

FireWorks Educational Program

Featuring Ponderosa, Lodgepole, and Whitebark Pines

2018*

High School Version

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March 2019

by Jane Kapler Smith, Ilana Abrahamson, Caitlyn Berkowitz, and Nancy E. McMurray

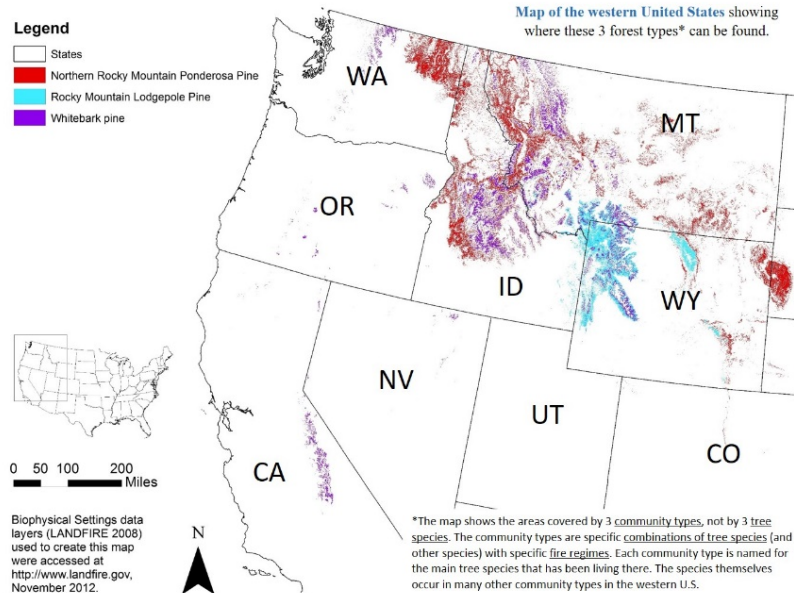
FireWorks: Why?

Change is an integral part of 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).

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 ecological communities (Lindholdt 1999; North American Association for Environmental Education 1999). This version of *FireWorks* focuses on 3 communities that occur from the northern Rocky Mountains through the “intermountain” region to the North Cascades: Northern Rocky Mountain Ponderosa pine¹ (dominated mostly by ponderosa

Ponderosa pine, lodgepole pine, and whitebark pine communities



¹ Common names are used for all species mentioned in the text and associated materials. Corresponding scientific names are available online in the Fire Effects Information System (<https://www.feis-crs.org/feis/>).

pine and Douglas-fir, Rocky Mountain Lodgepole pine (dominated by lodgepole pine and subalpine fir, and Whitebark Pine (dominated by whitebark pine, sometimes with subalpine fir).

The 3 forest types featured in this curriculum have long, intimate relationships 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. **Table I-1** summarizes this information.

Table I-1—Summary of ecology and "fire story" of some forest communities of the northern Rocky Mountains and North Cascades.

Elevation		Low	Middle	High
Pine species (grows well in sunny, open areas with bare soil)		ponderosa pine	lodgepole pine	whitebark pine
Shade-tolerant species (grows better than pine in shady places and in litter and duff)		Douglas-fir	subalpine fir	subalpine fir
Pine traits for surviving or reproducing well after fire		Open, high crown thick buds thick bark	serotinous cones	Trees in clusters open, high crown seeds planted by nutcrackers
Historical fire regime	Fire severity	Majority of fires are low-severity; some mixed-severity & occasional stand-replacing	Stand-replacing and mixed-severity, with occasional low-severity	Often patchy, mixed-severity. Highly variable in size and severity
	Average fire interval	Ranges from about 6 years to 50 years	Ranges from about 90 years to more than 300 years	Ranges from about 40 years to more than 250 years
Some animals in this community (not limited to this community)		Pileated woodpecker Flammulated owl Elk (especially spring)	Black-backed woodpecker Mountain pine beetle Elk (hiding cover in fall)	Clark's nutcracker Grizzly bear Elk (summer)
Example of traditional use by Native Americans		Peeled bark for nutrition	Cut poles for tipis	Collected pine nuts for nutrition
Disturbances besides fire		Douglas-fir dwarf mistletoe	Mountain pine beetle	Mountain pine beetle, white pine blister rust

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).

Design and Layout of Lessons in This Curriculum

Each *FireWorks* activity has the following sections:

Lesson Overview

Lesson Goal

Objectives

Teacher Background

Materials and Preparation

Procedure

Assessment

Evaluation rubrics

Handouts (if needed)

Subjects: Science, Writing, etc...

Duration: a guess

Group size: whole class, teams, etc.

Setting: classroom, lab, outdoors, etc.

Vocabulary (not needed in all lessons)



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 suggested vocabulary terms. 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 answer keys, 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 required curriculum and meet required standards by using hands-on materials based on science from the local area. To help teachers identify the ways in which *FireWorks* can be used to meet their curriculum requirements, each activity is linked to relevant standards from:

- Common Core State Standards in English Language Arts (CCSS-ELA), Math (CCSS-Math), Science, and Technical Subjects
- Next Generation Science Standards (NGSS)
- Excellence in Environmental Education: Guidelines for Learning standards (EEEEGL)²

² 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>)

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. This diagram shows how to use the table of standards provided with each activity:

Standards:		6th	7th	8th
CCSS	Writing	2, 4, 7, 10	2, 4, 7, 10	2, 4, 7, 10
	Speaking and Listening	1, 2, 4, 6	1, 2, 4, 6	1, 2, 4, 6
	Language	1, 2, 3, 4, 6	1, 2, 3, 4, 6	1, 2, 3, 4, 6
	Writing Standards Science/Tech	1, 2, 4, 7, 10	1, 2, 4, 7, 10	1, 2, 4, 7, 10
	Math	MP.4	MP.4	MP.4
NGSS	Matter and Its Interactions	ETS1.B		
	Earth's Systems	ESS2.D		
	Earth and Human Activity	ESS3.A, ESS3.B, ESS3.C		
	Engineering Design	ETS1.B		
EEEGL	Strand 1	A,B,C,E,F,G		

Safety

Many of the experiments in *FireWorks* use fire and natural fuels. 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 you run the activities smoothly and help your students grow in responsibility and competence regarding lab safety and fire safety:

- Inform 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 may be required to 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.

Three Curricula for Three Grade Levels

FireWorks includes curricula for 3 grade levels: Elementary (grades 1-5), Middle (grades 6-8), and High (grades 9-12). The Elementary curriculum encourages students to learn from demonstrations and simple models and to become acquainted with plants and animals in the local area. The Middle School curriculum challenges students to conduct experiments to answer questions and use information from technical readings to describe fire's role in various ecosystems. The High School curriculum asks students to design and conduct experiments and to apply information from technical articles to management questions. Activities for different grade levels may use the same materials, but the curricula differentiate across grade levels; content is more detailed and the activities are more challenging for older students. You can use **Table I-2** to compare activities on the same theme for different grade levels and select the best approach for meeting your objectives with your students.

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- 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

Table I-2. FireWorks Curriculum Plan for the Northern Rocky Mountains and the North Cascades. Read across the table to find similar activities for students at all 3 grade levels.

Unit & Theme	ELEMENTARY	MIDDLE	HIGH
Unit I. Introduction to Wildland Fire	E01. Visiting Wildland Fire in the Northern Rocky Mountains and North Cascades	M01. Visiting Wildland Fire in the Northern Rocky Mountains and North Cascades	H01. Introduction to Wildland Fire in the Northern Rocky Mountains and North Cascades
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?	H11-1. 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	E08-1. What's a Community? All the Living Things in the Ecosystem	M11. Who Lives Here? Adopting a Plant, Animal, or Fungus	H14. Researching a Plant, Animal, or Fungus
	E08-2. Who Lives Here? Adopting 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 Lodgepole Pine Forest: Serotinous Cones	E11. Is appropriate for middle school	
		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' Annual Rings		
		M17-H16. Dating Fires Using Dendrochronology	M17-H16. Dating Fires Using Dendrochronology
		M18-H17. History of Stand-replacing Fire	M18-H17. History of Stand-replacing Fire
	E13-2. Tree Biography, Forest Biography	M19-H18. History of Low-severity Fire	M19-H18. History of Low-severity Fire
		M20. Fire History in Ponderosa, Lodgepole, and Whitebark Pine Forest Communities	H19. History of Mixed-severity Fire
	E14. Story Time: Fire and Succession	M21. Drama in the Forest: Fire and Succession, a Class Production	H20. Why Do Historical Fire Regimes Matter?
		M22. Fire Ecology Puzzler	
Unit VII. People in Fire's Homeland	E15. Carrying Fire the Pikuni Way	M23. Carrying Fire the Pikuni Way	H21. Carrying Fire the Pikuni Way
	E16. Homes in the Forest: An Introduction to Firewise Practices	M24. Homes in the Forest: An Introduction to Firewise Practices	
	E17. Revisiting Wildland Fire	M25. Revisiting Wildland Fire	H22. Northern Rocky Mountain and Northern Cascades Forests Today



Unit I.
Introduction to Wildland Fire



1. Introduction to Wildland Fire in the Northern Rocky Mountains and North Cascades

Lesson Overview: Students consider their thoughts and feelings about wildland fire before and after a photo presentation. Then students read and analyze a chapter from a book about the fires of 1988 in Yellowstone National Park.

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

Vocabulary: *ecosystem, ecological community, fire behavior, wildland, wildland fire*

Objectives:

- Students can use images to make observations and inferences about wildland fire.
- Students can describe and discuss information about the impacts of the 1988 fires in Yellowstone National Park.

Standards:		9th	10th	11th	12th
CCSS	Writing	2, 4, 10		2, 4, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 6		1, 2, 3, 4, 6	
	Reading Standards Science/Tech	1, 2, 3, 4, 7, 10		1, 2, 3, 4, 7, 10	
	Writing Standards Science/Tech	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	From Molecules to Organisms: Structure and Processes	LS1.B			
	Ecosystems: Interactions, Energy, Dynamics	LS2.A, LS2.C, LS4.D			
	Biological Evolution: Unity and Diversity	LS4.C			
	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.A, ESS3.B			
EEEGL	Strand 1	A, B, C, E, F, G			
	Strand 2.2	A, C			

Teacher Background: If you walk through a recently burned area, you will probably encounter some places where all the vegetation looks dead and other places that have a lot of green vegetation left. You will probably see deep holes in the ground where roots have burned away and also patches of leaf litter that is barely scorched. You may also see homes that have burned, fences and outbuildings destroyed, washed-out roads, or burned bridges.

Wildland fire can be a powerful force for renewal or destruction – or both. Fire behavior and fire effects vary with topography, weather, and vegetation. The impacts of wildland fire on people and human communities vary as well. As an introduction to the study of wildland fire, this photo presentation highlights variation in fire behavior and its relationship to people and human communities.

This curriculum focuses on fire ecology and the challenges that people face when living with fire. It features especially the ecology and management of 3 kinds of forest that occur in the northern Rocky Mountains and the North Cascades: forests at low elevations dominated by ponderosa pine and Douglas-fir, middle-elevation forests dominated by lodgepole pine mixed with subalpine fir and other trees, and high-elevation forests of whitebark pine mixed with subalpine fir.

Materials and preparation:

- Make a copy of the technical reading *Exerpts_ YellowstoneInTheAfterglow.pdf* for each student or arrange for them to read it online at (<https://www.nps.gov/yell/planyourvisit/upload/full-2.pdf>). This technical reading is 5-7 pages long. Students do not need to write on the handout so, if you are making printed copies, consider printing a classroom set to use repeatedly.
- Make a copy of **Handout H01-1. Reading “Yellowstone in the Afterglow”** 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 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 and why. This discussion may draw out some strong feelings about wildland fire.
3. Ask students to turn their paper over and divide it in half. Label one half “Observations” and the other “Questions.” Go through the presentation *H01_WildlandFireObservations.pptx* (below). The photos are arranged in 5 groups. 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.

Slide 1

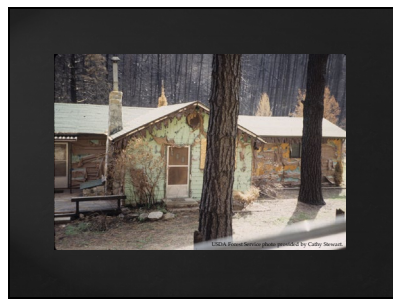


Slide 2

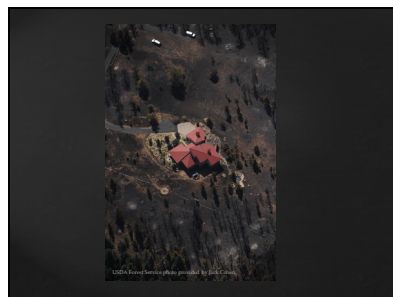


Theme: houses burning/burned

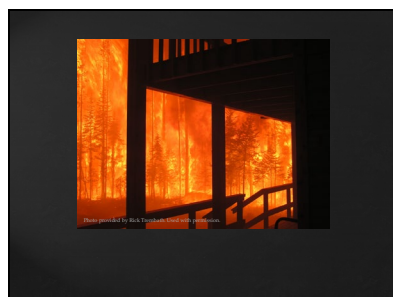
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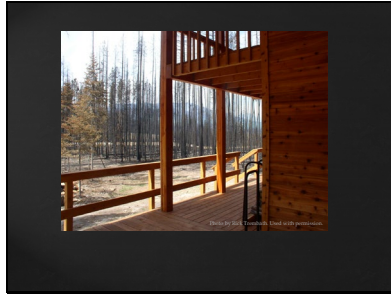
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Slide 5



Slide 6

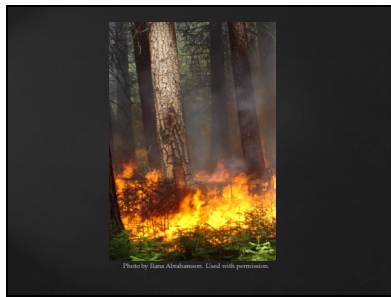


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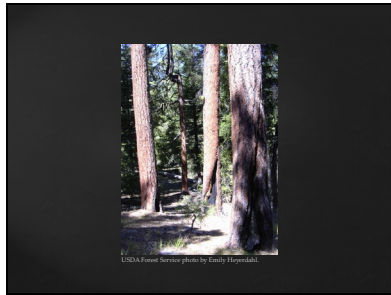


Theme: low-severity fire

Slide 8



Slide 9



Slide 10

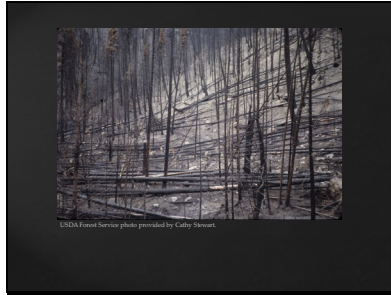


Theme: stand-replacing fire

Slide 11



Slide 12



Slide 13



Slide 14



Slide 15



Theme: postfire photos

Slide 16



Slide 17



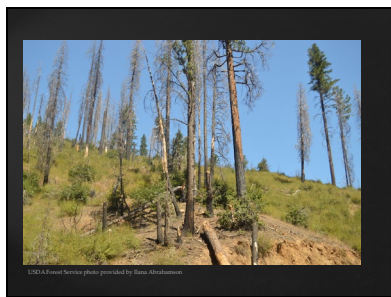
Slide 18



Slide 19



Slide 20

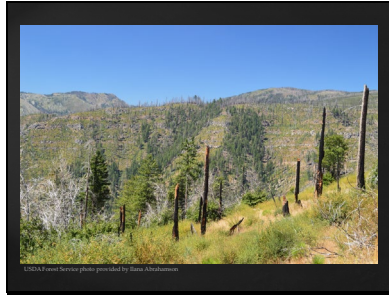


Slide 21

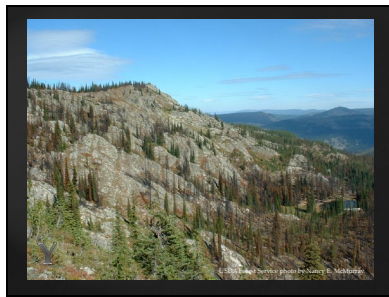


Theme: more postfire photos

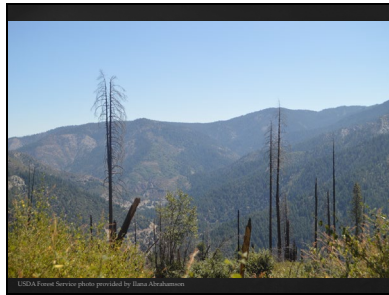
Slide 22



Slide 23



Slide 24



4. Ask students to share their observations and questions. Ask for any items that they added to their lists of pros and cons during the presentation.
5. For the reading assignment, 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 ***Exerpts_ YellowstoneInTheAfterglow.pdf*** or arrange for them to read it online (<https://www.nps.gov/yell/planyourvisit/upload/full-2.pdf>). Break the class into five groups and assign of these sections to a different group:
 - “A Tale of Two Fires” and “Fire as an Ecological Event”
 - “Fire as a Human Experience”
 - “Yellowstone in the Year 2000”
 - “The Debate Continues”
 - “Yellowstone’s Clouded Crystal Ball”
7. Give each student a copy of **Handout H01-1. Reading “Yellowstone in the Afterglow”**. Explain: Students in each group will become experts on the questions about their section and will answer **ONLY** the questions about their section on the handout. Have them do the reading and write answers to the questions on their section.
8. Regroup the class so each new groups has at least 1 student from each of the 5 original groups. Have students from each group share their answers to the handout with the rest of the group, while students **NOT** in that original group ask questions and take notes on **THEIR** handouts.
9. Ask students to discuss connections among their pro-con lists, the presentation, the article, and their answers to the final question on the handout.

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

Handout H01-1. Reading “Yellowstone in the Afterglow”

Name: _____

Instructions: Please use “*Yellowstone in the Afterglow*” by Mary Anne Franke to answer the following questions in complete sentences.

“A Tale of Two Fires” and “Fire as an Ecological Event”	
1.	Define each of these terms as it is used in the article: <i>millennium, alleged, subterranean, intrinsic.</i>
2.	What are the “two fires” that the author discusses?
3.	The author suggests that people should think of Yellowstone as a place that is always changing. What is one of her examples of things that may change?
4.	How did most of Yellowstone’s wildlife respond to the fires?
5.	What does the author think is the main reason to accept the presence of fires in Yellowstone?
“Fire as a Human Experience”	
1.	Define each of these terms as it is used in the article: <i>futile, repository, feasible, mission.</i>
2.	What were the two conflicting messages (“mixed smoke signals”) that park managers sent during the fires?
3.	What did the firefighting efforts accomplish?
4.	Describe two of the hardships for people that the fire caused.
5.	Why does the author say that it is not logical to eliminate fires?
“Yellowstone in the Year 2000”	
1.	Define each of these terms as it is used in the article: <i>proximity, aptness, trifling, gateway.</i>
2.	The author suggests that the fires were not as “cataclysmic” as other events in Yellowstone. Describe the example she gives.
3.	What are dead trees good for?
4.	How did the numbers of park visitors change during the year of the fires (1988) and afterward?
5.	When this article was written, how were Yellowstone’s managers handling lightning-caused fires?
“The Debate Continues”	
1.	Define each of these terms as it is used in the article: <i>prescription burn, hazardous fuels, conflagration, incompatible.</i>
2.	Describe the first big fire in the West during the year 2000.
3.	What was one criticism of government fire management at the end of the summer of 2000?
4.	Why does the author consider fires important to Yellowstone?
5.	What is the “one indisputable benefit” of the 1988 fires?
“Yellowstone’s Clouded Crystal Ball”	
1.	Define each of these terms as it is used in the article: <i>quantifiable, runoff, fire breaks, debris flows.</i>
2.	How could large fires cause flooding? Have the 1988 fires caused this in Yellowstone?
3.	How could large fires cause another “big fire season” in Yellowstone after 1988? Did this happen?
4.	What kinds of trees are growing in the areas burned by the 1988 fires?
5.	How have people’s attitudes toward wildland fire changed since the 1988 fires?

Handout H01-1. Possible responses to questions about “Yellowstone in the Afterglow”

“A Tale of Two Fires” and “Fire as an Ecological Event”	
1.	Define each of these terms as it is used in the article: <i>millennium, alleged, subterranean, intrinsic.</i>
2.	What are the “two fires” that the author discusses?
	1. The ecological event that burned a huge area of Yellowstone in 1988 2. The human event, including economic and emotional impacts
3.	The author suggests that people should think of Yellowstone as a place that is always changing. What is one of her examples of things that may change?
	The Old Faithful geyser can be changed by what happens underground. Severe winters can change the number and distribution of plants and animals. So can fire.
4.	How did most of Yellowstone’s wildlife respond to the fires?
	Most of them did not flee, but instead they went about their activities as usual. Few were killed by smoke or flames.
5.	What does the author think is the main reason to accept the presence of fires in Yellowstone?
	The main reason is because fires are intrinsic to Yellowstone’s ecology.
“Fire as a Human Experience”	
1.	Define each of these terms as it is used in the article: <i>futile, repository, feasible, mission.</i>
2.	What were the two conflicting messages (“mixed smoke signals”) that park managers sent during the fires?
	1. Persuade the public that the fires were not an ecological disaster. 2. Spend \$120 million to try to put them out.
3.	What did the firefighting efforts accomplish?
	Firefighting efforts protected buildings in the park, but they did not reduce the area burned very much.
4.	Describe two of the hardships for people that the fire caused.
	Here are three: 1. Two people died. 2. Many people were inconvenienced or worried about the park. 3. Local businesses suffered financial losses.
5.	Why does the author say that it is not logical to eliminate fires?
	Eliminating fires would be illogical because they are one of the forces that determine which plants and animals live there.
“Yellowstone in the Year 2000”	
1.	Define each of these terms as it is used in the article: <i>proximity, aptness, trifling, gateway.</i>
2.	The author suggests that the fires were not as “cataclysmic” as other events in Yellowstone. Describe the example she gives.
	Her example is the series of volcanic eruptions 630,000 years ago.
3.	What are dead trees good for?

	Dead trees can provide shelter and a source of food for insects and birds, which then provide food for other animals.
4.	How did the numbers of park visitors change during the year of the fires (1988) and afterward?
	In 1988, visitation was 15% lower than in 1987. In 1989, however, visitation was higher than ever – and has continued to increase.
5.	When this article was written, how were Yellowstone’s managers handling lightning-caused fires?
	If lightning-caused fires did not pose a risk to human life or property, they were permitted to burn under “certain conditions.”
“The Debate Continues”	
1.	Define each of these terms as it is used in the article: <i>prescription burn, hazardous fuels, conflagration, incompatible.</i>
2.	Describe the first big fire in the West during the year 2000.
	In May, a prescription burn intended to reduce hazardous fuels near Bandelier National Monument burned many homes in local communities.
3.	What was one criticism of government fire management at the end of the summer of 2000?
	Some claimed that the government had not used enough prescription burns to prevent the fires.
4.	Why does the author consider fires important to Yellowstone?
	The author considers fires important because they are an essential to the Park’s nature; they are needed to “let Yellowstone continue to be Yellowstone.”
5.	What is the “one indisputable benefit” of the 1988 fires?
	The fires have provided the opportunity to learn how the Park has responded – both the people and the wild inhabitants of the Park.
“Yellowstone’s Clouded Crystal Ball”	
1.	Define each of these terms as it is used in the article: <i>quantifiable, runoff, fire breaks, debris flows.</i>
2.	How could large fires cause flooding? Have the 1988 fires caused this in Yellowstone?
	Increased water flow (“runoff”) from burned hillsides could have caused flooding, but this did not happen after the 1988 Yellowstone fires.
3.	How could large fires cause another “big fire season” in Yellowstone after 1988? Did this happen?
	The many dead and down trees could have fueled another big fire season, but they didn’t.
4.	What kinds of trees are growing in the areas burned by the 1988 fires?
	Millions of lodgepole pine seedlings are growing in burned areas, and aspen seedlings are growing in places where they did not occur before the fires.
5.	How have people’s attitudes toward wildland fire changed since the 1988 fires?
	People seem to better understand and accept the fact that fires have a role to play in wildlands.



Unit II. Physical 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 (fuel, heat, and oxygen). The lesson includes 3 separate 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 conceptual understanding to real-world questions.

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.

Subjects: Science, Mathematics, Writing, Speaking and Listening, Health and Safety
Duration: Three ~20 minute experiments.
Class Arrangement: Whole class and groups.
Setting: Indoors
Vocabulary: *chemical change, combustion, Fire Triangle, fuel, heat, heat plume, model, oxygen, physical change*



Standards:		9th	10th	11th	12th
CCSS	Writing	2, 4, 10		2, 4, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 7, 10		1, 2, 3, 4, 7, 10	
	Writing Standards Science/Tech	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	Matter and Its Interactions	PS1.A, PS1.B			
	Energy	PS3.D			
	Earth's Systems	ESS2.D			
EEEEGL	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 investigate whether fires really require oxygen.

This activity also contains a **Technical Reading**, 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.

Materials and preparation:

- Choose your laboratory arrangement. These experiments can produce flames as long as 20 cm.
- Locate a video online of an airplane or helicopter dropping water on a wildland fire. You can find one by searching with these terms: helicopter airplane drop water fire.
- The day before doing this activity, ask students to follow safety guidelines about clothing and hair when they get ready for school tomorrow, especially:
 - 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 (*FireWorks_Safety_poster.pptx*).

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.

- Have a fully charged dry chemical fire extinguisher handy. Know how to use it.
- Make copies of **Handouts H01-1, 2, 3, and 4** for each student or team.
- Set up each laboratory bench with the following equipment:
 - Spray bottle, filled with water (Some trunks contain only 2; you may need to provide more.)
 - 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**
 - OPTIONAL: Thermocouple (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 $\frac{1}{4}$ c per student team
 - Container of white vinegar (labeled as vinegar, acetic acid, or CH_3COOH), approximately $\frac{1}{2}$ c per student team
 - Scoop or spoon for measuring 15 to 60 mL (1 Tablespoon to $\frac{1}{4}$ cup)

Procedure:

1. **Hook:** Show a video of an airplane or helicopter dropping water on a wildfire. Ask: How does putting water on a wildfire help put the fire out? **This is a time for speculation. You can go into more detail with step 3 below.**
2. Draw a triangle on the board. Explain/ask: You are going to investigate what makes fires burn and what puts them out. What three components are necessary for fire to burn? **Responses are likely to include fuel, heat, and oxygen. If not, show that the responses you do get (i.e., “matches,” “gasoline,” “wood,” “air”) fit in these 3 categories.** Label the sides of the Fire Triangle with the 3 categories.
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 water drop shown in the video could help put 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 that is needed for combustion. Note that vaporization is a physical change (as opposed to a chemical change, such as combustion) 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 (*FireWorks_Safety_poster.pptx*) 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 °C (100 °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 “rescue breaths” in 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, have one student read part A, one part B, and one part C. Then have each student 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:

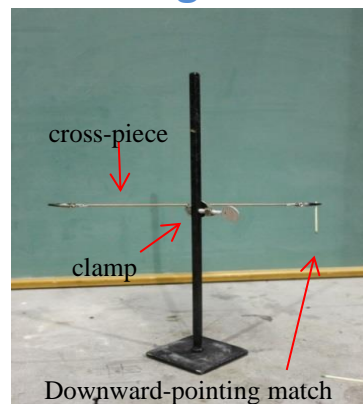
	Handouts (25 points each)		
Excellent	100%		
Good	88%		
Fair	75%		
Poor	62%		
	Technical Reading (25 points)		
	Full Credit	Partial Credit	No Credit
Explanations	Clearly explained strong connections between the Fire Triangle and how the fire extinguisher works.	Made weak connections between fire extinguisher 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.	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.

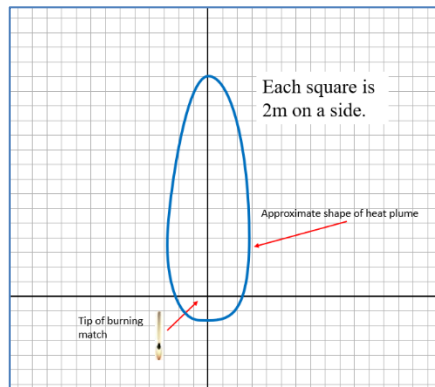


Before beginning, read all of these directions together.

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. 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. Sketch should look something like this.



5. Underneath your sketch, answer these questions using complete sentences:
- 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 what is shown above. This graph shows that heat could be felt from 30 cm above, 4-5 cm from the sides, and only 3 cm from below.
 - 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.

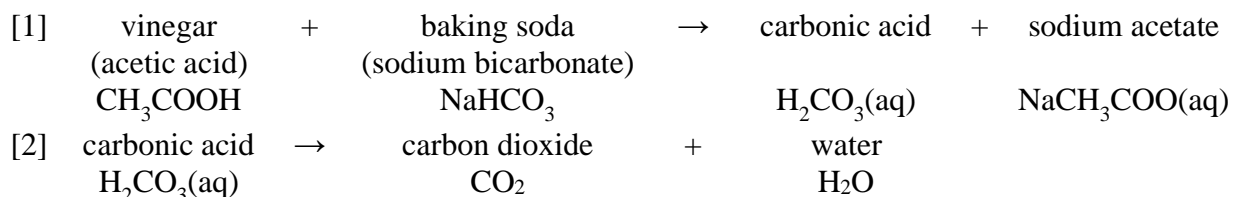
Handout H02-3. Experiment 3. Prove that fire requires oxygen.

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.



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. Use 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 CO₂ 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 CO₂ layer.
 - Place a candle inside a container. Spoon 10-20 cm³ 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 CO₂ layer.
 - Place a candle on the metal tray. Make CO₂ in a container. After the froth settles a bit, pour the CO₂ from the container over the candle – without pouring out any of the liquid that has formed at the bottom of the container. (This feels a little bit like pantomime, since the CO₂ is invisible.) The CO₂ 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 CO₂ will pour out.
 - The flame can get long (and hot) on the long fireplace match. Don't hesitate to blow out the match and try again. You 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 CO₂ and O₂ and the Fire Triangle to explain how your demonstration proves that fire requires oxygen.

After the chemical reaction is complete, the container contains CO₂ rather than O₂. The CO₂ stays on the bottom of the container because it is heavier than O₂, as we can see from this calculation of the molecular weights of the two compounds:

<u>Element</u>	<u>Atomic weight</u>
Carbon (C)	12 g
Oxygen (O)	16 g

A mole of CO₂ weighs $12\text{ g} + 2 * 16\text{ g} = 44\text{ g}$

A mole of O₂ weighs $2 * 16\text{ g} = 32\text{ g}$

Fires cannot burn in this oxygen-deprived environment.

Handout H02-4: Three Kinds of Fire Extinguishers

Read your assigned section. 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. The information below is taken from https://www.osha.gov/SLTC/etools/evacuation/portable_about.html.

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.
B: CO₂ 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.
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.

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. The water may also block the fuel surface from its contact with oxygen. For more details see step 3 in “Procedure” above.
B: CO₂ 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, which separates 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 global carbon cycle.

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

Duration: one 90 minute session

Group size: Whole class/groups.

Setting: Classroom

Vocabulary: *atom, carbon, carbon cycle, carbon dioxide, carbon sink, carbon source, cellular respiration, chemical equation, photosynthesis*



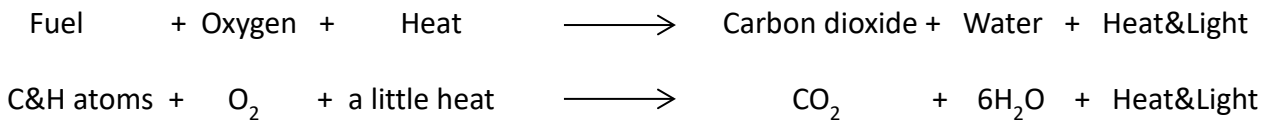
Objectives:

- 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.

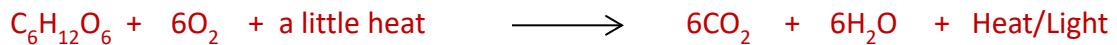
Standards:		9 th	10 th	11 th	12 th
CCSS	Writing	2, 4, 10		2, 4, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 7, 10		1, 2, 3, 4, 7, 10	
	Science/Technical Subjects	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	Matter and Its Interactions	PS1.A, PS1.B			
	Energy	PS3.D			
	Earth's Systems	ESS2.D			
EEEEGL	Strand 1	A,C,D,E,F,G			
	Strand 2.1	A			

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:



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:



The same equation represents cellular respiration, the process by which cells convert sugar into the energy that keeps living things – including us – alive. How can cells do this without burning up? They have enzymes! These are catalysts that make sure the energy in carbohydrates is released in multiple tiny steps. At each step, a little energy from the bonds in the carbohydrate molecule is captured in special energy-storage molecules, such as adenosine triphosphate (ATP).

Because the equation for combustion and cellular respiration is the *reverse* of the chemical formula for photosynthesis...



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

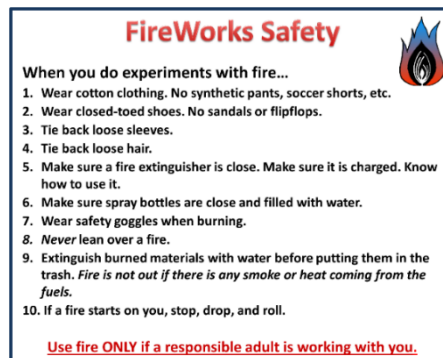
For additional information, see William Cottrell's *The Book of Fire* (2004, available from <http://mountain-press.com/>). This is a well-illustrated, easy-to-read description of the physical science of combustion and wildland fire.

Materials and preparation:

Read the technical reading assignment “Sink or Source: Fire and the Forest Carbon Cycle” – either the full article (online at www.firescience.gov/projects/briefs/03-1-1-06_FSBrief86.pdf) or the 1-page excerpt/adaptation on **Handout 03-2**. Decide which version to have students use.

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

- Display the FireWorks Safety poster (*FireWorks_Safety_poster.pptx* in Activity H02)
- 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 and know how to use it
- 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.

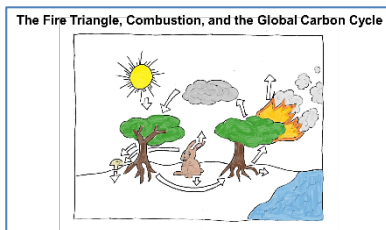


Setup for water-drop demonstration. Hot plate is heat source on the left; lighted candle is heat source on the right.

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

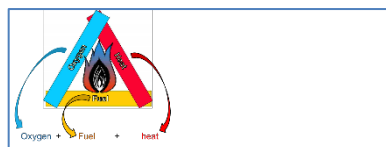
1. Go through *H03_FireTriangle_CarbonCycle_Connection.pptx*, Slides 1-5:

Slide 1



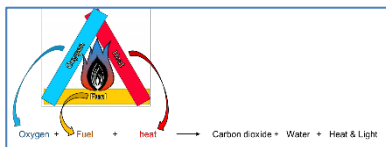
Explain: We've been studying the Fire Triangle and the process of combustion. Let's explore combustion a little more deeply and then fit it in with the basic life processes on Earth, as described in the Global Carbon Cycle.

Slide 2



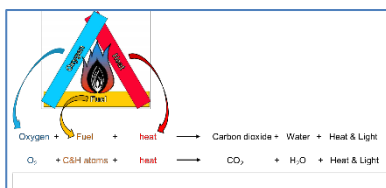
We'll start with the Fire Triangle: oxygen, fuel, and heat. If you break it apart and line up the "ingredients," you have an arithmetic expression for what makes fires "go" – what makes combustion happen.

Slide 3



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

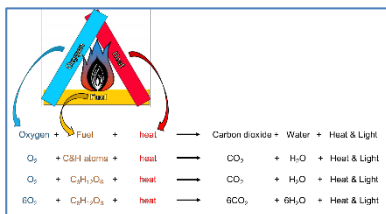
Slide 4



We can use chemical symbols for both the ingredients and the products of combustion. However, 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 use 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 each product. ~~~~~ **Part 1 of the lesson ends here. Part 2 is a lab investigation.**

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 cups (actually post-caps, in which you froze some ice yesterday) 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 the chemical reaction of 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 cup, where it should cool rapidly 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 cup, so this cup should remain dry.**
6. Place a cup (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 cup 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 cup over the hot plate will be dry. The bottom of the cup over flame will be covered with water droplets, and a large drop may collect right above the flame.**



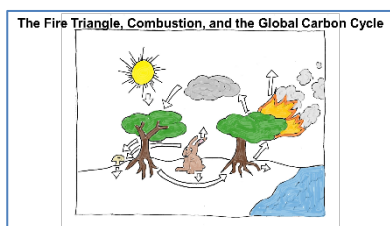
Results of water-drop demonstration. No water is visible on the electrically-heated post cap; water droplets have condensed on the combustion-heated post cap.

9. **Discuss:** What differences did you observe? What caused the differences? Were any of our hypotheses verified? **The bottom of the cup over the hot plate is dry because the heat source is not producing water vapor. The bottom of the cup over the candle is moist because water produced by combustion is condensing on the cold surface of the cup.**
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 (remainder of)

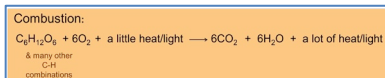
11. Return to **H03_FireTriangle_CarbonCycle_Connection.pptx** at slide 6, and finish the presentation. Use the final slide to introduce the assessment:

Slide 6



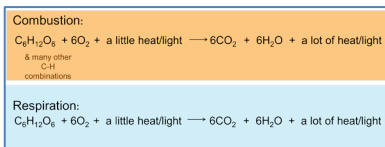
Procedure Part 3. Now let's see how the process of combustion fits into the life processes on Planet Earth.

Slide 7



Here's our model of combustion.

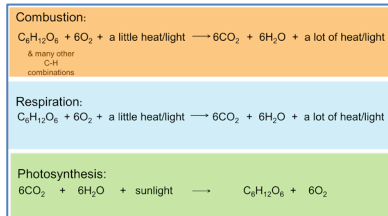
Slide 8



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? Discuss or explain: **Fire isn't the only process that takes**

energy from carbohydrates and releases CO₂ and water into the air. *Respiration* is just a fancy word for breathing; breathing is how we get oxygen to our cells so they can produce energy, a process called *cellular respiration*. Almost EVERY living thing uses cellular respiration to get energy from carbohydrates – animals, plants, algae... even the tiniest microorganisms use cellular respiration. But if plants and animals just kept on doing respiration, all the carbohydrates and oxygen on earth would be converted to CO₂. We wouldn't last very long. **Ask:** How do carbohydrates and oxygen get replenished—how do we reverse the process?

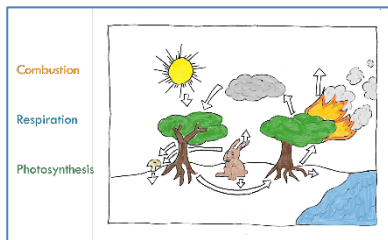
Slide 9



Discuss or explain: Lucky for us, plants are able to reverse the processes of combustion and respiration by grabbing the energy from sunlight and storing it in the high-energy bonds of carbohydrates. This is *photosynthesis*. The chemical equation for photosynthesis is the mirror

image of the equation for combustion of glucose and respiration. So all living things – especially animals - ensure that there is abundant CO₂ 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

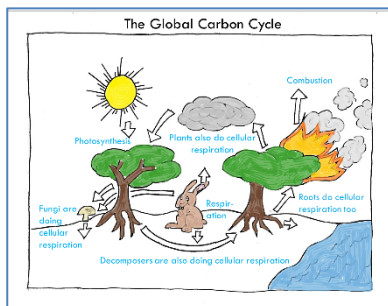


Ask: Where are combustion, respiration, and photosynthesis occurring in the image?

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. **Discuss/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:** Where in this diagram are forests storing carbon? **Forests are**

storing carbon wherever photosynthesis is occurring – in the diagram, that is ONLY the arrow that goes from the sun to the tree. Storage reservoirs of carbon are

called *carbon sinks*. Where are forests releasing carbon? **Forests are releasing carbon everywhere else in the diagram.** These locations are called *carbon sources*. Overall, do forests function as *carbon sources* or *carbon sinks*?

Slide
12



Explain: Your assignment is to read this article (or the excerpt/adaptation on **Handout H03-2**) so you can answer that question. Let's review terms so we'll "get" what the article is saying: When carbon accumulates and is being stored for an indefinite period, it is considered to be a **carbon sink**. When carbon is being released to the atmosphere, it is

called a **carbon source**.

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 excerpt/adaptation on **Handout H03-2**.

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

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 “Sink or Source: Fire and the Forest Carbon Cycle” (or excerpts on **Handout H03-2**). 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: Excerpted/adapted from “Sink or Source: Fire and the Forest Carbon Cycle”*



Forests have a life cycle. In that cycle, trees die after disturbance, such as stand-replacing fire, and their death sets the stage for new growth to begin. If a forest has completely replaces itself after a fire, there is no net carbon change. The fire itself consumed only about 10 to 20 percent of the carbon and immediately emitted it back into the atmosphere. But the fire killed some trees without consuming them. Then new trees began to grow (storing carbon), dead trees decompose (emitting carbon), and the organic layer of the soil accumulates (storing carbon) and also begins to decay (emitting carbon). The balance between simultaneous production and decomposition of carbon at any given time determines whether the forest is a carbon 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. That’s the “magic number,” so to speak, that tells us whether a forest is a carbon source (negative NEP) or sink (positive NEP) at any given 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.

During 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. But that is a short-term measure. The strongest effect of fire on carbon cycling 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 after fire can release up to three times as much carbon as that lost in the initial combustion. 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 gradually “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 over the first century after stand-replacing fire, the landscape first becomes a carbon source and then becomes 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 with slow regeneration and stands that replace biomass quickly. The take-home message is that the replacement of biomass for a given stand over multiple fire intervals determines 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 “Sink or Source: Fire and the Forest Carbon Cycle” (or excerpts on **Handout H03-2**). 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 a few decades. Then – if trees regenerate successfully - the forest gradually changes back into a carbon sink after about a century. A lot of carbon is released during a severe wildfire, and then even more carbon is released through the 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 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

Vocabulary: *heat transfer, radiation, convection, conduction*

Standards:		9th	10th	11th	12th
Common Core ELA	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 7, 10		1, 2, 3, 4, 7, 10	
NGSS	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.B			
EEEEGL	Strand 1	A,C,D,E,F,G			

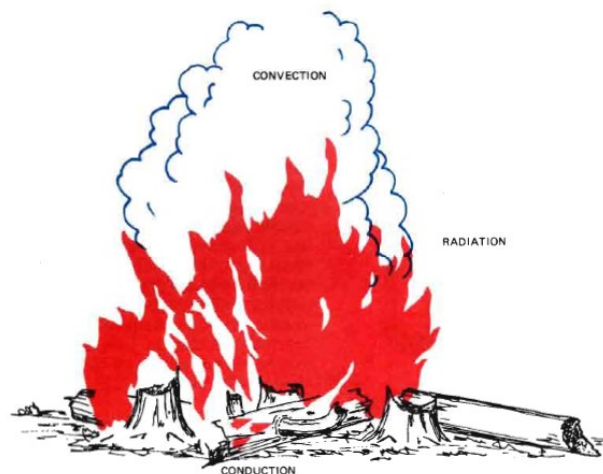
Teacher Background: This lesson is a review of the mechanisms of heat transfer. See the "Procedure" section.

Materials and Preparation:

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

Procedure:

1. Project *Heat Transfer image.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.
2. Ask the class to point out the strengths and weaknesses of the models. Maybe have students vote on the model that most clearly represents each method of heat transfer.

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: This is a credit/no credit activity. Evaluate students on their contributions during the planning process, engagement in the presentations, and follow-up discussion.



Unit III.
The Wildland Fire Environment



5. Fuel Properties

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

Lesson Goal: Increase students' understanding of how fuel properties affect burning and how to design experiments.

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.


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

Duration: 90 minutes

Group size: Whole class

Setting: Indoors

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



Standards:		9th	10th	11th	12th
CCSS	Reading Informational Texts	1, 2, 4, 7, 10		1, 2, 4, 7, 10	
	Language	1, 2, 3, 4, 6		1, 2, 3, 4, 6	
	Reading Standards Science/Tech	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.A, ESS3. B			
EEEGL	Strand 1	A,C,D,E,F,G			

Teacher Background: See **Handout H05-1** "Fuel Properties: Pre-Lab Reading and Scavenger Hunt".

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. **Handout H05-1** contains instructions for both. The reading can be done as homework. The outdoor activity can be done as homework or as a mini-field trip.

Handout H05-2 contains instructions for the lab. It is presented here as a highly structured activity. However, you could easily do it in an unstructured, inquiry-based way, as follows:

- Through discussion, make sure students understand the principles of experimental design AND the fuel properties to be investigated (fuel size and shape, moisture content, quantity, and spatial arrangement).
- Distribute materials and supplies.
- Have students plan their experiments.
- Check/approve their plans.
- Have them complete the experiments.
- Discuss the whole process, including methods, results, and conclusions.

Student needs:

- **Handout H05-1: Fuel Properties: Pre-Lab Reading and Scavenger Hunt**, one for each student. Students should complete this 4-page handout before doing their experiments.
- **Handout H05-2: Fuel properties**, one for each team, to be completed in the 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 4-page handout requires students to read and also to go outside, find examples of different kinds of fuels, and collect or sketch them. 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/discuss questions about it. Ask for examples of fuels with contrasting properties (size and shape, moisture content, amount, and spatial arrangement)?

3. Distribute a copy of **Handout H05-2: Fuel Properties** to each student. Explain: Let's distinguish between an **experiment** (investigating a variable) and a **treatment** (the way that variable is altered within an experiment). You will do 4 experiments; each experiment will investigate 1 variable by doing 2 treatments.
4. Together, examine the data table on the second page. Explain: This table shows the measurements you need to make. The final column is important because it asks you to interpret your data – that is, what you have learned from your observations. If your results surprise you – if they are not what you expect – that's fine. Record your conclusions about them anyway. You can also note how they surprised you and why you think that happened.
5. Stress the following:
 - Within each **experiment**, keep all **variables** constant except the one you're investigating. For example, your method of ignition should always be the same. Don't use colored newspaper for one treatment and black-and-white for the other.
 - Plan your measurement methods before igniting a treatment. For example, who is going to time the burn? Who is going to measure flame height? Will you measure maximum flame height or typical or average? If the ruler is meltable or burnable, how can you avoid wrecking it?
6. Have students get into groups and complete the experiments on **Handout 05-2: Fuel Properties**.
7. In class, discuss students' results and conclusions from each experiment.

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 most 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: Use any or all of the evaluation methods below. Evaluation of **Handout H05-1** will be based on individual student performance, while evaluation of **Handout H05-2** and the campfire will be based on team efforts and thus could be more difficult to parse out for individual students.

	Full Credit	Partial Credit	No Credit
Handout H05-1. Fuel Properties (reading & Scavenger Hunt)	All collections and sketches complete	Collections and sketches 75% complete	Collections and sketches less than 50% complete
Handout H05-2 (fuel properties)	All experiments completed. Interpretation of results consistent with data.	All experiments completed. Interpretation of results inconsistent with data.	Experiments not completed or interpretation of results missing.
Assessment campfire	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 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. Include a measurement or an object to show how big the fuel actually is:



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. Moisture may also make them fuels incompletely, producing a lot of smoke.

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 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 spacing of fuel particles – close together or far apart.

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 spot 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).

Handout H05-2: Fuel Properties

Name _____

Investigate the effects of these fuel properties - particle size, moisture, loading, and spatial arrangement - on the behavior of a fire burning in newspaper fuel.

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

For each experiment, ignite the fuels in one pie tin at a time and record your 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 what you’ll measure and how you’ll measure it before igniting a treatment.

Keep all variables constant except the one you’re investigating. Examples: Use the same method of ignition for every treatment. Don’t use colored newspaper for one treatment and black-and-white for another.

Experiment 1 - particle size. Manipulate 1 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 1 sheet of newspaper so one pie tin contains moist newspaper and one pie tin contains dry newspaper.

Experiment 3 - loading. Manipulate 1 or more sheets of newspaper so one pie tin contains more newspaper and one pie tin contains less.

Experiment 4 – spatial arrangement. Manipulate 1 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)	What do you conclude about this variable's influence on fire? <u>Base your conclusions on your observations and data.</u>
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 or demonstrations.

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

Objectives:

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

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


Duration: 40 minutes

Group size: Whole class

Setting: Indoors

Vocabulary: *cellulose, pyrolysis*

*Fire activity is optional



Standards:		9th	10th	11th	12th
CCSS	Writing	2, 4, 10		2, 4, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 6		1, 2, 3, 4, 6	
	Writing Standards Science/Tech	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	Matter and Its Interactions	PS1.B			
	Energy	PS3.D			
EEEEGL	Strand 1	A, B, C, E, F, G			

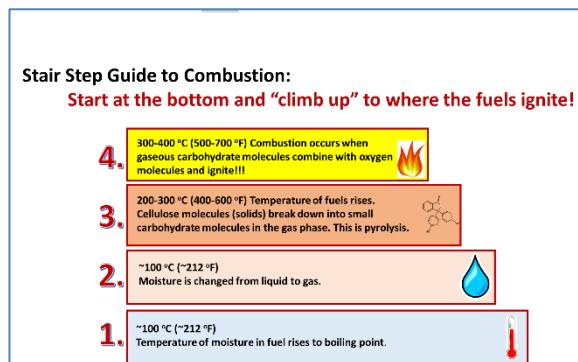
Teacher Background: In order for wildland fuels to burn, several things have to occur:

1. The temperature of the fuels and any moisture in the fuels must rise to the boiling point of water (~100° C (212° F))
2. The moisture must change from liquid phase to gas phase (stays at 100° C (212° F))
3. The temperature of fuels must rise to the point where carbohydrates pyrolyze—that is, break down into small gaseous molecules (200°-300° C (400°-600° F))
4. The small, gaseous carbohydrate molecules must combine with oxygen. This is combustion!


See ***StairstepGuideToCombustion.pptx*** for a diagram of this process. View videos of pyrolysis online for further explanation. There are many. Two are suggested in Step 3 below.

Materials and Preparation:

- Make sure you can play the video referred to in Step 1 and the Assessment:
<https://www.frames.gov/documents/fireworks/videos/Pyrolysis.mp4>.
- Decide whether to have students try this demonstration in the lab. If you do, set up the materials needed.
- Download ***StairStepGuideToCombustion.pptx***.
- Decide whether to use an online video of pyrolysis in Step 3 or do a similar demonstration in class.



Procedure:

1. Show this 33-second video of a candle being lighted:
<https://www.frames.gov/documents/fireworks/videos/Pyrolysis.mp4>. If possible, set up a lab so students can try this themselves. Ask students to describe what they see. You may need to show the video several times for them to pick up on it. **When the candle is lighted for the second time, the match does not come in contact with the wick.**
- 
2. Ask how this can happen. **Discussion. Perhaps no one can explain it. That's OK.** Explain: You will get some explanation from the next video (or demonstration).
 3. EITHER watch a video demonstration of pyrolysis (2 possibilities are listed below) or do a demonstration like one of these for the class:
 - <https://www.youtube.com/watch?v=XEbnWfCtxSE> (1:41 min), in which a structural firefighter shows pyrolysis of wood chips in an Erlenmeyer flask
 - https://www.youtube.com/watch?v=Rpm_L6WiYtw (4:17 min), in which a scientist shows 2-3 forms of ignition, emphasizing the need for fuels to be in the gas phase (pyrolyzed) in order to combust
 4. Review the video/demonstration by asking: When you light something on fire, what exactly is burning? What is making the flames? **The burning material is actually a cloud of tiny carbohydrate molecules in the gaseous phase, which were produced when heat broke apart the big carbohydrate particles in the fuel. Flaming combustion occurs only when the fuel has been pyrolyzed into gaseous molecules.**
 5. OPTIONAL: Review from study of the Fire Triangle: **Wood is the main fuel in forest fires. It is composed mainly of cellulose, which consists of long chains of glucose molecules. Glucose**

(C₆H₁₂O₆) is the molecule that we used in the chemical equation for combustion in **Activity H03**.

6. Project **StairStepGuideToCombustion.pptx**. Let's watch the second video/demonstration (https://www.youtube.com/watch?v=Rpm_L6WiYtw) again and use the stair step guide to explain what is happening.
- When you first observe a white fog in the container, what are you seeing? **Water is being driven off from the fuel (Steps 1-2 of the stair step diagram). We're seeing some of it, condensed into fog, as it leaves the hot wood. As the fuels get hotter, the cloudy substances in the container become more yellowish. These are fuel particles that have been partly broken down by pyrolysis (Step 3 in the stair step diagram).**
 - When a flame is held at the top of the fuel container, it ignites whatever gases are at the top but does not easily ignite what's inside. Why is that? **The container is filled with pyrolyzed fuels in the gas phase. They are crowding the oxygen out of the container, and they can't ignite without oxygen. That happens only at the top of the container, where oxygen is available (Step 4 in the stair step diagram).**

Assessment: Show the video from Step 1 (<https://www.frames.gov/documents/fireworks/videos/Pyrolysis.mp4>) again. Have students answer this question orally or in writing:

When the candle is lit for the second time, what material is burning in the flame?

The material burning in the flame is a cloud of gaseous carbohydrate molecules that have been broken apart from - pyrolyzed from - large fuel particles. When the candle was first lighted, the fire produced these flammable gases. However, they had not all burned up before the flame went out. (It went out because pyrolyzed gases had filled the cup and crowded the oxygen out.) The flammable gases were trapped under the cup, so they were still present when the second match reached them and ignited them. Combustion of these gases then re-ignited the wax beneath, in the candle wick.

Evaluation:

Fully successful	Moderately successful	Not successful
-Student explained that pyrolyzed fuels from the first ignition remained and were ignited before the wick ignited.	-Student's explanation referred to pyrolysis but was incomplete or only partly correct.	-Student did not refer to either pyrolysis or interpreted it incorrectly.



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 research currently underway at the Missoula Fire Sciences Laboratory (<https://firelab.org/>).

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

Duration: 40 minutes

Group size: Whole class

Setting: Indoors classroom

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

Objectives: Students can use their understanding of radiation, convection, and conduction to explain how wildland fuels of different sizes and shapes are heated to ignition.

Standards:		9th	10th	11th	12th
CCSS	Writing	2, 4, 10		2, 4, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 6		1, 2, 3, 4, 6	
	Writing Standards Science/Tech	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	Matter and Its Interactions	PS1.B			
	Energy	PS3.D			
	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.B			
EEEEGL	Strand 1	A, B, C, 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 the physics of basic fire spread processes. It was assumed that rate of spread was controlled by radiant heating, although this assumption was not tested experimentally at the time. The resulting fire spread models, which fire managers still use to predict the spread of wildland fires and for many other purposes, are based on the assumption that radiation drives fire spread.

Recent observations on wildland fires and on highly controlled laboratory fires, including many experiments conducted by Dr. Sara McAllister, Dr. Jack Cohen, and Dr. Mark Finney 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 fires burn 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.

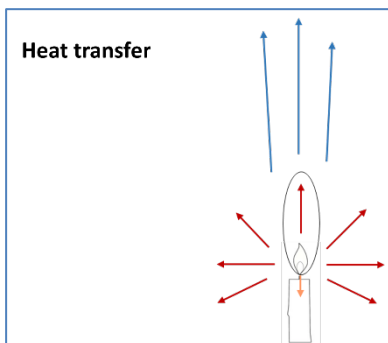
Materials and Preparation:

- Download **H07_HeatTransferAndFuelProperties.pptx**. Check that the video segments work.
- Make 1 copy of **Handout H07-1** per student.

Procedure:

1. Explain: From our lab experiments, we already know a lot about how wildland fuels burn, but recent research has shown some surprising things. We're going to build on what we know so we can understand what's going on in current research.
2. Go through the presentation **H07_HeatTransferAndFuelProperties.pptx**:

Slide
1



Let's start with a review of the **HEAT** and **FUEL** parts of the Fire Environment Triangle. The diagram shows 3 methods of transferring heat. What are they? **Blue: convection. Orange: conduction. Maroon: radiation.**

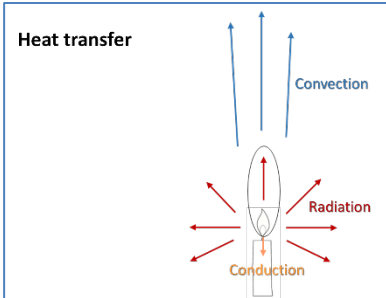
Describe them:

Convection: Heat is transferred when hot gases (or liquids) expand and move from a hot area into a cooler area. 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.

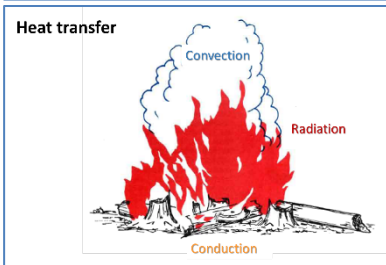
Radiation: Heat is transferred through space. Heat from a fire travels as waves or particles through the space between air molecules and heats the first molecules it touches – gas molecules in the air, water, or solids.

Conduction: Heat is transferred through direct contact between atoms or molecules within solid objects and liquids.

Slide
2



Slide
3



Describe how each of the heat transfer methods is working in this diagram of fire in wildland fuels.

Convection: The hot gases coming off the burning fuels (water vapor, carbon dioxide, and partly-burned carbohydrates) are much hotter than the surrounding air. They'll expand and rise (unless driven sideways by

wind), gradually losing thermal energy, until they reach an altitude where the surrounding air is the same temperature.

Radiation: Heat and light from the fire travel through space until they contact a molecule – any molecule, whether in the air or in moisture or in fuel particles. The radiant energy helps drive off moisture in fuels and heats them up so they will ignite more easily. Once a fuel particle is heated, it also transfers radiant heat into its cooler surroundings.

Conduction: Heat is transferred from burning wood into the interior of logs. Heat is transferred from burning materials on the ground down into the duff and soil. This process drives off moisture and heats the fuels so they will ignite more easily when they are exposed to oxygen.

Slide
4




Fuels: What are some examples of fine fuels and coarse fuels in wildlands? **Fine fuels** include grass, dead leaves, pine needles, and dead twigs. **Coarse fuels** include logs, stumps, thick branches.

Which kind of fuel has the greater ratio of surface area to volume, and how does that affect their response to heat and fire? **Fine fuels** have a lot of surface area in relation to their volume, so the whole particle heats quickly and has good exposure to oxygen; these fuels generally ignite easily. They also lose heat easily if they are not ignited by the time the heat source is removed. **Coarse Fuels** have a small surface area in relation to their volume, so heat penetrates slowly and oxygen is only available to the outer surface; they are generally harder to ignite than fine fuels. Once on fire, however, coarse fuels are likely to burn for a long time. Large logs, for example, can burn for hours: The outer surface gradually burns away, exposing the pre-heated wood beneath it to oxygen.

Slide
5

The models that land managers and IC teams use to predict fire behavior are based on radiant heating.




Scientists at the USDA Forest Service's Missoula Fire Sciences Lab want to improve the models.

Ask: Do you think radiant heating is the only – or most important – kind of heat transfer in wildland fires? From your experiments, have you seen any influence from convection and conduction? **Discussion. Students are likely to identify the importance of convection from their campfire-building experience. It may be more difficult to describe the importance of conduction.**

Slide
6

The scientists investigated the importance of convection. Here is one of their experiments:



Fine fuel (excelsior)
600°C air,
ignited in 1 second

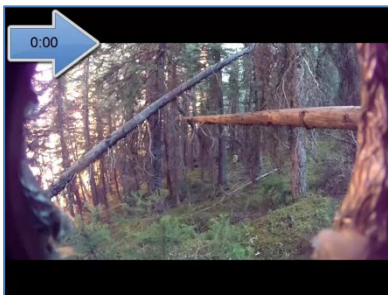
Coarse fuel (square stick, 6mm)
600°C air,
ignited in 17 seconds

The scientists put fine and coarse fuel particles at the same distance above a cylinder containing a hot air torch and timed how long it took to ignite the fuels. A hot air torch works like a very powerful hair dryer. Ask: How did they avoid having radiation and conduction influence their results? **There is no hot surface or light**

beneath the fuels to produce radiation. The fuels are not touching any hot surfaces that could conduct heat into them.

Explain: According to this diagram, the fine fuels ignited at 1 second, while the coarse stick ignited in 17 seconds. Ask: Does this result agree with what you would expect, based on your knowledge and experiments? **Discussion. Yes, it probably does.**

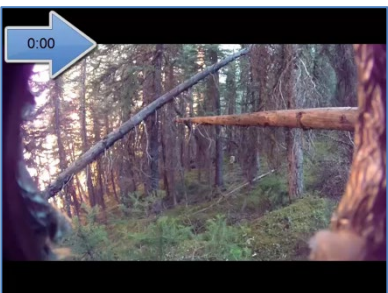
Slide
7



Look at this photo with students. It is the opening frame of a video, but **DON'T PLAY THE VIDEO RIGHT AWAY**. Explain/ask: This image shows a crown fire burning through a forest, moving from left to right. Which fuels do you expect to ignite first as the fire comes into the foreground? **Discussion. Most likely, students will say that the fine fuels, especially the seedlings in the foreground, will ignite first.**

NOW PLAY THE VIDEO. Ask: What do you observe? Does this fire behavior meet our expectations about what fuels would ignite first? **Discussion. Don't require an answer yet; show the next slide, which is the same video at half-speed.**

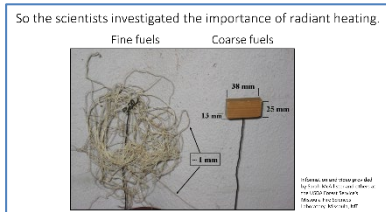
Slide
8



Explain: This is the same video played at half speed. What do you observe? **A lot of smoke is produced in surface fuels and in the big horizontal log before they ignite; that is probably moisture and pyrolyzed material being driven off. The big log is ignited quite a while before the seedling trees and other fine fuels in the foreground.**

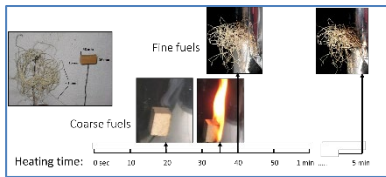
Ask: Are you surprised? Is this fire behavior consistent with what we've learned and what we've observed in the lab - that fine fuels always ignite most easily and convection always drives ignition? **Discuss.** Explain: *Even if you weren't surprised or puzzled, the scientists at the Fire Lab were puzzled with this observation!*

Slide 9



These are the materials used to test radiant heating and ignition of fine and coarse fuels. (FYI: 37 kW/m^2 irradiance was used in these experiments. This is roughly equivalent to 37 times the strength of the sun at sea level.)

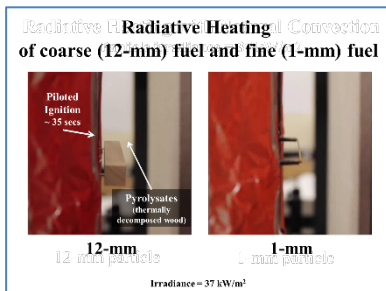
Slide 10



They 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. Go through the axis and units of measure. Ask students to interpret the results: The coarse wood block began to pyrolyze 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 when subjected to radiant heat.

Slide 11

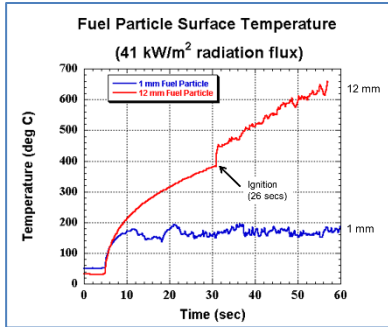


Here is another Fire Lab demonstration showing that coarse fuel can ignite more quickly than fine fuel. The fuel on the left is a small wooden block. The fuel on the right is a thin piece of wood. The radiant heat source is on the right in both photos. Ask: How does this experimental setup prevent convection and conduction from influencing the results? **Convective heat rising from the hot surface on the right will rise so it won't**

horizontally cross the gap to the fuels. There is no solid contact between the heater and the fuels, so conduction cannot occur.

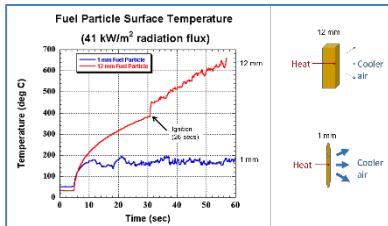
Show both of the videos. Ask: What did you observe? **The coarse wood block began to pyrolyze at about 10 seconds. The fine wood particle did not pyrolyze at all and therefore could not get hot enough to produce flammable gases that would ignite.**

Slide 12



Here are data from their experiment. Examine the axes and labels. Ask students to interpret the results: **The temperature of the coarse fuel (in red) rose quickly, and the particle was ignited at about 400 degrees C. The temperature of the fine fuel (in blue) did not rise above 200 C, the minimum temperature for pyrolysis, so combustion could not occur.**

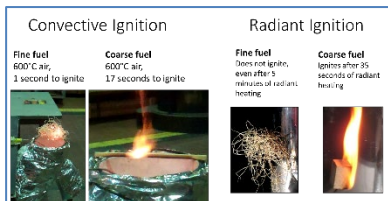
Slide 13



Why doesn't the fine fuel particle heat up as quickly as the coarse fuel? **Discuss.** Here is the answer from the Fire Lab scientists: **The sides of the fuel particles that face the heat source heat up in both fine and coarse fuels; that is, heat is being transferred from the heat source to the fuel particles. Then the heat is being conducted through the particles. 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.**

Explain: Another reason – not included in these results - is that air flows around the two particles differently because of their different sizes. Heat is lost more efficiently from around the fine particle.

Slide 14



Ask students to summarize the conclusions from the 2 sets of experiments: **Convection heats fine fuels more efficiently than coarse fuels, and radiation heats coarse fuels more efficiently than fine fuels.**

Why does this matter? **Discussion.**

Slide 15

Why does it matter?

- Managers use fire behavior models for many things – for example, to manage wildfires, to plan prescribed fires, to improve wildlife habitat, and to provide for public safety.
- Current models are based only on the physics of radiant heating.
- Recent experiments show **HOW** radiant heating influences fire spread.
- They also show **how** convection influences fire spread.
- Scientists are also investigating the importance of conduction in fire spread.
- New models are being developed to use all of this new understanding.

Photos and videos of laboratory experiments courtesy of Dr. Sara Muckelbauer and other scientists at the Missoula Fire Sciences Laboratory, USDA Forest Service, Rocky Mountain Research Station.

Here is how the Fire Lab scientists answer that question.

Assessment: Have students complete [Handout H07-1](#).

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

Handout H07-1: Heat transfer and fuel properties

Name _____

1. This diagram shows a common way to build and ignite a campfire. (Imagine that there are lots more fine and coarse fuels in it.) Use the diagram to answer the following questions.



- a. All 3 kinds of heat transfer are occurring. What kind is likely to start the fire, and which kind of fuel is likely to start on fire first?
- b. Where does the heat from convection go in this campfire? How does it help the fire continue to burn?
- c. Where does the heat from conduction go in this campfire? How does it help the fire continue to burn?
- d. Where does the heat from radiation go in this campfire? How does it help the fire continue to burn?
- e. What would happen to the fire if you knocked the tipi over and scattered the coarse fuels around your fire ring? Use the methods of heat transfer to explain.

Handout H07-1 KEY: Heat transfer and fuel properties

1. This diagram shows a common way to build and ignite a campfire. (Imagine that there are lots more fine and coarse fuels in it.) Use the diagram to answer the following questions.



- a. Which method of heat transfer has the greatest influence on STARTING the fire, and which kind of fuel is likely to be ignited first? **Convection rising from the match into the fine fuels is the strongest influence on starting the fire, and fine fuels will be ignited first.**
- b. Once the campfire has started, where does the heat from convection go? How does it help the fire continue to burn? **Most of the heat from convection goes up, driving off moisture from the fuels above and heating them up.**
- c. Where does the heat from conduction go? How does it help the fire continue to burn? **The heat from conduction goes into the ground, heats the interior of fuel particles, and transfers heat from one fuel particle to another wherever they touch.**
- d. Where does the heat from radiation go? How does it help the fire continue to burn? **The heat from radiation goes in through space in any direction, until it is intercepted by a molecule. That means it is heating the air, the surface of the ground under the fire, and the surface of all fuel particles that lie between it and the open air. Anything that is heated up (by convection, conduction, or radiation) then radiates heat from its own surface. Lots of radiant heat is thus trapped inside the tipi structure, drying the fuels and heating them up.**

Use the methods of heat transfer to explain what would happen to the fire if you knocked the tipi over and scattered the coarse fuels around the fire ring. **The fine fuels would probably burn quickly and almost completely. The coarse fuels would burn slowly and would most likely go out before burning completely. Why? There is no convective heat from beneath, no radiant heat from materials burning nearby, and no conductive heat from adjacent fuels to keep the coarse fuels at ignition temperature. All of the radiant heat that was trapped by the tipi is now escaping into the open air.**



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) affects fire spread.

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.



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

Duration: 45-90 minutes

Group size: lab groups

Setting: Indoor laboratory or outdoors

Vocabulary: *controlled experiment, Fire Environment Triangle, slope, stand/forest stand/standing fuels, stand density, trial, treatment*

Standards:		9th	10th	11th	12th
CCSS	Writing	2, 4, 6, 7, 10		2, 4, 6, 7, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 6		1, 2, 3, 4, 6	
	Writing Standards Science/Tech	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.A, ESS3.B, ESS3.C, ETS1.B			
EEGL	Strand 1	A, B, C, 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 models provide 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 these experiments can reach 30-40 cm in height. Plan accordingly. If you choose to do the experiment outdoors, keep in mind that 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 their matchstick models 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; in all of these fuels, 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, and air movement outdoors will affect them even more.

- The day before the activity, remind students to follow safety guidelines about clothing and hair when they get ready for school tomorrow. Use the ***FireWorks_Safety_poster.pptx*** in **Activity H02**.
- Get four boxes of wooden kitchen matches (not provided in the trunk).

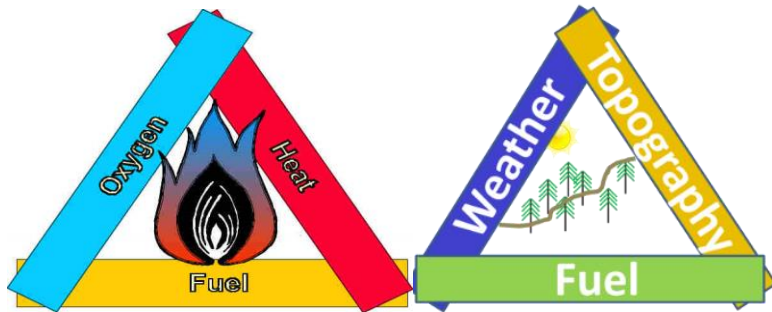
FireWorks Safety 

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.

- Display the Fire Triangle poster (left) and Fire Environment Triangle poster (right) (*FireTrianglePoster.pptx* and *FireEnvironmentTrianglePoster.pptx*).



- Make 1 copy/student or lab group of **Handout H08a-1**.
- 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 team¹, 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:

INTRODUCTION.

1. Do a **safety checkup** with students using the FireWorks Safety poster (*FireWorks_Safety_poster.pptx* in **Activity H02**).
2. Refer to the posters for the Fire Triangle and the Fire Environment Triangle (*FireTrianglePoster.pptx* and *FireEnvironmentTrianglePoster.pptx*) - or draw/ 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**.

¹ The trunk is supplied with 4 sets of equipment.

3. Explain: You will design and carry out controlled experiments to learn about the relationships between fire spread and specific 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 aspect of the Fire Environment Triangle, 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 or team a copy of **Handout H08a-1**.

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 snow (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).
 - **Trial**- an individual “run” of the experiment,
 - **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 examine relationships between parts 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 from all of the experiments.
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** for their experimental design before proceeding. 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 while keeping all others constant.** If they don't, they won't be able to attribute their results to the experimental variable alone.
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 (Step 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.	Reports experimental results but does not interpret appropriately.	Does not address hypothesis or interpret experimental results appropriately.
4	Answer is clear and refers to Question 1.	Answer refers to Question 1.	Answer is unclear or 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 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 unclear.	Student answered 1 question or none.

Handout H08A-1.

Name(s): _____

INSTRUCTIONS:

- Develop your experimental plan (this page).
- Get the teacher's approval to proceed (bottom of this page).
- Carry out your 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 we will observe and measure – which will be 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 your 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 example of the 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 (or duration – using a stopwatch), number of match tips burned.

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				
Duration (sec)				
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 your 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 model 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: <https://www.nfpa.org/Public-Education/By-topic/Wildfire/Preparing-homes-for-wildfire>)).

(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 model tree crowns are much easier to ignite than actual tree crowns. Trees are distributed uniformly in the model, unlike in real forests. The topography is completely uniform – no gullies or ridges. Trees tilt with the slope. The board is very small, 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 revise 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: In this activity, students design a model landscape to investigate the relationships among fuels, topography, weather, and fire spread.

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

Objectives:

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



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

Duration: 2 class periods

Group size: Pairs

Setting: Indoor laboratory or outdoors

Vocabulary: *density/stand density, Fire Environment Triangle, slope, stand/forest stand/standing fuels, topography, wildland-urban interface*

Standards:		9th	10th	11th	12th
CCSS	Writing	2, 4, 6, 7, 10		2, 4, 6, 7, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 6		1, 2, 3, 4, 6	
	Writing Standards Science/Tech	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.A, ESS3.B, ESS3.C, ETS1.B			
EEEEGL	Strand 1	A, B, C, E, F, G			

Teacher Background: This activity has similar goals and objectives as the previous lesson, **H08A** but 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/or other fuels. Then they observe fire spread, record their observations, and use them to create (a) a timeline for the fire and (b) a news article about the fire.

This activity includes 3-4 steps:

1. Students complete a 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 news article about the fire that incorporates their timeline and explains how various aspects of the Fire Environment Triangle influenced fire spread.


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

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.

- 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 (*FireWorks_Safety_poster.pptx* from **Activity H02**), Fire Triangle (*FireTrianglePoster.pdf* from **Activity H08A**), and Fire Environment Triangle (*FireEnvironmentTrianglePoster.pdf* from **Activity H08A**)
- 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 team¹, 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

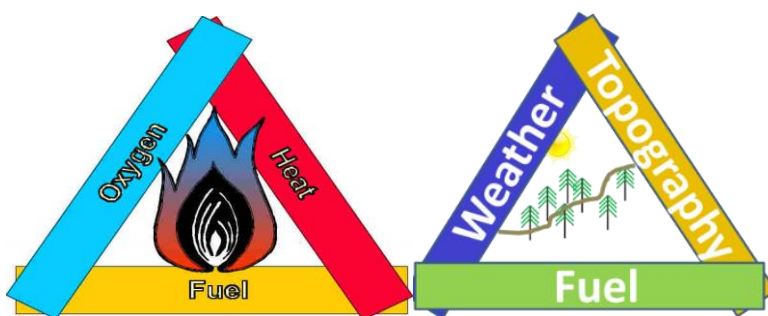
FireWorks Safety



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.



¹ The trunk is supplied with 4 sets of equipment.

- Materials not provided in trunk:
 - 1 box of matches
 - Timing device
 - Materials to create landscape (e.g., clay (recipe below), cardboard, toothpicks, aluminum foil)
 - Camera/smart phones for taking 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 copy/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**, 1/team
 - **Handout H08B-3: Fire behavior news article**, 1/student or team

Procedures:

1. Do a **safety checkup** with students using the FireWorks Safety poster (*FireWorks_Safety_poster.pptx* from **Activity H02**).
2. Refer to the posters for the Fire Triangle and the Fire Environment Triangle (*FireTrianglePoster.pdf* and *FireEnvironmentTrianglePoster.pdf* from **Activity H08A**) - or project or draw 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 the Fire Behavior Triangle). This model reminds fire managers and firefighters of the three factors that control how wildland fires behave: fuel, weather, and topography.
3. **OPTIONAL REVIEW:** Distribute **Handout H08B-1: Fire Behavior In Wildland Fuels**, 1/student. This handout gets students thinking about the factors that influence fire behavior and lets you gauge their prior knowledge. Take students to an outdoor setting so they can complete

the handout. Or use 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**, 1/team. Instruct students to follow **steps 1-4. Remind them that they need to have you check the model** when it is completed and that **you will tell them when to ignite it.**
8. When models are complete, gather students around each model. Have the team 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 article.
11. After each model is burned, have students compare predictions to what actually occurred.

Assessment:

Give each student or team a copy of **Handout H08B-3. Fire behavior news article**. Have them use their notes, photos, and videos to write a **timeline** and then an article. They should use the components of the Fire Environment Triangle to describe how the fire spread (or didn't spread) across their model.

Evaluation – news article:

	Excellent	Good	Fair	Poor
Image:	Includes timeline and other images	Does not include both timeline and images.	Does not include both timeline and images.	Does not include any images.
Topography	Article describes features of landscape that impacted fire spread.	Article describes some features of landscape that impacted fire spread, but either left some out or added some that were irrelevant.	Article describes some features of landscape that impacted fire spread but did not connect them to fire behavior.	Article does not address landscape features relevant to fire spread.
Weather	Article describes in detail how weather impacted fire spread.	Article provides basic explanation for how weather impacted fire spread.	Article’s description of weather’s impact on fire spread is partially inaccurate or incomplete.	Article’s description of weather’s impact on fire spread is incorrect or missing.
Fuel	Article describes different kinds of fuels and how they impacted fire spread.	Article describes fuels and how they impacted fire spread.	Article’s description of fuels is partially inaccurate or incomplete.	Article’s description of fuels is incorrect or not present.

Handout H08B-1: Fire Behavior In Wildland Fuels

Name: _____

1. List some things 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. Include details that would probably influence fire spread. Then write a few sentences in the empty space that describe 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. 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: _____

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 to write a news article 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 these important resources relative to the fire and transportation network?	Fire protection techniques:
<ul style="list-style-type: none"> • Wind speed • Precipitation • Humidity 	<ul style="list-style-type: none"> • Hilly vs flat • Gullies • Canyons • Slope steepness • Aspect • Water & waterways 	<ul style="list-style-type: none"> • Forest (various tree densities) • Surface fuels (various amounts, depths, fluffiness, continuity) • Fuel moisture 	<ul style="list-style-type: none"> • Homes • Other structures • Power lines • Cell towers • Roads 	<ul style="list-style-type: none"> • 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 outdoors.
4. Use your sketch to create your landscape. Be creative! Make up names for the fire, communities, streets, valleys, ridges, mountains, etc.
5. When you are satisfied with your model landscape, **STOP! Get approval from your teacher.** Then wait for your teacher to tell you when to ignite it so all class members can watch.
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. Ignite your model. Video, photograph, and take notes while it burns.
8. Discuss the accuracy of your predictions.

Handout H08B-3: Fire behavior news article

Name: _____

Overview: Using your notes, photographs, and videos...

1. Write a **timeline** to describe your fire. Include at least 5 points in time. Give specific details about the development of your fire from ignition until it went out.
2. Write a news article about your fire, to be published either in a news magazine or as a blog, along with your timeline and any other illustrations. Describe 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; you may use additional other photos to 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 fuels, weather, and topography):

- At each point in time, where did the fire spread and what influenced it (fuels, weather, topography)?

- Ending location and reasons why it ended (fuels, weather, topography)?



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

Vocabulary: *crown fire, crown fuels, ladder fuels, surface fire, surface fuels, succession*



Objectives:

- Students can differentiate between surface fires and crown fires, and they can describe the wildland fuels that contribute to these kinds of fire spread.
- 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, 6, 7, 10		2, 4, 6, 7, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 6		1, 2, 3, 4, 6	
	Writing Standards Science/Tech	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	From Molecules to Organisms: Structure and Processes	LS1.B			
	Ecosystems: Interactions, Energy, and Dynamics	LS2.C, ETS1.B			
	Biological Evolution: Unity and Diversity	LS4.C, ETS1.B			
	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.A, ESS3.B, ETS1. B			
EEEEGL	Strand 1	A, B, 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 are known as ladder fuels. Once fire is in a tree crown, it can spread directly from one crown to the next, especially if the winds are strong. Crown fires are usually much more dangerous and harder to control than surface fires.

This activity has 2 parts:

- I. Complete pre-lab reading/vocabulary worksheet. This should be done as homework or in the class period before the lab.
- II. Complete the lab exercise.

The **Assessment** requires that students create a storyboard that applies concepts from the lab in this activity and the previous one (**Activity H08A or H08B**) to real-world forests and fuel conditions.

The lab exercise in this activity (**Part II**) is a competition among student teams. Each team constructs a model tree out of a support stand, wire rods, and newspaper fuels. An example is shown in Step 6 in the **Procedures** below. The goal is to design a tree that can “survive” a fire passing beneath (a 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 the model tree. 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, so students can see the effects of two different amounts and arrangements of surface fuels. **Phase 1** uses relatively light surface fuels. **Phase 2** uses more surface fuels and adds some ladder fuels. Thus Phase 2 models the effects of succession without fire. Because students use the same model tree for both phases, **it is important not to 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 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, 1/student:

- **Handout H09-1: Lab Preparation**
- **Handout H09-3: Real-World Ladder Fuels and Fire Spread**

Copy 1 of the following for each lab group: **Handout H09-2. Ladder Fuel Experiment**

Prepare (or get students to prepare) the following “fuels” before the lab, 1 set for each of the 4 lab groups:

- Bag filled with ~20 strips of newspaper, each approximately 40 cm long and 4 cm wide. Each strip has to be folded accordion-wise and hole-punched so it can be threaded onto a wire rod to represent tree foliage in the model.
- 10 half-sheets of newspaper, ~25 x 35 cm. These will represent litter in the model.
- 5 quarter-sheets of newspaper, approximately 25 x 20 cm. These will represent saplings in the model (Phase 2).

Set up 4 lab benches, 1 for each lab group. Each bench should have 1 set of newspaper fuels (as described above), paper towels for clean-up, and the following from the trunk:

- 1 chemistry support stand with holes drilled through
- 1 pair of safety goggles
- 1 ashtray
- 1 spray bottle, filled with water
- 1 metal tray
- ~10 segments of wire rod


Teacher station should have 1 measuring tape (in the trunk) and these 3 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

Have an empty METAL trash can WITHOUT A PLASTIC LINER available.

Display the FireWorks safety poster (*FireWorks_Safety_poster.pptx* from **Activity H02**) and the Fire Environment Triangle (AKA Fire Behavior Triangle) poster (*FireEnvironmentTriangle_poster.pdf* from **Activity H08A**).

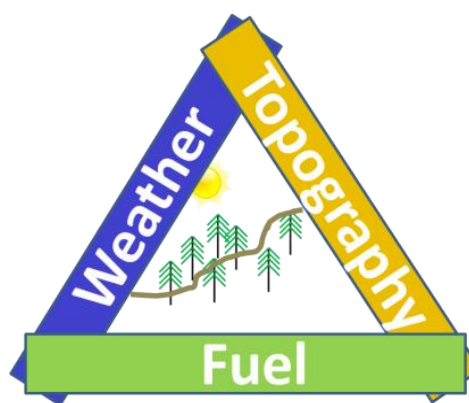
FireWorks Safety



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.



On the day of the lab, download *H09_LadderFuelAndFireSpread.pptx*.

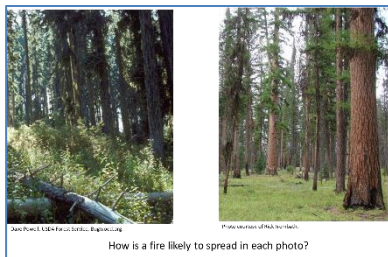
Procedure - Part I:

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

Procedure – Part II:

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_LadderFuelAndFireSpread.pptx**.

Slide
1



Using what you learned by doing the Lab Preparation (**Handout H09-1**), explain how the fire would likely spread in each of these forests on a windy day.

Left: 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 (**H08, “matchstick” forests**). Thus a *crown fire* could develop if it is dry enough and windy enough.

Right: A surface fire could spread in these fuels but would not be able 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.

Slide
2



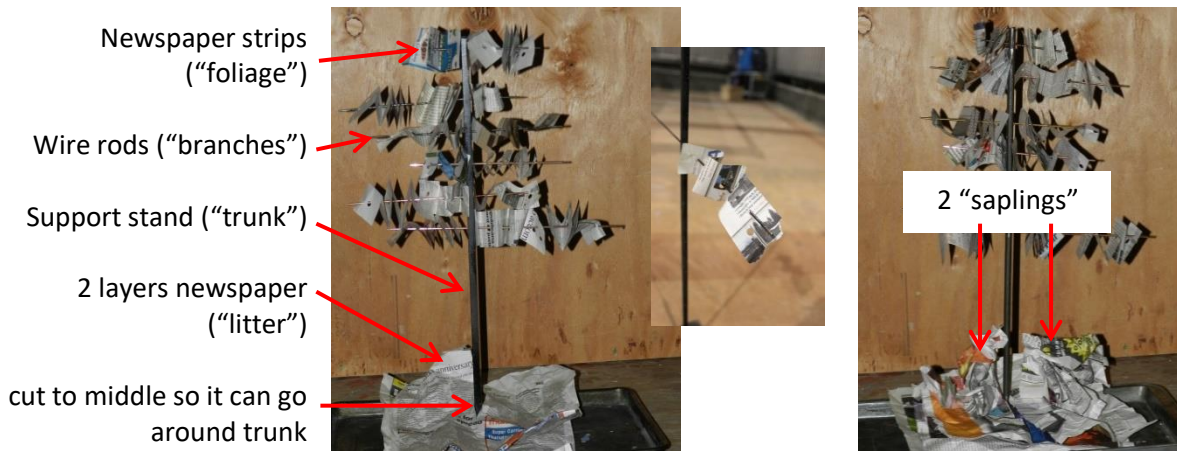
What kinds of fuels are burning in each fire? What kinds of fires are these?

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).

4. Give each lab group a copy of **Handout H09-2. Ladder Fuel Experiment**. Explain: Your goal is to design a tree that can survive surface fire and will not allow fire to climb from the forest floor into the 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!

5. 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), add more sheets of newspaper and make some larger crumpled sheets (placed under the branches) to model shrubs or saplings.

6. 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. Explain that they must not change any of their models after the surface fire in Phase 1, because they will be needed for Phase 2.
7. Draw these headers on the board for keeping score:

Team Name	Phase 1	Phase 2
-----------	---------	---------

8. **Phase 1:** Give lab groups ~10 minutes to construct their model 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 (2 layers of newspaper) to make them similar among models. Explain: As in any experiment, we want to test only 1 variable at a time. In this experiment, we are testing the students’ tree designs. We’ll keep the surface fuels similar so variation in surface fuels will not confound the results of the experiment.
 - 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 (see the illustration in **Handout H09-2**). 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.
9. Ask: What might happen to the surface fuels as a forest changes through many decades without surface fires (a process called succession)? **After many years of succession without surface fires, forests tend to accumulate a lot of surface fuels. Litter piles up under the trees; although some decays, it gets deeper every year. Shrubs grow in. Tree seedlings become established and grow taller every year. Eventually, these ladder fuels may reach or interweave with the tree crowns.**
 10. **Phase 2:** 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 with a paper towel. Then instruct them to put in new newspaper fuels to represent changes that might occur with succession if no surface fires occur. They can use any of the remaining newspaper at their stations.
 11. Have each team describe how their Phase 2 fuels show what has happened during succession. **(Teams should have more layers of newspaper than in Phase 1, probably 4-6 sheets, and some "shrubs" and/or "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 the score for each tree as for Phase 1.
 12. 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?

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

Evaluation:

	Full Credit	Partial Credit	No Credit
Content	See Answer Key/Suggestions for Handout H09-3: Real-World Ladder Fuels and Fire Spread below.		
Images	Student used images that clearly illustrated the answer.	Student used images that illustrated the answer but were sometimes confusing or incorrect.	Student used images that were irrelevant or incorrect.
Explanation	Student's captions showed thorough understanding of the relationship of fuel arrangement to fire spread potential.	Student's captions showed basic understanding of the relationship of fuel arrangement to fire spread.	Student's captions showed little or no understanding of the relationship of fuel arrangement to fire spread.

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 (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 dry out quickly and help surface fires spread rapidly. Heavy surface fuels such as logs, stumps, and wood piles dry slowly and burn slowly, so fires in these fuels can smolder for a long time.



Surface fires burn in *surface fuels*. Surface fires reduce *ladder fuels*, so they also reduce the likelihood that a future fire will burn into the tree crowns. Surface fires can be severe enough to kill a tree if they kill the its roots or kill the living cells under the trees' bark.



Ladder fuels include trees and tall shrubs growing under the crowns of mature trees. These provide a way for surface fires to climb up into the tree crowns. Ladder fuels include tree branches that grow low to the ground.



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



Crown fires burn in the crowns of trees and tall shrubs. Crown fires are often ignited by surface fires that spread upward through ladder fuels; then they spread from crown to crown, especially if winds are strong. 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.

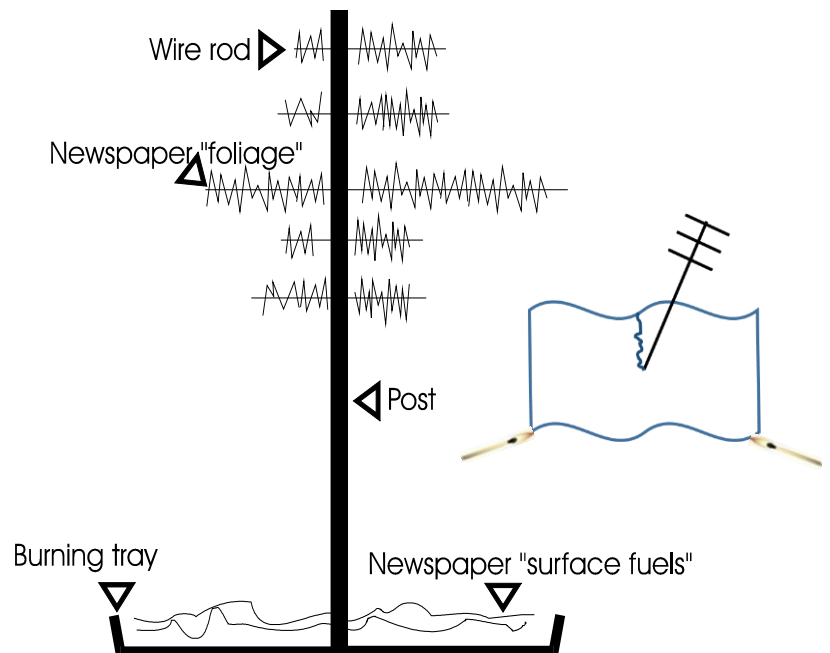


Handout H09-2. Ladder Fuel Experiment

Design a model of a tree. Its trunk is a lab support stand. Its branches are rods stuck through holes in the support stand. 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 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. The teacher may rearrange your surface fuels before burning so everyone's surface fuels are similar.
 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 model 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 burned it.
 - Keeping score: After you have underburned your model 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 used a model to explore 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.

To show your understanding of the relationship between vertical fuel arrangement and fire spread, **create a storyboard for one of the following scenarios**. A storyboard is a sequence of drawings with captions that explain what is occurring in the drawings. Storyboards are often used to develop a movie or documentary film.

Scenario 1. A mountainside that has patches of dense 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 a variety of patches and the resulting differences in fire behavior.

Scenario 2. A forest where some patches have been burned recently by surface fire, some burned recently in crown fire, and other patches have gone more than 100 years 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 “ages” and the resulting differences in fire behavior.

Drawing					
Caption					

Answer Key/Suggestions for Handout H09-3: Real-World Ladder Fuels and Fire Spread

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

Scenario 1. A mountainside that has patches of dense 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 a variety of patches and the resulting differences in 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 of forest with tall shrubs have lots of ladder fuels so they can support crown fire; if the shrub layer is low and does not reach the lowest branches of the tree, crown fire is unlikely. Meadows can serve as fuel breaks when wet, and they can 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, forcing it to spread only through 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, some burned recently in crown fire, and other patches have gone more than 100 years 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 “ages” and the resulting differences in fire behavior.

Possible explanation: Forest patches with recent surface fire tend to have less surface and ladder fuels than forests that have not underburned recently. 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. Forests that recently burned in crown fire will obviously not support crown fire, but they are likely to have abundant herbaceous cover that will support surface fire if it dries out. Forest patches that have not burned in 100 years or more may have lots of surface, ladder, and crown fuels. In addition, the tree crowns are likely to touch or be interwoven. Forest stands with these properties are likely to have crown fires in dry, windy weather.



10. Fire weather, fuels, and topography: Modeling for management on a real fire

Lesson overview: In this activity, students study the history of a real wildland fire, the Lolo Peak Fire of 2017 in western Montana. They read excerpts from an official planning document to learn how fire managers predicted fire spread. Then they use weather data to make their own predictions of fire spread. Finally, they synthesize day-by-day reports from the official records of the Incident Command (IC) Team and other sources to create “Weather Channel”-type video reports on the fire’s progress for a national audience. In the closing section of the activity, students review the IC Team’s use of models and discuss a map of fire severity in the burned area.

Subjects: Science, Mathematics, Geography, Reading, Speaking and Listening

Duration: Homework and 2-3 class periods

Group size: small groups



Setting: Classroom

Vocabulary: *basal area*, *contained* (status of fire), *Incident Command (IC) Team**, *mop-up*, *suppression repair*, *synthesize*

*Many of these terms and other technical terms about fire management are defined in the *Glossary of Wildland Fire Terminology* (<https://www.nwcg.gov/glossary/a-z>).

NOTE TO TEACHER: A simpler version of this lesson is available in the Middle School curriculum, Activity M08. It replaces the initial technical reading with a PowerPoint presentation and has students create a radio podcast rather than a video production.

Lesson Goals: Increase students’ understanding

- of the interactions of weather, topography, and fuels as they influence fire behavior
- of the ways in which fire managers use data, modeling, and experience to manage a wildland fire.

Objectives: Given a variety of weather data, maps, news articles, and reports from an Incident Command Team, students can

- predict times when a wildland fire is likely to spread rapidly and times when it will spread little if at all
- synthesize information on a wildland fire into a video report for a national audience

Standards:		9th	10th	11th	12th
CCSS	Reading Informational Texts	1, 2, 4, 10		1, 2, 4, 10	
	Writing	2, 4, 6, 7, 10		2, 4, 6, 7, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Reading Standards Science/Tech	1, 2, 3, 4, 7, 10			
	Writing Standards Science/Tech	1, 4, 6, 7, 10			
NGSS	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.A, ESS3.B, ESS3.C, ESS3.D, ETS1.B			
EEEEGL	Strand 1	A, C, E, F, G			

Teacher background: From activities in **Units II** and **III**, students have gained a theoretical understanding of combustion and wildland fire behavior. In this activity, they apply their understanding to a real - and very complex – wildland fire, the Lolo Peak Fire of 2017 in western Montana. The fire began with a lightning strike on July 15, 2017, and was contained 87 days later, in early October. It burned more than 53,000 acres and cost approximately 48 million dollars. One firefighter died on the fire when he was struck by a falling tree. Two homes were burned. A major highway was closed for several days, and hundreds of residents were evacuated – some of them more than once. The fire generated considerable controversy – which is not covered in this lesson but is included in **Activity H22**.

A tremendous amount of information is available about the Lolo Peak Fire. You could use this activity as the basis for a research project and have students locate their own information and evaluate its quality, but that would be very time consuming. (If you really want to do that, you can use the original files in the zipped file **OriginalReadingsAndDataForTeachers**.) To help meet the objectives of the activity in a short time, we have selected a subset of the information available and packaged it in **6 Fire Reporting Packets**, which students use to report on the fire at 6 different times while it was burning. The packets are available in the trunk or downloadable from the folder **FireReportingPackets**. Each packet contains information on a specific time period, so the name of each packet includes the starting date of the period in yymmdd format. Information in the packets includes:

- **Statistics:** Daily reports of fire size, number of personnel on the fire, and estimated cost.
- **Narratives:** Excerpts from the official record of the fire as published on “Inciweb” (<https://inciweb.nwcg.gov/>). Inciweb is the official database for reporting on national emergencies such as fires, floods, and hurricanes. Each emergency is managed by an Incident Command (IC) Team, whose members have extensive training and experience and have worked together in emergency management for many years.
- **Articles** from two local newspapers, the *Missoulian* and the *Ravalli Republic*. We selected news reports and guest editorials from scientists and other experts. We did not include letters to the editor, but some of these are included in **Activity H22**.
- **Graphics**, including photos and maps that show the growth of the fire.

The activity begins with a review of the Fire Environment Triangle, which was introduced in **Activity H08** (the “Matchstick Forest” activity), and with viewing of a 3:12-minute video created by the IC Team to describe their strategy for managing the fire. Then students read the “Decision Summary” (provided at the end of this lesson, in "Fire Reporting Packets" in the trunk, and available in **170804_LoloPeakFireDecisionSummary.pdf**). This is a 6-page document excerpted from the official 48-page plan for managing the fire. We recommend assigning the reading as homework before the next steps. From this Fire Decision Summary, students learn how the IC team applied concepts from the Fire Environment Triangle in their plan.

After reading the Fire Decision Summary, students work in 6 teams to predict fire spread. They analyze weather records to identify times when the fire might be expected to spread rapidly and times when it might stop spreading. They use weather data from the National Weather Service station at the Missoula airport (10 to 15 miles from the fire). For this lesson, rather than provide data on all variables measured, we extracted the hourly data for just 8 variables related to fire behavior. You’ll need to project the data from **FireWeatherTimelines.jpg** and also provide a copy for each of the 6 student teams. (Either provide digital access or provide paper copies printed from **FireWeatherTimelines_LedgerSize.pdf**; 6 copies are in the trunk.)

Atmospheric inversions influenced the behavior of the Lolo Peak Fire and caused poor air quality throughout the region during the summer of 2017. The relationship between fire and air quality is addressed in **Activity H11**, so it is not given much attention in this lesson .

For **Assessment** of this activity, each student team presents a 3.5-minute “Weather Channel” video report on the progress of the fire during 1 of 6 time periods. (The Weather Channel - <https://weather.com/> - often broadcasts features about weather-driven events that have a broader focus than weather alone.) The information needed for student reports is contained in the **Fire Reporting Packets** described above. Student reports must describe the fire’s growth during that specific time period. As the reports are given, students can compare their predictions of fire behavior to what actually occurred.

At the end of the activity, students discuss the accuracy of their predictions, view a 2:58-minute video about the use of modeling to predict fire behavior, and discuss the severity of the fire.

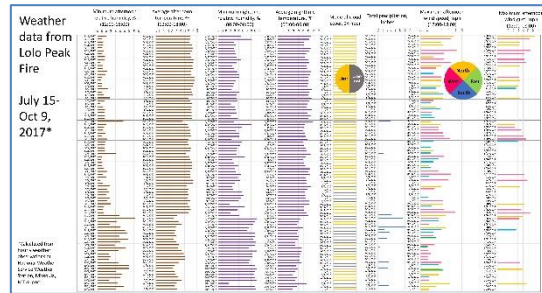
If you are interested in exploring the history of other wildland fires or the current status of fires throughout the United States, consult some of these websites:

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.

Materials/Preparation:

1. Decide how to make the technical reading about planning for management of the fire (**170804_LoloPeakFireDecisionSummary.pdf**) available to students – from copies in the trunk? from copies that you print? from an electronic source?
2. Find the packets of information for student reports in the folder entitled **FireReportingPackets**. A printed copy of each packet is in the trunk, and the contents of the packets is described in **Teacher Background** above. There are 6 packets, one for each time period to be covered by a student report. Each packet is identified by the starting date of the reporting period, expressed in yymmdd format. Provide each team with either a printed copy or digital access to the packet they need.

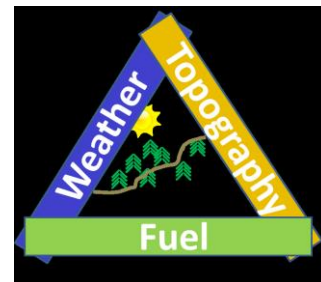
3. Find the 6 ledger-size printouts of fire weather data (**FireWeatherTimelines_LedgerSize.pdf¹**) in the trunk or print them yourself or provide digital access to **FireWeatherTimelines.jpg**. In addition, project the poster-size copy of this file in your classroom².



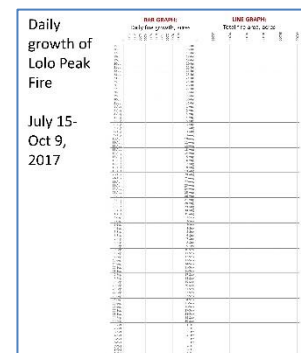
4. Decide whether or not to use a student host for the Weather Channel reports. If you decide to do this, explain to the student that he or she only needs to give a very short introduction of each presentation, and he or she should also be on one of the 6 reporting teams.
5. Decide on the format to be used for student reports and set up the technology needed: a live presentation with graphics? a video-recorded presentation? other?

6. Display in the classroom:

- Fire Environment Triangle poster (**FireEnvironmentTrianglePoster.pdf**).



- The empty graph where students will record daily growth of the fire (**FireSizeAndGrowthTimeline_EmptyChart.pdf**). Since students will need to record data on this graph, either use the laminated poster or project it on a whiteboard. If possible, place it to the right of your display of **FireWeatherTimelines.jpg**.



7. Have dry-erase markers and clean-up materials on hand.

¹ This document is designed for 11 X 17” (ledger size) paper. However, if that size of paper is not available, it will print OK on two pages of 8.5 X 11” paper.

² If you want students to use the original data, it is all available in the zipped folder **OriginalReadingsAndDataForTeachers**.

8. Access online and prepare to show (at the start of the activity) the 3:12-minute video “Lolo Peak Fire Strategy and Tactics”:
<https://www.youtube.com/watch?v=4CCHlzM5Tzk&feature=youtu.be>
9. Access online and prepare to show (at the end of the activity) the 2:58-minute video “Fire Science on the Lolo Peak Fire”:
<https://www.youtube.com/watch?v=Cxr2rg4dCy4&feature=youtu.be>
10. Find the digital fire severity map (**FireAbovegroundSeverityPoster.pdf**) to project at the end of the activity.
11. Print 1 copy/student: **Handout H10-1. Report to the nation about the Lolo Peak Fire**

Procedure:

Day 1 - Introduce the activity and assign reading


1. Refer to the Fire Environment Triangle poster (**FireEnvironmentTrianglePoster.pdf**). Explain: We’ve studied the theory of combustion and fire spread. Now we will apply this knowledge to a real wildland fire, the Lolo Peak Fire, which occurred in western Montana in the summer of 2017. Lightning started the fire on July 15. Toward the end of July, a team of 15 fire experts studied the fire behavior, weather forecasts, historical weather records, and historical fire records for that geographic area. They talked to local fire specialists, managers, and scientists. They ran mathematical models of weather and fire behavior. They studied the ways in which fire could spread across that specific landscape. In less than 2 weeks, they published a 48-page report that described what the fire was likely to do and explained how it could be managed. The report guided decisions for the next 2 months by members of Incident Command (“IC”) teams, but specific plans were developed day by day. An IC team is a group of national experts that handle large, dangerous emergency events.
2. View the 3:12-minute video “Lolo Peak Fire Strategy and Tactics” (<https://www.youtube.com/watch?v=4CCHlzM5Tzk&feature=youtu.be>), which shows one of the IC Team leaders describing the management strategy.
3. Hand out the **Decision Summary** document (shown at the end of this lesson, available from **170804_LoloPeakFireDecisionSummary.pdf**) or make it available electronically to all students. Explain: Before our next class session, read this document - August 4, 2017: A Plan for the Lolo Peak Fire - which was extracted from the IC Team’s 48-page report. Pay attention to ways in which the three parts of the Fire Environment Triangle – fuels, weather, and topography – interact and how they influence the strategy for

August 4, 2017: A Plan for the Lolo Peak Fire
By Jane Kapler Smith. This report is summarized from the Incident Decision published on August 4, 2017, provided by LaWan Hollingsworth, USDA Forest Service, Rocky Mountain Research Station. The Decision documented the analysis of fire weather, topography, and fuels that was used to develop plans for managing the fire from July 29 through mid-August.

Situation When the Fire Started

The Lolo Peak Fire started on July 15, 2017, at the southern end of the Lolo National Forest. The fire was started by lightning when a thunderstorm moved through the northern Rocky Mountains. There were 68 new fires in the Northern Rockies Geographic Area on that date, totaling 2,105 acres. Eight of these fires were on the Lolo National Forest. From Jan. 1 to July 15, 2017, there had already been 880 fires in this Geographic Area started by

On July 15, 2017, the Northern Rockies Geographic Area had 68 new fires.




Beginning of Fire Decision Summary

managing the fire safely. Pay special attention to the information written in *italics*. You will need that knowledge for the next class session.

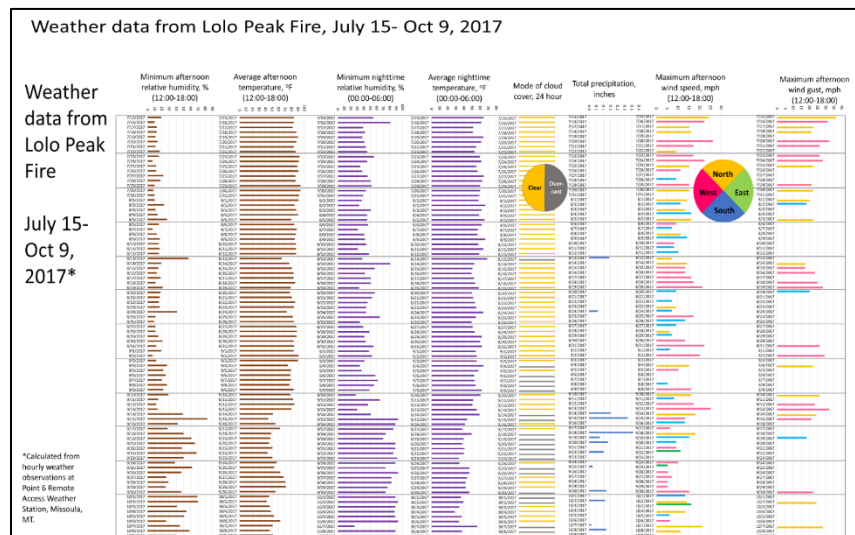
DAY 2 – Use what we know to predict fire behavior:

4. Ask students to describe some of the main points in the **Decision Summary** reading, especially what combinations of fuels, weather, and topography are expected to cause rapid fire spread. Any questions? Discuss. Then explain: We’re going to work in teams to:
 - First, use our knowledge and weather data from the Lolo Peak Fire to make predictions about when the fire was likely to grow rapidly and when it was likely to stop growing. These will be our hypotheses, and we’ll find out how accurate they are later on.
 - Second, use fire records, reports from the Incident Command teams (“IC reports”), news articles, photos, and maps to report on the fire’s growth and management from the time it started (July 15, 2017) until it was declared contained (October 9, 2017). “Contained” means that a fire is fully surrounded by control lines and other features that can be reasonably expected to stop its spread.
5. Set up 6 student teams.
6. Project **FireWeatherTimelines.jpg** and give each team digital access to - or a printout of - the same data. (It is in the trunk, and you can print it from **FireWeatherTimelines_LedgerSize.pdf**). Explain: These graphs show some of the weather data recorded during the fire. They show only a fraction of the data available, but the 8 variables shown here have a critical influence on fire spread. In your teams, discuss the weather patterns shown here and then hypothesize:

- What day or group of days you expect the greatest fire growth.
- What day or group of days you expect the fire to die down and stop spreading significantly.

At the end of 5-10 minutes, be prepared to record your hypotheses on the board. **Students**

probably won’t have much trouble finding the time when the fire died down: It is associated with the cooler temperatures, higher humidities, and precipitation that occurred in early September. Students may find it much harder to guess at day(s) of large fire growth. If you want to offer hints, have them think about the **ALIGNMENT** of strong winds with east-west drainages that was referred to, and italicized, in the **Decision Summary**. The most useful



information on the weather charts is in the 2 graphs of wind speed associated with wind direction. As suggested in the **Decision Summary**, when strong westerly winds persist for a long time, rapid fire spread can be expected in the east-west-oriented drainages.

7. While students are discussing, copy this table on the board:

Team	Hypothesized important fire dates	
	Day(s) with greatest fire growth	Day(s) when fire is about done spreading
1		
2		
3		
4		
5		
6		

8. After 5-10 minutes, have each team report their hypotheses and explain their reasoning. Write the hypotheses on the board. Explain: We'll revisit your hypotheses after we've learned more about the fire.

DAY 2-3 - Assessment:

1. Explain:

- The Weather Channel, a national TV network centered in Atlanta, Georgia, has heard that there's a wildfire brewing in western Montana – the Lolo Peak Fire – that could be of national interest. They've invited our class to report on this fire in a series of Saturday night broadcasts. We're going to respond to their invitation by working in teams to produce broadcasts for 6 different time periods during the fire.

- Your team's broadcast must be 3.5 minutes long and must include information on the fire's growth. During your broadcast, be sure to graph the fire's growth each day on the "empty chart" displayed in the classroom



Top of "empty chart" where students record fire growth during each time period.

(**FireSizeAndGrowthTimeline_EmptyChart.pdf**). Use a horizontal bar for each day, like the ones used in the graphs of weather data in **FireWeatherTimelines.jpg**. Also graph the fire's total size each for each day using a line. Other than that, it's up to your team to select information and pull it together – *synthesize* it - for your audience. Include important facts, maps, pictures, graphs, videos, a human-interest angle, current controversy, and/or anything else that will help the Weather Channel's national audience understand the importance of the Lolo Peak Fire.

- **You do not have to do the detective work** for this report. That might be fun, but you'd have to sift through hundreds of websites and news articles to do it, and you don't have the time. Instead, your team has access to a **Fire Reporting Packet** for your time period, which contains everything you need.
- Explain the role of the student/Weather Channel host if you plan to use one.

2. Give each student or team a copy of **Handout H10-1: Report to the nation about the Lolo Peak Fire**. Assign a time period to each team from this table:

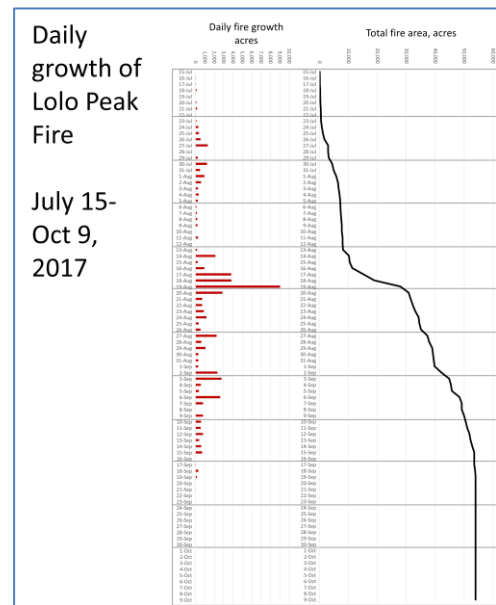
Team	Time period (2017)
1	July 15 through July 29
2	July 30 through August 12
3	August 13 through August 19
4	August 20 through August 26
5	August 27 through September 9
6	September 10 through October 9

3. Have students read the handout. Answer questions and explain when reports will be presented. We suggest you give them no more than 1 class period to prepare. That's journalism!

4. Give each team the **Fire Reporting Packet** that they need.

5. As students prepare and rehearse, work with each team to make sure they can confidently graph the fire's growth and its total size on each day of their reporting period. The final graph should look something like this:

(It is also available in [FireSizeAndGrowthTimeline_CompletedChart.pdf](#).)



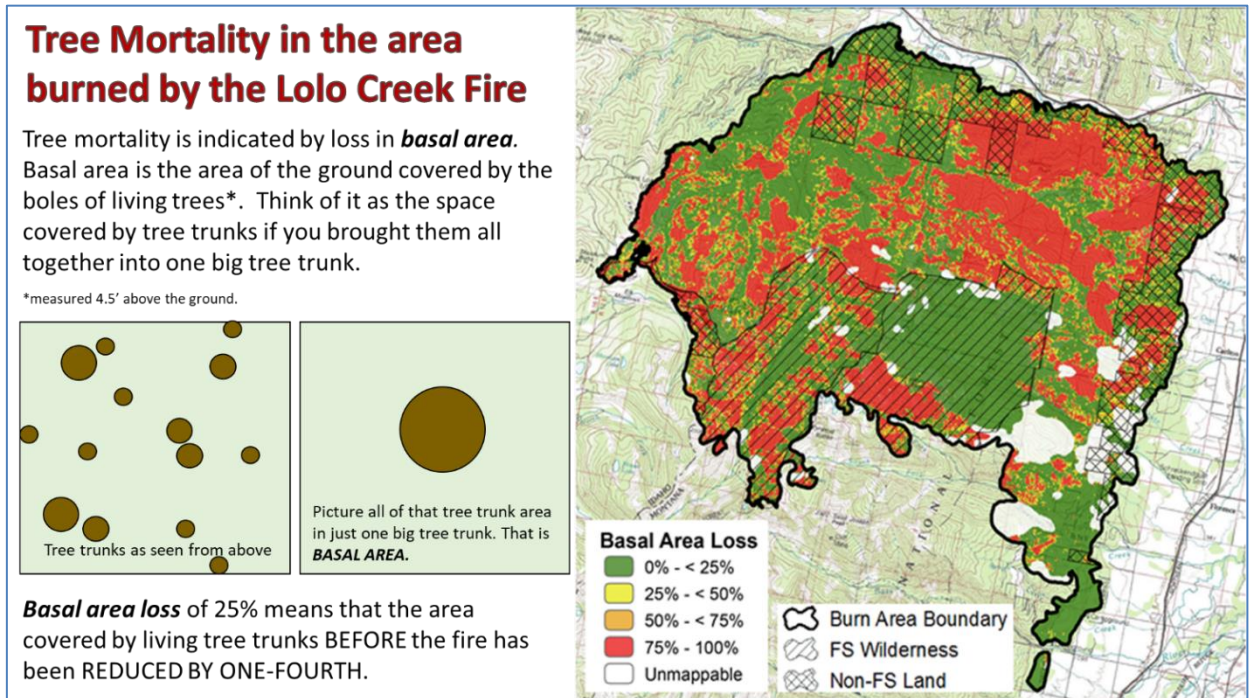
Evaluation: Evaluate each “Weather Channel Report” as follows:

Excellent	Good	Poor
<ul style="list-style-type: none"> • Reported fire’s growth and connected it to weather, topography, and/or fuels • Reported additional facts about fire to illustrate main points • Contained technical material at level appropriate for national audience (which has little understanding of wildland fire) • Contained engaging human-interest touch • Clearly explained national significance of fire - why it is important, unique, an example, etc. 	<ul style="list-style-type: none"> • Reported fire’s growth • Reported on weather, topography, and/or fuels • Reported additional facts about fire to illustrate main points • Contained too much or too little technical information for audience • Contained human-interest touch • Referred to national significance of fire - why it is important, unique, an example, etc. 	<ul style="list-style-type: none"> • Did not report fire’s growth • Did not describe fire weather, topography, or fuels • Included few additional facts about fire • Contained too much or too little technical information for audience • Did not contain human-interest touch • Did not give information on national significance of fire

Closure:

1. The “empty chart” display, which students filled in for their reports, should look a lot like the one shown in **Step 5** above (**FireSizeAndGrowthTimeline_CompletedChart.pdf**). You can project it, if you like.
2. Explain/ask: Let’s compare our hypotheses to the actual fire growth data. How well did we predict fire behavior from fire weather data? **Discussion.**
3. Ask: How severe do you think this fire was? Did it kill most of the trees inside the fire perimeter? **Discussion.**

- Project the map of fire severity that was made after the fire ([FireAbovegroundSeverityPoster.pdf](#)). Use the information on the left side of the poster to explain basal area, the metric used to indicate aboveground fire severity. Ask: How well does this map match your expectations? How well does it match the news coverage about the fire? **Discussion.** People are usually surprised to learn that most wildland fires produce a mosaic of severities. Much of the area inside a fire's perimeter may be unburned or show less than 25% tree mortality. News media tend to cover a fire only when it does something spectacular, like the Lolo Peak Fire's huge run that occurred on August 18-19.



- Explain: We found it pretty challenging to predict fire behavior. IC teams use complex models so they can understand the interactions of fuels, weather, and topography, and then predict fire behavior so they can manage a fire safely and effectively. Let's listen to one of the fire analysts on the Lolo Peak IC team describe the modeling that we read about at the start of the activity:
- Show the 2:58-minute video "Fire Science on the Lolo Peak Fire": <https://www.youtube.com/watch?v=Cxr2rq4dCy4&feature=youtu.be>

Handout H10-1: Report to the nation about the Lolo Peak Fire

You are on a photojournalism production team. Your team is scheduled to give a report on the national Weather Channel about the Lolo Peak Fire at the end of one of these time periods. Circle the time period assigned to you.

Team	Time period (2017)
1	July 15 through July 29
2	July 30 through August 12
3	August 13 through August 19
4	August 20 through August 26
5	August 27 through September 9
6	September 10 through October 9

Your team's Fire Reporting Packet contains all of the information you need³:

- **Statistics** contains daily reports of the fire's growth and size, the number of personnel on the fire (if reported), and the current cost estimate (if reported).
- **Narrative** contains excerpts from the IC Team's narrative report for each day.
- **Articles** contains one or more newspaper articles about the fire and related issues
- **Graphics** contains several photos of the fire from that time period and a map that shows fire growth. The introductory slide describes how to find additional graphics.

If you find a term that you do not understand, look it up. You may find it in the official glossary of the National Wildfire Coordinating Group (<https://www.nwcg.gov/glossary/a-z>).

These are requirements for your report:

- Graph the fire's daily growth on the empty chart displayed in the classroom.
- Make your report exactly 3.5 minutes long, give or take 15 seconds. If you make it longer or shorter, you will mess up the Weather Channel's daily programming.
- Report the fire's growth (or lack of growth). Explain in terms of weather, fuel, and/or topography – the 3 sides of the Fire Environment Triangle. Use the map at the end of your **Fire Reporting Packet**.
- Use additional facts about the fire and photos from your packet to illustrate your points.
- Keep the level of technical information appropriate for your audience. Don't assume that they know anything about fire other than – maybe – what was in a presentation from a previous team. Avoid using jargon and acronyms.
- Engage your audience with a human-interest touch – something about the real people who are affected by the fire or trying to manage it and stay safe.
- Show or explain the national significance of this fire – perhaps why it is especially interesting or unique, or perhaps why it is an example of a crisis occurring throughout the region.

³ The materials may be in computer files with names that begin with Narrative, Statistics, Graphics, and Articles... and end with the range of dates included.

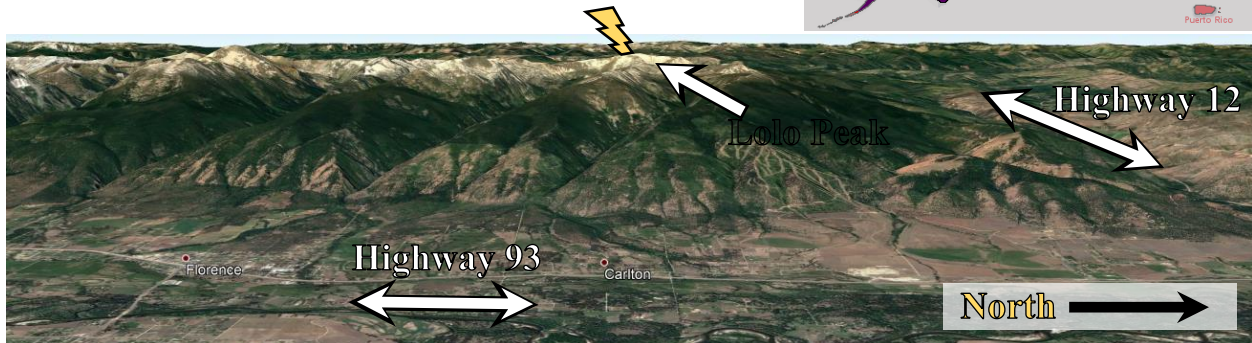
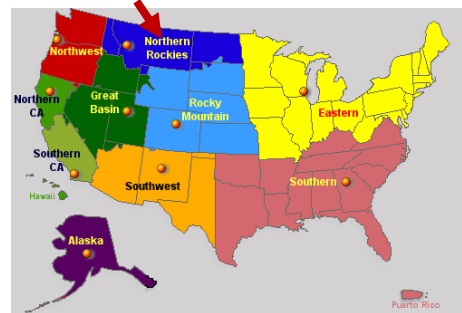
August 4, 2017: A Plan for the Lolo Peak Fire

By Jane Kapler Smith. This report is summarized from the Incident Decision published on August 4, 2017, provided by LaWen Hollingsworth, USDA Forest Service, Rocky Mountain Research Station. The Decision documented the analysis of fire weather, topography, and fuels that was used to develop plans for managing the fire from July 29 through mid-August. After this Decision was made, plans for managing the fire were adjusted day by day.

Situation When the Fire Started

The Lolo Peak Fire started on July 15, 2017, at the southern end of the Lolo National Forest, which is in western Montana. The fire was started by lightning when a thunderstorm moved through the northern Rocky Mountains. There were 68 new fires in the Northern Rockies Geographic Area on that date, totaling 2,105 acres. Eight of these fires were on the Lolo National Forest. From Jan. 1 to July 15, 2017, there had already

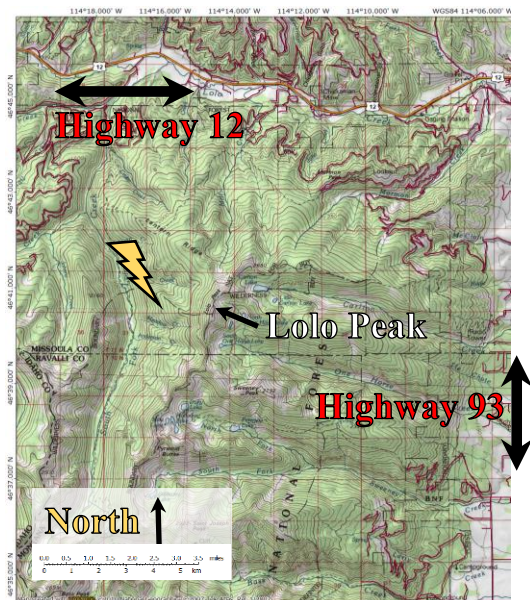
On July 15, 2017, the Northern Rockies Geographic Area had 68 new fires.



Above: Looking west into Bitterroot Mountains. Lightning symbol shows where fire originated, behind Lolo Peak. **Right:** Topographic map of fire area. Lightning symbol shows fire origin. Note east-west orientation of Highway 12 and north-south orientation of Highway 93 (just off right edge of map).

been 880 fires in this Geographic Area started by humans (29,414 acres) and 400 fires started by lightning (32,654 acres). The Lolo National Forest had already had 7 fires from Jan. 1 to July 15, which had burned 4,514 acres.*

The Lolo Peak Fire originated between Lolo Peak and the South Fork of Lolo Creek at 6,600 ft elevation. The fire was on a west-facing slope dominated by subalpine firs, with many whitebark pine snags. The fire originated in the Selway-Bitterroot Wilderness, approximately 0.5 mile south of the wilderness



* Information on regional situation provided by Faith Ann Heinsch, Rocky Mountain Research Station Fire Science Lab, March 7, 2018.

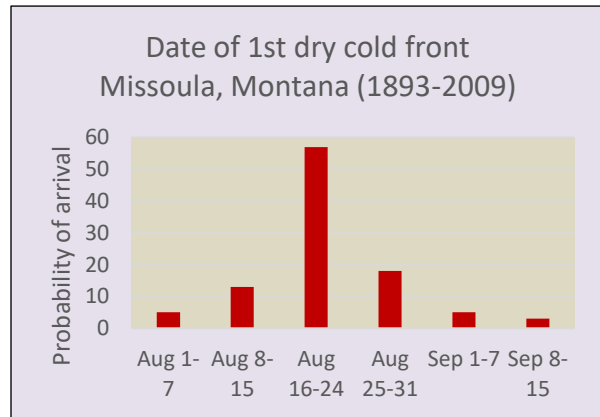
boundary. Lolo Peak is in the northern part of the Bitterroot Mountains, which is a steep, craggy range with many prominent rocky ridges.

Weather Outlook for next 1-2 weeks (starting August 4)

Both the 6-10 day and 8-14 day weather forecasts show a high probability of above normal temperatures over the fire area. The 6-10 day forecast shows below-normal precipitation. Chances of precipitation move back to normal (average) in the 8-14 day forecast.

Critical Fire Weather Patterns

In mid to late summer, movement of dense, cold, high-altitude air across the northwestern United States usually causes turbulent weather and dry thunderstorms in the northern Rocky Mountains. Analysis of data from the past 117 years shows that the first of these “dry cold fronts” is likely to arrive during the third week of August. Dry cold fronts can significantly affect fire growth. They cause increased rates of spread and mid- to long-range spotting. Outflow winds created by thunderstorms can spread spot fires in all directions.



Fuels

Fuel composition strongly affected behavior of the Lolo Peak Fire so far (through Aug. 4). Most of the area is covered by these 3 types of forest:

- From the valley floor up to approximately 5000' elevation, ponderosa pine dominates the overstory. On north- and east-facing slopes in these forests, ponderosa pine stands are dense and contain many fir trees because no fires have occurred in the past 100 years. On south- and west-facing slopes, ponderosa pine stands are typically more open and have a grassy understory.



Fuels in ponderosa pine stand. USDA Forest Service photo by LaWen Hollingsworth.

- From 5000-7500' elevation, the forest is dominated by a mixture of conifer species. These stands have heavy loads of dead and down fuels, because many mature trees have been killed by pathogens. The species in these stands include lodgepole pine, subalpine fir, grand fir, Douglas-fir, and western larch. During the last two weeks of July, the fire was most active in this fuel type. During the nighttime hours, a "thermal belt" of warm air has tended to stay in place in this elevation band. Because of the thermal belt, the fire has shown slow but consistent growth through the nighttime, and fuels have stayed very dry rather than recovering some moisture from the higher humidity in cool nighttime air.
- Above 7500' elevation, the forest is primarily dominated by subalpine firs of all ages and sizes, intermixed with whitebark pine snags. There are also extensive stands of alpine larch. Near the ridge tops, bands of forest are interspersed with bands of rock and meadow.

Fuels at all elevations are critically dry, as defined by local fire personnel. Thermal belts are likely to persist and continue to keep nighttime humidities low and fuels very dry.



Fuels in lodgepole pine/mixed conifer stand. USDA Forest Service photo by LaWen Hollingsworth.



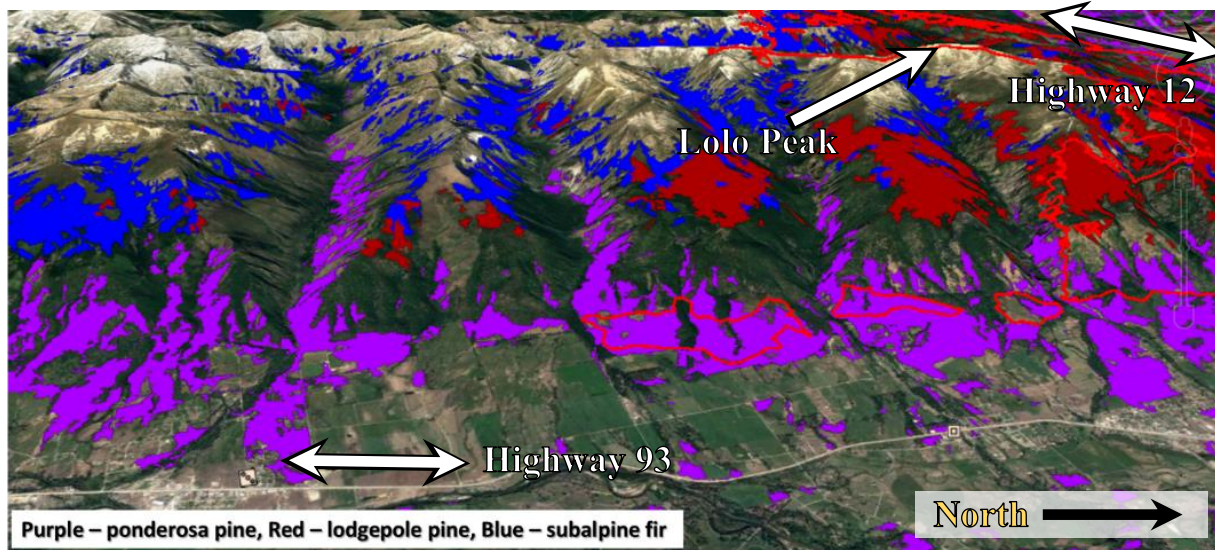
Forests at high elevations contain large numbers of dead, standing whitebark pines ("snags"). USDA Forest Service photo by LaWen Hollingsworth.

Fire Behavior Expected in Fuel Types and Potential Management Actions

In the low-elevation ponderosa pine forests, fire managers will use burnouts to create a buffer between the fire and control lines. They will use nighttime ignitions to keep fire intensities low. This will limit mortality of ponderosa pines in larger size classes (about 10 inches or more in diameter). Mortality of other conifer species will be greater than that of ponderosa pine.

In middle-elevation lodgepole pine forests, stand-replacing fire is likely because this species and associated firs have little resistance to heating and tend to grow in dense stands. Lodgepole pine stands already contain many large patches of dead trees killed by mountain pine beetles. On north-facing slopes where the forest is dominated by western larch, fire is expected to be less intense and less likely to burn continuously through crowns.

Forests at high elevations, comprised of subalpine firs and whitebark pine snags, are susceptible to the strong winds that flow along ridge tops. In many locations, a wide buffer of rock lies between the high-elevation forest and the ridge top, so surface fires are unlikely to spread



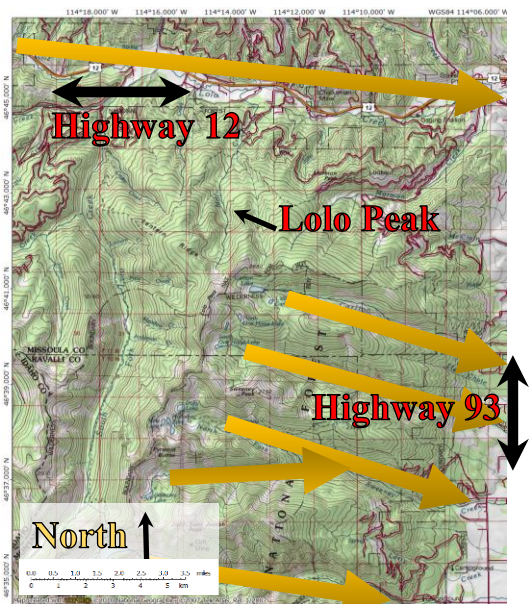
Looking west into the Bitterroot Mountains. Colors show three important forest/fuel types in the area of the Lolo Peak Fire. Red lines indicate areas at low elevations that were burned out by fire crews at night to keep fires at low severity and limit mortality of ponderosa pines.

across ridges. However, subalpine firs, once ignited, are likely to torch rapidly and shower thousands of firebrands downwind, igniting spot fires.

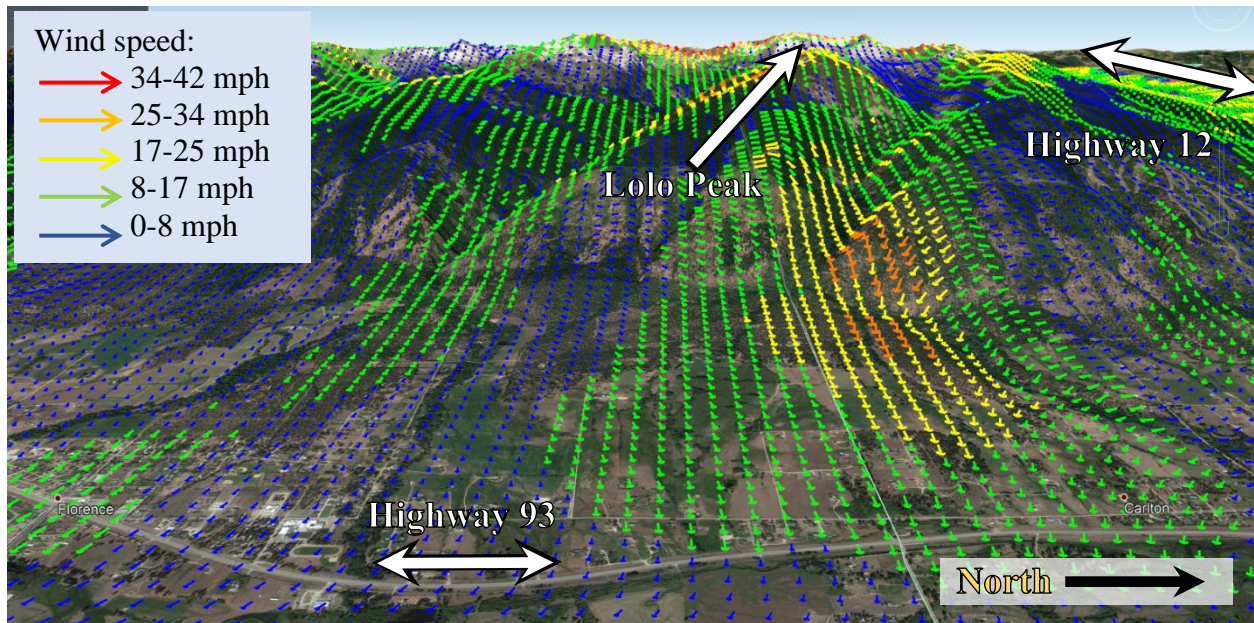
Fire Weather and Topography

The major factors that have influenced the fire's growth to date (August 4) have been:

- The atmosphere was quite dry during much of July and early August, and occasionally the atmosphere was also quite turbulent. This allowed for rapid fire growth and promoted long-range spotting even when there was little wind.
- Forests consist largely of old, decadent conifer stands that have not burned in more than a century. These stands are often dense, and fuel loads are heavy.
- *Rapid fire runs have occurred in drainages that align with prevailing winds. This alignment increases fire's rate of spread and may promote crown fire in some vegetation types.*
- The fire has been most active between 5000' and 7500' elevation, where strong thermal belts prevent nighttime temperatures from cooling off and keep nighttime humidities from rising, so fuels do not recover moisture overnight.



Arrows show where prevailing winds align with drainages. Arrows point downwind and downhill.



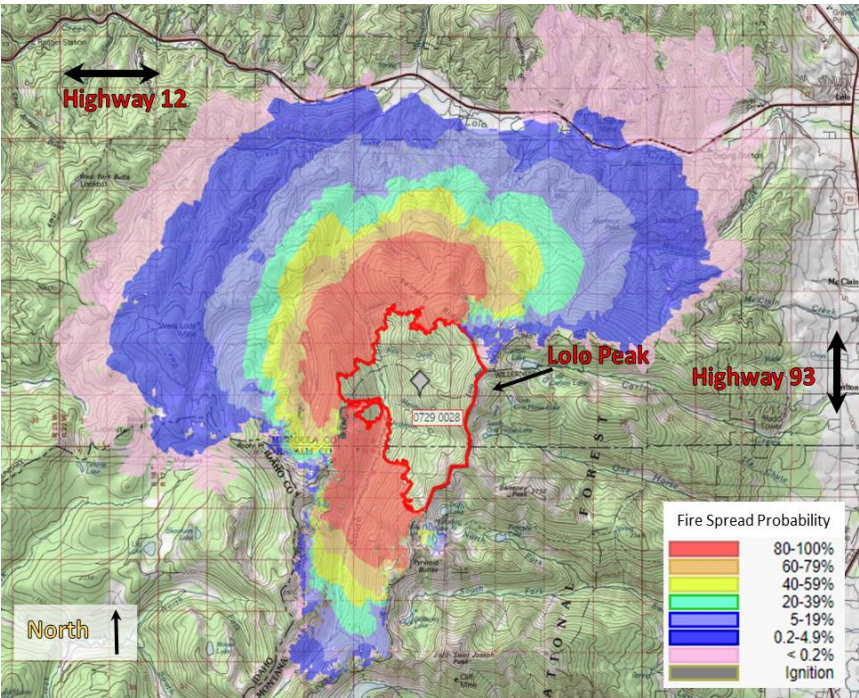
Wind speed and direction, modeled from observations on the afternoon of July 20, 2017, are overlaid on the topography. This view looks west into the Bitterroot Mountains. While fires usually tend to spread uphill, the alignment of westerly winds with east-west drainages could favor fire spread downstream in the Lolo Creek drainage (along Highway 12) and downhill from the ridge tops (toward Highway 93).

Model runs indicate that these influences on fire growth will probably continue. Moistures of both live and dead fuels are critically low as we enter the month of August, which is the historical peak of the fire season in the northern Rocky Mountains.

Use of Fire Spread Probability Model

The Fire Spread Probability model (FSPro) helps managers establish priorities for fire management. FSPro is based on analyses of historical climate data and weather forecasts for a specific area, current fire growth, and past experience – especially experience of large fire growth in the area. FSPro compiles a variety of scenarios and then models fire growth for thousands of possible combinations of conditions. Using FSPro, we identified the probability of specific fire spread patterns, and also the likelihood of rare events that could have important consequences, from July 29 to the current date - August 4, 2017. The map on the next page shows the results*, based on analysis of the fire’s previous growth, weather, and previous experience in the northern Rocky Mountains.

* The following assumptions and caveats were applied: The model runs did not include suppression actions. We used Highway 93 as a barrier to fire spread. We altered fuels based on results of on-the-ground measurements. We used the “Scott and Reinhardt” approach to modeling crown fire. We did not include extreme wind events, because this was done in separate analyses.



Red outline at the center of the map shows fire perimeter on July 29, 2017. Colored areas show probabilities of fire spread from that date to August 4. These results were calculated from thousands of iterations of the FSPro model. As conditions change and new forecasts are obtained, fire managers will develop new FSPro model runs to help them plan the location of control lines, use of retardant and water drops, and timing of burnouts. Model runs will also help managers anticipate days of large fire growth – when evacuations and removal of crews and equipment might be needed.

conditions usually don't occur until late August. Model results suggest a high probability that the fire will become established in the Lolo Creek drainage and move to the east and northeast towards developed areas along Highway 12 and the town of Lolo. *Once the fire is established in the Lolo Creek drainage, alignment of the drainage with the prevailing westerly winds will tend to increase rates of spread and push the fire eastward more rapidly.* Additional spread to the south (further into the Selway-Bitterroot Wilderness) and west is also likely.

As of this time, the fire has not become established east of the Bitterroot Divide. Discontinuous fuels along the crest of the Bitterroot Mountains may prevent this. However, the high-elevation forests have abundant subalpine fir trees, which produce massive quantities of firebrands when they ignite. *A significant wind event or outflows from thunderstorms could cause the fire to crown in subalpine fir forest, then spot over the Divide and become established on the eastern side of the Bitterroot range, in the main Bitterroot River drainage and the Highway 93 corridor.*

FSPro model results helped us identify criteria for days when the fire could grow rapidly in future weeks. **A combination of three or more of the following conditions sets the stage for a day of large fire growth:**

1. Sunny skies (intense solar radiation)
2. Temperature > 85° F
3. Relative humidity < 20%
4. Very dry and sometimes turbulent atmosphere
5. Wind speeds > 10 mph (measured 20 ft above the ground)

Conclusions

Fuels are extremely dry for the last week in July; such dry burning



Unit IV.
Fire Effects on the Environment



11. Smoke from Wildland Fires

Lesson Overview¹: This activity helps students learn how smoke from wildland fires can reduce visibility, degrade air quality, and threaten human health. They look for patterns in data on weather and air quality from a wildland fire that occurred in 2017. They explain patterns in the data by applying the concepts of inversions and stable vs. unstable air. Then they use their knowledge to develop an editorial for a newspaper or news blog that makes recommendations to specific groups (citizens, health experts, fire managers, etc.) about what to do regarding smoke from wildland fires.

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

Duration: 2-3 class periods

Group size: Many options, from individual to whole class

Setting: Classroom

Vocabulary: *inversion, particulate matter, PM2.5, stable/unstable air, thermal belt, turbulence*

Lesson Goal: Increase students' understanding of the nature of smoke from wildland fires, how it disperses - and doesn't, how it affects human health, how it might be minimized, and how people might be better able to live with it.

Objectives:

- Students understand the composition and health impacts of smoke from wildland fires.
- Students understand how temperature inversions affect smoke dispersal.
- Students can use weather data to predict air quality.
- Students can identify actions that might reduce smoke from wildland fires or help reduce the adverse health impacts of smoke.

¹ Thanks to the following experts who provided data, photos, and suggestions for this lesson: Sarah Coefield (Air Quality Division, City-County Health Department, Missoula, MT) and Faith Ann Heinsch and LaWen Hollingsworth (USDA Forest Service, Missoula Fire Sciences Lab, Missoula, MT). Thanks to the Helen Riaboff Whiteley Center at the University of Washington's Friday Harbor Laboratories for hosting part of this work.

Standards:		9th	10th	11th	12th
Common	Reading Informational Text	2, 4, 10		2, 4, 10	
	Writing Standards	2, 4, 8, 10		2, 4, 8, 10	
	Speaking and Listening Standards	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3		1, 2, 3	
	Reading Science/Technical Subjects	1, 2, 4, 9, 10		1, 2, 4, 9, 10	
	Writing Science/Technical Subjects	2, 4, 9, 10		2, 4, 9, 10	
NGSS	Earth's Systems	ESS2.D			
	Earth and Human Activity	ETS1.B, ESS2.D, ESS3.B			
EEEEGL	Strand 1	A, B, C, E, F, G			
	Strand 2.2	A, C			

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 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. Smoke produces some benefits to ecosystems (for example, by stimulating seeds of some species to germinate²). When people are exposed to dense smoke, however, it becomes hard to breathe and can cause long-term damage to the lungs. Dense smoke is especially dangerous for babies, older adults, and anyone with respiratory illnesses (such as asthma) or heart disease.

For technical information on smoke from wildland fires and smoke dispersion, go through the presentation and notes in the PowerPoint presentation (*H11_SmokeRiceRidge.pptx*) shown below. Also view the YouTube video demonstration linked from **Slide 21** (<https://www.youtube.com/watch?v=LPvn9ghVFbM>).

This activity uses a lot of data. Students are asked to interpret 24-hour data on temperatures, wind speeds, and particulate matter for 57 days in the summer of 2017. This constitutes nearly 14,000 data points! Note that the time of day is expressed on a 24-hour clock, rather than the a.m./p.m. clock that students may be used to. That is explained in Slide 4, where it first occurs. The presentation below provides a systematic way for the class to analyze and interpret the data, but an alternative method would be to examine the data in the spreadsheet itself (*H11_SmokeRiceRidge.xlsm*) – either together as a class, or as a challenge for students to do on their own. No matter which approach you use, we suggest supplementing the data-heavy material with at least one experimental demonstration (two are suggested in **Slide 21** of the presentation) and using occasional kinesthetic (“acting-out”) demonstrations as well.

² See this short article from *Chemical and Engineering News*: <https://cen.acs.org/articles/82/i28/SMOKE-SIGNALS.html>.

Color clues: We used a consistent color scheme on graphs in both the data file and the PowerPoint file to help distinguish different kinds of data:

- a. Air quality graphs are in multiple colors to follow the color scheme used by the Montana Department of Environmental Quality in their recommendations for outdoor activities based on air quality (<http://deq.mt.gov/Air/SF/breakpointsrevised>).
- b. Temperature graphs go from gray tones (representing cold to cool temperatures) to red tones (representing warm to hot temperatures).
- c. Wind speed graphs go from gray tones (representing low wind speeds) to lavender to purple to dark blue (representing very high wind speeds).
- d. In 2-dimensional graphs, data from the Seeley Lake Airport are shown with solid black lines and square symbols; data from Point 6 are shown with dashed black lines and triangular symbols.
- e. Where the PowerPoint demonstrations use data from **RiceRidgeData.xlsm**, the PowerPoint notes show the Excel worksheet where the data are located [boldface purple font in square brackets].

Looking for a less data-heavy alternative to this lesson? Use Activity M09. Smoke from Wildland Fire: Just Hanging Around?

Preparation and materials:

1. Download **H11_SmokeRiceRidge.pptx**. If you plan to teach directly from the presentation, go through it a couple of times so you know how to pace the slides – especially those that contain animation.
2. If you plan to teach directly from the spreadsheet, download it (**RiceRidgeData.xlsm**). When you open the file, you may get 1-2 warnings – click “enable” for both. This will allow the macros and programs embedded in the file to operate. Then edit the PowerPoint presentation (**H11_SmokeRiceRidge.pptx**) to just a few slides so you can provide students with background information. To navigate the many worksheets in the Excel file, use references provided in the PowerPoint. (As mentioned above, each slide taken from the Excel file contains a reference to the worksheet where the data are located [denoted in boldface purple font within square brackets]. If you plan to have students explore the spreadsheet data on their own, you can select some questions from the PowerPoint presentation to guide their work.
3. Decide how to demonstrate an atmospheric inversion in your class. See **Slide 21** in the PowerPoint presentation. You can either:
 - Watch a 2:49-minute video about inversions by clicking on the link in the upper-left photo (<https://www.youtube.com/watch?v=LPvn9qhVFbM>). The video is about winter air quality in Denver, but the principles apply perfectly to smoke dispersion from wildland fires.--OR--

- Create a live demonstration using the instructions described in **H11_InversionDemonstration_Boiling-vs-Ice.pdf** (illustrated in the lower-right photo on the slide). *Use the thermocouple thermometer in the FireWorks trunk. Make sure it has a working battery.*
4. Download the **Smoke Information Packet (SmokeInformationPacket.zip)** and decide how to make it available to students for the **Assessment**.
 5. Print 1 copy of **H11_TargetAudiences.pdf** to use in the **Assessment**.
 6. Decide if you want to use kinesthetic activities to help students better understand patterns of temperature, air quality data, and inversions. We highly recommend doing so! Here's one way to do it:

Print signs for the 24-hour clock (**24hourClock.pdf**). Post them across the front of classroom so midnight (0:00) is at the far left and at the far right, noon (12:00) is in the middle, and the other hours are posted between. Whenever you are examining a 2-dimensional graph in the presentation (for example, **Slides 4, 9, and 15**), ask a student to move from left to right across the front of the room, showing the height of the data on the graph at each point in time. This could get more complex – or more ridiculous – as you proceed through the presentation. For example, when temperature inversions are first shown (**Slide 17**), one student might hold a square symbol and another student hold a triangle to show the relationship between temperatures at different elevations. When wind and particulate data are shown along with temperature data (**Slides 24 and 29**), another student might be included to show the interrelationships of the variables.

7. After you have read through the PowerPoint presentation, decide if you want to use the **SUPPLEMENT: EXPLORE MORE DATA, BECAUSE IT'S MORE COMPLICATED** at the end of this lesson, either with the whole class or as a challenge to individual students. The SUPPLEMENT describes the difference between inversion patterns at Seeley Lake Airport and Seeley Lake Ranger Station, which is about 260 feet lower in elevation than the airport and located on the shore of the lake (rather than inland about 2 miles, where the airport is located). It is not a full lesson plan, but you can use graphics in **H11_Supplement.pptx**, and/or work directly with the data in **RiceRidgeData.xlsx**. Objectives, standards, and assessment are not provided for this supplement³.

Procedures: Go through **H11_SmokeRiceRidge.pptx**. Black text shows content or questions for the teacher to present. **Red text shows content that (we hope) will emerge from students' answers and discussion.** [Purple text and square brackets show information for the teacher.

³ In addition to the data used in this lesson, **RiceRidgeData.xlsx** contains data on temperatures at the Seeley Lake Ranger Station; average wind speeds at the Seeley Lake Airport and Point 6; temperature and PM2.5 data from the same time period in Missoula, MT; and calculated inversion data for Missoula (Point 6 minus Missoula airport). If you have a couple of data geeks in your class, the file provides many opportunities to explore.

This information includes – for slides that contain graphs – a reference to the worksheet in [RiceRidgeData.xlsm](#) where the data can be found.]

Slide 1



Explain: Look at these headlines. All of them are related to the 2017 “fire season” in western Montana, when dozens of large fires were burning and pumping smoke into the mountain valleys.

Smoke from wildland fires can be a tremendous problem for western communities. Let’s learn how something this serious can occur, and then we’ll think about what can be done about it.

Slide 2



We’ll study the weather and smoke from the fire that triggered those particular headlines – the Rice Ridge Fire. The fire was started by lightning on July 24, 2017, just a few miles from the little town of Seeley Lake, Montana (population 1,659). Seeley Lake is in a very appealing location: It is in a deep mountain valley alongside a beautiful, clear lake. The

downtown has a charming rural feel. The area has plenty of wildlife, hunting opportunities, and snow sports. It also has a thriving, progressive lumber mill. The photo on the right shows Seeley Lake’s main street on an ordinary day in late winter.

Slide 3



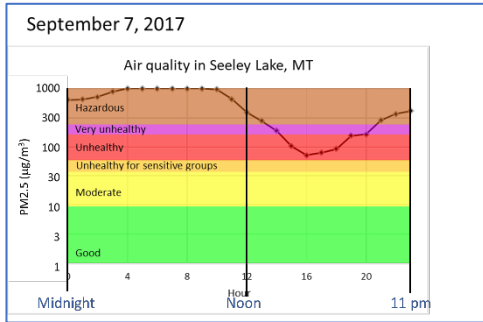
Here’s the same street during the fire, which eventually burned about 160,000 acres (240 sq mi, 630 sq km). Can you picture how big an area that is? (Use the scale of miles in the lower right corner.) Calculate: If the fire burned in a perfect square, how big would it be on each side? **It would be about 15 miles along each side.**

The Rice Ridge Fire was only one of dozens of large fires that burned in the northern Rocky Mountains during the summer of 2017 and contributed smoke to the Seeley Lake area.

As the photo shows, smoke from the fires reduced visibility. At times when the smoke layer was really deep, it probably looked from above like the photo in the lower left (which shows smoke from wildfires in California during 2018). If the smoke was stuck mainly in the valleys, it would have looked like a gray stream flowing down the drainages – like the photo in the lower right (which shows the Bitterroot Valley in

western Montana in September 2012). Either way, the air in the valleys was full of smoke. Just how bad was the air quality in Seeley Lake?

Slide 4



This graph shows the air quality on one of the worst days during the fire. What is on each axis? The horizontal axis shows time: It uses a 24-hour clock, so it goes from 0:00 (midnight) on the left through 12:00 (noon) in the middle, to 23:00 (11:00 pm) on the right. The vertical axis is color-coded to show categories of air quality. These are based on the effects of pollution on people’s health: The scale goes from “good” (green) at the bottom to terrible - “hazardous” – (brown) at the top.

Why does the graph level off at the top? That’s because the amount of smoke in the air was greater than what the recording instruments could measure. (Note that the measurements are shown on a logarithmic scale, so we can see very small values and very large ones on a single graph.) [Tab 1. Interactive plot 1 or Tab 8. SeeleyPM2.5 in RiceRidgeData.xlsm.]

Slide 5

PM2.5 (µg/m³)

Weight of Particulate Matter less than or equal to 2.5 microns across, expressed in micrograms (µg) per cubic meter (m³)

Picture a cubic meter:

How big is 2.5 microns (micrometers)?

What exactly is PM2.5? It is the weight of very tiny particles in 1 cubic meter of air. How tiny? PM2.5 particles are smaller than 1/20th the width of a human hair!

Slide 6

Visibility and Recommendations for Outdoor Activities Based on Air Quality
(<http://deq.mt.gov/Air/DEQ/healthinfo/revise/>)

Health Effects Category	Visibility (miles)	Health Index (0-10)	Health Effect	Caution - Recommendation
Good	7.0 or More	1	Little or no effect on the respiratory system. Healthy people with no respiratory disease, children, and people with chronic respiratory disease can engage in outdoor activities.	Enjoy the health benefits of outdoor activities. Continue with your normal outdoor activities. People with chronic respiratory disease should consult their physician before engaging in strenuous activities.
Very Unhealthy	2.1 - 3.7	5	Exacerbation of respiratory disease and potential for acute respiratory distress. People with chronic respiratory disease should consult their physician before engaging in outdoor activities.	People with chronic respiratory disease should avoid strenuous outdoor activities. People with acute respiratory distress should seek medical attention.
Unhealthy	3.7 - 5.0	4	Exacerbation of respiratory disease and potential for acute respiratory distress. People with chronic respiratory disease should consult their physician before engaging in outdoor activities.	People with chronic respiratory disease should avoid strenuous outdoor activities. People with acute respiratory distress should seek medical attention.
Unhealthy for Sensitive Groups	5.0 - 6.4	3	Exacerbation of respiratory disease and potential for acute respiratory distress. People with chronic respiratory disease should consult their physician before engaging in outdoor activities.	People with chronic respiratory disease should avoid strenuous outdoor activities. People with acute respiratory distress should seek medical attention.
Moderate	6.4 - 8.0	2	Exacerbation of respiratory disease and potential for acute respiratory distress. People with chronic respiratory disease should consult their physician before engaging in outdoor activities.	People with chronic respiratory disease should avoid strenuous outdoor activities. People with acute respiratory distress should seek medical attention.
Good	8.0 or More	1	Little or no effect on the respiratory system. Healthy people with no respiratory disease, children, and people with chronic respiratory disease can engage in outdoor activities.	Enjoy the health benefits of outdoor activities. Continue with your normal outdoor activities. People with chronic respiratory disease should consult their physician before engaging in strenuous activities.

In Seeley Lake, “hazardous” levels of PM2.5 occurred during 39 days out of 44 between August 1 and September 13, 2017. During that month and a half, there were only 5 days (44 minus 39) without any hours of hazardous air quality!

What are some of the consequences of “bad air” for human health? How would Seeley Lake’s smoke affect people’s lives? In particular, how would it affect students’ lives? Use the chart to consider effects on students, infants, sick people, elderly people, outdoor laborers, firefighters, and any other categories you can think of.

Slide 7

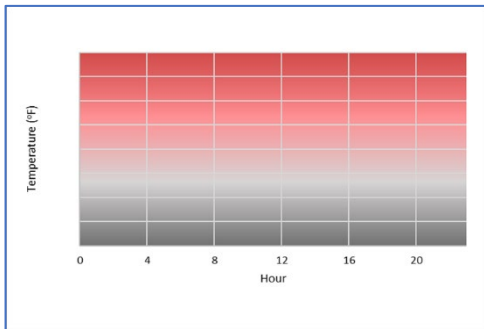


Here are some ways the smoke affected school kids.

To understand how smoke can get to be such a problem, we have to look at weather patterns. We'll study weather records from the Seeley Lake area from July 19, 2017 (a few days before the Rice Ridge fire started) through September

14 (after which fires throughout the area did not spread much). Then we'll connect patterns in weather data to patterns in smoke data. Finally, we'll read the articles behind the headlines that we read in the 1st slide and develop some recommendations on what to do about smoke from wildland fires in the future. [The full articles are available in the folder [ArticlesOnSchoolsAndSports](#).]

Slide 8

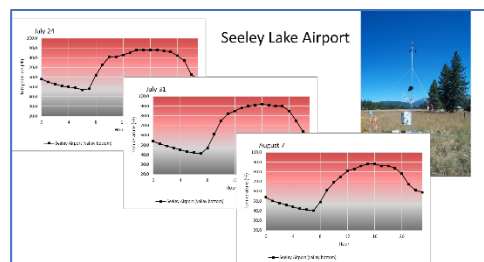


Let's start with what we know about daily temperatures. What do you expect the temperature pattern to be every day in the middle of summer – let's say, from midnight to midnight? The graph shows cold temperatures in gray tones and warm-to-hot temperatures in red tones.

The vertical axis – *Temperature* – isn't labeled.

What should the range of temperatures be along that axis? (20 to 100 °F is a good range for summer.) **Get students to describe the temperature pattern to expect in a typical 24-hour cycle. Have them sketch the pattern they expect. Make sure they label the axes. We expect temperature to generally be cool at night, warm up through most of the day, and cool down at night.**

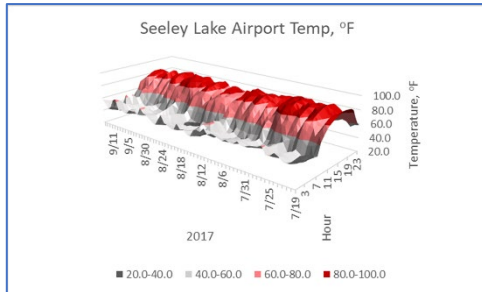
Slide 9



Let's see if the data actually support our predictions. Here's a 3-day sample of temperatures measured near the local Seeley Lake airport. The Rice Ridge Fire started on Monday, July 24. These graphs show the temperature each Monday during the first three weeks of the fire. Do you see the daily

pattern that you expect? **Yes, it was cool at night and warm in the daytime.** But we're only looking at 3 days. Do you think that pattern was consistent throughout the summer? [Tab 1. [Interactive plot 1 in RiceRidgeData.xlsm](#)]

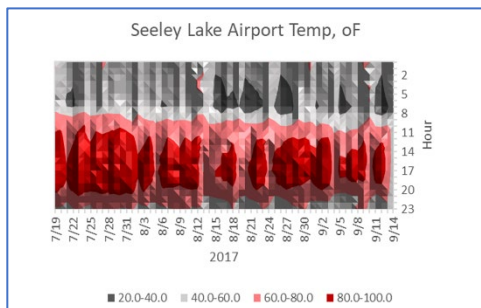
Slide 10



We can use this 3-dimensional graph to answer that question. What are the axes? Read the dates from the front corner (7/19) to the back left corner (9/14). Read the hour of the day from the front corner (midnight) to the back right corner (23:00).

The vertical axis – that is, the height of the surface – shows the temperature at a particular date and time. The colors on this 3-dimensional “surface” help us read the vertical axis. They use the same general colors that were used in the last slide: gray tones for cool, red tones for warm to hot. Can you find an especially cold time? Sometime around August 20, there’s a dark gray patch in the early morning; that must have been below 40. What time of day is usually hottest? Around 16:00, give or take a couple of hours. [Tab 3. SeeleyAirptTemp in RiceRidgeData.xlsm]

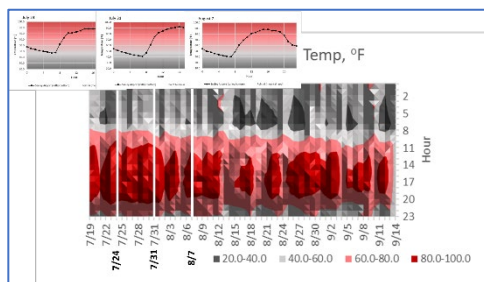
Slide 11



Let’s rotate the graph so we can look at it from above. Then we can pinpoint the cold periods more easily. We can read it like a topographic map, where dark gray shows the coldest temperatures and bright red shows the hottest. Identify the cold periods. There are several cold (dark gray) patches in the early mornings between August 14 and September 14.

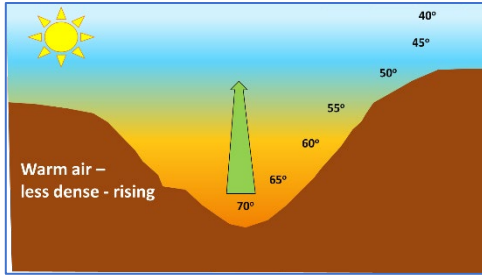
Can you find a couple of days when the temperature never reached 80 °F? August 5, August 13-14, and the last two days recorded, September 13-14. The color for these days is pink but there’s no red. [Tab 3. SeeleyAirptTemp in RiceRidgeData.xlsm]

Slide 12



Can you see how the temperature graphs that we looked at earlier – the ones that show temperature patterns on 3 Mondays - are just 1-day “slices” from this whole surface? [Tab 3. SeeleyAirptTemp in RiceRidgeData.xlsm]

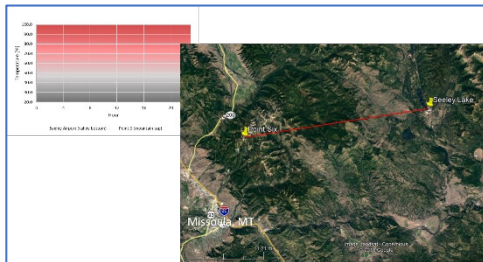
Slide 13



Why is the heating-cooling pattern so strong? Use what you know from our study of heat transfer (**Activity H04**) to explain. **The pattern is caused by convection. Radiation from the sun warms the earth during the day, and the warm earth transfers energy to the air lying on top of it. As the surface air is heated, it expands, becoming less dense, and therefore it rises until**

it reaches an elevation where its density (temperature) is the same as that of the surrounding air. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude.

Slide 14

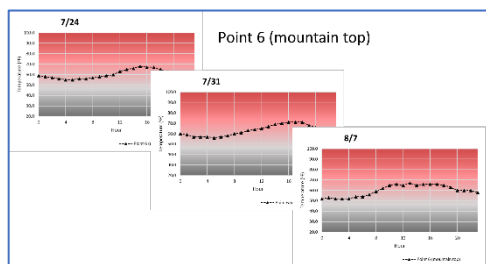


Would you expect the same temperature pattern on a mountaintop? **The pattern of cool nights and warm days should be similar. However, because air cools as it rises, mountain tops tend to be cooler than valleys on hot summer days.** Sketch it on a graph.

Let's see what the data show from a weather station at a higher elevation. We're going to look at daily temperatures measured at a mountaintop about 25 miles from Seeley Lake. It is called Point 6. The elevation at Seeley Lake Airport is 4256 ft; the elevation at Point 6 is 7920 ft.

[Note: This presentation often refers to data from Seeley Lake Airport as just "Seeley Lake data", even though there are data on file from a second weather station in the area, the Seeley Lake Ranger Station. See the **SUPPLEMENT: EXPLORE MORE DATA, BECAUSE IT'S MORE COMPLICATED** at the end of this lesson.]

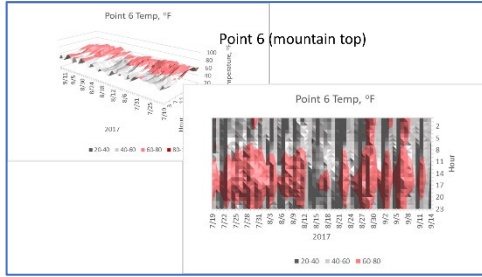
Slide 15



Here are the temperature patterns from Point 6 for the same 3 Mondays we looked at earlier. Ask: Do the data support your predictions? Explain why or why not. **Yes, they probably do...** Do you think the pattern was consistent throughout the "fire season" – when the Rice Ridge Fire and many others were burning in the region? **Let's see. [Tab 1. Interactive plot 1 in**

RiceRidgeData.xlsx]

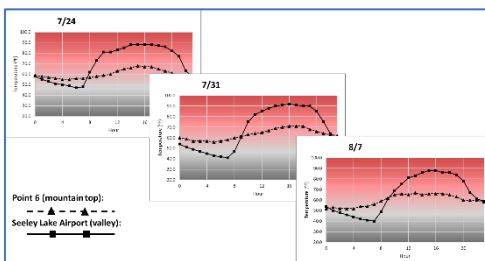
Slide 16



Here are the temperature data from the mountain top – Point 6 - throughout the fire season. Is this what you expected? Do you see any surprises? **The cooler-nights, warmer-days pattern is as expected. The fact that the mountain top doesn't get as hot as the valley bottom in the afternoons is as expected.** It may be surprising – or not noticed - that the daily

range of temperatures on the mountain top is less than in the valley bottom. [It's ok if it's not noticed, since it will come up soon. Data are in **Tab 4. Point6Temp in RiceRidgeData.xlsm**]

Slide 17

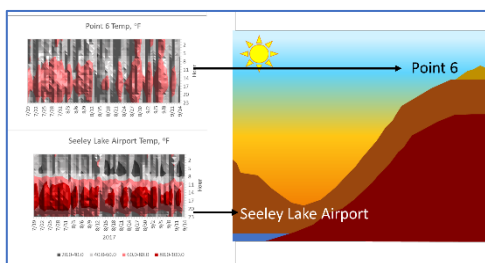


How are the temperature patterns at the mountain top (Point 6) and in the valley (Seeley Lake) related? These graphs show temperatures at the low-elevation Seeley Lake Airport (solid black line with squares) and the high-elevation Point 6 (dashed black line with triangles) for the same 3 Mondays we've been

looking at.

What do you notice about these data? Hint (if needed): Look at the morning hours. **For a fairly long time almost every night through morning, Point 6 is actually warmer than the Airport – even though it is more than 3600 feet higher in elevation. This event – when high elevations are warmer than low ones – is called an “inversion.”** How consistent do you think this inversion pattern is throughout the season? [**Tab 1. Interactive plot 1 in RiceRidgeData.xlsx**]

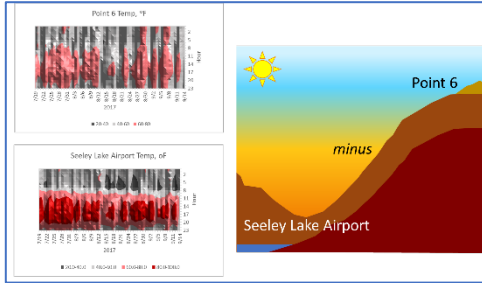
Slide 18



Here are the temperature data for the whole season from both elevations. The legend at the bottom refers to both graphs. (Review: Gray tones show cooler temperatures, and reddish tones show warmer temperatures.) Is the inversion pattern consistent? **Yes. The lowest temperatures occurred in the valley (Seeley Lake)**

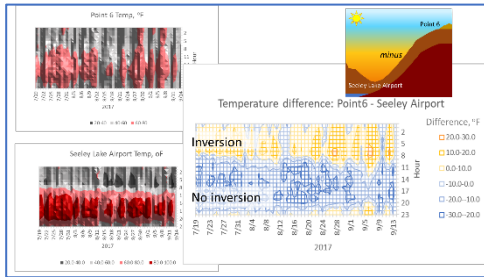
during the night and early morning. The dark gray patches show that the valley was often colder than the mountain top at night. The opposite was true in the afternoons and evenings: The highest temperatures (lots of bright red) occurred in the valley, while the the mountain top temperatures were cooler (pinkish but very little red). [Top: **Tab 4. Point6Temp in RiceRidgeData.xlsm**. Bottom: **Tab 3. SeeleyAirptTemp.**]

Slide 19



We can do the same comparison mathematically by subtracting every data point on the Seeley Lake graph from every data point on the Point 6 graph.

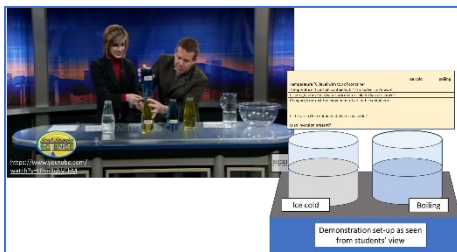
Slide 20



Here's the result – a new graph that shows the subtraction “answers”. Study the legend – what do the colors mean? **Orangeish colors show positive differences, when Point 6 (the mountain top) was warmer than Seeley Lake (the valley), and thus orangeish colors mean there was an inversion. Blue colors show negative differences, when Point 6 was cooler than Seeley Lake. Thus blue means there was no inversion.**

Describe the pattern in the data: **Inversions (when Point 6 was warmer – orangeish colors) occurred consistently between approximately midnight and 08:00. Non-inversions (when Seeley Lake was warmer – bluish colors) occurred consistently from late morning until about 22:00.** Is the pattern of nighttime inversions and daytime non-inversions (also called “mixing” or “ventilation”) consistent throughout the fire season? **Yes!** [Top: Tab 4. Point6Temp in RiceRidgeData.xlsm. Bottom: Tab 3. SeeleyAirtTemp. Right: Tab5. Point6-SeeleyAirport.]

Slide 21

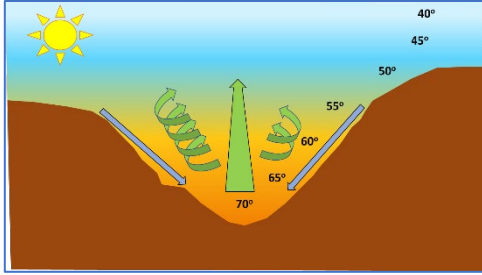


Inversions have some interesting effects. Let's look at a demonstration of actual inversions on a miniature scale.

EITHER

- Click on the link (upper-left photo) for a 2:49-minute YouTube video (<https://www.youtube.com/watch?v=LPvn9ghVFbM>) about inversions from “Steve Spangler Science” in Denver, CO. The video is about winter air quality in Denver, but the principles apply perfectly to smoke dispersion from wildland fires. ... **OR** ...
- Create a demonstration yourself. Use the instructions described in **H11_InversionDemonstration_Boiling-vs-Ice.pdf**, which uses temperature measurements in containers of frozen and boiling water to illustrate inversions.

Slide 22

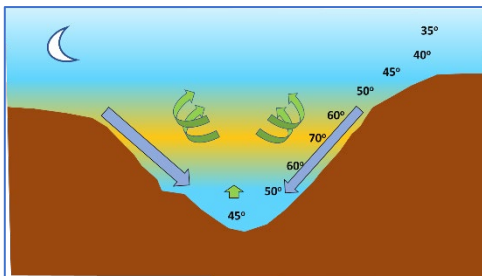


Why do inversions occur? Use what you know about the earth, the sun, and gravity to explain. As we saw in an earlier slide, air in the valley bottom rises due to convection. It stops rising when it reaches the same temperature (density) as the air around it. But cool air is denser than warm air, and denser (heavier) stuff tends to flow downhill due to gravity. So

while convection is lifting air upward during the day, cooler air from above is flowing into the valley to replace it. During the daytime, that cool air is in turn heated and rises. Meteorologists say a lot of “mixing” or “ventilation” occurs during the day, and the rising air can be quite turbulent.

Ask: How would you expect that turbulence to affect fire behavior and the use of aircraft to manage fires? Expect more rapid fire spread, possibly in any direction. Expect increased danger for aircraft or conditions that are too turbulent for flying.

Slide 23

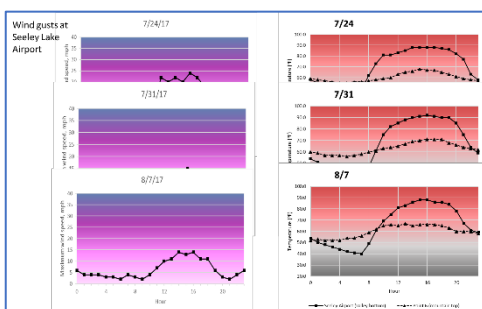


At night, convection slows down and may even stop. The wind might be strong and gusty in the evening, but it usually slows down right at sunset. The cool (dense) air from above does not stop moving though. It continues to sink into the valley. Without the sun’s warmth, mountaintop air cools quickly and increases the downhill flow. Throughout the night, this cool

air pools in the valley bottom, causing an inversion. The layer of cool air gradually displaces the warm air. It lifts the warm air just as you lift your blankets when you crawl into bed. The layer of warm air above the valley bottom is called the “thermal belt”. Mixing and turbulence continue in the thermal belt, but – because of the inversion - the air at the valley bottom accumulates and stays put until it can be heated up in the morning. Meteorologists say the valley-bottom air is “stable”.

We might say that mountain valleys “breathe” once a day: They inhale slowly during the night and then make a giant, powerful exhale during the day. Let’s see if we can find that pattern in the wind data from the summer of 2017.

Slide 24



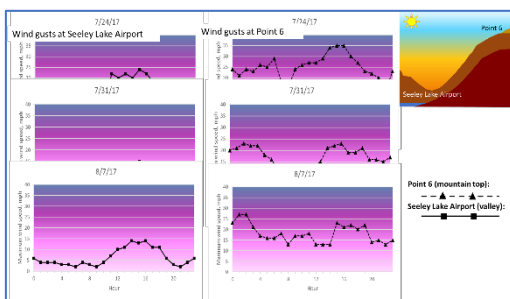
The first graph shows the strongest wind gust (gust: “a sudden brief rush of wind”) recorded every hour on July 24 at the Seeley Lake Airport. Next... here’s the temperature/ inversion pattern for that day. Is the wind pattern consistent with how inversions work? Yes: At the airport, we should see stable air in the nights and mornings – that is, we should

see light breezes but no strong wind gusts. Why? Because the mountain top is warmer than the valley bottom, so an inversion is occurring.

In the afternoons and evenings, we should see turbulence – gusty winds - at the airport. Why? Because Seeley Lake is warmer than the Point 6 mountaintop at that time of day, so no inversion is occurring.

Next look at data for 2 more Mondays. What do you see? Is the pattern consistent? Yes. Now... what pattern in wind gusts do you expect in the Point 6 data? Inversions and nighttime cooling should have less influence; we should see turbulence both day and night. [Tab 2. Interactive plot 2 in RiceRidgeData.xlsm.]

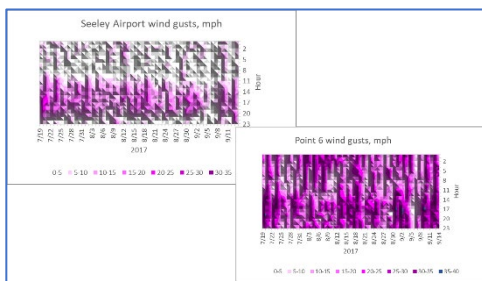
Slide 25



Compare the wind gusts in the valley – at Seeley Lake Airport (left, with data shown by solid lines and black squares) with wind gusts on the mountain top - Point 6 (right, with data shown by dashed lines and black triangles). What pattern do you see? We see much stronger wind gusts on the mountain top. Why? The air on the mountain top is

mixing with air from adjacent valleys, and it is also mixing with air high above the surface that's being pushed around by regional weather and air masses at high altitudes, so it can be pretty chaotic up there. The pattern of stable nights/mornings and turbulent afternoons/evenings is clear in the valley data. No such pattern occurs at Point 6. [Tab 2. Interactive plot 2 in RiceRidgeData.xlsm.]

Slide 26



How consistent were these wind patterns throughout the fire season? You can assess it in these 3-dimensional graphs, where white and gray show very low (or no) wind, shades of lavender show light to moderate wind, purple shows strong wind (a steady 20-mph wind has large branches in continuous motion*), and dark blue shows very strong wind (whole trees

in motion – or breakage occurring*). The nighttime stable/daytime turbulent pattern is pretty consistent at Seeley Lake (the valley) and pretty weak at Point 6 (the mountaintop). The only noticeable pattern at Point 6 is that the strongest wind gusts – shown in dark blue – occurred in the late afternoons and early evenings.

[*The verbal categories are based on information from <https://www.weather.gov/pqr/wind>. Note that, while we used wind gusts in the graphics here, average wind speeds for this time period follow the same pattern – it's just less dramatic.] [Top: Tab 11. SeeleyAirptGust in RiceRidgeData.xlsm. Bottom: Tab 13. Pt6Gust.]

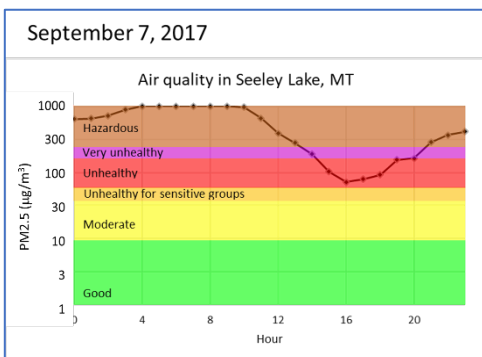
Slide 27



We've spent a lot of time learning about weather, but we started out trying to learn about smoke. Not only was the Rice Ridge Fire burning right next to Seeley Lake in the summer of 2017, but there were large fires in all of the northwestern states, as you can see in this satellite photo taken on September 4,

2017. Smoke was pouring into the Seeley Lake area from fires to the west. At this point, hundreds of square miles were burning in Montana, Washington, Idaho, and Oregon. Now let's look at air quality data.

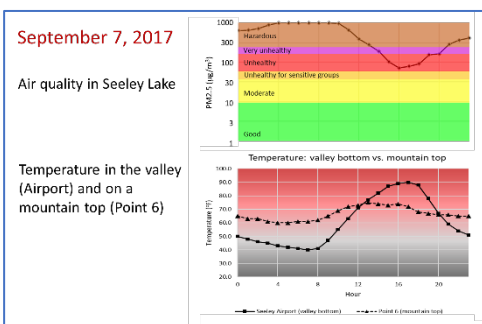
Slide 28



Remember this graph? It shows the air quality in Seeley Lake on September 7, one of the worst days during the summer of 2017. Now we have the knowledge to connect air quality data with weather patterns. What do you expect to the temperature pattern to be on this day, based on your knowledge of daily air flow patterns? **When there are high levels of particulates (night and early morning), there are temperature inversions in the valley.** **When the particulates decline in the afternoon, the valley is warmer than the mountaintop, the air is**

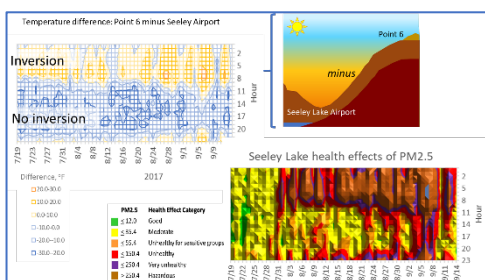
unstable, and no inversion is occurring. [Tab 8. SeeleyPM2.5 in RiceRidgeData.xlsm.]

Slide 29



Here's the air quality data we just looked at, along with the temperature pattern for the same day. Is this what you expected? **Probably yes... It looks like bad air quality is connected to inversions, as predicted.** Do you think the pattern was consistent throughout the fire season? [Tab 1. Interactive plot 1 in RiceRidgeData.xlsm]

Slide 30



Here are graphs of the inversion pattern and air quality for the entire season. The graph in the upper left is the one we looked at earlier. Review: How did we get that graph? **It was created by subtracting the Seeley Lake temperatures from Point 6 temperatures.** What do the colors mean? **Shades of yellow-to-orange show inversions (mountaintop warmer**

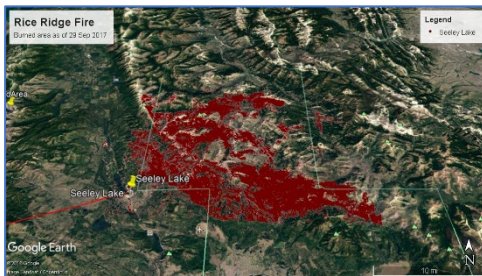
than valley, valley air stable) and shades of blue show good mixing (valley warmer than mountain top – no inversion – valley air turbulent).

Describe the relationship between inversions and smoke throughout the fire season: Valley “breathing” occurred throughout the season, and nighttime inversions were common even before fires began to produce large amounts of smoke (around the end of July). Then the air quality got worse nearly every day until early September. On most days, there was some relief from the smoke as the inversion “broke” in the late morning, the valley bottom became warmer than the mountaintop, and the valley winds increased. For a few days in early September – when inversions lasted until late morning or even noon – air quality stayed unhealthy or worse throughout the day.

Could smoke itself influence an inversion? Could smoke make an inversion worse? **Yes**, because the smoke can become so thick that it is hard for the sun's rays to reach the ground and heat it up. Thus smoke can increase the intensity and length of an inversion.

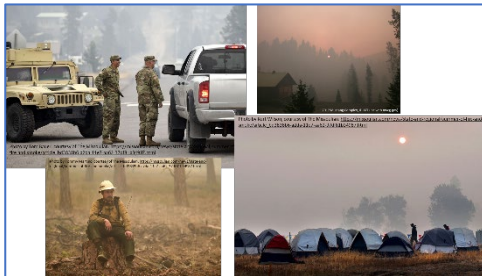
Why do you think the inversions (and bad air quality) lasted longer into the day as the season progressed? **The nights got longer and colder as summer turned to early fall. Thus time of year influences how long inversions stick around each day.** [Top: **Tab 5. Point6-SeeleyAirport** in **RiceRidgeData.xlsm**. Bottom: **Tab 8. SeeleyPM2.5.**]

Slide 31



So while the lightning-caused Rice Ridge Fire grew from a tiny spot to nearly 160,000 acres (240 sq mi, 630 sq km)... and dozens of fires poured smoke into the Seeley Lake valley...

Slide 32



... the people in the valley, including firefighters, were enduring air that looked like this.

Slide 33



And while the air might have been better for firefighters in the thermal belt on higher slopes and ridges, they didn't get much of a break from dangerous, gusty winds - even at night.

Slide 34



Can you think of some ways in which inversions might influence firefighting efforts? **Stable air at night (in valley bottoms) gives firefighters a chance to work close to the fire and make substantial progress in containing the fire, even though nighttime firefighting increases risks because of poor visibility, exhaustion, and lack of support from aircraft.**

Unstable, turbulent air in the thermal belt means that gusty winds may continue through the night. These conditions can be very hazardous for firefighters: The fire may spread

rapidly, and it could spot - igniting new fires (which will be harder to detect due to low visibility and lack of air patrol). Intense burning in the thermal belt could also cause debris to roll downhill into the quieter valleys, endangering firefighters below and possibly starting more spot fires, which could then spread uphill and entrap firefighters above.

Slide 35



With all of our knowledge about weather, smoke, and firefighting, we now return to the disturbing headlines that we saw at the start of this activity. What can be done about the smoke from wildland fires? We'll read the 5 articles connected to these headlines, and we'll also get some information from records made

by Incident Commanders on the Rice Ridge Fire and another 2017 fire nearby, the Lolo Peak Fire. Then we'll come up with recommendations for how to handle smoke when it occurs and how we might be able to prevent smoke from getting this bad, even if our fire seasons get longer and more areas are burned.

Assessment: This assessment can be done individually or in teams. We describe it here as a team effort.

1. Form 6 student teams. Give each team a copy of (or electronic access to) the 7 articles in the **Smoke Information Packet (SmokeInformationPacket.zip)**. Assign a “Target Audience” to each team (see list at right), and give them the row from your printout of **H11_TargetAudiences.pdf** that lists their audience.

General public. This includes people in “vulnerable groups” (infants, the elderly, and anyone who has asthma or other respiratory problems) and the people who care for them.
School administrators, teachers, and coaches
Fire managers, fire suppression staff, firefighters, and managers of wildlands
Health boards, air quality specialists
Doctors, counselors, other health-care providers, and managers of health-care facilities
Scientists

2. Explain: We’re going to write an editorial for a newspaper or blog. It will contain our recommendations on what to do about smoke from wildland fires. A good editorial is based on facts and ideas from experts, and we’re going to get that information from what you already know and from the articles in your **Smoke Information Packet**. Each team will make recommendations to a specific Target Audience. Your team’s audience is listed on the printout I gave you.

3. Explain: We will develop the heart of the editorial – the main content – first. Each team will write one paragraph addressing their target audience. When we’ve completed these “main-content paragraphs” we’ll put them all together and then develop an introduction section and a closing section. To develop the main-content paragraph for your target audience, follow these steps:

- a) Discuss and think about your assigned target audience. Brainstorm about how smoke affects them and what they might be able to do about smoke.
- b) Read the 7 articles. (Not every student in the team has to read all 7, but make sure every article gets read by a couple of students.) While you’re reading, keep your target audience in mind and make notes on anything that those people already do – or could do – or maybe could try – about smoke and long periods of inversions. **NOTE TO TEACHER:** If you intend to read students’ notes as part of the **Evaluation**, tell them that now.
- c) Get together as a team and list all of your ideas. You are not limited to what’s in the articles. You can be creative – health experts and managers need new ideas! From your list, write a paragraph to your Target Audience that starts with “We call on you to...” or “We challenge you to...” or “We ask you to...” or something like that. Your main-content paragraph must list at least 3 actions that could help reduce smoke, keep people safe during smoke periods and inversions, reduce smoke in the future, or improve people’s ability to deal with smoke from wildland fires.

4. When the teams have finished, have someone from each team read their paragraph to the class. Ask the class for suggestions on improving or adding to the paragraph.

5. Explain: A guest editorial is usually no more than 1000 words long. Have each team revise their paragraph, cut it down to 100-150 words, and hand it in. Then...

6. Explain: The readings in your **Smoke Information Packet** contained two guest editorials – one by professional counselor Nancy Seldin and one by scientist Doug Coffin. Look again at those articles. What are some important things that we should include in our introductory and closing paragraphs⁴? **A good way to begin is to identify yourself (“We are a group of high school students...”), explain why you are writing (“We are worried about...”), and explain your credentials (“We have studied...”).** A good conclusion should re-state the urgency of the problem and urge the audience(s) to take action.
7. Draft the introductory and closing paragraphs on the board with the class. Have a couple of student volunteers pull all of the paragraphs together and revise them to make a good, coherent essay, and submit it to a local newspaper or publish it on a website or blog. If you do not live in an area that experiences smoke from wildland fires, consider submitting your editorial to a newspaper in an area that does.

⁴ In April 2018, the *Missoulian* published guidelines for guest editorials and letters-to-the-editor in regard to political campaigns (see **GuestEditorials.pdf**); these guidelines can also be applied to the class’s writing project. The *Missoulian* is published in Missoula, MT, in the same county where the Rice Ridge Fire occurred, and is the source of many of the articles in the **Smoke Information Packet**.

Evaluation:

	Excellent	Good	Poor
Content – see Teacher’s Key to information from articles below.	Team used relevant information from article(s) or provided relevant suggestions based on other sound information	Team used information from article(s) or provided suggestions based on other sound information	Team did not use information from article(s) and/or provided suggestions that were irrelevant or without sound basis
Reading (if you are collecting and evaluating students’ notes)	Student read and took notes on more than required number of articles	Student read and took notes on required number of articles	Student read and took notes on fewer than required number of articles
	Notes were appropriate for target audience	Notes were somewhat appropriate for target audience	Notes did not fit target audience
Team discussion and writing	Participated fully. Showed leadership without dominating project.	Participated.	Did not participate.
Presentations	Listened respectfully. Contributed to discussion of at least 1 student presentation. Contribution showed careful listening.	Listened respectfully. Contributed to discussion of at least 1 student presentation.	Did not listen respectfully <u>OR</u> did not contribute to discussion <u>OR</u> contribution was not relevant to discussion.
Follow up writing	Helped revise team’s paragraph and finalize introduction or conclusion.	Helped revise team’s paragraph <u>OR</u> finalize introduction or conclusion.	Did not help with any of these efforts.

Teacher’s Key to information from articles

Audience	Potential ways to address problems with smoke and inversions ⁵
General public, including people in “vulnerable groups”:	<p>Prepare by having air filters in homes, schools, etc; by installing air filters in buildings’ heating/cooling systems (Coefield2). Know how to find out about air quality (Coefield2). Pay attention to air quality alerts and follow guidelines (Briggeman, Coefield1, Coffin, Seldin). Guidelines may include: Stay indoors (Briggeman, Coffin, Seldin). Stay in environments with clean air (Coefield1). Limit aerobic activity (Briggeman, Coffin, Seldin). Address climate change (Coffin, Seldin). Other ideas – not in articles: Support ecologically appropriate fuels management and use of prescribed fire. For vulnerable groups, before start of fire season, ensure medications are up-to-date.</p>
Schools administrators, teachers, coaches:	<p>Know how to find out about air quality (Coefield2). Pay attention to air quality alerts, follow guidelines (Briggeman, Coefield1, Coffin, Seldin). Find alternate locations for practice, games (Coefield1). Obtain HEPA filters (Coefield1). Install filtering systems in heating/cooling systems (Coefield2). Other ideas – not in articles: Plan alternatives to outdoor activities. If indoor air is smoky, cancel or postpone activities.</p>
Fire managers, wildland managers:	<p>Be alert for intense, dangerous fire behavior overnight in thermal belt (Inciweb). Plan to do without use of aircraft when smoke limits visibility (Inciweb). Take advantage of times when inversion reduces fire intensity in valley bottoms to use aggressive fire suppression techniques (Inciweb, Briggeman). Be alert for active fire spread under the thermal belt when inversion breaks up (Inciweb). Use ecologically appropriate “ecosystem management” (Coffin). Use prescribed fire to reduce fuels; these fires will produce much less smoke (Chaney). Other ideas - not in articles: Plan to do without use of aircraft when smoke limits visibility. Be alert for active fire spread under the thermal belt when inversion breaks up. Reduce fuels without using prescribed fire.</p>
Health Boards, Air quality specialists:	<p>Keep everyone informed. Send out info 1-2 times/day, if needed (Coefield1, Briggeman). Educate people about fire and smoke (Coefield1,2). Advise people and institutions to have filters and replacement parts on hand (Coefield1,2). Provide air filters for loan to vulnerable groups (Coefield1). Encourage installation of air filtering in heating/cooling systems as buildings are designed (Coefield2).</p>

⁵ Names in parentheses refer to the author or source of the article in the **Smoke Information Packet**.

<p>Doctors, counselors, other health-care providers:</p>	<p>Advise patients to pay attention to understand visibility index and air quality alerts and to follow guidelines (Briggeman, Coefield1 and 2, Seldin). Watch for depression and help patients find ways to cope with it (Seldin). Equip clinics, hospitals, and nursing homes with HEPA filters (Coefield1). Install air filtering in heating/cooling systems (Coefield2). Other ideas – not in articles: Contact vulnerable patients at start of fire season to help them prepare. Seek financial help for medications for vulnerable patients.</p>
<p>Scientists:</p>	<p>Find out what information on smoke and dispersal is needed to protect health (Coefield1). Investigate what firefighters need to know to stay safe in thermal belts and when inversions break up (Chaney, Coefield1). Investigate long-term health impacts of prolonged exposure to smoke (Chaney, Coefield1). Other ideas – not in articles: Investigate what information fire managers need to take advantage of inversions for fire suppression. Investigate best practices for ecologically appropriate forest and fuel management.</p>

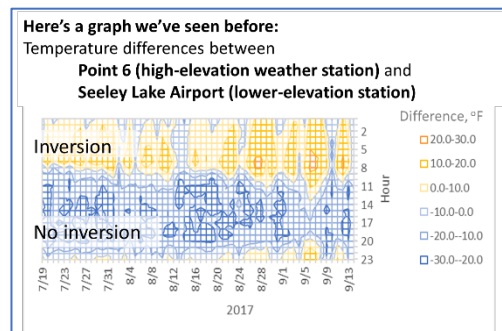
SUPPLEMENT: EXPLORE MORE DATA, BECAUSE IT'S MORE COMPLICATED

One aspect of Seeley Lake meteorology not covered in the lesson above probably complicated the smoke situation in the valley and could have made it worse: The very lowest layer of air in the valley, the 260 or so feet between the level of the airport (4256 ft) and the level of the lake (3993 ft elevation) had an inversion pattern that was *opposite the pattern at the airport*.

You can use the presentation below ([H11_Supplement.pptx](#)) to help students see the two inversion patterns, that is, the two simultaneous daily “breathing” patterns in the Seeley Lake valley during the summer of 2017. It is possible that the midday inversion at the very bottom of the valley reduced the possibility that daytime convection could clear smoke out of the valley in the afternoons. *Did the warm nights and cool days along the lake exacerbate the already dismal air quality in Seeley Lake that year?* The final slide in the presentation points out that particulate data from higher elevation(s) would be needed to figure that out.

You can explore the data further in [RiceRidgeData.xlsm](#), which contains a lot of other data too: average wind speeds at the Seeley Lake Airport and Point 6; temperature and PM2.5 data from the same fire season in Missoula MT; and additional inversion calculations. **NOTE:** When you first open the data file, you may get 1-2 warnings – click “enable” for both so the embedded macros and programs will work.

Slide
1



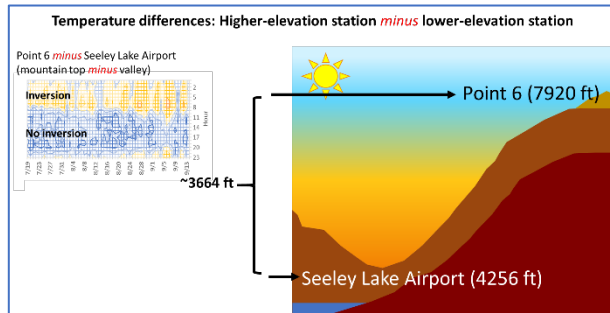
Here's a graph that we looked at in the main part of the lesson (**Slide 20** from [H11_SmokeRiceRidge.pptx](#)). It shows the pattern of daily inversions in the Seeley Lake area during the Rice Ridge Fire. Review: What do the colors mean?

Orangeish colors show positive differences, when Point 6 (the mountain top) was warmer than Seeley Lake (the valley bottom); thus orangeish colors indicate inversion conditions, when the air was stable, trapping any pollutants. Blue colors show negative differences, when Point 6 was cooler than Seeley Lake; thus blue means there was no inversion during those hours and the air was unstable, “mixing” well, enabling the valley to “breathe.”

Review the pattern in the data: **Inversions (when Point 6 was warmer – orangeish) occurred consistently between approximately midnight and 08:00. Non-inversions (when Point 6 was cooler – bluish) occurred consistently from late morning until about 22:00.** Is the pattern of nighttime inversions and daytime non-inversions (also called “mixing” or

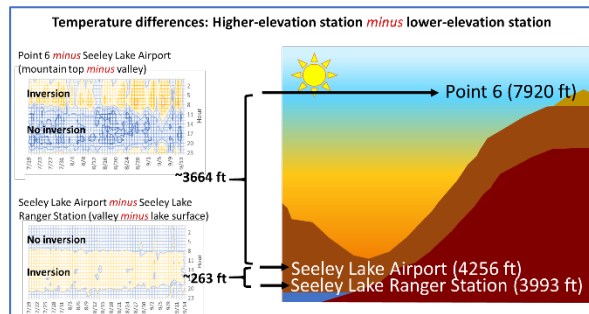
“ventilation”) consistent throughout the summer, even before the Rice Ridge fire got big? **Yes!** [Tab 5. Point6-SeeleyAirport in RiceRidgeData.xlsm]

Slide
2



Here you can see the range of elevations where those inversions occurred each night. Point 6 is more than 3600 feet higher in elevation than the Seeley Lake Airport. (It is also about 25 miles away “as the crow flies.” That is the nearest dataset from a high elevation site that was available for this activity.)

Slide
3

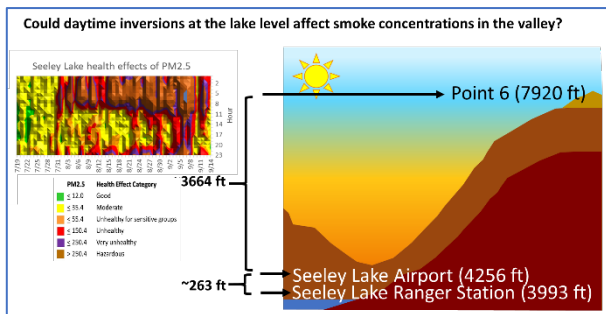


Let’s consider some additional data. The lower graph shows the daily temperature pattern in the layer of air that lies between the Seeley Lake Airport and the Seeley Lake Ranger Station, which is about 260 feet lower and right on the edge of the lake (while the Airport is about 2 miles inland) [Tab 7. SeeleyAirport-SeeleyRS in RiceRidgeData.xlsm].

What’s the inversion pattern in this bottom layer of air? **Temperature changes were less dramatic in this layer of air than in the layer above, and inversions occurred during the day, not at night. The inversion pattern is opposite that in the air above the airport.** These two inversion patterns occurred simultaneously each day of the summer, before and during the Rice Ridge fire.

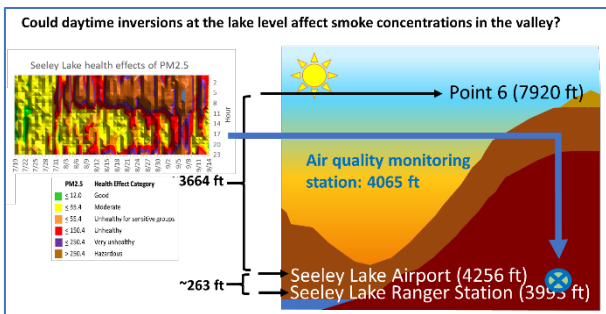
The bottom graph shows a pattern that is called “lake effect.” It is common in locations with large bodies of water, because water absorbs heat and releases it much more slowly than air does. On lake shores, nights are usually a little warmer than inland because they cool off more slowly, and days are a little cooler than inland. This mild weather is one reason why people love to own property along lake shores!

Slide 4



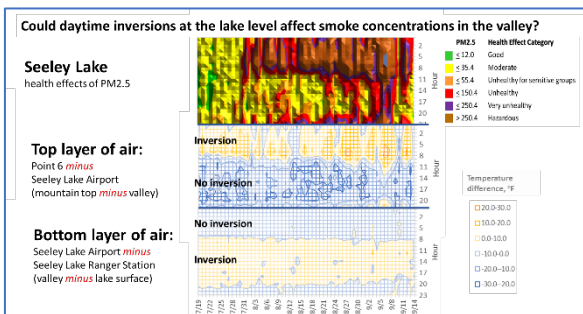
Could daytime inversions at the lake level affect smoke concentrations in the valley? Here's another graph we've seen before (**Slide 30** from **H11_SmokeRiceRidge.pptx**). It shows air quality (based on particulate concentrations) during the Rice Ridge Fire. [**Tab 8. SeeleyPM2.5 in RiceRidgeData.xlsx**]

Slide 5



The air quality data were measured in the town of Seeley Lake, next to the Elementary school, at an elevation of 4065 feet. This elevation is near the lake level, so the data provide a good description of the air quality in that bottom layer of air.

Slide 6



Could daytime inversions at the lake level affect smoke concentrations in the valley? **That's a good question! Discuss possibilities (hypotheses) and how they could be tested.**

Here's one hypothesis that could come up: **The layer of air on the lake surface could have kept particulates trapped in the valley during the daytime, even while the upper air in the valley was able to "breathe" and disperse some smoke. Thus the bottom layer of air would never completely clear out.** This seems like a reasonable explanation – a good hypothesis. Can

we test it with the data we have? **No, we would need air quality data from at least one place at a higher elevation to test it.** If this hypothesis is true, what are some implications for safety and health of firefighters and residents? **Discussion.**



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. They also 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. They apply this information to management of a real-world landscape after a large wildland fire.

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.

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=im4HVXMG168>. **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 6-8 weeks before. But consider -- you may be able to use a cut piece of sod instead.

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

Objectives:

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

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

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

Standards:		9th	10th	11th	12th
CCSS	Reading Informational Text	2, 4, 10		2, 4, 10	
	Writing Standards	2, 4, 8, 10		2, 4, 8, 10	
	Speaking and Listening Standards	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3		1, 2, 3	
	Reading Science/Technical Subjects	1, 2, 4, 9, 10		1, 2, 4, 9, 10	
	Writing Science/Technical Subjects	2, 4, 9, 10		2, 4, 9, 10	
NGSS	Ecosystems: Interactions, Energy, and Dynamics	LS2.A, LS2.C			
	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.B			
EEEEGL	Strand 1	A,B,C,D,E,F,G			

Teacher Background: Fire severity is a concept that includes all of the physical, biological, and ecological effects of a wildland fire. Vegetation burn severity refers to changes aboveground; soil burn severity refers to changes belowground, the degree of change in soil characteristics caused by fire. Changes in the soil have profound effects on what happens in a burned area after fire. These can 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, increases in invasive plant populations, 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 itself for more details.

After fire, common changes to the soil include:

- loss of ground cover due to consumption of litter and duff;
- changes in soil 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** includes all 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 the type of vegetation present.
- **Weather** conditions, including temperature, relative humidity, wind, and rainfall (before and after the 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, the duration of burning, and the type of fire (crown, surface, or ground fire).

The more severe a fire's effects on the soil, the more likely the soil will erode in subsequent rainstorms – especially in places with steep slopes. In the first year or two after a fire, fire-caused erosion can damage watersheds and destroy buildings and infrastructure downstream.

This lesson is assessed by an activity in which students read a technical document about soil burn severity in a real fire - the Lolo Peak Fire of 2017 in western Montana (**LoloPeakFire_BAER-ReportSummary.pdf**) - and communicate its results to a local audience in the area of the fire. The report was created by a Burned Area Emergency Response (BAER) team. BAER is a program in which resource professionals assess a burned area during and/or shortly after a fire. 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 <https://www.fs.usda.gov/naturalresources/watershed/burnedareas-background.shtml>).

This activity focuses mainly on the potential for negative effects of fire on soils. But some fire effects on soils are positive; for instance, while fire's consumption of litter and duff may increase weed populations, it also prepares an ideal seedbed for the establishment of many plant species, including most pine trees. Ecological effects of fire on soils, streams, and aquatic organisms are described in articles cited below by DeBano (1990), Howell (2006), Neary and others (1999), Neary and others (2008), and Rieman and others (2012).

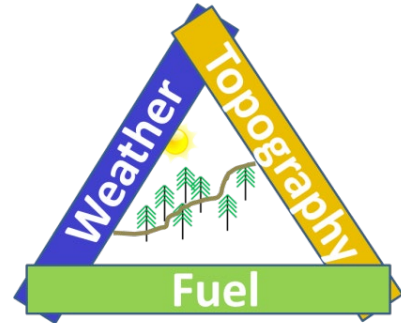
Sources and additional reading:

- DeBano, Leonard F. 1990. The effect of fire on soil properties. Paper presented at the Symposium on Management and Productivity of Western-Montane Forest Soils, Boise, ID, April 10-12, 1990. Available: http://forest.moscowfs.wsu.edu/smp/solo/documents/GTRs/INT_280/DeBano_INT-280.php
- Howell, Philip J. 2006. Effects of wildfire and subsequent hydrologic events on fish distribution and abundance in tributaries of North Fork John Day River. *North American Journal of Fisheries Management*. 26: 983-994. <https://www.tandfonline.com/doi/abs/10.1577/M05-114.1>
- 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.treeseearch.fs.usda.gov/pubs/33598>
- Neary, Daniel G.; Ryan, Kevin C.; DeBano, Leonard F.; Landsberg, Johanna D.; Brown, James K. 2005. [revised 2008]. Introduction. In: Neary, Daniel G.; Ryan, Kevin C.; DeBano, Leonard F., eds. *Wildland fire in ecosystems: effects of fire on soil and water*. Gen. Tech. Rep. RMRS-GTR-42-vol. 4. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 1-18. In <https://www.fs.usda.gov/treeseearch/pubs/20912>
- 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.treeseearch.fs.usda.gov/pubs/36236>
- Rieman, Bruce; Gresswell, Robert; Rinne, John. 2012. Fire and fish: a synthesis of observation and experience. In: Luce, Charles; Morgan, Penny; Dwire, Kathleen; Isaak, Daniel; Holden, Zachary; Rieman, Bruce, eds. *Climate*

change, forests, fire, water, and fish: building resilient landscapes, streams, and managers. General Technical Report RMRS-GTR-290. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 159-175. <https://www.fs.usda.gov/treearch/pubs/41933>

Materials and preparation:

1. Display the Fire Environment Triangle (you can use the ***FireEnvironmentTriangle poster.pptx*** poster from **Activity H08** or sketch it yourself).
2. Download the presentation ***H12_FireSoilWater.pptx***.
3. Arrange for each student to have a printed copy or electronic access to:
 - a) the **Lolo Peak Post-Fire BAER Assessment Report Summary (LoloPeakFire_BAER-ReportSummary.pdf)**. (This is the students' main source of information for the **Assessment**.)
 - b) the full Burned-Area Report for the Lolo Peak Fire (**LoloPeakFire_BAER-ReportFull.pdf**). (This is supplemental information that students may or may not need to complete the assessment.)
4. Make 1 copy/student or team: **Handout H12-1. Effects of the Lolo Peak Fire on Soils.**
5. View this video about erosion: <https://www.youtube.com/watch?v=im4HVXMGI68>. In step 4 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 4-8 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 Fire Environment Triangle that we studied in **Activity H08**, when we experimented with the “matchstick forests.” The 3 parts of the Fire Environment Triangle are fuels, weather, and topography. All of these things influence how

fires affect soils, and these changes can affect plants, wildlife, and us – if we use the burned area or live downstream from it. That’s what we’ll learn about today.

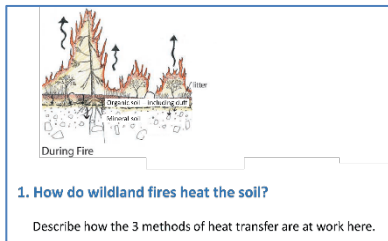
2. Present and discuss the presentation: **H12_FireSoilWater.pptx**:

Slide 1



What do wildland fires do to soils? Why should we care? This presentation answers 7 questions about fires’ effects on soils and how those changes affect things that we care about, such as human safety, water quality, and plant and animal habitat.

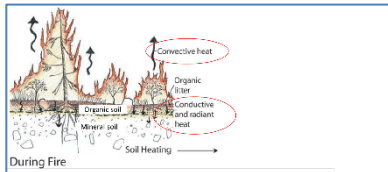
Slide 2



What is soil anyway? **Soil is the surface layer of the earth. It contains mineral particles and also organic matter – duff, plant roots, fungi, dead wood, and microorganisms. Organic materials are often mixed with mineral particles.**

So here’s the first of our 7 questions: **How do wildland fires heat the soil?** The arrows show where the heat from the fire is going. How are the 3 methods of heat transfer at work here?

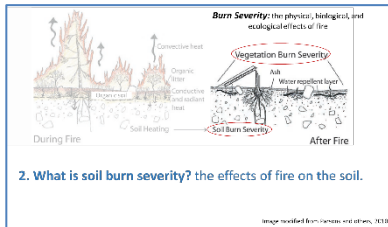
Slide 3



The 3 methods of heat transfer are convection, conduction, and radiation. During a wildland fire, convection lifts some of the fire’s heat up, away from the soil. Conduction transfers some of the heat through solids, including wood and soil

particles. Radiation transfers heat through space, including the spaces between soil particles. The downward flow of heat is not as dramatic as the upward flow, but it can have dramatic consequences.

Slide 4

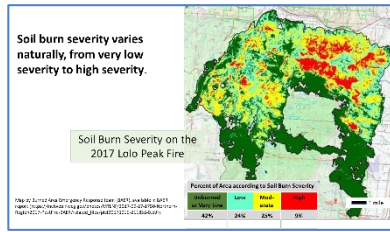


Ask/explain: Here’s our 2nd question: **What does the heat from burning fuels do to plants, ground cover, and soil?** It depends on many things, so it varies! The physical, biological, and ecological effects of fire – all lumped together – are called burn severity.

The diagram shows that there are 2 kinds of burn severity: **Vegetation burn severity** describes how the vegetation changes as a result of the fire. 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: Most of the duff and other organic matter has been consumed, and a few patches of water-repellent soils have formed. This

is *soil burn severity* - the effects of fire on the soil. That's what we'll learn about today.

Slide
5



Variation in *soil burn severity* is part of the natural variation that wildland fires cause on a landscape. The 2017 Lolo Peak Fire that occurred in western Montana had an area of more than 80 square miles, but much of the area inside the fire's boundary was either unburned or had low soil burn severity. About how many square miles had high soil burn severity? You can estimate it from this graphic. **About 7 square miles.**

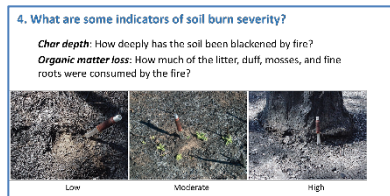
Slide
6



Question 3. If severely burned soils are natural, why should we care about them – why do they matter? Where soils are severely burned, there are increased chances of erosion and flooding; vegetation recovery may be slow, and weeds may increase. Managers identify the locations with

high soil burn severity and then try to prevent some of the negative consequences, such as damage to homes, roads, trails, drainages, fish habitat, and other parts of the ecosystem.

Slide
7

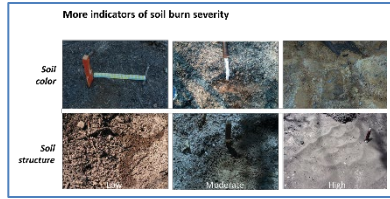


Question 4. What are some indicators of soil burn severity? How can we measure it? Scientists use satellite imagery to make a map that shows an estimate of soil burn severity. That's what we saw in the previous slide). Then the map is refined using the results of on-the-ground measurements.

These photos show *char depth* (depth to which the soil has been blackened by ash) and *organic matter loss* (duff consumed and other indicators) for plots with low, moderate, and high soil burn severity.

If a fire burns through the duff layer and burns most of the organic particles within the soil – such as tree roots, underground plant stems, seeds, and partly-decayed wood – we call it a ground fire. How are ground fires different from surface fires and crown fires (which we studied in **Activity H09_Ladder Fuels**)? **Ground fires tend to burn much more slowly than the other 2 kinds of fire. When they burn in deep duff, they may continue for many days after the fire's flames have moved on.**

Slide 8

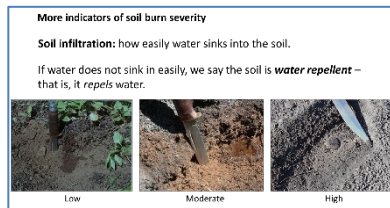


Soil burn severity includes *changes in soil color and structure*. How might a fire change soil color? Look at the top row of photos. **Soil color is typically black or brown in areas with low soil burn severity (that is, very little change from the color of unburned soils).** It is gray to white in

more severely burned soils, and it 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 apart as soil burn severity goes from low to high.** Soils with high burn severity may look powdery or loose.

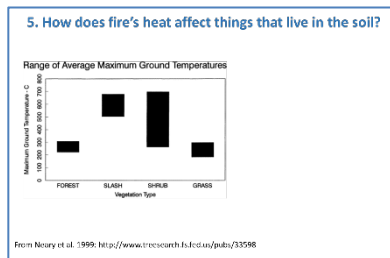
Slide 9



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 repellent; it repels water.** If water-repellent soil is on a steep slope, it is likely to wash away in heavy rainstorms. But note that water repellency is affected by many things, so some soils repel water even when they have not been burned.

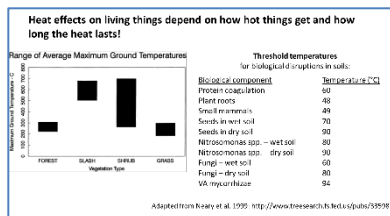
Slide 10



Question 5. How does fire's heat affect the living things 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 that lack woody fuels usually have maximum ground temperatures <225 °C, although higher temperatures have been measured.

Slide 11



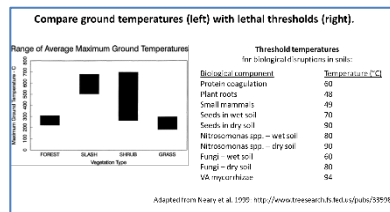
Fire's effects on living things in the soil depend on how hot they organisms get, how long the heat lasts, and how moist the soil is. This data table shows the "threshold temperatures" for harm to living things – that is, the lowest temperatures at which they are likely to be injured or die. Interpret

the table: **Protein structures change at around 60 °C, give or take 10 degrees or**

so. When proteins change their shape, living tissues can't function anymore, so the organisms die. Things that live in the soil begin to die at about 40 to 70 °C.

- Roots and small mammals can be killed at soil temperatures around 50 °C.
- The embryos in seeds often die between about 70 and 90 °C, depending on the soil moisture.
- Microbes (including *Nitrosomonas*, an important soil bacterium) generally die between 50 and 121 °C, depending on soil moisture.
- Fungi may be more vulnerable to high temperatures than bacteria, dying between 60 and 80 °C.
- Vesicular-arbuscular (“VA”) mycorrhizae, which are important companions of plant roots, die when temperatures get above 90 °C.

Slide
12

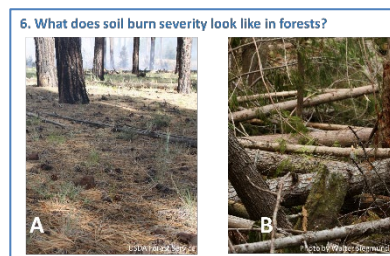


Can lethal temperatures occur underground in wildland fires? Interpret the data (compare the information in the table with the data in the graph). **Yes.** The range of maximum ground temperatures (shown in the graph) greatly exceeds the lethal temperatures of the things that live in the soil (listed in the table).

So how do you think anything in the ground can survive?

- The graph reports maximum ground temperature. Temperatures are not likely to exceed those listed here, but they do not always get this high, and they may not persist long at these temperatures.
- Some areas are missed by the fire. That is, fires do not burn uniformly across the land, and some areas that do burn experience lower temperatures than the maximum.
- It takes more energy to heat wet soils than dry soils (although wet soils hold the heat longer than dry soils do).
- Duff is 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.
- Mineral soil (without any organic matter) is another good insulator. 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 fire.

Slide
13



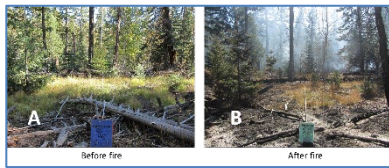
Question 6. What does soil burn severity look like in forests? Since soil burn severity depends mainly on the amount of heat and duration of heating, think about these 2 photos. If a fire burned the surface fuels in these 2 photos under the same conditions, which fire would produce more heat? Which would 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.

More details: Recall the activity about fuel properties (**Activity H05_FuelProperties_generic**). A fire burning in the fine fuels of Photo A is likely to move quickly. But a fast fire in fine fuels will not burn long enough to transfer a lot of heat into the soil. A fire burning in the heavy fuels of Photo B may spread more slowly, but it is likely to burn a long time, transferring a lot of heat into the soil and therefore causing much greater soil burn severity than a fast-moving fire, regardless of how much energy is produced aboveground and how long the flames are.

Slide
14



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 diversity in soil burn severity? Describe

differences in severity by using the measurement methods that we learned earlier: **char depth, 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 high soil burn severity.

Slide
15



Now try to estimate soil burn severity over a larger area. Which areas of soil do you think burned most severely in this photo? 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 patches of white ash and no remaining stems of small trees or shrubs. You can also see white lines where logs have been completely consumed, leaving nothing but white ash. If the site had duff cover before the fire, it is all gone from these patches. Underneath some of these white ash patches may be patches of severely burned soil.
- In the left foreground, it looks like some of the surface fuels aren't completely consumed, so maybe the soil was only moderately burned.

A caution: Just because the vegetation appears severely burned, the soil may not be and vice-versa (i.e., vegetation burn severity does not necessarily equal soil burn severity). How can that happen? **It could be caused by variation in the duff layer, organic matter within the soil, soil texture, moisture content, and other factors.**

Slide
16



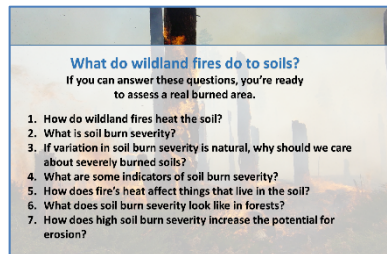
Finally, Question 7. How does high soil burn severity increase the potential for erosion? Both of these photos show places where most of the vegetation and most of the ground cover have burned away. The soil does not have any protection from raindrops. What will happen in the next big thunderstorm? **Erosion is likely, especially on steep slopes. In other words, if there is no litter, duff, plant cover, or root material to hold the soil in place, the soil is vulnerable to washing away after heavy rains – even if it is not water repellent.** (Water repellency was covered in Slide 9).

Slide
17



In the corner, you can see the splash from a single raindrop. What happens when billions of raindrops fall 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 very vulnerable to erosion. Sometimes heavy rain on these soils removes tons of soil, causes big mudslides, fills in drainages downstream, and leads to floods that destroy roads, bridges, houses, and other structures.**

Slide
18



We've looked at several important questions about fire effects on soils. With this understanding, we can now study a report that describes soil burn severity for a specific fire and consider the management actions that might reduce the negative impacts of the fire due to high soil burn severity.

3. Explain: We've seen that soil erosion is a big worry after fire. Let's see how that occurs – whether or not the soil has been burned.
4. Either watch this video as a class: <https://www.youtube.com/watch?v=im4HVXMG168> or do the activity shown in the video.

Assessment:

1. Explain: Now that you are experts on soil burn severity and soil erosion, you can study a report from a wildland fire that occurred in western Montana in 2017 and present some of its results to the public in a radio spot.
2. Explain: Your main information source will be the **Summary of the Lolo Peak Post-Fire BAER Assessment Report (LoloPeakFire_BAER-ReportSummary.pdf)**. Hand out copies of the report or provide it online.
3. Explain: You may also want information from the full report (**LoloPeakFire_BAER-ReportFull.pdf**). Explain how to access it – online? printed copies?
4. Explain: The BAER report was produced by a team of 26 specialists, experts in fire, soils, hydrology, and ecology. It came out on September 29, 2017, when the fire was nearly out. BAER (Burned Area Emergency Response) reports are completed to
 - identify places where the fire changed the soil in ways that might endanger people or degrade important habitats, and
 - recommend ways to minimize these damages.
4. Explain: You are a news reporter for a local radio station. The report has just come out. You are going to use it to answer some urgent questions from your listeners.
5. Give each student or team a copy of **Handout H12-1. Effects of the Lolo Peak Fire on Soils**. Go through the instructions at the top of the handout. Assign ONE of the 5 assessment question sets (A-E) to each student or team.
6. Explain/provide technology for students to record their radio spots.
7. When the radio spots are completed and recorded, play them in class. After each, ask the class to discuss (or assess on a half-sheet of paper) if the radio spot answers the question set. Explain why or why not.

Evaluation: An annotated copy of this report – without illustrations - is shown at the end of this activity (**Answer Key to Handout H12-1. Effects of the Lolo Peak Fire on Soils**); it contains text boxes to help you assess the content of students’ radio productions.

Criterion		Completely successful	Partially successful	Unsuccessful
Appropriate, accurate technical information		Evaluate based on content of the Summary of the Lolo Peak Post-Fire BAER Assessment Report . The Answer Key below is an annotated copy of this document. It contains text boxes that identify the passages most relevant to each of the 5 question sets in the assessment.		
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.
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.
Creativity		Recording uses 2 or more sound effects appropriately.	Recording uses at least 1 sound effect appropriately.	Recording does not use any sound effects.

Handout H12-1. Effects of the Lolo Peak Fire on Soils

Read the **Summary of the Lolo Peak Fire Burned-Area Report (LoloPeakFire_BAER-ReportSummary.pdf)**, which was completed by a group of 26 experts when the fire was mostly contained. Use the information in the report to answer ONE of the question sets below in a 3-minute broadcast for a local radio station. If you need more information, consult the full Burned-Area Report (**LoloPeakFire_BAER-ReportFull.pdf**). You may also obtain information on your topic from other sources.

Since you cannot include graphics in your radio spot, be careful to explain any information that you get from maps and graphs very clearly. Include appropriate sound effects. Do not use jargon or acronyms. If you absolutely must use technical terms, define them.

Record your radio spot. It will be “assigned listening” for the class.

Address ONE of these question sets:

- A. **FLOODS:** How has the Lolo Peak Fire increased the possibility of flooding in the forest and in areas downstream? When is flooding most likely to occur? How long will the danger last? What can listeners do to stay safe?
- B. **FISHERIES:** It is hard for fish to stay healthy if their water gets murky with sediment or gets too warm in the summer. How might severely burned soils in the Lolo Peak Fire damage fish populations and habitat, especially that of the endangered bull trout? What can be done to prevent or reduce the damage?
- C. **SAFETY:** How have fire-caused changes to soils created hazards for people who are working or recreating in the burned area? Recreational activities could include hiking, skiing and snowshoeing, hunting, fishing, biking, and sledding. Local residents might be logging or cutting firewood in the burned area. What can be done to protect these people?
- D. **WEEDS:** Weeds are likely to invade and spread in places with bare soil, where there is little native vegetation. How have fire-caused changes to soils increased the likelihood that weeds will invade and spread in the burned area? What can be done to prevent or reduce increases in weeds?
- E. **HYDROPHOBICITY:** What are hydrophobic soils? Why should we worry about them? How much of the area burned by the Lolo Peak Fire has hydrophobic soils? What can be done about them? Will they stay hydrophobic forever?

Answer Key to Handout H12-1.

Effects of the Lolo Peak Fire on Soils

Below is the text of the **Summary of the Lolo Peak Post-Fire BAER Assessment Report** (*LoloPeakFire_BAER-ReportSummary.pdf*). Text boxes indicate what parts of the report may be most useful for student radio spots on each of the 5 question sets above (on floods, fisheries, safety, weeds, and hydrophobicity).

FS-2500-8 Burned-Area Report: Watershed Analysis, Condition, and Response

The Lolo Peak Fire, which was ignited by a lightning strike on July 15, 2017, is located on the Bitterroot, Lolo and Nez Perce-Clearwater National Forests (NFs), southwest of Lolo, Montana. The fire was managed for full suppression since its start, but steep terrain, high temperatures, low relative humidity, high pre-existing tree mortality, and gusty winds promoted fire spread. For about six weeks, the fire spread steadily to the east toward Lolo. As of September 28, 2017, the fire burned 43,096 acres on Forest Service System (NFS) land, 845 acres on state land, and 9,522 acres on private land.

The Lolo Peak Fire includes a variety of vegetation types that are aspect, elevation, and slope dependent. The dominant vegetation types within the burned area are dry, mixed coniferous forests (lodgepole pine, western larch, Douglas fir, and ponderosa pine) and cool moist coniferous forests (subalpine fir). At lower elevations and on south facing slopes, open grown ponderosa pine forests are common.

The burned area was surveyed and assessed by a BAER team comprised of Forest Service scientists and specialists. The BAER team evaluated the burned watersheds to determine post-fire conditions, and identify values-at-risk such as threats to human life and safety, property, and critical natural and cultural resources. In addition to these critical values, other threats were also assessed, such as the risk for increased post-fire flooding, sediment flows, rock slides, hazard trees and noxious weed spread.

Relevant to all questions

The BAER assessment team's analysis of the burned area and recommended emergency treatments are documented in a Forest Service (FS) Burned-Area 2500-8 Report. This report was submitted to the Northern Region (Region 1) Regional Forester by the Forest Supervisor for the Bitterroot and Lolo NFs for review and funding.

The following is a summary of the BAER team's burned area assessment report for the Lolo Peak Fire:

- 10 sub-watersheds were analyzed and modeled to compare pre-fire conditions to post-fire predicted response: East Fork Lolo Creek, West Fork Butte Creek, South Fork Lolo Creek, Lower Lolo Creek, Bass Creek, Sweeney Creek, Upper Brushy Fork, Larry Creek-Bitterroot River, One Horse Creek-Sin-tin-tin-em-ska Creek, and North Woodchuck Creek-Bitterroot River.

- There are 38 miles of perennial stream, and 123 miles of intermittent streams.

Relevant to flooding & fisheries

- There are 74.4 miles of NF system roads, 23.9 miles of NF non-system roads, and 39.5 miles of NF trails.

Relevant to safety & weeds

- Post-fire, there are 6,047 acres with high hazard ratings for soil erosion, 24,731 acres with moderate ratings for soil erosion, and 5,123 acres with low hazard ratings for soil erosion. Elevated soil erosion hazard is only applicable for the first few years following the Lolo Peak Fire - until revegetation occurs to stabilize the slopes.

Relevant to flooding & fisheries

- There are about 13,914 (32%) unburned acres, 10,137 (23%) acres of low soil burn severity, 13,487 (31%) acres of moderate soil burn severity and 6,507 (14%) acres of high soil burn severity.

Relevant to all questions

- There are 6,507 acres of water repellent (hydrophobic) soils scattered around the fire area. Hydrophobic soil conditions are common within moderate and high burn severity areas and rare in the low burn severity areas.

Relevant to hydrophobicity

Hydrophobic soil conditions may be the result of two processes; the first is a natural accumulation of waxy resins at the soil surface as plant litter and organic material decomposes. The second is a result of hot temperatures volatilizing organic compounds, destroying soil structure and redepositing water-resistant compounds deeper in the soil profile, and is common of areas of high and moderate severity burn. Increased run-off due to hydrophobic conditions is reflected in the peak flow analysis of the watersheds. Hydrophobic layers usually take 6 months to 2 years to break down. Plant root development, soil microbial activity, and freeze-thaw cycling all contribute to the degradation of hydrophobic conditions. Rains in September and October have started the breakdown of the hydrophobic layer. Recovery of pre-fire slope stability and watershed hydrologic response is dependent on many factors and typically occurs within 3-5 years following the fire. Recovery of high burn severity areas is slower because little or no vegetative ground cover remains and soils may be susceptible to erosion.

The different soil burn severity categories reflect changes in soil properties and are a key element BAER specialists use to determine if post-fire threats exist. The distribution of unburned, low, moderate, and high soil burn severity levels become a baseline for resource specialists to monitor changes in soil hydrologic function and vegetative productivity as the burned watersheds recover.

High and moderate soil burn severity categories often have evidence of severe soil heating and the consumption of organic material. Soil seedbank and water infiltration characteristics are reduced in areas that have burned at high or moderate severity. Natural recovery is slower where little or no vegetative ground cover remains, and increased surface water runoff will result in increased soil erosion at these sites. Areas of moderate soil burn severity may have viable roots and some soil cover, but may still be vulnerable to erosion on steep slopes. The low to very low soil burn severity areas still have good surface soil structure, intact fine roots and organic matter, and will recover more quickly as revegetation begins very soon after the fire and the soil cover is re-established.

Relevant to weeds

Relevant to flooding & fisheries

Field observations and modeling of the burned area support a general trend of increased flows, sedimentation, and erosion due to post-fire effects especially in sub-watersheds with the most burned acres, specifically moderate and high soil burn severity, high erosion hazard ratings, and the steepest slopes. Areas most at-risk from post-fire flooding, erosion, and sedimentation are within the burn area or within close proximity to the burn area, although some sites outside of the burn perimeter that are down slope or downstream of the burn

Relevant to flooding & fisheries

area are still at-risk from increased post-fire effects. Ash transport into area streams is virtually guaranteed to occur several times before plant re-growth stabilizes the soil.

Identified Values-at-Risk, Threats, and Emergency Conditions

Summer thunderstorms have the greatest likelihood of generating large run-off and soil erosion events. If large summer thunderstorms occur, the primary values-at-risk within the burned area are human life and safety, transportation infrastructure (roads and trails), soil productivity, water quality, bull trout habitat, and native vegetation communities. The primary threats caused by the fire include 1) increased run-off, which is expected to intensify the first 2-3 years following the fire until the burned watersheds recover, and 2) accelerated hillslope erosion - as a result of increased run-off and decreased infiltration rates. High intensity, short duration rainfall may result in valley bottom flooding and localized debris flows, primarily in Mormon and John creeks. Additional threats originating from the destabilized hillslopes throughout the burned area include falling trees and rolling rocks.

Relevant to flooding, safety, fisheries, & weeds

Emergency post-fire conditions for the Lolo Peak Fire were identified by the BAER team for the following on-forest values-at-risk:

- Human Life and Safety: There are potential impacts to the safety of forest recreating visitors and Forest Service employees entering the burned area, and residents of private lands within and adjacent to the burned area. Generally, increased risk occurs within or directly down-slope from high and moderate soil burn severity areas. Potential threats exist along roads, trails, trailheads, and other recreation areas. Risks for the general public include rolling rocks, flash flooding, flooding, debris flows, slope failure, falling trees, and loss of ingress/egress access. Locations with increased risk include road systems within the upper Mormon Creek drainage, Mill Creek Trail, and long the South Fork of the Lolo Creek drainage.

Relevant to safety

- Property: There are potential impacts and threats to Forest Service System roads, trails, and associated infrastructure during and following high-intensity precipitation events. During these events, there is high potential for failure to road drainage due to increased post-fire flows and thus potential for erosion of trail surface tread and sediment delivery to streams. Soil deposition on road and trail surfaces from adjacent hillslopes may also occur. The potential threats are from increased water, sediment flows, soil erosion, loss of capacity, and overtopping and breaching during flood events. Roads at-risk include the Mormon Peak road, Mormon Creek road and associated spurs, John Creek road, Tevis Creek road, Elk Meadows road and surrounding roads, McClain Creek roads within the McClain Creek area, and Johnny Creek road.

Relevant to flooding, fisheries, safety

- Natural Resources: There are threats and increased risks to water quality, fish (bull trout) communities and habitat, native plant vegetation recovery, increased spread of noxious weeds, reduced soil productivity and hydrologic function from increased sediment flows and accelerated erosion. Mormon Creek and South Fork Lolo Creek are the primary streams of interest for potential risk to bull trout populations and its critical habitat, due to the fire coverage within those watersheds. Over 1,500 acres of known noxious weed infestations occur within the Lolo Peak Fire. There are no known aquatic invasive species with the fire perimeter.

Relevant to fisheries, safety, weeds

- Cultural/Heritage Resources: A low to moderate risk is anticipated to cultural and heritage resources within the Lolo Peak burn perimeter, due to the increased threat of flooding, deposition, and erosion from upslope burned areas due to loss of pre-fire ground cover.

Emergency Stabilization Treatments

Treatment Objectives

The BAER assessment team’s emergency stabilization objectives for the burned areas are to protect, mitigate and reduce the potential for identified post-fire threats, including increased water run-off flows and soil erosion/sediment yield, for:

1. Human life, safety, and property within and downstream of the burned area;

Relevant to fisheries & safety

2. Forest Service infrastructure and investments such as roads and trails;

Relevant to flooding & safety

3. Critical natural and cultural resources; and

Relevant to fisheries

4. Native and naturalized plant communities from new noxious weed infestations.

Relevant to weeds

In addition to on-Forest efforts to reduce the threats to National Forest values and resources, the BAER team and the Forest warn users of Forest Service roads and trails of hazards present in the burned area, and communicate and coordinate with other agencies such as the National Resource Conservation Service (NRCS), National Weather Service (NWS), State of Montana, local counties, and cities to assist private entities and communities including private residents and businesses to achieve post-fire recovery objectives.

The following post-fire emergency stabilization measures and treatments have been approved:

Relevant to all questions

- Continue to communicate risks to the public, community groups, and cooperating agencies.

- Continue to work and coordinate with interagency cooperators, partners, and affected parties and stakeholders.

- Assist cooperators, including local, county, state, and federal agencies with the interpretation of BAER assessment findings to identify potential post-fire impacts to communities and private land owners, domestic and agricultural water supplies, and public utilities (such as power lines, state roads, county roads, and other infrastructure).

Relevant to flooding & safety

- Install burned area warning signs to caution forest visitors traveling and recreating within the burned area.

Relevant to safety

- Storm-proof and stabilize approximately 34 miles of Forest Service (FS) System transportation roads and stream crossings with improved water drainage structures and features to prevent damage resulting from post-fire watershed conditions such as soil erosion, storm water run-off, and public safety hazards to improve the safety of forest visitors and employees. Conduct storm patrol monitoring to ensure road treatments are functioning as intended.

Relevant to flooding, fisheries, safety

- Provide for worker safety during implementation of road and trail drainage improvements by removing hazard trees along the roads and trails where treatment crews are operating for extended periods of time.

Relevant to safety

- Storm-proof and stabilize approximately 12 miles of burned area FS trails with improved water drainage structures and features to prevent damage resulting from post-fire watershed conditions. Conduct post-storm inspection of problem areas and implement emergency repairs if needed.

Relevant to flooding, fisheries, safety

- Conduct early detection surveys and rapid response eradication with herbicide application on noxious weeds along areas disturbed by fire suppression activities, equipment concentration points, high and moderate soil burn severity areas near these fire suppression disturbed areas, and other high priority areas, to reduce the potential for impaired native vegetative recovery and the introduction and spread of invasive weeds. The total treatment area comprises approximately 940 acres. Educational signage would be installed at trailheads to reduce noxious weed spread and encourage users to stay on trails. Early detection would also be conducted by surveying backcountry lakes for aquatic invasive species (AIS). An eradication plan would be developed if any AIS are detected.

Relevant to weeds

- Cultural resource concerns will be evaluated at a later time within the burned area to determine if future management actions are required.

SPECIAL NOTE: *Everyone near and downstream from the burned areas should remain alert and stay updated on weather conditions that may result in heavy rains over the burn scars. Flash flooding may occur quickly during heavy rain events. BAER actions are intended to reduce, but cannot eliminate risks. Current weather and emergency notifications can be found at the **National Weather Service** (<https://www.weather.gov/mso/>) website.*

Relevant to flooding & safety



Unit V. Fire's Relationship with Organisms and Communities



13. Tree Identification: Create a Dichotomous Key

Lesson Overview: In this activity, students use photographs and botanical specimens to create a dichotomous key for 10 tree species native to forests of the northern Rocky Mountains and the North Cascades.

Lesson Goals: Increase students' understanding of morphological characteristics of trees, and increase their ability to identify tree species in the northern Rocky Mountains and the North Cascades.

Subjects: Science, Speaking and Listening, Writing

Duration: One 30- to 40-minute session

Group size: whole class/groups

Setting: Classroom

Vocabulary: *dichotomous key*



Objectives:

- Students will use botanical specimens and photographs to create a dichotomous key for 10 tree species.

Standards:		9th	10th	11th	12th
CCSS	Writing Standards	2, 4, 8, 10		2, 4, 8, 10	
	Speaking and Listening Standards	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3		1, 2, 3	
	Writing Science/Technical Subjects	2, 4, 9, 10		2, 4, 9, 10	
NGSS	From Molecules to Organisms: Structure and Processes	LS1.B			
	Ecosystems: Interactions, Energy, and Dynamics	LS2.C, LS4.D			
EEEEGL	Strand 1	A, B, C, E, F, G			

Teacher Background: Wildland ecosystems are characterized by diversity. The diversity and species of trees in a forest influence the kinds of fire that occur there. 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 10 tree species that are important in forests of the northern Rocky Mountains and the North Cascades. An example key for these species is included at the end of the activity, but each student's (or team's) key will be unique.

As an introduction to the concept of developing a key, students construct a “practice” key for identifying a few members of the class. Then in the **Assessment**, they create a key for identifying 10 tree species. If you are able to take the class to a field site that contains a few of these tree species, it would be great to do a second, real-world assessment: Have them use their keys (possibly supplemented by other keys or natural history books) to identify trees in the field.

Materials and preparation:

- Decide how you will have students work on the keys – individually, in pairs, or in larger teams. Also consider both options for **Assessment** described below. Your decisions will determine how you set up the classroom.
- Obtain a few examples of dichotomous keys from a library.
- Assemble 10 stations in the classroom. Each station should have the following items from the trunk for every tree species:

- Photos for the species from **Tree_ID_photos.pdf**.
(There are 2 pages of photos for each species, labeled with a code letter for the species.)
- Tree Bark/trunk specimen
- Cone or flower specimen
- Foliage specimen
- Species name label from **Tree_spp_labels.pdf**
(contains the species letter code and name)
- Ruler

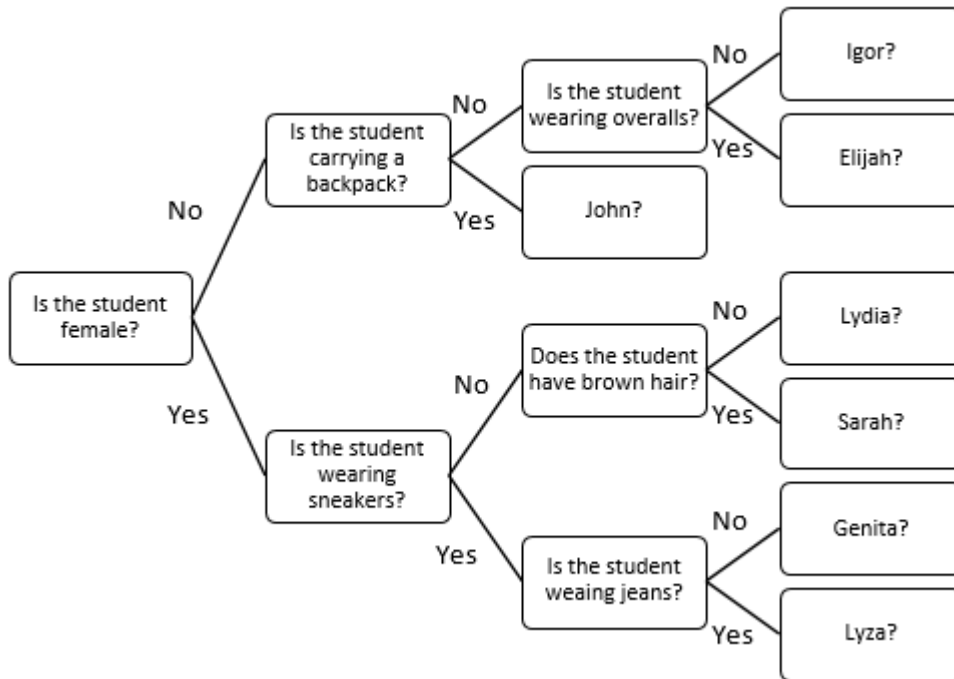
Code letters for tree species:	
Black cottonwood	B
Douglas-fir	V
Engelmann spruce	H
Lodgepole pine	E
Ponderosa pine	O
Quaking aspen	L
Subalpine fir	C
Western larch	T
Western redcedar	D
Whitebark pine	J

Procedure:

1. Ask: Name some tree species that live in the northern Rocky Mountains and the North Cascades. **List species names on the board. Names of classes of trees (pines, oaks, firs, etc.) would also be good.** Are all of these kinds of trees native to the wildlands of our area? **If you are uncertain, have students consult http://www.treesforme.com/a-z_common_name.html, a list of all tree species native to North America; select the species name to find a map and a list of the states where it occurs.**
2. Ask: When we see a person in school or a tree in the woods, how do we 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 word *dichotomous*

comes from the Greek *dich-* (“in two”) and *temnein* (“to cut”). The yes-no 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. You might want to provide the first question. Then have students create the rest of the key until all eight students are identified. Here is an example of a dichotomous key for 8 students:



5. Explain: Dichotomous keys usually contain additional information in narrative form 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 distinguish John from Elijah: “John is a male student who is 6 feet tall, has brown hair, and often carries a backpack. He plays the trombone. Elijah is also male; he is wearing a brown t-shirt today and carrying most of his stuff in the pockets of his overalls. He drives a car that he rebuilt himself.”
6. Ask: Do you see any problems with this key? 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.**

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. Now we’re going to create a dichotomous key for some important tree species that grow in the

forests of the northern Rocky Mountains and North Cascades.¹ We'll identify only 10 species, even though the keys used by professionals (land managers, ecologists, botanists, wildlife biologists, microbiologists) cover ALL of a kind of organism (trees, insects, etc.) – often hundreds or even thousands of kinds.

7. Distribute copies of a few field guides with dichotomous keys or show examples from the internet so students can see what a dichotomous key looks like and how it is used.

Assessment – Option 1.

1. Explain: Each team will create a dichotomous key for 10 important tree species that occur in the northern Rocky Mountains and North Cascades. We'll refer to these species often in the rest of our fire-related activities, because they all have different ways of dealing with fire.
2. Each station has information on **one species**: a label with the species' name and code letter, 2 pages of photos that show its characteristics in the field, and a collection of botanical specimens (bark, foliage, and cones or flowers).
3. Circulate among the stations to find characteristics that can be used to distinguish groups of species and individual species from one another. Take notes on these distinguishing characteristics.
4. Use the distinguishing characteristics to create a draft of your key. This process will probably require several iterations, so it will be easiest if you draft it in pencil.
5. When you think you're done, have another student or team try your key out to see if it is accurate and easy to use.
6. Make a clean copy of your key for evaluation. It can be digital² or done by hand. It can use text only (like most field guides), or include graphics (like the pasta example).
7. To accompany your key's diagram, write a short narrative description of each tree species (2-3 sentences) that can be used to confirm the identification.

¹ Consider having students practice making one more dichotomous key with something easy, such as different kinds of pasta. There are many examples available online. If you do this, you will need additional supplies (e.g., pasta).

² **Tip:** Students can use computer software to create their keys, if they want to. Here's a way to do it in Microsoft Word: 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 those used for examples in this activity. First, you insert the decision criteria into the hierarchy. Then, to make the resulting chart into a key, insert text boxes (without borders or fill) that label the decision lines "yes" or "no."

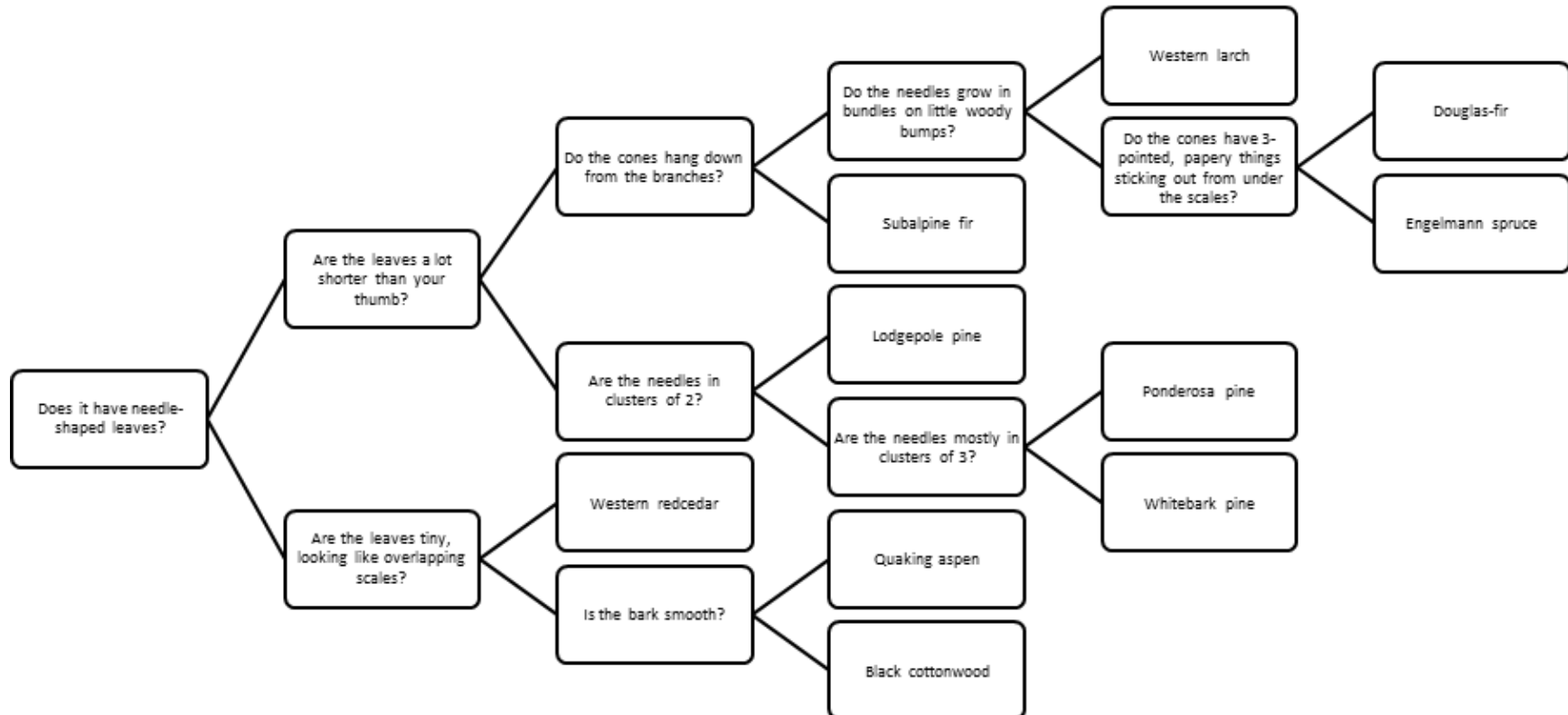
Assessment – Option 2: This approach simplifies the key-building process for the students and may be more fun to evaluate than Option 1:

1. Split the class in half, so half of the teams are on one side of the classroom and half on the other.
2. Split the collections of tree specimens in half too – placing the materials for 5 species on one side of the classroom and the materials for the other 5 species on the other side.
3. Have the student teams create keys for the 5 tree species on their side of the room.
4. Then remove the trees’ name labels from the displays.
5. Have each student team exchange keys with a team from the other side of the room, use the other team’s key to identify the 5 “unknown” tree species. Then have the teams critique the keys.

Evaluation (written for Option 1 Assessment): Each team’s key will be unique, but you can refer to the **Example for Teachers** below to see one sample of a dichotomous key and narrative descriptions.

	Excellent	Good	Fair	Poor
Dichotomous key	Created clear, accurate key for identifying 9-10 species.	~Created key useful for identifying 7-8 species. ~Key contained ambiguity or errors for 2-3 species.	~Created key useful for identifying 5-6 species. ~Key contained ambiguity or errors for 4-5 species.	~Created key useful for identifying <5 species. ~Key contained ambiguity or errors for >5 species.
Species descriptions	Created clear, concise descriptions for 9-10 species.	Created clear, concise descriptions for 7-8 species.	Created clear, concise descriptions for 5-6 species.	Created clear, concise descriptions for <5 species.

Example for Teachers: Dichotomous key for 10 tree species in the northern Rocky Mountains and North Cascades



Example for Teachers: Narratives for 10 tree species:

1. **Black cottonwoods** have wide leaves that may be very shiny. The buds at the ends of their twigs are pointy. In spring, they are very sticky. Old cottonwoods have gray, deeply furrowed bark. Cottonwood seeds are packaged with lots of cottony fluff, which helps them float a long way on wind and water.
2. **Douglas-firs** have short, flat needles and brown, furrowed bark. The buds at the ends of their twigs are pointy. Their cones feel kind of papery (like spruce cones) but with this difference: Little, 3-pointed “wings” stick out from under the cone scales. It looks like tiny mice are trying to burrow in, but they can’t hide completely!
3. **Engelmann spruces** have short needles with very sharp tips, which gives them the name “Sticky Spruce.” Their cones feel kind of papery. Their bark is grayish, with roundish scales that sometimes flake off.
4. **Lodgepole pines** have fairly long needles that usually grow from the twig in bundles of 2. Their cones are pointy and very prickly. Sometimes their cones are closed tight so the seeds can’t get out; sometimes they are open. Lodgepole pine bark is dark and scaly.
5. **Ponderosa pines** have long needles that usually grow from the twig in bundles of 3. Their cones are big and have prickles on the scales. Their 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.
6. **Quaking aspens** have roundish leaves with a pointed tip. Their leaves move almost constantly because they are very sensitive to wind. Their bark is mostly grayish-white and smooth, although old trees can have furrowed bark down near the ground. Their seeds are packaged with cottony fluff that helps them float long distances on wind and water.
7. **Subalpine firs** have short, flat needles and gray bark. Their bark often looks like it has spots or blisters in it. Their cones grow at the very tops of the trees, pointing upward toward the sky. The cones don’t fall off. Instead, they fall apart on the tree, and the pieces fall to the ground.
8. **Western larches** have short, soft needles, which grow in tufts of 10 or more out of little woody bumps on the twigs. Their leaves turn gold in the autumn and then fall off. Therefore, they are conifers (cone bearers) but not evergreens like pines, firs, and spruces. Western larch cones are small and lightweight. The tree’s bark is brown to reddish-brown.
9. **Western redcedars** have leaves that look like tiny, overlapping scales. Because many leaves grow together, the trees may look a little like they have small ferns for leaves. Their cones are small—about as big across as your thumbnail. Western redcedar bark is grayish, with furrows and loose strands. It looks like someone tried to peel or shred the bark.
10. **Whitebark pines** have fairly long needles that grow from the twig in clusters of 5. Their cones are purplish-brown. The cones don’t usually fall off the tree. Most of them ripen in the treetops and then get pulled apart by Clark’s nutcrackers, who want their large seeds. The pieces of cone that the nutcrackers remove fall to the ground under the tree. Whitebark pine’s bark is whitish on young trees but gray to black on older trees.



H14. Researching a Plant, Animal, or Fungus

Lesson Overview: Each student selects a plant, animal, or fungus to study. He/she writes a research paper on this species and shares the results with the class in a multimedia presentation. During presentations, classmates 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

Vocabulary: *adaptation, biodiversity, fire regime*

Lesson Goals:

- Increase students' understanding of how species living in the northern Rocky Mountains and North Cascades survive and even thrive in an environment that includes wildland fire.
- Increase students' understanding that species may be adapted to specific fire regimes.

Objectives:

- Each student will become well informed on the fire ecology of one species in the northern Rockies and North Cascades, as demonstrated by a research paper and presentation.
- All students can describe adaptations to fire for several species and predict the potential consequences of fire exclusion for these species.

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 that unit. You might save the presentation on Rocky Mountain lodgepole pine for **Activity H17. History of Stand-replacing Fire**.

Standards:		9th	10th	11th	12th
CCSS	Reading Informational Text	2, 4, 10		2, 4, 10	
	Writing Standards	2, 4, 6, 7, 10		2, 4, 6, 7, 10	
	Speaking/Listening Standards	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3		1, 2, 3	
	Reading Science/Technical Subjects	1, 2, 4, 9, 10		1, 2, 4, 9, 10	
	Writing Science/Technical Subjects	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	From Molecules to Organisms: Structure and Processes	LS1.B			

	Ecosystems: Interactions, Energy, and Dynamics	LS2.A, LS2.B, LS2C
	Biological Evolution: Unity and Diversity	LS4.C, LS4.D
EEEEGL	Strand 1	A, B, C, E, F, G

Teacher Background: This lesson challenges students to find, read, interpret, and summarize information on fire ecology from the technical and scientific literature. Through student reports on individual species, the class will learn about the fire ecology of many species that occur in forests of the northern Rocky Mountains and the North Cascades.

Make species assignments from **Table H14-1. Species assignments for research papers.** This is a list of more than 30 species representative of forests in the northern Rocky Mountains and North Cascades. If you do not need this many species for your class, **assign those shown in bold print (and shaded in blue)** first. This subset will give you good coverage of the 3 forest types that this curriculum focuses on: forests dominated by ponderosa pine with Douglas-fir; forests dominated by lodgepole pine with subalpine fir; and forests dominated by whitebark pine with subalpine fir.

Table H14-1 also lists whether or not each species is described in the Fire Effects Information System (FEIS, at <http://www.feis-crs.org/feis/>). This website contains syntheses of the scientific literature about fire effects on plants and animals and about fire regimes in the plant communities where they occur. FEIS syntheses are written for professional land managers and reviewed by fire ecologists before publication. If a species is covered in FEIS, students may be able to find all the information they need for their presentations in that publication alone. You could choose to assign to students only the species that are covered in FEIS.

A second helpful resource for students may be the *FireWorks Encyclopedia (Middle_FireWorksEncyclopedia_NRM-NC.pdf* located in **Activity M11**), a collection of 2-page essays on the species listed in **Table H14-1**. These essays are written for younger readers, but they summarize the information that should be covered in the high school research papers.

Before students begin their research projects, you may want 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, etc.) so students can select appropriate sources and cite them appropriately.

Materials and preparation:

- Provide computer and internet access for each student
- Make 1 copy/student: **Handout H14-1: Species research project**
- Make 1 copy/student: **Handout 14-2. Quiz on species' relationships with fire**

- Decide whether to have students use MLA format for their papers and citations or use another style.

Procedure:

1. Explain: Now that you know about the physics and chemistry of fire, it's time to learn how wildland fire, which seems very destructive, can be important to some of the species that live in forest ecosystems of the northern Rocky Mountains and the North Cascades. We'll learn about a few dozen species, but that is a tiny fraction of the number of species present in these ecosystems – that is, their biodiversity. In Glacier National Park, for example, there are more than 1,100 species of plants, 276 species of birds, and 71 species of mammals. Think how many kinds of insects, worms, and fungi there must be!
2. We need to know (or review) a few terms:
 - *Adaptation*: modification of an organism or its parts that makes it more fit for existence under the conditions of its environment. A heritable physical or behavioral trait that serves a specific function and improves an organism's fitness or survival (<https://www.merriam-webster.com/dictionary/adaptation>). Remind students that adaptations are not deliberately chosen by the species but instead result from natural selection.
 - *Biodiversity*: biological diversity, especially the variety of species of plants and animals and the genetic variation present within species (<http://www.oxfordreference.com/>).
 - *Fire regime*: the pattern of fire frequency, severity, type (crown, surface, or ground), spatial continuity, and other characteristics in a particular area or ecosystem (<http://www.fs.usda.gov/database/feis/glossary2.html>).
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.
1. Give each student a copy of **Handout H14-1: Species research project**. Go over the directions and answer questions. Tell students whether to use MLA format (as specified in the handout) or another style.

Assessment:

2. Assign each student a species from **Table H14-1. Species assignments for research papers**. If you do not need all 38 species, be sure to assign at least the species in **bold print and blue highlighter**.
3. Schedule presentations.

4. When presentations begin, remind students of Step #3 in the project: They will need their notes on other students' presentations – especially the information on fire – to succeed in the quiz (**Handout 14-2**).
5. If possible, post students' research papers and presentations in a forum where other students can reread them and possibly add to their notes on species' adaptations to fire.
6. Assign/administer the quiz (**Handout 14-2. Quiz on species' relationships with fire**).

Evaluation: See **Teacher's Key to Handout 14-2. Quiz on species' relationships with fire** (below).

Assignment	Evaluation criteria
Research paper (20 points total)	Two points for each criterion listed in Handout H14-1, Step #1 : <ol style="list-style-type: none"> 1. Physical description of your species 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 fire regimes 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 with MLA format
Presentation (10 points total)	Two points for each criterion listed in Handout H14-1, Step #2 : <ol style="list-style-type: none"> 1. Limit your presentation to 7 minutes or less. 2. Using PowerPoint, Google Slides, or similar software, include at least 7 slides with at least 5 images. 3. Be sure to include information on the species' relationships to fire and typical fire regimes in its habitat. 4. Be clear, well organized, and grammatically correct. 5. Rehearse so that you can give your presentation clearly and concisely.
Quiz (15 points total)	<ul style="list-style-type: none"> • 1 point for complete information on each animal and plant (10 points total) • 10 points for accurate definition of "fire-dependent" and mention of 2 or more fire-dependent species

Table H14-1. Species assignments for research papers

Organism	Main forest ecosystem*	In FEIS**?	Student assigned
American black bear (<i>Ursus americanus</i>)	All	Yes	
American marten (<i>Martes americana</i>)	All moist, old forests. Especially likes fir trees	Yes	
Armillaria root fungus (<i>Armillaria</i> species)	PP, in fir trees	No	
Arrowleaf balsamroot (<i>Balsamorhiza sagittata</i>)	PP	Yes	
Beargrass (<i>Xerophyllum tenax</i>)	Mainly LP	Yes	
Black cottonwood (<i>Populus balsamifera</i> subsp. <i>trichocarpa</i>)	PP or moist ravines at higher elevations	Yes	
Black fire beetle (<i>Melanophila acuminata</i>)	All, especially LP because of tendency toward crown fire	No	
Black-backed woodpecker (<i>Picoides arcticus</i>)	All, especially LP because of tendency toward crown fire	Yes	
Blue huckleberry (<i>Vaccinium membranaceum</i>)	Mainly LP	Yes	
Clark's nutcracker (<i>Nucifraga Columbiana</i>)	All, but especially adapted to WB	Yes	
Douglas-fir mistletoe (<i>Arceuthobium douglasii</i>)	Mainly PP, also LP	No	
Elk (<i>Cervus elaphus</i>)	Mainly PP, also LP	Yes	
Engelmann spruce (<i>Picea engelmannii</i>)	Uses all forest types, depending on season and food.	Yes	
Fireweed (<i>Chamerion angustifolium</i>)	Mainly LP, but also moist ravines at lower and higher elevations	Yes	
Flammulated owl (<i>Oteus flammeolus</i>)	Mainly LP but also PP and some WB forests	No	
Glacier lily (<i>Erythronium grandiflorum</i>)	PP	Yes	
Grizzly bear (<i>Ursus arctos horribilis</i>)	LP, WB, some PP	Yes	
Grouse whortleberry (<i>Vaccinium scoparium</i>)	All, but especially loves WB because of its seeds	Yes	
Heartleaf arnica (<i>Arnica cordifolia</i>)	WB, some LP	Yes	
Mountain pine beetle (<i>Dendroctonus ponderosae</i>)	Mainly PP and LP	No	
Northern flicker (<i>Colaptes auratus</i>)	LP. Also occurs mixed with PP & WB.	No	
Pileated woodpecker (<i>Drycopus pileatus</i>)	LP & PP. Thrives especially in dense LP forests that develop after crown fire.	Yes	
Pinegrass (<i>Calamagrostis rubescens</i>)	All	Yes	

Ponderosa pine (<i>Pinus ponderosa</i>)	PP	Yes	
Quaking aspen (<i>Populus tremuloides</i>)	Mainly PP	Yes	
Red squirrel (<i>Tamiasciurus hudsonicus</i>)	Mainly PP, also some LP	Yes	
Red-backed vole (<i>Myodes rutilus</i>)	LP, also moist spots in PP	Yes	
Rocky Mountain Douglas-fir (<i>Pseudotsuga menziesii</i> var. <i>glauca</i>)	All. Really likes WB cones.	Yes	
Rocky Mountain lodgepole pine (<i>Pinus contorta</i> var. <i>latifolia</i>)	All habitat that is shady and moist	Yes	
Saskatoon serviceberry (<i>Amelanchier alnifolia</i>)	PP, also some LP	Yes	
Smooth woodrush (<i>Luzula hitchcockii</i>)	Mainly WB, also in LP if enough moisture is available.	Yes	
Snowbrush ceanothus (<i>Ceanothus velutinus</i>)	LP and PP	Yes	
Subalpine fir (<i>Abies lasiocarpa</i>)	LP & WB	Yes	
Three-toed woodpecker (<i>Picoides tridactylus</i>)	All, especially LP because of tendency toward crown fire	No	
Western larch (<i>Larix occidentalis</i>)	PP & LP	Yes	
Western redcedar (<i>Thuja plicata</i>)	PP, mainly in deep, moist valleys	Yes	
White pine blister rust (<i>Cronartium ribicola</i>)	WB	No	
Whitebark pine (<i>Pinus albicaulis</i>)	WB, some LP	Yes	
Wild onion (<i>Allium</i> species)	All	No	

*PP=ponderosa pine/Douglas-fir forests; LP=lodgepole pine/subalpine fir forests; WB=whitebark pine/subalpine fir forests.

**FEIS refers to the Fire Effects Information System (<https://www.feis-crs.org/feis/>).

Handout H14-1: Species Research Project

Directions:

Step #1: Research and write a paper about a species that lives in forest ecosystems of the northern Rocky Mountains and the North Cascades. Your paper should be 3 to 5 pages long, double spaced, using MLA format. Use at least 3 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/), start by consulting this resource – but don't let that limit you. Find other references too, if you can. Include the following details in your paper:

1. Physical description of your species
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 fire regimes in its habitat (ground or 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 with MLA format

Step #2: Present your research to the class. Present facts, photos, and other graphics that will engage your audience. Requirements:

1. Limit your presentation to 7 minutes.
2. Using PowerPoint, Google Slides, or similar software, include at least 7 slides with at least 5 images.
3. Include information on the species' relationships to fire and typical fire regimes in its habitat.
4. Be clear, well organized, and grammatically correct.
5. Rehearse so that you can give your presentation clearly and concisely.

It is very important that you deliver a good presentation. If most of your classmates do poorly on the assessment pertaining to YOUR species, then YOU may be responsible because you didn't provide the information they needed.

Step #3: Take notes on your peers' presentations, especially on the **fire regimes** the species typically experiences and its **adaptations (or lack of adaptations) to fire**. You will use your notes later for a quiz.

Handout 14-2. Quiz on species' relationships with fire

Name: _____

1. Select 5 animal species and 5 plant species from those covered in class. In the table below, describe each species' relationship with fire and explain what might happen to that species if fire does not occur for hundreds of years.

Species name	What is its relationship with fire?	What might happen without fire?
Animals:		
1.		
2.		
3.		
4.		
5.		
Plants:		
1.		
2.		
3.		
4.		
5.		

2. Ecologists and land managers sometimes say that a plant or animal is "fire dependent". On the back, explain what you think this term means. Use at least 1 plant and 1 animal species as examples.

Teacher's Key to Handout 14-2. Quiz on species' relationships with fire

1. Select 5 animal species and 5 plant species from those covered in class.....

Species name	What is its relationship with fire?	What might happen without fire?
American black bear (<i>Ursus americanus</i>)	Can escape almost any kind of fire. Feeds well on postfire herbs.	Some of its foods, especially berries, will decline.
American marten (<i>Martes americana</i>)	OK with surface fire, prefers no fire.	Will thrive... unless/until severe fire comes through.
Armillaria root fungus (<i>Armillaria</i> species)	Survives most fires underground but grows best in old forests.	Will thrive.
Arrowleaf balsamroot (<i>Balsamorhiza sagittata</i>)	Sprouts after any fire from caudex (thick underground stem).	Will produce fewer flowers and sprouts less as shade increases.
Beargrass (<i>Xerophyllum tenax</i>)	Grows back after fire from thick rhizomes, but these are close to surface and can be killed by fire.	Will not be as widespread.
Black cottonwood (<i>Populus balsamifera</i> subsp. <i>trichocarpa</i>)	Thick bark protects from some surface fires. May sprout from base & roots if top is killed by fire.	Will not be affected much.
Black fire beetle (<i>Melanophila acuminata</i>)	Uses sensors for smoke and heat to find fires while they are burning. Lays its eggs under bark of just-burned trees. Larvae feed on cambium of dead and dying trees after fire.	Will probably decline.
Black-backed woodpecker (<i>Picoides arcticus</i>)	Prefers severely burned forests because beetles are abundant.	Will decline.
Blue huckleberry (<i>Vaccinium membranaceum</i>)	Sprouts after most fires. Grows well in openings created by severe fires. Produces abundant berries decades after fire.	Will not be as widespread or produce as many berries.
Clark's nutcracker (<i>Nucifraga Columbiana</i>)	Escapes fires. Caches seeds in fire-created openings.	May not cache whitebark pine seeds in best places for new trees to grow.
Douglas-fir mistletoe (<i>Arceuthobium douglasii</i>)	Survives surface fires because they do not kill host tree. Killed by crown fire.	Will thrive... unless/until severe fire comes through.
Elk (<i>Cervus elaphus</i>)	Can escape any kind of fire. Thrives on variety in habitat, including abundant browse in years after fire.	Some foods, especially shrubs for browse, will be less abundant.
Engelmann spruce (<i>Picea engelmannii</i>)	Does not usually survive any kind of fire.	Will thrive.
Fireweed (<i>Chamerion angustifolium</i>)	Sprouts from rhizomes after fire, then produces abundant seedlings in openings created by severe fire.	Will be less abundant and produce fewer flowers.
Flammulated owl (<i>Oteus flammeolus</i>)	Prefers a mix of thickets and openings created by surface fires, especially if they are patchy.	Will decline as openings between thickets fill in with young trees.
Glacier lily (<i>Erythronium grandiflorum</i>)	Sprouts from deep corm (underground stem) after any fire.	May flower less.

Grizzly bear (<i>Ursus arctos horribilis</i>)	Can escape any kind of fire. Finds abundant food in the years after fire, but food declines if fire kills whitebark pines.	Will find some foods less abundant, especially berries. Whitebark pine cone crops may become smaller if the trees reproduce poorly.
Grouse whortleberry (<i>Vaccinium scoparium</i>)	Sprouts from rhizomes after most fires unless fire burned off the duff layer. Fires are often patchy in its habitat.	May produce fewer berries.
Heartleaf arnica (<i>Arnica cordifolia</i>)	Sprouts from rhizomes after most fires. Produces abundant seedlings after fire.	Will produce fewer flowers.
Mountain pine beetle (<i>Dendroctonus ponderosae</i>)	Can survive surface fire and ground fire but not crown fire. Pine regeneration after crown fire provides optimum habitat 80-100 years later.	Will thrive as pine forests age and become susceptible. Will decline if pines are replaced by firs.
Northern flicker (<i>Colaptes auratus</i>)	Escapes fires. Thrives in fire-killed trees because they have abundant beetles.	Will probably not be affected much.
Pileated woodpecker (<i>Drycopus pileatus</i>)	Escapes fires. Needs large trees in mature forest for nesting, so can nest in stands with surface fire but not in stands regenerating from crown fire.	Will probably not be affected much... unless/until crown fire comes through.
Pinegrass (<i>Calamagrostis rubescens</i>)	Sprouts from rhizomes after most fires. Thrives and produces abundant seed in sunny conditions after fire.	Will probably produce fewer flowers and seeds.
Ponderosa pine (<i>Pinus ponderosa</i>)	Has thick bark so can thrive where surface fires kill competitors. Fires that remove duff create good conditions for regeneration.	May reproduce only in dense thickets where trees grow poorly. Will gradually be replaced by firs.
Quaking aspen (<i>Populus tremuloides</i>)	Has thin bark so is top-killed by most fires. Usually sprouts from roots after fire.	May grow too old for roots to sprout as the mature trees die out.
Red squirrel (<i>Tamiasciurus hudsonicus</i>)	Avoids habitat with big openings created by large, severe fires.	Will probably thrive, except that food may decline as whitebark pines decline.
Red-backed vole (<i>Myodes rutilus</i>)	Can hide in burrow from fires but finds little food in recently burned environment.	Will probably thrive.
Rocky Mountain Douglas-fir (<i>Pseudotsuga menziesii</i> var. <i>glauca</i>)	Young trees are killed by most fires. Old trees survive surface fire because of thick bark.	Will do OK because it can reproduce in shade, but denser forests will become more vulnerable to crown fire.
Rocky Mountain lodgepole pine (<i>Pinus contorta</i> var. <i>latifolia</i>)	Can survive some surface fires. Killed by crown fire, but reproduces very well from seed in serotinous cones. Fires that remove duff create good conditions for regeneration.	Many stands will be killed by mountain pine beetles. Lodgepole stands may be replaced by firs.
Saskatoon serviceberry (<i>Amelanchier alnifolia</i>)	Sprouts from rhizomes after most fires. Produces best berry crops in sunny openings.	Will not produce as many berries.
Smooth woodrush (<i>Luzula hitchcockii</i>)	Sprouts from rhizomes after fire, thrives in fire-created openings. Fires are often patchy in its habitat.	Will probably not be affected much.

Snowbrush ceanothus (<i>Ceanothus velutinus</i>)	Crown fires produce heat that opens seeds. Plants can also sprout from roots after fire kills top.	Will become less abundant.
Subalpine fir (<i>Abies lasiocarpa</i>)	Does not usually survive any kind of fire.	Will probably thrive.
Three-toed woodpecker (<i>Picoides tridactylus</i>)	Prefers forests after crown fire/severe fire.	Will decline.
Western larch (<i>Larix occidentalis</i>)	Has thick bark so survives surface fires and sometimes survives crown fires. Reproduces very well in sunny, fire-created openings.	Will gradually become less abundant because seedlings cannot thrive in shade or on duff.
Western redcedar (<i>Thuja plicata</i>)	Habitat rarely burns. Can survive some surface fires because of thick bark.	Will probably thrive.
White pine blister rust (<i>Cronartium ribicola</i>)	Dies if host tree (whitebark pine) is killed by fire, but spores are widely available to infest other, living whitebark pines.	Will decline as whitebark pines decline.
Whitebark pine (<i>Pinus albicaulis</i>)	Habitat does not burn often. When it does, fires are usually patchy. Can survive some surface fires. Fires that remove duff create good conditions for regeneration.	Will reproduce less as duff accumulates and Clark's nutcrackers cache seeds in areas where young trees grow poorly.
Wild onion (<i>Allium</i> species)	Can sprout after any fire that does not kill its bulb.	Will probably not be affected much.

2. Scientists and land managers sometimes say that a plant or animal is fire dependent. On the back, explain what you think this term means. Use at least 1 plant and 1 animal species as examples. Fire dependent¹ describes plants, animals, and ecological communities that have evolved adaptations to fire and require fire to thrive. They often have traits (“adaptations”) that protect them from the adverse effects of fire. They may rely on fire to modify their habitat or environment. They may need fire to regenerate or reproduce well. They may require a particular kind of postfire condition (immediately after fire or years or decades later) to persist and thrive.

If a species is described in the right-hand column above as declining or failing to reproduce after hundreds of years without fire, it can be used as an example of a fire-dependent species.

¹ Description adapted from <http://www.nwccg.gov/glossary/a-z>.



15. Forest Communities and Climate Change

Lesson overview: In this activity, students assemble a graphical model of the forest communities on a mountainside in the northern Rocky Mountains/North Cascades region. They use the model to describe specific forest communities and to assess the potential for tree distributions to change in response to climate change. Then they read and take a stand on the use of assisted migration to conserve species.

Subjects: Science, Mathematics, Reading, Speaking and Listening
Duration: 1-3 class periods
Group size: small groups, whole class
Setting: Classroom
Vocabulary: *aspect, assisted migration, biological conditions, distribution, elevation, environmental conditions, gradient, range*

Depending on how you choose to teach it, this activity may require independent work by students to prepare for the assessments. Depending on the need for independent work, the activity may require 2-3 class sessions.

Lesson Goal: Increase students' understanding that species with similar needs may occur together, that forest communities occur in locations with 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 and comprise unique forest communities.
- Students can predict some potential effects of climate change on the distributions of tree species.
- Students can express their observations and opinions about assisted migration, a method that could be used to mitigate the effects of climate change on species.

Standards:		9th	10th	11th	12th
CCSS	Reading Informational Text	2, 4, 10		2, 4, 10	
	Speaking/Listening Standards	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3		1, 2, 3	
	Reading Science/Technical Subjects	1, 2, 4, 9, 10		1, 2, 4, 9, 10	
NGSS	Ecosystems: Interactions, Energy, and Dynamics	LS2.A, LS2.B, LS2.C, LS4.D, ETS1.B			
	Biological Evolution: Unity and Diversity	LS4.C, LS4.D, ETS1.B			

	Earth's Systems	ESS2.D
	Earth and Human Activity	ESS2.D, ESS3.A, ESS3.B, ESS3.C, ESS3.D, E TS1.B
EEEEGL	Strand 1	A, B, C, E, F, G

Teacher background: Every species needs certain environmental conditions to survive, grow, and reproduce. Trees, for example, need a certain amount of sunlight and moisture and certain temperature conditions. They may also need a specific day length to begin growing, specific soils to provide nutrients, specific fungi to associate with their roots, and many other conditions. Tree species with similar needs – or the potential to meet each other’s needs - are likely to occur together, forming unique forest communities. This version of FireWorks covers 10 tree species and ways in which they are associated in forest communities. It focuses especially on the 3 community types in the northern Rocky Mountains and the North Cascades:

- Northern Rocky Mountain Ponderosa Pine (dominated by ponderosa pine, often with a lot of Douglas-fir)
- Rocky Mountain Lodgepole Pine communities (dominated by lodgepole pine, sometimes with subalpine fir)
- Whitebark Pine (dominated by whitebark pine with, often with subalpine fir)

Students learned how to identify the 10 tree species in **Activity 13**, and they learned about the species’ ecology in **Activity 14**. Now they will use information about those species (provided in **Handout H15-1**) to create a graphical model that shows the distribution of each tree species based on its temperature and moisture requirements. (See Slide 3 in **H15_ForestCommunitiesGradientModel.pptx** for an example of a completed model.)

This activity has 2 assessments. In **Assessment #1**, students develop models that illustrate the species likely to occur in each forest community and then use their models to predict the consequences of a warmer, drier climate, since locations that favored certain tree species in the past may no longer provide conditions in which they can thrive and reproduce.

In **Assessment #2**, students read about assisted migration, a technique that could be used to mitigate the effects of climate change. While a species may not be able to persist in its current habitat, there may be other locations where it could thrive, but first its seeds must first reach those locations. For this reason, some people propose to deliberately introduce species to locations that may be more hospitable to them in the future. This is called assisted migration.

Assisted migration is controversial. In **Assessment #2**, students read an article about the controversy. Then they participate in a “Walk the Line” activity to express their own opinions. Finally, they write an essay in which they take a stand on the issue and explain their reasoning.

If you want your students to read primary research on assisted migration, we suggest: 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.

Materials/Preparation:

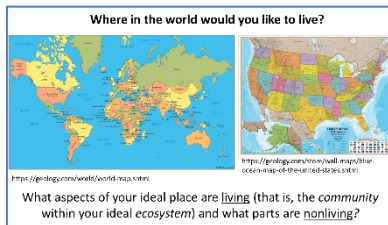
1. Download *H15_ForestCommunitiesIntroduction.pptx* and *H15_ForestCommunitiesGradientModel.pptx*.
2. Print 1 copy/student:
 - Handout H15-1. Distributions of 10 tree species
 - Handout H15-3. Use a model to predict the future
3. You may also want 1 copy/student of **Handout H15-2: Modeling forest communities**. Read the options in Step 6 below before you decide.
4. Make sure each student has markers or colored pencils - 10 colors in addition to black.
5. Decide whether to have students do the reading assignment for **Assessment #2** online (<https://earlycareerecologists.wordpress.com/2013/01/16/trees-on-the-move-debating-assisted-migration-in-climate-change-mitigation/>) or from paper copies (**Reading_TreesOnTheMove.pdf**). Make copies if necessary.

Procedure:

DAY 1 – Hook and developing the gradient model:

1. Introduction: Go through *H15_ForestCommunitiesIntroduction.pptx*:

Slide
1



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 and point to the places where they would like to live.

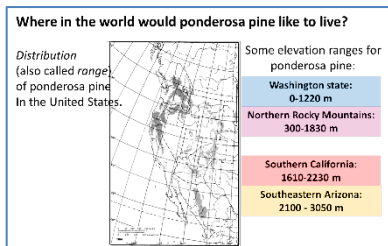
Review the distinction (covered in **Activity H01**) between *community* and *ecosystem*. (Community includes only living things in the environment; ecosystem includes both living and nonliving things.)

Then ask more about the places where your students would like to live – their “preferences”:

- What aspects of this ideal place are living – such as other people, parks, wildlands, animals?
- What parts are nonliving – such as weather/climate, clean air, highways, museums, fast-food places, concert venues?

Have a few students identify places where they don’t think they could live. What conditions would make those places hard for them to live in?

Slide
2



Explain: Tree species also have what we might call preferences: They grow best in certain *environmental conditions* and cannot grow at all in other conditions. The actual locations where a species occurs are called its *distribution* or its *range*. As an example, here is a map of ponderosa pine's current distribution. What do you notice

about the elevations where it lives? **Ponderosa pine lives at high elevations in the southern part of its range and at lower elevations as you go north.** Why might this be? **Conditions at low elevations in the south are probably too hot for ponderosa pine; conditions at high elevations in the north are probably too cold.**

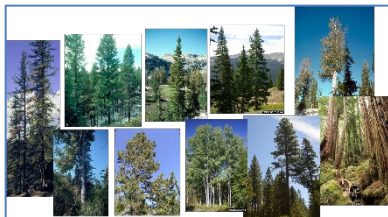
Slide
3



We've been focusing on individual tree species and their needs, but species do not live in isolation; they have neighbors. Trees live in forest *communities*, and species that need similar environmental conditions - or create good conditions for others - tend to live together.

Fire does not interact with individual species in isolation either; it interacts with communities and ecosystems. So we're going to assemble a model that shows how the tree species we've been studying form **forest communities** in the northern Rocky Mountains and the North Cascades, and how these communities are related to **environmental conditions**.

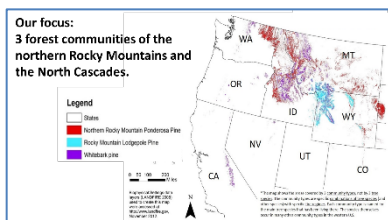
Slide
4



Explain: Here are the 10 tree species we've been studying and know how to identify. Can you name the main tree(s) shown in each photo? Photos, clockwise from left: [Western larch](#). [Rocky Mountain Douglas-fir](#) by Dave Powell, USDA Forest Service (retired), Bugwood.org. [Subalpine fir](#) by

[Dave Powell](#), Bugwood.org. [Engelmann spruce](#) by Mary Ellen (Mel) Harte, Bugwood.org. [Whitebark pine](#) by Dave Powell, Bugwood.org. [Western redcedar](#). [Ponderosa pine](#) by Ilana Abrahamson. [Quaking aspen](#) by Steven Katovich, Bugwood.org. [Rocky Mountain lodgepole pine](#): NPS photo FD40F555-155D-451F-67431611D92BDB83.JPG. [Black cottonwood](#) by Dave Powell, Bugwood.org.

Slide
5



Explain: We're going to create a model that shows some of the environmental conditions needed by our 10 tree species. That will help us understand the *forest communities* that we're focusing on as we study wildland fire: Northern Rocky Mountain

Ponderosa Pine communities, Rocky Mountain Lodgepole Pine communities, and Whitebark Pine communities.

These communities are named for individual tree species, but only because those species tend to predominate there. Many other plants – trees, shrubs, and herbs - occur in each of these communities. And the “named” tree species (ponderosa, lodgepole, and whitebark pine) can occur in other places, but they don’t predominate there.

For example, ponderosa pines can be found from the Canadian border all the way into southern California, but this map shows where you could find the specific mix of ponderosa pine, Douglas-fir, and particular shrubs and herbs that characterizes northern Rocky Mountain ponderosa pine communities.

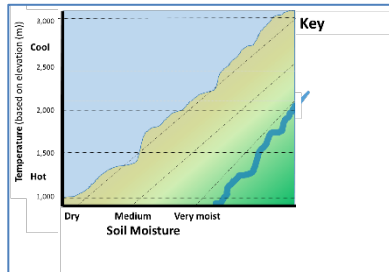
2. Ask: What are some important conditions that affect species distribution? Why do they matter? Try to draw out the following. Note that some relate to nonliving conditions and some to living things in the ecosystem.
 - **Elevation** matters because it influences the temperature, length of summer vs. 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. Soil cover (litter and duff) also influences these conditions.
 - **Amount of moisture** matters because it influences how much water is available to plants and its seasonal availability.
 - **Other important conditions** may include abundance of pollinators, availability of fungi that help roots absorb moisture (“mycorrhizae”), density and vigor of competing vegetation, presence of animals that feed on plants, presence of parasites and pathogens, and nearness of seed sources for the species.
 - **History of the site – including the pattern of fire type, size, and severity** - influence the species present and many of the conditions listed above.
3. Explain: We’re going to focus on just 2 environmental conditions: elevation (which represents temperature – hot at low elevations and cold at high elevations) and moisture.
4. Give each student a copy of **Handout H15-1. Distributions of 10 tree species**. Explain: We will use this handout to create a model that shows how our 10 tree species are associated with each other in forest communities. Then we will zero in on 3 specific forest communities: forests historically dominated by ponderosa pine and Douglas-fir, those

dominated by lodgepole pine and subalpine fir, and those dominated by whitebark pine and subalpine fir.

5. Using the information given in **Handout 15-1** and the directions in **Handout 15-2**, complete a gradient model with the class. Use 1 of these options, depending on how intensively you want to guide the students. Use slides from **H15_ForestCommunitiesGradientModel.pptx**, as needed.
 - A. **Fully guided:** Project or trace the template for the gradient model (Slide 1 in **H15_ForestCommunitiesGradientModel.pptx**, shown below) onto butcher paper or a whiteboard. Then use markers to develop the model together as a class; the result should resemble Slide 3. Have each student copy this model onto **Handout H15-2** so he/she has a copy for answering questions on **Handout 15-3**.
 - B. **Sort-of guided:** Introduce the template for the gradient model using Slides 1 and 2 in **H15_ForestCommunitiesGradientModel.pptx**. Have students use **Handout H15-2** to create their own gradient models.
 - C. **Least guided:** Have students develop their own graphical models of where the species occur in relation to moisture & temperature gradients; these could be drawings, graphs, or other media.

H15_ForestCommunitiesGradientModel.pptx:

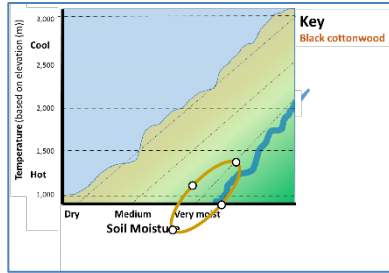
Slide
1



Explain: Here's a template for assembling a gradient model using the information on forest communities in **Handout H15-1 (Distributions of 10 tree species)**. The model is like a graph. It will show where tree species are most likely to live according to temperature conditions (represented by elevation – hot in the valley bottom and cool near the mountaintops) and soil moisture conditions (represented by distance from a stream).

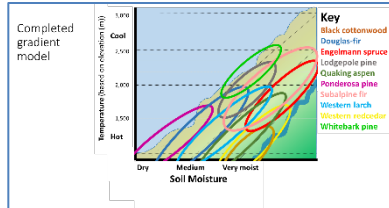
In reality, elevation may not always follow this temperature gradient. Any idea how it might vary? **If a mountainside is exposed to frequent inversions, as studied in Activity H11, it may be cooler at the bottom than in the middle. The same thing can happen if frost “pools” in a basin at the bottom of the mountain and cannot flow downhill.** In reality, moisture is influenced by many things in addition to distance from a stream. Can you think of some? **Soil texture and organic content influence moisture. So does the aspect of a slope. (North-facing slopes tend to be moister than south-facing slopes because they have less direct exposure to sunlight.) Patterns of wind, deposition of snow, and snow-melt all matter.**

Slide
2



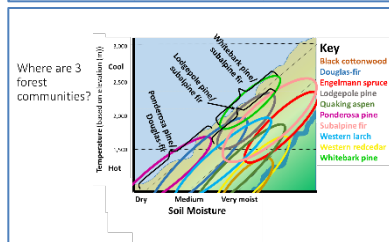
Here's the template with 1 species described, as shown in **Handout H15-2. Modeling forest communities.**

Slide
3



Here's an example of a completed gradient model using the template. Your class's model should resemble this one, but don't worry about the details.

Slide
4



This model shows some of the environmental conditions needed by the 3 “focus” forest communities: Northern Rocky Mountain Ponderosa Pine communities (dominated by ponderosa pine and sometimes Douglas-fir), Rocky Mountain Lodgepole Pine communities (dominated by Rocky Mountain lodgepole pine, sometimes with a lot of subalpine fir), and Whitebark Pine communities (which can also have a lot of subalpine fir). It also shows species that have similar needs, so they may also occur in the focus communities.

6. Regardless of which option you used for developing the graphical models, either:
 - a) have students mark on their graphs where these 3 forest communities are likely to occur: ponderosa pine/Douglas-fir, lodgepole pine/subalpine fir, and whitebark pine/subalpine fir....
 - b) or use Slide 4 to show the environmental conditions where these communities occur.

DAY 2 – Interpreting and using the model(s)

1. Have students get together in small groups. If you used Option B or C in Step 5 above, have students compare and discuss their models. Are the models fairly similar? What might account for differences? Check with each group to make sure the models are all fairly accurate; if they're way off, the students can't complete **Handout H15-3** successfully.
2. Ask each group to list 2 strengths of this approach to modeling (use of elevation and moisture, also the graphical techniques) and 2 weaknesses, then share these with the class. Possibilities:
 - The models are useful because we can easily see which species are most likely to occur together

- With the models, you can compare one species' needs to those of another species.
- Substituting elevation for temperature... and distance from a stream for moisture... oversimplifies the species' real needs.
- Other species combinations might occur – or these species might be absent - based on other environmental conditions – for example, presence of animals that graze on seedlings, insects that eat the trees' leaves or cambium, parasites and pathogenic fungi, mycorrhizal fungi that enhance roots' ability to absorb moisture...
- You can't use these models to explore the complexities of topography (what about shade in narrow canyons?) or history (what about a site's history of logging? fire? insect epidemics?).
- The models can't help us account for species whose seeds just never got to a certain place – whether the environmental conditions are a good fit or not.

Assessment #1 – Using a model for predictions: With the whole class or in groups or as homework, have students complete **Handout H15-3. Use a model to predict the future.** Before proceeding with the second assessment, discuss answers in class.

Assessment #2 – Should we use assisted migration?

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 **Reading_TreesOnTheMove.pdf**.
2. Explain: In this reading, you'll find out what “assisted migration” is and why it's controversial. In the next class, after you've read the article, you'll express your opinions about assisted migration. Then you will write a short essay explaining your opinions.
3. **DAY 3 - Walking the Line activity:**
 - On opposing walls of the classroom, write or put signs that say AGREE and DISAGREE.
 - Review what species migration and assisted migration mean.
 - Explain: Because we are thinking about moving species 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” to show their personal opinions and reactions to the statement. After students have moved in response to each question, invite discussion about it.

Questions for “Walking the Line”:

- a. This article surprised me. I had not heard about plant species naturally migrating before reading this article.
 - b. All of the tree species that we’ve studied will be able to “...keep pace with shifting climate and regenerate under suitable habitat conditions,” as the article puts it. In other words, they’ll be OK.
 - c. All of our 10 tree species will be able to migrate approximately 10 kilometers per year.
 - d. If our tree species cannot migrate fast enough, then they will become extinct.
 - e. Inaction (that is, NOT using assisted migration) will lead to extinction of some tree species.
 - f. Assisted migration will produce unintended, unpredictable consequences.
 - g. Assisted migration will preserve tree species that are now in rapid decline.
 - h. Assisted migration will preserve forest communities that are now in rapid decline.
 - i. Assisted migration will negatively affect plant communities that currently live on the transplant sites.
 - j. I agree with the use of assisted migration, at least on some occasions.
 - k. I understand why assisted migration “...is one of the most controversial, divisive debates within the ecological community.”
4. Write an essay stating your opinion about the use of assisted migration to mitigate the effects of climate change. Back up your opinion with examples from the graphical model that you developed and quotations from the article. You may use other sources as well.

Evaluation:

Excellent	Good	Poor
Assessment #1. Handout H15-3. Use a model to predict the future. See Teacher Key below.		
Correctly answered 8-10 questions.	Correctly answered 5-7 questions.	Correctly answered fewer than 5 questions.
Assessment #2. Reflection on assisted migration		
<ul style="list-style-type: none"> • Student’s reflection is clear and well written. • Student expressed a clear opinion on assisted migration. • Student backed up opinion with more than 1 example from the graphical model. • Student backed up opinion with more than 1 quotation from or reference to the article on assisted migration. • Student supplemented arguments for/against assisted migration with thoughts from “Walk the Line” activity or other sources. 	<ul style="list-style-type: none"> • Student’s reflection contains some confusion or writing problems. • Student expressed a clear opinion on assisted migration. • Student backed up opinion with at least 1 example from the graphical model. • Student backed up opinion with at least 1 quotation from or reference to the article on assisted migration. 	<ul style="list-style-type: none"> • Student’s reflection is confusing and/or poorly written. • Student did not express a clear opinion on assisted migration. • Student did not back up opinion with examples from the graphical model. • Student did not back up opinion with quotation or other reference to the article on assisted migration.

Handout H15-1: Distributions of 10 tree species

Here are moisture conditions and elevations where 10 tree species occur in a particular mountain range. The summit of these mountains is at 3,000 m elevation. The valley at the base of the mountains is at 900 m. The lowest elevation in the region, and thus the lowest elevation where any species can occur, is around 500 m.

Tree Species	Moisture conditions where this species is most common	Elevations (m)/temperature conditions where this species is most common
Black cottonwood	Very moist	500-1400
Douglas-fir	Dry to medium	500-2000
Engelmann spruce	Medium to very moist	1300-2400
Lodgepole pine	Dry to medium	1500-2300
Quaking aspen	Medium to very moist	500-2000
Ponderosa pine	Dry	500-1700
Subalpine fir	Medium	1400-2500
Western larch	Medium	800-2000
Western redcedar	Very moist	500-1700
Whitebark pine	Dry	1800-2600

Sources:

[Fire Effects Information System \(http://feis-crs.org/feis/\)](http://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.

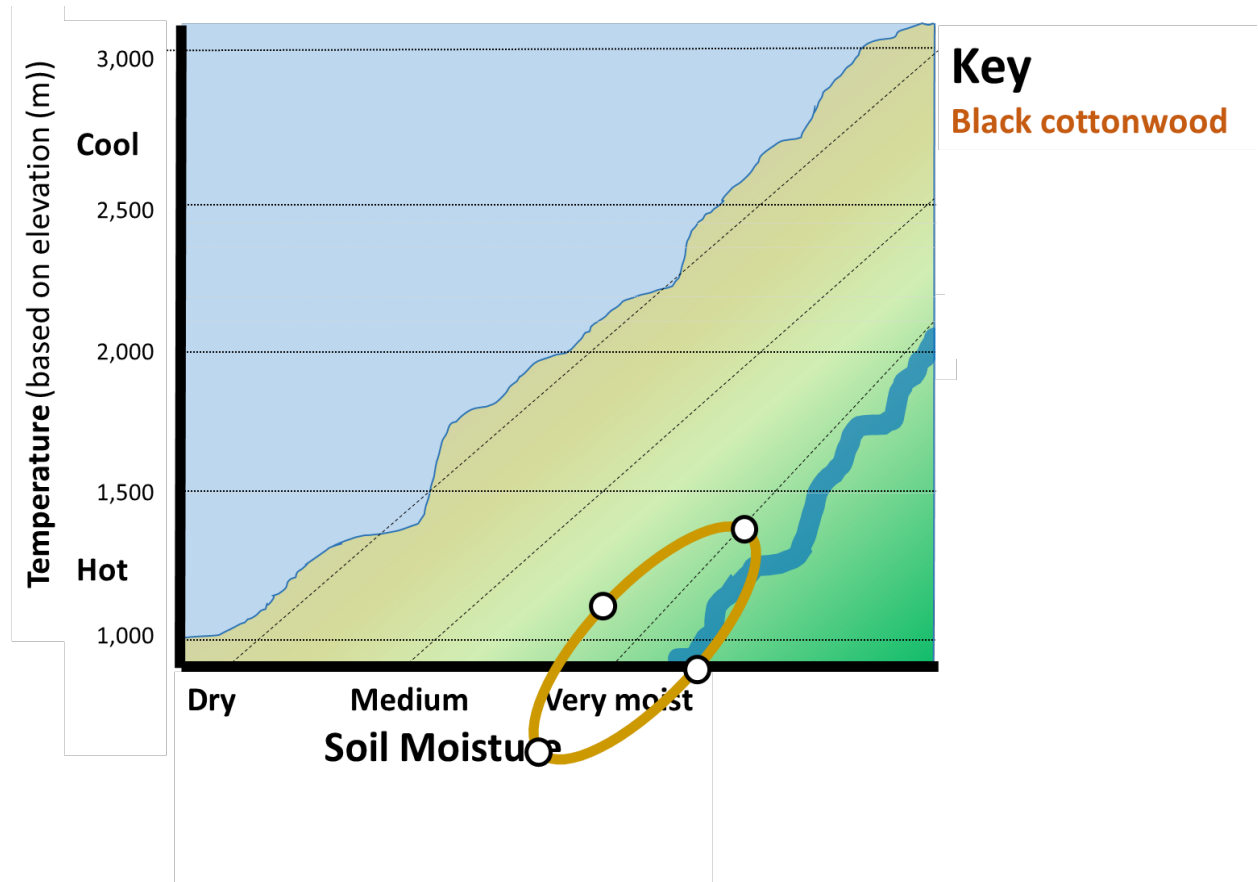
Burns, Russell M.; Honkala, Barbara H., tech. coords. 1990. *Silvics of North America. Vol. 2. Hardwoods*. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.

Handout H15-2: Modeling forest communities

Name: _____

Use this diagram to show the distributions of tree species based on the information in **Handout H15-1**. The x axis shows a *gradient* of moisture conditions, from **dry** along the ridge to **very moist** next to the stream. The y axis shows a *gradient* of temperature conditions based on elevation, from **hot** at low elevations to **cool** at high elevations. For each species:

1. Under "Key," use a unique color to write the species name (except black cottonwood, which is already done).
2. Figure out where the species fits best in regard to moisture. Is it centered on a dashed line (for dry, medium, or very moist), or is it between lines?
3. Find the highest elevation where the species occurs. In the appropriate area for **moisture** at that **elevation**, place a small dot.
4. Find the lowest elevation where the species occurs. In the appropriate area for **moisture** at that **elevation**, place another dot. If the table lists an elevation below 900 m, estimate where the lowest mark should be below the graph.
5. Connect your 2 dots with a light pencil line. Midway down this line, move to the right and left and use dots to mark the approximate **driest and wettest conditions** for the species.
6. Using the color that matches this species in your key, draw an oval connecting your 4 dots. This shows the approximate *distribution* of the species.



Handout H15-3. Use a model to predict the future

Name: _____

1. Describe the environmental conditions where **ponderosa pine/Douglas-fir forest communities** live:
 2. Name 1 species that might occur with ponderosa pine and Douglas-fir if a site is not too dry:
 3. What species might be found in places where there's a little more moisture (like in a gully or along a river bed)?
-

4. Describe the environmental conditions in **lodgepole pine/subalpine fir communities**:
 5. What additional species could occur there?
 6. What will happen to lodgepole pine/subalpine fir communities if the climate gets warmer and drier?
-

7. Describe the environmental conditions in **whitebark pine/subalpine fir communities**:
8. What is likely to happen to whitebark pine/subalpine fir communities if the climate becomes warmer and drier? ?
9. What tree species are likely to show up on these sites if the climate becomes warmer and drier?
10. Could whitebark pine "just move north" so it would have a better environment?

Teachers' Key to Handout H15-3.

Use a model to predict the future

1. Describe the environmental conditions where **ponderosa pine/Douglas-fir forest communities live**: **Low elevations. Hot and dry.**
 2. Name 1 species that might occur with ponderosa pine and Douglas-fir if a site is not too dry? **Western larch.**
 3. What species might be found in places where there's a little more moisture (like in a gully or along a river bed)? **Quaking aspen... also possibly black cottonwood and western redcedar.**
-
4. Describe the environmental conditions in **lodgepole pine/subalpine fir communities**: **Higher and cooler than at the base of the mountain. Occurs at middle elevations. Fairly dry.**
 5. What additional species could occur there? **Whitebark pine in cold, dry places... western larch with a little extra warmth and moisture... Douglas-fir unless it's too cold... spruce and aspen on small areas ("microsites") where moisture permits.**
 6. What will happen to lodgepole pine/subalpine fir communities if the climate gets warmer and drier? **Whitebark pine, spruces and aspen are less likely to be present. Subalpine fir may not do as well. Ponderosa pine may become more plentiful.**
-
7. Describe the environmental conditions in **whitebark pine/subalpine fir communities**: **High elevations. Cool to cold. Dry.**
 8. What is likely to happen to whitebark pine/subalpine fir communities if the climate becomes warmer and drier? **The current sites where whitebark pine lives may get too hot. Whitebark pine may fail to reproduce. Subalpine fir may do poorly if conditions get drier.**
 9. What tree species are likely to show up on these sites if the climate becomes warmer and drier? **Lodgepole pine and Douglas-fir, possibly even ponderosa pine. Species that require more moisture, such as western larch, are not likely to do very well because conditions will continue to be dry.**
 10. Could whitebark pine "just move north" so it would have a better environment? **Whitebark can only move north if its seeds are carried there. Clark's nutcrackers can deliver seeds many kilometers, but that probably won't be far enough to get them into a substantially cooler environment. If conditions on north-facing aspects get dry enough, whitebark pine could thrive there.**



Unit VI. Fire History and Succession



M17 & H16. Dating Fires Using Dendrochronology

Lesson Overview: Students discuss the current prevalence of wildfires in their region and ways to find out if those fires are typical for the 3 forest types they have been studying – forests historically dominated by ponderosa, lodgepole, and whitebark pine. Then they either view a presentation or complete an electronic tutorial covering 10 terms that are important for understanding fire history.

Subjects: Science, Technical reading, Technical writing

Duration: One 30-40-minute session

Group size: Entire class

Setting: Classroom or computer lab

Vocabulary: *annual ring, catface, cohort, dendrochronology, fire scar, increment core, low-severity fire, pith, stand-replacing fire, tree cookie*

Lesson Goal: Ensure that students have a working understanding of dendrochronology and fire history methods so they can interpret the fire history of individual trees and forests in subsequent activities.

Objectives: Students understand all of the new FireWorks vocabulary (see list above and in Step 3 of **Materials and preparation**) well enough to use them in a paragraph about how to use trees' annual growth rings to learn about fire history.

Middle School Standards:		6th	7th	8th
CCSS	Reading Informational Text	4, 7, 10	4, 7, 10	4, 7, 10
	Writing	1,4,10	1,4,10	1,4,10
	Speaking/Listening	1,2,4,6	1,2,4,6	1,2,4,6
	Language	1, 2, 4, 6	1, 2, 4, 6	1, 2, 4, 6
	Reading Standards Science/Tech	1, 3, 4, 7, 10		
	Writing Standards Science/Tech	3, 4, 7, 9, 10		
NGSS	Structure and Function	LS1.A		
	Interdependent Relationships in Ecosystems	LS2.A		
	Ecosystem Dynamics, Functioning, and Resilience	LS2.C		
	Natural Selection	LS4.B		
	Adaptation	LS4.C		
	Weather and Climate	ESS2.D		
	Natural Hazards	ESS3.B		
EEEEGL	Strand 1	A,B,C,E,F,G		
	Strand 2.2	A		

High School Standards:		9th	10th	11th	12th
Common Core ELA	Reading Informational Text	4, 10		4, 10	
	Writing	2, 4, 7, 10		2, 4, 7, 10	
	Speaking/Listening	1, 2, 4, 5, 6		1, 2, 4, 5, 6	
	Language	1, 2, 4, 6		1, 2, 4, 6	
	Reading Science/Technical Subjects	3,5,7,10		3,5,7,10	
	Writing Science/Technical Subjects	7,10		7,10	
NGSS	Structure and Function	LS1.A			
	Interdependent Relationships in Ecosystems	LS2.A			
	Ecosystem Dynamics, Functioning, and Resilience	LS2.C			
	Social Interactions and Group Behavior	LS2.D			
	Adaptation	LS4.C			
	Weather and Climate	ESS2.D			
	Natural Hazards	ESS3.B			
EEEEGL	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. A forest’s fire history is evident in its tree-ring record. The study of trees’ annual growth rings is called dendrochronology. For more information on that field of science, use the presentation/tutorial ***M17andH16_UsingDendroForFireHistory.pdf***. The slides from that tutorial are reproduced in Step 6 below.

Fire ecologists classify the severity of fires on standing forests into 3 categories:

- *Stand-replacing fires* kill most of the trees on a site, creating conditions that favor the establishment of a new forest where most of the trees are about the same age – a new cohort.
- *Low-severity fires* kill some trees (especially young ones and older ones of species with thin bark) and burn around others. They often leave scars on some of the surviving trees. Low-severity fire is not exactly the same as surface fire: Many surface fires are of low severity, but some are severe enough to kill most of the trees in a stand and are thus stand-replacing.
- *Mixed-severity fires* cause some stand replacement and some low-severity within a single burn or alternate between low-severity and stand-replacing fires over time.

You’ll notice that these categories are based on tree mortality rather than changes in the soil, which were studied in **Activity M10 or H12**.

This activity begins with a question – “Are our forests OK, or are today’s wildfires destroying them?” This question leads to brainstorming for ways to learn about past patterns of fire – the fire history in which native species have managed to survive and even thrive for thousands of years. After brainstorming, students work through a presentation/electronic tutorial on ways to learn about fire history. (If you use this as a tutorial, you can download the pdf file to individual computers and provide students with an Internet connection.)

If students would like to learn more about how trees respond to injuries on a metabolic and cellular level, encourage them to look at the following article, available at: https://www.fs.usda.gov/nrs/pubs/jrnl/2016/nrs_2016_smith-k_002.pdf. The article includes beautiful photos that show changes in tree cells and how they grow after a tree has been injured by fire.

Smith, Kevin T.; Arbellay, Estelle; Falk, Donald A.; Sutherland, Elaine Kennedy. 2016. **Macroanatomy and compartmentalization of recent fire scars in three North American conifers.** Canadian journal of forest research. 46: 535-542.

If students would like to learn more about the potential for fire-scar sampling to injure or kill trees, encourage them to read the following (at <https://firelab.org/project/condition-live-fire-scarred-ponderosa-pine-twenty-one-years-after-removing-partial-cross>):

Heyerdahl, Emily K.; McKay, Steven J. 2017. Research report: Condition of live fire-scarred ponderosa pine twenty-one years after removing partial cross-sections. Tree-ring research. 73(2): 149-153.

Materials and Preparation:

1. Download ***M17andH16_UsingDendroForFireHistory.pdf*** to EITHER present in class OR have the class use it as a tutorial to be accessed digitally.
2. If you choose to use the matching exercise for assessment, make 1 copy/student of **Handout M17 & H16-1. Vocabulary for Fire Historians.**
3. Write this list of terms on the board:
 - Annual ring
 - Cambium
 - Catface
 - Cohort
 - Dendrochronology
 - Fire scar
 - Increment core
 - Low-severity fire
 - Pith
 - Stand-replacing fire
 - Tree cookie

4. Find in the trunk: Actual fire-scarred tree cookies (not essential for this lesson, but very helpful in making the photos of fire-scarred cookies seem more real)

Procedures:

1. **Hook:** Explain: We've been studying how fires behave and how plants and animals deal with fires. Now we want to ask "Are our forests OK, or are today's wildfires destroying them?" Other ways to put it: Are today's wildfires too big or too small? Are they too severe? Are the forests we've been studying (ponderosa pine, lodgepole pine, and whitebark pine) threatened because of fire or lack of fire? Just as important is this question: How could we answer these questions?
2. Provide some information on the extent of recent wildfires in your area and have students discuss them in relation to the questions above. There are many ways to provide such information. A few are listed here. **Students are most likely to identify with information from their local area.**
 - a. Go to the Incident Information System website (<https://inciweb.nwccg.gov/>) and obtain recent data on wildland fires in your area. You can do this ahead of time or with the students. If students all have computers, they can do this themselves.
 - b. Go to the National Interagency Fire Center's homepage (https://www.nifc.gov/fireInfo/fireInfo_statistics.html) - or have students do so - and obtain information on historical fire statistics.
 - c. Go to the "Historically Significant Wildfires" page (https://www.nifc.gov/fireInfo/fireInfo_stats_histSigFires.html) and examine information on a few of the wildfires that have caused deaths or destroyed homes from 1804 to recent years.
 - d. Display the table below, which contains data from a single 365-day period in the area from the northern Rocky Mountains to the North Cascades. Or just quote a few numbers from the table, such as the number and area of wildfires just in your state over this 365-day period.

Major wildfires during 365 days, 18 July 2016 to 17 July 2017

Data from the United States Incident Information System:

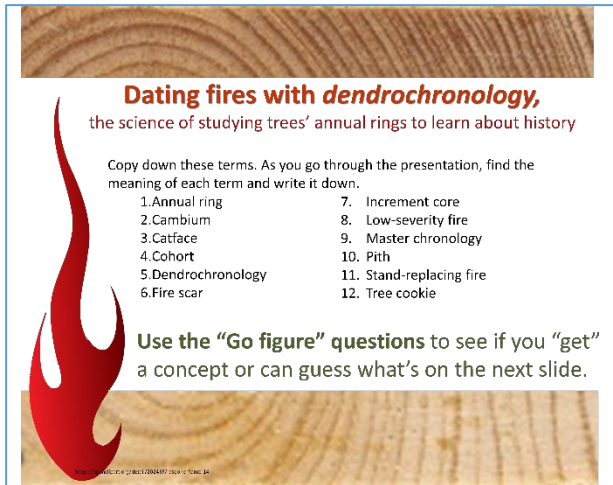
<https://inciweb.nwcg.gov/>

State	Number of fires	Area (acres)	Area (square miles)	Area (square kilometers)
Idaho	18	276,224	432	1,118
Montana	23	92,881	145	376
Oregon	13	114,319	179	463
Washington	20	321,306	502	1,300
Wyoming	24	200,538	313	812
Total:	98	1,005,268	1,571	4,068

3. Explain: One way to answer the question “Are our forests OK?” is to compare current patterns of wildland fire with the historical patterns, since native plants and animals are adapted to historical patterns. How many fires? How big? How severe? We need to become FIRE HISTORIANS.
4. Ask: How can we get information about the history of fire in a forest? Open discussion. Here are some methods used by scientists: Analyze annual rings in trees (increment cores and cross sections); analyze charcoal in peat cores from bogs, lakes, etc.; refer to Native American traditions; refer to journals, letters, maps, and other records from historical explorations; refer to records of the trees that marked section corners in early surveys.
5. Explain: We’ll become fire historians by studying data from trees’ annual rings. Before we can do this, we need to understand some basic information about tree growth, fire effects, and sampling methods. That’s what we’ll do with the presentation/tutorial in this activity. By the end of the activity, you need to understand the terms listed on the board and know how to use the science of dendrochronology to learn about fire history.
6. We suggest 3 different ways to use ***M17andH16_UsingDendroForFireHistory.pdf***.
 - a) Have students go through the slides on their own, treating it as a scavenger hunt to find the terms listed on the board and figure out what they mean.
 - b) Have students go through the slides as a tutorial (in class or as homework).
 - c) Go through the slides as a presentation/discussion with the class.

The blue information boxes in the slides and the notes in the PowerPoint version contain information that supplements the slides and answers questions sometimes asked by students, but this information is not essential for completing the activity.

Slide
1



Dating fires with *dendrochronology*,
the science of studying trees' annual rings to learn about history

Copy down these terms. As you go through the presentation, find the meaning of each term and write it down.


1. Annual ring	7. Increment core
2. Cambium	8. Low-severity fire
3. Catface	9. Master chronology
4. Cohort	10. Pith
5. Dendrochronology	11. Stand-replacing fire
6. Fire scar	12. Tree cookie

Use the "Go figure" questions to see if you "get" a concept or can guess what's on the next slide.

Slide
2

A tree's *annual ring* is the wood produced during 1 year of growth. An annual ring is shaped sort of like a circle. Each ring surrounds all of the wood that the tree produced in previous years.

Because trees usually produce 1 ring per year, you can estimate a tree's age by counting its rings.

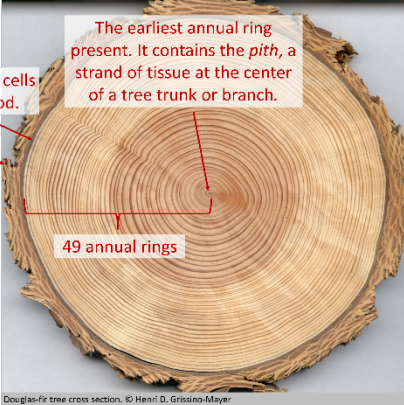


Douglas-fir tree cross section. © Henri D. Grissino-Mayer

Go figure: How many years did this tree live?

Slide
3

Answer: The tree lived at least 49 years. It could be a little older than 49, if the sample was cut from high above the ground.



Cambium, the layer of cells that makes new wood.

Bark

The earliest annual ring present. It contains the *pith*, a strand of tissue at the center of a tree trunk or branch.

49 annual rings

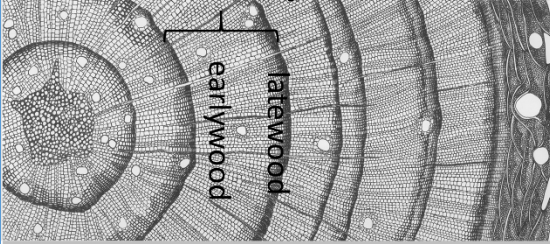
Douglas-fir tree cross section. © Henri D. Grissino-Mayer

Although we call tree rings "annual," they can be tricky. Some years a tree might produce 2 rings. Sometimes it might produce a ring just part-way around, and sometimes it might not produce any ring at all.

The height of the sample matters because of the way trees grow. They get wider and taller by producing brand-new wood every year, not by making the existing wood longer or wider. **What might cause a missing or extra ring?** Severe stress – perhaps a late, dry spring or damage from leaf-eating insects – could keep a tree from producing a ring. A summer with a deep cold spell or a spring with early drying followed by soaking

rains could cause a tree to produce an extra, or "false," ring.

Slide
4



Annual ring

earlywood
latewood

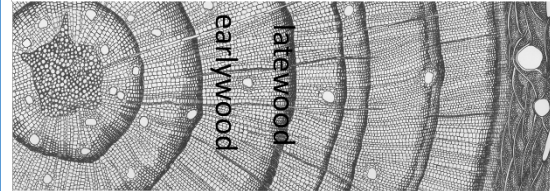
From Stokes, Marvin A.; Smiley, Terah A. 1996. An introduction to tree-ring dating. Tucson: University of Arizona Press. 73 p. Courtesy of Laboratory of Tree-Ring Research.

An annual ring consists of a thick row of large, thin-walled, light-colored cells plus a thin row of tiny, dark-colored cells. The large cells ("earlywood") are produced in spring and early summer. The tiny cells ("latewood") are produced later in the growing season.

Go figure: Why would a tree produce its biggest cells in the early summer?

Slide
5

Answer: Early summer is when the days are longest, moisture is usually abundant, the soil is warming up, and the tree can use nutrients stored up during the previous growing season.



earlywood
latewood

From Stokes, Marvin A.; Smiley, Terah A. 1996. An introduction to tree-ring dating. Tucson: University of Arizona Press. 73 p. Courtesy of Laboratory of Tree-Ring Research.


Annual rings are very sensitive to climate patterns. For example, if there is a 3-year drought, trees throughout the area are likely to produce very narrow rings – or no rings – during those years.

Go figure: If annual rings are so "tricky," how can you find out the exact year when one was formed?

Slide
6

Answer: Use dendrochronology. Dendrochronology is usually based on information from *increment cores*. These are thin cylinders of wood removed from a tree so the tree's annual rings can be studied.

Dendrochronologists compare the widths of annual rings in their samples with the width of rings in a *master chronology*. A master chronology is a record of the pattern of wide and narrow rings over time throughout a large area. A master chronology is based on data from dozens to hundreds of increment cores.



Sampled increment core:

Cores from the master chronology:

Does coring injure trees? Coring does injure the sampled tree, but the injury is usually minor. Most trees have ways to protect themselves from the fungi and insects that could invade through the hole left by an increment borer.

Slide
7

Learn more about finding the exact dates of annual rings at this National Park Service website:

Using the growth rings of trees to measure time into the past.




Let's try it >>

dendrochronology

Slide
8


Go figure: How can you connect information on annual rings to fire history?




USDA FS photo by Emily Heyer/ANL

Photo by Amy Probst

Slide
9

A.  **Answers:** Use scars on trees that survived past fires. If you can find out the years of the annual rings in each scar, you'll know when the fires occurred.


B.  Find a stand where most of the trees are about the same age. They may have become established after a fire.


A group of living things that are all about the same age is called a *cohort*. If you can find out when this cohort of trees began, you'll know that the fire happened shortly before that.

Go figure: How severe were the fires that scarred Tree A? How severe was the fire that left so many standing dead trees in Forest B?

Not every scar or catface on a tree is caused by low-severity fire. Scars can be caused by many things, including lightning, frost, insects and diseases, and mechanical injuries.


Slide 10


A.  **Answers:**
Tree A was scarred by many low-severity fires.
 Even though these low-severity fires killed some of the tree's cambium, they did not kill the tree.

B.  **Forest B was established after a very severe, stand-replacing fire killed the old lodgepole pines.**
 The fire burned through the tree crowns, and its heat opened their cones. Millions of seeds fell to the ground. The burned soil was a perfect place for lodgepole pine seedlings to grow. The new seedlings are replacing the forest that was killed by fire.

Slide 11

Look closely at this fire-scarred tree.

 The big, black wound on this tree, called a *catface*, tells us that the tree was scarred by fire. A close-up look (below) shows many vertical creases in the catface. These are *fire scars*. Each scar was made by a low-severity fire that killed part of the tree's cambium. But cambium cells survived along the edge of the injured area, and they grew well after the fire.

 Close-up showing fire scars in a catface (photo courtesy of Peter Brown).

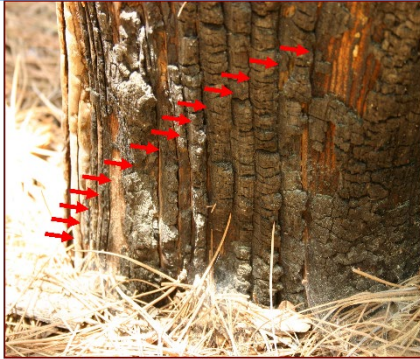
Go figure: How many fire scars are in this catface?

The origin of the term *catface* comes from the turpentine industry of southeastern United States. It refers to the scars left behind by the extraction of resin from pine trees. Pine resin was at one time in high demand because it could be used for waterproofing ships and making turpentine, and was once a major part of the southern economy. Turpentiners wounded trees in V-shaped streaks down the length of tree trunks to channel resin into cups, where it was collected and processed into the

spirits of turpentine. The V-shaped streaks were called "catfaces" for their resemblance to a cat's whiskers.

Slide 12

Answer: The catface contains 14 scars from low-severity fires.

 Close-up showing fire scars in a catface (photo courtesy of Peter Brown).

Go figure: Can you figure out a tree's fire history without cutting it down?

These features can help you identify fire scars when you're out in the woods:

- Catfaces caused by fire start at the ground. They hardly ever start part-way up the tree trunk.
- Catfaces caused by fire are sort of triangle-shaped. They are wider at the base and narrower at the top.
- If a lot of fires have scarred a tree, the scars look like a series of vertical creases or folds of wood on the catface. A tree's first fire does not

blacken the wood. (The fire is hot enough to kill the bark and the cambium

under it, but the fire is not hot enough to burn the bark away.) Later fires blacken the wood if the fire-killed bark has fallen off and exposed the wound to heat and flames.

- When you look at a cross-section from a fire-scarred tree (a *tree cookie*), you see that each scar is curved, following the annual ring that formed the year of the fire. If a scar is not parallel to the annual rings, it was not formed by fire.
- Fire scars are kind of symmetrical – that is, new wood tends to curl over the injured wood from both sides of the injured area. If you don't watch out for this, you could count each fire twice! However, a fire might scar only one side of a big catface, so you might “miss” a fire if you sample only one side.

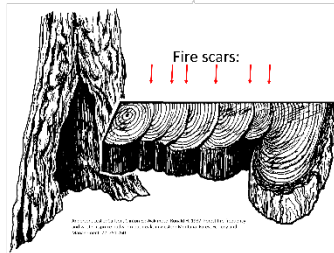
Slide
13

Answer: Yes, you can figure out a tree's fire history from a narrow section of wood.

To figure out the years of fire scars, dendrochronologists collect *tree cookies*. A tree cookie could be a full cross section or a partial one – a narrow section cut from one side of the catface.



JDAK Forest Service photo by Emily Legendal.



Does it injure the tree to cut a partial section? One scientist has checked up on trees that she sampled 20 years ago. She found that they were no more likely to die than similar trees that she hadn't sampled.

Slide
14

Go figure: How many fires have scarred this lodgepole pine?



Slide
15

Answer: Just one fire has scarred this tree.

Red arrows point to the two ends of the fire-killed cambium. The blue line beneath the arrows shows where the cambium was killed. The green line above the arrows shows where the cambium survived. Only about 1/3 of the cambium survived the fire! But living cells grew at the edge of the dead cambium every year, and gradually these annual layers of new wood began to cover the scar. Eventually, a curl of living wood covered much of the scar.

Slide
16

Go figure: Do you know what these terms mean? If not, go back through the program to find out.

1. Annual ring	7. Increment core
2. Cambium	8. Low-severity fire
3. Catface	9. Master chronology
4. Cohort	10. Pith
5. Dendrochronology	11. Stand-replacing fire
6. Fire scar	12. Tree cookie

Slide
17

As a FIRE HISTORIAN, you can now figure out the fire history of individual trees and whole forests.

USDA Forest Service Region 2 photo
Kris Wick Stegler, USDA Forest Service,
Bismarck, ND

USDA Forest Service photo
Joe Chap of Emily Hagerhall

USDA Forest Service photo
Joe Chap of Emily Hagerhall

Assessment: Use one of these 2 assessments:

OPTION 1: Matching (**Handout M17 & H16-1**)

OPTION 2: Writing assignment. Refer to the list of terms on the board:

- Annual ring
- Cambium
- Catface
- Cohort
- Dendrochronology
- Fire scar
- Increment core
- Low-severity fire
- Pith
- Stand-replacing fire
- Tree cookie

Have students write a paragraph that explains to a classmate how he/she could use trees' annual rings to learn about fire history. In the paragraph, they should use at least 8 of the terms listed.

Evaluation:

	Excellent	Acceptable	Poor
OPTION 1: Matching (Handout M17 & H16-1)	10-11 answers correct	7-9 answers correct	Fewer than 7 answers correct
OPTION 2: Writing assignment	Paragraph uses 8-11 terms correctly.	Paragraph uses 6-7 terms correctly.	Paragraph uses fewer than 6 terms correctly.
	Paragraph accurately describes use of dendrochronology to study fire history.	Paragraph describes use of dendrochronology to study fire history with moderate accuracy.	Paragraph contains numerous inaccuracies or omits important concepts.
	Paragraph contains an appropriate topic sentence.	Paragraph contains an appropriate topic sentence.	Paragraph does not contain an appropriate topic sentence.
	Paragraph uses complete sentences.	Paragraph uses complete sentences.	Paragraph does not use complete sentences.
	Paragraph is clear and coherent.	Paragraph is clear.	Paragraph is not clear.

Handout M17 & H16-1. Vocabulary for Fire Historians

Name: _____

Next to each term, write the letter of the correct definition.

A.	Annual ring	_____ A fire that has does not change the soil very much and kills very few of the mature trees.
B.	Catface	_____ The science of learning about the past by dating annual rings in living and dead trees.
C.	Cohort	_____ A large wound on a tree trunk or branch, where living wood is gradually growing from the edges over the dead wood in the injured area.
D.	Dendrochronology	_____ A layer of wood produced during 1 year of tree growth. This layer encircles all of the wood that the tree produced in previous years.
E.	Fire scar	_____ A fire that kills all or most of the mature trees and provides good conditions for growing a new generation of trees.
F.	Increment core	_____ A thin cylinder of wood that is removed from a tree so the tree's annual rings can be studied.
G.	Low-severity fire	_____ A cross section or narrow sample of wood taken from a tree trunk so the tree's annual rings can be studied.
H.	Pith	_____ A mark on a tree trunk where a fire killed the tree's cambium part-way around. When you look at one of these marks on the outside of a tree, it looks like a vertical crease or fold in the wood.
I.	Stand-replacing fire	_____ A group of living things that are similar in age.
J.	Tree cookie	_____ A strand of spongy tissue that runs through the center of a tree trunk or branch.
K.	Cambium	_____ The layer of living cells under a tree's bark that produces the annual rings

Teachers' Key to Matching, Handout M17 & H16-1:

G, D, B, A, I, F, J, E, C, H, K

Teachers' Glossary for Evaluation of Writing assignment:

This is a list of definitions of the terms that students should use in the assigned paragraph. All of the terms are defined, illustrated, and used in the presentation/tutorial

M17andH16_UsingDendroForFireHistory.pdf. The definitions are adapted from the Merriam-Webster Dictionary (<https://www.merriam-webster.com/>), the "FireWords" Glossary of Fire Science Terminology (<http://www.firewords.net/>), and/or the FireWorks program (<https://www.firelab.org/project/fireworks-educational-program>).

1. **Annual ring:** A ring of wood produced during 1 year of a tree's growth. Annual rings are nearly circular in shape (unless the tree has a catface). Each annual ring surrounds all of the wood that the tree produced in previous years.
2. **Cambium:** the layer of living cells under a tree's bark that produces the annual rings. If the entire cambium is killed, the tree will die. If only a portion of the cambium is killed, it can still produce new cells including annual rings.
3. **Catface:** A large wound on a tree trunk or branch, where living wood is gradually growing from the edges over the dead wood in the injured area.
4. **Cohort:** A group of living things that are similar in age. A group of students who are all in a particular grade-level in school is a cohort. A group of trees that all began growing after a severe fire is a cohort.
5. **Dendrochronology:** The science of learning about the past by dating annual rings in living and dead trees.
6. **Fire scar:** A mark on a tree trunk where a fire killed the tree's cambium part-way around. When you look at a fire scar from the outside, it looks like a vertical crease or fold in the wood.
7. **Increment core:** A thin cylinder of wood that is removed from a tree so the tree's annual rings can be studied.
8. **Low-severity fire:** A fire that does not change the soil very much and kills few of the mature trees. Low-severity fires often leave fire scars on the trunks of mature trees.
9. **Pith:** A strand of spongy tissue that runs through the center of a tree trunk or branch. In an increment core or tree cookie, the pith shows the earliest year of growth.
10. **Stand-replacing fire:** A fire that kills all or most of the mature trees and provides good conditions for growing a new generation of trees. The young trees then "replace" the trees killed by fire.
11. **Tree cookie:** A sample of wood taken from a tree trunk so the tree's annual rings can be studied. The sample may be a full cross section – that is, a piece cut all the way across the tree trunk, so it looks a little like a cookie; or it may be a partial cross section – that is, a narrow piece cut from the side of a catface.



M18 & H17. History of Stand-replacing Fire

Lesson Overview: Students use information from 11 cross-dated increment cores to figure out the approximate age of a forest stand that originated after stand-replacing fire.


Lesson Goals: Understand how scientists can estimate the time when a stand-replacing fire occurred. Be able to assemble and interpret a *stand history diagram* and discuss evidence for a stand-replacement *fire regime*.

Objectives:

- Students can follow technical directions to record observations and contribute their information to a class diagram that shows the history of a forest stand.
- Students can describe the fire history shown by a stand history diagram that contains cohorts of trees.

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

Duration: one 30- 40-minute session

Group size: Whole class 

Setting: Classroom

Vocabulary: *fire regime, stand history diagram*

ABOUT STUDENT PRESENTATIONS: If you did **Activity M11 or H14**, this would be a great time for the presentation **on a species with serotinous cones, such as lodgepole pine.**

Middle School Standards:		6th	7th	8th
CCSS	Writing	2, 7, 8, 10	2, 7, 8, 10	2, 7, 8, 10
	Speaking/Listening	1,2,4,6	1,2,4,6	1,2,4,6
	Language	1, 4, 6	1, 4, 6	1, 4, 6
	Writing Science/Tech	3,4,7,9,10	3,4,7,9,10	3,4,7,9,10
NGSS	Interdependent Relationships in Ecosystems	LS2.A		
	Cycle of Matter and Energy Transfer in Ecosystems	LS2.C		
	Weather and Climate	ESS2.D		
	Natural Hazards	ESS3.B		
EEEEGL	Strand 1	A,B,C,E,F,G		
	Strand 2.2	A		

High School Standards:		9th	10th	11th	12th
Common Core ELA	Writing	2, 7, 10		2, 7, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 4, 6		1, 4, 6	
	Writing Science/Tech	7, 8, 9, 10		7, 8, 9, 10	
NGSS	Interdependent Relationships in Ecosystems	LS2.A			
	Ecosystem Dynamics, Functioning, and Resilience	LS2.C			
	Weather and Climate	ESS2.D			
	Natural Hazards	ESS3.B			
	Human Impacts of Earth Systems	ESS3.C			
	Global Climate Change	ESS3.D			
EEEEGL	Strand 1	C,E,F,G			

Teacher Background: In this activity, students continue to build their skill in using trees' annual rings to figure out a forest's fire history. They use increment cores collected for the following study:

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 forest research. 44(6): 593-603.

Each team determines the years of the earliest and final annual rings on a photo of an increment core. Then the class compiles the information from 11 cores into a stand history diagram. This is a vivid quantitative way to depict the history of a forest. Stand history diagrams will be used in the next two activities; by the end of **Activity M20 & H19**, students will be able to use a stand history diagram to describe the historical fire regime of a forest.

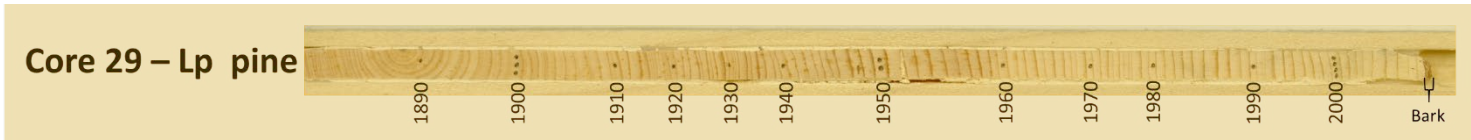
Scientists use dendrochronology to learn about the historical pattern of stand-replacing fire by analyzing the ages of all of the mature trees in a stand. If most of the trees originated within a few years of each other, they are generally considered a cohort. However, not all cohorts are initiated by fire. To figure out what disturbance allowed so many trees to establish in such a short time, scientists look for additional evidence: For example, cut stumps suggest logging; the presence of large numbers of old logs (without scorched wood) suggests windthrow; the presence of scorched wood and charcoal in the soil suggests fire.

Materials and preparation:

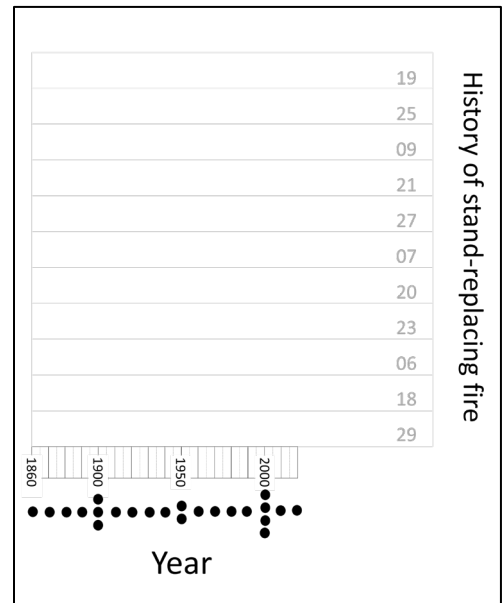
1. Project **PotholesStudyArea.pptx**, which shows a map and photos of the area where the increment cores and tree cookies used in FireWorks were collected.
2. Find in the trunk: 11 photos of increment cores. (These are about 20-40 cm long and quite narrow. An example is shown below.) They may be in the same case as the photo posters of fire-scarred tree cookies. The core photos can also be printed from **IncrementCorePhotos.pptx**.

Tree cookies, increment cores, and fire history data are from research on the Deschutes National Forest, central Oregon:

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 Forest Research*. 44(6): 593-603.



3. Find in the trunk and display the background poster for the stand-replacing stand history diagram, shown on right. It is also available for download from **FireHistBackground_stand-replacing.pptx** (right-hand side). Students will attach their timelines (next step) to this background poster. We suggest laying the background poster on a large table or on the floor for assembly. Have tape available for attaching the students' timelines that represent individual cores.



4. Prepare timelines for students to use in constructing the stand history diagram by doing one of the following:
 - **OPTION 1.** Use 11 of the laminated timeline strips provided in the trunk (shown below – they are actually about half a meter long). Provide 1/team. These can also be printed from the left-hand side of **FireHistBackground_stand-replacing.pptx**. If you use this option, each team will also need a copy of the half-page **Handout M18 & H17-1. Record tree history on a timeline** and a dry-erase marker, preferably the same color for every team. To clean the strips after they are used, you will also need a cloth, an eraser, and cleaning fluid.

1860	1900	1950	2000	Tree number	Species	No. fire scars	Av. fire interval (years)
						0	X

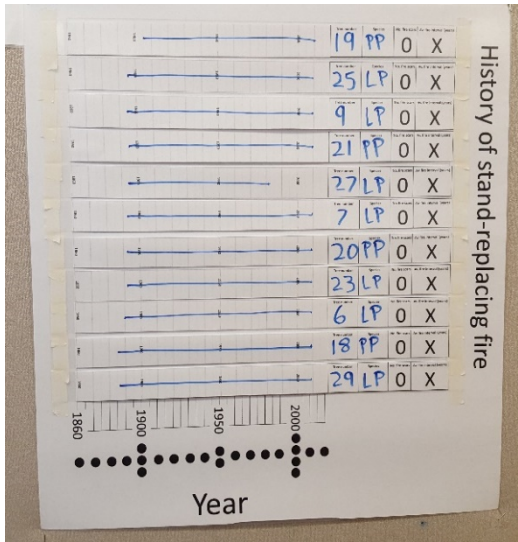
- OPTION 2. Make 11 copies (1/team) of *FireHistTemplate_stand-replacing.pptx*, one for each team. Each team will also need scissors and tape.

5. Make 1 copy/student of **Handout M18 & H17-2. You find an older cohort!**

Procedure:

1. Explain: In the last activity, we learned how fire historians use dendrochronology to learn how many fires have occurred in past centuries and how severe the fires were. In this activity, we'll use dendrochronology to figure out the history of STAND-REPLACING FIRE in a forest in central Oregon. Refer to the projection of *PotholesStudyArea.pptx*.
2. Explain: Once we figure out the historical fire regimes for forests in this particular area – that is, the frequency, severity, and spatial uniformity of past fires - we'll be able to understand fire regimes of the ecosystem(s) that we've been studying. We can use what we learn to address one of the most important questions about today's forests, the question that we asked at the start of the last activity: "Are our forests OK, or are today's wildfires destroying them?"
3. Hand out to each team: a photo of an increment core, plus EITHER (1) a dry-erase marker, a blank timeline, and a half-page handout with instructions (**Handout M18 & H17-1. Record tree history on a timeline**) or (2) a copy of *FireHistTemplate_stand-replacing.pptx*.
4. Have the students place the rings so they can read the print from left to right. Have them examine their cores as you explain:
 - a) Dendrochronologists have already dated each of these increment cores. They used small dots to mark the ring at the start of every decade. They also marked the earliest ring on the core – usually the pith – with a short black line. Find this line near the left end of your core.
 - b) The most recent ring is at the right end of your core. Find this ring. Ignore any bark that lies outside (to the right of) the annual rings.
 - c) Count rings to the left of the earliest dot to figure out the earliest year shown on your core. Count rings to the right of the most recent dot to figure out the most recent year.
 - d) Transfer that information to your timeline, as instructed on your half-page handout, and place the timeline on the class's stand history diagram background.

- Have students follow the instructions on the handout and add their completed timeline to the background. When all are completed, it should look something like this. Data are on the right.



Species	Tree number	Earliest date	Final date
Lodgepole pine	6	1890	2009
Lodgepole pine	7	1902	2009
Lodgepole pine	9	1895	2009
Ponderosa pine	18	1887	2009
Ponderosa pine	19	1906	2009
Ponderosa pine	20	1893	2009
Ponderosa pine	21	1895	2009
Lodgepole pine	23	1893	2009
Lodgepole pine	25	1896	2009
Lodgepole pine	27	1894	1982
Lodgepole pine	29	1887	2009

- Review/Ask: What is a cohort? Give an example. **A cohort is a group of living things that are all about the same age. Our class is a cohort.**
- Explain: Dendrochronologists figure that a lot of trees that all got established in a short time constitute a cohort. Scientists decide what “a short time” is depending on the location and growing conditions. In the study we’re using, the scientists decided on about 20 years to define a cohort. Do the trees in our increment cores form a cohort? **Yes, because all of the trees became established within a 20-year period (between 1887 and 1906).**
- Ask: How might a fire have gotten this cohort started? **The cohort could have become established after the overstory trees were killed by a stand-replacing fire, perhaps a crown fire. That would have made excellent conditions for young pines to germinate and start growing. What other events could have started the cohort? Possibilities include a pine beetle epidemic, logging, or a severe wind storm....** How could we be certain that fire was the cause? **Find other clues, like fire-scarred trees or charcoal in the soil or a nearby bog.**
- Summarize: Remember the name for the pattern of fire frequency and severity over a long time: a fire regime. Our increment cores suggest that the forest we’re studying had a STAND-REPLACING fire regime. How certain can we be about that? **We should probably be cautious about that conclusion, since we only have 11 samples and only 1 cohort. It would be better if we could go deeper into the past and get more samples.**
- DON'T TAKE THE STAND HISTORY DIAGRAM OR THE STUDY AREA PROJECTION DOWN YET. YOU'LL NEED THEM BOTH FOR THE NEXT 2 ACTIVITIES.**

Assessment:

1. Explain: Now we'll get a little more practice at discovering a history of stand-replacing fire.
2. Give each student a copy of **Handout M18 & H17-2. You find an older cohort!** and have them complete the assignment.

Evaluation:

	Excellent	Good	Poor
Format	Used correct business letter format	Used letter format	Did not use letter format
Writing	Writing is clear. Used full sentences. Used topic sentences for paragraphs.	Writing is clear. Used full sentences.	Writing is unclear or sentences are incomplete.
Content:			
Identified period when old cohort began growing	approximately 1770-1785	approximately 1770-1785	One or both dates inaccurate by more than 5 years.
Identified possible cause for beginning of old cohort	Old cohort could have started after fire, but we don't have charcoal evidence for a fire around 1770. Other possible explanations include wind storm and beetle epidemic.	Old cohort could have started after fire (or other cause). Did not discuss lack of evidence for fire.	Did not suggest a reasonable cause for beginning of old cohort.
Identified year of death for old cohort	Most of the trees died around 1877, although two of them died earlier.	Most of the trees died around 1877.	Date inaccurate by more than 5 years.
Gave explanation for death of old cohort	Fire was probably the cause, since so many of the logs in this cohort were black and charred.	Fire was probably the cause, since so many of the logs in this cohort were black and charred.	Did not identify a cause or did not explain evidence.
Connected death of old cohort to beginning of more recent (1887-1906) cohort	Old cohort was killed by stand-replacing fire around 1877, which is about 10 years before the earliest date in the cohort that we described in class. The fire that killed the trees in the old cohort may have cleared the way for establishment of the new cohort between 1887 and 1906.	Explained that old cohort died just before the more recent cohort began growing but did not explain the possible connection between the two.	Did not identify a reasonable explanation for the relationship between the two cohorts.

Handout M18 & H17-1. Record tree history on a timeline

Using a dry-erase marker, record the fire history of your tree core on your timeline:

1. Record your tree's number and species in the correct boxes at the right end of the timeline. Use "PP" for ponderosa pine and "LP" for lodgepole pine. Make the print large so people can see it from across the room.
2. Find the tiny pencil-marked dots on your increment core. Find the left-most dot and its year (written below the dot). Count the rings to the left to figure out your core's earliest year, but don't count rings to the left of the pith (marked with a vertical line).
 - On your timeline, draw a vertical bar to show that year.
3. Find the right-most dot on your increment core and its year. Count the rings to the right to figure out your core's final year.
 - On your timeline, draw a vertical bar to show that year.
4. Draw a dark horizontal line to connect the 2 vertical bars.



Attach your core's timeline to the poster that has information from all increment cores:

5. Find your core's number on the poster.
6. Attach your timeline to the poster right on top of your core's number and the box it is in. Carefully line up the edges of your timeline with edges of the box.

Handout M18 & H17-1. Record tree history on a timeline

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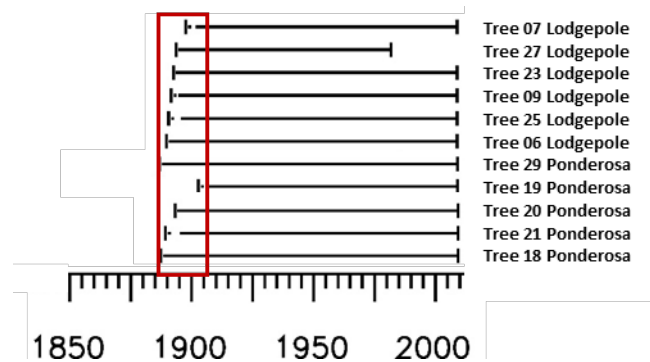
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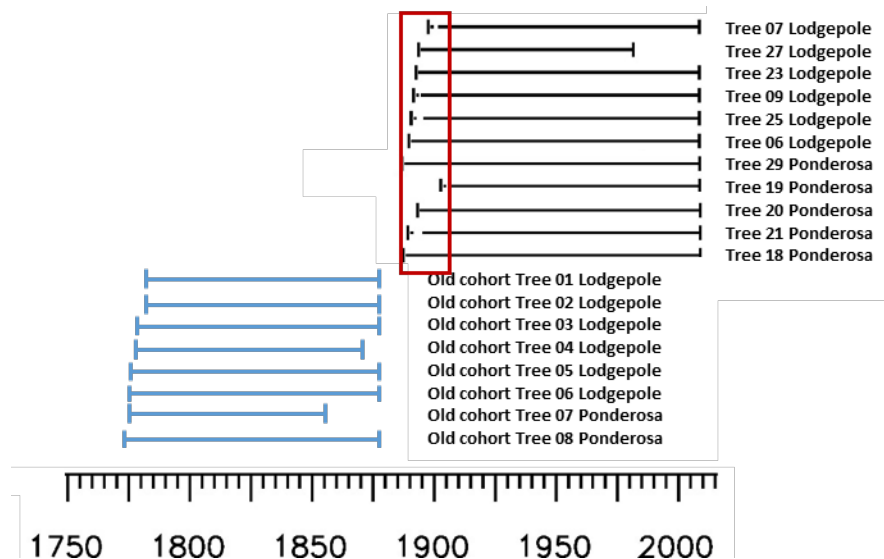
Handout M18 & H17-2. You find an older cohort!

Name: _____

At right is a copy of the stand history diagram that you completed in class. The trees are in a different order, but their timelines are the same. A red outline shows the cohort of trees that you identified in class.



Suppose you go back to the place in central Oregon where those 11 cores were collected and find 8 fallen logs buried in the ground. These were not sampled in the earlier study, so they provide new information. The logs look very old. Their bark is all gone, but they are not rotten. Many of them have black char on the outside of the wood. You collect increment cores from all of them. You return to the lab and cross-date them to find the years of their earliest and most recent annual rings. Then you add your new data to the class's stand history diagram. Now it looks like this:



You have found evidence that there was a cohort of trees that started back in the 1700s! Call it the "old cohort." Write a letter to the scientists who did the original research. In the letter, explain:

- When your "old cohort" started growing (give a range of dates)
- What may have caused the old cohort to start growing (do you have any evidence for that?)
- When the old cohort died
- What probably caused so many trees in the old cohort to die at one time (do you have any evidence for that?)
- How your discovery might explain what caused the 1887-1906 cohort of trees (the ones in the gray shaded box) to start growing.



M19 & H18. History of Low-severity Fire

Lesson Overview: Students create a living model to demonstrate how fire can leave scars on a living tree. They use dendrochronology to describe the history of low-severity fire for a single tree and then a whole forest. They assemble a stand history diagram and use it to identify years when low-severity fire occurred and to describe the spatial uniformity of past fires. Then they use information from the stand history diagram to discuss the historical policy of complete fire suppression.

Subjects: Science, Technical reading, Technical writing, Mathematics

Duration: One 30-40-minute session

Group size: Entire class

Setting: Classroom

Vocabulary: *fire interval*



Lesson Goals: Students understand that low-severity fires were common in some forests during the past. They understand that historical fires were sometimes patchy in their spread pattern and sometimes more uniform. Students understand that low-severity fires are less common now, at least partly due to the policy of suppressing all fires as soon as possible after they are detected. Students are able to express an informed opinion about fire policy and support their opinion with evidence.

Objectives: Students can

- identify annual rings on tree cookies and identify scars made by low-severity fire.
- describe the history of low-severity fire for a single tree and for a whole forest.
- express an informed opinion and support it with evidence.

WANT TO USE STUDENT PRESENTATIONS ON INDIVIDUAL SPECIES TO INTEGRATE CONCEPTS? If you did one of the activities in which students researched a specific organism and its relationship to fire (**Activity M11 or H14**), this would be a great time for student presentations on all of the tree species that haven't yet been covered.

Middle School Standards:		6 th	7th	8th
CCSS: Disciplinary Core Ideas	Reading Informational Text	1, 2, 4, 10	1, 2, 4, 10	1, 2, 4, 10
	Writing	2, 4, 10	2, 4, 10	2, 4, 10
	Speaking/Listening	1,2,4,6	1,2,4,6	1,2,4,6
	Language	1, 2, 4, 6	1, 2, 4, 6	1, 2, 4, 6
	Reading Standards Science/Tech	1, 3, 7, 9, 10	1, 3, 7, 9, 10	1, 3, 7, 9, 10
	Writing Standards Science/Tech	3,4,7,9,10		
NGSS	From Molecules to Organisms: Structure and Process	LS1.A, LS1. B		
	Ecosystems: Interactions, Energy, and Dynamics	LS2.C, ETS1.B		
	Heredity: Inheritance and Variation of Traits	LS1.B		
	Biological Evolution: Unity and Diversity	LS4.C		
	Earth's Systems	ESS2.D		
EEEEGL	Strand 1	A,B,C,E,F,G		
	Strand 2.2	A		

High School Standards:		9th	10th	11th	12th
CCSS: Disciplinary Core Ideas	Reading Informational Text	1, 2, 4, 10		1, 2, 4, 10	
	Writing	2, 4, 10		2, 4, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 4, 6		1, 2, 4, 6	
	Reading Standards Science/Tech	1, 3, 7, 10		1, 3, 7, 10	
	Writing Standards science/Tech	2, 4, 7, 10		2, 4, 7, 10	
NGSS	From Molecules to Organisms: Structure and Processes	LS1.A, LS1.B			
	Ecosystems: Interactions, Energy, and Dynamics	LS2.C, ETS1.B			
	Biological Evolution: Unity and Diversity	LS4.C			
	Earth's Systems	ESS2.D			
EEEEGL	Strand 1	C,E,F,G			

Teacher Background: In this activity and the next one, students continue to analyze samples and data from the following study:

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 forest research. 44(6): 593-603.

Contrary to the impression created by news media during the height of wildfire season, wildland fires vary a lot in how frequently they occur, their spatial pattern of spread, and their severity. The variation is caused by all 3 of “sides” of the Fire Environment Triangle (weather, topography, and fuels), which students learned about in Activity **M05** or **H08**. See step 12 under **Procedures** for some discussion of things that might cause such variation.

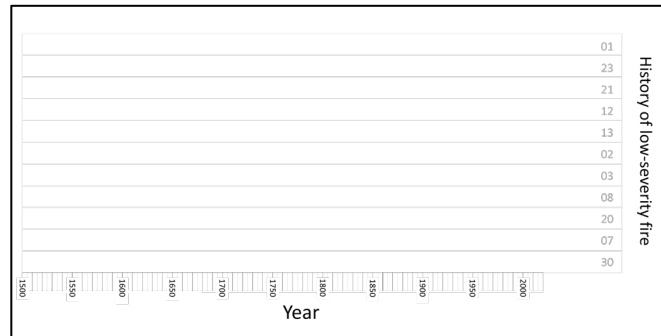
In this activity, students examine tree-cookie photos that have scars from past fires. The following information on fire scars and wood may help you answer some questions that could arise:

- After a tree has one fire scar, it is more vulnerable to further scarring because the fire-killed bark has fallen off from the area where the cambium was damaged, so the scarred portion of the trunk dries out and has no insulating bark. Another reason for the tree’s increased vulnerability is that the edge of the scar may contain a lot of pitch, which protects the sapwood from invading insects and fungi – but which is also easy to ignite.
 - Trees do not “heal” in the same way animals do: 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 bark that grow in from the edges of the injured area. “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 leeward side of any obstacle in a 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 of the tree since branches, cones, litter, and duff accumulate there as they roll downhill.
 - Why is some of the wood in a tree cookie dark while other areas are very light? The outer wood (xylem, also called sapwood) is often lighter than the inner wood (heartwood) because it is filled with a sappy mixture of water and minerals. The heartwood and other wood in injured areas of the trunk is dark because it is filled with pitch rather than sap. Pitch can help tree survive after it is injured by keeping fungi and insects from invading the healthy wood – at least for a time. The pitch-filled cells do not transport water and nutrients throughout the tree, but they do provide important structural support for the tree.
 - Other unusual marks in wood include patches of rot, holes made by wood-boring beetles, damage from fungi, checks (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. Note that the Stand History Diagram created in the previous activity and the projection of the study area from that activity (*PotholesStudyArea.pptx*) should still be on display.
2. Find a piece of black plastic or cloth about 25 cm wide and 0.5-1.0 m long. Plastic from a black garbage bag works well.
3. Find in the trunk:
 - a small whisk broom or red cloth napkin
 - actual fire-scarred cookies

- the background poster for the low-severity stand history diagram (shown on right and available for download in *FireHistBackground_low-severity.pptx*). Display it in the classroom. Have tape on hand for attaching timelines.



- the set of 11 laminated photo posters of fire-scarred tree cookies. These are usually stored in a pillowcase or large envelope. They are also available for download and printing from *CookiePostersNRM-Cascades.pptx*.
- the FireWorks Cookie Book, also available in this file: *CookieBookNRM-Cascades.pptx*.

4. Make 1 copy/student or team: **Handout M19 & H18-1. A Tree’s Story.**
5. Make 1 copy/student of the short handout: **Handout M19 & H18-3. How well did the policy work?** (There are 3 copies on a page.) Also provide 1 copy/student of **Reading_ForestHistSociety_FireSuppression.docx**. You can print this from the file, copy it from the **Appendix** at the end of this lesson, OR provide computer access so students can read it. This reading is an excerpt from a longer article. If you want them to read the full article, find it online at <https://foresthistory.org/research-explore/us-forest-service-history/policy-and-law/fire-u-s-forest-service/u-s-forest-service-fire-suppression/>.
6. Prepare timelines for students to use in constructing the stand history diagram by doing one of the following:
 - a) **OPTION 1.** Use 11 of the laminated timeline strips provided in the trunk (shown in miniature below – they are actually about 1.4 m long), one timeline/team. If you use this option, also provide each team with a copy of **Handout M19 & H18-2. Record fire history on a timeline.** Each team will also need 2 dry-erase markers, preferably in 2



contrasting colors. (Blue and black were used in the photo shown in Step 9 below.) To clean the strips after they are used, you will also need a cloth, an eraser, and cleaning fluid.

- b) **OPTION 2.** Make 11 copies (1/team) of *FireHistTemplate_low-severity.pptx*. Print the pages 1-sided. Each team will also need 2 markers, preferably in contrasting colors, as well as scissors and tape.

Procedures:

1. Explain: Let's return to the question "Are our forests OK?" We need to know more about a place's fire history to answer that question.
2. Refer to the projection of the study area (*PotholesStudyArea.pptx*): Now that we know how to construct a stand history diagram, we're going to figure out the history of low-severity fire for a single tree and then for a forest in the same study area we looked at before, in central Oregon.
3. **REVIEW: Human model of fire scar formation.** Explain: We're going to look at tree cookies with scars made by past fires. Some of them have a pretty complicated fire history. Before we start, let's review the way in which a fire scar is formed. We'll construct a living model of the process.
4. 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 or red cloth napkin 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 fire!
 - d) Tell the students that the fire was hot enough to kill the cambium part-way around the tree – in fact, right where the student's hands meet. 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 annual 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,**

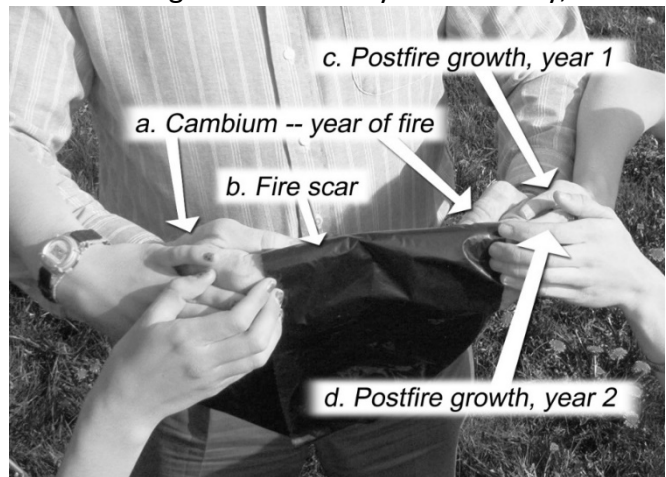
and litter accumulate there as they roll downhill. The duff is generally deeper on the uphill side as well.

f) Get two more students to help, one standing on each side of the model tree. They are the next year's annual 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" or "curl" 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 students 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.

5. Explain: Now we'll analyze fire history from 11 tree cookies collected in central Oregon. We'll analyze the first one together. Then we'll do the others in teams and build a stand history diagram with all of the data.

6. Give each student a copy of Handout **M19 & H18-1. A Tree's Story.**

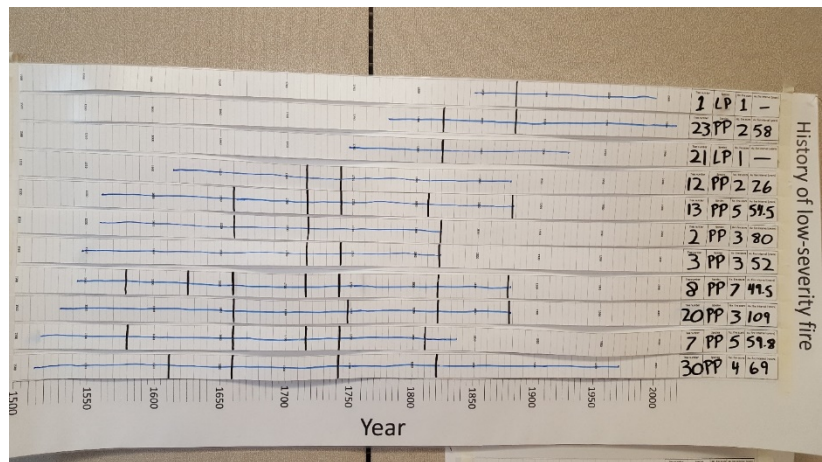
7. Explain: The handout contains a photo of a cookie taken from a catface on a tree that survived many low-severity fires. Dendrochronologists have figured out the exact year of each fire scar. Your job is to figure out the years between fires – called *fire intervals* – and then calculate the average fire interval. Work through the handout, and then we'll discuss the results.

8. Have students complete the handout in class or as homework. Go through the answers in class so they can check their results and ask questions. (See the **Answer Key** below.) Then discuss:

- a) Did this tree grow well or poorly in the years after fire? **After the 1626 and 1659 fires, the tree grew well. After the 1580 and 1819 fires, the tree grew poorly. The 1741 fire did not seem to influence growth very much. The tree died a year after the 1877 fire.**
- b) What might be some reasons for changes in the tree's growth after fire? **Slow growth is likely to occur if the fire killed a lot of the tree's foliage or much of the cambium. Rapid growth after fire may occur if the fire killed nearby plants, thus reducing competition for moisture and nutrients, or if nutrients in the ash from burned vegetation enriched the soil.**
- c) Could a tree or forest be injured by lack of fire? **Answers to this question vary from place to place and from one forest type to another. In forests that have experienced little or no fire in the past, lack of fire does not injure the forest. In forests that have a long history of low-severity fires, however, lack of fire can injure the forest. For example, when low-severity fire is excluded for a long time from a forest where it used to occur every decade or so, dense undergrowth and deep duff may develop. These conditions can make fires that are very severe 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 can also reduce diversity across the landscape, so a forest that used to have patches of different vegetation and ages becomes more and more uniform. Increased uniformity increases the potential for fires to spread across large areas when burning conditions are just right.**

9. Hand out 10 of the cookie photo posters, one to each team. Do not use Tree 08, since you already analyzed it in class. However, have one team complete a timeline for Tree 08 – perhaps the team doing Tree 01 or Tree 21, since those both have just 1 fire scar. Give each team a timeline, instructions, and the other materials needed to complete their timeline (see Step 6 under **Materials and Preparation**).

10. Have each team follow the instructions (that is, do the calculations, plot the tree's history on their timeline, then attach the timeline to the background poster). The resulting stand history diagram should look something like this:



11. As a class:

- a) List every year when at least one tree was scarred. **(1580, 1612, 1626, 1659, 1715, 1741, 1819, 1877)**
- b) Count the number of years when a fire occurred – that is, at when least 1 tree was scarred. **(8)**

- c) Calculate the intervals between years when a fire occurred (32, 14, 33, 56, 26, 78, and 58 years)
- d) Calculate the average interval between years when a fire occurred. Explain: This is the fire interval for the whole forest. (42 years)
12. Ask/discuss: What was the historical fire regime for this forest? **The data show a low-severity fire regime, at least before 1900.** How does the stand history diagram give us more information than the data from a single tree, such as Tree 08 on the handout? **In the stand history diagram, we can see how many years had low-severity fires over the whole area. We can see that the fire interval for the whole forest is shorter than the intervals for most of the individual trees. We can see that not every fire scarred every tree; this means that some of the fires were either small or patchy. We can see that some fires scarred most of the trees, so they must have been larger or more uniform. We can see that a lot of trees died shortly after the 1877 fire, suggesting that it was pretty severe.**
13. Ask/discuss: What could cause fires to be patchy – to scar or kill some trees and not others? Refer back to the 3 of “sides” of the Fire Environment Triangle (weather, topography, and fuels), which students learned about in Activity **M05** or **H08**. You can display the poster from that activity, if you wish (***FireEnvironmentTrianglePoster.pdf***). Consider these possible sources of variation:
- If the weather has been hot and dry for a long time, the surface fuels could be uniformly dry and the fire could burn uniformly. But if the fuels are patchy – a bare spot here, a grassy opening there, a pile of fallen trees somewhere else – the burn will probably be patchy too.
 - If the trees are close together on one hillside and far apart on another, the two sites will have different susceptibility to crown fire.
 - A fire that burns through a gently rolling landscape is likely to burn more uniformly than a fire in an area with deep gullies and steep slopes.
 - Variation in the species, size, and vigor of trees also influences the frequency of fire, its severity, and the footprint it leaves on the landscape. Ponderosa pines, for example, develop thick bark at an early age, so they can survive surface fires that kill young fir trees. As our climate grows warmer and fire seasons grow longer, the “weather” side of the Fire Environment Triangle is likely to alter fire regimes in many plant communities.
14. **DON'T TAKE THE STAND HISTORY DIAGRAMS OR THE STUDY AREA PROJECTION DOWN YET. YOU'LL NEED THEM FOR THE NEXT ACTIVITY.**

Assessment:

1. Give each student a copy of **Handout M19 & H18-3. How well did the policy work?**
2. Give each student a copy of – or computer access to – **Reading_ForestHistSociety_FireSuppression.docx.** (See Step 5 in **Materials and preparation** above for options on how to provide the reading.)
3. Explain: Read the instructions and the article and then complete the assignment.
4. AN ALTERNATIVE ASSESSMENT: Have the students do the reading and then discuss the questions posed in the handout in small groups. This option will be harder to evaluate but may be more engaging for the students.

Evaluation:

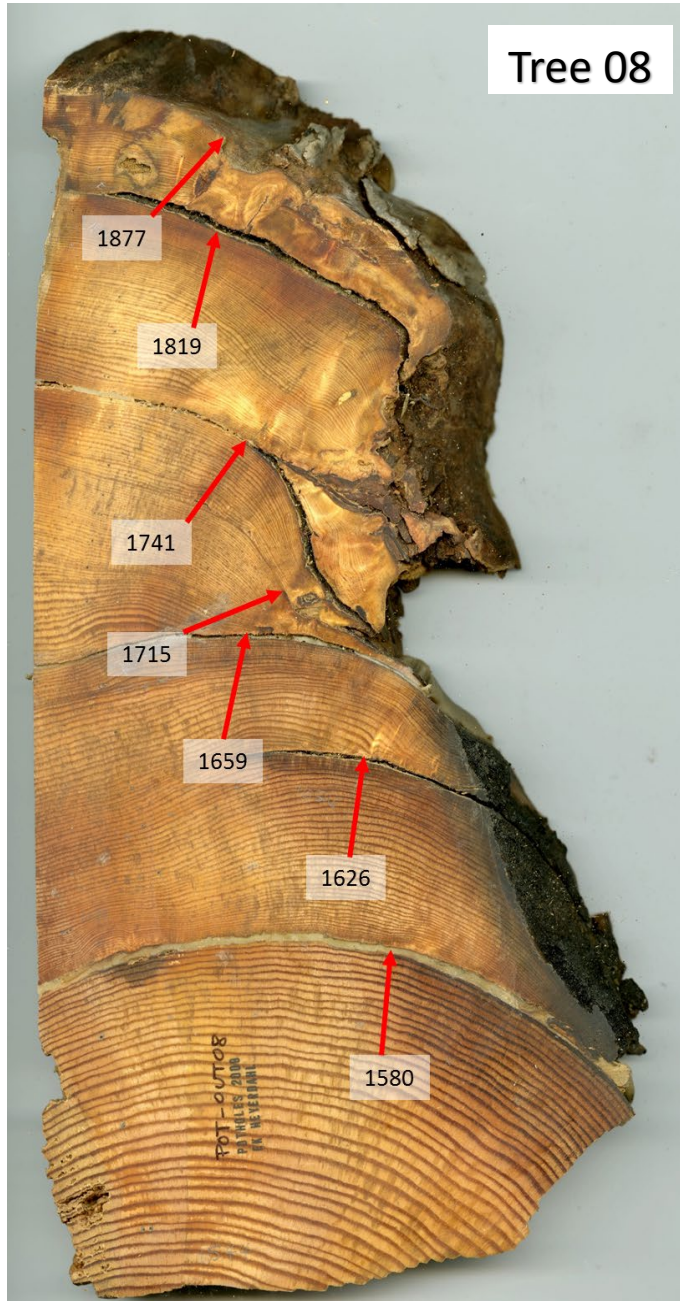
	Excellent	Good	Poor
Following directions in handout	Student used 2 or 3 paragraphs.	Student used 2 or 3 paragraphs.	Student did not use multiple paragraphs.
Writing quality	Student used effective topic sentences, complete sentences throughout, and clear writing style.	Essay was lacking in 1 of these qualities.	Essay was lacking in 2 or more of these qualities.

Content:

Do you think the policy was effective in the 1900s? Yes. The stand history diagram from tree cookies shows that no low-severity fires occurred in the 1900s. The diagram from increment cores shows that no stand-replacing fires occurred in the 1900s. Students may add other information from personal experience or their study of individual species.	Student answered the question and gave supporting information.	Student answered the question but support was weak or lacking.	Student did not answer the question.
Do you think the policy would be effective now? Either “yes” or “no” answer could be defended - “Yes” because full fire suppression would protect people, watersheds, and property... if it were successful. “No” because full suppression degrades habitat for many species and seems infeasible, especially in the face of fuel accumulation and climate change over the past century.	Student answered the question and gave supporting information.	Student answered the question but support was weak or lacking.	Student did not answer the question.

Handout M19 & H18-1. A Tree's Story

Name: _____



Tree 08

Here is a photo of a tree cookie from a forest in central Oregon. Each fire scar is marked with a red arrow and the year when the fire occurred.

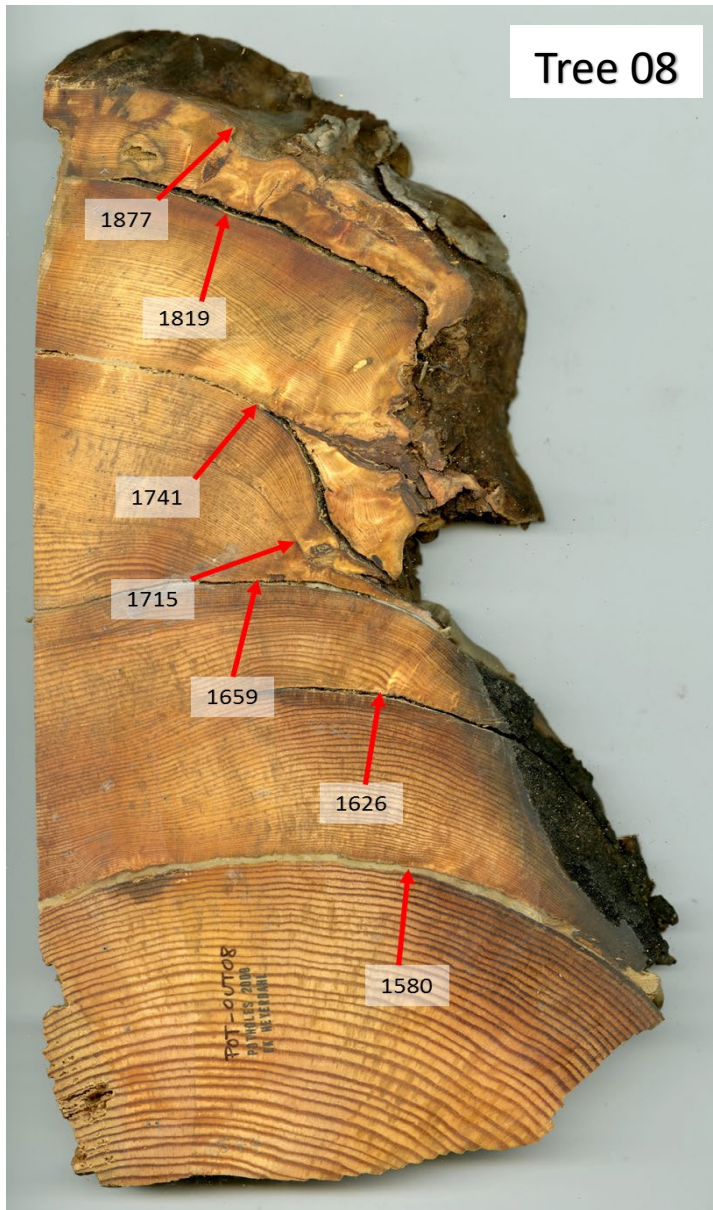
1. In the table below, under "Fire year," write the date of every fire scar on the cookie. Write the dates in order, from most recent to oldest.

Fire year	Fire interval (years)

Specimen furnished by Dr. Emily Heyerdahl.

- How many years occurred between each pair of fires?
Record your answers above under "Fire interval."
- What is the longest fire interval? _____ years
- What is the shortest fire interval? _____ years
- What is the average fire interval? _____ years

Answer key to Handout M19 & H18-1. A Tree's Story



Here is a photo of a tree cookie from a forest in central Oregon. Each fire scar is marked with a red arrow and the year when the fire occurred.

1. In the table below, under "Fire year," write the date of every fire scar on the cookie. Write the dates in order, from most recent to oldest.

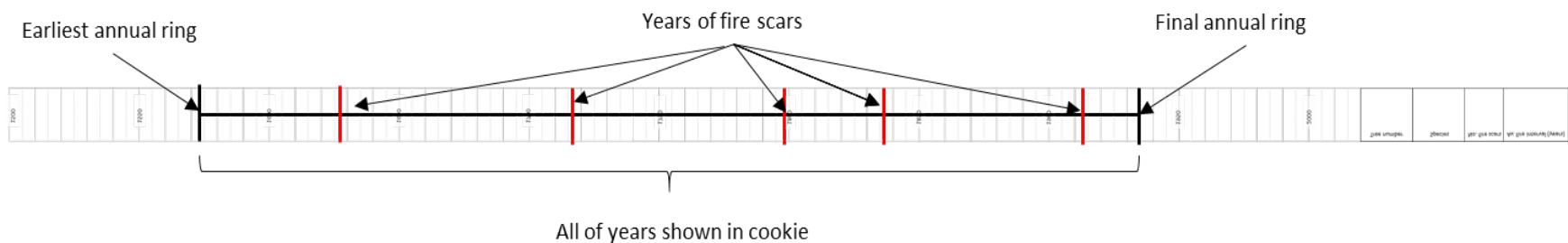
Fire year	Fire interval (years)
1877	
1819	58
1741	78
1715	26
1659	56
1626	33
1580	46

2. How many years occurred between each pair of fires? Record your answers above under "Fire interval."
3. What is the longest fire interval? 78 years
4. What is the shortest fire interval? 26 years
5. What is the average fire interval? 49.5 years

Handout M19 & H18-2. Record fire history on a timeline

Using dry-erase markers, record the fire history of your tree cookie on your timeline:

1. Record your tree's number and species in the correct boxes at the right end of your timeline. Use "PP" for ponderosa pine and "LP" for lodgepole pine. Make the print large so people can see it from across the room.
2. Count the number of fire scars on your cookie and record it in the correct box. If your cookie has scars that were NOT made by fire, ignore them.
3. Calculate the average fire interval for your tree and record it in the correct box. If your cookie has scars that were NOT made by fire, ignore them. If your cookie has only 1 fire scar, put an "X" in this box because you cannot calculate an average fire interval.
4. Draw a DARK vertical bar across your timeline to mark the year of your cookie's earliest annual ring. (See the example below.)
5. Draw another DARK vertical bar across the timeline to mark the year of your cookie's final annual ring.
6. Draw a DARK horizontal line across the middle of your timeline to connect the year of the earliest ring with the year of the final ring. Draw this line right across the dates printed on the timeline. This line spans all of the years shown in your cookie.
7. USING A CONTRASTING COLOR, draw a vertical bar across your timeline to mark the year of every fire scar on your tree cookie.
8. HAVE SOMEONE CHECK YOUR WORK. If you have errors, the class's pooled data will not make sense.



Attach your cookie's timeline to the stand history diagram for fire-scarred cookies:

1. Find your cookie's number on the poster.
2. Attach your timeline to the poster right on top of your cookie's number and the box it is in. Carefully line up the left edge of your timeline with the left edge of the box.

Handout M19 & H18-3. How well did the policy work?

Read the excerpt from “U.S. Forest Service Fire Suppression.” This article was published by the [Forest History Society](#). Here is a quote from the article:

Three of the men who had fought the 1910 fires—William Greeley, Robert Stuart, and Ferdinand Silcox—served from 1920 to 1938 as Forest Service chief, which put them in a position to institute a policy of total fire suppression.... This policy had two goals: preventing fires, and suppressing a fire as quickly as possible once one started.

Write a 2- or 3-paragraph essay that answers these questions:

- Do you think the policy was effective in the 1900s?
- Do you think the policy would be effective now?

Explain. Use information from your class’s 2 stand history diagrams and from your other knowledge about fire to support your answer.

Handout M19 & H18-3. How well did the policy work?

Read the excerpt from “U.S. Forest Service Fire Suppression.” This article was published by the [Forest History Society](#). Here is a quote from the article:

Three of the men who had fought the 1910 fires—William Greeley, Robert Stuart, and Ferdinand Silcox—served from 1920 to 1938 as Forest Service chief, which put them in a position to institute a policy of total fire suppression.... This policy had two goals: preventing fires, and suppressing a fire as quickly as possible once one started.

Write a 2- or 3-paragraph essay that answers these questions:

- Do you think the policy was effective in the 1900s?
- Do you think the policy would be effective now?

Explain. Use information from your class’s 2 stand history diagrams and from your other knowledge about fire to support your answer.

Handout M19 & H18-3. How well did the policy work?

Read the excerpt from “U.S. Forest Service Fire Suppression.” This article was published by the [Forest History Society](#). Here is a quote from the article:

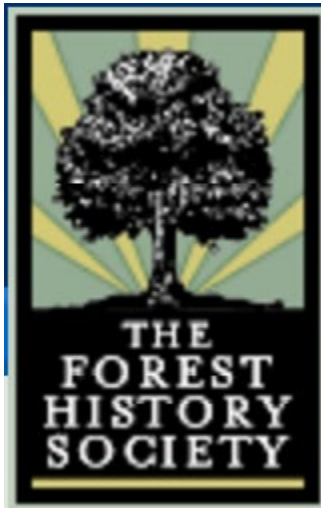
Three of the men who had fought the 1910 fires—William Greeley, Robert Stuart, and Ferdinand Silcox—served from 1920 to 1938 as Forest Service chief, which put them in a position to institute a policy of total fire suppression.... This policy had two goals: preventing fires, and suppressing a fire as quickly as possible once one started.

Write a 2- or 3-paragraph essay that answers these questions:

- Do you think the policy was effective in the 1900s?
- Do you think the policy would be effective now?

Explain. Use information from your class’s 2 stand history diagrams and from your other knowledge about fire to support your answer.

Appendix. Reading on the history of Fire Suppression Policy



U.S. Forest Service Fire Suppression

Legendary forest fires in the late 1800s like the Peshtigo Fire of 1871 bolstered the argument by early conservationists like Franklin Hough and Bernhard Fernow that forest fires threatened future commercial timber supplies. Concern for protecting those supplies and also watersheds helped conservationists convince the U.S. government in 1891 to begin setting aside national forest reservations. When the U.S. Forest Service was established in 1905, it was given managerial control of these lands, soon renamed national forests. Forest management necessitated fire protection. After all, foresters argued, why create national forests if they were going to burn down.

Just five years later, in what has become known as the "Big Blowup," a series of forest fires burned 3 million acres in Montana, Idaho, and Washington in only two days. The 1910 fires had a profound effect on national fire policy. Local and national Forest Service administrators emerged from the incident convinced that the devastation could have been prevented if only they had had enough men and equipment on hand. They also convinced themselves, and members of Congress and the public, that only total fire suppression could prevent such an event from occurring again, and that the Forest Service was the only outfit capable of carrying out that mission. Three of the men who had fought the 1910 fires—William Greeley, Robert Stuart, and Ferdinand Silcox—served from 1920 to 1938 as Forest Service chief, which put them in a position to institute a policy of total fire suppression.



Fire fighters building a fire line, Gifford Pinchot National Forest, 1934.

The other goal the Forest Service had was to develop a systematic approach to fire protection. In the decades following the Big Blowup, this would involve building networks of roads, communications systems, lookout towers, and ranger stations.

This policy had two goals: preventing fires, and suppressing a fire as quickly as possible once one started. To prevent fires, the Forest Service came out in opposition to the practice of light burning, even though many ranchers, farmers, and timbermen favored because it improved land conditions. It must be remembered that at this time foresters had limited understanding of the ecological role of fire. Forest Service leaders simply argued that any and all fire in the woods was bad because it destroyed standing timber. Educating the public about the need for fire prevention became an important part of this goal. In 1944, the Forest Service introduced the character Smokey Bear to help deliver its fire prevention message.

Following several severe fire seasons in the early 1930s, fire suppression took on even greater urgency. In 1933, the federal government created the Civilian Conservation Corps, which put thousands of men to work building fire breaks and fighting fires. In 1935, the Forest Service established the so-called 10 a.m. policy, which decreed that every fire should be suppressed by 10 a.m. the day following its initial report. Other federal land management agencies quickly followed suit and joined the campaign to eliminate fire from the landscape. Fire suppression efforts were aided by the development of new technologies, such as airplanes, smokejumpers, and fire suppression chemicals. With such tools, fires could be fought anywhere—and were.



Civilian Conservation Corps fire fighting crew, Clark National Forest, 1937.

Until around 1970, federal land managers remained obsessed with controlling large fires. But during the 1960s, scientific research increasingly demonstrated the positive role fire played in forest ecology. This led in the early 1970s to a radical change in Forest Service policy—to let fires burn when and where appropriate. It began with allowing natural-caused fires to burn in designated wilderness areas. From this the "let-burn" policy evolved, though it suffered a setback in the wake of the 1988 Yellowstone fires. Since around 1990, fire suppression efforts and policy have had to take into account exurban sprawl in what is called the wildland-urban interface. Another issue the Forest Service now faces is that fires have grown in size and ferocity over the last 25 years. The fire-fighting budget has grown to about 50 percent of the agency's entire budget, which limits funds available for land management activities such as land restoration and forest thinning that could aid in fire suppression.

Available at: <https://foresthistor.org/research-explore/us-forest-service-history/policy-and-law/fire-u-s-forest-service/u-s-forest-service-fire-suppression/>



H19. History of Mixed-severity Fire

Lesson Overview: Students use the stand history diagrams that they assembled in the 2 previous activities to learn about mixed-severity fire regimes. They interpret stand history diagrams to check their skill in identifying historical fire regimes. In the assessment, they depict the appearance of a forest with a historical regime of either low-severity, mixed-severity, or stand-replacing fire.

Lesson Goals: Understand the nature of low-severity, stand-replacing, and mixed-severity fire regimes. Be able to interpret stand history diagrams showing these regimes and envision a forest stand based on its fire history.

Objectives:

- Students can identify historical fire regimes from stand history diagrams.
- Students can describe or depict the appearance of a forest that has experienced a specific historical fire regime.

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

Duration: One 30- to 40-minute session

Group size: Whole class

Setting: Classroom

Vocabulary: *mixed-severity fire*

Standards:		9th	10th	11th	12th
Common Core ELA	Writing		9, 10		9, 10
	Speaking and Listening		1,4,		1,4
	Language Standards		1, 2, 4, 6		1, 2, 4, 6
	Writing Science/Technical Subjects		7,10		7,10
NGSS	Interdependent Relationships in Ecosystems			LS2.A	
	Ecosystem Dynamics, Functioning, and Resilience			LS2.C	
	Biodiversity and Humans			LS4.D	
	Natural Selection			LS4.B	
	Weather and Climate			ESS2.D	
	Natural Hazards			ESS3.B	
EEGL	Strand 1			C,E,F,G	

Teacher Background:

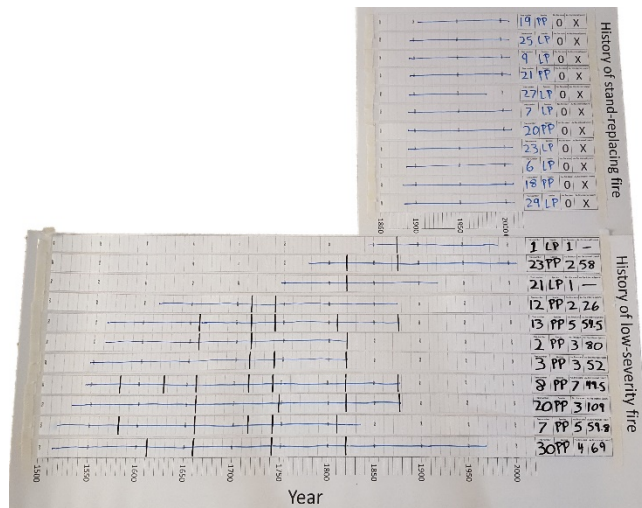
In the 2 previous activities, students used data from a published research study to assemble stand history diagrams that showed low-severity and stand-replacing fire regimes. Both of these patterns were common historically. Another common pattern was the mixed-severity fire regime.

A forest with a mixed-severity fire regime has some places where fires were severe enough to replace old stands with young ones... and other places where some of the big trees were killed but others survived (perhaps with fire scars)... and yet other places that have not burned at all in a long time. A forest with a mixed-severity fire regime may also experience low-severity fires that alternate over time with stand-replacing fires. In other words, its fire history is all mixed up – and that history produces complex forests with a mixture of tree species and ages.

Materials and preparation:

- Note that the Study Area projection should still be on display (***PotholesStudyArea.pptx*** from **Activity M18andH17_High-sevFireHist**).

- Take the stand history diagrams from the previous 2 activities and move them so the one showing stand-replacing fire is above the one showing low-severity fire. Tuck the “Dot Diagram” information on the stand-replacement diagram under the top of the low-severity diagram to make them look more continuous. IF YOU DON’T HAVE THESE DIAGRAMS, YOU CAN JUST START WITH THE PRESENTATION BELOW.



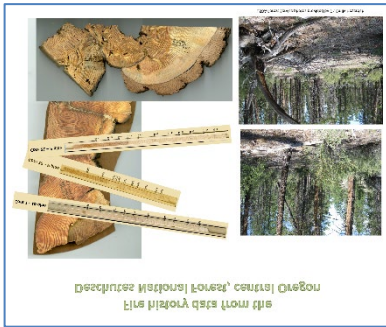
- Download ***H19_MixedSeverityRegimes_generic.pptx***.
- Make 1 copy/student of **Handout H19-1. Fire Severity Patterns in Forest Stands**.

Procedure:

1. Explain: The increment cores and tree cookies that we’ve studied were sampled in different ways, but all of them came from the same research study and the same area in central Oregon. Let’s combine them to see if we can learn more about the fire history of the area. Look at the combined stand history diagram on display. What new information can we get from putting the 2 diagrams together? **Open discussion. Answers are suggested within the slide show (see Slide 2).**

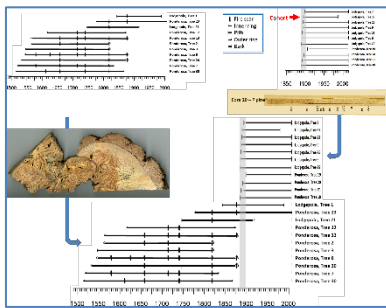
2. Go through and discuss the slides. Take as much time as you need on Slides 3-5, so students can begin to visualize and describe forest stands at different times through their history.

Slide 1



All of the increment cores and fire-scarred tree cookies that we've looked at came from the same study area in central Oregon. Let's see what happens when you have a mixture of low-severity and stand-replacing fire over time and space.

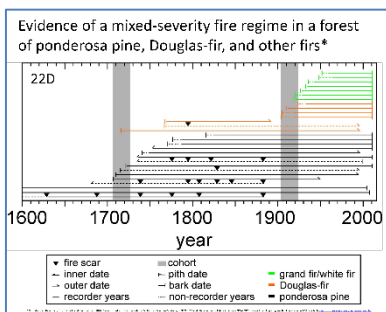
Slide 2



The top diagrams here are like the ones we constructed in class. The diagram based on fire scars – showing a history of low-severity fires - is on the left. The diagram based on increment cores – showing a history of stand-replacing fire - is on the right. When we combine them to describe the whole area and all of the variety it contains, what can we say about the history of the whole, big area?

Over the past 500 years, the area has experienced both low-severity and stand-replacing fire. The cohort that started in the late 1800s (mostly lodgepole pine) probably started after the 1877 fire. This fire also scarred 5 ponderosa pines, and 3 of them died the next year. So the 1877 fire must have had some low-severity areas and some stand-replacing areas. When we put all of our data together – from fire scars and increment cores - what can we say about the area's fire regime? Perhaps the area has had a mixed-severity fire regime. Or perhaps the fire regime changed from low-severity to stand-replacing in the early 1900s.

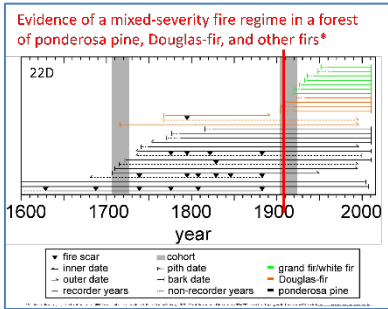
Slide 3



Let's look at more information about mixed-severity fire regimes. They are pretty common. Here's an example from a stand with ponderosa pines, Douglas-firs, and other firs. The design of this diagram is just a little different from the ones we put together: First, the fire scars in this diagram are shown with black triangles rather than straight lines... and second, the different tree species are shown with different colors. So... what is the story of this forest?

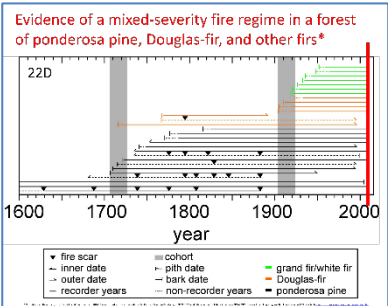
The forest had a lot of low-severity fires until around 1900 but has had none since then. There was a stand-replacing fire in the early 1700s. It didn't scar any trees that we know of, but it led to establishment of the oldest Douglas-fir tree on the site. There was another stand-replacing fire around 1900, which led to the establishment of lots of Douglas-firs and other firs but no ponderosa pines.

Slide 4



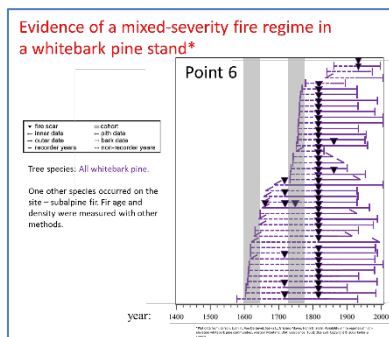
If we draw a line through the year 1910, can you picture what that forest probably looked like then? There were a lot of big old ponderosa pines and a couple of big Douglas-firs. There may have been a lot of dead Douglas-firs too, killed by a recent stand-replacing fire. There were probably also a lot of tiny Douglas-firs and other firs, the beginning of that new cohort.

Slide 5



If we draw a line through the year 2010, can you picture that forest? There were just a couple of big old ponderosa pines, and there were a lot of Douglas-firs and other firs. They were be grown-up but not nearly as big as the old pines. There would probably be a lot of smaller firs too, since they can reproduce well in shade – unlike ponderosa pines.

Slide 6



Here's another example of a forest with a history of mixed-severity fire. This diagram shows the history of a stand of whitebark pines in a high-elevation forest. What is the story of this forest? There are 2 cohorts – one from the early 1600s and one from the mid 1700s. There seem to be just 3 years with low-severity fire until around 1815, when a fire scarred nearly every tree on the site. That same fire may have helped the 3 youngest whitebark pines (at the top of the diagram) start growing. A few whitebarks died in the 1800s, and

then mortality increased dramatically through the 1900s. By the year 2000, every whitebark pine was dead. Based on student presentations and other things we've learned, can you guess why they died? Many of the trees were probably killed by mountain pine beetles, and many others by white pine blister rust. In addition, the trees may have been too weak to resist beetles and rust because low-severity fire had not killed off the competing fir trees over the past 100 years or so. Draw some imaginary lines for the years 1650, 1750, 1850, 1950... and ask students to describe how this whitebark pine stand looked at these different times.

3. Summarize: Now we can look at a stand history diagram, figure out what historical fire regime it shows (stand-replacing, low-severity, or mixed-severity), and describe the "story" of that forest – whether it's a small sample plot or a whole big area. Let's check our skill at identifying the kind of fire regime. Then we'll use a project to tell – or show – how some of forest stands looked at different times in their history.

Assessment:

1. Give each student a copy of **Handout H19-1. Fire Severity Patterns in Forest Stands.**
 - Have students complete **Part 1. Skills check** in class or as homework. Check it – possibly in class - to make sure they understand the connection between the stand history diagrams and the 3 kinds of fire regimes.
 - Have students complete **Part 2. Telling or Showing the Story** on their own. This is either an art project or a writing or speaking project.
2. After the projects are completed, make time for students to tell the speaking projects. Provide a way for them to read the written projects. Display the art projects in the classroom, grouped by plot and time. Then have students circulate and discuss the differences among plots and the changes depicted over time.

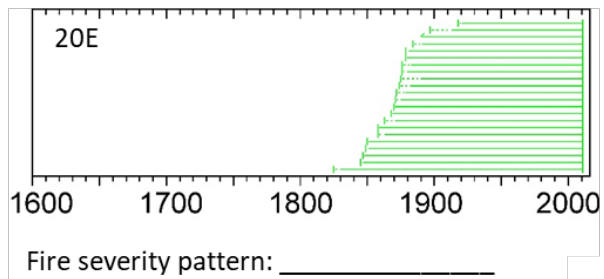
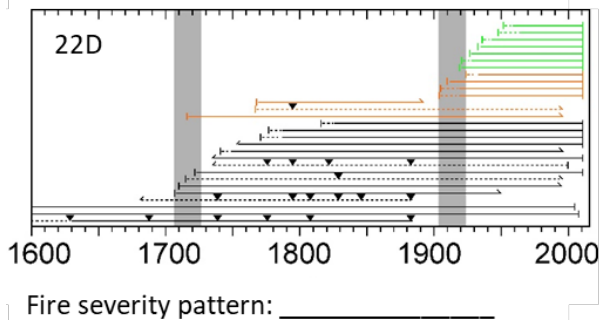
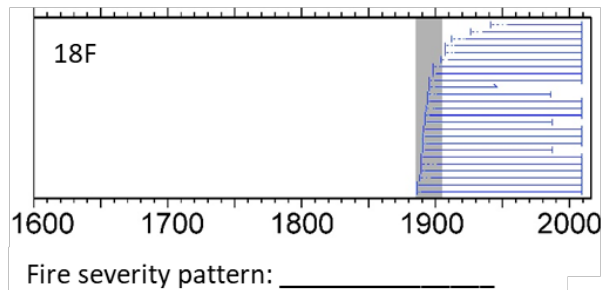
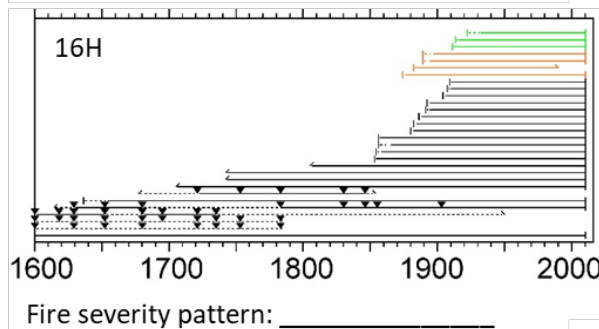
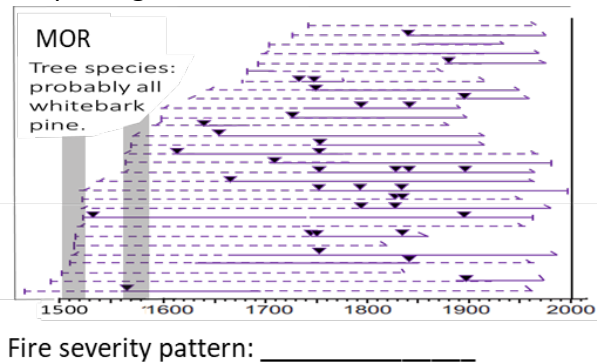
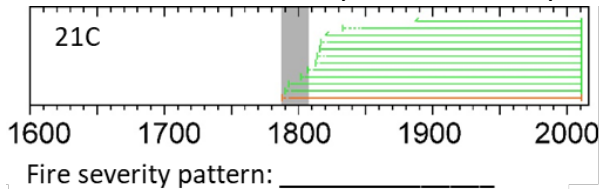
Evaluation: Use the **Answer key** below to evaluate Part 1. Evaluate the projects created for Part 2 based partly on how well they met the criteria in the instructions, but also consider creativity, esthetics, and imagination.

	Excellent	Good	Poor
Part 1. Skills check	All 6 answers correct	4 or more answers correct	3 or fewer answers correct
Part 2. Telling/ Showing the Story	Story/art work is labeled with plot number, year, and fire regime	The art work is labeled with 2 of these features.	The art work is labeled with 1 or none of these.
	Trees of different species (if present) are visibly different.	3 or more of these features are present.	Fewer than 3 of these features are present.
	Trees in a cohort (if present) are the about the same size.		
	Fire scars (if present) are visible.		
	Dead trees (if present) are shown.		
	Saplings/undergrowth are shown if appropriate.		
Uses creativity and imagination. Is esthetically appealing.	Uses limited creativity and imagination. Is esthetically appealing.	Uses little or not creativity or imagination, or is not esthetically appealing.	

Handout H19-1. Fire Severity Patterns in Forest Stands

Name: _____

Part 1. Skills check: Below each stand history diagram, write the historical fire regime that describes it best: low-severity, mixed-severity, stand-replacing, or no fire at all.



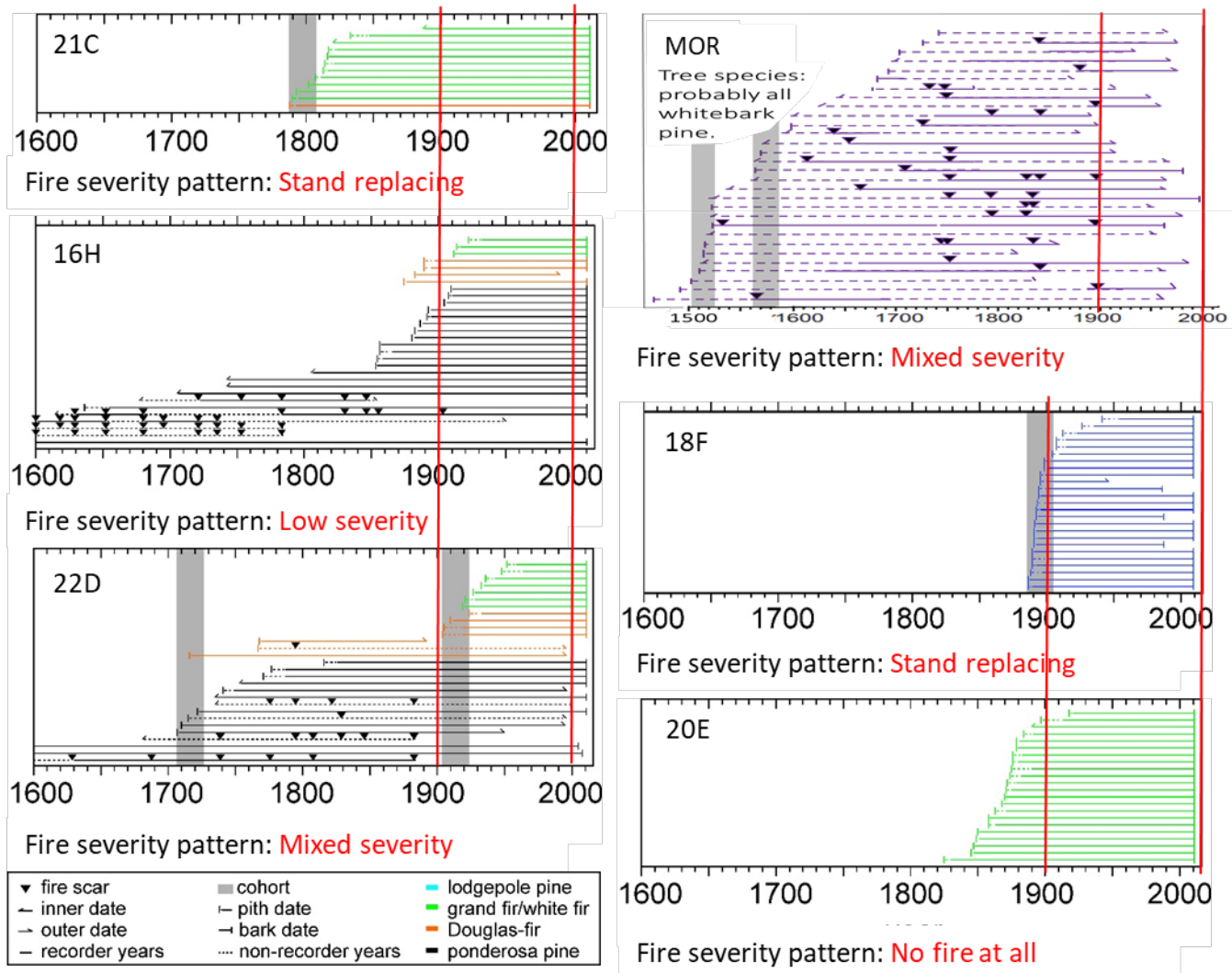
▼ fire scar	■ cohort	■ lodgepole pine
— inner date	— pith date	■ grand fir/white fir
— outer date	— bark date	■ Douglas-fir
— recorder years	— non-recorder years	■ ponderosa pine

Part 2. Telling or showing the story:

- Select one of the stand history diagrams above. Select either the year 1900 or the year 2000. In the stand history diagram that you're using (above), draw a vertical line through the year you chose.
- Create an art work that shows what that stand probably looked like in the year you chose. **LABEL YOUR CREATION WITH THE PLOT NUMBER, YEAR, and FIRE REGIME.** You can create a written or oral story, or a drawing, painting, computer graphic, 3-dimensional model, or some other medium. Make trees of different species look different. Make trees in a cohort about the same size if your stand had a cohort at that time. Show some fire scars if trees on your stand had them in that year. Show dead trees if your stand had some in that year. Show some seedling or sapling trees if your stand probably had them in that year. (Those don't show on the stand history diagrams.)

Answer key to Handout H19-1. Fire Severity Patterns in Forest Stands

Answers to Part 1. Skills check:



*Sources:

- Data for all plots except MOR were provided by: Heyerdahl, E.K., D.A. Falk, and R.A. Loehman. 2014. Data archived with the International Multiproxy Paleofire Database, IGBP PAGES/World Data Center for Paleoclimatology. NOAA/NCDC Paleoclimatology Program, Boulder, Colorado, USA. Available www.ncdc.noaa.gov/paleo/impd/paleofire.html.
- Data for MOR plot were obtained from: Larson, Evan R.; Van De Gevel, Saskia L.; Grissino-Mayer, Henri D. 2009. Variability in fire regimes of high-elevation whitebark pine communities, western Montana, USA. *Ecoscience*. 16(3): 282-298. Copyright © 2009 Taylor & Francis.

Answers to Part 2. Telling or showing the story: Red lines above show the years 1900 and 2000. Refer to **Evaluation** above for guidelines on evaluating student projects.



H20. Why Do Historical Fire Regimes Matter?

Lesson Overview: Students apply their knowledge about fire regimes (low-, mixed-, and stand-replacement) to 3 forest types that occur from the northern Rocky Mountains to the North Cascades – forests historically dominated by ponderosa, lodgepole, and whitebark pine. Students read a technical article about 1 of these forest types and summarize it for a high-school science blog. **Note:** **Handout 20-1** in Step 3 below repeats much of the content of the slide presentation in Step 2 (*FireRegimes_3ForestTypes.pptx*). If you think the repetition is needed, use both. If not, use just one or the other.

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

Duration: 1 30-minute session

Group size: Whole class, working singly, then in groups of 3

Setting: Classroom

Lesson Goals: Students can recognize the most prevalent fire regime for each of 3 forest community types that occur from the northern Rockies to the North Cascades. They determine whether a fire regime has changed over the past century and explain possible effects of a changed fire regime.

Objectives:

- Students can interpret a map and a table of data on historical fire regimes.
- Students can understand a 1-page technical article on a fire regime.
- Students can write a concise blog that summarizes information on a fire regime, how it has changed over the past century, and why that matters.
- Students can identify strengths and weaknesses in blogs written by other students.

Standards:		9 th	10 th	11 th	12 th
CCSS	Reading Informational Text	2, 4, 10		2, 4, 10	
	Writing Standards	2, 4, 6, 7, 10		2, 4, 6, 7, 10	
	Speaking/Listening Standards	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3		1, 2, 3	
	Reading Science/Technical Subjects	1, 2, 4, 9, 10		1, 2, 4, 9, 10	
	Writing Science/Technical Subjects	1, 4, 6, 7, 10		1, 4, 6, 7, 10	

NGSS	From Molecules to Organisms: Structure and Processes	LS1.B
	Ecosystems: Interactions, Energy, and Dynamics	LS2.A, LS2.C, ETS1.B
	Biological Evolution: Unity and Diversity	LS4.C, LS4.D, ETS1.B
	Earth's Systems	ESS2.D
	Earth and Human Activity	ESS2.D, ESS3.A, ESS3.B, ESS3.C, ESS3.D, ETS1.B
EEEEGL	Strand 1	A, B, C, E, F, G

Teacher Background: The pattern of fire in a plant community – its severity, frequency, spatial uniformity, and other characteristics – is called its fire regime. In the previous 3 activities, students learned the characteristics of low-severity, stand-replacement, and mixed-severity fire regimes. In this activity, they learn which fire regimes were most important historically in the 3 forest communities they have been studying in FireWorks activities:

- Most ponderosa pine/Douglas-fir forests from the northern Rocky Mountains to the North Cascades had fire regimes of frequent, low-severity fire in past centuries, but they also had occasional mixed-severity fires, and sometimes they also had stand-replacing fires.
- Most lodgepole pine/subalpine fir forests in the region had historical regimes of either stand-replacing or mixed-severity fire, depending on fuels, topography, and weather patterns. They also had low-severity fire regimes in a few areas.
- Most whitebark pine forests had mixed-severity fire regimes.

For more details on these fire regimes, how they have changed in the past century, and why the changes are important, see the **Evaluation** section below. Further discussion of these 3 forest types and fire regimes is available in the technical readings that students summarize in the **Assessment** for this activity. The essays are in the **Appendix** and also available for download from **3FireRegimes_TechnicalReadings.docx**.

The table of historical fire intervals and severities used in the slides and handout for this activity is derived from two sources:

The range of average fire intervals is from the Fire Effects Information System, which incorporates data from the LANDFIRE project:

- The **Fire intervals** column shows the shortest and longest average fire intervals for that plant community type. The ranges for Rocky Mountain lodgepole pine and whitebark pine communities are the results of modeling for individual Biophysical Settings in [LANDFIRE](#). The range of values for northern Rocky Mountain ponderosa pine communities is based on modeling and also an extensive literature review (Fryer, Janet L. 2016. Fire regimes of Northern Rocky Mountain ponderosa pine communities. In: Fire Effects Information System,[Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: www.fs.usda.gov/database/feis/fire_regimes/Northern_RM_ponderosa_pine/all.html)

- The 3 columns on **Percent of fires by severity (low, mixed, and stand-replacement severity)** are a simplified representation of results from [LANDFIRE](#) succession modeling. Here is the process used to reduce dozens of numbers for each cell to the one number in each cell of the table:
 - First, the minimum and maximum values for percent of fires of each severity was obtained through the [Fire Effects Information System](#). (Minimum and maximum values are the results of LANDFIRE succession modeling for all Biophysical Settings within each community type.)
 - Second, the midpoint of those values was calculated.
 - Third, the midpoints for all 3 severities were totaled for that plant community.
 - Fourth, the midpoint for each severity was expressed as a percentage of the total of midpoints for that plant community.
-

Materials and preparation:

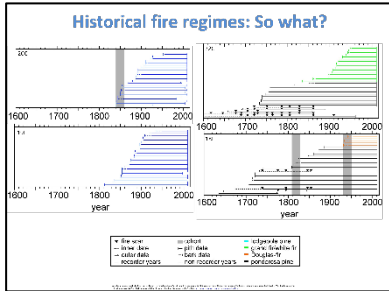
1. Download *FireRegimes_3ForestTypes.pptx*.
2. Make 1 copy/student: **Handout H20-1. Fire Regimes for Ponderosa, Lodgepole, and Whitebark Pine Forests from the Northern Rocky Mountains to the North Cascades.**
3. Make 1 copy/student: **Handout H20-2. News blog.**
4. Make copies of (or arrange for students to read online at [3FireRegimes_TechnicalReadings.docx](#)) the three 1-page essays on fire regimes (shown in the **Appendix** below). If you have students read from a printed copy, note that only 1/3 of the class will need a copy of each essay.

Procedure:

1. **Hook:** Explain: We've spent a lot of time studying historical fire regimes so we could answer these questions:
 - Are our forests OK, or are today's wildfires destroying them?
 - Are today's wildfires too big or too small?
 - Are they too severe?
 - Are the forests we've been studying (ponderosa pine, lodgepole pine, and whitebark pine) threatened because of fire or lack of fire?

In this activity, we'll learn about historical fire regimes for our 3 forest types and then we'll develop answers to these questions.
2. Go through *FireRegimes_3ForestTypes.pptx*:

Slide 1



Review/discuss: Here are some stand history diagrams. What are the main tree species in each diagram? 20c and 19E: lodgepole pine. 22C: ponderosa pine and grand or white fir. 18E: ponderosa pine and Douglas-fir. What fire regime does each diagram show? 20C: stand-replacing fire. 19E: no evident fire history. 22C: low-severity fire. 18E: mixed-severity fire. What changes do the diagrams show over the past 100

years? The main change is lack of fire since about 1900, especially lack of low-severity fire. There may not be any change in 19E; it seems to have a pattern of continuous reproduction. Do the changes matter? Discussion based on what students have learned in their reports on individual species and in the previous 3 activities. A few points: If the fire regime now is different from that in historical times (more frequent or less frequent fires, more severe or less severe fires), some native plant and animal species may not have the habitat they need anymore. If the fire regime is becoming more severe, that may pose increasing risks to watersheds and to people’s lives and property.

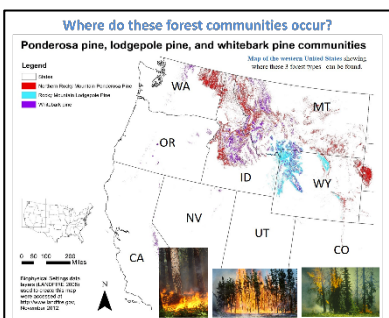
Slide 2



Let’s apply our understanding of fire regimes to the 3 forest types of the northern Rocky Mountains and North Cascades that we’ve been studying. Review: What are these 3 forest communities? Forests dominated by ponderosa pine (on the left), lodgepole pine (upper right), and whitebark pine (lower right). Keep in mind that we’re talking about COMMUNITY TYPES, not individual tree species. The community

types are named for the tree species that was most plentiful there in past centuries, but many other tree species can occur in each type. Review: What other tree species occur in the ponderosa pine type? Douglas-fir, other fir species, western larch, lodgepole pine.... What other tree species occur in the lodgepole pine type? Douglas-fir, subalpine fir, western larch, Engelmann spruce, whitebark pine.... What other tree species occur in the whitebark pine type? Subalpine fir, Engelmann spruce, lodgepole pine....

Slide 3



Where do the 3 forest types occur? Discuss the extent of these forest types and their locations relative to your location. Note that all of the plants and animals we’ve been studying – and the fire weather we have studied and the smoke data we’ve studied – come from ponderosa pine, lodgepole pine, or whitebark pine communities in this region. What fire regime do you think was most prevalent in each of these types?

Slide
4

Estimates of average historical fire intervals and severities in three plant communities of the northern Rocky Mountains and North Cascades (from the Fire Effects Information System, feis-crs.org).

Forest type	Average Fire interval (years)	Percent of fires by severity		
		Replace-ment	Mixed	Low
Northern Rocky Mountain ponderosa pine forest type	6-50	6	27	68
Rocky Mountain lodgepole pine forest type	92-307	75	16	9
Whitebark pine forest type	43-250	28	41	31

This table summarizes information for our 3 forest types from dozens of research studies. Let's read it carefully. [Go through the caption at the top, then the row and column titles.]

What is the most common fire severity for ponderosa pine forests?

Low-severity, at 68% of fires.

What is the most common fire severity for lodgepole pine forests?

Stand replacement, at 75% of fires.

What is the most common fire severity for whitebark pine forests?

Mixed severity, since about 41% of fires were of mixed severity. But low-severity and stand-replacement fire occurred a lot too (31% and 28%). How would you describe the historical fire regime for the whitebark pine type? **They seem to vary a lot. They're all mixed up!**

3. **OPTIONAL** Skills check – This exercise reviews what was just covered in the slide show. If the students “got it” there, this may be superfluous.
 - a) Give each student a copy of **Handout H20-1. Fire Regimes in 3 Forest Types from the Northern Rocky Mountains to the North Cascades.**
 - b) Explain: This is a skills check, to confirm that we understand the historical fire regimes of the 3 forest types we've been studying. After we feel confident about that, we'll divide up into groups of 3 and write short blogs about fire regimes in these forest types.
4. Have students complete the handout. Check it against the **Answer key to Handout H20-1** below to make sure the students can interpret the map, data table, and stand history diagrams correctly.

Assessment:

1. Divide the class into groups of 3. Each member of a group will write a short blog about the historical fire regime in one of the communities we've been studying (forests dominated by ponderosa pine, lodgepole pine, and whitebark pine).
2. Give a copy of the 3 technical readings to each group or arrange for them to do the readings electronically. The readings are printed in the **Appendix** below and available electronically in **3FireRegimes_TechnicalReadings.docx**.
3. Assign – or have students choose – who in each group will write about each forest type. Each group must cover all 3 forest types.
4. Give each student a copy of **Handout H20-2. News blog**. Explain that news articles should get the reader's attention, be very clear, and be as short as possible while still getting the point across. An illustration can be very helpful.
5. Go through the directions in the handout, then have them do the assignment.

6. When the writing is completed, post the blogs on a school website, if possible, and encourage students in other classes to read them.

Evaluation:

Excellent	Good	Poor
Headline is 8 words or less, accurate, and interesting.	Headline is accurate but more than 8 words or dull.	No headline is included, or headline is inaccurate.
Article is 150 words or less.	Article is too long.	Article is too long.
Article is accurate.	Article has minor inaccuracies.	Article has major inaccuracies.
Article includes accurate fire interval and severity information.	Article includes accurate fire interval or severity information but not both.	Article includes inaccurate information.
Article correctly describes 2 or more changes in last 100 years.	Article correctly describes 1 change in last 100 years.	Description of change is inaccurate or missing.
Article gives 2 or more valid reasons why change(s) matter.	Article gives 1 valid reason why change(s) matter.	Article gives no reason or incorrect reasons why change(s) matter.
Article includes appropriate illustration with accurate caption, credited appropriately.	Article includes illustration with caption.	Article includes irrelevant illustration or no illustration, or caption/credit is incorrect.

Suggested content for essays on each of the 3 forest types:

Forest type:	Northern Rocky Mountain ponderosa pine	Rocky Mountain lodgepole pine	Whitebark pine
General fire regime:	Mostly frequent, low-to moderate-severity surface fires. Firest often burned in a patchy/mosaic pattern.	Infrequent stand replacement fires were most common. Some forest types that contain lodgepole pine were likely to have more mixed-severity fire.	Mixed-severity fire regime, that is, fires of severities that varied in space and time, creating complex patterns of tree survival and mortality.
Fire intervals from table:	6-50 years	92-307 years	43-250 years
Fire severity from table:	68% low severity (27% mixed severity, very	75% replacement, (16% mixed severity, 9% low severity)	41% mixed - but other severities are close – 28-31%

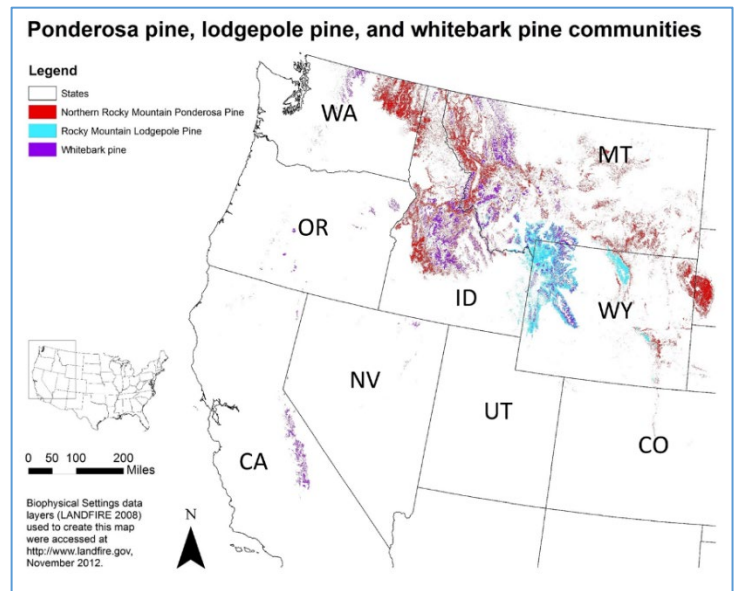
	little stand replacement)		
How vegetation and fire regime have changed:	Fuel loads, particularly ladder fuels, have increased. Forest patches have become denser and young stands have become more continuous than in presettlement forests. Fire exclusion may cause more severe fire than what occurred historically.	Some studies indicate little change over the past century. However, fire exclusion could gradually make the landscape more uniform, since fewer new patches of burned forest are created by stand-replacing or mixed-severity fire.	Blister rust and mountain pine beetle have nearly wiped out this species in many areas. In addition, fire exclusion in some areas may be leading to further loss of whitebark pine and replacement by fir and spruce.
Why changes matter	Native plants and animals may not survive in the changed environment. Many people have homes and live in this forest type; increased fire severity increases risks to watersheds, people, and property.	Native plants and animals may not survive in the changed environment. Many people have homes and live in this forest type, often in areas remote from fire control resources. Increased uniformity of vegetation could increase the possibility of large, uncontrollable, more uniformly severe fires.	Native plants and animals may not survive in the changed environment. Establishment of rust-resistant whitebark pine may fail if fire has not prepared a seedbed. If rust-resistant whitebark pines do become established, they may be shaded out by already-established subalpine firs and spruces. Large, uncontrollable, more severe fires at lower elevations could spread into whitebark stands and kill the remaining rust-resistant trees.

Handout H20-1. Fire Regimes for Ponderosa, Lodgepole, and Whitebark Pine Forests from the Northern Rocky Mountains to the North Cascades

Name: _____

Map of the western United States showing where these 3 forest types can be found.

The map shows the areas covered by 3 community types, not by 3 tree species. The community types are specific combinations of tree species with specific fire regimes. Each community type is named for the main tree species that has been living there. The species themselves occur in many other community types.



- Which of the 3 forest types is most prevalent in:
 - the northwestern corner of Wyoming? _____
 - the northeastern corner of Washington? _____
 - California, east-central Montana, and the North Cascades? _____

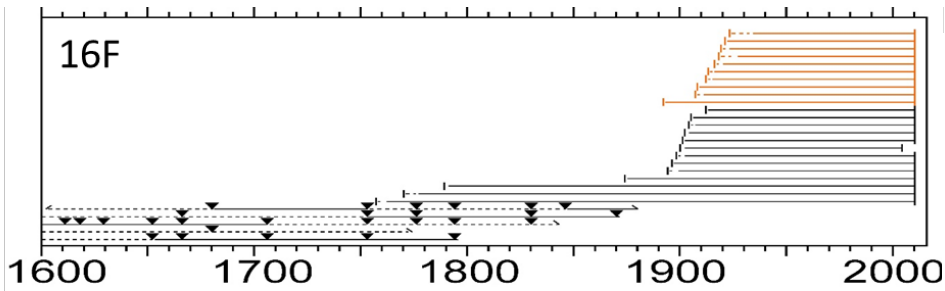
Historical fire intervals and severities in 3 forest types. The numbers here give a very simplified idea of fire severity patterns. In reality, all characteristics vary from place to place.

Forest type	Average Fire interval (years)	Percent of fires by severity		
		Replacement	Mixed	Low
Northern Rocky Mountain ponderosa pine	6-50	6	27	68
Rocky Mountain lodgepole pine	92-307	75	16	9
Whitebark pine	43-250	28	41	31

- According to the table, which forest type has:
 - the shortest average fire intervals? _____
 - the longest average fire intervals? _____
- According to the table, what is the most prevalent fire severity in:
 - northern Rocky Mountain ponderosa pine forests? _____
 - Rocky Mountain lodgepole pine forests? _____
 - whitebark pine forests? _____

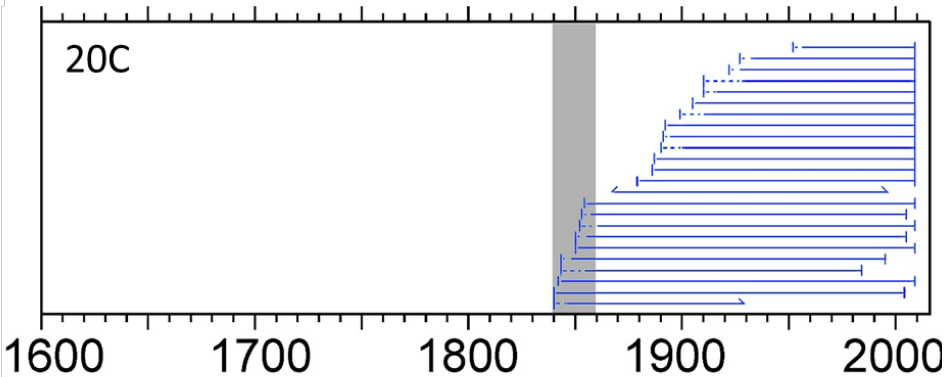
Stand history diagrams from actual research plots.

4. Below on the right-hand side, circle the fire severity that each diagram shows best.



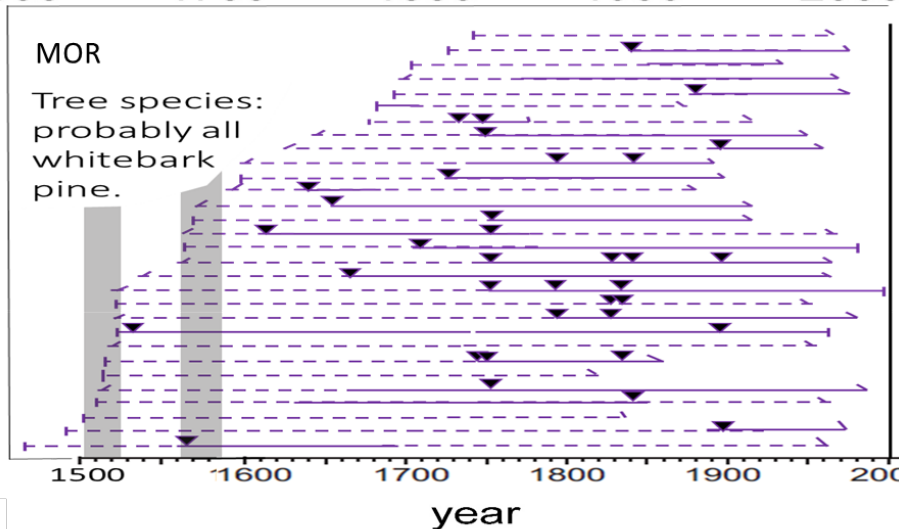
A. Stand 16F:

- Stand replacement
- Mixed severity
- Low severity



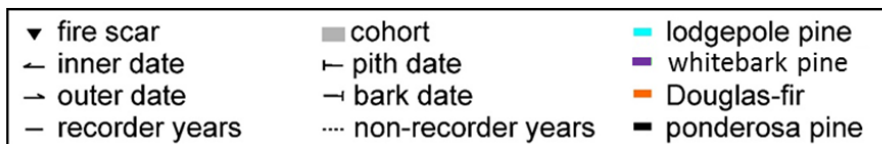
B. Stand 20C:

- Stand replacement
- Mixed severity
- Low severity



C. Stand MOR:

- Stand replacement
- Mixed severity
- Low severity



Answers to Handout H20-1. Fire Regimes for Ponderosa, Lodgepole, and Whitebark Pine Forests from the Northern Rocky Mountains to the North Cascades.

1. Which forest type is most prevalent in:
 - a) the northwestern corner of Wyoming? **Rocky Mountain lodgepole pine type**
 - b) the northeastern corner of Washington? **Northern Rockies ponderosa pine type**
 - c) California (and also the Rockies and North Cascades)? **Whitebark pine type**
2. Which forest type has:
 - a) the shortest average fire intervals? **Northern Rockies ponderosa pine type**
 - b) the longest average fire intervals? **Rocky Mountain lodgepole pine type**
3. According to the table, what is the most prevalent fire severity in:
 - a) northern Rocky Mountain ponderosa pine forests? **Low-severity fire**
 - b) Rocky Mountain lodgepole pine forests? **Stand-replacing fire**
 - c) whitebark pine forests? **Mixed-severity fire**
4. Circle the historical fire severity that each diagram shows best.
 - a) **Low-severity fire**
 - b) **Stand-replacing fire**
 - c) **Mixed-severity fire**

Handout H20-2. News blog.

Name: _____

My forest community type: _____

1. Write a short blog about your forest community type and its fire regime for a high-school science website. It should be no more than 150 words long.
 - Describe your forest community type (what are the most important trees?)
 - Describe the forest type's historical fire regime (how often fires occurred and how severe they were).
 - Describe 1 major change in your forest type's vegetation and fire regime during the past 100 years.
 - Tell your readers why that change matters.
 - Write a headline no more than 8 words long. Make it catchy but also accurate.
 - You may include 1 photo or other illustration. If you do, include a caption and credit the source.
2. Exchange papers with 2 students who wrote about the OTHER two forest community types. Have them write their suggestions for your blog in the spaces below.
3. Read their blogs and write your suggestions on their handouts, then give them back.
4. Hand in your blog and this completed handout.

Suggestions from student writing on ANOTHER forest type:

Name: _____

Write at least 1 strength and 1 way to improve the blog. You may write on the back too.

Suggestions from student writing on YET ANOTHER forest type:

Name: _____

Write at least 1 strength and 1 way to improve the blog. You may write on the back too.

Appendix. Technical readings on historical fire regimes in northern Rocky Mountain ponderosa pine, Rocky Mountain lodgepole pine, and whitebark pine forests.

Fire regimes of Northern Rocky Mountain ponderosa pine forests

Ponderosa pine dominates low-elevation forests and savannas from the northern Rocky Mountains to the North Cascades. Douglas-firs and other fir trees are also common among the large, old trees. Historically, ponderosa pine forests were a mosaic of open stands, dense patches of young trees, and areas without any trees at all. Frequent fires maintained ponderosa pines as the biggest, oldest trees, even in places where fir trees would probably take over without fire.

Before the time when fires were kept out of the forests (the early 1930s), there was plenty of litter and undergrowth in ponderosa pine forests, but there were not many young trees or woody fuels. Lightning fires occurred in summer, and American Indians set fires in spring and fall.

Most of the fires were surface fires of low to moderate severity that burned in a patchwork pattern. Stand-replacement fires were infrequent, but they were an important part of the fire regime.

Results from fire history studies show that average fire intervals in ponderosa pine forests of the northern Rocky Mountains ranged from 6 years to 50 years. Most studies report averages of 6 to 15 years. Fires were less frequent but more severe at higher elevations, in moist sites, and on north-facing slopes.

As fires have been kept out of ponderosa pine forests in the northern Rocky Mountains, fuel loads have increased - particularly ladder fuels. Many ponderosa pine forests have a lot of Douglas-firs and other fir species in the understory, and not many ponderosa pines. Many forests are denser than they were in the past. Cheatgrass has invaded some ponderosa pine forests, increasing the fine fuels.

Many ponderosa pine forests of the northern Rocky Mountains have changed over the past century. They now have longer fire intervals, but when fires occur they tend to be more severe and possibly larger than what occurred historically. The size and frequency of severe fires are likely to continue to increase with climate change. Large, severe fires threaten the integrity of ponderosa pine ecosystems.



Adapted from: Fryer, Janet L. 2016. Fire regimes of Northern Rocky Mountain ponderosa pine communities. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/fire_regimes/Northern_RM_ponderosa_pine/all.html [2017, April 24].

Fire Regimes in Rocky Mountain Lodgepole Pine/Subalpine Fir Forests

Wildland fires usually occurred at intervals from about 100 years to 300 years in lodgepole pine/subalpine fir forests, although sometimes fires were more frequent. Most fires were either stand-replacing or mixed-severity, but low-severity fires occurred occasionally. Where there are a lot of ladder fuels, fallen logs and branches, and dense tree crowns, these forests are likely to have stand-replacing fires. They can be crown fires or severe surface fires – or a combination of crown and surface fire. In dry locations where fuels are sparse, fires are likely to be a patchwork of mixed severities.

In forests dominated by Rocky Mountain lodgepole pine, the amount of fuel is related to stand age. If a young stand is very dense, with interlocking crowns, sparse lower limbs, and few understory plants, it is unlikely to burn at all unless the wind is very strong; then it may burn in a crown fire. As the forest gets older, the trees may be killed by bark beetles or dwarf mistletoe, and young fir trees may grow in, increasing the ladder fuels. Then the stand becomes likely to burn in either stand-replacing or mixed-severity fire.



Research from two national parks shows how fire regimes in lodgepole pine forests can vary:

- A study in forests containing western larch and Rocky Mountain lodgepole pine in Glacier National Park showed that forests with a dry climate and gentle topography experienced mixed-severity fires about every 25 to 75 years. Forests on wetter, steeper, sites experienced stand-replacing fires at longer average intervals, ranging from 140 to 340 years.
- A study in Yellowstone National Park showed that low-elevation lodgepole pine forests experienced mixed-severity fires about every 25-150 years; higher-elevation forests experienced stand-replacing fires at longer intervals, ranging from 300-400 years.

Because fire intervals are long in most Rocky Mountain lodgepole pine forests, it is hard to say for sure whether fire suppression efforts have changed these forests substantially. Where these forests had some low-severity fires in the past, they now have almost none. Lack of fire may be making forests more uniform and therefore more susceptible to epidemics of bark beetles. In addition, the uniform fuels could mean that future fires will be mostly stand-replacing; there will be little mixed-severity fire.

Adapted from: Anderson, Michelle D. 2003. *Pinus contorta* var. *latifolia*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: <https://www.fs.usda.gov/database/feis/plants/tree/pinconl/all.html> [2017, April 26]. **and** Arno, Stephen F. 2000. Fire in western forest ecosystems. In: Brown, James K.; Smith, Jane Kapler, eds. Wildland fire in ecosystems: Effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 97-120.

Fire Regimes in Whitebark Pine Forests



Whitebark pine fire regimes vary a lot in space and time. The most common kind of fire is of mixed-severity. A history of mixed-severity fire creates a complex pattern of tree survival and mortality on the landscape. Mixed severity fires occurred in the past at 60- to 300-year intervals; sometimes they occurred at intervals longer than 500 years!

Some fires in whitebark pine stands burn in sparse surface fuels and have low severity, killing only the smallest trees and the thinnest-barked overstory trees, such as subalpine fir. Fires are likely to be more severe if they burn in areas with heavy fuel loads or when the weather is especially dry and windy. These conditions help fire spread into the tree crowns and kill large patches of whitebark pines that may be hundreds of years old. Burned openings in whitebark pine stands provide good locations for Clark's nutcrackers to cache the heavy, nutrient-rich seeds of whitebark pine.

Many whitebark pine forests from the northern Rockies to the North Cascades have had occasional large, stand-replacing fires. These fires occurred at intervals of 250 years or even longer. The fires were usually driven by strong winds. They often originated in dense forests at lower elevations. Whitebark pines were often the first trees to become established on these large burns because their seeds were brought in by Clark's nutcrackers. Fir, spruce, and lodgepole pine trees seeded in more gradually from the edges, since they did not get any help from birds!



Because fire intervals are very long in whitebark pine forests, it is hard to say how fire suppression has changed them. In some areas, lack of fire could be leading to loss of whitebark pine and replacement by more shade-tolerant trees, such as spruce and fir. Even if whitebark pine seedlings are resistant to infection from white pine blister rust, they could have trouble getting a start on life if fire has not first cleared the soil and killed the small trees of competing species.

Adapted from: <http://whitebarkfound.org/ecology-management/fire-regimes/>, <http://whitebarkfound.org/ecology-management/threats/> and Larson, Evan R.; Van De Gevel, Saskia L.; Grissino-Mayer, Henri D. 2009. Variability in fire regimes of high-elevation whitebark pine communities, western Montana, USA. *Ecoscience*. 16(3): 282-298.



Unit VII.
People in Fire's Homeland

Carrying Fire the Pikunii Way: the Fire Carrier

Marvin Weatherwax

2/21/2009

Revised 2/27/2019

Lesson Overview: Students learn how the Pikunii (Blackfeet) people met the challenge of transporting fire from one camp to another as they traveled along historical migration routes. First, students build their own campfires to learn about the technological challenge of starting a fire and protecting “live” (smoldering) coals. Then they speculate on ways to carry fire, and they examine a model of a Pikunii fire carrier. Then they view a video in which a Blackfeet elder describes the construction and use of a traditional fire carrier. Finally, they review what they have learned using a cumulative-listening activity, in which they repeat what previous speakers have said and add their own statements.

Subjects: Science, Speaking and Listening, Health and Safety

Duration: Three half-hour sessions

Group size: Teams of 3-4

Setting: Outdoors and classroom

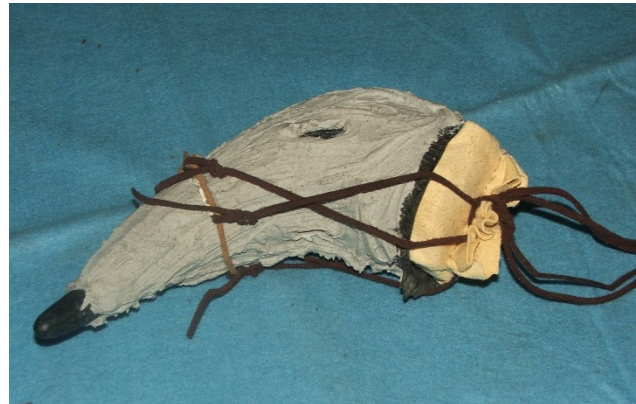
Vocabulary: *cumulative, elder, migratory people, oral teaching.*

These terms are defined within the steps under **Procedures** (below).

This lesson is an excellent complement to activities on the Fire Triangle and the science of wildland fire.

Lesson Goal:

- Increase students’ understanding of one native people’s technology and ways of life
- Increase students’ ability to listen respectfully and contribute to a discussion
- Increase students’ understanding of combustion and their skill in handling fire safely



Objectives:

- Students can explain or demonstrate the technological difficulty of starting a fire and transporting live coals.
- Students can explain why it was important for the Pikunii people to have continuous fire during their migrations and how the people met this challenge.
- Students can listen attentively enough to one another so they can repeat what previous speakers have said and add to the discussion.

Standards	Elementary School	1st	2nd	3rd	4th	5th
CCSS	Speaking and Listening	1,3,4,6	1,3,4,6	1,3,4,6	1,3,4,6	1,3,4,6
	Language	1	1,3,4,5,6	1,3,4,5,6	1,3,4,5,6	1,3,4,5,6
NGSS	Engineering Design		ETS1.A,B,C		ETS1.A	ETS1.A,B,C
	Earth's Systems					ESS3.C
EEEEGL	Strand 1	A,C,E				A,C,E
	Strand 2.2	C				C

Standards:	Middle School	6th	7th	8th
CCSS	Speaking and Listening	1,2,6	1,2,6	1,2,6
	Language Standards	1,4,5,6	1,4,5,6	1,4,5,6
NGSS	Waves and Electromagnetic Radiation	PS4.B		
	Energy	ETS1.A, ETS1.B		
	Earth's Systems	ESS3.A		
EEEEGL	Strand 1	A,B,C,E,F,G		
	Strand 2.2	A		

Standards:	High School	9th	10th	11th	12th
CCSS	Speaking and Listening	1,4,6		1,4,6	
	Language Standards	1,3		1,3	
NGSS	Energy	ETS1.A			
EEEEGL	Strand 1	A,C,D,E,F,G			
	Strand 2.1	B, C			

Teacher Background:

Many Native American peoples developed technology and traditions so they could carry fire from one place to another. The Pikunii people (one branch of the Blackfeet Nation) of the western Great Plains and Rocky Mountain Front used fire carriers made of buffalo

horns¹ to carry burning coals from one camp to the next and to start a fire in the new camp. This was very helpful for the people as they arrived in the new camp, but the fire also served another important purpose: The fire provided spiritual and cultural continuity for the people because the same fire was used in one camp after another, even while the people traveled thousands of miles in their yearly migrations.



The Pikunii made fire carriers from a buffalo horn that was filled with pieces of wood and other fuel, arranged carefully so the fire would burn slowly but not go out. The horn had small slits in the sides to allow oxygen in so the coals would keep burning. The horn was covered on the outside with a combination of sand and dirt mixed with homemade glue, which provided insulation. Then the fire carrier was dried for several days. When it was ready for use, burning coals were placed on a flat rock inside and a few pieces of wood were placed on top of the coals. A rawhide-wrapped stone or piece of wood was placed in the open end and tied tightly in place with strips of leather.

This activity is part of *FireWorks for the Pikunii Nation*, an educational program that combines information on the way of life of the Pikunii people with information on the science and technology of wildland fire. The project was developed through a partnership between the Native Science Field Center at Blackfeet Community College, Browning, MT, and the Forest Service's Rocky Mountain Research Station Fire Sciences Laboratory, Missoula, MT. The project was supported by a Diversity Grant from the USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

For more information on this project, contact the Missoula Fire Sciences Laboratory (<https://www.firelab.org/>) or the Native Science Field Center at Blackfeet Community College (<https://bfcc.edu/native-science-field-center/>).

Many thanks to: Audrey Peterson, Cass Cairns, Chuck Haney, David Hanna, Faith Ann Heinsch, Garon Smith, Greg Dillon, Helen Augare, Ian Grob, Ilana Abrahamson, Jim McCallum, Kinnerly Croisant, Kristine Lee, Mark Pieper, Marvin Weatherwax, Maure Sand, Melissa Little Plume-Weatherwax, Nancy McMurray, Nancy Trembath, Nathan P. Birkeland, Patti Bartlett, and Rick Thompson.

¹ **Appendix 3** lists scientific names for all plants and animals mentioned or shown in this activity.

This lesson has 4 parts--

- A hands-on activity and discussion in which students build small campfires and investigate various aspects of fire, such as how to start a fire, how to make it last a long time, and/or how to insulate coals so they will smolder without flaming.
- Examination of a physical model of a Pikunii fire carrier, which has been constructed to look like a real fire carrier but is NOT useable with actual coals. If you do not have access to a model of the fire carrier, you can use the photos available in https://www.frames.gov/documents/fireworks/curriculum/Pikunni/FireCarrierLesson/Printable_fire_carrier_diagram.pdf or follow the directions in **Appendix 2** to construct one.
- A 12-minute video interview with Pikunii elder Marvin Weatherwax (https://www.frames.gov/documents/fireworks/curriculum/Pikunni/FireCarrierLesson/CarryingFirePikunniWay_video.mp4) as he describes the importance, technology, and use of the fire carrier. The transcript for the video is available in **Appendix 1**. Scientific names for species mentioned in the video are listed in **Appendix 3**.
- An **Assessment** that emphasizes understanding of fire behavior and also concise speaking and attentive, respectful listening.

You can do this activity just with brainstorming and discussion, but it is much more engaging for students if they are first challenged to safely build a successful campfire. See Step 1 under Procedures.

This activity can be enriched by including activities in art (possibly constructing model fire carriers from materials such as clay or sugar cones) and music (learning about traditional Pikunii drumming and singing).

Materials and Preparation:

- Obtain a model fire carrier to show students (available from the Missoula Fire Sciences Laboratory, <https://www.firelab.org/>). If you cannot obtain a model fire carrier, download https://www.frames.gov/documents/fireworks/curriculum/Pikunni/FireCarrierLesson/Printable_fire_carrier_diagram.pdf – but don't show it until **Step 6** below.
- Make sure you have access (on the Internet or downloaded) to the 12-minute video "Carrying Fire the Pikunii Way" available at https://www.frames.gov/documents/fireworks/curriculum/Pikunni/FireCarrierLesson/CarryingFirePikunniWay_video.mp4.
- For the **Assessment (Part IV)**, consider finding some quiet, wordless music or recordings of Indian drumming or singing to set the mood. Also, consider your class's ability to listen attentively throughout the activity. If that seems too difficult, break the activity up with short, wordless mimicking games (such as clapping a rhythm or doing body motions for students to mimic).

Procedures:

Part I. Build or imagine a campfire

1. Ask: Have you or your family ever built a campfire? What materials did you use? How did you light it? How long did it last? How did you put it out? **Short brainstorming session. Maybe list materials and tools on the board.**
2. Ask: Among all the materials and tools that we use to build a campfire, which ones were NOT available to Indian people hundreds of years ago? How did they manage without these conveniences? **Open discussion, maybe with a list on the board.**
3. Explain: In this lesson, we're going to learn about one group of Native Americans, the Pikunii ("Pih-KUN-ee") people, and how they used fire and moved it from one camp to the next. Who are the Pikunii people? **"Pikunii" (spelled in several ways, including Pikuni, Pikunni, Pikani, and Piikáni) is the name for one of the four main branches of the Blackfeet Nation (<http://blackfeetnation.com/>). The Pikunii have lived for hundreds of years in the western half of Montana, especially in the prairies east of the Continental Divide. The center of their government and culture is now in Browning, Montana.** Show it on a map. Even better, show it on Google Earth so you can zoom in and out, look at the kind of terrain in the area (mountains and prairies), and help students relate the location of Browning, Montana, to their own location.
4. If you want students to build a fire, this is the time for it. After the campfire activity, discuss how it went: What were their challenges and solutions? **Open discussion.**

This activity was written to fit with activities in the FireWorks curriculum

(<https://www.frames.gov/fireworks/home>).

If you are not using that curriculum, decide what you'd like students to do to learn about fuel arrangement, ignition, and banking coals. If you would like students to learn how to bank a fire, this website may help:

[http://www.infobarrel.com/How to Bank a Fire](http://www.infobarrel.com/How_to_Bank_a_Fire).

Part II. Examine a model fire carrier

5. Explain: We've learned about some aspects of starting a fire and keeping it going. But those are not all of the challenges faced by the Pikunii people hundreds of years ago. Like many Native Americans, they were a migratory people – that is, they moved from one place to another throughout the seasons to obtain the foods, medicines, and other materials that they needed. They carried fire with them as they traveled. If you were asked to move a fire, how would you do it? What equipment would you need? Could you do it without modern technology, using only materials available in forests and prairies? **Discussion.**
6. Explain: Let's look at how the Pikunii carried fire. (Show the fire carrier and cross-section or display the printable version

https://www.frames.gov/documents/fireworks/curriculum/Pikunni/FireCarrierLesson/Printable_fire_carrier_diagram.pdf) These are *models* of a fire carrier – not the real thing. We call them “models” because they help us understand how a real fire carrier works but they contain glue and plastic materials, so they cannot actually be used.

7. Explain: We will all handle the fire carrier and the cross-section, and we’ll do so with respect because they represent something that is very important to the Pikunii people. When the materials come to you, **either make 1 observation about it or ask 1 question about it. You may take a moment of quiet before you speak.** The rest of us will listen quietly, and I will record your questions without trying to answer them.
8. Pass the fire carrier model(s) around the class. Record questions on the board.

Part III. Learn about carrying fire from a Pikunii elder (video)

9. Explain: We’ve made some observations and asked some questions. Now let’s listen to Mr. Marvin Weatherwax, an elder of the Pikunii people, to get answers to our questions and learn more about the fire carrier. What does it mean to be an “elder”? **An elder is not just someone who is older than other people, but someone who has a lot of knowledge and wisdom, so he or she is an authority for the people and an important teacher for children.**
10. Explain: As we view this video and listen to Mr. Weatherwax, we’re going to practice a skill that was extremely important to the Pikunii people in past centuries – LISTENING. This skill was ESSENTIAL TO THE PEOPLE’S SURVIVAL because they did not use writing to record their history and legends or to explain how to do things. There were no user manuals, no recipes in books, no online directions. Instead, they taught everything orally – that is, by speaking. If you were a Pikunii child, you needed to learn about your history and how to survive by listening very carefully and remembering EXACTLY what you heard. Then someday you could give that same information orally to the next generation, and they would listen very carefully to you.
11. FOR ELEMENTARY-AGE STUDENTS: Have students sit in a half-circle, perhaps with several rows. Remind them that, as Pikunii children, they would probably be sitting in a tipi or outdoors.
12. Explain: We’ll watch the video once without speaking or making any noise. Then we’ll see if we have found answers to our questions and if we have new questions. If we want, we can watch it again and stop it at any time to discuss it.
13. Show the 12-minute video “Carrying Fire the Pikunii Way”
(https://www.frames.gov/documents/fireworks/curriculum/Pikunni/FireCarrierLesson/CarryingFirePikunniWay_video.mp4).

14. Ask if students can answer the questions on the board. Ask if they have new questions, and record them.
15. Optional: View the video again. The table below contains explanatory notes keyed to times in the video. Entries in bold print are points where you could stop the video and ask the students to discuss or answer a question. **Appendix 1** contains the full transcript for the video.
16. If students still have questions, discuss ways to learn the answers.

Information and cues for studying “Carrying Fire the Pikunii Way”	
Background:	
Speaker	Mr. Marvin Weatherwax is an elder of the Pikunii people and a teacher of Blackfeet Language and Culture at Blackfeet Community College, Browning, Montana (http://bfcc.edu/). The other voice heard on the video is the interviewer, Jane Kapler Smith, an employee of the U.S.D.A. Forest Service.
Location	The video was filmed in the Tipi Ceremonial Room at Blackfeet Community College. This room has been constructed to look and function like the inside of a tipi. It is built and ventilated so students and instructors can burn smudges and use ceremonial fires.
Art work	Several art pieces are visible in the video. They include: ~~A painting of running horses called “Winter Count,” created by Blackfeet Studies students at Blackfeet Community College. ~~Designs shown in vertical strips on otherwise plain walls. These represent decorations that are painted on the liners of Pikunii tipis.
Sound	The audio track in the video contains occasional background noise from voices. This is because the video was taped while classes were in session at Blackfeet Community College, and students in the hallways were conversing as they moved from class to class. In addition, Mr. Weatherwax moved around the room while he described the annual migration of the Pikunii people, so some sections of the audio have varying volume and an “echoey” sound.
Cues for the video:	
0:45	Interviewer asks, “How did they do that [carry fire], and why? You could stop here and have students answer the question.
1:06	Take note of the surroundings. We are inside the Tipi Ceremonial Room, and the background is dominated by the “Winter Count” painting referred to above.
1:23	Shows plains prickly-pear, a type of cactus.
1:40	Mr. Weatherwax says that, after fire, the land will “renew.” You could stop the video and ask students what that might mean.
1:43	Shows quaking aspen sprouting from a top-killed tree after fire.
1:49	Mr. Weatherwax refers to “pharmacies,” meaning materials that can be used for health and healing. For more information about his and others’

	remarkable work in healing, see http://nativenews.jour.umt.edu/native2011.html .
1:54	The bright yellow flower is arrowleaf balsamroot.
1:54	Mr. Weatherwax refers to various plants as “weeds” – not meaning plants that are unwanted, but rather plants that grow aggressively after the trees have been removed.
1:56	Shows glacier lily
2:11	Shows willow leaves and western yarrow leaves and flowers
2:17	Interviewer asks, “Why was it important to carry fire from one camp to the next?” You could stop the video and ask students to answer.
3:32	You could stop the video after the discussion of continuity and “It was a very spiritual meaning” and ask students what they have in their lives that ensures continuity – what knowledge or things get passed on from generation to generation?
4:35	When Mr. Weatherwax points to slits on the sides and bottom, you could stop the video and ask students what those might be for.
5:11 & after	Mr. Weatherwax mentions using “hardwoods” because they burn a long time and “softwoods” because they are easy to ignite. The softwoods he is referring to include pine, Douglas-fir, and fir species. The hardwoods include aspen, cottonwood, chokecherry, sarvisberry (also called Saskatoon serviceberry), birch, willow, and buffaloberry. Buffaloberry was used because the wood smells bad when it burns—a warning to the runner that the fuels are nearly all burned.
6:49	The interviewer asks, “How long do you think fire would last in a fire carrier?” You could stop the video and ask students what they think.
7:06	The interviewer asks, “Who carried fire for the people?” You could stop the video and ask students what would make a person good at carrying fire.
8:36	This begins the section on the Cycle of the Buffalo, the Pikunii people’s annual migration. Here is a guide to place names that you could locate on a map or using Google Earth: Augusta (Aw-GUS-tuh) Choteau (SHOW-toe) Calgary (CAL-guh-ree) Cypress Hills Great Falls Pincher Creek Shelby
9:08	Mr. Weatherwax refers to “Ulm Pis’kun,” a cliff formation in west-central Montana that was used as a buffalo jump (a way to hunt and kill plains buffalo in large numbers). “Pis’kun,” also spelled “Pishkun,” is the Pikunii word for “buffalo jump.” Ulm Pishkun lies within First People’s

	Buffalo Jump State Park (http://stateparks.mt.gov/first-peoples-buffalo-jump/) in Montana.
9:24	Shows several buffalo. The one on its back is wallowing in dust to reduce parasites and soothe bites on the skin.
9:45	Shows sarvisberry leaves and berries (also called Saskatoon serviceberry)
10:07	Shows common chokecherries
10:12	Shows blue huckleberries
10:14	Shows limber pine cones. The seeds of these trees and of whitebark pines are very large and nutritious.
10:25	The interviewer asks, “Do the Pikuni still carry fire?” Maybe stop the video and ask students if they think it is still important to carry fire.
11:31	The interviewer mentions “Sharing knowledge about the Pikuni way.” Ask students how they have learned about their own way of life. Have they had a special family member or teacher who was especially helpful? How might they go about learning so they could become elders for their school, family, community, or country?

Part IV. Assessment:

15. FOR ELEMENTARY STUDENTS: Have students sit in a circle on the floor, as if inside a tipi.
16. Start some quiet, wordless music (if you think that will help set a listening mood for the class).
17. Explain: We are going to use a cumulative-listening activity to review what we’ve learned. It is important for us to share knowledge, but it is **just as important to show that we can learn from one another by listening well**, just as we listened to Mr. Weatherwax in the video. “Cumulative” means that our knowledge will accumulate – it will get bigger and bigger – as we progress through the activity.
18. Explain: Each student will hold the fire carrier and say ONE SENTENCE about it, then pass it on to the next student. **When it is your turn, repeat what the last 2 students said and then add your one sentence. (To make this more challenging, increase the number of statements that should be repeated – or try to get them all!)** This means you must listen to everyone rather than be just thinking of what you are going to say when it is your turn. It is OK to take a moment of quiet to think before you speak. We will listen respectfully even during moments of silence. If you cannot remember what previous students said, ask them politely to repeat it. If you cannot think of anything to add, raise your hand and I will suggest an idea or ask a question to help.
19. Start the activity. If a student makes a serious error, correct it quietly and gently. If it is too difficult for them to listen quietly through the whole circle, break the activity up with short, wordless mimicking games (such as clapping a rhythm or doing body motions for students to mimic). Or have the class work in a small group (4-5

students) and remember everyone's statements. If you need to keep the discussion moving, try some of these prompts:

- Who are the Pikunii people? **The Pikunii are a native American people, one branch of the Blackfeet Nation.**
- Where did the Pikunii live in the times of the buffalo? **The traditional territory of the Pikunii was thousands of square miles in central and western Montana, east of the Continental Divide.**
- Where do the Pikunii live now? **Pikunii people live all over the world, but their cultural center and the center of government for the Blackfeet Nation are on the Blackfeet Reservation in Montana, centered in the town of Browning.**
- Why did the Pikunii travel so much? **The most important resource for the Pikunii people was the buffalo. The people needed to travel so they could be near the herds of buffalo as they moved and grazed throughout the western Great Plains. The people also needed to travel so they could collect other foods and medicines, which could only be found in certain places at certain times of the year.**
- Did the Pikunii ever burn the land? Why? **They did burn the land to “clean up” their camps and to regenerate the plants that they needed for foods and medicines.** (Additional information: Other traditional uses of fire included burning to improve forage, to defend a camp against enemies, and to keep enemies away.)
- What is a fire carrier? **A fire carrier is something that holds smoldering coals so they can be moved safely from one place to another. Many native peoples in the Americas used fire carriers.**
- Why were fire carriers important to the Pikunii people? **Fire carriers were convenient because the people could move to a new camp and have a fire ready to use when they arrived. But fire carriers were even more important as a sign of continuity. The people had the same fire day after day, year after year, even though they moved from one place to another throughout the year.**
- How does the fire carrier's design protect the runner from getting burned? **The clay around the fire carrier provides insulation, and the fire inside burns very slowly so it doesn't produce as much heat as an open campfire.**
- How are “hardwoods” and “softwoods” used differently in a fire carrier? **Softwoods are used in the inner ring of fuels because they are easy to ignite. Hardwoods are used in the outer ring because they burn a long time.**
- How is a fire carrier made? **See the video and the directions in Appendix 2 for details.** Followup questions could address the materials used, the steps in construction, the fuels used, and their arrangement.

- Who carried fire for the Pikunii and how did they learn? **Good runners were selected to carry fire because they needed to get to the next camp and prepare it before the rest of the people arrived. The runners learned from others who had carried fire before them.**
- What would a runner do if the fuels in a fire carrier were almost all burned up? **The runner would stop and transfer the coals to another fire carrier.**
- ***If you are using the FireWorks curriculum:*** How does the Fire Carrier include all parts of the Fire Triangle while making sure that the fire burns very slowly? **The fire carrier contains lots of sticks and moss as FUEL. SMOLDERING COALS are its source of heat. OXYGEN comes in slowly through the slits in the sides and at the tip of the carrier.**
- Can you think of additional ways to carry fire that would not use modern technology? **Open-ended question. Might include ceramics, baskets, animal bones, thick and damp hides, turtle shells...**

Evaluation:

Activity	Full credit	Partial credit	No credit
Building a campfire	Worked safely and carefully. Listened respectfully to other team members. Contributed suggestions. Helped team work together.	Worked safely and carefully. Listened respectfully to other team members. Contributed suggestions.	Ignored safety precautions, did not participate with others on team, or dominated project without input from other team members.
Examining fire carrier, listening to video	~~Handled fire carrier gently. ~~Offered 1 observation or question. ~~Listened respectfully to video.	Met 2 of the 3 criteria under Full credit.	Met 0-1 of the 3 criteria under Full credit.
Cumulative listening activity	~~Repeated previous 2 speakers' statements. ~~Contributed 1 sentence with accurate information.	Met 1 of the criteria under Full credit.	~~Did not repeat previous 2 speakers' statements accurately. ~~Did not contribute 1 sentence with accurate information.

Appendix 1.

Script for “Carrying Fire the Pikunii Way”

Interviewer: Carrying Fire the Pikunii Way

The Pikunii people, also called the Blackfeet, have lived in the Northern Great Plains of the United States for hundreds and hundreds of years.

In the time before railroads, before European-American settlement, and before Reservations, they were a migratory people. Every year, they moved from one place to another so they could hunt the buffalo and harvest other foods and medicines.

As the Pikunii traveled, they took fire with them. How did they do that, and why?

Listen to the stories of Marvin Weatherwax, an elder of the Pikunii people. He will explain about the Pikunii way to carry fire throughout the year, as the people followed the buffalo.

Weatherwax: Fire is very important to us in many areas. One of the most important areas was conservation. The Pikunii people were very, very conscious of making sure that, when they left an area, it was clean and it was going to come back just the way they found it. So when they left camp, they would burn the area, so that the things they left there was all burned. Everything was burned, all the grounds and all, and what that did was it left it to renew. It would grow back and renew.

Fire was very important in another aspect. That was how they built their pharmacies. After a fire, the first thing that comes up is the “weeds.” And many of them are the medicines that we use for various ailments and the things that we need. And we’ll make a fire, deliberately burn an area

where we know that certain plants are.
It'll burn them down and then they'll grow back.

Interviewer: Why was it important to carry fire from one camp to the next?

Weatherwax: When we talk about the longevity
and the continuity of our people,
the fire played a very important part in that.
When we moved from one camp to the other,
it was very important that they took fire from the main fire.
They took some of that and brought it to the next camp
and started that fire with it.
In this sense, we had the same fire that went on and on and on.

In doing so, they had to have some way to transport it
because sometimes the camps were 20, 30, 40 miles apart.
And they had to have a way to transport that flame
from THAT fire to the new fire.
It would be very easy to go and start a new fire,
just to send someone to start a new fire, but the meaning,
the importance of taking the fire from one camp to the other,
the continuity, was very important.
It was a very spiritual meaning,

The vessel that they used was very important,
and that was the fire carrier.
This is a fire carrier here, that is a completed one
and this is the outer covering, which is mud or clay.
That goes on the outside,
then the covering, which is made out of wood or stone,
and that covers the top of it.

Sometimes they carried two or three of them,
depending on how far they were going to travel.
And they'd begin with one of them that had fire in it.
And then if they got to the point where this was getting hot down here on the end,
they would know it's coming to the end of this,
and then they would change, stop and take that,
and put that fire into another one,
and then they would start out again.

A slit on the sides and down on the bottom:
Not only ventilation, to get air - oxygen in there, to keep it going.
But the bottom one was

to let you know that it was time to change it.
The ingenuity that was used in building these
was absolutely phenomenal.
We'll go through one here that's built.

This is the horn, and down on the bottom of here,
we have moss, and it was usually kind of damp,
and that was pushed all the way down to the bottom.

And then they would put the wood on top of it,
going in a round circle.
But they would have softwoods in the middle.
There's a flat stone here,
where they would put the original piece of coal on there.
And they used the softwoods
because the softwoods are easier to ignite.

So from the coal, the softwood would ignite,
and then outside of that was the hardwood,
right on the outside.
And then after this burned, then the hardwood would burn.

And the thing that is good about the hardwoods
is that the hardwoods,
such as the cottonwood or the aspen,
it does not go out.
It'll burn until there is no more wood.
But the heat from the softwood
is what would get the hardwood going,
because that was a little harder to get started burning.
But once that got going, it went on and on.

The moss was not only on the bottom,
it was also around the outer edge,
and this was to keep it from flaming.
It would not flame, it would just stay a coal.

And then the top part was the cover,
which was very important, a very important part of it.
It was a stone, and most of the time it was wrapped
with something that would burn away,
like a piece of rawhide, sometimes,
but it would be wet, soaked in water,
so that when it was put down on there,

it made a seal, it covered it up, and it was tied down.

The bottom inside of that would normally burn from the heat.
This would be very very hot.

Interviewer: How long do you think fire would last in a fire carrier?

Weatherwax: Really, it depended on how big the fire carrier was, because that would depend on what the length of the hardwood would be, that you put in there.

Interviewer: Who carried fire for the people?

Weatherwax: There were special people that were chosen, and it was normally the long distant runners, because they ran not only to find out where the buffalo were, but they ran to get new camps, to where the camp was. They didn't walk, they literally ran, sometimes for 40, 50 miles, nonstop.

The people that put it together were someone that had done it for a long time, and he would teach someone else to do it. And just my sense – I would think that the runners that carried it were the ones, that it was – the knowledge of how to make it was passed on to them.

In my readings and talking with people, most all the tribes had their own way of continuing. Even the Indians in Alaska. They used the whale bones and did something similar to this and they transported their fires the same way, and for the same reasons. So the continuity of the fire was important amongst all the native people. All of us are so conscious about carrying things on and making sure that things are continued.

Interviewer: The Pikunii traveled hundreds of miles each year, carrying fire. This was “the Cycle of the Buffalo.”

Weatherwax: It was right around the Choteau area -

that's where our main camps always were.
In the spring of the year, this is where the buffalo were.

Up here and down toward, right above the Great Falls area,
there was usually a herd of female buffalo calving.

In this area down here by Great Falls,
there's a pishkun down there now.
They called it the Ulm Pishkun,
and it was used primarily for the elders.
What they would do is, some warriors would go down,
and they would take part of a herd - not a real large part –
and then they would run them off of that pishkun.
They did it in the spring of the year before the cows gave birth.

Previous to us being on the Reservation,
we traveled pretty much through the whole half of the state.

And they came around over by Shelby along the Marias River,
and they hunted the Sweet Grass Hills,
and they brought that back to Shelby,
and then they camped there for awhile.
And then they continued on over into Canada,
by the Cypress Hills.
Normally when they hit the Cypress Hills it was around July.

And then they came up from there toward Calgary.
They turned down along the mountains.
And then about this time of the year,
they were probably right in this area along the mountains,
right in the mountains by Pincher Creek,
right above Pincher Creek.
And then they would move down into the winter camp area.

Interviewer: Do the Pikunii still carry fire?

Weatherwax: What my grandfather told me about the fires:
He was told probably about the middle of the 1800s
was when they say the last fires went out.
It was probably just previous to the buffalo being gone.
And the reason for that was that
they moved their camps to follow the buffalo.
And then when the buffalo were gone,

then it was not necessary for them to move their camps anymore and follow the buffalo.

They could stay stationary,
and then they had to begin to depend on the wildlife that was there
or the cattle that the government was going to provide them...
the rations that the government was going to provide them.

That's when they all had to start living on reservations,
so that's when the fire ended.

Interviewer: Sharing knowledge about the Pikunii way

Weatherwax: One of my responsibilities in my life
is to pass on things that I have learned
from my grandparents and from the other elders.
Because I have finally become, I believe I've become an elder,
and I can pass this on.

Appendix 2.

Constructing a Replica or Model of a Pikunii Fire Carrier

These instructions explain how to make a useable fire carrier. If you would like to make a model of the fire carrier like the ones available at Blackfeet Community College or the Missoula Fire Sciences Laboratory, follow the instructions below, except for the following:

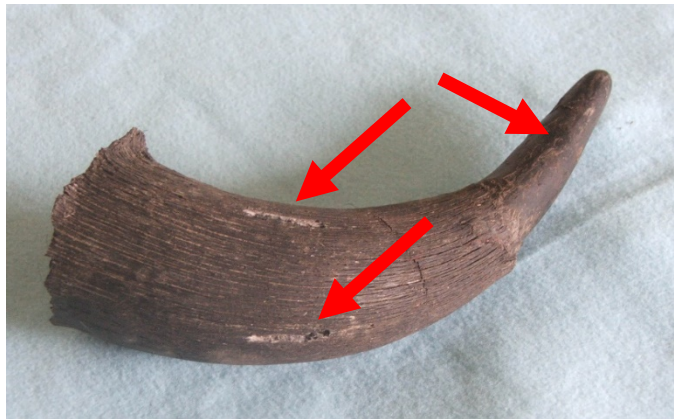
1. Use a complete buffalo horn, as below, and also a cross-section of a buffalo horn.
2. Cover the outside of the horn and cross-section with car-body putty or plastic clay instead of making coating from soil and glue.
3. As you assemble the fire carrier and the cross section, attach everything using a glue gun.

Do not try to use a model fire carrier (made with glue and other synthetic materials) to actually carry live coals.

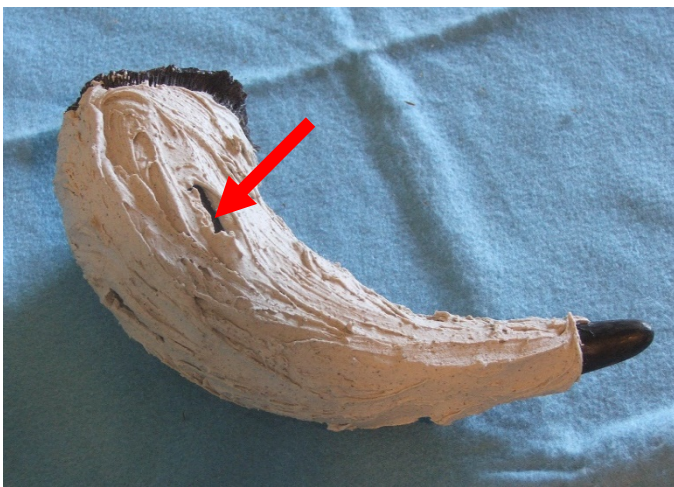
Materials for making a fire carrier are found in our surroundings:

- Large buffalo horn
- Sand and dirt
- Glue (made from the insides of the hooves of a horse)
- FUELS:
 - Wood—small branches of...
 - Softwoods:
 - Douglas-fir
 - Other fir species
 - Pine
 - Hardwoods:
 - Cottonwood
 - Aspen
 - Chokecherry
 - Sarvisberry (also called Saskatoon serviceberry)
 - Birch
 - Buffaloberry (used because they smell bad when they burn—a warning to the runner that the fuels are nearly all burned)
 - Willow (any species)
 - Moss
 - Sage leaves
 - Stone (one small, flat stone that will fit inside horn and hold the burning coals)
 - Rawhide piece about 10" square
- Block of wood large enough to cover opening of horn—or—piece of stone that is cone shaped. (Either can be shaped to cover the horn's opening.)
- Strip of leather or rawhide ¼" wide and 30-36" long

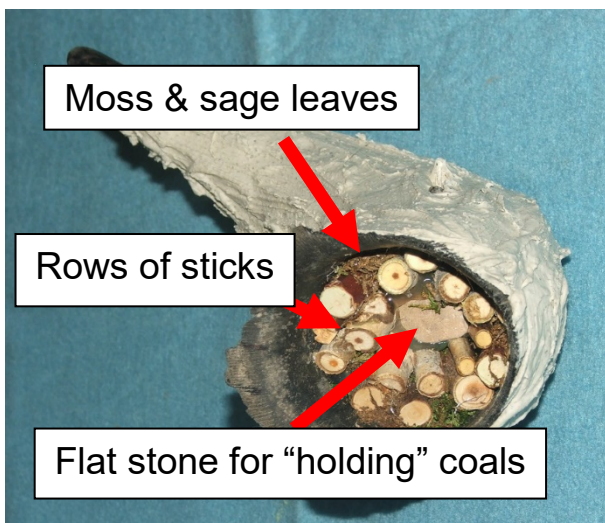
1. **Constructing the fire carrier:** Using a knife, drill, or other sharp object, cut 4 small openings in the buffalo horn about $\frac{3}{4}$ of the way up from the small end. Make the openings 1-2" long and $\frac{1}{8}$ " wide. Make additional openings at the narrow tip of the horn.



2. Mix sand, dirt, and glue. Knead into the consistency of dough.
3. Apply mixture to outside of horn in a layer about $\frac{1}{2}$ " thick. Make sure that you don't cover up the openings in the horn. Press down firmly to make sure that this insulating material has good contact with the horn and sticks well.

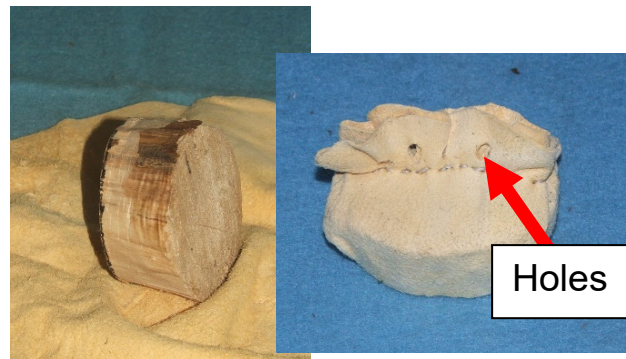


4. Let dry for about 3 days.
5. Fill the bottom of the horn with moss. Then line the inside of the horn with moss and sage leaves about $\frac{1}{2}$ " deep all the way to within $\frac{1}{2}$ " of the top, leaving enough room at the top for the cover to fit in tightly.
6. Place sticks in concentric circles inside the horn: The first row, just on the inside surface of the horn, should be hardwood. Put in more hardwood rows until about half of the horn's cross-section is filled.



7. Inside the hardwood sticks, add 1-2 rows of softwood sticks in rows until $\frac{3}{4}$ of the horn's cross-section is filled. Leave enough open area in the middle for the flat stone (see step 9).
8. More about the sticks:
 - In the outside row, reaching all the way to the bottom of the horn, place one stick of buffaloberry. This will give off a very distinct, unpleasant odor to let you know when the fuels in the carrier are almost burned out.
 - Put at least one cottonwood stick in each row of sticks. Cottonwood continues to burn and does not go out until it is completely burned up. This will help ensure that the fire carrier will stay lit.
9. Place a flat, round stone in the center and push it down as far as it will go. This will wedge the sticks in place and hold the live coal.
10. **Closing and sealing the fire carrier:** Get a block of wood or stone and cut it to the size of the opening of the horn. Carve it into a tapered or cone shape that will fit inside the horn. Leave enough space for the rawhide covering.

11. Cut the rawhide so it will wrap around the wood/stone cover.
12. Soak the rawhide in water for at least 15 minutes before using. This will make it expand and seal the opening of the horn tight. Wipe excess moisture off the cover before use.



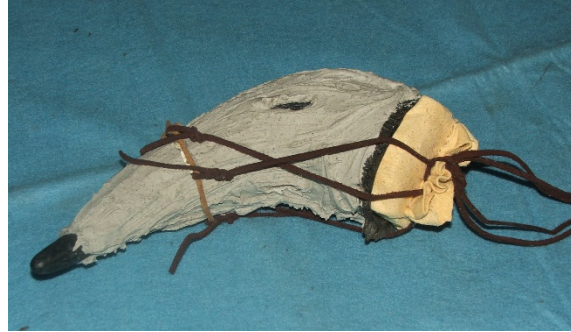
11. Cover the wood/stone with the damp rawhide and attach it to the cover with sinew. Make it tight. Make holes in the top of the rawhide cover about $\frac{1}{4}$ " long to hold the strips of leather that secure the cover.



12. Cut leather into 5 strips, each about 14" long. These will be used to secure the cover.
13. Tie ends of four leather strips onto the fifth piece, which goes around the horn.
14. Tie the 5th piece of leather around the horn, about $\frac{1}{3}$ of the way up from the bottom of the horn. Adjust the four loose strips so they are placed evenly around the horn.

15. Crisscross and lace the strips through the ¼" cuts made in the rawhide that covers the carrier cover.

16. When you have all pieces completed and they fit together perfectly, the fire carrier is ready to use. Open it and place burning coals on the flat stone in the middle. Put several pieces of hardwood on top of the burning coals to keep them in place. Put the cover on and tie the straps tight.



Appendix 3. Scientific names of plants and animals shown or mentioned in this lesson

Common name	Scientific name
buffalo	<i>Bos bison</i>
sarvisberry/Saskatoon serviceberry	<i>Amelanchier alnifolia</i>
arrowleaf balsamroot	<i>Balsamorhiza sagittata</i>
glacier lily	<i>Erythronium grandiflorum</i>
blue huckleberry	<i>Vaccinium membranaceum</i>
common chokecherry	<i>Prunus virginiana</i>
limber pine	<i>Pinus flexilis</i>
whitebark pine	<i>Pinus albicaulis</i>
willow	<i>Salix species</i>
western yarrow	<i>Achillea millefolium</i>
elk	<i>Cervus elaphus</i>
cottonwood	<i>Populus species</i>
quaking aspen	<i>Populus tremuloides</i>
pine	<i>Pinus species</i>
Fir, Douglas-fir	<i>Abies species</i> and Douglas-fir (<i>Pseudotsuga menziesii</i>)
birch	<i>Betula species</i>
buffaloberry	<i>Shepherdia canadensis</i>
prickly-pear	<i>Opuntia species</i>



22. Changing Landscapes, Changing Fires

Lesson Overview: In this activity, students envision how they would like a wildland area to look in the future and how that might be achieved. First, they study photos and read articles that describe changes over the past 100 years in landscapes, fire regimes, fire management, and other issues. Then they create art work that shows their own vision of a future landscape and write an editorial explaining their vision and what should be done (or not done) to achieve it.

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

Duration: 2-3 class periods

Group size: Full class

Setting: Indoors

Lesson Goal: Students will understand that ecosystems change over time, sometimes due to changes in human needs and wants, and many forests from the northern Rocky Mountains to the North Cascades are now very different from past conditions. Students will be able to describe changes likely to occur in the future and how people’s actions may influence those changes.

Objectives:

- Students can identify the main points in an article about changes in wildlands and fire management and recognize the level of authority of the authors or interviewees.
- Students can examine photographs of landscapes taken over 50-100 years, envision a desirable future for that landscape, and describe how that future condition could be achieved.

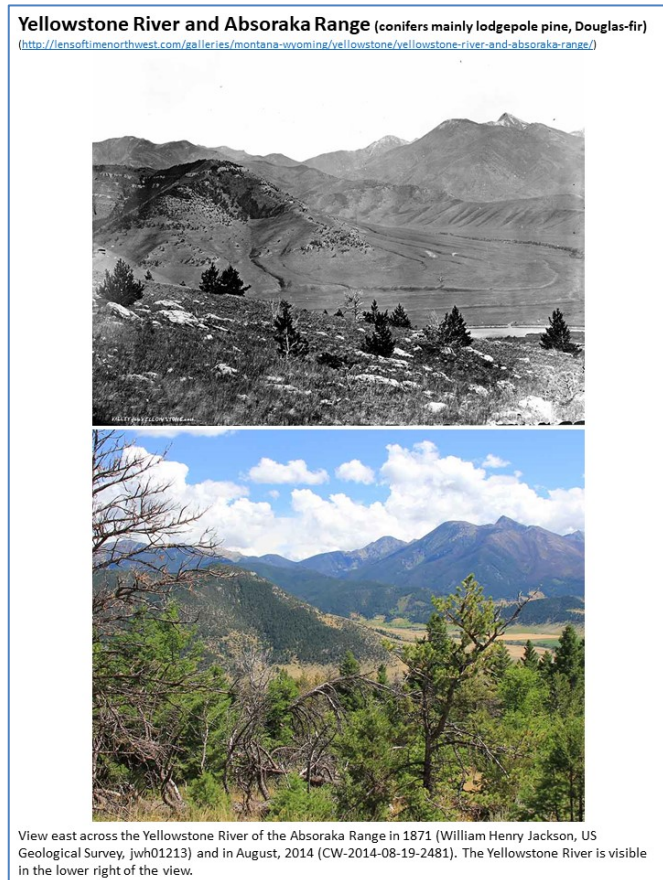
Standards:		9th	10th	11th	12th
Common Core ELA	Reading Informational Text	2, 4, 10		2, 4, 10	
	Writing Standards	2, 4, 8, 10		2, 4, 8, 10	
	Speaking and Listening Standards	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3		1, 2, 3	
	Reading Science/Technical Subjects	1, 2, 4, 9, 10		1, 2, 4, 9, 10	
	Writing Science/Technical Subjects	2, 4, 9, 10		2, 4, 9, 10	
NGSS	Ecosystem Dynamics, Functioning, and Resilience	LS2.C			
	Biodiversity and Humans	LS4.D			
	Developing Possible Solutions	ETS1.B			
	Weather and Climate	ESS2.D			
	Natural Hazards	ESS3.B			
EEEEGL	Strand 1	A, E, G			

	Strand 2.2	C
	Strand 2.4	A, E
	Strand 3.1	A, B, C
	Strand 4	B, C, D

Teacher Background: A lot has changed on Planet Earth in the past few centuries. While we often think of forests as stable and unchanging, they are just as dynamic as other landscapes and seascapes on Earth, and they are strongly influenced by the choices people make in using and managing them.

We can identify many landscape-level changes in forests from the northern Rocky Mountains to the North Cascades by looking at photographs taken at different times from the same location. The website “Lens of Time Northwest” (<http://lensoftimenorthwest.com/>), developed by ecologist Dr. Cliff White of Canmore, Alberta, contains a collection of photo series that show changes in wildlands of the northwestern United States and southwestern Canada over the past 100-150 years. This collection provides striking documentation of changes in landscapes, vegetation, and human influence since the early 1900s. One example is given at right (from **PhotoSeriesForStudents.zip**).

This activity challenges students to select one photo series, envision how they would like that landscape to look 100 years in the future, and explain how that could be achieved. To prepare for this art/writing project, they read and report on at least 1 article that offers opinions on landscape change, fire regime change, and fire management policy. They learn about other articles from student presentations.



Materials and preparation:

1. Decide:
 - a. How to provide the 9 articles for students to read (electronically from **Articles.zip** or from printouts). Unless you have a very small class, more than 1 student will read each article.
 - b. Whether to assign the articles as homework or in-class reading. This lesson is written assuming that students will read the articles as homework.
 - c. Whether to assign articles to students randomly or more deliberately. The articles vary in length from 559 words to 1105 words (length is given in bold print in the **Teacher's guide to Handout H22-1** below). The shorter articles are somewhat simplistic, and the longer ones are more complex and technical. The students who present the two articles by White may need a little extra time both for preparation and presenting – or perhaps they should break the article into sections so each student can present a different section.
 - d. How students will choose a photo series for developing their visions of the future (see Step 1 in **Assessment** below) - from the 8 series available in **PhotoSeriesForStudents.zip** and also on printouts in the trunk - or from browsing the “Lens of Time” website (<http://lensoftimenorthwest.com/>). If students can access the photos digitally, they will have the option of creating their vision of the future using either original art work or a photo editor.
2. Download all of the articles (**Articles.zip**) to your classroom computer so students can project any illustrations needed for their presentations.
3. Access the “Lens of Time Northwest” website (<http://lensoftimenorthwest.com/>). Try to find a browser that “fades” the images from one to another rather than changing the image suddenly. As of this writing (2018), the authors have had better luck with *OneDrive* and *Internet Explorer* than with *Chrome* and *Mozilla Firefox*. **NOTE:** If the website is not available, you can use the files in **PhotoSeriesForStudents.zip**.
4. Browse “Lens of Time” yourself to decide what photos to use for introducing the activity. Don't make it complicated. You can use any of the photo pairs featured on the homepage – or go to the map and find images from a location that your students may find interesting.
5. Make 1 copy/student of **Handout H22-1. Changing landscapes, changing fires** – OR – give students other instruct on taking notes during the presentations (see Step 8 under **Procedures** below).

Procedures:

DAY 1: Introduction:

1. Explain: To complete our study of the science of wildland fire, we're going to look at how landscapes have changed over the past century or so, and then we'll create our own pictures of how WE would like them to look in the future. We'll ask
 - How did the landscape get to be the way it is now?
 - How would we like it to look in another hundred years?
 - What could we do – or what must we avoid doing – to make that happen?
2. Open the “Lens of Time” website (<http://lensoftimenorthwest.com/>). If possible, use a browser that “fades” from one image to another. (See Step 3 under **Materials and preparation** above.) Ask students to describe the changes they see as the images go from past to present and back again. If the website is not available, you can use the files in **PhotoSeriesForStudents.zip**.
 - Try to draw out comments on the most vivid changes observed. These may have more to do with population change and people's actions than with vegetation change, and it is good for students to notice that.
 - When vegetation changes are mentioned, ask if they have anything to do with people's choices (decline in populations of American Indians, use of the land for grazing and farming and timber harvest, use of fire and fire suppression, etc.).
3. Explain: To get some ideas about how things have changed and why and possible ways to influence future changes, we'll read some articles and report on them to the class. Everyone will read at least 1 article. As you read, take some notes on:
 - Who wrote the article – or, in the case of news articles, who is interviewed – and what authority/credibility they have to speak about the issue.
 - What problem they address – perhaps change in a landscape or fire regime, perhaps actions by managers, perhaps other issues.
 - What they think can be done about the problem – or what actions should be avoided in the future.
4. Explain: During the next class, you will have a few minutes to work with other students who have read the same article, and then you will present it to the class as a team. This way, everyone will get to consider a variety of opinions on problems we have with wildland fire, how they originated, and what might be done about them.
5. Assign articles and explain how students will access them (electronically from **Articles.zip** or in printed form). See Step 1c in **Materials and preparation** for some notes on considerations about assigning articles.

DAYS 2-3: Presentations on articles:

6. Get the students who have read each article to team up (up to 9 teams). Give them about 10 minutes to prepare a presentation for the class.
7. Explain: Your presentations should be about 5 minutes long. You may display the article on the computer so you can show the graphics to the class. In your presentation, describe:
 - The author, date, and nature of the article (whether it is an editorial, news article, or technical article).
 - The credentials of the writer or – in the case of a news article – the people interviewed for the article.
 - The main points of the article, especially information about WHY there is a problem and WHAT SHOULD BE DONE or not done about it.
8. Give each student a copy of **Handout H22-1. Changing landscapes, changing fires** (or explain how to take notes on presentations). Explain: Black out the line for the article you're presenting. For every other article, take notes on what has changed or is changing, why the changes have occurred, and what might be done – or not done – to make things better. You will use these notes to develop YOUR OWN vision of a landscape a hundred years from now.
9. Have students present their articles in the following order (since some of the articles are responses to previous articles):
 - A. Wuerthner (2017)
 - B. Atkins and others (2017)
 - C. Chaney (2019)
 - D. Arno (2017)
 - E. Caton and others (2018)
 - F. White (a) (2018) (on Ross's Hole)
 - G. Cromwell (2017)
 - H. Erickson (2017)
 - I. White (b) (2018) (on the Yellowstone River)

Assessment:

1. Explain: Now it's your turn to plan for the future. You will select a photo series and envision what you'd like that place to look like in 100 years.
2. Explain how to select a photo series – from digital copies in **PhotoSeriesForStudents.zip**, from printouts of these 8 files, or from the "Lens of Time" website (<http://lensoftimenorthwest.com/>). The 8 files in **PhotSeriesForStudents.zip** include the 2 already viewed in the articles by White (**YellowstoneRiver.jpg** and **RossHole.jpg**), but it's OK to use them in the Assessment too.

3. Explain: Think about what you would like that landscape to look like 100 years from now. Keep in mind that the vegetation will change during that time, with or without human intervention.
- Then figure out what should be done – or should NOT be done – to make the landscape look the way YOU would like it to look in another 100 years.
 - Then create an art work that shows how you envision the future of that landscape. If students have access to digital copies of the photos, they could use a photo editor to create the art piece. Use the same topography shown in the photo series, but show the vegetation – and possibly wildlife – as you’d like it to be 100 years from now.
 - Then write an editorial for a newspaper or web blog (500 words or less). In it, display your photo series and art work and explain:
 - how you would like your landscape to look in 100 years
 - why that would be good
 - what should be done – or should be avoided – to make it happen.

Evaluation: The main vehicles for assessment are the art work and accompanying editorial. If you want, you can also evaluate the students’ presentations and their notes from the presentations.

	Excellent	Good	Poor
Team presentation	Helped give clear, concise, accurate summary of important points in article.	Helped give accurate summary of important points in article.	Was not helpful or gave inaccurate information.
Notes on presentations	Recorded relevant information on 8 presentations (all except the one he/she participated in).	Recorded information on 6-7 presentations. Some information was not relevant.	Recorded information on fewer than 6 presentations. Some information was not relevant.
Art work	-Art piece showed similar topography to that of photo series. -Art piece showed reasonable changes in vegetation and other features, based on explanation in editorial. -Art piece showed creativity and attention to detail.	-Art piece showed similar topography to that of photo series. -Art piece showed reasonable changes in vegetation and other features, based on explanation in editorial.	Art piece did not use original topography OR showed changes that were not reasonable or conflicted with explanation in editorial.

<p>Editorial (≤500 words)</p>	<p>Editorial gave thorough, logical explanation for anticipated changes, desired landscape, and actions that should (or should not) be done to achieve it.</p>	<p>Editorial explained the desired landscape and actions that should (or should not) be done to achieve it.</p>	<p>Editorial did not explain the desired landscape or did not explain steps needed to achieve it.</p>
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Handout H22-1. Changing landscapes, changing fires.

Name: _____

Author (date)	What's changing, why, what might be done
A. Wuerthner (2017)	
B. Atkins and others (2017)	
C. Chaney (2019)	
D. Arno (2017)	
E. Caton and others (2018)	
F. White (a) (2018) – Ross's Hole	
G. Cromwell (2017)	
H. Erickson (2017)	
I. White (b) (2018) – Yellowstone R.	

Teacher's guide to Handout H22-1. Changing landscapes, changing fires.

Name of .pdf file	Author (date) - length	What's changing, why, what might be done	Authority, credibility
A-Wuerthner_170802-Missoulia-NoFuelTmt.pdf	Wuerthner (2017) - 636 words	Fuel treatments have been suggested to make fires smaller and easier to control, but they are the same as logging. Fuel treatments do not work during extreme fire weather and are too small to make a difference in big fires anyway.	Author is ecologist and writer.
B-Atkins_170827-Missoulia-FuelTmt.pdf	Atkins and others (2017) - 674 words	Fuel treatment is not the same as logging. Fuel treatments and past wildfires reduce the intensity of new fires and make them safer and easier to control, even though extreme fire weather reduces effectiveness of treatments.	12 authors, including managers, scientists, professors.
C-Chaney_180212-Missoulia-WhoOwnsFires.pdf	Chaney (2019) - 1024 words	Communities need to work together to reduce impacts of wildfire, including smoke. Prescribed fire is needed.	Author interviews scientists and a county commissioner.
D-Arno_170831-Missoulia-ForestsNeedFire.pdf	Arno (2017) - 703 words	Fire exclusion has led to current problems. Thinning and prescribed fire are needed, especially around private property on edge of wildlands.	Author is scientist, author, and land manager.
E-Caton_180103-Missoulia-ClimateChange.pdf	Caton and others (2018) - 716 words	Climate change is affecting agriculture, tourism, and fire. Support measures to stop climate change.	5 authors, including scientists and professors.
F-White-a-LensOfTime-RossHole.pdf	White (a) (2018) - 921 words – Ross's Hole	The change from open ponderosa pine forest to dense forest and then high-severity fire was caused by loss of Native American burning, which was followed by grazing and fencing by Euro-American settlers, which was then followed by fire exclusion.	Author is a biologist who studies fire and eco-cultural influences on the landscape. Article cites sources.
G-Cromwell_170906-Missoulia-PutOutFires.pdf	Cromwell (2017) - 559 words	Every fire can be put out while small. Large fires (Lolo Peak, 2017) indicate negligence by managers.	Author is retired engineer. Does name calling ("bozos") give him a better claim to authority?
H-Erickson_171020-Missoulia-Safety.pdf	Erickson (2017) - 994 words	Fires cannot all be put out safely while small. Lolo Peak Fire (2017) was too dangerous because of dense vegetation and steep, inaccessible terrain. This makes reduction of fuels around private property very important.	Author interviews IC team member and fire manager.
I-White-b-LensOfTime-Yellowstone.pdf	White (b) (2018) - 1105 words – Yellowstone River	Historical landscape pattern was complex and strongly influenced by Native American burning. Fire regime is now mainly severe fire during very dry periods. The change is caused by loss of Native American burning, then fire exclusion, then proliferation of grazing animals in greater numbers than occurred historically.	Author is a biologist who studies fire and eco-cultural influences on the landscape. Article cites sources.