Climate Forest Workshop

2019

Activity: Exploring Historical and Future Climate data

Background: Data on past, present, and future climate and climate effects is readily available online, allowing for the public/students to explore hypotheses about changes with observations. With this activity, we'll answer questions about the changes that face a user-selected location or region.

Part I: Historical Climate, 1895-2019:

1) Navigate to: https://wrcc.dri.edu/wwdt/time/

2) Select "satellite view" and choose a location within the US. Your location can be at any scale—a city, county, state, etc. Once you click on your point or area, that location will be selected in the "Time Series" options on the right.

3) Under "Time Series" options, explore climate "Variables", "Span" (i.e. Time of year), and "Month" (starting month). Add a value to "Running Average" to see longer-term trends. Answer the questions below:

Location: _____

What variables did you examine, and what trends did you see over time? Were trends consistent, or did climate oscillate over the last century? How did trends compare across seasons?

_____
_____
_____
_____

Choose a different location _____

How are the trends at the second location similar or different from your original location? Why?

_____
_____
_____

Do you think the data you saw shows signs of global climate change? Why or why not? What does the presence/absence of clear global warmings signals indicate to you?

_____

_____
_____

Part II: Climate Projections:

1) Navigate to : https://climatetoolbox.org/tool/Climate-Mapper . Choose a location within the US and zoom to it. Your location can be at any scale—a city, county, state, etc.

2) Now, under "Focus", select "Projections: Climate". These will show multi-model projections of future climate. Now, explore projected changes to climate variables. Under "Future Scenario", choose "Future Changes" emissions scenarios to see the differences between present and future conditions. Explore different climate "Variables" and "Calendar Time Periods" to see how future changes will be affected by time of year. Answer the questions below:

 What climate variables did you explore and how are they anticipated to change in the future? Why do you think those changes are projected to occur and did any results differ from what you expected?

_____
_____
_____
_____

_____

How might the projected changes affect natural systems?

_____
_____
_____

How might the projected changes affect society?

_____
_____
_____

How do the changes compare to nearby areas and to other regions? Why do you think that is?

_____
_____
_____
_____

_____

Extras and Resources:

- Explore the many other tools of the Climate Toolbox (they're awesome!). https://climatetoolbox.org/
Note: It's easy to download most of the data that the tools visualize, allowing for offline activities.

- Use the Climate Toolbox Climate Mapper to show the difference between weather (short term) and climate (long term). Look at how large the "anomalies" are when contrasting weather and climate.

- "Carbon in the atmosphere"—a multimedia lab activity
https://serc.carleton.edu/eslabs/carbon/lab3.html

-Visualizing the greenhouse effect: GHG concentrations and resulting energy "escaping" the Earth's atmosphere: http://climatemodels.uchicago.edu/modtran/

General climate resources:

(NOAA) https://esrl.noaa.gov/gmd/aggi/aggi.html

(NASA) https://climate.nasa.gov/climate_resource_center/interactives

(EPA) https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Activity: Deforestation and the Climate Cycle

Background: Forest are a major piece in the global carbon cycle. Loss of forests to land conversion has a large impact on carbon cycling and stocks. According to the *Scientific American,* deforestation from logging, agricultural production and other economic activities adds more CO_2 to the atmosphere than the sum total of all the world's cars and trucks combined. Slowing the rate of deforestation thus becomes a valuable tool in slowing the rate of climate change. The objective of this activity is to expose you to the Global Forest Watch interactive tool. Use this time to explore the tool and understand its potential as a teaching and learning tool.

Materials: https://serc.carleton.edu/eslabs/carbon/4b.html

Instructions:

1) Work in your teams and navigate to: https://serc.carleton.edu/eslabs/carbon/4b.html

2) We will complete step 1 together

3) Explore the tool (step 2)

4) After you have explored the tool, generate a research question and note it below. (Step 3)

5) As time permits, begin to collect data to answer your research question.

Research question:

Data needed to answer the question:

Questions to think about post-activity:

1. What did you learn from answering your research questions?
2. What was most interesting about the data you explored?
3. How useful is the online tool for your classroom?
4. How could you use this tool in your classroom?

Activity: Time lapse of Disturbance/land conversion

Background: Natural and anthropogenic disturbances drastically alter the surface of the earth. These disturbances may be sudden and occur only once, or progress over time. Due to the strong ties between land and atmosphere, changes to the surface affect local, regional, and global climate. In turn, some of the observable landscape changes are themselves a consequence of a changing climate. Decades of satellite imagery (since the 1980s) allow us to explore these trends nearly anywhere on earth and at unprecedented spatial scales.

Materials: https://earthengine.google.com/timelapse/

Instructions:

1) Navigate to: "https://earthengine.google.com/timelapse/", and pause the time lapse feature (bottom of map).

2) Below, find X (x) locations that show clear changes to the surface of the earth. Choose at least one location outside of North America. You can enter locations into the map search bar or navigate freely (zoom, drag). Example locations and changes can be clicked on the left side of the page for ideas.

3) For each location, play the time-lapse images from 1984-2018. Then, hit pause and click the forward arrow to manually progress through the years. Check the total difference between 2018 and 1984.

4) Answer the fields below, including the location, type of ecosystem or land surface affected, type of disturbance, and changes that will impact climate.

Location #1:

Location: _____

Ecosystem/Land Cover type affected:_____

What type of disturbance(s) or change(s) is affecting this landscape? Is the disturbance human, natural, or a combination? Is the disturbance sudden or continuous?

_____
_____
_____
_____

How might this land cover change affect climate and why? Look at changes to the amount of light reflected (albedo), and the amount of biomass/vegetation that is on the landscape (carbon, transpiration), and the total area affected by the change.

_____
_____
_____
_____

_____

How might the landscape change in the future due to climate change or human activities?

_____
_____
_____

Location #2:

Location: _____

Ecosystem/Land Cover type affected:_____

What type of disturbance(s) or change(s) is affecting this landscape? Is the disturbance human, natural, or a combination? Is the disturbance sudden or continuous?

_____
_____
_____
_____

How might this land cover change affect climate and why? Look at changes to the amount of light reflected (albedo), and the amount of biomass/vegetation that is on the landscape (carbon, transpiration), and the total area affected by the change.

_____
_____
_____
_____
_____

How might the landscape change in the future due to climate change or human activities?

_____
_____
_____

Location #3:

Location: _____

Ecosystem/Land Cover type affected:_____

What type of disturbance(s) or change(s) is affecting this landscape? Is the disturbance human, natural, or a combination? Is the disturbance sudden or continuous?

_____
_____
_____
_____

How might this land cover change affect climate and why? Look at changes to the amount of light reflected (albedo), and the amount of biomass/vegetation that is on the landscape (carbon, transpiration), and the total area affected by the change.

_____

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How might the landscape change in the future due to climate change or human activities?

_____

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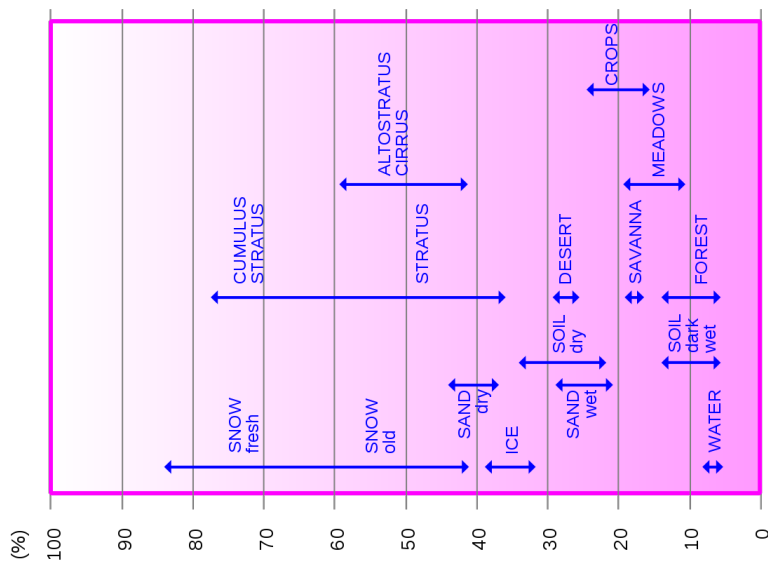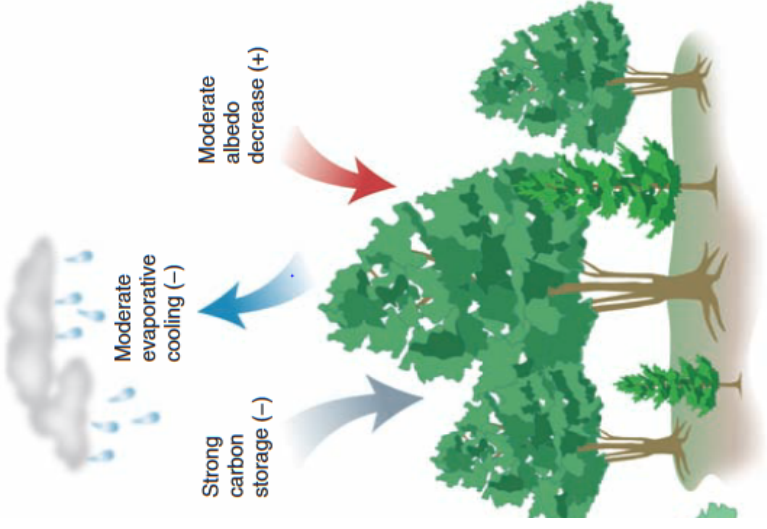Figure 1. Reflectance of different earth surfaces

Figure 2. One example of how the land surface can affect climate (From Bonan 2008)

B   Temperate forests

Moderate evaporative cooling (−)

Moderate albedo decrease (+)

Strong carbon storage (−)

Earth's Energy Budget, Greenhouse Gases, and Climate Change

Presentation

Citizen Science Project- Teacher Workshop 2018- Foliar N Collection Instructions

As a class, decide what your treatment/experiment will be (stand density, recently disturbed, species variation, age variation, canopy position, etc). Split class into groups and assign each group a group number and a treatment type (if your treatment is canopy position, groups would be assigned top, middle, or bottom). Each student in a group will collect <u>one sample</u> from a tree of the same treatment. **If the class is collecting at different locations, you should make sure to coordinate aspect, canopy position, and location on branch (new or old needles).**

Fill out sample info sheets for each sample. Note whether you collected samples from the same or different trees (as a class). This may seem repetitive, but will help with your report and keeping track of samples.

<u>**Sample Collection steps:**</u>
1) Each sample will go in its own brown bag and should consist of a good handful of needles. The sample needs to roughly fill up the bottom third of a half pint mason jar.
2) NEEDLES must be removed from the branch before sending in.
3) Label the brown bag with Sample ID and your name.
4) Take pictures of the needles and whole plant of each tree you collect from. These will be useful to include with your samples and ensure correct species ID.
5) Take site notes and collect site/tree data on the sample label
   a. DBH and height of tree; Canopy position of collected needles; Site description (include photos!)
   b. Include sample label in brown bag along with sample.
6) Once the sample is collected, keep it frozen until you can mail it back to us.

<u>**Sample Collection component descriptions:**</u>

Sample ID: Teachers last name and student group number. Example: Hudiburg1

Tree species identification: Ideally, you have chosen a species that you can identify. If you are not certain, take pictures of the needles, cones and the entire tree. We can hopefully help you identify it later. Don't choose an ornamental tree in town if you can't identify it, we likely won't be able to help you.

Diameter at breast height (1.3 meters from ground): Use the class DBH tape and record the diameter of the tree in centimeters.

Height: Using the height angle/clinometer tool (instructions are on tool) and the DBH tape (reverse side), figure out and record the height (helps to have two people).

Canopy position: Bottom, middle, or top- split into thirds.

Site description: Take detailed notes on the site.
- Aspect/Slope (compass apps on smart phones work for this)
- Location (coordinates if possible- some smartphones have coordinates- or take a Google maps point)
- Tree species present
- Elevation (can look up on Google earth later, or use a GPS or altimeter in phone or watch)
- Is it a dense forest or open? If in town, is it in a park or on the side of a street?
- Take pictures of the site.

<u>**Collection tips:**</u>
1. Clip branch tips (use pruning poles or other methods). Remove the needles of interest and put them in the paper bag. Needles should be 'young' unless you are investigating young versus old needles.
2. For broadleaf species, remove long petioles (stem). Collect enough to fill 1/3rd of the paper bag.
3. Work in pairs/groups.
4. As a class, pick a 'stand' of trees and collect from each tree to get a nice sample size from one location/treatment.

Mailing instructions:

1. When you are ready to mail your samples to us, email Tara at thudiburg@uidaho.edu so she can set up a pre-paid postage for you to print out and attach to your box.

2. When you receive the postage from Tara, pack frozen samples in the large flat rate shipping box and the icepack provided. Attach the postage, and mail!

Forest Disturbance Talk

Presentation

Activity: Match Stick Forest – how do fires burn forest fuels and spread?

Background: As the climate changes disturbance regimes are also projected to change. Understanding the dynamics of forest fires and the effect of climate change on them is fundamental for forest management. Scientist use vegetation-climate-disturbance models to understand the fundamentals of these interactions and emergent properties. You will build your own fire model using the characteristics of vegetation, landscape conditions, and weather to test your theories of these interacting conditions.

Materials: Putty/play doh, matches (various lengths), biodegradable packing peanuts and/or cotton balls, natural/artificial litter materials (dry leaves, newspaper fragments, etc), large tiles, fan, a nearby bucket of water, stopwatch. Optional: Lighter

Instructions:

1) For each fire, first develop a scenario of how the forest will be structured (see fire characteristics information below for context and ideas). How dense will the forest be, what fuels will be present (live/dead), what size trees will be present (understory, overstory?), will your fuels be dry or wet, what is the terrain like (sloped, flat), is the wind blowing (how fast, what direction), and what fuel will be ignited? These are just some questions you could consider, think of others (maybe forests you hike in or live by) as you explore the background information and materials you have in front of you. Be creative, this is your landscape and simulation!

2) For each scenario, generate a hypothesis about how the fire will progress. Potential questions to answer: How severe will the fire be? How much of the biomass will the fire consume and what types of fuels will be burned? How long will the fire burn? How many ignitions will it require? Think about how you will quantify these metrics.

3) Construct your model forest and take "aerial photography" with your phone.

4) Have one group member light a single ignition, initiate timing, and let the forest burn (or not, you may need multiple ignitions)! (From a safe distance).

5) Take a post-burn aerial photo. Record the results of the burn in relation to the hypotheses you created in step #2. Discuss how your fire results agreed or disagreed with your hypotheses, and what factors might differ in a real forest fire.

6) Extension work: contemplate the additional questions below.

Fire Scenario #1:

Scenario design:

_____

_____

Burn effects hypothesis:

_____

_____

Results & Discussion:

_____
_____
_____
_____

Fire Scenario #2:

Scenario design:

_____
_____

Burn effects hypothesis:

_____
_____

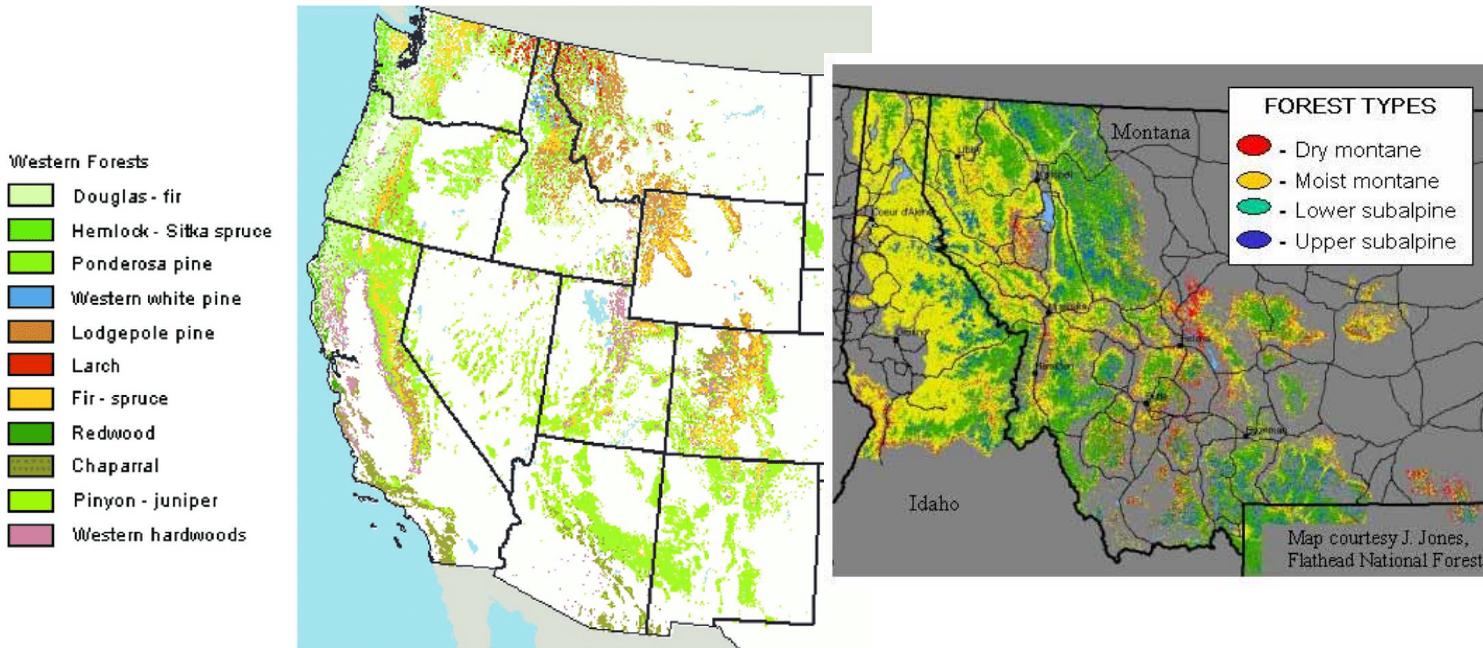Results & Discussion:

_____
_____
_____
_____

Additional Questions:

1. Did anything unexpected happen to your forest?
2. How is your model similar to computer fire models?
3. How well did your simulated forest represent the forest you conceptualized?
4. How would you improve your model?
5. What role does remote sensing play in understanding/monitoring terrestrial fires?
6. How would you analyze the before and after photos of the fire to improve quantifying fire effects?

Background information:

Fire and forest information booklet- matchstick fire activity

1) Forest types & western trees

Western Forests
- Douglas - fir
- Hemlock - Sitka spruce
- Ponderosa pine
- Western white pine
- Lodgepole pine
- Larch
- Fir - spruce
- Redwood
- Chaparral
- Pinyon - juniper
- Western hardwoods

FOREST TYPES
- Dry montane
- Moist montane
- Lower subalpine
- Upper subalpine

Map courtesy J. Jones, Flathead National Forest

Ponderosa pine (*Pinus ponderosa) /***Douglas-fir** (*Pseudotsuga menzeziii*)

- Dry, lower elevation forests in the intermountain west
- Experience high-frequency fire
- These fires are normally low-severity
- Thick bark (fire tolerant/adapted)

Engelmann's spruce (*Picea englemanni) / ***Subalpine fir** (*Abies lasiocarpa*)

- Grows together (spruce/fir forests)
- Subalpine species (high elevation)
- Thin bark (fire sensitive)
- Spruce/fir forests are less dense than lodgepole forests
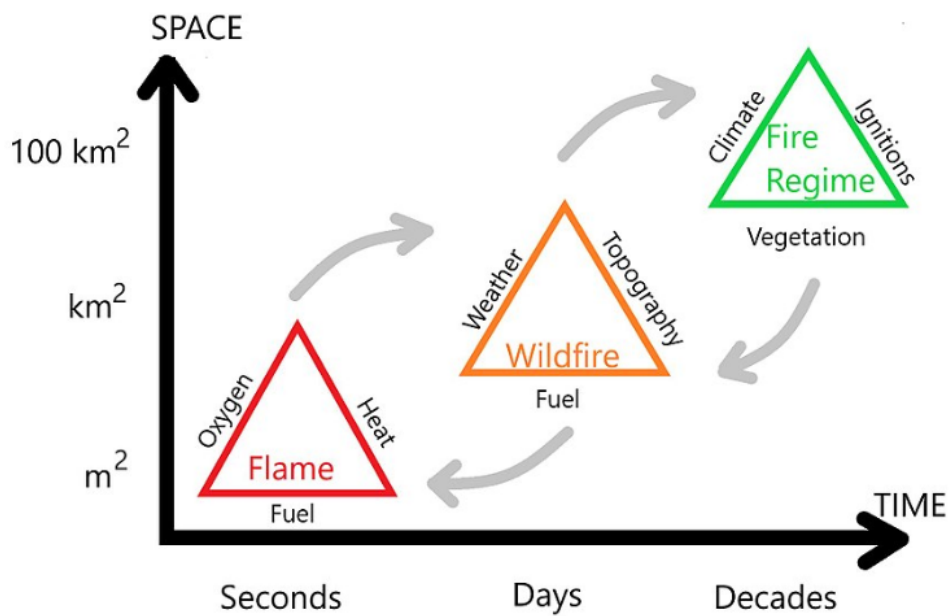- Subalpine species (high elevation)
- Thin bark (fire sensitive)

Lodgepole pine (*Pinus contorta*)
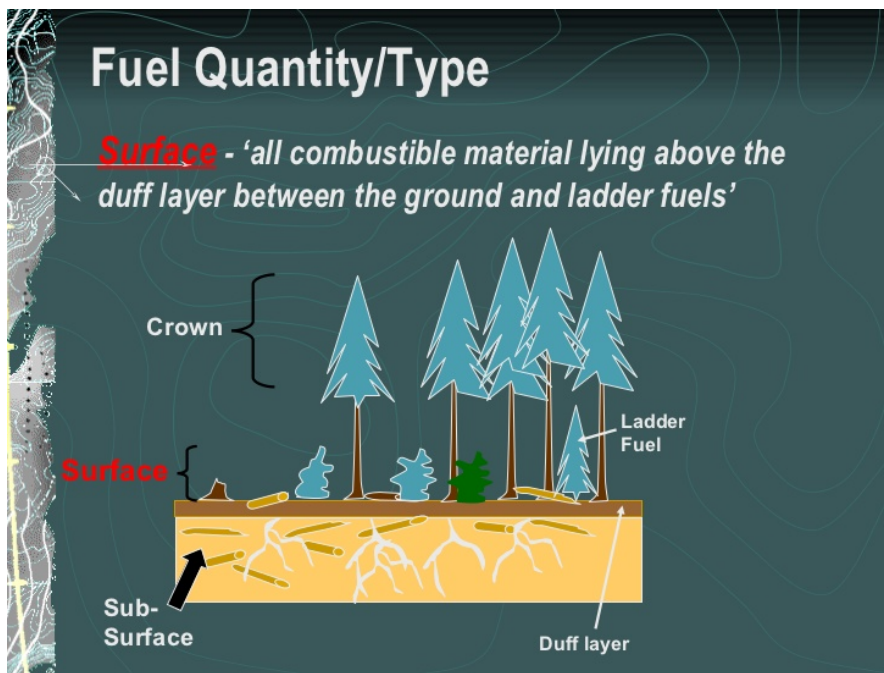
- Thin bark (fire sensitive)
- Serotinous cones
- Infrequent, stand-replacing fires (i.e. all trees are killed)
    o These are normally high-severity crown fires
- Lodgepole forests grow in dense, thick stands with smaller diameter trees
- Sub-alpine species (high elevation)
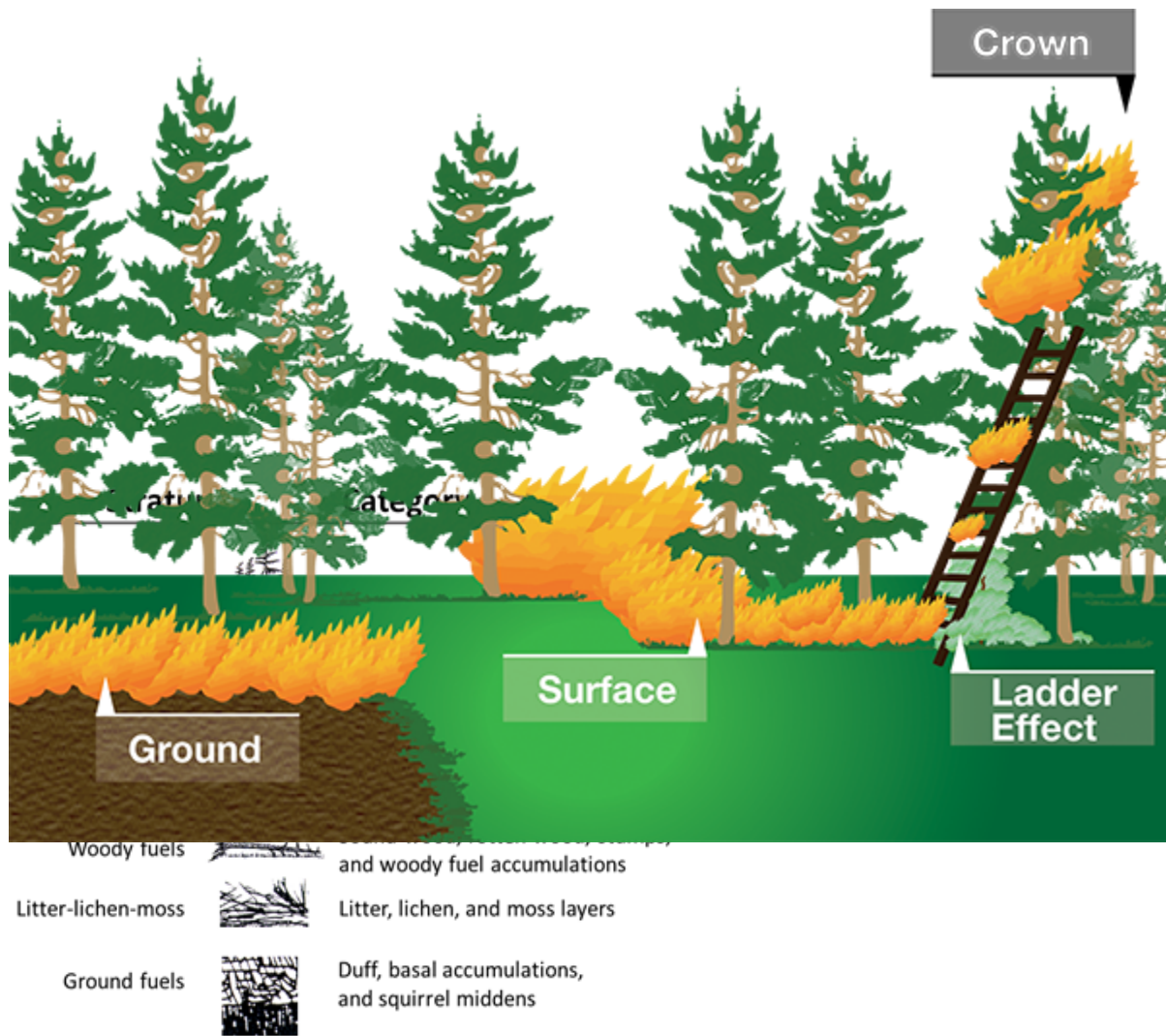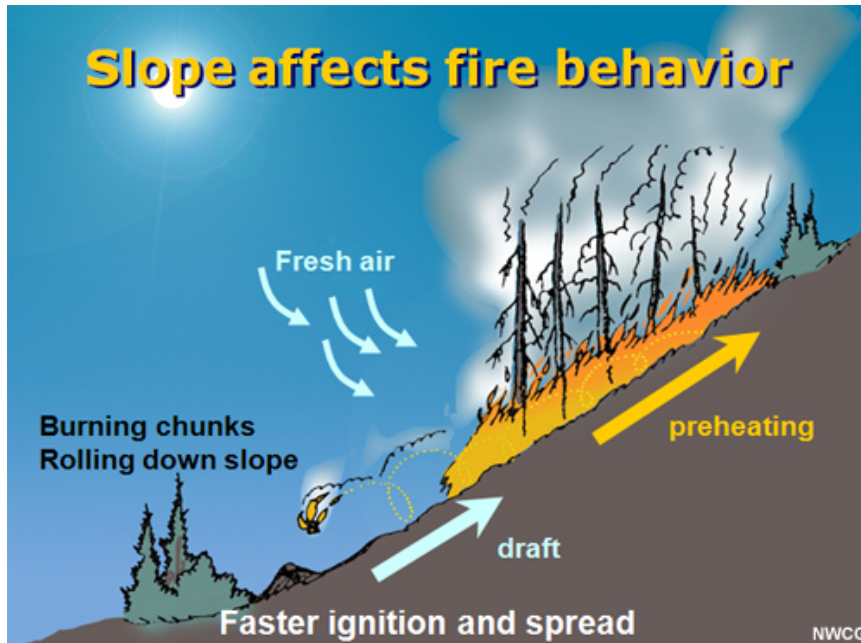
2) Fire ignitions and needs

3) Fuel types

Fuel Quantity/Type

Surface - 'all combustible material lying above the duff layer between the ground and ladder fuels'

Crown

Ladder Fuel

Surface

Sub-Surface

Duff layer

4) Fire types

Figure 1: FCCS fuelbed strata used in describing the characteristics of fuels, including fuel structure and loading.

5) Topography influences

Remote Sensing and Terrestrial Fires

"NASA's satellite instruments are often the first to detect wildfires burning in remote regions, and the locations of new fires are sent directly to land managers worldwide within hours of the satellite overpass. Together, NASA instruments, including a number built and managed by NASA's Jet Propulsion Laboratory in Pasadena, California, detect actively burning fires, track the transport of smoke from fires, provide information for fire management, and map the extent of changes to ecosystems, based on the extent and severity of burn scars." https://www.nasa.gov/feature/goddard/2018/nasa-covers-wildfires-from-many-sources

For more information, see NASA's Fire and Smoke page: **https://www.nasa.gov/fires**

Intermediate Disturbance Hypothesis Talk

Presentation

Teacher Projects

a. A project where teams of two explore their daily experiences and tie what they learned from the class, field, and web-based resources with their teaching. The goal is for teachers to use the information obtained from these sources to spark ideas and peak interests in the dynamics of the systems being explored, and the potential ways to explore them with their students. The presentations are an opportunity to share with the whole group what your experience was like, what you see value in, why, and how you will communicate it to your students.

b. For a strategy: you do not have to dig deep into any single topic; there are 2.5 days of activities to pull from. At the end of day 1 and 2 reflect on that day's activities and pick the one or maybe two things that really stood out and peaked your interests, explore the websites, data, and questions that are suggested for each topic: maybe formulate a question or explore a topic you don't understand, try to answer it, and explain what you learned in the process, not only about the data but the delivery method of the data and interaction with the web resources; discuss with your partner what s/he thinks, divide and conquer, and put a presentation together.

c. Presentations 10-12 min with 3-5 min of questions/conversation: it's ok to jump outside the box. You do not have to do a power point; try an interpretative dance, a poem, story, paintings, pictures, or a combination. Whatever you see fit to convey your team's experience and message.

d. Please Have Fun with This! This is your opportunity to teach us.

Forest Ecosystems, Feedbacks, Carbon Pools, and Climate

Presentation

Activity: Wood Core Lab

Background: Tree rings provide a variety of information of past conditions because they reflect tree growth sensitivities to climate and disturbance. These data can provide insight into changing environmental conditions across hundreds to thousands of years. Tree rings can also be used to calculate annual biomass increments and aboveground net primary productivity to gain a better understanding of forest productivity.

Materials: Increment borer, core mount, glue, twine, sharpie, ruler, calculation worksheet, sandpaper/sander.

Instructions:

Day 1: During the Carbon Budgets Lab, take a wood core from 1 dominant/codominant tree that seems approximately representative of trees in the stand.

1) Find a good location to take a core. Look for furrows in thick bark that will make access easier. Height should be 1.37 m (4.5 ft). Measure and record DBH (diameter at breast height) at this height.

2) If the coring location has thick bark, use a chisel for targeted removal of most of the outer bark.

3) Use the increment borer + assist tool to begin boring. The borer should be approximately level and you should aim for where you imagine the center of the tree to be. The goal is to be able to measure yearly radial growth, as tree wood is accumulates outwards from the center of the tree (secondary growth)

4) Aim to bore through about 10 years of growth (see example from beginning of activity).

5) Once the approximate depth is reached, insert the "spoon".

6) Back the borer out with one full turn (360 degrees).

7) Carefully pull the spoon out. The goal is to have an intact core with the bark/phloem/cambium still attached to the most outer wood.

8) Store your core: Carefully put the core in a straw and seal with tape. Label the outside of the straw with the tree species, location (Ponderosa Pine State Park—PPSP), and DBH.

Day #2: Evaluating wood cores

1) Gently remove the core from the straw and place on a table.

2) Observe your core. Look for differences in growth across years. Look for changes in wood color within years. Typically, dark 'latewood' from the latter portion of the growing season is denser and contains smaller diameter xylem the light 'earlywood' from the spring. Note the transition from sapwood to heartwood—sapwood is wood that still functions to conduct water up the height of the tree, and should be saturated. You can feel this with your skin. If you align the xylem of the wood with a light source (the sky), the saturated xylem will also transmit light and appear to "glow". This is a better indication of the sapwood/heartwood transition than wood color.

3) Make a mark w/ a sharpie at the boundary of the sapwood and the heartwood.

4) Record approximate growth (rounding to the nearest 1/2 mm) of each year. Note: The tree should still be growing this year!

5) Use the worksheet to calculate growth increments and compare to past climate.
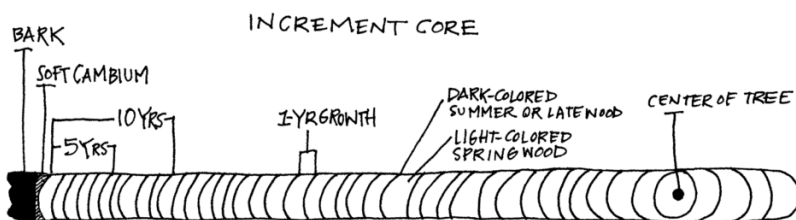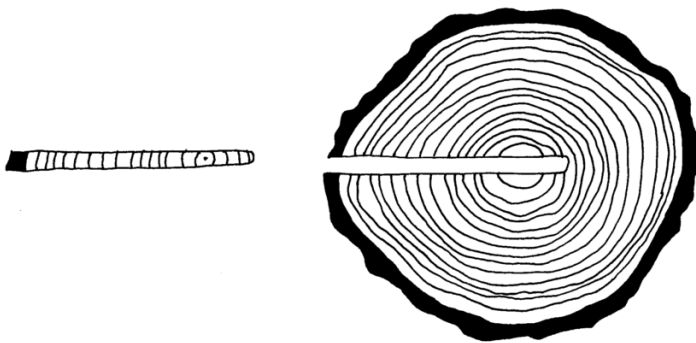
Questions:

1. What patterns did you notice in your core?
2. Do the patterns seem to relate to the annual climatic conditions? Why do you think this is?
3. How could you analyze the incremental growth and climatic conditions of the past?
4. What else could the wood cores be used to assess?
5. How can you relate the incremental growth to disturbance events such as drought?

Resources:

COLLECTING, PREPARING, CROSSDATING, AND MEASURING TREE INCREMENT CORES
https://pubs.usgs.gov/wri/1985/4148/report.pdf

NASA
https://climate.nasa.gov/news/2540/tree-rings-provide-snapshots-of-earths-past-climate/

Basics of Ring Formation
From: University of Arizona Tree Ring Lab
https://ltrr.arizona.edu/about/treerings

This provides an overview of common wood characteristics and anomalies that are used in Crossdating (matching ring-growth characteristics across many samples from a homogeneous area).
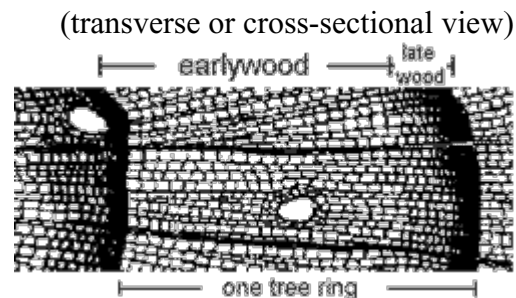
Conifer Tree Ring

(transverse or cross-sectional view)

earlywood
> appears light in color
> cells have thin walls, large diameter

latewood
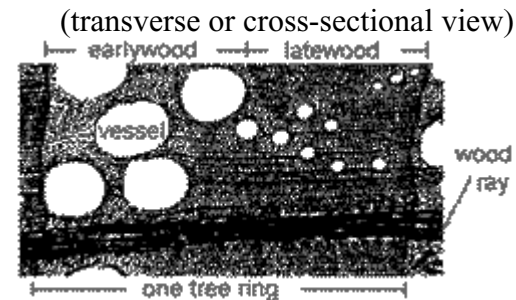> appears dark in color
> cells have thick walls, small diameter

Angiosperm Tree Ring

(transverse or cross-sectional view)

earlywood
> cells have large diameter vessels
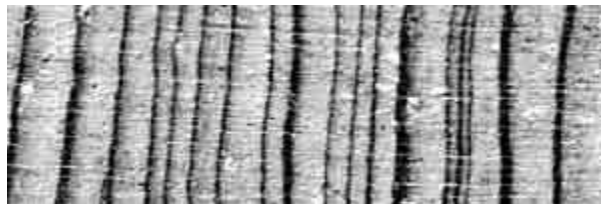
latewood
> cells: small diameter vessels

Ring Width Variation

This is a picture of a conifer wood. The rings display much variation:

1. variation in total ring width:
   a light and a dark band
2. variation in latewood width:
   just the dark bands
3. variation in latewood density:
   darkness of dark band

Variation in these rings is due to variation in environmental conditions when they were formed. Thus, studying this variation leads to improved understanding of past environmental conditions and is the basis for many research applications of dendrochronology.

A key distinction of dendrochronology is that all trees rings being analyzed are dated to their correct year of formation. At first glance, it appears easy to date tree rings by just counting them, but reality is often more complicated than that.

Locally Absent Rings

Full Ring

- Top part of this photo has 3 full rings.
- Lower part of this photo has 4 full rings.
- The wedge that is the 4th ring is "locally absent" from part of this tree.
- This sample is dateable, but NOT by mere ring counting.
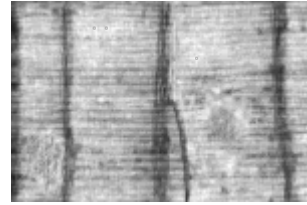
False Bands/Rings

False Band

- This sample has 2 full rings; the right-most ring has a false band.
- The false band appears to go through a resin duct.
- False bands are differentiated from true rings by their cellular structure.
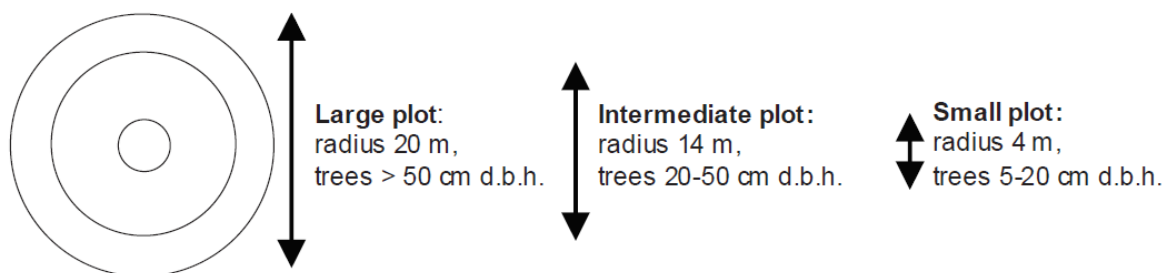- This sample is dateable, but NOT by mere ring counting.
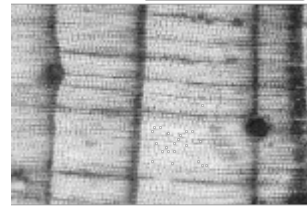
Activity: Ponder in the Ponderosas: Carbon Budgets Lab, what is the stock?

Background: Forest play a major role in the global carbon cycle. Estimating forest carbon stocks is important for tracking carbon pool changes, forest carbon management, carbon credit trading, national reporting of greenhouse gas inventories to international bodies, and various state and regional greenhouse gas programs. There are differing methods to estimate the differing pools of forest carbon, which range in complexity. In this lab, you will use a simplified set of methods to measure just a few of the forest carbon pools. You will use equations to extrapolate the individual measurements to total biomass and carbon on a per area basis. We encourage you to compare and contrast your estimates of these carbon pools to published data to explore the uncertainties of your estimates.

Materials: dbh tape, data sheets, calculation worksheet

Instructions: Adapted from: **Measurement Guidelines for the Sequestration of Forest Carbon. General Technical Report NRS-18**

1. Establish survey plots and mark boundaries.

Large plot:
radius 20 m,
trees > 50 cm d.b.h.

Intermediate plot:
radius 14 m,
trees 20-50 cm d.b.h.

Small plot:
radius 4 m,
trees 5-20 cm d.b.h.

   a. Nested plots are composed of several full circular or rectangular plots; each nested plot should be viewed separately.
   b. Extrapolation by use of expansion factors occurs by calculating the proportion of a hectare that is occupied by a given plot. For example, if a series of nested circles measuring 4, 14, and 20 m in radius were used, their areas equal 50, 616 and 1,257 m2 respectively. The expansion factors for converting the plot data to a hectare basis are 198.9 for the smallest, 16.2 for the intermediate, and 8.0 for the largest nested circular plot (1 ha = 10,000 m2).

2. Select carbon pools to measure
    a. We are measuring live trees, standing dead trees (snags), and if time permits

Carbon Pool	Definition
Live trees	Live trees: above ground
	Live trees: below ground
Understory vegetation	Tree seedlings
	Shrubs, herbs, forbs, grasses
Standing dead trees	Standing dead trees: above ground
	Standing dead trees: below ground
Down dead wood	Down dead wood
	Stumps and dead roots
Forest floor	Fine woody debris
	Litter
	Humus
Soil carbon	Soil carbon
Wood products	Harvested wood mass

downed woody debris. The table above is to give you a complete idea of what can be measured in a monitoring program.

3. Measure the selected Pools
    a. Trees
        i. All the trees in the sample plots above 5 cm in d.b.h are measured. The plot size determines the trees within specified dbh ranges to measure. See the diagram above.
            1. Identify the species/species type
                a. Cedar/larch
                b. Douglas-fir
                c. True fir/hemlock
                d. Pine
                e. Spruce
        ii. Measure the dbh and record on data sheets
    b. Standing Dead Wood
        i. Measure the dbh of standing dead trees
            1. Record dead standing trees that resemble live trees except for the lack of leaves
                a. Estimating biomass of trees with more decay (missing limbs and branches) is more complicated and beyond the scope of this lab. Please see the Measurement Guidelines (page 26) for more detailed info
            2. Note the species if possible
    c. Downed Woody Debris

  i. Establish a 100m line transect in the plot that traverses the center of the plot.
   1. Note: this will extend beyond the boundaries of the plot, that is ok, because the scaling equations are in units on a per ha basis.
  ii. Measure the diameter of downed woody debris
   1. The diameters of all pieces of wood > 10 cm that intersect the line are measured
  iii. Record the density class
   1. Each piece of dead wood is assigned one of several density classes- *sound, intermediate, and rotten*
    a. Common practice in the field is to strike the wood with a strong sharp blade. If the blade bounces off, it is sound, if it enters slightly, it is intermediate, if the wood falls apart, it is rotten

4. Calculate the Carbon Pool

We have provided a worksheet to easily calculate biomass. Just input your data from the data sheets in the Excel file. Below are the basic explanations of how the calculations are done. Please see in the Guidelines starting on page 15 for more in-depth explanations.

  a. Trees
   i. Calculate the biomass of each tree measured using the following equation:
    1. $AGB_{live} = y(kg) = e^{(\beta_0 + (\beta_1 \cdot (\ln x)))}$

    Where:

    y = total aboveground biomass (AGB) (kg) for trees 2.5 cm and larger in d.b.h.,
    x = d.b.h. (cm),
    Ln = natural log base "e" (2.718282).

     a. Biomass and carbon stock are estimated using appropriate allometric equations applied to the tree measurements. Tree biomass often is estimated from equations that relate biomass to d.b.h. only. Although the combination of d.b.h. and height as the independent variables is often superior to d.b.h. alone, measuring tree height can be time consuming and will increase the cost of a monitoring program.
     b. Biomass equations often are reported for individual species or groups of species. See the Measurement

Guideline (page 15) for a complete explanation of the Biomass equations. We are using the Table 3 coefficient values for tree biomass calculations.

b. Standing Dead Wood
   i. From the measurement of its d.b.h., the amount of biomass can be estimated using the appropriate biomass regression equation from above and subtracting the biomass of leaves (2 to 3 percent of above-ground biomass).
      1. $AGB_{standingdead} = y(kg) = [e^{(\beta_0 +(\beta_1 \cdot (\ln x)))}] \cdot 0.97$
   ii. Note: we will sum the AGB of live trees and AGB of Standing Dead Trees to estimate a total AGB

c. Calculate below-ground biomass (fine and course roots) (BGB)
   i. Equation for temperate forests:
      1. $BGB = e^{(-1.0587 +(0.8836 \cdot (\ln AGB)) + 0.2840)}$
         a. Measuring above-ground biomass is relatively established and simple. Measuring below-ground biomass (coarse and fine roots) is time consuming so it is more efficient to apply a regression model to estimate below-ground biomass (living and dead) as a function of above-ground biomass. The above regression models can be used to estimate below- ground biomass (Cairns et al. 1997).

d. Downed Woody Debris
   i. Calculate the biomass of downed woody debris
      1. Calculate the volume of downed dead wood per density class
         a. The volume per unit area calculated for each density class is:

         Volume (m^3/ha) = $\pi^2 \cdot [\sum(d1^2 + d2^2 \dots \dots dn^2) /8L]$

         Where:

         d1, d2,…. dn = diameter (cm) of each of the n pieces intersecting the line,

         L = the length of the line (100 m recommended; Harmon and Sexton 1996).
   ii. Estimate the density of downed dead wood

1. The simplest method for estimating the density of dead wood is to obtain a density value for undecomposed wood, i.e., wood density and multiply it by the proportion of undecomposed wood that each density classes represents. Undecomposed wood densities are widely available in the literature (e.g., U.S. Forest Products Laboratory 1974 or Data Dryad: https://datadryad.org/stash). Here we use a simple regional value of 0.54 g/cm^3 = 0.54 metric ton/m^3 from Table 2 of *Towards a worldwide wood economics spectrum*: https://doi.org/10.1111/j.1461-0248.2009.01285.x

2.

   a. We are using the Heath and Chojnacky (2001) calculated proportions of 90 percent (sound), 70 percent (intermediate), and 40 percent (rotten) for this example lab as an estimate for the proportion of undecomposed density in each density class
      i. Sound Dead Wood Density= (0.54 · 0.9) = 0.486
      ii. Intermediate= (0.54 · 0.7) = 0.378
      iii. Rotten =(0.54 · 0.4) = 0.216

iii. Calculate the biomass of downed dead wood

Biomass Stock (metric tons/ha) = (Volume (m^3/ha)$_{sound}$ · 0.486) + **(**Volume (m^3/ha)$_{Intermediate}$ · 0.378) + **(**Volume (m^3/ha)$_{rotten}$ · 0.216)

Carbon stock (metric tons C/ha) = Biomass Stock · 0.5

5. Landscape expansion

a. Live and Standing dead trees

   i. The biomasses of each individual tree are summed at the plot level (sum live and standing dead of each plot) and then multiplied by an expansion factor proportional to the size of the plot to estimate a mass per unit area of biomass. Biomass is then converted to carbon mass.

      1. **Above Ground Live and Standing Dead Biomass (AGB) (kg/ha)** = (subplot total tree biomass$_{small}$ x 198.9) + (subplot total tree biomass$_{medium}$ x 16.2) + (subplot total tree biomass$_{large}$ x 8)

   ii. Next use the above ground estimate AGB and input into the BGB equation to estimate the total belowground biomass stock

   BGB= $e^{(-1.0587 +(0.8836 \cdot (\ln AGB)) + 0.2840)}$

   iii. **Biomass Stock**$_{live\ and\ dead}$ **(kg/ha)** = AGB + BGB

      1. **Convert** to metric tons: Biomass Stock(kg/ha) · 0.001 =Biomass Stock (Mg/ha) =Biomass Stock (metric tons/ha)

   iv. **Carbon stock (kg/ha) =** Biomass Stock * 0.5

1. **Convert** to metric tons: Carbon Stock(kg/ha) · 0.001 =Carbon Stock (Mg/ha) =Carbon Stock (metric tons/ha)
   b. Downed Woody Debris: this is already on a mass per area basis, i.e, metric tons/ha = MegaGrams(Mg)/ha
   c. You now have three landscape level stocks: AGB, BGB, and Downed Woody Debris.

Resources

- The LandCarbon assessment
  - https://www.usgs.gov/apps/landcarbon/tools/
- USDA Carbonscapes
  - https://carbonscapes.org/atlas/#
- Second State of the Carbon Cycle Report
  - https://carbon2018.globalchange.gov/chapter/9/

Questions

1. How do the measured carbon stocks compare to published estimates?
   - Using the USDA Carbonscapes (https://carbonscapes.org/atlas/#)
2. How will the stocks change in the future
   a. Using the LandCarbon Explore (https://www.usgs.gov/apps/landcarbon/tools/)
3. What are your thoughts about how carbon stocks are measured?
4. What can your students learn from this and how would you teach it?
5. What will you students find interesting; what will they find uninteresting?

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Order of magnitude	Prefix	Symbol
10^{24}	yotta	Y
10^{21}	zetta	Z
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da

Plot	Tree Species	Live or Dead	dbh	Dead Woody Debris (dbh)	Dead Woody Debris (density class)

Morning of Misinformation/Uncertainty

Discussion