Forests

FINALIST
Environmental Film Festival in the Nation's Capital
2021

OFFICIAL SELECTION
Wildlife Conservation Film Festival
2021

AWARD OF EXCELLENCE
Nature Without Borders International Film Festival
2021

OFFICIAL SELECTION
St. Louis International Film Festival
2021

Platinum Remi Award
WorldFest-Houston International Film Festival
2021

HUMANS HAVE TRIGGERED EARTH'S OWN CYCLES OF WARMING— IS IT TOO LATE TO STOP THEM?

CLIMATE EMERGENCY: FEEDBACK LOOPS

MOVING STILL PRODUCTIONS, INC. PRESENTS "CLIMATE EMERGENCY: FEEDBACK LOOPS"

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JOURNEYS IN FILM™
educating for global understanding

About *Journeys in Film*

Journeys in Film is a 501(c)(3) nonprofit organization that amplifies the storytelling power of film to educate the most visually literate generation in history. We believe that teaching with film has the power to help educate our next generation with a richer understanding of the diverse and complex world in which we live.

We transform entertainment media into educational media by designing and publishing cost-free, educational resources for teachers to accompany carefully chosen feature films and documentaries while meeting mandated standards in all core subjects. Selected films are used as springboards for lesson plans in subjects like math, science, language arts, social studies and more. Our resources support various learning styles, promote literacy, transport students around the globe, and foster learning that meets core academic objectives.

In addition to general subject areas, Journeys in Film's programs engage students in meaningful examinations of human rights, poverty and hunger, stereotyping and racism, environmental issues, global health, immigration, and gender roles. Our teaching methods are successful in broadening perspectives, teaching for global competency, encouraging empathy, and building new paradigms for best practices in education. We seek to inspire educators, school administrators, community members and home-schooling parents to use our innovative curriculum to capture the imagination and curiosity of their students.

We also develop discussion guides for films that don't necessarily lend themselves to academic standards but cover topics and themes that are valuable for classroom discussions and in other settings, such as after school clubs, community screenings, and college classes.

Journeys in Film is a 501(c)(3) nonprofit organization.

Why use this program?

In an age when literacy means familiarity with images as much as text and a screen has become a new kind of page, 21st-century students are more connected to media than any previous generation. This offers educators unprecedented opportunities to engage students in learning about a variety of subjects and issues of global significance. Films, television, documentaries, and other media platforms can provide an immediate, immersive window to a better understanding of the world and matters affecting all of us.

We teach our students literature that originated from all around the world, but we tend to forget that what often spurs the imagination is both visual and auditory. Films evoke emotion and can liven up the classroom, bringing energy to a course. We believe in the power of films to open our minds, inspire us to learn more, provide a bridge to better understanding the major issues of 21st-century concern, and compel us to make a difference.

When properly used, films can be a powerful educational tool in developing critical thinking skills and exposure to different perspectives. Students travel through these characters and their stories: They drink tea with an Iranian family in *Children of Heaven*, play soccer in a Tibetan monastery in *The Cup*, find themselves in the conflict between urban grandson and rural grandmother in South Korea in *The Way Home*, and watch the ways modernity challenges Maori traditions in New Zealand in *Whale Rider.* Journeys in Film brings outstanding and socially relevant documentaries to the classroom that teach about a broad range of social issues in real-life settings, such as famine-stricken and war-torn Somalia, a maximum-security prison in Alabama, and a World War II concentration camp near Prague. They explore complex and important topics like race and gender. Students tour an African school with a Nobel Prize–winning teenager in *He Named Me Malala* and experience the transformative power of music in *The Music of Strangers: Yo-Yo Ma & the Silk Road Ensemble* and *Landfill Harmonic.*

Our hope is that this generation of youth will contribute to the betterment of humankind through kindness and understanding, together with scientific knowledge to help solve some of the world's most pressing issues.

Our goal is to create relevant and engaging curricula and programming around media that encourage cross-cultural understanding, empathy, and knowledge of the people and environments around the world. We aim to prepare today's youth to live and work as globally informed, media- literate, and competent citizens.

Why We Must Act Now

"We're reaching the stage in the heating of the earth when fundamental systems are disrupted: the jet stream, the Gulf Stream, even the way the planet reflects and absorbs sunlight. As these five films will make clear to to all who view them, we are kicking off feedback loops beyond our ability to control—once we've melted the Arctic no one has a plan for refreezing it; the great forest fires pour ever more carbon into an already overloaded atmosphere. We've run out of margin—we must act now to stop the burning of fossil fuel that lies at the bottom of this cascading crisis."

—Bill McKibben, author, environmentalist, and co-founder of anti-carbon campaign group *350.org*

"The global average temperature continues to set new records. Extreme heat waves and intense droughts now affect much of the globe, damaging agriculture and facilitating wildfires. Simultaneously some regions are experiencing extreme storms, precipitation, and flooding. These specific changes were anticipated by some scientists 40 years ago, but the changes were not supposed to happen until 2100 or later. Why now? The direct warming has melted reflective ice and snow and released additional heat trapping gases from permafrost and other lands. These feedbacks have amplified the warming and disrupted the climate decades to a century sooner than anticipated. We can unwind this accelerating downward spiral by rapidly reducing heat trapping gases and by allowing more forests and other natural systems that are already removing 31% of our annual emissions each year to accumulate additional carbon out of the atmosphere. This will eventually slow global warming and diminish the feedbacks, facilitating the return to a more benign climate. The feedback loop videos identify four major feedbacks and clearly demonstrate how they interact to accelerate further warming and increase the resulting climate change consequences."

— William Moomaw, Professor Emeritus, The Fletcher School, Tufts University
Lead author of the Nobel Prize-winning Intergovernmental Panel on Climate Change

Introducing *Climate Emergency: Feedback Loops*

The five short films of *Climate Emergency: Feedback Loops* were released in 2021, a year after one of the hottest years on record. In 2020, the Earth experienced a range of extreme weather that may have finally caught the attention of policy-makers:

- A Siberian heat wave set temperature records in excess of 100 degrees Fahrenheit within the Arctic Circle.
- Wildfires ravaged the western United States and Australia.
- The Atlantic hurricane season, with an extraordinary 30 named storms, caused over $46 billion in damages to property.
- The area of Arctic sea ice was at a record low.
- Super Typhoon Goni hit the Philippines with sustained winds of 195 miles per hour.
- Monsoon flooding in China destroyed or damaged 1.4 million homes and businesses.

Extreme as these events were, scientists are even more worried about the Earth's natural feedback loops that have the potential to create even more disastrous weather events. According to an article in *Scientific American,* "…catastrophic climate change could render a significant portion of the Earth uninhabitable consequent to continued high emissions, self-reinforcing climate feedback loops and looming tipping points."[1]

What is a feedback loop? Feedback loops are a continuous system in which a change in one (or more) parts of the system act to influence the rest of the system, either positively (increasing the effects of the system) or negatively (decreasing the effects of the system). A positive feedback loop is a circular chain of events that can amplify a change within a system. In a negative feedback loop, series of events dampen the change within the system, helping make it more stable.

1 *https://www.scientificamerican.com/article/the-climate-emergency-2020-in-review/*

The five films of *Climate Emergency: Feedback Loops* use stunning video, interviews with leading climate scientists, and thoughtful narration by Richard Gere to educate the viewer on key feedback loops greatly accelerating climate change. The "Introduction" film drives home the point that human activity is increasing global warming and leading to climate change. It explains the concept of feedback loops and shows briefly how this concept applies to forests, atmosphere, permafrost, and albedo.

"Forests" explains that the world's trees have long served as a "carbon sink," removing carbon dioxide from the air, storing carbon in wood, leaves, branches, and trees' soils, and in turn releasing water vapor and oxygen. The shrinking of forests, due to human activities like logging and clearing areas for agriculture, means that less carbon is captured and global temperatures increase.

In the video "Permafrost," the viewer learns that this area of frozen ground, which covers about a quarter of the Northern Hemisphere, stores massive amounts of carbon underground. As it begins to thaw, microscopic animals are waking and feeding on frozen vegetation and animals and then releasing more gases into the atmosphere, creating additional warming.

"Atmosphere" deals with warming that is altering the Earth's weather pattern and making extreme weather events more common. Even the jet stream is being affected, resulting in warmer weather moving north and stalling for longer periods of time, with consequent changes in rainfall patterns and flooding.

"Albedo" refers to the ability of Arctic ice to reflect the sun's rays and temper their warming effect. However, the volume of ice is decreasing; it has shrunk 75% in the past forty years, and consequently the albedo effect has diminished. The Arctic may soon be ice-free in the summer.

Taken together, these five short films make the case that time is running out to prevent catastrophic climate change, change that could result in the extinction of whole species and drastically affect human societies. Unless we demand and implement dramatic changes, the Earth will reach a "tipping point" from which there is no return.

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Forests

Enduring Understandings

- Forests help cool a warming Earth.
- Feedback loops can amplify either the worsening or the improvement of the climate crisis.
- Forests play an important role in the climate crisis.
- Trees have complex structures (leaves, trunks, and roots).
- There are three dominant types of forests on Earth: tropical, boreal, and temperate.

Essential Questions

- What is a feedback loop?
- How can forests be both carbon sources and carbon sinks?
- What is photosynthesis?
- What is transpiration? How does it differ from evaporation?
- What is the structure and function of wood in the carbon cycle?

Notes to the Teacher

This lesson is designed to teach students about anthropogenic climate change (climate change resulting from human activity) and the role that forests play in the Earth's carbon cycle. Topics include photosynthesis, transpiration and how it differs from evaporation, the structure and function of wood in the carbon cycle, carbon sources and sinks, and the three dominant forest types and their respective roles in the carbon cycle.

The lesson is divided into five parts that build on one another. Part 1 introduces the concept of feedback loops. After reading the first two paragraphs of **Handout 1: Feedback Loops**, students will view the video "Forests" and complete most of the handout together as a class. If they have already seen the "Introduction" video at https://feedbackloopsclimate.com/ and are familiar with the concept, you may wish to skip the first step in this part of the lesson.

Part 2 introduces students to the processes of photosynthesis and transpiration and explains a tree's "day job" as a source (of water vapor) and sink (uptake of CO_2) relative to the water and carbon cycles. The goal is learning about the light-dependent and light-independent reactions of photosynthesis to make sure students know when each reactant and product is used in the process. The video on photosynthesis from Paul Anderson's Bozeman Biology site is excellent, especially for high school biology classes. Be sure to view it first (14 minutes long) before showing it to your students.

Part 3 introduces students to the structure of trees, from their leaves and/or needles, to the structure of their wood and bark, and finally to their roots and their interaction with other trees and the soil. If possible, before the lesson, visit a local lumberyard and collect wood samples of both hardwoods (Angiosperms) and softwoods (Gymnosperms). Often there will be discarded pieces of such wood samples available at no cost if you explain the reason why you are collecting them. Cut pieces of each type of wood to expose the end-grain surfaces, allowing you and your students to see growth rings, and with the help of a 10X hand lens, the porosity of the hardwood samples. If available, select red oak (ring porous) and maple (diffuse porous), as well as pine or spruce (non-porous). Collect enough samples of each type of wood for the number of groups you plan to have in your class.

Also collect some twig samples with attached leaves of each of the three types of trees: a softwood (such as pine or spruce), an oak, and a maple. If you do not have these types of trees available, collect at least twigs of a conifer (softwood) and a deciduous (hardwood) tree. Be sure to collect enough twig samples for the number of students in your class. Trim each twig to expose a clean cross section of the end-grain, exhibiting both wood and bark. If possible, select twigs old enough to have produced two or three or more growth rings. You should also locate a dichotomous tree identification key for trees in your area; many are available on a statewide basis. Be sure to familiarize yourself with how to use the key before the class begins.

At the end of the lesson is a set of magnified images of wood sections on **Teacher Resource 1** which you may wish to project for the class to supplement this part of the lesson. You will also find text describing each of the slides.

Part 4 is concerned with the impact of forest dieback, as the result of disease, air pollution, and fires, on the carbon cycle. Students brainstorm the impact of the death of one tree and then read about large-scale forest dieback due to fires and other environmental conditions. They investigate the series of wildfires that occurred in the United States in 2020 and 2021 and research the most recent forest dieback situations. Finally, they discuss the impact of the loss of photosynthesis and transpiration across large areas of land and the feedback loop that occurs as a result.

Part 5 introduces the three dominant forest types and their sensitivity to human pressures, including the climate crisis. According to the "Forests" video, the tropical and boreal forests are the most susceptible to the warming climate. The tropical forest is most at risk and the closest to collapse, due to human destruction (burning to clear land for agriculture, cutting and exporting of valuable tropical hardwoods, etc.). The boreal forest, which holds two-thirds of all forest carbon, is the next most vulnerable, due to thawing of permafrost and wildfires in dead and dying forests. The temperate forest is noted as the least vulnerable, since these forests in the eastern United States are now growing back after the early clearing, and old growth forests in the Northwest continue to store large amounts of carbon. The video points out that green management of these forests is our best hope of the three forest types for maintaining a stable and functional climate system.

This lesson on forests is designed to teach students about the basic inputs and outputs of photosynthesis and transpiration and the role each process plays in the Earth's climate system. This will help students understand that trees do not convert carbon dioxide into oxygen as many people believe. Instead, the oxygen we breathe comes from the splitting of water molecules; the carbon dioxide is transformed into carbohydrates, such as wood, bark, and energy molecules (sugar and starch) needed for tree growth. In addition, students will learn how wood structure and leaves facilitate water and nutrient transport from soil to leaves, and eventually (in the case of oxygen and water vapor) to the atmosphere. Root function (absorbing water and dissolved soil nutrients) is facilitated by beneficial fungi (mycorrhizae), allowing interactions between trees in a collaborative manner. (Note the Woodwell quote in the video at 0:30–1:13.)

The Earth's climate has changed throughout history. Just in the last 650,000 years, there have been seven glacial cycles of advance and retreat, with the abrupt end to the most recent ice age about 12,000 years ago, marking the beginning of the modern climate era—and of human civilization. Most of the previous climate changes were attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives. The current warming is of significance because most of it is extremely likely (greater than 95 percent probability) the result of human activity, primarily the burning of fossil fuels since the mid-20th century. This is proceeding at a rate that is unprecedented in millennia.

This lesson focuses on the significant role that forests must play in acting as an important carbon sink, and the potential of feedback loops in that role, as our planet continues to warm dramatically. Living forests are an example of a negative feedback loop, removing CO_2 from the atmosphere and storing carbon, and thus acting as a carbon sink; dead or dying forests are an example of a positive feedback loop, releasing the stored carbon through wildfires, etc., and thus becoming a carbon source.

Here are some additional helpful resources:

The NASA Global Climate Change website https://climate.nasa.gov/ is suggested to provide a brief introduction and background for the teacher on the facts surrounding climate change.

The Union of Concerned Scientists website https://www.ucsusa.org/climate presents a solid climate-change science source. Other sources listed on that site and in the Additional Resources section of the lesson plan also will be useful for this lesson.

Project Drawdown has several relevant webpages about possible solutions for the temperate forest, the tropical forest, tree intercropping, tree plantations, and more. They are listed at https://drawdown.org/solutions/table-of-solutions.

Laurie David and Heather Reisman's *Imagine It: A Handbook for a Happier Planet* (New York: Rodale Books, 2020) provides suggestions for individuals and families to change their own habits in order to reduce their use of natural resources.

Common Core Standards addressed by this lesson

CCSS.ELA-Literacy.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-Literacy.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

CCSS.ELA-Literacy.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

CCSS.ELA-Literacy.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Next Gen Science Standards addressed by this lesson

HS-LS1-3 From Molecules to Organisms: Structures and Processes
Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

HS-LS1-5 From Molecules to Organisms: Structures and Processes
Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

HS-LS2-5 Ecosystems: Interactions, Energy, and Dynamics
Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

HS-LS2-6 Ecosystems: Interactions, Energy, and Dynamics
Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.

HS-LS2-7 Ecosystems: Interactions, Energy, and Dynamics
Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Duration of Lesson

This lesson could take 2–3 class meetings depending on the level of detail you feel is required for your students. Watch the "Forest" video ahead of time and prepare notes for class discussion. If you use one or more of the optional extended activities provided at the end of this lesson plan, you will need additional time.

Assessments

Brainstorming notes
Handouts and worksheets
Class discussions
Student or group projects and presentations

Materials

Video "Introduction" at https://feedbackloopsclimate.com
Video "Forests" at https://feedbackloopsclimate.com/forests/
Handout 1: Feedback Loops
Handout 2: The Carbon Cycle
Handout 3: Photosynthesis and Transpiration
Handout 4: Tree Structure
Handout 5: Forest Dieback
Handout 6: The Three Types of Forests
Teacher Resource 1: Light Microscope and SEM Images of Wood

Procedure

Part 1: Introduction to feedback loops

1. If time permits and students have not already seen the video "Introduction" at https://feedbackloopsclimate.com, begin the class by showing this video.

2. Explain to students that they are now going to see another short video that will explain more about the impact of climate change on forests and demonstrate how this is part of an important feedback loop. Distribute copies of **Handout 1: Feedback Loops** to students and read through the first two paragraphs together.

3. Ask students if they have heard the term "feedback loops" before. Have them define the term in their own words and give examples of feedback loops they are familiar with. (For example, milking a cow stimulates the production of more milk; a drop in the stock market can lead to a rush to sell which in turn leads to a further drop.)

4. Show the video "Forests" at https://feedbackloopsclimate.com/forests/ and conduct a discussion based on the second question on the handout. Give them a few minutes to answer the question after the discussion.

5. Explain that the class is going to learn much more about forests and the processes described in the video in the next few classes.

6. Have students complete the rest of the handout. For Question 3, suggest that they may want to solicit ideas from their family and friends as well. Answers to Question 4:

> Positive Feedback Loop: Fewer trees, leading to more CO_2, leading to higher temperatures, leading to fewer trees, etc.

Negative Feedback Loop: More trees, leading to less CO_2, leading to lower temperatures, leading to more trees, etc.

7. Distribute copies of **Handout 2: The Carbon Cycle** and have students read it for homework, making notes of any questions they have.

Part 2: Photosynthesis and Transpiration

1. Begin class by asking students, “Where does most of the matter of a tree come from?” Have students brainstorm a list of what makes up the tree (e.g., wood, bark, leaves, flowers, roots, and fruit).

2. Next, brainstorm a list of possibilities of what plants and trees need to grow. Accept all ideas at first and list them on the board. (Students may say light, carbon dioxide, water, oxygen, chlorophyll, chloroplasts, minerals, soil, leaves, etc.)

3. Start a class discussion to see what students know or remember about photosynthesis. Then distribute copies of **Handout 3: Photosynthesis and Transpiration** and have students read about photosynthesis. Hold a discussion to clarify any questions that they have.

4. Show students how to construct the basic photosynthesis chemical formula of inputs and outputs by working together as a group: light + carbon dioxide gas + water yields oxygen gas + glucose (food). This can then lead to writing the formula using the chemical symbols: $6CO_2 + 6H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6O_2$.

5. Show the video from Paul Anderson’s Bozeman Biology site on photosynthesis at https://www.youtube.com/watch?v=g78utcLQrJ4 and assign any relevant reading from your student textbook.

6. Now ask students, “How do water and dissolved soil nutrients move up the trunk of a tree?” Have students brainstorm ideas on how water flows from the soil, up the trunk, and out into the leaves, describing potential mechanisms. Define *transpiration* as the loss of water vapor from leaves out through stomates when they open. Ask: Could this be a part of the mechanism that drives the upward water flow? Then have them read the second part of the handout, on transpiration.

7. Have a discussion on how the process of photosynthesis may be involved in the production of oxygen, which also exits the leaf through open stomates. Water vapor, produced in the process of transpiration, condenses in the atmosphere to become clouds. Explain to students that more atmospheric water vapor is produced from transpiration than is produced from evaporation from the surface of rivers, lakes, and the oceans.

8. For homework, give students copies of **Handout 4: Tree Structure** and ask them to read it carefully to prepare for the next class.

Part 3: The structure of trees

1. Spend some time at the beginning of class reviewing with students what they learned from **Handout 4** and answering any questions they may have.

2. Arrange students into groups and give each group a set of the sample twigs to study.

3. Using a dichotomous identification key for your region, have your students identify each of the three types of twigs provided. Often such keys will be based on leaf characteristics.

4. Have the students use either a magnifying glass or a 10X hand lens to examine each type of twig, looking at the cut end and identifying the bark, the wood, any evidence of growth rings, possibly a central pith, etc. Is the bark layered? If possible, have them identify pores in the hardwood twigs.

5. Once they have identified some of the differences in wood structure of the three types of twigs (porous or non-porous, ring or diffuse porous, etc.), have them look at the wood samples, again with a magnifying glass or 10X hand lens, focusing on the cut end-grain wood structure. Do all of the wood samples exhibit growth rings? Have them consider the width of the growth rings. Are the ring dimensions uniform or are they variable for each type of wood? If you have been unable to procure wood samples, show magnified images of hardwood or softwood using the images on Wood Micro-structure and Identification from **Teacher Resource 1: Light Microscope and SEM Images of Wood**, which can be found at the end of this lesson. At the end of the slide show, you will find text identifying and describing the slides; adapt this material as appropriate for your class.

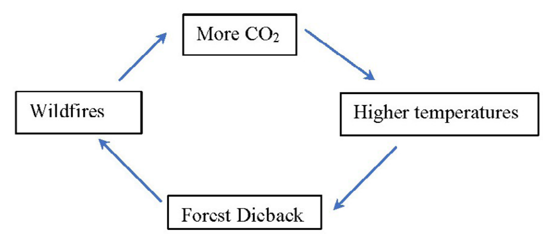
6. Have students hypothesize about what the growth ring dimensions suggest about the climatic conditions in which each species was growing. Can the students identify earlywood (also known as spring wood) and latewood (also known as summer wood) portions of each growth ring?

7. Describe how the water and nutrients move through the wood, traveling either in the pores of the hardwoods, or in the tracheids of the softwood.

Part 4: The impact of forest dieback on the carbon cycle

1. Ask the students to brainstorm about the impact on the carbon cycle when a tree dies, either due to disease, drought, or fire.

2. Copy this diagram onto the board and explain that this illustrates a feedback loop represented by this scenario. Ask: Is this an example of a negative or positive feedback loop? (Positive)



3. Distribute copies of **Handout 5: Forest Dieback** and give students time to read it, underlining words with which they are unfamiliar. Then discuss the content of the reading to answer any questions they might have.

4. Remind students about the long-term drought across the western part of the U.S. and the disastrous forest fire damage of 2020 and 2021. Divide students into groups and give them time to research this topic on the Internet. Assign one of the following websites to each group. Have them prepare a summary of the information that they find; then ask them to check for more recent information as well:

https://www.cnn.com/2021/07/31/weather/us-western-wildfires-saturday/index.html

https://www.nifc.gov/fire-information/nfn

https://www.usatoday.com/story/news/nation/2021/08/02/western-wildfires-progress-poor-air-quality/5453352001/

https://www.npr.org/2021/07/21/1018865569/the-western-wildfires-are-affecting-people-3-000-miles-away https://apnews.com/article/fires-environment-and-nature-california-5129408f55d27e9a3ebb426453014003

https://www.sciencemag.org/news/2020/09/wildfires-continue-western-united-states-biologists-fear-vulnerable-species

https://www.nytimes.com/spotlight/wildfires-west?.?mc=aud_dev&ad-keywords=auddevgate&gclid=CjwKCAjwr56IBhAvEiwA1fuqGrdEcwB-D7IwLE1VAXRq_8ewHuUK_BoMkZEHq-tvQpowk_zhMXqjcABoCIt0QAvD_BwE&gclsrc=aw.ds

5. Ask students to report on the information that they have found. Discuss the impact of the loss of photosynthesis and transpiration across large areas of land (dramatic reduction in CO_2 uptake and water vapor release), making the temperatures higher and the landscape drier. In addition, all the stored carbon in the trees (the carbon sink) becomes a carbon source, the fire releasing CO_2 into the atmosphere, also raising the temperature.

Part 5: The tropical, boreal, and temperate forests as carbon sinks

1. Have the students watch the "Forests" video again, this time with a focus on the relative roles each of these three forest types have in acting as carbon sinks in the Earth's carbon cycle.

2. Ask the students to compare tropical forest carbon sinks (most carbon stored above ground in forest biomass) with boreal forest carbon sinks (much stored underground in the permafrost) and the temperate forest sinks (both above and below ground). Here are some questions to ask to guide discussion:

- Which of these forest types is least susceptible to damage from climate change, and why? (Temperate forests, since early clearing of these forests in the eastern U.S. are now growing back, and old growth forests in the Northwest continue to store large amounts of carbon.)
- Which of these carbon sinks are likely to become carbon sources if the climate crisis continues unabated? (Both tropical and boreal forests.)
- What role does the production of wood pellets play in the temperate forest as part of the forest feedback loop? (This is the major threat to the extensive evergreen forests of the Southeast, since it results in the cutting and removal of these forests, reducing the uptake of CO_2, and burning wood pellets, releasing their stored carbon as CO_2.)
- Is the burning of wood pellets to heat homes in the winter really an environmentally sound idea? Why or why not? (It is not sustainable, even if replanting is involved, because it will take 60–100 years to replace the logged forests. It is not an environmentally sound idea. It may have seemed like a good idea at the time because forests are a source of renewable energy, but young forests store less carbon than older forests.)

3. Conclusion: Give students time to write in their journals or notebooks: What are the three most important things you have learned in this lesson on forest feedback loops? Why are they so important?

Handout 1

Feedback Loops

Feedback loops are part of a closed system (the weather system is an example) in which a change to one or more component parts impacts (changes) the other parts. Feedback loops can be either negative or positive. In a positive feedback loop, an increase in one or more parts amplifies or increases the other parts. In a negative feedback loop, a decrease in one part results in decreases in the others.

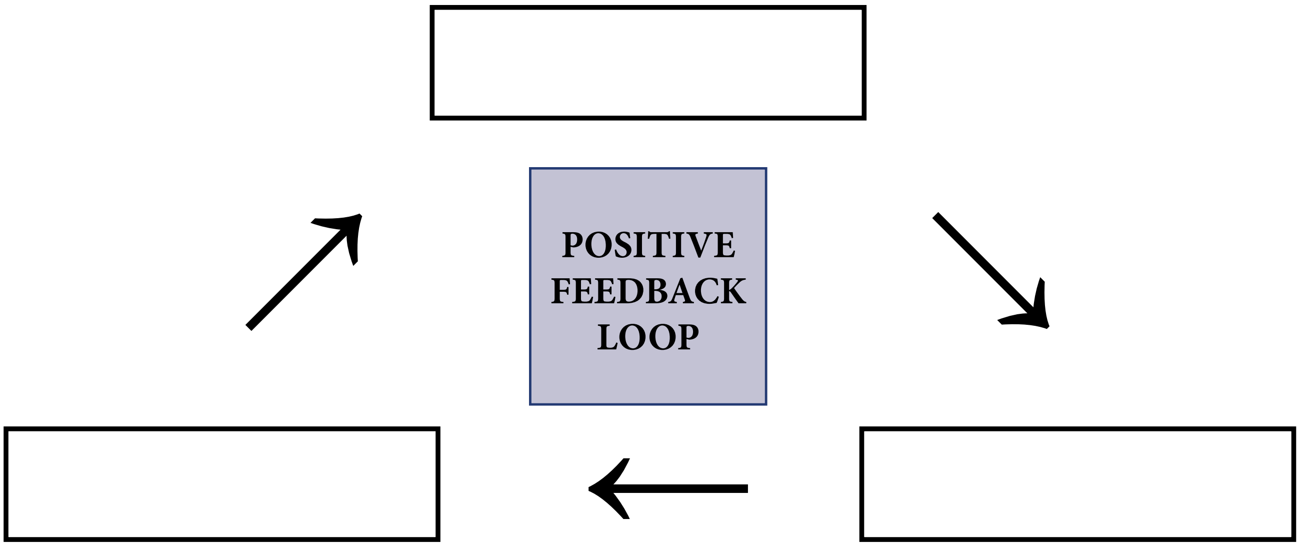
The "Forests" video introduces several examples of both positive and negative feedback loops that are related to changes in forests. We know that forests cool the Earth, and changes in the number and size of forests will affect the climate system. More forests will result in the removal of CO_2 in the atmosphere, as the result of increased photosynthesis, thus cooling the climate (a negative feedback loop). Loss of forests, as the result of logging, disease, forest fires, or overall forest dieback, results in more CO_2 in the atmosphere, warming the planet and amplifying occurrence of disease, forest fires, and forest dieback (a positive feedback loop).

1. Had you ever heard of feedback loops before seeing the video? If so, where?

2. In trying to limit future climate change, why is it important to understand the role that feedback loops play?

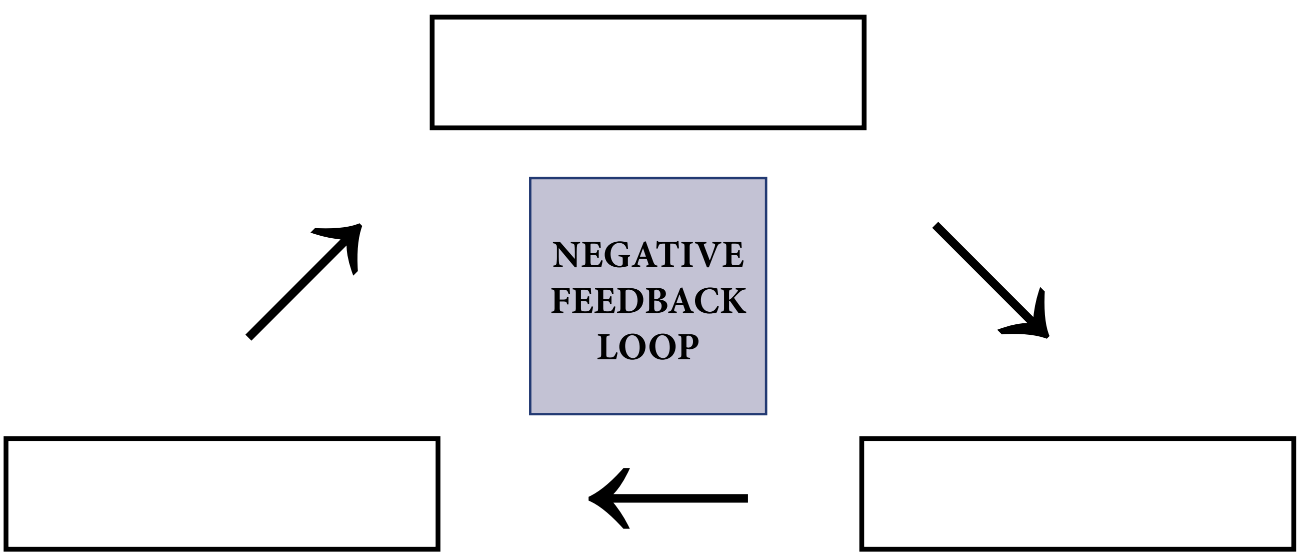
3. What are some steps that you could take in your own home and school to address the current climate crisis?

4. In the diagram below, using words provided in the Word Bank, give an example of a negative feedback loop and a positive feedback loop.



WORD BANK

More CO_2	Higher Temperatures	More trees
Shorter days	Less CO_2	Fewer Trees
Fewer trees	Lower Temperatures	More O_2
More sunlight	Less sunlight	Less O_2
		Longer Days

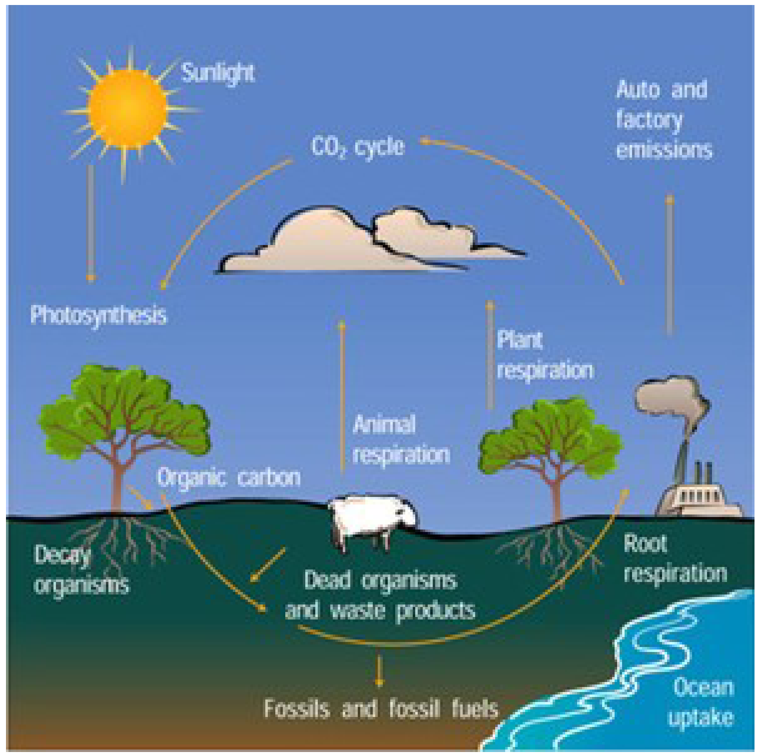


Handout 2

The Carbon Cycle

All life on Earth is carbon-based, and forests play a major role in the cycling of carbon through Earth's systems: the atmosphere, the hydrosphere, the biosphere, and the lithosphere (sometimes called the geosphere). As the result, the carbon cycle is a biogeochemical cycle whereby a wide range of carbon compounds (carbohydrates, hydrocarbons, etc.) are exchanged within the four Earth Systems.

There are four steps to the carbon cycle. First, CO_2 is absorbed by green plants through the process of photosynthesis. As we know, forests store large amounts of carbon as wood. Second, these plants are consumed by animals and the carbon accumulates in their bodies. Third, both the animals and plants eventually die, decay, and release much of that carbon back into the atmosphere. Due to geological processes, some of the carbon is not released back into the atmosphere but is buried and becomes fossil fuels (coal, oil, and natural gas). Lastly, these fossil fuels are used as a source of energy, powering our motor vehicles, heating our homes, and driving our economies, pumping large amounts of CO_2 back into the atmosphere; this warms the atmosphere, creating the current climate emergency.



[Image source: Mrs. McComas, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons]

Look at the simple diagram of the carbon cycle above. In the "Forests" video, the point is made that forests collectively represent a significant carbon sink. A carbon sink refers to a mechanism that removes and stores carbon. In the case of forests, the formation of wood is a major sink, as is stored carbon in forest soils. As we will see, the relative amounts of above-ground and below-ground sinks vary with the type of forest (tropical, temperate and boreal).

Handout 3

Photosynthesis and Transpiration

The process of **photosynthesis** occurs in some microbes (cyanobacteria and bacteria) and in green plants, including all forest trees (both hardwoods and softwoods), as well as palm trees, bamboo, and some tropical ferns. Photosynthesis occurs in cellular organelles called **chloroplasts**. The chemical process of photosynthesis requires three things: a source of visible light (sunlight or artificial light), water (taken in through a tree's root system), and carbon dioxide (CO_2, which enters the leaves through small pores called stomates or stomata). The basic formula for photosynthesis is shown below.

$$CO_2 + H_2O \overset{\text{Light}}{=} C_6H_{12}O_6 + O_2$$

The process of photosynthesis occurs in two steps. The first, called the Light Reaction, results in the splitting of water molecules (H_2O) into hydrogen atoms (H_2) and oxygen atoms (O), as well as chemical energy involving the hydrogen atoms. The second step is called the Calvin cycle, in which CO_2 is combined with other carbon compounds using the chemical energy to produce carbohydrates, such as glucose or fructose. Oxygen, which humans and all other aerobic organisms use for respiration, is produced as a by-product of the light reaction of photosynthesis. Trees use the carbohydrates to make wood, which is composed of cellulose. Thus, wood is stored CO_2.

Transpiration is the process whereby water vapor (water in the form of a gas) passes out of the leaf, through the stomates in the epidermal layers of the leaf, into the atmosphere. The water lost as water vapor is then replaced in the leaf by water in the wood from twigs, pulling more water from the wood of the tree trunk, and in turn, pulling water into the roots from the soil. The process of transpiration in the leaves is the way trees move water and dissolve soil nutrients from the roots into the wood. So wood is not just stored CO_2; it is also the pipeline through which the water needed for photosynthesis moves up the tree to the leaves.

Transpiration is also a way of moving soil water into the atmosphere, where it condenses into water droplets around tiny dust particles (aerosols) to form clouds. Evaporation is another way that water vapor enters the atmosphere. (Trees are cloud generators! In tropical forests, 60% or more of the rain that falls in the tropics has come from the tropical forests themselves!)

Transpiration is much more efficient at adding water vapor to the atmosphere than evaporation alone. That is because evaporation occurs only over open bodies of water (rivers, lakes, oceans, etc.). Transpiration adds more water vapor to the atmosphere because the extensive roots systems of plants, especially of trees, cover a greater area of soil when compared with the same area of open water. Combined, evaporation and transpiration are called **evapotranspiration**.

When forest dieback occurs, as the result of disease, insect damage, fire, etc., the photosynthetic capacity of forests is greatly diminished; the transpiration process is interrupted as well. This results in a warmer climate (less CO_2 being absorbed and stored as carbohydrates, especially wood) and a drier one (less transpiration). It is really important that our actions let trees do their job!

Handout 4

Tree Structure

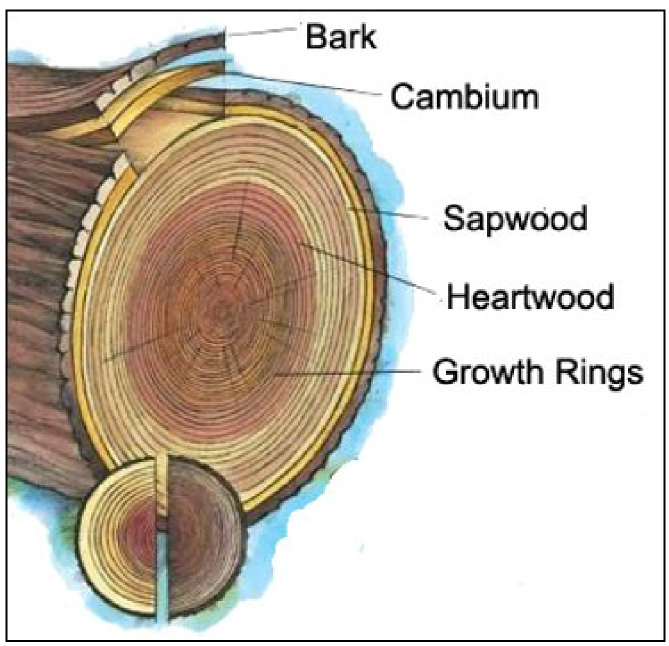
The Wood

The wood in a tree has three functions: first, to conduct water and dissolved soil nutrients upward from the roots to the leaves; second, to support the tree's **canopy** (its twigs and leaves) and raise it to the sunlight where it competes with the canopies of other trees in the forest; and third, to store carbohydrates (sugars converted to starch) produced by photosynthesis in the leaves. The wood cells of trees are 95% dead at functional maturity when they are performing the functions of conducting and supporting. The remaining 5% of the cells of the wood are living and function as starch storage cells. All of these cells—conductive, support, and storage—are produced by the **vascular cambium**, a site of active **mitosis** (cell division) during the spring and early summer months. The cambium is located between the wood and the bark.

The active vascular cambium produces a new growth ring each spring. The most recent growth rings are called **sapwood** and function in conducting the sap (water and nutrients). The older growth rings constitute the **heartwood** of a tree, which functions primarily in support and storage, but not conduction. Each growth ring is composed of thin-walled earlywood cells and thick-walled latewood. The conductive cells of each growth ring are **pores** in hardwoods (angiosperms or deciduous trees) and **tracheids** in softwoods (gymnosperms or evergreen trees). The terms *hardwoods* and *softwoods* are deceptive and do not refer to the hardness of the wood. Some hardwoods (angiosperms) have very soft wood, such as balsawood, and some softwoods (gymnosperms) have very hard wood, such as some species of pine.

The wood of each tree is produced by cell division (mitosis) in the vascular cambium each spring. Each wood cell has cell walls composed mostly of cellulose, a structural carbohydrate made from the sugars (glucose and fructose) produced in photosynthesis. Thus, the cellulose cell walls of wood are an example of stored carbon (a sink) that was produced from atmospheric CO_2 produced in the Calvin cycle of photosynthesis.

The diagram below illustrates the parts of a tree stem. Note the growth rings, the sapwood and heartwood, the cambium (vascular cambium), and the bark to the outside of the cambium. The inner part of the bark, the phloem, conducts photosynthetic products (sugars) down from the leaves to where the cambium can use them to make the cellulose cell walls of the wood, the main carbon sink of the tree.

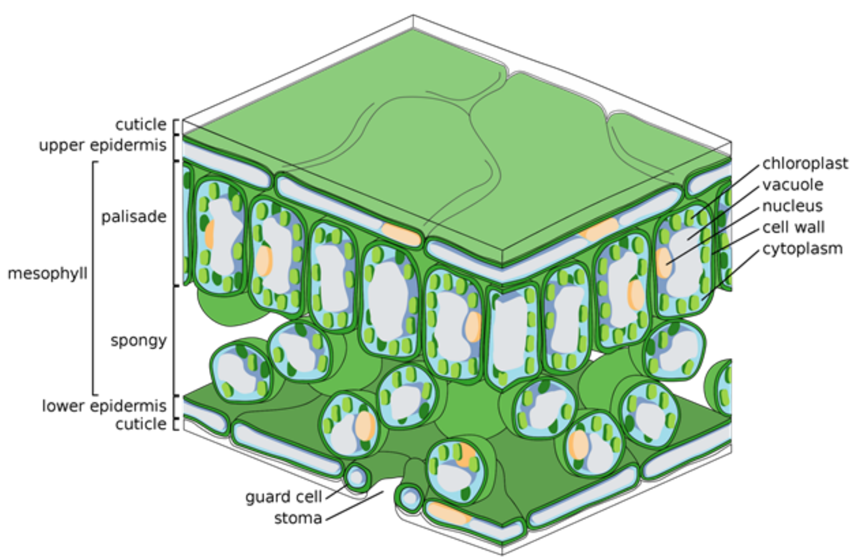


[Source: U.S. Forest Service at https://www.fs.usda.gov/learn/trees/anatomy-of-tree

The Leaves

The leaves of a tree are the site of photosynthesis and the capture of CO_2 from the atmosphere. The CO_2 enters the leaf through **stomates** in the **epidermis** of the leaf. Once inside the leaf, the CO_2 diffuses into the main photosynthetic cells of the **mesophyll**, mostly the palisade cells, and from there, into chloroplasts. In the **chloroplasts**, the light reaction breaks water molecules into hydrogen atoms and oxygen atoms. In the process of splitting the water, chemical energy in the form of ATP is produced. The hydrogen atoms and the ATP will be used in the Calvin cycle to capture CO_2 to make sugars, and the oxygen (a by-product of the light reaction) will diffuse out of the mesophyll through stomates and into the atmosphere.

Photosynthesis produces sugars (glucose and fructose containing the captured atmospheric CO_2) and oxygen. The oxygen enters the atmosphere as a waste product and the sugars are taken out of the leaf in the phloem and carried down to where the vascular cambium converts them into cellulose in the cell walls of the wood cells. Below are diagrams of the leaf structure and the photosynthetic process. If all of this sounds like magic, it is! Just trees doing their job!



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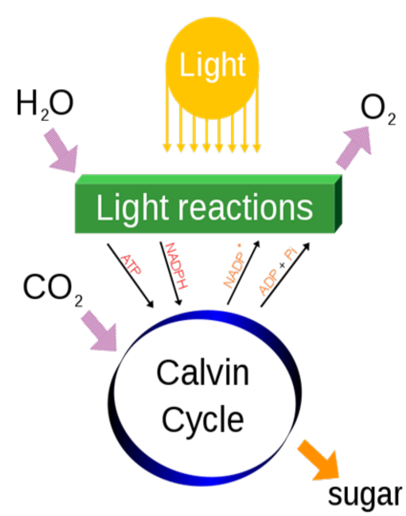


Daniel Mayer (mav) - original imageVector version by Yerpo, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

The Roots

The roots of a tree are the organs that extend throughout the soil, absorbing soil water and dissolved soil nutrients. The roots also become woody, anchoring the tree in place. Most tree species have beneficial fungi growing on their roots, called **mycorrhizae**, an example of a symbiotic relationship where both the tree and the fungi benefit. The tree benefits from the fungus, which collects water and dissolves nutrients from organic and inorganic material in the soil, while the fungus benefits by receiving sugar from the tree. The term mycorrhiza comes from "myc-" meaning "fungus," and "rhiza" meaning "root." In the soil, the roots and their mycorrhizae come in contact with the roots and mycorrhizae of neighboring trees. This is how trees communicate with one another—through their root/fungus network. This has been called the "Wood Wide Web," a term coined by Dr. Suzanne Simard, a forest ecologist from the University of British Columbia.

The dissolved soil nutrients are used by the tree to make a wide range of organic, carbon-based molecules needed in the tree's metabolism. Some of these nutrients come from inorganic minerals in the soil, while others come from organic debris in the soil, including decaying leaf litter and animal matter. Below is a diagram of a seedling, showing its root system. Once the seedling matures into a tree, it will have a much more extensive root system.

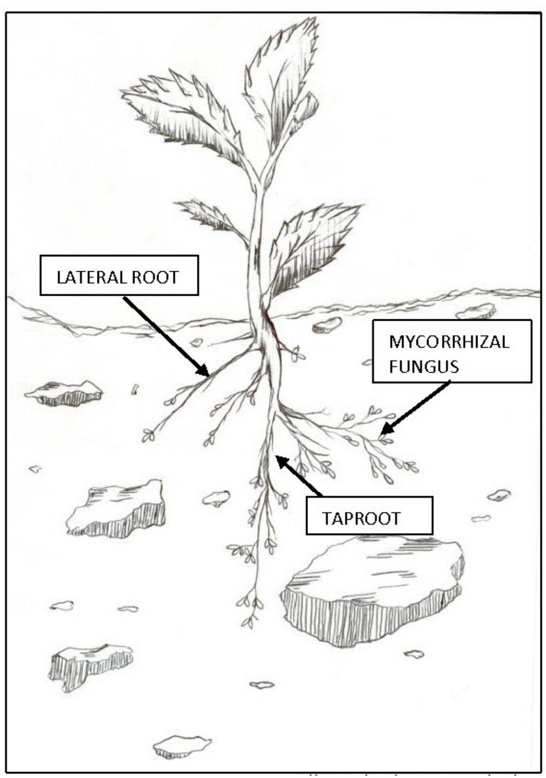


Image by M. Mattingly

Handout 5

Forest Diebacks

Forest dieback or forest decline occurs when large numbers of trees, even an entire forest, suddenly dies, often due to an unknown cause. Typical causes of recent forest diebacks have been prolonged drought, dramatic temperature changes (too cold or too hot), pathogens (insects, such as bark beetles, or fungal pathogens), parasites, and/or pollution, such as ground-level ozone or acid rain. Physical climate change (increased warming due to heat-trapping atmospheric gases) and chemical climate change (air pollution or water pollution) often have a negative impact on forests. Such impacts may affect forest functions such as photosynthesis, nutrient uptake, and normal water transport in wood or bark. Below are two examples of recent forest diebacks or declines.

Acid Rain Damage

When air pollutants, like nitrogen dioxide from automobile exhaust and sulfur dioxide from coal-burning factory smokestacks, combine with cloud moisture, **acid rainfall** of nitric acid or sulfuric acid occurs. Acid rain damage had a significant impact on high-elevation conifer forests in the northeastern United States during the 1970s and 1980s, and a similar type of damage, termed *Waldsterben* (*Wald* is the German word for forest and *Sterben* means death or dying), also occurred on high-elevation conifer forests in Central Europe during the same period. Both were thought to be due to air pollution and acid precipitation impacts on red spruce needles in the United States and Norway spruce needles in Germany, Czechoslovakia (now the Czech Republic and Slovakia), Hungary, and other Eastern European countries.

Recent research has shown that ground level ozone (O_3, also a pollutant) was also involved, entering through the stomates of the needles and weakening the cellular membranes of the mesophyll cells. Acid cloud moisture then had the effect of destroying the chloroplasts in the mesophyll cells, especially of older needles, dramatically reducing their photosynthetic activity. The one-two punch of ground-level ozone followed by exposure to acid cloud chemistry resulted in large-scale dieback of spruce forests across the northeastern United States and Central Europe.

Forest diversity also played a significant role in the impact of acid rain damage in conifer forests. In the United States, red spruce trees were very susceptible to acid rain damage, but balsam fir trees were not. Since the high-elevation conifer forests in the Appalachian Mountains consisted of a mix of the two conifer species plus hardwood species such as birch, the decline of the red spruce was not as obvious because the other types of trees were unaffected. In Central Europe, however, the conifer forests were a monoculture of only Norway spruce, resulting in a total collapse of those forests. Political action in both the U.S. and Europe dramatically reduced the amount of air pollution by the early 1990s, resulting in significant improvements in forest health in the high-elevation conifer forests in the Northern Hemisphere in the 1990s.

Bark Beetle Damage

Bark beetle damage continues to be a significant problem in conifer forests of the western U.S. The beetles bore into the bark of conifer trees in order to lay their eggs in the inner bark (the phloem) and the cambial zone, thus giving their larvae a supply of sugars and other organic compounds for their growth. As the beetles eat these tissues required for tree growth (i.e., to produce new wood), the trees die over a period of a few years. In addition to eating the tender tissues, fungal spores are often introduced by the egg-laying activities and they germinate. This results in filling those tissues and the new growth ring of wood with fungal cells that clog the conductive cells of the wood; this prevents water and nutrients from reaching the canopy.

Healthy conifer trees produce a range of **resins** (a highly viscous substance) and **terpenes** (aromatic compounds) that inhibit insects like bark beetles from boring holes in the bark. These protective chemicals are long chains of carbon atoms with attached hydrogen atoms, a class of compounds called hydrocarbons, resulting from the capture of carbon dioxide from the atmosphere. The process of making these protective **hydrocarbons** requires water, and when a drought occurs, the trees are unable to make the protective chemicals, and thus the trees become susceptible to bark beetle attacks. A prolonged drought, like the recent one in the western United States, has resulted in extensive areas of dead trees unable to protect themselves, killed both by bark beetles and the drought. Lightning strikes, careless campers, or other causes can result in massive and destructive wildfires like the ones that we are now experiencing across the western states.

The 2018 Camp Fire in Paradise, California, destroyed over 11,000 homes, and 85 people lost their lives. In 2021, the Dixie Fire in California has now surpassed 2018's Mendocino Complex Fire (459,123 acres) and 2020's Southern California Lightning Complex Fire (396,624 acres). Climate models indicate that such drought-induced wildfires may become the "new normal" across large areas of the West. In addition to the loss of life and property, consider the loss of photosynthetic CO_2 capturing capacity and transpiration-fed cloud moisture and rainfall patterns, as well as the release of massive amounts of CO_2 into the atmosphere from the burning trees. Such conditions convert trees that had been carbon sinks into carbon sources. Consider the feedback loops, both positive and negative, at play in such forest dieback scenarios.

Handout 6

The Three Types of Forests

As the "Forest" video shows, there are three dominant types of forests on Earth: tropical forests, temperate forests, and boreal forests. Each of these types of forests is a carbon sink while alive, but may become a carbon source once it dies. While living, all forests capture carbon dioxide (CO_2) from the atmosphere through the process of photosynthesis in their leaves (either broad-leaves in deciduous trees, or needles or scales in conifers), converting sunlight into chemical energy and CO_2 into sugars (carbohydrates, chemically $C_6H_{12}O_6$). In the process, oxygen (O_2) is released as a waste product. The sugars produced are converted into cellulose cell walls that make up wood, a stored form of carbon, thus making trees a carbon sink.

One of the important ways of dealing with the climate emergency presented in the "Forests" video is to develop ways of protecting and promoting these carbon sinks. How do these types of forests differ as carbon sinks? As carbon sinks, the three types of forests store carbon differently, some storing more carbon above ground in the tree trunks (tropical and warm temperate forests) and some storing more carbon below ground in the soil (moist, cool temperate, and boreal forests).

A below-ground carbon sink is characterized by lots of organic matter, typically made up of roots, soil organisms, such as earthworms and insects, bacteria, fungal (mycorrhizal) hyphae, decaying wood, and leaf litter, etc. Soil rich in organic matter is often referred to as *topsoil,* while soil poor in organic matter is mostly mineral matter and is called *subsoil*. Go to the U.S. Forest Service web page at https://www.fs.usda.gov/ccrc/topics/global-carbon to see a graph of the biomass (i.e., stored carbon) of the different types of forests and the differences in the amounts of topsoil and subsoil that characterize the three forest types. Also note that cool moist temperate soils and boreal moist soils exhibit the most organic matter and thus represent the greatest soil carbon sinks.

Tropical Forests

It is apparent from the graph that tropical forests (both wet and moist) store much of their carbon above ground. Due to the rapid turnover rate, little leaf litter develops in tropical forests. A wet tropical forest is a tropical rainforest growing mostly in equatorial regions of the Earth. These wet tropical forests have no dry season, while moist tropical forests have a limited dry season. They too are equatorial in their distribution, and both wet and moist tropical forests are characterized by very high species diversity. They are dominated by a large number of deciduous broadleaf species.

Their continually warm, wet climate makes them more productive than any other terrestrial environment on Earth. Due to extensive deforestation over the past 40–50 years, there is approximately 30% less carbon being stored here in tropical forest than in the 1990s. In fact, due to human pressure from logging and ranching, tropical forests ecosystems are on the verge of going from carbon sinks to carbon sources, converting their stored carbon back into CO_2.

Temperate Forests

Temperate forests are found in the temperate regions of the Earth (eastern and northwestern North America, Central Europe and northeast Asia). Temperate forests occur between 25 degrees and 50 degrees of both north and south latitudes; they are mild-climate forests. Warm temperate forests store about equal amounts of carbon above and below ground. (Warm moist temperate forests may also be called sub-tropical forests.) The cool temperate moist and cool temperate dry forests store more carbon below ground. Temperate forests are composed mostly of deciduous tree species, spending about half of the time in a dormant leafless condition.

Boreal Forests

Boreal forests are characterized by the fact that they store most of their carbon below ground and are often associated with permafrost. The term *boreal* means "north," and most of the boreal forest trees are conifers (evergreen) species. Most boreal forest soils represent the largest carbon sinks, with many boreal soils also characterized by permafrost. The ice of permafrost soils locks in the gases released by the decay process, CO_2 and methane (CH_4), not allowing them to enter the atmosphere to cause increased warming. As the northern latitudes warm more rapidly than the rest of the planet, the thawing of permafrost soils beneath boreal forests presents a dangerous feedback loop in which stored carbon can decay, releasing CO_2 and CH_4, a greenhouse gas 30 times more powerful at trapping heat than CO_2. The large-scale thawing of permafrost has been labeled as a potential "carbon bomb" in the climate crisis.

Teacher Resource 1

Light Microscope and SEM Images of Wood

On the following pages you will find magnified images of wood to share with your students. The images are as follows:

Slide 1. A comparison of scanning electron microscope (SEM) images of a softwood (a red pine) and a hardwood (white oak), illustrating the differences between the two major types of wood, as seen in cross section (XS), radial section (RS), and tangential section (TS). Note the 3-D nature of the cells. Remind the students that the cell walls of all cells shown in both wood types are made up of cellulose (i.e. stored carbon dioxide). It took 6 CO_2 molecules to make each carbohydrate molecule ($C_6H_{12}O_6$), and there are hundreds of millions of cellulose molecules in each cell wall!

Slide 2. This is a light microscope 35X image of a cross section of a six-year-old white pine twig with the wood stained red and the bark stained blue. The red wood cells (vascular tracheids) are dead and the blue (parenchyma) cells are living. Note the blue vascular ray cells radiating out through the wood cells from the central pith. Also note the blue resin ducts in the growth rings of the wood. The purpose of the resin canals or ducts is to produce resin that protects the tree from insects such as bark beetles.

Slide 3. This is light microscope 100X image of a cross section of the wood of white pine, showing one complete growth ring with one resin duct. The radial files of small, more or less circular cells are the dead vascular tracheids that conduct water and nutrients from the soil up to the leaves (needles) in the tree's canopy. The tracheids also function as support cells, in addition to conduction. The very narrow files of cells are the living vascular rays, which store starch and conduct water and nutrients laterally to older growth rings. The next slide is a longitudinal section of white pine wood.

Slide 4. This is a light microscope 100X image of a longitudinal (radial) section of the wood of white pine, showing one complete growth ring. Note the vertical orientation of the vascular tracheids that appeared to be circular in cross section in the previous slide. Remind the students that these dead vascular tracheids conduct water and nutrients from the soil up to the leaves (needles). Running horizontally across the image is a vascular ray. Compare slides 3 and 4 with the SEM image of red pine seen in Slide 1.

Slide 5. This is a scanning electron microscope (SEM) 200X image of a radial section (RS) of white pine wood, showing the vertically-oriented vascular tracheid cells and the horizontally-oriented vascular ray cells. Note that the tracheids have circular openings (pits) in their cell walls that allow water and nutrients to pass from one tracheid to the next, while the ray cells have larger, window-like pits that allow water and nutrients to pass from tracheids to ray cells. All of the cell walls seen here are made of cellulose molecules (stored CO_2).

Slide 6. This is a scanning electron microscope (SEM) 200X image of a cross section (XS) of red oak wood showing ring porosity, a much more complicated cellular structure. In hardwood trees, the function of conduction and support of the wood is done by two separate cell types: vessel elements conduct and fibers support. The large pores or vessel elements seen here are part of the earlywood of a growth ring, and the smaller pores or vessel elements are part of the latewood of the previous growth ring. Most of the smaller cells surrounding the vessel elements (pores) are the fibers that support the tree as it grows into the forest canopy. Vascular rays are also seen in this image. All of the cell walls in the wood of most hardwoods are much thicker, and thus harder, than the thin cell walls of tracheids in softwoods.

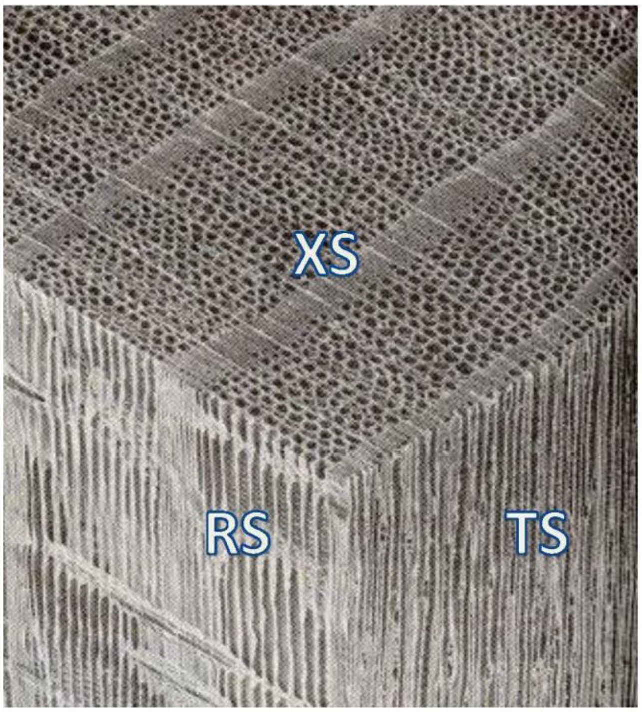
Slide 7. This is a scanning electron microscope (SEM) 500X image of a cross section (XS) of a diffuse porous hardwood. The large circular cells, all about the same size, are the vessel elements or pores, that conduct water and nutrients from the soil to the leaves of the tree's canopy. Most of the smaller cells surrounding the vessel elements (pores) are the fibers that support the tree as it grows into the forest canopy. Vascular rays are also seen in this image.

Slide 8. This is a scanning electron microscope (SEM) 500X image of a tangential section (TS) of a diffuse porous hardwood. Note that the vessel element cells are linked vertically in a continuous chain of cells that stretch all the way from the roots to the leaves, an amazingly functional design for conducting water and nutrients from the soil to the leaves.

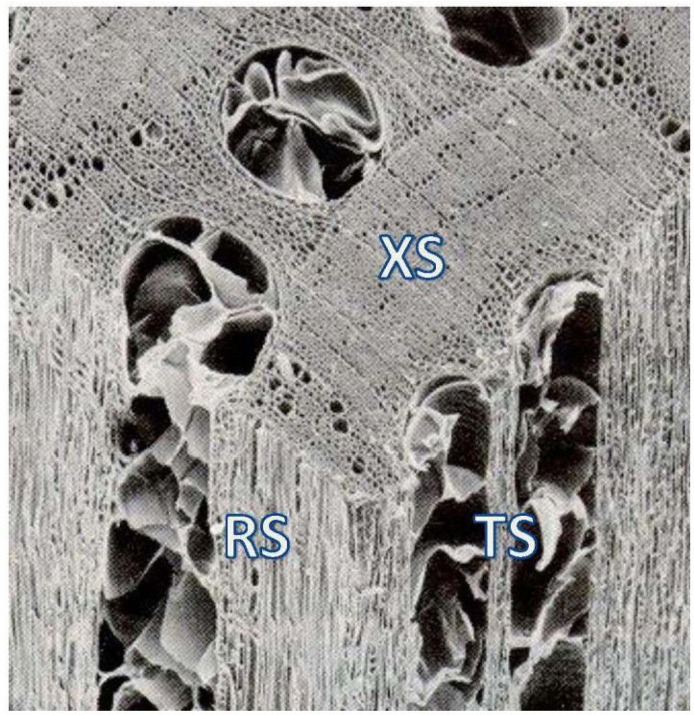
Slide 1

Scanning Electron Microscope (SEM) Images of Wood

Softwood (Red Pine)

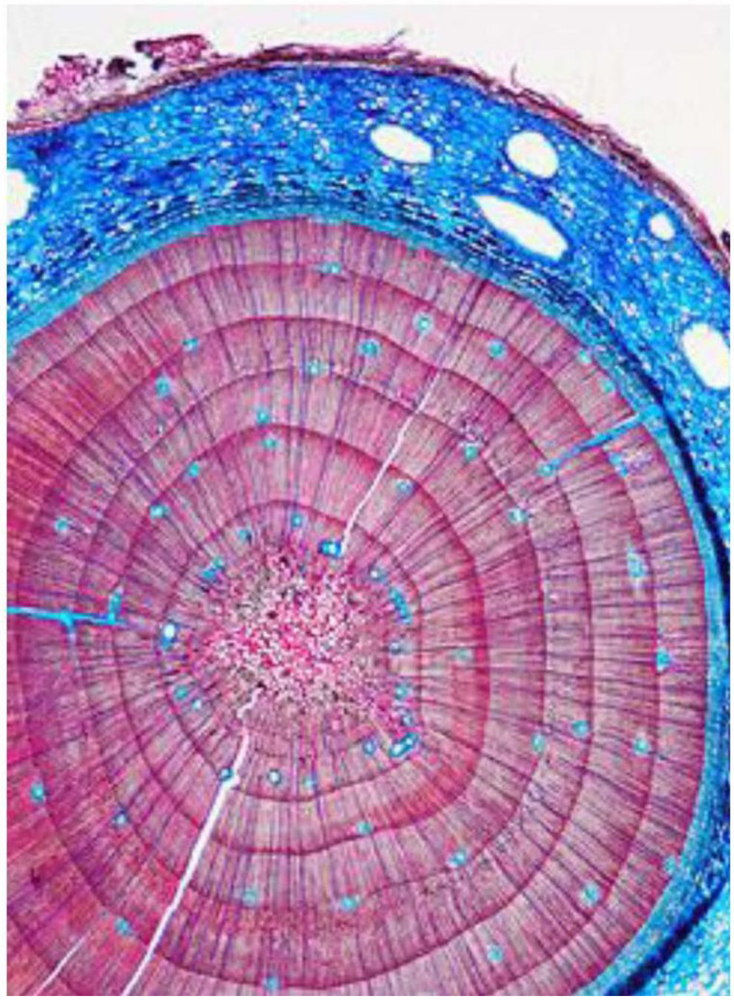


Hardwood (White Oak)



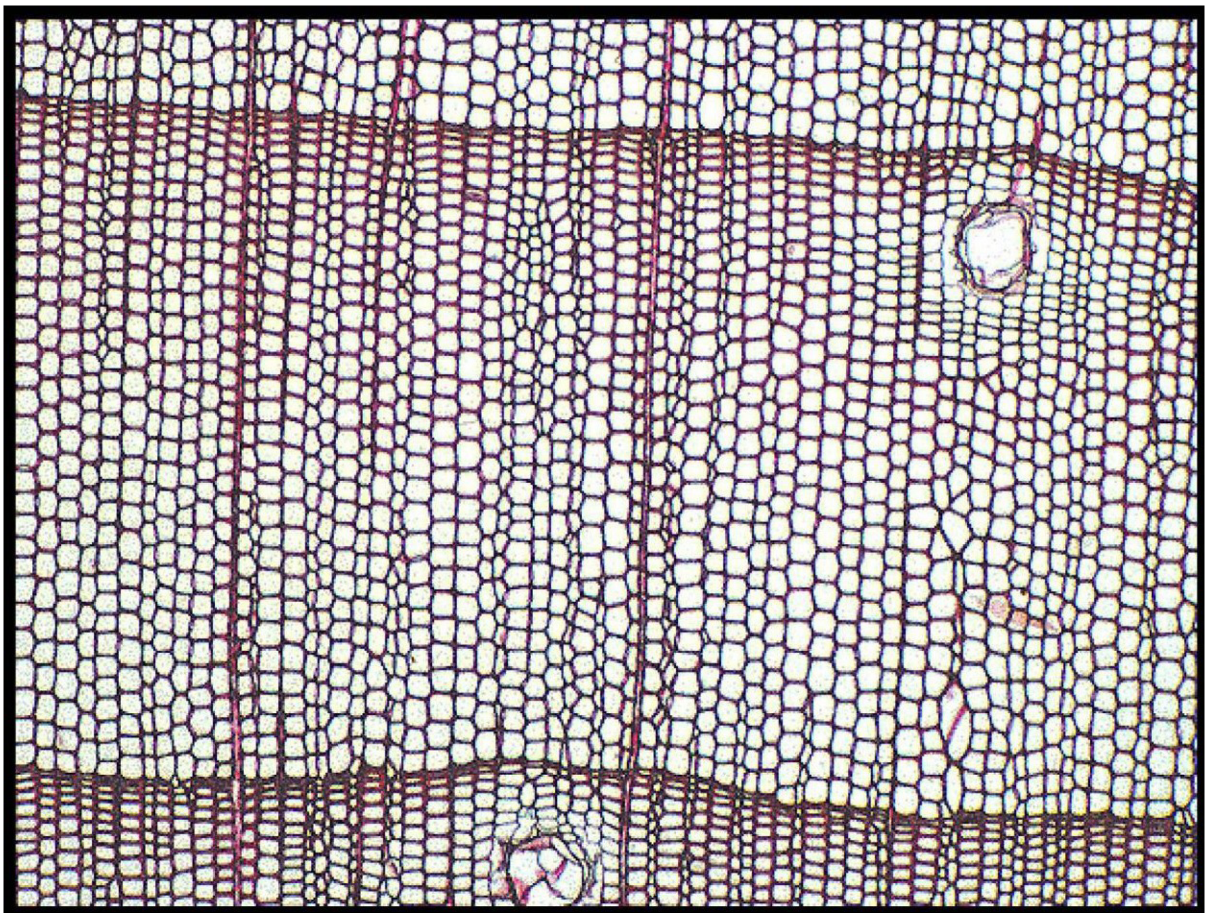
Slide 2

A cross section of a six-year-old white pine twig with the wood stained red and the bark stained blue. The red cells are dead and the blue cells are living. Note the blue vascular rays radiating out through the wood cells from the central pith. Also note the blue resin ducts in the wood.



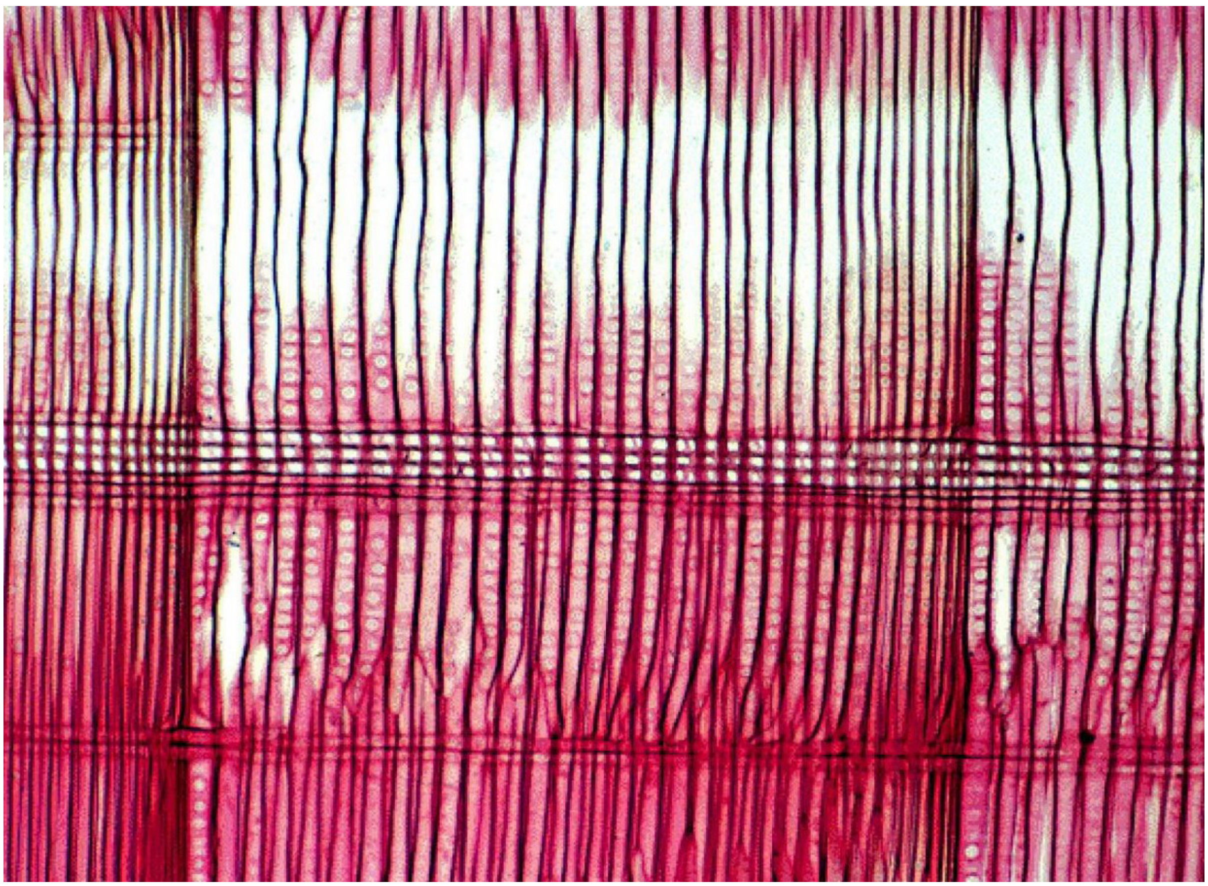
Slide 3

White Pine wood XS showing two resin ducts



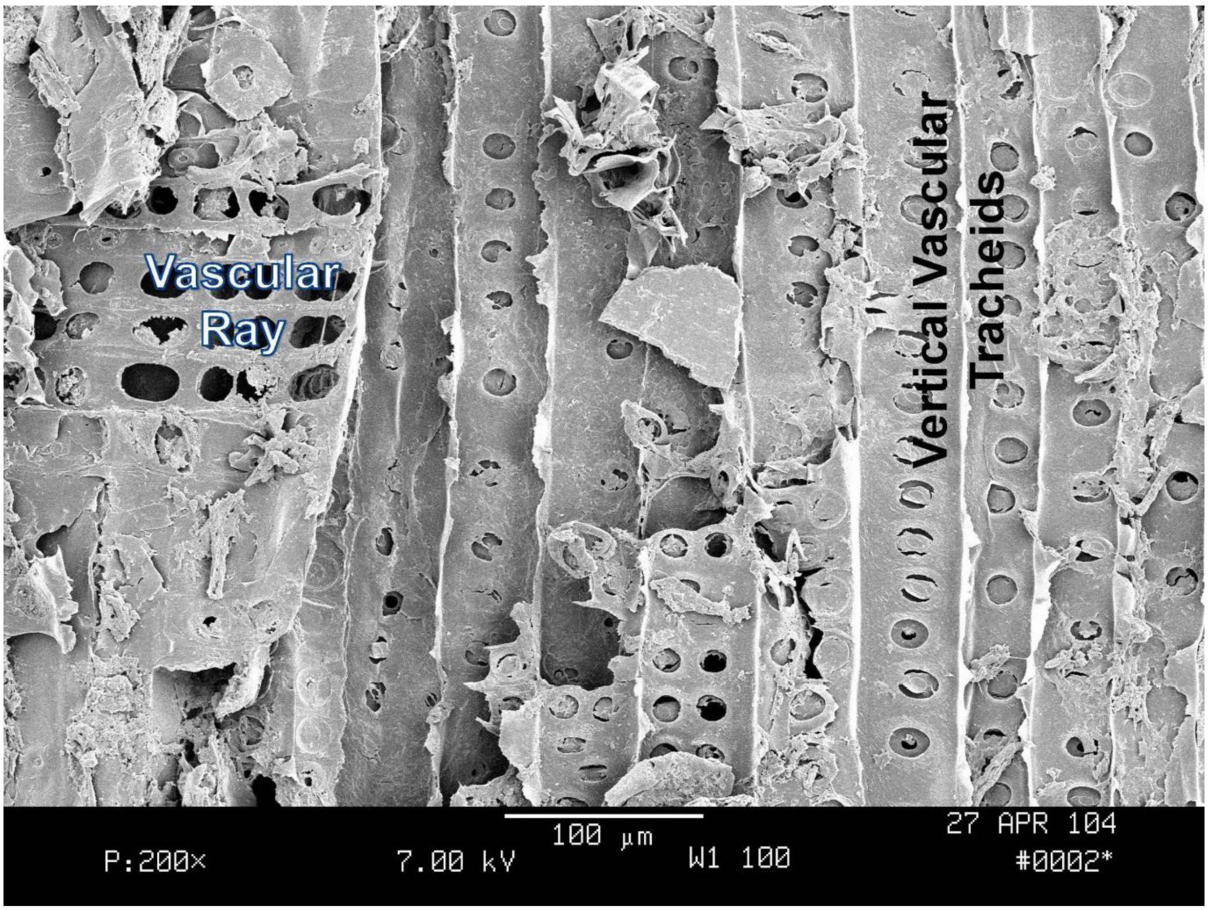
Slide 4

White Pine RS, showing longitudinal tracheids



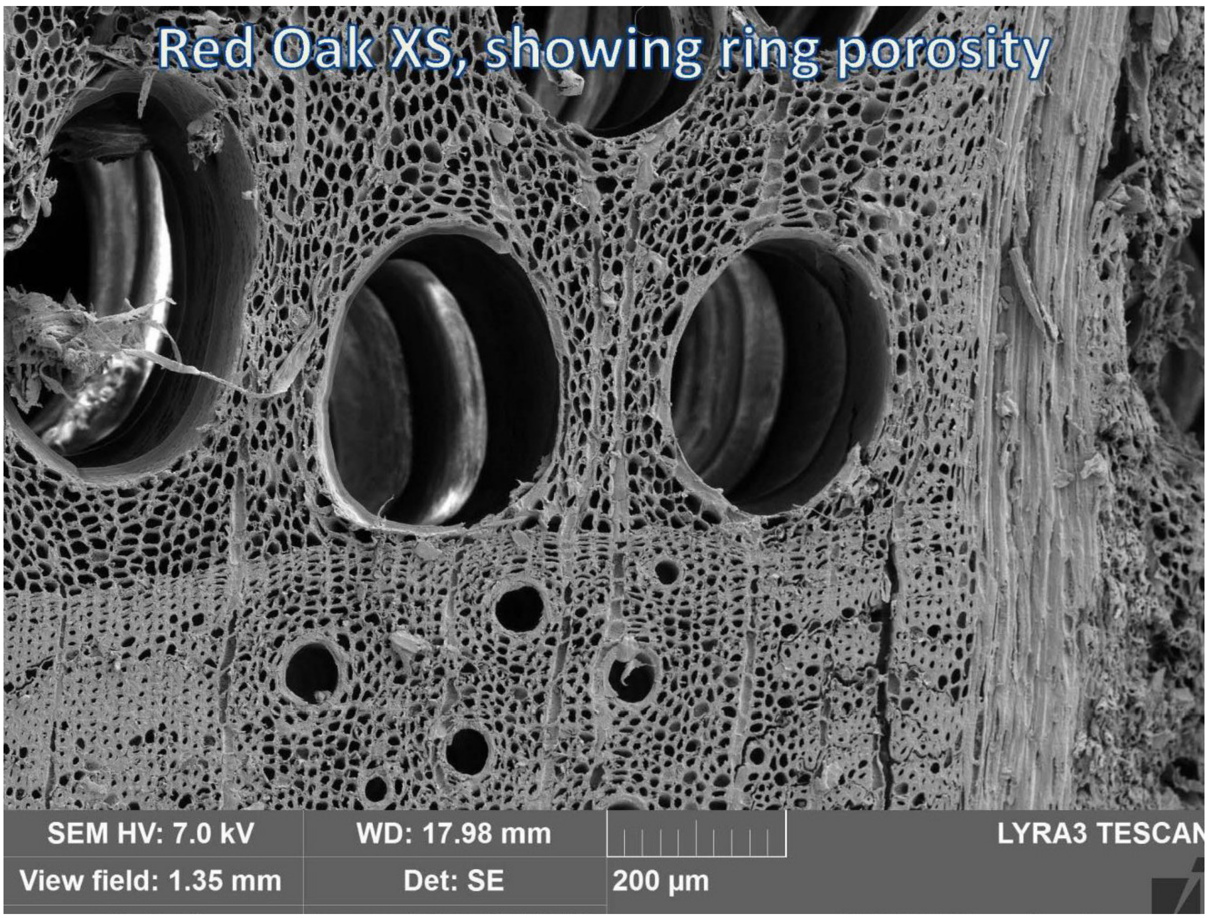
Slide 5

Vascular Cells



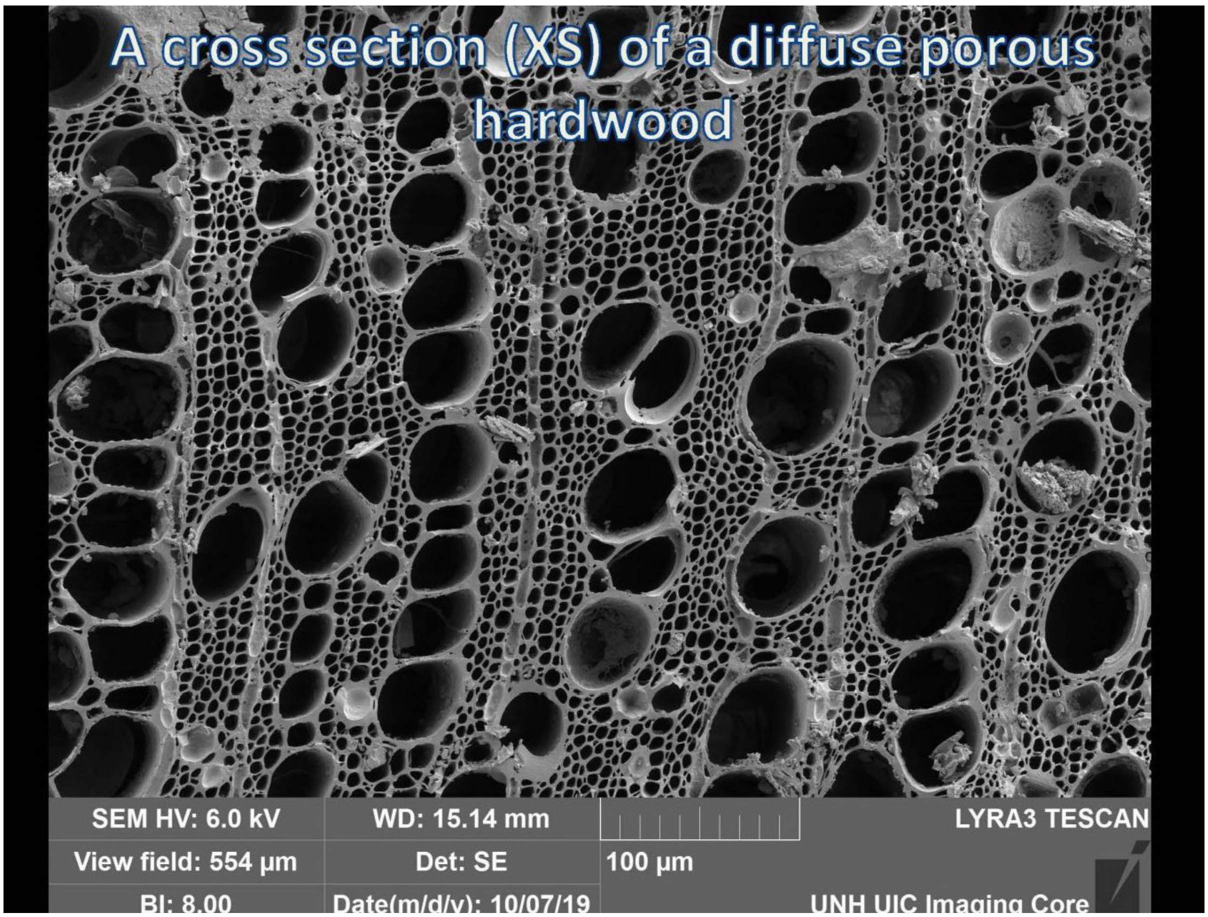
Slide 6

Red Oak XS, showing ring porosity



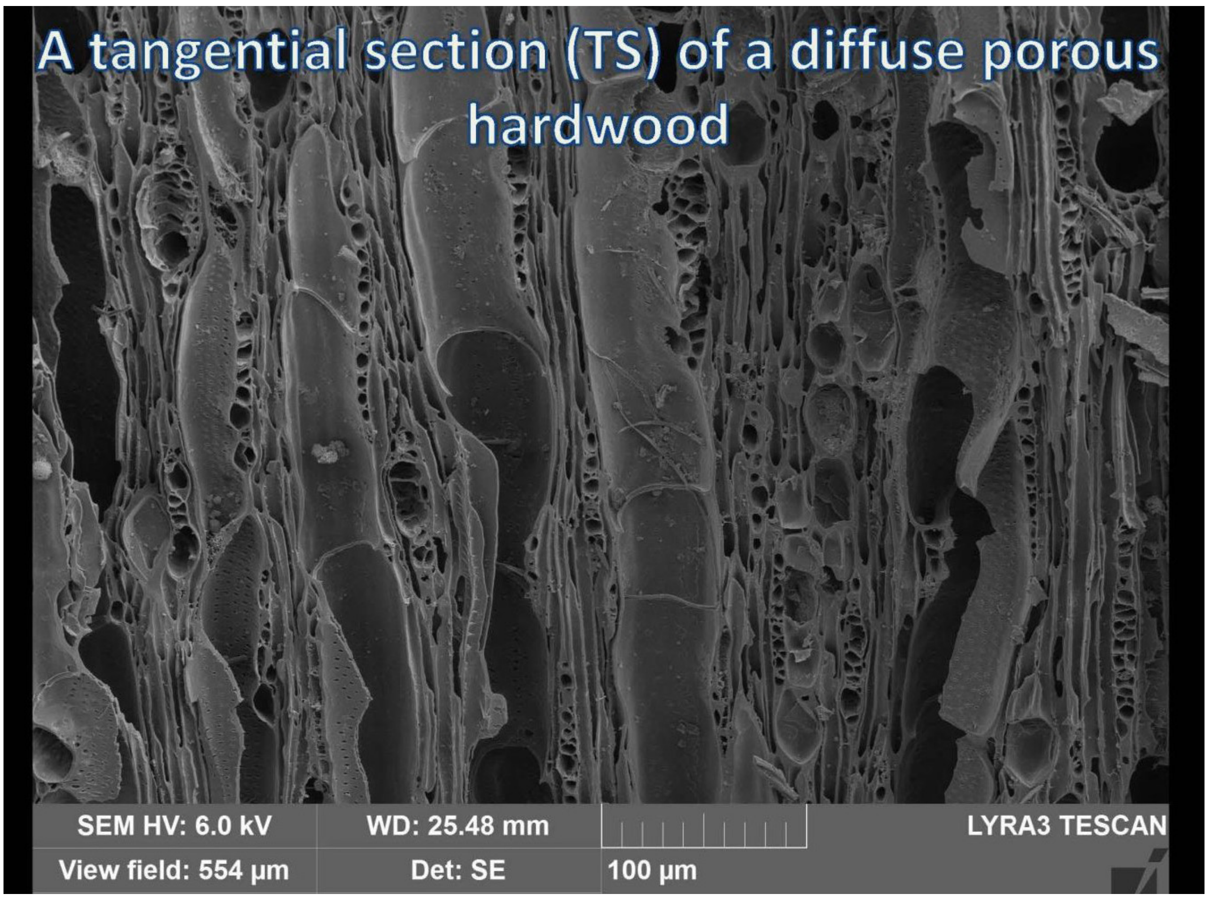
Slide 7

A cross section (XS) of a diffuse porous hardwood



Slide 8

A tangential section (TS) of a diffuse porous hardwood



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