Forest Carbon and Climate Program
Department of Forestry
MICHIGAN STATE UNIVERSITY

NIACS
Northern Institute of Applied Climate Science

Forest Carbon and Climate Change in the Pacific Northwest Region of the United States

This white paper summarizes topics such as forest densities and cover types, carbon storage pools, climate considerations, and adaptive management suggestions for the US Pacific Northwest region.

In collaboration with the Northern Institute of Applied Climate Science (NIACS), this summary was developed from content found in our FCCP Intensive: US Regions course on the US Pacific Northwest, available for purchase on our Professional Development Courses page. Visit our Projects + Research page to learn more about the development of this project.

Forest Carbon and Climate Change in the Pacific Northwest Region of the United States

Table of Contents

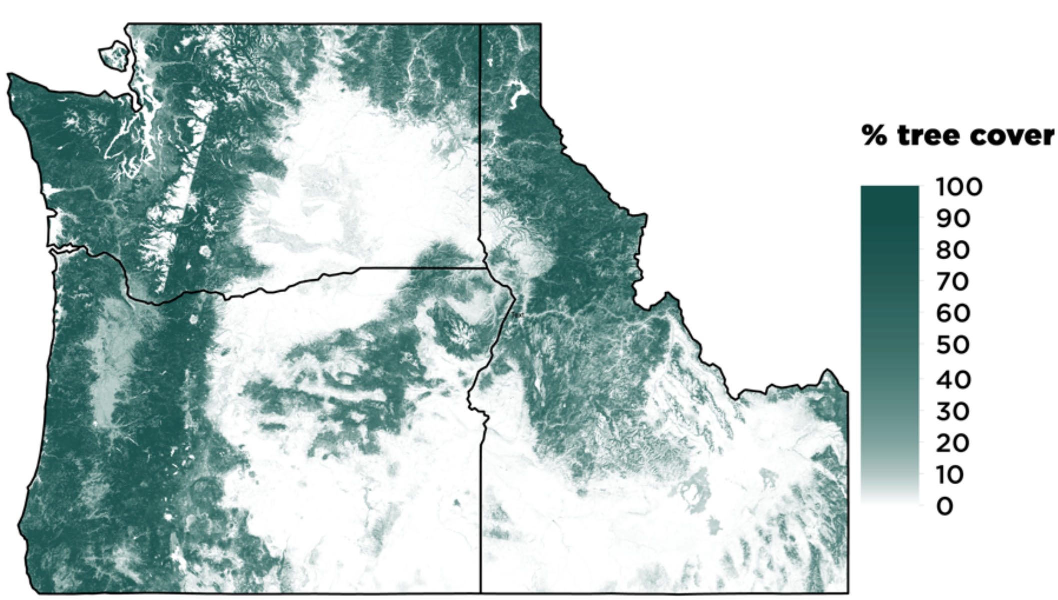
The Pacific Northwest Region Overview

For the purposes of this document, the Pacific Northwest region of the United States (US PNW) includes Idaho, Oregon, and Washington. The region is often split into two major climatic zones—dry to the east of the Cascade Range and wet to the west. While this is a generalization, it can be a useful distinction for landscape-scale forest management and protection. One key exception to note is southwestern Oregon, which tends to have a much drier climate than the areas that surround it.

A map of percent of tree canopy cover across the US PNW, can be seen in **Figure 1.** As this map demonstrates, forest cover is generally highest on the wetter western side of the region but is also dense in the Northern Rocky Mountains of Idaho and in the dry southwest pocket of Oregon mentioned previously. This illustrates the fact that forest cover is influenced by many factors beyond how wet or dry the local climate is.

Figure 1

Percent Tree Canopy Cover in the Pacific Northwest Region of the United States

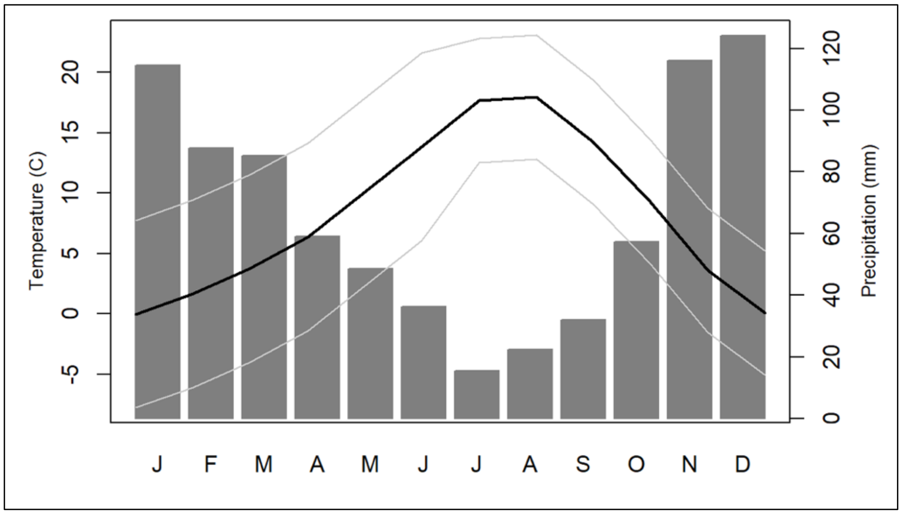


Data Source: Sexton et al, 2013
30m resolution

Climate Overview

Figure 2

Average Climate in the Pacific Northwest Region of the United States from 1970–2000



Note. Grey lines represent high and low temperatures (°C) observed each day/night and black line represents the mean temperature (°C) observed for the 24-hour cycle. Bars represent observed monthly mean precipitation (mm). Created by FCCP, using data from Fick & Hijmans (2017).

Compared to other US regions, the climate of the US PNW is cooler and wetter, particularly in the central-north and inland mountainous areas. Some describe the region as having a "Mediterranean-like climate" with warmer, drier summers in the south. The drier areas, east of the Cascades and in the southwest corner of Oregon, are caused by the Cascade Range rain shadow. Most precipitation in the region occurs between October and March in the form of snowfall and snowpack, along with significant rainfall west of the Cascade Range. The warmest months are June through September **(Figure 2)**, with relatively low precipitation levels.

Temperature and Precipitation

Two major factors affecting forest carbon and productivity are regional temperature and precipitation. **Figure 3** shows normal mean temperatures throughout the US PNW between 1981 and 2010. The warmest mean temperatures, represented by zones with orange and red shading, occur primarily in the southwest corner of Oregon and in south-central Washington along the border with Oregon. The coolest regions, represented by blue shading, are found on high-altitude sites in the Rocky Mountains of central Idaho and the Cascade Mountains of northern Washington. Across the region, normal mean temperatures over this 30-year period ranged from below -5 °C to just over 12 °C.

Figure 4 shows normal mean precipitation for the same period in centimeters. Note the highest rainfall zones, represented by deep blue shading, occur on the coast and in the Cascade Mountains; and the driest zones, represented by red shading, dominate much of the region east of the Cascades. With the range of annual precipitation spanning from <25 cm to >230 cm—a nearly tenfold difference—the US PNW contains areas that are considered desert as well as areas that are considered rainforest.

Figure 3

Normal Mean Temperature (°C) from 1981–2010 in the Pacific Northwest Region of the United States

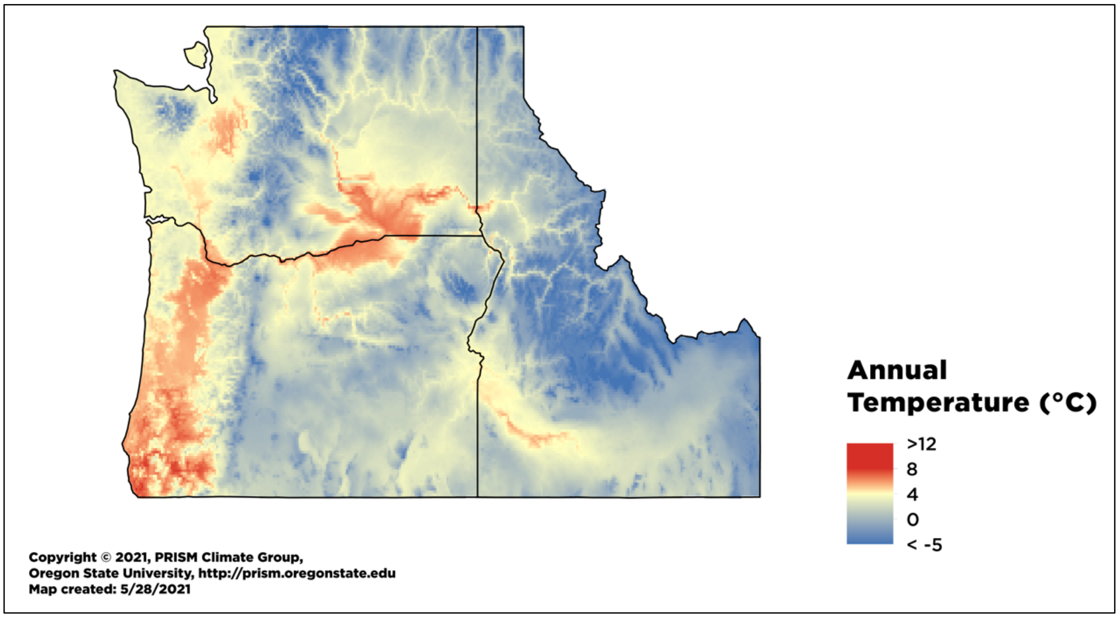
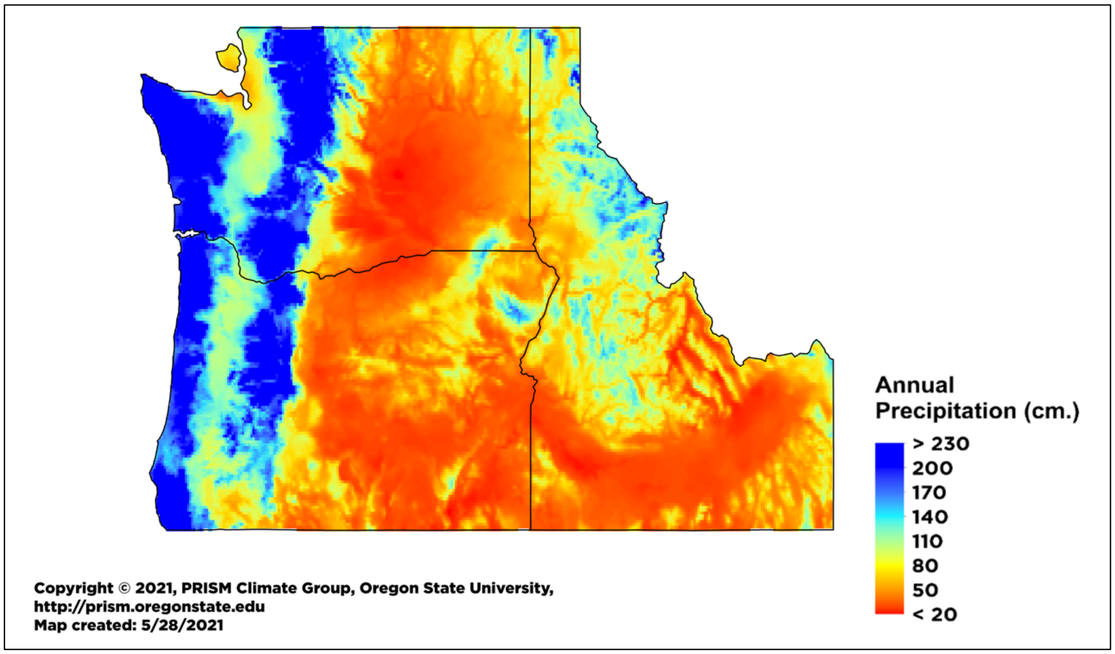


Figure 4

Normal Mean Precipitation (cm) from 1981–2010 in the Pacific Northwest Region of the United States

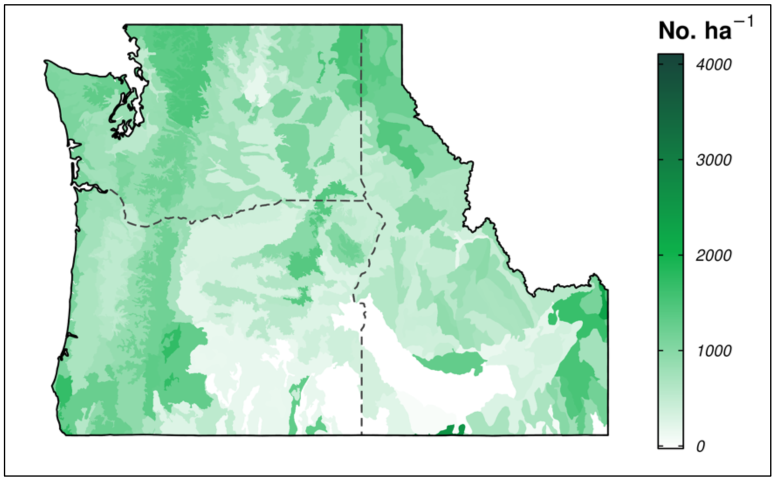


Forest Density

Forest density is both a structural characteristic of a forest and a reflection of forest dynamics. Forest density can be measured as the number of trees per unit area (i.e., trees per hectare, trees per acre, or another spatial unit; **Figure 5**). It can also be measured in terms of tree volume, expressed as basal area (**Figure 6**). Live tree basal area is the amount of ground that is covered by living trees in two-dimensional space. Forests in the western part of Washington and Oregon have the highest density in the region, as is indicated by the areas with darker green shading (Figure 5, Figure 6). Note that while the western portion of the region has a comparable number of trees to the drier eastern side (Figure 5), live tree basal area trends higher in the west, where trees typically grow larger (Figure 6), indicated by the deepest shades of green.

Figure 5

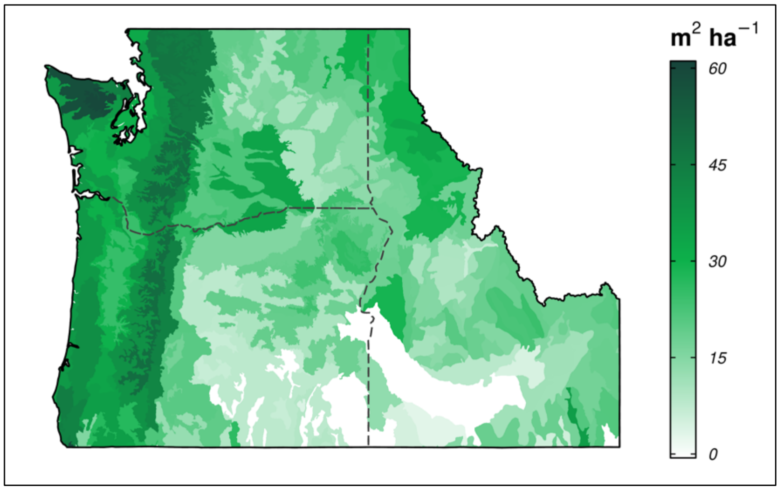
Forest Density as Live Tree Density (No. ha^{-1}) in the Pacific Northwest Region of the United States



Note. Created by FCCP, using USFS FIA data accessed 05-08-2021.

Figure 6

Forest Density as Live Tree Basal Area (m^2 ha^{-1}) in the Pacific Northwest Region of the United States



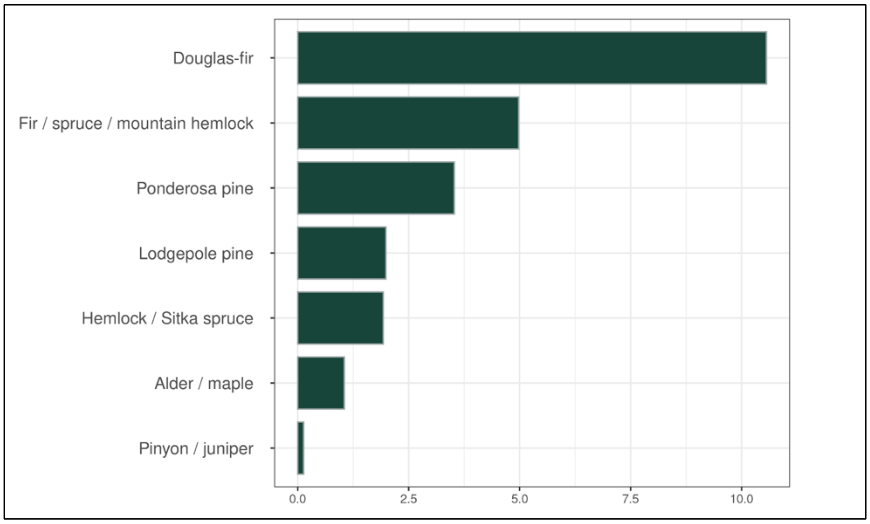
Note. Created by FCCP, using USFS FIA data accessed 05-08-2021.

Regional Cover Types

The Pacific Northwest region is dominated by seven key forest cover type groups: Douglas-fir, Fir/spruce/mountain hemlock, Ponderosa pine, Lodgepole pine, Hemlock/Sitka spruce, Alder/maple, and Pinyon/juniper. **Figure 7** and **Figure 8** show region-level data for total forested area and total forest carbon for each of the major cover types. As these figures show, the Douglas-fir group is by far the most widespread cover type and holds the most landscape-scale carbon with >2500 million tons stored regionally. By comparing the two figures, one can see that different cover types store carbon in different amounts relative to their regional extent. For example, the Lodgepole pine and Hemlock/Sitka spruce groups occupy similar regional land area—about 1.8 million hectares each (Figure 7). Yet, the Hemlock/Sitka spruce group is much more important when it comes to carbon storage, as it contains roughly three times the carbon per unit area as that of Lodgepole pine stands (Figure 8). The higher levels of carbon in Hemlock/Sitka spruce stands can be partially attributed to the high moisture levels of the sites they occupy, which are often characterized by slow decomposition rates and high accumulations of woody debris on the forest floor.

Figure 7

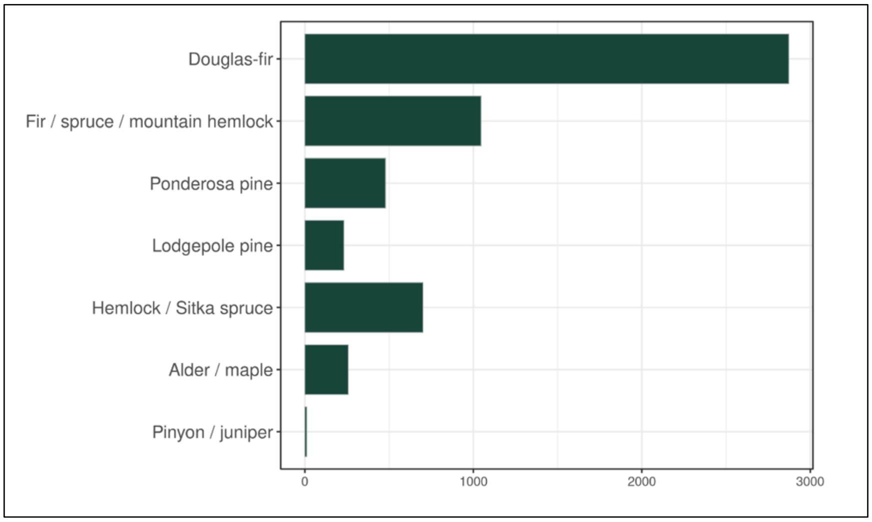
Total Forest Area (million hectares) by Forest Type in the Pacific Northwest Region of the United States



Note. Created by FCCP, using USFS FIA data accessed 05-08-2021.

Figure 8

Total Forest Carbon (million tons) by Forest Type in the Pacific Northwest Region of the United States



Note. Created by FCCP, using USFS FIA data accessed 05-08-2021.

Forest Carbon Density

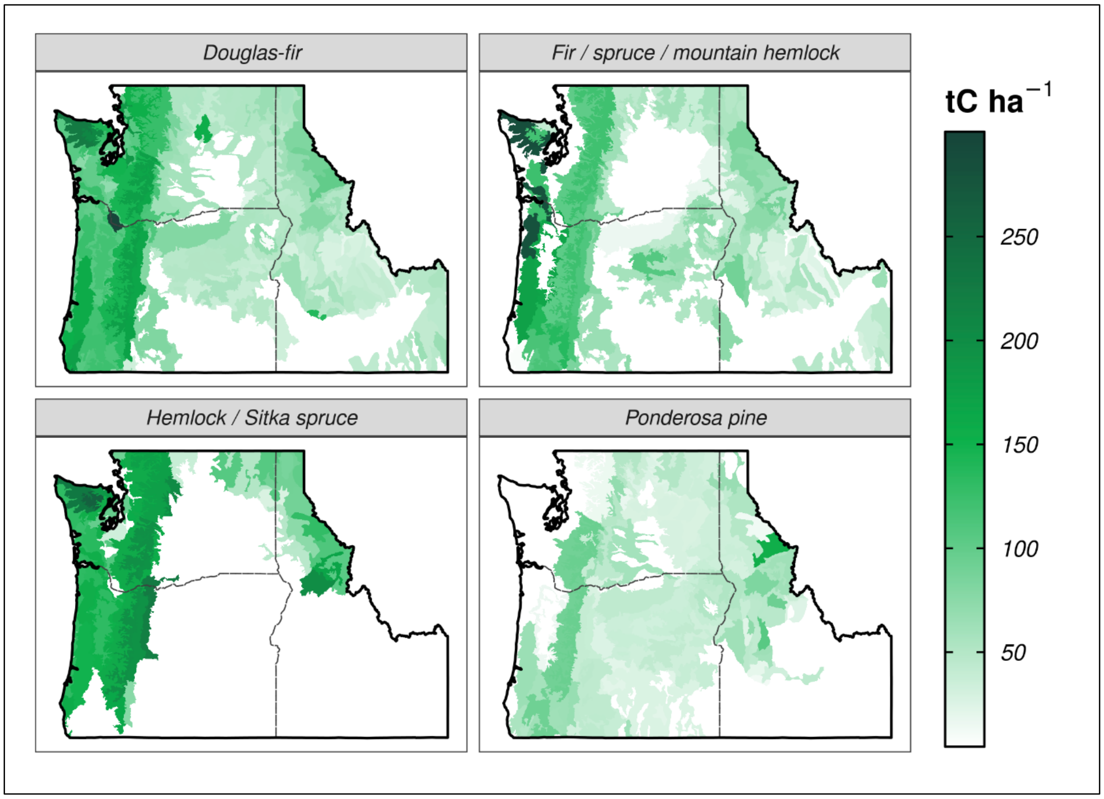
Forest carbon density can be influenced by many ecosystem traits, such as tree density, age, species mix/cover type, soils, and disturbance and management history. In **Figure 9,** the carbon density of aboveground (AG) living biomass is shown for four key cover types in the US PNW. Overall, forests found on the western side of the region have the highest carbon densities, as moist climates tend to foster dense plant growth, with larger pools of living carbon existing in trees and other plants. The Hemlock/Sitka spruce forest type, which only grows in very moist climates, has the highest carbon density per unit area (Figure 9).

This climate-driven trend is also reflected in the distribution of living aboveground carbon within the Fir/spruce/mountain hemlock group, with stands near the coast containing much higher carbon densities than their inland counterparts.

Conversely, drier forests generally hold less living carbon per unit area. This is abundantly clear when comparing Douglas-fir stands east of the Cascade Mountains with those along the coast. The Ponderosa pine cover type, whose range is largely restricted to inland dry sites, holds the least living aboveground carbon per unit area across its distribution (Figure 9).

Figure 9

Aboveground Live Forest Carbon Density (tC ha^{-1}) by Forest Type in the Pacific Northwest Region of the United States



Note. Created by FCCP, using USFS FIA data accessed 05-08-2021.

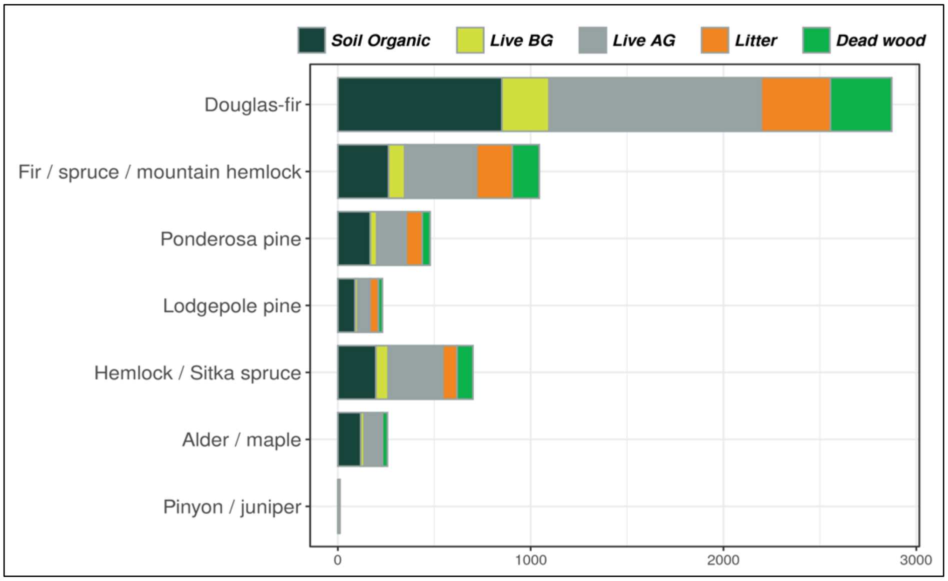
Carbon Pools by Cover Type

Within a forest ecosystem, carbon can be stored in soil organic matter; in live belowground (BG) biomass (e.g., living roots); in live aboveground (AG) biomass (e.g., living stems, branches, leaves); in litter (e.g., dead leaves, twigs on forest floor); or in dead wood (e.g., logs, branches, standing dead trees). **Figure 10** shows the total carbon stored in different carbon pools by seven key forest types in the US PNW. The regional importance of *where* carbon is stored in a forest is influenced by how different forest types allocate carbon into various carbon pools and the prevalence of those forest types on the landscape.

Traits such as species mix, stand density, and site factors drive variances in the allocation of carbon to different forest carbon pools across cover types. For instance, Alder/maple forests store similar amounts of carbon in soil organic matter and live aboveground biomass, but this is not true for forest types such as Hemlock/Sitka spruce, which store proportionally more carbon in aboveground biomass (Figure 10). Because the Douglas-fir group is so widespread, individual carbon pools of Douglas-fir forests across the US PNW are much larger and more regionally significant than pools of other groups. In fact, the dominant presence of this cover type on the landscape means that the amount of carbon stored in these forests is approximately equal to the carbon stored in all six of the other major forest types shown in Figure 10 combined. The carbon stored in Pacific Northwest Douglas-fir litter pools alone is larger than the total carbon stored by all carbon pools combined in Lodgepole pine stands across the region.

Figure 10

Total Forest Carbon (million tons) by Pool and Forest Type in the Pacific Northwest Region of the United States



Note. Created by FCCP, using USFS FIA data accessed 05-08-2021.

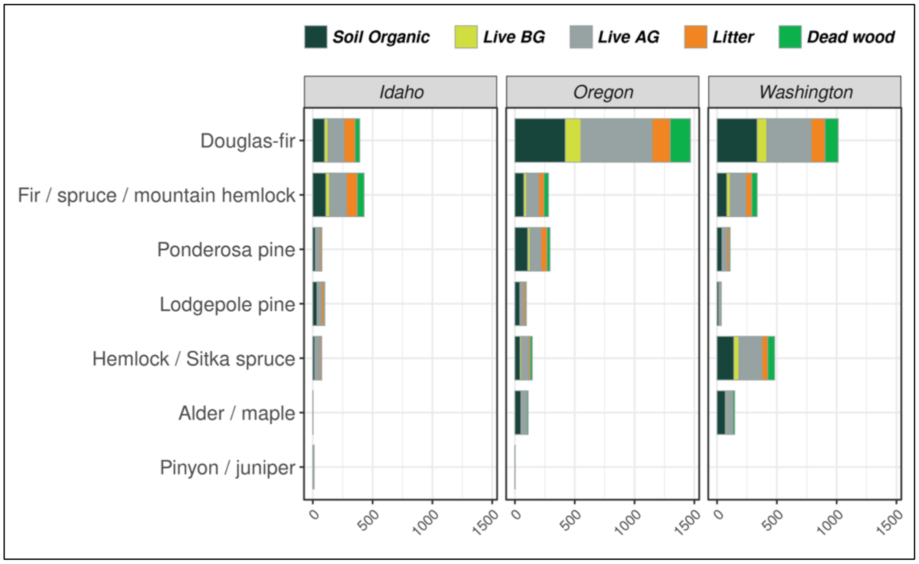
Carbon Pools by State

Forest carbon storage can be further assessed at the state-level. **Figure 11** shows the amount of carbon stored in different forest carbon pools by key cover types within Idaho, Oregon, and Washington. Variations in forest carbon allocation can be seen across cover types within a state, as well as across states within a given forest type. For instance, in Oregon and Washington, Douglas-fir forests have the largest dead wood and litter pools. Whereas in Idaho, Douglas-fir contains slightly less dead wood carbon than the Fir/spruce/mountain hemlock group. In another example, moist climates in parts of Oregon and Washington support the development of large belowground carbon pools, which are important for long-term storage. Moist soils contain less oxygen, leading to slower decomposition rates. Therefore, pools of soil organic carbon in Oregon and Washington tend to be more significant across cover types than they are in Idaho (Figure 11). These belowground pools are important for long-term ecosystem carbon retention.

Variations in carbon storage within a forest cover type across states can be important to note as well. Recall from **Figure 8** that Ponderosa pine forests rank fourth in terms of carbon storage at a region level. Yet, at the state-level, carbon storage by this cover type is highly important in Oregon, where Ponderosa pine stands hold roughly the same total carbon as Fir/spruce/mountain hemlock stands (Figure 11). Similarly, Figure 11 shows the relative importance of Hemlock/Sitka spruce forests to the state of Washington. These stands are so carbon-rich, that despite their lower prevalence in Idaho and Oregon, they remain regionally significant, ranking third in total forest carbon across the US PNW (Figure 8).

Figure 11

State-level Total Forest Carbon (million tons) by Pool and Forest Type in the Pacific Northwest Region of the United States



Note. Created by FCCP, using USFS FIA data accessed 05-08-2021.

Carbon Management in the Pacific Northwest

Manage for Existing Species that Tolerate Variable Moisture and Temperature

Climate change has increased year-to-year variability in both temperature and precipitation, which can result in conditions of both drought and excessive wetness across short time periods. This has important consequences for potential declines in forest health that negatively impact both productivity and carbon sequestration.

Favoring a variety of species and genotypes with a wide range of moisture and temperature tolerances may better distribute risk from drought, extreme storms, and regeneration issues, increasing the capacity of forests to sequester carbon as the climate changes. Example management actions include:

- Planting supplemental trees in understocked stands
- Protecting trees that exhibit adaptation to water stress and collecting seed from these trees for future regeneration
- Managing for drought-resistant species during regeneration
- Maintaining variability in species and forest structure

Promote Species that Tolerate Disturbance

Promoting disturbance-resilient species provides carbon benefits by reducing the risk of carbon losses to climate-related disturbances and stressors such as wildfire, drought, warming winters, insect pests, diseases, and regeneration issues. Promoting species that are well-adapted to disturbance can lead to increased survival in the face of disturbance, as well as improved regeneration and carbon recapture rates following a disturbance. Tactics for promoting disturbance-resilient species may include:

- Using prescribed fire to reduce fuel loads, invasive species, and promote fire-adapted species
- Encouraging early successional species diversity by retaining these species during pre-commercial thinning
- Creating larger openings during thinnings, and planting disturbance-adapted (e.g., drought-tolerant) species in these openings

Figure 12

Prescribed burn in the Idaho Panhandle National Forest

Note. Image from USDA Forest Service, public domain.

Promote Species and Structural Diversity

Late-successional and old-growth forests store more carbon compared to young or secondary forests. This is in large part because they have greater structural complexity, including higher densities of carbon stocks in both living and dead trees. Promoting greater species diversity provides carbon benefits by improving stand-level resilience to climate change and related disturbances. Forests with higher species diversity are less likely to suffer major losses when disturbances that target certain species or a group of species occur (e.g., species-specific insect pests or diseases). Diverse forest stands with species adapted to a variety of environmental conditions, microclimates, and stressors, are better equipped to withstand and adapt to changing conditions. Example tactics for promoting structural complexity and species diversity include:

- Utilizing variable density thinning
- Using gaps in silvicultural prescriptions and other practices that create uneven-aged conditions
- Planting microsites with diverse species mixes

- Maintaining species diversity during thinning
- Interplanting to supplement natural regeneration
- Protecting older or larger-diameter legacy trees
- Leaving greater amounts of dead wood including snags, downed logs, and coarse woody debris on-site during harvest operations

Adaptive management approaches such as these can play an important role in species persistence and colonization of new habitat as environmental conditions change. These approaches are potentially appropriate for a variety of forest cover types in the US PNW and, when implemented strategically, encourage increased forest resilience, carbon storage, and ecosystem health.

Resources & References

Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International journal of climatology*, *37*(12), 4302-4315.

Ontl, T. A., Janowiak, M. K., Swanston, C. W., Daley, J., Handler, S., Cornett, M., Hagenbuch, S., Handrick, C., Mccarthy, L., & Patch, N. (2019). Forest Management for Carbon Sequestration and Climate Adaptation. Journal of Forestry, 118(1), 86–101. https://doi.org/10.1093/jofore/fvz062

PRISM Climate Group. (n.d.). Oregon State University. Retrieved December 20, 2022, from http://prism.oregonstate.edu

Sexton, J. O., Song, X. P., Feng, M., Noojipady, P., Anand, A., Huang, C., Kim, D. H., Collins, K. M., Channan, S., DiMiceli, C., & Townshend, J. R. (2013). Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS vegetation continuous fields with lidar-based estimates of error. *International Journal of Digital Earth*, *6*(5), 427–448. https://doi.org/10.1080/17538947.2013.786146

USDA Forest Service. (n.d.). Forest Inventory and Analysis National Program. Retrieved December 20, 2022, from https://www.fia.fs.usda.gov/