FireWorks Curriculum
For High School
Featuring Ponderosa, Lodgepole, and Whitebark Pines
2018

Jane Kapler Smith,
Ilana Abrahamson,
and Caitlyn Berkowitz

Produced by:
U.S. Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory,
Missoula, Montana
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Intro i</td>
</tr>
<tr>
<td>Unit I. Introduction to Wildland Fire</td>
<td>1</td>
</tr>
<tr>
<td>H01. Introduction to Wildland Fire in the Northern Rocky Mountains and North Cascades</td>
<td>3</td>
</tr>
<tr>
<td>Unit II. Physical and Chemical Science of Wildland Fire</td>
<td>15</td>
</tr>
<tr>
<td>H02. The Fire Triangle: Fuel, Heat, and Oxygen</td>
<td>17</td>
</tr>
<tr>
<td>H03. The Fire Triangle, Combustion, and the Carbon Cycle</td>
<td>31</td>
</tr>
<tr>
<td>H04. Heat Transfer</td>
<td>45</td>
</tr>
<tr>
<td>Unit III. The Wildland Fire Environment</td>
<td>49</td>
</tr>
<tr>
<td>H05. Fuel Properties</td>
<td>51</td>
</tr>
<tr>
<td>H06. Pyrolysis</td>
<td>61</td>
</tr>
<tr>
<td>H08A. Fire Environment Triangle and Fire Spread: The Matchstick Forest Model (Option A)</td>
<td>79</td>
</tr>
<tr>
<td>H08B. Fire Environment Triangle and Fire Spread: The Landscape Matchstick Model (Option B)</td>
<td>91</td>
</tr>
<tr>
<td>H09. Ladder Fuels and Fire Spread</td>
<td>99</td>
</tr>
<tr>
<td>H10. Fire weather, fuels, and topography: Modeling for management on a real fire</td>
<td>111</td>
</tr>
<tr>
<td>Unit IV. Fire Effects on the Environment</td>
<td>129</td>
</tr>
<tr>
<td>H11. Smoke from Wildland Fires</td>
<td>130</td>
</tr>
<tr>
<td>H12. Fire, Soil, and Water Interactions</td>
<td>149</td>
</tr>
<tr>
<td>Unit V. Fire’s Relationships with Organisms and Communities</td>
<td>167</td>
</tr>
<tr>
<td>H13. Tree Identification: Create a Dichotomous Key</td>
<td>169</td>
</tr>
<tr>
<td>H14. Researching a Plant, Animal, or Fungus</td>
<td>177</td>
</tr>
<tr>
<td>H15. Forest Communities and Climate Change</td>
<td>189</td>
</tr>
<tr>
<td>Unit VI. Fire History</td>
<td>203</td>
</tr>
<tr>
<td>M17 &amp; H16. Dating Fires Using Dendrochronology</td>
<td>205</td>
</tr>
<tr>
<td>M18 &amp; H17. History of Stand-replacing Fire</td>
<td>217</td>
</tr>
<tr>
<td>M19 &amp; H18. History of Low-severity Fire</td>
<td>225</td>
</tr>
<tr>
<td>H19. History of Mixed-severity Fire</td>
<td>241</td>
</tr>
<tr>
<td>H20. Why Do Historical Fire Regimes Matter?</td>
<td>248</td>
</tr>
<tr>
<td>Unit VII. People in Fire's Homeland</td>
<td>263</td>
</tr>
<tr>
<td>H21. Carrying Fire the Pikunii Way: The Fire Carrier</td>
<td>265</td>
</tr>
<tr>
<td>H22. Changing Landscapes, Changing Fires</td>
<td>289</td>
</tr>
</tbody>
</table>
**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: ponderosa pine\(^1\)/Douglas-fir, lodgepole pine/subalpine fir, and whitebark pine/subalpine fir.

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\(^1\) 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/](https://www.feis-crs.org/feis/)).
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.

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

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

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

Links to Educational Standards
FireWorks need not compete with core curriculum for classroom time. Instead, it can help teachers cover 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), History and Social Studies, Science, and Technical Subjects
- Next Generation Science Standards (NGSS)
- Excellence in Environmental Education: Guidelines for Learning standards (EEGEL)
- the C3 Framework - College, Career and Civic Life for Social Studies State Standards (C3 SSSS)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)
- EEGEL: 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:

1. Find the relevant grade(s).
2. Find the relevant standards and access a copy of the respective publication (use the links below).
3. Open standards publication to the appropriate grade and section.
4. Locate these numbers and read the associated standards.

<table>
<thead>
<tr>
<th>Standards</th>
<th>Section</th>
<th>Sixth</th>
<th>Seventh</th>
<th>Eighth</th>
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<td>Writing</td>
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<td>4,10</td>
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<td>1,2,4,6</td>
<td>1,2,4,6</td>
<td>1,2,4,6</td>
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<td>1,2,3,6</td>
<td>1,2,3,6</td>
<td>1,2,3,6</td>
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<td>Reading Standards</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Science/Tech</td>
<td>4,7,9</td>
<td>4,7,9</td>
<td>4,7,9</td>
</tr>
<tr>
<td></td>
<td>Writing Standards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Science/Tech</td>
<td>4,7,10</td>
<td>4,7,10</td>
<td>4,7,10</td>
</tr>
<tr>
<td>NGSS</td>
<td>Structures/Properties of Matter</td>
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<td></td>
<td>Energy</td>
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<td>PS3.A</td>
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<tr>
<td></td>
<td>Waves/Electromagnetic Radiation</td>
<td></td>
<td></td>
<td>PS4.B</td>
</tr>
<tr>
<td>EEEGL</td>
<td>Strand 1</td>
<td></td>
<td>A,C,E,F,G</td>
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</tr>
</tbody>
</table>

**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 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 perhaps select the best approach for meeting your objectives with your students.

Literature cited

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.

<table>
<thead>
<tr>
<th>Unit &amp; Theme</th>
<th>ELEMENTARY</th>
<th>MIDDLE</th>
<th>HIGH</th>
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<tbody>
<tr>
<td>Unit I. Introduction to Wildland Fire</td>
<td>E01. Visiting Wildland Fire in the Northern Rocky Mountains and North Cascades</td>
<td>M01. Visiting Wildland Fire in the Northern Rocky Mountains and North Cascades</td>
<td>H01. Introduction to Wildland Fire in the Northern Rocky Mountains and North Cascades</td>
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<tr>
<td>Unit II. Physical Science of Wildland Fire</td>
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<td></td>
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<td>H05. Fuel Properties</td>
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<td>H06. Pyrolysis</td>
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<td></td>
<td>H07. Fire Spread Processes: Putting it all together: Heat transfer, fuel properties, and pyrolysis</td>
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<td>H08A. Fire Environment Triangle and Fire Spread: The Matchstick Model</td>
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<td>H09. Ladder Fuels and Fire Spread</td>
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<td>H10. Fire Behavior, Fire Weather, and Climate</td>
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<td>----------------------------------------</td>
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<tr>
<td></td>
<td>M10. Fire, Soil, and Water Interactions</td>
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<td>H12. Fire, Soil, and Water Interactions</td>
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<table>
<thead>
<tr>
<th>Unit V. Fire’s Relationship with Organisms and Communities</th>
<th>E08-1. What’s a Community? All the Living Things in the Ecosystem</th>
<th>M11. Who Lives Here? Adopting a Plant, Animal, or Fungus</th>
<th>H14. Researching a Plant, Animal, or Fungus</th>
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<tbody>
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<td>E08-2. Who Lives Here? Adopting a Plant, Animal, or Fungus</td>
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<td>E10. Tree Identification: Using a Key to Identify “Mystery Trees”</td>
<td>M13. Tree Identification: Figure out the “Mystery Trees”</td>
<td>H13. Tree Identification: Create a Dichotomous Key</td>
</tr>
<tr>
<td></td>
<td>E11. Recipe for a Lodgepole Pine Forest: Serotinous Cones</td>
<td>E11. Is appropriate for middle school</td>
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<tr>
<td></td>
<td></td>
<td>M14. Who Lives Here and Why? Modeling Forest Communities</td>
<td>H15. Forest Communities and Climate Change</td>
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<td>M15. Bark and Soil: Nature’s Insulators</td>
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Unit I.
Introduction to Wildland Fire
Lesson Overview: Students consider their thoughts and feelings about wildland fire before and after a photo presentation. Then, using a reading activity, 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.

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.

<table>
<thead>
<tr>
<th>Standards:</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
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<td>Reading Literature</td>
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<td>1,4,10</td>
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<td>Speaking and Listening</td>
<td>1,2,3,4</td>
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<td>1,2,3,4</td>
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<td>1,2</td>
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<td>Earth's Systems</td>
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<td>ESS2.A</td>
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<td>Human Sustainability</td>
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<td>Strand 2.1</td>
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<td>Strand 2.2</td>
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<td></td>
<td>C</td>
</tr>
<tr>
<td>Strand 2.3</td>
<td></td>
<td></td>
<td></td>
<td>B,E</td>
</tr>
<tr>
<td>Strand 2.4</td>
<td></td>
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<td>A</td>
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</tbody>
</table>
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, and there is no need for students to write on it. 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 the pros (good things) and cons (bad things) about wildland fire.

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

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

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

5. For the reading assignment, 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 one each of these sections to a different group:
   - A Tale of Two Fires
   - 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** (questions about the reading). 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 and have students from each group to share their questions and answers on the handout with the entire class, while students NOT in that group can 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.

Slides and Narrative for 
H01_WildlandFireObservations.pptx

Slide 1

Wildland fire: Observations & Questions

Slide 2

Theme: houses burning/burned

Photo Group #1

Slide 3
Slide 4

Slide 5

Slide 6

Slide 7

Photo Group #2

Theme: low-severity fire

Slide 8
Slide 9

Slide 10

Theme: stand-replacing fire

Photo Group #3

Slide 11

Slide 12

Slide 13
Slide 14

Slide 15

Photo Group #4

Theme: more postfire photos

Slide 16

Slide 17

Slide 18
Slide 19

USDA Forest Service photo provided by Ilana Abrahamson

Slide 20

USDA Forest Service photo provided by Ilana Abrahamson

Slide 21

Photo Group #5

Theme: more postfire photos

Slide 22

USDA Forest Service photo by Nancy E. McMurray.

Slide 23
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.

<table>
<thead>
<tr>
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<td>4. How did most of Yellowstone’s wildlife respond to the fires?</td>
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<td>4. Describe two of the hardships for people that the fire caused.</td>
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<td>3. What are dead trees good for?</td>
</tr>
<tr>
<td>4. How did the numbers of park visitors change during the year of the fires (1988) and afterward?</td>
</tr>
<tr>
<td>5. When this article was written, how were Yellowstone’s managers handling lightning-caused fires?</td>
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<td>2. How could large fires cause flooding? Have the 1988 fires caused this in Yellowstone?</td>
</tr>
<tr>
<td>3. How could large fires cause another “big fire season” in Yellowstone after 1988? Did this happen?</td>
</tr>
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<td>4. What kinds of trees are growing in the areas burned by the 1988 fires?</td>
</tr>
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<td>5. How have people’s attitudes toward wildland fire changed since the 1988 fires?</td>
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</table>
Handout H01-1 answer key

### “A Tale of Two Fires” and “Fire as an Ecological Event”

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</tr>
<tr>
<td>2.</td>
<td>What are the “two fires” that the author discusses?</td>
</tr>
<tr>
<td></td>
<td>1. The ecological event that burned a huge area of Yellowstone in 1988</td>
</tr>
<tr>
<td></td>
<td>2. The human event, including economic and emotional impacts</td>
</tr>
<tr>
<td>3.</td>
<td>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?</td>
</tr>
<tr>
<td></td>
<td>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.</td>
</tr>
<tr>
<td>4.</td>
<td>How did most of Yellowstone’s wildlife respond to the fires?</td>
</tr>
<tr>
<td></td>
<td>Most of them did not flee, but instead they went about their activities as usual. Few were killed by smoke or flames.</td>
</tr>
<tr>
<td>5.</td>
<td>What does the author think is the main reason to accept the presence of fires in Yellowstone?</td>
</tr>
<tr>
<td></td>
<td>The main reason is because fires are intrinsic to Yellowstone’s ecology.</td>
</tr>
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</table>

### “Fire as a Human Experience”

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<table>
<thead>
<tr>
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<tr>
<td>1.</td>
<td>Define each of these terms as it is used in the article: <em>futile, repository, feasible, mission</em>.</td>
</tr>
<tr>
<td>2.</td>
<td>What were the two conflicting messages (“mixed smoke signals”) that park managers sent during the fires?</td>
</tr>
<tr>
<td></td>
<td>1. Persuade the public that the fires were not an ecological disaster.</td>
</tr>
<tr>
<td></td>
<td>2. Spend $120 million to try to put them out.</td>
</tr>
<tr>
<td>3.</td>
<td>What did the firefighting efforts accomplish?</td>
</tr>
<tr>
<td></td>
<td>Firefighting efforts protected buildings in the park, but they did not reduce the area burned very much.</td>
</tr>
<tr>
<td>4.</td>
<td>Describe two of the hardships for people that the fire caused.</td>
</tr>
<tr>
<td></td>
<td>Here are three:</td>
</tr>
<tr>
<td></td>
<td>1. Two people died.</td>
</tr>
<tr>
<td></td>
<td>2. Many people were inconvenienced or worried about the park.</td>
</tr>
<tr>
<td></td>
<td>3. Local businesses suffered financial losses.</td>
</tr>
<tr>
<td>5.</td>
<td>Why does the author say that it is not logical to eliminate fires?</td>
</tr>
<tr>
<td></td>
<td>Eliminating fires would be illogical because they are one of the forces that determine which plants and animals live there.</td>
</tr>
</tbody>
</table>

### “Yellowstone in the Year 2000”

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>1.</td>
<td>Define each of these terms as it is used in the article: <em>proximity, aptness, trifling, gateway</em>.</td>
</tr>
<tr>
<td>2.</td>
<td>The author suggests that the fires were not as “cataclysmic” as other events in Yellowstone. Describe the example she gives.</td>
</tr>
<tr>
<td></td>
<td>Her example is the series of volcanic eruptions 630,000 years ago.</td>
</tr>
<tr>
<td>3.</td>
<td>What are dead trees good for?</td>
</tr>
<tr>
<td></td>
<td>Dead trees can provide shelter and a source of food for insects and birds, which then provide food for other animals.</td>
</tr>
</tbody>
</table>
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: prescription burn, hazardous fuels, conflagration, incompatible.

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: quantifiable, runoff, fire breaks, debris flows.

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

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

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.

<table>
<thead>
<tr>
<th>Standards:</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
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<tr>
<td><strong>Common Core ELA</strong></td>
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<tr>
<td>Writing Standards</td>
<td></td>
<td>1,4</td>
<td></td>
<td>1,4</td>
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<tr>
<td>Speaking and Listening</td>
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<td>1,2,4</td>
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<td>1,2,4</td>
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<td>1,2</td>
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<td>1,2</td>
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<tr>
<td>Science/Technical Subjects</td>
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<td><strong>NGSS</strong></td>
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<tr>
<td>Chemical Reactions</td>
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<td>PS1.A, PS1.B</td>
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<td><strong>EEEGL</strong></td>
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<tr>
<td>Strand 1</td>
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<td></td>
<td>A,C,D,E,F,G</td>
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<tr>
<td>Strand 2.1</td>
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<td></td>
<td></td>
<td>B, C</td>
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</tbody>
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Subjects: Science, Mathematics, Writing, Speaking and Listening, Health and Safety
Duration: Three ~20 minute experiments.
Class Arrangement: Whole class and groups.
Setting: Indoors
New FireWorks vocabulary: chemical change, combustion, Fire Triangle, fuel, heat, heat plume, model, oxygen, physical change
**Teacher Background:** Students explore the conceptual model called the *Fire Triangle*. They use the Fire Triangle to describe how fires are extinguished and how wildland fires spread.

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

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

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

**Materials and preparation:**
- Choose your laboratory arrangement. These experiments can produce flames as long as 20 cm.
- Locate a video online of an airplane/helicopter dropping fire water on fire. (Example: [https://www.youtube.com/watch?v=lx7ISzYU2zE](https://www.youtube.com/watch?v=lx7ISzYU2zE) (accessed February 2016). Try searching with these terms: “helicopter dropping water on fire”).
- The day before doing this activity, ask students to follow safety guidelines about clothing and hair when they get ready for school tomorrow:
  - Tie back loose hair.
  - Avoid wearing open-toed shoes, loose sleeves, and clothes made of meltable fabric such as nylon or polyester.
- Get a box of long fireplace matches and enough boxes of wooden kitchen matches so each lab bench can have a least 40.

---

**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 *FireWorks Safety* poster ([FireWorks_Safety_poster.pptx](#)) in the classroom.
• 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:
  o Spray bottle, filled with water
  o Ruler
  o Metal tray (i.e., cookie sheet)
  o Ashtray
  o Safety goggles
  o Oven mitt
  o Support stand
  o Cross-piece for support stand and clamp, as shown on Handout H02-1
  o Thermocouple (optional for Experiment 2 – only 1 is provided in the trunk)
  o 2 votive candles
  o Box of wooden kitchen matches and 1-2 long fireplace matches
  o Beaker or other container ~20 cm tall
  o Container of baking soda (labeled as baking soda, sodium bicarbonate, or NaHCO₃), approximately ¼ c per student team
  o Container of white vinegar (labeled as vinegar, acetic acid, or CH₃COOH), approximately ½ c per student team
  o Scoop or spoon for measuring 15 to 60 mL (1 Tablespoon to ¼ cup)

**Procedure:**

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

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

3. Explain: If one component of the Fire Triangle is removed, the fire goes out. Ask students to use the Fire Triangle to explain how the method used in the video puts out a fire. Water removes heat from the fire because (1) it is cooler than the burning fuel so it absorbs heat until it reaches the boiling point; (2) as it boils (vaporizes), it absorbs even more heat (the latent heat of vaporization); (3) any water that remains in the liquid phase forms a barrier between fuel and the oxygen needed for combustion. Vaporization is a physical change because the water changes from liquid to gaseous phase but atoms are not recombined to form new substances.
4. Split students into teams, one for each lab bench. Have each team review the FireWorks Safety poster (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, one student will read part A, one will read part B, and one will read part C. Instruct each student to read his/her assigned section. Then each student will describe that particular fire extinguisher to the rest of the group and use the Fire Triangle to explain how that kind of extinguisher works.
Circulate among groups during presentations and listen in. (Refer to the Teacher Key at the end of the reading assignment.)

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

Evaluation:

<table>
<thead>
<tr>
<th></th>
<th>Handouts (25 points each)</th>
<th>Technical Reading (25 points)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Excellent (100%)</td>
<td>Full Credit</td>
</tr>
<tr>
<td></td>
<td>Good (88%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fair (75%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poor (62%)</td>
<td></td>
</tr>
<tr>
<td>Explanations</td>
<td>Clearly explained strong connections between the Fire Triangle and how the fire extinguisher works.</td>
<td>Student made weak connections between fire extinguisher and Fire Triangle.</td>
</tr>
<tr>
<td>Presentation</td>
<td>Comfortable with information. Presentation was well organized. Speech was clear. Took presentation seriously.</td>
<td>Student was mostly comfortable with information but unsure at times. Fairly organized. Clear speech.</td>
</tr>
</tbody>
</table>
Handout H02-1. Experiment 1. Explain where the heat goes.

Name ___________________________

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

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

Before beginning, read all of these directions together.

1. Plan your team roles:
   - **Observer:** Use your hand to detect how far from the burning match you can detect a change in temperature. This is the edge of the heat plume. Always start your observation from at least 30 centimeters out from the burning match and bring it in toward the flame until you detect a temperature change. This is the outer edge of the heat plume. The point is to detect heat, not to determine how much heat you can tolerate!! Check a ruler so you know how big 2 centimeters is. Never bring your hand closer than that to a burning match. Never place your hand directly under a burning match, in case the tip should fall off; instead, place your hand slightly off to the side.
   - **Measurer:** When the observer has detected heat, measure the distance from the flame to the observer’s hand. Use a ruler, but do not place it close to or in the flame. If the observer does not detect heat from the match at the 2-centimeter distance, record the 2-centimeter point as your measurement.
   - **Igniter/Recorder:** Record the Measurer’s data.

2. Figure out how to record your data. Design a data sheet.

3. When everyone is ready, use a separate match to light the downward-pointing match in the alligator clip. Make observations from one side. Record your data. Use the oven mitt to remove the burned match and insert a new one. Repeat this step until you have at least 2 measurements from each side of the flame, from beneath the flame, and from above it.

4. On a sheet of graph paper, make a sketch of your experimental set-up and graph your data. Then smoothly connect the points to show the approximate shape of the heat plume.

5. Underneath your sketch, answer these questions using complete sentences:
   a) When you burn a match in still air, where does most of the heat go? Use the results of your experiment in your explanation.
   b) How would you expect this pattern to change if there is a slight breeze in the air?
Handout H02-1. Answer Key to Experiment 1. Explain where the heat goes.

4.

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

   b) **How would you expect this pattern to change if there is a slight breeze in the air?** The flame and the heat plume are likely to lean in the direction of any air movement. Wind is not likely to make the heat plume lean over very far though, because it will probably extinguish the match first (by blowing the heat away from the fuel).
Handout H02-2. Experiment 2. Explain why matches go out.

Name _________________________________

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

Before beginning, read all of these directions together.

1. Decide what you will observe and how you will measure it. Develop a table for recording your data.

2. Plan your team roles. Write them down below your data table.

3. Show your data table and team roles to the teacher. When you have his/her approval, proceed:

4. Attach a downward-pointing match to one alligator clip and an upward-pointing match to the other.

5. When everyone is ready for his/her role, use a separate match to light either the downward- or upward-pointing match. Record your observations. You may burn as many matches as needed to meet your objective. **Burn one match at a time. Always use the oven mitt to remove burned matches.**

6. Observe how each match burns and goes out.

7. Discuss how the Fire Triangle might explain why the matches go out.

8. Below your data table, use complete sentences to explain why the matches went out. Use the Fire Triangle. You may have several explanations. You may have different explanations for the downward-pointing and upward-pointing matches.

9. These explanations are your hypotheses. Now figure out how to further test your hypotheses. Do you need to repeat the experiment, change it in some way, or record different information? Write down your next step, design a data table, and determine your team roles. Check with the teacher. Once you have his/her approval, proceed.

10. In complete sentences, write your final hypothesis for why downward-pointing matches go out and your final hypothesis for why upward-pointing matches go out. Use the Fire Triangle.

11. Use complete sentences to explain how you could use what you have learned from Experiments 1 and 2 to predict the spread of a wildland fire that starts on a hillside.
Handout H02-2. Answer key to Experiment 2. Explain why matches go out.

A potential data table might look like this:

<table>
<thead>
<tr>
<th>Match is pointing...</th>
<th>Down</th>
<th>Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame length (centimeters).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of burning (seconds)?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

\[
\begin{align*}
[1] \text{vinegar} & \text{ + baking soda} \\
\text{CH}_3\text{COOH} & \text{NaHCO}_3 \\
\rightarrow & \text{carbonic acid} + \text{sodium acetate} \\
& \text{H}_2\text{CO}_3(aq) + \text{NaCH}_3\text{COO}(aq) \\
[2] \text{carbonic acid} & \text{ + water} \\
\text{H}_2\text{CO}_3(aq) & \text{CO}_2 + \text{H}_2\text{O}
\end{align*}
\]

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

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

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

1. Describe your favorite or final method.
2. Record all safety issues that arose and how you addressed them.
3. Record one experimental approach you tried that did not work as well as your favorite/final approach.
4. Consider the molecular weights of CO₂ and O₂ 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 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 match and try again. Might use the oven mitt to hold the match.

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

4. Consider the molecular weights of 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:

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (C)</td>
<td>12 g</td>
</tr>
<tr>
<td>Oxygen (O)</td>
<td>16 g</td>
</tr>
<tr>
<td>A mole of CO₂ weighs</td>
<td>12 g + 2 * 16 g = 44 g</td>
</tr>
</tbody>
</table>
A mole of O\textsubscript{2} weighs \(2 \times 16 \text{ g} = 32 \text{ g}\)

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.

<table>
<thead>
<tr>
<th>A: Air Pressurized Water Fire Extinguishers</th>
</tr>
</thead>
<tbody>
<tr>
<td>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\textsubscript{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. <a href="https://www.osha.gov/SLTC/etools/evacuation/portable_about.html">https://www.osha.gov/SLTC/etools/evacuation/portable_about.html</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B: CO\textsubscript{2} Fire Extinguishers</th>
</tr>
</thead>
<tbody>
<tr>
<td>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\textsubscript{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\textsubscript{2}), a non-flammable gas, under extreme pressure. Because of the high pressure, when you use a CO\textsubscript{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\textsubscript{2} cylinders are red and range in size from five to 100 pounds or heavier. <a href="https://www.osha.gov/SLTC/etools/evacuation/portable_about.html">https://www.osha.gov/SLTC/etools/evacuation/portable_about.html</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C: Dry Chemical Fire Extinguishers</th>
</tr>
</thead>
</table>
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, CO₂ (carbon dioxide), and dry chemical. A dry chemical fire extinguisher (labeled C) should be used to put out fires in wiring, fuse boxes, energized electrical equipment, computers, and other electrical resources. Dry chemical extinguishers put out fires by coating the fuel with a thin layer of fire retardant powder. The powder also works to interrupt the chemical reaction, which makes these extinguishers extremely effective. They contain an extinguishing agent and use a compressed, non-flammable gas as a propellant. [https://www.osha.gov/SLTC/etools/evacuation/portable_about.html](https://www.osha.gov/SLTC/etools/evacuation/portable_about.html)
### A: Air Pressurized Water Fire Extinguishers
Air pressurized water extinguishers put out fires by cooling the surface of the fuel to remove the "heat" element of the Fire Triangle. For more details see step 3 in “Procedure” above. The water may also block the fuel surface from its contact with oxygen.

### B: CO₂ Fire Extinguishers
CO₂ fire extinguishers put out fires by cooling the surface of the fuel to remove the "heat" element of the Fire Triangle. The carbon dioxide also displaces oxygen.

### C: Dry Chemical Fire Extinguishers
Dry chemical extinguishers put out fires by coating the fuel with a thin layer of fire retardant powder, separating the fuel from the oxygen. The powder also works to interrupt the chemical reaction, which makes these extinguishers extremely effective. “Interrupting the chemical reaction” means that less heat is produced, which slows the burning process.
Lesson Overview: Students use an experiment, a PowerPoint presentation, and a technical article to explore how the Fire Triangle relates to the chemical equation (model) for combustion and the carbon cycle.

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

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.

| Subjects: Science, Mathematics, Speaking and Listening, Health and Safety |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Duration: one 90 minute session |
| Group size: Whole class/groups. |
| Setting: Classroom |

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

### Standards:

<table>
<thead>
<tr>
<th>Common Core ELA</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
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<tr>
<td>Writing Standards</td>
<td>1,4</td>
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<td>1,2,4</td>
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<tr>
<td>Science/Technical Subjects</td>
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<tr>
<th>NGSS Chemical Reactions</th>
<th>PS1.A, PS1.B</th>
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<table>
<thead>
<tr>
<th>EEEGL Strand 1</th>
<th>A,C,D,E,F,G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strand 2.1</td>
<td>B, C</td>
</tr>
</tbody>
</table>
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:

![Diagram of the Fire Triangle]

\[
\text{Fuel} + \text{Oxygen} + \text{Heat} \rightarrow \text{Carbon dioxide} + \text{Water} + \text{Heat & Light}
\]

\[
\text{C&H atoms} + \text{O}_2 + \text{a little heat} \rightarrow \text{CO}_2 + 6\text{H}_2\text{O} + \text{Heat & Light}
\]

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

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + \text{a little heat} \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Heat/Light}
\]

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

\[
6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Heat/Light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]

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

For additional information, see William Cottrell’s *The Book of Fire* (2004, available from http://mountain-press.com/) in the FireWorks trunk. This is a well-illustrated, easy-to-read description of the physical science of combustion and wildland fire.
Materials and preparation:
Read the technical reading assignment “Sink or Source: Fire and the Forest Carbon Cycle”. You can either read the entire article, which is online at [www.firescience.gov/projects/briefs/03-1-1-06_FSBrief86.pdf](http://www.firescience.gov/projects/briefs/03-1-1-06_FSBrief86.pdf), or only the excerpts on Handout 03-2.

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

- Display the FireWorks Safety poster ([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.

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

1. **Explain:** Let’s explore the model of the Fire Triangle a little more deeply so we can see how fire fits in with the functioning of life on Planet Earth. Use slides 1-5 in H03_FireTriangle_CarbonCycle_Connection.pptx to teach about the chemistry of combustion. (A copy of the slides with notes is printed at the end of this section.) STOP ON SLIDE 6.

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

2. **Hook:** Look again at the chemical equation for combustion. It says that combustion produces water! But that seems counter-intuitive, since we use water to PUT FIRES OUT. Let’s treat that idea as our hypothesis and then try to verify experimentally that combustion does produce water.

3. **Write on the board:** Hypothesis: Combustion produces water.

4. **Ask and discuss:** Have you ever seen water dripping down the sides of a glass of ice water in the summer, when the weather is hot and perhaps humid? What is happening there? (Water vapor in the air is touching the cold surface of the glass, where it is rapidly cooled from gas to liquid phase. It condenses on the surface of the glass, and eventually droplets come together and run down the sides.)

5. **Explain and discuss:** We can use the fact that water vapor condenses on cold surfaces to test our chemical equation, our model of combustion – to see if combustion actually does
produce water. We’re going to melt the ice in the two post caps using heat from two different sources: a candle flame and an electrical hot plate.

- How is the heat transferred from these two heat sources? (The heat from the candle is transferred mainly by convection of hot gases produced by combustion. The heat from the hot plate is transferred mainly by radiation. There is no chemical change going on, and no hot gases are produced by the heating process.)

- What do you expect to happen? Write expectations on the board below “Hypotheses.” (The ice will melt.)

- Based on your understanding of the combustion equation, do you expect any differences between the two procedures? (Water vapor produced by the burning candle will touch the cold surface of the cap, where it will rapidly cool and condense into droplets. No water vapor is being produced by the hot plate (combustion is not occurring), and its heat is vaporizing any water from the atmosphere that might otherwise condense on the outside of the post-cap, so the cap will remain dry.)

6. Place a post cap (with water frozen) in each ring.

7. Light the candle and turn on the hot plate.

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

9. Discuss: What differences did you observe? What caused the differences? Were any of our hypotheses verified? (The bottom of the post cap over the hot plate will be dry. The bottom of the post cap over flame will be covered with water droplets, and a large drop may collect right above the flame.)

10. Additional discussion points: Smoke contains partly-burned particles of fuel. Water vapor condenses especially well on particle surfaces, so it condenses on the smoke particles. A wildland fire may produce so much water vapor that it eventually condenses in the cold upper atmosphere and creates rain that falls along the edges of the fire.
Procedure – Part 3. The Carbon Cycle (use the rest of the PowerPoint)

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

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

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

Slides and Narrative for
H03_FireTriangle_CarbonCycle_Connection.pptx

Slide 1

The Fire Triangle, Combustion, and the Global Carbon Cycle

Procedure – part 1.

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

Slide 2

We’ll start with the Fire Triangle: oxygen, fuel, and heat. If you break it apart and line up the “ingredients,” you have an arithmetic expression for what makes fires “go” – what makes combustion happen.
Now let’s list the products of combustion. They are carbon dioxide, water, heat, and light.

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

It’s a little tricky to give a specific formula for fuels, because they could be any mixture of millions of compounds. But all fuels contain carbon and hydrogen, and they usually contain oxygen and other kinds of atoms as well. Let’s plug in the formula for glucose, C₆H₁₂O₆, 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.

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

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

Part 1 of the lesson ends here. Part 2 is a lab investigation.
Procedure Part 3.

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

Here’s our model of combustion.

Here’s another chemical equation. It describes the process that living things use to obtain energy – a process called respiration:

What do you notice about these two equations?

**Explain:** Fire isn’t the only process that takes energy from carbohydrates and releases 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. Animals aren’t the only living things that use respiration to get energy. Nearly EVERY living thing does – animals, plants, algae... even the tiniest microorganisms use respiration. But if plants and animals just kept on doing respiration, all the carbohydrates and oxygen would be converted to CO₂. We wouldn’t last very long.

**Ask:** How do carbohydrates and oxygen get replenished—how do we reverse the process?
**Slide 9**

<table>
<thead>
<tr>
<th>Combustion:</th>
<th>$\text{C}<em>6\text{H}</em>{12}\text{O}_6 + 6\text{O}_2 + \text{a little heat/light} \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{a lot of heat/light}$ and many other C-H combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiration:</td>
<td>$\text{C}<em>6\text{H}</em>{12}\text{O}_6 + 6\text{O}_2 + \text{a little heat/light} \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{a lot of heat/light}$</td>
</tr>
<tr>
<td>Photosynthesis:</td>
<td>$6\text{CO}_2 + 6\text{H}_2\text{O} + \text{sunlight} \rightarrow \text{C}<em>6\text{H}</em>{12}\text{O}_6 + 6\text{O}_2$</td>
</tr>
</tbody>
</table>

**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 called photosynthesis. And the chemical equation for photosynthesis is the mirror image of the equation for combustion of glucose and respiration.

Animals ensure there is abundant $\text{CO}_2$ in the atmosphere, which means plants can grow well, which means there’s plenty of food for animals (including us!) to eat. It also means fuels are abundant, which means there’s plenty of fuel for fires to burn.

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

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

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

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

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

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

Terminology:
When carbon accumulates and is being stored for an indefinite period, it is considered to be a carbon sink. The process by which carbon sinks remove carbon dioxide (CO₂) from the atmosphere is known as carbon sequestration. When carbon is being released to the atmosphere, it is called a carbon source.
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.

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

3. Read the article on Handout H03-2 (or the full article). Then write 1-2 paragraphs that answer these questions. Use specific evidence and quotes from the article to support your answers.
   a) Based upon the information in the article, how does stand-replacing fire affect whether forests are a source or sink for carbon?
   b) Does a forest change over time from source to sink, or from sink to source?
   c) What is the most important variable that makes an ecosystem gain or lose carbon after fire?
Forests have a life cycle: trees die after disturbance, such as a stand-replacing fire, setting the stage for new growth to begin. If a forest fully replaces itself, there will be no net carbon change over that life cycle. The fire consumes only about 10 to 20 percent of the carbon and immediately emits it back into the atmosphere. It kills trees but doesn’t consume them. So, new trees grow (storing carbon), old trees decompose (emitting carbon), and the organic layer of the soil accumulates (storing carbon). This balance between simultaneous production and decomposition determines whether the forest is a net source or sink. The net ecosystem carbon balance, also known as net ecosystem production (NEP), specifically quantifies the annual net change in carbon stored in the ecosystem. And that’s the “magic number,” so to speak, needed to gauge whether a forest is a carbon source (negative NEP) or sink (positive NEP) at any given point in time. NEP is often quantified on an annual basis and for a single forest stand. But to determine whether an entire landscape (which is composed of many stands of different ages) is a carbon source or sink over a longer time frame, annual NEP must be assessed over both space and time.

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

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

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

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

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

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

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

3. Read the article on Handout H03-2 (or the full article online). Then write 1-2 paragraphs that answer these questions. Use specific evidence and quotes from the article to support your answers.
   a) Based upon the information in the article, how does stand-replacing fire affect whether forests are a source or sink for carbon?
   b) Does a forest change over time from source to sink, or from sink to source?
   c) What is the most important variable that makes an ecosystem gain or lose carbon after fire?

Answer: Forests are usually a carbon sink. Stand-replacing fires convert forests into a carbon source for about 30 to 40 years, and then – if trees regenerate successfully - the forest gradually changes back into a carbon sink after about 80 to 100 years. During a severe wildfire, a lot of carbon is released, and then even more carbon is released through decomposition that follows the fire. That is why, during this time, the forest is a carbon source. As the forest grows back, it manufactures and stores a lot of carbohydrates. Eventually, the pace of storing new carbohydrates surpasses the pace of decomposition. That means the forest has become a carbon sink again.
The most important variable that determines whether the ecosystem gains or loses carbon after fire is tree regeneration. If trees grow back successfully after a stand-replacing fire, forests usually become carbon sinks again in about 80 to 100 years. If trees do not regenerate and the forest becomes a grassland or shrubland, it may remain a carbon sink for many centuries. It may not ever store as much carbon as before the fire.
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.

Standards:

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<td>Indoors</td>
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<td>FireWorks vocabulary:</td>
<td>heat transfer, radiation, convection, conduction</td>
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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.

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

Here we give 1 possible example of each demonstration:

- **Radiation**: Students can demonstrate radiation by using balls of yarn, pieces of candy, or other small objects to represent heat. One student could represent the heat source (sun, fire, or other), and other students could represent molecules in air and in solid objects, including fuels. The heat source would throw the objects, and only the molecules they touch are heated.

- **Conduction**: Students can demonstrate conduction by standing side by side in a long line, shoulder to shoulder. The students would represent atoms within a solid object, like a metal. Heat would be represented by a bag of candy or other small objects. The students would pass the bag from one student to the next, each one taking a piece from the bag (i.e., absorbing some heat) and passing the bag on to the next student.... all the way to the end of the line or until the bag is empty.

- **Convection**: Students can demonstrate convection by lining up shoulder-to-shoulder. They should imagine that their line is vertical rather than horizontal. One or two students represent a parcel ("bubble") of hot air; they carry a bag of candy or other small objects. They walk from one end of the line (the imaginary bottom of a column of air) toward the other end (the imaginary top). Their bubble of hot gases is expanding from the bottom toward the top, transferring heat (small objects) to the surrounding air and thus cooling as they go. If they empty the bag of objects, they stop. This means that their air bubble has roughly the same amount of energy per molecule (is the same temperature) as the molecules in the air around them.
Evaluation: The class will vote on the model that most clearly represents each method of heat transfer. This is a credit/no credit activity. Evaluate students on their contributions during the planning process, engagement in the presentations, and student feedback.
Now that students understand the basic principles of combustion as described by the Fire Triangle, they will apply that understanding to how fires behave in wildlands. Fire professionals use a second triangle model, the Fire Environment Triangle (also known as the Fire Behavior Triangle), to describe the complexities of wildland fire behavior. Each activity in this section addresses some features of the Fire Environment Triangle.
Lesson Overview: Students explore the properties of wildland fuels through reading, a fuel scavenger hunt, and by designing and conducting experiments with fuels.

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

Objectives:

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

Standards:

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<td>Strand 1</td>
<td>A,C,D,E,F,G</td>
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</tbody>
</table>

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

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

Student needs:
- Handout H05-1: Fuel Properties: Pre-Lab Reading and Scavenger Hunt, one for each student. Students should complete this handout before doing the lab.
- Handout H05-2: Fuel properties, one for each student, to be completed in lab.
Set up your lab. It should have heat-resistant work surfaces and good ventilation or a hood. You also need:

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

Set up each student lab bench with:

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

Procedure:

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

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

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

4. Have students get into groups and complete the experiments on Handout 05-2: Fuel Properties.
Assessment: Take students to an outdoor setting where they can collect fuels and safely build small campfires. Have them work in pairs to apply their knowledge of fuel properties. Each pair needs:

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

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

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

<table>
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<th>Full Credit</th>
<th>Partial Credit</th>
<th>No Credit</th>
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<tr>
<td></td>
<td>Students’ fire ignited easily and remained burning until the majority of the fuel was consumed.</td>
<td>Students’ fire was difficult to ignite but eventually ignited and consumed some fuel.</td>
<td>Students’ fire could not be ignited. No fuel was consumed.</td>
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</table>
Handout H05-1. Fuel Properties: Pre-Lab Reading and Scavenger Hunt

Name: _______________________

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

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

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

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

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

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

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

June 8, 2018		H05
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:

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

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

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

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

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

Scavenger Hunt assignment: Find a landscape with heavy fuel loading and find a landscape with light fuel loading. Sketch and label them in the boxes below.
4. Spatial Arrangement means how fuels are arranged in space, both horizontally and vertically. Fuel continuity describes the arrangement of fuels.

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

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

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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.

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c. Fuel particles can be so \textbf{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.)

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

\begin{center}
\includegraphics[width=0.7\textwidth]{tightly_packed_fuel_box}
\end{center}

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

\begin{center}
\includegraphics[width=0.7\textwidth]{loosely_packed_fuel_box}
\end{center}

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

\textbf{Sources}:
Introduction to Wildland Fire Behavior, S-190 Wildfire Coordination Group’s (NWCG), Wildland and Prescribed Fire Curriculum.

http://learningcenter.firewise.org/Firefighter-Safety/1-5.php
Handout H05-2: Fuel Properties

Name________________________

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

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

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

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

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

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

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

**Experiment 4 – spatial arrangement.** Manipulate a sheet of newspaper so one pie tin contains loosely packed newspaper and one pie tin contains tightly packed newspaper.
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<th>Treatments</th>
<th>Preburn weight (g)</th>
<th>Postburn weight (g)</th>
<th>Amount combusted (g)</th>
<th>Percent combusted (%)</th>
<th>Burn time (sec)</th>
<th>flame height (cm)</th>
<th>Describe how you manipulated the fuels</th>
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<td>4. Spatial</td>
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Lesson Overview: Students learn the steps of combustion and pyrolysis through videos, class discussions, and an optional activity.

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

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

Standards:

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Teacher Background: In order for wildland fuels to burn, several things have to occur:
1. Temperature of moisture must rise to the boiling point (~100° C (212° F))
2. Moisture must be changed from liquid phase to gas phase (stays at 100° C (212° F))
3. Temperature of fuels must rise to the point where carbohydrates pyrolyze—that is, break down into small molecules (200°-300° C (400°-600° F)) in the gas phase
4. The small, gaseous carbohydrate molecules must combine with oxygen. This is combustion!

See Figure H06-1 on Handout H06-1 for a diagram of the process – the Stair Step Guide to Combustion. This guide is referred to throughout the activity.

This activity examines these 4 steps in the processes of combustion, in particular combustion of wood. Watch the video in Step 3 below for further, detailed background.
The assessment for this activity can be done either through watching a video or through setting up a laboratory investigation of pyrolysis in a burning candle.

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

**Procedure:**
1. Ask: When you light something on fire, what exactly is burning? What is making the flames?
2. Show this 1.5-minute video: [https://www.youtube.com/watch?v=Ky5AvnXGqC0](https://www.youtube.com/watch?v=Ky5AvnXGqC0). Ask:
   a. Just before you see the first flame coming off the wood, what do you see occurring?
   b. Why does the lighter fail to ignite the wood the first three times it comes near?
   c. Once the lighter does ignite the wood, what is actually creating the flames?
   Explain: We’ll learn about some subtle aspects of combustion in this activity.
3. Give a copy of **Handout H06-1: Combustion and Pyrolysis** to each student. Explain: Look at the figure at the top of the handout, **Figure H06-1: Stair Step Guide to Combustion**. Let’s look at the video again ([https://www.youtube.com/watch?v=Ky5AvnXGqC0](https://www.youtube.com/watch?v=Ky5AvnXGqC0)) and use the stair step guide to explain what is happening.
   a. Just before you see the first flame coming off the wood, what do you see occurring? Water is being driven off. We’re seeing some of it (condensed into tiny droplets) as it leaves the hot wood. We’re seeing Steps 1-2 in the stair step guide. Explain: There may be tars and other volatile substances in the vapors too.
   b. Why does the lighter fail to ignite the wood the first three times it comes near? **Two things may be going on:** First, the water may still be heated and vaporized from the wood, absorbing the heat from the lighter (steps 1-2 in the stair step guide). Second, the heat from the lighter has not yet gotten the **cellulose** (fuel) hot enough to break down – that is, to **pyrolyze** (step 3) – into particles small enough to combine with oxygen molecules and burn (step 4). As we learned in Activity H03, cellulose is just a very, very long chain of glucose molecules strung together. It is the formula for glucose (C₆H₁₂O₆) that we used in the chemical equation (model) for combustion.
   c. Once the lighter does ignite the wood, what is actually burning? **Carbohydrates that have been pyrolyzed** – that is, broken down into flammable gases (pyrolysates).
4. Explain: Now we will watch a 13-minute video that explains the pyrolysis and combustion of wood in detail. We’ll pause the video several times so you can answer the questions on **Handout H06-1**. Use the stair step guide as you answer the questions.
5. Start the video: [https://www.youtube.com/watch?v=15ah91txQAE](https://www.youtube.com/watch?v=15ah91txQAE)

June 8, 2018

H06
• **Pause at 3:35.** Have students answer Question 1 - “What is the white stuff in the cylinder?” - or discuss the answer as a class. For an explanation, see the answer key. Press play.

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

• **Pause at 6:10.** ... Question 3 – “What is burning to create the flames?” ...

• **Pause at 9:05.** ... Question 4 – “What has left the wood?” ...

• **Pause at 9:26.** ... Question 5 – “What is left after all of the cellulose has been pyrolyzed?” ...

• **Pause at 11:05.** ... Question 6 – “Why does wood burn with a flame, while charcoal smolders without a flame?” ...

• **Pause at 12:00.** ... Question 7 – “What is ash, why doesn’t it burn, and why is it good for the soil?” ...

• Press play and watch until the end.

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

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

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

**Evaluation:**

<table>
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<tr>
<th>Fully successful</th>
<th>Moderately successful</th>
<th>Not successful</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Student explained that pyrolysates from the first ignition remained and were ignited before the wick ignited.</td>
<td>-Student’s explanation referred to either pyrolysis or the stair step guide, but not both – or interpreted one of them incorrectly.</td>
<td>-Student did not refer to either pyrolysis or the stair step guide – or interpreted them incorrectly.</td>
</tr>
</tbody>
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<tbody>
<tr>
<td>June 8, 2018</td>
<td>H06</td>
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</tr>
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</table>
1. What is the white stuff in the cylinder? Use the stair step guide to answer.

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

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

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

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

7. What is ash, why doesn’t it burn, and why is it good for the soil?
Answer Key: H06-1: Combustion and Pyrolysis

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

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

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

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

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

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

7. What is ash, why doesn’t it burn, and why is it good for the soil? Ash consists of minerals, which do not burn. Some of these are essential nutrients for plants; they may enrich the soil for a few years after wildland fires.
Lesson Overview: This culminating lesson on the physical science of wildland fire challenges students to expand their understanding and link their knowledge of heat transfer processes, fuel properties, pyrolysis, and ignition through a series of thought-provoking videos and a presentation about current research — in particular, research currently underway at the Missoula Fire Sciences Laboratory on heat transfer and ignition.

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

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

<table>
<thead>
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<th>10th</th>
<th>11th</th>
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<td>Writing Standards</td>
<td>1,4,7,10</td>
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<td>EEEGL</td>
<td>Strand 1</td>
<td>A,B,C,D,E,F,G</td>
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</tbody>
</table>

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

To better understand how wildland fires spread, current research is focusing on the physics of fire spread. Recent observations on wildland fires and on highly controlled laboratory fires, including many experiments conducted by Dr. Sara McAllister, 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 fire burns in live fuels.

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

Materials and Preparation:
- Download H07_HeatTransferAndFuelProperties.pptx. Check that the video segments work.
- Make 1 copy of Handout H07-1 per student.

Procedure:
1. Begin the PowerPoint presentation. Show only slides 1 and 2.
   - Slide 1 reviews heat transfer processes (conduction, radiation, and convection).
   - Slide 2 reviews the fuel characteristics of fine and coarse fuels.
2. Pass out Handout H07-1. Have students answer question 1.
3. Return to the PowerPoint. View slide 3, a video recording of a crown fire spreading through a forest. Ask students to watch for anything that surprises them. Pause the PowerPoint. Have students answer question 2 on the handout.
4. Very observant students may have been surprised to see that the large, horizontal log in the foreground ignites before the fine surface fuels near it. If no one mentioned this, point it out. Return to the PowerPoint, slide 4, in which you view the same video at half speed. Pause and discuss preconceptions (that fine fuels always drive fire spread) and what the video shows (ignition of a large log ahead of fine fuels). Is anyone surprised? Even if the students weren’t, tell them that scientists studying fire behavior were puzzled with this observation!
5. Continue the PowerPoint presentation to learn about the complicated relationship between heat transfer processes and fuel particle size and shape.

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

Evaluation: Refer to the Handout H07-1 answer key.
**Slides and Narrative for H07_HeatTransferAndFuelProperties.pptx**

**Slide 1**

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

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

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

**Slide 2**

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

**Fine Fuels**
- Have a lot of surface area in relation to their volume, so the whole particle heats quickly, and they generally ignite easily. Examples: grass, dead leaves, pine needles, and dead twigs.

**Coarse Fuels**
- Have a small surface area in relation to their volume, so heat penetrates slowly, and they are harder to ignite. Once on fire, however, they can burn for a long time. Examples: logs, stumps, thick branches.

June 8, 2018  H07
Show this video, which is played at actual speed. Pause the presentations so students can answer Question 2 on the handout.

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

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

Scientists at the Missoula Fire Sciences Laboratory in Missoula, MT, tested fuel particle heating and ignition of fine and coarse fuels using radiant heat. (FYI: 37 kW/m² Irradiance.)

- Scientists put fine and coarse fuel particles at the same distance away from a radiant heater and timed how long it took to ignite the fuels.
- They found that the coarse wood block began to 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.
Here is another demonstration of radiant heat, showing that coarse fuel may ignite more quickly than fine fuel. Watch the two videos (both images are videos).

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

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

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

The sides of the fuel particles facing the heat source are heating up (heat is being transferred from the heat source to the fuel particles), and then the heat is conducted through the particle.
Because the coarse particle is so big, only a little heat makes it all the way through the particle. This means that there is not much heat on the backside of the coarse particle that can be transferred to the cooler air on the side away from the heat source.

Because the fine particle is so small, heat is easily conducted through it. This means that a lot of heat can be transferred from the back side of the fine fuel particle to the cooler air on the side away from the heat source.

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

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

Current state of knowledge, based on Sara McAllister’s and Jack Cohen’s research at Missoula Fire Lab.

The relationship between heat transfer processes (radiation vs. convection) and fuel size and shape matters. (Conduction is not directly addressed in these experiments.)

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

- They put fine and coarse fuel particles at the same distance above a hot air torch (works like a very powerful hair dryer) and timed how long it took to ignite the fuels.
- The fine fuels ignited at 1 second, while the coarse stick ignited in 17 seconds.
- This result is the opposite of what they found with radiant heat.
Convective Ignition
- Fine fuel: 600°C air, 1 second to ignite
- Coarse fuel: 600°C air, 17 seconds to ignite

Radiant Ignition
- Fine fuel: Does not ignite, even after 5 minutes of radiant heating
- Coarse fuel: Ignites after 35 seconds of radiant heating

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

Why does this matter?
- Fires spread primarily through fine fuels (litter, small sticks, leaves) rather than through coarse fuels (logs, tree trunks).
- This means that convective heating is more important than radiant heating in wildland fire spread.
- Understanding the relationship between heat transfer and particle size is essential to improve the fire spread models that fire managers use to predict the rate of spread of wildland fires.
- Current models assume fires spread mainly through radiant heating. New fire spread models will be improved because their calculations will be based on convective heat transfer.

Why does it matter how heat is transferred through different types of fuels?
- Photos and videos of laboratory experiments courtesy of Dr. Sara McAllister, Missoula Fire Sciences Laboratory, USDA Forest Service Rocky Mountain Research Station.
Handout H07-1: Heat transfer and fuel properties
Name ___________________________

View slides 1-2 of the presentation. Then answer this question.
1. This image shows a crown fire burning through a forest. The fire is moving from the left to the right. Predict which fuels will ignite first as the fire passes into the center of the image.

View slide 3 of the presentation. Then answer this question.
2. Was your prediction correct? Which fuels ignited first? If your prediction was not correct, are you surprised by what you observed?

After the presentation, answer these questions.
3. Describe and draw how you would build a campfire to ignite readily and then keep burning. Label your fine fuels and coarse fuels. Show where you would ignite the campfire.
4. Where is the heat from the match going? What kind of heat is igniting the fuels and what fuels do you expect to ignite first/last?

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

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

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

8. What kind of heat usually causes fine fuels to ignite very quickly and usually be at the forefront of fire spread?
Handout H07-1 KEY: Heat transfer and fuel properties
Name _________________________________

View slides 1-2 of the presentation. Then answer this question.
1. This image shows a crown fire burning through a forest. The fire is moving from the left to the right. Predict which fuels will ignite first as the fire passes into the center of the image. Any answer is okay. This question is to get students thinking.

View slide 3 of the presentation. Then answer this question.
2. Was your prediction correct? Which fuels ignited first? If your prediction was not correct, are you surprised by what you observed? Student answers should reflect their answer to question 1.

After the presentation, answer these questions.
3. Describe and draw how you would build a campfire to ignite readily and then keep burning. Label your fine fuels and coarse fuels. Show where you would ignite the campfire. I would put the fine fuels on the bottom and coarse fuels on top. I would ignite the fine fuels from the bottom.
4. Where is the heat from the match going? What kind of heat is igniting the fuels and what fuels ignite first/last?

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

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

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

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

8. What kind of heat usually causes fine fuels to ignite very quickly and usually be at the forefront of fire spread?
   Convective heat.
**Note: This lesson has goals and objectives similar to those of Activity 8B, The Landscape Matchstick Model**

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

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

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

**Standards:**

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<tr>
<th>Standards:</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
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<tr>
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<td>A,B,C,D,E,F,G</td>
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**Teacher Background:** In this activity, students build physical models of fuel arrays in which standing fuels are represented by individual matches. Because the model provides a graphic demonstration of the way running crown fires behave in a forest, we call it the “matchstick forest” model. However, it could represent any array of standing fuels, including shrubs with highly flammable crowns and even a dense stand of grasses.

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

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

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

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

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

**Materials and preparation:**
Do this activity in a lab or outdoors. Note that even the air currents created by the lab’s ventilation system will affect the experimental results.

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

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

Procedure:
1. Do a safety checkup with students using the FireWorks Safety poster
   (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 or project them.
   Explain: We’ve been studying the chemistry of combustion. We used the model of the Fire
   Triangle, which can be applied to any fire – from a campfire to the fire in an internal
   combustion engine. Now we’ll narrow our focus to combustion in wildlands, and we’ll use a
   slightly different model, the Fire Environment Triangle (also known as the Fire Behavior
   Triangle). This model reminds fire managers and firefighters of the three things in the
   environment that control how wildland fires behave: fuel, weather, and topography.
3. Explain: You will design and carry out controlled experiments to learn about the
   relationships between fire spread and some of the variables in the Fire Environment
   Triangle. “Controlled” means that you will change just 1 thing about the procedure each

\(^{1}\) The trunk is supplied with 4 sets of equipment.

June 8, 2018 H08a
time you repeat it (that is, in each trial), “controlling” everything else so you can find out how that one thing, the experimental variable, affects your results.

4. Ask students for some specific aspects of the Fire Environment Triangle that affect the behavior of wildland fires. Examples:
   - **Topography**: slope steepness, aspect, position in relation to heat source, number and location of ignition points, potential for heat to escape (open slope vs. within canyon)
   - **Fuels**: arrangement (both vertical and horizontal), moisture, amount, height, density, patchiness (vs. uniform spatial arrangement)
   - **Weather**: wind direction and strength, relative humidity, temperature, precipitation amount and duration

5. Give each student a copy of **Handout H08a-1**.

**PART 1- Discuss an example using a thought experiment.**

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

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

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

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

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

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

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Burning time (sec)</th>
<th>Max flame height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49 matches</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37 matches</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 matches</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 matches</td>
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### Example 2 - Experimental variable: Slope

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Matches burned (%)</th>
<th>Max flame height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very steep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately steep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat</td>
<td></td>
<td></td>
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### Example 3 - Experimental variable: Ladder fuels

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Matches burned (%)</th>
<th>Burning time (sec)</th>
</tr>
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<tbody>
<tr>
<td>No Ladder fuels (all full matches)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some matches cut shorter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some matches are cut to different lengths</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Example 4 - Experimental variable: Ignition location

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Matches burned (%)</th>
<th>Burning time (sec)</th>
<th>Max flame height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignite top row</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ignite outside column (start with top match, work down)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ignite middle column (start with top match, work down)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ignite bottom row</td>
<td></td>
<td></td>
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</tbody>
</table>

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

12. Monitor for safety while they conduct their experiments.
13. As the groups complete their experiments, have them prepare to project their results or have them copy their results to the board (Step H on the handout).

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

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

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

<table>
<thead>
<tr>
<th>Question(s)</th>
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<th>Moderately successful</th>
<th>Unsuccessful</th>
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<tr>
<td>1-2</td>
<td>Hypothesis addresses question.</td>
<td>Hypothesis addresses question.</td>
<td>Hypothesis does not address question.</td>
</tr>
<tr>
<td>3</td>
<td>Refers to experimental results that demonstrate or contradict hypothesis.</td>
<td>Does not interpret or use experimental results appropriately.</td>
<td>Does not address hypothesis or use experimental results appropriately.</td>
</tr>
<tr>
<td>4</td>
<td>Answer is clear and refers to Question 1.</td>
<td>Answer refers to Question 1.</td>
<td>Answer is unclear and does not refer to Question 1.</td>
</tr>
<tr>
<td>5</td>
<td>Student listed 2 or more questions.</td>
<td>Student listed 1 question.</td>
<td>Student listed no questions.</td>
</tr>
<tr>
<td>6</td>
<td>Student made at least 1 clear recommendation to each of the 3 groups.</td>
<td>Student made at least 1 suggestion to 1-2 groups, or suggestions were vague, unclear.</td>
<td>Student either made no suggestions or made suggestion to just 1 group.</td>
</tr>
<tr>
<td>7</td>
<td>Student answered all 3 questions with specifics.</td>
<td>Student answered 1-2 questions or answers were vague, unclear.</td>
<td>Student answered 1 question or none.</td>
</tr>
</tbody>
</table>
OUR INSTRUCTIONS:
Develop your experimental plan (this page).
Get the teacher’s approval to proceed (bottom of this page).
Carry out the experiment.
Share your results (next page).
Write and submit your report (next page).

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

B. Our hypothesis:

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

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

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

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

G. Our table for recording record data from each trial burn.
TEACHER’S APPROVAL: Teacher’s initials approving our experimental design: ______________

SHARING EXPERIMENTAL RESULTS

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

I. Describe your experiment and results to the class. Indicate if there are any changes that you would make if you were to redo 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 experimental variable

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

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

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

C. Our experimental variable, the one thing that we will change from one trial to the next.
   Stand density (number of matchsticks on the board).

D. Our treatments, the way we change our experimental variable from one trial to the next:
   - Treatment 1 (high density): 49 matches
   - Treatment 2 (medium density): 37 matches
   - Treatment 3 (low density): 25 matches
   - Treatment 4 (least dense): 12 matches

E. Our controlled conditions, things that we will not change from one trial to the next:
   - Ignition point, slope, moisture, matchstick height, wind, etc.

F. The things (variables) we will observe and measure – which become our experimental results:
   - Maximum flame height, start time, stop time, burn time, and number of match tips burnt.

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

<table>
<thead>
<tr>
<th></th>
<th>Least dense (12 matches)</th>
<th>Low density (25 matches)</th>
<th>Medium density (37 matches)</th>
<th>High density (49 matches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. flame Height (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start Time</td>
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<tr>
<td>End Time</td>
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<tr>
<td>Burn Time (secs)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Number of Matches burned</td>
<td></td>
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</tbody>
</table>
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 “forest” with only a few matches burned more slowly, had shorter flames, and burned fewer matches than the “forest” with lots more matches.

4. Did your results help answer your question about fire? If so, how?
   
   Yes, my results showed three ways in which stand density affects fire behavior.

5. Did any new experimental questions emerge during your experiment? If so, what are they?
   
   What if there’s wind? What if the trees are different heights? How do real trees differ from matches?

6. Based on your results, what practices would you recommend to (a) firefighters, (b) people with homes in forests, and (c) wildland managers?

   (a) Firefighters should use extreme caution when fires are burning in dense forests. They may not be able to work safely on these fires when it is very dry or hot, or if the wind is strong. (In fact, firefighters are cautioned against “direct attack” when flame lengths are high. That is, they cannot work right at the edge of the fire, especially not at the leading edge. Instead, they might use other techniques such as setting backfires or using water drops from aircraft. (National Wildfire Coordinating Group. 2014. Incident response pocket guide. PMS 461. National Wildfire Coordinating Group. 112 p.))

   (b) People with homes in the forest (especially dense forest) should clear an area around their homes and perhaps thin the forest nearby. (It is recommended that home owners reduce fuels for at least 200 feet from their house (National Fire Protection Association, Firewise Communities. 2016. The basics of defensible space and the “home ignition zone. National Fire Protection Association. Available: http://firewise.org/wildfire-preparedness/be-firewise/home-and-landscape/defensible-space.aspx?so=0)).

   (c) Wildland managers could consider thinning forests or creating wide fuel breaks to reduce flame heights and slow the spread of fire in dense forests that are near homes or other valuable resources.
7. (a) What are some limitations of the matchstick forest model? (b) What “real-world” influences on fire spread could not be tested with this model? (c) Could you revise the model or develop a different model to test them?

(a) The model doesn’t include surface fuels. The tree “crowns” are much easier to ignite than actual tree crowns. Trees are distributed uniformly in the model, unlike real forests. The topography is completely uniform – no gullies or ridges. Trees tilt with the slope. The board is very small in size, whereas real forests can extend for many miles...

(b) Real wildland fuels were not tested. Uneven topography could not be tested. Large-scale fire spread was not tested...

(c) I would revised the model to use a larger board, perhaps add uneven terrain. I would use real wildland fuels. I would add surface fuels...
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 newspaper article describing how the components of the Fire Environment Triangle influenced fire spread.

Standards:

<table>
<thead>
<tr>
<th>Standards:</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
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<tr>
<td><strong>EEGEL</strong></td>
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<td>A,B,C,D,E,F,G</td>
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</tbody>
</table>

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

This activity includes 3-4 steps:
1. Students complete 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 case study of the fire that incorporates their timeline and explains how various aspects of the Fire Environment Triangle influenced fire spread.

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

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

- The day before the activity, remind students to follow safety guidelines about clothing and hair when they get ready for school tomorrow.
- Display these posters: FireWorks Safety, Fire Triangle, and Fire Environment Triangle
- Set up the work space with this equipment:
  - Fire extinguisher, fully charged
  - Empty metal trash can without a plastic liner
• Set up a lab bench or other safe space for each student team\(^1\), using the following equipment:
  o Materials provided in trunk:
    o 1 metal tray (i.e., cookie sheet)
    o 1 ashtray
    o 1 ruler
    o 1 spray bottle filled with water
  o Materials not provided in trunk:
    o 1 box of matches
    o Timing device
    o Materials to create landscape (e.g., clay (recipe below), cardboard, toothpicks, aluminum foil)
    o Camera/smart phones for taking photos and video
• Have these materials available for teams to select from:
  o Small fan with at least two speeds
  o 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:
  o Ingredients for Salt-based Clay: 1 cup salt (280 grams), 1 cup flour (140 grams), \(\frac{1}{2}\) cup warm water (112.50 milliliters)
  o Combine the dry ingredients in a large mixing bowl.
  o Add the water, mixed with food coloring if you wish.
  o 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.
  o Store in a plastic bag until lab time.
• Print one handout for each student:
  o **Handout H08B-1**: Fire Behavior in Wildland Fuels – **only** if you choose to do optional Step 3 below
  o **Handout H08B-2**: Landscape Matchstick Model
  o **Handout H08B-3**: Fire Behavior Case Study

**Procedures:**

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

2. Refer to the posters for the Fire Triangle and the Fire Environment Triangle - or draw or project them. Explain: We've been studying the chemistry of combustion. We used the model of the Fire Triangle, which can be applied to any fire – from a campfire to the fire in an internal combustion engine. Now we'll narrow our focus to combustion in wildlands, and we’ll use a different model, the Fire Environment Triangle (AKA Fire Behavior Triangle). This model reminds fire managers and firefighters of the three things that control how wildland fires behave: fuel, weather, and topography.

\(^1\) The trunk is supplied with 4 sets of equipment.
3. Distribute **Handout H08B-1: Fire Behavior In Wildland Fuels**. This handout gets students thinking about the factors that influence fire behavior and lets you gauge their prior knowledge. To complete the handout, you could take students to an outdoor setting, find a window with a view of a wild landscape, or project an image of a wild landscape.

4. Refer again to the Fire Environment Triangle. Explain: the Fire Environment Triangle is an extension of the Fire Triangle, but it is very practical: It reminds fire managers and firefighters of the three things in the wildland fire environment that affect how wildland fires behave: fuel, weather, and topography.

5. Ask students to name some specific aspects of the Fire Environment Triangle that affect fire behavior. Examples:
   - **Topography**: slope steepness, aspect, direction of fire spread (fire spreading from top of slope vs. bottom of slope), number and location of ignition points
   - **Fuels**: arrangement (both vertical and horizontal), moisture, amount and height
   - **Weather**: wind direction and strength, relative humidity, temperature, precipitation amount and duration

6. Explain: Given a variety of materials, you will design a model landscape to observe and test how various aspects of the Fire Environment Triangle affect fire spread.

7. Distribute **Handout H08B-2: Landscape Matchstick Model** and instruct students to follow steps 1-4. Remind them that they need to have you check the model when it is completed and you will tell them when to ignite it.

8. When models are complete, gather students around each model. Have the student group describe their design, the components of the Fire Environment Triangle they are testing, and how they expect the fire to spread (e.g., rates of spread, flame lengths, burn uniformity).

9. Make sure the team is ready to take notes and to record their fire with photos and video. Then have them ignite—one model at a time.

10. Note: If fires fail to spread, students can modify variables such as ignition points or fuel arrangement and ignite their model again. All ignitions and associated fire spread should be described in their timeline and case study.

11. After each model is burned, have students compare predictions to what actually occurred.

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

<table>
<thead>
<tr>
<th></th>
<th>Excellent/Credit</th>
<th>Good/No Credit</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image:</td>
<td>Student included images</td>
<td>Student did not include images.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topography</td>
<td>Student describes all features of their landscape in detail and how those features impacted/didn't impact fire spread.</td>
<td>Student describes most features in landscape and how those features impacted/didn't impact fire spread.</td>
<td>Student described some features in landscape and how those features impacted/didn't impact fire spread.</td>
<td>Student failed to describe any features in landscape and/or did not explain how the features impacted/didn't impact fire spread.</td>
</tr>
<tr>
<td>Weather</td>
<td>Student describes in detail how weather impacted fire spread.</td>
<td>Student provides basic explanation for how weather impacted/didn't impact fire spread.</td>
<td>Student’s description of how weather impacted/didn’t impact fire spread was partially inaccurate or incomplete.</td>
<td>Student’s description of how weather impacted/didn’t impact fire spread was incorrect or not present.</td>
</tr>
<tr>
<td>Fuel</td>
<td>Student describes the fuels in detail and how they impacted/didn’t impact fire spread.</td>
<td>Student basic description of fuels and how they impacted/didn’t impact fire spread.</td>
<td>Student’s description of fuels was partially inaccurate or incomplete.</td>
<td>Student’s description of fuels was incorrect or not present.</td>
</tr>
</tbody>
</table>
Handout H08B-1: Fire Behavior In Wildland Fuels

Name: _________________________________

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

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

Landscape A:

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

Landscape B:
Handout H08B-2: Landscape Matchstick Model

Name: ________________________________

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

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

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

2. Sketch your landscape to show how your selected variables will be incorporated. On your sketch, label and explain how each variable will be changed during the burn so you can see its effect on fire behavior.

3. Make a list of materials you need to create your landscape, such as: clay, tinfoil, cups, rocks, toothpicks, pine needles, matches etc. Obtain the materials from your teacher, around the school, or from outdoors.

4. Use your sketch to create your landscape. Be creative! Make up names for the fire, town, communities, streets, valleys, ridges, mountains, etc.

5. When you are satisfied with your model landscape, **STOP!** You need to show it to the teacher and your class before igniting it.

6. When your teacher indicates, describe your model to the class. Tell them where you will ignite your model and predict how the fire will spread.

7. When your teacher indicates, ignite your model. Video, photograph, and take notes while your model burns.

8. Discuss the accuracy of your predictions.
Handout H08B-3: Fire Behavior Case Study

Name: ________________________________

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

1. Write a timeline to describe your fire. Include at least 5 entries (points in time). Give specific details about the development of your fire from ignition until it went out.

2. Write a 1-paragraph (or longer) Case Study of your fire to accompany the timeline. This is a description of your fire and its behavior. Use all three components of the Fire Environment Triangle to describe how the fire spread (or didn't spread) across your model landscape. Include photos of your model before and after it burned, as well as other photos that illustrate the fire behavior and how it is related to the Fire Environment Triangle.

Getting Started--Brainstorming Space:

- Name of fire:
- Starting location description (include fuel type, weather, topography):

- At each point in time, where did it spread and what influenced it (fuel type, weather, topography)?

- Ending location? (fuel type, weather, topography):
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.

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.

Subjects: Science, Writing, Health and Safety
Duration: 90 minutes
Group size: Whole class, working in small groups
Setting: Indoor laboratory or outdoors
New FireWorks vocabulary: crown fire, crown fuels, ladder fuels, surface fire, surface fuels, succession

Standards:

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<th>Standards</th>
<th>9th</th>
<th>10th</th>
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<td>Strand 1</td>
<td>C,E,F,G</td>
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</table>

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 B. Fire Environment Triangle and Fire Spread: The Matchstick Forest Model*) 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 exercise 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 Tinker Tree support stand
• 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.pptx from Activity H08a or b).

![FireWorks Safety Poster]
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.

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 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.
What kind of fire is burning in each photo? 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:

![Image of model tree components]

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

<table>
<thead>
<tr>
<th>Team Name</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
</table>

8. **Phase 1:** Give lab groups ~10 minutes to construct their trees. Monitor to make sure they don’t moisten the fuel.
   - Ask each group for its team name. Write it on the board.
   - Check and modify the surface fuels to make them similar among trees. Explain: 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 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:**

<table>
<thead>
<tr>
<th></th>
<th>Full Credit</th>
<th>Partial Credit</th>
<th>No Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content</strong></td>
<td>See <a href="#">Answer Key/Suggestions for Handout H09-3: Real-World Ladder Fuels and Fire Spread</a> below.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Images</strong></td>
<td>Student used images that clearly illustrated the answer.</td>
<td>Student used images that illustrated the answer but were sometimes confusing or incorrect.</td>
<td>Student used images that were distracting or incorrect.</td>
</tr>
<tr>
<td><strong>Explanation</strong></td>
<td>Student’s captions showed thorough understanding of the relationship of fuel arrangement to fire spread potential.</td>
<td>Student’s captions showed basic understanding of the relationship of fuel arrangement to fire spread.</td>
<td>Student’s captions showed little or no understanding of the relationship of fuel arrangement to fire spread.</td>
</tr>
</tbody>
</table>
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 shrubs. Crown fires are often ignited by surface fires that spread up through ladder fuels into the tree crowns; 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 trunk. Its leaves are strips of newspaper. Your goal is to build a tree with a crown that does not burn when a fire burns the surface fuels beneath it. Your job could be easy—just put together a tree with no leaves. But your tree must also have foliage (leaves) to win—the more, the better. You have to figure out how much foliage to use and how to arrange it 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.
4. Slide wire “branches” through the holes in the post. You may use as many or as few branches as you want.
5. Use the long, narrow strips of newspaper for foliage. Slide foliage strips onto each branch. For short branches, you may shorten the newspaper strip. Use the branch to poke a small hole at the outer end of the foliage strip rather than using a punched hole, so the newspaper won’t fly off the branch once you start burning.
6. Lab groups will ignite their tinker trees one at a time. When the teacher tells you it’s time to ignite yours, start the fire by igniting two corners along one long edge of the metal tray.

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

**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.

<table>
<thead>
<tr>
<th>Drawing</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Caption</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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. 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.
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 reports on the fire’s progress for a national audience. In a closing section of the activity, students review the IC Team’s use of models and a map that shows the variety in fire severity in the area burned.

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.

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
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, 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 as zipped files (FireReportingPacket... followed by a range of dates in yyyyMMdd format). Information in the packets includes:

- **Narratives**: Excerpts from the official record of the fire as published on “Inciweb” ([https://inciweb.nwcg.gov/](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.

- **Statistics**: Daily reports of fire size, number of personnel on the fire, and estimated cost.

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 in early August to describe their strategy for managing the fire. Then students
read the “Decision Summary” (170804_LoloPeakFireDecisionSummary.pdf), a 6-page document excerpted from the official 48-page plan for managing the fire. We recommend assigning the video and the Decision Summary reading assignment as homework before the next steps. From the Decision Summary, they learn how the IC team applied concepts from the Fire Environment Triangle to fire management.

After completing the technical reading, 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 record these hypotheses. At the end of the activity, they compare their predictions to what actually happened. Students use weather data from the official National Weather Service station at the Missoula airport (10 to 15 miles from the fire). We extracted hourly data for 8 variables that are related to fire behavior. The data are displayed graphically in FireWeatherTimelines_PosterSize.pdf, and 6 copies are available in the trunk (FireWeatherTimelines_LedgerSize.pdf).

Atmospheric inversions influenced the behavior of the Lolo Peak Fire and caused poor air quality throughout the region during the summer of 2017. This activity does not address smoke and inversions, but Activity H11 does. It explains the nature of inversions and challenges students to identify inversions during the time of the Lolo Peak Fire and predict the resulting impacts on air quality.

For the Assessment section of this activity, each student team presents a 3.5-minute “Weather Channel”-type 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. Thus, 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:

<table>
<thead>
<tr>
<th>Website</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="https://inciweb.nwcegov/">https://inciweb.nwcegov/</a></td>
<td>Information on the size, status, and other features of current fires throughout the United States</td>
</tr>
<tr>
<td><a href="https://www.nifc.gov/fireInfo/fireInfo_main.html">https://www.nifc.gov/fireInfo/fireInfo_main.html</a></td>
<td>National Interagency Fire Center – coordination and information for wildland fire programs nation-wide</td>
</tr>
<tr>
<td><a href="https://gacc.nifc.gov/">https://gacc.nifc.gov/</a></td>
<td>Geographic Area Coordination Center – a portal for each major geographic region in the United States. Content differs by region, but most sites feature regional news, maps, and other detailed information.</td>
</tr>
</tbody>
</table>
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 digital copies?

2. Find the Fire Reporting Packets in the trunk or make them available from zip files entitled FireReportingPacket... with a range of dates attached. There are 6 packets, one for each time period to be covered by a student report. The contents of the packets are described in Teacher Background above.

3. Find the 6 ledger-size displays of fire weather data in the trunk or print from FireWeatherTimelines_LedgerSize.pdf. NOTE: 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.

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).
   - Poster showing weather during the Lolo Peak Fire (FireWeatherTimelines_PosterSize.pdf)¹
   - Next to the weather poster, display this one: FireSizeAndGrowthTimeline_EmptyChart.pdf

7. Find a dry-erase marker that can be used to chart fire size and growth on the above “empty” chart.

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=Cxr2rq4dCy4&feature=youtu.be

10. Find in the trunk or download the fire severity poster (FireAbovegroundSeverityPoster.pdf) and prepare to display at the end of the activity.

¹ If you want students to use the original data, it is all available in the zipped folder OriginalReadingsAndDataForTeachers.
11. Print 1 copy/student: **Handout H10-1. Report to the nation about the Lolo Peak Fire**

**Procedure:**

**Briefly introduce the activity and assign homework**

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 of July 15. Toward the end of July, a team of 15 fire experts studied the fire behavior, weather forecasts, historical weather records, and 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 on what the fire was likely to do and how it would be managed. A team that manages a national emergency like the Lolo Peak Fire is called the *Incident Management* – or “IC” Team.

2. Assign homework:
   - a. Students will watch the 3:12-minute video “Lolo Peak Fire Strategy and Tactics”: [https://www.youtube.com/watch?v=4CCHlzM5Tzk&feature=youtu.be](https://www.youtube.com/watch?v=4CCHlzM5Tzk&feature=youtu.be) of one of the IC Team leaders describing the management strategy.
   - b. Hand out the Decision Summary document ([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 report. Pay attention to ways in which the three parts of the Fire Environment Triangle – fuels, weather, and topography – interact and how they influenced the strategy for managing the fire safely. You will need that knowledge for the next class session.

**DAY 1 – Using what we know to predict fire behavior:**

3. Ask if students have questions or need to discuss the Decision Summary reading. 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 IC reports, photos, 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.

4. Set up 6 student teams.

5. Point to FireWeatherTimelines_PosterSize.pdf displayed in the classroom and give each team a printout of these graphs (FireWeatherTimelines_LedgerSize.pdf). Explain: Here’s some of the weather data recorded during the fire. These graphs show only a fraction of the data available, but these variables 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 in the Decision Summary that they just read. 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.

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

<table>
<thead>
<tr>
<th>Team</th>
<th>Hypothesized important fire dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day(s) with greatest fire growth</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
7. 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 OR 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.
   
   - Each broadcast must be 3.5 minutes long and must include information on the fire’s growth. Before or during each broadcast, you must use a dry-erase marker to graph the fire’s growth and total area on the empty graphs displayed in the classroom (FireSizeAndGrowthTimeline_EmptyChart.pdf). Use a bar graph, like the weather graphs, to show fire growth. (You can use this opportunity to discuss the kind of graph appropriate for different kinds of data.) Use a line graph to show the total fire size. 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:

<table>
<thead>
<tr>
<th>Team</th>
<th>Time period (2017)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>July 15 through July 29</td>
</tr>
<tr>
<td>2</td>
<td>July 30 through August 12</td>
</tr>
<tr>
<td>3</td>
<td>August 13 through August 19</td>
</tr>
<tr>
<td>4</td>
<td>August 20 through August 26</td>
</tr>
<tr>
<td>5</td>
<td>August 27 through September 9</td>
</tr>
<tr>
<td>6</td>
<td>September 10 through October 9</td>
</tr>
</tbody>
</table>

3. Have students look through 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.

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

<table>
<thead>
<tr>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
</table>
| • Reported fire’s growth and connected it to weather, topography, and/or fuels | • Reported fire’s growth  
  • Reported on 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. | • Did not report fire’s growth  
• Did not describe fire weather, topography, or fuels  
• Included too much or too little technical information for audience  
• 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.  
• Did not contain human-interest touch  
• Did not give information on national significance of fire |
1. The “empty chart” display, which students filled in for their reports, should look a lot like this one (which is available in FireSizeAndGrowthTimeline_PosterSize.pdf).

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.

4. Display 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.

5. 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:

6. 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.

<table>
<thead>
<tr>
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<tr>
<td>1</td>
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<td>August 20 through August 26</td>
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<td>5</td>
<td>August 27 through September 9</td>
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<tr>
<td>6</td>
<td>September 10 through October 9</td>
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</table>

Your team’s Fire Reporting Packet contains all of the information you need:

- **Narrative** contains excerpts from the IC Team’s narrative report for each day.
- **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).
- **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.
- **Articles** contains one or more newspaper articles about the fire and related issues.

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:

- Use a dry-erase marker to 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. Explain fire growth (or lack of it) in terms of weather, fuel, and/or topography. You may use the map in your **Graphics** file.
- 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.

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2 The materials may be in computer files with file 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.

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 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 1-2 weeks
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 has strongly affected behavior of the Lolo Peak Fire to date. Most of the area is covered by these 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.
• 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.

Fire Behavior Expected in Fuel Types
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.
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 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 nighttime humidities from rising, so fuels do not recover moisture overnight.
April 30, 2018

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) is a long-term analysis tool that 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 August 4, 2017.

The FSPro map below depicts possible growth of the Lolo Peak Fire from July 29 to August 4, 2017*, based on analysis of fire growth, weather, and previous experience in the northern Rocky Mountains.

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* 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.
FSPro model results helped us identify criteria for days when the fire may grow rapidly. 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 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.
Unit IV brings students’ attention to the effects of wildland fires on non-living parts of the ecosystem: air (Activity 11), and soil and water (Activity 12).

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

In this activity, students learn about 3 concepts: the nature of smoke from wildland fires (through a technical reading), the ways in which smoke disperses into the atmosphere (through a demonstration and presentations), and some of the ways in which people can live with and reduce the smoke from wildland fires (through a reading/writing/speaking activity).

Lesson Goal: Increase students’ understanding of the nature of smoke from wildland fires, how it disperses, what its effects are, and how it might be minimized – or 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 graphs of weather data to predict concentrations of particulate matter.
- Students can identify actions that might reduce smoke from wildland fires or help reduce the adverse health impacts of smoke.

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

Duration: 3 class periods

Group size: Entire class

Setting: Classroom

New FireWorks vocabulary: inversion, particulates/particulate matter, PM2.5, smoke, stable/unstable atmospheric conditions, thermal belt
**Teacher Background:** There's no wildland fire without smoke, but the amount of smoke produced and the way in which it disperses differ from one fire to another and even from one time to another on a single fire. If the smoke disperses upward rapidly, powered by convection, high-altitude winds will scatter it downwind, and the only result we notice may be the beautiful, orange-tinged sunrise and sunset colors produced by particles in the air. However, if the smoke is trapped near the fire by an inversion (or by a high-pressure ridge – not discussed in this lesson), it can make the air difficult to see through and even difficult to breathe. This can be especially hazardous for anyone who has asthma or other respiratory illness and for those who engage in strenuous exercise.

This activity has 4 parts: First, students read a 2-page technical article about the nature of smoke from wildland fire and its impacts on human health.

Then they learn from a demonstration and a presentation about smoke dispersal, especially as it is affected by “normal” vs. “inversion” atmospheric conditions.

Once students understand the nature of atmospheric inversions, they use weather data from the time of the Lolo Peak Fire (the same fire studied in Activity H10-1) to predict air quality in the Missoula valley, which lies about 15 miles from the fire. They check the success of their predictions with a presentation that shows actual particulate levels during the fire.

Finally, students read several articles about smoke - all written while the Lolo Peak Fire was burning - and use these articles along with what they have learned to write a guest editorial about smoke management for a local newspaper.

**Summary of content:** On most summer days, sunlight warms the earth’s surface and the layer of air on the earth’s surface. The warming, expanding air rises. Its temperature decreases due to the expansion. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude. As a result of this natural cooling, mountain tops tend to remain much cooler than valleys even on hot summer days. Because the air is constantly moving and mixing under these circumstances, we call the atmospheric condition *unstable*.

Every night, when the sun is no longer warming and stirring up the atmosphere, cold air from the mountain tops – which is more dense than warm air - flows downhill into the valleys. Sometimes the sun doesn’t warm the surface air back up in the morning. Perhaps clouds are blocking the incoming light... or smoke is blocking it... or (in winter) snow is reflecting the light rather than absorbing it. When this happens, the cold air is stuck on the ground. It is not expanding, therefore not rising, and therefore “trapped” on the ground until something stirs up the atmosphere. This is called an *inversion* because the normal daytime pattern (warm air on the bottom, rising into cooler air on top) is upside-down. The blanket of warm air that lies on

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1 Although metric units of measure are used in most of this curriculum, we used “standard” units of measure in parts of this lesson because fire managers still use mostly standard units. This is because they rely on fire behavior models developed in the 1960s, which use standard units of measure.
top of the cold air is called a thermal belt. During an inversion, the cold surface air is very stable. It cannot be dislodged until it is heated or stirred up by wind.

During an inversion, dust and other particles are trapped in the cold air at the earth's surface. Inversions during wildland fires trap smoke, which may be so dense that you can’t see very far and the city streetlights come on in the middle of the day. When people are exposed to dense smoke, it becomes harder to breathe. Dense smoke is especially dangerous for babies, older adults, and anyone with asthma or other respiratory illness. It is a good idea for people to limit aerobic activities and even stay indoors (provided the indoor air is clean) until the air quality improves.

For further background, see the readings and presentations included in the lesson.

Materials and preparation:

1. Access the 7:42-minute radio feature from Montana Public Radio: “Summer of Smoke Exposes Need For Clean Indoor Air In Montana” (http://mtpr.org/post/summer-smoke-exposes-need-clean-indoor-air-montana). In this program, the reporter interviews health experts and members of the public who were severely impacted by smoke from the fires of 2017 in western Montana. A transcript of the program is available in 180103_MTPR.pdf.

2. Decide how to make the introductory reading (Pre-reading_EPA_SmokeGuide.pdf) available to students – with printed copies or electronically. Each student needs 1 copy. Decide if the reading will be done as homework or in class.

3. Decide how to make the Assessment readings available to students – with printed copies or electronically. There are 6 readings/set. They are available in SmokeInformationPacket.zip, and the trunk contains 4 sets. Each student must read at least 2 of the articles in the set. Decide if the reading will be done as homework or in class.

4. Download these 3 presentations:
   - 1_SmokeDispersion.pptx introduces discussion of smoke dispersal.
   - 2_InversionExplanation.pptx reviews the demonstration and further explains the nature and causes of inversions.
   - 3_AnswerToHandout_H11-2_ParticulatePredictions.pptx provides the basis for discussing the relationship between inversion conditions and smoke concentrations.

5. Decide how to demonstrate atmospheric inversions: by viewing an online video (https://www.youtube.com/watch?v=LPvn9qhVFbM), creating the same demonstration in class, or creating a demonstration that compares temperatures and air circulation above ice vs. boiling water (described in InversionDemonstration_Boiling-vs-Ice.pdf).

6. Decide how to manage the reading/writing part of the Assessment, in which students use 6 reports (IC narratives from Inciweb plus 5 newspaper articles) to write a guest editorial for a
local newspaper. You can have students work individually, which would be easiest to evaluate, or have them work in teams – which would be more difficult to evaluate but potentially more creative and more fun. This lesson is written with a team-writing approach.

7. Print 1 copy of H11_TargetAudiences.pdf, which lists the 6 groups to be addressed by the class’s guest editorial (the public, school workers, fire managers, health board and air quality specialists, health-care providers, and scientists). Cut the rows apart so you can give one of these target audiences to each student team.

8. Print 1 copy/student:
   - Handout H11-2. Are inversions connected to smoke?

Procedures:

**Day 1 – Radio program and technical reading**

1. Explain: Smoke from wildland fires impacts visibility and threatens people’s health – that of firefighters and that of people living in the path of the smoke. Smoke also influences options for fire managers. In this activity, we’ll learn what smoke is, how it disperses, and the choices people can make to protect their health and to “manage” smoke in some ways. Then we’ll use our knowledge to write an editorial for a local newspaper.


4. Explain: Do the reading and complete the handout to make sure you understand the main points.

**Day 2 – How smoke disperses – or doesn’t**

5. Ask for questions on the technical reading. Discuss answers to the handout, especially Questions 5-8. See the Answer Key for Handout H11-1: Questions on “Wildfire Smoke: A Guide for Public Health Officials” below.

6. Explain: Now we know what smoke is and how it affects us. Let’s learn about where it goes, and then we’ll figure out what can be done about it.
7. Go through the 1st presentation (**1_SmokeDispersion.pptx**):

**Slide 1**
We’ve observed smoke from experiments and read about what smoke is composed of. But anyone who’s ever sat around a campfire knows the most important question about smoke is: Where does it go? You can make some guesses from these photos. Smoke from wildland fires usually goes up, just like heat does. It cools off as it rises. When its temperature is about the same as that of the surrounding air, it stops rising and just travels wherever the wind takes it.

**Slide 2**
Satellite photos show that smoke can travel a long way. Use the 25-km scale on the photos to estimate the width of these smoke plumes: 50-75 km on the Rim Fire (left) and 100-200 km on the Mustang Complex (right). About how far has the smoke traveled? 300 km or so. What are some towns or other landmarks that far from our location?

**Slide 3**
But smoke doesn’t always move up and away. Sometimes it settles near the ground and stays there for days or even weeks. This might be smoke from a fire nearby, or it could be smoke from fires hundreds of miles away. This thick, messy, hazardous air is often caused by a weather phenomenon called an inversion.

8. Explain: A demonstration will help us understand inversions better.

9. Choose one of these options:
   a. View the 2:49-minute video about inversions from “Steve Spangler Science” ([https://www.youtube.com/watch?v=LPvn9qhVFBM](https://www.youtube.com/watch?v=LPvn9qhVFBM)).
   b. Create the demonstration described above in class.
c. Create the demonstration described in InversionDemonstration_Boiling-vs-Ice.pdf, which compares temperatures and air circulation above ice vs. boiling water. The trunk contains supplies needed for this demonstration.

10. Review the concept of inversions with the 2nd presentation (2_InversionExplanation.pptx):

Slide 1

Which diagram describes...
Normal air temperature pattern? inversion?

Cold
Hot
Cold

Ask: If the cylinders represent parcels of air, which diagram shows normal conditions and which one shows inversion conditions?

Slide 2

Normal
Cold
Hot
Cold
Inversion

Discuss:
If you viewed or created the demonstration in the video: The demonstration with warm water on the bottom and cold water on top represented normal conditions. With warm water below cold water, the liquids were unstable; instead, they were circulating – moving - and the colors were mixing. With cold water below warm water, liquids were stable – not moving, not circulating - and the colors were not mixing. These stable conditions represent an inversion.

If you used the ice/boiling water demonstration: The air above boiling water showed normal conditions because the air was unstable, even turbulent; pollutants in the air would disperse upward. The air above ice showed an inversion because the air was very stable; pollutants would be trapped in the cold air and would not disperse.

Slide 3

Normal Atmospheric Condition: Air moves up from the ground. Air is unstable.

Explain: Normal atmospheric conditions occur when sunlight warms the earth’s surface in the morning, and this warms the air on the ground. The warming air expands and therefore rises. As it rises, it gradually cools off. If the air is dry, the temperature falls about 1°C for every 100-meter rise in altitude (about 5°F for every 1000 ft). As a result of this natural cooling, mountain tops are usually cooler than valleys on hot summer days. Due to all the air movement, these conditions are described as unstable.
Explain: Inversions occur when air at the earth’s surface is cold. It is not getting warmed by the sun, so it is not expanding and rising. It is stuck on the ground. It cannot be dislodged until it is heated or stirred up by wind. We say the cold, surface air is very stable.

Explain: Inversions often occur at night. The cool air on the mountain tops is denser than the warm air in the valleys. When the sun goes down and stops stirring up the surface air, the cool, dense mountaintop air flows downhill into the valley bottoms. The blanket of warm air at middle elevations is called the thermal belt.

Ask: So how do inversions affect fires ... and how do they affect us? Discuss the points in the slides; this discussion leads into the Assessment.

11. Give each student a copy of Handout H11-2. Are inversions connected to smoke? Explain: Use the handout (1) to check your understanding of inversions and (2) to predict episodes of “good” and “bad” air during the Lolo Peak Fire of 2017 – the same fire we studied in Activity 10-1.

Day 3 or when handouts are completed – What can be done about smoke?

12. Discuss the answers to questions 1-5 on Handout 11-2 to make sure students understand the nature of inversions and can read the graphs. (See Teacher’s Key to Handout H11-2. Are inversions connected to smoke? below.) When you get to Question 6, open the third presentation (3_AnswerToHandout_H11-2_ParticulatePredictions.pptx) for more discussion:
Explain: Let’s see how successful we are at predicting “smoky” and “clean air” days from inversion data. Here’s the graph showing when there were inversions in the Missoula valley, about 15 miles from the fire. This is the same graph that’s on your handout.

**Question 6.** How many days during the fire had at least 1 hour when the temperature in the valley was cooler than at the mountain top? \textbf{35 days.}

**Question 7.** How many days during the fire had inversion conditions for at least part of the day? The same - \textbf{35 days.} (There were probably many more, because the top of the thermal belt could have been below the mountain top where data were recorded.)

**Question 8.** Which day had the longest-lasting inversion? September 6. How long did it last? \textbf{16 hours.}

**Questions 9 and 10.** Which week(s) did you choose as most likely to have severe smoke? Clean air?

**Discussion.** The week of September 3-9 had the most hours of inversion, plus inversion on every day but one, so that’s a good candidate for SMOKY. So is the previous week. The week of September 17-23 had no inversions, so that’s a good choice for CLEAN AIR. So is the week of August 13, which only had 2 hours of inversion – and only on 1 day.

Explain: Now let’s see what really happened. This graph shows the average PM2.5 concentration each day during the Lolo Peak Fire. How successful were our predictions? **Discussion.** Students probably predicted the smoky and clean air episodes pretty well. However, there are a lot of periods without inversions that had fairly high levels of particulates. Why? The mountain top weather station could have been above the thermal belt, so the air above the inversion had cooled before it reached the mountain top sensors. Also, a high pressure “ridge” stayed in the upper atmosphere over the region during much of the summer; this made the surface air hot and reduced circulation even without inversion conditions. Finally, keep in mind that the smoke in the Missoula valley was not all from the Lolo Peak Fire.
Explain/ask: Here are the air quality indicators, according to Environmental Protection Agency standards, from the time of the Lolo Peak Fire. When particulate levels were high, what was the air quality? **Unhealthy.** What were the recommendations for limiting activity to protect health? Have students refer to the table to discuss.

This map shows all of the areas burned in 2017 that received “repair” or “restoration” work from Burned Area Emergency Response (BAER) teams. (BAER work was discussed in **Activity 10-1.**) There were hundreds of fires in northern Rocky Mountains, the Pacific Northwest, British Columbia, and Alberta during the summer of 2017.

The Rice Ridge Fire, about 40 miles northeast of Lolo Peak, burned 3 times as much area as the Lolo Peak Fire. Smoke in the little town of Seeley Lake, on the edge of the fire, had much MUCH worse air than Missoula did during the summer of 2017.

Both graphs are on the same scale. Compare the air quality in Seeley Lake with that in Missoula. Compare the recommended limitations for people in the Seeley Lake area.

**Assessment:** This assessment can be done individually or in teams. We describe it here as a collaborative team effort.
1. Form 6 student teams. Give each team a copy of (or electronic access to) the 6 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 **TargetAudiences.pdf** that lists their audience.

2. Explain: We’re going to write a guest editorial for a newspaper. 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: 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 6 articles. At least 2 people on each team should read every article, and every student must read at least 2 articles. While you’re reading, keep your target audience in mind and make notes on anything that they 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 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 our ability to deal with it.

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 600-700 words long. Have each team revise their paragraph, cut it down to 100 words or less (if necessary), 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. Based on those articles, what are some important things that we should include in our introductory and closing paragraphs²? **A good way to begin is to identify yourself (“We are a group of**

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² 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.
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. 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.

Evaluation:

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content – see Teacher’s Key to information from articles on smoke</strong> below.</td>
<td>Student used relevant information from article(s) or provided relevant suggestions based on other sound information</td>
<td>Student used information from article(s) or provided suggestions based on other sound information</td>
<td>Student did not use information from article(s) and/or provided suggestions that were irrelevant or without sound basis</td>
</tr>
<tr>
<td><strong>Reading</strong></td>
<td>Student read and took notes on more than 2 articles</td>
<td>Student read and took notes on 2 articles</td>
<td>Student read and took notes on fewer than 2 articles</td>
</tr>
<tr>
<td><strong>Notes</strong></td>
<td>Notes were appropriate for target audience</td>
<td>Notes were somewhat appropriate for target audience</td>
<td>Notes did not fit target audience</td>
</tr>
<tr>
<td><strong>Team discussion and writing</strong></td>
<td>Participated fully. Showed leadership without dominating project.</td>
<td>Participated.</td>
<td>Did not participate.</td>
</tr>
<tr>
<td><strong>Presentations</strong></td>
<td>Listened respectfully. Contributed to discussion of at least 1 student presentation. Contribution showed careful listening.</td>
<td>Listened respectfully. Contributed to discussion of at least 1 student presentation.</td>
<td>Did not listen respectfully OR did not contribute to discussion OR contribution was not relevant to discussion.</td>
</tr>
<tr>
<td><strong>Followup writing</strong></td>
<td>Helped revise team’s paragraph and finalize introduction or conclusion of letter.</td>
<td>Helped revise team’s paragraph OR finalize introduction or conclusion of letter.</td>
<td>Did not help with either effort.</td>
</tr>
</tbody>
</table>

The Missoulian is published in Missoula, MT, 10 to 15 miles from the Lolo Peak Fire, and is the source of many articles in this curriculum.
## Teacher’s Key to information from articles on smoke

<table>
<thead>
<tr>
<th>Audience</th>
<th>Potential ways to address problems with smoke and inversions$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General public, including people in “vulnerable groups”:</strong></td>
<td>Pay attention to air quality alerts and follow guidelines (Briggeman, Coefield, Coffin, Seldin). <strong>Guidelines may include:</strong> Stay indoors (Briggeman, Coffin, Seldin). Stay in environments with HEPA filters (Coefield). Limit aerobic activity (Briggeman, Coffin, Seldin). Address climate change (Coffin, Seldin). <strong>Other ideas – not in articles:</strong> Support ecologically appropriate fuels management and use of prescribed fire. For vulnerable groups, before start of fire season, make sure medications are up-to-date.</td>
</tr>
<tr>
<td><strong>Schools administrators, teachers, coaches:</strong></td>
<td>Pay attention to air quality alerts, follow guidelines (Briggeman, Coefield, Coffin, Seldin). Find alternate locations for practice, games (Coefield). Obtain HEPA filters (Coefield). <strong>Other ideas – not in articles:</strong> Plan alternatives to outdoor activities.</td>
</tr>
<tr>
<td><strong>Fire managers, wildland managers:</strong></td>
<td>Be alert for intense, dangerous fire behavior overnight in thermal belt (Inciweb). Plan to do without use of aircraft when smoke limits visibility (Inciweb). Be alert for active fire spread under the thermal belt when inversion breaks up (Inciweb). Take advantage of times when inversion reduces fire intensity in valley bottoms to use aggressive fire suppression techniques (Inciweb, Briggeman). Use ecologically appropriate “ecosystem management” (Coffin). Use prescribed fire to reduce fuels; these fires will produce much less smoke (Chaney). <strong>Other ideas - not in articles:</strong> Reduce fuels without using prescribed fire.</td>
</tr>
<tr>
<td><strong>Health Boards, Air quality specialists:</strong></td>
<td>Keep everyone informed. Send out info 1-2 times/day, if needed (Coefield, Briggeman). Educate people about fire and smoke (Coefield). Advise people and institutions to obtain HEPA filters (Coefield). Provide HEPA filters for loan to vulnerable groups (Coefield). <strong>Other ideas – not in articles:</strong> Arrange for air quality “respite” locations equipped with HEPA filters.</td>
</tr>
<tr>
<td><strong>Doctors, counselors, other health-care providers:</strong></td>
<td>Advise patients to pay attention to air quality alerts and follow guidelines (Briggeman, Coefield, Seldin). Watch for depression and help patients get through it (Seldin). Equip clinics, hospitals, and nursing homes with HEPA filters (Coefield). <strong>Other ideas – not in articles:</strong> Contact vulnerable patients at start of fire season to help them prepare. Seek financial help for medications for vulnerable patients.</td>
</tr>
<tr>
<td><strong>Scientists:</strong></td>
<td>Investigate what we need to know about smoke and its dispersal to protect our health (Coefield). Investigate what firefighters we need to know to stay safe in thermal belts and when inversions break up (Chaney, Coefield). Investigate long-term health dangers of prolonged exposure to smoke (Chaney, Coefield). <strong>Other ideas – not in articles:</strong> Investigate what information fire managers need to take advantage of inversions for fire suppression. Investigate best practices for ecologically appropriate forest and fuel management.</td>
</tr>
</tbody>
</table>

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$^3$ Names in parentheses refer to the author or source of the article in the **Smoke Information Packet**.

1. What is the purpose of this publication?

2. What groups are mentioned in the first paragraph and what questions do they have?

3. Think of another group that isn’t mentioned. What question do you think they might have?

4. What materials and chemicals are in smoke?

5. Describe particulate matter.

6. What is PM2.5?

7. Describe 3 effects of smoke particulate matter on human health.


1. What is the purpose of this publication? The guide is written to provide local public health officials with the information they need to prepare for smoke events and, when wildfire smoke is present, to communicate health risks and take measure to protect the public.

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

3. Think of another group that isn’t mentioned. What question do you think they might have? Here are some possible answers: the elderly, parents of young infants, health care providers, coaches, and outdoor educators. They need to know how smoke will impact them, how long it will last, how they can keep it out of their homes, and whether they should leave the area — and where they might go to get out of the smoke.

4. What is the composition of smoke from wildland fires? Smoke contains carbon dioxide, water vapor, carbon monoxide, particulate matter, hydrocarbons and other organic chemicals, nitrogen oxides, trace minerals, and thousands of other compounds.

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

6. What is PM2.5? PM2.5 is the amount (by weight) of particulate matter less than 2.5 micrometers (microns) in diameter per cubic meter of air.

7. Describe 3 effects of smoke particulate matter on human health. Answers may include any of these:
   - Eye and respiratory tract irritation
   - Reduced lung function
   - Bronchitis
   - Exacerbation of asthma
   - Heart failure
   - Premature death
   - Persistent cough, phlegm, wheezing and difficulty breathing.
   - Other respiratory symptoms, transient reductions in lung function, and inflammation in the lungs.
   - Reduced ability to remove foreign materials, such as pollen and bacteria, from the lungs.

8. Describe 2 long-term health effects of exposure to smoke. These could include:
   - Slightly increased risks of cancer
   - Increased risk of other chronic health problems.
Handout H11-2. Are inversions connected to smoke?

Name: ______________________

1. These words describe air circulation at the earth’s surface:
   
   Unstable         Mixing         Stagnant
   Still            Stable         Turbulent
   
   Copy each word into one of the boxes below:

   ![Normal conditions](image)
   ![Inversion conditions](image)

2. These graphs show temperatures every hour during 2 days while the Lolo Peak Fire was burning. Red dashed lines show data from the Missoula airport, a **valley-bottom** location at 3192 ft. Blue dotted lines show data from Point 6, a **mountain top** location at 7920 ft.

   ![July 16, 2017](image)
   ![Sept. 6, 2017](image)

   On July 16, was the valley bottom ever cooler than the mountain top? ____ If yes, for about how many hours? ____

   On Sept. 6, was the valley bottom ever cooler than the mountain top? ____ If yes, for about how many hours? ____

3. Which day had normal air circulation? __________

4. Which day had inversion conditions? __________

July 16, 2018
This graph shows the number of hours in each day during the Lolo Peak Fire when the valley bottom was cooler than the mountain top for at least 1 hour. The Lolo Peak Fire was not the only one in the area during the summer of 2017, but it was the one closest to these weather recording stations.

6. How many days during the fire had at least 1 hour when the temperature in the valley was cooler than at the mountain top? __________

7. How many days during the fire had inversion conditions for at least part of the day? __________

8. Which day had the longest-lasting inversion? _____ How long did it last? __________

9. Find 1 week during the fire when you would expect a lot of smoke in the valley because of inversion conditions. Label that week “SMOKY.”

10. Find 1 week when you would expect the air to be very clear of smoke because there were no inversions. Label that week “CLEAN AIR.”
Teacher’s Key to Handout H11-2. Are inversions connected to smoke?

1. These words describe air circulation at the earth’s surface:
   - Unstable
   - Mixing
   - Stagnant
   - Still
   - Stable
   - Turbulent

   Copy each word into one of the boxes below:

<table>
<thead>
<tr>
<th>Normal conditions</th>
<th>Inversion conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable, Mixing, Turbulent</td>
<td>Stagnant, Still, Stable</td>
</tr>
</tbody>
</table>

2. These graphs show temperatures every hour during 2 days while the Lolo Peak Fire was burning. Red dashed lines show data from the Missoula airport, a valley-bottom location at 3192 ft. Blue dotted lines show data from Point 6, a mountain top location at 7920 ft.

2. On July 16, was the valley bottom ever cooler than the mountain top? **No.** If yes, for about how many hours? **Not applicable**

3. On Sept. 6, was the valley bottom ever cooler than the mountain top? **Yes.** If yes, for about how many hours? **For about 16 hours, from midnight until noon and from about 20:00 to midnight.**

4. Which day had normal air circulation? **July 16.**

5. Which day had inversion conditions? **September 6.**
This graph shows the number of hours in each day during the Lolo Peak Fire when the valley bottom was cooler than the mountain top for at least 1 hour. The Lolo Peak Fire was not the only one in the area during the summer of 2017, but it was the one closest to these weather recording stations.

6. How many days during the fire had at least 1 hour when the temperature in the valley was cooler than at the mountain top? 35 days.

7. How many days during the fire had inversion conditions for at least part of the day? The same - 35 days.

8. Which day had the longest-lasting inversion? September 6. How long did it last? 16 hours.

9. Find 1 week during the fire when you would expect a lot of smoke in the valley because of inversion conditions. Label that week “SMOKY.” The week of September 3-9 has the most hours of inversion, plus inversion on every day but one, so that’s a good candidate. So is the previous week.

10. Find 1 week when you would expect the air to be very clear of smoke because there were no inversions. Label that week “CLEAN AIR.” There are several good candidates. The week of September 17-23 had no inversions, so that’s a good choice. So is the week of August 13, which only had 2 hours of inversion – and only on 1 day.
Lesson Overview: In this activity, students discuss a presentation that describes fire’s effects on soils and how these effects are measured. Then they either observe or conduct an experiment that illustrates how wildland fires affect the potential for soil erosion. They learn that soil burn severity varies greatly and that when fires remove the litter, duff, and plant cover on the ground, the risk of soil erosion increases.

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

Before beginning this lesson, watch the video demonstration of precipitation’s impact on bare soil versus vegetation-covered soil: https://www.youtube.com/watch?v=im4HVXMGi68. Decide if you want to do the demonstration in class or just view the video. If you decide to do the demonstration in class, you need a container containing young grass stems that were started from seed 4-8 weeks before. You may be able to use a cut piece of sod instead.

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

Objectives:

- Students can use information from a PowerPoint presentation and a demonstration (on video or done in the classroom) to interpret 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.
Standards:

<table>
<thead>
<tr>
<th>Standards</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCSS--ELA</td>
<td>Speaking and Listening</td>
<td>1,4</td>
<td>1,4</td>
<td></td>
</tr>
<tr>
<td>NGSS</td>
<td>History of Earth</td>
<td>ESS2.A</td>
<td></td>
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<td></td>
<td>Earth's Systems</td>
<td>ESS2.C, ESS2.D</td>
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<tr>
<td>EEEGL</td>
<td>Strand 1</td>
<td>A,B,C,D,E,F,G</td>
<td></td>
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</tbody>
</table>

**Teacher Background:** Soil burn severity is the degree of change in soil characteristics caused by fire. Changes in the soil may have profound effects on what happens in a burned area after fire. Potential impacts include reduced water infiltration and hence increased runoff, accelerated erosion, changes in stream channels, loss of cover and resultant warming of streams, death of underground plant parts that enable sprouting, 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 included some 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, duration of burning, and fire type (crown, surface, or ground fire).
The more severe a fire’s effects on the soil are, the more likely those soils will erode in subsequent rainstorms – especially in places with steep slopes. Erosion after fires can damage watersheds and destroy buildings and roads downstream in the first year or two after a fire.

This lesson is assessed by an activity in which students read a technical document (the Post-Fire BAER Assessment Report Summary for the Lolo Peak Fire of 2017 - LoloPeakFire_BAER-ReportSummary.pdf) and communicate its results to a local audience in the area of the fire. Burned Area Emergency Response (BAER) is a program in which a team of resource professionals assesses a burned area during and/or shortly after the fire is out. They figure out what actions are needed to protect human life, property, and critical natural and cultural resources and then get this work started as soon as possible (see http://www.fs.fed.us/biology/watershed/burnareas/background.html).

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:


Materials and preparation:

1. Display the Fire Environment Triangle (use the FireEnvironmentTriangle poster.pptx poster from Activity H08 or sketch it yourself).

2. Download and view the PowerPoint presentation: H12_FireSoilWater.pptx. The slides and notes for the presentation — including cues for discussion and main discussion points - are shown in Step 2 below.

3. Provide electronic access or 1 copy/student of the Lolo Peak Post-Fire BAER Assessment Report Summary. Either provide students with electronic access to the report or make printed copies from one of these sources: (LoloPeakFire_BAER-ReportSummary.pdf; https://inciweb.nwcg.gov/photos/MTLNF/2017-09-27-1750-Northern-Region2017-PostFire-BAER/related_files/pict20171002-200829-0.pdf). 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); this version contains text boxes to help you assess the content of students’ radio productions.


6. View this video about erosion: https://www.youtube.com/watch?v=im4HVXMGi68. In step 3 below, you will either conduct this demonstration in class or show the video. If you do the demonstration in class you will need:
   • Three empty 2-liter plastic soda bottles
   • Three empty plastic soda bottles (about 1-liter size)
   • Three pieces of string/yarn
   • Soil
   • Dead leaves/needles
   • Grass seed (planted in the soil 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 PowerPoint presentation: *H12_FireSoilWater.pptx*:

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.

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 question: 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?

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.

The diagram shows that there are 2 kinds of burn severity (the physical, biological, and ecological effects of fire): 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.

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 very low soil burn severity. About how many square miles had high soil burn severity? About 7 square miles.

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.

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 (slide 5). 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.

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.

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.

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, which lack woody fuels, usually have maximum ground temperatures <225 °C, although higher temperatures have been measured.

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 to 20 degrees. 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.
- 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.

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

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

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 and cause much greater soil burn severity than fast-moving fires, regardless of how much energy is produced aboveground and how long the flames are.

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

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 many other factors.

7. How does high soil burn severity increase the potential for erosion? Both of these photos show places where most of the vegetation and ground cover have burned away. The soil does not have any protection from raindrops. What will happen in the next 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 (see slide 9).
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.

We’ve looked at several important questions about fire effects on soils. With this understanding, we can study a report that describes soil burn severity for a specific fire and 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=im4HVXMGi68 or do the activity shown in the video.

Assessment:

1. Explain: Now that you are experts on soil burn severity and soil erosion, you will be able to 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. Your main information source will be the Summary of the Lolo Peak Post-Fire BAER Assessment Report (LoloPeakFire_BAER-ReportSummary.pdf, available online at https://inciweb.nwcg.gov/photos/MTLNF/2017-09-27-1750-Northern-Region2017-PostFire-BAER/related_files/pict20171002-200829-0.pdf).

2. Hand out copies of the report or provide it to students online.

3. Explain: This report was produced by a team of 26 specialists. 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.
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.

4. Give each student or team a copy of Handout **H12-1. Effects of the Lolo Peak Fire on Soils.** Also provide each student with access to the full BAER report (LoloPeakFire_BAER-ReportFull.pdf, available online at [https://inciweb.nwcg.gov/photos/MTLNF/2017-09-27-1750-Northern-Region2017-PostFire-BAER/related_files/pict20171015-211852-0.pdf](https://inciweb.nwcg.gov/photos/MTLNF/2017-09-27-1750-Northern-Region2017-PostFire-BAER/related_files/pict20171015-211852-0.pdf)).

5. Go through the instructions at the top of the handout. Explain/provide technology for students to record their radio spots.

6. Assign ONE of the 5 assessment question sets (A-E) to each student or team.

7. When the radio spots are completed, play them in class. After each one, 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:**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Completely successful</th>
<th>Partially successful</th>
<th>Unsuccessful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate, accurate technical information</td>
<td>Evaluate based on content of the <strong>Summary of the Lolo Peak Post-Fire BAER Assessment Report</strong>. The <strong>Answer Key</strong> 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.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clarity of communication in radio spot</td>
<td>Information is clear. No jargon or acronyms are used. Technical terms are used only as needed and are defined.</td>
<td>Information is slightly unclear; or jargon, acronyms, or technical terms are used without definitions.</td>
<td>Information is unclear. Jargon or acronyms are used. Technical terms are used without definitions.</td>
</tr>
<tr>
<td>Relevance of information to local audience</td>
<td>Recording gives persuasive reasons why the information is important to listeners.</td>
<td>Recording gives at least one reason why the information is important to listeners.</td>
<td>Recording does not give any reasons why listeners should care.</td>
</tr>
<tr>
<td>Creativity</td>
<td>Recording uses 2 or more sound effects appropriately.</td>
<td>Recording uses at least 1 sound effect appropriately.</td>
<td>Recording does not use any sound effects.</td>
</tr>
</tbody>
</table>
Handout H12-1. Effects of the Lolo Peak Fire on Soils

Read the Summary of the Lolo Peak Fire Burned-Area Report (https://inciweb.nwcg.gov/photos/MTLNF/2017-09-27-1750-Northern-Region2017-PostFire-BAER/related_files/pict20171002-200829-0.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 at https://inciweb.nwcg.gov/photos/MTLNF/2017-09-27-1750-Northern-Region2017-PostFire-BAER/related_files/pict20171015-211852-0.pdf. You may also obtain additional information on your topic.

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.

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? Will they stay remain 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), which students will consult for the assessment. Text boxes indicate what parts of the report may be most useful for student radio spots on each of the 5 question sets (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.

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.

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

- 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.

- 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.

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.

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...
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.

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.

- **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.

- **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.
- 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;

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

3. Critical natural and cultural resources; and


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:

- 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).

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

- 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.
- 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.

- 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.

- 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.

- 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 (www.weather.gov/mso/) website.
In this unit, students integrate their knowledge of fire with knowledge about living things - specifically, some of the organisms that live in forests of the northern Rocky Mountains and the North Cascades. They will construct a dichotomous key for identifying some of the most important tree species in these forests. They will learn and report to the class about specific plants, animals, and fungi and the characteristics that help them survive fire and/or reproduce successfully after fire. They will learn how different assemblages of tree species comprise different forest communities, and how these communities may be changing as the current climate changes.
H13. 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.

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

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<tr>
<th>Standards</th>
<th>9th</th>
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<td>Strand 1</td>
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<td></td>
<td>B,C,E,F,G</td>
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Teacher Background: Wildland ecosystems are characterized by diversity. The diversity and species of trees in a forest influences 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 2 “practice” keys – one for identifying a few members of the class, and then one for identifying different kinds of pasta. 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 from a library) to identify trees in the field.

**A second, fun approach to assessment**: This approach simplifies the key-building process for the students and may be more fun to evaluate:

- Split the class in half, so half of the teams are on one side of the classroom and half on the other.
- 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.
- Have the student teams create keys for the 5 tree species on their side of the room.
- Then remove the trees’ name labels from the displays.
- Then 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, and critique the key for the team that created it.

**Materials and preparation:**

- Decide how you will have students work on the keys – individually, in pairs, or in larger teams. (Consider the **second approach to assessment** above.) Your decision will determine how you set up the classroom and also how many cups of mixed pasta you will prepare for Steps 8-10 below (building a key for identifying different kinds of pasta).
- 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 a single 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

<table>
<thead>
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<th>Code letters for tree species:</th>
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<tbody>
<tr>
<td>Black cottonwood  B</td>
</tr>
<tr>
<td>Douglas-fir           V</td>
</tr>
<tr>
<td>Engelmann spruce   H</td>
</tr>
<tr>
<td>Lodgepole pine     E</td>
</tr>
<tr>
<td>Ponderosa pine     O</td>
</tr>
<tr>
<td>Quaking aspen      L</td>
</tr>
<tr>
<td>Subalpine fir       C</td>
</tr>
<tr>
<td>Western larch      T</td>
</tr>
<tr>
<td>Western redcedar   D</td>
</tr>
<tr>
<td>Whitebark pine     J</td>
</tr>
</tbody>
</table>

- For Steps 8-10, in which students create a key to different kinds of pasta:
  - Obtain empty bowls (1/student team)
  - Obtain uncooked pasta (at least 5 different types), enough so each student/team can have at least 1 piece of each type
  - Put a mixture of pasta types in each bowl (1 bowl/student team)
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](http://www.treesforme.com/a-z_common_name.html), a list of all native tree species in 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 a narrative 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.

7. Explain: We’ve just built a key for identifying **individual people**. In the sciences, keys are
used for identifying whole **groups of things** – people, rocks, plants, animals, micro-
organisms, etc. We’ll get a little more practice at building a key by classifying the pasta in
these bowls. The key will consist of a series of yes-no choices that will lead the user to the
correct name for each kind of pasta. At each choice point, the person using the key
examines a characteristic of the pasta and answers a yes-no question about it. This brings
the user to a new choice point, and the process continues until the user can identify the
unknown pasta.

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

9. Have students or teams exchange keys, use them to sort the pasta, and comment on how
well they worked, any points that were confusing, etc.

---

**Example Descriptions:**

**Tortiglioni:** A pasta that is cylindrical and hollow. It is often eaten with tomato sauce.

**Fusilli Lunghi Bucati:** A pasta that is cylindrical but not hollow. It takes 8 minutes to cook.
10. Explain: 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. 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.

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

Assessment: Explain:

1. 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 and revisions, so it will probably be easiest to 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 digital 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.

Evaluation: Each team’s key will be unique, but you can refer to the Example for Teachers at the end of this lesson to see one sample of a dichotomous key and narrative descriptions.

______________________________

1 Tip: Students can create their keys in Microsoft Word. Have them 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, they will insert the decision criteria into the hierarchy. Then, to make the resulting chart into a key, they will insert text boxes (without borders or fill) that label the decision lines “yes” or “no.”
<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichotomous key</td>
<td>Created clear, accurate key for identifying 9-10 species.</td>
<td>~Created key useful for identifying 7-8 species.</td>
<td>~Created key useful for identifying 5-6 species.</td>
<td>~Created key useful for identifying &lt;5 species.</td>
</tr>
<tr>
<td></td>
<td>~Key contained ambiguity or errors for 2-3 species.</td>
<td>~Key contained ambiguity or errors for 4-5 species.</td>
<td>~Key contained ambiguity or errors for &gt;5 species.</td>
<td></td>
</tr>
<tr>
<td>Species descriptions</td>
<td>Created clear, concise descriptions for 9-10 species.</td>
<td>Created clear, concise descriptions for 7-8 species.</td>
<td>Created clear, concise descriptions for 5-6 species.</td>
<td>Created clear, concise descriptions for &lt;5 species.</td>
</tr>
</tbody>
</table>
Example for Teachers: Dichotomous key for 10 tree species in the northern Rocky Mountains and North Cascades

Does it have needle-shaped leaves?  
  No  
  Yes  
  Are the leaves shorter than your thumb?  
    No  
    Yes  
    Are the leaves tiny, looking like overlapping scales?  
      No  
      Yes  
      Is the bark smooth?  
        No  
        Yes  
        Western redcedar  
          Yes  
          Are the needles in clusters of 2?  
            No  
            Yes  
            Lodgepole pine  
              Yes  
              Are the needles mostly in clusters of 3?  
                No  
                Yes  
                Ponderosa pine  
                  Yes  
                  Do the cones have 3-pointed, papery things sticking out from under the scales?  
                    No  
                    Yes  
                    Douglas-fir  
                      Yes  
                      Western larch  
                        No  
                        Yes  
                        Englemann spruce  
                          No  
                          Yes  
                          Whitebark pine  
                            No  
                            Yes  
                            Quaking aspen  
                              No  
                              Yes  
                              Black cottonwood
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 prickers 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.
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.

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:

- Students 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.
- 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.

<table>
<thead>
<tr>
<th>Standards:</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Core ELA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing</td>
<td>4,7,10</td>
<td>4,7,10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading Information Texts</td>
<td>1,4,10</td>
<td>1,4,10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science/Technical Subjects</td>
<td>2,4,5,6,7,8,9,10</td>
<td>2,4,5,6,7,8,9,10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NGSS</strong></td>
<td></td>
<td></td>
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<tr>
<td>Structure and Function</td>
<td>LS1.A</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Natural Selection and Evolution</td>
<td>LS4.C</td>
<td></td>
<td></td>
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<tr>
<td><strong>EEEGL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strand 1</td>
<td>C,E,F,G</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**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 38 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/](http://www.feis-crs.org/feis/)). This website contains reviews of the scientific literature about fire effects on plants and animals and about fire regimes in the plant communities where they occur. FEIS reviews 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* ([FireWorks Encyclopedia.pdf](FireWorks%20Encyclopedia.pdf)), a collection of 2-page essays on the species listed in **Table H14-1**. These essays are written for juvenile readers, but they summarize the information that should be covered in the high school research papers.

Before students begin their research projects, you may need to discuss the reliability of different kinds of information (e.g., peer-reviewed journal articles, government technical reports, unpublished documents, blogs, personal opinions of experts, etc.) so students can select appropriate sources.

**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**

**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](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/](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.fed.us/database/feis/glossary2.html](http://www.fs.fed.us/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.

4. Give each student a copy of **Handout H14-1: Species research project**. Go over the directions and answer questions.

**Assessment**:

1. 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**.

2. Schedule presentations.

3. 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.

4. If possible, post students’ research papers and presentations in a forum where other students can review them and possibly add to their notes.

5. Assign/administer the quiz (**Handout 14-2. Quiz on species’ relationships with fire**).

**Evaluation**:

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Evaluation criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research paper (20 points total)</td>
<td><strong>Two points</strong> for each criterion listed in <strong>Handout H14-1</strong>. Step #1:</td>
</tr>
<tr>
<td></td>
<td>1. Physical description of your species</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2.</td>
<td>Geographic distribution (where it occurs)</td>
</tr>
<tr>
<td>3.</td>
<td>Habitat requirements</td>
</tr>
<tr>
<td>4.</td>
<td>Associated species (name a few other plants and/or animals in the community)</td>
</tr>
<tr>
<td>5.</td>
<td>Information on how your species reproduces</td>
</tr>
<tr>
<td>6.</td>
<td>Information on where it gets energy and what other organisms feed on it</td>
</tr>
<tr>
<td>7.</td>
<td>Adaptations to fire and relationships with fire (do certain types of fire kill it or help it? If so, how?)</td>
</tr>
<tr>
<td>8.</td>
<td>Information on typical fire regimes in its habitat (surface or crown fires? How often?)</td>
</tr>
<tr>
<td>9.</td>
<td>Effects of fire exclusion (what happens if fire does not occur for a long time?)</td>
</tr>
<tr>
<td>10.</td>
<td>Information sources, cited with MLA format</td>
</tr>
</tbody>
</table>

**Presentation**

(10 points total)

**Two points for each criterion listed in Handout H14-1, Step #2:**

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)

See **Teacher’s Key to Handout 14-2. Quiz on species’ relationships with fire** below.

- 1 point for complete information on each animal and plant (10 points total)
- 5 points for thorough description of fire-dependent species
<table>
<thead>
<tr>
<th>Organism</th>
<th>Main forest ecosystem*</th>
<th>In FEIS**?</th>
<th>Student assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>American black bear (<em>Ursus americanus</em>)</td>
<td>All</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>American marten (<em>Martes americana</em>)</td>
<td>All moist, old forests. Especially likes fir trees</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Three-toed woodpecker (<em>Picoides tridactylus</em>)</td>
<td>All, especially LP because of tendency toward crown fire</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Armillaria root fungus (<em>Armillaria species</em>)</td>
<td>PP, in fir trees</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Arrowleaf balsamroot (<em>Balsamorhiza sagittata</em>)</td>
<td>PP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Beargrass (<em>Xerophyllum tenax</em>)</td>
<td>Mainly LP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Black cottonwood (<em>Populus balsamifera</em> subsp. <em>trichocarpa</em>)</td>
<td>PP or moist ravines at higher elevations</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Black-backed woodpecker (<em>Picoides arcticus</em>)</td>
<td>All, especially LP because of tendency toward crown fire</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Blue huckleberry (<em>Vaccinium membranaceum</em>)</td>
<td>Mainly LP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Clark’s nutcracker (<em>Nucifraga Columbiana</em>)</td>
<td>All, but especially adapted to WB</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Douglas-fir mistletoe (<em>Arceuthobium douglasii</em>)</td>
<td>Mainly PP, also LP</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Elk (<em>Cervus elaphus</em>)</td>
<td>Mainly PP, also LP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Engelmann spruce (<em>Picea engelmannii</em>)</td>
<td>Uses all forest types, depending on season and food.</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Fireweed (<em>Chamerion angustifolium</em>)</td>
<td>Mainly LP, but also moist ravines at lower and higher elevations</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Flammulated owl (<em>Oteus flammeolus</em>)</td>
<td>Mainly LP but also PP and some WB forests</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Glacier lily (<em>Erythronium grandiflorum</em>)</td>
<td>PP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Grizzly bear (<em>Ursus arctos horribilis</em>)</td>
<td>LP, WB, some PP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Grouse whortleberry (<em>Vaccinium scoparium</em>)</td>
<td>All, but especially loves WB because of its seeds</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Heartleaf arnica (<em>Arnica cordifolia</em>)</td>
<td>WB, some LP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Mountain pine beetle (<em>Dendroctonus ponderosae</em>)</td>
<td>Mainly PP and LP</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Northern flicker (<em>Colaptes auratus</em>)</td>
<td>LP. Also occurs mixed with PP &amp; WB.</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Pileated woodpecker (<em>Dryocopus pileatus</em>)</td>
<td>LP &amp; PP. Thrives especially in dense LP forests that develop after crown fire.</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Pinegrass (<em>Calamagrostis rubescens</em>)</td>
<td>All</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Plant Name</td>
<td>Distribution</td>
<td>Presence</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>--------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>Ponderosa pine (&lt;em&gt;Pinus ponderosa&lt;/em&gt;)</td>
<td>PP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Quaking aspen (&lt;em&gt;Populus tremuloides&lt;/em&gt;)</td>
<td>Mainly PP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Red squirrel (&lt;em&gt;Tamiasciurus hudsonicus&lt;/em&gt;)</td>
<td>Mainly PP, also some LP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Red-backed vole (&lt;em&gt;Myodes rutilus&lt;/em&gt;)</td>
<td>LP, also moist spots in PP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Rocky Mountain Douglas-fir (&lt;em&gt;Pseudotsuga menziesii var. glauca&lt;/em&gt;)</td>
<td>All. Really likes WB cones.</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Rocky Mountain lodgepole pine (&lt;em&gt;Pinus contorta var. latifolia&lt;/em&gt;)</td>
<td>All habitat that is shady and moist</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Saskatoon serviceberry (&lt;em&gt;Amelanchier alnifolia&lt;/em&gt;)</td>
<td>PP, also some LP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Smooth woodrush (&lt;em&gt;Luzula hitchcockii&lt;/em&gt;)</td>
<td>Mainly WB, also in LP if enough moisture is available.</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Snowbrush ceanothus (&lt;em&gt;Ceanothus velutinus&lt;/em&gt;)</td>
<td>LP and PP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Subalpine fir (&lt;em&gt;Abies lasiocarpa&lt;/em&gt;)</td>
<td>LP &amp; WB</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Western larch (&lt;em&gt;Larix occidentalis&lt;/em&gt;)</td>
<td>PP &amp; LP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Western redcedar (&lt;em Thuja plicata&lt;/em&gt;)</td>
<td>PP, mainly in deep, moist valleys</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>White pine blister rust (&lt;em&gt;Cronartium ribicola&lt;/em&gt;)</td>
<td>WB</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Whitebark pine (&lt;em&gt;Pinus albicaulis&lt;/em&gt;)</td>
<td>WB, some LP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Wild onion (&lt;em&gt;Allium species&lt;/em&gt;)</td>
<td>All</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

*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. 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 (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 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.

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.

<table>
<thead>
<tr>
<th>Species name</th>
<th>What is its relationship with fire?</th>
<th>What might happen without fire?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animals:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
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<tr>
<td>3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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........

<table>
<thead>
<tr>
<th>Species name</th>
<th>What is its relationship with fire?</th>
<th>What might happen without fire?</th>
</tr>
</thead>
<tbody>
<tr>
<td>American black bear (Ursus americanus)</td>
<td>Can escape almost any kind of fire. Feeds well on postfire herbs.</td>
<td>Some of its foods, especially berries, will decline.</td>
</tr>
<tr>
<td>American marten (Martes americana)</td>
<td>OK with surface fire, prefers no fire.</td>
<td>Will thrive... unless/until severe fire comes through.</td>
</tr>
<tr>
<td>Three-toed woodpecker (Picoides tridactylus)</td>
<td>Prefers forests after crown fire/severe fire.</td>
<td>Will decline.</td>
</tr>
<tr>
<td>Armillaria root fungus (Armillaria species)</td>
<td>Survives most fires underground but grows best in old forests.</td>
<td>Will thrive.</td>
</tr>
<tr>
<td>Arrowleaf balsamroot (Balsamorhiza sagittata)</td>
<td>Sprouts after any fire from caudex (thick underground stem).</td>
<td>Will produce fewer flowers and sprouts less as shade increases.</td>
</tr>
<tr>
<td>Beargrass (Xerophyllum tenax)</td>
<td>Grows back after fire from thick rhizomes, but these are close to surface and can be killed by fire.</td>
<td>Will not be as widespread.</td>
</tr>
<tr>
<td>Black cottonwood (Populus balsamifera subsp. trichocarpa)</td>
<td>Thick bark protects from some surface fires. May sprout from base &amp; roots if top is killed by fire.</td>
<td>Will not be affected much.</td>
</tr>
<tr>
<td>Black-backed woodpecker (Picoides arcticus)</td>
<td>Prefers severely burned forests because beetles are abundant.</td>
<td>Will decline.</td>
</tr>
<tr>
<td>Blue huckleberry (Vaccinium membranaceum)</td>
<td>Sprouts after most fires. Grows well in openings created by severe fires. Produces abundant berries decades after fire.</td>
<td>Will not be as widespread or produce as many berries.</td>
</tr>
<tr>
<td>Clark’s nutcracker (Nucifraga Columbiana)</td>
<td>Escapes fires. Caches seeds in fire-created openings.</td>
<td>May not cache whitebark pine seeds in best places for new trees to grow.</td>
</tr>
<tr>
<td>Douglas-fir mistletoe (Arceuthobium douglasii)</td>
<td>Survives surface fires because they do not kill host tree. Killed by crown fire.</td>
<td>Will thrive... unless/until severe fire comes through.</td>
</tr>
<tr>
<td>Elk (Cervus elaphus)</td>
<td>Can escape any kind of fire. Thrives on variety in habitat, including abundant browse in years after fire.</td>
<td>Some foods, especially shrubs for browse, will be less abundant.</td>
</tr>
<tr>
<td>Engelmann spruce (Picea engelmannii)</td>
<td>Does not usually survive any kind of fire.</td>
<td>Will thrive.</td>
</tr>
<tr>
<td>Fireweed (Chamerion angustifolium)</td>
<td>Sprouts from rhizomes after fire, then produces abundant seedlings in openings created by severe fire.</td>
<td>Will be less abundant and produce fewer flowers.</td>
</tr>
<tr>
<td>Flammulated owl (Oteus flammeolus)</td>
<td>Prefers a mix of thickets and openings created by surface fires, especially if they are patchy.</td>
<td>Will decline as openings between thickets fill in with young trees.</td>
</tr>
<tr>
<td>Glacier lily (Erythronium grandiflorum)</td>
<td>Sprouts from deep corm (underground stem) after any fire.</td>
<td>May flower less.</td>
</tr>
<tr>
<td>Animal/Marine Species</td>
<td>Ecological Response</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Grizzly bear (<em>Ursus arctos horribilis</em>)</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Grouse whortleberry (<em>Vaccinium scoparium</em>)</td>
<td>Sprouts from rhizomes after most fires unless fire burned off the duff layer. Fires are often patchy in its habitat. May produce fewer berries.</td>
<td></td>
</tr>
<tr>
<td>Heartleaf arnica (<em>Arnica cordifolia</em>)</td>
<td>Sprouts from rhizomes after most fires. Produces abundant seedlings after fire. Will produce fewer flowers.</td>
<td></td>
</tr>
<tr>
<td>Mountain pine beetle (<em>Dendroctonus ponderosae</em>)</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Northern flicker (<em>Colaptes auratus</em>)</td>
<td>Escapes fires. Thrives in fire-killed trees because they have abundant beetles. Will probably not be affected much.</td>
<td></td>
</tr>
<tr>
<td>Pileated woodpecker (<em>Drycopus pileatus</em>)</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Pinegrass (<em>Calamagrostis rubescens</em>)</td>
<td>Sprouts from rhizomes after most fires. Thrives and produces abundant seed in sunny conditions after fire. Will probably produce fewer flowers and seeds.</td>
<td></td>
</tr>
<tr>
<td>Ponderosa pine (<em>Pinus ponderosa</em>)</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Quaking aspen (<em>Populus tremuloides</em>)</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Red squirrel (<em>Tamiasciurus hudsonicus</em>)</td>
<td>Avoids habitat with big openings created by large, severe fires. Will probably thrive, except that food may decline as whitebark pines decline.</td>
<td></td>
</tr>
<tr>
<td>Red-backed vole (<em>Myodes rutilus</em>)</td>
<td>Can hide in burrow from fires but finds little food in recently burned environment. Will probably thrive.</td>
<td></td>
</tr>
<tr>
<td>Rocky Mountain Douglas-fir (<em>Pseudotsuga menziesii var. glauca</em>)</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Rocky Mountain lodgepole pine (<em>Pinus contorta var. latifolia</em>)</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Saskatoon serviceberry (<em>Amelanchier alnifolia</em>)</td>
<td>Sprouts from rhizomes after most fires. Produces best berry crops in sunny openings. Will not produce as many berries.</td>
<td></td>
</tr>
<tr>
<td>Smooth woodrush (<em>Luzula hitchcockii</em>)</td>
<td>Sprouts from rhizomes after fire, thrives in fire-created openings. Fires are often patchy in its habitat. Will probably not be affected much.</td>
<td></td>
</tr>
<tr>
<td>Plant/Species</td>
<td>Description</td>
<td>Fate</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Snowbrush ceanothus (<em>Ceanothus velutinus</em>)</td>
<td>Crown fires produce heat that opens seeds. Plants can also sprout from roots after fire kills top.</td>
<td>Will become less abundant.</td>
</tr>
<tr>
<td>Subalpine fir (<em>Abies lasiocarpa</em>)</td>
<td>Does not usually survive any kind of fire.</td>
<td>Will probably thrive.</td>
</tr>
<tr>
<td>Western larch (<em>Larix occidentalis</em>)</td>
<td>Has thick bark so survives surface fires and sometimes survives crown fires. Reproduces very well in sunny, fire-created openings.</td>
<td>Will gradually become less abundant because seedlings cannot thrive in shade or on duff.</td>
</tr>
<tr>
<td>Western redcedar (<em>Thuja plicata</em>)</td>
<td>Habitat rarely burns. Can survive some surface fires because of thick bark.</td>
<td>Will probably thrive.</td>
</tr>
<tr>
<td>White pine blister rust (<em>Cronartium ribicola</em>)</td>
<td>Dies if host tree (whitebark pine) is killed by fire, but spores are widely available to infest other, living whitebark pines.</td>
<td>Will decline as whitebark pines decline.</td>
</tr>
<tr>
<td>Whitebark pine (<em>Pinus albicaulis</em>)</td>
<td>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.</td>
<td>Will reproduce less as duff accumulates and Clark’s nutcrackers cache seeds in areas where young trees grow poorly.</td>
</tr>
<tr>
<td>Wild onion (<em>Allium species</em>)</td>
<td>Can sprout after any fire that does not kill its bulb.</td>
<td>Will probably not be affected much.</td>
</tr>
</tbody>
</table>

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 dependent* 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/reproduce prolifically. 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.

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1 Description adapted from [http://www.nwsg.gov/glossary/a-z](http://www.nwsg.gov/glossary/a-z).
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.

Depending on how you choose to teach it, this activity may require independent work by students to prepare for later team or class work. The need for independent work means the activity will 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.

<table>
<thead>
<tr>
<th>Standards:</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCSS</td>
<td>Reading: Literature</td>
<td>1,2,4,10</td>
<td>1,2,4,10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reading: Informational Text</td>
<td>1,2,4,10</td>
<td>1,2,4,10</td>
<td></td>
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<td></td>
<td>Speaking and Listening</td>
<td>1,2,6</td>
<td>1,2,6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reading: Science and Technical Subjects</td>
<td>1,2,4,9,10</td>
<td>1,2,4,9,10</td>
<td></td>
</tr>
<tr>
<td>EEEGL</td>
<td>Strand 1</td>
<td>B,C,E,F,G</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**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 are likely to occur together, forming unique forest communities. This version of *FireWorks* covers 10 tree species and how they are associated within forest communities, especially the 3 community types that are the focus of this curriculum:

- forests dominated by ponderosa pine and Douglas-fir
- forests dominated by lodgepole pine and subalpine fir
- forests dominated by whitebark pine and subalpine fir

Students learned how to identify the 10 tree species in **Activity 13. Tree Identification: Create a Dichotomous Key**, and they learned about the species’ ecology in **Activity 14. Researching a Plant, Animal, or Fungus**.

In this activity, students use information from a table (see **Handout H15-1: Distributions of 10 tree species**) 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). Then, in **Assessment #1**, they use the model to:

- describe temperature and moisture conditions in 3 forest communities
- identify the species that might occur in these 3 forest communities
- predict how climate change might alter conditions in a particular location and thus alter the distribution of tree species and the species composition of the community

As the world’s climate changes, locations that favored certain tree species in the past may no longer provide conditions in which they can thrive and reproduce. There may be other locations where they could live, but if their seeds cannot reach those places, they may gradually die out. For this reason, some people propose to deliberately introduce the species to locations that may be more hospitable to them in the future. This is called **assisted migration**.

After creating their graphical models, students read an article about the controversy over assisted migration. The article should get students thinking about the issue. Then they participate in a “Walk the Line” activity to clarify their opinions. Finally, in **Assessment #2**, 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 and prepare to present *H15_ForestCommunitiesIntroduction.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. Review the Procedures for **DAY 1** below. In Step 6, decide how you will have students create their gradient models. If you plan to use Option A or B – “Fully guided” or “Sort-of guided”:
   - print 1 copy/student of *Handout H15-2: Modeling forest communities*
   - Download *H15_ForestCommunitiesGradientModel.pptx*
   - Make sure each student has markers or colored pencils - 10 colors other than black.

4. 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/](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](https://earlycareerecologists.wordpress.com/2013/01/16/trees-on-the-move-debating-assisted-migration-in-climate-change-mitigation/)). Make copies if necessary.

Procedure:

**DAY 1 – Hook and developing the gradient model:**

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

Where in the world would ponderosa pine like to live?

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 too cold.

Slide 3

Where in the world would ponderosa pine like to live? And who would its neighbors be?

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 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.
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? Photo credits available in slide.

We’re going to create a model that shows some of the environmental conditions needed by our 10 tree species. That will show us the species that are likely to occur in the forest communities we’ll focus on as we study the history and management of wildland fire: Northern Rocky Mountain Ponderosa Pine communities, Rocky Mountain Lodgepole Pine communities, and Whitebark 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.


5. Explain: We will create a model to show how our 10 tree species are associated with each other in forest communities. Then we will zero in on the 3 forest communities that we’ll focus on as we study fire: 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.

6. Complete gradient models using 1 of these options, depending on how intensively you want to guide the students:

   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 draw this model on Handout H15-2. Modeling forest communities 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. Modeling forest communities to create their own gradient models using this template.

   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.

7. Regardless of which option you used (above) for developing the graphical models, have students label these 3 forest communities: ponderosa pine/Douglas-fir, lodgepole pine/subalpine fir, and whitebark pine/subalpine fir – or use Slide 4 to show the environmental conditions where these communities occur.

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**H15_ForestCommunitiesGradientModel.pptx:**

Here’s a template for assembling a gradient model using the information on forest communities in the table (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.

Here’s the template with 1 species described, following the directions on Handout H15-2. Modeling forest communities.

Here’s an example of a completed gradient model using the template.

This model shows some of the environmental conditions needed by the 3 “focus” forest communities. It also shows species that have somewhat similar needs, so they could also occur in the 3 focus communities.

**DAY 2 – Interpreting and using the model(s)**

1. Have students get together in small groups. If you used Option B or C above, have students compare and discuss their models. Are the models fairly similar? (You should expect some variation.) What might account for the 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 correctly.
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 a species’ needs to those of another species.
- Substituting elevation for temperature... and distance from a stream for moisture... oversimplify 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 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:

1. With the whole class or in groups or as homework, have students complete Handout H15-3. Use a model to predict the future.

Assessment #2:

2. 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.

3. 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 about the issue and your opinions.

4. **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:

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.”

5. 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:

<table>
<thead>
<tr>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gradient model:</strong> See Slides 3-4 in <strong>H15_ForestCommunitiesGradientModel.pptx</strong>. Most students should be very successful with this if they checked their models in class (see DAY 2, Step 1 above).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correctly showed 8-10 species distributions.</td>
<td>Correctly showed 5-7 species distributions.</td>
<td>Correctly showed fewer than 5 species distributions.</td>
</tr>
<tr>
<td>Correctly showed locations of 3 forest communities.</td>
<td>Correctly showed locations of 2 forest communities.</td>
<td>Correctly showed locations of 0-1 forest community.</td>
</tr>
</tbody>
</table>

**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. |

**Reflection essay**

- 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.
- 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.
- 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.
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.

<table>
<thead>
<tr>
<th>Tree Species</th>
<th>Need for moisture</th>
<th>Elevations where this species is most common (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black cottonwood</td>
<td>high</td>
<td>500-1400</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>low to medium</td>
<td>500-2000</td>
</tr>
<tr>
<td>Engelmann spruce</td>
<td>medium to high</td>
<td>1300-2400</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>low to medium</td>
<td>1500-2300</td>
</tr>
<tr>
<td>Quaking aspen</td>
<td>medium to high</td>
<td>500-1900</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>low</td>
<td>500-1700</td>
</tr>
<tr>
<td>Subalpine fir</td>
<td>medium</td>
<td>1400-2500</td>
</tr>
<tr>
<td>Western larch</td>
<td>medium</td>
<td>800-2000</td>
</tr>
<tr>
<td>Western redcedar</td>
<td>high</td>
<td>500-1700</td>
</tr>
<tr>
<td>Whitebark pine</td>
<td>low</td>
<td>1800-2600</td>
</tr>
</tbody>
</table>

Sources:

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


Handout H15-2: Modeling forest communities

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 changes as predicted?

9. What tree species are likely to show up on these sites as climate changes?

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... and black cottonwood, although the graphic does not suggest this.

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.


8. What is likely to happen to whitebark pine/subalpine fir communities if the climate changes as predicted? 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 as climate changes? 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.
Students have been learning about the physical science of fire and the ecology of 3 forest communities that occur from the northern Rocky Mountains to the North Cascades: forests historically dominated by ponderosa pine, lodgepole pine, and whitebark pine. Each of these forest types is comprised of species that, together, are adapted to a particular pattern of fire frequency, severity, and spatial pattern – a particular historical fire regime. In this unit, students learn about different fire regimes and the regimes historically typical of the 3 forest types. They consider the changes in these fire regimes that have occurred over the past century and the potential effects of these changes on forest communities.

Throughout the unit, students use specimens, photos, data, diagrams, and maps from the studies cited below. We selected the data from these studies to illustrate specific concepts, and we included increment cores and tree cookies from the studies only if they could be scanned at high enough resolution to be interpretable by students. Therefore, the FireWorks activities do not fully cover scope and implications of the research:


In the first activity of this unit (Activity M17 & H16), students learn about the methods that scientists use to determine the history of fire for a specific area. They are required to learn 10 terms that are used throughout the unit.

In the second activity (M18 & H17), students examine tree increment cores to determine when a cohort of trees began to grow. They construct a stand history diagram, which shows that the trees all originated within a 20-year period. This provides evidence that the trees became established shortly after a stand-replacing fire.
In the third activity (M19 & H18), students examine cross sections (tree cookies) sampled from trees that were scarred by low-severity fires. A stand history diagram shows evidence of spatial variation in fire spread throughout the forest.

In the fourth activity (H19), students combine the information they have already gleaned about stand-replacing fire and low-severity fire to understand the nature of mixed-severity fire. By the end of this activity, they can visualize how a forest might have looked at different times in its history.

In the final activity (H20), students connect their new understanding about the 3 kinds of historical fire regimes with the 3 forest types they have been studying throughout the curriculum (forests dominated by ponderosa, lodgepole, and whitebark pines). They learn about the historical fire regime and recent changes in each of these types, and they can articulate some of the effects of those changes on wildlands and/or human communities.
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.

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.

<table>
<thead>
<tr>
<th>Middle School Standards:</th>
<th>6th</th>
<th>7th</th>
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<td>1,4,10</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>NGSS</td>
<td>Structure, Function, and Information Processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Selection and Adaptation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>History of Earth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEEGL</td>
<td>Strand 1</td>
<td>A,B,C,E,F,G</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strand 2.2</td>
<td>A</td>
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**High School Standards:**

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<th>10th</th>
<th>11th</th>
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<tr>
<td></td>
<td>3,5,7,10</td>
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<tr>
<td>Writing Science/Technical Subjects</td>
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<td></td>
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<tr>
<td>Science/Technical Subjects</td>
<td>7,10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Structure and Function</td>
<td>LS1.A</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>History of Earth</td>
<td>ESS1.C, ESS1.A</td>
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<td></td>
</tr>
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<td></td>
<td>Earth's Systems</td>
<td>ESS2.A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEEGL</td>
<td>Strand 1</td>
<td>C,E,F,G</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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.fed.us/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.


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:


**Materials and Preparation:**

1. Download *M17andH16_U singDendroForFireHistory.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? 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.nwcg.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.
Wildfires during 365 days, 18 July 2016 to 17 July 2017

Data from the United States Incident Information System:
https://inciweb.nwcg.gov/

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

3. Explain: One way to answer the question “Are our forests OK?” is to compare current patterns of wildland fire with the historical patterns to which native plants and animals are adapted. 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.
A note about the blue information boxes in the slides: These contain interesting information that supplements slide content and answers questions sometimes asked by students, but this information is not essential for completing the activity.

Slide 1

**Aging Trees Using Dendrochronology**

The science of studying tree rings to learn about history.

- **Go figure:** How many years did this tree live?

Slide 2

Annual rings are the yearly produced distinct layer of growth. An annual ring is shaped like a circle. Each ring contains all of the wood that the tree produced in previous years.

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

Slide 3

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

Slide 4

Annual rings are the yearly produced distinct layer of growth. An annual ring is shaped like a circle. Each ring contains all of the wood that the tree produced in previous years.

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

Slide 5

**Answer:** In summer, when the days are longest, moisture is usually abundant. The sap is moving up, and the tree can use nutrients stored up during the previous growing season.

Slide 6

**Answer:** Use dendrochronology. Dendrochronology is usually based on information from increment cores.

- **Go figure:** How can you connect information on annual rings to the past?
Go figure: How many fires are in this cattail?

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, collect a piece of wood. A thin slice cut from a tree’s trunk, usually near the base, can be taken to identify the tree’s fire history. Fire scars are the raised, brown rings that appear on the tree’s bark. Each ring represents a year of growth, and the width of the ring can indicate the intensity of the fire. A wider ring suggests a more severe fire, while a narrow ring indicates a less severe fire.

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

Answer: The cattails contain scars from many fires.

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

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

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

Go figure: How many fires are in this cattail?

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, collect a piece of wood. A thin slice cut from a tree’s trunk, usually near the base, can be taken to identify the tree’s fire history. Fire scars are the raised, brown rings that appear on the tree’s bark. Each ring represents a year of growth, and the width of the ring can indicate the intensity of the fire. A wider ring suggests a more severe fire, while a narrow ring indicates a less severe fire.

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Go figure: How many fires are in this cattail?

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6. Fire scars
7. Increment core
8. Low-severity fire
9. Major fire
10. Pith
11. Stand-replacing fire
12. Tree core
**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.
<table>
<thead>
<tr>
<th>Evaluation:</th>
<th>Excellent</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OPTION 1: Matching</strong>&lt;br&gt;(Handout M17 &amp; H16-1)</td>
<td>8-11 answers correct</td>
<td>6-7 answers correct</td>
<td>Fewer than 6 answers correct</td>
</tr>
<tr>
<td><strong>OPTION 2: Writing assignment</strong></td>
<td>Paragraph uses 8-11 terms correctly.</td>
<td>Paragraph uses 6-7 terms correctly.</td>
<td>Paragraph uses fewer than 6 terms correctly.</td>
</tr>
<tr>
<td></td>
<td>Paragraph accurately describes use of dendrochronology to study fire history.</td>
<td>Paragraph describes use of dendrochronology to study fire history with moderate accuracy.</td>
<td>Paragraph contains numerous inaccuracies or omits important concepts.</td>
</tr>
<tr>
<td></td>
<td>Paragraph contains an appropriate topic sentence.</td>
<td>Paragraph contains an appropriate topic sentence.</td>
<td>Paragraph does not contain an appropriate topic sentence.</td>
</tr>
<tr>
<td></td>
<td>Paragraph uses complete sentences.</td>
<td>Paragraph uses complete sentences.</td>
<td>Paragraph does not use complete sentences.</td>
</tr>
<tr>
<td></td>
<td>Paragraph is clear and coherent.</td>
<td>Paragraph is clear.</td>
<td>Paragraph is not clear.</td>
</tr>
</tbody>
</table>
## Handout M17 & H16-1. Vocabulary for Fire Historians

Name: ______________________________

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

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Annual ring</td>
<td>___ A fire that has does not change the soil very much and kills very few of the mature trees.</td>
</tr>
<tr>
<td>B. Catface</td>
<td>___ The science of learning about the past by dating annual rings in living and dead trees.</td>
</tr>
<tr>
<td>C. Cohort</td>
<td>___ 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.</td>
</tr>
<tr>
<td>D. Dendrochronology</td>
<td>___ 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.</td>
</tr>
<tr>
<td>E. Fire scar</td>
<td>___ A fire that kills all or most of the mature trees and provides good conditions for growing a new generation of trees.</td>
</tr>
<tr>
<td>F. Increment core</td>
<td>___ A thin cylinder of wood that is removed from a tree so the tree’s annual rings can be studied.</td>
</tr>
<tr>
<td>G. Low-severity fire</td>
<td>___ A fire that has does not change the soil very much and kills very few of the mature trees.</td>
</tr>
<tr>
<td>H. Pith</td>
<td>___ A fire that kills all or most of the mature trees and provides good conditions for growing a new generation of trees.</td>
</tr>
<tr>
<td>I. Stand-replacing fire</td>
<td>___ A thin cylinder of wood that is removed from a tree so the tree’s annual rings can be studied.</td>
</tr>
<tr>
<td>J. Tree cookie</td>
<td>___ A cross section or narrow sample of wood taken from a tree trunk so the tree’s annual rings can be studied.</td>
</tr>
<tr>
<td>K. Cambium</td>
<td>___ 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.</td>
</tr>
<tr>
<td></td>
<td>___ A group of living things that are similar in age.</td>
</tr>
<tr>
<td></td>
<td>___ A strand of spongy tissue that runs through the center of a tree trunk or branch.</td>
</tr>
<tr>
<td></td>
<td>___ The layer of living cells under a tree’s bark that produces the annual rings</td>
</tr>
</tbody>
</table>
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/), the Swiss Federal Institute for Forest, Snow and Landscape Research WSL (http://www.wsl.ch/index_EN), 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.
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 determine 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 in order to record observations and help assemble a stand history diagram.
- Students can describe the fire history shown by a stand history diagram that contains 2 cohorts of trees.

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

Duration: one 30-40-minute session

Group size: Whole class

Setting: Classroom

FireWorks 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.

<table>
<thead>
<tr>
<th>Middle School Standards:</th>
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<th>7th</th>
<th>8th</th>
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<td>1,2,4,6</td>
<td>1,2,4,6</td>
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<td>1,4,10</td>
<td>1,4,10</td>
<td>1,4,10</td>
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<tr>
<td>CCSS Writing: Science and Technology</td>
<td></td>
<td>3,4,7,9,10</td>
<td></td>
</tr>
<tr>
<td>NGSS Structure, Function, and Information Processing</td>
<td></td>
<td>LS1,A</td>
<td></td>
</tr>
<tr>
<td>NGSS Natural Selection and Adaptation</td>
<td></td>
<td>LS4,C</td>
<td></td>
</tr>
<tr>
<td>NGSS History of Earth</td>
<td></td>
<td>ESS2.C</td>
<td></td>
</tr>
<tr>
<td>EEEGL Strand 1</td>
<td></td>
<td>A,B,C,E,F,G</td>
<td></td>
</tr>
<tr>
<td>EEEGL Strand 2.2</td>
<td></td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>
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:


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: 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. Find in the trunk and display in classroom: the poster that shows a map and photos of the area where the increment cores and tree cookies used in FireWorks were collected. You can also project the poster from this file: *PotholesStudyArea.pptx.*

2. Find in the trunk: 11 photos of increment cores. (These are about 20-40 cm long and quite narrow. They are usually bundled into an envelope or a roll. An example is shown below.) The core photos can also be printed from *IncrementCorePhotos.pptx.*

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.* You can assemble the stand-replacing stand history diagram (on this poster) on a large table or on the floor. Have masking 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 (then laminated) from *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 perhaps cleaning fluid.

- 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 poster or 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. Then we can 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, a dry-erase marker, a blank timeline, and a half-page handout with instructions (Handout M18 & H17-1. Record tree history on a timeline). Explain: Dendrochronologists have already dated each of your increment cores. They used small dots to mark the rings every 10 years, and each dot on your core photo identifies the year of that ring. Some core photos are also marked to show where the bark begins. Figure out the earliest and most recent years shown on your core (don’t count the bark), transfer that information to your timeline, and place the timeline on the stand history diagram background. These instructions are on your half-page handout.

4. 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.

<table>
<thead>
<tr>
<th>Species</th>
<th>Tree number</th>
<th>Earliest date</th>
<th>Final date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lodgepole pine</td>
<td>6</td>
<td>1890</td>
<td>2009</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>7</td>
<td>1902</td>
<td>2009</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>9</td>
<td>1895</td>
<td>2009</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>18</td>
<td>1887</td>
<td>2009</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>19</td>
<td>1906</td>
<td>2009</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>20</td>
<td>1893</td>
<td>2009</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>21</td>
<td>1895</td>
<td>2009</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>23</td>
<td>1893</td>
<td>2009</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>25</td>
<td>1896</td>
<td>2009</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>27</td>
<td>1894</td>
<td>1982</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>29</td>
<td>1887</td>
<td>2009</td>
</tr>
</tbody>
</table>
5. 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.

6. 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).

7. 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.

8. 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.

9. DON’T TAKE THE STAND HISTORY DIAGRAM OR THE STUDY AREA POSTER 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:**

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Format</strong></td>
<td>Used correct business letter format</td>
<td>Used letter format</td>
<td>Did not use letter format</td>
</tr>
<tr>
<td><strong>Writing</strong></td>
<td>Writing is clear. Used full sentences. Used topic sentences for paragraphs.</td>
<td>Writing is clear. Used full sentences.</td>
<td>Writing is unclear or sentences are incomplete.</td>
</tr>
<tr>
<td><strong>Content:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identified period when old cohort began growing</td>
<td>approximately 1770-1785</td>
<td>approximately 1770-1785</td>
<td>One or both dates inaccurate by more than 5 years.</td>
</tr>
<tr>
<td>Identified possible cause for beginning of old cohort</td>
<td>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.</td>
<td>Old cohort could have started after fire (or other cause). Did not discuss lack of evidence for fire.</td>
<td>Did not suggest a reasonable cause for beginning of old cohort.</td>
</tr>
<tr>
<td>Identified year of death for old cohort</td>
<td>Most of the trees died around 1877, although two of them died earlier.</td>
<td>Most of the trees died around 1877.</td>
<td>Date inaccurate by more than 5 years.</td>
</tr>
<tr>
<td>Gave explanation for death of old cohort</td>
<td>Fire was probably the cause, since so many of the logs in this cohort were black and charred.</td>
<td>Fire was probably the cause, since so many of the logs in this cohort were black and charred.</td>
<td>Did not identify a cause or did not explain evidence.</td>
</tr>
<tr>
<td>Connected death of old cohort to beginning of more recent (1887-1906) cohort</td>
<td>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.</td>
<td>Explained that old cohort died just before the more recent cohort began growing but did not explain the possible connection between the two.</td>
<td>Did not identify a reasonable explanation for the relationship between the two cohorts.</td>
</tr>
</tbody>
</table>
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 & H17-2. 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 gray box 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 for your work. 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 determine 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
Lesson Overview: Students create a living model to demonstrate how fire scars form. 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 policy of full fire suppression.

Lesson Goals: Students understand that low-severity fires were common in some forests during the past and were sometimes patchy, sometimes more uniform in their pattern of spread. Students understand that low-severity fires are less common now, at least partly due to a decades-long policy of fire suppression. They 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:

<table>
<thead>
<tr>
<th>CCSS</th>
<th>6th</th>
<th>7th</th>
<th>8th</th>
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<tbody>
<tr>
<td>Speaking and Listening</td>
<td>1,2,4,6</td>
<td>1,2,4,6</td>
<td>1,2,4,6</td>
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<tr>
<td>Writing</td>
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<tbody>
<tr>
<td>Structure, Function, and Information Processing</td>
<td></td>
<td>LS1.A</td>
<td></td>
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<tr>
<td>Natural Selection and Adaptation</td>
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<td>LS4.C</td>
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<tr>
<td>History of Earth</td>
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<tr>
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<td>A,B,C,E,F,G</td>
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<tr>
<td>Strand 2.2</td>
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<tr>
<td>Structure and Function</td>
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<td>Earth's Systems</td>
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<tbody>
<tr>
<td>Strand 1</td>
<td></td>
<td>C,E,F,G</td>
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</table>

**Teacher Background:** In this activity and the next one, students continue to analyze samples and data from the following study:

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 discussion of causes of variation.

In this activity, students examine tree-cookie photos with fire scars. The cookies are more complicated than the increment cores used in the last activity. 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 inner wood and other wood in injured areas of the trunk is dark because it is filled with pitch rather than sap. Pitch helps a 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 Study Area poster and the Stand History Diagram from the previous activity 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 (cut a piece of plastic from a black garbage bag).
3. Find in the trunk:
   - a small whisk broom
   - 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 masking tape on hand for attaching timelines.
   - the set of 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: Handout M19 & H18-3. How well did the policy work? 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 http://www.foresthistory.org/ASPNET/Policy/Fire/Suppression/Suppression.aspx.

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. Each team will also need 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 perhaps 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 scissors and tape.
Procedures:

1. Explain and refer to the poster 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 tree and then for a forest in the same study area we looked at before, in central Oregon.

2. **REVIEW: Human model of fire scar formation.** Explain: We’re going to look at tree cookies with fire scars. 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.

3. Follow these directions or see a demonstration online at: www.youtube.com/watch?v=MyFBYQh_S_M.
   
   a) One student holds his/her arms out in a circle, forming a ring that represents the tree’s cambium – that is, the sheath of living cells right under the bark that form xylem and phloem – and are essential for continued growth.

   b) Ask the students to imagine that the “tree” is facing uphill and a low-severity surface fire is coming up from behind it, running uphill. Select a student to represent the surface fire, using the whisk broom to burn from the “downhill” side of the tree around it to the other side, then continuing “uphill” and away from the tree.

   c) Interview the “tree.” Ask how the fire felt. Point out that the tree is still alive, since it is talking, so this must have been a low-severity 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.

4. Explain: Now we’ll describe fire history from 11 tree cookies collected in central Oregon. We’ll do one together. Then we’ll do the other 10 in teams, and finally we’ll build a stand history diagram with all of the data.

5. Give each student a copy of Handout M19 & H18-1. A Tree’s Story.

6. 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.

7. 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 these changes in the tree’s growth after fire? Slow growth is likely to occur if the fire killed many of the tree's needles or much of the cambium. Rapid growth after fire may be caused if the fire killed nearby plants and...
reduced competition for moisture and nutrients, or by an increase in nutrients in the ash from burned vegetation.

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 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. This uniformity increases the potential for fires to spread across large areas when burning conditions are just right.

8. Hand out 10 of the cookie photo posters, one to each team. Do not use Tree 08, since you already did 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).

9. 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:

10. 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)
11. Ask/discuss: What was the historical fire regime for this forest? The data show a low-severity fire regime, although there have been no low-severity fires since 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.

12. 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. 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 is burning in 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 different plant communities.

13. DON’T TAKE THE STAND HISTORY DIAGRAMS OR THE STUDY AREA POSTER 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:**

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<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
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<tbody>
<tr>
<td>Following directions in handout</td>
<td>Student used 2 or 3 paragraphs.</td>
<td>Student used 2 or 3 paragraphs.</td>
<td>Student did not use multiple paragraphs.</td>
</tr>
<tr>
<td>Writing quality</td>
<td>Student used effective topic sentences, complete sentences throughout, and clear writing style.</td>
<td>Essay was lacking in 1 of these qualities.</td>
<td>Essay was lacking in 2 or more of these qualities.</td>
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**Content:**

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<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
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</thead>
<tbody>
<tr>
<td>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.</td>
<td>Student answered the question and gave supporting information.</td>
<td>Student answered the question but support was weak or lacking.</td>
<td>Student did not answer the question.</td>
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<tr>
<td>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.</td>
<td>Student answered the question and gave supporting information.</td>
<td>Student answered the question but support was weak or lacking.</td>
<td>Student did not answer the question.</td>
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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.

<table>
<thead>
<tr>
<th>Fire year</th>
<th>Fire interval (years)</th>
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2. How many years occurred between each pair of fires? Record your answers above under “Fire interval.”

3. What is the longest fire interval? ________ years

4. What is the shortest fire interval? ________ years

5. What is the average fire interval? ________ years

Specimen furnished by Dr. Emily Heyerdahl.
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.

<table>
<thead>
<tr>
<th>Fire year</th>
<th>Fire interval (years)</th>
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<td>1877</td>
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<td>1741</td>
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<td>33</td>
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<td>1626</td>
<td>46</td>
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<tr>
<td>1580</td>
<td></td>
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</table>

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.
Appendix. Reading on the history of Fire Suppression Policy

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.

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.

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.

Selected Resources:

See  [http://www.foresthistory.org/index.html](http://www.foresthistory.org/index.html)
Lesson Overview: Students use the stand history diagrams that they assembled in the 2 previous activities to learn about mixed-severity fire regimes. They check their skill in identifying historical fire regimes by interpreting stand history diagrams. Finally, in the assessment, they describe or depict the appearance of a forest that has had a historical regime of low-, 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 to 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.

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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 very complicated forests with a mixture of tree species and ages.

In this activity, the class combines the stand-replacing stand history diagram (Activity M18 & H17) with the low-severity one (Activity M19 & H18) to learn about the nature of mixed-severity fire regimes.

Materials and preparation:

- Note that the Study Area poster should still be on display.
- 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.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 or Slide 1 in H19_MixedSeverityRegimes.pptx.
Then go through/discuss the rest of the slides. Take as much time as you need on Slides 3-5, so students learn to visualize the forest at different times in its history.

Slide 1

What happens when you have a mixture of low-severity and stand-replacing fire over time and space? Our stand history diagram showing the fire scars – the low-severity fire regime - is on the left. Our stand history diagram showing the increment cores – the stand-replacing fire regime - is on the right. When we combine them to describe the whole area and all the variety in it, we have a mixture of low-severity and stand-replacing fire. So this whole, big area has a *mixed-severity* fire regime. Can we learn anything new from the big diagram? The cohort that started in the late 1800s probably started after the 1877 fire. This fire also scarred 5 trees, and 3 of them died the next year. The 1877 fire must have had some low-severity areas and some stand-replacing areas.

Slide 2

Mixed-severity fire regimes are pretty common. Here’s an example from a stand with ponderosa pines, Douglas-firs, and other firs. It’s a little more complicated than the diagrams we’ve been using, but the only important difference for us is that the fire scars are shown with black triangles... and the different tree species are shown with different colors. So... tell me 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 grand firs.

Slide 3

If we draw a line through the year 1910, can you picture what that forest probably looked like? 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 grand firs, the beginning of that new cohort.
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 grand firs. They would 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.

Here’s another example of a forest with a history of mixed-severity fire. [Teacher, please note that this graph has a slightly different key, and it will be replaced with a clearer version when the data from the study become available.] This diagram shows the history of whitebark pines in a high-elevation forest. Tell me 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 2 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 whitebarks (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. 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 the whitebark pines looked at these different times.

2. **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.

<table>
<thead>
<tr>
<th>Part 1. Skills check</th>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All 6 answers correct</td>
<td>4 or more answers correct</td>
<td>3 or fewer answers correct</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part 2. Telling/Showing the Story</th>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Story/art work is labeled with plot number, year, and fire regime</td>
<td>The art work is labeled with 2 of these features.</td>
<td>The art work is labeled with 1 or none of these.</td>
<td></td>
</tr>
<tr>
<td>Trees of different species (if present) are visibly different.</td>
<td>3 or more of these features are present.</td>
<td>Fewer than 3 of these features are present.</td>
<td></td>
</tr>
<tr>
<td>Trees in a cohort (if present) are the about the same size.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire scars (if present) are visible.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dead trees (if present) are shown.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saplings/undergrowth are shown if appropriate.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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.

Part 2. Telling or showing the story:
- Select one of the stand history diagrams above. Circle it.
- Select either the year 1900 or the year 2000. 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:

21C

Fire severity pattern: Stand replacing

16H

Fire severity pattern: Mixed severity

22D

Fire severity pattern: Mixed severity

18F

Fire severity pattern: Stand replacing

20E

Fire severity pattern: No fire at all

*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](http://www.ncdc.noaa.gov/paleo/impd/paleofire.html).


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.
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.

Lesson Goals: Students can recognize the most prevalent fire regime for each of 3 forest community types that occur from the northern Rocky Mountains to the North Cascades. They determine whether a fire regime has changed over the past century and explain why changes in fire regimes matter.

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.

<table>
<thead>
<tr>
<th>High School Standards:</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Core ELA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading Informational Texts</td>
<td>1,2,4,</td>
<td></td>
<td>1,2,4</td>
<td></td>
</tr>
<tr>
<td>Speaking and Listening</td>
<td>1,4,</td>
<td></td>
<td>1,4</td>
<td></td>
</tr>
<tr>
<td>Reading Science/Technical Subjects</td>
<td>3,5,7,10</td>
<td></td>
<td>3,5,7,10</td>
<td></td>
</tr>
<tr>
<td>Writing Science/Technical Subjects</td>
<td>7,10</td>
<td></td>
<td>7,10</td>
<td></td>
</tr>
<tr>
<td>Science/Technical Subjects</td>
<td>2,4,5,6,7,8,9,10</td>
<td></td>
<td>2,4,5,6,7,8,9,10</td>
<td></td>
</tr>
</tbody>
</table>
**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.
- 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 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 slide 4 and the 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 information from an extensive literature review in addition to modeling (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:
The Percent of fires by severity columns (low, mixed, and stand-replacement severity for each plant community type) is 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 H20_FireRegimes_3ForestTypes.pptx.
4. Make copies of (or arrange for students to read from the file 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?
2. Go through the presentation H20_FireRegimes_3ForestTypes.pptx:
Review/discuss: Here are some stand history diagrams. What changes do they show? The main change is lack of fire – especially low-severity fire - since 1900. Do the changes matter? Discussion based on what students have learned in their reports on individual species and in the previous 3 activities on fire regimes. A few points: If the fire regime now is radically different from that in historical times (more or less frequent fires, more 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.

Now it’s time to find out if fire regime changes in the 1900s have affected the 3 forest community types we’ve been studying. What are they? 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? Mainly 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....

All of the plants and animals we’ve been studying – and the fire weather we studied – and the smoke data we studied – come from ponderosa pine, lodgepole pine, or whitebark pine communities in this region. Look at where they occur relative to your location. Let’s find out about the historical fire regimes of these 3 forest types.
This table summarizes information from dozens of research studies. We’ll use it in a skills check, and then you can use it in your assignment. Let’s take a little time to read it carefully. [Go through the caption at the top, then the row and column titles.] Let’s try to answer some questions with this information. What are the shortest and longest average fire intervals reported here for the whitebark pine forest type? 43 years and 250 years. Look at the 3 percentages of fire severity in whitebark pine forests. What is the most common kind of fire severity? Mixed severity, since about 41% of fires were of mixed severity. What is the least common fire severity? Low-severity fire, since about 28% of fires were of this severity. But stand-replacement fire (28%) is pretty close. How would you summarize the historical fire regime for the whitebark pine type? It looks like whitebark pine communities can have pretty much any kind of fire regime … they’re all mixed up!

3. Skills check:
   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 make sure 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. One member of each group will write a short blog about fire regimes in ponderosa pine communities, one on lodgepole pine communities, and one on whitebark pine communities.

2. Give copies 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:**

<table>
<thead>
<tr>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headline is 8 words or less, accurate, and interesting.</td>
<td>Headline is accurate but more than 8 words or dull.</td>
<td>No headline is included, or headline is inaccurate.</td>
</tr>
<tr>
<td>Article is 150 words or less.</td>
<td>Article is too long.</td>
<td>Article is too long.</td>
</tr>
<tr>
<td>Article is accurate.</td>
<td>Article has minor inaccuracies.</td>
<td>Article has major inaccuracies.</td>
</tr>
<tr>
<td>Article includes accurate fire interval and severity information.</td>
<td>Article includes accurate fire interval or severity information but not both.</td>
<td>Article includes inaccurate information.</td>
</tr>
<tr>
<td>Article correctly describes 2 or more changes in last 100 years.</td>
<td>Article correctly describes 1 change in last 100 years.</td>
<td>Description of change is inaccurate or missing.</td>
</tr>
<tr>
<td>Article gives 2 or more valid reasons why change(s) matter.</td>
<td>Article gives 1 valid reason why change(s) matter.</td>
<td>Article gives no reason or incorrect reasons why change(s) matter.</td>
</tr>
<tr>
<td>Article includes appropriate illustration with accurate caption, credited appropriately.</td>
<td>Article includes illustration with caption.</td>
<td>Article includes irrelevant illustration or no illustration, or caption/credit is incorrect.</td>
</tr>
</tbody>
</table>

**Suggested content for essays on each of the 3 forest types:**

<table>
<thead>
<tr>
<th>Forest type:</th>
<th>Northern Rocky Mountain ponderosa pine</th>
<th>Rocky Mountain lodgepole pine</th>
<th>Whitebark pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>General fire regime:</td>
<td>Mostly frequent, low-to moderate-severity surface fires. Fires often burned in a patchy/mosaic pattern.</td>
<td>Infrequent stand replacement fires were most common. Some forest types that contain lodgepole pine were likely to have more mixed-severity fire.</td>
<td>Mixed-severity fire regime, that is, fires of severities that varied in space and time, creating complex patterns of tree survival and mortality.</td>
</tr>
<tr>
<td>Fire intervals from table:</td>
<td>6-50 years</td>
<td>92-307 years</td>
<td>43-250 years</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Fire severity from table:</td>
<td>68% low severity (27% mixed severity, very little stand replacement)</td>
<td>75% replacement, (16% mixed severity, 9% low severity)</td>
<td>41% mixed - but other severities are close – 28-31%</td>
</tr>
<tr>
<td>How vegetation and fire regime have changed:</td>
<td>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.</td>
<td>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.</td>
<td>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.</td>
</tr>
<tr>
<td>Why changes matter</td>
<td>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.</td>
<td>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.</td>
<td>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.</td>
</tr>
</tbody>
</table>
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.

1. Which of the 3 forest types is most prevalent in:
   a) the northwestern corner of Wyoming? ___________________________________
   b) the northeastern corner of Washington? ___________________________________
   c) 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.

<table>
<thead>
<tr>
<th>Forest type</th>
<th>Average Fire interval (years)</th>
<th>Percent of fires by severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Replacement</td>
</tr>
<tr>
<td>Northern Rocky Mountain ponderosa pine</td>
<td>6-50</td>
<td>6</td>
</tr>
<tr>
<td>Rocky Mountain lodgepole pine</td>
<td>92-307</td>
<td>75</td>
</tr>
<tr>
<td>Whitebark pine</td>
<td>43-250</td>
<td>28</td>
</tr>
</tbody>
</table>

2. According to the table, which forest type has:
   a) the shortest average fire intervals? ____________________________
   b) the longest average fire intervals? ____________________________

3. According to the table, what is the most prevalent fire severity in:
   a) northern Rocky Mountain ponderosa pine forests? ________________________
   b) Rocky Mountain lodgepole pine forests? ____________________________
   c) whitebark pine forests? ________________________________
Stand history diagrams from actual research plots.
4. 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

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 article in the spaces below.

3. Read their papers and write your suggestions on their handouts, then give them back.

4. Hand in your article and this completed handout.

Suggestions from student writing on ANOTHER forest type:
Name: ____________________________________________

Write at least 1 strength and 1 way to improve the article. 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 article. 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.
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 firs 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 there 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. 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 probably 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.

Wildland fires usually occurred at intervals from about 100 years to 300 years in these 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 severity.

In Rocky Mountain lodgepole pine forests, the amount of fuel is related to stand age. If a young stand contains a thick crowns and lot of ladder fuels or fallen logs – perhaps from a pine beetle epidemic or a previous fire – it is likely to burn in a mixed-severity or stand-replacing fire. If a young stand becomes very dense, with sparse lower limbs and few plants growing under the crowns, it unlikely to burn at all unless the wind is very strong; then it may burn in a stand-replacing crown fire. As the forest gets older, the trees may be killed by bark beetles or dwarf mistletoe, and young trees may grow in underneath, increasing the ladder fuels. Then the stand becomes more likely to burn in 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. However, lack of fire may be making the landscape more uniform, since fewer there is almost no low-severity fire and new patches of burned forest are being created by mixed-severity fire.


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.

Carrying Fire the Pikunii Way: the Fire Carrier

Marvin Weatherwax
Jane Kapler Smith
2/21/2009
Revised 2/28/2017

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.

This lesson is an excellent complement to activities in the FireWorks curriculum on the Fire Triangle and the science of wildland fire.

Lesson Goal:
- Increase students’ understanding of 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 and how the Pikunii 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.
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### 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
horns\textsuperscript{1} 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 materials, 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 the 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 (http://bfcc.edu/academics/academic-affairs/native-science-field-center/).


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.

\textsuperscript{1} Appendix 3 lists scientific names for all plants and animals mentioned or shown in this activity.
• 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 online or follow the directions in Appendix 2 to construct one.

• A 12-minute video interview with Pikunii elder Marvin Weatherwax 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 exercise for review, which emphasizes concise speaking and attentive, respectful listening.

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:
• 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. Here are 2 possible approaches:
  1. Integrate this lesson with activities from the FireWorks curriculum. This lesson would fit well after FireWorks Elementary Lesson E05 or Middle School Lesson M07 (“Fuel Properties: The Campfire Challenge”) or after High School Lesson H05 (“Fuel Properties”).
  2. If you are not using the FireWorks curriculum, decide what you’d like students to do, especially in regard to ignition and banking of coals. Determine how and where to have the students work. Obtain the fuels and other materials needed or have students collect them. Arrange for adults to help supervise. If you would like students to try starting a fire with a bow drill, this 5-minute Youtube video may help: https://www.youtube.com/watch?v=DC_54ICw-ao. 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.

• Obtain a model fire carrier to show students (available from the Missoula Fire Sciences Laboratory). If you cannot obtain a model fire carrier, download Printable fire carrier diagram.pptx for display – 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” (also available at https://videos.firelab.org/ffs/Other/ConEd/weatherwax-captions/weatherwax-captions.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, 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.

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? Open discussion.
6. Explain: Let’s look at how the Pikunii carried fire. (Show the fire carrier and cross-section or display Printable fire carrier diagram.pptx.) 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. 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.

7. 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)**

8. 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.

9. 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 – 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.

10. 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.

11. 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. Then, if we want, we can watch it again and stop it at any time to discuss it.


13. Ask if students can answer the questions on the board. Ask if they have new questions, and record them.

14. 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.
**Detailed information about “Carrying Fire the Pikunii Way”**

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Mr. Marvin Weatherwax is an elder of the Pikunii people and a teacher of Blackfeet Language and Culture at Blackfeet Community College, Browning, Montana <a href="http://bfcc.edu/">http://bfcc.edu/</a>. (The other voice heard on the video is the interviewer, Jane Kapler Smith, an employee of the U.S.D.A. Forest Service.)</th>
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<tr>
<td>Location</td>
<td>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.</td>
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| 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. |
| 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](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 Pish’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/](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.
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.

The interviewer reads, “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. 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...
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<th>Partial credit</th>
<th>No credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building a campfire</td>
<td>Worked safely and carefully. Listened respectfully to other team members. Contributed suggestions. Helped team work together.</td>
<td>Worked safely and carefully. Listened respectfully to other team members. Contributed suggestions.</td>
<td>Ignored safety precautions, did not participate with others on team, or dominated project without input from other team members.</td>
</tr>
<tr>
<td>Examining fire carrier, listening to video</td>
<td>~Handled fire carrier gently. ~Offered 1 observation or question. ~Listened respectfully to video.</td>
<td>Met 2 of the 3 criteria under Full credit.</td>
<td>Met 0-1 of the 3 criteria under Full credit.</td>
</tr>
<tr>
<td>Cumulative listening activity</td>
<td>~Repeated previous 2 speakers’ statements. ~Contributed 1 sentence with accurate information.</td>
<td>Met 1 of the criteria under Full credit.</td>
<td>~Did not repeat previous 2 speakers’ statements accurately. ~Did not contribute 1 sentence with accurate information.</td>
</tr>
</tbody>
</table>
Appendix 1.
Narrative 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)
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 ¾ of the way up from the small end. Make the openings 1-2” long and 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 ½” 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 ½” deep all the way to within ½” 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 information on 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 ¼” 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 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. **Using the fire carrier:**

- Place burning coals on the flat rock in the center of the carrier.
- 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

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>buffalo</td>
<td>Bos bison</td>
</tr>
<tr>
<td>sarvisberry/Saskatoon serviceberry</td>
<td>Amelanchier alnifolia</td>
</tr>
<tr>
<td>arrowleaf balsamroot</td>
<td>Balsamorhiza sagittata</td>
</tr>
<tr>
<td>glacier lily</td>
<td>Erythronium grandiflorum</td>
</tr>
<tr>
<td>blue huckleberry</td>
<td>Vaccinium membranaceum</td>
</tr>
<tr>
<td>common chokecherry</td>
<td>Prunus virginiana</td>
</tr>
<tr>
<td>limber pine</td>
<td>Pinus flexilis</td>
</tr>
<tr>
<td>whitebark pine</td>
<td>Pinus albicaulis</td>
</tr>
<tr>
<td>willow</td>
<td>Salix species</td>
</tr>
<tr>
<td>western yarrow</td>
<td>Achillea millefolium</td>
</tr>
<tr>
<td>elk</td>
<td>Cervus elaphus</td>
</tr>
<tr>
<td>cottonwood</td>
<td>Populus species</td>
</tr>
<tr>
<td>quaking aspen</td>
<td>Populus tremuloides</td>
</tr>
<tr>
<td>pine</td>
<td>Pinus species</td>
</tr>
<tr>
<td>Fir, Douglas-fir</td>
<td>Abies species and Douglas-fir (Pseudotsuga menziesii)</td>
</tr>
<tr>
<td>birch</td>
<td>Betula species</td>
</tr>
<tr>
<td>buffaloberry</td>
<td>Shepherdia canadensis</td>
</tr>
<tr>
<td>prickly-pear</td>
<td>Opuntia species</td>
</tr>
</tbody>
</table>
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 they write an editorial explaining their vision and what should be done (or not done) to achieve it.

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 articles 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: Not identified yet

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.

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 several articles that offer opinions on landscape change, fire regime change, and fire management policy.

**Materials and preparation:**

1. Decide:
   a. How to provide the 9 articles for students to read (electronically from Articles.zip or from printouts in the trunk). Unless you have a very small class, more than 1 student will read each article.
   
   b. Whether to assign the articles as homework or as 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 (see the second column of Teacher’s guide to Handout H22-1. Changing landscapes, changing fires 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” a little 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 – instruct students on how to take notes during 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 (removal 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 changes, we’ll read some articles and report on them to the class. Everyone will read 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 period, 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.

DAY 2: 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. The teams presenting the two articles by White may need a little extra time both for preparation and presenting.

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 it to look like in 100 years.
2. Explain how students will 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/). Note that the 8 files in PhotoSeriesForStudents.zip include the 2 already studied in the articles by White (YellowstoneRiver.jpg and RossHole.jpg).

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, explain that 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 website (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, and what should be done – or should be avoided – to make it happen.

**Evaluation:** The main vehicle 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.

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Student presentation</strong></td>
<td>Helped give clear, concise, accurate summary of important points in article.</td>
<td>Helped give accurate summary of important points in article.</td>
<td>Was not helpful or gave inaccurate information.</td>
</tr>
<tr>
<td><strong>Notes on presentations</strong></td>
<td>Student recorded relevant information on 8 presentations (all except the one he/she participated in).</td>
<td>Student recorded information on 6-7 presentations. Some information was not relevant.</td>
<td>Student recorded information on less than 6 presentations. Some information was not relevant.</td>
</tr>
<tr>
<td><strong>Art work</strong></td>
<td><strong>Editorial (≤500 words)</strong></td>
<td><strong>Art piece did not use original topography OR showed changes that were not reasonable or conflicted with explanation in editorial.</strong></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
| - 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. | Editorial gave thorough, logical explanation for anticipated changes, desired landscape, and actions that should (or should not) be done to achieve it. |  
| - 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. | Editorial gave logical explanation for desired landscape and actions that should (or should not) be done to achieve it. |  
| Editorial did not give logical explanation for desired landscape or did not explain steps needed to achieve it. |  |  

### Handout H22-1. Changing landscapes, changing fires.

Name: ___________________

<table>
<thead>
<tr>
<th>Author (date)</th>
<th>What’s changing, why, what might be done</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Wuerthner (2017)</td>
<td></td>
</tr>
<tr>
<td>B. Atkins and others (2017)</td>
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</tr>
<tr>
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<tr>
<td>F. White (a) (2018) – Ross’s Hole</td>
<td></td>
</tr>
<tr>
<td>G. Cromwell (2017)</td>
<td></td>
</tr>
<tr>
<td>H. Erickson (2017)</td>
<td></td>
</tr>
<tr>
<td>I. White (b) (2018) – Yellowstone R.</td>
<td></td>
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</tbody>
</table>
## Teacher’s guide to Handout H22-1. Changing landscapes, changing fires.

<table>
<thead>
<tr>
<th>Name of .pdf file</th>
<th>Author (date) - length</th>
<th>What’s changing, why, what might be done</th>
<th>Authority, credibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Wuerthner_170802-Missoulian-NoFuelTmt.pdf</td>
<td>Wuerthner (2017) - 636 words</td>
<td>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.</td>
<td>Author is ecologist and writer.</td>
</tr>
<tr>
<td>B-Atkins_170827-Missoulian-FuelTmt.pdf</td>
<td>Atkins and others (2017) - 674 words</td>
<td>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.</td>
<td>12 authors, including managers, scientists, professors.</td>
</tr>
<tr>
<td>C-Chaney_180212-Missoulian-WhoOwnsFires.pdf</td>
<td>Chaney (2019) - 1024 words</td>
<td>Communities need to work together to reduce impacts of wildfire, including smoke. Prescribed fire is needed.</td>
<td>Author interviews scientists and a county commissioner.</td>
</tr>
<tr>
<td>D-Arno_170831-Missoulian-ForestsNeedFire.pdf</td>
<td>Arno (2017) - 703 words</td>
<td>Fire exclusion has led to current problems. Thinning and prescribed fire are needed, especially around private property on edge of wildlands.</td>
<td>Author is scientist, author, and land manager.</td>
</tr>
<tr>
<td>E-Caton_180103-Missoulian-ClimateChange.pdf</td>
<td>Caton and others (2018) - 716 words</td>
<td>Climate change is affecting agriculture, tourism, and fire. Support measures to stop climate change.</td>
<td>5 authors, including scientists and professors.</td>
</tr>
<tr>
<td>F-White-a-LensOfTime-RossHole.pdf</td>
<td>White (a) (2018) - 921 words – Ross’s Hole</td>
<td>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.</td>
<td>Author is a biologist who studies fire and eco-cultural influences on the landscape. Article cites sources.</td>
</tr>
<tr>
<td>G-Cromwell_170906-Missoulian-PutOutFires.pdf</td>
<td>Cromwell (2017) - 559 words</td>
<td>Every fire can be put out while small. Large fires (Lolo Peak, 2017) indicate negligence by managers.</td>
<td>Author is retired engineer. Does name calling (“bozos”) give him a better claim to authority?</td>
</tr>
<tr>
<td>H-Erickson_171020-Missoulian-Safety.pdf</td>
<td>Erickson (2017) - 994 words</td>
<td>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.</td>
<td>Author interviews IC team member and fire manager.</td>
</tr>
<tr>
<td>I-White-b-LensOfTime-Yellowstone.pdf</td>
<td>White (b) (2018) - 1105 words – Yellowstone River</td>
<td>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.</td>
<td>Author is a biologist who studies fire and eco-cultural influences on the landscape. Article cites sources.</td>
</tr>
</tbody>
</table>