NYC STEM Summer Institute: Climate To Go!
Photosynthesis: Calculating Biomass and Carbon Storage for Trees

Standards
NGSS LS1.C Organization for matter and energy flow in organisms
NGSS ESS3.D Global climate change
Grade Level: Middle School

Equipment: Tape measure or forester's DBH tape
Graph of DBH v. Tree Biomass
Tree

Overview
Photosynthesis is the process that builds the biomass of plants.
Within leaves, carbon dioxide enters through pores called *stomata*, where it reacts with water to form glucose and oxygen molecules. The oxygen exits the leaf through the same stomata.

$$6CO_2 + 6H_2O \overset{light}{=} C_6H_{12}O_6 + 6O_2$$

carbon dioxide + water = glucose + oxygen

In this reaction light energy from the sun is converted into chemical energy stored in the glucose molecule. Once in the leaf, the glucose is transformed through additional reactions into a range of new compounds, such as the lignin ($C_{31}H_{34}O_{11}$) and cellulose ($C_6H_{10}O_5$) that form the mass of trees. While a plant needs a small amount of additional nutrients for healthy growth (N, P, K), the mass of these additions is very small and accounts for only a tiny fraction of the mass of the plant. In a tree, approximately 50% of the biomass is derived from the carbon that enters the leaves as the invisible atmospheric gas CO_2.

Can we measure the mass of a tree and find out how much CO_2 it holds? That would be easy to do if we were to cut it down, and cut it into small enough pieces to put onto a scale. But that job itself is difficult, and it is certainly hard on the tree. If we could measure or estimate the volume of a tree we could calculate its mass. But trees have very irregular shapes, and it might at first seem difficult or impossible to calculate the biomass of such an unusually-shaped object. Fortunately, the US Forest Service (and others) have taken the trouble to cut down and weigh a lot of trees of many species, and from these data have developed relationships between the mass of trees and measurements that are easy to make. Graph 1 is a graph of the relationship between a tree's Diameter at Breast Height (DBH) and mass for ten different species of trees. In this relationship the diameter is measured in centimeters and the mass is given in kilograms.

Procedure

DBH is measured 4.5 feet above the ground. It is not critical to measure at exactly this height; it is more important to avoid bumps and branches on the trunk. DBH is not measured directly, rather, we measure the circumference of the trunk and calculate the diameter, as in Figure 1:

Figure 1: The circumference and diameter of a circle are related by the factor pi: π=3.14159. Measure the circumference of the tree (photo) in order to calculate the diameter.

Step 1: Identify the tree species

Species:______________________________

If you are working with a regular tape measure you will measure and record the circumference, in units of centimeters, then divide the circumference by π to find the diameter. If you have a forester's DBH tape you can read the circumference from one side, then flip the tape over to read the diameter on the back side.

Step 2: Measure the circumference and calculate diameter

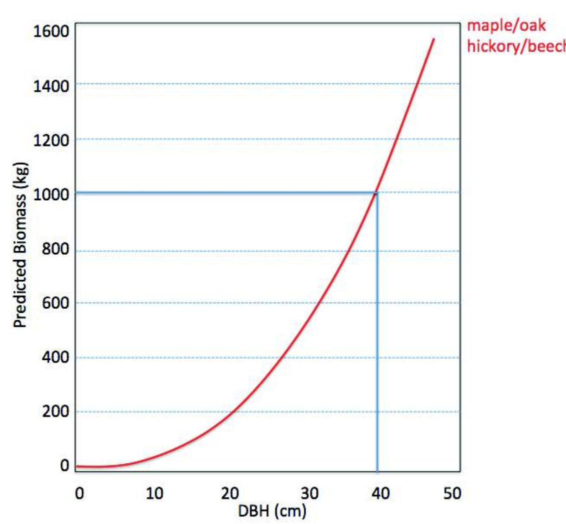
Circumference (cm): __________________

Diameter (cm): _______________________

Once you have calculated the diameter, use Graph 1 to find the appropriate mass in kilograms.

Example: A Sugar Maple tree with a DBH=40cm has a mass of 1000kg (see small graph).

Step 3: Use Graph 1 to find the mass



Mass (kg): _________________________

One kilogram is approximately 2 pounds
(1 kg = 2.2 lb). A 1000kg tree weighs 2200 pounds!

We also know that half of the mass of the tree is made of carbon. So we can also calculate how much atmospheric carbon the tree stores.

Step 4: Calculate the mass of carbon in the tree (carbon = mass/2)

Mass C (kg): _______________________

This is important because carbon dioxide is a Greenhouse Gas – a gas that absorbs long-wavelength (heat) energy – that keeps the atmosphere warm. A little CO_2 in the atmosphere keeps Earth comfortably habitable for human beings, but too much atmospheric CO_2 leads to global warming which disrupts normal Earth system processes. All of the carbon that you calculated for your tree came from the atmosphere. It was incorporated into the tree during photosynthesis. So we can show that trees are able to remove a lot of excess CO_2 from the atmosphere! And in fact, we can take the mass of carbon calculated in Step 4 and turn it into the mass of carbon dioxide that each tree stores.

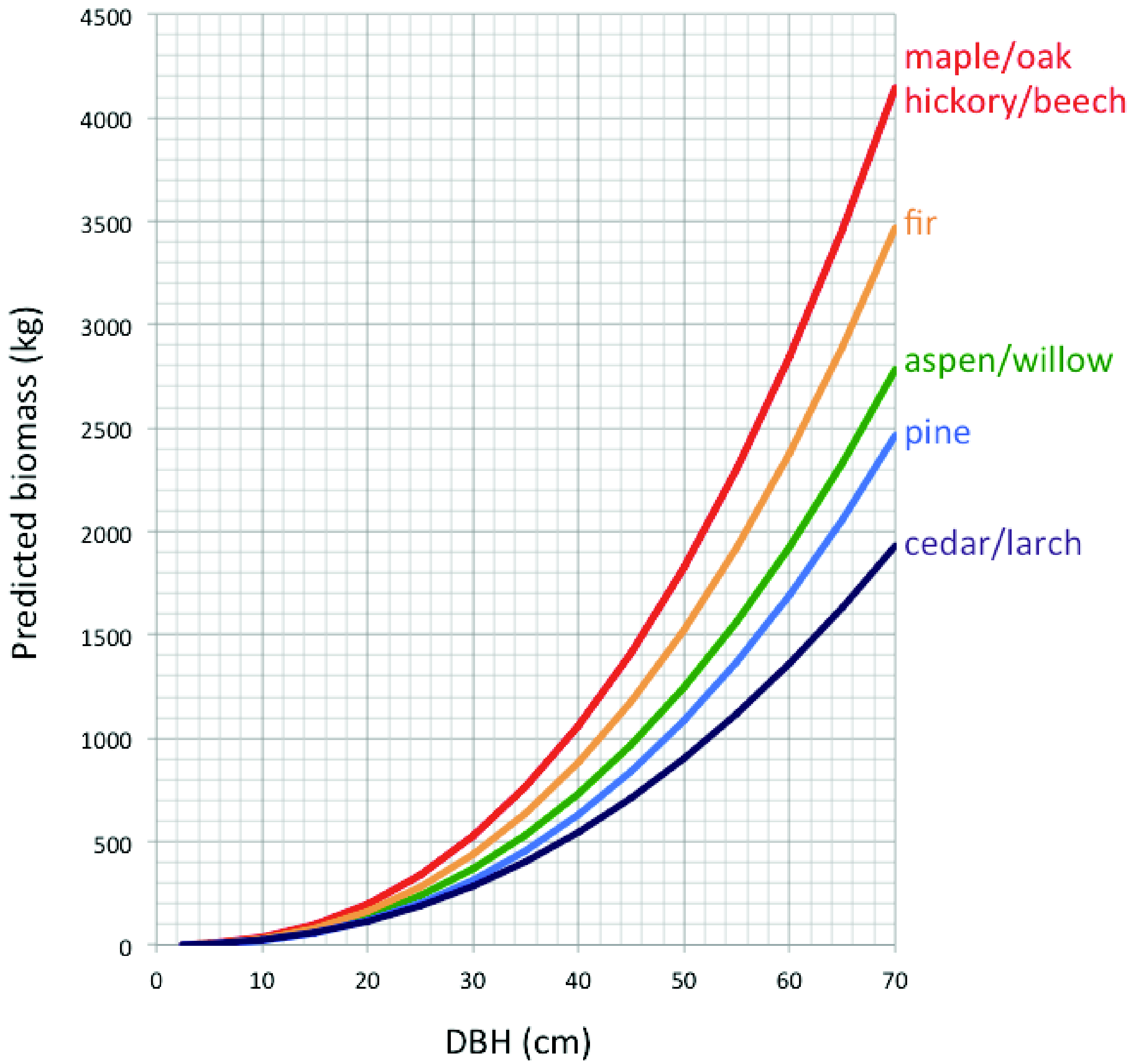
Step 5: Use the mass of carbon in the tree to find the mass of carbon dioxide the tree has removed from the atmosphere. For every carbon atom, a CO_2 molecule also contains two oxygen atoms. So the amount of CO_2 per kg of carbon in the tree is the ratio of the mass of CO_2 (atomic mass=44) to the mass of carbon (atomic mass=12).

Mass CO_2 (kg) = result from Step 4 x (44/12): ___________________________________

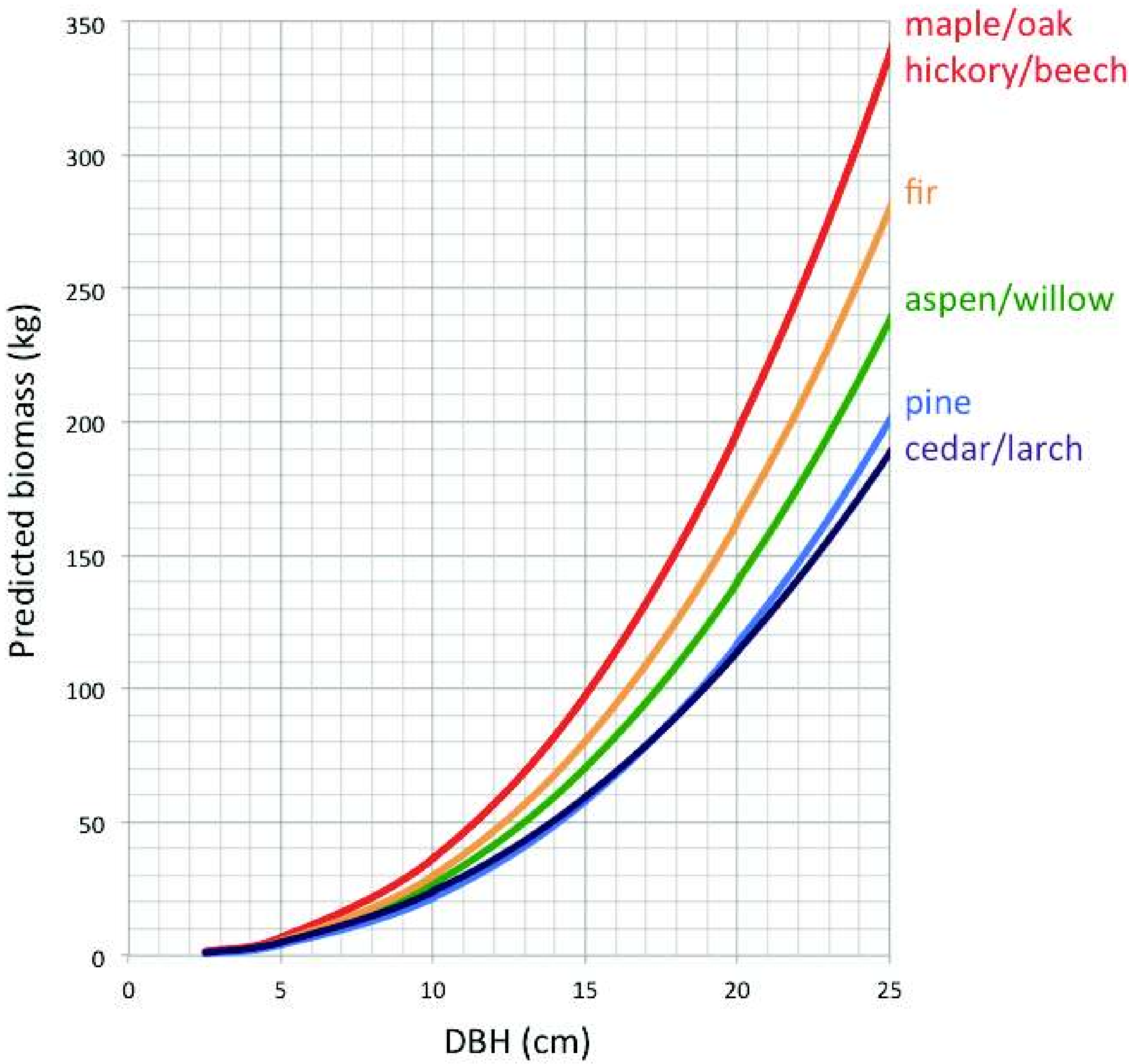
Finally we can think about one more important aspect of out tree – the roots! Roots contribute to the total mass of the tree and thus the total amount of CO_2 stored. The biomass charts - and the underlying equations that we use to make the charts – come from the work of foresters who are interested in the above-ground part of the tree. If we assume that there is an additional 25% of the tree belowground we can refine out calculation from Step 5 by multiplying it by 1.25.

Step 6: Find the total mass of CO_2 in both the “roots and shoots” of the tree (=CO_2 x 1.25)

Total Mass of stored CO_2 (kg): ________________________________



Graph 1: USFS data relating tree diameter at breast height to biomass (Jenkins et al., 2003)



Graph 2: USFS data for small diameter trees (Jenkins et al., 2003)