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.

Standards:

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

This activity has 2 parts:

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

II. Complete the lab exercise.

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

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

The lab has two phases, so students can see the effects of two different amounts and arrangements of surface fuels. **Phase 1** uses relatively light surface fuels. **Phase 2** uses more surface fuels and adds some ladder fuels. Thus Phase 2 models the effects of succession without fire. Because students use the same model tree for both phases, **it is important not to moisten or disturb the trees after they are burned in Phase 1.**

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

Copy each of the following, 1/student:

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

Copy 1 of the following for each lab group: **Handout H09-2. Ladder Fuel Experiment**
Prepare (or get students to prepare) the following “fuels” before the lab, 1 set for each of the 4 lab groups:

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

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

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

Teacher station should have 1 measuring tape (in the trunk) and these 3 items (not in the trunk):

- 1 fire extinguisher, fully charged
- 1 box of kitchen matches
- A handful of hair ties, in case students need them

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

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

On the day of the lab, download H09_LadderFuelAndFireSpread.pptx.
Procedure - Part I:
1. The day before the lab, have students complete the Handout H09-1: Lab Preparation – or assign as homework.

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

3. Project H09_LadderFuelAndFireSpread.pptx.

Slide 1

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

Left: A surface fire could easily climb into the tree crowns because there are a lot of surface fuels and ladder fuels. In addition, the trees are close together. This is a dense stand, like some of those modeled in the previous activity (H08, “matchstick” forests). Thus a crown fire could develop if it is dry enough and windy enough.

Right: A surface fire could spread in these fuels but would not be able to climb into the tree crowns because there is no ladder fuel. In addition, the trees are spaced far apart so their crowns are not interconnected. Surface fire could occur, but crown fire could not.

Slide 2

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

Left: A crown fire is burning through surface, ladder, and crown (also called aerial) fuels.

Right: A surface fire is burning through surface fuels (seedlings, logs, litter).

4. Give each lab group a copy of Handout H09-2. Ladder Fuel Experiment. Explain: Your goal is to design a tree that can survive surface fire and will not allow fire to climb from the forest floor into the crown. Your job could be easy—just put together a tree with no leaves. But your tree must also have foliage to photosynthesize; it should have as much foliage as possible so it can be healthy and vigorous and withstand attacks from insects and fungi. The tree with the most foliage left after the surface fire (measured according to the length of branch covered with foliage) is the most successful!
5. Show the class the parts of the model tree and how to assemble it, as shown below:

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

6. Show the class how you will determine the tree’s score after burning: You will measure the length of branch (cm) that still has unburned newspaper (“live foliage”) on it. You will NOT measure the total amount of newspaper or its weight. Explain that they must not change any of their models after the surface fire in Phase 1, because they will be needed for Phase 2.

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

<table>
<thead>
<tr>
<th>Team Name</th>
<th>Phase 1</th>
<th>Phase 2</th>
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8. Phase 1: Give lab groups ~10 minutes to construct their model trees. Monitor to make sure they don’t moisten the fuel.
   - Ask each group for its team name. Write it on the board.
   - Check and modify the surface fuels (2 layers of newspaper) to make them similar among models. Explain: As in any experiment, we want to test only 1 variable at a time. In this experiment, we are testing the students’ tree designs. We’ll keep the surface fuels similar so variation in surface fuels will not confound the results of the experiment.
   - After teams have built their trees, have them ignite the surface fuels one team at a time, so everyone gets to see every fire. Each team should ignite two corners along one
long edge of the metal tray (see the illustration in Handout H09-2). A consistent ignition pattern will keep this variable from confounding the results.

- After each fire goes out, use the measuring tape to determine the tree's score: the length of branch, in centimeters, that still has unburned newspaper (“live foliage”) on it. Record this on the board under “Phase One” for that team.

- After all teams have completed a burn, discuss the design for the most successful and least successful trees.

9. Ask: What might happen to the surface fuels as a forest changes through many decades without surface fires (a process called succession)? After many years of succession without surface fires, forests tend to accumulate a lot of surface fuels. Litter piles up under the trees; although some decays, it gets deeper every year. Shrubs grow in. Tree seedlings become established and grow taller every year. Eventually, these ladder fuels may reach or interweave with the tree crowns.

10. Phase 2: For all teams whose trees survived phase one, have them leave the “surviving” foliage intact on their tree but gently remove the ash of the burned surface fuels with a paper towel. Then instruct them to put in new newspaper fuels to represent changes that might occur with succession if no surface fires occur. They can use any of the remaining newspaper at their stations.

11. Have each team describe how their Phase 2 fuels show what has happened during succession. (Teams should have more layers of newspaper than in Phase 1, probably 4-6 sheets, and some “shrubs” and/or “saplings” made from crumpled newspaper.) Then have them burn one tree at a time, igniting in the same manner as for Phase One. Measure and record the score for each tree as for Phase 1.

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

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<th>No Credit</th>
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<tr>
<td>Content</td>
<td>See <a href="#">Answer Key/Suggestions for Handout H09-3: Real-World Ladder Fuels and Fire Spread</a> below.</td>
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<tr>
<td>Images</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 irrelevant or incorrect.</td>
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<tr>
<td>Explanation</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>
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Read each term’s definition and sketch the described fuel or fire in the box. These terms refer mainly to plant communities such as forests, woodlands, and shrublands, which have tree crowns (a “canopy”).

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

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

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

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

**Crown fires** burn in the crowns of trees and tall shrubs. Crown fires are often ignited by surface fires that spread upward through ladder fuels; then they spread from crown to crown, especially if winds are strong. Crown fires have longer flames than surface fires and are very powerful. They can have unpredictable fire behavior and be very difficult to control. Crown fires are common in some kinds of coniferous forests and chaparral-type shrublands.
Handout H09-2. Ladder Fuel Experiment

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

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

- Do not use any moisture on your tree or experimental setup before it is burned.
- Do not move or remove your tree’s foliage after you have burned it.
- Keeping score: After you have underburned your model tree, the teacher will assign it a score: the number of centimeters of branch still covered by unburned foliage.
You have used a model to explore how the vertical arrangement of fuels affects the potential for fire to spread from surface fuels into a single tree crown. Fire spread in real forests and across landscapes is much more complicated.

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

**Scenario 1.** A mountainside that has patches of dense forest mixed with patches of meadow and patches of shrubs. How would the patchiness of vegetation affect fire spread and the likelihood of crown fire? Use as many frames as you need to show a variety of patches and the resulting differences in fire behavior.

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

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<td>Caption</td>
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Handout H09-3: Real-World Ladder Fuels and Fire Spread
Name______________________________
Create a storyboard with captions to answer the prompt for one of the following scenarios:

**Scenario 1.** A mountainside that has patches of dense forest mixed with patches of meadow and patches of shrubs. How would the patchiness of vegetation affect fire spread and the likelihood of crown fire? Use as many frames as you need to show a variety of patches and the resulting differences in fire behavior.

**Possible explanation:** Large patches of dense forest can support crown fire because there are lots of fuels and the crowns of trees are connected and may even be intertwined. Areas of forest with tall shrubs have lots of ladder fuels so they can support crown fire; if the shrub layer is low and does not reach the lowest branches of the tree, crown fire is unlikely. Meadows can serve as fuel breaks when wet, and they can support surface fires when dry. However, meadows cannot act as ladder fuels; therefore meadows prevent crown fires from starting and can interrupt a crown fire, forcing it to spread only through surface fuels. (Not covered in this activity but interesting: Meadows are likely to have stronger winds than dense forests, so surface fires are likely to spread more rapidly.)

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

**Possible explanation:** Forest patches with recent surface fire tend to have less surface and ladder fuels than forests that have not underburned recently. Consequently, these patches will prevent fires from climbing into tree crowns. However, since forests are not all uniform and fires do not burn evenly across the landscape, some patches could have enough surface and ladder fuels to enable fires to spread into tree crowns. Forests that recently burned in crown fire will obviously not support crown fire, but they are likely to have abundant herbaceous cover that will support surface fire if it dries out. Forest patches that have not burned in 100 years or more may have lots of surface, ladder, and crown fuels. In addition, the tree crowns are likely to touch or be interwoven. Forest stands with these properties are likely to have crown fires in dry, windy weather.