Climate Change Effects on Forests and Grasslands: What You Need to Know

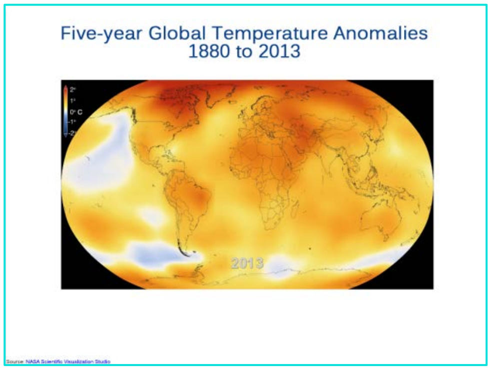
Title Slide

Climate Change Effects on Forests and Grasslands: What You Need to Know

This is a screenshot of the title slide. The title is centered on the screen, and the Forest Service shield is in the bottom left corner.

Introduction

The average annual temperature in the United States has increased over the last century, and most of this warming has occurred since the 1970s. In fact, each decade since the 1980s has set a new record for the warmest decade on record.



This is a screenshot of the first introduction slide. It shows a video of temperature anomalies by year from 1880-2013.

Introduction (second)

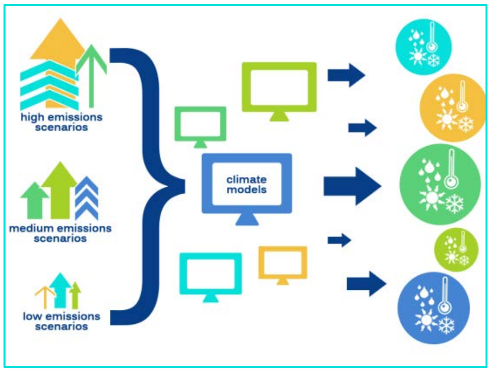
The average temperature in the United States has risen more than two degrees Fahrenheit in the past 50 years. Increasing temperatures are having wide-ranging effects on forests and grasslands, including streamflow, precipitation patterns, snowpack, insects, and invasive plant species, and influencing drought, heat waves, and wildfire. These are just a few examples of the observed effects of climate change around the United States, and most effects are expected to continue and intensify during this century.

Greenhouse gas emissions have been increasing and affecting the current climate. The choices humans make about land use, energy, and development will influence the future amount of greenhouse gas emissions. To project the future effects of climate change, different future emissions scenarios of greenhouse gases, also known as “pathways”, are used as inputs to climate models. Each climate model, in turn, simulates the climate system differently. Future emissions scenarios combined with different climate models result in a range of temperature and precipitation outcomes from warmer to much hotter, and drier to wetter. In general, higher emissions scenarios or pathways lead to projections of more severe changes, and lower emissions scenarios or pathways lead to projections of less severe changes.

The range of emissions scenarios and outputs from climate models represents most of the uncertainty in future climate projections. The climate is certainly changing and will continue to change, but because we still have some unknowns about the future, we need to work with a plausible range of future climates that incorporates the variety of emission pathways and model projections.

This is a screenshot of the introduction slide. This image shows different graphic icons of the effects of climate change, such as insects, drought, and changes in temperature, precipitation, and snowpack.

This is a screenshot of the introduction slide. This image illustrates the impact human choice has on greenhouse gas emissions. The emissions are represented with clouds, and icons of people are thinking about different choices.



This is a screenshot of the introduction slide. It represents the path to the range of future climate projections. Different emissions scenarios, shown with arrows, are input into different climate models, shown with computer icons, which output a range of future climate.

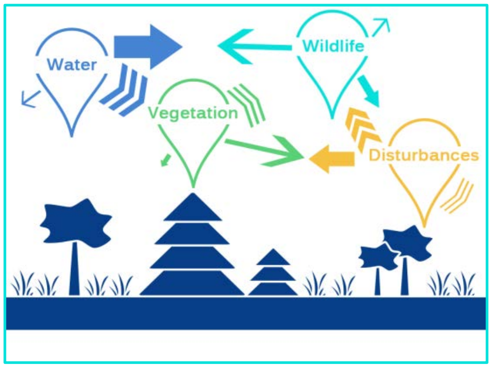
Benefits/Stresses

Under the right set of conditions, some ecosystems may benefit from climate change. These benefits may last only for a few decades, or they may last longer. However, it is more likely that climate change will worsen existing stressors in an ecosystem or add new stressors. Often, these benefits and stressors that we identify are part of personal values and beliefs about how ecosystems should look and function. It is critical to think about where benefits and stresses may occur, so we can be ready to take advantage of climate change benefits and overcome challenges from climate change stressors.

This is a screenshot of the benefits/stresses slide. It shows an icon of the Earth with call-outs coming from it. The call-outs have both positive and negative signs (benefits/stressors).

Effects

There are many ways to describe the effects of climate change on forests and grasslands. In this module, the major effects on forests and grasslands are grouped into four broad categories: water, vegetation, wildlife, and disturbances. Each category may include both stresses and benefits to ecosystem health and function. The effects may not occur in isolation, and are, in fact, very likely to interact with each other. Let's begin with water.

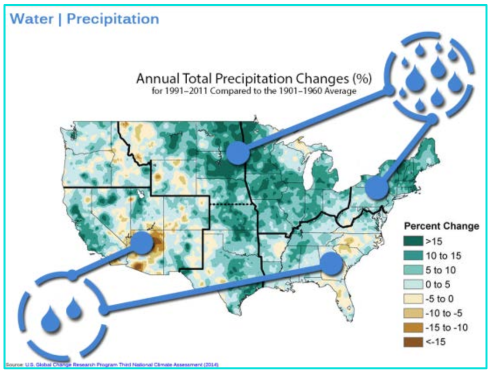


This is a screenshot of the Effects slide. The image is of trees and grasses with a different bubble for each category of effects: water, vegetation, wildlife, and disturbances. The bubbles have arrows between them to indicate interactions.

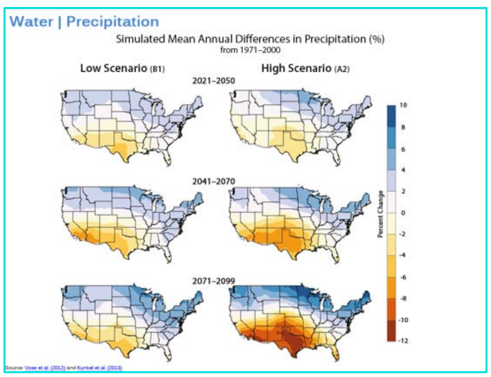
Water/Precipitation

Different regions across the United States have already experienced changes from historical precipitation; some areas are receiving more precipitation or more heavy precipitation, and others are becoming drier. Precipitation in many places has become more variable, sometimes obscuring clear trends. Changes in precipitation patterns and amounts affect soil moisture, groundwater levels, and wildfire risk.

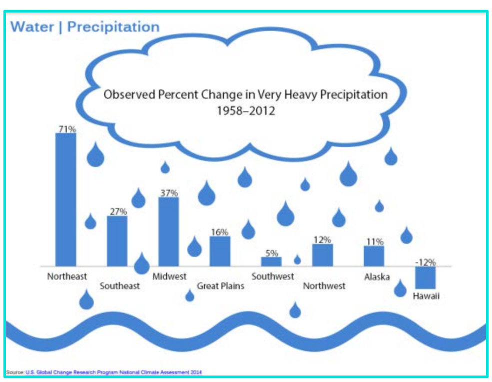
Projections of future precipitation show high variability, and sometimes different models or emissions scenarios project opposite patterns in rainfall during the same season. Regions that are projected to experience more annual precipitation in the future may not necessarily benefit, because more of that precipitation is expected to fall during intense storms. This is already occurring in some areas, resulting in more frequent flooding and erosion. Some forests are experiencing longer dry periods between heavy precipitation events. These dry periods can result in water stress in forests, and the heavy rains may not help reduce water stress because more precipitation flows directly into streams instead of filtering into the soil.



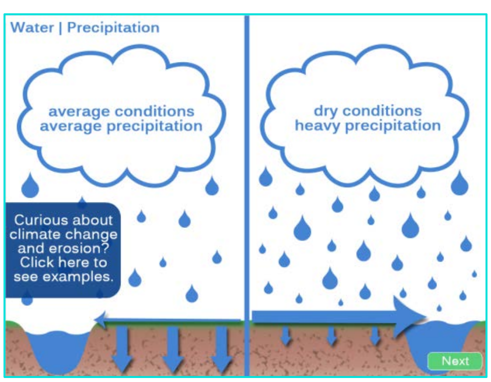
This is a screenshot of the Water/Precipitation slide. The map shows annual total precipitation changes (percent) for 1991 to 2011.



This is a screenshot of the Water/Precipitation slide. There are six different maps of the United States showing simulated mean annual differences in precipitation for three future time periods: 2021-2050, 2041-2070, and 2071-2099. Maps on the left side are modeled with a low emissions scenarios, and maps on the right are with a high scenario.



This is a screenshot of the Water/Precipitation slide. The bar graph shows observed percent change in very heavy precipitation from 1958 to 2012 for different regions in the United States.



This is a screenshot of the Water/Precipitation slide. The left side of the screen features a graphic with average conditions and average precipitation, where most of the rain filters into the soil, with some running into the stream. The right side features a graphic with dry conditions and heavy precipitation. The rain hardly filters into the soil, and instead mainly runs into the stream. A box on the left-hand side of the screen asks, “Curious about climate change and erosion? Click here to see examples.” See the box on the next page in this document for more information.

This slide features hyperlinks to different figure sources. The map of precipitation changes in the continental U.S. and the bar graph of observed changes in heavy precipitation were both obtained from the U.S. Global Change Research Program Third National Climate Assessment (2014). The figure of simulated mean differences in precipitation for the U.S. under different climate scenarios was obtained from Vose et al. (2012) and Kunkel et al. (2013).

This slide also features an interaction as indicated by the box on the left-hand side of the screen that pops in after the slide animations and narration have finished. The box says, "Curious about climate change and erosion? Click here to see examples." Clicking on the box shows a pop-up screen with two examples. Use the labeled tabs to click through the examples.

Mount Rainier National Park in southwestern Washington is adapting its access management to climate change.

In November 2006, Mount Rainier National Park experienced a historic flood after 18 inches of rain fell in 36 hours. The flood washed out roads, campgrounds, and trails, and closed the park for 6 months.

Approximately two miles of the Carbon River Road along the Carbon River were significantly damaged by flooding. Parts of the road are lower than the river, and have been vulnerable to repeated flooding for decades.

Heavy precipitation events and an increase in flood frequency are some of the projected effects of climate change in the Pacific Northwest.

Repairing and maintaining the vulnerable Carbon River Road would be costly, with a high risk for further damage as the climate changes.

Park managers worked with the public and other agencies to develop a plan to convert the road to a bike and hiking trail.

The old road is now a trail, continuing to provide access to campsites, other trails, historic structures, and amazing sights.

For more information visit Mount Rainier National Park.

Photo courtesy of Mount Rainier National Park

The Green Mountain National Forest in southwestern and central Vermont has experienced damage from heavy rainfall and flooding events.

In August 2011, heavy rainfall and subsequent flows from Tropical Storm Irene caused significant damage in New England. Many rivers exceeded predicted 100-year flood flow estimates.

Irene caused nearly 25 miles of damage to transportation infrastructure on the Green Mountain National Forest, costing about $6.4 million.

The upper White River watershed on the Forest experienced substantial flood damage, mainly from debris build-up at road–stream crossings. Most of this damage was due to undersized culverts, which had already been identified as aquatic organism barriers.

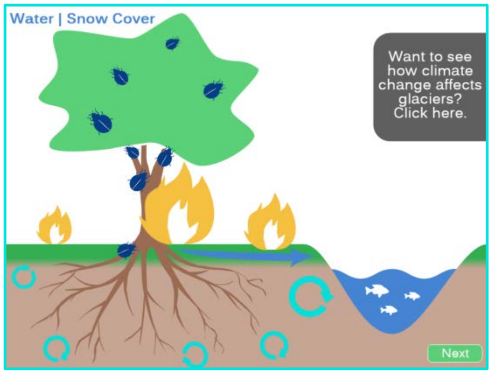
Stream simulation design culverts are designed to facilitate aquatic organism passage and reduce culvert failure, storm damage, and associated costs and impacts from flooding. Prior to Irene, the Forest had installed two stream simulation design culverts, both of which survived the storm and required no repair costs.

More stream simulation design culverts are planned on the Forest. These culverts have survived flooding and promoted aquatic organism passage on other national forests.

For more information visit the Green Mountain National Forest or read Gillespie et al. 2014.

Water/Snow Cover

In the last few decades, snow cover across much of the United States has decreased in depth, extends over a smaller area, and melts sooner in the spring. Changes in snow cover and snowmelt have wide-ranging effects. Less snowpack combined with earlier melting provides less insulation for plants and soil, exposing them to frosts and freezing temperatures. Early snowmelt also alters the timing of runoff into streams, with large flows happening earlier, followed by diminished flows late in the growing season. Low flows in summer and fall can lead to water stress for plants, which can lead to increased risk of insect infestations and wildfire, and affect soil processes. Lower flows late in summer also result in lower water volume and higher temperatures in streams, which may negatively affect fish populations.



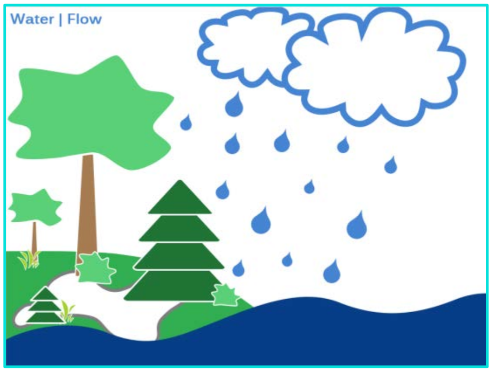
This is a screenshot of the Water/Snow Cover slide. It features a representation of the effects of diminishing snowpack. The tree image has fire and beetle icons, the soil has circle arrow to represent changes in soil cycles, and the stream shows fishes. A box on the right-hand side of the screen asks, "Want to see how climate change affects glaciers? Click here." See the box on the next page in this document for more information.

This slide also features an interaction as indicated by the box on the right-hand side of the screen that pops in after the slide animation and narration have finished. The box says, "Want to see how climate change affects glaciers? Click here." Clicking on the box opens up a new website for the U.S. Geological Survey glacier repeat photography project.

Water/Flow

Together, changes in precipitation patterns and snow cover affect the timing and amount of runoff and streamflow. In particular, rain-on-snow events, when rain falls on snow, are projected to become more frequent and intense as temperature increases. Warmer temperatures shift winter precipitation from snow to rain, and the warmer rain filters into the snowpack, causing it to melt, increasing runoff and the risk of flooding and erosion.

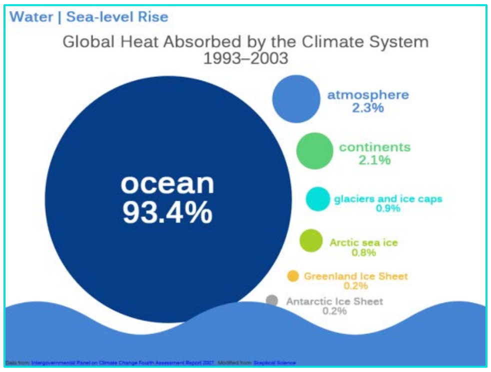
Decreases in summer seasonal flows and increases in flash floods and short periods of high flows from more intense storms are projected effects of climate change during this century.



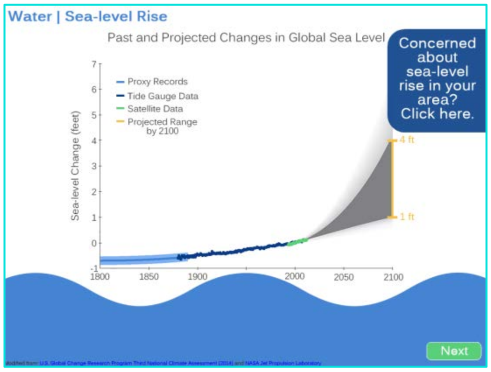
This is a screenshot of the Water/Flow slide. It features a graphic representation of the effects of changes in precipitation and rain-on-snow. A forest is receiving rain, the snow is melting, and the stream is rising.

Water/Sea-level Rise

Oceans absorb over 90 percent of the extra heat in the atmosphere from human-caused emissions. As the water heats up, it expands, contributing to the rise in sea level. Global sea levels have risen 8 inches since the 1880s; and since 1992, global sea level has risen twice as fast as the long-term trend. By the end of the century, global sea level is projected to rise by one to four feet. This rise, along with the projections for more coastal storms, will increase the risk for erosion, storm surge, and flooding events, affecting coastal ecosystems and infrastructure.



This is a screenshot of the Water/Sea-level Rise slide. It features a circle graph of global heat absorbed by the climate system from 1993 to 2003. Oceans is the large circle with 93.4% of heat absorbed, then atmosphere at 2.3%, continents (2.1%), glaciers and ice caps (0.9%), Arctic sea ice (0.8%), and the Greenland and Antarctic Ice Sheets at 0.2% each.



This is a screenshot of the Water/Sea-level Rise slide. This graph is of past and projected changes in global sea level from 1800 to 2100. A box on the right-hand side of the screen asks, "Concerned about sea-level rise in your area? Click here." See the box below for more information.

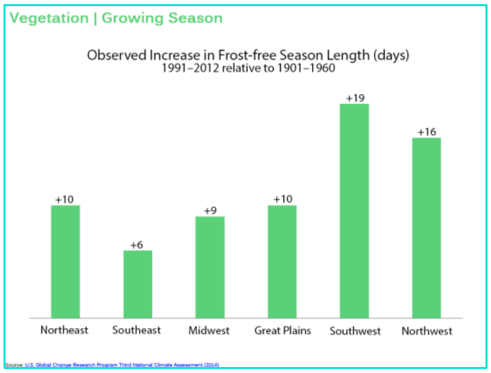
This slide features links to different figure sources. Data for the circle figure comes from the Intergovernmental Panel on Climate Change Fourth Assessment Report 2007 and is modified from Skeptical Science. The past and projected changes in sea level graph is modified from the U.S. Global Change Research Program Third National Climate Assessment (2014) and NASA Jet Propulsion Laboratory.

This slide also features an interaction as indicated by the box on the right-hand side of the screen that pops in after the slide animation and narration have finished. The box says, "Concerned about sea-level rise in your area? Click here" Clicking on the box opens up a new website with a sea-level rise map viewer created by NOAA.

Vegetation/Growing Season

The frost-free season, often used to define the length of the growing season, has lengthened around the country since the 1980s, with the largest increase observed in the West. The first freeze is happening later in the fall, and the first thaw is happening earlier in the spring. The increase in length of the frost-free and growing seasons is expected to continue in this century.

Earlier snowmelt and springtime has led to earlier emergence of leaves, or leaf out, and earlier flowering in some plants. Longer warm periods mean that plants have a longer time to grow, which may increase the productivity of forest and grasslands if the plants have adequate water and nutrients. This could be a beneficial effect of climate change. However, there may also be some negative aspects to a longer growing season, click on the box to learn more.



This is a screenshot of the Vegetation/Growing Season slide. The bar graph shows observed increase in frost-free season length from 1991 to 2012 relative to 1901 to 1960 by region in the United States.

This is a screenshot of the Vegetation/Growing Season slide. It shows a graphic of a tree with its leaves out that has gone through an earlier leaf-out. A box on the bottom of the screen says, "There may be negative aspects to a longer growing season. Click here to learn more." See the box below for more information.

This slide features a link to a data source for the frost-free season length bar graph. This graph was obtained from the U.S. Global Change Research Program Third National Climate Assessment (2014).

This slide also features an interaction as indicated by the box on the top of the screen that pops in after the slide animations and narration have finished. The box says, "Interested in the earlier emergence of leaves or flowers? Click here." This box sends users to the Project Budburst homepage. Another interaction is indicated by a box on the bottom of the screen. This box says, "There may be negative aspects to a longer growing season. Click here to learn more." Clicking on the box shows a pop-up screen with several bullet points with citations.

Negative aspects to a longer growing season may include:

An increase in moisture stress and drought conditions (Dale et al. 2001)

An increase in wildfire activity (Westerling et al. 2006)

Accelerated insect lifecycles and increased susceptibility to insects from moisture stress (Bentz 2009)

Shortening of the snow season and declines in spring snowfall (Groisman et al. 2004)

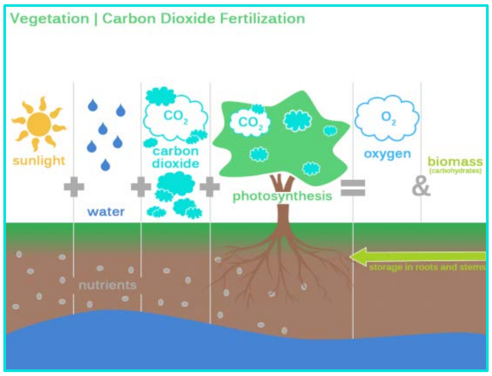
Changes in the timing of biological events and mismatches in predator-prey and pollinator-flowering plant relationships (Parmesan 2006)

Altered groundwater storage and recharge and declines in seasonal summer flow (Huntington 2004)

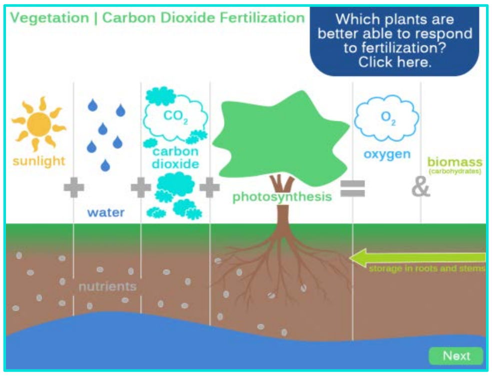
Vegetation/CO_2 Fertilization

Plants use sunlight, water, carbon dioxide, and nutrients to make the carbohydrates necessary for growth, releasing oxygen as a byproduct. This is the process known as "photosynthesis." Atmospheric carbon dioxide levels are increasing because of human use of fossil fuels, and some of this extra carbon dioxide in the atmosphere can be used by plants. More carbon dioxide may increase photosynthesis and water use efficiency, creating more biomass. This is known as "carbon dioxide fertilization."

In many plants, carbon dioxide fertilization may be only temporary, elevating photosynthesis for a short time until the extra carbon dioxide no longer produces more biomass. Increased photosynthesis is also dependent on nutrient and water availability, so carbon dioxide fertilization will not be as effective in areas without an adequate supply of these resources. Sites with suitable resources are better able to support carbon dioxide fertilization, and certain plants are better able to respond to carbon dioxide fertilization, regardless of site. This all means that carbon dioxide fertilization will be beneficial for some, but not all, plants and forests.



This is a screenshot of the Vegetation/Carbon Dioxide Fertilization slide. This graphic represents the major parts of photosynthesis: sunglight, water, nutrients, carbon dioxide, to equal oxygen and biomass (carbohydrates). Fertilization is the addition of carbon dioxide to a point and the creation of more biomass.



This is a screenshot of the Vegetation/Carbon Dioxide Fertilization slide. This graphic is the same as the previous, except the extra carbon dioxide is gone. A box on the top of the screen asks, “Which plants are better able to respond to fertilization? Click here.” See the box below for more information.

This slide also features an interaction as indicated by the box on the top of the screen that pops in after the slide animation and narration have finished. The box says, “Which plants are better able to respond to fertilization? Click here.” Clicking on the box opens a pop-up screen with information about the Free-air Carbon Dioxide Enrichment (FACE) experiments.

The Free-air Carbon Dioxide Enrichment (FACE) experiments are designed to increase the concentration of carbon dioxide for plants in a natural setting.

Increasing the concentration of carbon dioxide allows for a realistic simulation of plant growth in future conditions.

There are many FACE experiments, testing the effects of carbon dioxide on different tree species, natural ecosystems, and crop types.

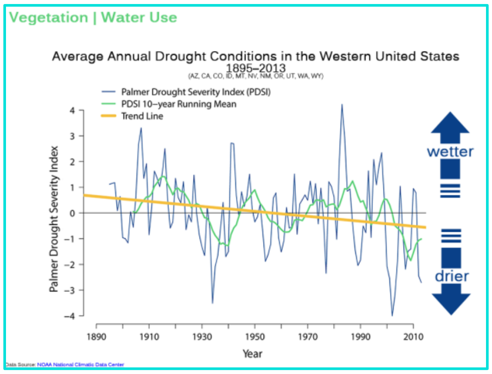
These experiments investigate photosynthesis rates, growth, root production, nitrogen and carbon cycling, water use, soil microbial activity, and species composition.

For more information on FACE projects in the United States visit the Oak Ridge National Laboratory. To learn more about the outcomes of FACE projects read Ainsworth and Long 2005.

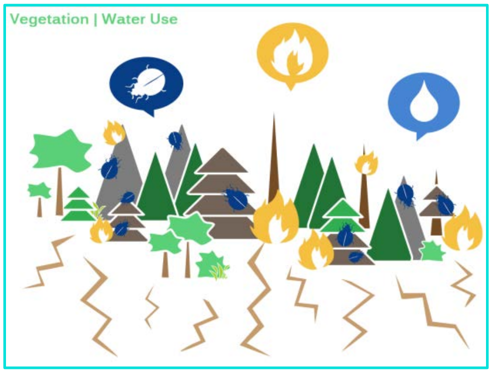
Vegetation/Water Use

After several decades of wet conditions, drought events are increasing in many places around the country, particularly in the West. With increases in heat waves and longer periods of higher temperatures and lower soil moisture, many trees become stressed and may even die. These droughts and prolonged dry periods can damage or kill trees during insect outbreaks, because insects thrive on trees already weakened from low water availability. Dead and dying trees increase wildfire risk by temporarily increasing downed and standing fuel, which are especially combustible during droughts.

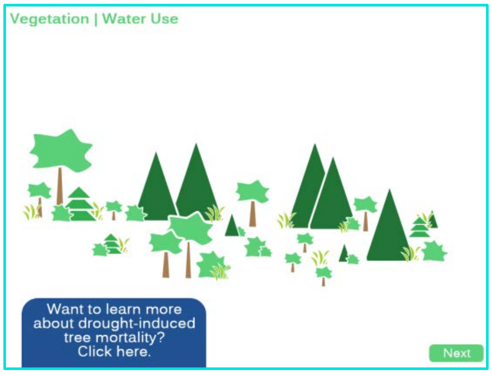
Tree mortality from drought, insects, wildfire, or interactions between these effects, can alter the species composition and structure of a forest. More frequent and severe droughts are projected for this century in the southern and western U.S., and it is likely that tree mortality will also increase, bringing more changes to forests in the future.



This is a screenshot of the Vegetation/Water Use slide. The graph shows the average annual drought conditions in the Western United States, with a trend line to drier conditions.



This is a screenshot of the Vegetation/Water Use slide. The graphic shows a forest that is in drought conditions, making it susceptible to wildfire and insect outreaks.



This is a screenshot of the Vegetation/Water Use slide. The graphic shows a forest that has changed in composition after an episode of drought, with possible wildfire and insect activity. A box on the bottom of the screen asks, "Want to learn more about drought-induced mortality?" Click here. See the box below for more information.

This slide also features an interaction as indicated by the box on the bottom of the screen that pops in after the slide animations and narration have finished. The box says, "Want to learn more about drought-induced tree mortality? Click here." Click on the box opens a pop-up screen with two examples. Use the labeled tabs to click through the examples.

The Coconino National Forest in central Arizona has been experiencing a rapid decline in its aspen population.

The recent aspen is large scale, affecting many aspen stands in the Southwest. The decline is mainly attributed to severe droughts.

Many parts of the Southwest, including the Coconino National Forest, experienced a very warm drought period in the early 2000s. This was followed by episodes of insect activity.

Regeneration in aspen stands is low because of heavy browsing and the encroachment of conifers into aspen understory.

Aspen mortality was 95% in dry low-elevation sites on the Coconino National Forest, compared to 61% on mid-elevation sites.

The Coconino National Forest is currently working on the Hart Prairie Fuels Reduction and Forest Health Project. This project will restore over 3000 acres of aspen in the Forest.

Restoration efforts for aspen include removal of encroaching conifers, prescribed fire, planting, and fencing.

For more information visit the Coconino National Forest.

The Lincoln National Forest in southern New Mexico is experiencing drought-induced mortality in forest stands.

The Lincoln National Forest, and many other parts of the Southwest, experienced an extended drought period in the early 2000s, and a more recent drought from 2010 to 2013.

The high temperatures and low water availability during the drought stressed many tree populations, such as piñon pines, ponderosa pines, Douglas-firs, and white firs, leaving them susceptible to insect infestations and pathogens.

In 2012, bark beetle activity caused mortality on more than 172,000 acres of forest in New Mexico. Ponderosa pines were especially affected by bark beetles, and piñon pines also saw a large increase in beetle-caused mortality. The bark beetle activity is mainly attributed to the recent drought and the dense conditions of forest stands

Drought events are projected to become more frequent and severe within this century, and it is possible that these events could result in insect and pathogen outbreaks.

The Lincoln National Forest uses thinning and prescribed fire to reduce stand competition and stress on the forests. Over the last decade 5,000 to 13,00 acres have been treated each year.

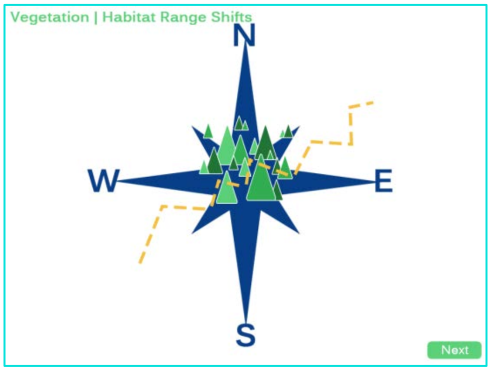
For more information visit the Lincoln National Forest.

Vegetation/Habitat Range Shifts

As temperature increases and precipitation changes, the range of suitable habitats for many plant species will also change. For example, the suitable habitat range of some plant species may shift northward or upslope to higher elevations, or shifts may even follow changing moisture conditions. Species growing outside ideal habitats will not immediately die off; instead, these species may experience more stress, reductions in productivity, or difficulty regenerating.

The largest initial responses of plants to habitat changes may be seen in the establishment of seedlings. Populations that live at the southern edge or lower elevation of their range may experience decreased establishment and growth of seedlings. Even as this is happening, populations living at the northern edge or higher elevations of their range may experience better establishment and growth of seedlings. However, forest fragmentation is already slowing natural rates of migration, and due to the speed at which climate change is occurring, it appears unlikely that most tree species will be able to migrate as fast as their suitable habitat is shifting.

This is a screenshot of the Vegetation/Habitat Range Shifts slide. The graphic shows icons of temperature, mountains, precipitation, northward shifts, and stressful growth.



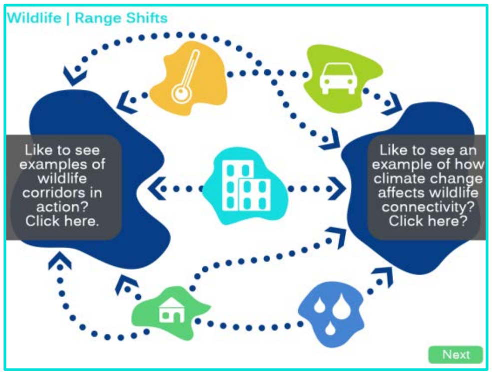
This is a screenshot of the Vegetation/Habitat Range Shifts slide. The graphic shows a compass with tree icons in the middle, representing possible changes in growth at ends of habitat range.

Wildlife/Habitat Range Shifts

Similar to vegetation, the current habitats of many wildlife species may become unsuitable with further temperature increases and changes in precipitation. The ranges and distributions of many wildlife species are already shifting northward and up in elevation, and these shifts are projected to continue. For species that may not be able to migrate to more suitable habitat, their range and distribution may contract.

Habitat connectivity is an important consideration in the distribution and movement of wildlife. Human development typically fragments the landscape, making it more difficult for wildlife to safely move to new places as suitable habitat shifts. As climate change alters ecosystems and humans continue to fragment the landscape, wildlife may need to pass through unsuitable habitat to avoid humans and reach new areas, or they may be forced to migrate through developed landscapes. Wildlife populations that cannot find safe corridors to new habitats may become isolated and experience declines.

This is a screenshot of the Wildlife/Habitat Range Shifts slide. This graphic says, “current habitats of many wildlife species may become unsuitable”, and has icons of mountains and an increase arrow pointing “north”.



This is a screenshot of the Wildlife/Habitat Range Shifts slide. This graphic shows habitat connectivity with paths from one habitat to another that encounter challenging climatic conditions and human development. A box on the left side of the screen asks, “Like to see examples of wildlife corridors in action? Click here.” A box on the right side of the screen asks, “Like to see an example of how climate change affects wildlife? Click here.” For more information, see the box on the next page in this document.

This slide also features two interactions as indicated by the boxes on the left-hand and right-hand side of the screen that pop in after the slide animations and narration have finished. The left-hand box says, “Like to see examples of wildlife corridors in action? Click here.” Clicking on this box opens a new website to [Conservation Corridor](), which includes descriptions of different types of wildlife corridors and real-life examples. The right-hand interaction box says, “Like to see an example of how climate change affects wildlife connectivity? Click here.” Clicking on the box will open a pop-up screen with an example.

The American pika (Ochotona princeps) is a climate-sensitive species that may experience difficulty migrating to new habitats as the climate changes.

Pikas are the smallest member of the rabbit family. They live in rocky alpine areas, called talus fields, and in high-elevation lava flows which helps them maintain a narrow range of body temperature.

Pikas do not hibernate in the winter; instead they gather food during the summer and use snowpack as an insulator to stay warm during long alpine winters.

Climate change effects, like increasing temperatures and decreasing snowpack, impact pika survival. Extended exposure to high temperatures can overheat and kill pikas; conversely, the loss of insulating snowpack in the winter can cause pikas to freeze.

Pikas have few places to migrate to escape the heat and diminishing snowpack. Also, it is likely that pikas might have to migrate through unsuitable habitat and climatic conditions to reach other talus fields.

The National Park Service Climate Change Response Program funded the Pikas in Peril Project to learn more about pika populations, vulnerability, and connectivity in eight National Parks in the western U.S.

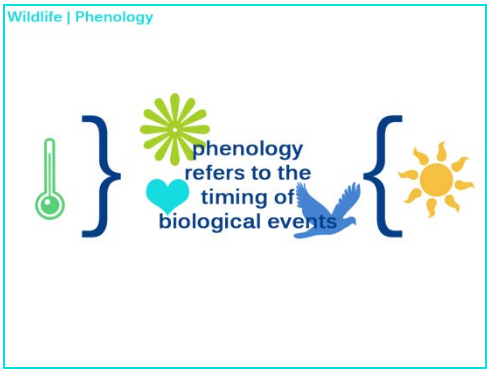
For information visit the National Park Service Pikas in Peril Project.

Wildlife/Phenology

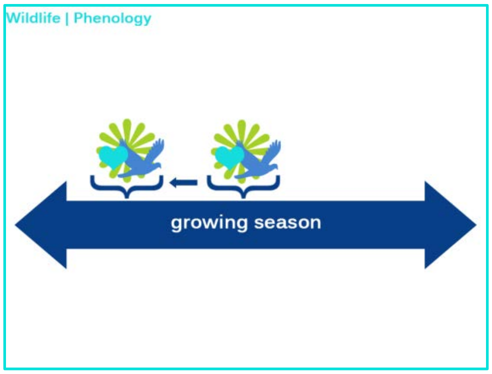
Phenology refers to the timing of biological events, such as flowering, migration, and breeding. Sunlight and temperature influence phenology, acting as the primary cues to begin these natural events.

Higher temperatures have already increased the length of the growing season. Longer growing seasons affect natural events that use temperature as cues, and as a result some migrations, breeding events, and pollination patterns are happening earlier than historically observed.

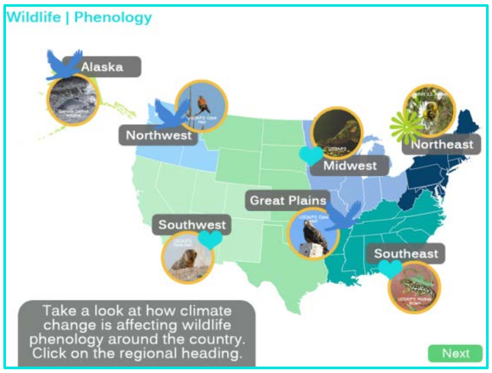
Biological events cued by temperature or sunlight often depend on each other. If temperature cues are changing and sunlight cues are staying the same, a mismatch could develop between the two dependent biological events. For example, insects cued by temperature may emerge earlier than bird migrations cued by sunlight. This could result in asynchrony, and the migrating birds may arrive too late for important food sources. Phenological mismatches are already happening around the country and can have cascading effects throughout the ecosystem.



This is a screenshot of the Wildlife/Phenology slide. The graphic says, “phenology refers to the timing of biological events with icons of a flower, bird, heart, temperature, and sunlight.



This is a screenshot of the Wildlife/Phenology slide. The graphic shows a double-sided “growing season” arrow with icons of a flower, bird, and heart moving to earlier in the growing season.



This is a screenshot of the Wildlife/Phenology slide. The graphic is a map of the U.S., with regions highlighted and a photo of a phenology example for each region. A box at the bottom of the screen says, “Take a look at how climate change is affecting wildlife phenology around the country. Click on the regional heading.” See the box on the next page in the document for more information.

This slide also features an interactions as indicated by the box on the bottom of the screen that pops in after the slide animations and narration have finished. The box says, “Take a look at how climate change is affecting wildlife phenology around the country. Click on the regional heading.” Clicking on the small box labeled with a region located on the map graphic will open a pop-up screen with an example of a phenological change specific to a region, along with a scientific citation.

Wildlife Phenology Examples by Region

Northeast: Bees and Plants – With increasing temperatures, many bee species are emerging earlier in the spring. This could cause a mismatch between bees and plants pollinated by bees. However, many bee-pollinated plants are also flowering earlier, and the earlier timing of bees and flowerings are currently continuing to match. For more information read Bartomeus et al. (2011).

Southeast: Amphibian Breeding – Species of autumn-breeding salamanders are arriving at breeding grounds later in the season, and species of winter-breeding salamanders and frogs are arriving earlier. Increases in overnight temperature and in cumulative precipitation during the pre-breeding and breeding season likely affect the timing of amphibian breeding. For more information read Todd et al. (2011).

Midwest: Walleye Spawning – Walleye spawning is related with ice-out events (when the water is free of ice) in rivers and lakes. As warming temperatures have extended the growing seasons, ice-out dates have been happening earlier in the spring. Walleye spawning has also shifted earlier, following the trend of earlier ice-out. For more information read Schneider et al. (2010).

Great Plains: Bird Migration – Many migratory bird species are arriving earlier to breeding grounds in the Northern Prairie region. Several species of earlier migrating birds were those associated with aquatic habitats. Earlier spring arrivals are likely in response to warmer winter temperatures in migration stopover sites and breeding grounds. For more information read Swanson and Palmer (2009).

Southwest: Marmot Hibernation – Yellow-bellied marmots are emerging earlier from hibernation as temperature increases. The marmots are also giving birth earlier, which allows them to reach larger sizes before hibernation. Larger and more fit marmots have led to decreased mortality and an increase in marmot population. For more information read Ozgul et al. (2010).

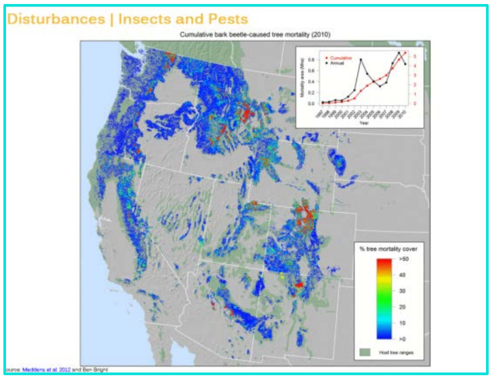
Northwest: Kestrel Migration – American kestrel populations are migrating shorter distances, increasingly overwintering in more northern areas, and nesting earlier. These trends are related to increases in winter minimum temperatures. For more information read Heath et al. (2012).

Alaska: Salmon Migration – Pink salmon fry are migrating from freshwater streams earlier in the spring, with trends in increasing air and sea surface temperature. Similarly, adult pink salmon are showing a trend in earlier migration back to freshwater streams. For more information read (Taylor 2008).

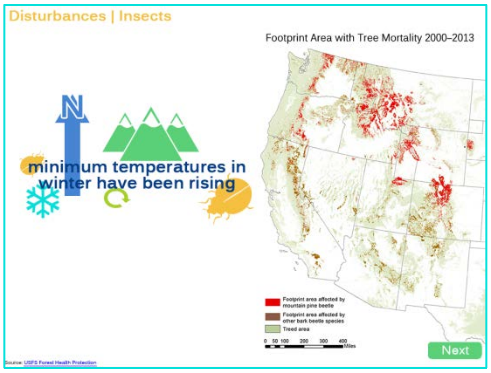
Disturbance/Insects

Disturbances from insects are a part of natural forest cycles, but insect outbreaks have increased in the last few decades as temperatures have increased and droughts have become more frequent. For example, between 2000 and 2012, 46.1 million acres in the western United States were affected by western bark beetles.

Minimum temperatures in winter have been rising across the United States, allowing insects, like bark beetles, to migrate north and to higher elevations, expanding into previously unaffected areas. Temperatures are warm enough for bark beetles to survive over the winter, and two-year lifecycles are often taking only one year to complete. Increased populations of bark beetles and other insects, like the nonnative hemlock woolly adelgid, are threatening the health and vigor of many forests.



This is a screenshot of the Disturbances/Insects slide. This shows an animation of cumulative bark beetle-caused tree mortality from 1997 to 2010 in the western U.S.



This is a screenshot of the Disturbances/Insects slide. The map shows the western U.S. with the footprint area of beetle tree mortality from 2000 to 2013. Icons around the words represent different issues like range expansion and life cycles of bark beetles.

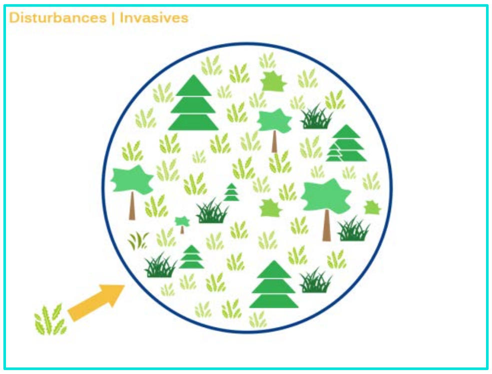
This slide features links to different figure sources. The cumulative bark beetle-caused mortality video/gif was obtained from Meddens et al. (2012) and Ben Bright (permission granted). The graph of the footprint area with tree mortality was obtained from the U.S. Forest Service Forest Health Protection.

Disturbances/Invasives

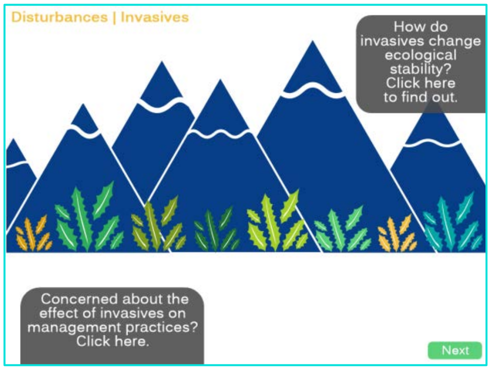
Invasives are nonnative species that are able to establish within native habitats, where they may alter how the ecosystem functions. Invasives can decrease native biodiversity and change the species composition of ecosystems. They can be plants, animals, diseases, or insects, but the focus here is on invasive plants. Invasive plants compete for resources with native species, reduce habitat for some wildlife species, and can affect soil nutrient cycling, water use, and disturbance patterns like wildfire regimes.

Observed and projected climate change effects such as higher temperatures, earlier springs and snowmelt, reduced snowpack, changes in disturbance patterns, and elevated carbon dioxide, also influence invasive species establishment and spread.

In some cases, the current ranges of some invasive species may actually contract with climate change, but there is widespread concern that the changing climate will more often result in faster spread of invasives due to more frequent disturbances and short-term stress in native ecosystems. Invasives are spreading fast in arid ecosystems, and there is an especially high risk of invasive species establishment in northern ecosystems and mountainous regions because cooler temperatures limited invasive establishments in the past.



This is a screenshot of the Disturbances/Invasives slide. The graphic represents an ecosystem of trees and plants in a circle, with an invasive plant being introduced and multiplying within the ecosystem.



This is a screenshot of the Disturbances/Invasives slide. The graphic shows mountains with invasive plant icons growing on the mountains. The box at the bottom of the screen asks, “Concerned about the effect of invasives on management practices? Click here.” The box on the right-hand side of the screen asks, “How do invasives change ecological stability? Click here to find out.” See the box below for more information.

This slide features two interactions as indicated by the boxes on the bottom and top right-hand side of the screen that pop in after the slide animations and narration have finished. The bottom box says, “Concerned about the effect of invasives on management practices? Click here.” Clicking on this box opens a new website to the landing page for the U.S. Forest Service National Strategic Framework for Invasive Species Management document. The top right-hand interaction box says, “How do invasives change ecological stability? Click here to find out.” Clicking on the box will open a pop-up screen with an scientific cited examples.

There are about 50,000 non-native species in the United States. The estimated cost of environmental damage and eradication efforts is approximately $137 billion per year (Pimentel et al. 2000).

Invasive plants can change fuel properties and affect fire behavior, frequency, intensity, extent, and seasonality (Brooks et al. 2004).

Non-native plants and animals can alter soil processes by causing erosion on stable sites or stabilizing soils in disturbed areas (Dukes and Mooney 2004).

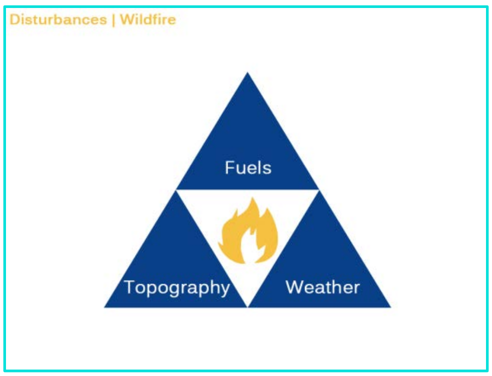
For more information on invasives, click here.

Disturbances/Wildfire

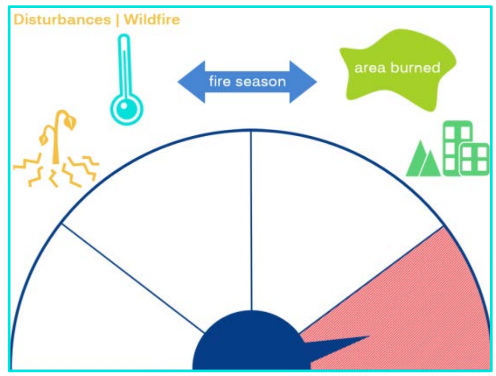
Climate and fuels are important drivers of wildfire in forest and grassland ecosystems. Climate influences the weather conditions that support fire occurrence, and the fuel amount and arrangement influence fire intensity and extent.

Drought conditions and increased temperature generally increase fire risk, although this varies by forest type, region, and fire regime. As a result of longer growing seasons and altered precipitation, the length of the fire season and the annual area burned have been increasing in the western United States and are expected to continue to increase in the future. A higher risk of fire poses a threat to the wildland-urban interface—places where people live and build near natural areas prone to wildfire.

Past and current fire management practices, combined with climate change, affect the risk, behavior, and severity of fire. The 1900s were dominated by a policy of fire suppression, and fires were fought and controlled in nearly all public and private lands. Decades of this policy allowed fuels to accumulate on the forest floor, fire no longer killed seedlings, and young trees were able to establish and grow in older stands. Although fuel reduction practices such as prescribed burning are now common, the accumulation of fuels and young trees that act as ladders to carry the fire into the canopy has contributed to an increase in large, severe fires in some areas. The connection between fire and fuels is an important consideration for forests, primarily dry forests in the western United States.

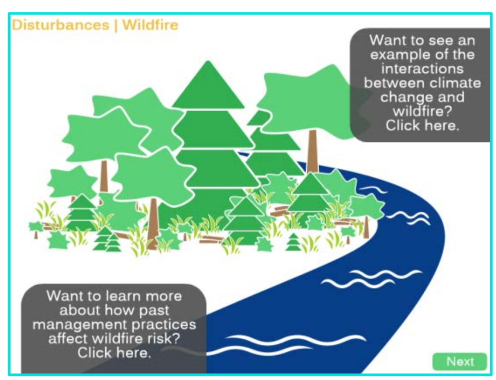


This is a screenshot of the Disturbances/Wildfire slide. The image is of three triangle creating a large triangle, and each triangle has an important aspect of wildfire: fuels, topography, and weather.



This is a screenshot of the Disturbances/Wildfire slide. The image is of a risk “gauge” with different icons of wildfire risk that appear as the gauge needle points to increasing risk. Icons are of drought, temperature, fire season, area burned, and the wildland-urban interface.

This is a screenshot of the Disturbances/Wildfire slide. The graphic shows an open forest with a stream. It represents a starting point for past management practices.



This is a screenshot of the Disturbances/Wildfire slide. The graphic shows a crowded forest with a stream. The slide shows several graphics with increasing forest crowding. The box on the right-hand side asks, “Want to see an example of the interactions between climate change and wildfire? Click here.” The box on the bottom of the screen asks, “Want to learn more about how past management practices affect wildfire risk? Click here.” For more information see the boxes on the next two pages in this document.

This slide features two interactions as indicated by the boxes on the bottom and top right-hand side of the screen that pop in after the slide animations and narration have finished. The top right-hand box says, "Want to see an example of the interactions between climate change and wildfire? Click here." Clicking on this box will open a pop-up screen with two examples. Use the labeled tabs at the top of the pop-up box to switch between examples.

The Kaibab National Forest in northern Arizona recently revised its Forest plan. The new plan considers climate change in management approaches.

Interactions between climate change and wildfire are a large concern for the Kaibab National Forest.

The Forest is historically a fire-adapted ecosystem, but now, because of past management practices, dense forests cover much of the landscape. These practices have altered the natural fire regime and increased the risk of large stand-replacing wildfires.

Fire frequency and severity are likely to increase in the Southwest with climate change.

Prescribed fires, mechanical thinning, aspen regeneration, and grassland encroachment cutting are all management strategies the Kaibab National Forest uses to increase forest resiliency in a changing climate.

Restoring the fire-adapted ecosystem and increasing the resiliency of frequent-fire plant communities through active management are high priorities for the Kaibab National Forest.

For more information visit the Kaibab National Forest.

The Tahoe National Forest in the California's northern Sierra Nevada Mountains is implementing fire management recommendations in its projects.

The Sagehen Project is a collaboration between the Tahoe National Forest, the Pacific Southwest Research Station, the University of California at Berkeley, and other stakeholders to actively manage the Sagehen Basin for adaptive capacity.

Much of the Sagehen Project area is dense forest, with low genetic and species diversity as a result of past logging, stand-replacing fires, and fire suppression. This leaves the forests vulnerable to more stand-replacing events such as wildfire, insect outbreak, and disease, all of which could become more severe with climate change.

The foundation, goals, and strategies of the Project were informed by North et al. (2009) and expanded on with North (2012).

Management prescriptions include variable thinning of smaller trees, creation of openings to reintroduce a variety of more resilient and genetically unique tree species, prescribed fire, and removal of young trees near old, large legacy trees.

The Sagehen Project will reduce fuels, help return active fire conditions to forest stands, and enhance the resiliency of the Sagehen Basin to stand-replacing disturbances and impacts from climate change.

For more information visit the Tahoe National Forest.

The second interaction, the bottom box, says, "Want to learn more about how past management practices affect wildfire risk? Click here." Clicking on the box will open a pop-up screen with more information about past management. The screen shows an introduction slide with three tabs on the left-hand side. Clicking through the tabs will display different information, as ordered by the tab numbers. To get back to the starting screen, click the "Introduction" tab in the lower right-hand corner.

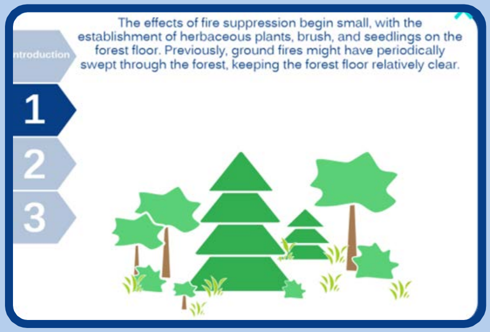
Federally supported fire suppression officially began with the Forest Fires Emergency Act in 1908, which authorized the Forest Service to spend any funds necessary on firefighting. Fire suppression continued until the 1970s when scientific research emerged showing the ecological importance of fire. Today the Forest Service works to promote healthy forests and mitigate threats to ecosystems and people. To learn more about the effects of fire suppression, click on the tabs.

The effects of fire suppression begin small, with the establishment of herbaceous plants, brush, and seedlings on the forest floor. Previously, ground fires might have periodically swept through the forest, keeping the forest floor relatively clear.

As fire suppression continues, herbaceous plants and brush grow and reproduce, covering much of the forest floor. Seedlings grow to become saplings, and saplings grow into mature trees. More seedlings establish and continue this cycle. Downed branches and other woody debris may accumulate, contributing to the fuels on the forest floor. The canopy closes, generating shade and promoting the establishment and growth of more shade-tolerant, and possibly fire-sensitive, species .

Now the forest floor is covered with potential fuels, and there are many saplings and trees of different ages and sizes. These effects of fire suppression create potential conditions for a devastating fire. A ground fire will be fed by the continuous cover on the forest floor, and the different sized trees act as ladder fuels to carry the fire up into the canopy. A fire in the canopy, known as a crown fire, can be very severe, killing even the oldest and healthiest trees.

This is a screenshot of the past management pop-up interaction on the Disturbances/Wildfire slide. This is the introduction that appears when the past management pop-in box is chosen. The image is of an open forest.



This is a screenshot of the past management pop-up interaction on the Disturbances/Wildfire slide. This is the first tab that appears when the 1 button is chosen. The image shows a taller forest with more brush and seedling establishment.

This is a screenshot of the past management pop-up interaction on the Disturbances/Wildfire slide. This is the second tab that appears when the 2 button is chosen. The image shows a taller forest, with saplings, more seedlings, and more undergrowth.

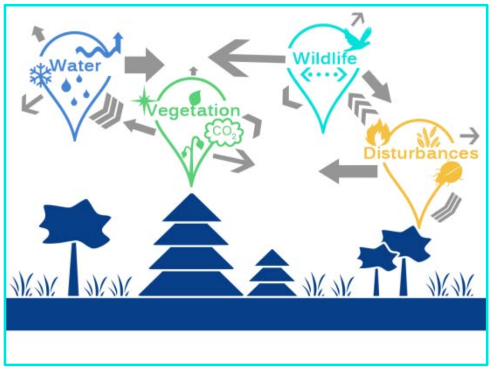
This is a screenshot of the past management pop-up interaction on the Disturbances/Wildfire slide. This is the third tab that appears when the 3 button is chosen. The image shows a crowded forest with many different stages of growth and a forest floor covered with brush, woody debris, and seedlings.

Conclusion

Climate change will affect forest and grassland ecosystems in many different ways. These effects are not confined to categories; instead they interact with and affect one another, often further increasing the impact of climate change on ecosystems.

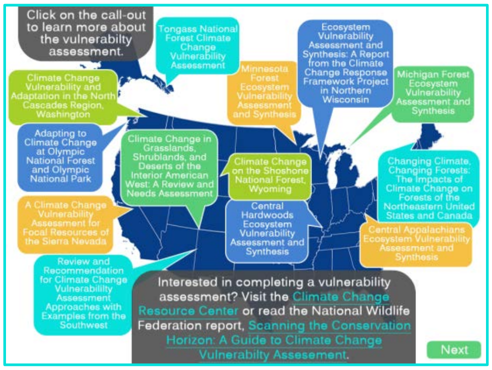
This module has provided a very general overview of major effects and interactions of climate change. There are an increasing number of scientific reports and assessments about climate change effects and vulnerabilities in forests and grasslands across the United States.

Where do you live and work? Have you seen any of these changes in your local forests or grasslands? What are some of the resources or conditions there that are particularly vulnerable? Check out some of these assessments to see trends, projections, and vulnerabilities.



This is a screenshot of the Conclusion slide. The image is of a few trees and grasses with a different bubble for each category: water, vegetation, wildlife, and disturbances. The bubbles have arrows between them to indicate interactions between effects.

This is a screenshot of the Conclusion slide. The graphic is a map of the United States with different icons placed throughout representing different effects that have been discussed.



This is a screenshot of the Conclusion slide. The graphic is a map of the United States with call-outs featuring vulnerability assessment publications that have been done around the country. The box at the bottom of the screen asks, "Interested in completing a vulnerability assessment? Visit the Climate Change Resource Center or read the National Wildlife Federation report, Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. The box at the top of the screen says, "Click on the call-out to learn more about the vulnerability assessment." For more information and a list of vulnerability assessments, see the box below.

This slide features two interactions as indicated by the boxes on the bottom and top left-hand side of the screen that pop in after the slide animations and narration have finished. The bottom box says, "Interested in completing a vulnerability assessment? Visit the Climate Change Resource Center or read the National Wildlife Federation report, Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment." This box has hyperlinks that lead to the appropriate website. The second top-left interaction box says, "Click on the call-out to learn more about the vulnerability assessment." Clicking on any of the call-outs on the map will lead to a landing page for the specific vulnerability assessment.

Vulnerability Assessments Shown in the Conclusion

Michigan Forest Ecosystem Vulnerability Assessment and Synthesis
Ecosystem Vulnerability Assessment and Synthesis: A Report from the Climate Change Response Framework Project in Northern Wisconsin
Minnesota Forest Ecosystem Vulnerability Assessment and Synthesis
Tongass National Forest Climate Change Vulnerability Assessment
Climate change Vulnerability and Adaptation in the North Cascades Region, Washington
Adapting to Climate change at Olympic National Forest and Olympic National Park
A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada
Review and Recommendation for Climate Change Vulnerability Assessment Approaches with Examples from the Southwest
Climate Change in Grasslands, Shrublands, and Deserts of the Interior American West: A Review and Needs Assessment
Climate Change on the Shoshone National Forest, Wyoming
Central Hardwoods Ecosystem Vulnerability Assessment and Synthesis
Central Appalachians Ecosystem Vulnerability Assessment and Synthesis
Changing Climate, Changing Forests: The Impacts of Climate Change on Forests of the Northeastern United States and Canada

Activity

The last slide in the module is a landing slide that allows users to either replay the module by hitting the Replay button or move on to the activity with the Activity button.

This is a screenshot of the transitional slide between the information portion of the module and the activity. There are two small vertical bars on the left and right side of the screen. These bars hold different icons of effects that were discussed throughout the module. The box at the top of the screen asks, "Need to review before starting the activity? Click on the Replay button to repeat the presentation." The box on the bottom of the screen asks, "Ready to start the activity on climate change effects on forests and grasslands? Click on the Activity button!" There are two button in the center of the screen. The left-hand button is the Replay button, and the right-hand button is the Activity button.

If you would like additional accessibility resources not available on the site, please contact us at ccrc@fs.fed.us.