Fire-Focused, Landscape Scale Restoration on Rowe Mesa

CRANE COLLABORATIONS

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Introduction

Youth coring an old growth piñon pine on Rowe Mesa.

In 2004, Crane Collaborations and the Quivira Coalition produced a curriculum to complement forest restoration on Rowe Mesa. This work was funded by the Collaborative Forest Restoration Program (CFRP) that is administered by the USDA Forest Service Region 3. Activities in the original curriculum were provided for grades K-12, and were correlated to state science standards. The curriculum has been used in Pecos Independent Schools, with Forest Guild/Pecos-Las Vegas youth crews, and by a variety of other restoration crews (both adult and youth) that have been a part of CFRP.

Nearly 10 years later, our knowledge of the mesa has grown as have some of the questions and concerns that drive forest restoration. In 2001, when the Collaborative Forest Restoration Program began, concerns were for preventing catastrophic wildfire, producing local jobs, creating markets for small diameter wood, and educating youth. Today these concerns remain, but are coupled with changing climate, an increased focus on landscape scale restoration and the return of fire to the landscape. To reflect these changes, we have revised and adapted some of the curriculum published in 2004. These additions can also be used by youth and thinning crews to increase their understanding of restoration in the field. These resources are focused on Rowe Mesa to reflect the goals, approach, and specific ecology of the mesa. However, they may also be of interest to other restoration projects that work in ponderosa pine, piñon-juniper, and the interface between the two.

Specific additions to the curriculum include:

Revisions to the *Burned Area Scavenger Hunt*, to include a discussion of fire severity in the context of prescribed fire or wildfire. (cont. p. 2)

This work was produced as part of the Collaborative Forest Restoration Program project titled: **Rowe Mesa Landscape-Scale Assessment: Planning for Fire-Focused Forest Restoration**, in partnership with the University of Arizona, Santa Fe National Forest Pecos/ Las Vegas Ranger District, Santa Fe National Forest Supervisors Office, Four Corners Institute, Crane Collaborations, Quivira Coalition and WildEarth Guardians.

New Activities

Introduction (continued)

Establishing Historical Patterns in Ponderosa Pine, which provides a method for understanding reference conditions.

Stump search, which provides a counterpoint to the reference condition approach to understanding historical forest structure and process.

Plants on the Move in space and time, which discusses the idea of encroachment by piñon and juniper into grasslands and ponderosa pine stands on the mesa and throughout the west.

Counting Carbon: Which discussed current thinking about the effects of climate change on forest composition and carbon budgets in the context of wildfire and management.

Restoration Thinking: What's New?

"CFRP RESTORATION HAS SHIFTED TO STRATEGIC TREATMENTS IN THE LARGER LANDSCAPE."

In general, CFRP-funded forest restoration seeks to shift from small projects of a few hundred acres to more strategic locations of projects in a larger landscape context. Among the benefits of this approach are greater cost effectiveness of treatments, and that treatment areas can be situated in locations that allow larger scale fires to burn as part of the restoration process.

The mesa is an interesting place for learning and adaptive management. The forested areas of the mesa are in a transition zone between ponderosa pine and piñon-juniper (PJ). While the historical fire regimes in ponderosa pine are fairly well understood, much less is known about the structure of PJ woodlands nor the frequency or severity of fires in these systems. When restoring ponderosa pine forests, managers and scientists generally use reference conditions from forests that have been well studied. However, these reference conditions do not exist or are much less clear for the transitional forest between ponderosa pine and PJ woodlands. By using a landscape scale assessment to determine fire history and fire frequency on Rowe Mesa, it is possible to determine what forests may have looked like in the past as well as where to strategically locate forest treatments to allow reintroduction of fire at a larger scale. This approach to restoration is reflected in the revisions to the curriculum, particularly in the *Stump Search* activity.

Pack Rat midden on Rowe Mesa

Project History

A brief history and ecology of Rowe Mesa are provided in the original Rowe Mesa Forest Restoration Curriculum. The mesa currently is used for cattle grazing, firewood collection, hunting, and collecting of piñon. Historically, it was used for production of railroad ties and sheep and cattle grazing. Like many places in the west, fire suppression began on the mesa around the turn of the century, resulting in changes to the processes and ecology of the landscape.

There have been multiple projects to restore forest structure and reintroduce fire on Rowe Mesa. Two completed CFRP projects (#25-01 and #23-04) were conducted within the grazing allotment known as the Valle Grande Grass Bank. This area is managed collaboratively to alleviate pressure on overgrazed land in the region. Both projects involved local users (grazing permittees and fuel wood collectors), a local conservation organization (Quivira Coalition), an environmental research organization (FCI) and the U.S. Forest Service. An ongoing CFRP project (# 33-09) is in the planning phase for thinning and burning on 3,200 acres of the Barbero grazing allotment. The USFS has also conducted prescribed burns on the mesa in 1998, 1999, and 2001.

Rowe Mesa: A mix of ponderosa pine , piñon-juniper and grassland

Revised. . . Activity 3. Burned Area Scavenger Hunt

This activity was revised from the original Rowe Mesa curriculum to include analysis/discussion of fire severity.

Low-intensity surface fires have been suppressed from ponderosa pine forests for many years. A primary goal of forest restoration is to reduce excess fuels in ponderosa pine stands in order to create more natural structures and processes for a ponderosa pine forest. This reduction of fuels will reduce the threat of high-intensity fires and will reduce the unhealthy competition of plants for scarce resources such as soil nutrients, light, and water.

A second goal is to establish conditions that can sustain a low-intensity fire on a regular, frequent basis. These fires would ideally be similar in effect and timing to those that probably existed before significant human activities in the forest. These surface fires are important because they help maintain a lower level of ground fuels and fewer excess small diameter trees.

To achieve these two goals on Rowe Mesa, some small diameter trees were removed, and the slash that resulted was spread across the site or removed by fuelwood collectors. This will be followed by a prescribed burn, to be set by the Forest Service, which will remove many of the ground fuels, help to release nutrients to the soil, and allow greater grass growth in newly opened areas.

This activity is specifically designed for use in the two Valle Grande treatment areas on Rowe Mesa, but can be used in any area burned by prescribed or wildfire.

What's the difference?

Often fire intensity is used interchangeably with fire severity, but the terms refer to 2 different things.

Fire intensity: refers to how hot the fire burns (or the energy produced)

Fire Severity: refers to how much the fire kills or the damage it does

Procedure

Introduce the lesson by telling students they will be going into the field to observe effects of a recent prescribed fire. Give a bit of history on the fire. If possible, have someone from the project present for this trip to share information and background on the project site and how it was burned.

Review safety guidelines, such as working in pairs, always being within eyesight of an adult, etc. Also review guidelines for working in the forest, such as using quiet voices, leaving all objects where they are found, returning rocks and logs to their original location, treating all objects in the forest with respect, observing but not disturbing wildlife, etc.

Depending on time limitations and group dynamics, this activity can work well with two variations:

Variation 1: Break students into 2-person teams. Assign 2 items from the scavenger hunt to each team. Give them approximately 10 minutes to find their items. Then have each team present their items to the class as a whole and explain what they've learned. This works particularly well with groups that are independent and interested in exploration.

Variation 2: Break students into 2-person teams. Give each team the entire scavenger hunt and have the team identify each item. Then have each team present 2 items that they think are unique or interesting to the entire class.

Objectives

In a recently burned area, students can find plants, animals, and animal sign, and use them to infer characteristics of the fire and fire ecosystem. They can then analyze the signs they find to understand fire severity.

Duration

30 minutes plus analysis time

Vocabulary

- Cavity-nesting birds
- Field site
- Habitat
- Old-growth forest
- Fire intensity
- Fire severity
- Prescribed fire
- Scat
- Snag
- Understory

Materials:

- Pencils & paper
- Photocopies of worksheet
- Clipboards or hard writing surface
- Optional: field guides for trees, shrubs, birds, mammals, scat

Burned Area Scavenger Hunt

Worksheet

Name _______________

See how many of these things you can find in the burned forest. Check them off as you go:

1. ___ Find a place where the fire burned in the tree crowns
2. ___ Find a place where the fire only burned some of the grass, shrubs, or needles
3. ___ Find a shrub or small plant that sprouted after the fire. How can you tell it was burned?
4. ___ Find a tree that burned but did not die. What kind of tree is it? ________

   How can you tell it burned?
5. ___ Find a tree killed by fire. What does the tree look like now? How old do you think the tree was?

   If there is time, core the tree.
6. ___ Find a "snag." Do you see signs of insects or birds at this tree? Was the snag burned in the fire? Or before? How do you know?
7. ___ Find a place where the soil is dark reddish orange. What do you think makes the soil this color?
8. ___ Find a place where the soil is covered with white ash. How much of the ground is covered with this ash?
9. ___ Find an area where there is dense plant growth on the ground. What color is the soil here?
10. ___ Find animal scat. Draw it on the back. What kind of animal left it there?
11. ___ Find a place where an animal made a hole in a tree. How big is the hole? Who do you think made it?
12. ___ Find signs that insects fed on a burned tree.

What is the Fire Severity?

You have just completed a scavenger hunt looking at different effects of fire in a burned area. Now use this information to try to see if the fire is low, medium or high severity (or if there are characteristics of more than one). Check the items that you found on your scavenger hunt in the table below.

Low Severity	Medium Severity	High Severity
Soils not affected	Soils darkened but not physically	Soils dark reddish orange & physi-
Duff partly burned	Duff burned but with needles still	Duff and debris entirely gone
Ash dark	Ash dark	Ash gray or white
Little hydrophobic soil	Low to medium hydrophobic soil	Medium to high hydrophobic soil
High plant survival with resprouts	Moderate plant survival	Plant roots burned up to 4" below surface; only plants with deeper roots can resprout
Quick recovery, 1-2 years	Recovery in 2-5 years	Recovery slow, natural recovery limited

Discussion Points

Ask the students to evaluate the burned area: did many trees died? Was there much regrowth of understory plants? Are there many trees resprouting? Did they find much sign of wildlife? Ask students to categorize positive and negative effects on the forest. Review the importance of snags for cavity-nesting birds (see the introduction on restoration goals for more information).

In the classroom, have students sketch, draw, paint, or write about what they learned and their perspectives on fire.

Low-Severity Burn on Rowe Mesa, NM

High-Severity Burn from the Trigo Fire, near Mountainair, NM

Activity 11: Establishing Historical Patterns in Ponderosa Pine

This activity was adapted from the methods described in Historical Forest Structure on the Uncompahgre Plateau: Informing restoration prescriptions for mountainside stewardship

While we know the basic ecological function and processes of ponderosa pine forests, sites vary across the range of ponderosa pine. As described in Activity 10 (Rowe Mesa Curriculum), a fundamental part of ecological restoration is to understand the natural or historical conditions of the system that is being restored. Scientists do this by establishing reference conditions and use this to understand past forest structure in order to develop future restoration goals.

In this activity, students will apply the concept of reference conditions to an actual forest stand. They will gather information about past conditions to describe the forest structure, or spatial arrangement of trees. They will discuss how this information can be used to develop restoration prescriptions. For best results, this activity should follow Activity 10.

Background

As described in Activity 10, researchers use a variety of tools to investigate past ecological conditions. Some are biological and some are cultural. Examples of biological evidence include tree rings and pack rat middens. Examples of cultural data include old photographs and documents such as diaries and logs of early explorers. Sometimes people have been influencing an ecosystem for so long that physical evidence – whether biological or cultural – does not exist to show its natural state. In these cases, scientists have to apply what they know from research to estimate historical conditions for a system or site. At other times, changes in an ecosystem are recent enough that scientists can reconstruct what the system was like with a much greater degree of accuracy.

In the case of Rowe Mesa, which has been used by people for centuries, it is much more difficult to reconstruct exactly what conditions were like on the site. In these instances, scientists rely more heavily on reference conditions from other ponderosa pine forests in the area that were used much less by humans or on fire scar evidence (See *Stump Search*, Activity 12). In addition, all ecosystems naturally change with time so there is no single set of conditions that existed in the past. More likely, any ecosystem had a natural range of variation in conditions, so that, for example, some ponderosa pine forests were more densely populated with trees, while others were open areas scattered with old, large pines.

The purpose of this activity is to apply one of the commonly used methods for establishing reference conditions for a forest stand so that students understand how reference conditions are established and how they can then be applied.

Objectives

Students will use data gathering and analysis skills to determine historic forest structure. Students will learn about different kinds of information that scientists can use and apply to understanding a system.

Duration

50 minutes plus analysis time

Vocabulary

- Forest structure
- Reference conditions
- Tree Rings
- Tree Cores

Materials

- Increment borers
- Drinking straws
- Hand lens
- Compass
- 300 foot measuring tape
- 150 foot measuring tape
- DBH tape
- Graph Paper
- Pencils

Activity 11: Establishing Historical Patterns in Ponderosa Pine (continued)

Preparation

You will need to identify a ponderosa pine stand that is accessible to the class, either near school grounds or on a short field trip. The stand does not need to have any particular characteristics, but it is helpful if you know or can find out some of the past land uses of the site. Students will be aging trees, and can determine how many trees existed at varying points in time. However, without knowledge of land use history, it will be more difficult to explain why trees existed (or did not exist) at any particular point in time.

Procedure

1. Re-introduce the term reference condition (from Activity 10) and explain the importance of this in restoration efforts.
2. Next explain to students that they will be developing a map that shows the spatial arrangement and ages of trees in the forest they will visit. Explain that this is a method used by ecologists to understand historical conditions of the forest at a specific site. Remind students that this information may also be applied to areas such as Rowe Mesa where land use history is so long and varied that site-specific reference conditions are difficult to determine.
3. Using a compass and measuring tapes, create a plot that is 150 feet wide by 300 feet long. Use the compass to align the tapes so that they are running in straight lines.
4. Next break the students into groups (from 4-5 students in each group). Assign each group to a sub-section of the plot.
5. Each group should then do the following for each tree in their section of the plot (using the attached data sheet):
    - Locate each tree in the plot and record the coordinates (students can use a GPS or can mark the location of the tree according to its location along the tapes)
    - Identify the tree species
    - Core the tree
    - Count the tree rings using a hand lens and record the age
    - Place the tree ring in a drinking straw so that it can be saved for future reference if necessary
    - Measure the DBH of each tree and record the diameter

    Sample data might look like this:

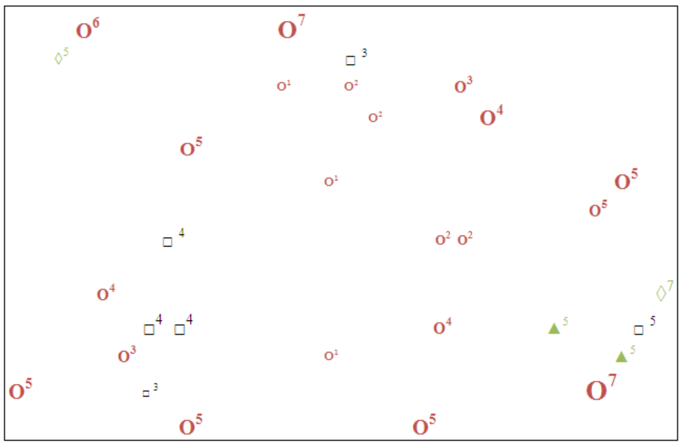
Location of Tree	Tree Species	Tree Age	Tree Diameter (DBH)
1.5 feet north x 15 feet west	Ponderosa pine	62 years	11 inches
4 feet north x 20 feet west	Pinyon pine	45 years	5 inches

6. When all trees have been located and described, gather students together for analysis.

7. Have students create a key for the map they will create. If time is limited, you can also use the key shown in the examples below. The key needs to include:
    - Tree species
    - Tree size (use ranges for diameters: 0-4 inches, 5-10 inches, 11-15 inches, 16-20 inches, and 21 or greater inches)
    - Tree age (use ranges for age: 0-10 years, 11-20 years, 21-30 years, 31-50 years, 51-75 years, 76-100 years, greater than 100 years)

8. Next, bring students together to create an overall map of the plot. Students will combine their data to create an overall map that includes the location of trees, tree species, tree size, and tree age according to the key developed above. Students can use large pieces of paper to create sub-group maps and then tape them together or can use graph paper to create the overall map. This can then be converted to the computer in excel by placing a scaled dot in the corresponding cell for each tree coordinate. Using excel makes it easier to eliminate trees in the reference maps, but it is not an essential component of the project. A sample map is below.

** *Note that tree size does not necessarily correlate with age. In some stands, this correlation works, but in others it is inconsistent. You can have students analyze data for age and size by each species to see if there is any relationship.*



Key:

Species: Ponderosa Pine: O   Pinyon pine: ◊   One-seed Juniper: □   Rocky mountain juniper: □

DBH: 0-4 inches: o   5-10 in: O   11-15 in: O   16-20 in: O   21+ in: O

Age: 0-10 years: 1   11-20 years: 2   21-30 years: 3

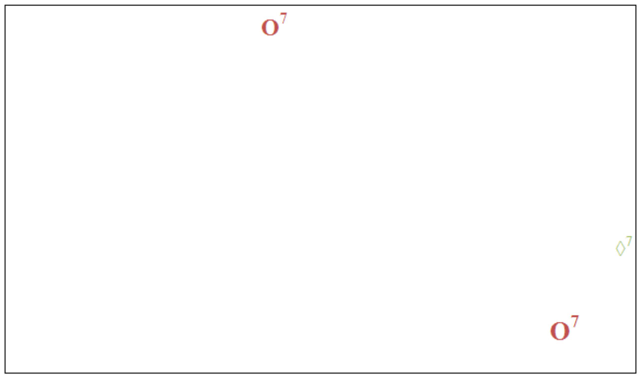
31-50 years: 4   51-75 years: 5   76-100 years: 6

Greater than 100 years: 7

9. Discuss the site history with students and determine as a group what, if anything, is a possible target year for reconstructing past forest structure. In other words, what period in history best represents human impacts or fire suppression? If none is known, you can experiment with the year 1910, which is when fires began to systematically be put out across the United States.

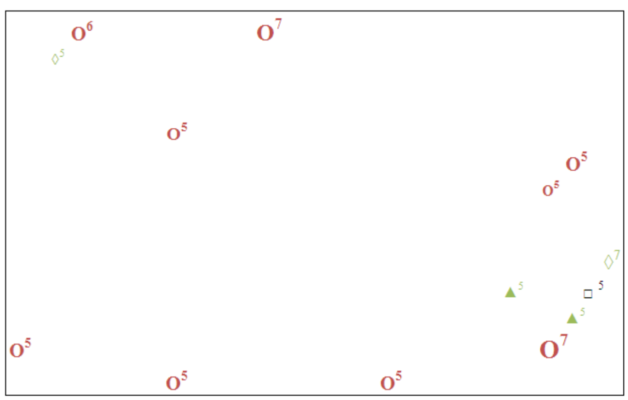
Activity 11: Establishing Historical Patterns in Ponderosa Pine (continued)

Now have students create a second map by eliminating all the trees that did not exist prior to the target year. What does the forest structure look like at that time? You can repeat this phase for different known time periods in history. The new map might look something like this for a 1910 target year:



1910 Target Year

Or, let's say you know the site history, and that sheep grazing had a large impact until 1950 (as in Rowe Mesa). The revised reference map would look like this:



1950 Target Year

Points of discussion

Ask students what they notice in the reference maps? Items for discussion might include:

- The 1910 map has very low tree density and tree species diversity
- The understory may have been a much larger component of the site than it is today
- The low density for this site may differ from other areas of the forest, which likely had higher densities
- Fire would behave differently in the pre-1910 stand, and would likely have been a low-intensity surface fire
- What are some of the strengths and limitations in using this method for establishing reference conditions? (Strengths are that the data are site specific and based on physical characteristics. Weaknesses include that using reference conditions in this way reflects only a single point in time. Forests are dynamic and were likely different at other periods in history, such as the "little ice age" in 1775. Another weakness is that this is a small sample, and that more sampling would need to be done to accurately represent the variations across the landscape that likely existed.)
- Did you have enough data? From the right years? To adequately determine reference conditions? If not, what would you need in addition? (Draw on the strengths and weaknesses to discuss this further).
- If you are trying to restore a forest today, how would you use these types of data in deciding how to manage the forest?

Activity 11: Establishing Historical Patterns in Ponderosa Pine DATA SHEET

Location of Tree	Tree Species	Tree Age	Tree Diameter	Notes

Activity 12. Stump Search

As described in Activities 10 and 11, a fundamental part of ecological restoration is to understand the natural or historical conditions of the system that is being restored. Like the Dendrochronology Detectives, this activity will develop students understanding of the process of fire in determining the composition and function of a forest.

In this activity, students will search for information about past conditions to understand the role of fire in the ecosystem. Forest processes, such as fire, are a primary factor in determining the number and types of trees present in a system. Students may also analyze landscape assessment data to further their understanding of fire as a process. For best results, this activity should follow Activities 7, 10 and 11.

Objectives

Students will use data gathering and analysis skills to learn about historic forest process. Students will learn about different kinds of information that scientists can use and apply to understanding a system.

Duration

About 30 minutes field search and 10 minutes discussion; extensions will add about 10 minutes each

Vocabulary

- Process
- Reference conditions
- Tree Rings
- Tree cores

Materials

- Hand lens
- Graph paper
- Pencils
- Increment borer (optional)
- Clipboard or hard writing surface
- Data Sheets

Background

Land use and fire suppression are closely tied to the structure and process of a forest. General trends across the southwest include:

Fire Suppression at the turn of the 20th Century, which took away an important process that maintained forest structure, composition, and health;

Railroad Construction and Fueling, for which large amounts of timber were harvested

Railroad Transportation, which brought livestock to the west

Increased Livestock Grazing, which (i) removed much of the understory grasses and forbs and altered the forest's ability to carry fire, and (ii) created bare mineral soil which supported greater ponderosa pine regeneration

From site analysis and local history, we know with some precision the dates associated with these events on Rowe Mesa:

1800-1900: Sheep and goat grazing on Rowe Mesa

1879: The Railroad at Lamy was completed. Ponderosa pine ties were cut from the mesa and elsewhere to build this railroad. Until creosote was used to preserve ties, they were replaced approximately every 2 years, resulting in extensive timber harvesting in the area. In addition, kilns in Lamy were build to produce charcoal to feed the trains. This also resulted in extensive harvesting of wood from the area.

1899: Fire suppression on the mesa began. No fire scars have been found on the mesa after this date

1907: Rowe Mesa became part of the Santa Fe National Forest. Sheep excluded from the mesa. Land uses of firewood, cattle grazing, hunting, and piñon collection continue.

Preparation

You will need to identify a ponderosa pine or pinon-juniper woodland and ponderosa/PJ mix that is accessible to the class, either near school grounds or on a short field trip. If it is possible to visit the mesa, the CFRP projects called Valle Grande I and II contain some stumps and lightning scars for this activity. You will need to print data sheets and may wish to make color reproductions of the assessment maps. You may also wish to have a map of the area to assign students to different parts of the forest they will be searching.

Activity 12. Stump Search (continued)

Procedure

1. Re-introduce the idea of processes, such as fire in shaping forest ecology.
2. Explain to students that they will be looking throughout the forest for evidence of fire.
3. Show students examples of fire scars using tree cookie samples and/or photographs of old stumps. (These can be found in Activity 10, Understanding Reference Conditions.) Explain that it is sometimes possible to see signs of charcoal within the fire scars.
4. Break students into groups of 2 (optional: assign them to specific areas of the forest using a map)
5. Have each student group search the forest for (i) lightning scarred trees, and (ii) old stumps that contain fire scars.
6. Each group should then do the following (recording their findings on the attached data sheet):

- Tally the number of trees with lightning strikes. Identify the tree species. Make qualitative observations about the strikes: (i) how much of the tree was struck by lightning? (ii) were the roots of the tree burned? (iii) was the tree killed? (iv) are there any other signs on the strike (for example, increased pitch from beetles?)
- Stump Search:

  i. Look for stumps (trees that have been cut either historically or in a recent restoration project)

  ii. Count the tree rings using a hand lens and record the age of the tree if possible

  iii. Look for signs of fire scars on the stump

  iv. Record how many fire scars there were

  v. Look for qualitative signs of the effects of the fire: did tree growth increase after the fire (as evidenced by larger width of tree rings)?

  vi. Look at trees located near the stumps with fire scars. Is there any indication that these trees also burned in the fire? If so, core and age the tree to the extent possible

Points of discussion

Bring students back together to discuss their findings. Questions/discussion can include:

- How many lightning strikes were observed?
- What were the general observations of these strikes?
- How many stumps were found?
- How many of these stumps had fire scars?
- What is the evidence for fire in these scars (charcoal, fire scar patterns, etc.)
- Were other trees adjacent to the fire scarred stumped also affected by fire?
- How old were these trees?
- What was the range of the number of fire scars on the stumps?
- What does this evidence tell you about the frequency of fire in the forest? About the density of trees in the forest? (It is possible that it will be hard to make strong conclusions about this, but students may find overall trends, such as: (i) fires were more frequent in the past; (ii) trees survived multiple fires and were not killed by the fire; (iii) many of the adjacent trees do not show signs of fire (in areas not burned by prescribed fire) and may have grown after fire suppression began.

Activity 12: Stump Search Data Sheet

Sources: Lightning	Tree Species Hit[1]	Qualitative Observations[2] for each strike
1		
2		
3		
4		

Common tree species on Rowe Mesa (with their abbreviations) are: Ponderosa Pine (Pipo), Pinon pine (Pied), Rocky Mountain Juniper (Jusc), One-seed juniper (Jumo)

Qualitative Observations may include: (i) how much of the tree was struck by lightning? (ii) were the roots of the tree burned? (iii) was the tree killed? (iv) are there any other signs on the strike (for example, increased pitch from beetles?)

Stumps	Approximate age of tree when cut	Number of fire scars	Qualitative signs of effect of fire[3]	Age of adjacent burned trees (if
1				
2				
3				
4				

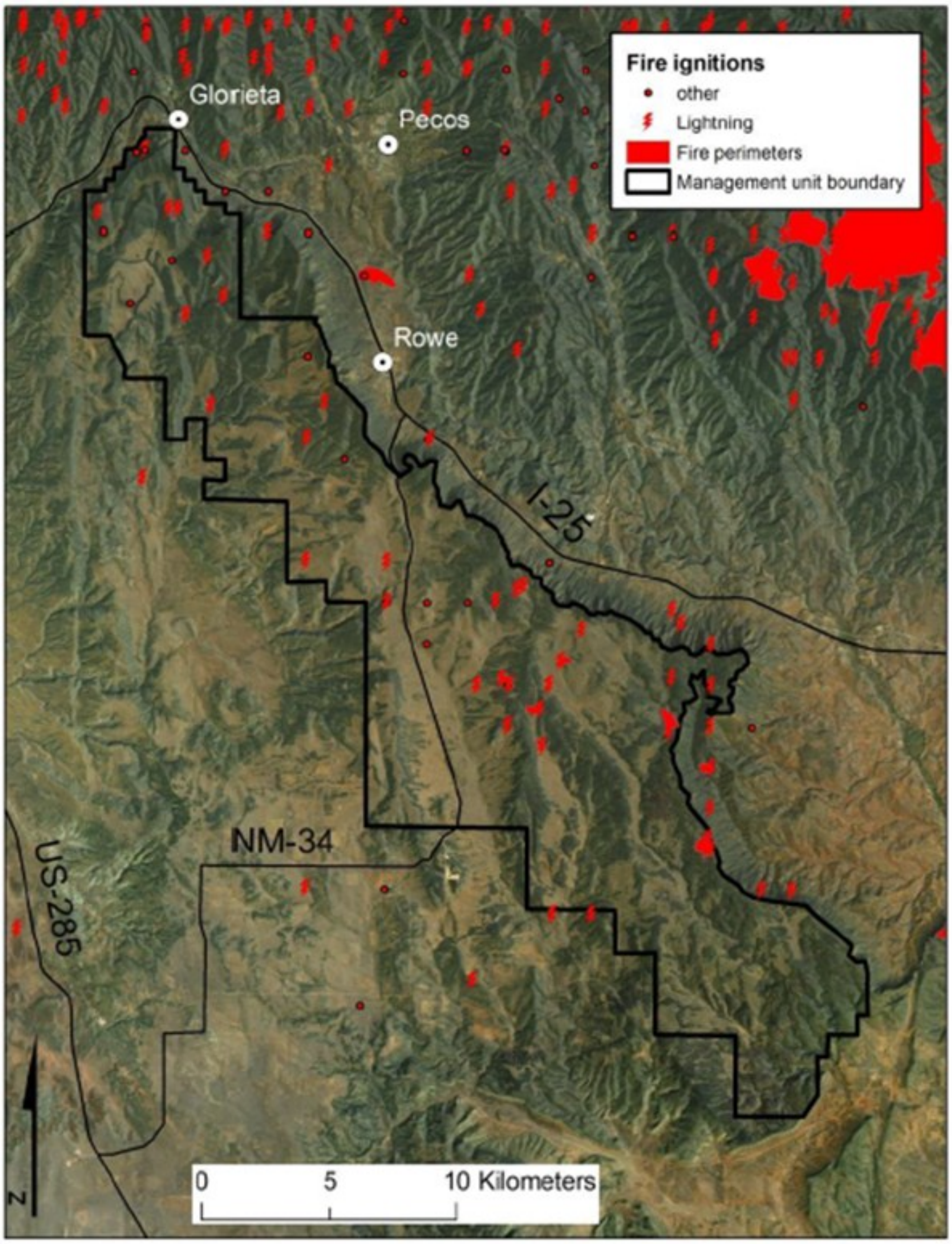
Are there any differences in tree rings after the fire (are they wider or darker?). Did you find any charcoal along the fire scar?

Ponderosa pine fire-scarred stump surrounded by young piñon trees (Source: E. Margolis, 2011: Rowe Mesa, NM Landscape Assessment)

Activity 12: Stump Search

Extension 1: Lightning Caused Fire on Rowe Mesa, 1973-2009

Print or project the map of lightning strikes that resulted in fires on and near Rowe Mesa. These fires were recorded between1973 and 2009. What does the map tell you? How many fires were there (45 ignitions)? What were the size of the fires (generally small, due to suppression and/or lack of surface fuels from grazing)? How do these lightning strikes compare to the data students gathered? If this is the frequency of lightning strikes, why hasn't there been more frequent or large scale fires on the mesa in recent years? (Some factors may include continued fire suppression, not enough ground fuels to carry the fire, or that sometimes lightning strikes a single tree and doesn't carry beyond that.)

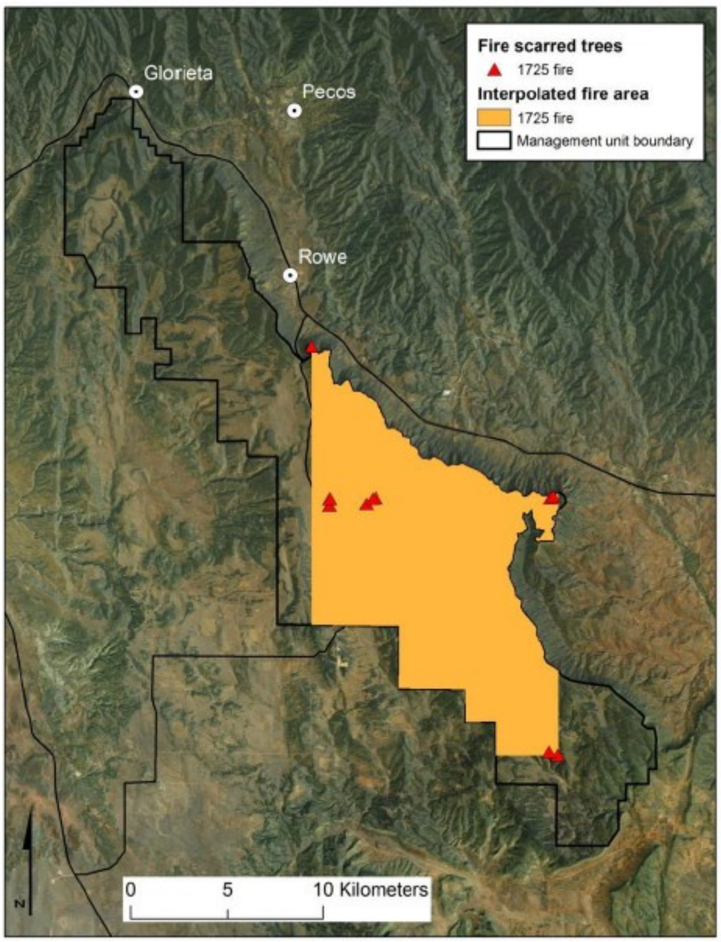


Source: E. Margolis 2011: Rowe Mesa, NM Lndscape Assessment

Activity 12: Stump Search

Extension 2: Landscape Scale Fire History

During the assessment of Rowe Mesa, fire history was reconstructed by looking for tree rings on fire scars. Evidence of a fire in 1725 was recorded in 30% of trees in 5 of 7 sites sampled on the mesa. This suggests a fire as large as 37,500 acres (see figure below). In general, the study of fire scars on the mesa showed that fires were generally low-severity fires in ponderos pine and PJ woodlands between the years 1546-1899. The last widespread fire was in 1876, just before the completion of the raliroad and intensive livestock grazing.



Source: E. Margolis, 2011: Rowe Mesa, NM, Landscape Assessment

As an extension, have students look at and evaluate the fire history recorded in the diagram (next page). Explain that 70 trees at a total of 7 sites were sampled. Each of the horizontal lines are individual trees sampled, and the dark, vertical bars represent fires (as evidenced by fire scars on the individual trees). Have students look at the trends in the data:

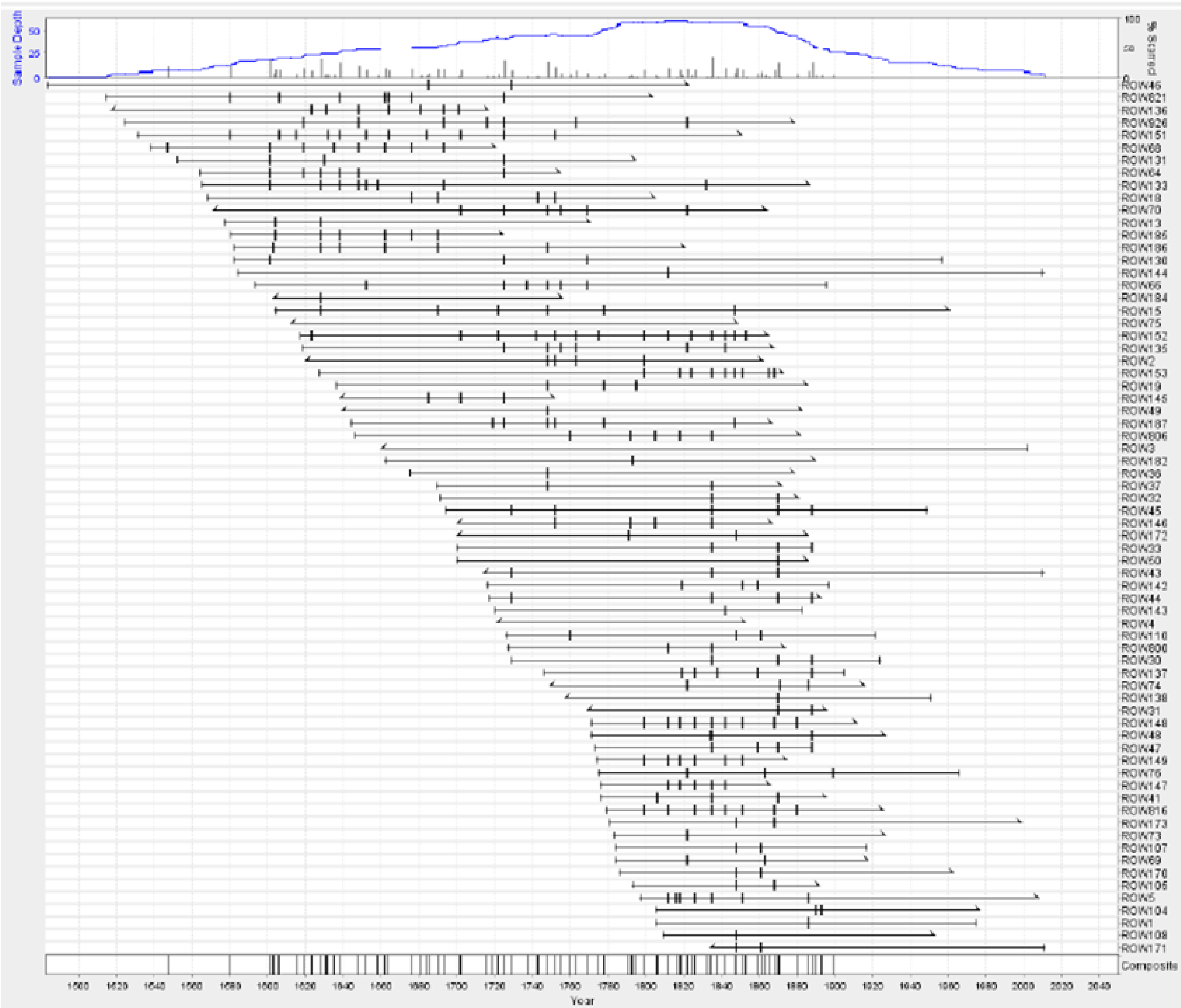
Can they tell when fire suppression began from the data?

How often did fires burn (look at the composite of all fires on the bottom of the figure)?

How often did individual trees burn?

Did trees burn more than once?

What does this tell us about the fire history on Rowe Mesa?



Rowe Mesa fire history reconstructed from 70 trees at 7 sites (1483 - 2011). Horizontal lines are trees and dark vertical lines are fires. (Source: E. Margolis, 2011: Rowe Mesa, NM, Landscape Assessment).

Activity 13: Encroachment: Plants moving in space & time

Background for Teachers

Piñon-juniper (PJ) woodlands are a widespread forest type in the western United States. Over the past 150 years, PJ woodland ranges have shifted, and in many areas are encroaching on other vegetation types. Of particular interest is the observation that PJ trees are spreading into grasslands, because in these areas, grasses decrease as the number of trees increases. Exactly why PJ woodlands are expanding into grasslands is uncertain. Three main theories are:

Lack of Fire. Frequent fires historically killed trees in grasslands before they could get established. Many grasses, however, are able to re-grow quickly after fires. When people began putting out all wildland fires (fire suppression) in the early 1900s, this allowed trees to survive in grasslands. As the trees got bigger, they started taking up more water and nutrients, which killed some of the grasses. The trees also shade the ground, reducing the amount of sunlight available for grasses and other groundcover. Now, these areas have so little grass that even when a fire does start, it will not spread because there is no grass for it to burn across the landscape.

Overgrazing. Widespread, intense grazing coincident with European settlement occurred in the mid– to late-1800s. This theory asserts that domestic animals, mostly cattle and sheep, ate so much of the non-woody plants in grasslands that fire decreased and/or competition for trees was removed. Trees were thus able to establish in grasslands and have since grown, taken more of the resources (water and nutrients) and made it impossible for grasses to come back even when domestic animals are removed from the site.

A combination of theories 1 and 2.

Other possible explanations exist, such as increased levels of carbon in the atmosphere giving trees an advantage over grasses, but lack of fire and introduction of grazing animals are two primary suspects.

On Rowe Mesa, this encroachment of PJ into grassland is observed. There are also sites on the mesa where PJ is encroaching into ponderosa pine forest. On Rowe Mesa, and throughout much of the southwest, Ponderosa pine forest health relies upon frequent fires that burn grasses and other growth low to the ground. The suppression of these fires may have allowed PJ trees to move into this forest type. Drought has also been found to allow PJ woodlands to encroach into ponderosa pine forest (Allen and Breshears 1998).

Objectives

Students will learn what plants need to survive and the differences between woody and non-woody species. They will apply this knowledge to understand how one vegetation association can displace another over time.

Duration

50 minutes plus analysis time. Can be extended for up to a full day by including extensions.

Vocabulary

- competition
- facilitation
- ecotone
- encroachment
- ground cover
- herbaceous

Materials

- Quadrat (four, 3 ft lengths of pvc pipe with corner connectors; Fig. 1)
- 50 foot measuring tape (x 3 or 4)
- Clipboards
- Blank paper
- Graph Paper
- Pencils

Plant Types

Plants are often sub-divided into broad groups. One common system of groupings is: grasses, forbs, shrubs, and trees. Grasses are defined by their seeds. In general, grasses have slender stems with small, narrow "leaves" (i.e., blades). The most common grasses on Rowe Mesa are gramas (Figure 1).

Forbs are low-growing, non-woody plants with broad leaves. Most plants thought of as wildflowers are forbs. Shrubs are woody, bushy plants. Common shrubs associated with PJ woodlands are chamisa (a.k.a. rabbitbrush) and sage. Trees are woody plants that are capable of growing tall, usually with one main stem (but in the case of juniper can often appear as a collection of stems). The crown of a tree is the collection of all of its upper branches and leaves.

Plant Resources

Plants have three essential needs: sunlight, nutrients and water[1]. These resources are all potentially limiting. In the case of sunlight, it is area that is limited (e.g., if a tree grows overtop shorter plants such as a grass, the grasses will be in the tree's shade and sunlight will be limited). Different plants have different strategies for getting these limited resources. In general, grasses have shallow roots and get water and nutrients (e.g., nitrogen, potassium, etc.) from the upper most soil layer. Trees have deeper, more extensive root systems and can get water from deep in the soil. As some trees, including piñon pine and juniper trees, get older, they grow roots that stay closer to the surface and spread outward from the tree. As this happens, these trees are able to take up shallow soil water and nutrients. When this happens, these trees actively compete with grasses and forbs for water and nutrients.

Competition and Facilitation

Plants, and all living things, can interact in several ways. Two plant interactions are competition and facilitation. Competition is when one or more of the interacting plants are negatively affected. For example, when trees encroach into grassland, they begin competing for resources. If the trees can get large enough to grow developed root systems, they will often out-compete grasses for water and nutrients. The grasses will start to die off as the trees continue to grow.

Facilitation is when one of the two plants is "helped" by the other. For instance, in PJ woodlands, young trees (seedlings) tend to grow better under existing plants as opposed to out in the open. This is because in PJ woodlands, the hot temperatures and dry conditions in the open spaces between plants are often too much for young trees to survive. The shade provided by other mature trees or shrubs or even grasses facilitates seedling growth by keeping the seedling cooler.

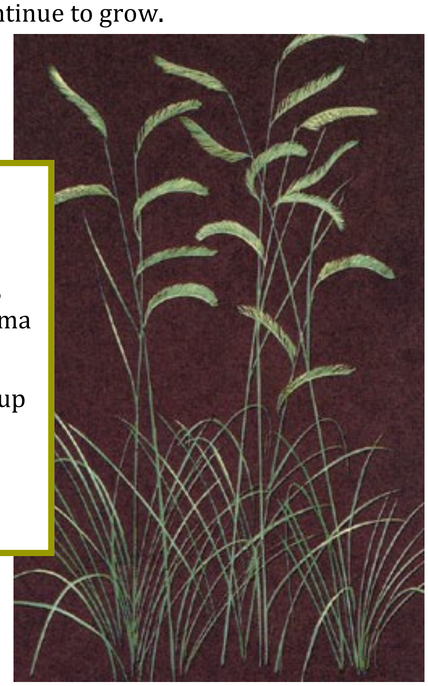


Figure 1. Blue grama grass

www.kaupag.com

Interspace vs. Under canopy

As noted above, conditions in the open are different from those under a plant. An individual tree crown includes all the branches and leaves/needles while the forest canopy is made up of all of the tree crowns in a forest. Tree crowns change the conditions under them. For instance, tree crowns cast shadows which can cool the area underneath them in summer (or keep it warmer in winter) and limit the amount of light that gets under them. Trees also lose their leaves/needles and as those leaves/needles decompose, thus changing soil conditions under the trees. For instance, the area under piñon and juniper trees

1. Plants also need carbon dioxide and oxygen, but these gases are generally only limited when the plant is attempting to reduce water loss.

has been found to be more acidic and have higher organic carbon than the interspaces, or areas not directly under a tree crown (Davenport et al. 1996). Due to the different environmental conditions, it is not uncommon to find differences in the groundstory, or the plants growing close to the soil surface, under trees compared to that of the interspaces.

Measuring Ground Cover

For this activity, ground cover will be measured using a 3 x 3 foot quadrat (Figure 2). This can be made by cutting four (4) three foot lengths of PVC pipe and connecting those using PVC elbows. Ground cover will be recorded as a percentage of the total area within the quadrat. The categories of ground cover to be used for this activity are: bare ground/rock, litter, grass, forb, shrub, tree seedling.

Vocabulary

<u>Competition</u>: interaction between two or more species that results in a negative outcome for at least one of the species.

<u>Ecotone</u>: a zone of transition between one ecosystem and another. On Rowe Mesa, there are two major ecotones: between grassland and piñon-juniper woodland, and between piñon-juniper woodland and ponderosa pine (Figure 3).

<u>Encroachment</u>: the process of one vegetation type (e.g., piñon-juniper) moving into the range of another vegetation type (e.g., grassland).

<u>Ground cover</u>: that which is covering the soil surface; often divided into categories such as bare ground, rock, grass, etc. and expressed as a percentage.

Figure 2. Mountainair middle school students model a quadrat in the field.

Preparation

You will need to identify a suitable area for this activity. An ideal site would be a grassland/piñon-juniper ecotone where tree encroachment is occurring but any site with piñon and/or juniper trees would suffice. Be sure to have all of the necessary materials with you (see Materials list in the sidebar of the first page of this lesson).

Procedure

Begin by covering the main, potentially limiting requirements of plants (sunlight, water and nutrients). Then, ask the students what happens when two plants live in the same place. Allow them time to generate ideas but usher them to the point where you can introduce the idea of *competition* and *facilitation* if they do not get there on their own. Provide an example of competition (two trees competing for light in a crowded rain forest) and facilitation. For the latter, you might be able to find a piñon tree growing up underneath a shrub or juniper tree to point out.

Tell the students that they will be observing how plants are interacting on Rowe Mesa. In particular, they will be studying how piñon pine and juniper trees are interacting with the other plants. To do this, they will collect data on groundstory cover using a quadrat. Show the students the quadrat and demonstrate how it is used, which is by placing it on the ground and estimating how much of the area within the quadrat is occupied by different ground cover types. Help them make data tables on their paper while pointing out the ground cover categories (bare ground/rock, litter, grass, forb, shrub, tree seedling) and the percentage categories (0-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100%). Take this opportunity to identify the main plants growing at the site as trees, shrubs, forbs or grasses and communicate that the ground cover percentages are estimates and will require their best judgment. Practice estimating ground cover with the group.

Figure 3. Picture depicting the ecotone between a grassland (foreground) and a pinon-juniper woodland (background). Note the smaller, young trees in the transition zone.

Source: http://www.tarleton.edu/Departments/range/Woodlands%20and%20Forest/Juniper-Pinon%20Woodland/juniperpinonwoodland.html

Next, allow students to formulate hypotheses about how they expect trees to affect the other plant groups (e.g., forb cover will be higher under trees than in the interspaces; grass cover will be higher the further away from a tree one is, etc.). Once each student has a hypothesis, divide them into smaller groups of three to five (or however many groups you can accommodate based on the number of 50 foot tapes you have) and go over the protocol. They will:

1) Go to a tree of your choosing[1]
2) Identify the next closest tree[2]
3) Run the 50-foot measuring tape from the stem of their tree to the stem of the next closest; it does not matter if the next closest tree is closer or further than 50 feet; the students should run the transect (i.e., the measuring tape) until they run out of tape or encounter the next closest tree.
4) Take ground cover measurements with the quadrat every five feet along the transect starting at 1 foot until they reach the end of the tape or the next closest tree.
5) Record cover percentages, note whether or not the quadrat is under a tree crown[3] and distance to the nearest tree[4].
6) Repeat as often as you are able given your time constraints while allowing time to aggregate and review the data.

Data Aggregation and Analysis

To aggregate the data, first rewrite the data such that the midpoint of the ground cover percentages is represented. For instance, a ground cover estimate of 0-5% would be rewritten as 2.5%. Once you have done this, average the data across all transects by adding the data from each transect and then dividing by the number of transects. (This is the same method of analysis as is used in CFRP monitoring protocols: http://www.nmfwri.org/index.php/collaborative-forest-restoration-program). For example, in the example on the following page, assume you collected data from 3 transects.

1. If the trees at your site are clumped, choose a tree at the outer edge of a clump and run the transect to the next closest clump; for sites with a high number of trees, you might need to run the transect in a direction other than toward the next nearest tree to capture enough interspace area
2. Record 'Y' if at least half of the quadrat is under a tree crown.
3. Distance to nearest tree will differ from the sampling point only if they have gotten to where they are closer to the nearest tree than they are to their starting tree.

Grass cover Distance from Tree	Transect 1	Transect 2	Transect 3
1-5 ft	0-5%	0-5%	0-5%
6-10 ft	0-5%	0-5%	5-25%
11-15 ft	5-25%	5-25%	25-50%
16-20 ft	5-25%	5-25%	25-50%
21-25 ft	50-75%	5-25%	25-50%
26-30 ft	50-75%	50-75%	50-75%
31-35 ft	25-50%	50-75%	50-75%
36-40 ft	50-75%	75-95%	75-95%
41-45 ft	75-95%	50-75%	75-95%

Transforming and averaging the data to mid-points would yield:

Grass cover Distance from Tree	Transect 1	Transect 2	Transect 3	Sum	Average
1-5 ft	2.5%	2.5%	2.5%	7.5	2.5%
6-10 ft	2.5%	2.5%	15%	20	6.67%
11-15 ft	15%	15%	37.5%	52.5	17.5%
16-20 ft	15%	15%	15%	45	15%
21-25 ft	62.5%	15%	37.5%	115	38.33
26-30 ft	62.5%	62.5%	62.5%	187.5	62.5%
31-35 ft	37.5%	62.5%	62.5%	162.5	54.17%
36-40 ft	62.5%	85%	85%	232.5	77.5%
41-45 ft	85%	62.5%	85%	232.5	77.5%

A graph of the aggregated data would look like Figure 4. If time allows, having the students graph the data themselves can be a valuable exercise. This can be done with graph paper in the field or using a spreadsheet program such as MS Excel on computers back in the school.

The sample data reflects only grasses, but you should analyze data for all of the ground cover classes.

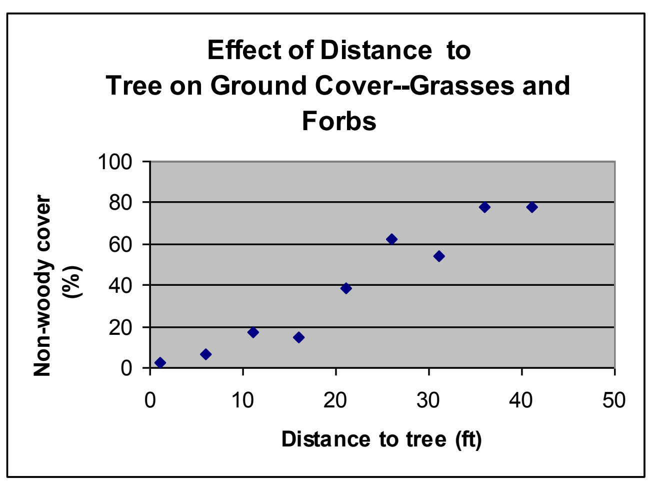


Figure 4. Graph depicting aggregated sample data.

Discussion

A starting point for discussion with the students is to simply allow them an opportunity to identify any trends in the data. Then, have the students evaluate their hypotheses based upon the data. Were their hypotheses supported or not supported by the data? If the data do not support the hypothesis, have the students generate new hypotheses based upon the data.

The sample data reflect what one would generally expect, which is that grass cover is greater the further away from trees one is. This may not, however, be what is observed in the field. Reviewing the data and developing hypotheses to explain the data is a valuable activity in which to engage with the students. For instance, perhaps the site you studied is actively grazed and non-woody ground cover is low in the interspaces as a result. It might also be that the interspaces are highly eroded decreasing ground cover. Whether the data match expectations or not, students will have an opportunity to explain what they observed and develop an understanding of the site's plant dynamics.

Extensions

An easy extension is to collect data from more than one site. Site pairings that could be particularly interesting include:

- one site that has been grazed recently and one that has not;
- one site with some scattered older trees and another site dominated by smaller, presumably younger trees;
- one site at the grassland/woodland ecotone and another at the pinon-juniper/ponderosa pine ecotone.

Instructors might also want to emphasize the mathematics involved in this activity by having the students calculate the mid-points for the cover classes and aggregate the data. Students can be asked to graph the data and, and if the students are using computers, they can also develop linear regression equations for the data. A linear regression equation is simply the equation of a line that best "fits" the data points (Figure 5). In MS Excel, one can draw a regression equation on their data chart by:

1) right-clicking on one of the data points in your graph;
2) selecting "Add a trendline";
3) in the "Type" tab, selecting "Linear";
4) in the "Options" tab, check the "Display equation on chart" and "Display R-squared value on chart" boxes.

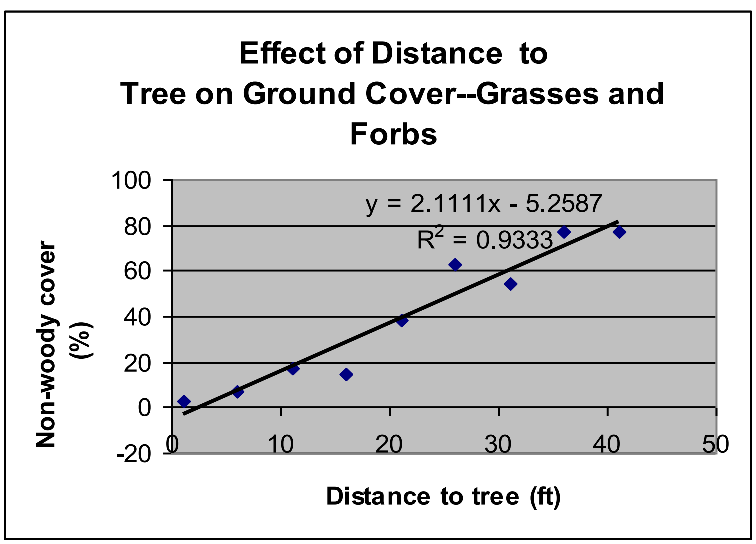


Figure 5. Graph of data with linear regression equation and R2 value.

The linear equation is given in the y = mx + b form, where

m = the slope of the line, and

b = the y-intercept.

The R^2 value tells you how well the line fits the data. In general, an R^2 greater than 0.70 is a pretty good fit but there is no universally accepted cutoff. Understanding the equation of a line typically meets certain math standards, and the development of a regression equation and its R^2 value falls under the umbrella of statistics.

Activity 13: Encroachment: Plants moving in space & time (continued)

Review

Review the main requirements of plants and the concepts of competition and facilitation. Restate the trends in your data and the ideas you generated to explain that data. You might conclude by developing or proposing ideas for a study to test the explanation(s) explanations.

Cited and Relevant Literature

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Activity 13: Encroachment DATA SHEET

Distance from Tree	Type of cover	Percent plant cover estimation					
		0 to 5%	5 to 25%	25 to 50%	50 to 75%	75 to 95%	95 to 100%
1-5 ft Under tree crown?	Grasses						
	Forbs						
	Bare soil/rock						
	Litter						
6-10 ft Under tree crown?	Grasses						
	Forbs						
	Bare soil/rock						
	Litter						
11-15 ft Under tree crown?	Grasses						
	Forbs						
	Bare soil/rock						
	Litter						
16-20 ft Under tree crown?	Grasses						
	Forbs						
	Bare soil/rock						
	Litter						
21-25 ft Under tree crown?	Grasses						
	Forbs						
	Bare soil/rock						
	Litter						
26-30 Under tree crown? ft	Grasses						
	Forbs						
	Bare soil/rock						
	Litter						
31-35 ft Under tree crown?	Grasses						
	Forbs						
	Bare soil/rock						
	Litter						
36-40 ft Under tree crown?	Grasses						
	Forbs						
	Bare soil/rock						
	Litter						
41-45 ft Under tree crown?	Grasses						
	Forbs						
	Bare soil/rock						
	Litter						

Activity 14. Counting Carbon: How Trees Affect the CO_2 in Earth's atmosphere

There are four parts to this activity, each of which can be taught independently:

Part I: Remote Sensing
Part II: Measuring Carbon in the Field
Part III: Dendrochronology and Carbon Accumulation
Part IV: Managing Forests for Resiliency

Background

When land managers and scientists consider land management choices today, they usually try to consider the influence of climate change on their decisions. Long term management of forests attempts to understand the conditions of forests of the past and to consider how different management choices will affect forests in the future. Generally, managers and scientists want to maintain forests within their "historic range of variability," or the range of natural conditions that existed for a specific type of forest. However, the potential impact of climate change makes this more difficult.

Most scientists predict that the Southwest United States will become warmer and drier with increased periods of drought over the next century. This likely will result in an increased number of trees that will die from drought or disease. It will also slow the growth of trees.

One study modeled forest conditions under different scenarios of climate and management in the forests of northern Arizona. This forest was dominated with ponderosa pine and Gambel's oak, with some Utah juniper, New Mexico locust, and piñon pine. From these models scientists projected that:

i. A warming climate will reduce forest density

ii. No management actions (but warming climate) will result in the most dense forest conditions

iii. Prescribed burning (with warming climate) will result in the least dense forest conditions

Another model considered the risk of forest fire on forest carbon budgets. Carbon budgets are ways of describing the locations and amounts of carbon in an ecosystem. Carbon is critical to the discussion of climate change because carbon dioxide (CO_2) is a greenhouse gas that contributes to global warming and the resulting climate change. Most simply put, greenhouse gases limit the amount of heat that can *escape* from the earth back into space. This results in a *warming* of the earth. Over the earth's geologic past, higher levels of CO_2 are associated with higher air temperatures.

Objectives

Part I: Students will learn how scientists can use remotely sensed information to estimate forest characteristics. This lesson component is mathematically focused.

Part II: Students will learn how researchers and land managers can use relationships between individual tree characteristics (allometry) to estimate larger-scale forest characteristics.

Part III: Students will use dendrochronology to estimate the amount of carbon being sequestered by trees in a given area each year.

Part IV: Students will learn about different management goals and mark trees to be cut to meet those goals.

Duration

Approximately 50 minutes per Part.

Vocabulary

- Allometry
- Biomass
- Carbon sink
- Carbon sequestration
- Remote sensing

Because of concerns over the effects of a warmer, drier climate that likely will result from climate change, *carbon sequestration* within forest systems is increasingly a management consideration. Carbon is everywhere in our world. It is in soils, dissolved in ocean waters, stored in coal deposits and peat bogs as well as the bodies of plants and animals, and held

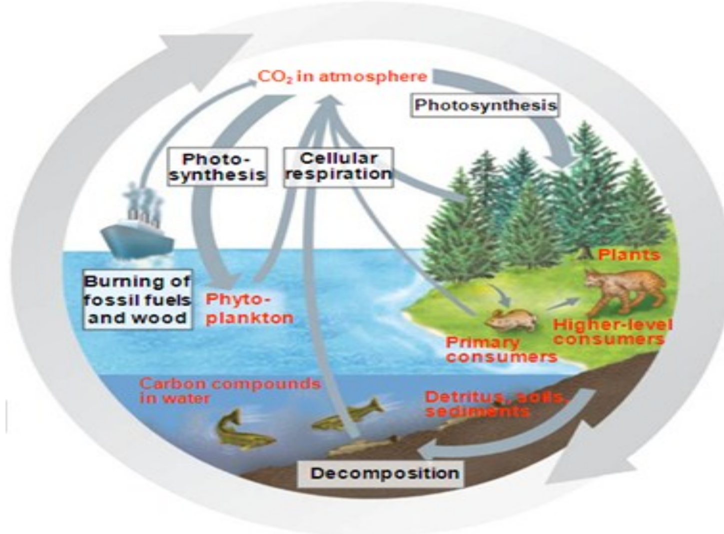


Figure 1. Carbon Cycle

For example, in the modeling of carbon budgets following wildfire, scientists from Northern Arizona University considered two different scenarios for a ponderosa pine forest: one in which the forest was left untreated, and one in which some of the trees were thinned. When burned, the untreated forest (Figure 2, below), resulted in most of the trees dying and the carbon was released into the atmosphere, contributing to more greenhouse gases. In contrast, the thinned forest was able to retain a greater proportion of carbon, stored in trees that survived the fire and in old logs that did not completely burn (Figure 2, below.)

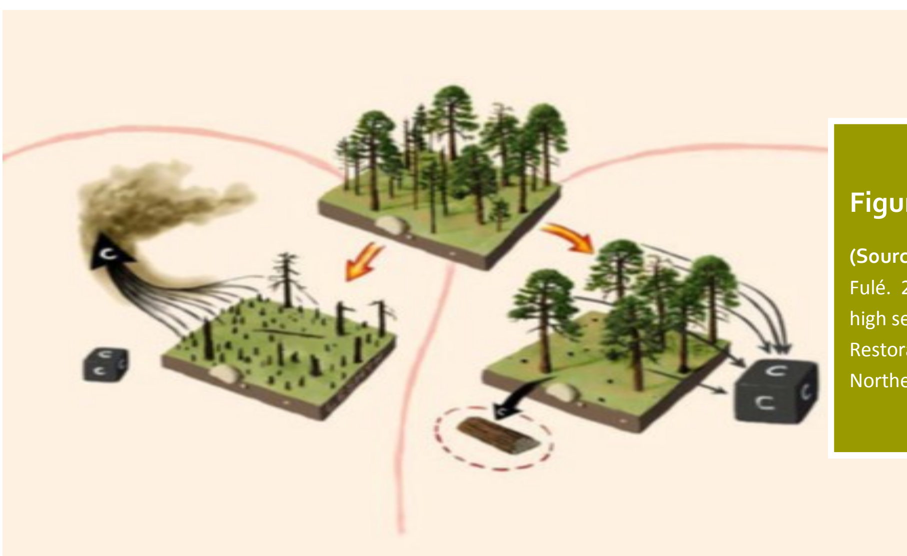


Figure 2. Carbon Scenarios

(**Source:** Hurteau, M., M. Stoddard, P. Fulé. 2010. Carbon costs of mitigating high severity wildfires. Ecological Restoration Institute Fact Sheet. Northern Arizona University)

The scientists concluded that this provided a win-win situation for forest restoration. Forest restoration reduced the risk of catastrophic wildfire. It can also help to maintain a longer term carbon budget, by creating a forest structure that would support lower intensity surface fires.

Another way managers think about climate change is to create forests that will have greater *resilience*, which will increase the ability of a forest to withstand changes related to climate. Most of the factors that increase resilience are essentially the same as the goals for forest restoration, including:

- Maintain the health of trees
- Minimize severe fire
- Increase or maintain species diversity

Activity 14. Counting Carbon: How Trees Affect the CO_2 in Earth's atmosphere

Part I: Remote Sensing

As carbon dioxide accumulates in the Earth's atmosphere, the need to better understand global carbon budgets becomes more pressing. Forests and woodlands are carbon sinks, meaning they store carbon. Accurately estimating the amount of carbon in forests across expansive landscapes, however, is a challenging task. To date, the most promising method to accomplish this goal is through remote sensing.

Remote sensing is simply the ability to detect or "sense" something from afar. While more sophisticated methods of remote sensing are available and actively used, we will focus on using aerial photographs for this activity. Students will use the aerial photograph to estimate the amount of canopy cover (in cm^2) on the mesa. They will then use that estimate in a mathematical equation that relates canopy cover to above ground biomass and then ultimately to carbon to estimate the amount of carbon being stored by the trees on Rowe Mesa at the time the picture was taken.

Vocabulary

Allometry: how characteristics of a living creature change with size. For example, in Part I of this study, students will use the relationship between canopy cover and biomass to estimate the amount of carbon stored in a forest based upon the canopy cover of that forest.

Biomass: the amount of a living thing, usually measured in grams or kilograms

Canopy cover: the amount of ground covered directly overhead by the leaves, twigs and branches of all the plants (including trees) in a given place, usually expressed as a percent or unit of area (i.e., cm^2).

Carbon sequestration: the process by which carbon dioxide is removed from the atmosphere and stored elsewhere on the earth where it is not contributing to atmospheric CO_2. For example, trees sequester carbon by using CO_2 and incorporating it into their plant bodies or storing it as a form of sugar.

Carbon sink: a part of the Earth's ecosystem where more carbon is stored than is released to the atmosphere. Forests are typically carbon sinks because they take CO_2 from the atmosphere and incorporate it into their wood, leaves and roots where it is stored until the tree dies and decomposes or is burned.

Dendrochronlogy: the dating and study of annual rings in trees (http://ltrr.arizona.edu/about/treerings)

Remote sensing: the collection of data from a distance. In the case of this activity, data was collected by taking a picture from an airplane (aerial photography). Often times, remotely sensed data is collected by satellites orbiting the Earth.

Preparation

You will want to print a copy of the aerial photograph of Rowe Mesabefore the lesson. Larger prints will be easier for the students to use. A map-sized print, however, can be expensive, and legal or even letter-sized prints can be used.

Objectives

Part I: Students will learn how scientists can use remotely sensed information to estimate forest characteristics. This lesson component is mathematically focused.

Duration

Approximately 50 minutes per Part.

Vocabulary:

- Allometry
- Biomass
- Carbon sink
- Carbon sequestration
- Remote sensing

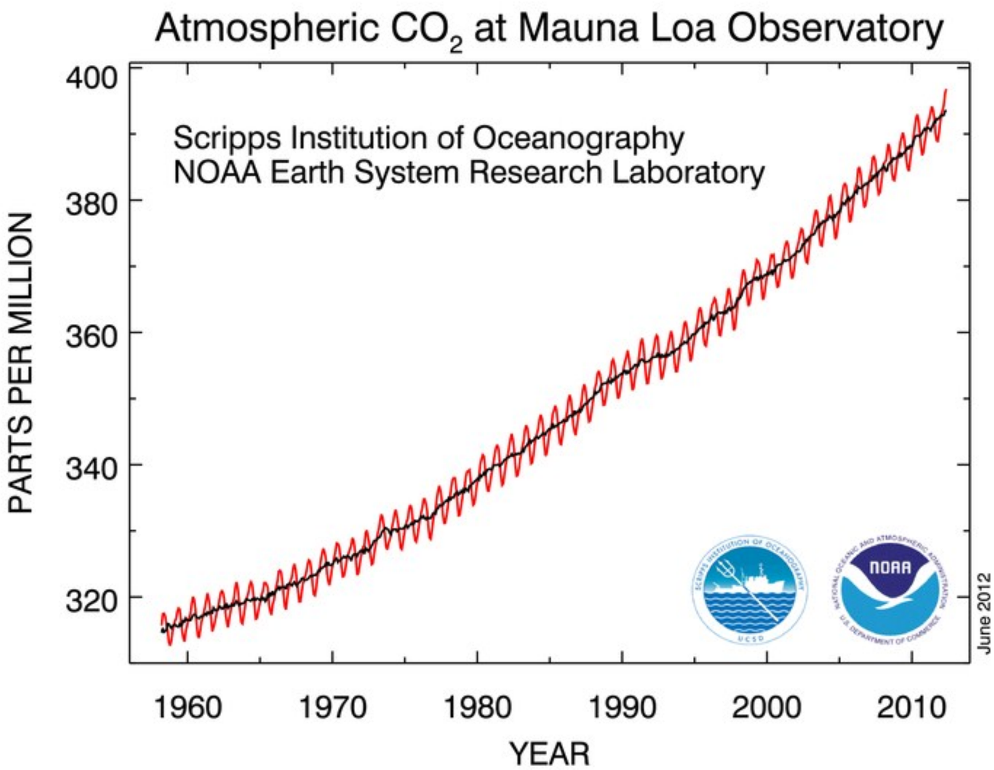
Materials

- Calculator with log function or computer with MS Excel or other spreadsheet software
- Print of Rowe Mesa aerial photo

Procedure

Ask students what they know about CO_2 in our atmosphere. After giving them time to share what they think, present them with the information contained in Figure 1. Allow them time to read the graph and ask them what it is showing. As a class, discuss how the amount of CO_2 (measured in parts per million [ppm]) in Earth's atmosphere has increased over the past 50 years. Then tell students that about 50% of a tree is carbon, and in fact, was in the atmosphere as CO_2 before the tree took it up and incorporated it into its biomass. Define *biomass* for the students. Carbon in tree and plant biomass is said to be sequestered in that this carbon will not contribute to CO_2 in the atmosphere until the plant or tree either dies and decomposes or is burned.

Figure 1.



Now show the students the copy of the aerial photograph you have printed (or the copies if you have made smaller prints). Tell them that they are going to estimate how much carbon is being stored in the trees on Rowe Mesa by using the aerial photograph. To do so, however, is going to require quite a bit of math. The first step will be to estimate how much of Rowe Mesa is under canopy cover. You may allow them to figure a way to do this on their own or walk them through the following procedure:

1) Draw gridlines on the aerial photo that represent 1 km increments based on the scale at the bottom of the aerial photo (You can use a coarser scale such as gridlines spaced 2 or more km apart to speed up this step). Note that the mesa boundary is outlined in white.
2) For each grid falling within the Mesa boundary, classify it as being either 'covered' or 'not covered', where a grid with 50% or more tree cover is 'covered.' Have the students keep a tally of the running total of each grid classification.
3) Calculate how much total area is under canopy cover my multiplying the number of 'covered' grids by 1 km^2 (or whatever size grid you used). This is your total canopy cover area.

Activity 14. Counting Carbon: How Trees Affect the CO_2 in Earth's atmosphere (Part I continued)

Tell the students that other researchers have done work to calculate a the biomass of a woodland based upon the woodlands canopy cover. One equation for doing this is:

$$\text{Log(biomass)} = -4.66 + 1.32 \log(\text{canopy cover})$$ (from Huang et al. 2009)

Where biomass is in kg and canopy cover is in cm^2. (Note that the canopy cover the students calculated is in km^2 and is converted to cm^2 in the MS Excel example in Appendix I.)

If your goal is to teach this level of math, share the equation with the students and have them solve it. If this is not your goal, you can solve the equation with a calculator or in MS Excel. Instructions for solving the equation are given in Appendix I. This calculation yields a biomass number in kg. So, according to this estimation process, the biomass number you get is how much wood in kg is on the mesa. Since trees are on average 50% carbon, divide the biomass number by 2 to get an estimate of how much carbon in kg is being stored in trees on the mesa.

Discussion

After the students have calculated the carbon estimate and you have had a chance to share the results, ask the students what they think of trying to use trees to help take out some of the carbon that we are putting into the atmosphere. Some points that might be raised include:

- We calculated total carbon in the trees on the mesa, but we are putting carbon into the atmosphere daily. For a better accounting, we need to know how much carbon Rowe Mesa is *sequestering* over time, which is done in Part III.
- Fire is a natural disturbance on Rowe Mesa, and at least part of the mesa would experience natural fire every so often. When trees burn, the carbon will go right back to the atmosphere.
- Whether or not land managers should be managing for carbon is a legitimate question. What would management for carbon on the mesa look like? How might that differ from other management goals (Part IV)?

Ask the students what they think of this method of estimating carbon for a given area. Estimation is a process that will include error. What are the possible sources of error and are they acceptable or would you not be comfortable using this data as an estimate? Some points that could be highlighted include:

- We assumed all vegetation cover were trees. How likely is this?
- We used the same conversion for pinon and juniper trees. Is this reasonable?
- We accounted only for the carbon in the above ground parts of the trees. We neglected the trees roots, other vegetation (grasses and shrubs), and carbon stored in the soil. Is this problematic?

Aerial Photo for Rowe Mesa

Activity 14. Counting Carbon:
How Trees Affect the CO_2 in Earth's atmosphere (Part I continued)

Appendix I

Solving the Canopy Cover to Biomass Equation

If you are using MS Excel, type the following into cells of the worksheet:

A	B	C	D	E
1	Canopy Cover (km2)	Canopy Cover (cm2)	log(biomass)	biomass
2	<Enter your canopy cover data here>	=A2*10000000000	= -4.66 + 1.32*LOG(B2)	=10^C2

Similarly, if you are using your calculator:

1) Multiply the canopy cover value the students calculated by 10,000,000,000. This gives you canopy cover in cm^2.
2) Find the log of the canopy cover (cm^2) by pressing the log function on your calculator.
3) Multiply that number by 1.32.
4) Subtract 4.66 from that number. This is your log(biomass) number.
5) Then, press the log function again. This gives you your biomass number in kg.

Activity 14. Counting Carbon: How Trees Affect the CO_2 in Earth's atmosphere

Part II: Allometry

Allometry in a general sense is the relationship between two characteristics of something. For example, in Part I, we used the relationship between canopy cover and above ground biomass to estimate how much carbon was stored on Rowe Mesa from an aerial photograph. More accurately, allometry is the relative change of one character trait compared to another with growth. For example, as a tree gets 1 inch larger in diameter, perhaps it grows 6 inches in height. In this lesson, students will learn about allometry and have an opportunity to use that to estimate tree carbon by measuring the diameters of trees in the field.

Procedure

Introduce the word allometry and define it for the students as the relationship between two different traits of a living thing. If the students have difficulty grasping the concept, tell them to not worry and just think about it while you have them do the first part of the lesson.

<u>Hand-to-Height</u>

The students will explore allometry by developing a relationship between the size of their hand and their height. To do this, the students will:

1) Measure the distance between the tip of their thumb and the tip of their pinky (Figure 2). (You can also use another body part, such as waist, foot length to compare to height. You can also let students' choose a body part.)
2) Have a partner measure their height, being sure to use the same units (i.e., cm, in, etc.)
3) Enter the data into a table (see Table 1 for example).
4) Plot the data onto a graph (see Figure 3 for example).

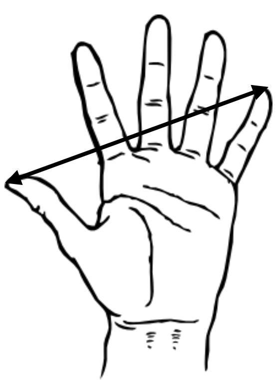


Figure 2. Hand width measurement.

Objectives

Part II: Students will learn how researchers and land managers can use relationships between individual tree characteristics (allometry) to estimate larger-scale forest characteristics.

Duration

Approximately 50 minutes per Part.

Vocabulary (see Part I)

- Allometry
- Biomass
- Carbon sink
- Carbon sequestration
- Remote sensing

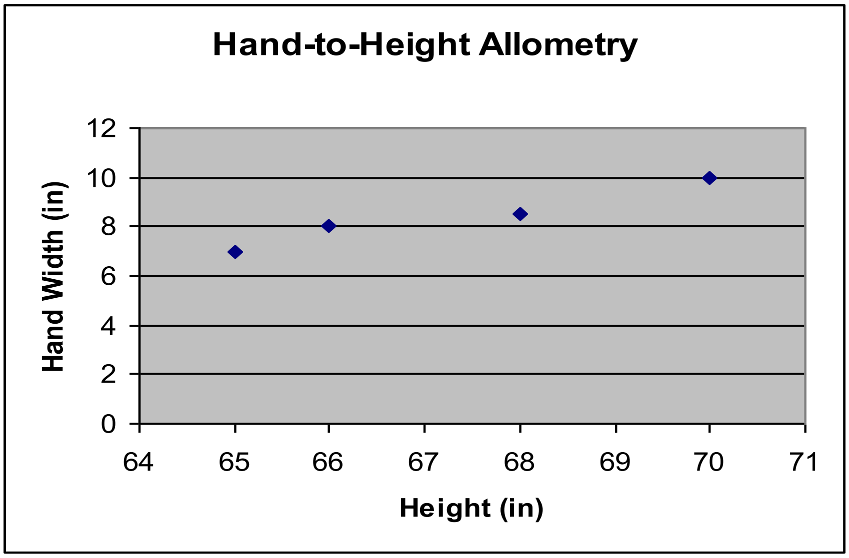
Materials

- Tree diameter tape
- Calculator with log function or computer with MS Excel or other spreadsheet software
- Measuring tapes

Table 1. Sample Data Table for Hand-to-Height Allometry

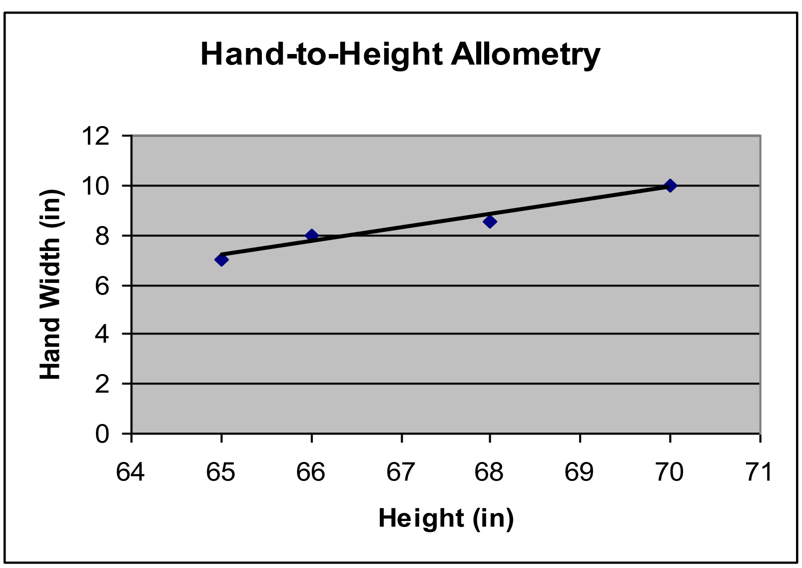
Student	Hand Width (inches)	Height (inches)
1	8	66
2	10	70
3	7	65
4	8.5	68

Figure 3. Sample Graph of Hand-to-Height Allometry Data



You can then draw a line on the graph that approximates your data (Figure 4). Tell the students that with this line, we can predict how wide someone's hand will be based upon their height or how tall someone is based upon their hand width. We probably will not be exactly right, but if we have a good sampling of people, our prediction ought to be pretty good.

Figure 4. Hand-to-Height Allometry with line.



Tree Allometry in the Field

Inform students that you will be using this same method of allometry to estimate the biomass of piñon trees. Define biomass for the students simply as the amount or total mass of the tree. Then, have the students measure piñon trees' diameters at root collar (DRC). (Have students use piñon rather than juniper. Junipers are trickier to measure, as they often grow with multiple stems instead of one trunk.). This is done by stretching the tape around the tree trunk as close to the ground as you can but above any obvious flaring (Figure 5a). If the tree trunk is growing at an angle, try to measure perpendicular to the trunk (Figure 5b).

Figure 5. Measuring DRC (lines denote where the measurement should be made).

5a. Tree with Flaring

5b. Tree with curved trunk

Students will need to record the diameters of the trees they measure on a data sheet. Once you have had the students measure the trees (the exact number they measure is up to the instructor, but should be at least 10 trees ranging in size), have them enter this data into a master data table. Complete the table using the following equation:

log(biomass in kg) = -1.468 + 2.582 * log (drc in cm) (from Grier et al. 1992),

If you are using MS Excel, an example of the formulas you can use is provided in Appendix II. You can then add all of the carbon totals and have an estimate of the amount of carbon stored in the trees they measured.

Discussion Points

- If you did Part I, ask the students if they feel more or less confident in the carbon estimate using the field data compared to the remotely sensed data and why.
- If you did not do Part I, simply ask them how confident they feel in the carbon estimate they calculate. What would sources of error in this exercise be?

Make the point that the carbon estimate is *only* for the trees they measured. Ask the students how they might get an estimate for all of the trees on the mesa. This could lead into the idea of random sampling by which one measures a randomly selected subset of all of the trees on the mesa and uses the carbon number to scale up to the whole mesa.

Extension

In addition to having the students measure DRC, you can have them measure some other tree characteristic. The easiest of these would probably be crown area. To measure crown area,

1. Find the long axis of the tree crown and measure it.
2. Measure the crown perpendicular to the first measurement (Figure 6).
3. Calculate the average of these two measurements.

Now treat the tree crown as a circle with a diameter equal to the average crown width calculated in Step 3:

Crown Area = pi * ½(crown diameter)^2.

You can then create an allometric equation of your own using the relationship between DRC and crown area. You can estimate this and do it by hand following the same method outlined in the hand-to-height activity or plug your data into MS Excel and calculate a regression equation.

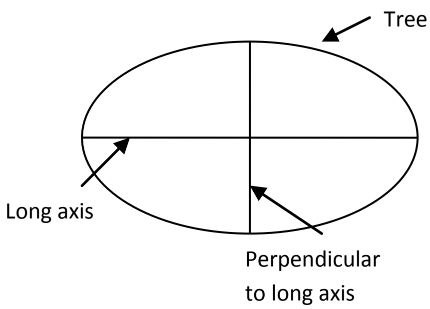


Figure 6. Finding the long and perpendicular axes of a tree crown.

Sample Data Sheet

Tree ID	DRC (cm)	Crown long axis (m)	Crown perpendicular axis (m)	Age

Note: Not all columns may be used depending upon which parts of the lesson are implemented

For this activity, tree ID does not have use scientific names, but it does have to identify each type of tree separately (e.g., ponderosa pine could be butterscotch tree).

Activity 14. Counting Carbon: How Trees Affect the CO_2 in Earth's atmosphere

Part III: Dendrochronology and Carbon Accumulation

In Part II, students estimate the amount of carbon stored in the tree's they measured. While this is a useful number, it does not tell one how much carbon a tree sequesters each year. To do this, you need to estimate a growth rate, which will require you to know the age of the tree.

Dendrochronology is the study of tree rings. In the temperate regions of the world (where there are strong winter/summer seasonal changes), a tree ring reflects one year's growth (Figure 7). The annual tree ring is made up of light colored, less dense "earlywood" that is formed at the beginning of the growing season (spring/early summer), followed by darker, more dense "latewood" that is formed at the end of the growing season (late summer/fall). In this part of the lesson, students will take tree cores using an increment borer. They will determine the age of the tree and calculate an annual growth rate based upon it and the total biomass of the tree calculated in Part II, and you should take tree cores from the same trees for which you have DRC measurements. If you do not do Part II, you can still use the equation to estimate a tree's total biomass.

Procedure

Begin by introducing the idea of tree rings to students. Explain to them why the rings form (differential growth from spring/early summer to fall/winter in New Mexico). Show them the increment borers and tell them they will use these to take small cores from trees and determine how old the trees are from the cores.

After you have identified the trees to be cored, demonstrate how to assemble the increment borer. You should know this from the instruction sheet that came with your borer. Beware to not loose or accidentally step on and bend the extractor. (One trick to avoide this is to wedge the extractor in the bark of the tree while coring.) It is not a bad idea to attaché colored tape or string to the end of the extractor so as not to loose it in the field. Then, show the students how to take a tree core.

1) Identify a spot on the tree from which to take a core. This should be as close to the ground as possible but high enough from the ground so that the borer can turn. Knots and tree trunk flaring should be avoided.
2) With the extractor out of the borer, turn the borer clockwise until it screws itself far enough into the main stem of the tree such that you have gotten to the center of the tree.
3) Insert the extractor into the borer so that the groove onto which the core will lay is facing down (is upside down).
4) Back the borer out of the tree one-half turn so that the extractor groove is now facing up.
5) Slowly pull the extractor from the borer; if the core does not come out, repeat steps 3 and 4.

Have the students look at the core they have extracted and count the rings. They will record the age of the tree on a data sheet (Part II).

Objectives

Part III: Students will use dendrochronology to estimate the amount of carbon being sequestered by trees in a given area each year.

Duration

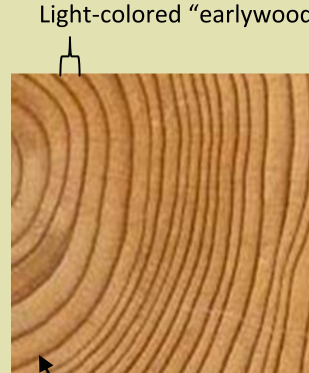
Approximately 50 minutes per Part.

Vocabulary (See Part I)

- Allometry
- Biomass
- Carbon sink
- Carbon sequestration
- Remote sensing

Materials

- Increment borer
- Diameter tape



If they have not already, students will also need to measure the trees diameter at root collar (DRC). This will be used to estimate the amount of carbon stored in the tree. If you have not done Part II, you will enter the DRC into the equation in Part II to get a carbon estimate for each tree. Once you have an estimate for the amount of carbon being stored by the tree, you will divide this by the age of the tree to get a rate of carbon sequestration.

$$\frac{\text{Amount of carbon in tree (kg)}}{\text{Tree age (yrs)}} = \text{rate of carbon sequestration (kg/yr)}$$

Discussion

Reinforce the idea that trees take carbon from the atmosphere and turn it into biomass, or growth. One-half, or 50%, of a tree is made up of carbon that used to be floating around in the atmosphere (the rest of it is nitrogen, phosphorous and other elements). So every year that a tree lives and grows, it takes more carbon out of the atmosphere. This is why some people are planting trees to "offset" their carbon emissions. For example, if a car emits 5205 kg of CO_2 per mile driven, a person could offset some of that carbon by planting a tree.

Ask students what they think about offsetting carbon emissions by planting trees or managing forests. Let them explore the pros and cons of this. In the next part, students will have an opportunity to develop a management strategy to maximize carbon sequestration and compare that to strategies for meeting other management goals.

Part IV: Marking Trees

Land managers need to make decisions about cutting trees. Which trees are cut and which are left is determined by the overarching management goals. In the case of a commercial plantation, a goal is to grow the healthiest trees that can be milled into the best wood without unduly compromising the health of the forest stand. For public land managers, goal setting can be more difficult. They often have to attempt to meet several goals, such as wood production, fire resistance and resilience and aesthetics, concurrently.

In this activity, students will be assigned different management goals and asked to mark the trees that they would cut to fulfill their goals. Some suggested management goals include:

- Highgrading: this was a common practice on public lands in the past. When a forest is high-graded, the best, healthiest and largest trees are cut to be processed and sold while the smaller and poorer trees are left on the site.
- Fire resistance/resilience: a common practice used to meet this goal involves the cutting of only the smallest diameter trees. By cutting many, but not all of, the smallest trees, one can reduce the amount of fuel in the forest and give the remaining trees access to more space and resources so that they might grow healthier.
- Carbon management: this has yet to be a common management goal but dialogues regarding this practice are emerging. Meeting this goal can be complicated as the goal is to have the highest number of trees growing at an optimal rate without putting the forest at high risk of fire, which would then release the vast majority of carbon stored in the trees back into the atmosphere. A project seeking to maximize carbon might selectively cut a percentage of smaller trees while thinning out some of the larger trees as well, leaving the healthiest and most efficient growing trees on site.

Procedure

Introduce the idea of management goals for a forest. Ask the students if they know of any examples of forest management and allow them an opportunity to share what they know. Then, provide them an example of a management goal, selecting from one of the above examples or choosing one of your own. Then split the class into smaller groups, assigning each group an area of forest or woodland to manage. Then, randomly assign each group a management scenario (i.e., high-grading, fire resistance/resilience, carbon). Give the students colored flagging, using a different color of flagging for each group. Tell the groups to tie a length of flagging around the trunk of each tree they would cut in order to meet management goals.

Activity 14. Counting Carbon:
How Trees Affect the CO_2 in Earth's atmosphere

Discussion

Walk each forest area with each group and have them explain why they chose to cut the trees they did. Also have them identify why they chose to leave the trees they did. Determine if they thought about what the forest might look like in twenty years. If they were managing for fire resistance/resilience, did they cut enough trees to provide space for the young trees they may have left? Did they leave any young trees? Were any larger, healthy trees left to provide seed for the next generation of trees?

After you have had an opportunity to discuss the various strategies, ask the students how they would manage a forest if they had to:

- provide enough trees for cutting to support a local timber industry, and
- maintain uncut forest for recreation and tourism such as cross-country skiing, camping and hiking.

Be sure to remove the flagging after you have completed the lesson.

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Objectives

Part IV: Students will learn about different management goals and mark trees to be cut to meet those goals.

Duration

Approximately 50 minutes per Part.

Vocabulary (see Part I)

- Allometry
- Biomass
- Carbon sink
- Carbon sequestration
- Remote sensing

Materials

- Flagging tape

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Since 2003, Crane Collaborations has provided education and training in forest restoration, monitoring, education and outreach to New Mexico communities. Projects include:

- *Training for ecological, socioeconomic, and multiparty monitoring*
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- *Grant writing for the Collaborative Forest Restoration Program*

"You can't lift a tree alone . . ." Francisco Muñoz

Stories About Our Work

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