hickory	Carya	texana
MapleOak	Black maple	Acer	nigrum
MapleOak	Black oak	Quercus	velutina
MapleOak	Blackjack oak	Quercus	marilandica
MapleOak	Blue oak	Quercus	douglasii
MapleOak	Bluejack oak	Quercus	incana
MapleOak	Bur oak	Quercus	macrocarpa
MapleOak	California black oak	Quercus	kelloggii
MapleOak	California live oak	Quercus	agrifolia
MapleOak	California white oak	Quercus	lobata
MapleOak	Canyon live oak	Quercus	chrysolepis
MapleOak	Cherrybark oak, swamp red oak	Quercus	falcata var. pagodaefolia
MapleOak	Chestnut oak	Quercus	prinus
MapleOak	Chinkapin oak	Quercus	muehlenbergii
MapleOak	Delta post oak	Quercus	stellata var. mississip-piensis
MapleOak	Durand oak	Quercus	durandii
MapleOak	Engelmann oak	Quercus	engelmannii
MapleOak	Hickory (general)	Carya	spp.
MapleOak	Interior live oak	Quercus	wislizeni

Species Group	Common Name	Genus	Species
MapleOak	Laurel oak	Quercus	laurifolia
MapleOak	Live oak	Quercus	virginiana
MapleOak	Mockernut hickory	Carya	tomentosa
MapleOak	Northern pin oak	Quercus	ellipsoidalis
MapleOak	Northern red oak	Quercus	rubra
MapleOak	Nuttall oak	Quercus	nuttalii
MapleOak	Oregon white oak	Quercus	garryana
MapleOak	Overcup oak	Quercus	lyrata
MapleOak	Pecan	Carya	illinoensis
MapleOak	Pignut hickory	Carya	glabra
MapleOak	Pin oak	Quercus	palustris
MapleOak	Post oak	Quercus	stellata
MapleOak	Scarlet oak	Quercus	coccinea
MapleOak	Scrub oak (general)	Quercus	spp.
MapleOak	Shagbark hickory	Carya	ovata
MapleOak	Shellbark hickory	Carya	laciniosa
MapleOak	Shingle oak	Quercus	imbricaria
MapleOak	Shumard oak	Quercus	shumardii
MapleOak	Southern red oak	Quercus	falcata var. falcata
MapleOak	Sugar maple	Acer	saccharum
MapleOak	Swamp chestnut oak	Quercus	michauxii
MapleOak	Swamp white oak	Quercus	bicolor
MapleOak	Turkey oak	Quercus	laevis
MapleOak	Water hickory	Carya	aquatica
MapleOak	Water oak	Quercus	nigra
MapleOak	White oak	Quercus	alba
MapleOak	Willow oak	Quercus	phellos
MixedHardwood	Ailanthus	Ailanthus	altissima
MixedHardwood	Allegheny chinkapin	Castanea	pumila
MixedHardwood	American basswood	Tilia	americana
MixedHardwood	American chestnut	Castanea	dentata
MixedHardwood	American elm	Ulmus	americana
MixedHardwood	American holly	Ilex	opaca
MixedHardwood	American hornbeam, musclewood	Carpinus	caroliniana
MixedHardwood	American mountain-ash	Sorbus	americana
MixedHardwood	Apple (general)	Malus	spp.
MixedHardwood	Ash (general)	Fraxinus	spp.
MixedHardwood	Basswood (general)	Tilia	spp.
MixedHardwood	Bigleaf magnolia	Magnolia	macrophylla

Species Group	Common Name	Genus	Species
MixedHardwood	Black ash	Fraxinus	nigra
MixedHardwood	Black cherry	Prunus	serotina
MixedHardwood	Black locust	Robinia	psuedoacacia
MixedHardwood	Black walnut	Juglans	nigra
MixedHardwood	Blackgum	Nyssa	sylvatica
MixedHardwood	Blue ash	Fraxinus	quadrangulata
MixedHardwood	Buckeye (except 331, 332)	Aesculus	spp.
MixedHardwood	Buckeye, horsechest-nut	Aesculus	spp.
MixedHardwood	Butternut	Juglans	cinerea
MixedHardwood	California buckeye	Aesculus	californica
MixedHardwood	California sycamore	Platanus	racemosa
MixedHardwood	California-laurel	Umbellularia	californica
MixedHardwood	Canada plum	Prunus	nigra
MixedHardwood	Catalpa	Catalpa	spp.
MixedHardwood	Cedar elm	Ulmus	crassifolia
MixedHardwood	Cherry, plum spp.	Prunus	spp.
MixedHardwood	Chinaberry	Melia	azedarach
MixedHardwood	Chinese tallowtree	Sapium	sebiferum
MixedHardwood	Chinkapin	Castanopsis	spp.
MixedHardwood	Chittamwood, gum bumelia	Bumelia	lanuginosa
MixedHardwood	Chokecherry	Prunus	virginiana
MixedHardwood	Common persimmon	Diospyros	virginiana
MixedHardwood	Cucumbertree	Magnolia	acuminata
MixedHardwood	Eastern hophornbeam, ironwood	Ostrya	virginiana
MixedHardwood	Eastern redbud	Ceriss	canadensis
MixedHardwood	Elm (general)	Ulmus	spp.
MixedHardwood	Eucalyptus (general)	Eucalyptus	spp.
MixedHardwood	European mountain-ash	Sorbus	aucuparia
MixedHardwood	Flowering dogwood	Cornus	florida
MixedHardwood	Golden chinkapin	Castanopsis	chrysophylla
MixedHardwood	Green ash	Fraxinus	pennsylvanica
MixedHardwood	Hackberry	Celtis	occidentalis
MixedHardwood	Hackberry (general)	Celtis	spp.
MixedHardwood	Hardwoods (general)	Hardwood	spp.
MixedHardwood	Hawthorn	Crataegus	spp.
MixedHardwood	Honeylocust	Gleditsia	triacanthos
MixedHardwood	Kentucky coffeetree	Gymnocladus	dioicus

Species Group	Common Name	Genus	Species
MixedHardwood	Loblolly-bay	Gordonia	lasianthus
MixedHardwood	Magnolia (general)	Magnolia	spp.
MixedHardwood	Mulberry (general)	Morus	spp.
MixedHardwood	Northern catalpa	Catalpa	speciosa
MixedHardwood	Ogeechee tupelo	Nyssa	ogeche
MixedHardwood	Ohio buckeye	Aesculus	glabra
MixedHardwood	Oregon ash	Fraxinus	latifolia
MixedHardwood	Osage-orange	Maclura	pomifera
MixedHardwood	Ozark chinkapin	Castanea	ozarkensis
MixedHardwood	Pacific dogwood	Cornus	nuttallii
MixedHardwood	Pacific madrone	Arbutus	menziesii
MixedHardwood	Paulownia, Empress tree	Paulownia	tomentosa
MixedHardwood	Pawpaw	Asimina	triloba
MixedHardwood	Pin cherry	Prunus	pensylvanica
MixedHardwood	Plums, cherries, except 762	Prunus	spp.
MixedHardwood	Pumpkin ash	Fraxinus	profunda
MixedHardwood	Red mulberry	Morus	rubra
MixedHardwood	Redbay	Persea	borbonia
MixedHardwood	Rock elm	Ulmus	thomasii
MixedHardwood	Sassafras	Sassafras	albidum
MixedHardwood	September elm	Ulmus	serotina
MixedHardwood	Serviceberry	Amelanchier	spp.
MixedHardwood	Siberian elm	Ulmus	pumila
MixedHardwood	Silverbell	Halesia	spp.
MixedHardwood	Slippery elm	Ulmus	rubra
MixedHardwood	Smoketree	Cotinus	obovatus
MixedHardwood	Sourwood	Oxydendrum	arboreum
MixedHardwood	Southern catalpa	Catalpa	bignonioides
MixedHardwood	Southern magnolia	Magnolia	grandiflora
MixedHardwood	Sparkleberry	Vaccinium	arboreum
MixedHardwood	Sugarberry	Celtis	laevigata
MixedHardwood	Swamp tupelo	Nyssa	sylvatica var. biflora
MixedHardwood	Sweetbay	Magnolia	virginiana
MixedHardwood	Sweetgum	Liquidambar	styraciflua
MixedHardwood	Sycamore	Platanus	occidentalis
MixedHardwood	Tanoak	Lithocarpus	densiflorus
MixedHardwood	Tung-oil tree	Ailanthus	fordii
MixedHardwood	Walnut	Juglans	spp.
MixedHardwood	Water tupelo	Nyssa	aquatica

Species Group	Common Name	Genus	Species
MixedHardwood	Water-elm	Planera	aquatica
MixedHardwood	Waterlocust	Gleditsia	aquatica
MixedHardwood	White ash	Fraxinus	americana
MixedHardwood	White basswood	Tilia	heterophylla
MixedHardwood	White mulberry	Morus	alba
MixedHardwood	Wild plum	Prunus	americana
MixedHardwood	Winged elm	Ulmus	alata
MixedHardwood	Yellow buckeye	Aesculus	octandra
MixedHardwood	Yellow-poplar	Liriodendron	tulipifera
Pine	Apache pine	Pinus	engelmannii
Pine	Arizona pine	Pinus	arizonica
Pine	Austrian pine	Pinus	nigra
Pine	Bishop pine	Pinus	muricata
Pine	Border pinyon	Pinus	discolor
Pine	Bristlecone pine	Pinus	aristata
Pine	California foothill pine	Pinus	sabiniana
Pine	Chihuahuan pine	Pinus	leiophylla
Pine	Coulter pine	Pinus	coulteri
Pine	Eastern white pine	Pinus	strobus
Pine	Foxtail pine	Pinus	balfouriana
Pine	Jack pine	Pinus	banksiana
Pine	Jeffrey pine	Pinus	jeffreyi
Pine	Knobcone pine	Pinus	attenuata
Pine	Limber pine	Pinus	flexilis
Pine	Loblolly pine	Pinus	taeda
Pine	Lodgepole pine	Pinus	contorta
Pine	Longleaf pine	Pinus	palustris
Pine	Monterey pine	Pinus	radiata
Pine	Pinyon pine	Pinus	edulis
Pine	Pitch pine	Pinus	rigida
Pine	Pond pine	Pinus	serotina
Pine	Ponderosa pine	Pinus	ponderosa
Pine	Red pine	Pinus	resinosa
Pine	Sand pine	Pinus	clausa
Pine	Scotch pine	Pinus	sylvestris
Pine	Shortleaf pine	Pinus	echinata
Pine	Singleleaf pinyon	Pinus	monophylla
Pine	Slash pine	Pinus	elliottii
Pine	Southwestern white pine	Pinus	strobiformis
Pine	Spruce pine	Pinus	glabra

Species Group	Common Name	Genus	Species
Pine	Sugar pine	Pinus	lambertiana
Pine	Table Mountain pine	Pinus	pungens
Pine	Virginia pine	Pinus	virginiana
Pine	Western white pine	Pinus	monticola
Pine	Whitebark pine	Pinus	albicaulis
SoftMapleBirch	Bigleaf maple	Acer	macrophyllum
SoftMapleBirch	Birch (general)	Betula	spp.
SoftMapleBirch	Boxelder	Betula	negundo
SoftMapleBirch	Florida maple	Acer	barbatum
SoftMapleBirch	Gray birch	Betula	populifolia
SoftMapleBirch	Mountain maple	Acer	spicatum
SoftMapleBirch	Paper birch	Betula	papyrifera
SoftMapleBirch	Red maple	Acer	rubrum
SoftMapleBirch	River birch	Betula	nigra
SoftMapleBirch	Silver maple	Acer	saccharinum
SoftMapleBirch	Striped maple	Acer	pensylvanicum
SoftMapleBirch	Sweet birch	Betula	lenta
SoftMapleBirch	Water birch	Betula	occidentalis
SoftMapleBirch	Western paper birch	Betula	papyrifera var. commutata
SoftMapleBirch	Yellow birch	Betula	alleghaniensis
Spruce	Black spruce	Picea	mariana
Spruce	Blue spruce	Picea	pungens
Spruce	Brewer spruce	Picea	breweriana
Spruce	Engelmann spruce	Picea	engelmannii
Spruce	Norway spruce	Picea	abies
Spruce	Red spruce	Picea	rubens
Spruce	Sitka spruce	Picea	sitchensis
Spruce	Spruce (general)	Picea	spp.
Spruce	White spruce	Picea	glauca
Woodland	Acacia (general)	Acacia	spp.
Woodland	Alligator juniper	Juniperus	deppeana
Woodland	Arizona cypress	Cupressus	arizonica
Woodland	Arizona white oak, Gray oak	Quercus	arizonica, grisea
Woodland	Bigtooth maple	Acer	grandidentatum
Woodland	Birchleaf mountain-mahogany	Cercocarpus	montanus var. glaber
Woodland	Bitter cherry	Prunus	emarginata
Woodland	California juniper	Juniperus	californica
Woodland	Common juniper	Juniperus	communis

Species Group	Common Name	Genus	Species
Woodland	Curlleaf mountain-mahogany	Cercocarpus	ledifolius
Woodland	Cypress	Cupressus	spp.
Woodland	Deciduous oak spp.	Quercus	spp.
Woodland	Emory oak	Quercus	emoryi
Woodland	Evergreen oak spp.	Quercus	spp.
Woodland	Gambel oak	Quercus	gambelii
Woodland	Hairy mountain-mahogany	Cercocarpus	montanus var. pauciden
Woodland	Littleleaf mountain-mahogany	Cercocarpus	intricatus
Woodland	Mesquite	Prosopis	spp.
Woodland	Mexican blue oak	Quercus	oblongifolia
Woodland	New Mexico locust	Robinia	neomexicana
Woodland	Oneseed juniper	Juniperus	monosperma
Woodland	Pinchot juniper	Juniperus	pinchotti
Woodland	Redberry juniper	Juniperus	erythrocarpa
Woodland	Rocky Mountain juniper	Juniperus	scopulorum
Woodland	Rocky Mountain maple	Acer	glabrum
Woodland	Silverleaf oak	Quercus	hypoleucoides
Woodland	Tesota (Arizona ironwood)		tesota
Woodland	True mountain-mahogany	Cercocarpus	montanus
Woodland	Utah juniper	Juniperus	osteosperma
Woodland	Western juniper	Juniperus	occidentalis

Appendix B - Predicted Biomass Graph (reproduced from Jenkins et al. 2003, Figure 1)

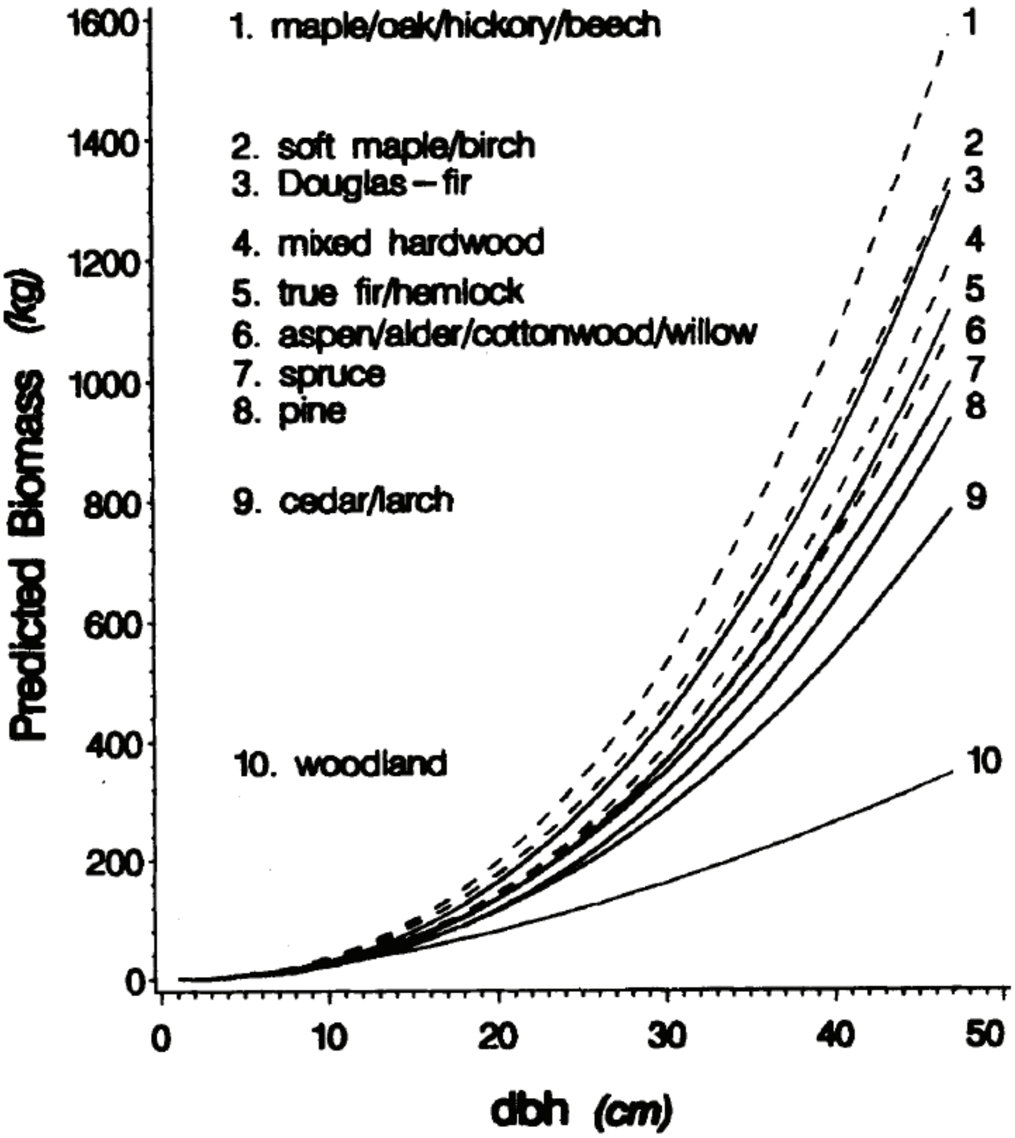

Figure 1. Graphs of ten equations for predicting total aboveground biomass by species group. Hardwoods are represented by dashed lines, softwoods by solid lines. (Source: National-Scale Biomass Estimators for United States Tree Species, Jenkins et al)

Appendix C: Tree Circumference Measurement Guide

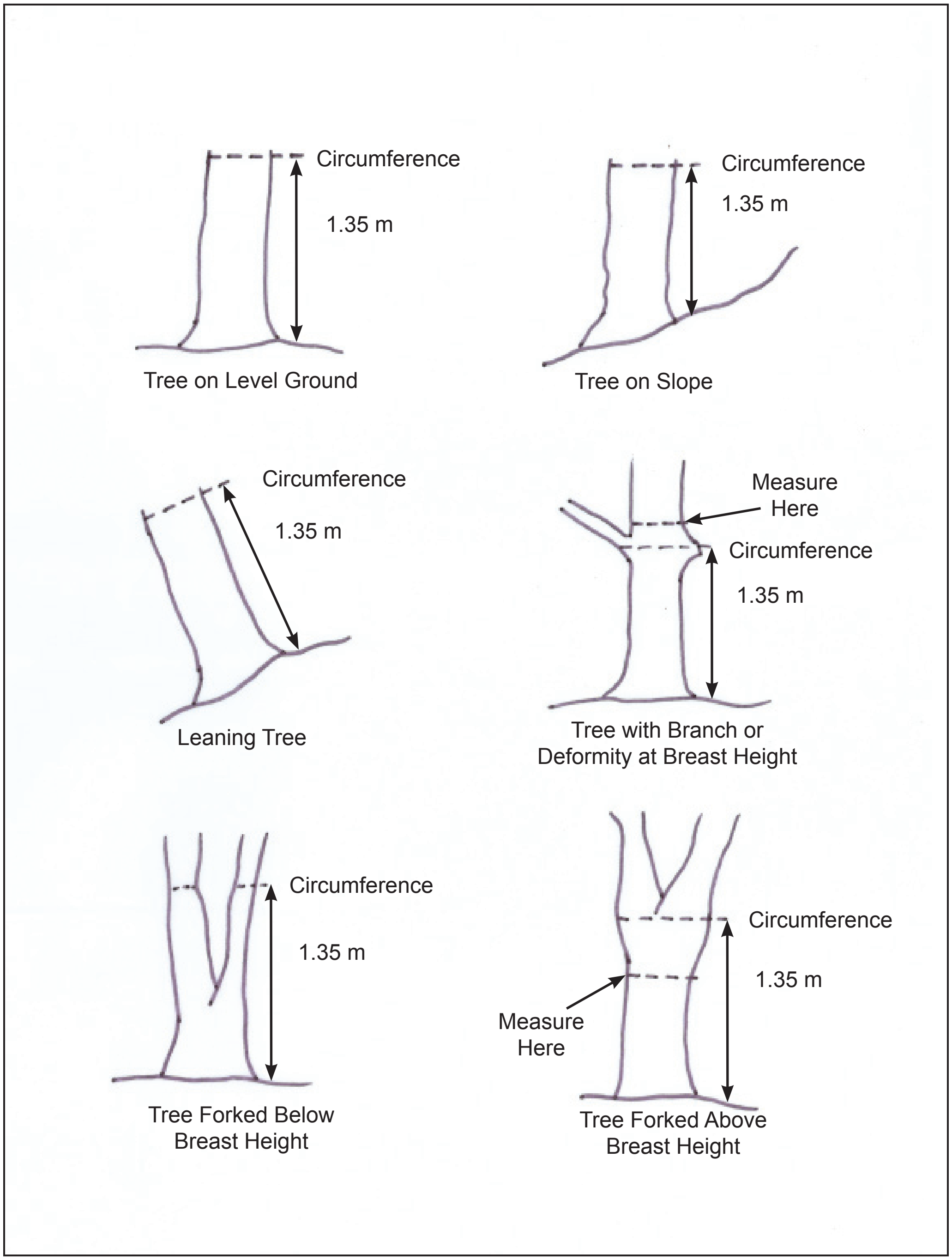

Figure 1, Tree Circumference Guide (GLOBE Carbon Cycle Tree Circumference Protocol adapted from USDA Forest Service DBH Protocol)

Appendix D: Tree Mapping Guide

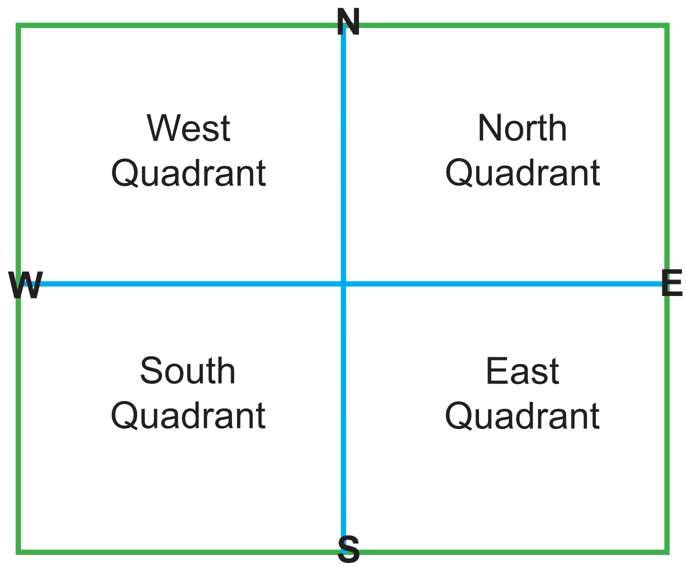

Figure 1a, Tree Mapping, Team Quadrants

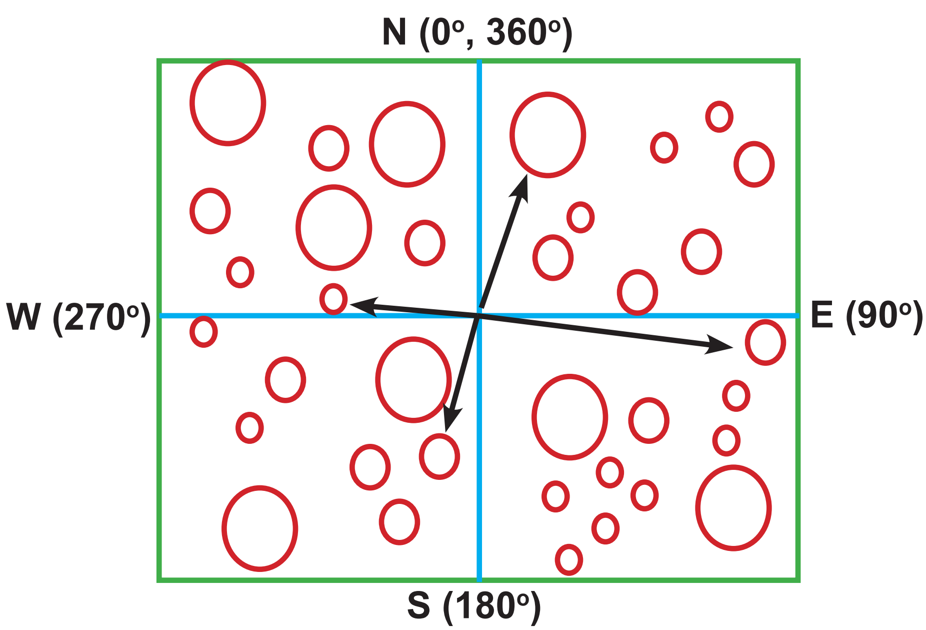

Figure 1b, Tree Mapping, Sample: First Tree in Each Quadrant

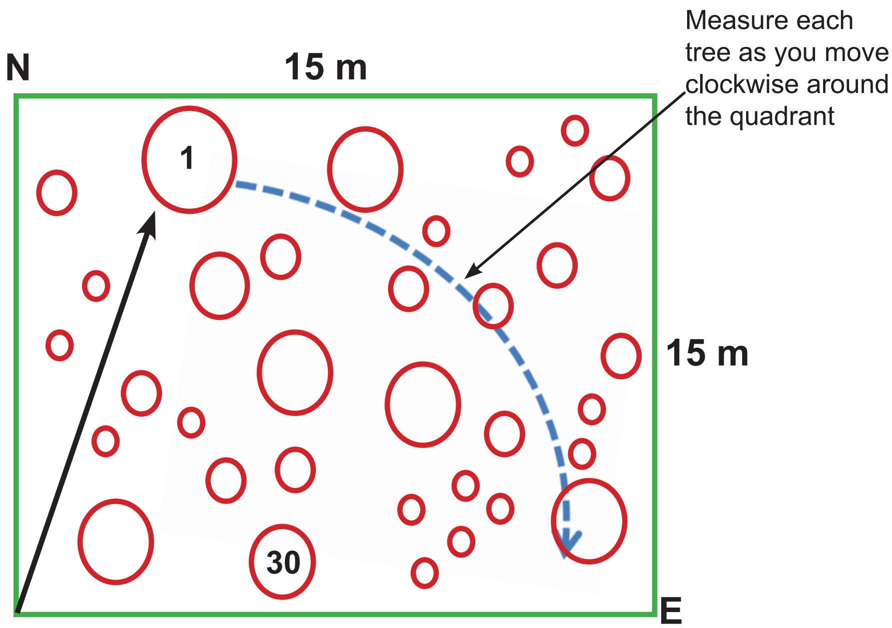

Figure 2a, Tree Mapping, Sample Quadrant

Azimuth	Distance	Species	Notes	Circumference (CBH)
15°	14 m	red maple		50 cm
85°	6.5 m	Pinus strobus	Forked, measured at 1.25 m	27 cm

Appendix E: Tree Data Collection Challenge – Team Scoring Rubric

Criteria	Developing *(Needs improvement)*	Proficient *(Average)*	Exemplary
Tool Use	Tools were used for purposes which they were not designed or were not used correctly	Demonstrated correct tool use after some teacher guidance	Demonstrated proficient use of tools without teacher assistance
Measurements – Precision and Accuracy	Did not follow resource directions for difficult to measure trees, correct units were used occasionally, data did not typically match measurements made during peer evaluation	Followed resource directions, used correct units on data sheet, data mostly matched measurements made during peer evaluation	Closely followed resource directions, double checked difficult to measure trees, used correct units on data sheet, data matched measurements made during peer evaluation
Tree Data Sheet	Data sheet is incorrect, incomplete, or illegible	Data sheet is completed, legible, and notes are filled out where appropriate	Data sheet is completed, legible, and any notes are clear, concise (scientific in nature)
Participation	Some team members are involved in the data collection process	All team members are involved in some part of the data collection process	Team delegates tasks so each member has an assigned role at all stages of the data collection process
Communication	Team members talk over one another, report data to recorder – but needs to be repeated often, do not seek answers to team questions from the teacher or each other	Team members listen when others are talking, report data to the recorder, ask the teacher questions when difficulties arise	Team members discuss procedures and tasks, report data loudly and clearly, ask each other questions when difficulties arise
Efficiency	Team was unable to work cooperatively to complete tasks, teacher assistance was required throughout the data collection process	Team worked cooperatively to complete tasks quickly and correctly with some teacher assistance on delegation of roles and problem solving	Team worked cooperatively to delegate and complete tasks quickly and correctly, problems were addressed and solved with little teacher assistance