Allometry-Not a Llama Tree Learning Activity

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 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.

NGSS (Black- covered directly, gray-addressed, but not directly covered)

- *Disciplinary Core Ideas*
  - Gr.6-8: LS1.A, LS2.A, ETS1.B, ETS1.C
  - Gr.9-12: LS1.A, LS4.D
- *Science and Engineering Practices*
  - Asking Questions
  - Developing and using models
  - Analyzing and interpreting data
  - Using mathematics and computational thinking
- *Crosscutting Concepts:*
  - Patterns
  - Scale, Proportion, and Quantity
  - Structure and Function

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
- *Scientific Paper*: Jenkins et al. [Optional-see Resources]
- *Species Groups* List adapted from Jenkins et al. paper (1 per group)
- Tree Identification Guide or online equivalent (http://plants.usda.gov)
- **AllometryNotALlamaTree_example.xls* includes a 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).

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:

$$y = mx + b \text{ (line equation)}$$

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.

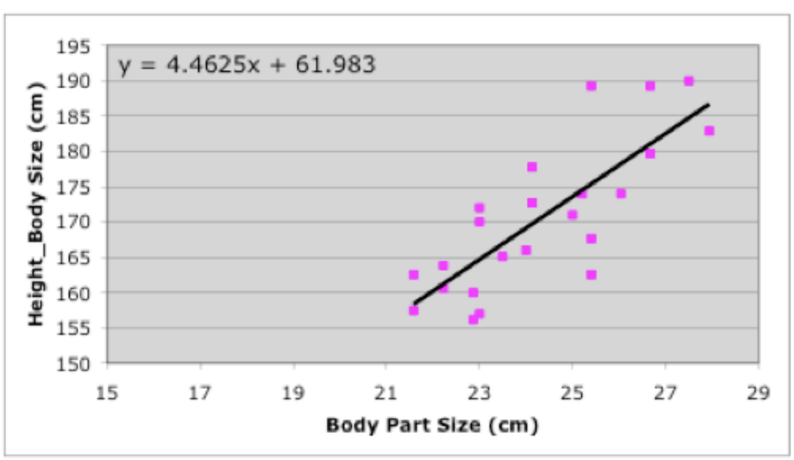
$$y = e^{(a + b[\ln(x)])}$$

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).

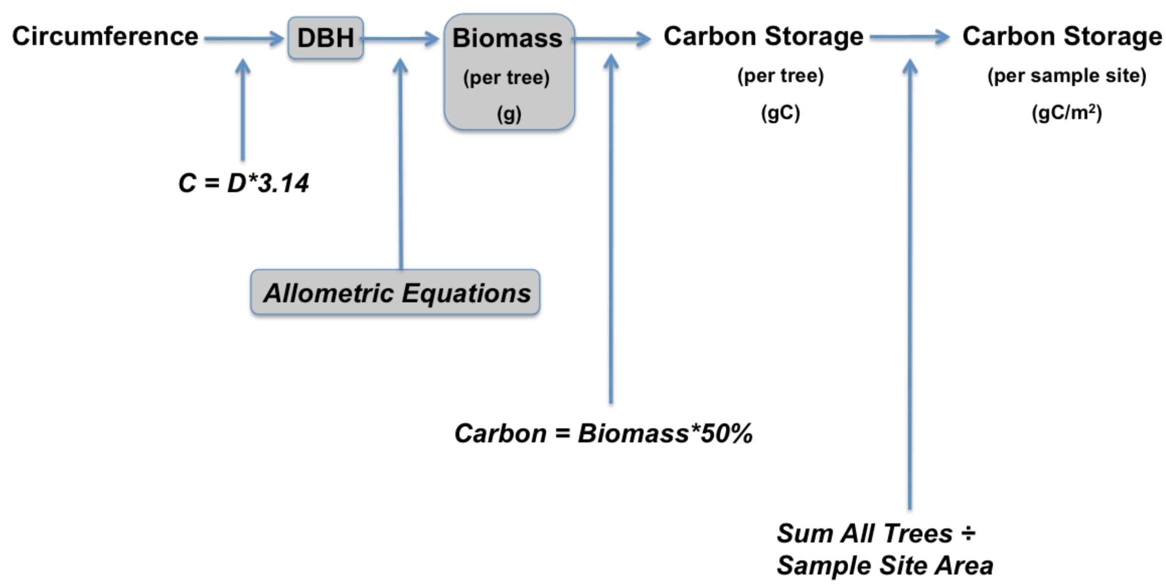
If your students participate in the tree data collection and analysis, they will need to understand the basics of tree allometry.

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.

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 growth 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
- *Scientific Paper*: 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

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?

   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.

Name: Date:

Allometry - Not a Llama

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 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 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 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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   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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   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 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.

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

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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 you will need to record this information when you collect field data, 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 you 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.

Species Group List

(Reproduced from Jenkins et al. 2003, Figure 1)

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
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. mississippiensis
MapleOak	Durand oak	Quercus	durandii
MapleOak	Engelmann oak	Quercus	engelmannii
MapleOak	Hickory (general)	Carya	spp.
MapleOak	Interior live oak	Quercus	wislizeni
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
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, horsechestnut	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
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
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
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
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)	Olneya	tesota
Woodland	True mountain-mahogany	Cercocarpus	montanus
Woodland	Utah juniper	Juniperus	osteosperma
Woodland	Western juniper	Juniperus	occidentalis

Predicted Biomass Graph

(Reproduced from Jenkins et al. 2003, Figure 1)

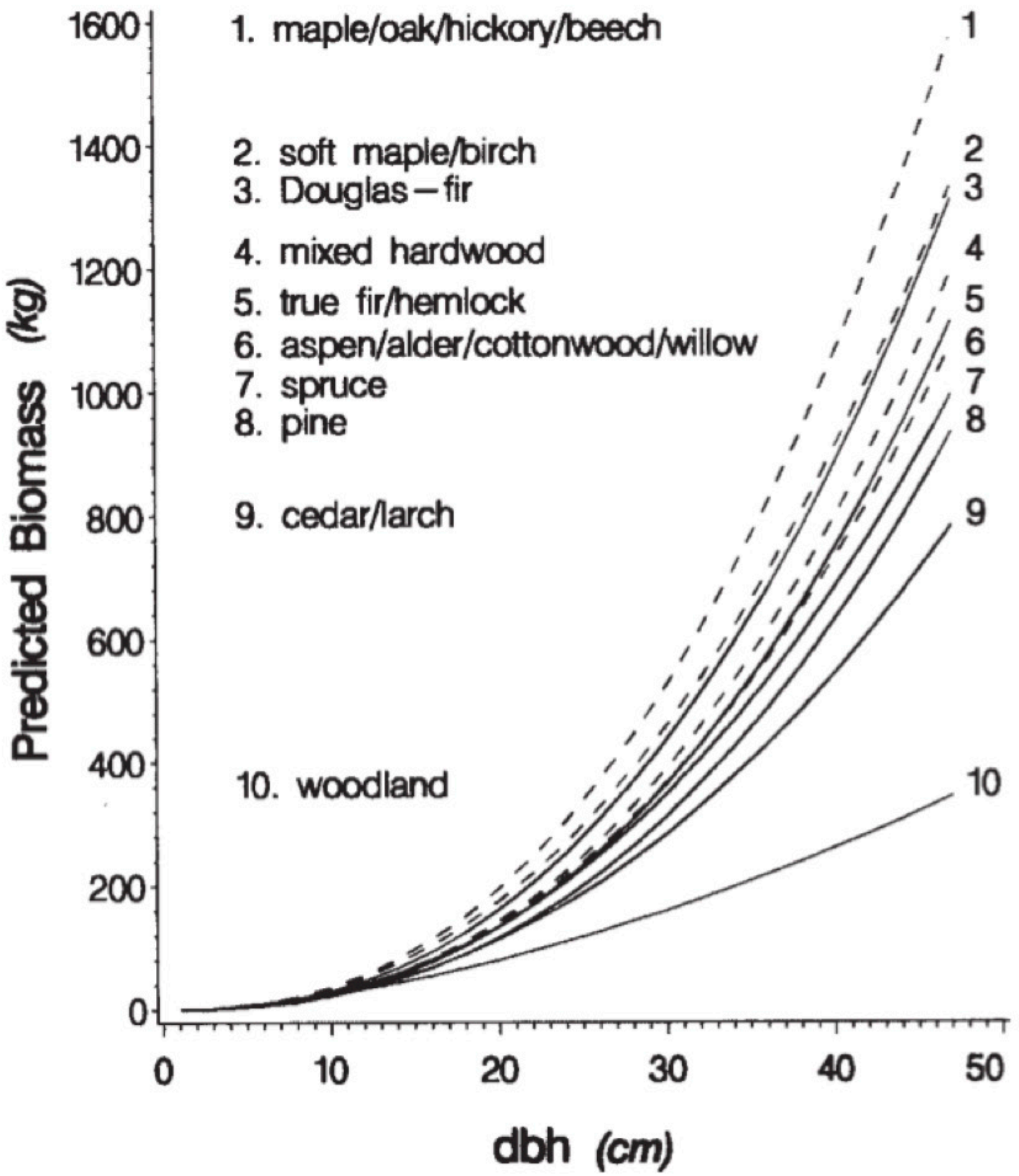

Figure 1. Graphs of ten equations for predicting total aboveground biomass by species group. Hardwoods are represented by dashed lines, softwoods by solid lines.