A CLIMATE RESILIENCE GUIDE FOR SMALL FOREST LANDOWNERS IN WESTERN WASHINGTON

Climate Impacts Group | EarthLab, University of Washington | Forest Service, U.S. Department of Agriculture | USDA Northwest Climate Hub, U.S. Department of Agriculture

Recommended Citation:
Raymond, C., Morgan, H., Peterson, D., Halofsky, J. 2022. A Climate Resilience Guide for Small Forest Landowners in Western Washington. A Collaboration of the University of Washington Climate Impacts Group, the U.S. Forest Service, and the Northwest Climate Hub.

Acknowledgments
The authors thank Kevin Zobrist, Glenn Ahrens, Andy Perleberg, Patricia Loesche, and Tess Wrobleski for valuable input during document review.

Funding
Funding for development of this guide was provided by the USDA Forest Service, Office of Sustainability and Climate, and Pacific Northwest Research Station, and the USDA Northwest Climate Hub. Support was also provided by the University of Washington, School of Environmental and Forest Sciences.

Image Citations:
Pg. 10 - Ruth Hartnup (used under CC BY 2.0)
Pg. 10 - Katie Moum, Unsplash
Pg. 11 - Nick Page (used with permission)
Pg. 15 - Butterfly bush small, Sue Thompson (used under CC BY-ND 2.0)
Pg. 15 - Butterfly bush large, Ben@Balade (used under CC BY-NC-ND 2.0)
Pg. 15 - Scotch broom small, Chris Tarnawski (used under CC BY-NC-ND 2.0)
Pg. 15 - Scotch broom large, Björn S. (used under CC BY-SA 2.0)
Pg. 15 - Saltcedar small, Sheila Sund (used under CC BY 2.0)
Pg. 15 - Saltcedar large, greenheron4 (CC BY-NC 2.0)
Pg. 15 - Knapweed small, stanze (used under CC BY-SA 2.0)
Pg. 15 - Knapweed large, Oregon Department of Agriculture (used under CC BY-NC-ND 2.0)
Pg. 17 - Balsam woolly adelgid, Gilles San Martin (used under CC BY-SA 2.0)
Pg. 17 - Douglas-fir beetle, Vancouver Island Free Daily
Pg. 18 - Swiss needle cast, Richard Buckley, Rutgers PDL
Pg. 18 - Laminated root rot, David Shaw (2006)
Pg. 20 - Red-breasted sapsucker, Harriet Morgan (used with permission)
Pg. 20 - Chum salmon, Harriet Morgan (used with permission)

WHY ACT AND WHY NOW?

Forests in western Washington are being affected by changes in the climate. As the climate continues to warm, and temperature extremes occur more often, forests will experience more impacts, with consequences for the values that small forest landowners derive from their forests. Some potential effects of climate change on forests are well understood. For example, we are seeing changes, such as dieback in western redcedar. Other effects will appear over time, requiring landowners to be flexible and adaptable in managing forest land.

As a landowner, you can take action now to ensure that your forest continues to be resilient to changes in the climate and meets the goals you have for your land. Climate change is a complex, global-scale issue, but many options are available for climate-smart management at the local scale.

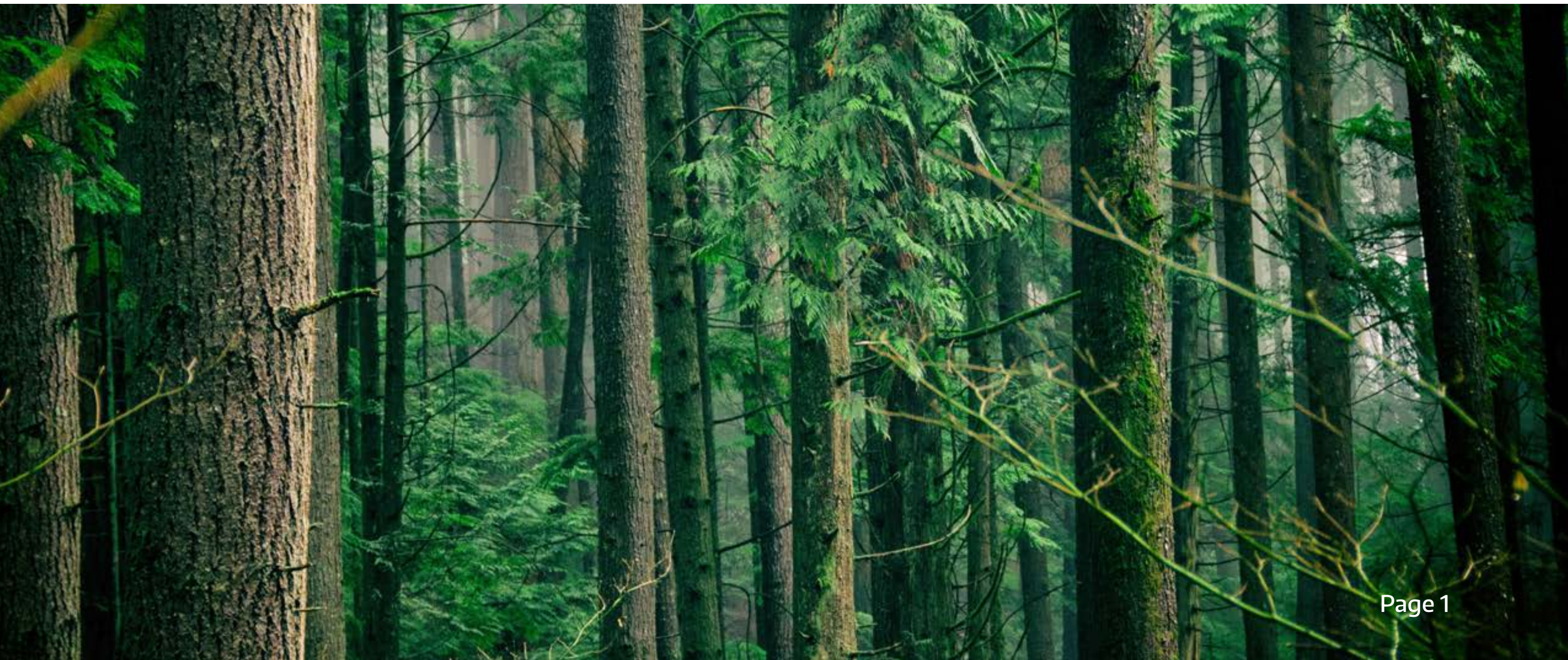
Climate-smart actions appropriate for your forest depend on the setting of your property:

- What is the geographic setting?
- What is the management history?
- Which stressors is the forest currently experiencing?

Your forest can contribute to resilient ecosystems and thriving habitat for plants, fish, and wildlife, while storing carbon to help reduce greenhouse gas emissions.

Actions also depend on your management goals over the next decade or more. Deciding which actions to implement depends on knowing how your goals might be affected by changes in the climate.

This guide provides forest landowners in western Washington with information to (1) understand how your forests may be affected by climate change, and (2) identify actions that you can take to reduce adverse impacts, increase resilience, and contribute to thriving forest lands and habitat across the region.



WHO ARE SMALL FOREST LANDOWNERS?

Small private landowners collectively own substantial forest area and have a variety of objectives for their lands. If these objectives include climate resilience, landowners can collectively increase the overall climate resilience of forests in western Washington.

Small forest landowners in western Washington are defined as owning at least 2 acres (1 acre of which is forested) and up to 2,500 acres; most own less than 20 acres. Statewide, this acreage accounts for 15% of all forested land. Primary land uses are residential (54%) and natural forest (40%), with only about 6% used for agriculture. The number of landowners has increased in the last five years, although the total acreage owned has decreased.[1]

In western Washington, landowners value their land most for its scenery, privacy, and personal attachment and prioritize environmental benefits such as wildlife habitat, high-quality water resources, and biodiversity. Those who own more land tend to include income and investment as an objective and are more likely to actively manage their forest. Regardless of why you value your land or what your objectives are, understanding the impact of a changing climate on forests is important. Which actions you take to increase climate resilience will depend on how active you want to be in shaping your forest for the future. Working to increase the climate resilience of your forest now will enhance your forest's legacy for future generations.

The geographic location and current condition of your forest will also affect the actions that are most appropriate for your land. Many forest landowners have forests that have been harvested at least once, resulting in simplified structure and species composition. These forests may need restoration, even in the absence of climate change, and more active management of these forests will be necessary to ensure long-term resilience relative to forests with more diverse species and structure.

Small forest land ownership in western Washington. Data Source: Comnick et al. (2021). Digital Data. "The 2019 Washington State Forestland Database." Seattle, WA: University of Washington.

CHANGES IN CLIMATE WILL AFFECT FORESTS

This guide summarizes four key impacts of climate change on forests in western Washington. For each impact, actions are listed that small forest landowners can take to reduce the negative consequences of climate change, increase forest health and resilience, and contribute to thriving forest lands and habitat across the region.

To implement climate-smart actions for your forest, you may also need to take an active approach to learn, plan, monitor, and collaborate on impacts and actions (pg. 24). This guide also includes information on education and collaboration opportunities to help you implement the recommended management actions.

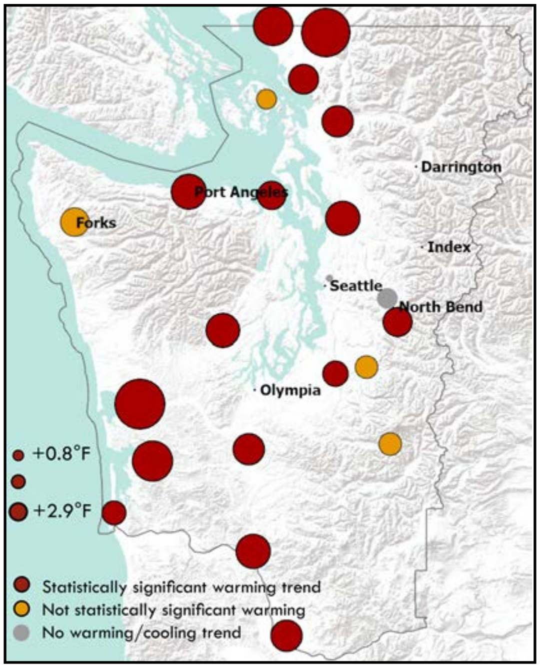
Climate Impact	Impacts on Forests	Actions You Can Take
Summer moisture stress	One of the most widespread effects of climate change on trees and plants in western Washington will be reduced growth and more mortality due to drier summer conditions.	Improve forest resilience on sites with low soil moisture by planting or retaining tree species and genetic varieties more tolerant of low soil moisture and by reducing the number of trees and competing understory vegetation.
Wildfire	Hotter, drier summers are expected to increase wildfire potential. Although wildfire is not frequent in western Washington forests relative to dry, fire-adapted forests in other parts of the state, large and severe wildfires have burned in the past and will burn in the future. Also, small fires may burn more frequently in the wildland-urban interface, affecting forests and other resources.	Protect people, property, and high-value resources near your forest: follow Firewise USA® guidelines, plan for response and evacuation, and ensure that firefighters have access to your property. Only in more fire-prone forests, selectively plant tree species with high resistance to wildfire and thin and remove small trees and understory vegetation not resistant to wildfire.
Invasive species	Invasive plants are expected to spread more easily, reducing forest health by competing with trees and other native plants for water, and in some cases, facilitating wildfire. A warmer climate may directly favor some invasive species, and others may establish and spread more easily after more frequent floods and wildfires.	Learn to identify common invasive species and monitor for their presence on your property. Minimize the effects of invasive species by preventing introduction and detecting and controlling them as soon as possible.
Forest insects and diseases	Some insects and diseases that reduce tree vigor or kill trees may directly benefit from changes in the climate. Others may become more widespread after wildfires or with declines in forest health due to other climate impacts.	Learn to identify signs of common forest insects and diseases. Prevent the introduction of insects and diseases into your forest. Diversify forest species to reduce widespread impacts of forest insects and disease.

OBSERVED CHANGES IN CLIMATE

The climate of western Washington has changed over the last century, with consequences for forest dynamics and health.[2]

Temperature

In the last 120 years, temperatures across western Washington have risen by 1.7°F. Temperature partially controls where different tree species are able to grow. Trees in western Washington are adapted to cool winters and mild summers. Higher temperatures affect tree growth rates and regeneration, and ultimately the distribution and abundance of tree species across the region.



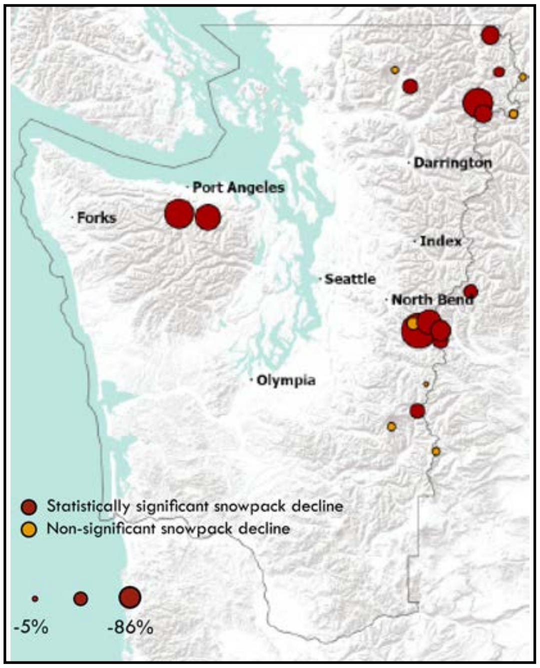
Observed temperature trends at weather stations between 1900 and 2019. Western Washington has warmed, with average annual temperature increasing 1.7°F between 1900 and 2019. Some locations have warmed as much as 3°F, others have warmed less. Data source: OWSC Trend Analysis Tool.

Precipitation

In western Washington, precipitation varies greatly from year to year. Given this high variability, there is no detectable long-term trend in precipitation over the past century. However, high temperatures contribute to dry conditions in summer, even without changes in precipitation. Western Washington has experienced several droughts in the last decade, notably 2015, 2019, and 2021. Although tree species in western Washington are adapted to dry summers, trees are stressed and can grow less or die in abnormally dry summers.

Snowpack

Warmer winters in western Washington have caused less snow to accumulate in the mountains. Washington's spring snowpack fluctuates from year to year but decreased by 30% on average between 1955 and 2016.[3] This means less snow melt is available in spring and summer, reducing water in the soil for tree growth and water in streams for fish. Less snow also means less insulating snowpack that prevents some trees at high elevations from being damaged by cold temperatures and frost.



(Right) Observed snowpack trends at weather stations between 1940 and 2019. Snowpack has decreased throughout the Cascade and Olympic Mountains in western Washington over the past 80 years. Data Source: OWSC Trend Analysis Tool.

Streamflow

Hotter summers and less mountain snowpack have shifted peak streamflow earlier in spring and lowered streamflows in summer.[4] In contrast, more rain instead of snow in winter has increased streamflow in winter. These changes degrade habitat of salmon, which depend on adequate streamflow in summer to migrate upstream to spawning grounds. In winter, high streamflows can scour salmon egg nests and flush young salmon downstream too early, increasing the risk of predation by larger fish.

DEFINITION OF KEY TERMS

Adaptation	The process of adjusting to actual or projected climate and its associated effects, including with human intervention to facilitate the adjustment.
Carbon sequestration	The process of capturing atmospheric carbon dioxide and storing it in solid (e.g., plants) or liquid (e.g., oceans) form.
Climate	Average weather conditions over multiple years.
Climate change	A change of climate that is linked directly or indirectly to human activity that alters the atmosphere and that is in addition to natural climate variability.
Greenhouse gas (GHG)	Gases (carbon dioxide, water vapor, methane) that absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into space. If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase, a phenomenon known as the greenhouse effect.
Ecosystem services	Ecological processes or functions that provide benefits or values to individuals or society (e.g., flood reduction, wildlife habitat, carbon storage).
Mitigation	A human intervention to reduce emissions or enhance the storage of greenhouse gases (e.g., carbon dioxide).
Natural climate variability	Fluctuation in temperature, precipitation, and other factors over long periods of time (years to centuries) caused by non-human forces (e.g., variation in the Earth's orbit around the sun, interactions between the atmosphere and ocean).
Representative Concentration Pathways (RCPs)	Scenarios of future greenhouse gas concentration trajectories used by the international climate science community in computer models to simulate change in the climate and its effects. The scenarios describe different climate futures; all are considered possible depending on near-term greenhouse gas emissions.
Resilience	The capacity of an environmental or human system to cope with and recover from a disturbance or extreme event to provide essential functions and structure.
Tree vigor	The health and productivity of a tree, including its resilience to stressors.
Weather	Short-term atmospheric conditions that are measured for minutes, hours, or days.

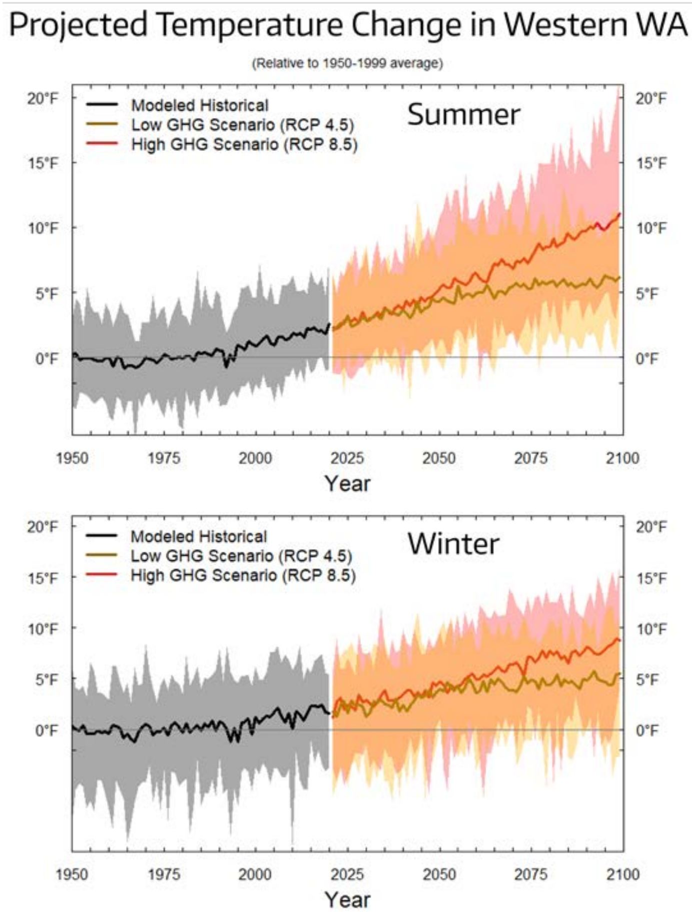
EXPECTED FUTURE CHANGES IN CLIMATE

Summer Temperature

Warming is projected to be greatest during summer in western Washington.[5] Higher summer temperatures increase evaporation, dry soils, and stress trees that are not tolerant of low soil moisture. Increasing summer temperatures also dry live and dead vegetation, increasing the potential for wildfires to spread. By mid-century, average summer temperature is expected to increase 3.3°F for a low GHG scenario and 3.5°F for a high GHG scenario, relative to the 1950-1999 average. These trends are based on the average of 33 climate models, and all models project warming.

Winter Temperature

Winters are projected to warm across western Washington.[5] Cold temperatures in winter control dormancy (times when little to no growth occurs) and the formation of new buds for many conifer species, such as Douglas-fir. Warmer winters can harm trees that have adapted to colder winter temperatures of the past by causing buds to form too early. On the other hand, warmer winters can lengthen the growing season for trees at mid to high elevations, improving growth of some species. By mid-century, average winter temperature is expected to increase 2.5°F for a low GHG scenario and 3.0°F for a high GHG scenario, relative to the 1950-1999 average. Similar to summer temperature, all models project warming in winter.



Average summer and winter temperatures in western Washington are projected to increase throughout the 21st century. Summer warming is projected to be greater than in other seasons. These figures show change in summer and winter temperature relative to the 1950-1999 average (horizontal line at zero). Solid lines: the climate model average; shaded areas: the range among models. Data source: https://climate.northwestknowledge.net/MACA/.

OBSERVED AND PROJECTED GREENHOUSE GAS EMISSIONS

The world has already warmed as a result of human activity. Since the Industrial Revolution, atmospheric concentrations of carbon dioxide (CO_2) and global temperatures have increased significantly as a result of human activities. Atmospheric CO_2 increased from about 290 ppm in 1880 to nearly 420 ppm today. Over the same period, global temperatures increased approximately 1.8°F.

Human-caused warming resulting from greenhouse gas emissions adds about 0.4°F to global average temperatures every decade. If this continues, global average warming is likely to reach 2.7°F between 2030 and 2052, which is within the lifetime of most people.

To make projections of future climate, scientists use 'what if' scenarios of plausible future greenhouse gas (GHG) emissions to drive computer model simulations of the earth's climate. GHG scenarios affect how much and how fast the earth warms. A "high" GHG scenario (RCP 8.5), which assumes continued increases in GHG until the end of the century, will cause faster and more warming than a "moderate" (A1B) or "low" (RCP 4.5) GHG scenario. For each GHG scenario, there is a range of future climate based on different climate models that use unique assumptions to simulate the climate.

Precipitation

Expected changes in the total amount of precipitation (rain or snow) in an average year are small compared to the expected high year-to-year variability. Summers in western Washington are typically dry, a limiting factor for tree growth and the distribution of tree species. Summers are projected to be drier by mid-century.[5] As with rising temperatures, drier summers are likely to stress tree species that are not tolerant of low soil moisture and could reduce the area of suitable habitat for some species in drier areas of western Washington.[6] Tree species more tolerant of dry conditions may expand their ranges.

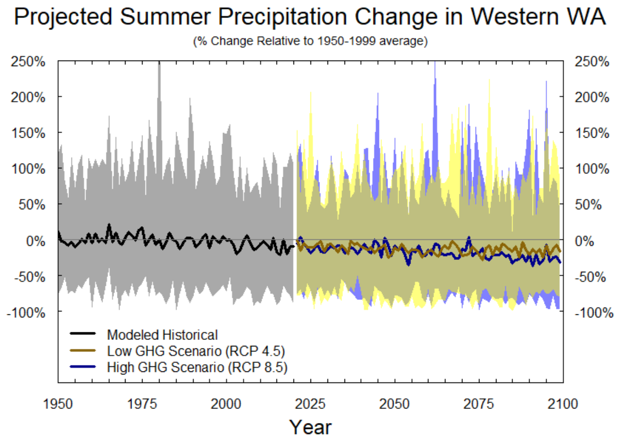
Snowpack

Despite little change in annual precipitation, snowpack is projected to further decrease in the Cascade and Olympic Mountains as temperatures increase. Low- to mid-elevation foothills near the freezing line in winter are expected to see the greatest snowpack loss. Less snow cover will enable trees to grow in places that were too cold in the past, but it will also decrease protective insulation for some species. Less snow will also reduce the amount of snow melt that contributes to soil moisture and supports tree growth.

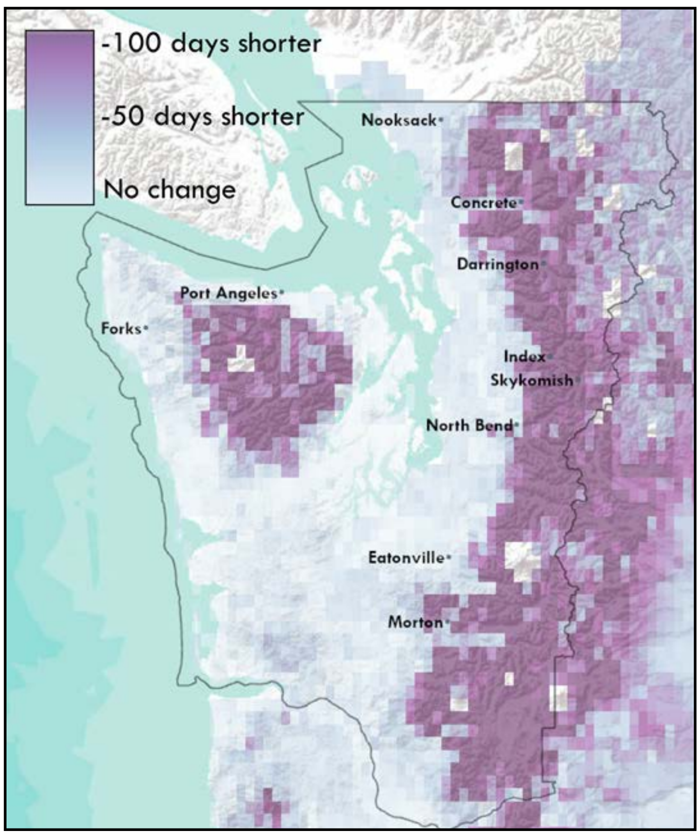
Storms and Wind

Western Washington frequently experiences severe storms in the winter with heavy rain and high winds. With climate change, heavier rainfall is expected in the most intense storms.[7] Heavier rainfall can lead to landslides, slope instability, and soil saturation. In contrast to heavier rainfall, current science does not indicate higher windspeed or more frequent windstorms.

The number of trees blown down by wind may increase if trees are weakened by less water in summer, excessively wet soils in winter, and more damage from insects and disease, even if climate change does not change the frequency of windstorms.



The long-term trend (dark blue and brown lines) is for summer precipitation to decrease across western Washington in the 21st century, but year-to-year variability will remain high. This figure shows percent change in total summer precipitation, relative to the average of 1950-1999 (horizontal line at zero). Years with positive values show an increase; years with negative values show a decrease. Data source: https://climate.northwestknowledge.net/MACA/.



Duration of the snow season is projected to decrease in mountainous areas of western Washington, except in the highest elevations. The map shows projected change in length of the snow season (difference between 1915-2006 and the 2040s) under a moderate greenhouse gas scenario. Purple shows the most change; light blue shows no change. The duration of the snow season is the number of days between 10% of maximum snowpack depth and 90% of the snowpack melt out. Data source: Hamlet et al. 2013.[8]

SUMMER MOISTURE STRESS

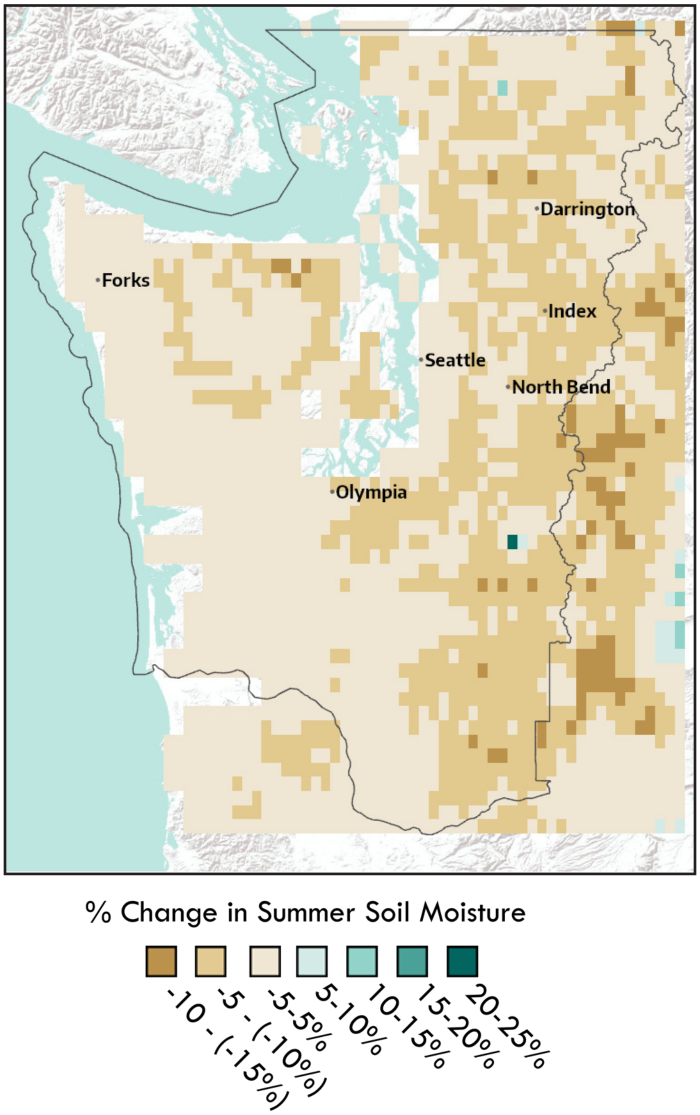
Climate Impacts

Most native tree species in western Washington have some tolerance of low soil moisture because of the region's normally dry summers (see Table of Tree Species, pg. 27). However, below-normal soil moisture can shorten the growing season and reduce tree growth and vigor. Higher temperatures will evaporate more water from the land and increase transpiration from plants. Less rain is expected to be available in summer to replenish moisture in the soil. At elevations where snow typically accumulates in winter, less snow and earlier melt is expected to decrease how much water enters the soil in spring, drying soils earlier in the summer.

Multiple climatic factors are expected to reduce water availability and increase moisture stress for trees and other plants during the growing season.

Some years will still be wetter than average because of natural climatic variability. So although summers are expected to be drier on average, trees (especially seedlings) will still need to tolerate variable conditions from one year to the next.

Tree species have a range of tolerance to low soil moisture conditions (see Table of Tree Species, pg. 27), and some are more sensitive than others to dry summers. For example, western redcedar has low to moderate tolerance for low soil moisture. In recent years, dead and dying cedars have been observed throughout western Washington, likely due to very dry summers in 2015, 2019, and 2021. If western redcedar grows in your forest, you can contribute to efforts to monitor its condition (see 'Citizen Science Used to Map and Monitor Western Redcedar Dieback', pg. 9).



Summer soil moisture is projected to decrease across many low- to mid-elevation regions in western Washington. The map shows expected percent change in summer (June, July, August) soil moisture (2010-2039 relative to 1971-2000) under a high greenhouse gas scenario. Darker shades of brown indicate a larger decrease change; lighter shades indicate little or no change. Data Source: Climate Toolbox

CITIZEN SCIENCE MONITORING OF WESTERN REDCEDAR DIEBACK

The Forest Health Watch initiative is a community-science program that monitors forest health. One project, focused on the health and mortality of western redcedar, uses the iNaturalist cellphone app to document tree canopy conditions. Community members share observations and photographs of cedars, showing canopy thinning, top dieback, and other characteristics. These data have created the Western Redcedar Dieback Map on iNaturalist. Scientists from Washington State University and the U.S. Forest Service are using the map to identify where cedars are vulnerable to summer moisture stress and other factors. If you are interested in sharing your observations of western redcedar, follow directions on the Forest Health Watch Initiative website.

Management Options

Although dead and dying trees may seem alarming, some dead trees are normal in most forests, providing habitat for insects, birds, small mammals, and amphibians. Consider accepting a slightly higher number of dead trees, recognizing benefits for wildlife habitat. However, in some locations, especially with well-drained soils and south-facing slopes, mortality rates may exceed what is acceptable for your forest objectives. Some management actions may help increase resilience to low moisture conditions.

- Learn about the topography and soils of your forest. Identify locations and soil types with lower moisture where trees are more likely to be affected by soil moisture stress in the future.
- Eliminate non-native and invasive tree and plant species that compete for limited water.
- In dense forests that have previously been harvested, thin smaller trees and remove species that are less tolerant of low soil moisture (see Table of Tree Species, pg. 27).
- When thinning or planting trees, consider soil moisture conditions at the time to ensure the best chance of survival for seedlings and adequate soil moisture for trees that remain after thinning. Plant trees in the fall if possible, or review seasonal climate outlooks and long-lead weather forecasts and plant in a year or time of year that is not expected to be abnormally hot and dry.
- Plant native tree and understory species that are tolerant of low soil moisture (see Table of Tree Species, pg. 27) in openings created by harvests or natural disturbances.
- Increase species diversity, including early-successional tree species, by retaining less common species during thinning or harvesting.
- Consider using assisted migration (see 'What is Assisted Migration?', pg. 11) to increase genetic and species diversity of trees. Select species that are compatible with species currently in your forest and that are likely to remain appropriate for the site even in a warmer climate because of their tolerance of low soil moisture (See Table of Tree Species, pg. 27).

When planting trees after a harvest or disturbance, consider seedling densities with respect to location and management objectives. Seedlings on well-drained soils, south aspects, and steep slopes (i.e., low moisture locations) may have higher mortality than in other locations, so higher densities may be appropriate unless using assisted migration. If you are managing for timber production, relatively high densities will allow for thinnings to adjust densities in the future. If you are managing for wildlife habitat or other values, lower tree densities, variable densities, and gaps will create a more variable forest structure, but perhaps with more competition from understory plants and invasive species.

WHAT IS ASSISTED MIGRATION?

Assisted migration (also called managed relocation) is a process of people facilitating the movement of tree species across the landscape in response to the changing climate. This process includes planting seeds or seedlings in new locations (1) within the current range of a species, (2) just outside the current range, or (3) far outside the current range. The primary objective is to increase genetic or species diversity to improve resilience to heat and low soil moisture. Assisted migration has benefits and challenges to carefully consider before implementation.[9]

BENEFITS

- Can help maintain productive forests as the climate changes by moving species to a suitable climate that may be beyond the species' historical range.
- Relatively inexpensive, especially for readily available species and seed sources.
- Can help maintain wildlife habitat.
- Can help species move across human-made barriers that may prevent natural migration in response to climate change.

CHALLENGES

- Introduced species may become invasive or compete with native species. However, most tree species in the western U.S. have low potential to become invasive.
- Outside their native range, species may be more susceptible to insects and diseases that are not in their native range.
- The seedling stage is the most susceptible to climate impacts. Introduced species or varieties may not survive the seedling stage if moved too far from their original range.

RECOMMENDATIONS

- Use detailed information on soils and topography to select species or seed sources to plant that are best suited for your forest.
- Plant tree seedlings from multiple seed zones for a given species to increase genetic diversity and enhance long-term survival.
- Do not move tree species or seed sources too far from their current ranges to avoid risk of seedling mortality and greater susceptibility to insects and diseases.
- Protect seedlings from non-climate stressors such as browse.

RESOURCES TO HELP WITH ASSISTED MIGRATION

To identify alternative seed sources that are adapted to the climate expected for your location in the future, explore the Seedlot Selection Tool. This tool identifies potential source areas for some Washington tree species under climate change scenarios. The Table of Tree Species (pg 27) indicates potential species for assisted migration depending on the changing conditions for your forest.

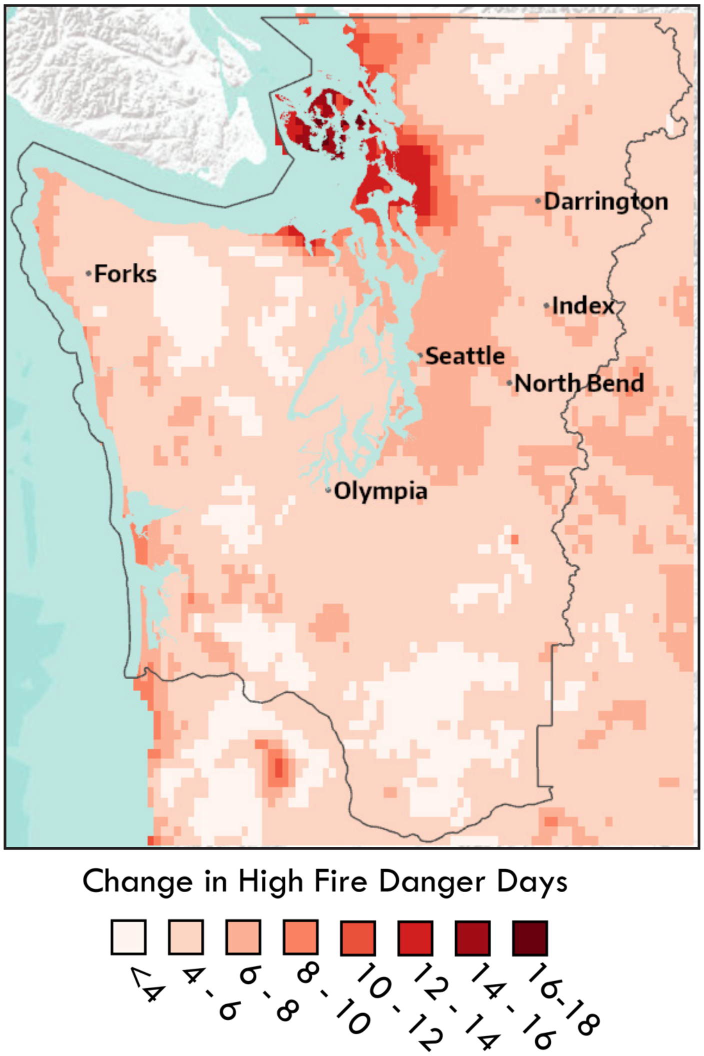
WILDFIRE

Climate Impacts

Wildfires in western Washington forests have both ecological benefits and costs for people, property, and communities. Wildfires create openings that are used for browse and easy travel by deer and elk. These openings also provide places where shade-intolerant tree species and plants can grow, thus increasing species diversity and food for wildlife. However, many fires threaten communities, homes, and safety in the wildland-urban interface and, in the short term, reduce forest values and resources.

With higher temperatures and less rain in summer, climate change is expected to increase the potential for wildfires in western Washington. With climate change, under a high greenhouse gas scenario, the region is expected to have up to 18 more days of high fire danger per year (for 2010-2039 relative to 1971-2000).

For fires to burn, there needs to be ignitions and short-term weather conditions that enable fire, such as high winds and low relative humidity. Warmer, drier summers are expected to increase fire danger, lengthen the fire season, and increase the area burned by drying vegetation, making it easier to burn.[10] For fires to spread, there still need to be ignitions and short-term weather conditions that enable fire, such as high winds.



The number of high fire-danger days is projected to increase across western Washington. This map shows the projected increase in high-danger days. Darker shades of red indicate a larger increase in the number of high fire-danger days. Under a high greenhouse gas scenario, the region is expected to experience up to 18 more days of high fire danger per year for 2010-2039 relative to 1971-2000. Data Source: Climate Toolbox

RESOURCES TO HELP MANAGE WILDFIRE RISK

The Washington Department of Natural Resources Wildland Urban Interface (WUI) map defines the extent of the WUI. If your property is located in the WUI, taking action can reduce wildfire risk.

Local natural resource departments and conservation districts provide resources for wildfire risk reduction. King County's Forestry Help for Landowners is one local resource.

The Fire Adapted Communities Learning Network offers resources, tools and connections to help individual communities to collectively reduce wildfire risk, while also engaging with similar communities in the state.

WESTERN WASHINGTON WILDFIRE REGIMES

The frequency, size, and severity of wildfire vary across western Washington. Historically, wildfires burned large areas. A single fire could burn hundreds of thousands of acres, killing most of the trees. However, these fires burned a given area only once every 200 to 600 years, constituting an "infrequent-high severity" fire regime.

Forests in drier areas, such as dry Douglas-fir forests on the northeast Olympic Peninsula, are in the moderately frequent-mixed severity fire regime, burning a given location every 50 to 200 years, with a mosaic of tree mortality and survival. Forests and oak woodlands in the southern Puget Sound region were historically in a frequent-mixed severity fire regime, in which fire burned every 15 to 50 years and many trees survived fires of low to moderate intensity.

A map of general fire regimes for regions of western Washington within the areas of the Northwest Forest Plan. A fire regime describes the typical frequency, size, and severity (proportion of trees killed) of fire in a forest. Most forests in western Washington have an Infrequent-high severity fire regime. Data Source: Adapted from Reilly et al. (2021).[11]

Management Options

Forests in western Washington have burned in the past and will continue to burn in the future. Large, high-severity wildfires, such as those that burned in western Oregon in 2020 (a total of over 700,000 acres) could also burn in western Washington. When fires burn in dense forests with abundant live and dead vegetation, fire behavior is typically extreme and embers can travel long distances. Managing forest vegetation to reduce wildfire risk may not be effective in preventing large, severe fires driven by high winds, but some management actions may effectively reduce wildfire risk for small and moderate fires, which burn in this region more frequently.

- Prevent human-caused ignitions by using caution in activities that could start fires on your land, especially when fire danger is high.
- Reduce invasive species, such as Scotch broom, that can facilitate the spread of fires, especially along roadways and in forest openings.
- Include in your forest management plan objectives and post-fire responses if your forest does burn, such as which trees and seed sources to plant.

If there are buildings or other valued infrastructure in your forest, take actions to reduce the risk of wildfire to structures and increase the potential for protection during a fire.

- Consider access to your property for firefighters by clearing vegetation along roads and increasing accessibility of roads.
- Implement Firewise USA® landscaping and vegetation management practices around homes and buildings to reduce damage and increase the potential for firefighters to protect lives and property during a fire, recognizing that some actions may not be effective under extreme wildfire conditions.

If your forest is located where fire historically burned more frequently (tan and purple areas in the above map), additional actions may increase fire resilience.

- Favor tree species with some resistance to fire (e.g., Douglas-fir, Oregon white oak). Plant these species in existing forest clearings and after harvest or fire. Retain fire-resistant species when harvesting or thinning.
- Thin dense forests and reduce understory vegetation. Reducing tree density and ladder fuels (fuels that connect the forest floor to the tree canopy) can slow fire spread and reduce the severity of a fire if one burns through forests with moderately frequent- and frequent-mixed severity fire regimes.

INVASIVE SPECIES

Climate Impacts

Invasive species are plants that are introduced to a new area (usually by humans) and spread pervasively, often competing with native species. Many invasive species are more tolerant of dry soil than are native species. They also often propagate easily and grow fast, allowing them to take advantage of openings along roads or after forest disturbances. As a result, several common invasive species in western Washington may become more abundant in a climate with more fire and other forest disturbances.

In addition to an increase in some common invasive species, four invasive species known to occur in western Washington — Scotch broom, butterfly bush, spotted knapweed, and saltcedar — are expected to be directly favored by changes in precipitation and temperature.[12] Some invasive species, such as Scotch broom, can facilitate fire spread. Other invasive species can reduce the quality of habitat for some wildlife species.

Invasive species can negatively affect forest health in ways that worsen the direct effects of climate on forests, competing with native plants for water and increasing moisture stress for natives.

Spotted knapweed

Saltcedar

Scotch broom

Butterfly bush

Management Options

- Learn to identify common invasive species. Monitor regularly for their presence, especially in openings associated with roads, timber harvest, or tree mortality.
- Report invasive species on the Washington Invasive Species Council website.
- Work with your county noxious weed control board to remove invasive species with biological controls, mechanical treatments, or chemical treatments.
- Remove invasive species as early as possible after detection to prevent further spread
- Prevent the introduction of invasive species during timber harvest or other forest management activities by using cleaned equipment, vehicles, and personal gear.
- Avoid potential invasive species in landscaping.
- Maintain healthy native species in the forest understory and in forest openings.
- Consider planting native shrubs, grasses, and perennial species in openings that are created by development, timber harvest, or wildfires.
- If livestock use your forest, reduce overgrazing which can encourage the establishment of invasive species.

RESOURCES TO IDENTIFY AND MANAGE INVASIVE SPECIES

- The Washington State Noxious Weed Control Board can help identify invasives with a database of 140 invasive weeds. Washington State University Extension provides information about the most problematic ones in the state.
- County Weed Board and local Weed District staff provide educational and technical assistance. Some Boards help identify invasives, suggest control strategies, and provide grant or voucher programs to help control invasives and/or purchase non-invasive replacement plants.
- Integrated pest management is an effective way to control invasives and develop healthy plant communities.

FOREST INSECTS AND DISEASES

Climate Impacts

Trees in western Washington can be affected by several insects and diseases that can reduce growth or even kill trees. Warmer temperatures and changes in precipitation patterns may affect the range and abundance of insects and disease-causing pathogens directly.[13] The effects of climate change on many of these insects and diseases are poorly known. In some cases, a warmer climate and changes in precipitation may increase the spread of insects and diseases indirectly by stressing host trees and reducing tree vigor.[14] Forest insects are often attracted to stressed or weakened trees. In addition, when low soil moisture or extreme temperatures compromise tree vigor, host trees are less capable of resisting or surviving disease.

Potential interactions with climate change for some insects and tree diseases of western Washington are described below:

Balsam woolly adelgid (host: true fir species such as grand fir and Pacific silver fir). This non-native insect slows new foliage growth. Adelgids can spread quickly through tree crowns, often killing the tree. Adelgid populations are limited by cold temperatures, so warming may expand the insect's range and increase infestations.

Balsam woolly adelgid

Douglas-fir beetle (host: Douglas-fir). Attacks stressed and recently fallen trees, and is more common in forests affected by wind and fire. It is unknown how climate change may affect the Douglas-fir beetle directly, but moisture stress may increase tree susceptibility to beetle attacks. More fire and heavier rain events may increase dead and down Douglas-fir trees that attract the beetle.

Douglas-fir beetle

Lymantria dispar (formerly known as gypsy moth) (host: many conifer and hardwood tree species). Non-native defoliator whose range has expanded in Washington in recent years. Climate change is expected to increase the area with suitable climate for the moth, enabling it to spread and establish in more areas in Washington.

Sudden oak death (host: Oregon white oak and other oak species) is a non-native disease that can kill infected trees quickly. It is common in California and has been detected in nurseries in Oregon and Washington, but it is still rare. With warmer and wetter springs, sudden oak death may expand in current and new locations.


Swiss needle cast


Laminated root rot

Swiss needle cast (host: Douglas-fir) is a disease of tree foliage that is particularly widespread in coastal Douglas-fir forests and has increased since the 1990s. It is more widespread in forests with high tree densities. In cool, wet locations, higher temperatures may increase the disease, whereas in warm, dry locations, higher temperatures and less precipitation in summer may decrease the disease.

Armillaria root disease (host: multiple conifer species, including Douglas-fir). This fungal pathogen reduces tree growth and can cause mortality. Unlike laminated root rot, Armillaria is likely to affect low vigor trees that are stressed by other factors such as low summer moisture. Therefore, Armillaria is expected to become more frequent and widespread in western Washington with hotter, drier summers as the climate continues to warm.

Laminated root rot (host: multiple conifer species, especially Douglas-fir). This fungal pathogen is often found in managed forests with limited species diversity. The effects of climate change on this common tree disease are unknown. It does not appear to be sensitive to changes in air temperature so may not be affected by warming. Laminated root rot affects trees of all sizes and vigor, so a reduction in host tree vigor caused by heat or moisture stress may not increase disease prevalence.

RESOURCES FOR MANAGING INSECTS AND DISEASE

- USDA Forest Service Forest Insect & Disease Leaflets provide information on forest insects and diseases, including those of concern in western Washington.
- Washington State University Extension Forestry provides resources on most forest insects and diseases in western Washington, including those described in this guide that may increase with climate change.

Management Options

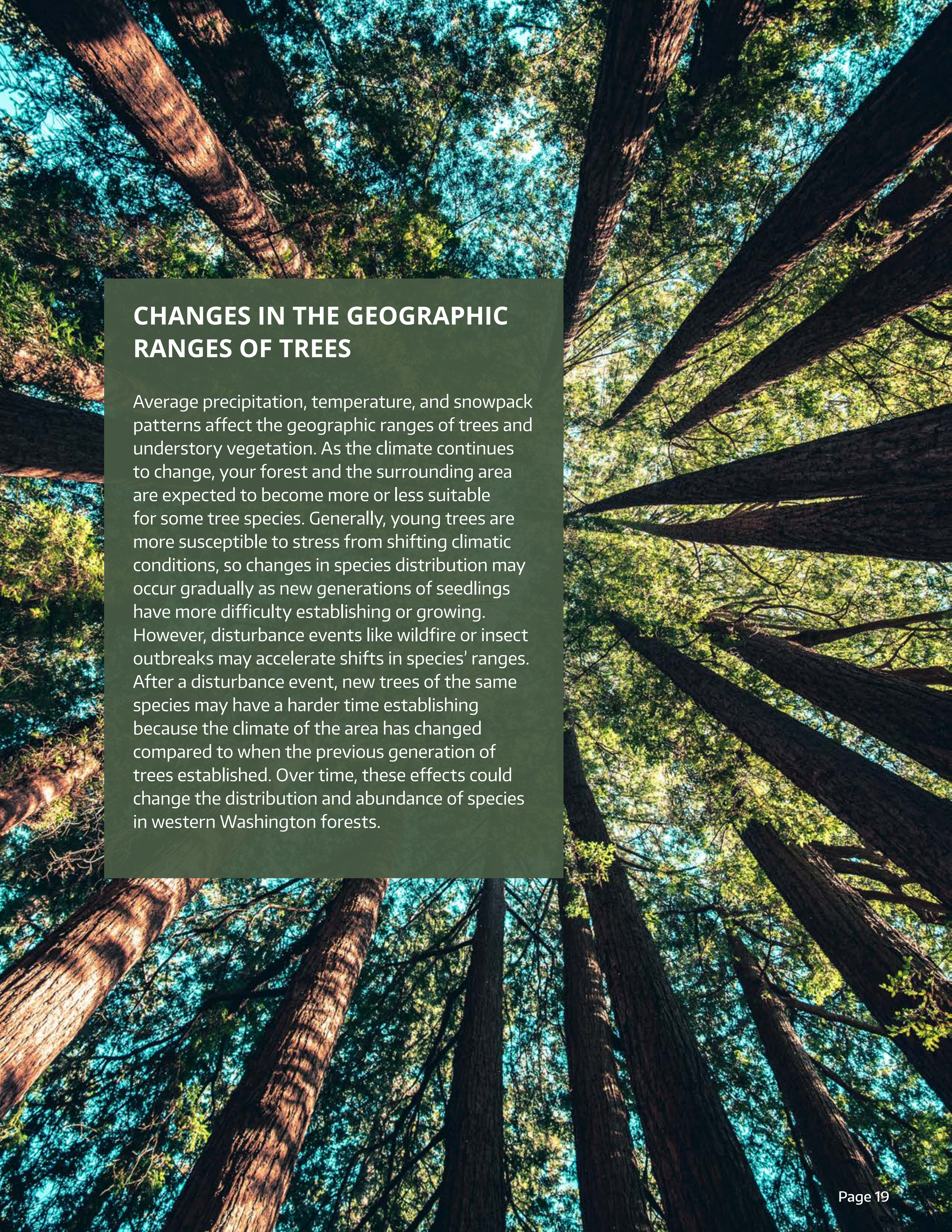
Although tree damage or mortality caused by insects or diseases may seem alarming, many tree species are resilient to them, especially if the insects and diseases are endemic to the area. Tree damage and mortality can create openings and structural diversity that allow different plant species to establish, improving habitat for some animal species. When mortality is widespread or caused by non-native insects or diseases, actively managing your forest for resilience can reduce negative outcomes.

Many management options to increase resilience to forest insects and diseases are consistent with practices to increase overall forest health and resilience.

- Learn to identify the signs of common forest insects and diseases and regularly monitor for their presence and effects on trees.
- Use best management practices to prevent introducing non-native insects and diseases to your forest.

Because forest insects and diseases typically depend on one or a few host tree species, management actions that maintain or increase tree species diversity can decrease the potential for any insect or disease to spread and affect large areas.

- When harvesting or thinning, leave trees of different species, both conifers and hardwoods.
- Plant more tree species that are native to western Washington (see Table of Tree Species, pg. 27), and consider increasing genetic and species diversity through assisted migration.
- If a specific insect or disease is already present in your forest, reduce the density of its host species by planting other species that are less susceptible to that insect or disease. For example, plant western redcedar in areas where Douglas-fir has been killed by laminated root rot.
- Use openings caused by tree mortality from insects or diseases as opportunities to diversify your forest. Openings can also be left unplanted to allow natural regeneration of understory plants and early-successional tree species.
- If forest openings do not meet your forest objectives, this is an opportunity to plant tree species that increase diversity and resilience to climate change. To increase resilience, plant species tolerant of low soil moisture and/or resistant to fire (see Table of Tree Species, pg. 27).



CHANGES IN THE GEOGRAPHIC RANGES OF TREES

Average precipitation, temperature, and snowpack patterns affect the geographic ranges of trees and understory vegetation. As the climate continues to change, your forest and the surrounding area are expected to become more or less suitable for some tree species. Generally, young trees are more susceptible to stress from shifting climatic conditions, so changes in species distribution may occur gradually as new generations of seedlings have more difficulty establishing or growing. However, disturbance events like wildfire or insect outbreaks may accelerate shifts in species' ranges. After a disturbance event, new trees of the same species may have a harder time establishing because the climate of the area has changed compared to when the previous generation of trees established. Over time, these effects could change the distribution and abundance of species in western Washington forests.

FOREST CO-BENEFITS

Co-benefits for Other Forest Resources

Managing your forest for climate resilience can also benefit forest resources and ecosystem services other than trees and timber. These non-timber resources and ecosystem services are also likely to be affected by climate change. You can manage your forest to increase water availability for people, plants, and wildlife; improve habitat for wildlife; and improve habitat for fish.

Water Resources

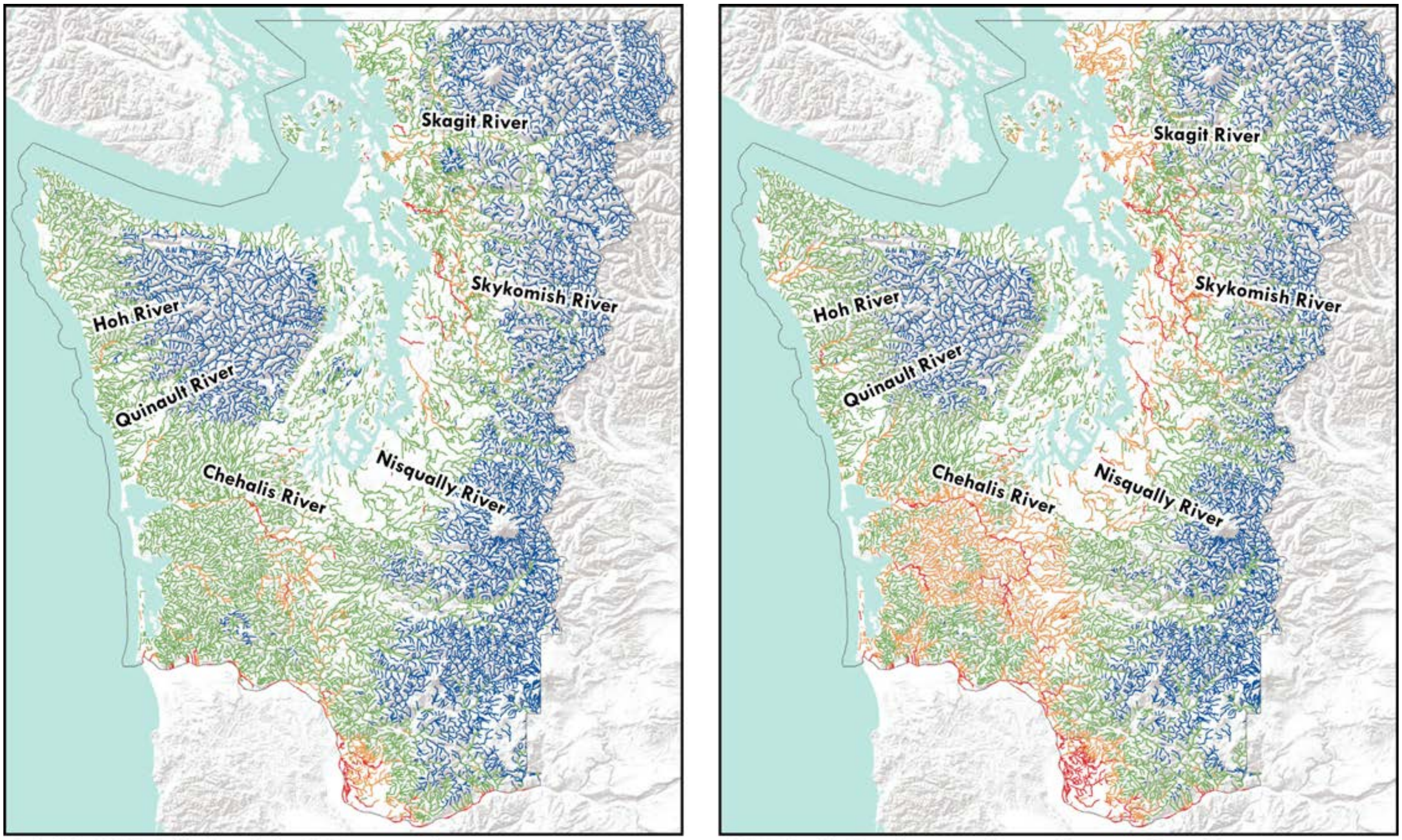
In forested watersheds, many processes influence streamflow and water quality. Forests and vegetation cover especially influence the retention and movement of water across watersheds. For example, tree canopies intercept rainfall which reduces the amount of water that reaches the ground. Trees also encourage precipitation infiltration by slowing runoff across the watershed. Healthy, well-managed forests can improve water quality and water storage, increase low flows in summer, reduce high flows in winter, and contribute to recharge of groundwater.

Wildlife Habitat

In a warmer climate, some animal species may move to areas with more suitable climate and habitat. Improving the quantity, quality, and connectivity of forest and riparian habitats can help wildlife populations persist and potentially migrate to other locations. Forest structure—including tree density, forest-stand age, and the presence of downed and standing dead trees—influences habitat suitability for many animal species. Managing forest structure to improve food availability (e.g., understory plants such as huckleberries) and cover (e.g., high tree crowns) can improve habitat quality. Vegetation that produces fleshy fruits is particularly important for birds and small mammals. Structural features (e.g., downed and standing dead trees) provide wildlife with resting locations, protection from weather exposure, and protection from predators.

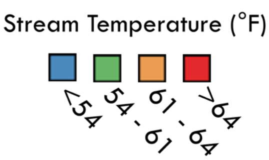
Fish and Aquatic Habitat

Managing your forest for climate resilience can contribute to high-quality habitat for fish and other aquatic species, some of which are expected to be stressed in a warmer climate. Trees and other vegetation along streams offer high-quality habitat for salmon and trout by shading streams and keeping water temperatures cool. Vegetation along river banks reduces sediment erosion into the water, which maintains water quality and prevents the smothering of salmon eggs. Fallen trees in streams can slow water flow, creating pools where salmon can rest and avoid predation. Maintaining and restoring riparian vegetation help to keep stream temperatures from exceeding tolerance levels for salmon and trout.



1993-2011 | Modeled Historical

2040s | Moderate Greenhouse Gas Scenario



Low- to mid-elevation stream temperatures are projected to increase in western Washington by mid-century. These maps show modeled historical (1993-2011) and projected August stream temperatures for the 2040s (2030-2059) under a moderate (A1B) greenhouse gas scenario. The coolest streams are shown in blue and green, and the warmest streams are shown in orange and red. Data source: NorWeST Stream Temperature.

Management Options | Water Resources

- Tolerate or welcome beaver activity on your property.
- Where possible, preserve older trees in your forest, because they grow more slowly than younger forests and use less water.[15]

Management Options | Wildlife Habitat

- Increase the diversity of native tree species, especially those that are tolerant of low soil moisture. This can include both hardwood and conifer species.
- Protect and create key forest structures (e.g., standing dead trees, downed logs, old trees) that are important habitat features for multiple wildlife species.
- Thin overly dense forests to create openings that facilitate understory plant establishment and increase food sources for wildlife.

Management Options | Aquatic Habitat

- Plant trees adjacent to stream banks to provide shade and keep the water cool. Trees also help reduce erosion into streams.
- Learn to identify non-native/invasive fish species that can negatively affect freshwater ecosystems (e.g., brook trout), and monitor for their presence.
- Keep livestock away from riparian areas near streams.

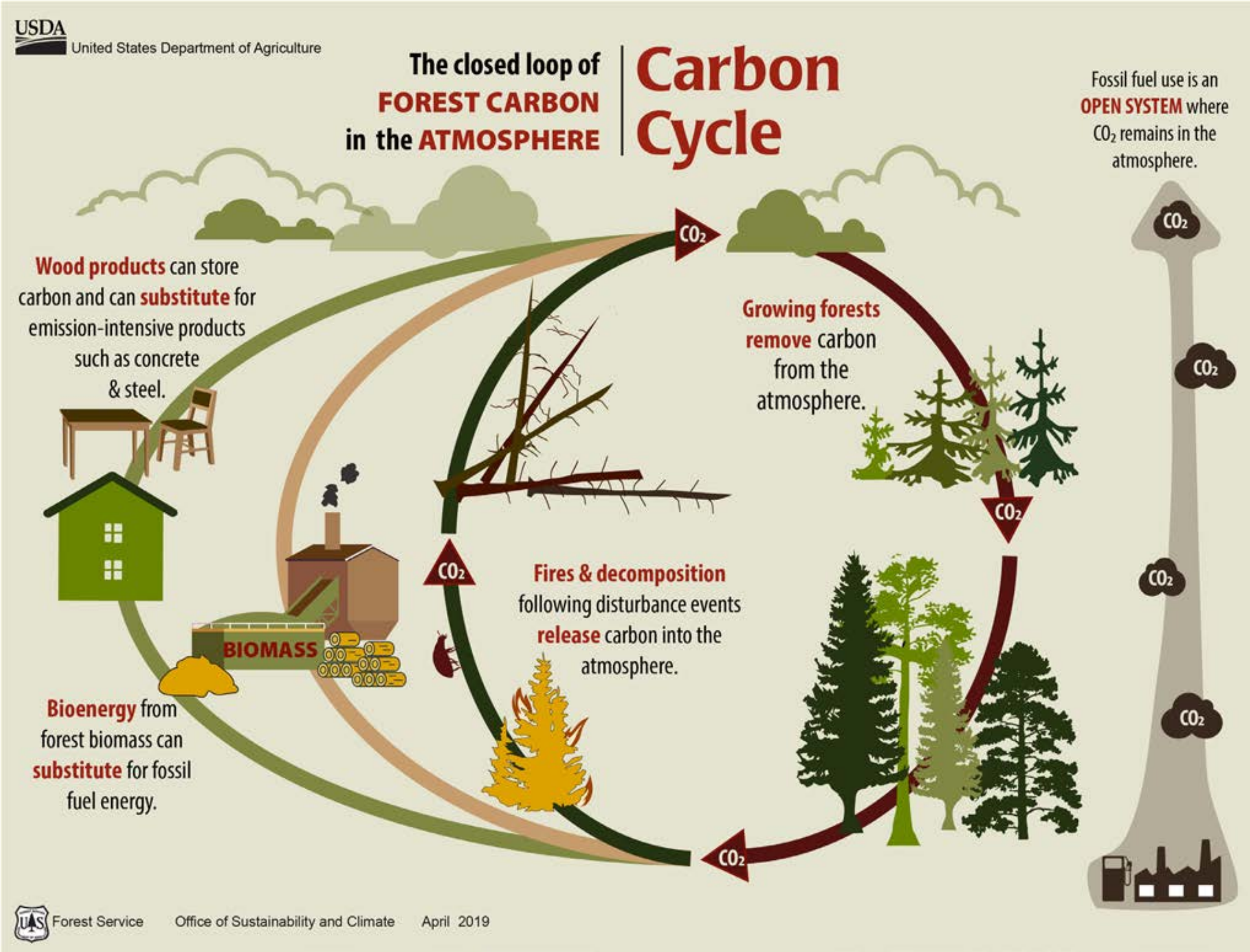
THE FOREST CARBON CYCLE

Carbon dioxide is one of the most abundant greenhouse gases in the atmosphere and is a major contributor to climate change.

Carbon dioxide is emitted by the burning of fossil fuels, but it is also both emitted by and stored in forests. Forest management actions can increase the amount of carbon that is released from the forest or contribute to more carbon storage. In addition to increasing the resilience of your forest to climate change with the actions in this guide, you can implement practices that remove carbon dioxide from the atmosphere and store it as organic carbon. Your forest can help reduce emissions of carbon dioxide that cause climate change.

The ongoing storage and release of carbon in forests is a natural cycle. Trees and other forest vegetation store carbon. As plants die, carbon is also stored in the forest floor and soil. Carbon is released from the forest when plant material decomposes or when trees and other organic material burn.

Carbon can also be released when timber is removed, although the amount and timing of that release depend on the life cycle of timber products. Some is released immediately through the process of converting trees to other materials. Some is stored in forest products such as wood used to build houses. When wood products are substituted for more carbon-intensive building materials such as steel and concrete, they further reduce the release of carbon dioxide.



Management Options

Some forest management actions can increase the carbon stored by your forest.

- Keep forest land covered by forests. Minimize converting land to agriculture or clearing land for development. This is the most effective way to store carbon over the long term.
- Maintain healthy forests to store more carbon over time. Some actions to adapt your forest to a changing climate, such as thinning, may require removing carbon in the short term. However, in the long term, a healthy forest ecosystem will store more carbon than one suffering from stress due to low soil moisture or impacts from insects and diseases.
- Plant trees to increase carbon storage. Fast-growing young trees have a high rate of carbon dioxide uptake from the atmosphere.

When planting, tree species and density should reflect other considerations in this guide for maintaining forests that are resilient to climate change (see Table of Tree Species, pg. 27). Avoid planting trees not well adapted to the future climate, or at densities higher than can be supported by available soil moisture; this will result in only short-term carbon storage.

Managing for carbon in your forest requires consideration of many aspects of forest management. Planting, thinning, harvesting, and other activities may be implemented to accomplish other objectives such as improving wildlife habitat and reducing fire risk. Each activity has different carbon gains and losses at different time scales, so trade-offs need to be considered when managing for multiple objectives.

LEARN, PLAN, MONITOR, COLLABORATE

The management actions described in the sections above increase forest resilience to climate change by taking action "on the ground." Additional actions involve education, monitoring and record keeping, planning, and collaboration with neighboring landowners and public agencies; these actions also increase your ability to improve forest resilience in a changing climate.

Learn

Getting to know your forest in detail provides a foundation for successful forest management. Not all actions are right for all forests, and the better you know your forest, the more you will be able to select appropriate actions to increase climate resilience. Here are some important learning objectives:

- Learn to identify common tree and plant species in your forest.
- Learn to identify soil characteristics and understand the geographic setting of your forest.
- Learn to identify common insects and forest diseases and their effects on trees and other vegetation.
- Learn to identify common invasive species that can have negative consequences for native species.
- Maintain awareness of changing fire season conditions. The Wildland Fire Potential Outlook for western Washington provides information on wildfire risk in a particular year. Elevated fire potential may lead to burn bans and a shorter season for forest management activities, such as burning or using chainsaws.

Monitor and Keep Records

- A forest inventory of your land will provide a starting point from which to monitor, plan, and prepare for climate impacts as they emerge.
- Monitor for tree mortality to identify emerging stressors such as the presence of new insects or diseases.
- Maintain a list of non-native or invasive plant and aquatic species on your property.

Plan

- Develop a forest stewardship plan that describes management objectives for your forest, including many of the actions listed in this guide. Consider how climate change may affect those objectives. How far into the future are you planning? Are you planning for multiple generations?
- Include in your planning some actions you would consider after a wildfire or other major disturbance. Will you plant trees? If so, which species and seed sources, and where would you get seedlings?

Collaborate

- Connect with other forest owners, Washington State University Extension Forestry staff, and others to identify nurseries and find sources of seeds and seedlings from alternative seed zones that can be used for assisted migration.
- Reach out to Washington Dept. of Natural Resources stewardship foresters who can help you achieve your management goals and sustainably manage your forest.
- Determine if there is a Fire Adapted Community in your area. Fire Adapted Community networks offer an opportunity to coordinate with your neighbors on fire risk reduction and response planning.
- Engage in partnerships with organizations that can help identify current and potential carbon storage in your forest.
- Coordinate with adjacent landowners and agencies to maintain and restore beaver habitat and populations.

REFERENCES

1. Rabotyagov, S., et al. 2021. Washington's small forest landowners in 2020: status, trends, and recommendations after 20 years of forests and fish. School of Environmental and Forest Sciences, University of Washington, Seattle.
2. Mauger, G.S., et al. 2015. State of knowledge: Climate change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle.
3. Mote, P. W., et al. 2018. Dramatic declines in snowpack in the western US. npj Climate and Atmospheric Science 1:1–6.
4. Stewart, I.T., et al. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate 18:1136–1155.
5. Snover, A.K., et al. 2013. Climate change impacts and adaptation in Washington state: Technical summaries for decision makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle.
6. Littell, J.S., et al. 2008. Douglas-fir growth in mountain ecosystems: Water limits tree growth from stand to region. Ecological Monographs 78:349–368.
7. Warner, M. D., et al. 2015. Changes in winter atmospheric rivers along the North American West Coast in CMIP5 climate models. Journal of Hydrometeorology 16:118–128.
8. Hamlet, A. F., et al. 2013. An overview of the Columbia Basin climate change scenarios project: Approach, methods, and summary of key results. Atmosphere-Ocean 51:392–415.
9. Halofsky, J. E., and D. L. Peterson. 2016. Climate change vulnerabilities and adaptation options for forest vegetation management in the northwestern USA. Atmosphere 7:46.
10. Littell, J.S., et al. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102:129–158.
11. Reilly, M. J., et al. 2021. Fire ecology and management in Pacific Northwest forests. Pages 393–435 in C. H. Greenberg and B. Collins, editors. Fire Ecology and Management: Past, Present, and Future of US Forested Ecosystems. Springer International Publishing, Cham.
12. Gervais, J. A., et al. 2020. Climate-induced expansions of invasive species in the Pacific Northwest, North America: A synthesis of observations and projections. Biological Invasions 22:2163–2183.
13. Kliejunas, J.T., et al. 2009. Review of literature on climate change and forest diseases of western North America. General Technical Report PSW-GTR-225. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 54 p.
14. Agne, M.C., et al. 2018. Interactions of predominant insects and diseases with climate change in Douglas-fir forests of western Oregon and Washington, U.S.A. Forest Ecology and Management 409:317–332.
15. Perry, T.D., and J. A. Jones. 2017. Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA. Ecohydrology 10:e1790.

The management options for climate resilience described in this guide are documented in several USDA Forest Service publications and the scientific literature. Sources and references for specific management actions can be found on the Adaptation Partners website http://adaptationpartners.org/library.php.

Common Name	Scientific Name
Alaska yellow cedar	*Callitropsis nootkatensis*
Armillaria root disease	*Armillaria* spp.
Balsam woolly adelgid	*Adelges piceae*
Bigleaf maple	*Acer macrophyllum*
Bitter cherry	*Prunus emarginata*
Black cottonwood	*Populus trichocarpa*
Black hawthorn	*Crataegus douglasii*
Butterfly bush	*Buddleja davidii*
Cascara	*Rhamnus purshiana*
Douglas-fir	*Pseudotsuga menziesii* var. *menziesii*
Douglas-fir beetle	*Dendroctonus pseudotsugae*
Engelmann spruce	*Picea engelmannii*
Grand fir	*Abies grandis*
Laminated root rot	*Phellinus weirii*
Lodgepole pine	*Pinus contorta* var. *latifolia*
Lymantria dispar (previously gypsy moth)	*Lymantria dispar*
Mountain hemlock	*Tsuga mertensiana*
Noble fir	*Abies procera*
Oregon ash	*Fraxinus latifolia*
Oregon white oak	*Quercus garryana*
Pacific crabapple	*Malus fusca*
Pacific dogwood	*Cornus nuttallii*
Pacific madrone	*Arbutus menziesii*
Pacific silver fir	*Abies amabilis*
Pacific yew	*Taxus brevifolia*
Paper birch	*Betula papyrifera*
Ponderosa pine	*Pinus ponderosa*
Quaking aspen	*Populus tremuloides*
Red alder	*Alnus rubra*
Rocky Mountain maple	*Acer glabrum*
Saltcedar	*Tamarix* spp.
Scotch broom	*Cytisus scoparius*
Shore pine	*Pinus contorta* var. *contorta*
Sitka spruce	*Picea sitchensis*
Spotted knapweed	*Centaurea stoebe*
Subalpine fir	*Abies lasiocarpa*
Sudden oak death	*Phytophthora ramorum*
Swiss needle cast	*Phaeocryptopus gaeumannii*
Vine maple	*Acer circinatum*
Western hemlock	*Tsuga heterophylla*
Western redcedar	*Thuja plicata*
Western white pine	*Pinus monticola*
Willow (Pacific, Scouler's, Sitka)	*Salix lucida* var. *lasiandra* (Pacific) *Salix scouleriana* (Scouler's) *Salix sitchensis* (Sitka)

TABLE OF TREE SPECIES

This table describes tree species that you may either now have in your forest or wish to plant; included is their relative tolerance for low soil moisture and for shade (i.e., whether they grow in openings or closed forests). The management considerations can help determine which species are compatible with your current forest species and climate, as well as which species may be good candidates for assisted migration as the climate changes.

Species	Tolerance of low soil moisture	Shade tolerance	Management considerations
Low-elevation conifers			
Douglas-fir	Moderate-high; forms a deep taproot in coarse-textured soils	Low-moderate	A resilient tree in a warmer climate. Plant only if plenty of light is available. Laminated root rot is a problem in many areas, but it is unclear if it will be affected by a warmer climate. Susceptibility to Douglas-fir beetles may increase in a warmer climate.
Grand fir	Moderate	High	A good tree for diversifying conifer forests. Can be underplanted in existing stands and may be preferred over western redcedar on drier sites. Balsam woolly adelgid may be a problem in some areas, especially as the climate gets warmer.
Pacific yew	Moderate	High	Can be underplanted in existing stands to provide a multi-storied canopy. Plant only in moist soils, particularly in drainages and on north aspects.
Ponderosa pine	High; a deep taproot in older trees makes it both drought tolerant and wind tolerant	Low	Native in the southern Puget Trough lowlands. Plant only if plenty of light is available. Resistant to fire. Susceptible to several insects, pathogens, and dwarf mistletoe on the east side; it is unclear if these will be problems if ponderosa pine is widely planted on the west side.
Shore pine	High; tolerates wet soils	Low	A good tree for providing low to mid-level structure in soils that will not support other conifers. It will not compete well with faster growing conifers and species such as willows.
Sitka spruce	Low	High	Typically grows in wet conifer forests. It may be appropriate to plant in riparian areas, in drainages, and on north slopes, but not on well-drained soils. Susceptible to Sitka spruce weevil; plant in partial (not deep) shade to discourage the weevil.
Western hemlock	Low	High	Although it often germinates in the understory, it can be planted on north aspects and in drainages to provide species diversity and a multi-storied canopy. Susceptible to several pathogens, but it is unclear if they will be affected by a warmer climate. Can grow slowly in the understory for decades.
Western redcedar	Low-moderate	High	Can be underplanted in conifer or hardwood stands in drainages, on north and east aspects, and somewhat poorly drained soils that retain moisture (but not with standing water). Resistant to most insects and pathogens.
Western white pine	Moderate	Low-moderate	A good tree for diversifying some westside forests. Plant only if plenty of light is available. White pine blister rust is a serious concern for this species, so it should be planted only in areas where no currants (*Ribes*) are present; use rust-resistant nursery stock if possible.

Species	Tolerance of low soil moisture	Shade tolerance	Management considerations
Mid-high elevation conifers			
Alaska yellow cedar	Moderate	High	Mid- to high-elevation tree, rarely the dominant species with other conifers. Few problems with insects and pathogens. Areas with declining snowpack may be susceptible to root freezing.
Engelmann spruce	Moderate	High	Mid- to high-elevation tree, often associated with subalpine fir. Susceptible to spruce beetles, especially in older, dense stands.
Lodgepole pine	Moderate; tolerant of shallow or rocky soils	Low	Mid- to high-elevation tree. Plant only if plenty of light is available. Susceptible to mountain pine beetles during drought periods when trees are stressed.
Mountain hemlock	Low	High	High-elevation tree, especially in high-snow areas. Can grow slowly in the understory for decades. Can spread by branch layering.
Noble fir	Low	Low-moderate	Mid-elevation tree, often associated with Pacific silver fir and mountain hemlock; Snoqualmie Pass is the northern extent of its distribution. Susceptible to foliar pathogens if grown in monocultures as Christmas trees.
Pacific silver fir	Low	High	Mid- to high-elevation tree, especially in high-snow areas. Can grow slowly in the understory for decades.
Subalpine fir	Moderate	High	High-elevation tree, especially in high-snow areas, and in drainages at mid elevation. Often associated with lodgepole pine and Engelmann spruce. Can spread by branch layering.
Hardwoods			
Bigleaf maple	Moderate	Moderate-high	Long-lived tree that occupies a variety of sites. Fast juvenile growth. Not typically susceptible to insects and disease. Recent dieback in some areas appears to be related to hot, dry summers.
Bitter cherry	Low	Low-moderate	Short-lived tree in young stands, often growing vigorously after timber harvest.
Black cottonwood	Low; tolerates wet soil, flooding, and sediment deposition	Low	Generally grows only in wet soils and riparian areas. Mature trees are tall with large crowns, often outcompeting other hardwoods.
Black hawthorn	Moderate; tolerates wet soils	Moderate	Small tree generally found in or near wetlands. Provides diversity and food for wildlife.
Cascara	Moderate	High	Small to medium-sized tree typically found in the understory of conifer forests. Can be underplanted in existing stands to provide a multi-storied canopy and berries for wildlife.
Oregon ash	Low	Moderate	Southwest Washington is the northern extent of this medium-sized tree, which is typically found in wet soils and riparian areas. Will be susceptible to emerald ash borer if this insect reaches the West Coast.
Oregon white oak	High	Low-moderate	Medium-sized tree typically found in drier soils where it competes well with other tree species. Juvenile growth is slow. Fire resistant. Provides acorns for wildlife. Sudden oak death may be a concern in the future.

Species	Tolerance of low soil moisture	Shade tolerance	Management considerations
Pacific crabapple	Moderate; tolerates wet soils and flooding	Moderate	Small, slow-growing, shrubby tree mostly found near wetlands. Can be planted with other conifers or hardwoods to provide diversity and a multi-storied canopy.
Pacific dogwood	Moderate	High	Widespread but uncommon, this medium-sized tree provides beauty in the forest understory. Can be planted with or under conifers to provide diversity and a multi-storied canopy. Susceptible to anthracnose, which is often fatal to seedlings.
Pacific madrone	High	Moderate	Medium-sized evergreen tree typically found in drier areas. Although drought tolerant, survival and vigor of seedlings can be low. Mature trees are susceptible to several fungal pathogens.
Paper birch	Moderate	Low	Northern Washington is the southern extent of his medium-sized tree. It is typically short-lived and susceptible to several insects. Planting south of its current distribution is not advised.
Quaking aspen	Moderate; grows in a variety of soils	Low	Tall, fast-growing tree that is sparsely distributed in western Washington. Small stands can provide diversity interspersed with conifer forests. Susceptible to several insects and pathogens.
Red alder	Moderate; grows in wet alluvial soils and disturbed upland sites	Low	Fast-growing tree in riparian areas and disturbed sites. Valuable timber species if it has good growth form. Fixes nitrogen. In anticipation of stand mortality (around 60 years old), can underplant with shade-tolerant species or harvest and plant another species.
Rocky Mountain maple	Moderate	Moderate	A small tree that can be planted with other conifers or hardwoods to provide diversity and a multi-storied canopy.
Vine maple	Low-moderate	High	Small, often sprawling understory tree. Can be planted in the understory of conifer forest to provide a multi-storied canopy.Small to medium-sized trees typically found in riparian areas and wetlands.
Willow (Pacific, Scouler's, Sitka)	Low-moderate; tolerates wet soils	Low-moderate	Small to medium-sized trees typically found in riparian areas and wetlands. A good tree for providing rapid shade in riparian restoration. Scouler willow tolerates dry sites better than the other willow species.

Some of the information in this table was derived from (1) Zobrist, K.W. 2014. Native Trees of Western Washington. Washington State University Press, Pullman, WA, and (2) Northwest Natural Resource Group. 2020. Climate adaptation strategies for western Washington and northwest Oregon forests. Report available at https://www.nnrg.org/climateadaptation.