9. Ladder Fuels and Fire Spread

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

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

Subjects: Science, Writing, Health and Safety

Duration: 90 minutes

Group size: Whole class, working in small groups

Setting: Indoor laboratory or outdoors

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

Objectives:

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

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

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

This activity has 3-4 parts:

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

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

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

Materials and preparation:

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

Copy each of the following:

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

Get students to prepare before class:

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

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

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

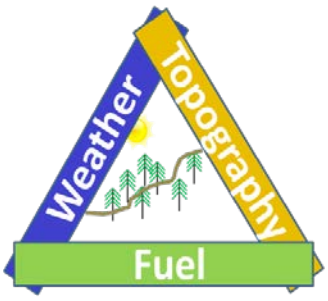
- 1 Tinker Tree support stand
- 1 pair of safety goggles
- 1 ashtray
- 1 spray bottle, filled with water
- 1 metal tray with a support stand on it
- 10-15 segments of wire rod
- 6 half-sheets of newspaper, 25 x 35 cm
- about 20 narrow strips of newspaper, —cut into strips and hole-punched
- 2 quarter-sheets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

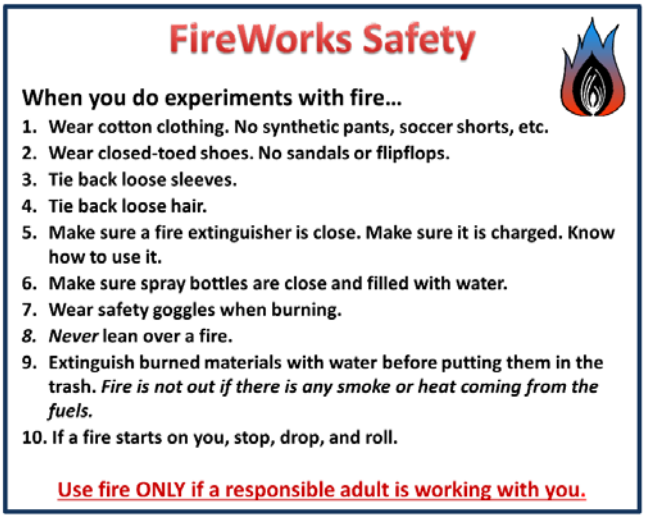
Teacher station should have these items, not in the trunk:

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

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

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





FireWorks Safety

When you do experiments with fire…

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

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

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

Slide 1

Slide 2

Procedure:

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

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

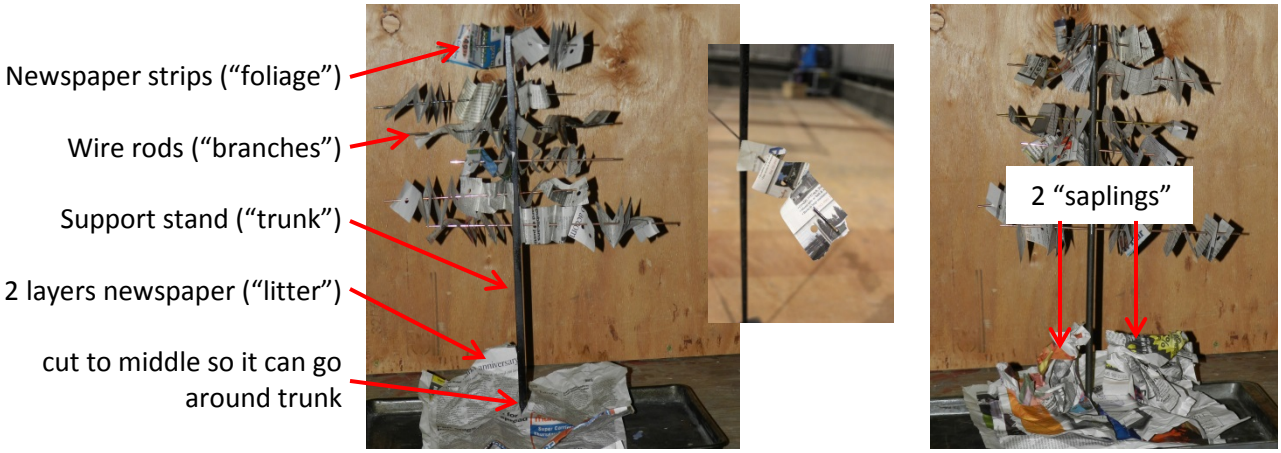
3. Project *H09_LadderFuels_FireSpread.pptx*. In regard to Slide 1, ask: Using what you learned by doing the Lab Preparation (Handout H09-1), explain how the fire would likely spread in each photograph.

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

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

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

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



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

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

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

Team Name	Phase One	Phase Two

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

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

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

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

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

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

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

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

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

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

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

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

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

Handout H09-1: Lab Preparation

Name _____

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

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

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

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

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

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

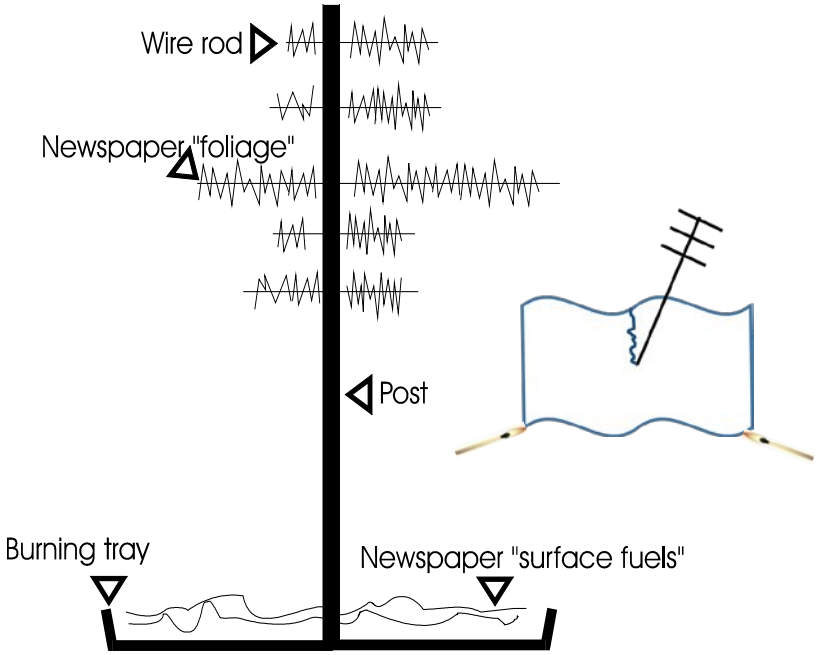
Handout H09-2. Ladder Fuel Experiment

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

Procedure:

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

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



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

Name_____

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

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

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

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

Drawing					
Caption					