Draft Assessment

Forest Plan Revision

Baseline Assessment of Carbon Stocks Report

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for:
Malheur, Umatilla, and Wallowa-Whitman National Forests

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Carbon Stocks

Introduction

Carbon storage and sequestration have become an important issue in forest and rangeland management. Increases in atmospheric carbon dioxide over the last century have been linked to rising global temperatures, resulting in climatic changes and associated effects (see the Climate Change Impacts report) for more information on these effects). Because forest and rangeland ecosystems can remove carbon dioxide from the atmosphere, they can help modulate atmospheric greenhouse gas concentrations and play an important role in regulating climate.

Policy on the role of climate change mitigation in forest management has evolved since the existing forest plans were signed and now requires consideration of this issue. The current 1990 forest plans of the Blue Mountains national forests, including amendments, did not include considerations of carbon storage or sequestration. The 2012 Planning Rule and agency directives state that the responsible official shall identify and assess available information relevant to the plan area for baseline assessment of carbon stocks[1] (36 CFR 219.6(b)(4)). A baseline assessment estimates existing carbon stocks and recent changes in carbon stocks. This assessment relies on information from a broad-scale (regional) and mid-scale (national forest) level assessment of carbon stocks for the Pacific Northwest Region (USDA Forest Service 2015) as well as national forest level assessments of carbon stock for the Malheur (McKinley et al. 2022a), Umatilla (McKinley and Halofsky 2022) and Wallowa-Whitman (McKinley et al. 2022b) National Forests.

The responsible official should use the assessment of carbon stocks to understand how:

- the plan area plays a role in sequestering and storing carbon.
- disturbances, projects, and activities influenced carbon stocks in the past and may affect them in the future; and
- where the carbon is stored, how the storage is changing, and how the storage might be influenced by management. (FSH 1909.12 Chapter 10 12.4)

Forests' role in the global carbon cycle is well described (Birdsey et al. 2006; McKinley et al. 2011; Janowiak et al. 2017). Forests play an important role in regulating the global carbon cycle by taking up (sequestering) and storing carbon (CO_2). Forests sequester CO_2 from the atmosphere through the process of photosynthesis and store this carbon in plant biomass. Over time, plant biomass carbon moves to other carbon pools in the forest and is eventually emitted back to the atmosphere through decomposition or combustion (fire).

Once carbon is sequestered, it is held in the forest as a carbon stock, the amount of carbon stored at

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[1] Carbon stocks are defined as the amount or quantity contained in the inventory of a carbon pool. A carbon pool is any natural region or zone, or any artificial holding area, containing an accumulation of carbon or carbon-bearing compounds or having the potential to accumulate such substances. Carbon pools may include live and dead above ground carbon, soil carbon including coarse roots, and harvested wood products.

any one time. Carbon is stored in different reservoirs or zones, called carbon pools. Typically, and in this assessment, forest carbon is divided into five carbon pools: live aboveground biomass, live belowground biomass, dead standing biomass or downed woody debris, forest floor, and soil. This assessment also describes carbon that is transferred off forest in harvested wood products but continues to be stored in long-lived wood products. Grasslands, wet and mesic meadows, and carbonaceous rocks also store carbon, but these have not been quantified in these national forests.

Forests are dynamic systems that naturally undergo fluctuations in carbon storage, including sequestration and release (Figure 1). Carbon accumulates, or is sequestered from the atmosphere, as forests establish and grow; it is released back to the atmosphere by respiration, decomposition of dead material, and by disturbances such as wildfire.

Current forest conditions in the Blue Mountains national forests reflect pre-Euro-American settlement patterns of natural fire and human fire use combined with recent histories of increased logging, grazing, the legacy of fire suppression, and other disturbances including invasive plant species introductions. As decades of fire suppression and climate change affect the Blue Mountains, disturbances may become more frequent, larger, or more severe, with impacts on forest recovery and carbon stability. Some stands that have experienced severe or repeated disturbances are showing difficulty recovering.

Management activities, such as timber harvests, thinning, and fuel-reduction treatments, remove carbon from forests in the short term; however, in some forest types, these management activities may help contribute to long-term resilience to uncharacteristic disturbance (see Terrestrial Ecosystems Report) and therefore increase carbon stability (Oliver et al. 2014; Coulston et al. 2023). Carbon impacts of management activities depend in part on the end use of the woody material produced during the treatment (Christensen et al. 2021; Fingerman and Carman 2021). Fuels treatments, such as pile burning and prescribed burning, emit carbon – as do harvesting, transporting, and processing wood products. The fossil fuel-related carbon emissions from harvest and transport represent a small percentage (less than 5 percent) of carbon stored in forest products overall where studied (Healey et al. 2009; Wiechmann et al. 2015), and no data exists for the local area that provides counter conclusions.

Forest management provides opportunities for maintaining or improving carbon storage and stability in some forest ecosystems through such actions as reducing the risk of uncharacteristic fire, improving resilience against disease, improving soil productivity on forest lands, and improving the integrity of forest ecosystems.

Process and Methods

Estimates of carbon stocks in the forests and harvested wood products for the National Forest System units in the Pacific Northwest Region have been compiled by national forest-level assessments for the Malheur (McKinley et al. 2022a), Umatilla (McKinley and Halofsky 2022) and Wallowa-Whitman (McKinley et al. 2022b) National Forests. These assessments were completed in 2022 with data through 2013; however, some of the data has been updated through 2020 using the same Forest Inventory and Analysis (FIA) datasets and methodologies and is available through the USDA Forest

Service Carbon Dashboard tool (USDA Forest Service Office of Sustainability and Climate - *In Review*)[2] Updated figures have been used in this report where available.

Estimates of forest carbon stocks are based on forest inventory data obtained from the FIA program. FIA is the only consistent data set across all ownerships and national forests of the United States. The official reporting tool for interpreting historical FIA data to develop timelines of carbon stock estimates is the Carbon Calculation Tool (CCT) (USDA Forest Service 2015). Currently, carbon data reported from this tool are available for the years 1990-2020. FIA data are collected in the Pacific Northwest on a return cycle of 10 years. This means that, for example, 2020 data includes plots that were visited most recently in 2011, 2012, etc., through 2019. As a consequence, very recent disturbances may not be reflected in carbon estimates provided here. Sources used in the national forests' carbon assessments for disturbance include the Forest Carbon Management Framework (ForCaMF) (Healey et al. 2014, Raymond et al. 2015, Healey et al. 2016, Birdsey et al. 2019). This report also contains estimates of the long-term relative effects of disturbance and non-disturbance factors on carbon stock change and accumulation, using the Integrated Terrestrial Ecosystem Carbon (InTEC) model for 1950 to 2011 (Chen et al. 2000; Zhang et al. 2012). These reports used FIA data in combination with validated, data-driven modeling tools to provide nationally consistent evaluations of forest carbon trends across the National Forest System.

Note that 1990 is used as the beginning year or baseline because of the consistency in FIA methods from then until now. This beginning year is not meant to imply that 1990 is a target for carbon stocks or is reflective of desired reference conditions for carbon stocks for the Blue Mountains national forests.

Scale

Data in the national forest carbon reports include some data at the scale of the Pacific Northwest Region and some at the national forest level. Data span from 1990 to 2013 in the national forest level reports (McKinley et. al. 2022a, b, McKinley and Halofsky 2022) with some updates to 2020 data where available. This assessment will discuss carbon stocks at the national forest level with some reference to the broader Pacific Northwest Region scale.

Current Forest Plan Direction

The current individual forest plans for the Malheur, Umatilla, and Wallowa-Whitman National Forests, including amendments, have no accounting for, or direction related to, carbon stocks.

Plan Direction Gaps

The existing forest plans do not explicitly address carbon stewardship, effects of management of carbon storage or sequestration, or the role of forest ecosystems in the carbon cycle. The forest plans also did not address the health and resilience of forest ecosystems that are highly departed from their

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[2] The national forest carbon reports may be updated with new editions during the course of this project's analysis. Information presented in this report reflect information as of the edition available January 2022.

natural ranges of variability, especially in concert with projected climatic changes. The long-term capacity of forest ecosystems and harvested wood products to sequester and store carbon depends on their health, resilience, adaptive capacity, and timber utilization (McKinley et al. 2011).

Management practices that move these national forests toward increased resilience, a more natural fire regime (see Terrestrial Ecosystems Report) while considering the impacts of future climate change, improving the age-class diversification of forest stands, and reducing the occurrence of high-severity, stand-replacing wildfires and other disturbances would help improve carbon stability in the national forests of the Blues Mountains over the long term. Peeler et al. (2023) identified the Blue Mountains as an opportunity hot spot for reducing wildfire-caused carbon loss (Fig. 13). This action may reduce carbon in the short term to achieve improved long-term stable carbon-storage conditions and other ecological benefits. Additional opportunities may exist for transferring wood products removed during thinning, harvests, or fuel treatments off forest to be used for wood products rather than being disposed of on site. These products would continue to store carbon or be used for bioenergy, which could offset carbon dioxide emissions derived from fossil fuels.

New Relevant Government and Agency Policy

Agency policy related to carbon assessment and stewardship evolved after the signing of the current forest plans in the Blue Mountains.

Now, in addition to the 2012 Planning Rule requiring inclusion of baseline carbon stocks, the Council on Environmental Quality (CEQ) published in 2023 the National Environmental Policy Act (NEPA) Guidance on Consideration of Greenhouse Gas (GHG) Emissions and Climate Change. The guidance includes the recommendation that agencies consider the projected GHG emissions or reductions for proposed actions and their reasonable alternatives (Section IV) and use this information to assess potential climate change effects (Section V). The CEQ guidance applies to NEPA analyses, and this report is not expected to comply with this guidance. However, information from this assessment report will eventually be used to support NEPA effects analysis of GHG emissions.

These policies set forth intend to provide information that allows for intentional and explicit decisions related to carbon stewardship. The Forest Service defines carbon stewardship as “actions informed by carbon science that provide for increased carbon uptake and storage or increased stabilization through land use and vegetation management strategies” (Janowiak et al. 2017). Thoughtful carbon stewardship seeks to optimize carbon within the context of ecosystem integrity and climate adaptation, not to maximize carbon at the expense of forest health or habitat. Carbon stewardship involves:

- The intentional analysis of the effects of management actions on carbon uptake, storage, and stability.
- Balancing carbon benefits with other ecosystem benefits.
- Considering landscape-scale ecosystem function and resilience.
- Enhancing net ecosystem carbon uptake and storage.
- Avoiding emissions from disturbance or tree mortality (carbon stabilization).

Carbon stewardship requires a broad definition because ecosystem carbon responses to land management actions may be different across site conditions and ecosystems. The following elements of carbon stewardship are described:

- **Carbon optimization:** While national forests and grasslands can play an important role in climate change mitigation through land management, balancing the numerous environmental benefits provided by healthy ecosystems is paramount to achieving our mission. Carbon stewardship aims to optimize carbon benefits on the landscape in a way that recognizes the importance of achieving other management objectives. Maximizing ecosystem carbon stocks can create undesirable tradeoffs with other environmental benefits (Littlefield and D'Amato 2022), and in some landscapes may result in lower carbon benefits where carbon stability is compromised. Maximizing carbon is therefore not necessary for, and is often counter to, achieving effective carbon stewardship.
- **Carbon stability:** Carbon stewardship actions may be in response to assessments that indicate current conditions are out of alignment with ecosystem dynamics. Projects in alignment with carbon stewardship actions may involve reducing carbon stocks to restore and maintain ecosystem conditions that reflect historical reference conditions. For example, reducing tree densities in overstocked stands will decrease carbon to lower the risk of carbon losses from mortality and wildfire. These actions can provide carbon benefits since the remaining ecosystem carbon is expected to have greater stability and a longer landscape residence time. Carbon stewardship actions that increase carbon stocks in live vegetation, dead wood, and soils, should not elevate the risk of disturbance that would cause widespread carbon emissions back to the atmosphere. Carbon stabilization refers to the reductions in the risk of either carbon emissions or reduced sequestration capacity from natural disturbance or biotic stressors resulting from carbon stewardship actions that increase the residence time of carbon in the ecosystem.
- **Climate adaptation:** Actions that provide adaptation benefits through reduced risk of unintended climate impacts can provide carbon benefits through avoided carbon emissions. Some disturbances or forest health issues may also decrease carbon uptake through plant growth. While not all adaptation-related actions provide carbon benefits, there are many actions, such as planting climate-resilient, productive species or genotypes, that address risks to ecosystem health while sustaining or improving the capacity of ecosystems to sequester carbon.
- **Time scale of carbon benefits:** Carbon benefits are not limited to immediate increases in carbon stocks, but instead may be realized over a variety of time scales and patterns. Carbon responses may even include near-term decreases in carbon stocks, whereas carbon benefits in the form of increases may take many decades to occur.

Existing Condition

Forests are an important carbon stock, according to recent estimates of net annual storage (Pan et al. 2011; USDA Forest Service 2015). Forests act as carbon sinks when they absorb more carbon than they emit, due to growing plants that remove carbon dioxide and store it (USDA 2015; Heath et al. 2011). Forest land, harvested wood products, woodlands, and urban trees, combined within the land sector, continue to represent the largest net carbon (C) sink in the United States, offsetting the equivalent of more than 12 percent of total (gross) GHG emissions in 2023 (Domke et al. 2023).

Carbon stocks are discussed and displayed below in terms of total forest ecosystem carbon, carbon-density, carbon flux, and harvested wood products (HWD) for the Pacific Northwest Region and the

Malheur, Umatilla and Wallowa-Whitman National Forests where data is available. Total forest ecosystem carbon is found in the seven pools stated below. Unit conversions are shown in Table 1 above-ground live tree,

- below-ground live tree,
- standing dead,
- understory,
- down dead wood,
- forest floor, and
- soil organic carbon.

Table 1. Carbon Units. The following table provides a crosswalk among various metric measurement units used in the assessment of carbon stocks and emissions.

Tonnes			Grams		
Multiple	Name	Symbol	Multiple	Name	Symbol
10^0	Tonne	t	10^0	Gram	g
10^3	Kilotonne	Kt	10^3	Kilogram	Kg
10^6	Megatonne, million metric tonnes	Mt, MMt	10^6	Megagram	Mg
			10^9	Gigagram	Gg
			10^{12}	Teragram	Tg

I hectare (ha) = 0.01 km2 = 2.471 acres = .00386 mi2
1 Mg carbon = 1 tonne Carbon = 1.1023 short tons (U.S.) carbon
1 General Sherman Sequoia Tree - 1,200 Mg (tonnes) carbon
1 Mg carbon mass = 1 tonne carbon mass = 3.67 tonnes CO_2 mass
A typical traditional combustion engine passenger vehicle emits about 4.6 tonnes of CO_2 a year.

Pacific Northwest Region

The Pacific Northwest Region likely increased in total forest ecosystem carbon stored on National Forest System land, from about 1,821.51±245.93 teragrams in 1990 to 2,115.14±281.62 teragrams in 2020 ((USDA Forest Service Office of Sustainability and Climate - *In Review*)). Most national forests in the Pacific Northwest Region had increasing biogenic forest carbon stocks, including the Malheur, Umatilla, and Wallowa-Whitman National Forests. Carbon density in the Pacific Northwest Region increased from 233.75 Mg/ha in 1990 to 270.78 Mg/ha in 2020.

In the dry forests east of the Cascade crest, which includes the Blue Mountains, forest structure was different from today before Euro-American settlement (see Terrestrial Ecosystems Report). However, reconstructing pre-Euro-American settlement baseline carbon stocks is difficult: “because individual large trees store much more carbon than small trees, it is not clear that current dense stands with fewer large trees store more carbon than pre-settlement era, fire-maintained forests.” (Hessburg et al. 2020).

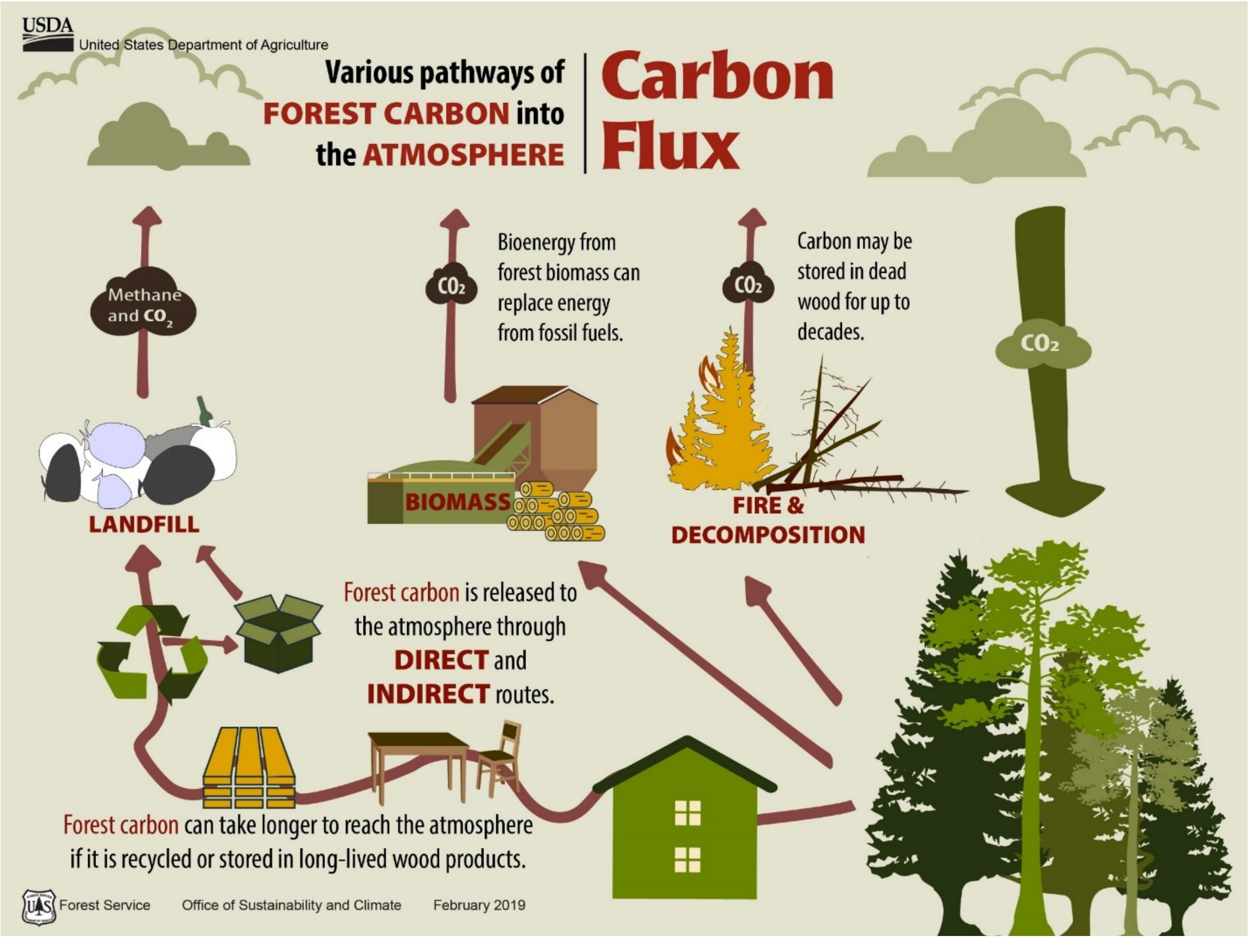


Figure 1. Pathways of Forest Carbon into the Atmosphere (USDA Forest Service Office of Sustainability and Climate 2019)

Rangelands

While there are many different definitions of rangelands, these ecosystems generally include natural grasslands, savannas, shrub lands, many deserts, tundras, alpine communities, marshes, or meadows (Reeves et al. 2018). The indigenous vegetation on these lands is predominately grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. Rangelands on these forests account for approximately 16 percent of the total area (see Rangeland Report). Most of the carbon in these systems is found belowground in soils and roots (Derner and Schuman 2007; McKinley et al. 2008; Janowiak et al. 2017). By contrast, forests typically store roughly one-half of the total carbon belowground (Domke et al. 2017). Soils generally provide a stable ecosystem carbon pool relative to other ecosystem carbon pools.

Large grazing ungulates, including domesticated livestock and bison, produce a variety of greenhouse gas (GHG) emissions.

Malheur NF

Carbon stocks in the Malheur NF increased from 70.61±8.01 teragrams of carbon (Tg C) in 1990 to 93.92±11.21 Tg C in 2020, a 33.01 percent increase in carbon stocks over this period (McKinley et al.

2022a, (USDA Forest Service Office of Sustainability and Climate - *In Review*). An estimated 57.2% of forest carbon stocks are stored in forest floor, litter, and organic soil carbon (down to 1 m, excluding roots) and 27.2% in aboveground live woody vegetation at least 1" diameter.

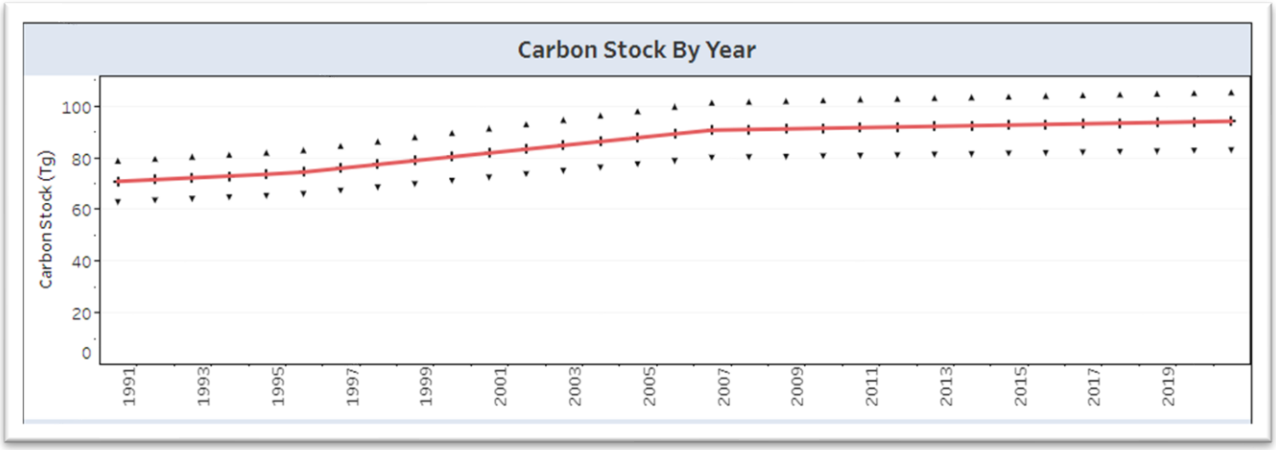


Figure 2 Total Forest carbon stocks (in teragrams) from 1990 to 2020 for Malheur National Forest, bounded by 95 percent confidence intervals. Estimates use Forest Inventory and Analysis Data and are derived from the Carbon Calculation Tool (updated in 2020 by the Northern Research Station), following methods described in Smith et al., 2007.

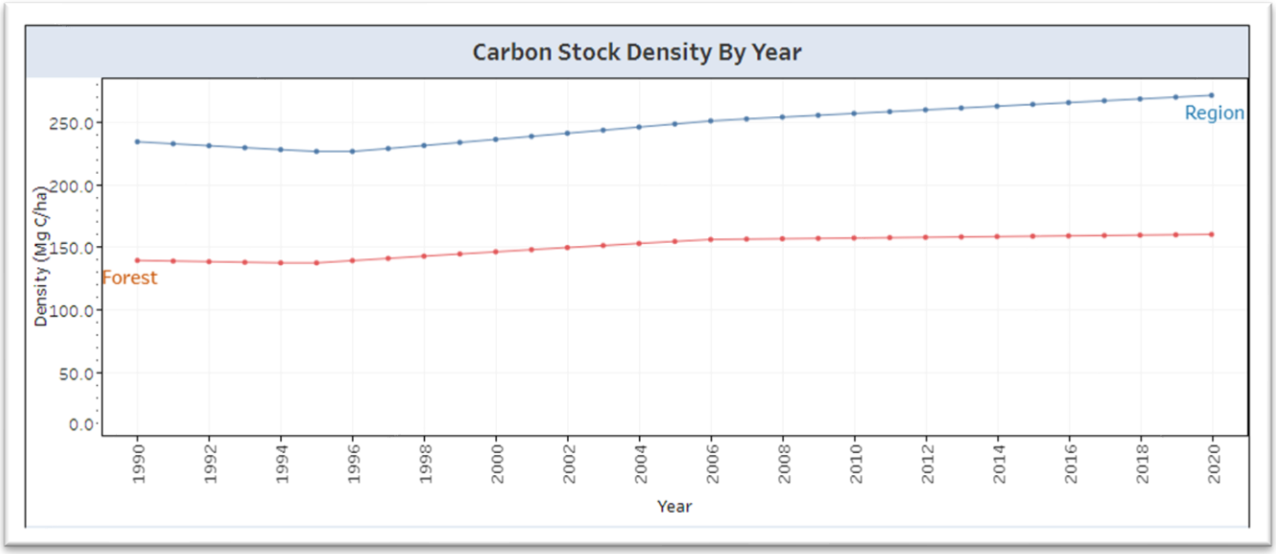


Figure 3. Average carbon stock density (in megagrams per hectare) in Malheur National Forest and for all units in the Pacific Northwest Region from 1990 to 2020. Estimates use Forest Inventory and Analysis Data and are derived from the Carbon Calculation Tool (updated in 2020 by the Northern Research Station), following methods described in Smith et al., 2007.

Umatilla NF

Carbon stocks in the Umatilla NF likely increased from 78.13±13.68 teragrams of carbon (Tg C) in 1990 to 92.78±18.88Tg C in 2020, a 18.75 percent increase in carbon stocks over this period (McKinley and Halofsky 2022, USDA Forest Service Office of Sustainability and Climate - *In Review*). An estimated 52.3% of forest carbon stocks are stored in forest floor, litter, and organic soil carbon (down to 1 m, excluding roots), and 29.6% in aboveground live woody vegetation at least 1” diameter.

In the Umatilla NF, carbon density increased from about 160.99 Megagrams of carbon (Mg C) per ha in 1990 to 189.06 Mg C per ha (76.54 Mg C per acre) in 2020. Carbon density in the Umatilla NF is lower than the average for all national forest units in the Pacific Northwest Region, which reflects the fact that the region is drier and less productive than many other areas in the region, notably areas west of the Cascades (McKinley and Halofsky 2022, USDA Forest Service Office of Sustainability and Climate - *In Review*).

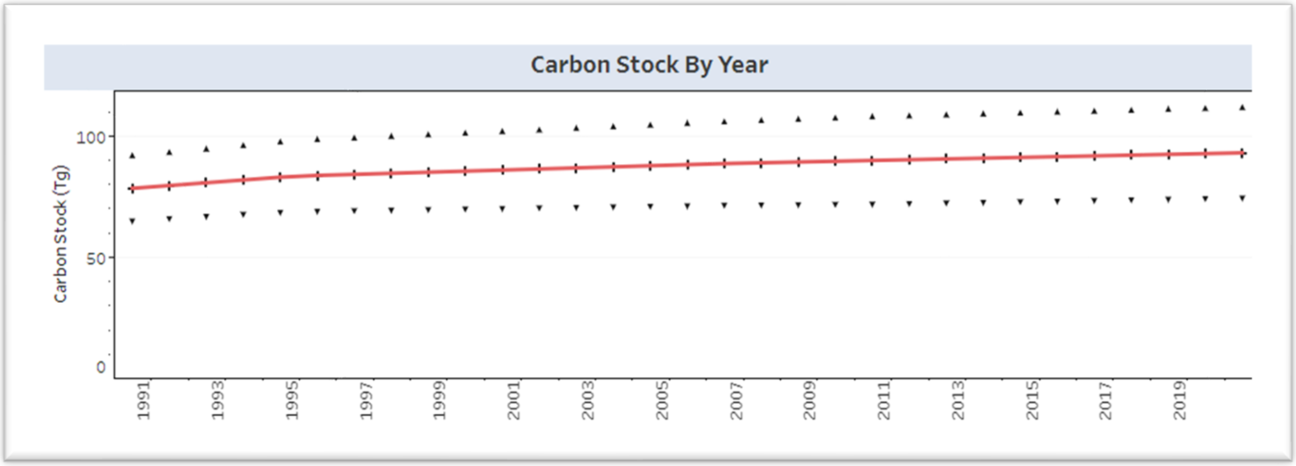


Figure 4. Total Forest carbon stocks (in teragrams) from 1990 to 2020 for Umatilla National Forest, bounded by 95 percent confidence intervals. Estimates use Forest Inventory and Analysis Data and are derived from the Carbon Calculation Tool (updated in 2020 by the Northern Research Station), following methods described in Smith et al., 2007.

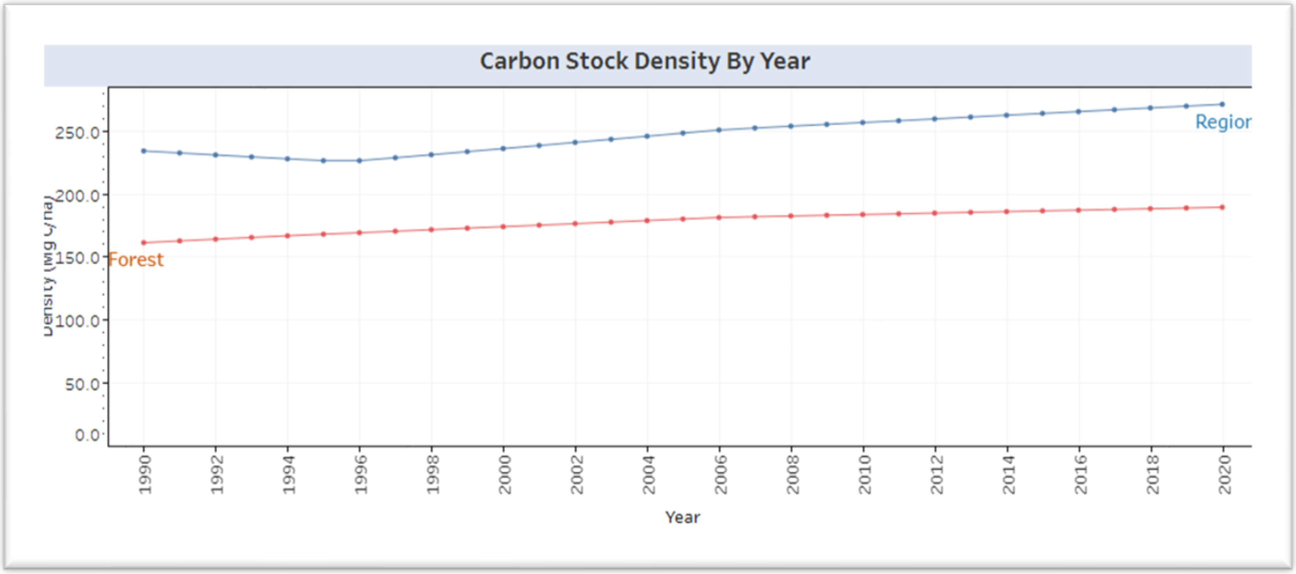


Figure 5. Average carbon stock density (in megagrams per hectare) in Umatilla National Forest and for all units in the Pacific Northwest Region from 1990 to 2020. Estimates use Forest Inventory and Analysis Data and are derived from the Carbon Calculation Tool (updated in 2020 by the Northern Research Station), following methods described in Smith et al., 2007.

Wallowa-Whitman NF

Carbon stocks in the Wallowa-Whitman NF increased from 95.49±12.77 teragrams of carbon (Tg C) in 1990 to 127.63±15.8 Tg C in 2020, a 33.65 percent increase in carbon stocks over this period (McKinley et al. 2022b, USDA Forest Service Office of Sustainability and Climate - *In Review*). An estimated 53.7% of forest carbon stocks are stored in forest floor, litter, and organic soil carbon (down to 1 m, excluding roots), and 30.3% in aboveground live woody vegetation at least 1" diameter.

In the Wallowa-Whitman NF, carbon density has remained relatively stable but increased some, ranging from about 149.48 Mg C per ha (60.52 Mg C per acre) in 1990 to 180.06 Mg C per ha in 2020. Carbon density in the Wallowa-Whitman NF is lower than the average for all national forest units in the Pacific Northwest Region. The Wallowa-Whitman NF began an accelerated reforestation program around 2020. It is possible that these efforts could impact carbon stocks and potentially result in reduced short-term carbon densities (relative to recent decades) (McKinley et al. 2022a, USDA Forest Service Office of Sustainability and Climate - *In Review*).

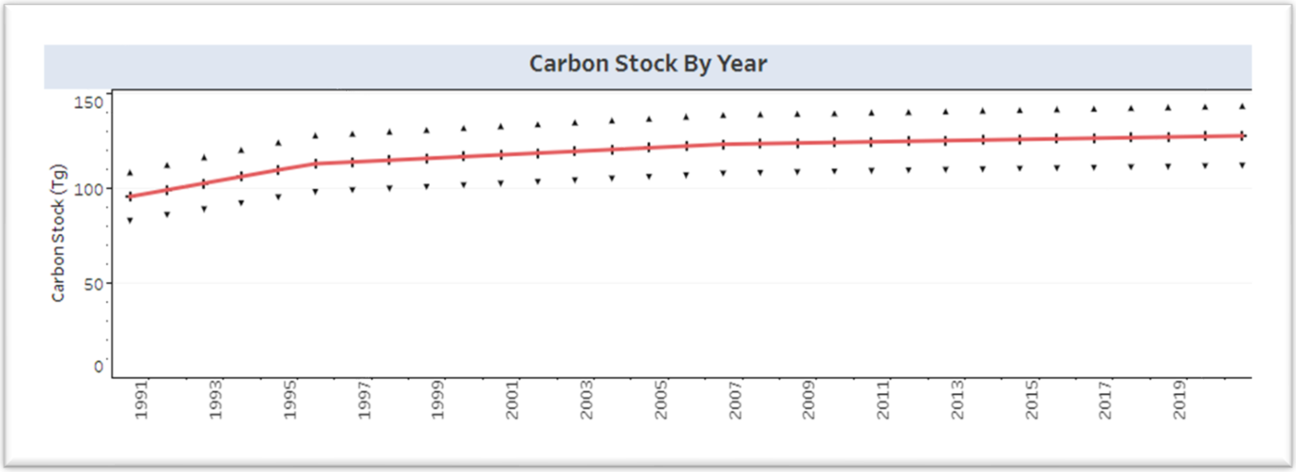


Figure 6. Total forest carbon stocks (in teragrams) from 1990 to 2020 for Wallowa-Whitman National Forests, bounded by 95 percent confidence intervals. Estimates use Forest Inventory and Analysis Data and are derived from the Carbon Calculation Tool (updated in 2020 by the Northern Research Station), following methods described in Smith et al., 2007.

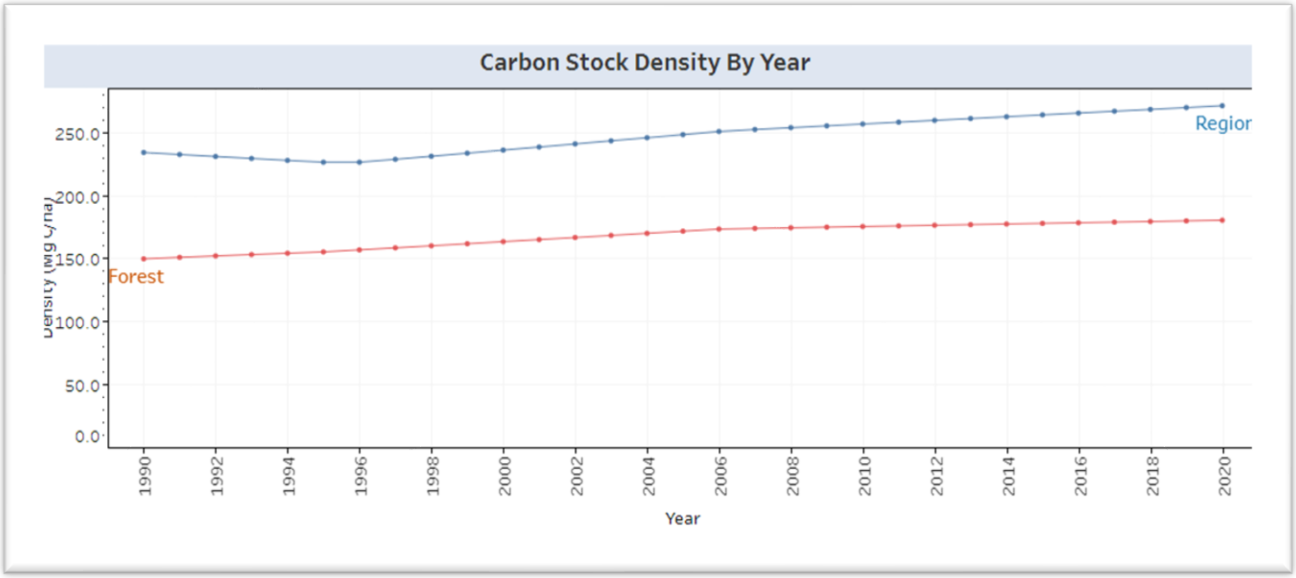


Figure 7. Average carbon stock density (in megagrams per hectare) in Wallowa-Whitman National Forests and for all units in the Pacific Northwest Region from 1990 to 2020. Estimates use Forest Inventory and Analysis Data and are derived from the Carbon Calculation Tool (updated in 2020 by the Northern Research Station), following methods described in Smith et al., 2007.

The Malheur, Umatilla and Wallowa-Whitman National Forests were carbon sinks between 1990 and 2020s.

Harvested Wood Products (HWP)

Increasing social interest in mitigating rising atmospheric carbon dioxide levels has focused attention on storage of forest carbon. Harvested wood product are an important carbon pool that is now considered in decision making associated with carbon monitoring and climate change adaptation and mitigation (Butler et al. 2014). Harvested wood products are a small fraction of the carbon pool compared to ecosystem carbon; however, they are an important component of national level carbon accounting and reporting (USDA Forest Service 2015; Butler et al. 2014). Products made from wood that are considered as harvested wood products include lumber, panels, paper, paperboard, and wood used for fuel (Butler et al. 2014). The harvested wood products pool includes both products in use and products that have been discarded to solid waste disposal sites. Regional harvest cut-and-sold reports were used to track the cycle of carbon from harvest to timber product to primary wood products to end use to disposal (USDA Forest Service 2015). Harvesting adds to the harvested wood products pool.

Starting in the 1940s, carbon stored in harvested wood products from Pacific Northwest national forests increased significantly, with a rapid increase in the 1950s through the 1990s. Carbon stored in wood products peaked in the early 1990s, with approximately 143.9 teragrams in storage (McKinley et al. 2022a, b, McKinley and Halofsky 2022). Since 1993, carbon storage in harvested wood products has decreased to 130.6 teragrams. Timber harvest declined in the mid-1990s, resulting in less harvested wood products carbon being added to this pool. It is estimated that the harvested wood products carbon stocks in the Pacific Northwest Region represent 6.4 percent of the total forest carbon storage in 2013. The Pacific Northwest Region harvested wood products pool is now in a period of negative net annual stock change because the decay of products harvested in earlier periods exceeds additions of carbon to the harvested wood products pool through harvest (Butler et al. 2014). Harvested wood products are currently not estimated for the Wallowa-Whitman, Umatilla, and Malheur National Forests individually.

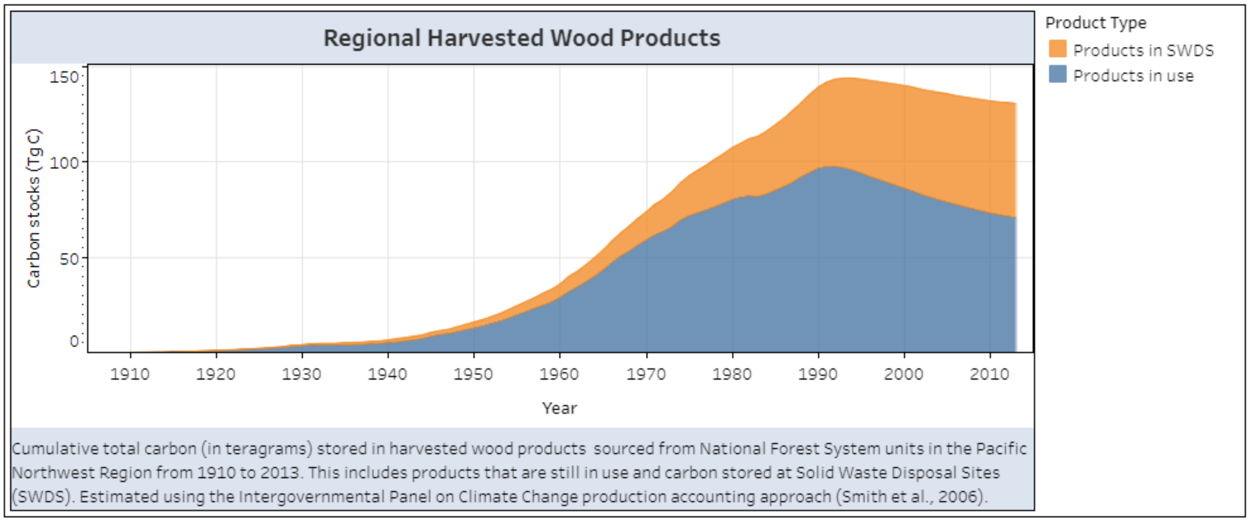


Figure 8. Cumulative total carbon (in teragrams) stored in harvested wood products sourced from National Forest System units in the Pacific Northwest Region from 1910 to 2013. This includes products that are still in use and carbon stored at Solid Waste Disposal Sites (SWDS). Estimated using the Intergovernmental Panel on Climate Change production accounting approach (Smith et al., 2006).

Contradictory Viewpoints

Large trees store and sequester more carbon than small trees (Hessburg et al. 2020). Larger trees made up a higher share of most stands in most forested landscapes on the national forests in the Blue Mountains before Euro-American settlement. Now, past harvest and fire exclusion have led to a greater proportion of trees and biomass being smaller, younger trees (see Terrestrial Vegetation Report). In restoration, the scientific community are in general agreement that older and larger trees are a priority to leave on the landscape when thinning for ecological restoration and improved resilience. However, there have been debates in the literature about how these efforts may affect forest carbon, particularly around the Eastside Screens and 21-inch diameter limit. Mildrexler et al. (2020) argue in support of this tree diameter limit by highlighting the higher proportion of carbon stored in larger trees. In a comment in response to Mildrexler et al. (2020), Johnston et al. (2021) point out that carbon has been increasing in the forests of eastern Oregon because of fire suppression and resulting stand densification, and that many trees over 21 inches are young, shade-tolerant trees like grand fir that would be less numerous on the landscape if left to natural conditions and regular fire regimes over the last century. They are less resilient to disturbance due to various traits like thinner bark and, in areas of fire suppression, are generally in high densities that increases competition, making them less likely to continue to store carbon in the long term. Johnston et al. do not suggest an alternative size limit but instead suggest focusing on retention of older trees, rather than young ones that may be larger than a 21-inch diameter limit.

Key Benefits to People

Increases in atmospheric carbon dioxide over the last century have been linked to rising global temperatures, resulting in climatic changes and associated effects (see the “Climate Change Impacts” section for more information on these effects). Because forest and rangeland ecosystems can remove carbon dioxide from the atmosphere, they can help modulate atmospheric greenhouse gas concentrations and play an important role in regulating climate (IPCC 2023). Carbon storage is an important benefit provided by the forests (USDA Forest Service 2015; Birdsey et al. 2019).

Risks and Stressors

Carbon stocks can be affected by disturbance such as wildfires, insect activity, timber harvesting and climate change as discussed above. Climate change, wildfire and other disturbances, and stand age are among the greatest future concerns related to carbon in the national forests of the Blue Mountains. A changing climate will impact forests and present a stressor to forest carbon sequestration and storage. Projected climatic changes described in the Climate Change Assessment Report (Warren et al. 2023) are expected to affect tree growth, disturbance dynamics, forest establishment, and composition of the various ecosystems in the national forests. Warmer temperatures, lower and more variable precipitation with less precipitation occurring as snow, and earlier snow melts—all of which are projected for the plan area—have been shown as factors in both increasing fire severity and diminishing the pace and success of post-fire recovery. The changes in climate and disturbance patterns, in turn, can cause vegetation to shift from forest to shrubland or grasslands. This would result in even longer-term effects on carbon stocks because the different ecosystems store different amounts of carbon (see the “Climate Change Impacts” section).

Although disturbances, forest succession, and forest management activities are often the primary drivers of changes in forest carbon, environmental factors, such as atmospheric carbon dioxide concentrations, climate variability, and the availability of forest nutrients (such as nitrogen), can also influence forest growth and carbon dynamics (Caspersen et al. 2000; Pan et al. 2009). Recent warmer temperatures and precipitation variability may have stressed forests, causing climate to have a negative impact on carbon accumulation in the 2000s. Conversely, increased atmospheric carbon dioxide and nitrogen deposition may have enhanced growth rates and helped to counteract ecosystem carbon losses from climate change. Modeling of climate effects on carbon trends suggests that carbon dioxide and nitrogen fertilization partially offset the declines in carbon accumulation associated with historical disturbance, aging, and climate until the 1990s, at which point modeling indicated a decrease in accumulated carbon due to climate effects (McKinley et al. 2022a, b, McKinley and Halofsky 2022). Regional projections of forest carbon stock changes in the Pacific Coast Region, which includes the Pacific Northwest Region, indicate continued increases in carbon stores but a potential age- and disturbance-related slowing of carbon sequestration through 2060 (Woodall et al. 2015; USDA Forest Service 2023); this slowing may already be underway.

For rangelands, there are several drivers that can cause carbon gains or losses. Altered wildfire regimes caused by fire suppression, grazing, and other factors is implicated in allowing many mesic and semi-arid grasslands in the United States to convert to shrublands (Van Auken 2009). Replacement of grassland with woody plants generally tends to increase total ecosystem carbon storage (McKinley and Blair 2008; Li et al., 2016; Abdallah et al. 2020). Conversely, some invasive species, such as *Bromus tectorum*, can reduce carbon in shrublands by propagating more intense fire that cause mortality of co-occurring woody species (Bradley et al. 2006; Koteen et al. 2011; Pilliod et al. 2017).

Trends and Drivers

See also the Trends and Drivers section of the Terrestrial Vegetation Report (Engelmann 2023) and the Climate Change Impacts Report (Warren et al. 2023).

Disturbances such as drought, forest fires, and insect outbreaks may substantially reduce carbon stocks, and climate change impacts threaten to amplify risks to forest carbon stocks by increasing the frequency, size, and severity of disturbances (Dale et al. 2001, Westerling and Bryant 2008, Littell et al. 2009, Boisvenue and Running 2010). This may limit post-disturbance forest regeneration, potentially shift forests to non-forested vegetation, and potentially convert areas from a carbon sink to a carbon source as severity of disturbance increases under projected climate changes (Ryan et al. 2010, USDA Forest Service 2017).

Regional

The Pacific Northwest Region's carbon stocks are estimated to have increased 16.1 percent between 1990 and 2020.

The Pacific Northwest Region's carbon density was relatively stable between 1990 and 2020 with some increase since the mid-1990s.

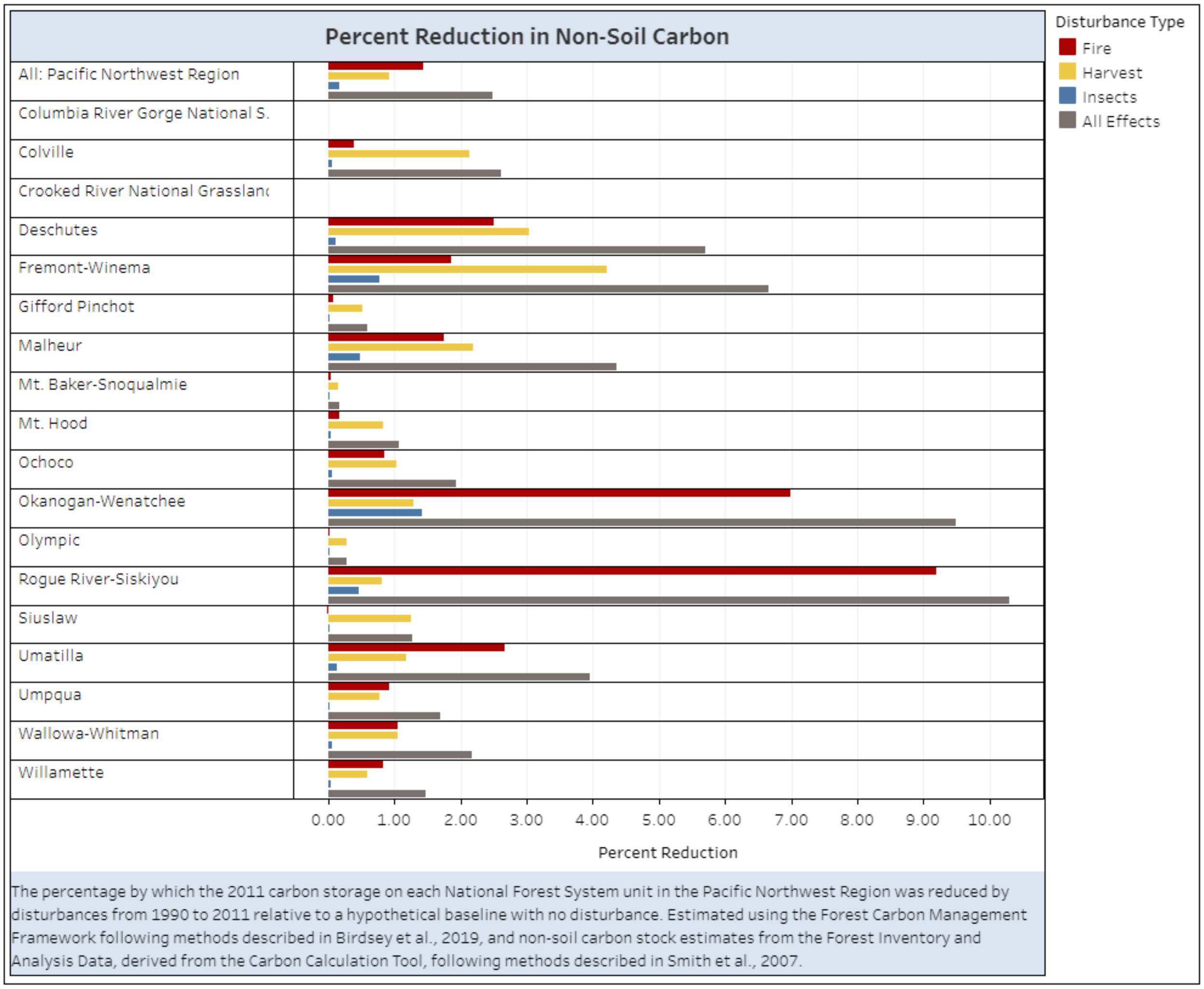
Forest carbon trends in the Pacific Northwest Region have been strongly influenced by the history of land use and policies as well as climate change. For parts of the Pacific Northwest east of the Cascade crest, carbon trends have been shaped largely by removals of forest carbon storage through intensive harvest. East of the Cascade crest, harvest removals have played a role as well, along with fire suppression and grazing. These changes in vegetative structure, combined with climate change, will continue to shape the trajectory of carbon east of the Cascades, including in the Blue Mountains.

Fire has been the most significant disturbance affecting carbon from 1990 to 2011, causing non-soil forest ecosystem carbon stocks to be 1.4 percent lower by 2011. Considering all national forests in the Pacific Northwest Region, by 2011, harvesting accounted for the loss of 0.9 percent of non-soil carbon stocks. Insect activity accounted for a loss of only 0.2 percent if non-soil carbon stocks.

The carbon accumulation in the Pacific Northwest Region national forests slowed starting in the mid-1980s through the current day. Declining rates of carbon stock accumulation are largely due to disturbances and aging effects (Pregitzer & Euskirchen, 2004), which can be explained by timing of Euro-American settlement, stand age relationships, and recent disturbances. Stand age in 2010 indicated that majority of stands in the Pacific Northwest Region are more than 80 years old. Most stands reach maximum productivity (most rapid carbon accumulation) between 30 and 60 years, though they continue to accumulate carbon after this point. Some stand types, like lodgepole pine, western larch, and fir/spruce/mountain hemlock, reach their highest accumulation rates later (40-100, 40-70, and 30-70, respectively).

Regional projections of forest carbon stock changes in the Pacific Coast Region, which includes the Pacific Northwest Region, indicate continued increases, but a potential age- and disturbance-related slowing of carbon sequestration through 2060 (Woodall et al. 2015; USDA Forest Service 2023); this slowing may already be underway.

Climate change is expected to increase the frequency and severity of disturbances as well as affect regeneration success. Overall climate change is expected to change the conditions and thus change the carbon carrying capacity at sites across the landscape influences. These factors are likely to change carbon dynamics and stocks across the Region.



The percentage by which the 2011 carbon storage on each National Forest System unit in the Pacific Northwest Region was reduced by disturbances from 1990 to 2011 relative to a hypothetical baseline with no disturbance. Estimated using the Forest Carbon Management Framework following methods described in Birdsey et al., 2019, and non-soil carbon stock estimates from the Forest Inventory and Analysis Data, derived from the Carbon Calculation Tool, following methods described in Smith et al., 2007.

Figure 9. The percentage by which the 2011 carbon storage on each National Forest System unit in the Pacific Northwest Region was reduced by disturbances from 1990 to 2011 relative to a hypothetical baseline with no disturbance. Estimated using the Forest Carbon Management Framework following methods described in Birdsey et al., 2019, and non-soil carbon stock estimates from the Forest Inventory and Analysis Data, derived from the Carbon Calculation Tool, following methods described in Smith et al., 2007.

Common to All Three Blue Mountains National Forests

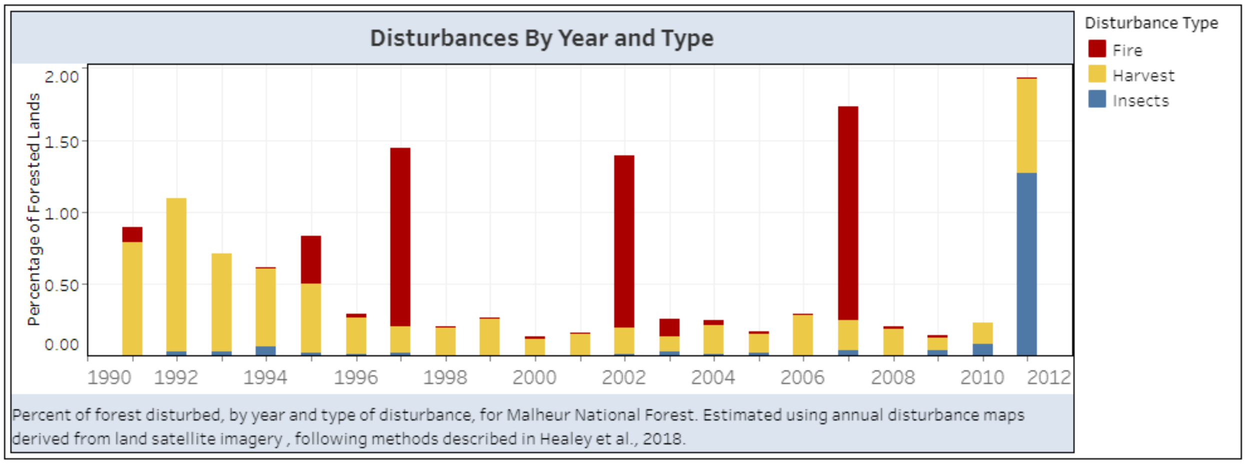
Current forest conditions make forests more vulnerable to fire, pest outbreaks, and other disturbances, resulting in aboveground carbon stocks that are less stable and more vulnerable to significant losses from future disturbance. This is especially true as changes in climate continue to affect the timing, frequency, intensity, and extent of disturbances, such as wildfire and pest outbreaks (Halofsky and Peterson 2017).

The extent to which factors like grazing history and changes in wildfire patterns influence rangeland carbon dynamics in these national forests is not well understood. However, these influences on total ecosystem carbon stocks are likely small. The greatest influence in rangeland ecosystem carbon stocks over time is land-use and land-cover change. It is generally assumed that federal grassland areas have negligible changes in carbon due to limited land use and management change (US EPA 2021). Because soil carbon in rangelands is generally stable, substantial changes in carbon pools and fluxes are typically a result of dramatic changes in land use or vegetation cover that persist indefinitely. For example, there can be substantial losses of soil carbon where rangelands have been converted to agricultural use (Derner and Schuman 2007). Like forests, managing the health of rangelands and avoiding land use and land cover change are key concerns for maintaining carbon stocks. Land-use change generally does not occur on the Malheur NF, although there is increasing development on private lands in the region, and climatic influences on vegetation type conversion may influence carbon stocks in the future.

- The Blue Mountains area is expected to get even warmer, which is expected to have effects on disturbance regimes and severity.
- Atmospheric carbon dioxide concentrations are expected to continue increasing for the foreseeable future. CO_2 fertilization may potentially counteract some negative effects of climate change.
- Stand age distributions indicate a modest pulse of establishment of young stands (less than 30 years old) between 2000 and 2020.

Malheur NF

- The Malheur National Forest was a carbon sink between 1990 and 2020. Stocks are estimated to have increased by 33%.
- The Malheur National Forest's carbon density was relatively stable between 1990 and 2020 with some increase since the mid-1990s.
- Stand aging appears to have had a strong influence on carbon trends in the Malheur NF. The Malheur NF was accumulating carbon at an increasing rate between the 1950s through the mid-1990s. Positive carbon accumulation during those decades is likely a result of regrowth following intensive logging, mining, and grazing activities in the 1910s to 1930s, with high productivity in the young to middle-aged forests (30-60 years old). About 50 percent of stands are now 70 to 100 years old. As stand establishment has declined and more stands have reached ages with slower growth stages starting around the 2000s, the rate of carbon accumulation has declined.
- In the early- to mid-1990s, harvest was by far the largest form of carbon removal from the forest. Between 1997 and 2011, fire had a greater impact but with greater annual inconsistency. In 2011, insects played the largest role in carbon impacts, followed by harvest.
- Timber harvest resulted in a 2.2% carbon reduction between 1990 and 2011, and fire resulted in 1.8% reduction in carbon.



Percent of forest disturbed, by year and type of disturbance, for Malheur National Forest. Estimated using annual disturbance maps derived from land satellite imagery , following methods described in Healey et al., 2018.

Figure 10. Percent of forest disturbed, by year and type of disturbance, for Malheur National Forest. Estimated using annual disturbance maps derived from land satellite imagery, following methods described in Healey et al., 2018.

Umatilla NF

- The Umatilla National Forest was a modest carbon sink between 1990 and 2020. Stocks are estimated to have increased by 18.8%.
- The Umatilla National Forest's carbon density increased steadily between 1990 and 2020.
- Stand aging appears to have had a strong influence on carbon trends in the Umatilla NF. The Umatilla NF was accumulating carbon at an increasing rate between the 1950s through the early 1990s. Positive carbon accumulation during those decades is likely a result of regrowth following intensive logging, mining, and grazing activities in the 1900s to 1930s combined with increased fire suppression after 1910 and are large drivers of the high productivity in the young to middle-aged forests (30-60 years old) in that 1950-1990s timeframe. FIA data shows a large cohort of stands aged 80 to 110 years old. As stand establishment has declined and more stands have reached ages with slower growth stages starting around the 2000s, the rate of carbon accumulation has declined.
- Until 1994, harvest was the largest form of carbon removal from the forest. Between 1995 and 2011, fire had a greater impact but with great annual inconsistency.
- Timber harvest resulted in 1.2% reduction in non-soil carbon stocks between 1990 and 2011, and fire resulted in a 2.7% reduction in carbon.

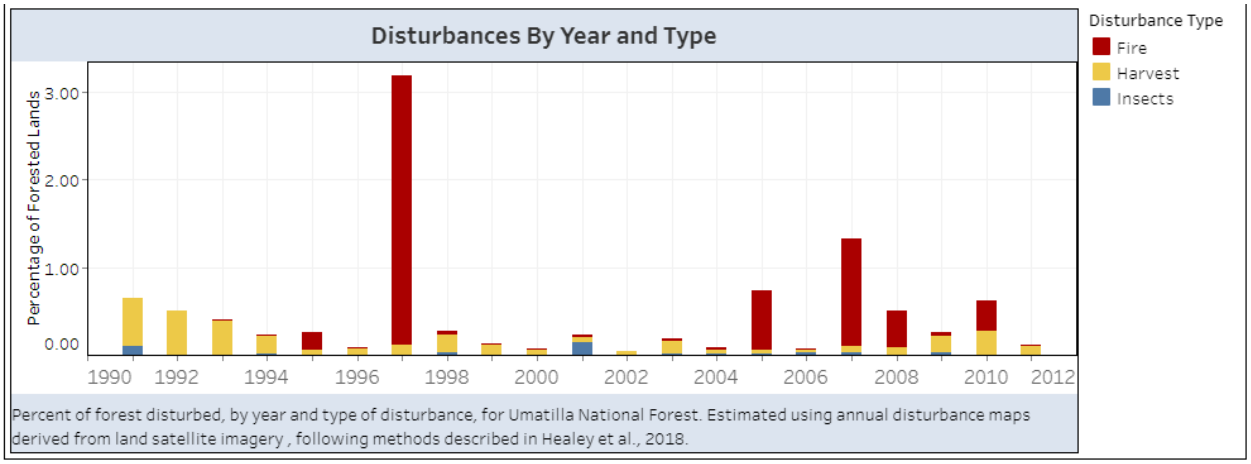
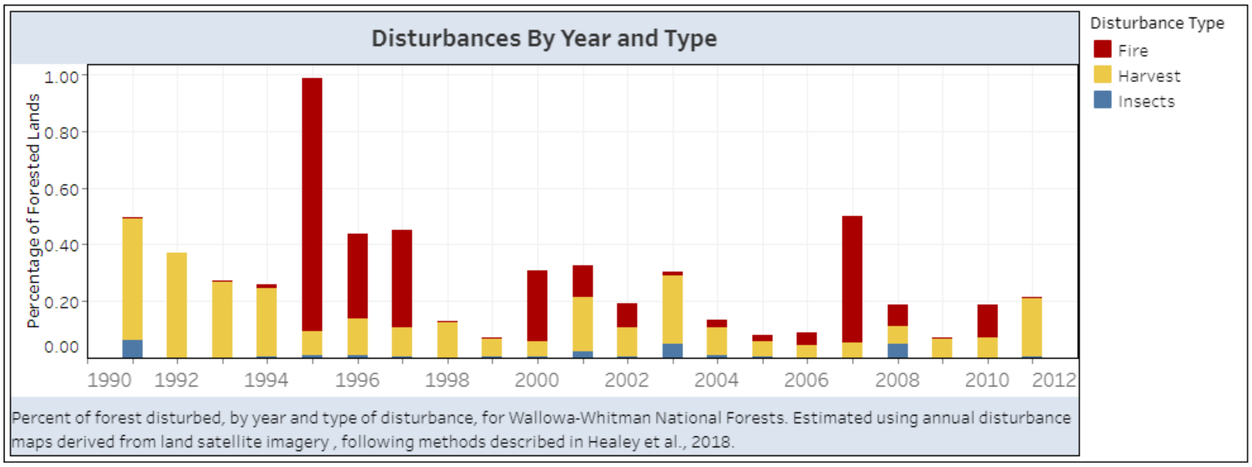


Figure 11. Percent of forest disturbed, by year and type of disturbance, for Umatilla National Forest. Estimated using annual disturbance maps derived from land satellite imagery, following methods described in Healey et al., 2018.

Wallowa-Whitman NF

- The Wallowa-Whitman National Forest was a carbon sink between 1990 and 2020. Stocks are estimated to have increased by 33.1%.
- The Wallowa-Whitman National Forest's carbon density was relatively stable between 1990 and 2020 with some increase since the mid-1990s.
- Stand aging appears to have had a strong influence on carbon trends in the Wallowa-Whitman NF. The Wallowa-Whitman NF was accumulating carbon at an increasing rate between the 1950s through the early 1990s. Positive carbon accumulation during those decades is likely a result of regrowth following intensive logging, mining, and grazing activities in the 1900s to 1930s combined with increased fire suppression after 1910 and are large drivers of the high productivity in the young to middle-aged forests (30-60 years old) in that 1950-1990s timeframe. FIA data shows a large cohort of stands aged 80 to 110 years old. As stand establishment has declined and more stands have reached ages with slower growth stages starting around the 2000s, the rate of carbon accumulation has declined.
- In the early- to mid-1990s, harvest was by far the largest form of carbon removal from the forest. Between 1997 and 2011, fire had a greater impact but with great annual inconsistency.
- Timber harvest resulted in a 1.1% carbon reduction between 1990 and 2011, and fire resulted in 1.1% reduction in carbon.


Disturbances By Year and Type

Percent of forest disturbed, by year and type of disturbance, for Wallowa-Whitman National Forests. Estimated using annual disturbance maps derived from land satellite imagery , following methods described in Healey et al., 2018.

Figure 12. Percent of forest disturbed, by year and type of disturbance, for Wallowa-Whitman National Forests. Estimated using annual disturbance maps derived from land satellite imagery, following methods described in Healey et al., 2018.

Anticipated Trends

Climate change, wildfire and other disturbances, and stand age are among the greatest future concerns related to carbon in the Blue Mountains national forests. Rising temperatures (see Climate Change Impacts Report) will increase the length of the growing season. This lengthening of the growing season could enhance vegetation growth, but elevated temperatures and lower snowpacks will likely increase water stressors on woody vegetation and could have a negative effect on growth rates and carbon accumulation overall. In addition, stressors compounded by climate change, like wildfire and insect-caused mortality, could shift some distribution of carbon from live aboveground pools to dead pools. Drought stress combined with other non-climate disturbances like invasive plant competition may challenge tree reestablishment after disturbance and could lead to long-term lowering of site carbon stocks, particularly at lower elevations. It is possible that some higher-elevation area climates may shift to allow forest types with denser carbon stocks.

Future warmer, drier conditions will likely cause more frequent wildfires with higher severity that will move carbon from biomass storage to the atmosphere (Kashian et al. 2006) (see Climate Change Impacts Report). Beetle susceptibility and outbreaks are expected to increase with warmer temperatures and increased drought stress. The ability of forests to continue to store or sequester carbon depends in part on their resilience to these stressors.

A changing climate introduces uncertainty about how forests—and forest carbon sequestration and storage—may change in the future. Projected climatic changes described in the climate change vulnerability assessment for the Blue Mountains ecoregion (Halofsky and Peterson 2017) are expected to affect tree growth, disturbance dynamics, forest establishment, and composition of ecosystems (see Climate Change Impacts Report). The changes in climate and disturbance patterns, in turn, can cause vegetation to shift from forest to shrubland or grasslands. This would result in even longer-term effects on carbon stocks because the different ecosystems store different amounts of carbon.

In summary:

> “Given the complex interactions among forest ecosystem processes, disturbance regimes, climate, and nutrients, it is difficult to project how forests and carbon trends will respond under novel future conditions. The effects of future conditions on forest carbon dynamics may change over time. For example, as climate change persists for several decades, critical thresholds may be exceeded, causing unanticipated responses to some variables like increasing temperature and CO_2 concentrations. The effects of changing conditions will almost certainly vary by species and vegetation type. Some factors may enhance vegetation growth and carbon uptake, whereas others may hinder the ability of vegetation to store carbon.” *(McKinley et al. 2022a, b, McKinley and Halofsky 2022)*

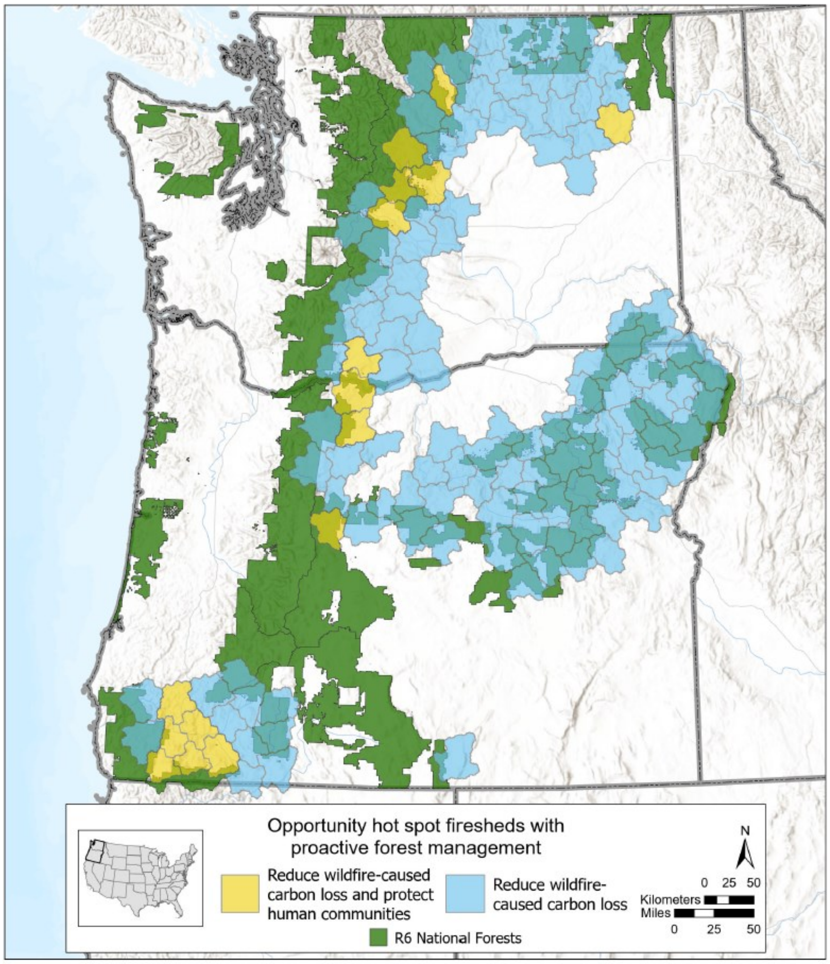


Figure 13. Identified optimal management options of biogenic carbon in Oregon and Washington. (Peeler et al. 2023)

Information Needs

There are several information gaps that prevent a comprehensive assessment of all carbon stocks on these national forests at this time. There is currently insufficient information on soil carbon, and potential soil carbon changes with disturbances, including disturbance involved with vegetation management. Grasslands, wet and mesic meadows, aquatic ecosystems, and carbonaceous rocks also store carbon, but these have not been quantified in these national forests. There is also limited information about harvested wood product destination and longevity for wood products originating from these national forests.

All results reported in this assessment are estimates that are contingent on models, data inputs, assumptions, and uncertainties. Baseline estimates of total carbon stocks and carbon stock change include 95 percent confidence intervals derived using Monte Carlo simulations[3] and shown by the error bars (Figs. 1, 3). These confidence intervals indicate that 19 times out of 20, the carbon stock or stock change for any given year will fall within error bounds. The uncertainties contained in the models, samples, and measurements can exceed 30 percent of the mean at the scale of a national forest, sometimes making it difficult to infer whether and how carbon stocks are changing.

The baseline estimates that rely on FIA data include uncertainty associated with sampling error (e.g., area estimates are based on a network of plots, not a census), measurement error (e.g., species identification, data entry errors), and model error (e.g., associated with volume, biomass, and carbon equations, interpolation between sampling designs). One such model error has resulted from a change in FIA sampling design, which led to an apparent change in forested area. Change in forested area may reflect an actual change in land use due to reforestation or deforestation.

However, given that the Wallowa-Whitman NF, Umatilla NF, and Malheur NF have experienced minimal changes in land use or adjustments to the boundaries of the national forests in recent years, the change in forested area incorporated in CCT is more likely a data artefact of altered inventory design and protocols (Woodall et al. 2013).

The inventory design changed from a periodic inventory, in which all plots were sampled in a single year to a standardized, national, annual inventory, where a proportion of all plots are sampled every year. The older, periodic inventory was conducted differently across states and tended to focus on timberlands with high productivity. Any data gaps identified in the periodic surveys, which were conducted prior to the late 1990s, were filled by assigning average carbon densities calculated from the more complete, later inventories from the respective states (Woodall et al. 2011). The definition of what constitutes forested land also changed between the periodic and annual inventory in some states, which may also have contributed to apparent changes in forested area.

In addition, carbon stock estimates contain sampling error associated with the cycle in which inventory plots are measured. Forest Inventory and Analysis plots are resampled about every 10 years in the Western United States, and a full cycle is completed when every plot is measured at least once. However, sampling is designed such that partial inventory cycles provide usable, unbiased samples annually but with higher errors. These baseline estimates may lack some temporal sensitivity because

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[3] A Monte Carlo simulation performs an error analysis by building models of possible results by substituting a range of values – a probability distribution – for any factor that has inherent uncertainty (e.g., data inputs). It then calculates results over and over, each time using a different set of random values for the probability functions.

plots are not resampled every year, and recent disturbances may not be incorporated in the estimates if the disturbed plots have not yet been sampled. For example, if a plot was measured in 2009 but was clear-cut in 2010, that harvest would not be detected in that plot until it was resampled in 2019. Therefore, effects of the harvest would show up in FIA/CCT estimates only gradually as affected plots are re-visited and the differences in carbon stocks are interpolated between survey years (Woodall et al., 2013). In the interim, re-growth and other disturbances may mute the responsiveness of CCT to disturbance effects on carbon stocks. Although CCT is linked to a designed sample that allows straightforward error analysis, it is best suited for detecting broader and long-term trends, rather than annual stock changes due to individual disturbance events.

Improved temporal (more frequent) and spatial (more locations on the landscape) gathering of data would help refine carbon information, whether from ground plots or remotely sensed data and imagery. Improved algorithms for interpreting imagery could help determine forest type, disturbance, and canopy height layer changes and inform changes to carbon stocks over time. This Assessment was completed with information available at the time of writing.

Key Findings

- In 2020, the Malheur National Forest had the lowest carbon density of the national forests in the Pacific Northwest Region. The Wallowa-Whitman and Umatilla were the fifth- and sixth-least dense.
- The Malheur and Wallowa-Whitman national forests had the largest percent change (around 33%) in carbon stock between 1990 and 2020 in the Region.
- These three forests are carbon sinks with slowing rates of carbon accumulation.
- In the data period between 1990 and 2011, fire replaced timber harvest as the primary disturbance affecting carbon stocks.
- Current forest conditions, which reflect the legacies of historic fire suppression and logging, make forests more vulnerable to fire, pest outbreaks, and other disturbances, resulting in aboveground carbon stocks that are less stable and more vulnerable to significant losses from increasing future disturbances compounded by climate change.
- Increasing the resilience of national forests and grasslands to disturbances is important in maintaining or improving their carbon stability over the long term.
- The 1990 Forest Plans do not address the role of forest ecosystems in the carbon cycle or management effects on carbon storage or sequestration.

Glossary[4]

Adaptation - Adjustments, both planned and unplanned, in natural and human systems in response to climatic changes and subsequent effects. Ecosystem-based adaptation activities use a range of opportunities for sustainable management, conservation, and restoration.

Biogenic carbon – carbon which cycles through living organisms, such as soil carbon, carbon stored in trees, or other plant parts.

Biomass - The mass of living organic matter (plant and animal) in an ecosystem. Biomass also refers to organic matter (living and dead) available on a renewable basis for use as a fuel; biomass includes trees and plants (both terrestrial and aquatic), agricultural crops and wastes, wood and wood wastes, forest and mill residues, animal wastes, livestock operation residues, and some municipal and industrial wastes.

Carbon carrying capacity – the amount of carbon that can be stored in a system as a function of prevailing climatic conditions and natural disturbance regimes, and a potential foundation for carbon management plans.

Carbon density - An estimate of forest carbon stocks per unit area (e.g., tonnes [Mg] per acre of carbon in standing live trees).

Carbon flux - The transfer of carbon from one carbon pool to another.

Carbon optimization - Aiming to optimize carbon benefits on the landscape in a way that recognizes the importance of achieving other management objectives. Maximizing ecosystem carbon stocks can create undesirable tradeoffs with other environmental benefits (Littlefield and D'Amato 2022), and in some landscapes may result in lower carbon benefits where carbon stability is compromised. Maximizing carbon is therefore not necessary for, and is often counter to, achieving effective carbon stewardship.

Carbon pool - Different types of biomass found within forests. The amount of carbon stored in pools changes over time and in response to various factors. Any natural region or zone, or any artificial holding area, containing an accumulation of carbon or carbon-bearing compounds or having the potential to accumulate such substances. Pools can be defined in several ways, but generally include the following: live aboveground biomass (trees, shrubs, herbs, grasses), live belowground biomass (roots), dead wood (standing dead trees, stumps, logs), forest floor (leaves, small branches), and soil (mineral soil, decaying organic matter).

Carbon sequestration - The process of plants using sunlight to capture CO_2 from the air and convert it into plant biomass, including wood, leaves, and roots. The process of increasing the carbon content of a carbon reservoir other than the atmosphere; often used narrowly to refer to increasing the carbon content of carbon pools in the biosphere and distinguished from physical or chemical collection of carbon followed by injection into geologic reservoirs, which is generally referred to as "carbon storage."

Carbon sink - In general, any process, activity, or mechanism that removes a greenhouse gas or a precursor of a greenhouse gas or aerosol from the atmosphere; in this report, a sink is any regime or pool in which the amount of carbon is increasing (i.e., is being accumulated or stored).

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[4] All definitions are a combination of Janowiak et al. 2017, US Forest Service 2015, FSH 1909.12 (zero code), Hurteau and Brooks 2011, Ontl et al. 2023, USDA Forest Service 2020, the Final Environmental Impact Statement for the Sierra and Sequoia National Forests, and in-progress USDA Forest Service carbon stewardship documents

Carbon source - In general, any process, activity, or mechanism that releases a greenhouse gas or a precursor of a greenhouse gas or aerosol into the atmosphere; in this report, a source is any regime or pool in which the amount of carbon is decreasing (i.e., is being released or emitted).

Carbon stability - Reduced risk of either carbon emissions or reduced sequestration capacity from natural disturbance or biotic stressors, with long residence time of carbon in the ecosystem.

Carbon stock - The amount or quantity of carbon contained in the inventory of a pool or reservoir. For purposes of carbon stock assessment for National Forest System (NFS) land management planning, carbon pools do not include carbon in fossil fuel resources, lakes or rivers, emissions from agency operations, or public use of NFS lands (such as emissions from vehicles and facilities).

Carbon storage - The amount of carbon retained long-term within the forest, stored in “carbon pools.”

Climate change adaptation – see “Adaptation”

Climate change mitigation – see “Mitigation”

Greenhouse gases - Gases 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. Greenhouse gases include, for example, carbon dioxide, water vapor, and methane.

Harvested Wood Products (HWP) – IPCC carbon pool that tracks carbon in long-lived wood products such as paper, wood panels, and sawn wood that are in use and store carbon over the products life cycle. Short-lived products, such as wood pellets, are considered immediate emissions of the biomass.

Mitigation - In the context of climate change, actions that reduce the amount of heat-trapping greenhouse gases, such as CO_2, in the atmosphere to minimize changes in the Earth’s climate. Actions can include avoiding or reducing emissions of greenhouse gases into the atmosphere, as well as removing greenhouse gases that are already present in the atmosphere.

Resilience - The capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering essential structures and functions and redundancy of ecological patterns across the landscape quickly.

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