Allometry - Not a Llama Tree

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

Overview
In this activity students measure the height, foot length and arm span of other students in the class. They then use this data to make a in order 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 then apply their understanding of allometry to the study of biomass and carbon in trees/shrubs.

Student Outcomes
Students will be able to:
- Develop and validate an allometric equation for human height.
- Relate human allometry to tree/shrub allometry.
- Understand why allometric equations are different for different species groups.

Questions
Content
- How is allometry used to calculate biomass?
- How are allometric equations developed?

Science Concepts
Grades 9-12

Scientific Inquiry
- Use appropriate tools and techniques to gather, analyze, and interpret data

Life Sciences
- Biological classifications are based on organism that are related

History and Nature of Science
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

Time/Frequency
75 minutes.

Level
Secondary (Middle & High School)

Materials and Tools
- 50 meter tape measure OR meter stick OR flexible measuring tape (1 per group)
- *Student Worksheet* (1 per student)
- Notebook and pencil (1 per student)
- Graph paper OR computers with a spreadsheet application
- National-Scale Biomass Estimators for United States Tree Species, Jenkins et al. [Optional] http://www.fs.fed.us/ne/newtown_square/publications/other_publishers/OCR/ne_2003jenkins01.pdf
- *Species Groups List* adapted from Jenkins et al. paper (1 per group)
- *Predicted Biomass Graph* adapted from Jenkins et al. paper (1 per group)
- Tree Identification Guide or online equivalent (http://plants.usda.gov/)
- **AllometryNotALlamaTree_example.xls*– includes sample dataset, printable datasheet and spreadsheet template

Prerequisites
- Knowledge of DBH and Biomass (See: *HowToMeasureTrees and BiomassUnits*)

Preparation
- Review & make copies of *Species Group List* and *Predicted Biomass Graph*.
- Review how to enter student data in: *AllometryNotALlamaTree_example.xls* so that you can help students see how equations are developed.
- Review, select and then copy the "Parts" of the *Student Worksheet* your students will perform (based on type of vegetation they will measure in the field).

Welcome
Introduction
Protocols
Learning Activities
Appendix

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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/shrubs 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/shrubs of different sizes and species to look for relationships between parts of the tree/shrub that can be measured easily, such as DBH, height, % cover and the whole tree/shrub'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. 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:

$y = mx + b$ (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 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.

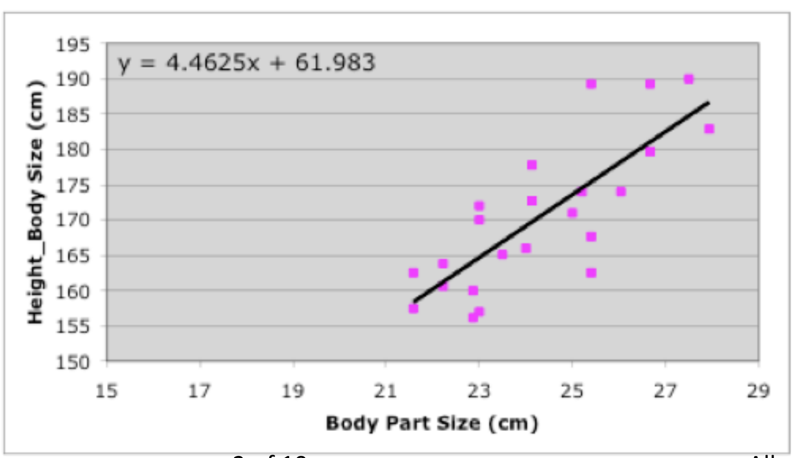
$y = e^{(a + b[\ln(x)])}$

The exact form of equations students will see in the Sample Site Tree Biomass Analysis is:

biomass = Exp(B0 + B1 ln dbh), where ln = log base e (or 2.718282).

If your students participate in the tree data collection and analysis, they will need to understand the basics of tree allometry.

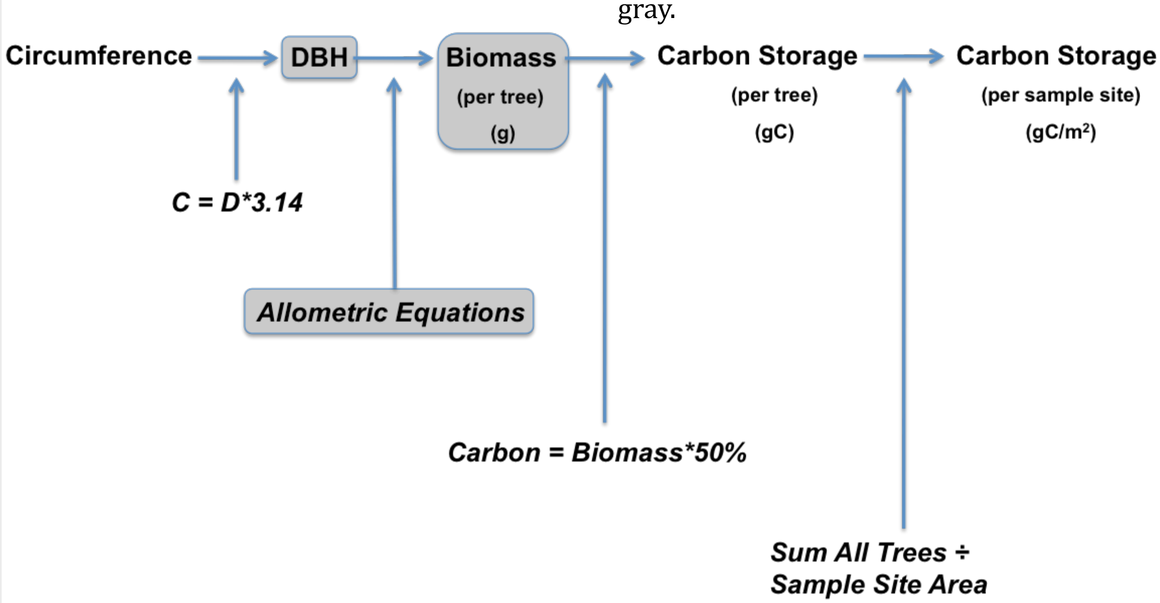
Likewise if there are shrubs or saplings on your site an allometric equation with two variables, percent cover and average shrub height will be used (See Part 2b for more details).



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 you can read the National-Scale Biomass Estimators for United States Tree Species (Jenkins et al. 2003) paper. Figure 1 (Predicted Biomass Graph) and Appendix A (Species Groups List) are of particular interest.

This 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.

The diagram below 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.



What To Do and How To Do It

ENGAGE **Grouping:** Class **Time:** 10 minutes

- Students share ideas about how vegetative biomass is measured/calculated.
- Discuss the implications of weighing trees/shrubs in order to calculate biomass (i.e. destructive sampling would result in loss of the trees/shrubs from the site).
- Present the idea to students that instead, scientists use something called allometric equations to calculate tree/shrub biomass without having to cut down tree/shrubs. In this case, part of the tree or shrub is measured and used to estimate the total biomass.
    - However they must have cut down tree/shrubs at some point to collect enough data that the relationship between the tree or shrub part and total biomass became evident.
- Define allometry.
- In order to understand how these types of equations are developed we want to create allometric equations for the people in our classroom. Do humans have allometric relationships? Can you think of any examples?

EXPLORE	**Grouping:** Small Groups	**Time:** 20 minutes

- Students follow the Student Worksheet 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.

EXPLAIN	**Grouping:** Class	**Time:** 15 minutes

- Students use the data to answer thought questions in Part 1b of their student directions.
- Examine data and graphs as a class. Discuss answers to questions 1-3.
  - If 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 *Extension: Analyze Class Data.*
- Discuss how this activity is related to the calculation of biomass using DBH or other factors.
  - Students share answers to question 4: How does this activity relate to measuring tree/shrubs? Also refer back to discussions from the Engage section.
  - Because there are differences between tree/shrubs (*Extension: 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: *Predicted Biomass Graph* adapted from the Jenkins et al. 2003 paper.
    - There may also be allometric equations for the specific tree species in your area, so it could be worth contacting the local forestry or science center to assist you in understanding those equations and then using them in the analysis of your field data instead of the generalized equations offered here.
    - Likewise Prichard et al. 2012 have developed two generalized equations for shrubs that divide them into either the evergreen or deciduous category.

ELABORATE	**Grouping:** Class	**Time:** 20 minutes

- If students will be measuring trees in the field they should complete Part 2a, an examination of the *Predicted Biomass Graph* and *Species Groups List*, 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/shrub identification guide for this section.
- If students will be measuring shrubs in the field they should read Part 2b, to be sure they understand a little more about shrub allometry.

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EVALUATE	**Grouping:** Class	**Time:** 10 minutes

- Discuss the answers to questions in Part 2.
- Discuss student assessment.

**See activity example with sample calculations and answers in *AllometryNotALlamaTree_example.xls.*

Assessment

- How would you use DBH and species/ species groups to calculate the carbon storage for one tree? Draw, diagram or describe.
- How are percent cover and shrub height used to predict biomass?

Extensions

- **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. OR Compare the class's R2 values to the R2 values that result from using a larger and more diverse dataset. (You may choose to have these data available ahead of time, e.g. from the sample data in *AllometryNotALlamaTree_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 largely wood density (although grow pattern differences influenced by growing location can also play a role). 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. To explore even further look at the internal structure of wood also called wood anatomy (using microscope slides) to see how cell organization relates to density.

Resources

Wood Anatomy- online microscope slides of tree/shrub species: www.woodanatomy.ch

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TEACHER VERSION

(Suggested student responses included)

Allometry - Not A Llama Tree/shrub

Content 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 fingertip to fingertip.
   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 AllometryNotALlamaTree/shrub_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 a "line of best fit" 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?

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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/shrub biomass?

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

Part 2a: Tree Allometry

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

1) 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.

2) 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 tree look like? Use the Species Groups List and a tree ID guide to find out a little more about 3 tree you are likely to find during a field investigation of your schoolyard. Describe or draw some of their primary characteristics.

Student's answers will vary depending on your location and the tree they select to investigate.

3) Describe how scientists use allometry to estimate tree biomass.

(See Background section of this activity.)

Part 2b: Shrub Allometry

Shrub and Sapling Biomass can also be determined using allometric equations. However, different from the equations for tree biomass, shrub allometry uses two measured variables: shrub percent cover and average shrub height. The equation differs slightly depending on whether the shrub is evergreen or deciduous, meaning that the students will need to record this information, but will not need to determine the specific shrub or sapling species. Because the equations use an average height and percent cover for all the shrubs/saplings on the sample site, you cannot follow the changes in biomass of individual shrubs as you can with the tree measurements. Instead the students will determine total percent cover and measure the heights of all (or a subsample) of the shrubs/saplings on the site to calculate an average value.

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GLOBE Carbon Cycle

Name: Date:

Allometry - Not A Llama Tree

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3) Record your data.

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

4) Enter your data into the class data table or spreadsheet.

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 a "line of best fit" 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/shrub biomass?

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1) 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. 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.

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