FireWorks Curriculum For High School

Featuring Lower and Upper Sierra Nevada Mixed Conifer Forests

2017

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Produced by:

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The *FireWorks* program was originally completed and the curriculum published in 2000 (Smith and McMurray 2000). This version incorporates new science, new teaching techniques, and new standards, and is adapted for Sierra Nevada ecosystems.

***FireWorks*: Why?**

Change is an integral part of a healthy, enduring ecosystems in most temperate regions of the world. *FireWorks* provides students with interactive, hands-on materials to study the forces that cause change, particularly wildland fire. The program is based on the science of wildland fire, a highly interdisciplinary field, so it provides a context for learning about properties of matter, chemical and physical processes, ecosystem fluctuations and cycles, habitat and survival, and human interactions with ecosystems. These concepts are considered important for science literacy (American Association for the Advancement of Science 1993). Students using *FireWorks* ask questions, gather information, analyze and interpret it, and communicate their discoveries. They often work in pairs or small groups. These are learning styles that enhance understanding, cognitive skills, and social skills (Moreno 1999; National Research Council 1996).

Goals

FireWorks aims to increase understanding

- of the physical science of combustion, especially in wildland fuels
- that an ecosystem has many kinds of plants and animals, which change over time and influence one another
- that fire is an important natural process in many ecosystems
- that native plants and animals have ways to survive fire or reproduce after fire, or both
- that people influence the fire-dependent ecosystems where they live, and they always have done so

Meeting these goals helps implement the vision of the National Cohesive Wildland Fire Management Strategy (U.S. Department of Agriculture, Forest Service; Department of the Interior, Office of Wildland Fire Coordination. 2011) "*To safely and effectively extinguish fire when needed; use fire where allowable; manage our natural resources; and as a nation, to live with wildland fire*."

FireWorks also aims to increase student skills in

- making observations
- classifying information
- measuring, counting, and computing
- stating and testing hypotheses

- describing observations, both qualitatively and quantitatively
- explaining reasoning
- identifying and expressing responses to science-related questions
- working in teams to solve problems and
- critical listening and reading

These skills are crucial for developing an adult citizenry literate in science and attracting students to professional work in the sciences (National Research Council 1996).

Local learning:

Students learn best about ecology when it is close to home—when they can study the plants, animals, and fire regimes typical of local ecosystems (Lindholdt 1999; North American Association for Environmental Education 1999).

This version of *FireWorks* focuses on selected *ecological communities* in the Sierra Nevada–forests dominated by conifers. These communities are often called lower and upper *mixed conifer* or lower and upper *montane* communities. These lower and upper montane mixed-conifer forests have a long, intimate relationship with fire. The photo presentation created for Activity 1 in the Elementary and Middle School curricula shows many inhabitants of these communities and the different types of fire that occur in them.

Lower montane forests grow just uphill from the grassy and shrubby *foothill* communities in the Sierra Nevada. Thus they occur at relatively low elevations, not high in the mountains. Lower montane forests are dominated by oaks, ponderosa pine, sugar pine, white fir, Douglas-fir, and incense-cedar. Many of these forests, especially in historical times, were dominated by pines. They had an open structure, with old, large trees spaced far apart and a few young trees. They had many kinds of grasses, wildflowers, and shrubs in the understory. A few of these old-growth, pine-dominated forests remain today. In the past, fires in this kind of forest tended to spread through the surface fuels. They rarely jumped into the tree crowns. Even when they did, they could not spread from crown to crown because most of the trees were spaced far apart. Because these forests are relatively dry, they typically burned frequently. Repeated fires keep the forest structure open. They favor grasses, wildflowers, and shrubs that can sprout easily after fire, and they provide habitat for mammals and birds that need large, old trees and an open understory.

Upper montane forests occur at fairly high elevations, but not all the way up on mountainsides. These forests are usually dominated by Jeffrey pine, red fir, and lodgepole pine. There is a lot of overlap between lower and upper montane forests, so species from these communities often intermix. Because upper montane forests grow higher in the mountains, they are colder, receive more snow, and have a shorter growing season. Thus historical fires generally burned less frequently than in lower montane communities, although there is considerable variability. In the past, fires in upper montane forests tended to spread through the surface fuels but sometimes also jumped into the tree crowns. Fires killed trees in small patches, but most large trees survived.

Mixed-conifer forests in the Sierra Nevada have experienced very few low-severity fires in the past century. Because of this, the forests tend to be very dense and have a lot of litter, logs, and *ladder fuels* (shrubs and young trees that increase in the absence of fire and enable fires burning on the forest floor to climb into the tree tops). The forest canopy is fairly continuous (*closed*), and trees that grow well in shade are more common than they were historically. This is true throughout the mixed-conifer forests, but especially so in lower montane communities. When fires burn through dense forests during hot, dry, windy conditions, they tend to burn in the tree crowns more often than they did when the forest structure was open. Crown fires kill more large trees than the frequent surface fires of the past. Nowadays, it is common to see large patches of *stand-replacing fires* in forests that used to experience stand-replacing fire in small, isolated patches.

High in the mountains of the Sierra Nevada are the subalpine forests, dominated by lodgepole pine, western white pine, mountain hemlock, and whitebark pine. This curriculum does not cover the high-elevation forests, but they are very important to the ecology of the Sierra Nevada and to the quality of life of its plants and wildlife, and to the human communities living in the watersheds below.

Table I-1—Summary of ecology and "fire story" of some forest communities of the Sierra Nevada

		Lower montane mixed conifer	Upper montane mixed conifer
Shade-intolerant tree species (grow well in sunny, open areas with bare soil)		Ponderosa pine Sugar pine California black oak	Jeffrey pine Sierra lodgepole pine
Shade-tolerant tree species (grow better than pine in shady places)		Douglas-fir White fir Incense-cedar	Red fir
Historical fire frequency	Crown fire	Infrequent, except in small patches	Infrequent, except in small to medium-sized patches
	Low-severity surface fire	4-14 per century	2-4 per century
Some animals		Mule deer Western gray squirrel Dusky-footed woodrat California spotted owl American black bear	Mule deer California spotted owl Yellow-legged frogs American black bear
Disturbances besides fire		Bark beetles White pine blister rust Drought	Bark beetles Drought

Design and Layout of Lessons in This Curriculum

Each activity has the following sections:

Lesson Overview
Lesson Goal
Objectives
Teacher Background
Materials and Preparation
Procedure
Assessment
Evaluation

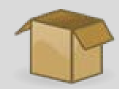
Subjects: Science, Writing, etc…

Duration:

Group size:

Setting:

FireWorks vocabulary (first introduced in to this activity):



Instructions for each activity also include a text box (example above) that lists subjects covered, the possible duration of the activity (a guess –take this with many grains of salt), group size, setting (laboratory, classroom, outdoors, etc.), and *FireWorks* vocabulary (list of terms in the *FireWorks Glossary* that are first introduced in this activity). The text box may also contain one or two icons – a red-and-white flame if the activity uses fire, and a brown box if the activity requires materials from a *FireWorks* trunk.

Handouts and other materials meant for students all begin with a large, bold-face header in **blue font**. Handout answer keys and other materials meant for teachers all begin with a large, bold-face header in **maroon font**. In the Procedures section and in handout answer keys for teachers, answers to questions are given in red font.

Links to Educational Standards

FireWorks need not compete with core curriculum for classroom time. Instead, it can help teachers cover core concepts and improve student skills by using hands-on materials based on science from their own local area. To help teachers identify the ways in which *FireWorks* can be used to meet their curriculum requirements, each activity is linked to educational standards.

FireWorks is correlated to the Common Core State Standards in English Language Arts (CCSS-ELA), Math (CCSS-Math), History and Social Studies, Science, and Technical Subjects; the Next Generation Science Standards (NGSS); the Excellence in Environmental Education: Guidelines for Learning standards (EEEGL); and the C3 Framework: College, Career and Civic Life for Social Studies State Standards (C3 SSSS)[1].

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[1] Abbreviations and links to standards:

- CCSS-ELA: Common Core State Standards—English Language Arts (http://www.corestandards.org/assets/CCSSI_ELA%20Standards.pdf)
- CCSS-Math: Common Core State Standards—Math (http://www.corestandards.org/wp-content/uploads/Math_Standards.pdf)
- NGSS: Next Generation Science Standards (http://www.nextgenscience.org/sites/ngss/files/NGSS%20DCI%20Combined%2011.6.13.pdf)
- EEEGL: Excellence in Environmental Education: Guidelines for Learning (http://resources.spaces3.com/89c197bf-e630-42b0-ad9a-91f0bc55c72d.pdf)
- C3 SSSS: College, Career and Civic life for Social Studies State Standards (http://www.socialstudies.org/system/files/c3/C3-Framework-for-Social-Studies.pdf)

Each lesson has been correlated to the relevant standards. If a lesson does not have standards listed from a particular standard framework, then it probably does not meet standards in that framework. However, teachers are encouraged to reinterpret standards and lessons and also to adapt lessons to meet their educational objectives and particular standards.

First, find the relevant grade(s).

Standards	Section	Sixth	Seventh	Eighth
Common Core ELA	Writing	4,10	4,10	4,10
	Speaking/Listening	1,2,4,6	1,2,4,6	1,2,4,6
	Language Standards	1,2,3,6	1,2,3,6	1,2,3,6
	Reading Standards Science/Tech	4,7,9	4,7,9	4,7,9
	Writing Standards Science/Tech	4,7,10	4,7,10	4,7,10
NGSS	Structures/Properties of Matter	PS3.A		
	Energy	PS3.A		
	Waves/Electromagnetic Radiation	PS4.B		
EEEGL	Strand 1	A,C,E,F,G		

Second, find the relevant standards and access a copy of the respective publication.

Third, open standards publication to the appropriate grade and section.

Fourth, locate these numbers and read the associated standard.

Safety

Many of the experiments in this curriculum use fire and natural fuels in the classroom or laboratory. In these structured, well supervised environments, students can make discoveries about fire and improve their habits regarding fire safety. Help students learn about safe laboratory practices, such as using protective eyewear and wearing appropriate clothing. Help them learn that professional skills and years of experience are needed to use fire safely in wildlands. The following steps will help your students grow in responsibility and competence regarding lab safety and fire:

- Inform your maintenance staff about activities in which you will use fire.
- Inform your local fire protection unit if you plan to use fire outdoors.
- Consider informing parents about your plans and goals for teaching about fire.
- Choose your work space carefully, especially if you will not be using a laboratory. The fire engine must respond to every alarm, even if you tell them it's "only" an experiment.
- If you are working outdoors, watch carefully to prevent smoldering material from igniting schoolyard vegetation.
- Keep spray bottles filled with water. Have students use them to extinguish smoldering material at the end of each experiment. This will prevent trash-can fires.
- If you are working outdoors, keep a hose available and ready to use. Have a bucket or two of water available as well.

- Keep a fire extinguisher ready for use. Know how to use it. If you discharge a fire extinguisher, refill or replace it immediately. Don't burn anything without a charged fire extinguisher in the room.
- If you or any of your students have asthma or other respiratory problems, consider having them wear protective masks while working with fire.

Literature cited

American Association for the Advancement of Science. 1993. Benchmarks for science literacy. New York: Oxford University Press. 418 p.

Lindholdt, Paul. 1999. Viewpoint: writing from a sense of place. Journal of environmental education: 30(4): 4-10.

Moreno, Nancy P. 1999. K-12 science education reform—a primer for scientists. BioScience. 49(7): 569-576.

National Research Council. 1996. National science education standards. Washington, DC: National Academy Press. 262 p.

North American Association for Environmental Education. 1999. Excellence in EE—guidelines for learning (K-12). Rock Spring, GA: NAAEE Publications and Membership Office. 107 p.

Smith, Jane Kapler; McMurray, Nancy E. 2000. FireWorks curriculum featuring ponderosa, lodgepole, and whitebark pine forests. Gen. Tech. Rep. RMRS-GTR-65. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 270 p.

U.S. Department of Agriculture, Forest Service; Department of the Interior, Office of Wildland Fire Coordination. 2011. A national cohesive wildland fire management strategy. Washington, DC: Wildland Fire Leadership Council. 43 p.

This table summarizes the content for each activity at each grade level. Read across the table to find similar activities for students at other grade levels.

Unit & Theme	ELEMENTARY	MIDDLE	HIGH
Unit I. Introduction to Wildland Fire	E01. Visiting Wildland Fire in the Sierra Nevada	M01. Visiting Wildland Fire in the Sierra Nevada	H01. Introduction to Wildland Fire in the Sierra Nevada
Unit II. Physical Science of Wildland Fire	E02. Making Fires Burn or Go Out 1: Introduction to the Fire Triangle	M02. Where Does Heat Go? The Heat Plume from a Fire	H02. The Fire Triangle: Fuel, Heat, and Oxygen
	E03. Making Fires Burn or Go Out 2: Demonstrating the Fire Triangle and Heat Plume	M03. What Makes Fires Burn? The Fire Triangle 1—Heat and Fuel	H03. The Fire Triangle, Combustion, and the Carbon Cycle
		M04. What Makes Fires Burn? The Fire Triangle 2—Oxygen	H04. Heat Transfer
Unit III. The Wildland Fire Environment			H05. Fuel Properties
			H06. Pyrolysis
			H07. Fire Spread Processes: Putting it all together: Heat transfer, fuel properties, and pyrolysis
	E04. How Wildland Fires Spread 1: Experiment with a Matchstick Forest	M05. How Do Wildland Fires Spread? The Matchstick Forest Model	H08A. Fire Environment Triangle and Fire Spread: The Matchstick Model
			H08B. Fire Environment Triangle and Fire Spread: The Landscape Matchstick Model
		M06. Ladder Fuels and Fire Spread: The Tinker Tree Derby	H09. Ladder Fuels and Fire Spread
	E05. Fuel Properties: The Campfire Challenge	M07. Fuel Properties: The Campfire Challenge	See H05.
	E06. Effect of Wind: How Wildland Fires Spread	M08. Fire Behavior, Fire Weather, and Climate	H10. Fire Behavior, Fire Weather, and Climate

Unit IV. Fire Effects on the Environment	E07. Smoke from Wildland Fire: Just Hanging Around?	M09. Smoke from Wildland Fire: Just Hanging Around?	H11. Smoke from Wildland Fire: Just Hanging Around?
		M10. Fire, Soil, and Water Interactions	H12. Fire, Soil, and Water Interactions
Unit V. Fire's Relationship with Organisms and Communities	E08. Who Lives Here? Adopting a Plant, Animal, or Fungus	M11. Who Lives Here? Adopting a Plant, Animal, or Fungus	H14. Researching a Plant, Animal, or Fungus
	E09. Tree Parts and Fire: The Class Models a Living Tree	M12. Tree Parts and Fire: "Working Trees" Jeopardy-style Game	
	E10. Tree Identification: Using a Key to Identify "Mystery Trees"	M13. Tree Identification: Figure out the "Mystery Trees"	H13. Tree Identification: Create a Dichotomous Key
	E11. Recipe for a Baker Cypress Grove: Serotinous Cones		
		M14. Who Lives Here and Why? Modeling Forest Communities	H15. Forest Communities and Climate Change
		M15. Bark and Soil: Nature's Insulators	
	E12. Buried Treasure: Underground Parts that Help Plants Survive Fire	M16. Buried Treasures: Identifying Plants by their Underground Parts	
Unit VI. Fire History and Succession	E13-1. My Tree Autobiography: Seeing History through Trees' Growth Rings		
	E13-2. Story of a Fire-Scarred Tree	M17. Fire History 1: Long Stories Told By Old Trees	H16. Fire History 1: Long Stories Told by Old Trees
		M18. Fire History 2: History of Stand Replacing Fire	H17. Fire History 2: History of Stand Replacing Fire
	E14. Story Time: Fire and Succession	M19. Drama in the Forest: Fire and Succession, a Class Production	H18. Fire History 3: Fire Regime across a Sierra Nevada Landscape
Unit VII. People in Fire's Homeland	E15. Homes in the Forest: An Introduction to Firewise Practices	M20. Homes in the Forest: An Introduction to Firewise Practices	
	E16. Revisiting Wildland Fire	M21. Revisiting Wildland Fire	H19. Sierra Nevada Forests Today

Unit I.
Introduction to Wildland Fire

1. Introduction to Wildland Fire in the Sierra Nevada

Lesson Overview: Students consider their thoughts and feelings about wildland fire before and after a presentation about wildland fire. Then, using a reading activity, students read and analyze an article about the Storrie Fire of 2000 on the Plumas and Lassen National Forests.

Lesson Goal: Increase students' understanding that wildland fire is a complicated process, has complicated effects, and may generate complicated feelings.

Subjects: Science, Writing, Speaking and Listening

Duration: 45 minutes

Class Arrangement: Whole class and groups

Setting: Indoors

FireWorks vocabulary: *ecosystem, ecological community, fire behavior, wildland, wildland fire*

Objectives:

- Students can use images to make observations and inferences about wildland fire.
- Students can explain details about the Storrie Fire.

Standards:		9th	10th	11th	12th
Common Core ELA	Reading Literature	1,4,10		1,4,10	
	Speaking and Listening	1,2,3,4		1,2,3,4	
	Language Standards	1,2		1,2	
	History/Social Studies	1,2,3,4,10		1,2,3,4,10	
	Science/Technical Subjects	2,4,8,10		2,4,10	
NGSS	Interdependent Relationships in Ecosystems	LS2.A, LS2.C, LS4.D			
	Earth's Systems	ESS2.A			
	Human Sustainability	ESS3.B			
	Natural Selection and Evolution	LS4.C			
EEEGL	Strand 2.1	A			
	Strand 2.2	C			
	Strand 2.3	B,E			
	Strand 2.4	A			

Materials and preparation:

- Make copies of H01-1 and H01-2 for each student.
- Download the presentation *H01_WildlandFireObservations.pptx.*

Procedure:

1. **Hook**: Ask students to take out a sheet of paper and make a list of the pros (good things) and cons (bad things) about wildland fire.

2. Have students share what they wrote. Ask which column has more written in it.

3. Ask students to turn their paper over and divide it in half. Label the 2 sides "Observations" and "Questions." Show the presentation *H01_WildlandFireObservations.pptx*. The photos are arranged in 5 groups. (See the photos and notes below.) Stop after each group of photos and ask students to add items to (a) their lists of observations and questions and (b) their list of pros and cons. If students want to back up and revisit some photos, that is OK.

4. After the presentation is over, ask your students to share their observations and questions. Then ask for any items that they added to their lists of pros and cons.

5. For the reading assignment (H01-1), students will need to understand the terms *ecosystem* and *ecological community*, so review: An ecological community includes all of the living things in an ecosystem – plants, animals, fungi, and microorganisms. An *ecosystem* includes the living things plus the nonliving parts of the ecosystem, such as soil, water, and air.

6. Give each student a copy of H01-1 "*What We Don't Know About Wildfire Can Hurt Us*" by Jane Braxton Little. Give students time to read the whole page.

7. Break the class into four groups and assign one of the four paragraphs in the article to each group. Explain that students in each group will become experts on the questions about their paragraph and will answer ONLY the questions about their section on the handout. They should ignore the final question ("Use your expertise") for now.

8. Regroup the class and select one person from each group to share their questions and answers with the entire class. After all groups have shared their questions and answers, discuss and answer the final question together ("Use your expertise").

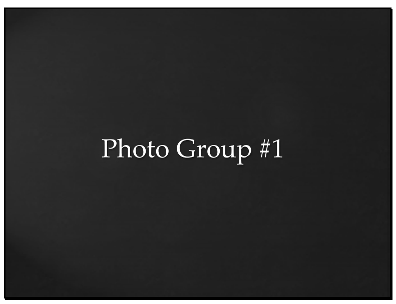
9. Ask students to describe connections among their pro-con lists, the presentation, the article, and their answers to the final question on the handout.

Assessment: Because this is an introductory lesson meant to evoke diverse thoughts and feelings about wildland fire, this activity does not have an assessment.

Slides and Narrative for *H01_WildlandFireObservations.pptx*

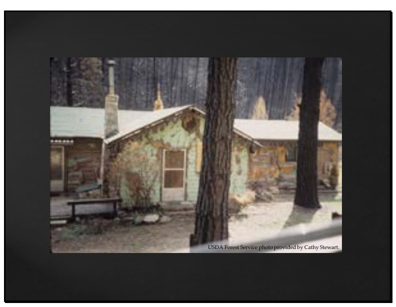
Slide 1

Slide 2

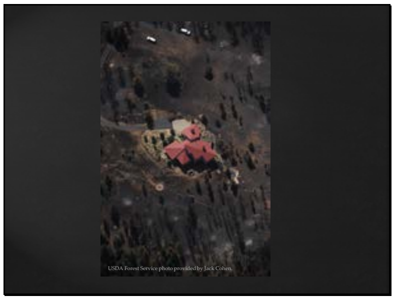


Theme: houses burning/burned

Slide 3



Slide 4



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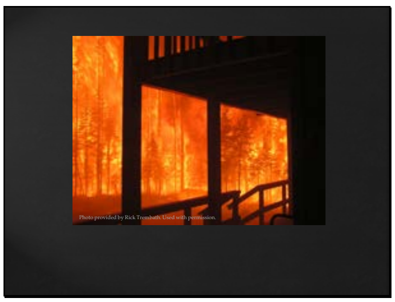
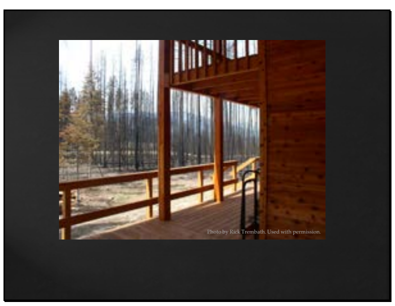


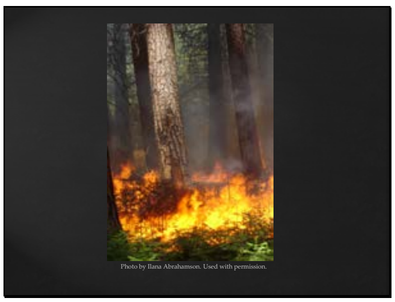
Slide 6



Slide 7

Theme: low-severity fire

Slide 8



Slide 9

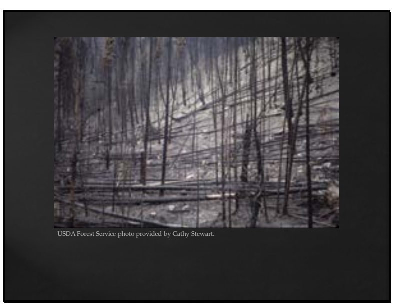
Slide 10

Photo Group #3

Theme: stand-replacing fire

Slide 11

Slide 12



Slide 13

Slide 14

Slide 15

Theme: more postfire photos

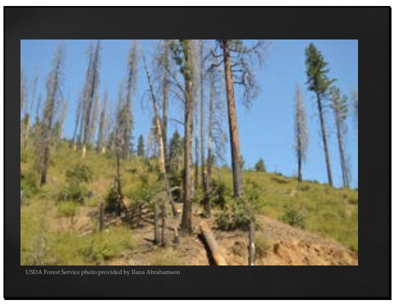
Slide 16

Slide 17

Slide 18

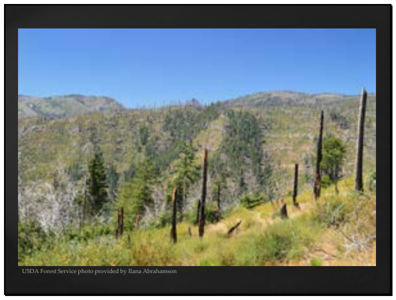
Slide 19

Slide 20



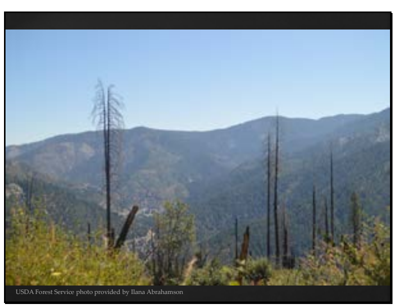
Slide 21

Slide 22



Slide 23

Slide 24



Handout H01-1: **Excerpts from “What We Don’t Know About Wildfire Can Hurt Us”**

Jane Braxton Little, High Country News (www.hnc.org)
Entire article available: https://www.hcn.org/wotr/13510

In my backyard in northeastern California, the Storrie Fire started Aug. 17, 2000, and burned 56,000 acres near the Feather River. Tearing up the steep canyon slopes, it romped through stands that had been heavily logged and through pristine areas where no roads had ever been built. Local loggers and environmentalists alike bemoaned the devastation, some mourning the loss of sawlogs, others the beauty of old-growth cathedrals. My on-the-ground exploration revealed far less catastrophe. Some forest stands within the Storrie fire were truly scorched - the heat so intense it cooked the soil, thwarting most new growth for years. Entire hillsides were reduced to black specters towering over charred ground.

But other places were not only spared devastation; the fire improved them. Above Yellow Creek tiny oaks were pushing through the soil beside still- smoking stumps. The following spring, a profusion of lilies, paintbrush and penstemon graced glades along Soda Creek, liberated by the fire from the young white firs that had been rapidly taking over. The fire killed several half-acre clusters of cedar, pine and red fir, creating sun-filled openings for nature to start afresh. Here the ground among the blackened snags was already green with tiny seedlings.

Most veteran trees survived, their needled canopies intact, still shading an open forest floor. Flames licked at their bases, sometimes marking the ancient trunks with black streaks running up as high as 15 feet. The fire scoured out the ground litter, cleansing mountainsides and creek canyons of decades of debris. Evening grosbeaks flashed golden among pine branches and fresh scratches in aspen bark marked the recent presence of a bear. This was no "nuclear winter." A U.S. Forest Service review of the Storrie Fire estimated that 14 percent of the area burned intensely. Two-thirds of it - an area twice the size of Manhattan - enjoyed the creeping surface* fires that forest managers struggle to set in imitation of natural fire regimes.

Federal officials blame the dearth of data on the agency's traditional preoccupation with fire suppression and timber harvest, a decades-old double-whammy generating management policies that ignore the role of natural fire in the evolution of ecosystems. As public values for national forestlands shift from sawlogs to recreation, managing wildland fire* becomes essential. We can't manage what we don't know. Understanding the effects of wildland fire is part of understanding and restoring Western ecosystems. Even armed with sound data about what happens inside the firelines, federal officials may never quell the public controversy over fire. Without it, they have no chance.

*These terms have been changed from the original article to be consistent with standard definitions used in wildland fire management and research. “Surface fires” was originally “ground fires”. “Wildland fire” was originally “wildfire”.

Handout H01-2.

Name: ____________________

Instructions: Please use "*What We Don't Know About Wildfire Can Hurt Us*" by Jane Braxton Little to answer the following questions in complete sentences.

Paragraph #1:
1. When did the Storrie Fire start and how many acres did it burn?
2. Describe the location and terrain of the Storrie Fire.
3. Explain how some people felt about the Storrie Fire.
4. Even though the author's "on-the-ground exploration" suggested "far less catastrophe" than mourned by locals, what negative ecological impacts did she reveal?
Paragraph #2:
1. Describe the Storrie Fire area immediately after the fire.
2. Describe the Storrie Fire area the following spring.
3. Explain how the fire created open spaces.
4. Why are open spaces ecologically important?
Paragraph #3:
1. Describe the veteran trees after the Storrie Fire.
2. How did the Storrie Fire impact ground litter?
3. What does the author mean when she says it was no "nuclear winter"?
4. What percentage burned intensely and what portion burned with "creeping" fire?
Paragraph #4:
1. What does the author mean by a "dearth of data"?
2. What does the author say that forest management policies are ignoring?
3. Why does the author think it is now essential to manage wildland fire?
4. What does the author hope will change if people have greater understanding of the effects of wildland fire?
Use your expertise: The author says, "federal officials may never quell the public controversy over fire". Describe one issue about fire that you think is controversial.

Handout H01-2 answer key

Paragraph #1:
1. When did the Storrie Fire start and how many acres did it burn? The fire started August 17, 2000, and 56,000 acres were burned. **2. Describe the location and terrain of the Storrie Fire.** Near the Feather River Canyon. Steep canyon slopes containing heavily logged stands and pristine roadless areas. **3. Explain how some people felt about the Storrie Fire.** People were "devastated". Different people were sad about different things. **4. Even though the author's "on-the-ground exploration" suggested "far less catastrophe" than mourned by locals, what negative ecological impacts did she reveal?** The heat from the fire scorched so intensely that soil was "cooked" and entire hillsides were charred.
Paragraph #2:
1. Describe the Storrie Fire area immediately after the fire. After the fire, tiny oaks pushed up through the soil. **2. Describe the Storrie Fire area the following spring.** The following spring, wildflowers were abundant. These included lilies, paintbrush, and penstemon. **3. Explain how the fire created open spaces.** The fire killed clusters of cedar, pine, and red fir, which created sun-filled spaces. **4. Why are open spaces ecologically important?** Open spaces create opportunities for nature to begin again, covering the ground with seedlings.
Paragraph #3:
1. Describe the veteran trees after the Storrie Fire. Most veteran trees survived but had black streaks on their trunks as high as fifteen feet. **2. How did the Storrie Fire impact ground litter?** The fire burned away litter on the ground in mountains and canyons. **3. What does the author mean when she says it was no "nuclear winter"?** It was not a "nuclear winter" because there was abundant life in the burned areas after the fire. **4. What percentage burned intensely and what portion burned with "creeping" fire?** Fourteen percent of the fire burned intensely and two-thirds burned with "creeping" fire.
Paragraph #4:
1. What does the author mean by a "dearth of data"? This is not completely clear. She may be saying that people do not have complete information on the effects of wildland fire, especially the beneficial effects. **2. What does the author say that forest management policies are ignoring?** The role of natural fire in the evolution of ecosystems. **3. Why does the author think it is now essential to manage wildland fire?** Managing wildfire becomes essential as the public's interest shifts from timber harvesting to recreation. **4. What does the author hope will change if people have greater understanding of the effects of wildland fire?** She hopes that understanding the effects of wildland fire will help people restore Western ecosystems.
Use your expertise: The author says, "federal officials may never quell the public controversy over fire". Describe one issue about fire that you think is controversial. Many issues could be mentioned: economic, environmental, social, and political.

Unit II.
Physical and Chemical Science of Wildland Fire

2. The Fire Triangle: Fuel, Heat, and Oxygen

Lesson Overview: In this activity, students explore the shape of the heat plume and the three components of the Fire Triangle. The lesson includes a total of 3 experiments and 1 technical reading activity.

Lesson Goals: Increase students' understanding of heat transfer and the components of the Fire Triangle. Increase their ability to develop and test hypotheses. Increase their ability to apply their understanding of a concept to real-world question.

Subjects: Science, Mathematics, Writing, Speaking and Listening, Health and Safety

Duration: Three ~20 minute experiments.

Class Arrangement: Whole class and groups.

Setting: Indoors

New FireWorks vocabulary: *chemical change, combustion, Fire Triangle, fuel, heat, heat plume, model, oxygen, physical change*

Objectives:

- Students can describe the shape of the heat plume from a fire.
- Students can use the Fire Triangle to explain why specific fires go out.
- Students can develop hypotheses, test them, and discuss their results.
- Students can apply theoretical knowledge to practical technology.

Standards:		9th	10th	11th	12th
Common Core ELA	Writing Standards	1,4		1,4	
	Speaking and Listening	1,2,4		1,2,4	
	Language Standards	1,2		1,2	
	Science/Technical Subjects	9		9	
NGSS	Chemical Reactions	PS1.A, PS1.B			
	Matter/Energy in Organisms/Ecosystems	LS1.C, LS2.B, PS.D			
EEEGL	Strand 1	A,C,D,E,F,G			
	Strand 2.1	B, C			

Teacher Background: Students explore the conceptual model called the *Fire Triangle.* They use the Fire Triangle to describe how fires are extinguished and how wildland fires spread.

The Fire Triangle describes the three things necessary for fires to start and keep burning: fuel, oxygen, and a heat source. If a fire runs out of any of these things, it will stop. This is an appealing *model* because the geometric properties of the triangle are a good analog to the requirements for combustion: A triangle is very stable as long as all three legs are present, and it collapses if one leg is removed.

This activity contains three experiments. In each successive experiment, the students take on a little more responsibility for developing methods of investigation and interpreting results. **Experiment 1** is highly directed, a "cookbook" experiment: Students observe and describe how the heat is dispersed from a burning match. **Experiment 2** has a cookbook section followed by a section in which students develop their own methods: Students observe burning matches pointed in different directions and use the model of the Fire Triangle to explain why the matches go out. **Experiment 3** requires students to fully develop their own methods: They combine vinegar and baking soda to produce carbon dioxide, and they use the carbon dioxide to demonstrate that fires require oxygen.

This activity also contains a **Technical Reading** component, in which students read descriptions of various kinds of fire extinguishers and then determine what part(s) of the Fire Triangle are removed when each is used.

Detailed science information for this activity is provided in the "Procedure" section (in red ink), the handouts, and in the answer key for each handout.

Materials and preparation:

- Choose your laboratory arrangement. These experiments can produce flames as long as 20 cm.
- Locate a video online of an airplane/helicopter dropping fire water on fire. (Example: https://www.youtube.com/watch?v=lx7ISzYU2zE (accessed February 2016). Try searching with these terms: "helicopter dropping water on fire").

- The day before doing this activity, ask students to follow safety guidelines about clothing and hair when they get ready for school tomorrow:
    - Tie back loose hair.
    - Avoid wearing open-toed shoes, loose sleeves, and clothes made of meltable fabric such as nylon or polyester.
- Get a box of long fireplace matches and enough boxes of wooden kitchen matches so each lab bench can have a least 40.
- Display the *FireWorks Safety* poster the in classroom.
- Have a fully charged dry chemical fire extinguisher handy. Know how to use it.

FireWorks Safety

When you do experiments with fire…

1. **Wear cotton clothing. No synthetic pants, soccer shorts, etc.**
2. **Wear closed-toed shoes. No sandals or flipflops.**
3. **Tie back loose sleeves.**
4. **Tie back loose hair.**
5. **Make sure a fire extinguisher is close. Make sure it is charged. Know how to use it.**
6. **Make sure spray bottles are close and filled with water.**
7. **Wear safety goggles when burning.**
8. ***Never* lean over a fire.**
9. **Extinguish burned materials with water before putting them in the trash. *Fire is not out if there is any smoke or heat coming from the fuels.***
10. **If a fire starts on you, stop, drop, and roll.**

Use fire ONLY if a responsible adult is working with you.

- Make copies of **Handouts H01-1, 2, 3, and 4,** and optional *GraphForDescribingHeatPlume* for each student or team.
- Set up each laboratory bench with the following equipment:
    - Spray bottle, filled with water
    - Ruler
    - Metal tray (i.e., cookie sheet)
    - Ashtray
    - Safety goggles
    - Oven mitt
    - Support stand
    - Cross-piece for support stand and clamp, as shown on Handout H02-1
    - Thermocouple (optional for Experiment 2 – only 1 is provided in the trunk)
    - 2 votive candles
    - Box of wooden kitchen matches and 1-2 long fireplace matches
    - Beaker or other container ~20 cm tall
    - Container of baking soda (labeled as baking soda, sodium bicarbonate, or $NaHCO_3$), approximately ¼ c per student team
    - Container of white vinegar (labeled as vinegar, acetic acid, or CH_3COOH), approximately ½ c per student team
    - Scoop or spoon for measuring 15 to 60 mL (1 Tablespoon to ¼ cup)

Procedure:

1. **Hook**: Show a video of an airplane or helicopter dropping water on a wildfire. Ask students to explain how putting water on a wildfire may put the fire out. This is a time for speculation. You can go into more detail with step 3 below.

2. Tell the students that they are going to investigate what makes fires burn and what puts them out. To begin, draw a triangle on the board and ask: What three components are necessary for fire to burn? Label the three sides of the Fire Triangle: fuel, heat, and oxygen.

3. Explain: If one component of the Fire Triangle is removed, the fire goes out. Ask students to use the Fire Triangle to explain how the method used in the video puts out a fire. Water removes heat from the fire because (1) it is cooler than the burning fuel so it absorbs heat until it reaches the boiling point; (2) as it boils (vaporizes), it absorbs even more heat (the latent heat of vaporization); (3) any water that remains in the liquid phase forms a barrier between fuel and the oxygen needed for *combustion*. Vaporization is a *physical change* because the water changes from liquid to gaseous phase but atoms are not recombined to form new substances.

4. Split students into teams, one for each lab bench. Have each team review the *FireWorks Safety* poster and report back to you when they are prepared to proceed safely.

5. Have students begin "**Experiment 1. Explain where the heat goes":** Give a copy of **Handout H02-1** to each student or team. Have them read the directions, paying particular attention to the safety precautions, and report back to you when they are prepared to proceed safely. Emphasize to each Observer that he/she needs to find out how far from a match they can first feel heat, **not** how close he/she can get before experiencing pain! Then instruct them to proceed with the experiment.
   - Alternative 1: Use thermocouple thermometers to measure how far out from a match they can detect a temperature of approximately 40 ^{o}C (100 ^{o}F). The *FireWorks* trunk provides only one thermocouple thermometer, so you will need to supply the others. If students are using thermocouples, they will also want to measure temperatures inside the flame. That is fine; the thermocouple can withstand these temperatures. **Do not use alcohol or mercury thermometers for this experiment**.
   - Alternative 2: Do this experiment as a demonstration, using the thermocouple available in the *FireWorks* trunk instead of having lab teams do it independently.

6. After all teams have completed Experiment 1 and written answers to Questions 5a and 5b, discuss their answers as a class. (Refer to the answer key for **Handout H02-1** below.)

7. Give a copy of **Handout H02-2** to each student or team. Have them read the directions and report back to you when they are prepared to proceed safely. When all groups have completed the experiment and written answers to Questions 8, 10, and 11, discuss their answers as a class. (Refer to the answer key for **Handout H02-2** below.)

8. In class discussion, explore the "Oxygen" part of the Fire Triangle in a little more depth: Oxygen comprises about 21 % of the air we breathe, and we use only about 20 % of that oxygen (5% of the volume of air) in a single breath. If we used it all, we couldn't use cardiopulmonary resuscitation (CPR) to help a person who is not breathing!

9. Give a copy of **Handout H02-3** to each student or team. Have them read the directions and report back to you when they are prepared to proceed safely. When all groups have completed the experiment and written answers to Questions 6-8, have each group present and explain their demonstration to the class. (Refer to the answer key for **Handout H02-3** below.)

10. **Technical reading:** Give each student a copy of **H02-4: Three Kinds of Fire Extinguishers** (below). Have students form groups of three. Within each group, one student will read part A, one will read part B, and one will read part C. Instruct each student to read his/her assigned section. Then each student will describe that particular fire extinguisher to the rest of the group and use the Fire Triangle to explain how that kind of extinguisher works. Circulate among groups during presentations and listen in. (Refer to the Teacher Key at the end of the reading assignment.)

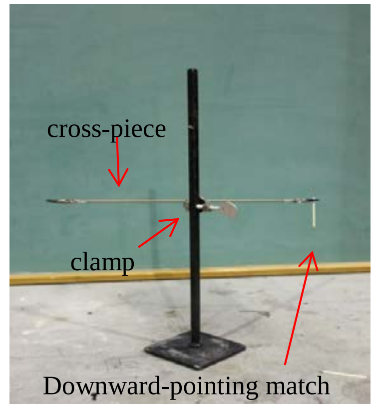
Assessment: Collect students' handouts and use the answer keys to check them.

Evaluation:

	Handouts (25 points each)		
Excellent	100%		
Good	88%		
Fair	75%		
Poor	62%		
	Technical Reading (25 points)		
	Full Credit	Partial Credit	No Credit
Explanations	Clearly explained strong connections between the Fire Triangle and how the fire extinguisher works.	Student made weak connections between fire extinguisher and Fire Triangle.	Made inaccurate or no connections between the fire extinguisher and Fire Triangle. Unclear if student understood how fire extinguisher worked.
Presentation	Comfortable with information. Presentation was well organized. Speech was clear. Took presentation seriously.	Student was mostly comfortable with information but unsure at times. Fairly organized. Clear speech.	Uncomfortable with information. Presentation was poorly organized. Difficult to hear. Student did not take presentation seriously.

Handout H02-1. Experiment 1. Explain where the heat goes.

Name ____________________________



Your objective is to describe the shape of the *heat plume* from a single, downward-pointing match. Set up your lab space:

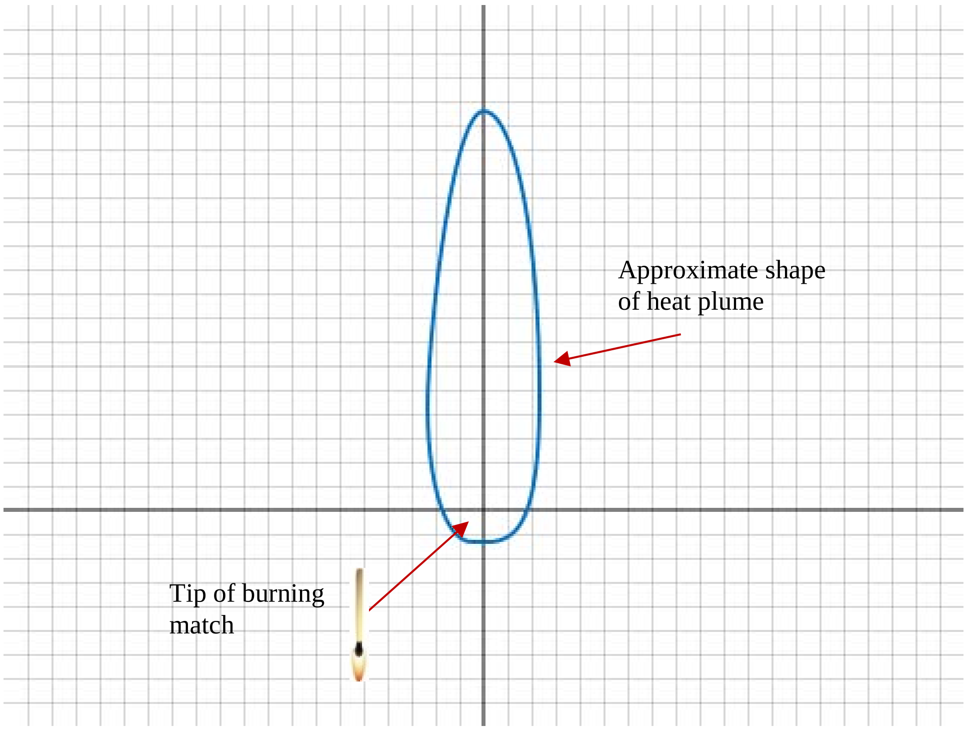
- Place the metal tray on a heat-resistant surface.
- Set the support stand in the center of the tray.
- Attach the clamp to the stand.
- Attach the cross-piece to the clamp so it forms a "+" with the stand.
- Attach one match to an alligator clip so the tip points down.

Before beginning, read all of these directions together.

1. Plan your team roles:
    - **Observer:** Use your hand to detect how far from the burning match you can detect a change in temperature. This is the edge of the *heat plume.* Always start your observation from at least 30 centimeters **out from the burning match** and bring it in toward the flame until you detect a temperature change. This is the outer edge of the heat plume. ***The point is to detect heat, not to determine how much heat you can tolerate!!*** Check a ruler so you know how big 2 centimeters is. **Never** bring your hand closer than that to a burning match. **Never** place your hand directly under a burning match, in case the tip should fall off; instead, place your hand slightly off to the side.
    - **Measurer:** When the observer has detected heat, measure the distance from the flame to the observer's hand. Use a ruler, but do not place it close to or in the flame. If the observer does not detect heat from the match at the 2-centimeter distance, record the 2-centimeter point as your measurement.
    - **Igniter/Recorder:** Record the Measurer's data.
2. Figure out how to record your data. Design a data sheet.
3. When everyone is ready, use a separate match to light the downward-pointing match in the alligator clip. Make observations from one side. Record your data. Use the oven mitt to remove the burned match and insert a new one. Repeat this step until you have at least 2 measurements from each side of the flame, from beneath the flame, and from above it.
4. On a sheet of graph paper, or on the *GraphForDescribingHeatPlume,* make a sketch of your experimental set-up and graph your data. Then smoothly connect the points to show the approximate shape of the heat plume.
5. Underneath your sketch, answer these questions using complete sentences:
    a) When you burn a match in still air, where does most of the heat go? Use the results of your experiment in your explanation.
    b) How would you expect this pattern to change if there is a slight breeze in the air?

Handout H02-1. Answer Key to Experiment 1. Explain where the heat goes.

4.



5. Underneath your sketch, answer these questions using complete sentences:
   a) **When you burn a match in still air, where does most of the heat go? Use the results of your experiment in your explanation.** Most of the heat goes upwards. Some of it goes down and sideways. Results may look something like this. This graph of the heat plume shows that heat could be felt from 20 cm above, 8 cm from the sides, and only 3 cm from below.

   b) **How would you expect this pattern to change if there is a slight breeze in the air?** The flame and the heat plume are likely to lean in the direction of any air movement. Wind is not likely to make the heat plume lean over very far though, because it will probably extinguish the match first (by blowing the heat away from the fuel).

Handout H02-2. Experiment 2. Explain why matches go out.

Name ________________________________

Your objective is to figure out what part(s) of the Fire Triangle are removed when downward-pointing and upward-pointing matches go out. Use the support stand set up from Experiment 1.

Before beginning, read all of these directions together.

1. Decide what you will observe and how you will measure it. Develop a table for recording your data.
2. Plan your team roles. Write them down below your data table.
3. Show your data table and team roles to the teacher. When you have his/her approval, proceed:
4. Attach a downward-pointing match to one alligator clip and an upward-pointing match to the other.
5. When everyone is ready for his/her role, use a separate match to light either the downward- or upward-pointing match. Record your observations. You may burn as many matches as needed to meet your objective**. Burn one match at a time. Always use the oven mitt to remove burned matches.**
6. Observe how each match burns and goes out.
7. Discuss how the Fire Triangle might explain why the matches go out.
8. Below your data table, use complete sentences to explain why the matches went out. Use the Fire Triangle. You may have several explanations. You may have different explanations for the downward-pointing and upward-pointing matches.
9. These explanations are your **hypotheses**. Now figure out how to further test your hypotheses. Do you need to repeat the experiment, change it in some way, or record different information? Write down your next step, design a data table, and determine your team roles. Check with the teacher. Once you have his/her approval, proceed.
10. In complete sentences, write your final hypothesis for why downward-pointing matches go out and your final hypothesis for why upward-pointing matches go out. Use the Fire Triangle.
11. Use complete sentences to explain how you could use what you have learned from Experiments 1 and 2 to predict the spread of a wildland fire that starts on a hillside.

Handout H02-2. Answer key to Experiment 2. Explain why matches go out.

A potential data table might look like this:

Match is pointing…	Down	Up
Flame length (centimeters).		
Duration of burning (seconds)?		

Roles might include an igniter, observer, measurer, and recorder.

Questions 8 and 10 – hypotheses:

Why did the downward-pointing matches go out? The downward-pointing matches went out mainly because they ran out of fuel. However, if a small piece of match was left in the alligator clip, lack of fuel cannot be the full explanation. Lack of heat probably contributed, since some of the heat was conducted away into the alligator clip. Lack of oxygen may have contributed a little as well, since the clip prevented oxygen from getting to the entire surface of that little remnant of fuel.

Why did the upward-pointing matches go out? Most of the upward-pointing matches probably went out before they burned down all the way down to the alligator clip. Thus, lack of fuel cannot be the explanation. It cannot be lack of oxygen either, since there is no evidence that the upward-pointing matches have less access to oxygen than the downward-pointing matches; furthermore, the students have not experienced any trouble breathing (unless someone is highly sensitive to smoke), which would indicate that there is no shortage of oxygen in the air. The matches went out mainly because **heat** was going up, away from the **fuel**. Thus the explanation lies in the relationship between two components of the Fire Triangle.

Question 11. Use complete sentences to explain how you could use what you have learned from Experiments 1 and 2 to predict the spread of a wildland fire that starts on a hillside.

Fire is likely to spread more rapidly uphill than downhill because most of the heat goes uphill. When the fuel is above the heat source (as with the downward-pointing match), it burns quickly and completely. When fuel is below the heat source (as with the upward-pointing match), it burns slowly or not at all.

Handout H02-3. Experiment 3. Prove that fire requires oxygen.

Name ______________________________

Your objective is to show that fire requires oxygen. To do this, you need to have some kind of gas to replace oxygen. You will create and use carbon dioxide for this purpose.

Background: When you were younger, you may have poured vinegar into a cup of baking soda to create a “volcano.” The process created a froth that quickly foamed up and out of the cup. The bubbles in the froth were made of carbon dioxide. You will use this technique to create a gas that can replace oxygen in a container. Here is the chemical explanation:

Vinegar combines with baking soda to produce carbonic acid and sodium acetate [equation 1]. The sodium acetate stays dissolved in water, while the carbonic acid breaks down into carbon dioxide and water [equation 2]. This process is a *chemical change* because atoms are rearranged to form different kinds of substances.

[1]	vinegar (acetic acid)	+	baking soda (sodium bicarbonate)	→	carbonic acid	+	sodium acetate
	CH_3COOH		$NaHCO_3$		$H_2CO_3(aq)$		$NaCH_3COO(aq)$
[2]	carbonic acid	→	carbon dioxide	+	water		
	$H_2CO_3(aq)$		CO_2		H_2O		

The atomic weight of carbon (C) is 12 g. The atomic weight of oxygen (O) is 16 g.

Procedure: Develop a plan for using the materials at your lab bench to create carbon dioxide and to show that fires require oxygen. Explain your plan to the teacher. When you have his/her approval, proceed. As you are working, note any safety issues that arise and address them right away. After your first attempt, spend some time changing your approach and trying different things.

Once you developed a method that works and demonstrated that it is repeatable, on a separate sheet of paper:

1. Describe your favorite or final method.
2. Record all safety issues that arose and how you addressed them.
3. Record one experimental approach you tried that did not work as well as your favorite/final approach.
4. Consider the molecular weights of CO_2 and O_2 and the Fire Triangle to explain how your demonstration proves that fire requires oxygen.

Handout H02-3. Answer key to Experiment 3. Prove that fire requires oxygen.

1. Describe your favorite/final method. Here are 3 possible demonstrations. No doubt there are others!

- Make CO_2 in a container by mixing vinegar with baking soda. Insert a burning match into the container. It will be extinguished as soon as it enters the CO_2 layer.
- Place a candle inside a container. Spoon 10-20 cm^3 of baking soda around its base. Pour about 50 mL of vinegar in. Then try to light the candle. Again, the match will be extinguished as soon as it enters the CO_2 layer.
- Place a candle on the metal tray. Make CO_2 in a container. After the froth settles a bit, pour the CO_2 from the container over the candle – without pouring out any of the liquid at the bottom of the container. (This feels a little bit like pantomime, since the CO_2 is invisible.) The CO_2 will put out the flame.

2. Record all safety issues that arose and how you addressed them. These could include:

- Because heat rises, it is best to use a long fireplace match to try to light a candle inside the container.
- Should you reach your hand into a container that contains a burning candle? You could try the oven mitt, but it could burn. You can tilt the container, but your CO_2 will pour out.
- The flame can get long (and hot) on the long fireplace match. Don't hesitate to blow out match and try again. Might use the oven mitt to hold the match.

3. Record one experimental approach you tried that did not work as well as your "final" approach. …..

4. Consider the molecular weights of CO_2 and O_2 and the Fire Triangle to explain how your demonstration proves that fire requires oxygen.

After the chemical reaction is complete, the container contains CO_2 rather than O_2. The CO_2 stays on the bottom of the container because it is heavier than O_2, as we can see from this calculation of the molecular weights of the two compounds:

Element	Atomic weight
Carbon (C)	12 g
Oxygen (O)	16 g

A mole of CO_2 weighs 12 g + 2 * 16 g = 44 g

A mole of O_2 weighs 2 * 16 g = 32 g

Fires cannot burn in this oxygen-deprived environment.

Handout H02-4: Three Kinds of Fire Extinguishers

<u>Read your assigned section.</u> Then describe your fire extinguisher to your group and explain how it works by stating which part(s) of the Fire Triangle is/are removed.

A: Air Pressurized Water Fire Extinguishers
Different types of fire extinguishers are designed to fight different types of fire. The three most common types of fire extinguishers are: air pressurized water, CO_2 (carbon dioxide), and dry chemical. An air pressurized water fire extinguisher (labeled A) should be used to put out fires in paper, cloth, wood, rubber, and many plastics. Water is one of the most commonly used extinguishing agents for type A fires. You can recognize an air pressurized water extinguisher by its large silver container. They are filled about two-thirds of the way with ordinary water, then pressurized with air. In some cases, detergents are added to the water to produce foam. They stand about two to three feet tall and weigh approximately 25 pounds when full. Air pressurized water extinguishers put out fires by cooling the surface of the fuel. https://www.osha.gov/SLTC/etools/evacuation/portable_about.html
B: CO_2 Fire Extinguishers
Different types of fire extinguishers are designed to fight different types of fire. The three most common types of fire extinguishers are: air pressurized water, CO_2 (carbon dioxide), and dry chemical. A carbon dioxide fire extinguisher (labeled B) should be used to put out fires in oils, gasoline, some paints, lacquers, grease, solvents, and other flammable liquids. This type of extinguisher is filled with carbon dioxide (CO_2), a non-flammable gas, under extreme pressure. Because of the high pressure, when you use a CO_2 extinguisher pieces of dry ice shoot from the horn. These pieces have a cooling effect on the fire. You can recognize this type of extinguisher by its hard horn and lack of a pressure gauge. CO_2 cylinders are red and range in size from five to 100 pounds or heavier. https://www.osha.gov/SLTC/etools/evacuation/portable_about.html
C: Dry Chemical Fire Extinguishers
Different types of fire extinguishers are designed to fight different types of fire. The three most common types of fire extinguishers are: air pressurized water, CO_2 (carbon dioxide), and dry chemical. A dry chemical fire extinguisher (labeled C) should be used to put out fires in wiring, fuse boxes, energized electrical equipment, computers, and other electrical resources. Dry chemical extinguishers put out fires by coating the fuel with a thin layer of fire retardant powder. The powder also works to interrupt the chemical reaction, which makes these extinguishers extremely effective. They contain an extinguishing agent and use a compressed, non-flammable gas as a propellant. https://www.osha.gov/SLTC/etools/evacuation/portable_about.html

Handout H02-4. Teacher Key:
Explanations for "Three Kinds of Fire Extinguishers" Reading

A: Air Pressurized Water Fire Extinguishers
Air pressurized water extinguishers put out fires by cooling the surface of the fuel to remove the "heat" element of the Fire Triangle. For more details see step 3 in "Procedure" above. The water may also block the fuel surface from its contact with oxygen.
B: CO_2 Fire Extinguishers
CO_2 fire extinguishers put out fires by cooling the surface of the fuel to remove the "heat" element of the Fire Triangle. The carbon dioxide also displaces oxygen.
C: Dry Chemical Fire Extinguishers
Dry chemical extinguishers put out fires by coating the fuel with a thin layer of fire retardant powder, separating the fuel from the oxygen. The powder also works to interrupt the chemical reaction, which makes these extinguishers extremely effective. "Interrupting the chemical reaction" means that less heat is produced, which slows the burning process.

3. The Fire Triangle, Combustion, and the Carbon Cycle

Lesson Overview: Students use an experiment, a PowerPoint presentation, and a technical article to explore how the Fire Triangle relates to the chemical equation (model) for combustion and the carbon cycle.

Lesson Goals: Increase students' understanding of combustion and the connections between combustion and the carbon cycle.

Subjects: Science, Mathematics, Speaking and Listening, Health and Safety

Duration: one 90 minute session

Group size: Whole class/groups.

Setting: Classroom

New FireWorks vocabulary: *atom, carbon, carbon cycle, carbon dioxide, carbon sink, carbon source, cellular respiration, chemical equation, photosynthesis*

Objectives:

- Students can explain that combustion produces water, carbon dioxide, heat, and light.
- Students can explain how forests and wildland fire store and release carbon, and how this process is related to fire.

Standards:		9th	10th	11th	12th
Common Core ELA	Writing Standards	1,4		1,4	
	Speaking and Listening	1,2,4		1,2,4	
	Language Standards	1,2		1,2	
	Science/Technical Subjects	9		9	
NGSS	Chemical Reactions	PS1.A, PS1.B			
	Matter/Energy in Organisms/Ecosystems	LS1.C, LS2.B, PS.D			
EEEGL	Strand 1	A,C,D,E,F,G			
	Strand 2.1	B, C			

Teacher Background: For a refresher on the chemistry of combustion and life, review the "Procedure" section below. Also download and review the presentation *H03_FireTriangle_CarbonCycle_Connection.pptx*. Here are some key concepts:

The three legs of the Fire Triangle actually represent the three inputs to the chemical equation for combustion, where H represents Hydrogen atoms, O represents Oxygen atoms, and C represents Carbon atoms:

Fuel + Oxygen + Heat ⟶ Carbon dioxide + Water + Heat&Light

C&H atoms + O_2 + a little heat ⟶ CO_2 + $6H_2O$ + Heat&Light

The equation above does not give a specific formula for fuels, because they could be any mixture of millions of compounds. The point is that all fuels contain a lot of carbon and hydrogen. They usually contain oxygen and many other kinds of atoms as well. For example, the equation for combustion of glucose (the main component of cellulose, which is the component of wood that burns), with numbers of molecules balanced to show conservation of matter, is this:

$$C_6H_{12}O_6 + 6O_2 + \text{a little heat} \longrightarrow 6CO_2 + 6H_2O + \text{Heat/Light}$$

The same equation represents cellular respiration, the process by which cells convert sugar into the energy that keeps living things – including us – alive. Furthermore, this equation is the reverse of the chemical formula for photosynthesis!

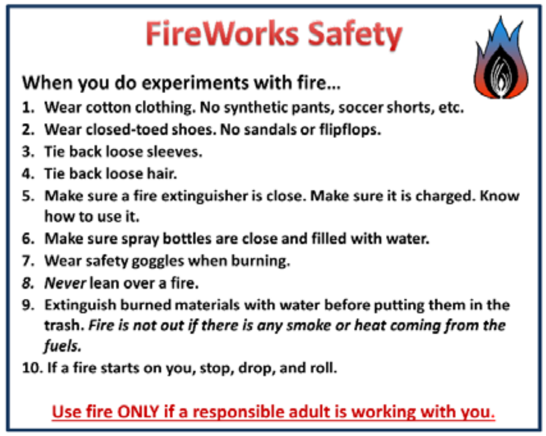
$$6CO_2 + 6H_2O + \text{Heat/Light} \longrightarrow C_6H_{12}O_6 + 6O_2$$

Thus the Fire Triangle can be used to introduce not only basic chemistry but also the basic principles of the biochemistry of life.

For additional information, see William Cottrell's *The Book of Fire* (2004, available from http://mountain-press.com/) in the FireWorks trunk. This is a well-illustrated, easy-to-read description of the physical science of combustion and wildland fire.

Materials and preparation:
Read the technical reading assignment “Sink or Source: Fire and the Forest Carbon Cycle”. You can either read the entire article, which is online at www.firescience.gov/projects/briefs/03-1-1-06_FSBrief86.pdf, or only the excerpts on **Handout 03-2**.

Decide on your laboratory arrangement. This demonstration produces a flame about 1-3 cm long.



- Display the *FireWorks Safety* poster.
- Download *H03_FireTriangle_CarbonCycle_Connection.pptx*
- Make 1 copy of **Handout H03-1** and 1 copy of **Handout H03-2** (reading assignment) for each student (but if students will read the technical article online, you do not need to print Handout H03-2).
- Have a fully charged dry chemical fire extinguisher handy
- At your lab demonstration bench, you need the following items from the FireWorks trunk:
    - Two support stands
    - Two ~2.5” (~7 cm) diameter rings
    - Votive candle or other candle
    - Two fence-post caps (aluminum chain-link fence caps)
    - Oven mitt
    - Safety glasses
    - Spray bottle filled with water
- At your demonstration bench, you need the following that are NOT provided in the trunk:
    - Electric hot plate
    - Matches or lighter
    - Tissue (optional)
    - Flashlight (optional)

Preparation:

1. The day before you do this demonstration, fill the fence-post caps with water and freeze. (To keep them upright in the freezer, prop them in an empty egg carton, ice cube tray, muffin tin, etc.)
2. Set up the first support stand with the ring above the candle, so the bottom of the cap will be ~3 cm from the candle flame.
3. Set up the second support stand with the ring above the hot plate, so the bottom of the cap will be ~3 cm from the hot surface.

Setup for water-drop demonstration. Hot plate is heat source on the left; lighted candle is heat source on the right.

Procedure – Part 1. Developing a bigger, better model of combustion. (Use the PowerPoint presentation.)

1. **Explain:** Let's explore the model of the Fire Triangle a little more deeply so we can see how fire fits in with the functioning of life on Planet Earth. Use slides 1-5 in *H03_FireTriangle_CarbonCycle_Connection.pptx* to teach about the chemistry of combustion. STOP ON SLIDE 6.

Procedure – Part 2. Does combustion really produce water? (Lab demonstration – get the fence-post caps out of the freezer.)

2. **Hook:** Look again at the chemical equation for combustion. It says that combustion produces water! But that seems counter-intuitive, since we use water to PUT FIRES OUT. Let's treat that idea as our hypothesis and then try to verify experimentally that combustion does produce water.
3. Write on the board: **Hypothesis: Combustion produces water.**
4. **Ask and discuss:** Have you ever seen water dripping down the sides of a glass of ice water in the summer, when the weather is hot and perhaps humid? What is happening there? (Water vapor in the air is touching the cold surface of the glass, where it is rapidly cooled from gas to liquid phase. It condenses on the surface of the glass, and eventually droplets come together and run down the sides.)
5. **Explain and discuss:** We can use the fact that water vapor condenses on cold surfaces to test our chemical equation, our model of combustion – to see if combustion actually does

produce water. We're going to melt the ice in the two post caps using heat from two different sources: a candle flame and an electrical hot plate.

- How is the heat transferred from these two heat sources? (The heat from the candle is transferred mainly by convection of hot gases produced by combustion. The heat from the hot plate is transferred mainly by radiation. There is no chemical change going on, and no hot gases are produced by the heating process.)
- What do you expect to happen? Write expectations on the board below "Hypotheses." (The ice will melt.)
- Based on your understanding of the combustion equation, do you expect any differences between the two procedures? (Water vapor produced by the burning candle will touch the cold surface of the cap, where it will rapidly cool and condense into droplets. No water vapor is being produced by the hot plate (combustion is not occurring), and its heat is vaporizing any water from the atmosphere that might otherwise condense on the outside of the post-cap, so the cap will remain dry.)

6. Place a post cap (with water frozen) in each ring.
7. Light the candle and turn on the hot plate.
8. Have the students go back and forth, observing each cap until the ice inside has melted to a 2-3 cm chunk. A flashlight may help them see what is happening more clearly. (The bottom of the post cap over the hot plate will be dry. The bottom of the post cap over flame will be covered with water droplets, and a large drop may collect right above the flame.)

Results of water-drop demonstration. No water is visible on the electrically-heated post cap; water droplets have condensed on the combustion-heated post cap.

9. **Discuss:** What differences did you observe? What caused the differences? Were any of our hypotheses verified? (The bottom of the post cap over the hot plate is dry because the heat source is not producing water vapor. The bottom of the post cap over the candle is moist because water produced by combustion is condensing on the cold surface of the cap.)
10. **Additional discussion points:** Smoke contains partly-burned particles of fuel. Water vapor condenses especially well on particle surfaces, so it condenses on the smoke particles. A wildland fire may produce so much water vapor that it eventually condenses in the cold upper atmosphere and creates rain that falls along the edges of the fire.

Procedure – Part 3. The Carbon Cycle (use the rest of the PowerPoint)

11. Return to *H03_FireTriangle_CarbonCycle_Connection.pptx* at slide 6, and finish the presentation. Use the final slide to introduce the assessment.

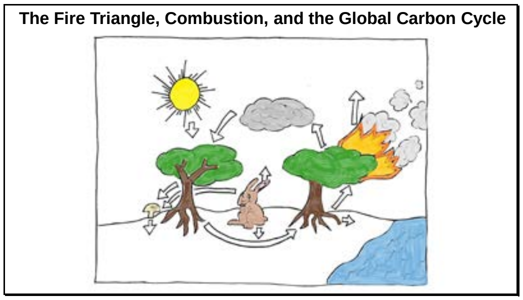
Assessment:

- Give each student a copy of **Handout H03-1**.
- Have them answer items 1 and 2 based on the demonstration and the presentation.
- Have them do the reading assignment and then complete item 3. Reading assignment: Have students read **EITHER** the full article entitled *Sink or source? Fire and the forest carbon cycle available at* www.firescience.gov/projects/briefs/03-1-1-06_FSBrief86.pdf **OR** the excerpts on **Handout H03-2**.

Evaluation: Use the answer key to Handout H03-1 to evaluate student responses.

Slides and Narrative for
H03_FireTriangle_CarbonCycle_Connection.pptx

Slide 1

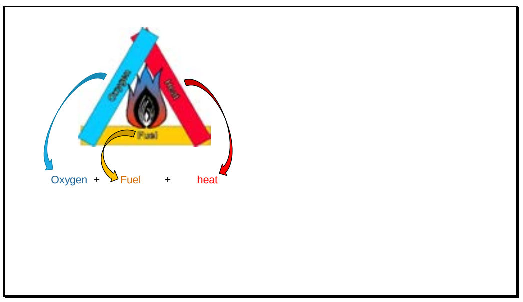


Procedure Part 1.

Explain: We've been studying the Fire Triangle and the process of combustion.

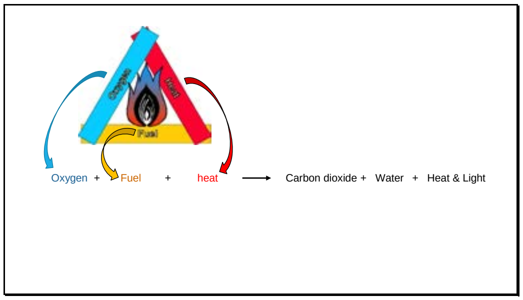
Let's explore combustion a little more deeply and then fit it in with the basic life processes on Earth, as described in the Global Carbon Cycle.

Slide 2



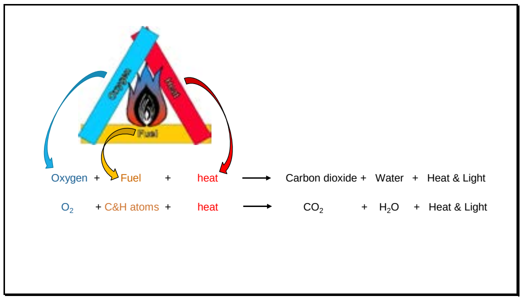
We'll start with the Fire Triangle: oxygen, fuel, and heat. If you break it apart and line up the "ingredients," you have an arithmetic expression for what makes fires "go" – what makes combustion happen.

Slide 3



Now let's list the products of combustion. They are carbon dioxide, water, heat, and light.

Slide 4

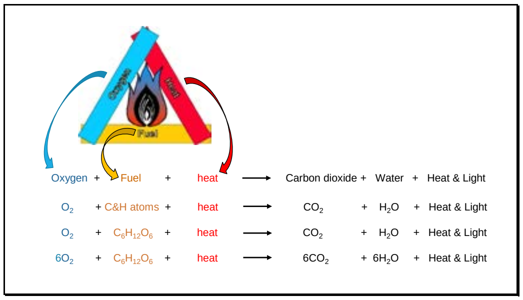


We can use chemical symbols for both the ingredients and the products of combustion.

It's a little tricky to give a specific formula for fuels, because they could be any mixture of millions of compounds. But all fuels contain carbon and hydrogen, and they usually contain oxygen and other kinds of atoms as well. Let's plug in the formula for glucose, $C_6H_{12}O_6$, since the main component of woody fuels is cellulose - a very long chain of glucose molecules.

Now we have a brand-new model – the chemical formula ("equation") for combustion.

Slide 5

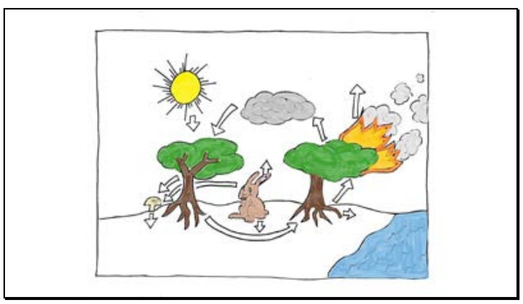


Finally, let's make sure the equation shows that the number of atoms going into the combustion process is the same as the number that are produced. This is called "balancing" the equation.

Our new model is more complicated than the Fire Triangle, but it is also more powerful. It helps us keep track of the atoms that are moved around in this chemical change, and it lets us predict how much of each "ingredient" ("reactant") is needed to produce a specific amount of products.

Part 1 ends here.

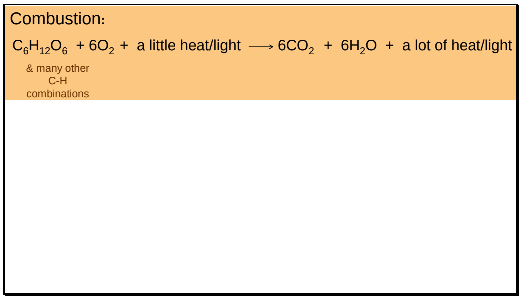
Slide 6



<u>Procedure Part 3.</u>

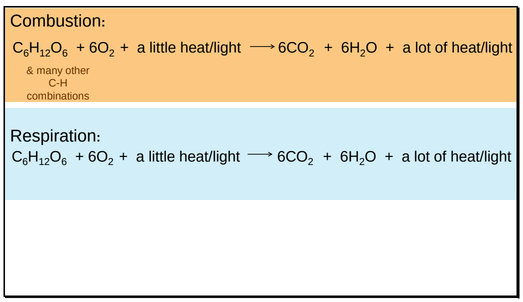
Now let's see how the process of combustion fits into the life processes on Planet Earth.

Slide 7



Here's our model of combustion.

Slide 8



Here's another chemical equation. It describes the process that living things use to obtain energy – a process called *respiration*:
What do you notice about these two equations?

Explain: Fire isn't the only process that takes energy from carbohydrates and releases CO_2 and water into the air. Respiration is just a fancy word for breathing; breathing is how we get oxygen to our cells so them can produce energy, a process called *cellular respiration*. Animals aren't the only living things that use respiration to get energy. Nearly EVERY living thing does – animals, plants, algae… even the tiniest microorganisms use respiration. But if plants and animals just kept on doing respiration, all the carbohydrates and oxygen would be converted to CO_2 . We wouldn't last very long.

Ask: How do carbohydrates and oxygen get replenished—how do we reverse the process?

Slide 9

Combustion:

$C_6H_{12}O_6 + 6O_2 +$ a little heat/light $\longrightarrow 6CO_2 + 6H_2O +$ a lot of heat/light

& many other C-H combinations

Respiration:

$C_6H_{12}O_6 + 6O_2 +$ a little heat/light $\longrightarrow 6CO_2 + 6H_2O +$ a lot of heat/light

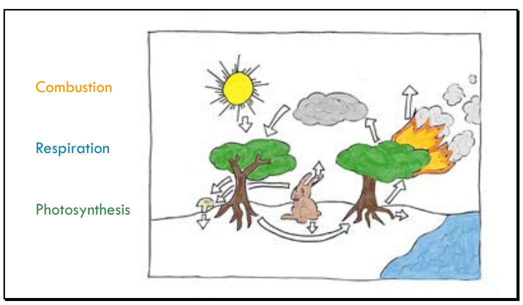
Photosynthesis:

$6CO_2 + 6H_2O +$ sunlight $\longrightarrow C_6H_{12}O_6 + 6O_2$

Explain: Lucky for us, plants are able to reverse the process of combustion and respiration by grabbing the energy from sunlight and storing it in the high-energy bonds of carbohydrates. This is called photosynthesis. And the chemical equation for photosynthesis is the mirror image of the equation for combustion of glucose and respiration.

Animals ensure there is abundant CO_2 in the atmosphere, which means plants can grow well, which means there's plenty of food for animals (including us!) to eat. It also means fuels are abundant, which means there's plenty of fuel for fires to burn.

Slide 10

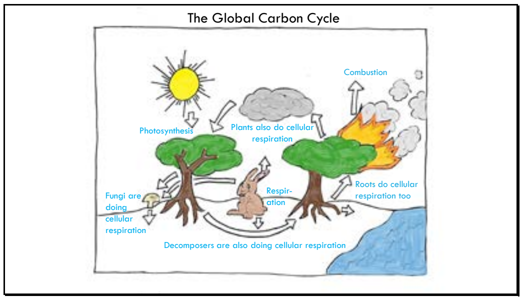


Ask: Where are combustion, respiration, and photosynthesis occurring in the image?

Answer: Photosynthesis occurs where sunlight & oxygen are going into the tree. Combustion is occurring where the tree is releasing carbon dioxide, water, and smoke into the air. All the other processes – growth, uptake of water and minerals by plants, decay, and defecation - are powered by cellular respiration.

Explain: All of these processes, put together, are called the Carbon Cycle. It is a cycle because you can trace carbon as it moves through one process after another, from one kind of molecule to another. Throughout the process, carbon is reused at every step.

Slide 11



Explain: See the labels on the picture. We often talk about "burning" calories or carbs. "Burning" is a short way of saying we use cellular respiration to get the energy we need to rearrange food molecules (carbs) into the molecules we need to live (proteins, DNA, etc. – which make muscle, eyeballs, babies, poop, etc.)

Ask: How do forests store carbon? When do forests release carbon? Overall, do forests function as *sources of carbon* or storage – reservoirs – of carbon (also called *carbon sinks*)?

Slide 12

Explain: Read the article "Sink or Source? Fire and the Forest Carbon Cycle". Based upon the information in the article, do forests function as storage for carbon or sources of carbon? This is the answer to question number three on your handout.

Terminology:
When carbon accumulates and is being stored for an indefinite period, it is considered to be a **carbon sink.** The process by which carbon sinks remove carbon dioxide (CO_2) from the atmosphere is known as carbon sequestration.
When carbon is being released to the atmosphere, it is called a **carbon source.**

Handout H03-1. Water, Combustion, and the Global Carbon Cycle

Name: ___________________________

1. Write one paragraph that explains what is going on in the white columns of smoke in this photo. Use what you know about where heat goes and the products of combustion.

Smoke produced by 2010 Eagle Trail Fire, Tok, AK. Photo by Larry Walsh (inciweb.nwcg.gov).

2. Write a few sentences that explain how the chemical processes of combustion, cellular respiration, and photosynthesis are related.

3. Read the article on **Handout H03-2** (or the full article). Then write 1-2 paragraphs that answer these questions. Use specific evidence and quotes from the article to support your answers.

a) Based upon the information in the article, how does stand-replacing fire affect whether forests are a source or sink for carbon?
b) Does a forest change over time from source to sink, or from sink to source?
c) What is the most important variable that makes an ecosystem gain or lose carbon after fire?

H03-2: Reading: Excerpts from "Sink or Source: Fire and the Forest Carbon Cycle"*

Forests have a life cycle: trees die after disturbance, such as a stand-replacing fire, setting the stage for new growth to begin. If a forest fully replaces itself, there will be no net carbon change over that life cycle. The fire consumes only about 10 to 20 percent of the carbon and immediately emits it back into the atmosphere. It kills trees but doesn't consume them. So, new trees grow (storing carbon), old trees decompose (emitting carbon), and the organic layer of the soil accumulates (storing carbon). This balance between simultaneous production and decomposition determines whether the forest is a net source or sink. The net ecosystem carbon balance, also known as net ecosystem production (NEP), specifically quantifies the annual net change in carbon stored in the ecosystem. And that's the "magic number," so to speak, needed to gauge whether a forest is a carbon source (negative NEP) or sink (positive NEP) at any given point in time. NEP is often quantified on an annual basis and for a single forest stand. But to determine whether an entire landscape (which is composed of many stands of different ages) is a carbon source or sink over a longer time frame, annual NEP must be assessed over both space and time.

Immediately after a fire, carbon is lost to the atmosphere through combustion. Stand-replacing fires kill living biomass in forests and reduce carbon gains to near zero. The strongest effect of fire on carbon cycling, however, occurs in the changing balance between carbon lost through subsequent decomposition and simultaneous carbon gains through growth of new vegetation. In fact, the decomposition of dead biomass that lasts for several decades post-fire can release up to three times as much carbon as that lost in the initial combustion. And during this period, carbon lost through decomposition exceeds the carbon accumulating in regrowth. Then, as the forest continues to reestablish and decomposition tapers off, carbon storage in trees eventually "catches up," and the carbon balance of loss and gains approaches an NEP of zero. According to Dr. Ryan [interviewed for this article], "In 30 to 40 years or so of regeneration, you cross the positive line because growth and accumulation is outpacing the decomposition of the dead matter. And then in approximately 80 to 100 years, the ecosystem has recovered completely to pre-fire carbon levels." So in the short-term, over the time frame of the first century post-fire, stand replacing fires convert the landscape into a carbon source and then back into a carbon sink. Long-term effects of fire (over centuries) on the carbon balance depend on post-fire regeneration and fire frequency. We see a large difference in the ability to recover pre-fire carbon storage levels between stands having low initial regeneration and those that replace biomass quickly. The take-home message here is that the replacement of biomass for a given stand over multiple fire intervals plays the critical role in the relationship between fire and the carbon balance. If, as a result of crown fire, a forest converts to grassland or meadow rather than regenerating, much carbon can be lost from the ecosystem. Dr. Ryan emphasizes the point: "Regeneration is absolutely critical to carbon. If you don't get regeneration, the ecosystem loses about half of its carbon." But if the forest does regenerate—and exists on the landscape long enough before the next stand-replacing fire—it will recover the carbon lost over the fire cycle.

*Frame, Christine. 2010. Sink or source? Fire and the forest carbon cycle. Fire Science Brief. Joint Fire Science Program. Issue 86. 6 p. Available: www.firescience.gov/projects/briefs/03-1-1-06_FSBrief86.pdf.

Handout H03-1: Answer Key/Evaluation
Water, Combustion, and the Global Carbon Cycle

1. Write one paragraph that explains what is going on in the white columns of smoke in this photo. Use what you know about where heat goes and what chemicals are produced by combustion.

Answer: The smoke is rising because heat usually does rise, as we observed in an earlier experiment. The model says that combustion produces water vapor, and we saw that in the demonstration that the water condenses into droplets when it cools. Water vapor produced by the fire must be cooling and condensing as it rises. The model also says that combustion produces carbon dioxide, so that must be in the plume too – even though we can't see it.

Optional details: Smoke contains partly-burned particles of fuel. Water vapor condenses especially well on surfaces, so it condenses on the smoke particles. A wildland fire may produce so much water vapor that it eventually condenses in the cold upper atmosphere and creates rain that falls along the edges of the fire.

2. Write a few sentences that explain how the chemical processes of combustion, cellular respiration, and photosynthesis are related.

The chemical reactions of combustion are basically the same as those in cellular respiration. The chemical process of photosynthesis is the reverse of combustion and cellular respiration.

3. Read the article on **Handout H03-2** (or the full article online). Then write 1-2 paragraphs that answer these questions. Use specific evidence and quotes from the article to support your answers.

a) Based upon the information in the article, how does stand-replacing fire affect whether forests are a source or sink for carbon?
b) Does a forest change over time from source to sink, or from sink to source?
c) What is the most important variable that makes an ecosystem gain or lose carbon after fire?

Answer: Forests are usually a carbon sink. Stand-replacing fires convert forests into a carbon source for about 30 to 40 years, and then – if trees regenerate successfully - the forest gradually changes back into a carbon sink after about 80 to 100 years. During a severe wildfire, a lot of carbon is released, and then even more carbon is released through decomposition that follows the fire. That is why, during this time, the forest is a carbon source. As the forest grows back, it manufactures and stores a lot of carbohydrates. Eventually, the pace of storing new carbohydrates surpasses the pace of decomposition. That means the forest has become a carbon sink again.

The most important variable that determines whether the ecosystem gains or loses carbon after fire is tree regeneration. If trees grow back successfully after a stand-replacing fire, forests usually become carbon sinks again in about 80 to 100 years. If trees do not regenerate and the forest becomes a grassland or shrubland, it may remain a carbon sink for many centuries. It may not ever store as much carbon as before the fire.

4. Heat Transfer

Lesson Overview: In this lesson, students work in small groups to create demonstrations that show the three ways that heat can be transferred.

Lesson Goal: Increase students' understanding of how heat is transferred.

Objectives: Students can create a way to demonstrate the three methods of heat transfer.

Subjects: Science, Reading, Writing, Speaking and Listening, Arts

Duration: 45 minutes (or less)

Group size: Whole class working in small groups

Setting: Indoors

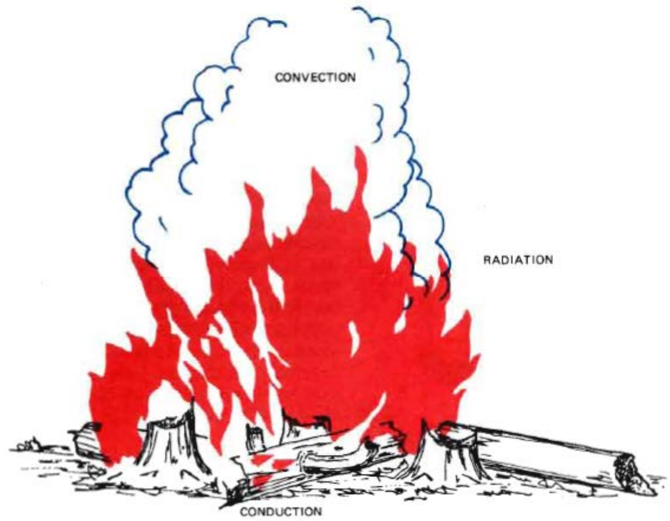
FireWorks vocabulary: *heat transfer, radiation, convection, conduction*

Standards:		9th	10th	11th	12th
Common Core ELA	Speaking and Listening	1,2,4		1,2,4	
	Language Standards	1,2		1,2	
	Science/Technical Subjects	9		9	
NGSS	Energy	PS3.B			
	Waves/Electromagnetic Radiation	PS4.A, PS4.B			
EEEGL	Strand 1	A,C,D,E,F,G			

Teacher Background: This lesson is a review of the mechanisms of heat transfer. See the "Procedure" section.

Materials and Preparation:

- Download *HeatTransferImage.pptx* (shown at right)
- Props such as bags of candy, balls of yarn, pingpong balls, etc.



Procedure:

1. Project *HeatTransferImage.pptx* and use it to review the three methods of heat transfer: conduction, convection, and radiation.
    - **Conduction**: Heat is transferred through direct contact between atoms or molecules within solid objects. In wildland fire, conduction enables heat to move from an object's outside to its inside and from one solid object to another one that is touching it.
    - **Convection**: Heat is transferred by hot gases as they expand into the cooler gases surrounding them. Since Earth's atmosphere becomes "thinner" (less dense) as you go up in altitude, "up" has less resistance to the expanding gases than "sideways" or "down." Thus hot air generally rises.
    - **Radiation**: Heat is transferred through space from the object where it is generated to the first atom or molecule that intercepts it. For example, heat from the sun travels through almost 100 million miles of space before it is intercepted by the leaves of plants, where photosynthesis occurs or our skin, where sunburn occurs. Radiation from a wildland fire can heat the fuels before they are actually ignited.

Assessment: Explain: Students will work in groups to model the three methods of heat transfer. Students can use props, group members, conversation, narration, skits, etc., to model how each method of heat transfer works.

Here we give 1 possible example of each demonstration:

- **Radiation:** Students can demonstrate radiation by using balls of yarn, pieces of candy, or other small objects to represent heat. One student could represent the heat source (sun, fire, or other), and other students could represent molecules in air and in solid objects, including fuels. The heat source would throw the objects, and only the molecules they touch are heated.
- **Conduction:** Students can demonstrate conduction by standing side by side in a long line, shoulder to shoulder. The students would represent atoms within a solid object, like a metal. Heat would be represented by a bag of candy or other small objects. The students would pass the bag from one student to the next, each one taking a piece from the bag (i.e.,

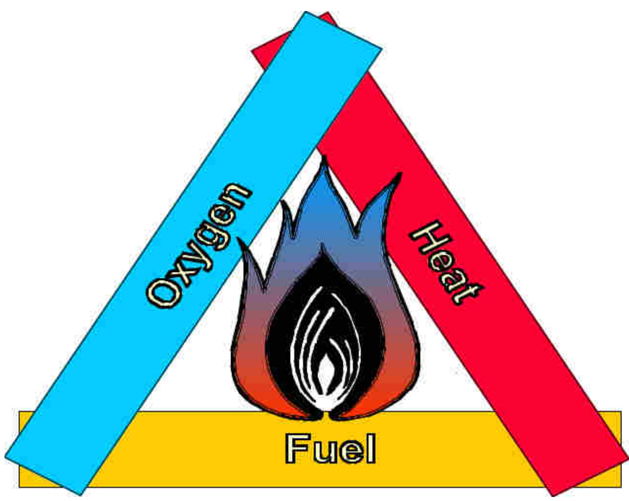
absorbing some heat) and passing the bag on to the next student.… all the way to the end of the line or until the bag is empty.

- **Convection:** Students can demonstrate convection by lining up shoulder-to-shoulder. They should imagine that their line is vertical rather than horizontal. One or two students represent a parcel ("bubble") of hot air; they carry a bag of candy or other small objects. They walk from one end of the line (the imaginary bottom of a column of air) toward the other end (the imaginary top). Their bubble of hot gases is expanding from the bottom toward the top, transferring heat (small objects) to the surrounding air and thus cooling as they go. If they empty the bag of objects, they stop. This means that their air bubble has roughly the same amount of energy per molecule (is the same temperature) as the molecules in the air around them.

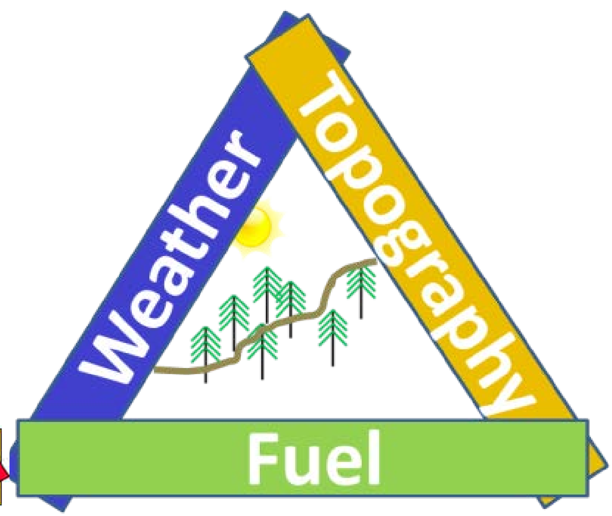
Evaluation: The class will vote on the model that most clearly represents each method of heat transfer. This is a credit/no credit activity. Evaluate students on their contributions during the planning process, engagement in the presentations, and student feedback.

Unit III.
The Wildland Fire Environment

Now that students understand the basic principles of combustion as described by the Fire Triangle, they will apply that understanding to how fires behave in wildlands. Fire professionals use a second triangle model, the Fire Environment Triangle (also known as the Fire Behavior Triangle), to describe the complexities of wildland fire behavior. Each activity in this section addresses some features of the Fire Environment Triangle.



Fire Triangle



Fire Environment Triangle

5. Fuel Properties

Lesson Overview: Students explore the properties of wildland fuels through reading, a fuel scavenger hunt, and by designing and conducting experiments with fuels.

Lesson Goal: Increase students' understanding of how fuel properties affect burning.

Subjects: Science, Reading, Writing, Speaking and Listening, Arts

Duration: 90 minutes

Group size: Whole class

Setting: Indoors

FireWorks vocabulary: *fine fuels, coarse fuels, fuel loading, fuel moisture, experiment, treatment, spatial arrangement*

Objectives:

- Students can design experiments that test how fuels with contrasting properties burn.
- Students can apply observations from experiments to explain how wildland fuels with various properties burn.

Standards:		9th	10th	11th	12th
CCSS	Reading: Informational Text	1,2,4,10		1,2,4,10	
	Reading: Science and Technology	2,3,4,7,9,10		2,3,4,7,9,10	
NGSS	Earth's Systems	ESS2.A			
EEEGL	Strand 1	A,C,D,E,F,G			

Teacher Background: See the Handout H05-1 "Fuel Properties: Pre-Lab Reading and Scavenger Hunt" for background information.

Materials and Preparation:
This activity requires that students do a technical reading and an outdoor search for various kinds of fuels before doing experiments in a laboratory. This preparation can be done as homework or as a mini-field trip the class period before the lab.

Student needs:

- **Handout H05-1: Fuel Properties: Pre-Lab Reading and Scavenger Hunt**, one for each student. Students should complete this handout before doing the lab.
- **Handout H05-2: Fuel properties**, one for each student, to be completed in lab.

Set up your lab. It should have heat-resistant work surfaces and good ventilation or a hood. You also need:

- 1 fire extinguisher
- 1 empty metal trash can without liner

Set up each student lab bench with:

- 8 sheets of newspaper (~57 x 63 cm)
- 2 Pie tins
- ~25 matches
- 1 pair safety goggles
- 1 ruler
- 1 water filled squirt bottle
- 1 digital scale
- 1 timer (phone, clock with second hand, stop watch)
- 1 metal tray (cookie sheet), if you would like the pie tins to sit on it

Procedure:

1. At least 1 day before the lab, distribute **Handout H05-1**: **Fuel Properties: Pre-Lab Reading and Scavenger Hunt,** 1 copy to each student. This handout requires students to read and also to go outside and find examples of different kinds of fuels. Have students complete the handout as homework or during a mini-field trip the class period before the lab.

2. Review Handout H05-1 as a class. Answer any questions that arise.

3. Distribute **Handout H05-2: Fuel Properties** to each student. Review the handout and stress:
    - There is a 1-page limit on how much newspaper students can burn in a single pie-tin treatment (except for experiment 3).
    - It is important to distinguish between *experiment* (investigating a variable) and *treatment* (the way that variable is altered within an experiment).
    - It is important to plan measurement methods <u>before</u> igniting a treatment. For example, who is going to time the burn? Who is going to measure flame height? Is it maximum flame height or typical or average? If the ruler is meltable, how will they get the measurement?
    - It is important to keep all variables constant except the one you're investigating. For example, method of ignition should always be the same. Don't use colored newspaper for one treatment and black-and-white for the other. Results for Experiments 1, 2, and 4 may be clearest if both treatments use about the same amount of fuel.

4. Have students get into groups and complete the experiments on Handout 05-2: Fuel Properties.

Assessment: Take students to an outdoor setting where they can collect fuels and safely build small campfires. Have them work in pairs to apply their knowledge of fuel properties. Each pair needs:

- 1 pie tin
- matches or lighter
- water bottle
- oven mitt
- 1 metal tray (cookie sheet), if you would like the pie tins to sit on it.

Have a fire extinguisher, charged hose, and/or bucket of water nearby and ready to use, if necessary.

Their goal is to collect fuel and make a mini-campfire that will **easily ignite**, **sustain burning, and consume the majority of their fuel**. They must fit all of their fuel within the pie tin—no overhanging fuel. For fun, consider distributing mini-marshmallows and kabab-skewers to roast over their mini-campfires!

Evaluation:	**Full Credit**	**Partial Credit**	**No Credit**
	Students' fire ignited easily and remained burning until the majority of the fuel was consumed.	Students' fire was difficult to ignite but eventually ignited and consumed some fuel.	Students' fire could not be ignited. No fuel was consumed.

Handout H05-1. Fuel Properties: Pre-Lab Reading and Scavenger Hunt

Name: ________________________

Read this information to learn about wildland fuels. This will help you design experiments to do in the lab. When you come to a "Scavenger Hunt assignment," you will need to go outdoors and either sketch something or collect something to bring to class.

Fuel Properties: Properties of wildland fuels influence how they burn. Specifically, fuel properties determine how fires heat the fuels and how much oxygen is in contact with them, and thus how quickly they will ignite and how long they will burn. Anyone who has built a campfire knows that you have to choose your fuels wisely and arrange them carefully. Several fuel properties influence fire behavior, including:

- Size and shape
- Moisture content
- Amount
- Spatial arrangement

1. Particle Size and Shape: The size and shape of fuel particles affect how fuels heat up. One component of size and shape is the surface-area-to-volume ratio (SA/V). SA/V describes fuel particle fineness – that is, the amount of outer surface exposed to air and heat, relative to its volume. Surface-area-to-volume ratio is important because it affects the rate at which a fuel particle will change temperature as a result of heat transferred from its surroundings.

Imagine lighting the fuels in a campfire by holding a match beneath them. As you know, the match's heat will rise, so the fuels will be heated by convection. Now ask: Which is easier to ignite - a thick, dead log or a dead pine needle? The pine needle is easier to ignite (if it is dry, of course), because the heat can penetrate the whole needle quickly, and the surface area exposed to oxygen is great relative to the needle's volume. The log is harder to ignite because the heat that reaches the surface is transferred to the inside (so the log heats slowly), and because the surface area exposed to oxygen is small relative to the log's volume.

a. Examples of fine (small) fuels: grasses, leaves, pine needles, and twigs. Because fine fuels are small, they burn up quickly – as long as they are dry.

Scavenger Hunt assignment: Find an example of a fine wildland fuel that is dry. Put the sample in a Ziploc bag and label it "fine fuel".

b. Examples of coarse (large) fuels: logs, stumps, and thick branches. Coarse fuels tend to burn slowly. Think of a log as having many concentric layers of fuel. The outer layer has to burn away before the next layer is exposed to oxygen and heat and can burn away, exposing the next layer to oxygen and heat, etc., etc.

Scavenger Hunt assignment: Find an example of a coarse wildland fuel. Draw it below:

2. Moisture Content: How well fuels ignite and burn depends, to a large extent, on their moisture content. The drier the fuels, the less heat is needed to remove the water they contain.

a. Wet Fuels: Moisture makes fuels hard to ignite and also makes them burn slowly. This is because the moisture must be heated up and vaporized before a particle can be heated to ignition temperature.

b. Dry Fuels: The drier the fuels, the less heat needed to remove water, so the more easily they will ignite and the more completely they will burn. That's why you don't use wet wood to make a campfire!

Scavenger Hunt assignment: Find an example of a moist wildland fuel and an example of a dry wildland fuel. Put them into separate Ziploc bags and label them "wet fuels" and "dry fuels".

3. Fuel Loading refers to the amount of fuel present. Fuel loading is measured in terms of weight per unit area (for example, tons per acre). The more fuel, the longer your fire can burn and the more heat it can produce.

Scavenger Hunt assignment: Find a landscape with heavy fuel loading and find a landscape with light fuel loading. Sketch and label them in the boxes below.

4. Spatial Arrangement means how fuels are arranged in space, both horizontally and vertically. Fuel continuity describes the arrangement of fuels.

a. Continuous Fuels: fuels that are in contact with each other with no substantial gaps between them. Continuous fuels provide an uninterrupted path for fire spread, either horizontally or vertically.

Scavenger Hunt assignment: Find a landscape with continuous fuels (either horizontal or vertical) and sketch it in the box**.**

b. Discontinuous Fuels: describes fuels that have gaps between them. Fuels are interrupted by bare ground, rock outcroppings, water, and/or vegetation that is highly resistant to ignition. Discontinuous fuels along the ground surface are also called "patchy fuels."

Scavenger Hunt assignment: Find a landscape with discontinuous fuels and draw it in the box.

c. Fuel particles can be so **tightly packed** that heat and oxygen cannot easily reach their surfaces. This makes it hard to ignite them, and they burn slowly. (For example, think of a thick pile of newspapers or deep duff on the forest floor.)

Scavenger Hunt assignment: Find a small area with tightly packed fuels and draw it in the box.

d. Fuels may look continuous but be so **loosely packed** that fire cannot spread easily from one particle to the next. (For example, think of a thin layer of sparse grasses.)

Scavenger Hunt assignment: Find a landscape with loosely packed fuels and draw it in the box.

Sources:
Introduction to Wildland Fire Behavior, S-190 Wildfire Coordination Group's (NWCG), Wildland and Prescribed Fire Curriculum.
http://training.nwcg.gov/pre-courses/s290/S-290%20Student%20CD/S-190_Student%20Workbook.pdf
http://learningcenter.firewise.org/Firefighter-Safety/1-5.php

Handout H05-2: Fuel Properties

Name______________________

Materials for each team:

- 8 sheets of newspaper (~57 x 63 cm)
- 2 aluminum pie tins
- ~25 matches
- 1 spray bottle filled with water
- 1 pair safety glasses
- 1 oven mitt
- 1 ruler
- 1 timer (phone, clock with second hand, stop watch)
- 1 digital scale

There is a 1-page limit on how much newspaper you can burn in a single pie-tin treatment (except for experiment 3). For each experiment, ignite the fuels in one pie tin at a time and record data in the table. **Hint:** To get the correct fuel weight, either "tare" the pie tin or subtract the weight of the tin from the weights of the fuels.

Plan your measurement methods before igniting a treatment. For example, who is going to time the burn? Who is going to measure flame height? Is it maximum flame height or typical or average? If the ruler is meltable, how will they get the measurement?

Be careful to keep all variables constant except the one you're investigating. For example, method of ignition should always be the same. Don't use colored newspaper for one treatment and black-and-white for the other.

Experiment 1 - particle size. Manipulate a sheet of newspaper (by cutting, rolling, folding, wrinkling, twisting, arranging, etc.), so one pie tin contains newspaper representing fine fuels and one pie tin contains newspaper representing coarse fuels.

Experiment 2 - moisture. Manipulate a sheet of newspaper so one pie tin contains moist newspaper and one pie tin contains dry newspaper.

Experiment 3 - loading. Manipulate one or more sheets of newspaper so one pie tin contains more newspaper and one pie tin contains less.

Experiment 4 – spatial arrangement. Manipulate a sheet of newspaper so one pie tin contains loosely packed newspaper and one pie tin contains tightly packed newspaper.

Experiment	Treatments	Preburn weight (g)	Postburn weight (g)	Amount combusted (g)	Percent combusted (%)	Burn time (sec)	flame height (cm)	Describe how you manipulated the fuels
1. Particle Size	Fine fuels							
	Coarse fuels							
2. Moisture	Moist fuels							
	Dry fuels							
3. Loading	Heavy fuels							
	Light fuels							
4. Spatial Arrangement	Loosely packed							
	Tightly packed							

6. Pyrolysis

Lesson Overview: Students learn the steps of *combustion* and *pyrolysis* through videos, class discussions, and an optional activity.

Lesson Goal: Increase students' understanding of the combustion process.

Subjects: Science, Reading, Writing, Speaking and Listening, Arts

Duration: 40 minutes

Group size: Whole class

Setting: Indoors

New FireWorks vocabulary: *ash, cellulose, pyrolysis, charcoal, pyrolysates*

*Fire activity is optional

Objectives:

- Students can explain the steps necessary for fuels to combust.
- Students can explain that gaseous, pyrolyzed molecules (pyrolysates) are the source of the flames from combustion.

Standards:		9th	10th	11th	12th
CCSS	Writing Standards	1,4,10		1,4,10	
	Speaking and Listening	1,4,6		1,4,6	
	Language	1,6		1,6	
	Writing: Science and Technical Subjects	1,4,7,10		1,4,7,10	
NGSS	Matter and Its Interactions	PS1.B			
EEEGL	Strand 1	A,C,D,E,F,G			

Teacher Background: In order for wildland fuels to burn, several things have to occur:

1. Temperature of moisture must rise to the boiling point (~100° C (212° F))
2. Moisture must be changed from liquid phase to gas phase (stays at 100° C (212° F))
3. Temperature of fuels must rise to the point where carbohydrates *pyrolyze*—that is, break down into small molecules (200°-300° C (400°-600° F)) in the gas phase
4. The small, gaseous carbohydrate molecules must combine with oxygen. This is combustion! See Figure H06-1 on Handout H06-1 for a diagram of the process – the Stair Step Guide to Combustion. This guide is referred to throughout the activity.

This activity examines these 4 steps in the processes of combustion, in particular combustion of wood. Watch the video in Step 3 below for further, detailed background.

The assessment for this activity can be done either through watching a video or through setting up a laboratory investigation of pyrolysis in a burning candle. This investigation is the "optional activity" referred to above.

Materials and Preparation:

- Access to internet. Make sure you can play the videos referred to in Steps 1 and 3.
- Make 1 copy of **Handout H06-1: Combustion and Pyrolysis** for each student

Procedure:

1. Ask: When you light something on fire, what exactly is burning? What is making the flames?
2. Show this 1.5-minute video: https://www.youtube.com/watch?v=Ky5AvnXGqC0. Ask:
   a. Just before you see the first flame coming off the wood, what do you see occurring?
   b. Why does the lighter fail to ignite the wood the first three times it comes near?
   c. Once the lighter does ignite the wood, what is actually creating the flames?

   Explain: We'll learn about some subtle aspects of combustion in this activity.
3. Give a copy of **Handout H06-1: Combustion and Pyrolysis** to each student. Explain: Look at the figure at the top of the handout, **Figure H06-1: Stair Step Guide to Combustion**. Let's look at the video again (https://www.youtube.com/watch?v=Ky5AvnXGqC0.) and use the stair step guide to explain what is happening.
   a. Just before you see the first flame coming off the wood, what do you see occurring? Water is being driven off. We're seeing some of it (condensed into tiny droplets) as it leaves the hot wood. We're seeing Steps 1-2 in the stair step guide. Explain: There may be tars and other volatile substances in the vapors too.
   b. Why does the lighter fail to ignite the wood the first three times it comes near? Two things may be going on: First, the water may still be heated and vaporized from the wood, absorbing the heat from the lighter (steps 1-2 in the stair step guide). Second, the heat from the lighter has not yet gotten the *cellulose* (fuel) hot enough to break down – that is, to *pyrolyze* (step 3) - into particles small enough to combine with oxygen molecules and burn (step 4). As we learned in Activity H03, cellulose is just a very, very long chain of glucose molecules strung together. It is the formula for glucose ($C_6H_{12}O_6$) that we used in the chemical equation (model) for combustion.
   c. Once the lighter does ignite the wood, what is actually burning? Carbohydrates that have been pyrolyzed – that is, broken down into flammable gases (pyrolysates).
4. Explain: Now we will watch a 13-minute video that explains the pyrolysis and combustion of wood in detail. We'll pause the video several times so you can answer the questions on Handout H06-1. Use the stair step guide as you answer the questions.

5. Start the video: https://www.youtube.com/watch?v=15ah91txQAE
   - Pause at 3:35. Have students answer Question 1 - "What is the white stuff in the cylinder?" - or discuss the answer as a class. For an explanation, see the answer key. Press play.

   - Pause at 4:10. Have students answer Question 2 - "What is the yellow smoke filling up the cylinder?" – or discuss. See the answer key. Press play.

   - Pause at 6:10. … Question 3 – "What is burning to create the flames?" …

   - Pause at 9:05. … Question 4 – "What has left the wood?" …

   - Pause at 9:26. … Question 5 – "What is left after all of the cellulose has been pyrolyzed?" …

   - Pause at 11:05. … Question 6 – "Why does wood burn with a flame, while charcoal smolders without a flame?" …

   - Pause at 12:00. … Question 7 – "What is ash, why doesn't it burn, and why is it good for the soil?" …

   - Press play and watch until the end.

Assessment: Show this video of a candle being lit – several times, if necessary https://www.youtube.com/watch?v=EJpVd6pcYOA OR rather than showing the video, have your students DO the video. This is the OPTIONAL ACTIVITY.

Have students answer this question orally or in writing: **When the candle is lit for the second time, what is igniting and creating the flame? Explain what is happening using the stair step guide.**

After viewing the video, especially in slow motion (or doing the activity), students should notice that the match does not come in contact with the wick when the candle is ignited for the second time. How does it ignite? The pyrolysates (flammable gases) that were produced from the candle wax during the first flame had not all burned before the flame was extinguished. Because they were trapped by the cup-shaped extinguisher, they had not dispersed before the second match reached them, so they were ignited by the second match. Combustion of these pyrolysates re-ignites the candle.

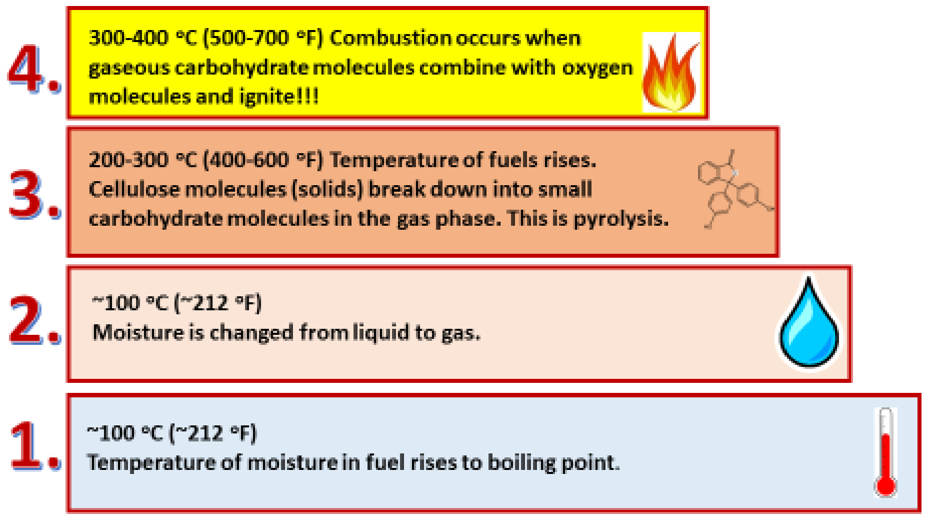
Evaluation:

Fully successful	Moderately successful	Not successful
-Student explained that pyrolysates from the first ignition remained and were ignited before the wick ignited. -Student referred to Steps 3-4 of the stair step guide.	-Student's explanation referred to either pyrolysis or the stair step guide, but not both – or interpreted one of them incorrectly.	-Student did not refer to either pyrolysis or the stair step guide – or interpreted them incorrectly.

Handout H06-1: Combustion and Pyrolysis

Name______________________________

Figure H06-1: Stair Step Guide to Combustion.



1. What is the white stuff in the cylinder? Use the stair step guide to answer.

2. What is the yellow smoke filling up the cylinder? Use the stair step guide to answer.

3. What is burning to create the flames? Use the stair step guide to answer.

4. What has left the wood?

5. What is left after all of the cellulose has been pyrolyzed?

6. Why does wood burn with a flame, while charcoal smolders without a flame?

7. What is ash, why doesn't it burn, and why is it good for the soil?

Answer Key: H06-1: Combustion and Pyrolysis

1. What is the white stuff in the cylinder? Use the stair step guide to answer. Water that has been driven off from the fuels. In the stair step guide, we are moving through Steps 1 (blue) and 2 (pink).

2. What is the yellow smoke filling up the cylinder? Use the stair step guide to answer. Products of pyrolysis, also called *pyrolysates*. The heat is breaking carbohydrates (long chains of *cellulose* and related molecules) into smaller molecules – small enough that they stay in the gas phase. This is *pyrolysis*, Step 3 (orange) in the stair step guide.

3. What is burning to create the flames? Use the stair step guide to answer. The small, gaseous carbohydrate molecules that were created by pyrolysis. This is *combustion*, Step 4 (yellow) in the stair step guide.

4. What has left the wood? Water and pyrolysates have left.

5. What is left after all of the cellulose has been pyrolyzed? *Charcoal*, which the presenter calls "coal" and refers to as elemental carbon, "C" in the periodic table.

6. Why does wood burn with a flame, while charcoal smolders without a flame? Flame is a sign that fuel has pyrolyzed and is burning, but also that the fuel is burning with less than 100% efficiency and produced soot. Flames are glowing particles of soot, which is elemental C. Since charcoal has already lost all of the cellulose that could be pyrolized, it does not burn with a flame. Watch this 7-minute video "What is a Flame?": https://www.youtube.com/watch?v=5ymAXKXhvHI

7. What is ash, why doesn't it burn, and why is it good for the soil? Ash consists of minerals, which do not burn. Some of these are essential nutrients for plants; they may enrich the soil for a few years after wildland fires.

7. Fire Spread Processes: Cutting Edge Research on Heat Transfer, Fuel Properties, Pyrolysis, and Ignition

Lesson Overview: This culminating lesson on the physical science of wildland fire challenges students to expand their understanding and link their knowledge of heat transfer processes, fuel properties, pyrolysis, and ignition through a series of thought-provoking videos and a presentation about current research – in particular, research currently underway at the Missoula Fire Sciences Laboratory on heat transfer and ignition.

Subjects: Science, Reading, Writing, Speaking and Listening, Arts

Duration: 40 minutes

Group size: Whole class

Setting: Indoors

No new FireWorks vocabulary

Lesson Goal: Students learn about current fire spread research and expand their understanding of basic fire spread processes.

Objectives:

- Students will use their understanding of radiation and convection to explain how wildland fuels of different sizes and shapes are heated to ignition in different ways.

Standards:		9th	10th	11th	12th
CCSS--ELA	Writing Standards	1,4,7,10		1,4,7,10	
	Speaking and Listening	1,4		1,4	
	Science/Technical Subjects	7,10		7,10	
NGSS	Energy	PS3.A, PS3.B, PS3.D			
EEEGL	Strand 1	A,B,C,D,E,F,G			

Teacher Background: Early research on fire behavior modeling (1960s-1970s) focused on predicting the rate of spread of wildland fires rather than understanding basic fire spread processes. It was assumed that rate of spread was controlled by heating through radiation, although this assumption was not tested experimentally at the time. The resulting fire spread models, which fire managers still use to predict the spread on wildland fires, are based on the assumption that radiation drives fire spread.

To better understand how wildland fires spread, current research is focusing on the physics of fire spread. Recent observations on wildland fires and on highly controlled laboratory fires, including many experiments conducted by Dr. Sara McAllister and Dr. Jack Cohen at the Missoula Fire Sciences Laboratory, have caused scientists to question the general assumption that radiation governs fire spread. They are now investigating flow dynamics at the flaming front, the conditions needed to sustain ignition in fuels of different sizes and shapes, the ways in which flames are propagated through fuels, and the ways in which fire burns in live fuels.

This activity focuses on just one aspect of current research: understanding how individual fuel particles are heated to the ignition point. This is important because it determines when the particle will ignite and how long it will continue to burn. The activity asks students to draw on their knowledge of heat transfer, fuel properties, and pyrolysis. With this knowledge, they learn that cutting-edge research sees fire spread as the result of a sequence of ignitions, and that particles are heated to ignition in different ways: Fine fuels are heated mainly by convection and coarse particles mainly by radiation.

Materials and Preparation:

- Download *H07_HeatTransfer_FuelProperties.pptx.* Check that the video segments work.
- Make 1 copy of ***Handout H07-1*** per student.

Procedure:

1. Begin the PowerPoint presentation. Show only slides 1 and 2.
   - Slide 1 reviews heat transfer processes (conduction, radiation, and convection).
   - Slide 2 reviews the fuel characteristics of fine and coarse fuels.

2. Pass out the handout. Have students answer question 1.

3. Return to the PowerPoint. View slide 3, a video recording of a crown fire spreading through a forest. Ask students to watch for anything that surprises them. Pause the Powerpoint. Have students answer question 2 on the handout.

4. Very observant students may have been surprised to see that the large, horizontal log in the foreground ignites before the fine surface fuels near it. If no one mentioned this, point it out. Return to the PowerPoint, slide 4, in which you view the same video at half speed. Pause and discuss preconceptions (that fine fuels always drive fire spread) and what the video shows (ignition of a large log ahead of fine fuels). Is anyone surprised? Even if the students weren't, tell them that scientists studying fire behavior were puzzled with this observation!

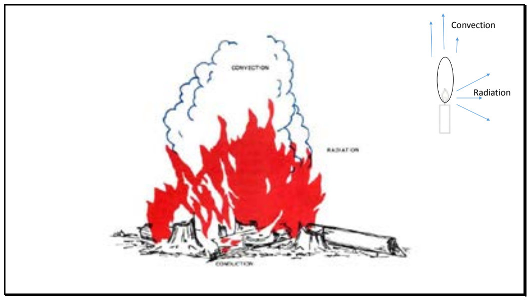
5. Continue the PowerPoint presentation to learn about the complicated relationship between heat transfer processes and fuel particle size and shape.

Assessment: Have students complete the rest of Handout H07-1.

Evaluation: Refer to the Handout H07-1 answer key.

Slides and Narrative for *H07_HeatTransfer_FuelProperties.pptx*

Slide 1



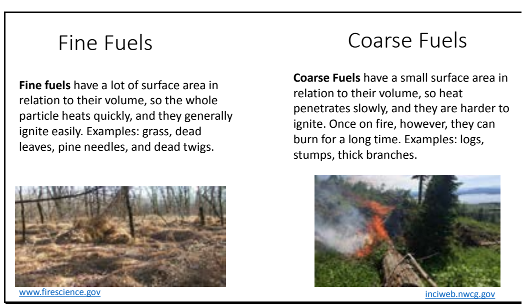
Review:

Conduction: Heat is transferred through the direct contact of atoms or molecules within solid objects. In wildland fire, conduction enables heat to move from an object's outside to its inside and from one solid object to another one that it is touching.

Radiation: Heat is transferred through space. Heat from a fire travels as waves or particles through the space between air molecules and heats the first molecules it touches, such as wildland fuels.

Convection: Heat is transferred as hot gases (or liquids) expand and move from a hot area into a cooler area. In gases, convection is the expansion of a bubble of hot gases into the cooler gases surrounding it. Since Earth's atmosphere becomes "thinner" (less dense) as you go up in altitude, "up" has less resistance to the expanding gases than "sideways" or "down." Thus hot air generally rises, as do the hot gases produced by fire.

Slide 2



Remind students what they learned in the fuel properties lesson: that fuels with higher surface area to volume ratio (SA/V) have more surface available to absorb heat than fuels with a lower SA/V. Thus one may expect that fine fuels, which have a high SA/V, should gain heat faster and ignite more quickly than coarser fuels, which have a low SA/V.

Slide 3

Show this video, which is played at actual speed.
Pause the presentations so students can answer Question 2 on the handout.

Slide 4

Show the same video played at half speed. Focus on the big log at the center of the video. What ignites first? After a class discussion and watching this video, students may wish to change their answers to Question 2.

Slide 5

This is surprising! We thought that fine fuels were easier to ignite than coarse fuels….

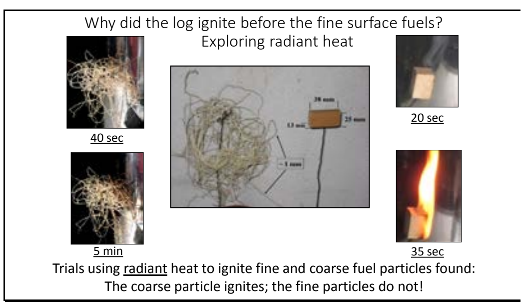
So why is it easier to light campfires when we put fine fuels on the bottom and coarse fuels on top?

The relationship among heat transfer processes (radiation vs. convection), fuel size, and fuel shape matters.

Let's take a closer look at this!

Did the video meet our expectations about ignition of fine vs. coarse fuels?

Slide 6

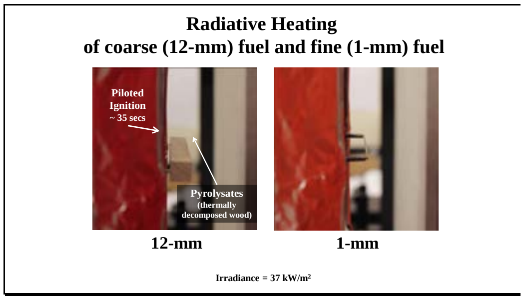


Scientists at the Missoula Fire Sciences Laboratory in Missoula, MT, tested fuel particle heating and ignition of fine and coarse fuels using <u>radiant heat.</u> (FYI: 37 kW/m^2 Irradiance.)

- Scientists put fine and coarse fuel particles at the same distance away from a radiant heater and timed how long it took to ignite the fuels.
- They found that the coarse wood block began to pyrolize after 20 seconds and ignited at 35 seconds, while the fine fuels did not ignite at all.

- This is surprising given the assumption that fine fuels should ignite more quickly than coarse fuels. However, it confirms what we observed in the video, that coarse fuels may ignite more quickly than fine fuels.

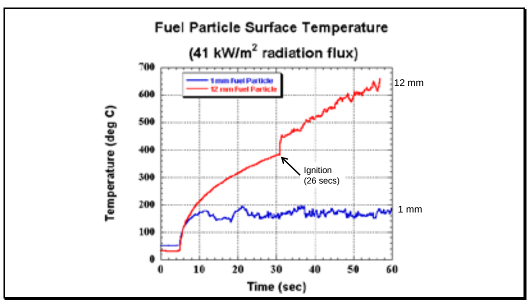
Slide 7



Here is another demonstration of radiant heat, showing that coarse fuel may ignite more quickly than fine fuel. Watch the two videos (both images are videos).

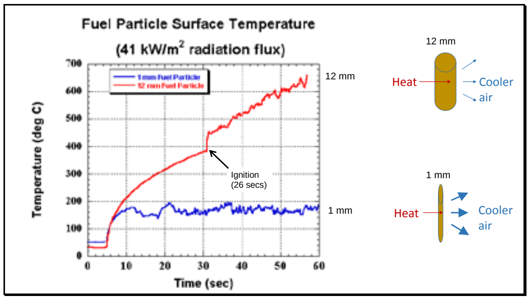
In these videos, you can see the coarse wood begin to pyrolyze at about 10 seconds. The fine wood particle does not pyrolyze at all and therefore would not ignite because it did not get hot enough to produce flammable gases.

Slide 8



Another trial.
This time scientists measured the surface temperature of coarse and fine fuel particles exposed to radiant heat.
We see that the temperature of the coarse fuel (12 mm- in red) rose quickly, and the particle was ignited at about 400 degrees C.
The temperature of the fine fuel (1 mm- in blue) did not rise above 200 C, the minimum temperature for pyrolysis, so combustion could not occur.

Slide 9



Why doesn't the fine fuel heat up as quickly as the coarse fuel?

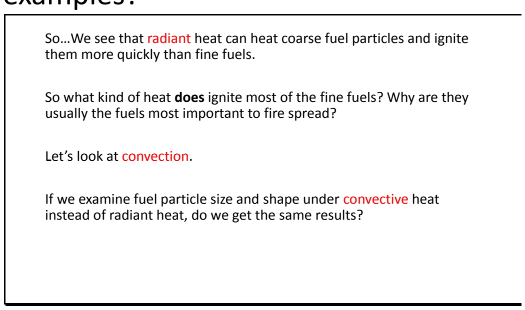
The sides of the fuel particles facing the heat source are heating up (heat is being transferred from the heat source to the fuel particles), and then the heat is conducted through the particle.

Because the coarse particle is so big, only a little heat makes it all the way through the particle. This means that there is not much heat on the backside of the coarse particle that can be transferred to the cooler air on the side away from the heat source.
Because the fine particle is so small, heat is easily conducted through it. This means that a lot of heat can be transferred from the back side of the fine fuel particle to the cooler air on the side away from the heat source.

Another reason that the fine particle does not heat up as quickly as the coarse particle is that air flows around the two particles differently because of their different sizes. Heat is lost is more efficiently around the fine particle than the coarse particle.

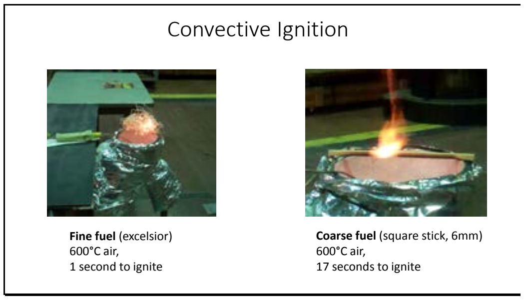
That is why cooling fins on refrigerators are thin. Can you think of other examples?

Slide 10



Current state of knowledge, based on Sara McAllister's and Jack Cohen's research at Missoula Fire Lab. **The relationship between heat transfer processes (radiation vs. convection) and fuel size and shape matters.** (Conduction is not directly addressed in these experiments.)

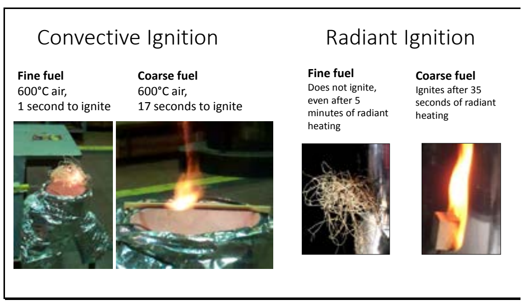
Slide 11



Scientists at the Missoula Fire Sciences Laboratory in Missoula, MT, tested heating and ignition of fine and coarse fuels using convective heat.

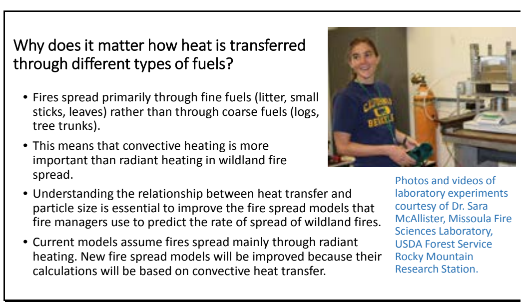
- They put fine and coarse fuel particles at the same distance above a hot air torch (works like a very powerful hair dryer) and timed how long it took to ignite the fuels.
- The fine fuels ignited at 1 second, while the coarse stick ignited in 17 seconds.
- This result is the opposite of what they found with radiant heat.

Slide 12



So we see that convective heat is more efficient at heating fine fuels (images on left), and radiant heat is more efficient at heating coarse fuels (images on right).
Why does this matter?

Slide 13



Handout H07-1: Heat transfer and fuel properties

Name ___________________________

View slides 1-2 of the presentation. Then answer this question.

1. This image shows a crown fire burning through a forest. The fire is moving from the left to the right. Predict which fuels will ignite first as the fire passes into the center of the image.

View slide 3 of the presentation. Then answer this question.

2. Was your prediction correct? Which fuels ignited first? If your prediction was not correct, are you surprised by what you observed?

After the presentation, answer these questions.

3. Describe and draw how you would build a campfire to ignite readily and then keep burning. Label your fine fuels and coarse fuels. Show where you would ignite the campfire.

4. Where is the heat from the match going? What kind of heat is igniting the fuels and what fuels do you expect to ignite first/last?

5. If you build a fire in a tepee shape, once the coarse fuels are burning, why does the teepee shape help to keep the coarse fuels (large sticks) burning?

6. What would happen to the burning large sticks if you knocked the tepee over and scattered the large sticks around your fire ring?

7. In the video, what kind of heat transfer caused the coarse log to ignite before the fine fuels around it?

8. What kind of heat usually causes fine fuels to ignite very quickly and usually be at the forefront of fire spread?

Handout H07-1 KEY: Heat transfer and fuel properties

Name ________________________________

View slides 1-2 of the presentation. Then answer this question.

1. This image shows a crown fire burning through a forest. The fire is moving from the left to the right. Predict which fuels will ignite first as the fire passes into the center of the image.
   Any answer is okay. This question is to get students thinking.

View slide 3 of the presentation. Then answer this question.

2. Was your prediction correct? Which fuels ignited first? If your prediction was not correct, are you surprised by what you observed?
   Student answers should reflect their answer to question 1.

After the presentation, answer these questions.

3. Describe and draw how you would build a campfire to ignite readily and then keep burning. Label your fine fuels and coarse fuels. Show where you would ignite the campfire.
   I would put the fine fuels on the bottom and coarse fuels on top. I would ignite the fine fuels from the bottom.

4. Where is the heat from the match going? What kind of heat is igniting the fuels and what fuels ignite first/last?

Convective heat from the match is rising, heating, and igniting the fine fuels. With enough heat, the coarse fuels above will ignite.

5. If you build a fire in a tepee shape, once the coarse fuels are burning, why does the teepee shape help to keep the coarse fuels (large sticks) burning?
When large sticks are burning and facing each other, heat, especially radiant heat, is trapped inside the tepee. This helps to sustain the burning.

6. What would happen to the burning large sticks if you knocked the tepee over and scattered the large sticks around your fire ring?
The large sticks would likely go out because the radiant heat is escaping, and there is no convective heat coming from the ground or radiating up around the fuels.

7. Based on what you have learned from the presentation, think again about the video that shows the coarse log igniting before the fine fuels around it. What kind of heat transfer probably caused the log to ignite before the fine fuels?
Radiant heat

8. What kind of heat usually causes fine fuels to ignite very quickly and usually be at the forefront of fire spread?
Convective heat.

8A. Fire Environment Triangle and Fire Spread: The Matchstick Forest Model (Option A)

****Note: This lesson has goals and objectives similar to those of Activity 8B, The Landscape Matchstick Model****

Lesson Overview: In this activity, students design and conduct an experiment to investigate how slope and the density of trees (or other kinds of standing fuels) affect fire spread.

Subjects: Science, Mathematics, Health and Safety, Writing, Speaking and Listening
Duration: 45-90 minutes
Group size: lab groups
Setting: Indoor laboratory or outdoors
New FireWorks vocabulary: *controlled experiment, Fire Environment Triangle, slope, stand/forest stand/standing fuels, stand density, trial, treatment*

Lesson Goal: Increase students' understanding of experimental methods and wildland fire spread.

Objectives:

- Students will design a controlled experiment to investigate relationships among slope, stand density, and fire spread.
- Students will write a hypothesis, conduct an experiment, summarize results, and draw conclusions.
- Students will compare their experiment and results to those of their classmates.

Standards:		9th	10th	11th	12th
Common Core ELA	Writing Standards	1,4,7,10		1,4,7,10	
	Language Standards	1,2,3		1,2,3	
	Science/Technical Subjects	3,7		3,7	
NGSS	Earth's Systems	ESS2.D, ESS2.E			
EEEGL	Strand 1	A,B,C,D,E,F,G			

Teacher Background: In this activity, students build physical models of fuel arrays in which standing fuels are represented by individual matches. Because the model provides a graphic demonstration of the way running crown fires behave in a forest, we call it the "matchstick forest" model. However, it could represent any array of standing fuels, including shrubs with highly flammable crowns and even a dense stand of grasses.

Note that the flames in this experiment can reach 30-40 cm in height. Plan accordingly. If you choose to do the experiment outdoors, even the slightest breeze will dramatically affect fire spread. Outdoor experiments may illustrate mainly that fire spread is complex and often unpredictable.

Students can use the matchstick model to investigate variables that affect the spread of wildland fire (and are aspects of the Fire Environment Triangle), such as:

Slope: If a fire is burning on a hillside, the fuels above it tend to be dried and warmed by its convective heat, and the flames are quite close to the uphill fuels. They are likely to ignite very quickly. The fuels below the fire are affected very little – at least until burning materials roll downhill and ignite new fires there. Thus fires tend to spread upslope, and a fire that starts at the bottom of a hill is likely to spread faster than one that starts on a hilltop.

Fuel density and contagion: If a fire is burning in dense forest, it may spread from treetop to treetop (*crown fire*). In more open forests, crown fires are less likely. (Here is a caveat, however: surface fires may spread more rapidly in open than dense forests because the wind speed is usually greater in openings.) Stand density has the same effect in other standing fuels, such as shrublands and thick grasslands: fire spread can be extremely rapid.

Wind: The effect of wind on fire spread is analogous to that of slope: Wind bends the flames and the heat plume so they are no longer vertical but instead lean downwind into the fuels, heating them more rapidly and increasing the rate of fire spread.

Materials and preparation:

Do this activity in a lab or outdoors. Note that even the air currents created by the lab's ventilation system will affect the experimental results.

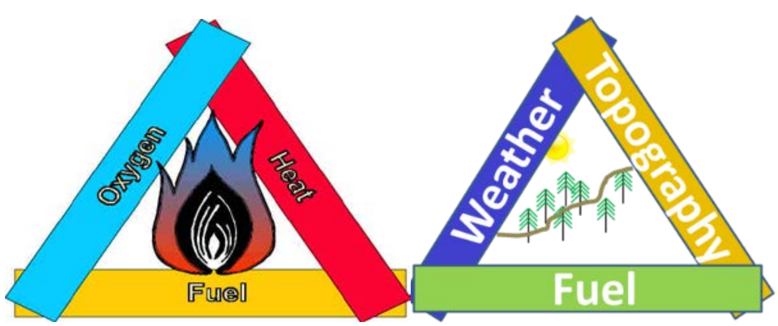
- The day before the activity, remind students to follow safety guidelines about clothing and hair when they get ready for school tomorrow.
- Get four boxes of wooden kitchen matches (not provided in the trunk).
- Display the Fire Triangle (left) and Fire Environment Triangle (right) posters.

FireWorks Safety

When you do experiments with fire…

1. Wear cotton clothing. No synthetic pants, soccer shorts, etc.
2. Wear closed-toed shoes. No sandals or flipflops.
3. Tie back loose sleeves.
4. Tie back loose hair.
5. Make sure a fire extinguisher is close. Make sure it is charged. Know how to use it.
6. Make sure spray bottles are close and filled with water.
7. Wear safety goggles when burning.
8. *Never* lean over a fire.
9. Extinguish burned materials with water before putting them in the trash. *Fire is not out if there is any smoke or heat coming from the fuels.*
10. If a fire starts on you, stop, drop, and roll.

Use fire ONLY if a responsible adult is working with you.



- Copy **Handout H08a-1** for each student or lab group.
- Have a fully charged fire extinguisher handy.
- Have an empty *metal* trash can *without a plastic liner* available*.*
- Set up a lab bench or other safe space for each student team[1], using the following equipment:
  - 1 metal tray (i.e., cookie sheet)
  - 1 ashtray
  - 1 spray bottle, filled with water
  - 1 box of matches
  - 1 matchstick forest board
  - 1 ruler
  - A short, medium, and long bolt and 1 nut from the matchstick forest kit
  - A small nail for removing burned match stubs from the board
- Make sure each student team has a time keeping device.

Procedure:

1. Do a **safety checkup** with students using the *FireWorks Safety* poster.
2. Refer to the posters for the Fire Triangle and the Fire Environment Triangle - or draw or project them. Explain: We've been studying the chemistry of combustion. We used the model of the Fire Triangle, which can be applied to any fire – from a campfire to the fire in an internal combustion engine. Now we'll narrow our focus to combustion in wildlands, and we'll use a slightly different model, the Fire Environment Triangle (also known as the Fire Behavior Triangle). This model reminds fire managers and firefighters of the three things in the environment that control how wildland fires behave: fuel, weather, and topography.
3. Explain: You will design and carry out *controlled experiments* to learn about the relationships between fire spread and some of the variables in the Fire Environment Triangle. "Controlled" means that you will change just 1 thing about the procedure each time you repeat it (that is, in each *trial*), "controlling" everything else so you can find out how that one thing, the *experimental variable,* affects your results.
4. Ask students for some specific aspects of the Fire Environment Triangle that affect the behavior of wildland fires. Examples:
   - **Topography:** slope steepness, aspect, position in relation to heat source, number and location of ignition points, potential for heat to escape (open slope vs. within canyon)
   - **Fuels:** arrangement (both vertical and horizontal), moisture, amount, height, density, patchiness (vs. uniform spatial arrangement)
   - **Weather:** wind direction and strength, relative humidity, temperature, precipitation amount and duration
5. Give each student a copy of **Handout H08a-1**.

[1] The trunk is supplied with 4 sets of equipment.

PART 1- Discuss an example using a thought experiment.

6. Using **Handout H08a-1**, discuss how to design an experiment that investigates one aspect of fire behavior. Do a "thought experiment" using an intuitively obvious example for the experimental variable, such as snow. Go through Steps A-G in the handout, discussing how to set up a controlled experiment to investigate the relationship between the experimental variable and fire behavior.

7. In the context of the thought experiment, review these terms:
   - ***Experimental variable***-the variable that they are testing by changing it from one trial to the next (e.g., snow).
   - ***Treatment***- the way they change that experimental variable from one trial to the next (e.g., no snow, light snow, moderate snow, very deep snow).
   - ***Variables measured***- the measurable results from trials in the experiment. These are things that are observable and measurable about fire behavior (e.g., matches burned, burning time, flame height).

PART 2-Students design and conduct experiments to measure fire spread.

8. Explain: Student groups will design and conduct their own experiments to figure out the relationship between an aspect of the Fire Environment Triangle and fire behavior. After the experiments are complete, each group will describe their experiment and report their results so the entire class can learn how each experimental variable affected fire behavior in the matchstick model.

9. Assign an experimental variable to each group. You may use the student answers from question 4 above, from the table below, or create your own.

10. Instruct students to use **Handout H08a-1** to investigate their experimental variable. Have them answer the questions A-G, then get your approval, before proceeding on the formal experiment. Suggest that they try their methods in a couple of test burns before doing the full experiment. Here are some examples of possible tables for results.

Example 1- Experimental variable: Density	Treatments	Burning time (sec)	Max flame height (cm)
	49 matches		
	37 matches		
	25 matches		
	12 matches		

Example 2- Experimental variable: Slope	Treatments	Matches burned (%)	Max flame height (cm)
	Very steep		
	Steep		
	Moderately steep		
	Flat		

Example 3- Experimental variable: Ladder fuels	Treatments	Matches burned (%)	Burning time (sec)
	No Ladder fuels (all full matches)		
	Some matches cut shorter		
	Some matches are cut to different lengths		

Example 4- Experimental variable: Ignition location	Treatments	Matches burned (%)	Burning time (sec)	Max flame height (cm)
	Ignite top row			
	Ignite outside column (start with top match, work down)			
	Ignite middle column (start with top match, work down)			
	Ignite bottom row			

11. As the groups proceed, check their experimental designs. **Emphasize that, in their design and completion of the experiment, they can change only their experimental variable and keep all others constant.** If they don't, they won't be able to attribute their results to the experimental treatment.

12. Monitor for safety while they conduct their experiments.

13. As the groups complete their experiments, have them prepare to project their results or have them copy their results to the board (Step H on the handout).

14. Ask each group to describe their experiment and results to the class (Step I on the handout).

Assessment: Have each student write a formal report (section J on the handout).

Evaluation: Assess students' responses to the questions in section J using these guidelines:

Question(s)	Highly successful	Moderately successful	Unsuccessful
1-2	Hypothesis addresses question.	Hypothesis addresses question.	Hypothesis does not address question.
3	Refers to experimental results that demonstrate or contradict hypothesis.	Does not interpret or use experimental results appropriately.	Does not address hypothesis or use experimental results appropriately.
4	Answer is clear and refers to Question 1.	Answer refers to Question 1.	Answer is unclear and does not refer to Question 1.
5	Student listed 2 or more questions.	Student listed 1 question.	Student listed no questions.
6	Student made at least 1 clear recommendation to each of the 3 groups.	Student made at least 1 suggestion to 1-2 groups, or suggestions were vague, unclear.	Student either made no suggestions or made suggestion to just 1 group.
7	Student answered all 3 questions with specifics.	Student answered 1-2 questions or answers were vague, unclear.	Student answered 1 question or none.

Handout H08a-1.

Name(s): ____

OUR INSTRUCTIONS:

Develop your experimental plan (this page).
Get the teacher's approval to proceed (bottom of this page).
Carry out the experiment.
Share your results (next page).
Write and submit your report (next page).

OUR EXPERIMENTAL PLAN:

A. Our experimental question: What is the effect of __________________________ on fire behavior?

B. Our hypothesis:

C. Our *experimental variable,* the one thing that we will change from one trial to the next. (Take this from "A" above):

D. Our treatments, the way we change our experimental variable from one trial to the next:

E. Our *controlled conditions*, things that we will not change from one trial to the next:

F. The things (variables) we will observe and measure – which become our experimental *results*:

G. Our table for recording record data from each trial burn.

TEACHER'S APPROVAL: Teacher's initials approving our experimental design: _____________

SHARING EXPERIMENTAL RESULTS

H. When you have finished your experiment, project your results or copy them onto the board.

I. Describe your experiment and results to the class. Indicate if there are any changes that you would make if you were to redo you experiment. Create two questions to ask the class about the data you collected. These questions should make your peers think critically about your experiment.

WRITE AND SUBMIT FINAL REPORT

J. **Formal Report:**

1. What is your question about fire? What are you trying to find out about fire behavior?
2. What is your hypothesis?
3. Do you accept or reject your hypothesis? Show how your results justify your answer.
4. Did your results help answer your question about fire? If so, how?
5. Did any new experimental questions emerge during your experiment? If so, what are they?
6. Based on your results, what practices would you recommend to (a) firefighters, (b) people with homes in forests, and (c) wildland managers?
7. (a) What are some limitations of the matchstick forest model? (b) What "real-world" influences on fire spread could not be tested with this model? (c) Could you revise the model or develop a different model to test them?

Handout H08a-1. Example Answer Key – using density as experimental variable

Actual answers will vary, depending on students' experimental variables and designs.

A. Our experimental question: What is the effect of ______density______on fire spread?

B. Our hypothesis:

If the matchstick boards are densely packed, then fire will spread more quickly and more matchstick tops will burn than if the fuels are sparse.

C. Our *experimental variable,* the one thing that we will change from one trial to the next.

Stand density (number of matchsticks on the board).

D. Our treatments, the way we change our experimental variable from one trial to the next:

Treatment 1 (high density): 49 matches

Treatment 2 (medium density): 37 matches

Treatment 3 (low density): 25 matches

Treatment 4 (least dense): 12 matches

E. Our *controlled conditions*, things that we will not change from one trial to the next:

Ignition point, slope, moisture, matchstick height, wind, etc.

F. The things (variables) we will observe and measure – which become our experimental *results*:

Maximum flame height, start time, stop time, burn time, and number of match tips burnt.

G. This is our table for recording data from each burn: **Suggest that students do a couple of preliminary trials to fine-tune their measuring procedures and data table. You may ask that each team have you review these before they begin the full experiment.**

	Least dense (12 matches)	Low density (25 matches)	Medium density (37 matches)	High density (49 matches)
Max. flame Height (cm)				
Start Time				
End Time				
Burn Time (secs)				
Number of Matches burned				

H. When you have finished your experiment, project your results or copy them onto the board.

I. Describe your experiment and results to the class. Indicate if there are any changes that you would make if you were to redo you experiment. Create two questions to ask the class about the data you collected. These questions should make your peers think critically about your experiment.

J. **Formal Report:**

1. What is your question about fire? That is, what are you trying to find out about fire behavior?
   How does stand density affect fire behavior?
2. What is your hypothesis?
   The denser the "forest," the faster fire will spread, the higher the flames will be, and the more match tips will be consumed.
3. Do you accept or reject your hypothesis? Show how your results justify your answer.
   I accept my hypothesis because, as predicted, the "forest" with only a few matches burned more slowly, had shorter flames, and burned fewer matches than the "forest" with lots more matches.
4. Did your results help answer your question about fire? If so, how?
   Yes, my results showed three ways in which stand density affects fire behavior.
5. Did any new experimental questions emerge during your experiment? If so, what are they?
   What if there's wind? What if the trees are different heights? How do real trees differ from matches?
6. Based on your results, what practices would you recommend to (a) firefighters, (b) people with homes in forests, and (c) wildland managers?
   - (a) Firefighters should use extreme caution when fires are burning in dense forests. They may not be able to work safely on these fires when it is very dry or hot, or if the wind is strong. (In fact, firefighters are cautioned against "direct attack" when flame lengths are high. That is, they cannot work right at the edge of the fire, especially not at the leading edge. Instead, they might use other techniques such as setting backfires or using water drops from aircraft. (National Wildfire Coordinating Group. 2014. Incident response pocket guide. PMS 461. National Wildfire Coordinating Group. 112 p.))
   - (b) People with homes in the forest (especially dense forest) should clear an area around their homes and perhaps thin the forest nearby. (It is recommended that home owners reduce fuels for at least 200 feet from their house (National Fire Protection Association, Firewise Communities. 2016. The basics of defensible space and the "home ignition zone. National Fire Protection Association. Available: http://firewise.org/wildfire-preparedness/be-firewise/home-and-landscape/defensible-space.aspx?sso=0)).
   - (c) Wildland managers could consider thinning forests or creating wide fuel breaks to reduce flame heights and slow the spread of fire in dense forests that are near homes or other valuable resources.

7. (a) What are some limitations of the matchstick forest model? (b) What “real-world” influences on fire spread could not be tested with this model? (c) Could you revise the model or develop a different model to test them?
    (a) The model doesn’t include surface fuels. The tree “crowns” are much easier to ignite than actual tree crowns. Trees are distributed uniformly in the model, unlike real forests. The topography is completely uniform – no gullies or ridges. Trees tilt with the slope. The board is very small in size, whereas real forests can extend for many miles…
    (b) Real wildland fuels were not tested. Uneven topography could not be tested. Large-scale fire spread was not tested…
    (c) I would revised the model to use a larger board, perhaps add uneven terrain. I would use real wildland fuels. I would add surface fuels…

8B. Fire Environment Triangle and Fire Spread: The Landscape Matchstick Model (Option B)

****Note: This lesson has goals and objectives similar to those of Activity 8A, The Matchstick Forest Model****

Lesson Overview: Students design a model landscape to investigate how fuels, topography, and weather affect fire behavior.

Lesson Goal: Increase students' understanding of how fuels, weather, and topography affect fire behavior in wildlands.

Subjects: Science, Mathematics, Health and Safety, Writing, Speaking and Listening
Duration: 90 minutes
Group size: Pairs
Setting: Indoor laboratory or outdoors
New FireWorks vocabulary: *density/stand density, Fire Environment Triangle, slope, stand/forest stand/standing fuels, topography, wildland-urban interface*

Objectives:

- Students can design a model of a landscape to investigate the relationships among fuels, topography, weather, and fire spread.
- Students can write a newspaper article describing how the components of the Fire Environment Triangle influenced fire spread.

Standards:		9th	10th	11th	12th
CCSS	Writing	2,3,4,10		2,3,4,10	
	Speaking and Listening	1,4,6		1,4,6	
	Language	1,2,4,6		1,2,4,6	
	Writing: Science and Technical Subjects	2,4,9,10		2,4,9,10	
NGSS	History of Earth	ESS2.B			
	Earth's Systems	ESS2.A, ESS2.D, ESS2.E,			
	Weather and Climate	ESS2.D			
	Human Sustainability	ESS3.B, ESS3.C, ETS1.B			
EEEGL	Strand 1	A,B,C,D,E,F,G			

Teacher Background: This lesson has similar goals and objectives as the previous lesson, H08A, *Fire Environment Triangle and Fire Spread: The Matchstick Forest Model*. However, this lesson takes a less structured approach. Instead of developing a controlled experiment using a small board with uniform distribution of fuels, students use clay to create models of diverse landscapes that they populate with matchsticks and other fuels. Then they observe fire spread, record their observations, and use them to create (a) a timeline for the fire and (b) a newspaper article about the fire.

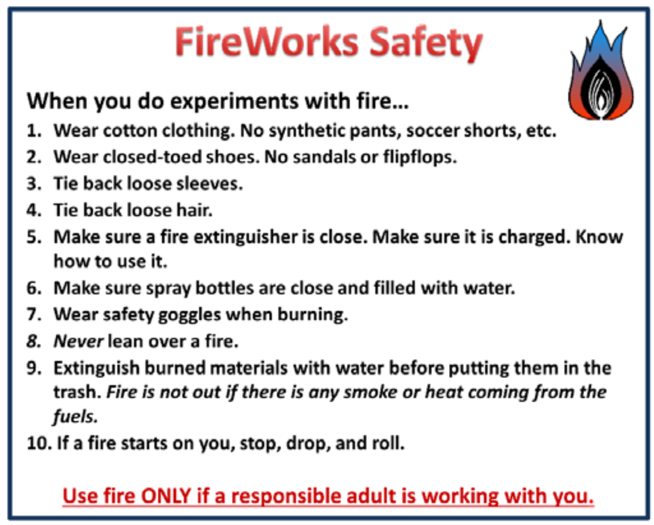
This activity includes 3-4 steps:

1. Students complete an **optional** preliminary activity (Procedure step 3, which uses Handout H08B-1) to get students thinking about fire spread in wildlands. While this is good preparation, it is not essential to the rest of the activity.
2. Student groups design a model landscape that demonstrates various aspects of the Fire Environment Triangle. Then they burn it, recording the fire with photos and video.
3. Students create a timeline of their fire.
4. Students create a case study of the fire that incorporates their timeline and explains how various aspects of the Fire Environment Triangle influenced fire spread.

Because the students need to create a timeline of their fire, it is essential that they video it. A smartphone video is adequate. Make sure they have access to the necessary equipment.

Materials and preparation:

Do this activity in a ventilated lab or outdoors, but be aware of air currents created by the ventilation system or wind. These will affect fire behavior.

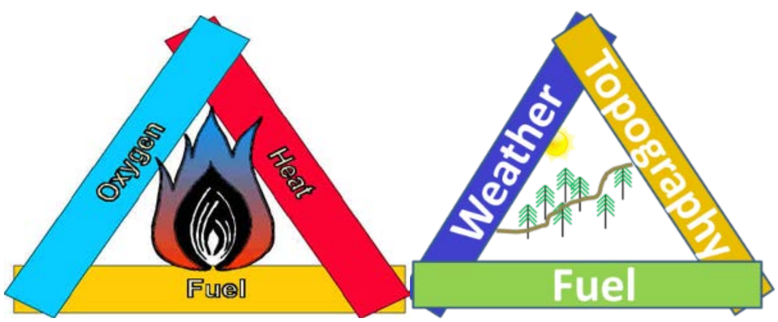

FireWorks Safety

When you do experiments with fire…

1. **Wear cotton clothing. No synthetic pants, soccer shorts, etc.**
2. **Wear closed-toed shoes. No sandals or flipflops.**
3. **Tie back loose sleeves.**
4. **Tie back loose hair.**
5. **Make sure a fire extinguisher is close. Make sure it is charged. Know how to use it.**
6. **Make sure spray bottles are close and filled with water.**
7. **Wear safety goggles when burning.**
8. ***Never* lean over a fire.**
9. **Extinguish burned materials with water before putting them in the trash. *Fire is not out if there is any smoke or heat coming from the fuels.***
10. **If a fire starts on you, stop, drop, and roll.**

Use fire ONLY if a responsible adult is working with you.

- The day before the activity, remind students to follow safety guidelines about clothing and hair when they get ready for school tomorrow.
- Display these posters: FireWorks Safety, Fire Triangle, and Fire Environment Triangle



- Set up the work space with this equipment:
  - Fire extinguisher, fully charged
  - Empty *metal* trash can *without a plastic liner*

- Set up a lab bench or other safe space for each student team[1], using the following equipment:
    - Materials provided in trunk:
        - 1 metal tray (i.e., cookie sheet)
        - 1 ashtray
        - 1 ruler
        - 1 spray bottle filled with water
    - Materials not provided in trunk:
        - 1 box of matches (not provided in trunk)
        - Clay (recipe below)
        - Cardboard squares or metal tray
        - Timing device
        - Toothpicks
        - Dixie cups or something similar (to create "hills" under the clay)
        - Aluminum foil
        - Camera/smart phones for taking both photos and video

- Have these materials available for teams to select from:
        - Small fan with at least two speeds
        - Other materials needed to model surface fuels, ladder fuels, houses, etc.
- Make 1-2 batches of salt-based clay or other clay substitute per student team:
        - Ingredients for Salt-based Clay: 1 cup salt (280 grams), 1 cup flour (140 grams), ½ cup warm water (112.50 milliliters)
        - Combine the dry ingredients in a large mixing bowl.
        - Add the water, mixed with food coloring if you wish.
        - Mix, then knead until the mixture has a smooth, dough-like texture. Add water if the dough is too dry. Add flour if it is too sticky.
        - Store in a plastic bag until lab time.

- Print one handout for each student:
        - **Handout H08B-1:** *Fire Behavior in Wildland Fuels* – **only** if you choose to do optional Step 3 below
        - **Handout H08B-2:** *Landscape Matchstick Model*
        - **Handout H08B-3:** Fire Behavior Case Study

Procedures:

1. Do a **safety checkup** with students using the *FireWorks Safety* poster.

2. Refer to the posters for *the Fire Triangle* and the *Fire Environment Triangle* - or draw or project them. Explain: We've been studying the chemistry of combustion. We used the model of the Fire Triangle, which can be applied to any fire – from a campfire to the fire in an internal combustion engine. Now we'll narrow our focus to combustion in wildlands, and we'll use a different model, the Fire Environment Triangle (AKA Fire Behavior Triangle). This

[1] The trunk is supplied with 4 sets of equipment.

model reminds fire managers and firefighters of the three things that control how wildland fires behave: fuel, weather, and topography.

3. [OPTIONAL] Distribute ***Handout H08B-1: Fire Behavior In Wildland Fuels***. This handout gets students thinking about the factors that influence fire behavior and lets you gauge their prior knowledge. To complete the handout, you could take students to an outdoor setting, find a window with a view of a wild landscape, or project an image of a wild landscape.
4. Refer again to the Fire Environment Triangle. Explain: the Fire Environment Triangle is an extension of the Fire Triangle, but it is very practical: It reminds fire managers and firefighters of the three things in the wildland fire environment that affect how wildland fires behave: fuel, weather, and topography.
5. Ask students to name some specific aspects of the Fire Environment Triangle that affect fire behavior. Examples:
   - **Topography:** slope steepness, aspect, direction of fire spread (fire spreading from top of slope vs. bottom of slope), number and location of ignition points
   - **Fuels:** arrangement (both vertical and horizontal), moisture, amount and height
   - **Weather:** wind direction and strength, relative humidity, temperature, precipitation amount and duration
6. Explain: Given a variety of materials, you will design a model landscape to observe and test how various aspects of the Fire Environment Triangle affect fire spread.
7. Distribute **Handout H08B-2: *Landscape Matchstick Model*** and instruct students to follow **steps 1-4**. **Remind them that they need to have you check the model** when it is completed and **you will tell them when to ignite it**.
8. When models are complete, gather students around each model. Have the student group describe their design, the components of the Fire Environment Triangle they are testing, and how they expect the fire to spread (e.g., rates of spread, flame lengths, burn uniformity).
9. Make sure the team is ready to take notes and to record their fire with photos and video. Then have them ignite—one model at a time.
10. Note: If fires fail to spread, students can modify variables such as ignition points or fuel arrangement and ignite their model again. All ignitions and associated fire spread should be described in their timeline and case study.
11. After each model is burned, have students compare predictions to what actually occurred.

Assessment:
Give each student or lab group **Handout H08B-3. Fire Behavior Case Study**. Have them use their notes, photos, and videos to write a **timeline** and then a 1-paragraph (or longer) **case study**. They should use the components of the Fire Environment Triangle to describe how the fire spread (or didn't spread) across their model.

Optional reading assignment: After the activity is complete, provide and discuss sections of: Fites, Jo Ann; Ewell, Carol; Bauer, Ryan. 2012. The 2012 Chips Fire, California: a case study of fire behavior. Unpublished report. Available: https://www.fs.fed.us/adaptivemanagement/reports/ChipsFireBehavior_Fullreport_16Jan13FINAL.pdf

Evaluation:

	Excellent/Credit	**Good/No Credit**	**Fair**	**Poor**
Image:	Student included images	Student did not include images.		
Topography	Student describes all features of their landscape in detail and how those features impacted/didn't impact fire spread.	Student describes most features in landscape and how those features impacted/didn't impact fire spread.	Student described some features in landscape and how those features impacted/didn't impact fire spread.	Student failed to describe any features in landscape and/or did not explain how the features impacted/didn't impact fire spread.
Weather	Student describes in detail how weather impacted fire spread.	Student provides basic explanation for how weather impacted/didn't impact fire spread.	Student's description of how weather impacted/didn't impact fire spread was partially inaccurate or incomplete.	Student's description of how weather impacted/didn't impact fire spread was incorrect or not present.
Fuel	Student describes the fuels in detail and how they impacted/didn't impact fire spread.	Student basic description of fuels and how they impacted/didn't impact fire spread.	Student's description of fuels was partially inaccurate or incomplete.	Student's description of fuels was incorrect or not present.

Handout H08B-1: Fire Behavior In Wildland Fuels

Name: ________________________________

1. Write a list of factors that influence how fires burn in wildlands.

2. Sketch Landscape A in the red box below, either from a location outdoors or from a photo provided by the teacher. Include details that would probably influence fire spread. Then write a few sentences in the empty space that describes how a fire would spread on this landscape if the lower left corner of the landscape was ignited.

Landscape A:

3. Sketch landscape B in the red box below, either from the landscape that surrounds your home or from a photo provided by the teacher. Include details that would probably influence fire spread. Then write a few sentences describing how you think a fire would spread on this landscape if the lower left corner of the landscape was ignited.

Landscape B:

Handout H08B-2: Landscape Matchstick Model

Name: ___________________________________

You will design a model landscape to investigate how fuels, topography, and weather affect fire behavior. **Be sure to record your fire with photos and video**, because you will need these records afterwards.

1. Select variables from the Weather, Topography, and Fuel columns below (components of the Fire Environment Triangle) to include in your model. Select additional variables (if desired) from the other columns.

Weather	Topography	Fuel	Concerns for fire managers – where are they relative to topography, fuels, and transportation network?	Fire protection techniques:
• Wind speed • Precipitation • Humidity	• Hilly vs flat • Gullies • Canyons • Slope steepness • Aspect • Water & waterways	• Forest (various tree densities) • Surface fuels (various amounts, depths, fluffiness, continuity) • Fuel moisture	• Homes • Other structures • Power lines • Cell towers • Roads	• Fuel break • Foil-wrap buildings • Spray or foam • Sprinkler system

2. Sketch your landscape to show how your selected variables will be incorporated. On your sketch, label and explain how each variable will be changed during the burn so you can see its effect on fire behavior.
3. Make a list of materials you need to create your landscape, such as: clay, tinfoil, cups, rocks, toothpicks, pine needles, matches etc. Obtain the materials from your teacher, around the school, or from outdoors.
4. Use your sketch to create your landscape. Be creative! Make up names for the fire, town, communities, streets, valleys, ridges, mountains, etc.
5. When you are satisfied with your model landscape, **STOP!** You need to show it to the teacher and your class before igniting it.
6. When your teacher indicates, describe your model to the class. Tell them where you will ignite your model and predict how the fire will spread.
7. When your teacher indicates, ignite your model. Video, photograph, and take notes while your model burns.
8. Discuss the accuracy of your predictions.

Handout H08B-3: Fire Behavior Case Study

Name: _________________________________

Overview: Using your notes, photographs, and videos…

1. Write a **timeline** to describe your fire. Include at least 5 entries (points in time). Give specific details about the development of your fire from ignition until it went out. For an example of an actual fire timeline and the important details that are included, read the "The 2012 Chips Fire, California: A Case Study of Fire Behavior" (below).
2. Write a 1-paragraph (or longer**) Case Study** of your fire to accompany the timeline. This is a description of your fire and its behavior. Use all three components of the Fire Environment Triangle to describe how the fire spread (or didn't spread) across your model landscape. Include photos of your model before and after it burned, as well as other photos that illustrate the fire behavior and how it is related to the Fire Environment Triangle.

Getting Started--Brainstorming Space:

- Name of fire:
- Starting location description (include fuel type, weather, topography):
- At each point in time, where did it spread and what influenced it (fuel type, weather, topography)?
- Ending location? (fuel type, weather, topography):

The 2012 Chips Fire, California:
A Case Study of Fire Behavior

Chips Fire, Aug.2, 2012.
Forest Service photo.

Observations of fire spread and behavior during the initial stages of the Chips Fire (modified from Fites and others, 2012*).

Time	Observations
1 (Jul 29)	Fire started on the lower, mid-slope in the Chips creek drainage.
2 (Jul 30)	Slow progression in the "footprints" (area previously burned) of 2000 Storrie and 2008 Belden fires. Extremely steep (>55% and >70%) slopes in Feather River canyon.
3 (Jul 31)	Fire spread further, moving up the Indian Creek drainage with the wind. Numerous hand crews (including six hotshot crews) built line around the flanks of the fire and worked direct attack to suppress the fire in very steep terrain that was difficult to access terrain. They experienced high "resistance to control" in the dense cover of big snags and logs. Firefighters were holding the fire along the ridge. Some retardant was used on the ridge in hopes that it would slow the fire when it reached there.
4 (Aug 1)	Fire spread rapidly up slope in the Indian Creek drainage to the top of Indian Springs Ridge and spotted more than a mile away on the ridge between Yellow Creek and the Caribou/North Fork Feather River drainage. Fire developed with an impressive vertical column. Post-fire observations show very high fuel consumption and other evidence of very high intensity.
5 (Aug 2)	Fire grew significantly (>2000 acres) to the northeast and east, exceeding the ability of crews to attack it directly. Fire rolled over Indian Springs ridge and ignited material that rolled downhill and ignited new spot fires at the bottom of the slope in Squirrel and Cub Creeks. These spot fires then burned rapidly, with very high intensity, up the slope. Similar behavior was experienced on the spot fire in the Caribou drainage.
6 (Aug 4)	Limited fire information was obtained this day due to poor visibility, which limited aerial observation, and due to inability of ground crews to safely access the fire.
7 (Aug 8)	Fire moved out of the Storrie fire footprint. It spread into Mosquito Creek and burned slowly for two days. Future large growth in the fire is expected.
8 (Aug 9)	Little fire growth occurred in Mosquito Creek, but great spread occurred to the east and northeast……….

*For the full report, see Fites, Jo Ann; Ewell, Carol; Bauer, Ryan. 2012. The 2012 Chips Fire, California: a case study of fire behavior. Unpublished report. Available: https://www.fs.fed.us/adaptivemanagement/reports/ChipsFireBehavior_Fullreport_16Jan13FINAL.pdf. For the full timeline, see p. 7.

9. Ladder Fuels and Fire Spread

Lesson Overview: In this activity, students create a physical model to learn how the vertical arrangement of fuels affects the potential for fires to spread into tree crowns.

Lesson Goal: Increase students' understanding of the relationship between fuel arrangement and vertical fire spread, especially in forests, shrublands, and woodlands.

Subjects: Science, Writing, Health and Safety

Duration: 90 minutes

Group size: Whole class, working in small groups

Setting: Indoor laboratory or outdoors

New FireWorks vocabulary: *crown fire, crown fuels, ladder fuels, surface fire, surface fuels, succession*

Objectives:

- Students can describe differentiate between surface fires and crown fires, and describe the wildland fuels that contribute to these kinds of fire behavior.
- Students can design model trees that can withstand surface fire.
- Students can create a storyboard that describes the relationship among stand structure, fuel arrangement, and fire spread.

Standards:		9th	10th	11th	12th
CCSS	Writing	2,4,5,6,7,8,9,10		2,4,5,6,7,9,10	
	Language	1,2,4,10		1,2,4,10	
	Writing: Science and Technical Subjects	4,7,9,10		4,7,9,10	
NGSS	Interdependent Relationships in Ecosystems	LS4.C			
	Natural Selection and Evolution	LS4.B, LS4.C			
	Earth's Systems	ESS2.A, ESS2.D, ESS2.E			
EEEGL	Strand 1	C,E,F,G			

Teacher Background: This activity explores the potential for a surface fire (burning in vegetation on the forest floor) to spread up into the crowns of overhanging trees. The more continuous the fuels, the more likely this will happen. Fuels that enable fire to climb from the forest floor to the crowns of trees is known as ladder fuels. Once fire is in a tree crown, it could spread directly from one tree crown to the next; such crown fires are usually more dangerous and harder to control than surface fires.

This activity has 3-4 parts:

1. Begin with a pre-lab reading/vocabulary worksheet, which should be done as homework or in the class period before the lab.
2. Designing and completing the lab.
3. **Optional** reading of a technical report, followed by class discussion
4. Assessment by drawing/writing a story board that applies concepts from the lab and from the previous activity (on stand density) to real-world forests and fuel conditions.

The lab part of the activity (part 2 above) is a competition among student teams. Each team constructs a model tree by using a support stand, wire rods, and newspaper fuels. An example is shown in Step 6 of the Procedures below. The goal is to design a tree that can "survive" a fire passing beneath (surface fire) but also has plenty of leaves so it can photosynthesize, continuing to grow and produce seeds. A team's success is tested by burning it. The tree that survives underburning with the greatest potential for photosynthesis is the winner. **Photosynthesis potential is quantified in this activity by the length of branch with unburned "foliage" (newspaper strips on branches) remaining after the fire.**

The lab has two phases, which enable students to see the effects of two different amounts of surface fuels. Phase 1 uses relatively light surface fuels. In Phase 2, the students assemble fuels to show the effect of many years of succession without fire. Because they use the same model tree for both phases, **it is important to not moisten or disturb the trees after they are burned in Phase 1.**

Materials and preparation:

Do this activity in a laboratory with good ventilation and a hood or a fairly high ceiling. Smoldering pieces of newspaper can rise as high as 20 feet on the heat plume from these experimental fires. If your laboratory space is not adequate, consider igniting the model trees outdoors - but not on a windy day. Use a large area that is far from dry grass, bark chips, and other fuels. Have a bucket of water and a hose available, with the water on. Have another adult help "patrol" for burning materials.

Copy each of the following:

- Handout H09-1: Lab Preparation, 1 per student
- Handout H09-2. Ladder Fuel Experiment, 1 per lab group
- Handout H09-3: Real-World Ladder Fuels and Fire Spread, 1 per student

Get students to prepare before class:

- Bag filled with 30 strips of newspaper approximately 40 cm long and 4 cm wide—one bag for each lab group. Each strip has to be folded accordion-wise and hole-punched so it can be threaded onto a wire rod to represent tree foliage.
- 20-30 half-sheets of newspaper, ~25 x 35 cm. These will represent litter in the model.

- 10 quarter-sheets of newspaper, approximately 25 x 20 cm. These will represent saplings.

Set up lab bench or work station for each lab group. Each station should have:

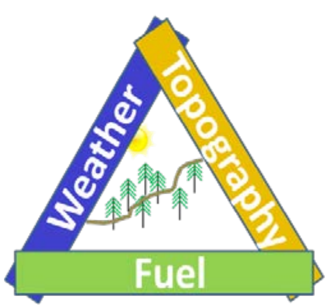
- 1 Tinker Tree support stand
- 1 pair of safety goggles
- 1 ashtray
- 1 spray bottle, filled with water
- 1 metal tray with a support stand on it
- 10-15 segments of wire rod
- 6 half-sheets of newspaper, 25 x 35 cm
- about 20 narrow strips of newspaper, —cut into strips and hole-punched
- 2 quarter-sheets of newspaper
- paper towels for clean-up

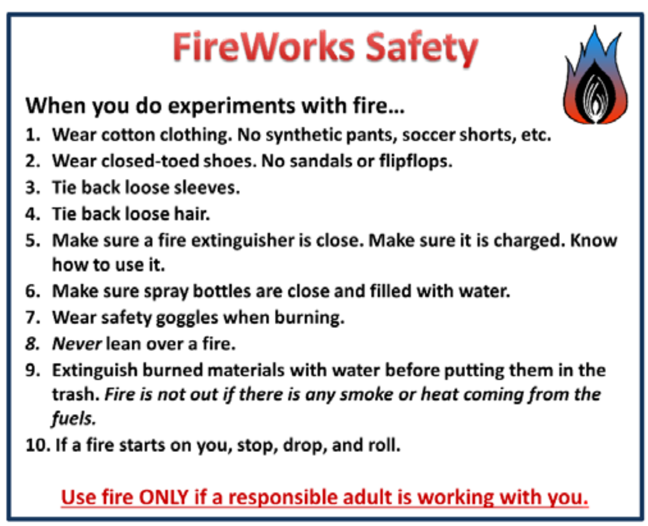
Teacher station should have these items, not in the trunk:

- 1 fire extinguisher, fully charged
- 1 box of kitchen matches
- A handful of hair ties, in case students need them.
- 1 measuring tape (in trunk)

Have an empty *metal* trash can *without a plastic liner* available.

Display the FireWorks safety poster and the Fire Environment Triangle (AKA Fire Behavior Triangle) poster.





On the day of the lab, download *H09_LadderFuels_FireSpread.pptx:*

Slide 1

Slide 2

Procedure:

1. The day before the lab, have students complete the **Handout H09-1: Lab Preparation** – or assign as homework.

2. On the day of the lab, explain: In this activity, we'll look more carefully at the Fuels side of the Fire Environment Triangle. We'll think about how fuels are arranged – especially in forests and shrublands – and how the arrangement of fuels changes as plant communities change over time, a process called *succession*.

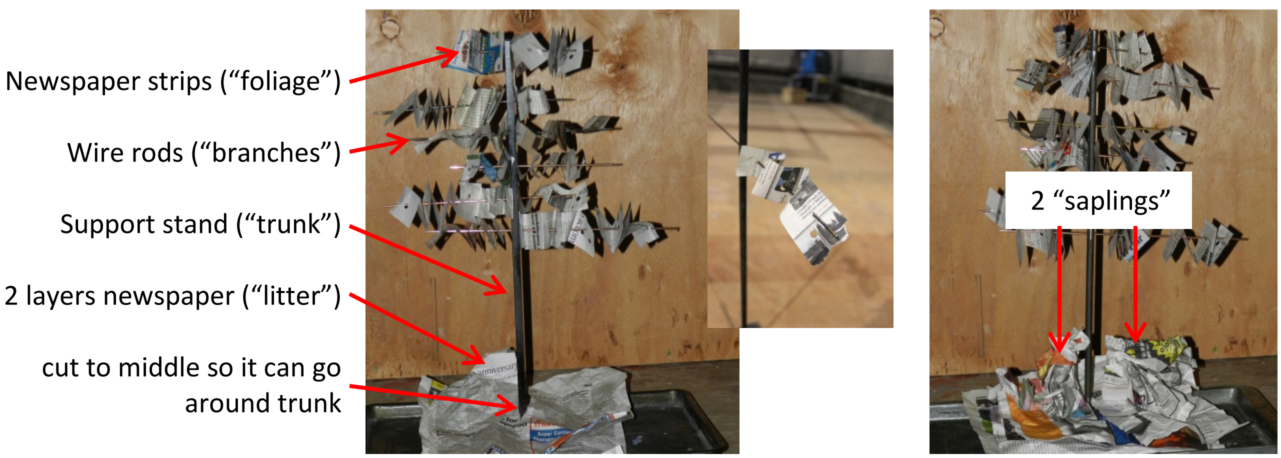
3. Project *H09_LadderFuels_FireSpread.pptx*. In regard to Slide 1, ask: Using what you learned by doing the Lab Preparation (Handout H09-1), explain how the fire would likely spread in each photograph.

- Left photograph: A *surface fire* could easily climb into the tree crowns because there are a lot of *surface fuels* and *ladder fuels*. In addition, the trees are close together. This is a dense stand, like some of those modeled in the previous activity ("matchstick" forests). Thus a *crown fire* could develop if it is dry enough and windy enough.
- Right photograph: A surface fire would be unable to climb into the tree crowns because there is no ladder fuel. In addition, the trees are spaced far apart so their crowns are not interconnected. Surface fire could occur, but crown fire could not.

4. In regard to Slide 2, ask: What kinds of fuels are burning in each fire? What kinds of fires are these?
   - Left: A *crown fire* is burning through *surface, ladder, and crown (also called aerial) fuels*.
   - Right: A *surface fire* is burning through surface fuels (seedlings, logs, litter).

5. Give each lab group a copy of **Handout H09-2. Ladder Fuel Experiment.** Explain: Your goal is to design a tree that can withstand *surface fire;* that is, it must prevent fire from climbing from the forest floor into the tree crown. Your job could be easy—just put together a tree with no leaves. But your tree must also have foliage to photosynthesize; it should have as much foliage as possible so it can be healthy and vigorous and withstand attacks from insects and fungi. The tree with the most foliage left after the surface fire (measured according to the length of branch covered with foliage) is the most successful!

6. Show the class the parts of the model tree and how to assemble it, as shown below:



Setting up a tree model for the Ladder Fuels experiment. Place support stand ("trunk") on burning tray. For Phase 1 (shown at left), place 2 crinkled sheets of newspaper ("litter") around base of tree. Insert as many wire rods ("branches") as desired into trunk. Thread hole-punched pieces of newspaper ("foliage") on branches. At outside end of foliage strips, use rod to punch hole (shown at center) so it won't slip off in convection from the fire. For Phase 2 (shown at right), students should add more sheets of newspaper and make some larger crumpled sheets to model shrubs or saplings.

7. Show the class how you will determine the **tree's score after burning:** You will measure the length of branch (cm) that still has unburned newspaper ("live foliage") on it. You will NOT measure the total amount of newspaper or its weight.

8. Draw these headers on the board for keeping score:

Team Name	**Phase One**	**Phase Two**

9. **Phase One:** Give lab groups ~10 minutes to construct their trees. Monitor to make sure they don't moisten the fuel.
   - Ask each group for its team name. Write it on the board.
   - Check and modify the surface fuels to make them similar among trees. Explain: This is so variation in surface fuels will not confound the results.
   - After teams have built their trees, have them ignite the surface fuels one team at a time, so everyone gets to see every fire. Each team should ignite two corners along one long edge of the metal tray. A consistent ignition pattern will keep this variable from confounding the results.
   - After each fire goes out, use the measuring tape to determine the **tree's score:** the length of branch, in centimeters, that still has unburned newspaper ("live foliage") on it. Record this on the board under "Phase One" for that team.
   - After all teams have completed a burn, discuss the design for the most successful and least successful trees.

10. Ask: What might happen to the surface fuels as a forest changes through many decades without surface fires (a process called *succession*)? Many forests tend to accumulate a lot of surface fuels after many years of succession without surface fires. The surface fuels simply pile up under the trees. Shrubs grow in. Tree seedlings become established and grow tall. Eventually, these ladder fuels may reach or interweave with the tree crowns, that is, with the crown fuels.

11. **Phase Two:** For all teams whose trees survived phase one, have them leave the "surviving" foliage intact on their tree but gently remove the ash of the burned surface fuels. Then instruct them to put in new newspaper fuels to represent changes that might occur with succession if no surface fires occur.

12. Have each team describe how their Phase Two fuels show what has happened during succession. (Teams should have more layers of newspaper than in Phase One and perhaps a few "saplings" made from crumpled newspaper). Then have them burn one tree at a time, igniting in the same manner as for Phase One. Measure and record score for each tree as for Phase One.

13. As a class, discuss the results: How well did the teams show succession? How successful were the tree designs for late-succession conditions with abundant fuels?

Optional Reading Assignment: Read and discuss as a class: pp. 2-7 (or more) in: North, Malcolm; Stine, Peter; O'Hara, Kevin; Zielinski, William; Stephens, Scott. 2009. An ecosystem management strategy for Sierran mixed-conifer forests. Gen. Tech. Rep. PSW-GTR-220. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 49 p. Available: https://www.treesearch.fs.fed.us/pubs/32916

Assessment: Use **Handout H09-3**. **Real-World Ladder Fuels and Fire Spread.**

Evaluation: Create a storyboard with captions to answer the prompt for one of the following scenarios:

Scenario 1. A mountainside that has patches of forest mixed with patches of meadow and patches of shrubs. How would the patchiness of vegetation affect fire spread and the likelihood of crown fire? Use as many frames as you need to show different forest, meadow, and shrub arrangements and the resulting fire behavior.

Possible explanation: Large patches of dense forest can support crown fire because there are lots of fuels and the crowns of trees are connected and may even be intertwined. Areas with tall shrubs have lots of ladder fuels so they can support crown fire. Meadows can serve as fuel breaks when wet, or support surface fires when dry. However, meadows cannot act as ladder fuels; therefore meadows prevent crown fires from starting and can interrupt a crown fire, limiting its spread to surface fuels. (Not covered in this activity but interesting: Meadows are likely to have stronger winds than dense forests, so surface fires are likely to spread more rapidly.)

Scenario 2. A forest where some patches have been burned recently by surface fire and other patches have gone 100 years or more with no fire at all. How would the variation in forest structure affect fire spread and the likelihood of crown fire? Use as many frames as you need to show different forest, meadow, and shrub arrangements and the resulting fire behavior.

Possible explanation: Forest patches with recent surface fire tend to have less surface and ladder fuels because they were consumed. Consequently, these patches will prevent fires from climbing into tree crowns. However, since forests are not all uniform and fires do not burn evenly across the landscape, some patches could have enough surface and ladder fuels to enable fires to spread into tree crowns. Forest patches that have not burned in 100 years or more are likely to have lots of surface, ladder, and crown fuels. In addition, the tree crowns are likely to touch or be interwoven. These forests are likely to have crown fires in dry, windy weather.

Evaluation:	Full Credit	Partial Credit	No Credit
Answered Question	Student answered question fully.	Student answered question partially.	Student did not answer question.
Images	Student used images that clearly illustrated the answer (see explanations above).	Student used images that illustrated the answer but were sometimes confusing or incorrect (see explanations above).	Student used images that were distracting or incorrect (see explanations above).
Explanation	Student's captions showed thorough understanding of the relationship of fuel arrangement to fire spread potential (see explanations above).	Student's captions showed basic understanding of fire spread (see explanations above).	Student's captions showed little or no understanding of fire spread (see explanations above).

Handout H09-1: Lab Preparation

Name ____________________

Read each term's definition and sketch the described fuel or fire in the box.
These terms refer mainly to plant communities such as forests, woodlands, and shrublands, which have tree crowns or a "canopy".

Surface fuels include all plants, litter, and woody material on or near the forest floor, including small trees and shrubs. In some forests that have not experienced fire for several decades, surface fuels become abundant and continuous. Fine surface fuels such as dead grass, leaf litter, and twigs can dry out quickly and help surface fires spread rapidly. Heavy surface fuels such as logs, stumps, and wood piles burn more slowly, so fires in these fuels can smolder for a long time.

Surface fires burn in *surface fuels*. Surface fires reduce ladder fuels (see below), so they may reduce the likelihood that a future fire will turn into a crown fire. Surface fires are sometimes severe enough to kill the roots of mature trees or to kill the living cells under the trees' bark, thus killing the trees.

Ladder fuels include small trees and shrubs growing under the crowns of mature trees. These can provide a way for surface fires to climb up into the tree crowns. Ladder fuels include branches of live and dead trees that grow low to the ground and saplings that are growing under taller trees.

Crown fuels, also called aerial fuels, are fuels that are not in contact with the ground. These fuels include tree limbs, foliage, and branches within the living tree canopy (not in contact with surface fuels). Crown fuels also include dead needles in the tree crown and lichens and mistletoe plants growing in tree crowns.

Crown fires burn in the crowns of trees and shrubs. Crown fires are often ignited by surface fires that spread through ladder fuels into the tree crowns; then they spread from crown to crown. Crown fires have longer flames than surface fires and are very powerful. They can have unpredictable fire behavior and be very difficult to control. Crown fires are common in some kinds of coniferous forests and chaparral-type shrublands.

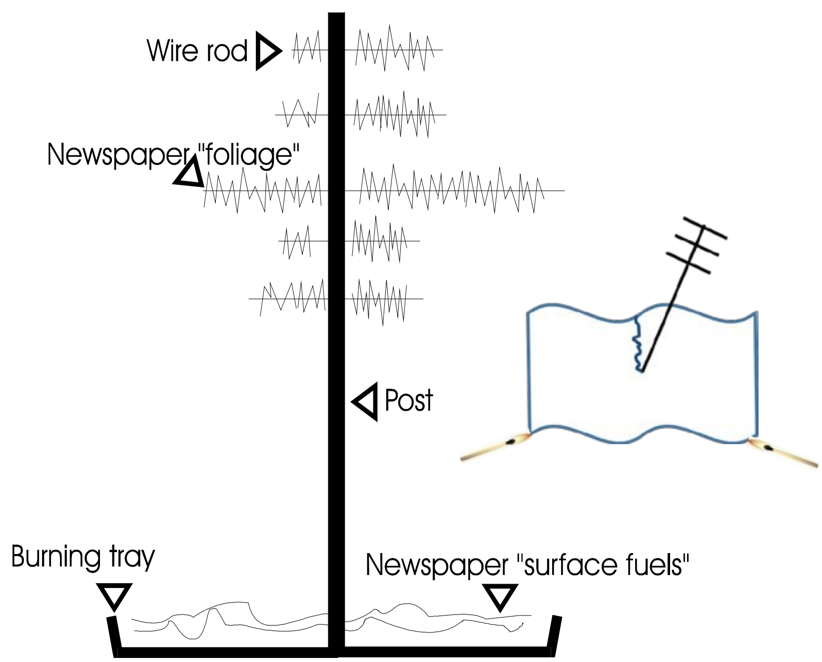
Handout H09-2. Ladder Fuel Experiment

Design a model of a tree. Its trunk is a lab support stand. Its branches are rods stuck through holes in the trunk. Its leaves are strips of newspaper. Your goal is to build a tree with a crown that does not burn when a fire burns the surface fuels beneath it. Your job could be easy—just put together a tree with no leaves. But your tree must also have *foliage* (leaves) to win – the more, the better. You have to figure out how much foliage to use and how to arrange it on the tree so the tree can survive a surface fire.

Procedure:

1. Place a support stand (metal post) in the center of the metal tray.
2. Crumple up two half-pages of newspaper. These are your surface fuels. Flatten them out a bit, but make sure that some air can get between the layers.
3. Cut or tear a line from one edge of the newspaper pieces to the middle. Then place both layers on the support stand base, with the stand's post at the center.
4. Slide wire "branches" through the holes in the post. You may use as many or as few branches as you want.
5. Use the long, narrow strips of newspaper for foliage. Slide foliage strips onto each branch. For short branches, you may shorten the newspaper strip. Use the branch to poke a small hole at the outer end of the foliage strip rather than using a punched hole, so the newspaper won't fly off the branch once you start burning.
6. Lab groups will ignite their tinker trees one at a time. When the teacher tells you it's time to ignite yours, start the fire by igniting two corners along **one long edge of the metal tray**.

- Do not use any moisture on your tree or experimental setup before it is burned.
- Do not move or remove your tree's foliage after you have underburned it.
- Keeping score: After you have underburned your tinker tree, the teacher will assign it a score: the number of centimeters of branch still covered by unburned foliage.



Handout H09-3: Real-World Ladder Fuels and Fire Spread

Name______________________

You have explored how the vertical arrangement of fuels affects the potential for fire to spread from surface fuels into a single tree crown. Fire spread in real forests and across landscapes is much more complicated.

You will create a storyboard for **<u>one</u>** of the following scenarios, in order to show your understanding of vertical fuel arrangement and fire spread. A storyboard is a sequence of drawings with captions that explain what is occurring in the drawings.

Scenario 1. A mountainside that has patches of forest mixed with patches of meadow and patches of shrubs. How would the patchiness of vegetation affect fire spread and the likelihood of crown fire? Use as many frames as you need to show different forest, meadow, and shrub arrangements and the resulting fire behavior.

Scenario 2. A forest where some patches have been burned recently by surface fire and other patches have gone 100 years or more with no fire at all. How would the variation in forest structure affect fire spread and the likelihood of crown fire? Use as many frames as you need to show different forest, meadow, and shrub arrangements and the resulting fire behavior.

Drawing					
Caption					

10. Fire Behavior, Fire Weather, and Climate

Subjects: Reading, Writing, Speaking and Listening, Math, Science

Duration: Two 30-minute sessions

Group size: Students work in groups of 2 or more

Setting: Classroom

New FireWorks vocabulary: *This activity uses specialized vocabulary used by wildland fire managers. Students may need to look up some definitions in order to complete this activity. The definitions are available at:* http://gacc.nifc.gov/nrcc/dc/idgvc/dispatchforms/glossary.pdf

Lesson Overview: In this activity, students learn about the behavior, weather, and other aspects of a real wildland fire – the Storrie Fire of 2000 on the Plumas and Lassen National Forests. They create a podcast about the fire, which describes potential effects of different weather, and potential effects of global climate change.

Lesson Goal: Students will be able to communicate the effects of changes in the weather on fire spread and interpret data on possible relationships between global climate change and wildland fires.

Objectives: Students can use information on the history of the Storrie Fire, weather conditions, fire behavior modeling, and global climate change to create a podcast that

- catches the audience's attention with a human-interest angle,
- describes relationships between fire weather and fire spread on a certain date,
- speculates on how things might have been different based on model results for different weather conditions, and
- discusses the possible influence of global climate change on wildland fires.

Standards:		9th	10th	11th	12th
Common Core ELA	Speaking and Listening	2,4,5,6		2,4,5,6	
	Reading: Science/Technical Subjects	1,7,10		1,7,10	
NGSS	Earth's Systems	ESS2.A, ESS2.D			
	Weather and Climate	ESS2.D, ESS2.A, ESS3.D			
EEEGL	Strand 1	C,E,F,G			
	Strand 2.4	A			

Teacher Background: Students will explore how weather affects fire behavior and consider how climate change may affect wildland fires. They can complete the activity and assessment with information in the handouts– which includes official records from the Storrie Fire (Plumas

National Forest, started on August 17, 2000), data from a nearby weather station, results from fire behavior modeling, and data describing global climate change. They may choose to supplement these resources with others (well documented, of course), but the information in the handouts is already very extensive. Many of the PowerPoint slides include examples or detailed explanations in the "notes" sections. You may choose to go through the slides with the students to prepare them for the assignment – or you may choose to have them read and study the materials on their own, then bring questions for discussion to class. There are 2 sets of slides:

- *H10_StorrieFireAndModelResultsAndClimateChangeData.pptx*, which contains all the information students need to complete the assessment
- *H10_StorrieFireAndModelResults_Demo.pptx*, which contains a complete worked example of the fire behavior modeling part of the assessment. This example uses slides 7-9 in the above presentation to do a complete prediction of fire behavior based on specific weather conditions. You can use this demonstration to work through an example with students and/or as a guide for grading.

The assessment for this activity (**Handout H10-1. Podcast for National Radio**) is to create a podcast in which students report to teenagers throughout the nation on how the Storrie Fire affected people, how its spread was related to weather, how it could have been different with different weather, and it might be an example of fires to come because of global warming.

This activity is very similar to FireWorks Activity **M08_Fire Weather**, with one significant exception: This activity asks students not only to use information on weather and fire growth reported during the fire, but also to use the national fire behavior model ("BEHAVE") to speculate on how the fire might have behaved differently if the weather had been different. Students do not actually run the model; instead, they interpret graphics that display model predictions. That's what is displayed in the worked example in *H10_StorrieFireAndModelResults_Demo.pptx*. You can go through this example to prepare the students to interpret model results for themselves.

If you are interested in exploring the history of specific wildland fires or would like more information on relationships between climate change and wildland fire, you may want to consult some of these websites. Several of them are referenced in the handouts and presentations:

https://inciweb.nwcg.gov/	Information on the size, status, and other features of current fires throughout the United States
https://www.nifc.gov/fireInfo/fireInfo_main.html	National Interagency Fire Center – coordination and information for wildland fire programs nation-wide
https://gacc.nifc.gov/	Geographic Area Coordination Center – a portal for each major geographic region in the United States. Content differs by region, but most sites have

	regional news, maps, and other detailed information.
https://gacc.nifc.gov/nrcc/dc/idgvc/dispatchforms/glossary.pdf	Glossary of Wildland Fire Terminology, published by the National Wildfire Coordinating Group in November 2008
https://www.fs.usda.gov/ccrc/topics/wildland-fire	Information on the relationship between climate and wildland fire, hosted by the Forest Service's Climate Change Resource Center. Includes links to many video segments, from 5 to 30 minutes long.

Materials and preparation:

1. Read through **Handout H10-1. Podcast for National Radio** and the PowerPoints (also available as pdfs for handouts). Decide how much of the information in the PowerPoints/pdfs to go through in class and how much to assign as independent learning. Students need to digest a lot of technical information to meet all the goals of the assignment. To simplify it and use less time, you may prefer to use the Middle School version of this activity (**M08_Fire Weather**), which leaves out the modeling task.

2. Download the following:

   Handout_H10-2_StorrieFireIncidentCommandTeamNarrative

   *H10_StorrieFireAndModelResultsAndClimateChangeData.pptx (*same information in **Handout_H10-3***).* This presentation has 4 distinct parts:

   1) Data on the Storrie Fire's growth and staffing (slide/page 2)

   2) Weather and fuel moisture data during the time of the fire (slides 3-6)

   3) Predictions of fire behavior based on model runs (slides 7-9)

   4) Information on global climate change (slides 10-14)

   H10_StorrieFireAndModelResults_Demo.pptx (same information in **Handout_H10-5**) has a completed example "run" of the fire behavior model that students use to complete the assessment. (It uses slides 7-9 of the PowerPoint referenced above and completes the exercise using specific weather data.)

   OPTIONAL: If you want to include technical reading of a source document on climate change, download **Handout_H10-4_FactSheet-ChangesInSnowmeltAndStreamflow.pdf**.

3. Give each student or team access to these files on a computer or handouts. For handouts use: **Handout_H10-3_StorrieFireAndModelResultsAndClimateChangeData.pdf** and **Handout_H10-5_StorrieFireAndModelResults_Demo.pdf**

4. Make a copy of the Assessment (**Handout H10-1. Podcast for National Radio**) for each student or team.

5. Make sure students have the equipment needed for recording their sound effects and podcast.

Procedure:

1. Explain: We have learned about theories and models of fire spread. Now we will study the spread of an actual fire, the Storrie Fire, which burned more than 56,000 acres (~90 square miles)[3] in the Plumas and Lassen National Forests, northern Sierra Nevada, in the year 2000.
    - You will look at daily reports from fire managers and graphs that show how much the fire grew each day.
    - You will also look at weather reports from the time when the fire was burning.
    - You will use the model that fire management professionals use to consider what might have happened if the weather had been different.
    - Finally, you will look at data on global climate change and consider whether climate change might be making fires like the Storrie Fire more common.
2. Give each student or team a copy of **Handout H10-1. Podcast for National Radio** and go through it with the class. Answer questions.
3. Briefly go through **Handouts H10-2** and **H10-3**) with the class, so they see what kinds of information they can use to make their podcast. Remind students that they may obtain additional information, but they must get it from reliable sources and document their sources.
4. Go through the *H10_StorrieFireAndModelResultsAndClimateChangeData.pptx* (the first set of PowerPoint slides shown at the end of this activity) or assign it for independent study (Handout H10-3). You may want to spend part of a class just focusing just on the fire behavior modeling (slides 7-9). If you wish, you can go through a fully worked example with the students using the "demonstration" PowerPoint, *H10_StorrieFireAndModelResults_Demo.pptx* (the second set of PowerPoint slides shown at the end of this activity).

Assessment: Handout H10-1. Podcast for National Radio.

[3] Data on wildland fires are still recorded in US Standard ("English ") units rather than metric units. US Standard units are used throughout this lesson and in most of the materials in the Student Packet. It is acceptable for students to use US Standard units in their podcasts.

Evaluation of podcast:

Criterion	Excellent	Poor
Structure: Introduction, Transitions, Conclusion, and Creativity	All present	Not Present
Length and sound effects	The presentation was close to 5 minutes in length and included three relevant sound effects that enhanced the podcast.	The presentation was either greatly under or over five minutes and failed to include sound effects or included sound effects that were irrelevant and distracting.
Human interest angle	Present, credible, and engaging	Not present, not credible, or not engaging.
Information about weather and fire spread	Accurate, based on information in packet (or other factual information with sources documented)	Inaccurate or not present; if based on information not in packet, not documented.
"What if?" question answered with model results	Valid speculation based on information in packet	Invalid or not present.
Relationship between climate change and occurrence of large, severe fires	Accurate, based on information in packet (or other factual information with sources documented)	Inaccurate or not present; if based on information outside packet, not documented.

Handout H10-1. Podcast for National Radio

Work with your partner(s) to create a 5-minute podcast for a national radio station that is run by and for teenagers. The year is 2000. The date is any day between Aug. 17 and Sept. 11 when a change in the weather affected fire spread. Look at records from the Storrie Fire in order to choose a date that might be interesting to report on.

You have the following sources of information:

- Daily narrative reports from the Incident Command Team (*Handout_H10-2_StorrieFireIncidentCommandTeamNarrative*)
- Four distinct sections in *Handout_H10-3_StorrieFireAndModelResultsAndClimateChangeData.pdf*:

  Part 1 (Slide 2): Data on the Storrie Fire's growth and staffing levels each day

  Part 2 (slides 3-6): Data on weather and fuel moisture during the time of the fire

  Part 3 (slides 7-9): Graphics for predicting fire behavior based on model runs

  Part 4 (slides 10-14): Information on global climate change.

  NOTE: another source on climate change is *Handout_H10-4_FactSheet-ChangesInSnowmeltAndStreamflow.pdf.* Your teacher may provide it, or you can find it online at https://pubs.usgs.gov/fs/2005/3018/pdf/FS2005_3018.pdf.

You may obtain other information for this project too. If you do, be sure to record your sources, in case someone in your audience – or your teacher – asks for documentation.

You have 4 goals:

1. Give your audience some reason to care about the fire – some human-interest angle. (Perhaps they've been hearing about it in the national news. Perhaps they know people who live in the area where the fire is occurring. Perhaps you want to emphasize highway closures, safety and injuries, or evacuations. Perhaps you want to emphasize potential effects on timber values or wildlife habitat.) **Here are some resources you could use:** journal entries from fire managers in *Handout_H10-2_StorrieFireIncidentCommandTeamNarrative;* reports from newspapers, magazines, and other media on other wildland fires.
2. Let your national audience know about the fire's recent behavior and how the weather in the last day or two has changed it. **Resources:** Use *Handout_H10-2_StorrieFireIncidentCommandTeamNarrative* and Parts 1 and 2 of the StorrieFireAndModelResultsAndClimateChangeData.*(pptx or pdf)*.

3. Something that could have been different – much better or much worse – if the weather had been different. **Resources:** Use the model results in Part 3 of StorrieFireAndModelResultsAndClimateChangeData.*(pptx or pdf)* to answer questions like, “What if the winds had gusted to 20 mph today?” or “What if the relative humidity had gone to 50% today?” or “How would fire behave differently in grassy areas vs. forest?”
4. Comment on whether some places in the world, including the Sierra Nevada, might see more fires like the Storrie Fire because of global climate change. **Resources:** Part 4 of StorrieFireAndModelResultsAndClimateChangeData.*(pptx or pdf)*.

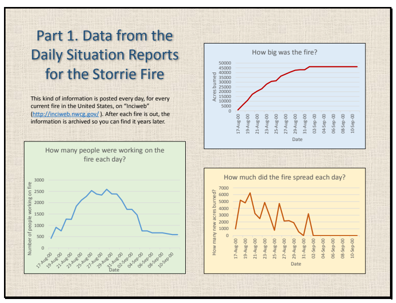
Your podcast must include an introduction, transitions, a conclusion, and at least three appropriately placed sound effects. It will help to have a written outline or script before you record.

Be as creative as you can. This is your opportunity to be artistic, unique, and show what you have learned!

Slides and notes for *StorrieFireAndModelResultsAndClimateChangeData.pptx* (4 parts: Storrie data, weather data, modeling graphics, and climate change data)

Slide 1

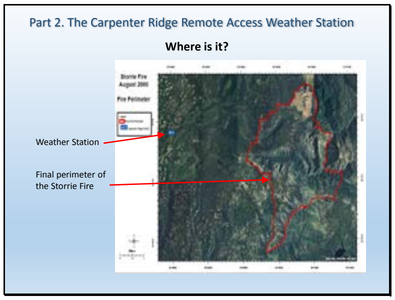
Slide 2



Part 1 contains information about the Storrie Fire. Don't forget to consult the fire managers' journal entries in the journal entries in a separate document – *StorrieFireIncidentCommandTeamNarrative.docx.*

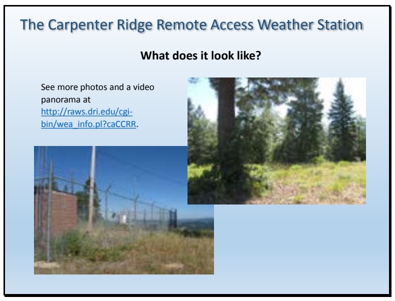
Here is information on the Storrie Fire's size each day, how many people were working on it, and how much it grew in the previous 24 hours. This information is taken from the Daily Situation Reports (journal entries). While the Situation Report showed the fire's size as about 45,000 acres, the fire was mapped carefully after it ended, and the results showed that it eventually burned 56,060 acres.

Slide 3



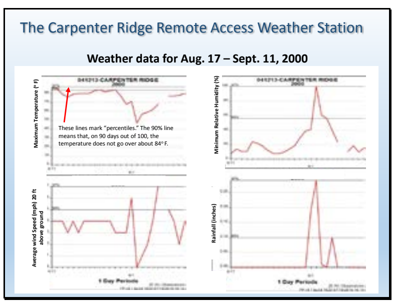
For your podcast, you will need information on weather conditions during the Storrie Fire. The next few slides show weather conditions during the time of the fire, but these records are not from the actual location of the fire; they are from a remote access weather station a few miles away. Remote Access Weather Station means that the station is operated electronically – not by people. Weather conditions are measured automatically at about 1 pm each day, and the data are transmitted by satellite to a recording center.

Slide 4



Here are some photos of the weather station.

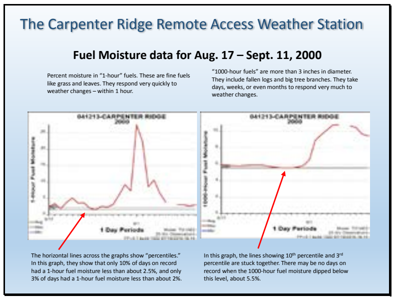
Slide 5



Here are records of maximum temperature, minimum relative humidity, average wind speed, and rainfall for each day. The red arrow points to percentile lines; they are explained in the text connected to the arrow.

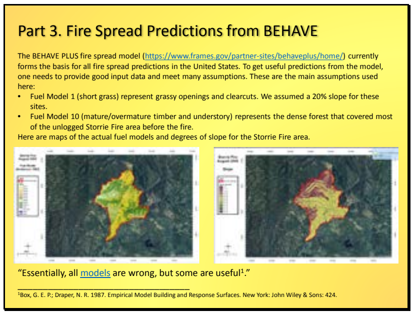
The wind speed in the lower left graph is not the average for ALL DAY; it is the average of the measurements taken in the 10 minutes before "transmit time" each day. That is the time when the previous 24 hours' weather is transmitted by satellite to the National Weather Service, around 1 pm.

Slide 6



Here are records of fuel moistures during the time of the Storrie Fire. Again, the red arrows point to percentile lines, and these are explained below the graphs.

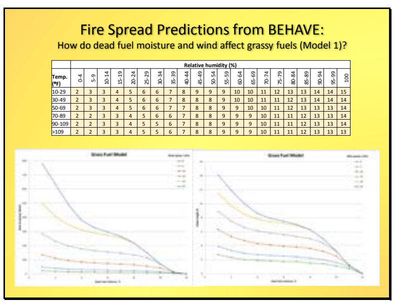
Slide 7



Part 3 shows some results from the fire spread model BEHAVE that could be use to predict fire spread rates and flame lengths from a variety of weather conditions on the Storrie Fire. BEHAVE is used by fire managers throughout the United States for managing wildland fires.

These maps show that there are a lot more than 2 fuel models in the Storrie Fire area. Models 1 and 10 were used here because they seemed to represent the majority of the area.

Slide 8



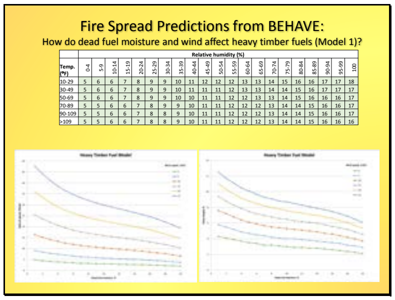
Fuel moisture is the weight of a fuel particle's moisture expressed as percent of the particle's dry weight. Suppose you bring a stick in from the field and weigh it right away, and it weighs 25 grams.

You then put it in the oven for a day, drying it until you can't get it any drier, and it weighs 20 grams. The moisture weighed 5 grams. Calculate the fuel moisture as 5 g/20 g = 0.25 or 25%. That is the particle's fuel moisture.

Use the table on top to estimate dead fuel moisture from temperature and relative humidity. Example: If temperature is 75 degrees F and humidity is 55%, dead fuel moisture in these grassy fuels will be 8%.

Use the graphs to answer "What if?" questions. Example: If dead fuel moisture is 8% and wind goes from 5 mph to 25 mph in these fine, grassy fuels, the fire's rate of spread is likely to go from 10 ft/minute to 220 feet/minute. If dead fuel moisture goes from 8% to 2% and wind stays at 5 mph, flame lengths are likely to go from 2 ft to 4 ft.

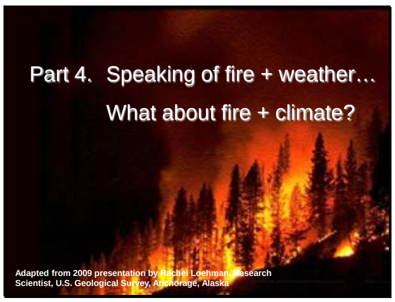
Slide 9



Use the table on top to estimate dead fuel moisture from temperature and relative humidity. Example: If temperature is 75 degrees F and humidity is 55%, dead fuel moisture in these closed forests with heavy timber will be 12%.

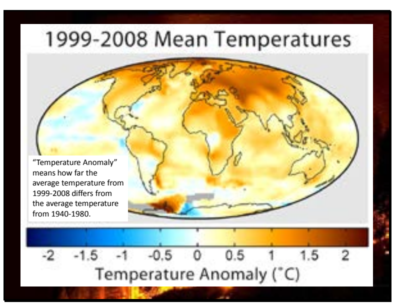
Use the graphs to answer "What if?" questions. Example: If dead fuel moisture is 8% and wind goes from 5 mph to 25 mph in these heavy fuels, the fire's rate of spread is likely to go from 6 ft/minute to 32 feet/minute. If dead fuel moisture goes from 8% to 2% and wind stays at 5 mph, flame lengths are likely to go from 4 ft to 5.5 ft.

Slide 10



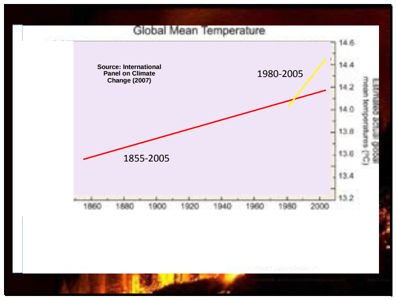
The slides in Part 4 have information about climate and how things have changed in the past century or two. You will need some of this information so your podcast can answer the question, "Is it possible that some places in the world, including the Sierra Nevada, might see more fires like the Storrie Fire because of global climate change?" (This is Question #4 in the assignment.)

Slide 11



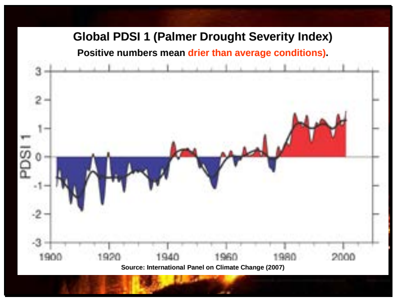
This figure shows the difference in the earth's surface temperatures from January 1999 to December 2008 and "normal" temperatures at the same locations. "Normal" temperatures are defined as the average over the interval January 1940 to December 1980. This graph shows an average increase of 0.48 °C. These widespread temperature increases are considered to be an aspect of global warming.

Slide 12



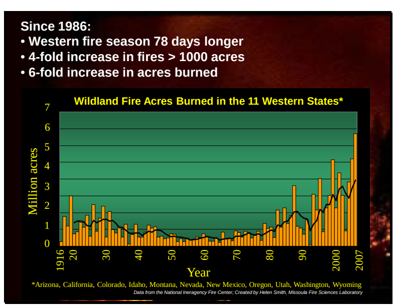
This graph has two lines. The long red line shows the trend in global average temperatures from 1855 to 2005, a period of 150 years. The short yellow line shows the trend in global average temperatures from 1980 to 2005, a period of 15 years. You may want to use this information in your podcast as you discuss whether global climate change is affecting wildland fires.

Slide 13



This graph shows trends over the last 220 years in the Palmer Drought Severity Index (PDSI). This index uses temperature and precipitation data to estimate dryness. Its scale is not a measurement but instead an "index" that goes from -10 (driest) to +10 (wettest). The PDSI has been reasonably successful at quantifying long-term drought conditions (https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi). Perhaps you will want to use this information in your podcast to talk about possible connections between climate change and wildland fire.

Slide 14

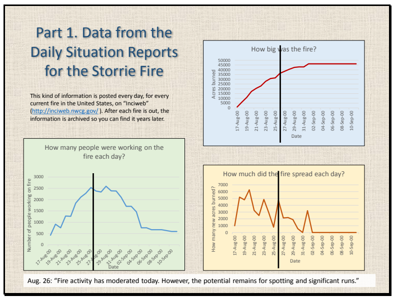


This graph shows how much area burned in 11 states of the American West from 1916 to 2007. You may want to use this information in your podcast as you talk about possible connections between climate change and wildland fire.

Slides and notes from *StorrieFireAndModelResults_Demo.pptx*

- A worked example showing how to use graphics from the BEHAVE fire model

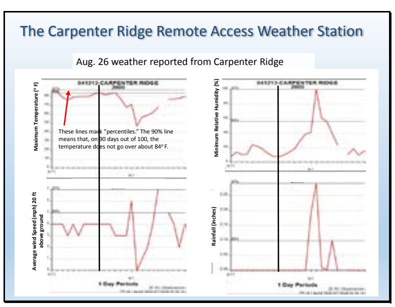
Slide 1



Demonstration of fire behavior modeling for Activity H10.
Pick a day that you're going to analyze. This example uses August 26.
The Incident Command Team's narrative says that, on that day, "Fire activity has moderated today. However, the potential remains for spotting and significant runs." Although the Team's report sounds optimistic, the lower right graph shows a nearly 5000 acre increase in area that day. Some of that area may be from backfiring or burning out. So… how might fire spread have been different with greater wind speeds?

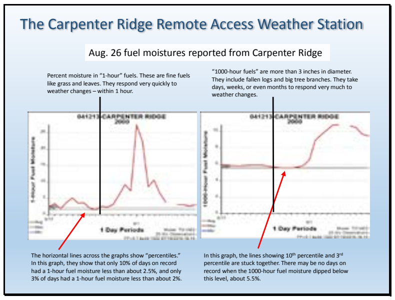
We marked Aug. 26 with a vertical line on each graph.

Slide 2



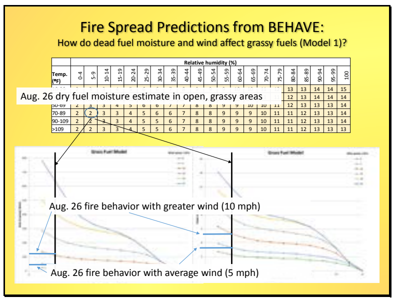
Vertical lines mark the weather reported from Carpenter Ridge on Aug. 26. While the average wind speed (average of the 10 minutes before reporting time, which was probably around 1 pm) was 4 mph, we're going to use 5 mph because that will make the subsequent graphs easier to interpret – and surely there were sustained periods during that day when the wind was a little stronger than 4 mph.

Slide 3



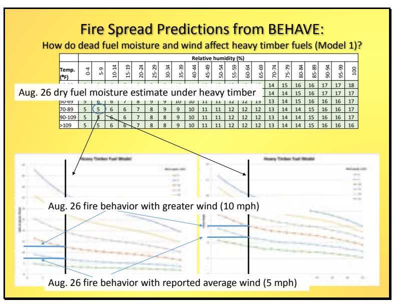
Vertical lines mark the fuel moistures reported from Carpenter Ridge on Aug. 26.

Slide 4



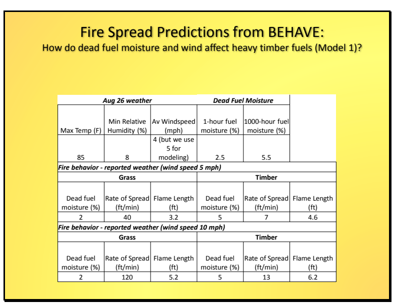
The fine dead fuel moisture for Aug 26 weather comes out to 2% (Carpenter Ridge reported about 2.5% - you can use either for the model). Vertical lines on the 2 graphs show the 2% dead fuel moisture line. Horizontal lines mark the predicted rate of spread (left) and flame length (right) for 5 mph winds and 10 mph winds…. For areas dominated by grassy fuels.

Slide 5



The fine dead fuel moisture for Aug 26 based on temperature and relative humidity in heavy timber comes out to 5%. Vertical lines on the 2 graphs show the 5% dead fuel moisture line. Horizontal lines mark the predicted rate of spread (left) and flame length (right) for 4 mph winds and 8 mph winds…. for surface fire in areas dominated by timber.

Slide 6



Here are results. BIG difference between the 2 fuel models! This will help answer the question, "What might the fire have done if weather had been different?"

Unit IV.
Fire Effects on the Environment

Unit IV brings students' attention to the effects of wildland fires on non-living parts of the ecosystem: air (Activity 11), and soil and water (Activity 12).

2010 Eagle Trail Fire, Tok, AK, by Larry Walsh (inciweb.nwcg.gov)

11. Smoke from Wildland Fire: Just Hanging Around?

Lesson Overview: In this activity, students learn about the composition of smoke from wildland fire, how it disperses, and its health impacts. They do a pre-class reading assignment and worksheet. During class, they discuss the pre-class reading, watch a video or demonstration of an inversion, and analyze Plumas county smoke data from two years when large wildland fires occurred.

Lesson Goal: Increase students' understanding of how smoke from wildland fires disperses, how it may affect people's health, and why smoke management is complicated.

Subjects: Science, Mathematics, Reading, Writing, Speaking and Listening, Social Studies, Health Enhancement

Duration: pre-class reading plus 45 minutes

Group size: Entire class

Setting: Classroom

New FireWorks vocabulary: *inversion, particulates/particulate matter, PM10/PM2.5, smoke, stable/unstable atmospheric conditions*

Objectives:

- Students will understand the composition and health impacts of smoke from wildland fires.
- Students will understand how temperature inversions affect smoke dispersal.
- Students will analyze and interpret graphs of particulate matter concentrations.

Standards:		9th	10th	11th	12th
CCSS--ELA	Reading Informational Texts	1,2,4,10		1,2,4,10	
	Writing	2,4		2,4	
	Speaking and Listening	1,4		1,4	
	Science/Technical Subjects	7,10		7,10	
NGSS	Earth's Systems	ESS2.A, ESS2.D			
EEEGL	Strand 1	A,B,C,D,E,F,G			

Teacher Background: There's no wildland fire without smoke, but the amount of smoke produced and the way in which it disperses differ from one fire to another and even from one time to another on a single fire. If the smoke disperses upward rapidly, high-altitude winds will scatter it downwind, and the only result we notice may be the beautiful, orange-tinged sunrise and sunset colors produced by particles in the air. However, if the smoke is trapped near the fire by an inversion, it can make the air difficult to breathe and even difficult to see through. These conditions benefit some plants by increasing seed germination. For humans, however, they are hazardous, especially for anyone who has asthma or other respiratory illness and for those who engage in strenuous exercise.

In this activity, students learn that smoke can disperse readily or be trapped by an inversion. Then they consider who be harmed by smoke from wildland fires. Finally, they analyze air quality data to figure out when air quality is at its best and worst throughout the year and what effect wildfires have had on air quality.

On most summer days, sunlight warms the earth's surface each morning, and the air lying on the earth's surface is heated too. This warming, expanding air rises, and its temperature decreases due to the expansion. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude. As a result of this natural cooling, mountain tops tend to remain much cooler than valleys even on hot summer days. Because the air is constantly moving and mixing under these circumstances, we call it unstable.

Sometimes the sun doesn't warm the earth's surface very much during the day. Clouds may block the incoming sunlight. In winter, the ground may be covered with snow that reflects sunlight instead of absorbing its energy. In summer, the smoke from a fire may be too dense to let sunlight through. When this happens, the cold air is stuck on the ground, and a warm layer of air rests on top of it. It is not expanding, therefore not rising, and therefore it is "trapped" on the ground until something stirs up the atmosphere. This is called an inversion because the normal daytime pattern (warm air on the bottom, cool air on top) is upside-down. The blanket of warm air lying on top of the cold air is called the inversion layer. During an inversion, the cold surface air is very stable. It cannot be dislodged until it is heated or stirred up by wind.

During an inversion, dust and other particulates in the air are trapped in the cold air at the earth's surface. Inversions during wildland fires trap smoke, which may be so dense that you can't see very far and the streetlights come on in the middle of the day. When seeds of some plants are exposed to dense smoke, it becomes easier for them to germinate. But when people are exposed to dense smoke, it becomes harder to breathe. Dense smoke is especially dangerous for babies and anyone with asthma or other respiratory illness. It is a good idea for some types of seeds to be outdoors during a smoke-filled inversion, but it is a good idea for people to limit aerobic activities and even stay indoors until the air quality improves.

At the end of this activity, you will find an optional "extension" activity that contains two possibilities for technical reading assignments.

Materials and preparation:

1. Decide how to demonstrate an inversion: You can use this 3-minute video (https://www.youtube.com/watch?v=LPvn9qhVFbM) or create the same demonstration yourself or use the demonstration with ice and boiling water that is described in the **Middle School curriculum (M09).**

2. Make 1 copy/student:
    - **Handout H11-1: Reading and Questions from "Wildfire Smoke: A Guide for Public Health Officials"** (3 pages)
    - **Handout H11-2: Plumas Air Quality through the Year** (2 pages)
3. Download *H11_Images.pptx.*

Procedures:

1. **Suggested homework:** Before doing this lesson, students should complete the reading/writing assignment on **Handout H11-1**.
2. **Hook**: Have students think of a time when they remember the air being really smoky. Ask some students to share their stories with the class. Tell students that this lesson is going to explore the composition of wildland fire smoke, how it moves through the atmosphere, the associated health impacts, and what precautions to take to avoid the health effects of smoke.
3. Discuss the reading/writing assignment (Handout H11-1) in small groups or as a class.
4. Explain: Now that we know what smoke is composed of and its associated health risks, we're going to investigate how air moves above hot and cold surfaces, which will help us understand where smoke goes and how it impacts health.
5. **Demonstrate an inversion:** Use this video (https://www.youtube.com/watch?v=LPvn9qhVFbM) or create the same demonstration yourself or use the demonstration with ice and boiling water that is described in the **Middle School curriculum (M09).**
6. **Diagrams and Discussion:** Start the PowerPoint *H11_Images.pptx*. Use the copy of slides and notes below, complete with notes for how to present the slides.

Assessment: Assign completion of **Handout H11-2: Plumas Air Quality through the Year.**

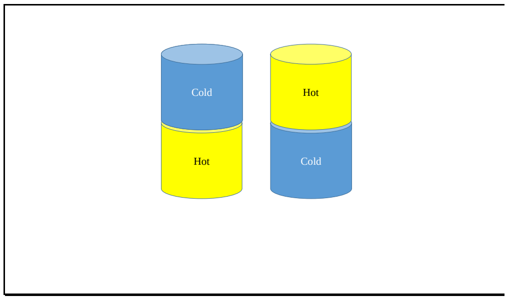
Evaluation: See Answer Key below.

Technical Reading Extensions: Assign students to read one of these two technical reports and write a 1-paragraph response to it, expressing any information in the report that they found surprising or alarming.

- **WhereTheresFireTheresSmoke.pdf** (*Where There's Fire, There's Smoke: Wildfire Smoke Affects Communities Distant from Deadly Flames* by the National Resource Defense Council. Available: https://www.nrdc.org/sites/default/files/wildfire-smoke-IB.pdf).
- **SmokeManagementPhotographicGuide.pdf** (Hyde, Joshua C.; Blades, Jarod; Hall, Troy; Ottmar, Roger D.; Smith, Alistair. 2016. *Smoke management photographic guide: a visual aid for communicating impacts.* Gen. Tech. Rep. PNW-GTR-925. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 59 p.)

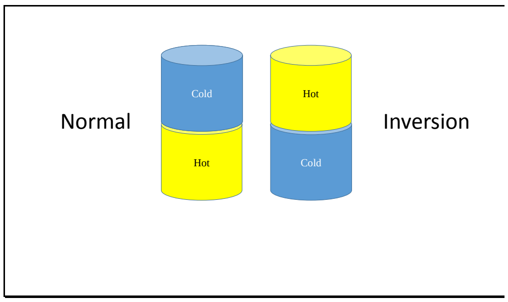
Slides and Notes for H11_Images.pptx

Slide 1



Ask: If the cylinders represent parcels of air, which diagram shows normal conditions and which one shows inversion conditions? The one on the left, with cold above hot, shows normal conditions. The one with hot above cold shows inversion conditions.

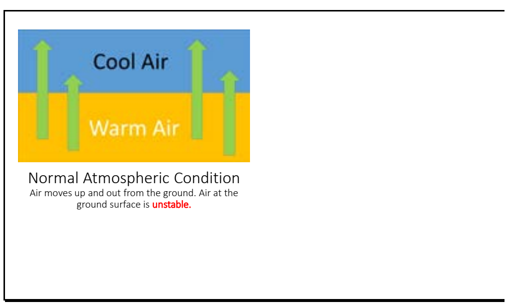
Slide 2



If you viewed the video demonstration: The demonstration with warm water on the bottom and cold water on top represented normal conditions because the liquids were circulating and pollutants were being dispersed. The demonstration with cold water on the bottom represented inversion conditions because the liquids were stable, not circulating.

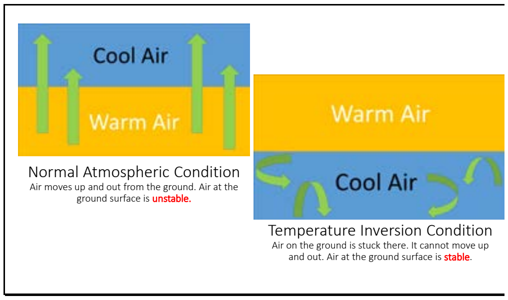
If you used the ice/boiling water demonstration: The air above boiling water showed normal conditions because the air was unstable. The air above ice showed an inversion because the air was very stable.

Slide 3



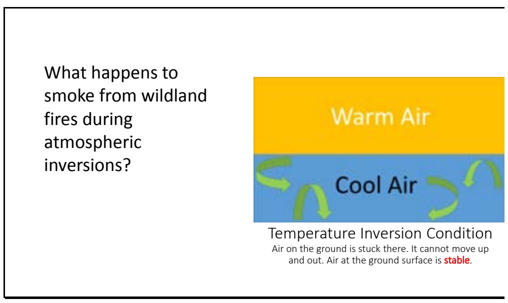
Normal atmospheric conditions occur when sunlight warms the earth's surface in the morning, and this warms the air on the ground. The warming air expands and therefore rises, and its temperature gradually falls due to the expansion. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude. As a result of this natural cooling, mountain tops tend to be cooler than valleys even on hot summer days. Due to all the air movement, these conditions are described as *unstable*.

Slide 4



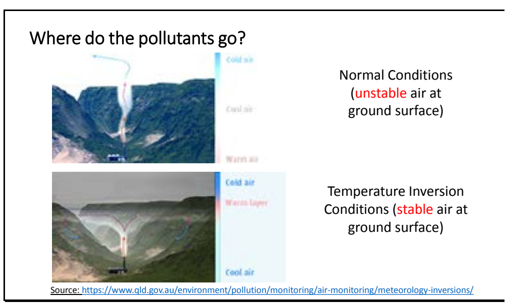
Inversions occur when the earth's surface is cold and the sun doesn't warm the earth's surface enough to heat the air above it. The cold air is not warming, expanding, and rising. Therefore, it is stuck on the ground until something stirs up the atmosphere. The blanket of warm air lying on top of the cold air is called the *inversion layer.* During an inversion, the cold, surface air is very *stable.* It cannot be dislodged until it is heated or stirred up by wind. In winter, this may happen when it is cloudy or when the ground is covered with snow that reflects the sunlight instead of absorbing it.

Slide 5



Ask students to get into groups of 2-3 and discuss answers to this question. After a couple of minutes, go to the next slide to discuss answers.

Slide 6



Here are two diagrams that show how pollutants from a factory are dispersed (or not) under different atmospheric conditions. Smoke from wildland fires behaves in the same way.

Handout H11-1: Reading and Questions from "Wildfire Smoke: A Guide for Public Health Officials"

Extracted from: Ammann, Harriet; Blaisdell, Robert; Lipsett, Michael; Stone, Susan Lyon; and Therriault, Shannon. 2001. Wildfire Smoke: A Guide for Public Health Officials. Unpublished report. 27 p. Available: https://www3.epa.gov/ttnamti1/files/ambient/smoke/wildgd.pdf

Introduction: Smoke rolls into town, blanketing the city, turning on streetlights, creating an eerie and choking fog. Switchboards light up as people look for answers. Citizens want to know what they should do to protect themselves. Schools officials want to know if outdoor events should be cancelled. The news media want to know how dangerous the smoke really is. Smoke events often catch us off-guard. This handout is intended to provide you and local public health officials with the information you need when wildfire smoke is present so you can adequately communicate health risks and precautions to the public. It is the product of a collaborative effort by scientists, air quality specialists and public health professionals from Federal, state and local agencies.

Composition of Smoke: Smoke is composed primarily of carbon dioxide, water vapor, carbon monoxide, particulate matter, hydrocarbons and other organic chemicals, nitrogen oxides, trace minerals and several thousand other compounds. The actual composition of smoke depends on the fuel type, the temperature of the fire, and the wind conditions. Particulate matter is the principal pollutant of concern from wildfire smoke for the relatively short-term exposures (hours to weeks) typically experienced by the public.

Particulate Matter (PM): Particulate matter is a generic term for particles suspended in the air, typically as a mixture of both solid particles and liquid droplets. Particles from smoke tend to be very small - less than one micrometer in diameter. For purposes of comparison, a human hair is about 60 micrometers in diameter. Particulate matter in wood smoke has a size range near the wavelength of visible light (0.4 – 0.7 micrometers). Smoke particles efficiently scatter light and reduce visibility. Moreover, such small particles can be inhaled into the deepest recesses of the lung and are thought to represent a greater health concern than larger particles.

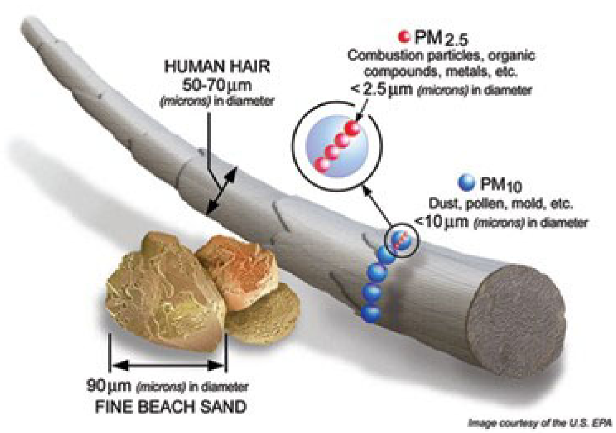


Image: www.airnow.gov

Health Effects of Particulate Matter: The effects of smoke range from eye and respiratory tract irritation to more serious disorders, including reduced lung function, bronchitis, exacerbation of asthma, and premature death. Studies have found that fine particles are linked (alone or with other pollutants) with increased mortality and aggravation of pre-existing respiratory and cardiovascular disease. In addition, particles are respiratory irritants, and exposures to high concentrations of particulate matter can cause persistent cough, phlegm, wheezing and difficulty breathing. Particles can also affect healthy people, causing respiratory symptoms, transient reductions in lung function, and pulmonary inflammation. Particulate matter can also affect the body's immune system and make it more difficult to remove inhaled foreign materials from the lung, such as pollen and bacteria. The principal public health threat from short-term exposures to smoke is considered to come from exposure to particulate matter.

Health Effects of Carbon Monoxide: Another pollutant of concern during smoke events is carbon monoxide. Carbon monoxide is a colorless, odorless gas, produced by incomplete combustion of wood or other organic materials. Carbon monoxide levels are highest during the smoldering stages of a fire. Carbon monoxide (CO) enters the bloodstream through the lungs and reduces oxygen delivery to the body's organs and tissues. The CO concentrations typical of population exposures related to wildfire smoke do not pose a significant hazard, except to some sensitive individuals and to firefighters very close to the fire line. Individuals who may experience health effects from lower levels of CO are those who have cardiovascular disease: they may experience chest pain and cardiac arrhythmias. At higher levels, as might be observed in a major structural fire, carbon monoxide exposure can cause headaches, dizziness, visual impairment, reduced work capacity, and reduced manual dexterity, even in otherwise healthy individuals. At even higher concentrations (seldom associated solely with a wildfire), carbon monoxide can be deadly.

Health Effects of Other Air Pollutants: Other air pollutants, such as acrolein, benzene, and formaldehyde, are present in smoke, but in much lower concentrations than particulate matter and carbon monoxide. Wildfire smoke also contains significant quantities of respiratory irritants. Formaldehyde and acrolein are two of the principal irritant chemicals that add to the cumulative irritant properties of smoke, even though the concentrations of these chemicals individually may be below levels of public health concern.

Long-Term Effects: One concern that may be raised by members of the general public is whether they run an increased risk of cancer or other long-term health impacts of exposure to wildfire smoke. People exposed to toxic air pollutants at sufficient concentrations and durations may have slightly increased risks of cancer or of experiencing other chronic health problems. However, in general, the long-term risk from short-term smoke exposure is quite low. Epidemiological studies have shown that urban firefighters exposed to smoke over an entire working lifetime have about a three-fold increased risk of developing lung cancer (Hansen 1990). This provides some perspective on the potential risks. The major carcinogenic components of smoke are polycyclic aromatic hydrocarbons (PAHs). Although the carcinogens benzene and formaldehyde are also present in smoke, they are thought to present a lesser risk.

Overall: Not everyone who is exposed to thick smoke will have health problems. The level and duration of exposure, age, individual susceptibility, including the presence or absence of pre-existing lung or heart disease, and other factors play significant roles in determining whether or not someone will experience smoke-related health problems.

Questions: "Wildfire Smoke: A Guide for Public Health Officials"

Answer these on a separate sheet of paper. Keep the handout for the table at the bottom.

1. What groups are mentioned in the first paragraph and what questions do they have?
2. Think of another group that isn't mentioned, what question do you suppose they'd have?
3. What is the purpose of this guide?
4. Of what is smoke composed?
5. Describe particulate matter.
6. Describe three health effects of smoke particulate matter?
7. What are two long-term effects of smoke exposure?
8. Now apply your knowledge to this problem:
   a) Access Air Now's Air Quality Index chart, at this webpage: https://www.airnow.gov/index.cfm?action=airnow.mapcenter&mapcenter=1
   b) Click on "Current AQI" tab. AQI stands for Air Quality Index. It incorporates PM and O_3.
   c) Find the current unhealthiest area in your state. Use the color key at the bottom of the map to answer: What is the current AQI? Use the table below to describe associated health risks.
   d) In the table below, read the cautionary statements for "very unhealthy" air. Describe some challenges that would be associated with implementing the cautionary statements.

EPA's Air Quality Index (AQI) for 24-hour Fine Particle Pollution ($PM_{2.5}$)

24-hr $PM_{2.5}$ ($\mu g/m^3$)	AQI Categories	AQI Values	AQI Cautionary Statements	AQI Health Effects Statements
0 – 12.0	Good	0 - 50	None	None
12.1 – 35.4	Moderate	51 - 100	Unusually sensitive people should consider reducing prolonged or heavy exertion.	Respiratory symptoms possible in unusually sensitive individuals, possible aggravation of heart or lung disease in people with cardiopulmonary disease and older adults.
35.5 – 55.4	Unhealthy for Sensitive Groups	101 - 150	People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion.	Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults.
55.5 – 150.4	Unhealthy	151 - 200	People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion.	Increased aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults; increased respiratory effects in general population.
150.5 – 250.4	Very Unhealthy	201 - 300	People with heart or lung disease, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.	Significant aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults; significant increase in respiratory effects in general population.
Greater than 250.5	Hazardous	Over 300	Everyone should avoid all physical activity outdoors; people with heart or lung disease, older adults, and children should remain indoors and keep activity levels low.	Serious aggravation of heart or lung disease and premature mortality in people with cardiopulmonary disease and older adults; serious risk of respiratory effects in general population.

Who is "SENSITIVE" to $PM_{2.5}$? "People with heart or lung disease, older adults, children, and people of lower socioeconomic status are the groups most at risk." See EPA's Technical Assistance Document (*link below*). Also at higher risk: **prenatal children** (low birth weight, pre-term birth, and IQ reduction), **diabetics**, and people with higher exposures such as **athletes** exposed during exercise.

Sources:

National Ambient Air Quality Standards for Particulate Matter - Final Rule, effective March 18, 2013, Federal Register, Vol 78, No. 10, Jan 15, 2013, p 3181 http://www.gpo.gov/fdsys/pkg/FR-2013-01-15/pdf/2012-30946.pdf

Revised Air Quality Standards for Particle Pollution and Updates to the Air Quality Index (AQI), Dec 14, 2012, p 4 http://www.epa.gov/pm/2012/decfsstandards.pdf

Technical Assistance Document for the Reporting of Daily Air Quality, Sept 2012, pp 2 and 8-11 http://www.epa.gov/airnow/aqi-technical-assistance-document-sep2012.pdf

Integrated Science Assessment for Particulate Matter - Final Report, Dec 2009 http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546

Answer Key for Handout H11-1: Reading and Questions from "Wildfire Smoke: A Guide for Public Health Officials"

1. What groups are mentioned in the first paragraph and what questions do they have? Citizens, school officials, and news media. They want to know what they should do to protect themselves, if outdoor events should be cancelled, and how dangerous the smoke really is.

2. Think of another group that isn't mentioned, what question do you suppose they'd have? Examples: the elderly, individuals with infants, health care givers, coaches, outdoor educators. They may be asking how smoke will impact them, how long it will last, how they can keep it out of their homes, and even whether they should leave the area for a while.

3. What is the purpose of this guide? The purpose is to provide local public health officials with the information they need when wildfire smoke is present, so they can adequately communicate health risks and precautions to the public.

4. Of what is smoke composed? Smoke is composed primarily of carbon dioxide, water vapor, carbon monoxide, particulate matter, hydrocarbons and other organic chemicals, nitrogen oxides, trace minerals and several thousand other compounds.

5. Describe particulate matter. Particulate matter is a generic term for particles suspended in the air. They are typically a mixture of solid particles and liquid droplets. Particles from smoke tend to be very small - less than one micrometer in diameter.

6. Describe three health effects of smoke particulate matter? Answers may include: Eye and respiratory tract irritation, reduced lung function, bronchitis, exacerbation of asthma, and premature death. It can cause persistent cough, phlegm, wheezing and difficulty breathing. Particles can also cause respiratory symptoms, transient reductions in lung function, and inflammation in the lungs. These impacts reduce the ability of the lungs to resist irritation from allergens and infection from bacteria and viruses.

7. What are two long-term effects of smoke exposure? Slightly increased risks of cancer or of experiencing other chronic health problems. Epidemiological studies have shown that urban firefighters exposed to smoke over an entire working lifetime have about a three-fold increased risk of developing lung cancer.

8. Now apply your knowledge to this problem:

a) Access Air Now's Air Quality Index chart, at this webpage: https://www.airnow.gov/index.cfm?action=airnow.mapcenter&mapcenter=1

b) Click on "Current AQI" tab. AQI stands for Air Quality Index. It incorporates PM and O_3.

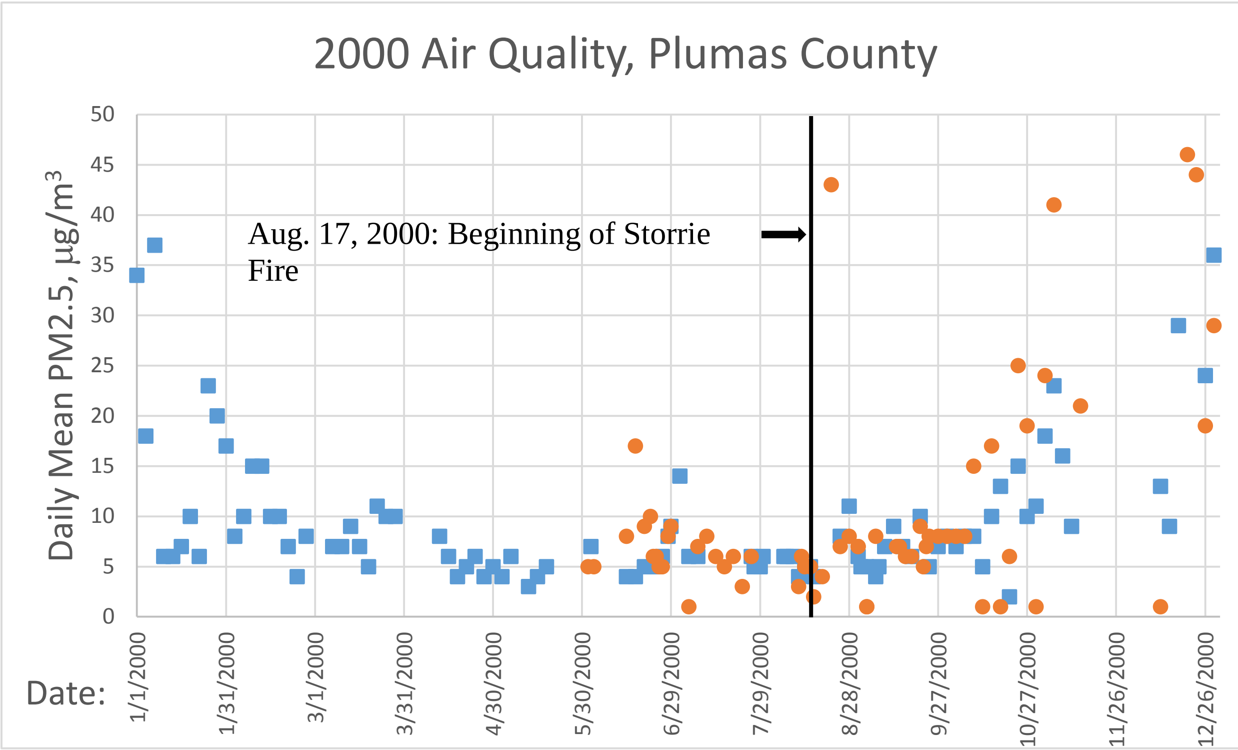
c) Find the current unhealthiest area in your state. Use the color key at the bottom of the map to answer: What is the current AQI? Use the table below to describe associated health risks.

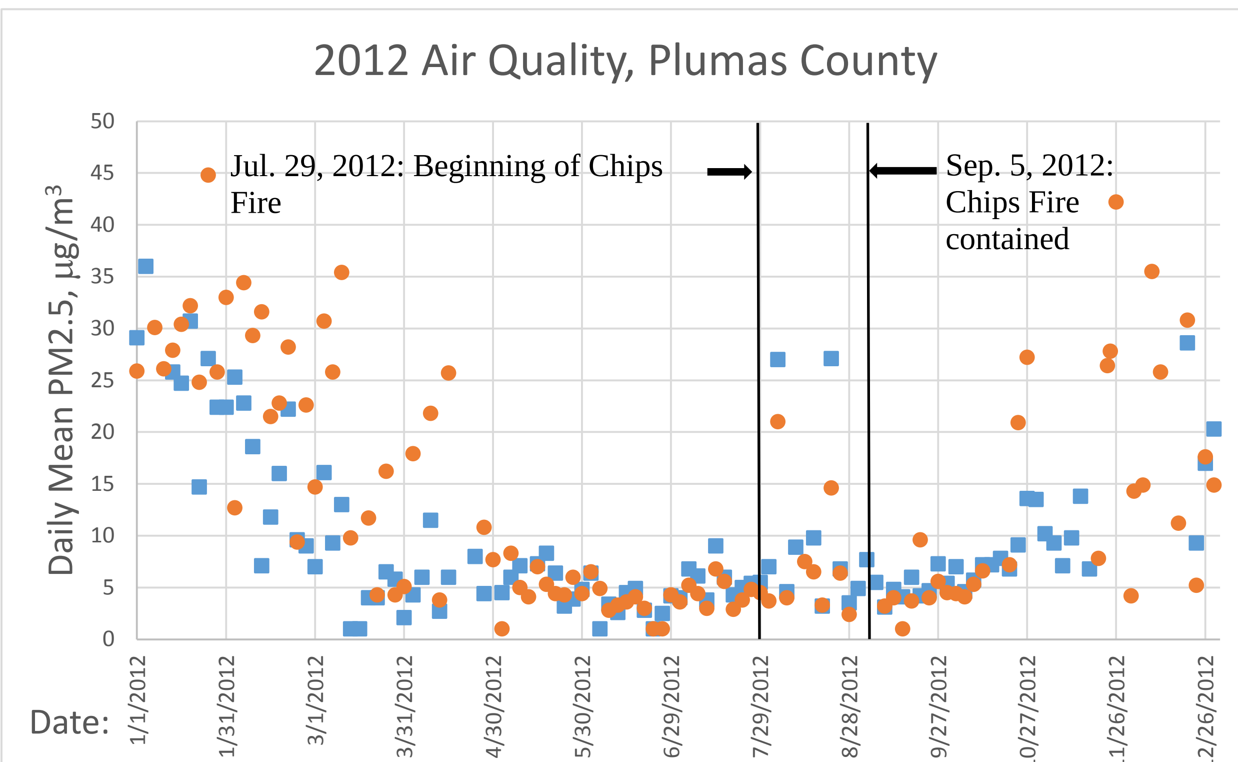
d) In the table below, read the cautionary statements for “very unhealthy” air. Describe some challenges that would be associated with implementing the cautionary statements. Challenges could be related to liability, costs, providing medical care or air purifiers, providing indoor locations for events that were planned outside, and possibly even paying for lodging if health-impaired people need to evacuate.

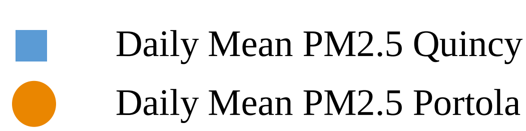
Handout H11-2: Plumas Air Quality through the Year

Directions: Answer these questions on a separate page. Use full sentences. The data you need are on the next page (the 2000 and 2012 air quality data from Plumas County, California) and at the bottom of Handout H11-1 (the EPA Air Quality Index table).

1. The 2000 air quality graph shows daily mean PM 2.5 data ($\mu g/m^3$) from the Quincy and Portola air quality stations. What was the highest recorded level of the PM 2.5 in 2000? When was it recorded? What are the associated health risks?
2. The Storrie Fire, a large wildfire in Plumas County, began on August 17, 2000. A few days after the fire began, there was a spike in particulate matter. How high did the PM 2.5 measurement get? How long did the PM 2.5 measurement stay this high? What are the associated health risks?
3. The 2012 air quality graph shows the daily mean PM 2.5 measurement from the Quincy and Portola air quality stations. What was the highest recorded level in all of 2012? When was it recorded? What are the associated health risks?
4. The Chips Fire, a large wildland fire in Plumas County burned throughout August, 2012. How would you describe the daily particulate levels during the fire? What were the associated health risks while the fire was burning?
5. Based on particulate matter data from 2000 and 2012, which months seem most likely to have poor air quality? Which months generally have the best air quality?
6. Based on what you know about temperature inversions, what do you think causes the worst episodes of air quality?


2000 Air Quality, Plumas County
Daily Mean PM2.5, µg/m3
Aug. 17, 2000: Beginning of Storrie Fire
Date:
1/1/2000
1/31/2000
3/1/2000
3/31/2000
4/30/2000
5/30/2000
6/29/2000
7/29/2000
8/28/2000
9/27/2000
10/27/2000
11/26/2000
12/26/2000


2012 Air Quality, Plumas County
Daily Mean PM2.5, µg/m3
Jul. 29, 2012: Beginning of Chips Fire
Sep. 5, 2012: Chips Fire contained
Date:
1/1/2012
1/31/2012
3/1/2012
3/31/2012
4/30/2012
5/30/2012
6/29/2012
7/29/2012
8/28/2012
9/27/2012
10/27/2012
11/26/2012
12/26/2012


Daily Mean PM2.5 Quincy
Daily Mean PM2.5 Portola

Answer Key:
Handout H11-2: Plumas Air Quality through the Year

1. The 2000 air quality graph shows daily mean PM 2.5 data (μg/m^3) from the Quincy and Portola air quality stations. What was the highest recorded level of the PM 2.5 in 2000? When was it recorded? What are the associated health risks? The highest recorded level of the daily mean PM 2.5 in 2000 was about 46. It occurred on 12/20/2000. 24-hour exposure to 46 PM 2.5 μg/m^3 is considered unhealthy for sensitive groups. There is increasing likelihood of respiratory symptoms in sensitive individuals.
2. The Storrie Fire, a large wildfire in Plumas County, began on August 17, 2000. A few days after the fire began, there was a spike in particulate matter. How high did the PM 2.5 measurement get? How long did the PM 2.5 measurement stay this high? What are the associated health risks? A few days after the Storrie Fire began, the daily mean PM 2.5 spiked at about 43. This lasted for only 1 day. 24-hour exposure to 43 PM 2.5 μg/m^3 is considered unhealthy for sensitive groups.
3. The 2012 air quality graph shows the daily mean PM 2.5 measurement from the Quincy and Portola air quality stations. What was the highest recorded level in all of 2012? When was it recorded? What are the associated health risks? The highest recorded level of the daily mean PM 2.5 μg/m^3 in 2012 was about 45. It occurred on 1/25/2012. 24-hour exposure to 45 PM 2.5 μg/m^3 is considered unhealthy for sensitive groups.
4. The Chips Fire, a large wildland fire in Plumas County burned throughout August, 2012. How would you describe the daily particulate levels during the fire? What were the associated health risks while the fire was burning? Throughout most of August, when the Chips fire was burning, the PM 2.5 levels mostly remained below 10 μg/m^3. This is good air quality. There were a few days of moderate air quality, when "unusually sensitive" people might be harmed.
5. Based on particulate matter data from 2000 and 2012, which months seem most likely to have poor air quality? Which months generally have the best air quality? The winter months tend to have the poorest air quality, while the summer months seem to have the best air quality – with occasional exceptions because of wildland fires.
6. Based on what you know about temperature inversions, what do you think causes the worst episodes of air quality? The air quality is poorest during the winter months. Inversions are typically more common in winter, when the air at the ground level doesn't warm up during the day, keeping it trapped on the earth's surface under a warmer layer of air. Any pollutants in the cold surface layer of air are also trapped – including particulates. In winter, the particulates probably come from wood-burning stoves, road dust, and possibly some industries.

12. Fire, Soil, and Water Interactions

Lesson Overview: In this activity, students view and discuss a presentation that describes fire's effects on soils and how these effects are measured. Then they either observe or conduct an experiment that illustrates how wildland fires affect the potential for soil erosion. They learn that *soil burn severity* varies greatly and that when fires remove the litter, duff, and plant cover on the ground, the risk of soil erosion increases.

Lesson Goal: Increase students' understanding of the effects of wildland fire on soil properties, things that live in the soil, and the likelihood of erosion after fire.

Subjects: Science, Mathematics, Reading, Writing, Speaking and Listening, Health Enhancement

Duration: Two half-hour sessions plus out-of-class preparation

Group size: Entire class

Setting: Classroom

New FireWorks vocabulary: *burn severity, char depth, duff, erode/erosion, ground cover, ground fire, infiltration, litter, organic matter loss, slash, soil burn severity, soil structure, vegetation burn severity, water repellency*

Before beginning this lesson, watch the video demonstration of precipitation's impact on bare soil versus vegetation-covered soil: https://www.youtube.com/watch?v=im4HVXMGI68. Decide if you want to do the demonstration in class or just view the video. If you decide to do the demonstration in class, you need a container containing young grass stems that were started from seed 2-4 weeks before. You may be able to use a cut piece of sod instead.

Also consider using Activity M15 (Bark and Soil: Nature's Insulators) as a lab for this class.

Objectives:

- Students can use information from a PowerPoint presentation and a demonstration (on video or done in the classroom) to interpret a technical report on the effects of a real wildland fire.
- Students can communicate technical information about a fire's effects on soils in a clear, engaging way.

Standards:		9th	10th	11th	12th
CCSS--ELA	Speaking and Listening	1,4		1,4	
NGSS	History of Earth	ESS2.A			
	Earth's Systems	ESS2.C, ESS2.D			
EEEGL	Strand 1	A,B,C,D,E,F,G			

Teacher Background: Soil burn severity is the degree of change in soil characteristics caused by fire. Changes in the soil may (or may not) have profound effects on what happens in a burned area after fire. Potential impacts include reduced water infiltration and hence increased runoff, accelerated erosion, changes in stream channels, loss of cover and resultant warming of streams, death of underground plant parts that enable sprouting, and damage to archaeological artifacts and other cultural resources.

Here is a summary of the information in the PowerPoint presentation used in this lesson (*H12_FireSoilWater.pptx*). Consult the presentation for more details.

> Indicators of soil burn severity include char depth, organic matter loss, altered color and structure, and reduced infiltration. After fire, common changes to the soil include:
>
> - loss of ground cover due to consumption of litter and duff;
> - changes in surface color due to char, ash cover, or soil oxidation;
> - changes in soil structure due to consumption of soil organic matter;
> - death and consumption of fine roots and microorganisms in the soil; and
> - formation of water repellent layers that reduce infiltration.
>
> The degree of soil burn severity varies widely from fire to fire, and within individual burns. It depends on many factors, including the **weather** at the time of burning, fire behavior, the amount, type, and distribution of **fuels**, type of soil, and **slope**. Notice that the Fire Environment Triangle studied in Unit III covered many of these factors:
>
> - **Fuel** loading, particle size, spatial distribution, chemical composition, and moisture (in both live and dead fuels) influence soil burn severity. So does that type of vegetation present.
> - **Weather** conditions, including temperature, relative humidity, wind, and rainfall (before and after fire) affect soil burn severity.
> - **Topography** (slope, aspect, landform) and the properties of soils themselves (texture, moisture, organic matter, and soil type) affect soil burn severity.
>
> **Behavior of the fire itself matters too –** its intensity, duration of burning, and fire type (crown, surface, or ground fire).
>
> The more severe fire's effects on the soil, the more likely those soils will erode in subsequent rainstorms – especially in places with steep slopes. Erosion after fires can cause tremendous damage to people's homes and other structures in the first year or two after a fire.

This lesson ends with an activity in which students read a technical document (the BURNED-AREA REPORT for the Storrie Fire of 2000 - *Storrie burned area report.pdf*) and communicate its results to a local audience in the area of the fire. Burned Area Emergency Response (BAER) is a program in which a team of resource professionals assesses a burned area very rapidly (often before the fire is out). They figure out what actions are needed to protect human life, property, and critical natural and cultural resources and then get this work started as soon as possible (see http://www.fs.fed.us/biology/watershed/burnareas/background.html).

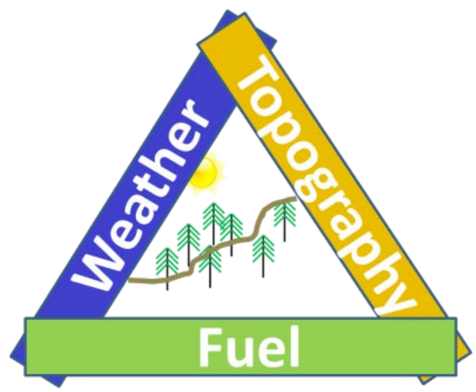
Sources and additional reading:

Parsons, Annette; Robichaud, Peter R.; Lewis, Sarah A.; Napper, Carolyn; Clark, Jess T. 2010. Field guide for mapping post-fire soil burn severity. Gen. Tech. Rep. RMRS-GTR-243. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p. http://www.treesearch.fs.fed.us/pubs/36236

Neary, Daniel G.; Klopatek, Carole C.; DeBano, Leonard F.; Ffolliott, Peter F. 1999. Fire effects on belowground sustainability: A review and synthesis. Forest Ecology and Management. 122(1-2): 51-71. http://www.treesearch.fs.fed.us/pubs/33598

http://forest.moscowfsl.wsu.edu/smp/solo/documents/GTRs/INT_280/DeBano_INT-280.php

Materials and preparation:



1. Display the Fire Environment Triangle (use the *M05_FireEnvironmentTriangle.pdf* poster or draw it).
2. Download and view the PowerPoint presentation: *H12_FireSoilWater.pptx*. The slides and notes for the presentation – including cues for discussion and main discussion points - are shown below.
3. Provide 1 copy (electronic or paper)/student of the Storrie Fire BURNED-AREA REPORT (**Handout H12-2. Storrie burned area report.pdf**)
4. Provide 1 copy/student: **Handout H12-1. Questioning the Effects of the Storrie Fire**
5. View this video about erosion: https://www.youtube.com/watch?v=im4HVXMGI68. In step 3 below, you will either conduct this demonstration in class or show the video. If you do the demonstration in class you will need:
   - Three empty 2 liter plastic soda bottles
   - Three empty plastic soda bottles (about 1 liter size)
   - Three pieces of string/yarn
   - Soil
   - Dead leaves/needles
   - Grass seed (planted in the soil 2-4 weeks ahead of time – a cut piece of sod may work instead)
   - Pitcher of water

Procedures:

1. Explain: Fires change more in the environment than just the aboveground plants; they change the soil too. Think about the three parts of the Fire Environment Triangle: fuels, weather, and topography. All of these things influence how fires affect soils. That's what we'll learn about today.

2. Present and discuss the PowerPoint presentation: *H12_FireSoilWater.pptx* (see slides and notes below).

3. Either watch this video as a class: https://www.youtube.com/watch?v=im4HVXMGI68 OR do the activity in the video as a class.

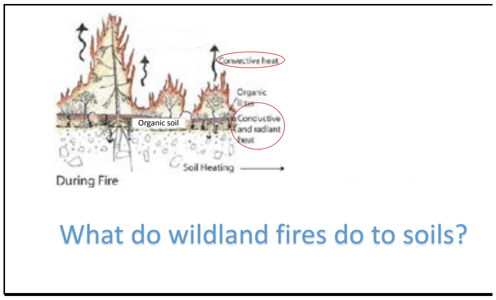
4. Explain: Now that you are experts on soil burn severity, you can read a report from a real wildland fire and present its results in a radio spot. You'll use The Storrie Fire **Handout H12-2. BURNED-AREA REPORT**. This was produced by a team of specialists just 9 days after the fire was "contained" – that is, when the burn was completely surrounded by either fireline or non-burnable landscape features (rocks, water, etc.)[1]

5. Provide a copy of the **Handout H12-2. BURNED-AREA REPORT** to each student. Ask them to browse through the report to figure out its purpose and audience. Then discuss:
   - What is the BAER project and report's main purpose? Determine how the soils were affected by the fire, what potential problems that may cause, what actions should be taken, and what those actions will cost.
   - Who prepared the report? Professionals from numerous resource specialties – see the list in Section V. C.
   - Who is the intended audience? Those who provide funding, local land managers, the public, and any organizations with interest in the burned area.
     Do you feel satisfied that the report covers the most important topics and makes valid recommendations? Why or why not? You could use this question to discuss the credentials of the BAER team, the possibility that some topics were missed, the possibility that critical problems could be missed because the assessment was "rapid," and any potential for bias in the process.

[1] Contained: The status of a wildfire suppression action signifying that a control line has been completed around the fire, and any associated spot fires, which can reasonably be expected to stop the fire's spread (http://www.nwcg.gov/glossary/a-z).

Slides and Notes for H12_FireSoilWater.pptx

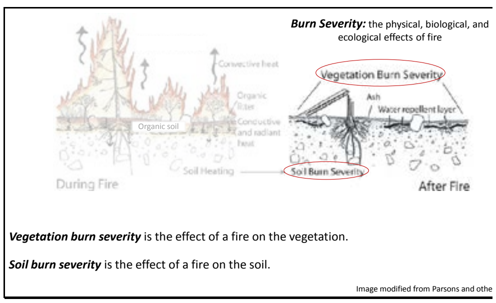
Slide 1



This image shows where the heat from wildland fire goes. What are the 3 methods of heat transfer? Convection, conduction, and radiation.

How are they at work here? Convection is lifting some of the fire's heat up, away from the soil. Conduction and radiation are transferring heat into the soil.

Slide 2

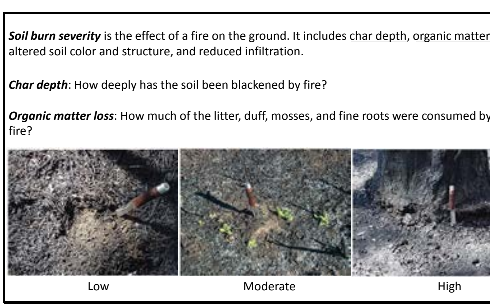


What does the heat from burning wildland fuels do to plants, ground cover, and soil after a fire? It depends on many things, so it varies! The physical, biological, and ecological effects of fire – all lumped together – are called *burn severity*.

Look at the right-hand diagram. How did the vegetation change as a result of the fire? It looks dead and partially consumed. Much of the *ground cover* (litter, duff, and surface vegetation) has been consumed.

Vegetation burn severity describes the effects of a fire on vegetation. Vegetation burn severity is likely the first thing you notice when you look at burned forest, and we'll study it more in later lessons. But we can also see changes in the soil surface and even deep into the soil. This is *soil burn severity* - the effects of fire on the soil. That's what we'll study today.

Slide 3

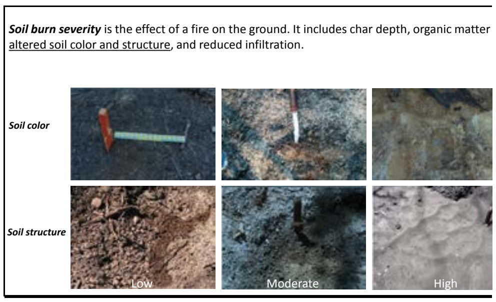


What does soil burn severity mean? It is the effect of a fire on the ground.

We describe soil burn severity in many ways: char depth, organic matter loss, altered soil color and structure, and reduced infiltration. ***Char depth*** refers to how deeply the soil has been blackened by fire. ***Organic matter loss*** refers to how much of the litter, duff, mosses, and fine roots on and within the soil were consumed by the fire. These photos shows char depth and organic matter loss from low, to moderate, to high soil burn severity.

If a fire burns the duff layer and organic particles within the soil – like tree roots, underground plant stems, seeds, and partly-decayed wood – we call it a *ground fire.* These fires tend to burn for a long time, unlike surface fires and crown fires, which we learned about in **Activity H09_Ladder Fuels.**

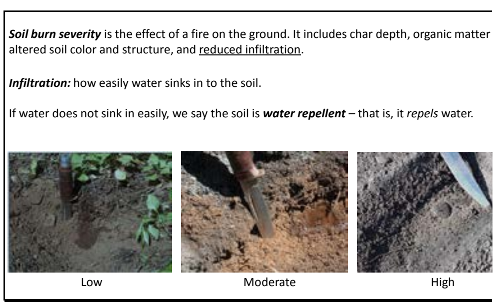
Slide 4



Soil burn severity includes changes in soil color and structure. How might a fire change soil color? Look at the top row of photos. Soil color is typically black or brown in areas with low soil burn severity (that is, very little change from the color of unburned soils). Soil color may be orangeish or reddish in areas with high soil burn severity.

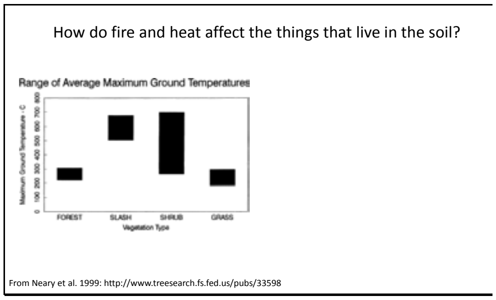
How might a fire change soil structure? Look at the bottom row of photos. Soil particles break down as soil burn severity goes from low to high. Soils with high burn severity may look powdery or loose.

Slide 5



Infiltration refers to how easily water sinks into the soil. Fires may change infiltration, although infiltration also depends on soil type. In these photos, a drop of water has been placed on each sample of burned soil. What differences do you see? The water on the severely burned soil does not sink in. Instead, it beads up on top. We say this soil is *water repellant;* it *repels* water. But note that water repellency is affected by many things, so some soils repel water even when they have not been burned.

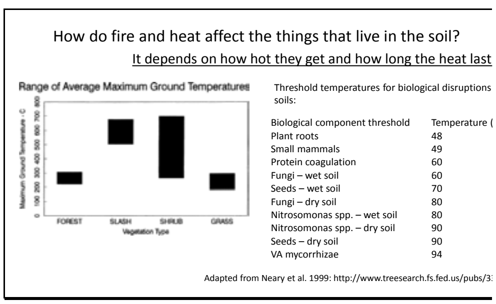
Slide 6



How do fire and heat affect things that live in the soil? First we have to know how hot it actually gets down there!

Interpret the graph: During forest fires, maximum ground temperatures typically range from 200 to 300 °C. In heavy fuels like slash (materials left on the ground after timber harvest), maximum ground temperatures are usually around 500 to 700 °C, but temperatures above 1500 °C can occur briefly. Fire-prone shrublands like chaparral commonly burn with lower maximum temperatures but have a wider range. Fires in grasslands, which lack woody fuels, usually have ground temperatures <225 °C, although higher temperatures have been measured.

Slide 7



How does heat affect the things that live in the soil? It depends on how hot they get and how long the heat lasts. It also depends on how moist the soil is. This table shows the "threshold temperatures" for harm to living things – that is, the lowest temperatures at which they are likely to be injured or die.

Interpret the data table: Things that live in the soil (plant roots, seeds, small mammals, and fungi) begin to die at about 40 to 70 °C. That is when protein degrades so plant tissues die.

- Roots can be killed at soil temperatures of 48 to 54 °C.
- Seeds often die between about 70 and 90 °C, depending on the soil moisture.
- Microbes generally die between 50 and 121 °C.
- Fungi are usually less resistant to high temperatures than bacteria.

Do lethal ground temperatures occur in wildland fires? Compare the information in the table with the data in the graph. The range of average maximum ground temperatures greatly exceeds the lethal temperatures of the things that live in the soil.

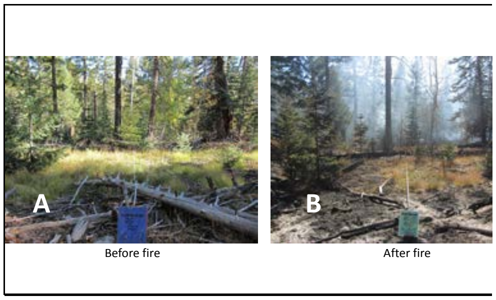
So how does anything in the ground survive?
- Some areas are missed by the fire.
- Some areas are exposed to lower temperatures than the maximum.
- It takes more energy to heat wet soils than dry soils – but wet soils hold the heat longer than dry soils do.
- Most importantly, soil is an excellent insulator from heat. The deeper you go in the soil, the lower the temperature. Therefore, things that are deep in the soil are protected from much of the heat from the fire.
- Duff is also an excellent insulator, as long as it does not burn. But when duff burns, much of its heat is conducted down into the soil. Areas where deep duff has burned may have high soil burn severity.

Slide 8

Since soil burn severity depends mainly on the amount of heat and duration of heating, think about these 2 photos. If a fire burned the surface fuels in these 2 photos under the same conditions, which fire would produce more heat? Which would burn for a longer time? If the large fuels are dry enough to burn, the fuels in Photo B, which include many logs, would produce higher temperatures and more heat than the fuels in Photo A, and the fuels in Photo B would also burn longer.

Remember lesson H5 about fuel properties? It is likely that the a fire burning in Photo B would result in much higher soil burn severity than a fire in Photo A. Fast-moving fires in fine fuels, such as grass, are often intense in terms of energy release per unit area, and thus they produce long flames. But they do not transfer as much heat to the soil as do slow-moving fires in moderate to heavy fuels. Slow-moving fires often have much greater soil burn severity than fast-moving fires, regardless of how much energy the fires produce aboveground and how long their flames are.

Slide 9



Let's look at soil burn severity in a small area – not much bigger than a classroom. Photo A shows this area before it was burned by a prescribed fire. Photo B shows what it looked like afterward. Can you see some diversity in soil burn severity?

Use what we learned earlier about char, soil color, and soil structure. Some patches show no evidence of fire at all. Some patches have low soil burn severity, based on the black ground surface and the fact that some woody fuels remain above the ash. Some patches show evidence of being severely burned: The ash is completely white (no carbon left), and woody fuels are nearly gone. The lines of thick white ash, where the logs were before the fire, are places where the soil probably experienced hotter temperatures for longer periods of time than most of the other areas in this photo. That is, the areas underneath the logs experienced very high soil burn severity.

Slide 10

Here is a video of a fire moving though a forest. Watch where the flaming occurs and where the big fuels are. Think about what type of fire you are seeing – surface fire, crown fire, and/or ground fire. There are no tree crowns in the video, so there is no crown fire. The flames are a reliable sign that surface fuels are burning, so there is obviously surface fire here. If deep duff is burning – or if there are roots, partly-decayed wood, and other plant parts mixed in with the soil, then ground fire may be occurring as well.

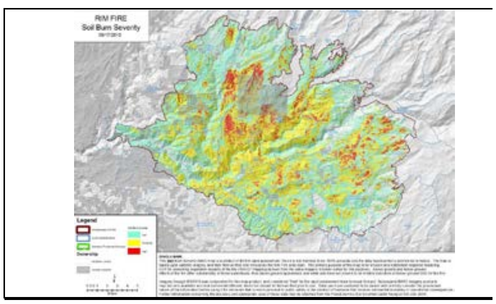
Let's talk about what areas might have low vs. high soil burn severity. The flames appear to be moving through the surface vegetation relatively quickly. If there is not much heavy fuel (like logs) underneath the vegetation, the soil may experience only low burn severity. But there are lots of heavy fuels from a previous fire. These include snags, stumps, and fallen logs. After the flames move through the vegetation, the logs and stumps will continue to flame and smolder, causing high soil burn severity in those spots.

Slide 11

This is a photo from that same fire. Any more thoughts about where soil burn severity will be low vs high? The flames are concentrated in stumps and logs, even in the background, where the fire is no longer actively spreading. The areas where the fire has gone out will probably have low soil burn severity. The areas where the flames are still burning in the background will probably have high soil burn severity.

Do you think there are patches of ground fire in the photo? There is ground fire where the fire is burning down into tree stumps and possibly through the root systems of the trees. There may be other underground fuels burning too.

Slide 12



Soil burn severity varies greatly over an entire landscape. This image shows the soil burn severity on the 2013 Rim Fire in California, as seen by satellite imagery. The green represents low severity, yellow is moderate, and red is high soil burn severity. Why do you think there is so much variation? Think about the many factors that affect the heat produced by a fire, the heat transferred into the soil, the temperatures reached in the soil, and how long those high temperatures last. Think back to the **Fire Environment Triangle in Activity H08**:

- Fuel properties -- Fuel loading, fuel size, fuel distribution, fuel moisture (of both live and dead fuels), vegetation type, fuel chemical content
- Fire weather -- Temperature, relative humidity, prior rainfall, wind
- Topography and soils -- Slope, aspect, landform, soil texture, soil organic matter, soil type, soil moisture
- Fire behavior itself -- Intensity, duration of burning, fire type (crown, surface, ground)

Slide 13

Soil burn severity varies greatly even over small areas within a fire. Which areas of soil do you think burned most severely? Which areas burned less severely?

- You can see lightly burned surface and ground fuels on the back-left side of this photo. Chances are the soil experienced low or moderate burn severity.
- In the middle of the photo, you can see areas of white ash and no remaining stems of small trees or shrubs. Underneath some of these white ash patches may be patches of severely burned soil.
- In the very foreground, it looks like some of the surface fuels aren't completely consumed, so maybe the soil was only moderately burned.

Just because the vegetation appears severely burned, the soil may not be severely burned and vice-versa. That is, vegetation burn severity does not equal soil burn severity. How could that happen? It could be caused by variation in soil composition, texture, moisture content, or other factors.

Slide 14

Both of these photos show places where most of the vegetation and ground cover have burned away. The soil does not have any protection from raindrops. What will happen in the next shower or big thunderstorm? Loss of ground cover is the aspect of soil burn severity that is most likely to increase soil erosion and runoff. If there is no litter, duff, or plant cover and roots to hold the soil in place after fire, the soil is vulnerable to washing away especially after heavy rains.

Slide 15

In the corner, you can see the splash from a single raindrop. What happens when lots of rain falls on an area with severely burned soils? What if the area is on a steep hillside? Areas with severely burned soils on steep slopes are the most vulnerable to erosion. Sometimes heavy rain on these soils causes big mudslides.

Slide 16

What locations in this post-fire photo are probably most vulnerable to erosion? What locations seem least vulnerable?

- Where the tree crowns have been burned and the ground is covered with grayish ash, these areas probably have high soil burn severity and are at high risk of soil erosion. Severely burned soils on steep slopes have greater risk of erosion than soils on level sites.
- Where the tree crowns are still green, even if the area was burned by surface fire, soil burn severity is likely low, as is the risk of erosion.
- Where the tree crowns are brown (because they have been scorched), the soils could have any level of soil burn severity. It depends partly on how much large fuel was on the ground. The brown needles will fall off the trees fairly soon, and that will protect the soils a little from raindrop impact. Thus they have less risk of erosion than the areas where the tree crowns have burned away.

Assessment:

1. Give each student or team a copy of Handout **H12-1. Questioning the Effects of the Storrie Fire.**
2. Explain: Return to the BAER report and read ALL of the sections that have headers highlighted in yellow.
3. Assign ONE of the four assessment questions (A-D) to each student or team.
4. Explain: Each student or team will prepare and present a 3-minute radio spot for a station in Plumas County, California – the location of the fire.

5. Read the objectives of the radio spots with the class and ask for a few ideas about what makes a radio presentation on a technical subject succeed or fail:
   Objective 1. Help the general public understand how the Storrie Fire has changed the soils in the burned area.
   Objective 2. Help them understand how those changes might affect their lives – in other words, why they should care?

Play each recording in class. After each, ask the class to discuss (or assess on a half-sheet of paper) if the radio spot meets the 2 objectives. Why or why not?

Evaluation:

Criterion	Completely successful	Partially successful	Unsuccessful
1. Appropriate, accurate technical information	Evaluate based on content in the BURNED-AREA REPORT or the Answer Key to **Handout H12-1. Questioning the Effects of the Storrie Fire**		
2. Clarity of communication in radio spot	Information is clear. No jargon or acronyms are used. Technical terms are used only as needed and are defined.	Information is slightly unclear; or jargon, acronyms, or technical terms are used without definitions.	Information is unclear. Jargon or acronyms are used. Technical terms are used without definitions.
3. Relevance of information to local audience	Recording gives persuasive reasons why the information is important to listeners.	Recording gives at least one reason why the information is important to listeners.	Recording does not give any reasons why listeners should care.

Handout H12-1. Questioning the Effects of the Storrie Fire

Use the Storrie Fire Burned-Area Report to address ONE of the questions below in a 3-minute radio spot for a popular radio station in Plumas County, California – the location of the fire. You cannot include graphics, so be careful to explain any information from maps and graphs very clearly. Include appropriate sound effects. Do not use jargon or acronyms—use technical terms only when needed and define them. Record the radio spot; it will be "assigned listening" for your class.

The fire is still smoldering, but it is not currently threatening any structures. There has been a lot of smoke in the air. There are no evacuations currently in effect, but the public is not being allowed into the burned area yet. You have 2 objectives:

1. Help the general public understand how the Storrie Fire has changed the soils in the burned area.
2. Help them understand how those changes might affect their lives – in other words, why they should care?

Address ONE of these questions:

A. What is the overall condition of the soil on the burned area? Focus especially on the statistics in Part III of the report ("WATERSHED CONDITION") and the "Burn Intensity Descriptions." Explain what proportion of the burned area has each kind of severity. Find a way to make the erosion potential and sediment potential real to your listeners. For example, you might give examples of just how much 97 tons is, or how many cubic yards of sediment would come off the fire if ALL of the high-severity burned area lost that much soil.

B. What is the report's recommendation regarding the Bucks Lake Wilderness? What is the rationale for this approach, based on the information the report gives on soil burn severity? The wilderness may be very precious to some of your audience and meaningless to others, so find a way to engage as many of your listeners as possible.

C. What is the likelihood that flooding and erosion will damage local roads and human communities? How extensive is that threat – over the entire burned area, or …? What can be done about it? How long will people have to worry about it?

D. How could soil burn severity affect aquatic species and riparian areas? How extensive are the threats – over the entire burned area, or… ? What can be done about the situation? Why should your listeners care?

Answer Key to
Handout H12-1. Questioning the Effects of the Storrie Fire

A. What is the overall condition of the soil on the burned area? Focus especially on the statistics in Part III of the report (“WATERSHED CONDITION”) and the “Burn Intensity Descriptions.” Explain what proportion of the burned area has each kind of severity. Find a way to make the erosion potential and sediment potential real to your listeners. For example, you might give examples of just how much 97 tons is, or how many cubic yards of sediment would come off the fire if ALL of the high-severity burned area lost that much soil.

   Burn Severity (acres): 37,000 (low) 11,000 (moderate) 8,000 (high)
   Water-Repellent Soil (acres): 5,500
   Soil Erosion Hazard Rating (acres): 32,000 (low) 12,000 (moderate) 12,000 (high)
   Erosion Potential: 97 tons/acre
   Sediment Potential: 9 cubic yards / square mile

B. What is the report’s recommendation regarding the Bucks Lake Wilderness? What is the rationale for this approach, based on the information the report gives on soil burn severity? The wilderness may be very precious to some of your audience and meaningless to others, so find a way to engage as many of your listeners as possible.

   Rely mainly on “Section A. Description of the Watershed Emergency.” None of the watersheds in the Bucks Lake Wilderness were burned to a level that warrants concern. The wilderness portion of the fire created a mosaic pattern of burn intensities, with no single drainage significantly impacted. Fern Canyon and Belden Ravine flow through the community of Belden and were not sufficiently changed by the burn to consider them for emergency treatment. Flows from these channels normally flood into the area during high flow events and usually carry low to moderate amounts of sediment.

C. What is the likelihood that flooding and erosion will damage local roads and human communities? How extensive is that threat – over the entire burned area, or …? What can be done about it? How long will people have to worry about it?

   Rely mainly on “Section A. Description of the Watershed Emergency” and “H. Treatment Narrative.” Highway 70 passes through a few small drainages that were impacted by high intensity fire. These drainages are in very steep terrain, where rock fall is common and debris torrents could occur, especially in the first 3 to 5 years after the fire. “The impacts caused by most occurrences would be localized, but those channels directly flowing to Highway 70 will likely cause damage. In addition, the small community at the mouth of Indian Creek and at the upper end of the Rock Creek Reservoir could experience damage from large amounts of sediment deposition at that location if a large storm event occurs before hydrologic recovery takes place. This risk would decrease each year. The Indian Creek community could expect this type of damage any year, even without the burn, but for the next several years, this likelihood is greater, although probably not to the same magnitude as what occurred in the January 1, 1997 storm." "Treatment would consist of (1) adding culvert pipe risers and associated trash racks and (2) constructing dips and overside-drains to provide controlled drainage if the pipes still plug. The pipes and their risers would be monitored and cleaned when accessible during the wet season."

D. How could soil burn severity affect aquatic species and riparian areas? How extensive are the threats – over the entire burned area, or… ? What can be done about the situation? Why should your listeners care?

   See these sections of the report: "Aquatic, Riparian, and Terrestrial Habitats" and "Treatment Narrative." "The primary aquatic resources at risk are the coldwater fisheries and Threatened, Endangered and Sensitive (TES) amphibian populations. There are potential short- and long-term effects of sedimentation and debris torrents to these aquatic populations. There is also the potential for reduced water quality and associated increased stream temperature due to sedimentation and lost vegetative cover within sections of the perennial drainages. Amphibian species of concern include the California red-legged frog and Foothill and Mountain yellow-legged frogs within the fire boundary. Fisheries of concern are the wild trout population within Yellow Creek and native rainbow trout populations throughout perennial drainages within the fire boundary". The report does not indicate what can be done to help the aquatic species and riparian areas. Treatment may not be warranted. However, "land treatments" such as rice straw mulch, "channel treatments" such as armoring channel banks could help in specific areas of concern.

Unit V.
Fire's Relationship with Communities

Having studied Units I-IV, students are now well informed about combustion, wildland fire behavior, fuels, and fire effects on nonliving parts of the ecosystem. In this unit, they will integrate their knowledge of fire with knowledge about living things, that is, specific organisms that live in montane ecosystems of the Sierra Nevada. They will construct a dichotomous key for identifying some of the most important tree species in the Sierra Nevada. They will learn and report to the class about specific plants, animals, and fungi and the characteristics that help them survive fire and/or reproduce successfully after fire. They will learn how different assemblages of tree species comprise different forest communities, and how these communities may be changing as the current climate changes.

13. Tree Identification: Create a Dichotomous Key

Lesson Overview: In this activity, students use photographs and botanical specimens to create a *dichotomous key* for 12 tree species native to montane forests of the Sierra Nevada.

Lesson Goal: Increase students' ability to identify some of the important tree species native to the montane forests of the Sierra Nevada and to increase their understanding of characteristics that can be used to identify trees.

Subjects: Science, Speaking and Listening, Writing
Duration: One 30-40 minute session
Group size: whole class/groups
Setting: Classroom
New FireWorks vocabulary: *dichotomous key*

Objectives:

- Students will use species names, botanical specimens, and photographs to create a dichotomous key for 12 tree species.

Standards:		9th	10th	11th	12th
CCSS	Reading: Informational Text	2,4,10		2,4,10	
	Reading: Science and Technical Subjects	2,4,7,9,10		2,4,7,9,10	
NGSS	Interdependent Relationships in Ecosystems	LS4.C			
EEEGL	Strand 1	B,C,E,F,G			

Teacher Background: A wildland ecosystem is characterized by diversity. The diversity of tree species is an important characteristic of forests and influences to the kinds of fire that occur in those forests. To understand the complexity of fire's role in forests, students must be able to distinguish among tree species. In this activity, students use their observation skills to create a dichotomous key for 12 important trees in the montane forests of the Sierra Nevada. An example of a key for these 12 species is included at the end of the activity, but each student's (or team's) dichotomous key will be unique, depending on their observations.

In the activity, students actually construct 3 keys:

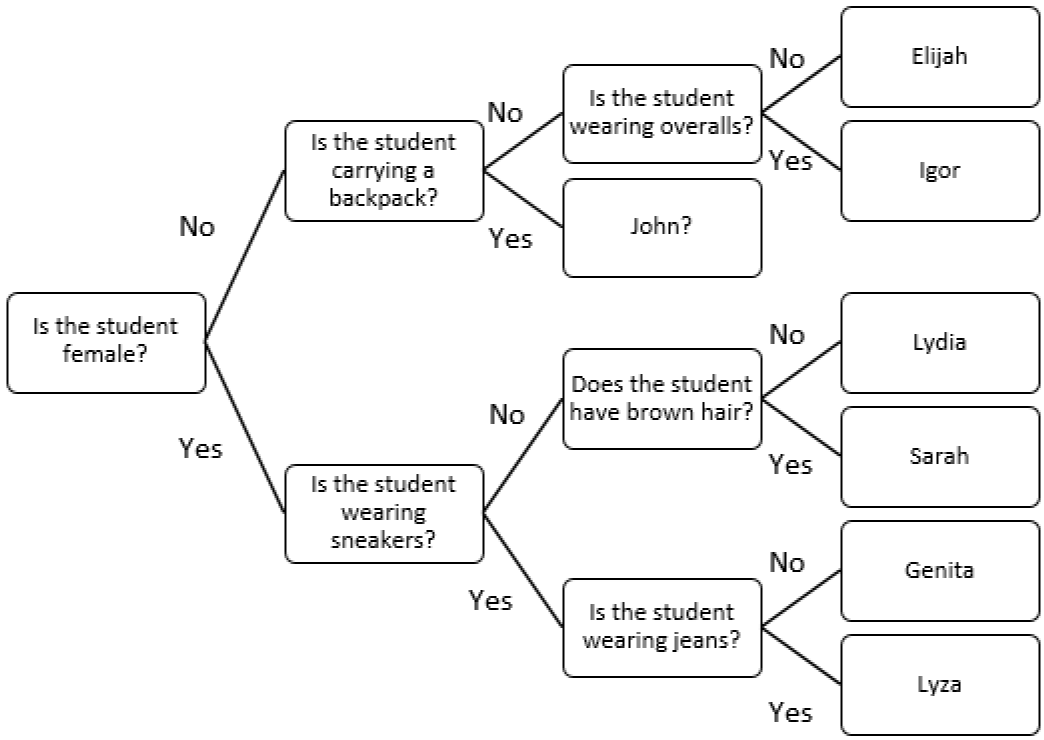
- a key to be used by a new student for identifying some members of the class;
- a key that could be used to identify different types of pasta (this one is optional – may not be needed by your students – see Steps 8-10 below);
- and finally, a key for identifying 12 tree species.

Materials and preparation:

- Decide how you will have students work on the keys – individually, in pairs, or in larger teams. This will determine how many cups of mixed pasta you need to prepare for Steps 8-10.
- Assemble 12 stations in the classroom, each with the following items for each tree species (all in the trunk):
  - Photos for that species from **H13_TreePhotoPacket.pdf** (also available online). Two pages of photos for each species, labeled with the species name.
  - Tree Bark/trunk specimen
  - Cone or flower specimen
  - Foliage specimen
  - Species name label
  - Ruler
- Provide some field guides of your own or from a library for students to examine – or find examples online.
- Obtain:
  - Empty cups or bowls (1/student or team)
  - Uncooked pasta (at least 4 different types), enough so each student/team can get at least 1 piece of each type of pasta
- Put a mixture of pasta types in each cup (1 cup/student or pair or team)

Procedure:

1. Ask: What tree species live on the mountainsides of the Sierra Nevada? Open-ended discussion. You could list species names on the board. Names of classes of trees (pines, oaks, firs, etc.) would also be good.
2. Ask: When you see a person in school or a tree in the woods, how can you identify him/her/it? We use distinguishing characteristics, that is, traits that are unique to that person or thing or group.
3. Let's figure out a way to help a new student at school identify some of our class members. We're going to build a *dichotomous key.* The new student will be able to go through a series of yes-no choices about characteristics of the class members. The choices will lead the new student to the right name for each person in the key.
4. Select eight volunteers. Write the key on the board as it develops. Provide the first question (e.g., "Is the student female?") and have students create the rest of the key until all eight students are identified. Here is an example of a dichotomous key for identifying 8 students:



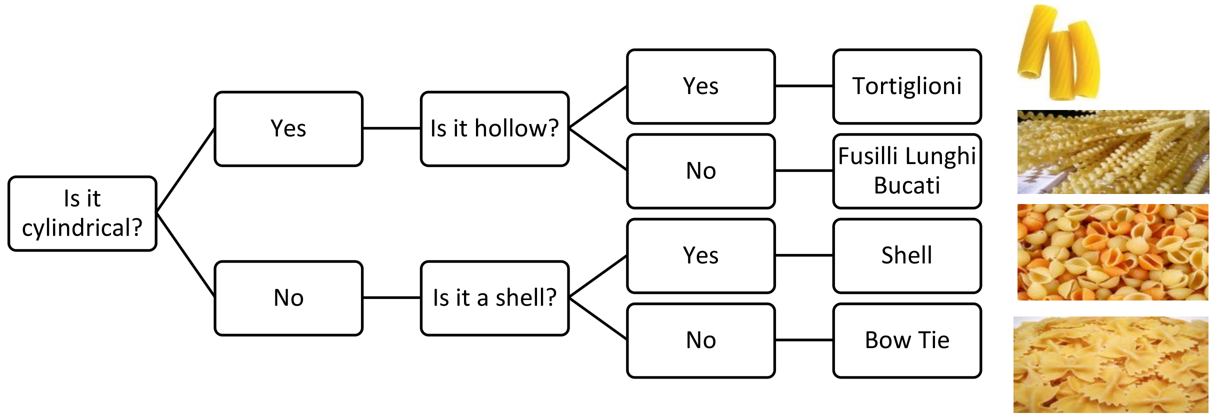
5. Explain: Dichotomous keys usually contain additional information in a narrative description that can be used to verify the identification. What additional information would you offer so the new student can confirm his/her identifications and learn more about his/her new classmates? Example narrative for the key above to describe Igor: "Igor is a male student who is 6 feet tall, has brown hair, and lives in Quincy, CA. Igor does not carry a backpack and wears overalls."

6. Ask: Do you see any problems the key you created? For example, will it work tomorrow if everyone changes clothes? … if they dye their hair or shave their heads? A key should be based on characteristics that do not change much from day to day or season to season or even year to year (unlike the example provided).

7. Explain: We've just built a key for identifying **individual people**. In the sciences, keys are used for identifying whole **groups of things** – people, rocks, plants, animals, micro-organisms, etc.

8. **TEACHER: IF YOU THINK STUDENTS ARE READY TO MAKE A KEY FOR 12 (or 6) TREE SPECIES, GO TO STEP 11. IF YOU THINK THEY NEED SOME PRACTICE, DO THIS PASTA-IDENTIFICATION ACTIVITY:** Let's practice by building a key for 4 types of pasta. The key will consist of a series of two choices (hence "dichotomous" - from Greek, *dich-* ("in two") and *temnein* ("to cut")) that will lead the user to the correct name for each kind of pasta. At each choice point, the user examines a characteristic of the pasta and picks the answer that best describes it ("yes" or "no"). This brings the user to a new choice point, and the process continues until the user can identify the unknown pasta.

9. Give each student (or team) a cup containing at least four different types of pasta. Ask them to create a dichotomous key for the types of pasta in the cup and – for 2-3 kinds - to create a narrative description 2-4 sentences long. Here's an example:



Example Descriptions:
Tortiglioni: A pasta that is cylindrical and hollow. It is often eaten with tomato sauce.
Fusilli Lunghi Bucati: A pasta that is cylindrical but not hollow. It takes 8 minutes to cook.

10. Have students or teams exchange keys, use them to sort the pasta, and comment on how well they worked, any points that were confusing, etc.
11. Explain: We're going to work individually (or in teams) to create a dichotomous key for some important tree species that grow in montane forests of the Sierra Nevada. We'll identify only 12 species, even though the keys used by professionals (land managers, ecologists, botanists, wildlife biologists, microbiologists) cover ALL of a kind of organism – often hundreds or even thousands of kinds.
12. Either distribute copies of a few field guides with dichotomous keys or show examples from the internet. Pass them around so students can see what a dichotomous key looks like and how it is used.

Assessment:

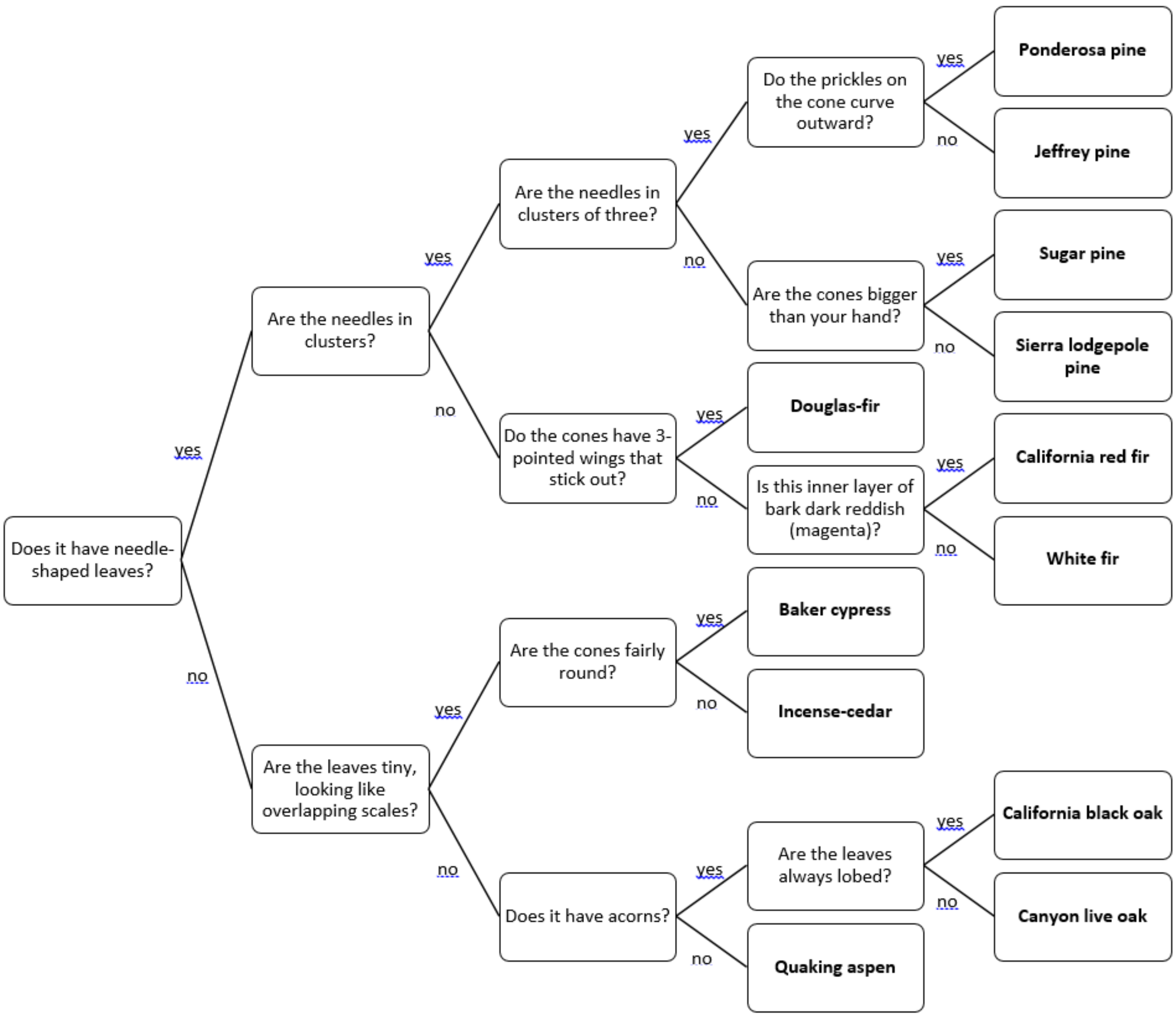
1. Explain: You will create a dichotomous key for 12 important tree species that occur in montane forests of the Sierra Nevada. Alternatively, split the class and the specimens into two groups, and have students create a key for six of the tree species. We'll refer to the trees often in the rest of our fire-related activities, because they all have different ways of dealing with fire. Each station has 2 pages of photos that show characteristics of 1 species and also the species name, plus a collection of botanical specimens (cones/flowers, bark, and foliage) for that species.

2. Circulate among stations to observe characteristics that are unique to a few species or even a single species. Take notes on these distinguishing characteristics.
3. Work with paper and pencil to create a draft of your key. Go back to the photos and specimens to fine-tune the key. The process will probably require several iterations and some erasing.
4. When you think you're done, have another student or team try your key out to see if it is accurate and can be used easily. If you split the class into two groups, have students exchange keys with someone in the other group to see if it can be used easily.
5. Make a clean copy of your key for evaluation. It can be digital[1] or done by hand. It can use text only (like most field guides), or include graphics (like the pasta example).
6. Along with your key's diagram, provide a narrative description of each tree species (2-4 sentences) that can be used to confirm the identification.

Evaluation:	**Excellent**	**Good**	**Fair**	**Poor**
Dichotomous key	Created clear and accurate key and descriptions for 11-12 (or 5-6) species.	Created clear and accurate key and descriptions for 9-10 (or 4-5) species.	Created clear and accurate key and descriptions for 7-8 (or 3-4) species.	Created key and descriptions for 6 (or 3) or fewer species. ~or~ Created an inaccurate and confusing dichotomous key.

[1] Tip: If students want to create their keys in Microsoft Word, they can use the *Insert* tab, select *SmartArt* in the *Illustrations* box, select *Hierarchy*, and then select *Horizontal Hierarchy*. This will set up a template similar to the one used in the examples used in this activity, but students will still need to learn the basics of adding shapes (mostly by "add shape below") and formatting to make it into a dichotomous key.

Teacher's Example:
Dichotomous key and tree descriptions for 12 tree species



Narrative Descriptions

Baker cypresses have tiny leaves that look like overlapping scales. The trees' bark is thin and reddish-brown. The cones are round and are sealed closed by a hard, waxy coating.

California black oaks have leaves with lobed (curvy) edges. The leaves fall off each winter. Adult trees have thick, rough bark. Like all oaks, they produce has acorns.

California red firs have short needles and brown, furrowed bark. If you break off a chunk of bark, you will see a deep red color. The buds at the ends of their twigs are round. Cones are on the top of the tree, and they stick straight up. The cones fall apart easily, so you rarely see whole cones on the ground. California red fir needles are typically shorter than those of white fir.

Canyon live oak leaves are often oblong and have smooth edges, but they can also have pointy teeth along their edges. The leaves are evergreen, so they do not fall off in the winter. The trees' bark is thin and flaky. Like all oaks, the trees produce acorns.

Douglas-firs have short, flat needles and brown, furrowed bark. The buds at the ends of their twigs are pointy. Their cones have little, 3-pointed "wings" that stick out from under the cone scales. It looks like tiny mice are trying to burrow in, but they can't hide completely!

Incense-cedar leaves look like overlapping scales, and their twigs look a little like fern fronds. Adult trees have thick reddish-brown bark with deep furrows. Narrow strips hang loose from the trunk. Cones are at the tips of leaves. Male cones are small and roundish. Female cones are a little larger; at the end of the summer, they flare open and release their seeds. Then they look like stiff brown flowers.

Jeffrey pines have long needles that usually grow from the twig in clusters of 3. Their cones are big. The cones have prickles that point inward. The trees' bark is yellowish or brown, sometimes even orange. It falls off in pieces that look like they belong in a jigsaw puzzle. Jeffrey pines produce a vanilla-like smell, especially in the springtime. Jeffrey pine needles and cones are typically bigger than those of ponderosa pine.

Ponderosa pines have long needles that usually grow from the twig in clusters of 3. Their cones are big. The cones have prickles that point outward. The trees' bark is yellowish or brown, sometimes even orange. It falls off in pieces that look like they belong in a jigsaw puzzle. Ponderosa pines produce a vanilla-like smell, especially in the springtime. Ponderosa pine needles and cones are typically smaller than those of Jeffrey pine.

Quaking aspens have roundish leaves with a pointed tip. Their leaves move almost constantly because they are very sensitive to wind. The leaves turn yellow and fall off in the fall. The trees' bark is mostly grayish-white and smooth, although old trees can have furrowed bark down near the ground. Aspen seeds are packaged with cottony fluff that helps them float on wind and water.

Sierra lodgepole pines have needles that grow from the twig in clusters of two. They have fairly thin, rough bark. The cones are about as long as the needles, and they open when their seeds are ripe. Sierra lodgepole pines grow high in the mountains.

Sugar pines have needles that grow from the twig in bundles of five. The trees grow tall and have thick, furrowed reddish-brown bark. Their cones are very long, often longer than a foot. Their branches spread wide from the trunk, and the cones dangle from the ends of the branches.

White firs have short needles. The bark on young trees is gray and smooth. The bark on old trees is gray with deep furrows that have orange streaks inside. If you break off a chunk, you will see a yellowish or orange color. The buds at the ends of their twigs are round. Cones are on the top of the tree, and they stick straight up. The cones fall apart easily, so you rarely see whole cones on the ground. White fir needles are typically longer than those of California red fir.

14. Researching a Plant, Animal, or Fungus

Lesson Overview: Students will each be assigned a plant, animal, or fungus to research. They will write a research paper on their species and present their findings. During presentations, classmates will take notes to be used later for an open-notebook quiz.

> **Subjects**: Science, Writing, Reading
> **Duration**: Homework and 2-3 class periods for student presentations
> **Group size:** Whole class
> **Setting**: Classroom
> **New FireWorks vocabulary:** *biodiversity, fire regime, montane (lower and upper)*

Lesson Goals:

- Increase students' understanding of how species living in the Sierra Nevada survive and even thrive in an environment that includes wildland fire.
- Increase students' understanding that species' adaptations to fire are attuned to specific kinds of fire.

> **ABOUT SCHEDULING PRESENTATIONS:** It may be helpful to spread presentations out over several class periods. If you plan to do the activities in **Unit VI. Fire History and Succession**, consider scheduling the presentations on tree species during that time or as an introduction to the unit. Save the presentation on Baker cypress for **Activity H17. Fire History 2: History of Stand Replacing Fire**.

Objectives:

- Students will become well informed on the fire ecology of at least one species in the Sierra Nevada, as demonstrated by a research paper and presentation to the class.
- Students can distinguish different kinds of fire (severity and frequency) and identify a few species adapted to each kind.

Standards:		9th	10th	11th	12th
Common Core ELA	Writing	4,7,10		4,7,10	
	Reading Information Texts	1,4,10		1,4,10	
	Science/Technical Subjects	2,4,5,6,7,8,9,10		2,4,5,6,7,8,9,10	
NGSS	Structure and Function	LS1.A			
	Inheritance of Traits	LS1.A,LS1.B,LS3B			
	Interdependent Relationships in Ecosystems	LS2.C,LS2.D,LS4.C			
	Natural Selection and Evolution	LS4.C			
EEEGL	Strand 1	C,E,F,G			

Teacher Background: This lesson challenges students to locate, read, interpret, and report information on fire ecology from the technical and scientific literature. Through individual students' reports on individual species, the class will learn about the fire ecology of many species that occur in montane ecosystems of the northern Sierra Nevada. Make species assignments from **Table H14-1 - Species assignments for research papers.** This is a list of species representative of northern Sierra Nevada montane ecosystems.

A few new terms are introduced in this activity: *biodiversity, fire regime,* and *montane ecosystem* (specifically, upper and lower montane ecosystems in the Sierra Nevada). See **Procedure, Step 2** for definitions.

For their research papers, students should definitely consult the following information source if it covers their species:

The Fire Effects Information System (FEIS) (available: https://www.feis-crs.org/feis/). This website contains reviews of the scientific literature about fire effects on plants and animals and about fire regimes in the plant communities where they occur. These literature reviews are written for professional land managers and include information on the distribution, life history, ecology, fire ecology of individual species (plants, animals, and lichens). Note, however, that not all of the species in Table H14-1 are reviewed in FEIS. You may want to limit student assignments to species that are reviewed in FEIS.

A second helpful resource may be the **FireWorks Encyclopedia_Older grades.pdf**, a collection of brief essays on all of the species listed in **Table H14-1**. These 2-page essays are written for juvenile readers, but they provide an overview of the information that the high school research papers should include.

Before students begin their research projects, you may need to discuss the reliability of different kinds of information (e.g., peer-reviewed journal articles, government technical reports, unpublished documents, blogs, personal opinions of experts and others). This way, students can select their sources based on the quality of information likely to be found there.

We recommend sharing students' research papers by using a collaborative online forum such as a class blog, webpage, wikispace, or Google documents.

For a brief review of the types of fire that is typical in lower and upper montane Sierra Nevada forests, see the **introduction** to this FireWorks curriculum**.**

Materials and preparation:

- Provide computer and internet access for each student
- 1 copy/student: **Handout H14-1: Species Research Project**
- 1 copy/student: **Handout H14-2: Species Research Project Quiz**

Procedure:

1. Explain: Now that you know about the physics and chemistry of fire, it's time to learn how fire, which seems destructive, can be an essential part of wildland ecosystems. We're going to learn about the role of fire in *montane* ecosystems of the Sierra Nevada.

2. We need to know (or review) a few terms:

   - *Biodiversity:* biological diversity, especially the numbers of different species of plants and animals, the complexity of the ecosystem, and the genetic variation present within species (http://www.oxfordreference.com/)
   - *Fire regime:* the pattern of fire ignition, seasonality, frequency, type (crown, surface, or ground fire), severity, intensity, and spatial continuity (pattern and size) in a particular area or ecosystem (http://www.fs.fed.us/database/feis/glossary2.html)
   - *Montane ecosystems in the Sierra Nevada:* This term refers to ecosystems above the foothills and below the alpine zone. ***Lower montane ecosystems*** begin near the 3,000 foot (900 m) elevation. Summers are hot and dry; winters are cool and moist; forests typically contain ponderosa pine mixed with other species. ***Upper montane ecosystems*** begin at higher elevations, near 7,000 feet (2,100 m). The climate is characterized by short, moist, cool summers and cold, wet winters. Snow begins to fall in November and remain until June. Stands of red fir and lodgepole pine (the indicator species) are typical of forests in upper montane ecosystems. (https://en.wikipedia.org/wiki/Ecology_of_the_Sierra_Nevada).

3. **Explain: YOU will all be the teachers in this activity. Each of you will become an expert on one species and teach the rest of the class about it.**

4. Give a copy of **Handout H14-1: Species Research Project** to each student. Go over the directions on the handout.

Assessment:

1. Assign each student a species from **Table H14-1. Species assignments for research papers**.
2. Schedule presentations.
3. When presentations begin, remind students of Step #3 in the project: They MUST take notes on other students' presentations so they can take the open-note quiz after all presentations are completed.
4. You may want to post students' research papers in a forum where all students can review them and add to their notes.
5. Assign or administer the open-notes quiz (**Handout H14-2: Species Research Project Quiz**).

Evaluation:

Assignment	Evaluation criteria
Research paper	Assess each of the 10 criteria in **Handout H14-1:** 1. Physical description 2. Geographic distribution (where it occurs) 3. Habitat requirements 4. Associated species (name a few other plants and/or animals in the community) 5. Information on how your species reproduces 6. Information on where it gets energy and what other organisms feed on it 7. Adaptations to fire and relationships with fire (do certain types of fire kill it or help it? If so, how?) 8. Information on typical kinds of fire in its habitat (surface or crown fires? How often?) 9. Effects of fire exclusion (what happens if fire does not occur for a long time?) 10. **Information sources, cited using MLA format**
Presentation	Assess each of the 4 criteria in **Handout H14-1:** 1. Make the presentation 3-5 minutes long 2. Be SURE to include information on the species' relationships to fire (#7-9 above) 3. Include at least 10 slides with at least 8 images 4. Be clear, well organized, and grammatically correct 5. **Be well-rehearsed so you can present clearly and concisely**
Open-notes quiz	1. **See Teachers' Answer Key to Species Research Project Quiz below.** 2. **Under Question 1 (the species/fire table), if the majority of students give an incorrect answer for one of the species,** re-evaluate the presentation of **the student** who **presented that species; he or she may not have provided the necessary information.**

Table H14-1. Species assignments for research papers

Species	Life form	In FEIS?	Student Name
American black bear (Ursus americanus)	mammal	yes	
Annosum root rot (Heterobasidion annosum)	fungi	no	
Baker cypress (Hesperocyparis bakeri)	tree	yes	
bark beetles (multiple species)	insect	no	
black fire beetle (Melanophila acuminata)	insect	no	
black-backed woodpecker (Picoides arcticus)	bird	yes	
Bracken fern (Pteridium aquilinum)	fern	yes	
California black oak (Quercus kelloggii)	tree	yes	
California red fir (Abies magnifica var. magnifica)	tree	yes	
California spotted owl (Strix occidentalis occidentalis)	bird	yes	
canyon live oak (Quercus chrysolepis)	tree	yes	
cheatgrass (Bromus tectorum)	graminoid (grasslike)	yes	
deer brush (Ceanothus integerrimus)	shrub	yes	
deer mouse (Peromyscus maniculatus)	mammal	yes	
Douglas-fir (Pseudotsuga menziesii var. menziesii)	tree	yes	
dusky-footed woodrat (Neotoma fuscipes)	mammal	no	
fisher (Pekania pennanti)	mammal	yes	
fox sparrow (Passerella iliaca)	bird	no	
incense-cedar (Calocedrus decurrens)	tree	yes	
Jeffrey pine (Pinus jeffreyi)	tree	yes	
Mariposa lily (Calochortus spp.)	forb (wildflower)	no	
mountain lion (Puma concolor)	mammal	yes	
mountain whitethorn (Ceanothus cordulatus)	shrub	yes	
Mountain yellow-legged frog (Rana sierrae and R. muscosa)	amphibian	no	
mule deer (Odocoileus hemionus)	mammal	yes	

northern goshawk (Accipiter gentilis)	bird	yes	
ponderosa pine (Pinus ponderosa var. benthamiana, P. p. var. ponderosa)	tree	yes	
quaking aspen (Populus tremuloides)	tree	yes	
Ross's sedge (Carex rossii)	graminoid (grasslike)	yes	
Sierra gooseberry (Ribes roezlii)	shrub	yes	
Sierra lodgepole pine (Pinus contorta var. murrayana)	tree	yes	
sticky whiteleaf manzanita (Arctostaphylos viscida)	shrub	yes	
sugar pine (Pinus lambertiana)	tree	yes	
wavyleaf soap plant (Chlorogalum pomeridianum)	forb (wildflower)	yes	
Webber's milkvetch (Astragalus webberi)	forb (wildflower)	no	
western gray squirrel (Sciurus griseus)	mammal	no	
western wood-pewee (Contopus sordidulus)	bird	no	
white fir (Abies concolor)	tree	yes	
white pine blister rust (Cronartium ribicola)	fungi	no	
yellow star thistle (Centaurea solstitialis)	forb (wildflower)	yes	

Handout H14-1: Species Research Project

Directions:

Step #1: Research and write a paper about a species that lives in Sierra Nevada montane ecosystems.

Step #2: Based on your research, create a presentation and deliver it to the class.

Step #3: During other presentations, take notes about each species and its relationship to fire. After the presentations are complete, you will use these notes to complete a quiz about the species covered and their relationships to fire.

Note: It is very important that you deliver a well-organized and well-researched presentation. If the majority your classmates do poorly on the assessment pertaining to YOUR species, then YOU may lose points for failing to effectively deliver the information they need.

Details:

Step #1: Make your paper 2-3 pages long, 1.5 spaced, MLA format, and use 3-5 sources from scientific journals or government documents. If your species is covered in the Fire Effects Information System (FEIS, at www.feis-crs.org/feis/), use this resource as a starting point. Your paper must include the following details about your species:

1. Physical description
2. Geographic distribution (where it occurs)
3. Habitat requirements
4. Associated species (name a few other plants and/or animals in the community)
5. Information on how your species reproduces
6. Information on where it gets energy and what other organisms feed on it
7. Adaptations to fire and relationships with fire (do certain types of fire kill it or help it? If so, how?)
8. Information on typical kinds of fire in its habitat (surface or crown fires? How often?)
9. Effects of fire exclusion (what happens if fire does not occur for a long time?)
10. Information sources, cited using MLA format

Step #2: Design your presentation using PowerPoint, Google Slides, or similar software. Summarize the information in your report. Be sure to include the information about fire, because that is the main focus of the project and the quiz that follows. Make your presentation as interesting as you can. Include facts, photos, and other graphics that will engage your audience. Requirements:

1. Make the presentation 3-5 minutes long
2. Be SURE to include information on the species' relationships to fire (#7-9 above)
3. Include at least 10 slides with at least 8 images
4. Be clear, well organized, and grammatically correct
5. Be well-rehearsed so you can present clearly and concisely

Step #3: Take notes on your peers' presentations. Make them neat and readable, so you can use them to complete an open-note quiz on the information delivered during the presentations. Therefore, be **sure** to take notes on the **kind(s) of fire** the species typically experiences and its **adaptations (or lack of adaptations) to fire**.

Handout H14-2: Species Research Project Quiz

Name: ________________

1. For each species, indicate its relationship to fire.	Does not need fire, but some fire OK	Thrives with surface fire OR small, patchy fires	Thrives with crown fires and fires that kill many trees	Thrives with almost any kind of fire	Not much known about relationship with fire
American black bear (Ursus americanus)					
Annosum root rot (Heterobasidion annosum)					
Baker cypress (Hesperocyparis bakeri)					
Bark beetles (multiple species)					
Black fire beetle (Melanophila acuminata)					
Black-backed woodpecker (Picoides arcticus)					
Bracken fern (Pteridium aquilinum)					
California black oak (Quercus kelloggii)					
California red fir (Abies magnifica var. magnifica)					
California spotted owl (Strix occidentalis occidentalis)					
Canyon live oak (Quercus chrysolepis)					
Cheatgrass (Bromus tectorum)					
Deer brush (Ceanothus integerrimus)					
Deer mouse (Peromyscus maniculatus)					
Douglas-fir (Pseudotsuga menziesii var. menziesii)					
Dusky-footed woodrat (Neotoma fuscipes)					
Fisher (Pekania pennanti)					
Fox sparrow (Passerella iliaca)					
Incense-cedar (Calocedrus decurrens)					
Jeffrey pine (Pinus jeffreyi)					
Mariposa lily (Calochortus spp.)					
Mountain lion (Puma concolor)					
Mountain whitethorn (Ceanothus cordulatus)					
Mountain yellow-legged frog (Rana sierrae and R. muscosa)					
Mule deer (Odocoileus hemionus)					
Northern goshawk (Accipiter gentilis)					
Ponderosa pine (Pinus ponderosa var. benthamiana, P. p. var. ponderosa)					
Quaking aspen (Populus tremuloides)					
Ross's sedge (Carex rossii)					
Sierra gooseberry (Ribes roezlii)					
Sierra lodgepole pine (Pinus contorta var. murrayana)					
Sticky whiteleaf manzanita (Arctostaphylos viscida)					
Sugar pine (Pinus lambertiana)					
Wavyleaf soap plant (Chlorogalum pomeridianum)					
Webber's milkvetch (Astragalus webberi)					
Western gray squirrel (Sciurus griseus)					
Western wood-pewee (Contopus sordidulus)					
White fir (Abies concolor)					
White pine blister rust (Cronartium ribicola)					
Yellow star thistle (Centaurea solstitialis)					

2. List three different animals and their relationship with fire.

3. List three different plants and their relationship (or adaptations) to fire.

4. Describe what would happen to each of the six species that you described in questions 2 and 3 if fire did not occur for a very long time.

5. Ecologists and land managers sometimes say that a plant or animal is *fire dependent.* Explain what this term means. Give 1 example of a fire-dependent species in the montane ecosystems of the Sierra Nevada and explain why it is fire dependent.

Teachers' Answer Key to Species Research Project Quiz

1. For each species, indicate its relationship to fire.[1]	Does not need fire, but some fire OK	Thrives with surface fire OR small, patchy fires	Thrives with crown fires and fires that kill many trees	Thrives with almost any kind of fire	Not much known about relationship with fire
American black bear (Ursus americanus)				x	
Annosum root rot (Heterobasidion annosum)					x
Baker cypress (Hesperocyparis bakeri)			x		
Bark beetles (multiple species)				x	
Black fire beetle (Melanophila acuminata)			x		
Black-backed woodpecker (Picoides arcticus)			x		
Bracken fern (Pteridium aquilinum)				x	
California black oak (Quercus kelloggii)		x			
California red fir (Abies magnifica var. magnifica)	x				
California spotted owl (Strix occidentalis occidentalis)		x			
Canyon live oak (Quercus chrysolepis)		x			
Cheatgrass (Bromus tectorum)				x	
Deer brush (Ceanothus integerrimus)				x	
Deer mouse (Peromyscus maniculatus)				x	
Douglas-fir (Pseudotsuga menziesii var. menziesii)	x				
Dusky-footed woodrat (Neotoma fuscipes)		x			
Fisher (Pekania pennanti)	x				
Fox sparrow (Passerella iliaca)				x	
Incense-cedar (Calocedrus decurrens)		x			
Jeffrey pine (Pinus jeffreyi)		x			
Mariposa lily (Calochortus spp.)				x	
Mountain lion (Puma concolor)				x	
Mountain whitethorn (Ceanothus cordulatus)				x	
Mountain yellow-legged frog (Rana sierrae and R. muscosa)	x				
Mule deer (Odocoileus hemionus)		x			
Northern goshawk (Accipiter gentilis)		x			
Ponderosa pine (Pinus ponderosa var. benthamiana, P. p. var. ponderosa)		x			
Quaking aspen (Populus tremuloides)				x	
Ross's sedge (Carex rossii)				x	
Sierra gooseberry (Ribes roezlii)			x		
Sierra lodgepole pine (Pinus contorta var. murrayana)				x	
Sticky whiteleaf manzanita (Arctostaphylos viscida)			x		
Sugar pine (Pinus lambertiana)		x			
Wavyleaf soap plant (Chlorogalum pomeridianum)				x	
Webber's milkvetch (Astragalus webberi)					x
Western gray squirrel (Sciurus griseus)		x			
Western wood-pewee (Contopus sordidulus)		x			
White fir (Abies concolor)	x				
White pine blister rust (Cronartium ribicola)				x	
Yellow star thistle (Centaurea solstitialis)				x	

[1] For a table covering more information on species and their adaptations to fire, see **Table M11-1** in the Middle School curriculum (**M11_AdoptingAPlant_Animal_Fungus**).

2. List three different animals and their relationship with fire. Answers will vary depending on which species they choose. Answers may include that animals run, fly, or burrow deep underground to escape injury from fire. Some animals may prefer habitats that have not burned in a long time (e.g., California spotted owl), while others prefer habitats that burned in a stand-replacing fire (e.g., fox sparrow).

3. List three different plants and their relationship (or adaptations) to fire. Answers will vary depending on which species they choose. Answers may include:

- Trees that have thick bark, which helps them survive surface fires (e.g., ponderosa pine, Jeffrey pine, incense-cedar, firs—when they are old).
- Baker cypress needs severe fire (usually crown fire) for its seeds to open and germinate.
- Shrubs that sprout vigorously after stand-replacing fire and/or require heat for seed germination.
- Forbs or shrubs that have deep underground parts that sprout after fire or have increased flowering/fruiting after fire.

4. Describe what would happen to each of the six species if fire did not occur for a very long time. Answers will vary because some species are more sensitive to fire frequency and severity than others. For example:

- Some species require frequent, low-severity fire to maintain open forest conditions with few ladder fuels. When fires do not maintain open forest conditions, these species may become overcrowded, drought-stressed, shaded, prone to insects or diseases, or may lack available foods. Their habitat may also become more vulnerable to crown fire.
- Some species will not regenerate without heat to open their seeds, so they will eventually die out.
- Some species will thrive in forests that have not burned in a long time because they have more hiding cover and can find sufficient resources (food or sunlight, water) in closed forests.
- Some species will thrive in forests that have not burned in a long time as long as there is a burned area or other open habitat nearby.

5. Ecologists and land managers sometimes say that a plant or animal is *fire dependent.* Explain what this term means. Give 1 example of a fire-dependent species in the montane ecosystems of the Sierra Nevada and explain why it is fire dependent. *Fire dependent* describes plants, animals, and ecological communities that have evolved adaptations to fire and require fire to thrive. They often have traits that protect them from the adverse effects of fire. They may rely on fire to modify their habitat or environment. They may need fire in order to regenerate/reproduce successfully or prolifically. They may require a particular kind of postfire condition (immediately after fire or years or decades later) to be sustained or meet their needs. (Adapted from http://www.nwcg.gov/glossary/a-z.)

15. Forest Communities and Climate Change

Lesson overview: In this activity, students assemble a graphic model of a forest community in the northwestern Sierra Nevada and then discuss species distributions in the context of climate change.

This activity includes some individual work by students to prepare for later classroom work. The individual work is treated here as homework, and thus the activity is divided into 2 days.

Subjects: Science, Mathematics, Reading, Speaking and Listening
Duration: 2 class periods
Group size: small groups, whole class
Setting: Classroom
FireWorks vocabulary: *aspect, climate/climate change, distribution, elevation, environmental conditions, gradient, migration/assisted migration/species migration, range/home range*

Lesson Goal: Increase students' understanding that forest communities develop under specific environmental conditions and that species distributions and community composition may change as climate conditions change.

Objectives:

- Students can list tree species that are likely to occur together.
- Students can predict possible effects of changing climate conditions on the distribution of tree species.
- Students can express their thoughts and observations about one potential way to mitigate the effects of climate change - *assisted migration* - in a speaking and listening activity.

Standards:		9th	10th	11th	12th
CCSS	Reading: Literature	1,2,4,10		1,2,4,10	
	Reading: Informational Test	1,2,4,10		1,2,4,10	
	Speaking and Listening	1,2,6		1,2,6	
	Reading: Science and Technical Subjects	1,2,4,9,10		1,2,4,9,10	
NGSS	Interdependent Relationships in Ecosystems	LS2.A, LS2.C, LS4.C			
EEEGL	Strand 1	B,C,E,F,G			

Teacher background: Now that students know about several tree species in the Sierra Nevada, they can learn how species are interrelated in forest communities. They will need this information to understand how patterns of fire over time have shaped forest communities.

In this activity, students use a graphical model to learn about communities. Then they use the same model to make predictions about species distributions in response to climate change. Finally, they study the pros and cons of assisted migration to conserve species threatened by climate change; they express and discuss their opinions as part of the **Assessment**.

The table in **Handout H15-1: Modeling Forests of the Sierra Nevada** lists the 12 tree species of the Sierra Nevada that have been studied in previous activities. The table describes the most common conditions in which each species occurs. Note that these are common conditions – the heart of the species' environmental requirements - rather than strict limits to where the species can live.

Given the descriptions in the table, students show where each species is likely to occur in a graphical model of a mountainside. They also predict which species are likely to occur together to form a forest community. Then they predict how the best locations for a species might change if climate conditions change. If individual trees in the current locations can spread their seeds or otherwise reproduce in a "new" location for them – and then thrive and reproduce there - we say the species has *migrated* to the new location. If they cannot, the species may gradually die out.

As the world's climate changes, conditions that favored certain species in the past may no longer provide conditions in which they can survive and reproduce. There may be other locations where they could live, but if their seeds cannot reach those places, they may gradually die out. For this reason, some people propose deliberately introducing the species to locations that may prove more hospitable to them in the future. This is called *assisted migration.* After creating their graphical models, students will read an article that describes the potential for assisted migration of trees. The article provides a concise introduction about how species are adapted to specific combinations of environmental and climatic conditions, and what may happen as these conditions are altered with climate change. It describes the controversy over assisted migration, so it should get students thinking. The "Walk the Line" activity in the **Assessment** forces them to discuss this issue and take a stand on it.

If you want your students to read primary research on assisted migration, have them read: McKenney, Daniel W.; Pedlar, John H.; Lawrence, Kevin; Campbell, Kathy; Hutchinson, Michael F. 2007. Potential impacts of climate change on the distribution of North American trees. BioScience. 57(11): 939-948.

Note that this curriculum does not cover subalpine communities, but subalpine communities are very important in the Sierra Nevada. Trees that occur in subalpine communities include Sierra lodgepole pine, whitebark pine, western white pine, and mountain hemlock.

Materials/Preparation:

- Print 1 copy/student in color:
  - **Handout H15-1: Modeling Forests of the Sierra Nevada**
  - **Handout H15-2: Interpreting a Model and a Map**
- Map of United States or of the world that can be projected. Several U.S. maps are available at http://geology.com/world/the-united-states-of-america-satellite-image.shtml.
- Download ***H15 ForestCommunities.pptx***, which contains the graphics for the Sasquatch Peak Forest Model. You will project selected slides from this file during the lesson.
- Make sure each student has markers or colored pencils - 12 colors other than black.
- Decide whether to have students do the 7-page reading assignment for the assessment on-line (https://earlycareerecologists.wordpress.com/2013/01/16/trees-on-the-move-debating-assisted-migration-in-climate-change-mitigation/) or from paper copies of **H15_Reading-TreesOnTheMove.** Make copies if necessary.
- Make AGREE and DISAGREE signs for the "Walking the Line" activity (see **Assessment**).

Procedure:

1. **DAY 1 – Introduction and assignment**: Project a map of the United States or the world (U.S. maps are available at http://geology.com/world/the-united-states-of-america-satellite-image.shtml). Ask: Where do you think you could live happily? Think of some locations where you could flourish and some areas where you would probably flounder. Have a few students come up to the board and mark the places they would like to live. Ask why. What conditions would make a good place for them? Have a few students circle places where they don't think they could live. What would make those places so hard to live in?

2. Explain: Tree species grow best in certain *environmental conditions* and cannot grow at all in other conditions. The actual locations where a species currently occurs are its *distribution.* (With animals, we often call this the *range* or *home range.*)

3. Ask: What are some important environmental conditions that affect species distribution? Why do they matter?

   - **Elevation** matters because it influences the temperature, length of summer vs. winter, amount of snow vs. rain, exposure to wind, etc.

   - **Slope, *aspect,* and steepness** matter because they control how much direct sunlight the plants receive (and thus temperature), how much wind they are exposed to, and how rain and snow are deposited and melted/absorbed/evaporated.

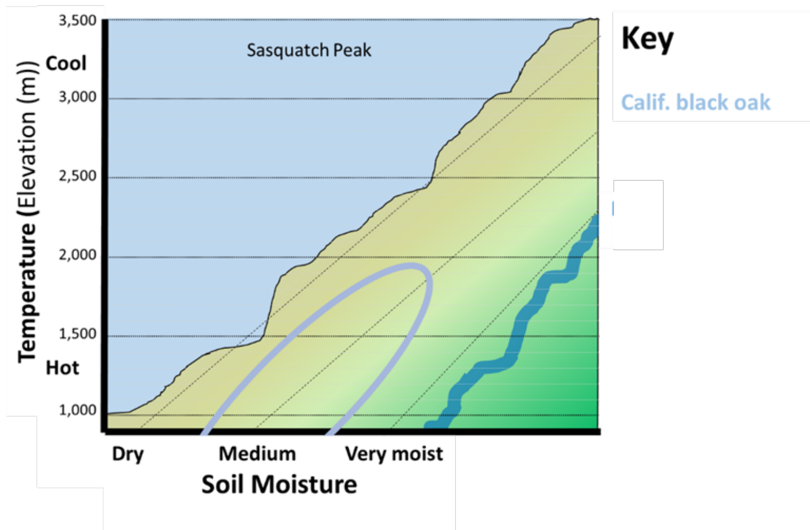
   - **Soil** matters because it influences the nutrients available to the plant, the air available to roots, and how well water is retained.

   - **Amount of moisture** matters because it influences how much water is available to plants and its seasonal availability.

4. We've talked about environmental conditions, but plants also need certain biological conditions to thrive. Can you think of any? Here are a few: abundant pollinators, fungi that help roots absorb moisture ("mycorrhizae"), sparseness of competing vegetation, limited numbers of animals feeding on plant parts, limited parasites and decay fungi.

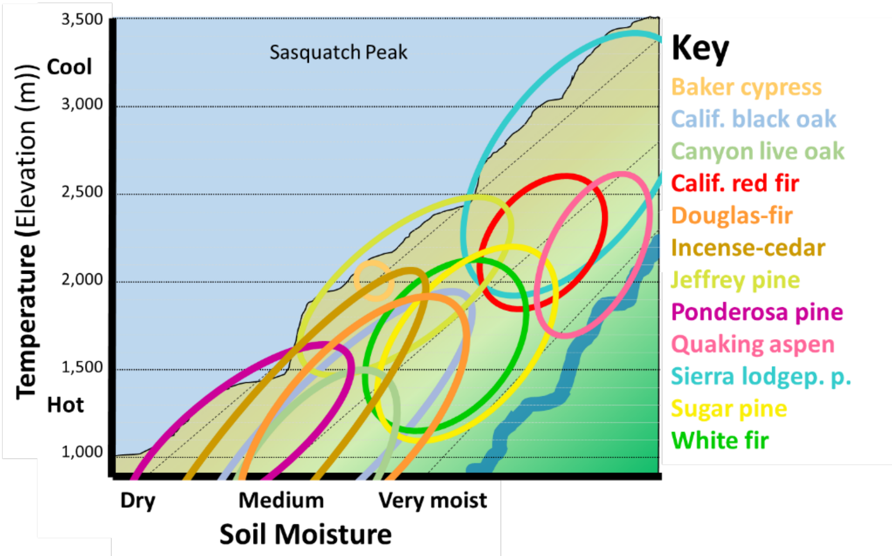
5. Explain: We are going to create a model that shows the typical forest communities in northwestern Sierra Nevada forests. The model is like a graph. It will show where tree species are most likely to live according to temperature conditions (represented by elevation) and soil moisture conditions (represented by distance from a stream). We will use a fictitious place called Sasquatch Peak to show the distribution of the 12 tree species that we've been studying and the communities where they commonly live.

6. Give each student a copy of **Handout H15-1: Modeling Forests of the Sierra Nevada**, and project **H15 Forest Communities.pptx, Slide 1** (at right). Go over the instructions. Use the example of California black oak (already graphed). Remind students that the data indicate where California black oak is common – that is, where it can best grow and thrive. The table does not show the limits of conditions that the species can tolerate.



7. Assign the rest of **Handout H15-1** for in-class work or homework.

8. **DAY 2 – Interpreting and using the model.** Project **H15 Forest Communities.pptx, Slide 2,** an example of a completed forest model. Have students get together in small groups and compare their models with this one. Ask: Are your models similar? What might account for differences?



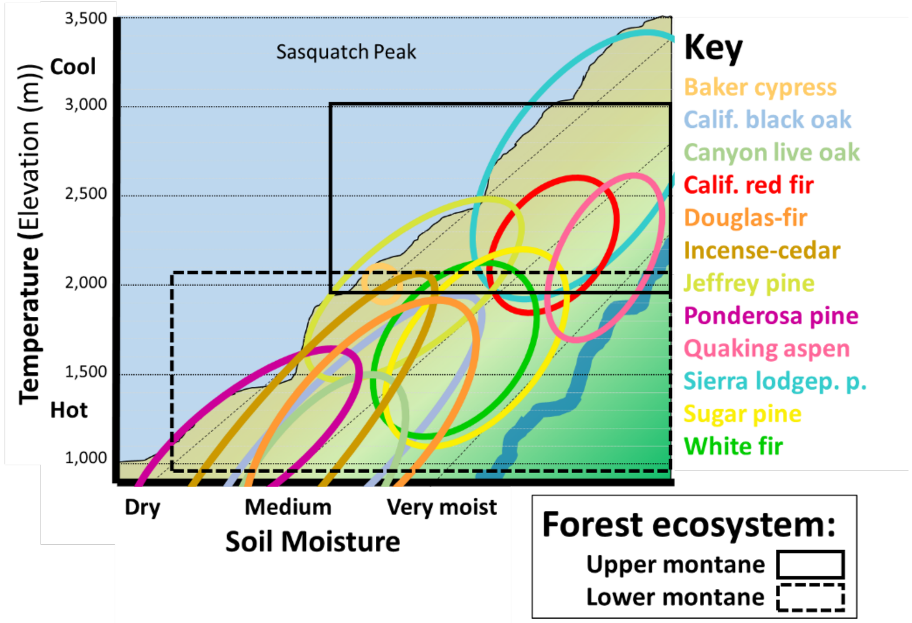
- Students may have misunderstood directions. If that happened, did they ask for help?
- Students may have created narrower or wider ellipses, which could reflect different interpretations of moisture conditions and would be valid, since the table does not offer much information on this.
- Students may have placed their ellipses at higher or lower elevations; very far off would be in error.
- Variation among models is expected, especially with regard to the width of ellipses. The example one is not perfect, partly because terms like "dry," "medium," and "very moist" are qualitative and can be interpreted somewhat differently.

9. Ask: What are some strengths and weaknesses of the model?

- The model describes where these species are common but not all of the places where they can occur, so it doesn't show limitations of the species. The model is useful because we can easily see which species are most likely to occur together, but many other species combinations can occur on the mountainsides of the northwestern Sierra Nevada. For example, the model suggests that sugar pine does not commonly occur with ponderosa pine – but it actually happens quite frequently. Can they think of other examples from their experience?
- This way of describing environmental conditions is simplistic. That means you can understand a species' needs and compare them to those of another species, but you can't explore the complexities of species distributions. For example, sites generally <u>do</u> get cooler as you go up in elevation, but not always. Other influences on temperature include aspect, presence of shade from other vegetation or mountains, presence of lakes or streams, wind patterns, and topography – such as narrow canyons vs open slopes. Sites generally <u>do</u> get moister as you get close to a creek or

lake, but that's not the only influence. Aspect, steepness, drainage patterns, soil properties, and presence of other vegetation are also important.

10. Project **H15 Forest Communities.pptx, Slide 3**. Explain: the black boxes represent the upper and lower montane plant communities on Sasquatch Peak. We'll use this distinction in future lessons, as we talk about the history and role of fire in montane communities.



11. Explain: We have used the model to **explore the relationships** among tree species and to **investigate** which species are likely neighbors. Now we'll use it to **make some predictions**.

12. Explain: Over the past 100 years, the climate in our area has gotten warmer. In some places, it has gotten drier too. Ask: What is *climate* anyway? Average weather patterns over a long time, such as decades or centuries. "What you're wearing today shows the weather. What's in your closet shows the climate."

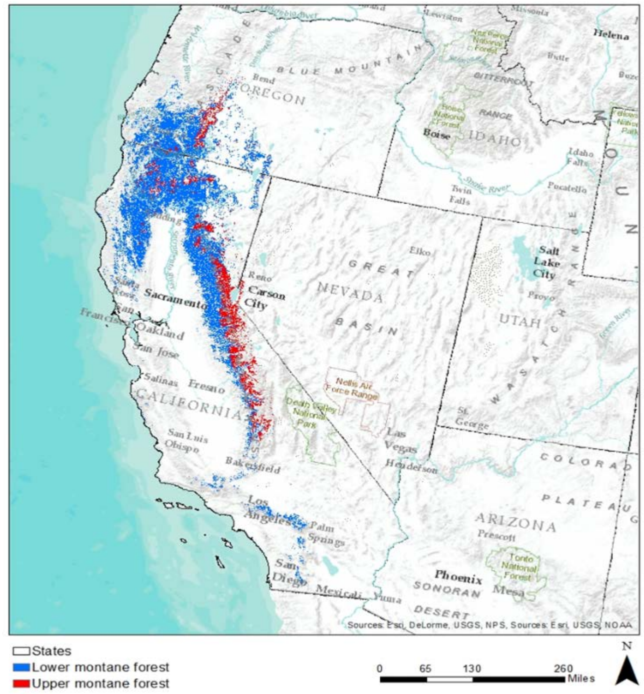
13. Explain: As climate changes, the environmental conditions for plant growth also change. We can use the model to predict how climate change might make a location more or less favorable for each tree species. Discuss this example: Suppose you were in a moist area around 1,100 m with a lot of sugar pine. Then the climate got much hotter and drier.

- What tree species might become more common in your neighborhood? Ponderosa pine, Douglas-fir, incense-cedar, California black oak, canyon live oak

- Suppose some sugar pine seeds land in a medium-moist area at 2,500 m elevation. Would they have much of a chance to grow up? Why or why not? Their chances would probably be better than they are now because it will probably be warmer. Still, that habitat is quite a distance above the conditions where it currently thrives, so it might still be cooler than this species likes, so it might be hard for the trees to establish and grow. Furthermore, the odds of ANY tree seed growing up are pretty small.

  What if sugar pine seeds land in a dry area at 2,500 m? Their chances are not good unless the climate becomes moister.

California lower and upper montane forests



Biophysical Settings data layers (LANDFIRE 2008) used to create this map were accessed at http://www.landfire.gov, November 2012.

14. Show **H15 ForestCommunities.pptx, Slide 4.** Explain: This map shows the places where lower and upper montane plant communities occur in California. Ask: What is the relationship between the Sasquatch Peak forest model that we've built and the map? The trees that compose the lower montane community on Sasquatch Peak would likely occur in the blue area on the map of California. The trees that compose the upper montane community on Sasquatch Peak would likely occur in red area on the map of California.

15. Give each student a copy of **Handout 15-2: Interpreting a Model and a Map**. Have the students answer the questions—in groups or individually. Review answers together to make sure the students understand how to interpret both graphics. Explain: There is a term for what happens when species move to new areas because conditions in their old homes have changed. It is called *species migration*. Now we'll consider whether we should help that process along in wildlands of the Sierra Nevada.

Assessment:

1. Hand out or provide electronic access to "Trees on the Move? Debating Assisted Migration in Climate Change Mitigation." It is available online at https://earlycareerecologists.wordpress.com/2013/01/16/trees-on-the-move-debating-assisted-migration-in-climate-change-mitigation/ or you can print it from **H15_Reading-TreesOnTheMove**.
2. Explain: After you've read the article, you'll participate in a "Walking the Line" speaking and listening activity (below). Then you will write a final reflection on the activity. In

your reflection, discuss how the figures, reading, and “Walk the line” activity shaped your understanding of how forest communities develop and how they may change as climate conditions change.

Walking the Line activity:

- On opposing walls of the classroom, put signs that say AGREE and DISAGREE.
- Use classroom discussion to review what *species migration* and *assisted migration* mean.
- Explain: Because we are thinking about species moving around, you are actually going to move around in this activity.
- Have all students stand. Read the following statements. For each one, have students move to a place on the gradient between “agree” and “disagree” that shows their personal opinions and reactions to the reading. After students have moved in response to each question, invite discussion about it.

Questions:

1. This article surprised me. I had not heard about plant species naturally migrating before reading this article.
2. All of the tree species that we’ve studied will be able to “…keep pace with shifting climate and regenerate under suitable habitat conditions.”
3. Tree species will be able to migrate approximately 10 kilometers per year.
4. If tree species cannot migrate fast enough, then they will become extinct.
5. Inaction (that is, NOT using assisted migration) will lead to extinction of some tree species.
6. Assisted migration will produce unintended, unpredictable consequences.
7. Assisted migration will preserve ecosystems and communities that are now in rapid decline.
8. Assisted migration will have detrimental effects on current communities at the transplant sites.
9. I agree with the use of assisted migration, at least on some occasions.
10. I understand why assisted migration “…is one of the most controversial, divisive debates within the ecological community.”

Evaluation: See **Teacher Key for Handout 15-2: Interpreting a Model and a Map**.
Assess the written reflection as follows.

Credit for reflection piece	No Credit reflection piece
Student discussed how the figures, reading, and walk-the-line activity shaped his/her understanding of • how forest communities develop • how forest communities may change as climate conditions change	Students did not discuss the graphs, reading, and cross-the-line activity in their discussion. They also failed to explain their understanding of how forest communities develop and how they may change as climate conditions change.

Handout H15-1: Modeling Forests of the Sierra Nevada

Use the data in the table below to illustrate the environmental conditions in which each species can grow and thrive: Plot the data on the graphic on the next page. As an example, the environmental conditions for California black oak are already shown on the graph. Graph the conditions for the remaining 11 species like this:

1. Under “Key,” use different-colored pencils or markers to write the names of all species in the table (except California black oak, since it is already done).
2. For each species:
   - On the model, figure out which moisture line to use for the species (dry, medium or very moist). If you think it should be in between, *lightly* sketch the line where it should go.
   - On the appropriate moisture line, use a dot to mark the lowest and highest elevations for the species. If the table lists an elevation below the range of Sasquatch Peak, estimate where the lowest mark should be.
   - About midway between these two dots, move to the left and right of the moisture line to mark the approximate driest and wettest conditions for the species.
   - Using the color that matches this species in your key, draw an oval shape connecting the 4 dots. This shows the environmental conditions in which the species can live and thrive.

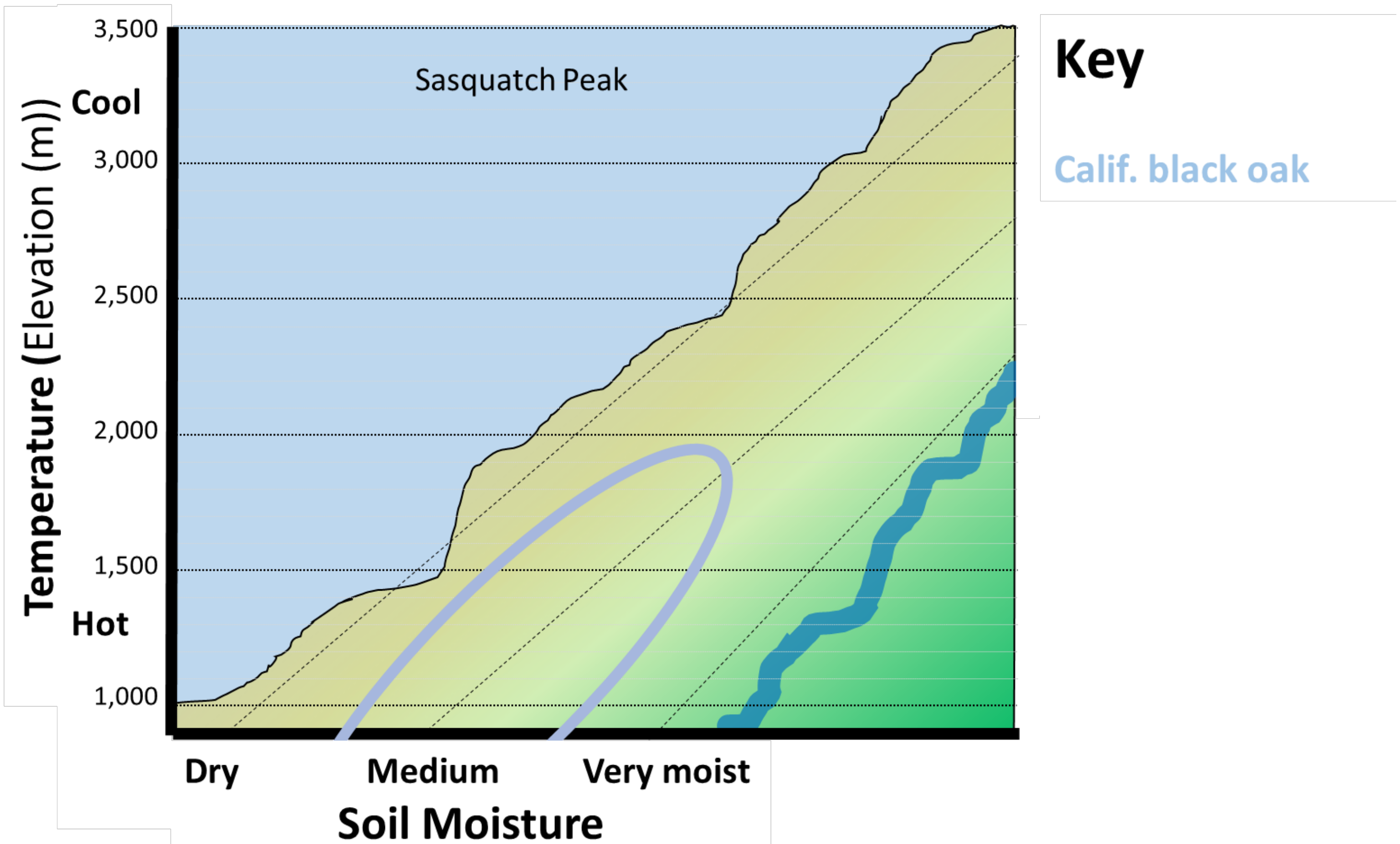
Ecological conditions for 12 tree species: Ecological conditions best for tree species on Sasquatch Peak**,** a fictitious mountain in the northwestern Sierra Nevada. The summit of the peak is at 3,500 m. The valley bottom is at 900 m elevation, but some species live and thrive at lower elevations than this.

Tree Species	Elevations where species is most common (m above sea level)*	Lives best in*
Baker cypress	1900-2100	Dry sites
Example: California black oak	500-1800	Medium sites
Canyon live oak	500-1300	Medium sites
California red fir	1900-2600	Medium sites
Douglas-fir	700-1700	Medium sites
Incense-cedar	700-2000	Dry to medium sites
Jeffrey pine	1500-2500	Dry to medium sites
Ponderosa pine	500-1700	Dry to medium sites
Quaking aspen	1600-2600	Very moist sites
Sierra lodgepole pine	1900-3400	Dry to moist sites
Sugar pine	1000-2100	Medium to moist sites
White fir	1200-2100	Medium sites

* Sources: Fire Effects Information System (https://feis-crs.org/feis/)
Burns, Russell M.; Honkala, Barbara H., tech. coords. 1990. *Silvics of North America. Volume 1. Conifers*. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 675 p.
Burns, Russell M.; Honkala, Barbara H., tech. coords. 1990. *Silvics of North America. Vol. 2*. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.

Sasquatch Peak Forest Model Name: ____________________

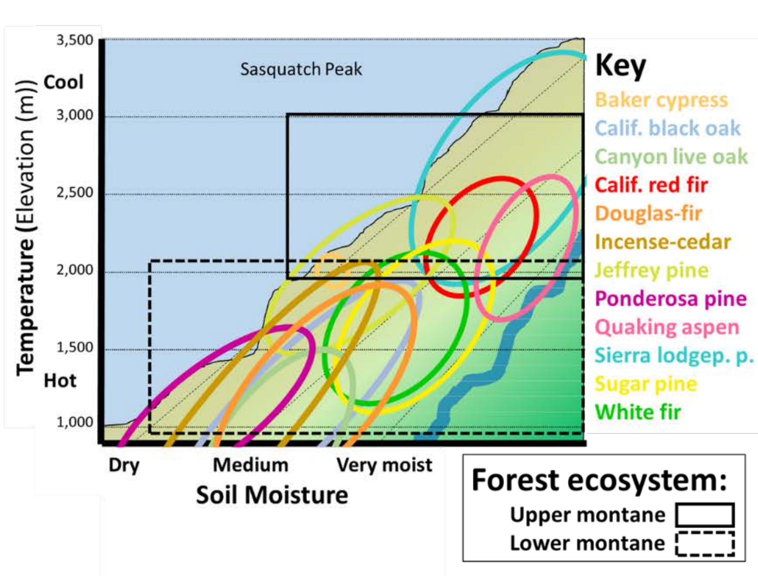
The vertical axis shows elevation, which is closely related to temperature. The horizontal axis and diagonal dashed lines show moisture on the site, from dry (very little moisture available) to very moist (lots of moisture available).

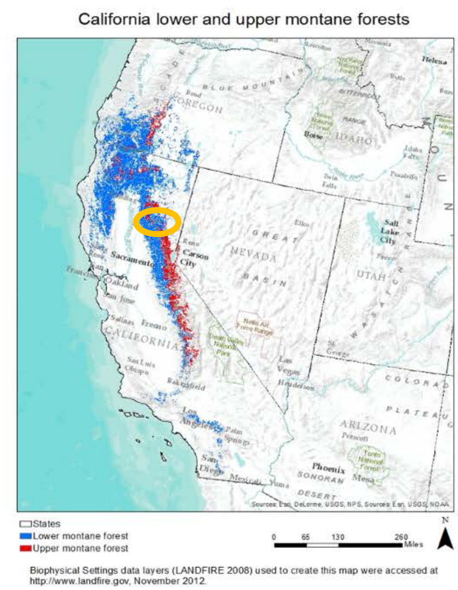


Handout H15-2: Interpreting a Model and a Map

Name: ___________________

Use the Sasquatch Peak Forest Model (left – or the one you made) and the map (right) to answer the questions below on a separate piece of paper.





1. What tree species commonly occur in lower montane forests? What tree species commonly occur in upper montane forests? What species commonly occur in both forest types?

2. Describe where on the map a red fir is most likely to live.

3. Describe where on the map you are NOT likely to find red fir.

4. Which species on Sasquatch Peak has the smallest distribution?

5. Suppose a California red fir lives at 1,900 m elevation and its habitat gets a lot warmer and drier. Are its seedlings likely to survive?

6. As you head north from Sasquatch Peak, would you expect Jeffrey pines to grow at lower or higher elevations than where they occur in your model? Explain why.

7. What biological factors would affect the ability of tree distribution to shift in response to climate change?

Teacher Key for Handout H15-2: Interpreting a Model and a Map

1. What tree species commonly occur in lower montane forests? What tree species commonly occur in upper montane forests? What species commonly occur in both forest types?
   There will be variation in these answers, depending on how students interpret "commonly occur." Here is one set of answers:
   - Lower montane forests: ponderosa pine, incense-cedar, California black oak, Douglas-fir, sugar pine, white fir, canyon live oak
   - Upper montane forests: Sierra lodgepole pine, California red fir
   - Species that commonly occur in both forest types: Jeffrey pine, quaking aspen, white fir, sugar pine

2. Describe where on the map a red fir is most likely to live.

   In the red-colored area

3. Describe where on the map you are NOT likely to find red fir.

   Anywhere other than in the red area.

4. Which species on Sasquatch Peak has the smallest distribution?

   Baker cypress

5. Suppose a California red fir lives at 1,800 m elevation and its habitat gets a lot warmer and drier. Are its seedlings likely to survive?

   It could have trouble. 1,600 m is already at the lower (hotter and dryer) end of its range. If it got even hotter and drier, it would be hard for seedlings to survive.

6. As you head north from Sasquatch Peak, would you expect Jeffrey pines to grow at lower or higher elevations than where they occur in your model? Explain why.

   Lower. As you head north, the climate typically gets cooler, so Jeffrey pines should be able to grow lower on the mountainsides.

7. What biological factors could make it easier or harder for a tree species' distribution to shift in response to climate change?

   There could be many answers. Here are a few:
   - competition with other trees, which stresses them
   - seed predation, so it can't regenerate even if environmental conditions are good
   - insects, fungi, or disease, so it can't produce seeds – or grow well in the new location
   - soil-related and land-use issues, such as use of herbicides and disturbance of soil
   - seed dispersal ability, so it can't deliver seeds far from the parent tree
   - variety in the species' traits and the rate of genetic change occurring, which could produce traits adaptive to environmental change

Unit VI.
Fire History and Succession

The structure of a forest is one of the most important influences on forest fires, and the history of fire is one of the most important influences on forest structure. In this unit, students learn about the history of fire in forests of lower and upper montane mixed conifer forests in California.

In the first activity of the unit, students focus on the scars left on tree trunks by *low-severity fires.* They learn how fire scars are formed. They examine photos and tree growth rings to find out how many fires have marked a tree and how many years have gone by between fires. With this information, they describe the history of low-severity fires for a single tree. Then they pool their data to describe the history of low-severity fire for a forest stand and briefly compare their results with those of a study conducted in mixed-conifer forests of the Plumas National Forest.

In the second activity, students focus on tree ages as recorded in *increment cores*. With this information, they can determine when the most recent *stand-replacing fire* occurred in a forest. This technique is applicable to Baker cypress stands in the northern Sierra Nevada, which the students learn about by reading a publication from the federal Joint Fire Science Program. With information on the frequency of both low-severity and stand-replacing fires, students can describe the *fire history* of a specific kind of forest and envision how forest stands might differ in appearance depending on their historical *fire regime*.

In the third activity, students integrate and apply what they learned in the first two. They focus on how fire regimes shape the pattern of vegetation on the landscape. They interpret data and textual information from a scientific article and an online database to learn about the prevalence of low-severity vs. stand-replacing fire regimes in the Sierra Nevada. They envision how variety in fire regimes may have been expressed in individual stands historically, and how a century with little low-severity fire has changed vegetation patterns on the landscape.

16. Fire History 1: Long Stories Told by Old Trees

Lesson Overview: Students study the scars left by low-severity fires on tree trunks – how these scars form, how many have marked a tree, and how many years went by between fires. With this information, they can describe the history of low-severity fire for that tree. With data from the whole class, they can describe the history of low-severity fire for a whole stand or forest. Finally, they can compare their results with those of two research studies and two efforts to summarize information on the history of low-severity fire in California.

Subjects: Reading, Writing, Speaking and Listening, Math, Science

Duration: Two or three 30-minute sessions

Group size: Whole class, working singly or in teams

Setting: Classroom

FireWorks vocabulary: *dendrochronology, fire scar, fire interval, growth ring, low-severity fire, stand-replacing fire*

This activity has 4 parts:

I. **Introduction to fire history of California montane forests**, in which the class discusses results from a modeling project and a literature review on fire history information for forests in the Sierra Nevada, and students also examine a real specimen of a fire-scarred tree cross section ("tree cookie").

II. **Living Model of Fire Scar Formation**, in which students learn how fire scars form by building a living model that shows a tree's response to surface fire. This is followed by the first part of the assessment, completion of **Handout H16-2. A Tree's Story.**

III. **Telling the Story of a Whole Forest**, in which students pool their fire history data on 17 individual trees and analyze the resulting diagram to better understand the history of low-severity fire in Sierra Nevada montane forests.

IV. **How Do Our Results Compare? i**n which students compare the results of their fire history analysis with results from professional research and modeling. This is followed by the **second part of the assessment**, a written description of the historical *fire regime* in California mixed-conifer forests.

ABOUT STUDENT PRESENTATIONS: If you did **Activity H14. Researching a Plant, Animal, or Fungus**, this would be a great time for student presentations on all of the tree species – except Baker cypress. Save that for **Activity H17. Fire History 2: History of Stand Replacing Fire**.

Lesson Goals: Students understand that some trees can survive frequent low-severity fire. They can describe the history of low-severity fire for a specific tree, a stand or forest, and (based on results from the literature) an entire kind of ecosystem, California mixed-conifer forests.

Objectives:

- Students can identify tree growth rings and fire scars.
- Students can describe the history of low-severity fire for a single tree.
- Based on pooled data, students can make inferences about the history of low-severity fire in a specific forest.
- Students can compare and contrast their results with those from sources in the scientific literature.

Standards:		9th	10th	11th	12th
Common Core ELA	Reading Science/Technical Subjects	3,5,7,10		3,5,7,10	
	Writing Science/Technical Subjects	7,10		7,10	
	Science/Technical Subjects	2,4,5,6,7,8,9,10		2,4,5,6,7,8,9,10	
NGSS	Structure and Function	LS1.A			
	Interdependent Relationships in Ecosystems	LS2.A, LS2.C,LS2.D, LS4.C			
	Natural Selection and Evolution	LS4.B, LS4.C			
	History of Earth	ESS1.C, ESS1.A			
	Earth's Systems	ESS2.A			
EEEGL	Strand 1	C,E,F,G			

Teacher Background: Fire has been a part of the history of most forests in North America for thousands of years. Tree *growth rings* and *fire scars* tell about a forest's fire history. The kind of fire that scars trees is called *low-severity* fire. Many surface fires have low severity, but not all of them. Some surface fires and all crown fires produce so much heat that they kill the crown, cambium, and/or roots of most of the trees. These are called *stand-replacing fires* because a whole new generation of trees must develop to replace the ones killed by fire. You can learn more about stand-replacing fires in **Activity H17. Fire History 2: History of Stand Replacing Fire**.

This activity incorporates a considerable amount of information from the scientific literature. In **Part I**, students examine data on historical *fire regimes* from a modeling project and a literature review[1]. After this brief analysis, they analyze the fire history of the real fire-scarred tree cookie in the FireWorks trunk[2]. (Each FireWorks trunk has its own unique fire-scarred tree cookie.) In **Parts II and III**, students reproduce the results from a fire history study on the Tahoe National Forest[3]. (They use photos of the tree cookies used for the study, not the specimens

[1] LANDFIRE modeling (www.landfire.gov/NationalProductDescriptions20.php) and Van de Water, Kip M.; Safford, Hugh D. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. Fire Ecology. 7(3):26-58.
[2] Trunks near the Plumas National Forest have cookies collected from: Moody, Tadashi J.; Fites-Kaufman, JoAnn; Stephens, Scott L. 2006. Fire history and climate influences from forests in the northern Sierra Nevada, USA. Fire Ecology. 2(1): 115-141.
[3] Vaillant, Nicole M.; Stephens, Scott L. 2009. Fire history of a lower elevation Jeffrey pine-mixed conifer forest in the eastern Sierra Nevada, California, USA. Fire Ecology. 5(3): 4-19.

themselves.) Finally, in **Part IV**, the students compare and contrast results from all of these sources in order to write their own description of fire regimes in California mixed-conifer forests. If you prefer to skip the work in this lesson with the scientific literature, consider using the Middle-School version, **Activity M17.**

Other information on fire scars and wood:

- After a tree has one fire scar, it is more vulnerable to further scarring because that region of the trunk has no insulating bark and it may contain a lot of pitch, which can be ignited easily.
- Trees do not "heal" in the same way animals do: The dead cambium does NOT recover to become functioning tissue again, as our skin and bones can do after an injury. However, the dead wood may gradually be covered by new cambium and new bark that grows in from the sides. "Trees do not heal, they conceal."
- Fire scars form most often on the uphill side of tree trunks. Why? A hot vortex of flame forms on the forward side of any obstacle in the fire's path. Since fires often spread uphill, the uphill side of the tree trunk tends to get more of this vortex heat than the other sides. Also, there is usually more debris on the uphill side since branches, cones, litter, and duff accumulate there instead of rolling downhill.
- Why is some of the wood in a tree cookie dark while other areas are very light? The outer wood (xylem or sapwood) is often lighter than the inner wood (heartwood) because it is filled with water and minerals. The dark wood is usually in the center and in damaged areas of the tree trunk. It is dark because it is filled with pitch rather than sap. Pitch helps a tree survive injury because it can keep fungi from spreading throughout the wood. The pitch-filled heartwood cells are not alive, but they provide structural support for the tree.
- Other unusual marks in wood include patches of rot, holes made by wood-boring beetles, checks (these are radial cracks where the wood has dried and split), and branch scars (where a branch originated or a broken branch stub was covered by later growth).

Materials and preparation:

1. Make 1 copy/student or team: **Handout H16-2. A Tree's Story** and (OPTIONAL) **Handout H16-1. Fire History for major California ecosystems.**
2. Find a piece of black plastic or cloth about 25 cm inches wide and about 1.0 m long.
3. Download **LowSeverityFire_GrowthRingFormation.pptx**.
4. Provide a way for students to electronically access **LowSeverityFire_GrowthRingFormation.pptx** and/or the 3 papers referenced in the activity:
    - **MoodyEtAl2006_FireHistPlumas.pdf**
    - **VaillantStephens_2009.pdf**
    - **VanDeWater_synthesis.pdf**

5. Find in the trunk:
   - small whisk broom
   - 1-2 hand lenses
   - Real fire-scarred tree cookie with the key that shows its unique fire history. (Each trunk has its own real fire-scarred cookie and key.)
   - Tree cookie photo posters (a set of 17, stored in a pillowcase)
   - The ***FireWorks Cookie Book – Low-severity Fire on the Plumas National Forest*** (also available online, ***CookieBook.pdf***). This document contains solutions to **Handout H16-2: A Tree's Story** for ALL OF THE PHOTO POSTERS IN YOUR TRUNK (posters also available online, ***TreeCookiePhotoPosters.pptx or .pdf***).

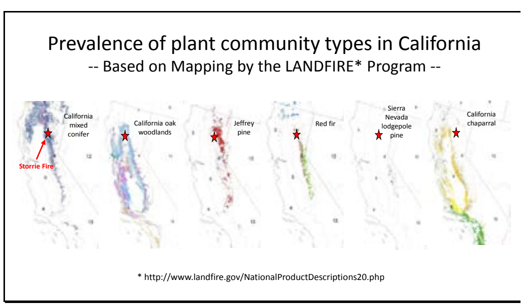
Provide one cookie photo poster for every 1-2 students. Students will use the photo posters to describe the fire history of individual trees (Part II). Then they will pool their data to describe the history of low-severity fire throughout the area of the study (Part III).

Procedure, Part I: Introduction to Fire History Research

1. Explain: The structure of a forest is one of the most important influences on forest fires, and the history of fire is one of the most important influences on forest structure. In this unit, we'll learn about the fire history of forests and woodlands in the Sierra Nevada, especially in the area burned by the Storrie Fire. A lot of scientists have studied the history of *low-severity fire* in the Sierras. Let's look at two summaries of their results.

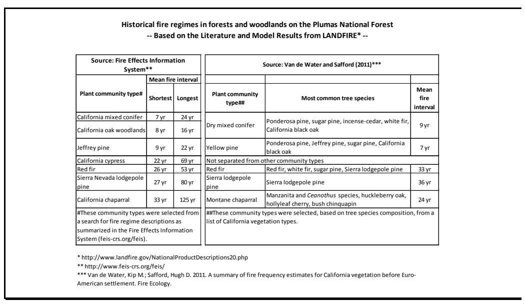
2. Display ***LowSeverityFire_GrowthRingFormation.pptx,*** Slide 1 AND/OR give each student a copy of **H16-1. Fire History for major California ecosystems**. Explain: This table gives information from two different summaries of data on fire history, as expressed by "mean *fire interval*," the average number of years between fires over a long period of time. The rows are aligned so you can compare results from the two studies for each vegetation type. Proceed with Slides 1-4 from **Slides 1-4** in **LowSeverityFire_GrowthRingFormation.pptx**:

Slide 1



We're going to try to figure out the fire history of the area burned by the Storrie Fire. These maps show several forest types that occur near that area. Pick out the types that are most common in the area of the Storrie Fire (marked by a star). California mixed conifer, oak woodlands, and Jeffrey pine. Let's learn what some other scientists have found out learned about fire history in these 6 forest types.

Slide 2



Historical fire regimes in forests and woodlands on the Plumas National Forest
-- Based on the Literature and Model Results from LANDFIRE* --

Source: Fire Effects Information System**			Source: Van de Water and Safford (2011)***		
	Mean fire interval				
Plant community type#	Shortest	Longest	Plant community type##	Most common tree species	Mean fire interval
California mixed conifer	7 yr	24 yr	Dry mixed conifer	Ponderosa pine, sugar pine, incense-cedar, white fir, California black oak	9 yr
California oak woodlands	8 yr	16 yr			
Jeffrey pine	9 yr	22 yr	Yellow pine	Ponderosa pine, Jeffrey pine, sugar pine, California black oak	7 yr
California cypress	22 yr	69 yr	Not separated from other community types		
Red fir	26 yr	53 yr	Red fir	Red fir, white fir, sugar pine, Sierra lodgepole pine	33 yr
Sierra Nevada lodgepole pine	27 yr	80 yr	Sierra lodgepole pine	Sierra lodgepole pine	36 yr
California chaparral	33 yr	125 yr	Montane chaparral	Manzanita and *Ceanothus* species, huckleberry oak, hollyleaf cherry, bush chinquapin	24 yr
#These community types were selected from a search for fire regime descriptions as summarized in the Fire Effects Information System (feis-crs.org/feis).			##These community types were selected, based on tree species composition, from a list of California vegetation types.		

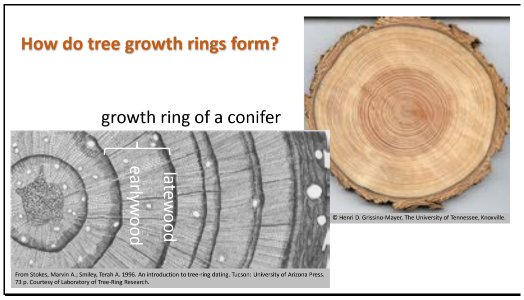
* http://www.landfire.gov/NationalProductDescriptions20.php
** http://www.feis-crs.org/feis/
*** Van de Water, Kip M.; Safford, Hugh D. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. Fire Ecology.

Here is information on historical patterns of fire intervals in the plant community types we just looked at. The table on the left is from a national modeling project. The one on the right is from a summary of more than 200 research studies on fire history. The results are listed so you can compare results for similar ecosystems.

Do the results from the 2 approaches look similar? Pretty much. The mean (shown on the right) is usually within the range (shown on the left). An exception is Jeffrey pine (left) vs yellow pine (right), but yellow pine communities can include both Jeffrey and ponderosa pine. How would you describe the historical fire intervals for the 3 communities we're studying most closely – mixed conifer, oak woodlands, and Jeffrey pine? Average fire intervals from 7 to 24 years, generally 7-9 years.

We're going to use the science of *dendrochronology* to see for ourselves what the history of low-severity fire has been like in mixed-conifer and Jeffrey pine ecosystems. California oak woodlands are mixed in with the conifers, which is typical of California montane forests.

Slide 3



Here's a review: Trees usually produce 1 *growth ring*/year. With the naked eye (as seen on the right), growth rings on a "tree cookie" (cross section of a tree trunk) look like concentric circles. With a microscope (as drawn on the left), we can see that the ring consists of a wide band of big, thin-walled cells produced in spring when there's plenty of moisture (called "earlywood") and a narrow band of dark, tiny cells produced later in summer and fall, when moisture is limiting and days get short (called "latewood").

Slide 4

To estimate fire intervals, we'll count the growth rings between *fire scars* on a tree cookie. How do you know it's a fire scar?

- Fire scars originate from the ground. They don't start part-way up the tree trunk.
- Viewed from the front of the tree, fire scars are roughly triangular in shape, wider at the base and narrower at the top.
- If many fires have scarred a tree, the scars look like a series of vertical folds on the blackened wood. (OPTIONAL: You could add that a tree's first fire does not char the wood, but later ones do. See the **Teacher Background** above.)
- Viewed from the top of a tree cookie, a fire scar looks like an indentation from the outside edge of the wood. The scar follows along a growth ring part-way into the wood. (OPTIONAL: Integrate some geometry: If you think of a growth ring as the circumference of a circle, then you know that a fire scar cannot be on a radius coming out from the center. Any radial marks are from other sources, such as branch scars or "checks" (crack) in the dried wood.)
- If you have a whole (roundish) tree cookie, you can see that fire scars are somewhat symmetrical – that is, new wood curls over the damaged wood from both sides of the damaged area. If you don't watch out for this, you may count each fire twice!

3. Use the real tree cookie from the trunk to look for identifying characteristics of fire scars.

4. Explain: We will use fire scars on tree cross sections ("tree cookies") to learn about the history of *low-severity fires* in the Sierra Nevada. Fires are *low-severity* if they kill few or none of the trees in a forest. They are *stand-replacing* if they kill most of the trees. Many surface fires have low severity, but some produce so much heat that they kill most of the trees and so are stand-replacing.

Procedure, Part II. Living Model of Fire Scar Formation

5. Explain: The class will construct a living model to show how fire scars are formed. Follow these directions or see a demonstration online at: *www.youtube.com/watch?v=MyFBYQh_S_M*

   a) One student holds his/her arms out in a circle, forming a ring that represents the tree's cambium – that is, the sheath of living cells right under the bark that form xylem and phloem – and are essential for continued growth.

   b) Ask the students to imagine that the "tree" is facing uphill and a low-severity surface fire is coming up from behind it, running uphill. Select a student to represent the surface fire, using the whisk broom to burn from the "downhill" side of the tree around it to the other side, then continuing "uphill" and away from the tree.

   c) Interview the "tree." Ask how the fire felt. Point out that the tree is still alive, since it is talking, so this must have been a low-severity surface fire!

   d) Tell the students that the fire was hot enough to kill a portion of the cambium – right where the student's hands are. Drape your piece of black cloth or plastic over the "killed" section to remind the class that these cells are dead and cannot produce a new growth ring next year.

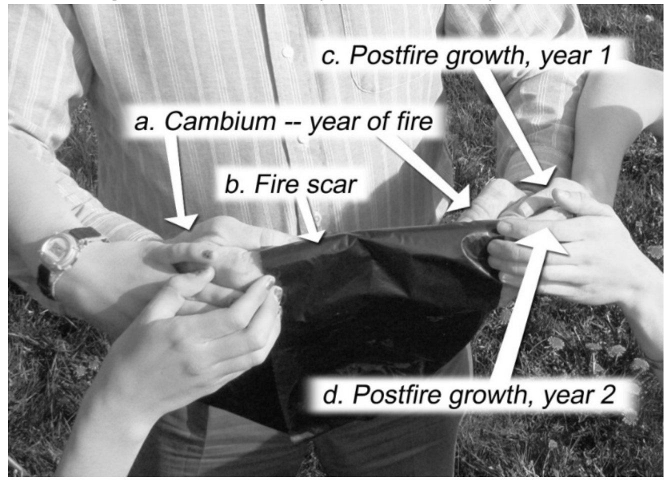
   e) Ask: Why is there more damage on the uphill side than the downhill side? Fires form a hot vortex of flame as they go around an obstacle and the flames come together from the two sides. Also, there is often more debris on the uphill side, since branches, cones, and litter accumulate there instead of rolling downhill. The duff is generally deeper on the uphill side as well.

   f) Get two more students to help, one standing on each side of the model tree. They are the next year's growth ring. Each places a hand against the arm of the "tree," right at the edge of the area "killed" by fire (which is now covered in black). New cells can't grow out of the black area because it has no living cambium.

g) Get two more students to represent the tree's growth in the second postfire year. They place their hands on top of those of the last two students. Their hands can overlap the black cloth a little, curling around the fingertips that represent last year's growth. This shows that the cells at the edges of the scar are dividing both outwardly and laterally, so they are beginning to grow over the scar. This is how the "bubble" of growth forms at each edge of a fire scar.

h) Use more pairs of students to represent more years of growth after fire so they can see how the new wood curls over the old scar.

i) Explain: Sometimes the growing wood from the two sides of the fire scar comes together and bark forms over the scar, hiding it from everyone who doesn't know about fire scars. To those "in the know," like this class, that caved-in look on the uphill side of the tree suggests a history of low-severity fires.



Students build a living model of tree cambium and fire scar with their hands.

Assessment, Parts I and II: Telling a Tree's Story.

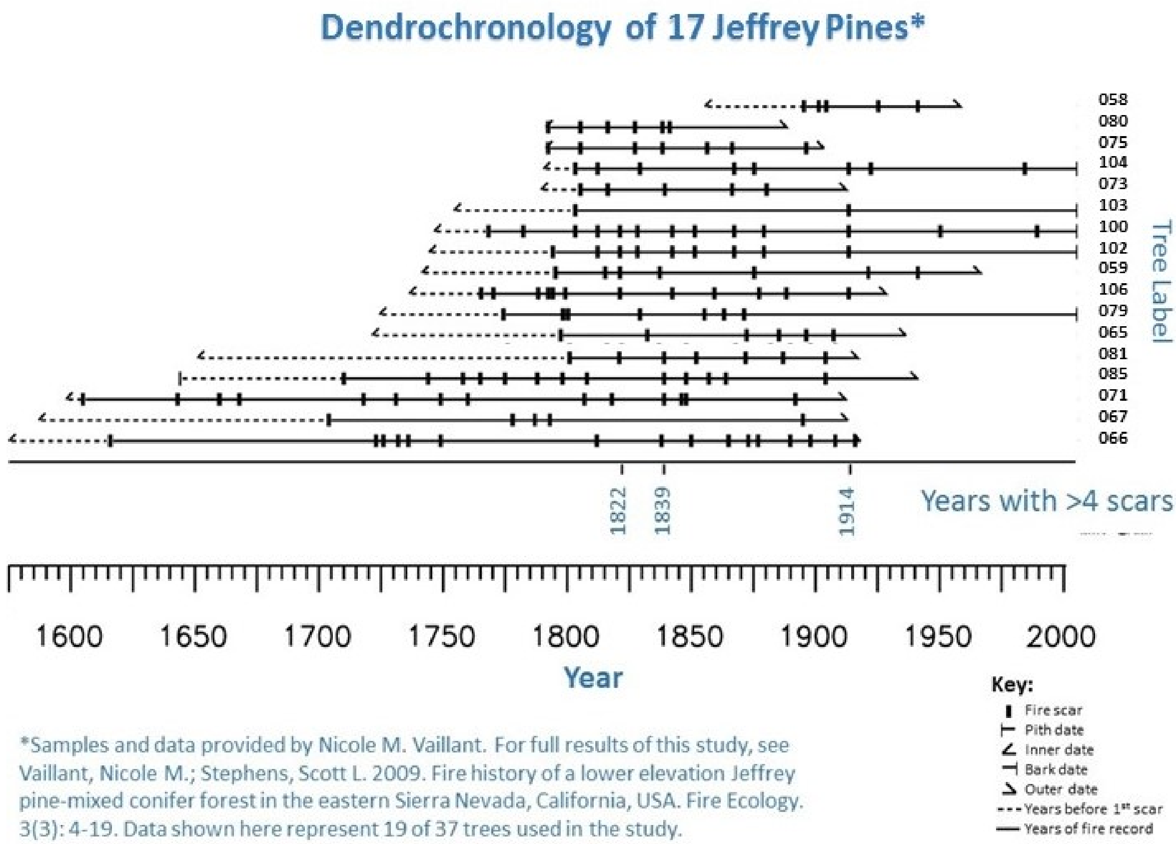
- Pass out copies of **Handout M16-2. A Tree's Story**, 1 per student or team.
- Explain: Each student or team will examine a photo poster that shows a fire-scarred tree cookie and lists the dates of earliest and most recent wood and all fire scars. You will fill out the handout to describe your specific tree; every team has a different one. These specimens are taken from a study of fire scars on Jeffrey pines that was conducted on the east slope of the Sierra Nevada and published in a journal (Vaillant and Stephens, 2009). We'll look at the full results of the study later.
- Explain: Follow the directions on the handout: Sketch the cookie, mark the location of each fire scar, calculate the intervals between fires, and complete the rest of the handout.
- Give a photo poster to each student or pair of students. Have them complete the handout. Circulate around the room to help.
- After all have finished the handout, ask students to report briefly, such as by asking for the shortest and longest fire intervals, the least and greatest numbers of fire scars. Discuss Questions 6-9.

Procedure, Part III. Telling the Story of a Whole Forest

6. **Pooling data:** Draw a timeline on the bottom of the board that goes from 1550 (at left) to 2010 (at right), with 5-year increments.

7. Explain: We'll pool our data to make a *stand history diagram.*

8. Have the students come up to the board with their handouts and sketches, one team at a time, starting with the oldest tree and progressing to the youngest.
9. Start at the bottom of the chart. For each tree cookie photo poster, have the team draw a line that starts with the earliest date and ends with the most recent date. Have them draw a short vertical bar across the line for each year when fire scarred the cookie. The class's chart should look sort of like this:



TAKE A PHOTO OF THE CLASS'S STAND HISTORY DIAGRAM TO USE IN THE NEXT ACTIVITY!

10. Summarize your findings information as a class.
    a) How many years were "fire years" – that is, years when low-severity fire scarred at least 1 tree? (94).
    b) How many fire intervals is that? (94-1=93)

c) How many years elapsed between the earliest and final fire scars? Add 1 to get the full number of years in the period when low-severity fires occurred (from 1605 to 1990, inclusive: 386 years).

d) What is the average number of years between low-severity fires? (386/93=4.2 years)

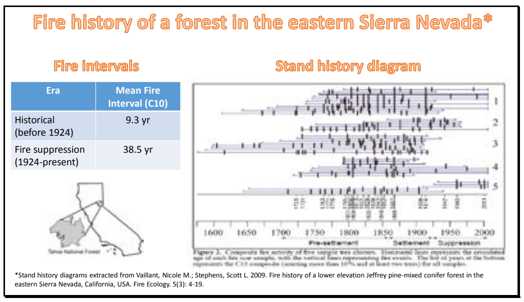
e) Has the fire pattern changed since 1900? (There have not been many low-severity fires since 1900.)

Procedure, Part IV. How Do Our Results Compare?

11. Ask: We've looked at 17 fire-scarred tree cookies. How can we know if our results are typical of the montane mixed-conifer forests of the Sierra Nevada? It's good to get more information and to get information from a wider-ranging area.

12. Explain/discuss: Our results are a subset of the results from a study led by Nicole Vaillant in the Lake Tahoe area of California. Let's compare our results with those of these studies, and then we'll go back and compare with the results from modeling and a literature that we looked at earlier. Display **Slides 5-7** in **LowSeverityFire_GrowthRingFormation.pptx**:

Slide 5

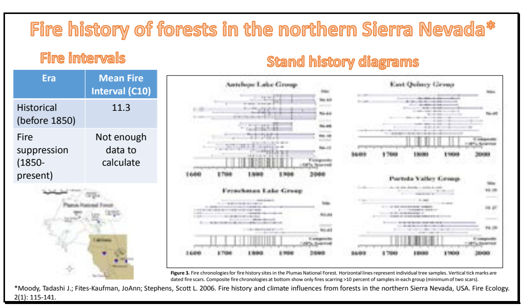


Here are the full results for the tree cookies we've been examining. The authors' list of fire years at the bottom shows ONLY the years that scarred at least 2 trees and at least 10% of the sample trees for that year. What difference does it make to show every year with a fire scar vs. only the "10%" years?

The "10%" number of fires will be less than the overall count, and the average interval will be longer. The "10%" approach emphasizes fires that were large enough to scar multiple trees, especially if the fires scarred trees in more than one location.

The authors split out their specimens according to the individual stands that were sampled, but still you should be able to pick out some of the trees studied by the class. How similar are our results to these? Overall, very similar: frequent fires before 1900, few afterward. (The study actually reported no STATISTCALLY SIGNIFICANT differences in C10 mean fire intervals between eras.)

Slide 6

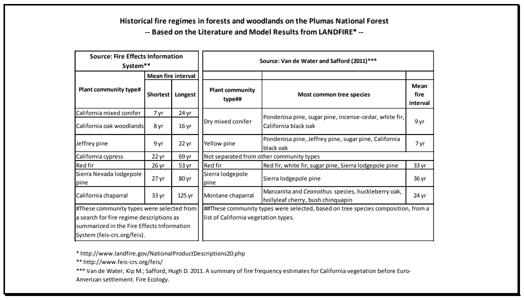


Here are the results for the whole study that our real tree cookie came from (if you have trunks affiliated with Plumas National Forest). Notice how the scientists analyzed data from different locations separately. How similar are our results to these? Overall, very similar: frequent fires before 1900, few afterward.

MORE DETAILS: Note that the fire years are labeled "Composite >10% scarred." This means the same thing as "C10" in the previous slide.

Which location had the most frequent fires (Antelope Lake – over a period of ~225 years), and which one had the least (East Quincy – over a period of ~ 175 years)? Do you think that difference is ecologically meaningful, or just random? There is no "right" or "wrong" answer to this question, but the discussion may help students recognize that statistics are useful for separating random variation from meaningful differences. The researchers found that there were no statistically significant differences in fire intervals between these two sites.

Slide 7



Historical fire regimes in forests and woodlands on the Plumas National Forest
-- Based on the Literature and Model Results from LANDFIRE* --

Source: Fire Effects Information System**		
Plant community type#	Mean fire interval: Shortest	Mean fire interval: Longest
California mixed conifer	7 yr	24 yr
California oak woodlands	8 yr	16 yr
Jeffrey pine	9 yr	22 yr
California cypress	22 yr	69 yr
Red fir	26 yr	53 yr
Sierra Nevada lodgepole pine	27 yr	80 yr
California chaparral	33 yr	125 yr
#These community types were selected from a search for fire regime descriptions as summarized in the Fire Effects Information System (feis-crs.org/feis).		

Source: Van de Water and Safford (2011)***		
Plant community type##	Most common tree species	Mean fire interval
Dry mixed conifer	Ponderosa pine, sugar pine, incense-cedar, white fir, California black oak	9 yr
Yellow pine	Ponderosa pine, Jeffrey pine, sugar pine, California black oak	7 yr
Not separated from other community types		
Red fir	Red fir, white fir, sugar pine, Sierra lodgepole pine	33 yr
Sierra lodgepole pine	Sierra lodgepole pine	36 yr
Montane chaparral	Manzanita and *Ceanothus* species, huckleberry oak, hollyleaf cherry, bush chinquapin	24 yr
##These community types were selected, based on tree species composition, from a list of California vegetation types.		

* http://www.landfire.gov/NationalProductDescriptions20.php
** http://www.feis-crs.org/feis/
*** Van de Water, Kip M.; Safford, Hugh D. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. Fire Ecology.

Let's return to the "big data" information we looked at earlier. On the left is a list of the range of average fire intervals estimated for different forest types in a nation-wide modeling project. On the right is information from a literature review that covered more than 200 fire history studies in the Sierra Nevada. How similar are our results (and Vaillant's and Moody's) to these? Again, very similar for historical times. There are no data here on recent times.

Assessment, Parts III and IV. Describe the history of low-severity fire.

- Write on the board: **What is the history of low-severity fires in mixed-conifer forests of the Sierra Nevada?**
- Provide students with electronic access to the slide show (**LowSeverityFire_GrowthRingFormation.pptx**) and/or the 3 research papers referred to in this activity.
- Explain: Write 1 paragraph to answer this question. Use information from your tree cookie and also from some of the studies we have looked at in the slide show. Your audience is a high-school History class. Include averages or ranges of numbers that describe how frequent low-severity fires were in past centuries and how frequent they are now. Document the basis for your claims - based on examining just one tree cookie, or based on evidence from a large area and variety of sources? (List them.)

Evaluation:

Parts I-II, A Tree's Story	Complete	Incomplete
Handout Questions 1-5	All questions answered consistent with *Cookie Book* results.	Not all answered.
Handout Question #6	Answer is consistent with photo poster.	Answer is not consistent with photo poster.
Handout Question #7	Poor growth is likely to occur after fire if the fire killed many of the tree's needles or much of the cambium. Rapid growth after fire may be caused by decreased competition from other vegetation for moisture and nutrients or by an increase in nutrients from burned vegetation.	Did not indicate a relationship between fire and the availability of water and/or nutrients.
Handout Question #8	Decreases in fire activity can be caused by moist time periods and increases by dry time periods. Not many trees in the Sierra Nevada have fire scars dating after 1900 because successful programs excluding fire from forests and grasslands began in those years and also because livestock grazing reduced fine vegetation (fuels) such as grass and shrubs.	Did not provide rationale or relevant examples.
Handout Question #9	Answers to this question vary from place to place and from one plant community type to another. When low-severity fire is excluded from a forest for a long time, dense undergrowth and deep duff may develop. These conditions make fires very hazardous and likely to kill even large, old trees. A dense understory can also weaken large, old trees by competing for moisture and nutrients. Lack of fire may also reduce diversity in patches of different vegetation and ages across the landscape, increasing the potential for fires to spread across large areas when burning conditions are right.	Student did not use evidence from photo poster to support answer.
Handout graphic	Consistent with *Cookie Book* photo.	Not provided or not consistent with *Cookie Book* photo.
Parts III-IV, the history of low-severity fire	-Wrote a complete paragraph -Used language and approach appropriate for high-school History class -Included specific numbers, i.e., average(s) or range(s) or fire intervals -Explained basis for claims. -Documented sources.	-Met 3 or less of these requirements.

Handout H16-1: Fire History for major California ecosystems.

Historical fire regimes in forests and woodlands on the Plumas National Forest
-- Based on the Literature and Model Results from LANDFIRE* --

Source: Fire Effects Information System**

Plant community type#	Mean fire interval: Shortest	Mean fire interval: Longest
California mixed conifer	7 yr	24 yr
California oak woodlands	8 yr	16 yr
Jeffrey pine	9 yr	22 yr
California cypress	22 yr	69 yr
Red fir	26 yr	53 yr
Sierra Nevada lodgepole pine	27 yr	80 yr
California chaparral	33 yr	125 yr

#These community types were selected from a search for fire regime descriptions as summarized in the Fire Effects Information System (feis-crs.org/feis).

Source: Van de Water and Safford (2011)***

Plant community type##	Most common tree species	Mean fire interval
Dry mixed conifer	Ponderosa pine, sugar pine, incense-cedar, white fir, California black oak	9 yr
Yellow pine	Ponderosa pine, Jeffrey pine, sugar pine, California black oak	7 yr
Not separated from other community types		
Red fir	Red fir, white fir, sugar pine, Sierra lodgepole pine	33 yr
Sierra lodgepole pine	Sierra lodgepole pine	36 yr
Montane chaparral	Manzanita and *Ceanothus* species, huckleberry oak, hollyleaf cherry, bush chinquapin	24 yr

##These community types were selected, based on tree species composition, from a list of California vegetation types.

* http://www.landfire.gov/NationalProductDescriptions20.php

** http://www.feis-crs.org/feis/

*** Van de Water, Kip M.; Safford, Hugh D. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. Fire Ecology.

Handout H16-2: A Tree's Story

Name: _______________

Species: _____________________ Cookie Number _______________

1. How many years of history does your tree cookie cover? _____________ years
2. On a separate page:
   - Sketch the outline of your tree cookie.
   - Label the sketch with the dates of the earliest and most recent growth rings.
   - Draw an arrow to each fire scar and label it with the date of the fire.
   - Calculate the number of years between each pair of fire scars. Write it in the space between each pair of arrows.
3. How many *low-severity fires* scarred your tree? ______________
4. How many *fire intervals* are recorded on your tree? ________
5. What is the average interval between fires? _________ years (If you only have 1 scar, go to the next step.)
6. Wide growth rings show years of fast tree growth, when moisture, sunlight, and nutrients were plentiful. Narrow rings show years of slow growth caused by drought, disease, injury, shading, or crowding by other trees. In what years did your cookie show fast growth? _____ In what years did it grow very slowly? ________
7. Were the years right after fire usually good or poor for growth? _____________________ What might be some reasons?
8. Did your tree record fewer fires after 1900 than before? _____ If so, what might be some reasons? (If your tree died before 1900, go to the next question.)
9. Could a tree be damaged by <u>lack</u> of low-severity fire? Explain why or why not.

Handout H16-2. A Tree's Story Key.

This is an example for Tree POT-Out07. For answers specific to all of the photo posters in your trunk, see the ***FireWorks Cookie Book – Low-severity Fire on the Plumas National Forest*** (in the trunk and also in the electronic folder **Fire History Materials/CookieBook**).

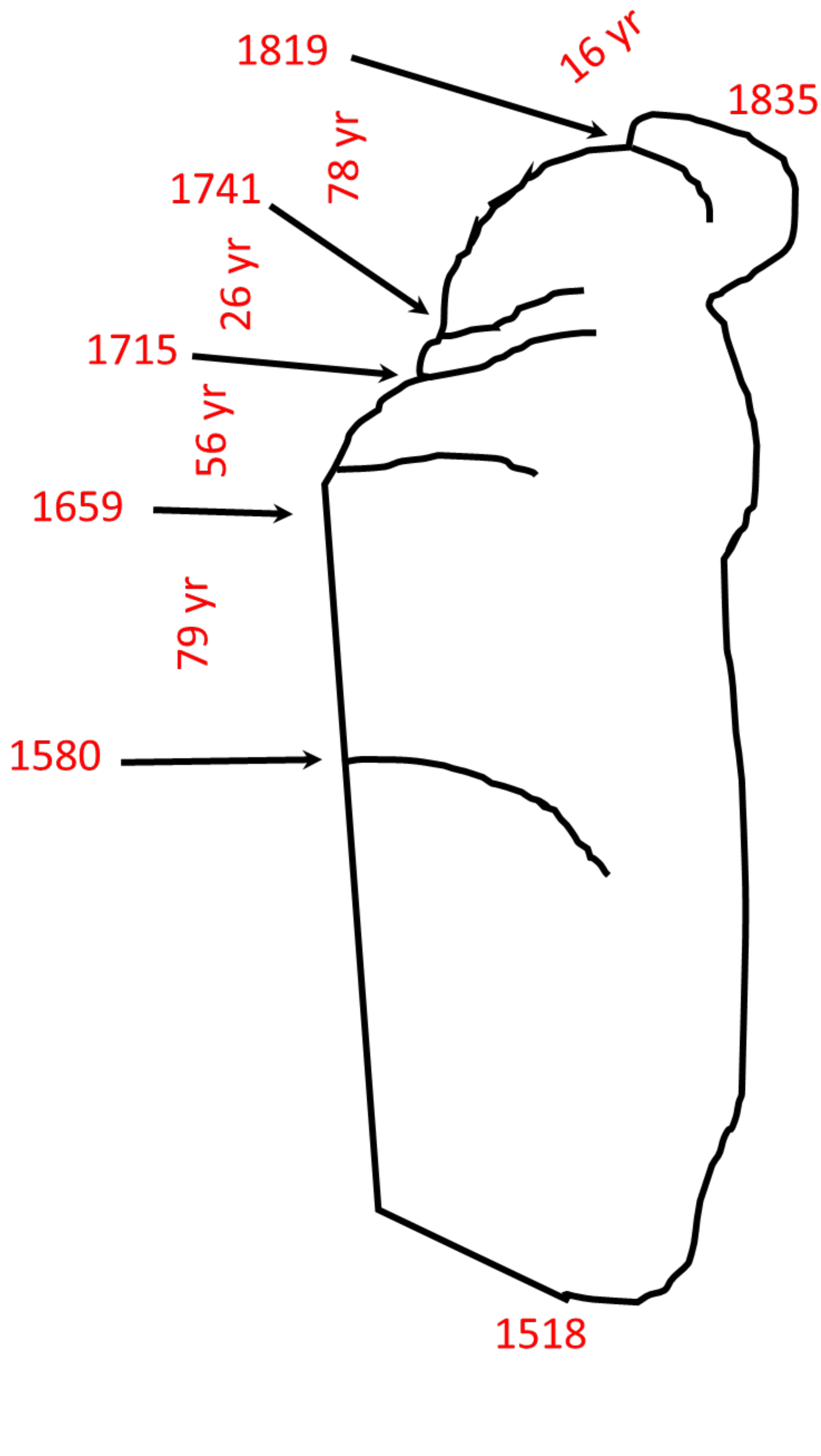
Species: Ponderosa pine Cookie Number 7

1. How many years of history does your tree cookie cover? 1835-1518= 317 years +1 to account for both earliest & most recent rings = 318 years
2. On a separate page:
   - Sketch the outline of your tree cookie.
   - Label the sketch with the dates of the earliest and most recent growth rings.
   - Draw an arrow to each fire scar and label it with the date of the fire.
   - Calculate the number of years between each pair of fire scars. Write it in the space between each pair of arrows.
3. How many *low-severity fires* scarred your tree? 5
4. How many *fire intervals* are recorded on your tree? 4
5. What is the average interval between fires? 57.9 years (If you only have 1 scar, go to the next step.)
6. Wide growth rings show years of fast tree growth, when moisture, sunlight, and nutrients were plentiful. Narrow rings show years of slow growth caused by drought, disease, injury, shading, or crowding by other trees. In what years did your cookie show fast growth? Around 1590

   In what years did it grow very slowly? After the last fire, 1819-1835
7. Were the years right after fire usually good or poor for growth? Both

   What might be some reasons? More or less competition, damage from loss of cambium and introduction of pathogens, short-term increases in nutrient availability
8. Did your tree record fewer fires after 1900 than before? No record in the 1900s for this tree. If so, what might be some reasons? (If your tree died before 1900, go to the next question.)

9. Could a tree be damaged by lack of low-severity fire? Explain why or why not. Yes. Competition from other trees may increase, reducing sunlight, water, and nutrients available to the tree. Ladder fuels may increase likelihood of lethal fire.


1819
16 yr
1835
78 yr
1741
26 yr
1715
56 yr
1659
79 yr
1580
1518

17. Fire History 2: History of Stand Replacing Fire

Lesson Overview: Students learn how to use *increment cores* from trees to discover the history of stand-replacing fire in a forest. They use what they have learned in both this activity and the previous one to depict how fire history influences the composition and structure of forest over a landscape.

Lesson Goals: Understand how to discover the history of stand-replacing disturbances in a forest. Understand that many forests have a history of both low-severity and stand replacing fire. Be able to depict a forest based on a description of its fire history.

Objectives:

- Students can depict the structure and appearance of forest on a landscape that has experienced both low-severity and stand-replacing fire.

Subjects: Reading, Writing, Speaking and Listening, Math, Science

Duration: 1-2 30-minute sessions

Group size: Whole class, working singly or in pairs

Setting: Classroom

FireWorks vocabulary: *cohort, increment core, pith*

ABOUT STUDENT PRESENTATIONS: If you did **Activity H14. Researching a Plant, Animal, or Fungus**, this would be a great time for the presentation on Baker cypress. If you have the student presentation here, you may want to skip Step 1 in the **Procedures.**

Standards:		**6th**	**7th**	**8th**
CCSS	Speaking and Listening	1,2,4,6	1,2,4,6	1,2,4,6
	Writing	1,4,10	1,4,10	1,4,10
	Writing: Science and Technology	3,4,7,9,10		
NGSS	Structure, Function, and Information Processing	LS1.A		
	Natural Selection and Adaptation	LS4.C		
	History of Earth	ESS2.C		
EEEGL	Strand 1	A,B,C,E,F,G		
	Strand 2.2	A		

Teacher Background:

In **Activity H16. Fire History 1: Long Stories Told By Old Trees**, students learned how low-severity surface fires leave scars on trees. They used fire scars to describe the history of low-severity fire for mixed-conifer and Jeffrey pine forests in the Sierra Nevada. Numerous studies have documented an extensive history of low-severity fire in the Sierra Nevada's montane forests[1], while large, severe, *stand-replacing fires* have not been considered a major influence on California mixed conifer, Jeffrey pine, or even red fir forests. However, we know that some kinds of forest in the Sierra Nevada thrive after stand-replacing fire and may even need it to persist. Baker cypress is one such forest type.

How can we learn about fire history when there are no fire-scarred trees? We can analyze the ages of trees in the stand; if most of them established within a short time, we call that a *cohort* – and cohorts usually establish after some kind of severe disturbance, such as fire.

To analyze the tree ages in a stand and look for cohorts, dendrochronologists use *increment cores* taken from living trees and dead wood. They figure out the approximate year when each tree was established – that is, when it germinated and started to grow. If most of the trees originated within 10 to 15 years of each other, they are considered a cohort. To figure out what disturbance allowed so many trees to establish in such a short time, scientists look for other evidence: Cut stumps would suggest logging; the presence of large numbers of old logs would suggest windthrow; the presence of scorched wood or charcoal in the soil would suggest stand-replacing fire.

In general, trees add one growth ring each year; however, tree growth is a little trickier than it looks. Sometimes a tree produces more than one growth ring during a single year; sometimes, especially in times of severe stress, it produces a ring only part-way around – or no ring at all. To determine the exact dates of rings on a core, dendrochronologists use a process called *cross dating.* They compare the rings on a core with descriptions of ring widths from a *master chronology* for the region. The master chronology is based on dozens to hundreds of cores. The scientists find especially narrow rings or groups of rings with a unique pattern of growth. Once they assign dates to these *marker years,* they can assign dates to the whole core. The year of the *pith* (the center of the tree, the oldest wood in the core) is close to the year when the tree germinated and started to grow. If the core was taken very close to the ground, it could even be the tree's first year of growth. More likely, the tree was a few years old by the time it reached the height where it was cored.

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[1]Here are three articles that document a history of low-severity fire in the Sierra Nevada:
Moody, Tadashi J.; Fites-Kaufman, JoAnn; Stephens, Scott L. 2006. Fire history and climate influences from forests in the northern Sierra Nevada, USA. Fire Ecology. 2(1): 115-141.
Scholl, Andrew E.; Taylor, Alan H. 2010. Fire regimes, forest change, and self-organization in an old-growth mixed-conifer forest, Yosemite National Park, USA. Ecological Applications. 20(2): 362-380.
Vaillant, Nicole M.; Stephens, Scott L. 2009. Fire history of a lower elevation Jeffrey pine-mixed conifer forest in the eastern Sierra Nevada, California, USA. Fire Ecology. 5(3): 4-19.

Historically, the forests of the Sierra Nevada experienced stand-replacing fires in relatively small areas. A few species seem well adapted to stand-replacing fire, such as the McNab cypress[2] and the Baker cypress[3], although their fire history has not been studied extensively. We do not have increment cores from these species for this activity, so instead we use photos of cores collected in a forest in central Oregon[4] as surrogates. Students will determine the earliest date on each core, draw a stand history diagram, and then describe the history of stand-replacing fire for the stand.

This lesson ends with students reading a qualitative description of the overall historical pattern of fires across the landscape, given in **Handout H17-1. How Fire Shaped the Landscape.** Students will look more closely at the article in **Activity H18. Fire History 3: Fire Regime across a Sierra Nevada Landscape**.

Dendrochronology is used for dozens of applications, including studies of climate change, archaeology, and even dating the age of old musical instruments! Lots of information about dendrochronology is available at http://ltrr.arizona.edu/about/treerings. If you would like to delve into this field and teach dendrochronology in your classroom, look for materials at http://ltrr.arizona.edu/educators.

Materials and preparation:

- Either display (or keep a photo ready to project) of the stand history diagram that the class constructed in **Activity H16. Fire History 1: Long Stories Told By Old Trees.** If you can't find it, you can use the stand history diagram from Step 15 of that activity, "Dendrochronology of 17 Jeffrey Pines."
- Download **Frame_2011_SavingTheCypress.pdf** so each student either has access to it on a computer or has a hard copy of pages 1-2.
- Make 1 copy/student: **Handout H17-1. How Fire Shaped the Landscape**
- Open and prepare to present the National Park Service's slide show on dendrochronology at http://www.nps.gov/webrangers/activities/dendrochronology/.

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[2] Mallek, Chris R. 2009. Fire history, stand origins, and the persistence of McNab cypress, northern California, USA. Fire Ecology. 5(3): 100-119.

[3] Frame, Christine. 2011. Saving the cypress: Restoring fire to rare, at-risk species. Boise, ID: Fire Science Brief. 126. 6 p. See also Rentz. Erin; Merriam, Kyle. 2011. Restoration and management of Baker Cypress in northern California and southern Oregon. In: Willoughby, J. W.; Orr, B. K.; Schierenbeck, K. A.; Jensen, N.; eds. Proceedings of the CNPS Conservation Conference: Strategies and Solutions; 2009 January 17-19. Sacramento, CA: California Native Plant Society: 282-289.

[4] Heyerdahl, Emily K.; Loehman, Rachel A.; Falk, Donald A. 2014. Mixed-severity fire in lodgepole pine dominated forests: are historical regimes sustainable on Oregon's Pumice Plateau, USA? Canadian Journal of Forestry. 44(6): 593-603.

- Download the following article so you can project it in a discussion of the nature of a literature review: **Skinner_Chang_1996_fireRegimes.pdf**

- Find in the trunk (or online):
  - ***DataFromSodaStraw_DotDiagr 2.pptx*** poster. Display it in your classroom.
  - Set of photos of increment cores (each is a thin strip of laminated paper, 20-40 cm long, with a tree identification number written at the end). ***IncrementCorePhotos.pptx***

Procedure:

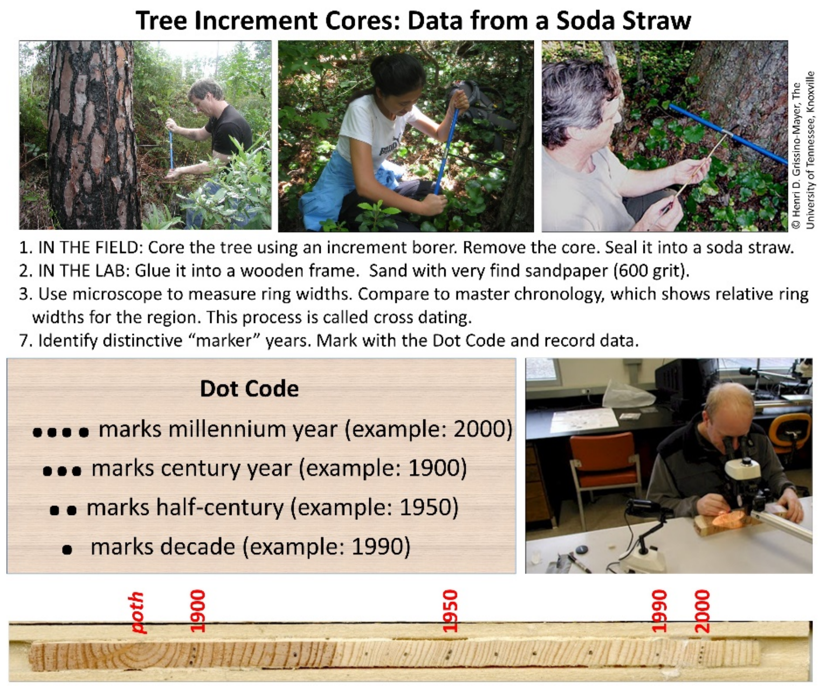
1. Either as homework or during a quiet period in class, have students read the Abstract and Key findings in **Frame_2011_SavingTheCypress.pdf**.

2. In class discussion, ask: Can fire-scar analysis be used to learn about the history of fire in a Baker cypress stand? Probably not, because these stands usually originate after fires that kill most or all of the trees, so few if any survive and develop fire scars. Because these fires results in development of a whole new forest stand, they are called stand-replacing fires. If fire scars cannot be used, what technique might work? This is an open-ended question. Try to lead students to the idea that, if the trees in a stand are all about the same age, and if they are mostly sun-loving species that germinate well after fire, then the year before this cohort began may be the year of the last stand-replacing fire.

3. Explain: We're going to try to get information on the history of stand-replacing fire from *increment cores.* (Refer to the ***DataFromSodaStraw_DotDiagr 2*** poster.)

4. Go through the National Park Service's slides on dendrochronology, http://www.nps.gov/webrangers/activities/dendrochronology/.

5. Hand out the photos of increment cores provided in the trunk. Explain: These cores were actually collected in central Oregon, but we are going to use them to represent the kind of information we might get from a mature stand of Baker cypresses that established after fire. Dendrochronologists have already dated each of these cores. This process is a little more complex than just counting rings, so the scientists have marked the cores to help us figure out their ages.



6. Review the dendrochronology procedures in ***DataFromSodaStraw&DotDiagr 2.pptx***, and keep the poster on display so students can refer to the Dot Code at the bottom. **Note:** The poster uses a few terms –*cross dating, increment borer,* and *master chronology* – that students do NOT need to know in order to complete this activity. Explain the terms as you go over the poster, but you don't need to emphasize them.

7. Have each student or team determine for their core and write on a slip of paper: (You can check students' data against the study results, which are shown in **Table H17-1. Tree ages from one cohort in one stand** below):

    a) the earliest date on the core (the year of the *pith*)

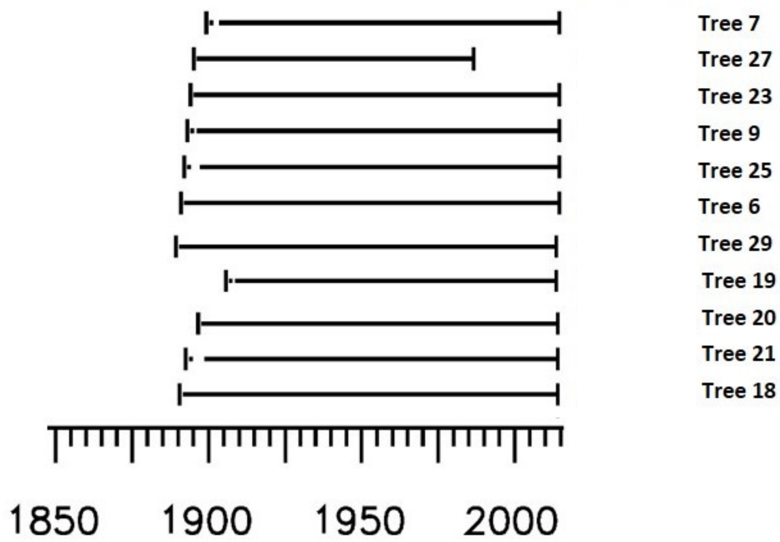
    b) a series of years when the tree had its best growth

    c) a series of years when the tree had its poorest growth

    d) the most recent date on the core

8. Draw a timeline along the bottom of the board, going from 1850 at left to 2010 on the right. Use increments of 5 years.

9. Starting with the oldest tree core at the bottom, have each student or team draw a line that shows the life span of their core. It should look a lot like the diagram at right – except in a slightly different order.



10. Explain: A group of living things that are all about the same age is called a *cohort.* You and your classmates constitute a cohort. Can you see evidence of a cohort in this stand history diagram? Almost all of the trees became established between 1880 and 1890. In dendrochronology, tree establishment within 10-15 years is considered a cohort because this much regeneration could all be due to a single disturbance.

11. Ask: Can you find any evidence of stand-replacing fire in the stand history diagram? The cohort could have become established after the overstory trees had been killed by fire, making excellent conditions for young pines to germinate and start growing.

12. What other disturbances might create a cohort of trees? Possibilities include a pine beetle epidemic, logging, a severe wind storm, etc.

13. Could you do anything to determine if fire was the cause? Look for nearby fire-scarred trees, charcoal in the soil, standing fire-killed snags and stumps, and fallen burned logs. Trees killed by severe fire often have an uneven, cupped surface where flames persisted a long time and burned part-way into the wood.

14. Project the first page of **Skinner_Chang_1996_fireRegimes.pdf**. Explain: The students will read a summary of some conclusions from this article.

15. Give each student a copy of **Handout H17-1. How Fire Shaped the Landscape**. Have students read it. After they have finished, ask for questions and discuss answers. Here are some potential discussion points:

    - What is an "extensive literature review"? It is an article based on information in other articles from the scientific literature. Scroll through the "References" section of the review (pp. 22-29) so students can see how many citations the article contains (about 200) and what the sources are – journals, government publications, books, etc. Go back into the body of the article so students can see how the authors back up their assertions by citing references.

- What is "Euro-American settlement"? This is the time when European immigrants began to settle in California and change the landscape with large-scale agriculture, logging, and control of fires and floods. Historians give various dates to the beginning of Euro-American settlement. Many of them date it from the "gold rush" years of the mid-1800s.
- What was the general appearance/structure of the forest in historical times? The forest was mostly open – big, tall trees and not a lot of trees in the understory. But there was a lot of variety. Since the authors say there was some stand-replacing fire, there must have been some patches with cohorts of trees.
- What is a "relatively fine" pattern? It means there are many patches, and they are fairly small. As you walked up a mountainside, you would come across patches that had burned recently and some that had not burned for quite a while. Most of the patches had burned in low-severity fire, so you would see multiple fire scars on the big trees. You would see a few patches with cohorts (trees all about the same size, whether small or large) that had burned in stand-replacing fires.

Assessment: Explain: Each student or team will create a depiction of the Sierra Nevada landscape that shows how the landscape looked in historical times (prior to Euro-American settlement).

- You will include the 2 forest histories we have just studied – a pattern of frequent low-severity fire in montane mixed-conifer forest and a pattern of infrequent stand-replacing fire in Baker cypress stands.
- You can refer to the stand history diagram completed in **Activity 16** and the one completed in this activity (shown above).
- You can use any art form - drawing, painting, computer graphics (possibly animated), a model forest in a sand box or clay substrate, etc.
- Your depiction should contain at least 20 mature trees of at least 3 different species. It should also contain at least some young trees and some understory plants.

Evaluation: For full credit, students' depictions should include these features.

Fire regime	Frequent low-severity fire (as illustrated in Activity H16)	Less frequent high-severity fire (as illustrated in this activity)
Overstory trees	Variety of sizes, including very large Many fire scars on trunks	Similar in size, none very large No fire scars on trunks
Tree species	Should contain either ponderosa pine or Jeffrey pine, plus other species	Should contain Baker cypress
Stand structure	Trees widely spaced	Trees close together
Understory trees	A few small trees	No small trees
Understory vegetation	Grass, wildflowers, and perhaps a patch or two of shrubs	Very sparse

Table H17-1. Tree ages from one cohort in one stand[1]

The table shows the species of each core. Students do not need to provide that information for this activity.

Species	Tree number	Earliest date
Lodgepole pine	6	1890
Lodgepole pine	7	1898
Lodgepole pine	9	1892
Ponderosa pine	18	1887
Ponderosa pine	19	1903
Ponderosa pine	20	1893
Ponderosa pine	21	1889
Lodgepole pine	23	1893
Lodgepole pine	25	1891
Lodgepole pine	27	1894
Lodgepole pine	29	1887

[1]Source: Heyerdahl, Emily K.; Loehman, Rachel A.; Falk, Donald A. 2014. Mixed-severity fire in lodgepole pine dominated forests: are historical regimes sustainable on Oregon's Pumice Plateau, USA? Canadian Journal of Forestry. 44(6): 593-603.

Table includes only data from samples collected for stand age analysis. Cores that could not be scanned are not included.

Handout H17-1. How Fire Shaped the Landscape

The authors of an extensive literature review published in 1996[5] consulted more than 200 scientific articles to learn about historical fire regimes in the Sierra Nevada. They wrote that, before Euro-American settlement, most of the landscape burned fairly often, and most of the fires were of low severity. However, there were definitely patches that seldom burned, and there were definitely patches that burned with stand-replacement severity.

The authors described the Sierra Nevada landscape as having a "relatively fine" pattern. Much of the landscape contained large, old trees and had mostly an open structure with few trees in the understory. But the landscape was very diverse and also included dense patches of trees that had established after stand-replacing fires.

Photo by Ilana Abrahamson. Used with permission.

Photo by Brady Smith, USFS

USDA Forest Service photo provided by Ilana Abrahamson.

Photo by Kyle Merriam.

[5] Skinner, Carl N.; Chang, Chi-ru. 1996. Fire regimes, past and present. In: Status of the Sierra Nevada. Sierra Nevada Ecosystem Project: Final report to Congress. Volume 2: Assessments and scientific basis for management options. Wildland Resources Center Report No. 37. Davis, CA: University of California, Centers for Water and Wildland Resources: 1041-1069.

18. Fire History 3: Fire Regime across a Sierra Nevada Landscape

Lesson Overview: Students learn about mixed-severity fire and the complexity of actual historical fire regimes. They study information from a published research project, model results, and maps showing present patterns of fire severity. Then they use their understanding to create a stand age diagram for a hypothetical forest in the Sierra Nevada with a mixed-severity fire regime and decide if their imagined forest has a fire regime that is substantially different from its historical fire regime.

Subjects: Reading, Writing, Speaking and Listening, Math, Science

Duration: 1-2 30-minute sessions

Group size: Whole class, working singly

Setting: Classroom

FireWorks vocabulary: *landscape-level diversity, mixed-severity fire*

Lesson Goals: Students understand the nature of mixed-severity fire regimes and their contribution to landscape-level diversity in the Sierra Nevada. Students can use a quantitative method to describe a hypothetical concept. Students can make a judgment call based on quantitative information.

Objectives:

- Students can draw a hypothetical stand age diagram that depicts a history of mixed-severity fire and shows how it influenced the distribution of two or more tree species in the forest.
- Students can judge whether their hypothetical forest shows a pattern of fire now that is substantially different from its historical fire regime.
- Students can state some potential ecological consequences of a changed fire regime.

Standards:		9th	10th	11th	12th
Common Core ELA	Reading Informational Texts	1,2,4,		1,2,4	
	Speaking and Listening	1,4,		1,4	
	Reading Science/Technical Subjects	3,5,7,10		3,5,7,10	
	Writing Science/Technical Subjects	7,10		7,10	
	Science/Technical Subjects	2,4,5,6,7,8,9,10		2,4,5,6,7,8,9,10	
NGSS	Structure and Function	LS1.A			
	Interdependent Relationships in Ecosystems	LS2.A, LS2.C,LS2.D, LS4.C			
	Natural Selection and Evolution	LS4.B, LS4.C			
	History of Earth	ESS1.C, ESS1.A			
	Earth's Systems	ESS2.A			
EEEGL	Strand 1	C,E,F,G			

Teacher Background: In the previous two lessons, students learned that low-severity fires were characteristic of some forest stands in centuries past (including California oak woodlands, mixed-conifer forests, and Jeffrey pine forests), and stand-replacement fires were characteristic of others (mainly Baker cypress, in the Sierra Nevada). However, ecosystems are not this simple in reality. Ponderosa pine forests did experience stand-replacing fire, and fire scars can be found on some of the trees that seem most vulnerable to fire, such as Sierra lodgepole pine. When a single fire has a variety of effects – some mortality in overstory trees, some trees only scarred or not even touched by fire – we call it a *mixed-severity fire.* When an ecosystem has a history of mixed-severity fires or experiences fires of different severities over time, we say it has a *mixed-severity fire regime.*

The fire regime for most of the montane forests in the Sierra Nevada was dominated by low-severity fire, but the pattern was far from uniform, especially when variation in fire severity was superimposed on a landscape with varying topography and vegetation. Students used a summary of fire history for mixed-conifer forests in the Assessment in the previous activity (**H18. Fire History 2: History of Stand Replacing Fire**):

> The majority of the landscape burned fairly often, and the majority of fires were of low severity. However, there were definitely patches that seldom burned, and there were definitely patches that burned with high (stand-replacement) severity. The authors call this landscape pattern a "relatively fine scale" that contained a lot of large, old trees and had an open structure – but that also had a variety of stand ages and combinations of species, all contributing to high diversity across the landscape.

In this activity, they learn about mixed-severity fire, and then they study evidence for the mixture of fire severities that characterized historical montane forests of the Sierra Nevada. Finally, they apply their understanding of fire regimes to judge whether the patterns of fire in current forests is substantially different from the historical fire regime – that is, are current forests "out of whack"? And if they are, what might be some consequences?

For more background, view the presentation and notes for the activity: ***H18_MixedSeverityFireRegime.pptx***.

Materials and preparation:

1. Download ***H18_MixedSeverityFireRegime.pptx***
2. Make 1 copy/student or team: **Handout H18-1: Imagine a forest with a mixed-severity fire regime.**

Procedure:

1. Explain: In the last two activities, we learned how low-severity fires and stand-replacing fires shape a forest stand, and we learned how to determine a stand's fire history. But we have focused on one kind of fire at a time, and that oversimplifies the real historical pattern

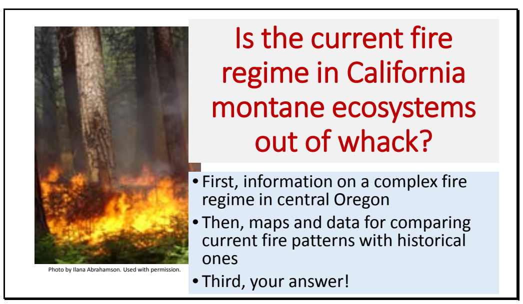
of fire across a landscape – its complete fire regime*.* In historical times, Sierra Nevada ecosystems often had a mixture of fire severities. Land managers want to know what the mixture was, and they want to know if today's fire regimes are "out of whack." Why do these things matter? The fire regime now could be so different from historical times that some native plant and animal species don't have the habitat they need anymore. It is managers' responsibility to make sure they provide for healthy populations of all native species – that is, to protect the land's biodiversity. To do that, they need to provide *landscape-level diversity* in habitat.

2. Explain: We're going to look at stand history diagrams from another location with a complicated historical fire regime – the Pumice Plateau in central Oregon. That will help us understand how diverse a fire regime can be. Then we'll compare data on the past and present fire severities in the area of the Plumas National Forest to help answer this question: "Is the current fire regime in California montane ecosystems out of whack?"

3. Go through the presentation ***H18_MixedSeverityFireRegime.pptx***:

Slides and notes for *H18_MixedSeverityFireRegime.pptx*

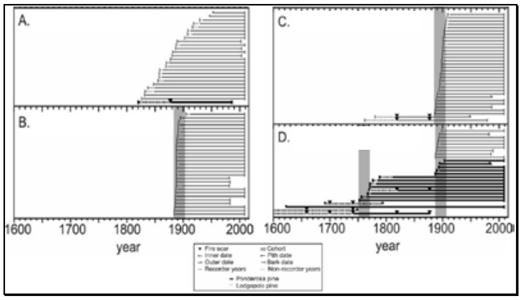
Slide 1



Slide 2

Some fire regimes are very complex. Here is information on a place in central Oregon where the historical fire regime had some low-severity fire and some severe fire – a *mixed-severity* fire regime. The study was conducted on the Deschutes National Forest. The ecosystem is unique because the forest has developed on pumice soil, which was formed by the eruption of the Newberry Crater 1300 years ago. The pumice is poor in nutrients for plant growth, and the site is prone to unusual summer frosts.

Slide 3



The researchers collected increment cores and samples of fire scars from 30 plots. The variety was amazing! Here are stand history diagrams from 4 of the plots. Let's make sure we can interpret these diagrams.

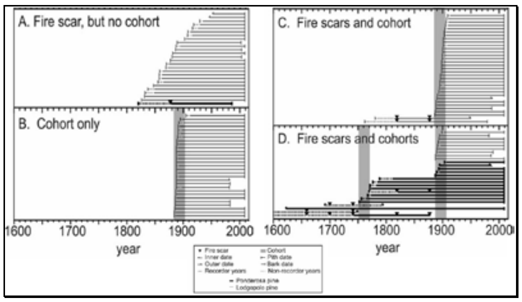
(Go through the key. The only new terms here are *recorder years* – the years <u>after</u> the first scar – and *nonrecorder years* – the years before the first scar or when the margin of the catface could be dated.)

Why are all those early years excluded from the data? It takes more heat to create the first scar than to create subsequent ones (because of the insulation from the thick bark). Several surface fires may have burned around the tree before one of them was intense enough to kill the cambium. So, if you included those first years, the average fire interval would seem longer than it truly was.

How would you describe the fire pattern in each of these stands?

- Graph A shows a stand that has recorded only 1 surface fire (on a ponderosa pine that is now dead) and has no cohorts to indicate any history of stand-replacing fire. The lodgepole pines in this plot have become established gradually over the past 200 years.
- Graph B shows 1 cohort, all lodgepole pines, and no fire scars; it is likely that every tree in this stand established after a stand-replacing fire, which killed the previous forest and provided lots of sunshine and nutrients for new trees.
- Graphs C and D show a mixed-severity fire history. In C, most of the trees (all lodgepole pines) are in a cohort that probably established after fire – perhaps the same fire that scarred 2 trees (now dead) on the plot. In D, there is evidence of stand-replacing fire in the mid 1700s and late 1800s, and there is also evidence of many low-severity fires that scarred ponderosa pines.

Slide 4

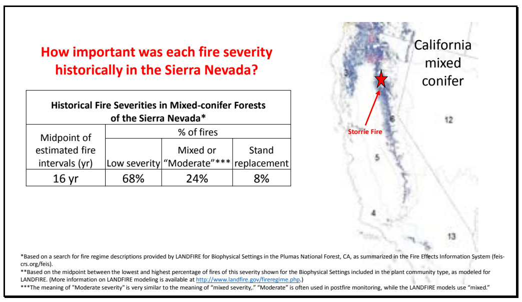


Here is how the scientists described the evidence for fire in each stand.

Slide 5

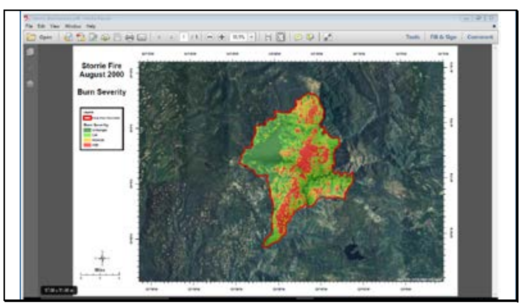
When an individual fire causes some stand replacement and some fire scarring, it's called a *mixed-severity fire*. This is a fairly new term in fire research. Scientists have also used "moderate-severity fire" and "mosaic fire" to describe complicated patterns of fire on the landscape. When the fire pattern <u>over a big landscape</u> and <u>over a long time period</u> is a mixture of stand replacement and low severity, it's called a *mixed-severity fire regime.*

Slide 6



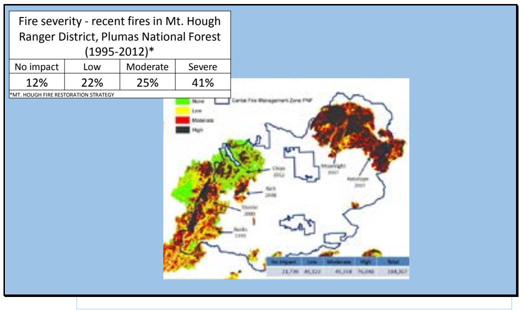
How important was each kind of fire (low-severity, moderate or mixed, and stand-replacement) in the area of the Plumas National Forest? Here are some estimates calculated by LANDFIRE modeling of fire and forest succession after fire in mixed-conifer forest of the Sierra Nevada. This forest type had lots of low-severity fire, but it also had moderate-severity fires and occasional patches of stand-replacement fire.

Slide 7



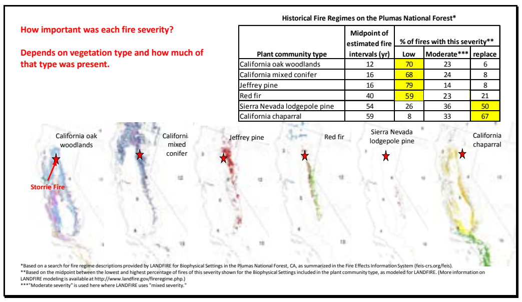
After a big wildland fire like the Storrie Fire of 2000, scientists use satellite imagery to create maps like this one. It shows a lot of variety in fire severity, including a large patch in the western part of the fire that was not burned but was surrounded by burned area. Managers use fire severity maps to decide where there might be high risk of erosion.

Slide 8



Do montane mixed-conifer forests in the Sierra Nevada still have a fire regime like the historical one? Recall: That was mostly low-severity fire, some mixed-severity, and occasional or small areas of stand replacement. The data from these 18 years show much more severe fire and much less low-severity fire than occurred in past centuries.

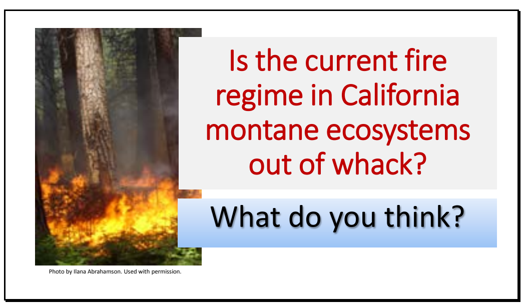
Slide 9



How important was each kind of fire (low-severity, mixed-severity, stand-replacement severity) in the variety of forests types on the Plumas National Forest? Here are some estimates calculated by modeling fire and succession.

We can see that the first 3 types (dominated by oaks, mixed-conifer forest, and Jeffrey pine) had lots of low-severity fire and were very prevalent in the area of the Storrie Fire. Red fir forests also had plenty of low-severity fire, but they had substantial amounts of the other severities too. Only the lodgepole pine and chaparral types showed more stand-replacement than low- or mixed-severity fire.

Slide 10



Assessment:

1. Give each student a copy of **Handout H18-1: Imagine a forest with a mixed-severity fire regime**.

2. Explain: This activity will challenge both your imagination and your quantitative skills. You will “make up” a forest with a mixed-severity fire regime, and you will describe it *quantitatively* – using a stand history diagram like the ones we’ve been creating from data in previous activities and the ones we’ve looked at in the presentation for this activity.

3. Go through the directions in the handout. Answer questions. Provide suggestions and help as needed while students draft their stand history diagrams.

Evaluation: See **Teacher's example solution for Handout H18-1: Imagine a forest with a mixed-severity fire regime** for an example of a stand history diagram that meets the requirements listed on the handout.

Excellent	**Good**	**Fair**	**Poor**
~Student included all 6 required features listed on Handout H18-1. ~Narrative and/or labeling was clear. ~Student selected appropriate fire-resistant species (most likely ponderosa pine or Jeffrey pine) and fire-vulnerable species (most likely white fir or Sierra lodgepole pine). ~Student answered the final question and gave a logical explanation.	~Student included 5 of required features or ~Narrative/labeling was unclear or ~Species selections were not ecologically appropriate. or ~Student did not answer the final question with a logical explanation.	~Student included 3-4 of required features or ~narrative/ labeling was incorrect or ~Species selections were not ecologically appropriate. or ~Student did not answer the final question with a logical explanation.	~~Student included less than 3 of required features or ~narrative/ labeling was incorrect or ~Species selections were not ecologically appropriate. or ~Student did not answer the final question.

Handout H18-1: Imagine a forest with a mixed-severity fire regime.

For this assignment, you will use what you know about historical fire regimes to imagine and describe a montane forest in the Sierra Nevada. Your description will be quantitative – that is, based on numbers and displayed as a *stand history diagram* – rather than qualitative, like the forests described for Activity H17.

Create a stand history diagram that describes a forest in a California montane ecosystem that had a history of mixed-severity fire before the fire suppression period. You can draw the stand history diagram by hand or use a computer program. No matter what medium you use, you may find it easiest to sketch the diagram in pencil before creating a finished product. Make it as complex as you like, but you must include at least the following:

a) A timeline at the bottom that goes back at least 400 years

b) Timelines for trees of at least two different species – one that grows thick bark at an early age so it can survive low-severity fires, and another that has less resistance to fire. Label each tree's timeline with its species or use a color key to show the species of each tree.

c) At least 1 severe fire – that is, one that initiated a new cohort

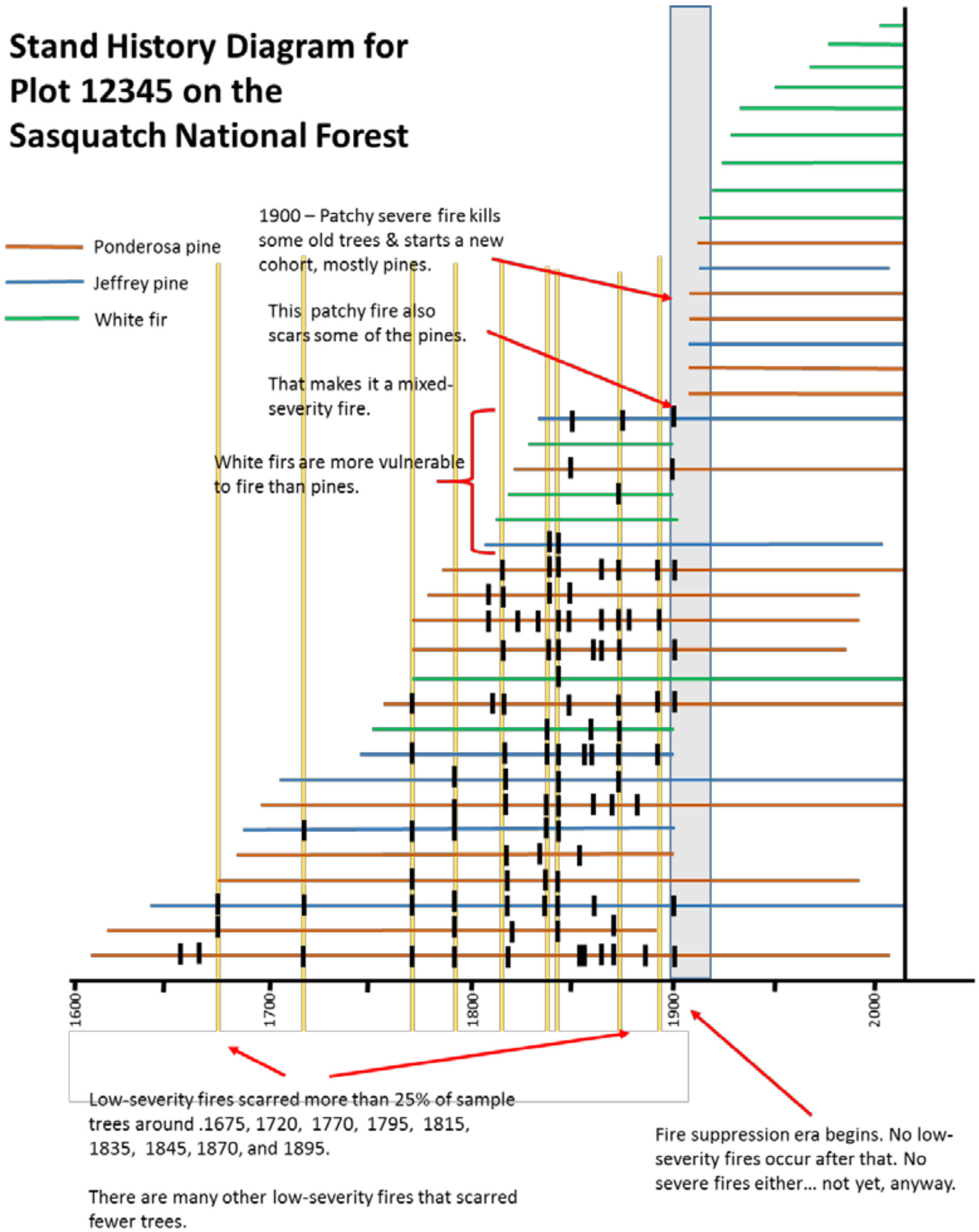
d) At least 4 low-severity fires – that is, they scarred some trees

e) The start of the fire suppression period

f) Either labels on the diagram or a separate paragraph that identifies all of these features

g) Answer these questions: **Is the fire regime of your imagined forest out of whack? How do you know it is (or isn't)? If it is, what are some possible ecological consequences?**

Teacher's example solution for Handout H18-1: Imagine a forest with a mixed-severity fire regime.



The forest looks out of whack because there have been no low-severity fires since 1900, there have been more and more white firs growing in, and there have been no ponderosa pines or Jeffrey pines establishing. The loss of the pines – and the closure of the forest due to white fir regeneration – alter the habitat for understory plants and for animals that rely on open habitat with big, old trees.

Unit VII. People in Fire's Homeland

19. Sierra Nevada Forests Today

Subjects: Science, Reading, Writing, Speaking and Listening, Arts
Duration: 2 class periods
Group size: Full class
Setting: Indoors
New FireWorks vocabulary*:* *fire manager*

Lesson Overview: Students will view a slide show that displays historical and recent photos of conditions in lower and upper montane Sierra Nevada forests. They will consider how current conditions differ from those of the past. A professional wildland manager will visit the classroom to discuss and answer student questions about historical and current forest conditions and the challenges of forest management.

Lesson Goal: Students will understand that forest management influences current and future conditions, and that in many locations, forests are very different from their historical conditions.

Objectives:

- Students will analyze photographs from "*Fire in Sierra Nevada forests: A photographic interpretation of ecological change since 1849*" by George E. Gruell to see how forests have changed over the past 150 years.
- Students will prepare questions to ask the fire manager.
- Students will listen to a guest presentation, then write a reflection on how montane forests of the Sierra Nevada have changed and how those changes affect forest managment.

Teacher Background: In order for this activity to work, you must contact someone with expert knowledge of local fire management and/or ecology (a fire manager, fire ecologist, district ranger etc.) and schedule a time for him or her to come to your classroom (or video conference with you) and speak with your students. The expert should be prepared to discuss or answer questions about current conditions of local forests and how they have changed from historical conditions, how the forest's relationship with fire has changed, and how local forests are managed today.

Materials and Preparation:

- Download ***H19_A Photographic Interpretation.pptx***. This slide show consists of 6 sets of photos – one from the 1800s or early 1900s, the other from the 1990s. In each set, the first photo is the early one, the second photo is the later one, and the third photo shows them together.

- Obtain Post-It Notes (10/student)
- Find and schedule a guest speaker (fire manager, fire ecologist, district ranger, etc.) to talk with your class about the current conditions of local forests, how they may differ from historical conditions, and how that affects land management decisions. Be sure to explain the goals of the presentation; if your guest wants to talk about something else (and you want that information), adjust the procedure below so the students will prepare appropriately.

Procedure:

1. Explain: To complete our study of wildland fire, we're going to have a professional land manager come to our class and tell us about his/her work, his/her concerns about fire in wildland ecosystems, and how he/she addresses these challenges. We'll use this class session to prepare for our guest.
2. Write the following questions on the board in three columns, so students can put Post-It notes under each topic.

"What did Sierra Nevada forests and woodlands look like before and during the early stages of Euro-American settlement?"	"How has the vegetation changed since Euro-Americans settled in the region?"	"What human activities and natural processes have influenced vegetation and landscape change?"

3. Hand out 10 Post-It notes to each student.
4. Go through ***H19_A Photographic Interpretation.pptx,*** (slides are shown below). The presentation contains 6 sets of photos, 3 photos in each set. For each photo set:
   - When you get to the 3rd photo (with both of the previous ones on it), have students use 3 Post-It notes to write a response to each question on the board. Remind them to write only one observation per Post-It.
   - Have them stick their Post-Its on the board under the respective questions.
   - Review the Post-Its and discuss the three questions on the board for that set of photos.
   - Move the Post-Its off to the side so the board is uncluttered for the next set of photos.
5. After you have completed the slide show, ask: What human influences have led to current conditions in the Sierra Nevada? Euro-American settlement, decline in Native American populations, forest management/harvesting, development of transportation corridors, fire

management, human influences on climate change, invasive species, the Industrial Revolution….

6. What natural processes have led to these conditions? Succession, fire, native insects and pathogens, climate change…
7. Ask/discuss: Under current conditions, what challenges do plants, animals, and humans face? Possible answers:
   - Fire exclusion has resulted in forests that are denser than they were historically. These dense forests are favored by shade-tolerant species such as white fir and Douglas-fir at the expense of shade-intolerant species such as ponderosa pine, Jeffrey pine, and sugar pine. Species that thrive in open, sunny forests are challenged to find suitable habitat in dense, shady forests.
   - Under hot, dry, and windy conditions, dense forests with a lot of surface, ladder, and crown fuels are more likely to burn intensely and result in large areas of stand-replacing fire. This kind of fire often threatens homes and communities in and near the forests. Large areas of stand-replacing fire make it difficult for many native plants and animals to survive and establish in those areas.
8. Ask: What challenges and considerations do forest and fire managers have to consider when managing today's forest? Managers have to consider native and nonnative plant and animal habitat needs, forest stand structure and composition, fuel levels, potential for high-severity fires, needs of threatened and endangered species, insect outbreaks, safety and potential evacuation of nearby communities, local economies, public and firefighter safety, changing future conditions, climate change, drought, etc.
9. Explain: Each individual or pair of students must prepare at least one relevant question for the guest speaker. Each individual or pair must ask one question or – if their questions have all been answered, they must ask a followup question. After the presentation, students will write a reflective paper on what they learned.
10. Have students write out their questions. You can review them ahead of time, if you wish.

When the guest speaker comes:

11. Have students get their questions out. Remind them of courteous behavior toward guests. Remind them that they will write a reflective paper on the presentation afterward.
12. Introduce the speaker, host the presentation, and have students ask their questions.

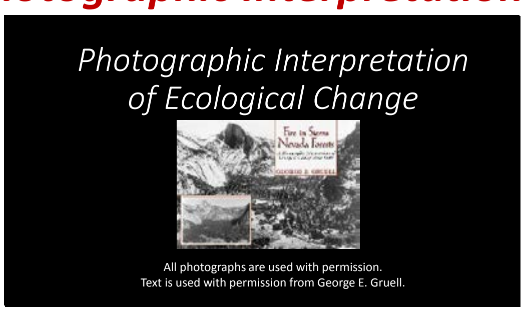
Assessment:
Explain: Write a reflection paper with a beginning, middle, and end. Explain how forests in the Sierra Nevada are different today than they were before Euro-American settlement and how this impacts the decisions of wildland managers.

Evaluation:

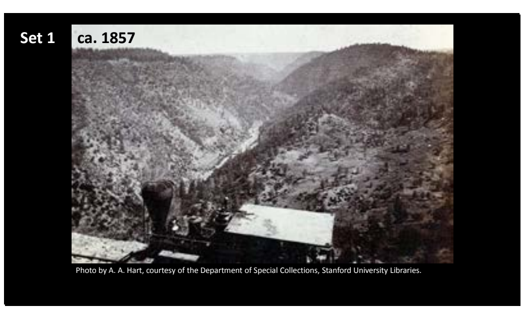
	Full credit	Partial credit	No credit
Active listening to guest presenter	Listened attentively, took notes, and asked 1 appropriate question.	Listened attentively and took notes.	Did not listen attentively or distracted speaker or other students.
Reflection paper: How are forests different today?	~Identifies at least 2 changes. ~Uses examples of individual species or ecosystem properties that have changed.	~Identifies at least 1 change. ~Uses examples of individual species or ecosystem properties that have changed.	~Answer is vague. Does not clearly identify changes. Does not give specific examples.
How do the changes impact decisions of wildland managers?	~Identifies how each change identified above affects specific decisions of wildland managers.	~Describes how change(s) affect decisions of wildland managers.	~Answer does not address decisions of wildland managers.

Slides in *H19_A Photographic Interpretation.pptx*

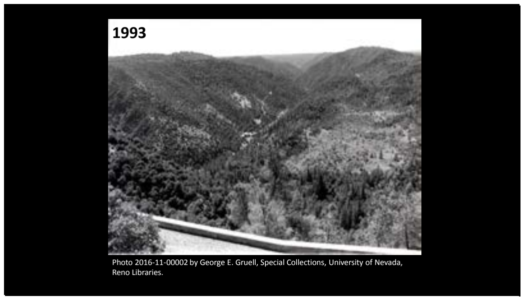
Slide 1



Slide 2



Slide 3



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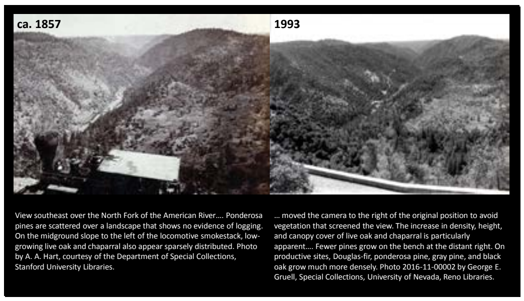

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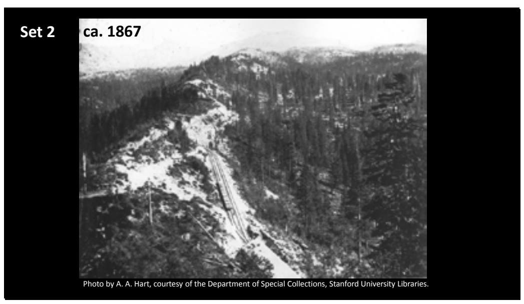

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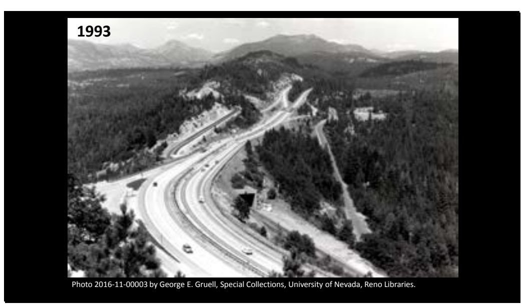

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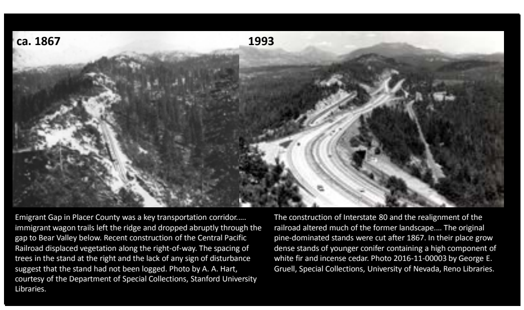
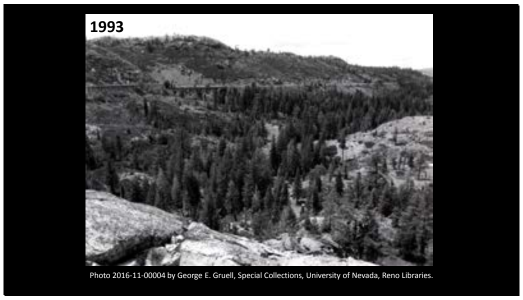


Slide 8

Slide 9



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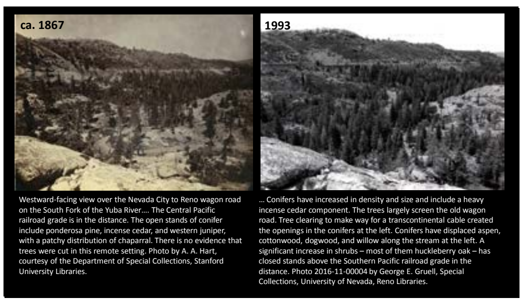
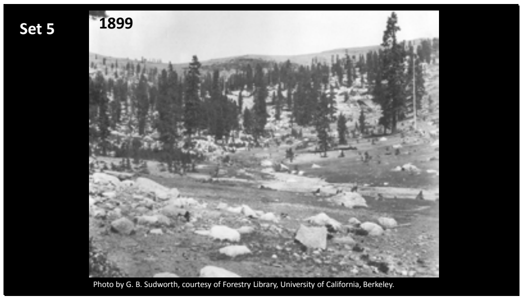


Slide 11

Slide 12

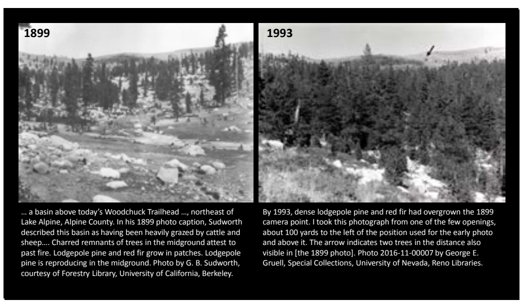
Slide 13

Slide 14



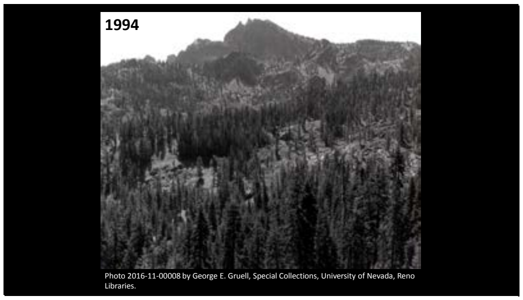
Slide 15

Slide 16



Slide 17

Slide 18



Slide 19

Slide 20

Gruell, George. 2001. Fire in Sierra Nevada forests: a photographic interpretation of ecological change since 1849. Missoula, MT: Mountain Press Publishing Company. 238 p.