Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Northern Region, Nez Perce-Clearwater National Forests R1-24-05 November 2023

Final Environmental Impact Statement for the Land Management Plan

Appendix D: Forest Carbon Assessment

Nez Perce-Clearwater National Forests

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Final Environmental Impact Statement for 2023 Land Management Plan for the Nez Perce-Clearwater National Forests

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Abstract: This Final Environmental Impact Statement documents the analysis of the Preferred Alternative and four additional action alternatives developed for programmatic management of the four million acres of National Forest system lands administered by the Nez Perce-Clearwater National Forests. The purpose is to provide land management direction for the Nez Perce-Clearwater National Forests, combining the 1987 Nez Perce National Forests Land Management Plan and the 1987 Clearwater National Forest Land Management Plan into one plan for the Nez Perce-Clearwater National Forests, now managed as one administrative unit.

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Introduction

Carbon uptake and storage are some of the many ecosystem services provided by forests and grasslands. Through the process of photosynthesis, growing plants remove carbon dioxide (CO2) from the atmosphere and store it in forest biomass (plant stems, branches, foliage, roots) and much of this organic material is eventually stored in forest soils. This uptake and storage of carbon from the atmosphere helps modulate greenhouse gas concentrations in the atmosphere. Estimates of net annual storage of carbon indicate that forests in the United States (U.S.) constitute an important carbon sink, removing more carbon from the atmosphere than they are emitting (Pan et al. 2011). Forests in the U.S. remove the equivalent of about 12 percent of annual U.S. fossil fuel emissions, or about 206 teragrams of carbon after accounting for natural emissions, such as wildfire and decomposition (U.S. Environmental Protection Agency 2015, Hayes et al. 2018).

The Intergovernmental Panel on Climate Change (IPCC) has summarized the contributions of global human activity sectors to climate change in its Fifth Assessment Report (Intergovernmental Panel on Climate Change 2014). From 2000 to 2009, forestry and other land uses contributed just 12 percent of human-caused global carbon dioxide (CO2) emissions. Fluxes from forestry and other land use (FOLU) activities are dominated by CO2 emissions. Non-CO2 greenhouse gas emissions from FOLU are small and mostly due to peat degradation releasing methane and were not included in this estimate. The forestry sector contribution to greenhouse gas emissions has declined over the last decade (Intergovernmental Panel on Climate Change 2014, Smith et al. 2014, Chaplin-Kramer et al. 2015). Globally, the largest source of greenhouse gas emissions in the forestry sector is deforestation (Pan et al. 2011, Houghton et al. 2012, Intergovernmental Panel on Climate Change 2014) defined as the removal of all trees to convert forested land to other land uses that either do not support trees or allow trees to regrow for an indefinite period (Intergovernmental Panel on Climate Change 2000). However, the United States is experiencing a net increase in forestland in recent decades because of the reversion of agricultural lands back to forest and regrowth of cut forests (Birdsey et al. 2006), a trend expected to continue for at least another decade (Wear et al. 2013, U.S. Department of Agriculture 2016).

Forests are dynamic systems that naturally undergo fluctuations in carbon storage and emissions as forests establish and grow, die with age or disturbances, and re-establish and regrow. When trees and other vegetation die, either through natural aging and competition processes or disturbance events (for example, fires, insects), carbon is transferred from living carbon pools to dead pools, which also release carbon dioxide through decomposition or combustion (fires). Management activities include timber harvests, thinning, and fuel reduction treatments that remove carbon from the forest and transfer a portion to wood products. Carbon can then be stored in commodities (for example, paper and lumber) for a variable duration ranging from days to many decades or even centuries. In the absence of commercial thinning, harvest, and fuel reduction treatments, forests will thin naturally from mortality-inducing disturbances or aging, resulting in dead trees decaying and emitting carbon to the atmosphere.

Following natural disturbances or harvests, forests regrow, resulting in the uptake and storage of carbon from the atmosphere. Over the long term, forests regrow and often accumulate the same amount of carbon that was emitted from disturbance or mortality (McKinley et al. 2011). Although disturbances, forest aging, and management are often the primary drivers of forest carbon dynamics in some ecosystems, environmental factors, such as atmospheric carbon dioxide concentrations, climatic variability, and the availability of limiting forest nutrients such as nitrogen, can also influence forest growth and carbon dynamics (Caspersen et al. 2000, Pan et al. 2009).

This assessment provides an evaluation of the amount of carbon stored on the Nez Perce-Clearwater and how disturbances, management, and environmental factors have influenced carbon storage over time. This assessment primarily used two recent U.S. Forest Service reports: the Baseline Report (U.S. Department of Agriculture 2015) and the Disturbance Report (Birdsey et al. 2019). Both reports relied on Forest Inventory and Analysis (FIA) and several validated, data-driven modeling tools to provide nationally consistent evaluations of forest carbon trends across the National Forest System lands.

The Baseline Report applies the Carbon Calculation Tool (CCT) (Smith et al. 2007), which summarizes available FIA data across multiple survey years to estimate forest carbon stocks and changes in stocks at the scale of the national forest from 1990 to 2013. The Baseline Report also provides information on carbon storage in harvested wood products (HWP) for each Forest Service region.

The Disturbance Report provides a national forest-scale evaluation of the influences of disturbances and management activities, using the Forest Carbon Management Framework (ForCaMF) (Healey et al. 2014, Raymond et al. 2015, Healey et al. 2016). 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 (Chen et al. 2000, Zhang et al. 2012).

Additional reports, including the most recent Resource Planning Act (RPA) assessment (U.S. Department of Agriculture 2016) and regional climate vulnerability assessments (Halofsky et al. 2018a;b, May et al. 2018) are used to help infer future forest carbon dynamics. Collectively, these reports incorporate advances in data and analytical methods, representing the best available science to provide comprehensive assessments of National Forest System carbon trends.

The Nez Perce-Clearwater is approximately 4 million acres within the administrative boundary and is about 2 percent of the nearly 190 million acres of National Forest System lands in the United States. The National Forest System constitutes one-fifth (22 percent) of the Nation’s total forest land area and contains one-fourth (24 percent) of the total carbon stored in all U.S. forests, excluding interior Alaska (U.S. Department of Agriculture 2015). The national forest system forest carbon resource has been growing since 1990, according to Forest Inventory and Analysis data.

Primary Forest Carbon Models and Carbon Units

The following models were used to conduct this carbon assessment:

- Carbon Calculation Tool (CCT): Estimates annual carbon stocks and stock change from 1990 to 2013 by summarizing data from two or more Forest Inventory and Analysis (FIA) survey years. CCT relies on allometric models to convert tree measurements to biomass and carbon.
- Forest Carbon Management Framework (ForCaMF): Integrates FIA data, Landsat-derived maps of disturbance type and severity, and an empirical forest dynamics model, the Forest Vegetation Simulator, to assess the relative impacts of disturbances (harvests, insects, fire, abiotic, disease). ForCaMF estimates how much more carbon (non-soil) would be on each NF if disturbances from 1990 to 2011 had not occurred.
- Integrated Terrestrial Ecosystem Carbon (InTEC) model: A process-based model that integrates FIA data, Landsat-derived disturbance maps, as well as measurements of climate variables, nitrogen deposition, and atmospheric carbon dioxide. InTEC estimates the relative effects of aging, disturbance, regrowth, and other factors, including climate, carbon dioxide fertilization, and nitrogen deposition on carbon accumulation from 1950 to 2011. Carbon stock and stock change estimates

reported by InTEC are likely to differ from those reported by CCT because of the different data inputs and modeling processes.

Table 1 provides a crosswalk among various metric measurements units used in the assessment of carbon stocks and emissions.

Table 1. Carbon stock and emission metric measurement units

Multiple	Name (Tonnes)	Symbol (Tonnes)	Name (Grams)	Symbol (Grams)
100	Tonne	t	Gram	G
103	Kilotonne	Kt	Kilogram	Kg
106	Megatonne	Mt	Megagram	Mg
109	Gigatonne	Gt	Gigagram	Gg
1012	Teratonne	Tt	Teragram	Tg
1015	Petatonne	Pt	Petagram	Pg
1018	Exatonne	Et	Exagrame	Eg
1021	Zettagram	--	Zettagram	Zg
1024	Yottagram	--	Yottagram	Yg

Additionally, the following information could be useful in understanding the assessment:

- 1 hectare (ha) = 0.01 km2 = 2.471 acres = 0.00386 mi2
- 1 Teragram carbon (Tg C) = 1,000,000 Megagram carbon (Mg C)
- 1 Megagram carbon (Mg C) = 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 CO2 mass
- A typical passenger vehicle emits about 4.6 tonnes CO2 per year

Background

The Nez Perce-Clearwater is located in the heart of north-central Idaho in a seven-county region, comprising Clearwater, Idaho, Latah, Shoshone, Benewah, Lewis, and Nez Perce counties. The Nez Perce-Clearwater is responsible for managing approximately four million acres across this landscape, with approximately 3.7 million acres (1,516,569 hectares) as forested lands. Western redcedar, western larch, western hemlock, Douglas-fir, grand fir, lodgepole pine, and Ponderosa pine are the dominant conifer species. Historically, western white pine and whitebark pine were found throughout the area.

The carbon legacy of the Nez Perce-Clearwater and other national forests in the region is tied to the history of Euro-American settlement, land management, and disturbances. Human activities associated with settlement, such as mining, logging, and grazing, began in the mid to late 1800's.

The dominant, historical fire regime that occurred within forested vegetation in the Inland Empire can be characterized as a variable or mixed-severity fire regime (Kilgore 1981, Brown 2000). The Inland Empire refers to an area of the Pacific Northwest that includes parts of Washington, Oregon, Idaho, and Montana. The type of fire regime found within the Inland Empire commonly had a moderately short fire-return interval for nonlethal or mixed severity fires, with lethal crown fires occurring less often. Relative to the other two common fire regimes that are often recognized for forested vegetation—the nonlethal and stand-replacement regimes—the mixed-severity fire regimes are the most complex (Agee 2005). Individual mixed-severity fires typically leave a patchy pattern of mortality on the landscape, which creates highly diverse communities. These fires kill a large percentage of the more fire-susceptible tree species, such as hemlock, grand fir, subalpine fir, and lodgepole pine, and a smaller proportion of the fire-resistant species, including western larch, Ponderosa pine, whitebark pine, and western white pine (Arno et al. 2000).

Wildfire is the most influential disturbance on the Nez Perce-Clearwater. From 2000 to 2018 fires burned on average approximately 725,000 acres per decade, or an average 80,560 acres annually. On average, 315,000 acres of large fires greater than 1,000 acres burned per decade from 1870 to 2017. Of particular note, from 1900 to 1939, fires burned approximately 2,347,828 acres. Many of these acres have entered their next burn cycle. Fire suppression efforts since 1935 have been relatively successful.

In recent years, however, the number and size of fires have increased throughout the west (Keane et al. 2002). This pattern is evident on the Nez Perce-Clearwater. Fuel accumulation in short and moderate and long fire interval groups have occurred, with the potential result being more acres burning at higher fire intensities. The historic pattern of disturbance has also been altered, particularly in long fire interval areas. Fuel accumulations, coupled with the warmer, drier weather of the past decade, have resulted in the current trend toward high-intensity fires. This is a departure from the historic pattern where fire intensities varied on the landscape. See the Fire Management section of the Final Environmental Impact Statement for further information regarding fire history on the Nez Perce-Clearwater.

Previous harvest activities within the project area set the stage for forest cover types to depart from historical species distributions. Harvest activities prior to the 1940s were associated with homesteading, mining, and railroad building. These activities were concentrated in easily accessible and productive forests. In some cases, forests were cleared for uses, such as fuelwood, while in others, only the selected removal of the largest and best trees, or “high-grading” occurred. Since the early 1900s, harvest has impacted roughly 40 percent of the Nez Perce-Clearwater’s land base. Table 2 displays the acres of harvest, prescribed fire, and fuel reduction vegetation treatments on the Nez Perce-Clearwater from 1987 to 2018. See the Forestlands section of the Final Environmental Impact Statement for further information regarding harvest history on the Nez Perce-Clearwater.

Table 2. Average number of acres of vegetation treatments, 1987-2018

Decade	Harvest[1]	Prescribed Fire[2]	Fuel Reduction[3]
1987-1996	25,827	24,706	20,443
1997-2006	10,299	39,154	15,667
2007-2016	4,999	5,810	7,905
2017-2018	6,200	971	655

1Harvest activities include even-aged, uneven-aged, and intermediate harvest treatments.

2Includes overlap of burning in harvested stands. Prescribed fire activities include broadcast burning, jackpot burning, site preparation burning, and underburning. Wildfire acres are not included; see the Fire Management section for information on past wildfires, including those used for resource benefit.

3Fuel reduction treatments include burning of piled material, chipping of fuels, compacting or crushing of fuels, fuel break, miscellaneous treatment of natural fuels, piling of fuels, rearrangement of fuels, and thinning for hazardous fuels reduction.

Data Source: FACTS database, acres completed by fiscal year up to September of 2018.

Baseline Carbon Stocks and Flux

Forest Carbon Stocks and Stock Change

Total Carbon Stock

According to results of the Baseline Report (U.S. Department of Agriculture 2015), carbon stocks in the Nez Perce-Clearwater increased from 238.29 teragrams of carbon (Tg C) in 1990 to 279.43 Tg C in 2013, a 17.3 percent increase in carbon stocks over this period. Despite some uncertainty in annual carbon stock estimates, there is a high degree of certainty that carbon stocks on the Nez Perce-Clearwater have increased from 1990 to 2013.

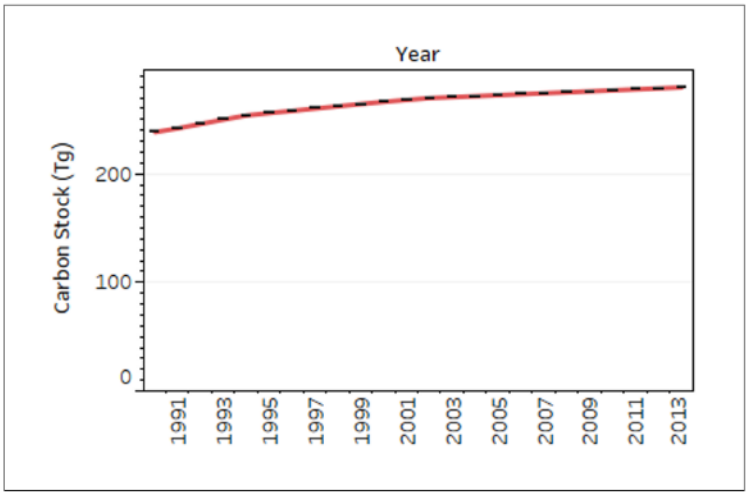


Figure 1. Total forest carbon stocks (in teragrams) from 1990 to 2013 for the Nez Perce-Clearwater. Confidence intervals were not calculated for combined forests

Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); estimated using the Carbon Calculation Tool (CCT).

Carbon Pools

About 23 percent of forest carbon stocks in the Nez Perce-Clearwater are stored in the soil carbon contained in organic material to a depth of one meter, excluding roots. The aboveground portion of live trees, which includes all live woody vegetation at least one inch in diameter, is the largest carbon pool, storing another 38 percent of the forest carbon stocks (Figure 2). Recently, new methods for measuring soil carbon have found that the amount of carbon stored in soils generally exceeds the estimates derived from using the methods of the Carbon Calculation Tool model by roughly 12 percent across forests in the United States (Domke et al. 2017).

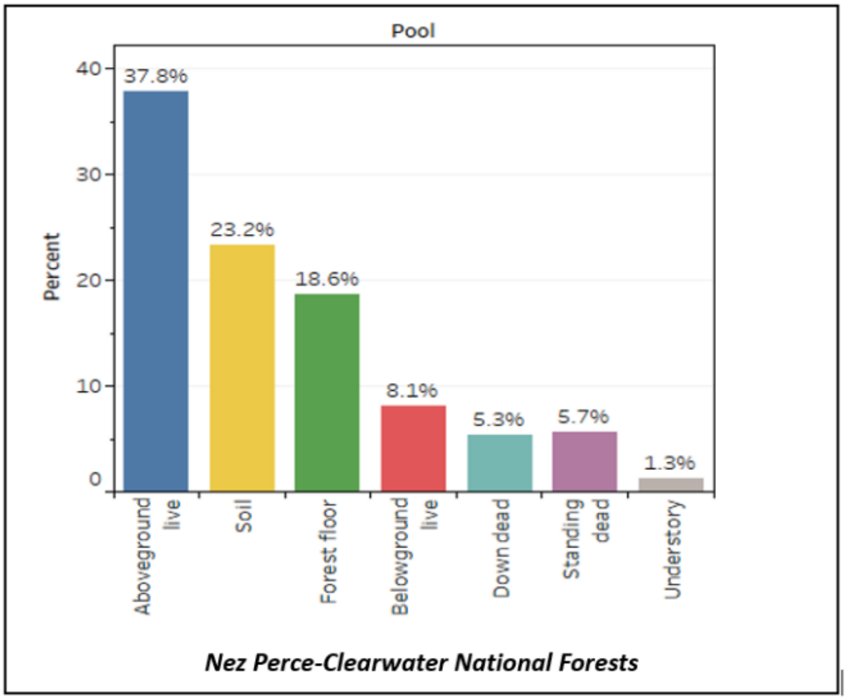


Figure 2. Percentage of carbon stocks in 2013 in each of the forest carbon pools for the Nez Perce-Clearwater

Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); estimated using the Carbon Calculation Tool (CCT).

Carbon Stock Changes

The annual carbon stock change can be used to evaluate whether a forest is a carbon sink or source in a given year. Carbon stock change is typically reported from the perspective of the atmosphere. A negative value indicates a carbon sink: the forest is absorbing more carbon from the atmosphere (through growth) than it emits (via decomposition, removal, and combustion). A positive value indicates a source: the forest is emitting more carbon than it takes up.

Annual carbon stock changes in the Nez Perce-Clearwater were -3.53 Tg C per year (gain) in 1990 and -0.89 Tg C per year in 2012 (gain) (Figure 3). The uncertainty between annual estimates can make it difficult to determine whether the forest is a sink or a source in a specific year (that is, uncertainty bounds overlap zero). However, the trend of increasing carbon stocks from 1990 to 2013 (Figure 3) over the 23-year period suggests that the Nez Perce-Clearwater is a modest carbon sink.

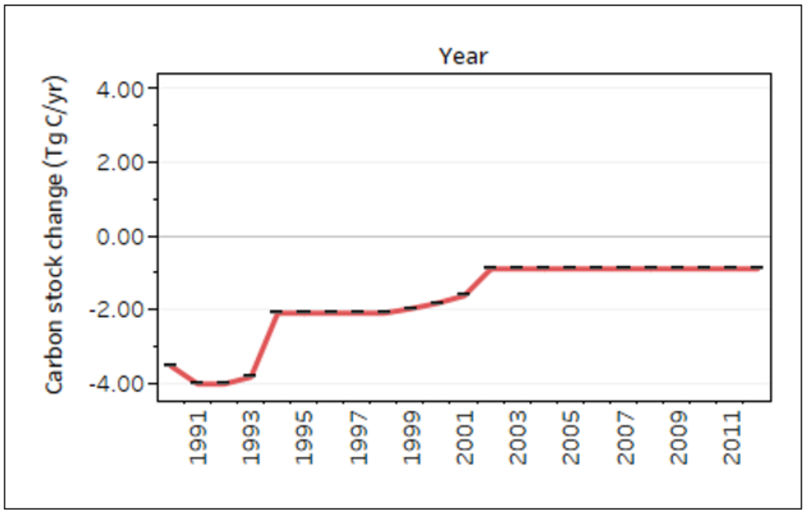


Figure 3. Carbon stock change (in teragrams per year) from 1990 to 2012 for the Nez Perce-Clearwater. Confidence intervals were not calculated for combined forests. A positive value indicates a carbon source, and a negative value indicates a carbon sink.

Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); estimated using the Carbon Calculation Tool (CCT).

Forested Areas Changes

Changes in forested area may affect whether forest carbon stocks are increasing or decreasing. The Carbon Calculation Tool (CCT) estimates from the Baseline Report (U.S. Department of Agriculture 2015) are based on Forest Inventory and Analysis (FIA) data, which may indicate changes in the total forested area from one year to the next. According to the FIA data used to develop these baseline estimates, the forested area in Nez Perce-Clearwater has increased from 1,425,581 ha in 1990 to 1,516,569 ha in 2013, a net change of 90,988 ha. Forested area used in the CCT model may differ from more recent FIA estimates, as well as from the forested areas used in the other modeling tools. When forestland area increases, total ecosystem carbon stocks typically also increase, indicating a carbon sink. The CCT model used inventory data from two different databases. This may have led to inaccurate estimates of changes in forested area, potentially altering the conclusion regarding whether or not forest carbon stocks are increasing or decreasing and, therefore, whether the National Forest is a carbon source or sink (Woodall et al. 2011).

Carbon Density

Carbon density, which is an estimate of forest carbon stocks per unit area, can help identify the effects of changing forested area. In the Nez Perce-Clearwater, carbon density increased from about 167 Megagrams of carbon per ha in 1990 to 184 Megagrams of carbon per ha in 2013 (Figure 4). This increase in carbon density suggests that total carbon stocks may have indeed increased.

Carbon density is also useful for comparing trends among units or ownerships with different forest areas. Similar to the Nez Perce-Clearwater, most national forests in the Northern Region have experienced increasing carbon densities from 1990 to 2013. Carbon density in the Nez Perce-Clearwater have been similar to, but slightly higher than, the average for all national forest units in the Northern Region (Figure 4). Differences in carbon density between units may be related to inherent differences in biophysical factors that influence growth and productivity, such as climatic conditions, elevation, and forest types.

These differences may also be affected by disturbance and management regimes, which is discussed in further detail below.

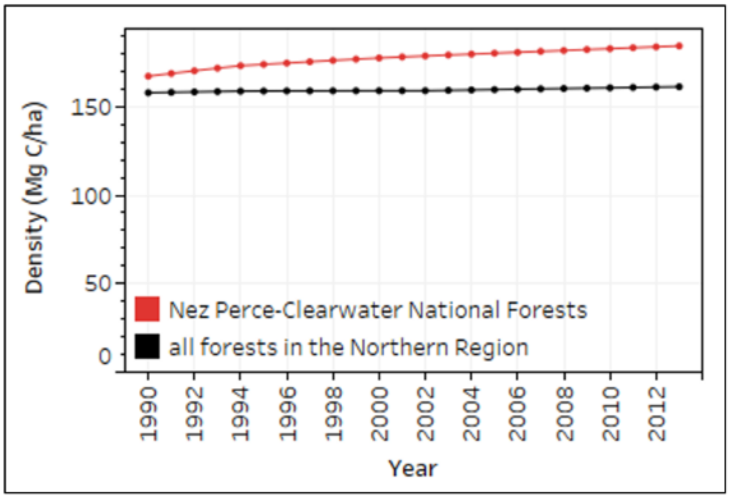


Figure 4. Average carbon stock density (Megagrams per hectare) in the Nez Perce-Clearwater (red lines) and the average carbon stock density for all forests in the Northern Region (black line) from 1990 to 2013

Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); estimated using the Carbon Calculation Tool (CCT).

Uncertainty Associated with Baseline Forest Carbon Estimates

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. 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 (for example, data inputs). It then calculates results over and over, each time using a different set of random values for the probability functions. 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 if or how carbon stocks are changing. Confidence intervals were not calculated for combined forests, so the 95 percent confidence interval error bars are not displayed in Figure 1 and Figure 4.

The baseline estimates that rely on Forest Inventory and Analysis (FIA) data include uncertainty associated with sampling error (for example, area estimates are based on a network of plots, not a census), measurement error (for example, species identification, data entry errors), and model error (for example, associated with volume, biomass, and carbon equations, interpolation between sampling designs). As mentioned above, 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 Nez Perce-Clearwater has 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 Carbon Calculation Tool (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, in which a proportion of all plots is 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 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 Forest Inventory and Analysis (FIA) and 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. 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.

In contrast, the Disturbance Report integrates high-resolution, remotely sensed disturbance data to capture effects of each disturbance event the year it occurred. This report identifies mechanisms that alter carbon stocks and provides information on finer temporal scales. Consequently, discrepancies in results may occur between the Baseline Report and the Disturbance Report (Dugan et al. 2017).

The baseline estimates that rely on FIA data do not include an assessment of soil carbon due to difficulty in determining how to measure regional forest soil C stocks and monitor change (Gray and Whittier 2014). Therefore, estimates for change in carbon stock are reported as non-soil soil carbon loss or gain.

Carbon in Harvested Wood Products

Although harvest transfers carbon out of the forest ecosystem, most of that carbon is not lost or emitted directly to the atmosphere. Rather, it can be stored in wood products for a variable duration depending on the commodity produced. Wood products can be used in place of other more emission intensive materials, like steel or concrete, and wood-based energy can displace fossil fuel energy, resulting in a substitution effect (Gustavsson et al. 2006, Lippke et al. 2011). Much of the harvested carbon that is initially transferred out of the forest can also be recovered with time as the affected area regrows.

Carbon accounting for harvested wood products (HWP) contained in the Baseline Report was conducted by incorporating data on harvests on national forests documented in cut-and-sold reports within a production accounting system (Smith et al. 2006, Stockmann et al. 2014). This approach tracks the entire cycle of carbon, from harvest to timber products to primary wood products to disposal. As more commodities are produced and remain in use, the amount of carbon stored in products increases. As more products are discarded, the carbon stored in solid waste disposal sites (landfills, dumps) increases. Products in solid waste disposal sites may continue to store carbon for many decades.

In national forests in the Northern Region, harvest levels remained low until the 1940s, when they began to rise, which caused an increase in carbon storage in HWP (Figure 5). Timber harvesting and subsequent carbon storage increased rapidly in the 1960s and 1970s. Storage in products and landfills peaked at about 34 Tg C in 1995. However, because of a significant decline in timber harvesting in the late 1990s and early 2000s (to 1950s levels), carbon accumulation in products in use began to decrease. In the Northern Region, the contribution of national forest timber harvests to the HWP carbon pool is less than the decay of retired products, causing a net decrease in product-sector carbon stocks. In 2013, the carbon stored in HWP was equivalent to approximately 2.2 percent of total forest carbon storage associated with national forests in the Northern Region.

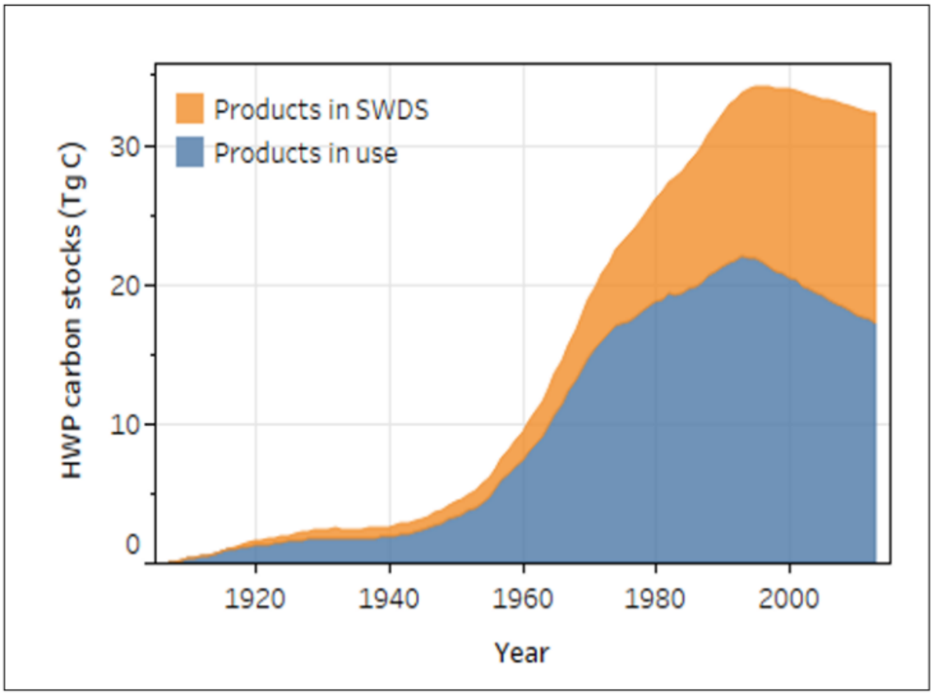


Figure 5. Cumulative total carbon (Tg) stored in harvested wood products (HWP) sourced from national forests in the Northern Region from 1907 to 2013[1]

[1] Carbon in HWP includes products that are still in use and carbon stored at solid waste disposal sites (SWDS).
Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); estimated using the Intergovernmental Panel on Climate Change (IPCC) production accounting approach.

Uncertainty Associated with Estimates of Carbon in Harvested Wood Products

As with the baseline estimates of ecosystem carbon storage, the analysis of carbon storage in harvested wood products (HWP) also contains uncertainties. Sources of error that influence the amount of uncertainty in the estimates include adjustment of historic harvests to modern national forest boundaries; factors used to convert the volume harvested to biomass; the proportion of harvested wood used for different commodities (for example, paper products, saw logs); product decay rates; and the lack of distinction between methane and carbon dioxide emissions from landfills. The approach also does not consider the substitution of wood products for emission-intensive materials or the substitution of bioenergy for fossil fuel energy, which can be significant (Lippke et al. 2011). The collective effect of uncertainty was assessed using a Monte Carlo approach (Dugan et al. 2017). Results indicated a ±0.05 percent difference from the mean at the 90 percent confidence level for 2013, suggesting that uncertainty is relatively small at this regional scale (Healey et al. 2018).

Factors Influencing Forest Carbon

Effects of Disturbance

The Disturbance Report builds on estimates in the Baseline Report by supplementing high-resolution, manually verified, annual disturbance data from Landsat satellite imagery (Healey et al. 2018). The Landsat imagery was used to detect land cover changes due to disturbances, including fires, harvests, insects, and abiotic factors (for example, wind, ice storms). Disturbance from disease was not calculated. The resulting disturbance maps indicate that fire has been the dominant disturbance type detected on the Nez Perce-Clearwater from 1990 to 2011, in terms of the total percentage of forested area disturbed over the period (Table 3, Figure 6a). In most years, except for 2007, fire affected less than 1 percent of the total forested area of the Nez Perce-Clearwater in any single year from 1990 to 2011. In total, fire affected about 5.38 percent (approximately 80,143 ha) of the average forested area (1,489,421 ha) during this period. Fires varied in the impact to change to canopy cover (magnitude) (Figure 6b). Harvest also played a disturbance role, contributing to 0.82 percent (approximately 12,282 ha) of the average forested area on the Nez Perce-Clearwater from 1990 to 2011 (Table 3, Figure 6a).

Table 3. Percentage of forest disturbed[1] from 1990 to 2011 in the Nez Perce-Clearwater and impacts of disturbance to non-soil carbon

	Fire	Harvest	Insect	Disease	Combined
Percent of total estimated forested area disturbed	5.38	0.82	0.56	NA	6.76
Total estimated forested area disturbed (hectare)	80,143	12,282	8,328	NA	100,752
Non-Soil carbon loss in 2011 (Mg C per hectare)	-2.47	-0.53	-0.01	-2.52	-5.33
Percent non-soil carbon loss in 2011	1.71	0.37	0.00	1.74	3.62

1Based on average forested area of 1,489,421 ha

Data Source: Disturbance Report (Birdsey et al. 2019) and Baseline Report (U.S. Department of Agriculture 2015).

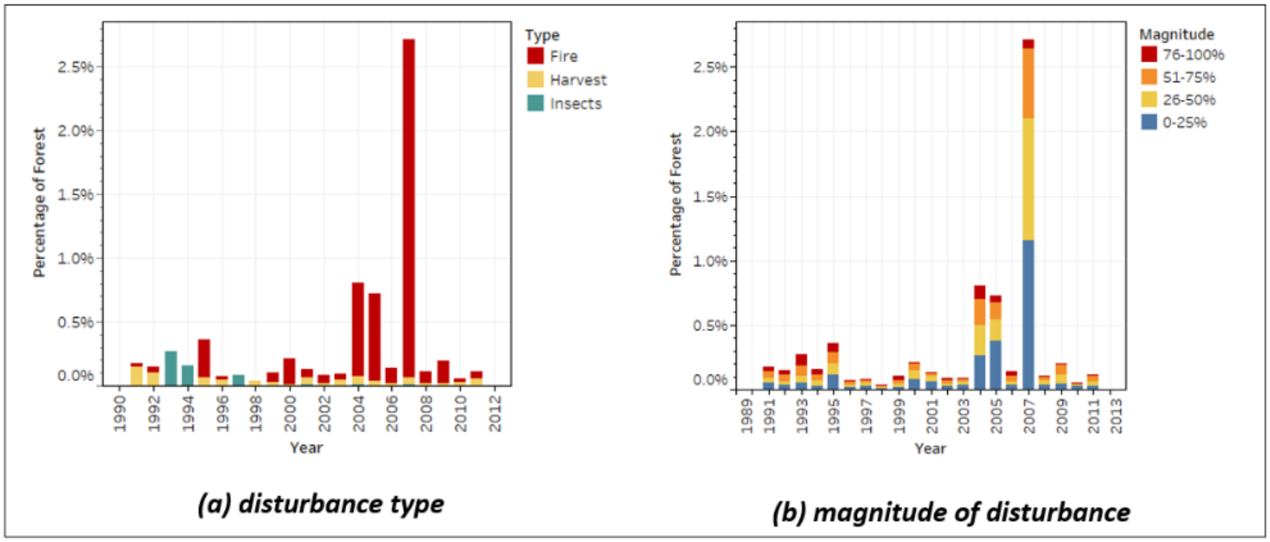


Figure 6. Percentage of forest disturbed from 1990 to 2011 in the Nez Perce-Clearwater by (a) disturbance type including fire, harvests, and insects and (b) magnitude of disturbance (change in canopy cover)

Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); estimated using annual disturbance maps derived from Landsat satellite imagery.

The Forest Carbon Management Framework (ForCaMF) incorporates Landsat disturbance maps summarized in Figure 6, along with Forest Inventory and Analysis (FIA) data in the Forest Vegetation Simulator (FVS) (Crookston and Dixon 2005). The FVS is used to develop regionally representative carbon accumulation functions for each combination of forest type, initial carbon density, and disturbance type and severity, including undisturbed (Raymond et al. 2015). The ForCaMF model then compares the undisturbed scenario with the carbon dynamics associated with the historical disturbances to estimate how much more carbon would be on each national forest if the disturbances and harvests during 1990-2011 had not occurred. ForCaMF simulates the effects of disturbance and management only on non-soil carbon stocks (that is, vegetation, dead wood, forest floor). Like Carbon Calculation Tool (CCT), ForCaMF results supply 95 percent confidence intervals around estimates derived from a Monte Carlo approach (Healey et al. 2014).

Fire and disease were the primary disturbances influencing carbon stocks on the Nez Perce-Clearwater NF from 1990 to 2011 (Figure 7). Fire and disease accounted for the majority of the total non-soil carbon lost from the forest due to disturbances, followed by losses from harvest and insects (Table 3) (U.S. Department of Agriculture 2015). The ForCaMF model indicates that, by 2011, Nez Perce-Clearwater contained 2.52 Mg C per ha less non-soil carbon (that is, vegetation and associated pools) due to disease (Table 3), 2.47 Mg C per ha less due to fire, 0.53 Mg C per ha less due to harvest, and 0.01 Mc C per ha due to insect, since 1990, as compared to a hypothetical undisturbed scenario (Figure 7), totaling 5.33 Mg C per ha from all disturbances. As a result, non-soil carbon stocks in the Nez Perce-Clearwater would have been approximately 3.6 percent higher in 2011 if disturbance had not occurred since 1990 (Figure 8).

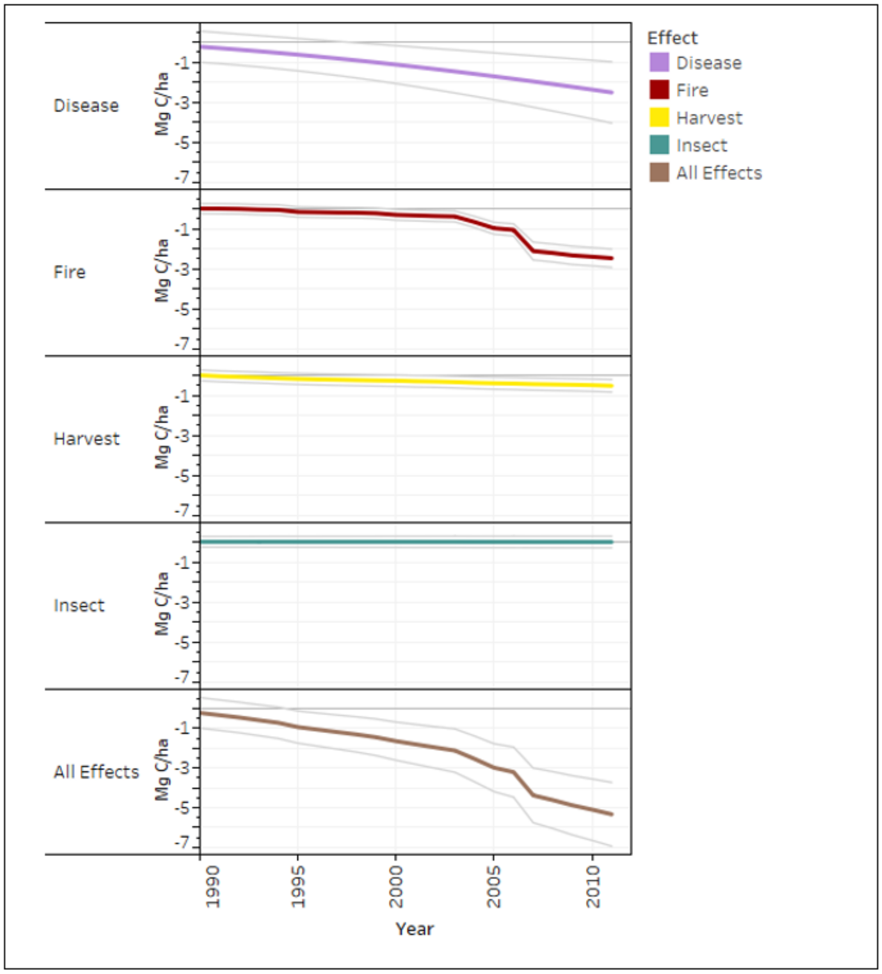


Figure 7. Lost potential storage of carbon (in megagrams per hectare) as a result of disturbance for the period 1990-2011 in Nez Perce-Clearwater. The zero line represents a hypothetical undisturbed scenario. Gray lines indicate 95 percent confidence intervals.

Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); estimated using the Forest Carbon Management Framework (ForCaMF) model.

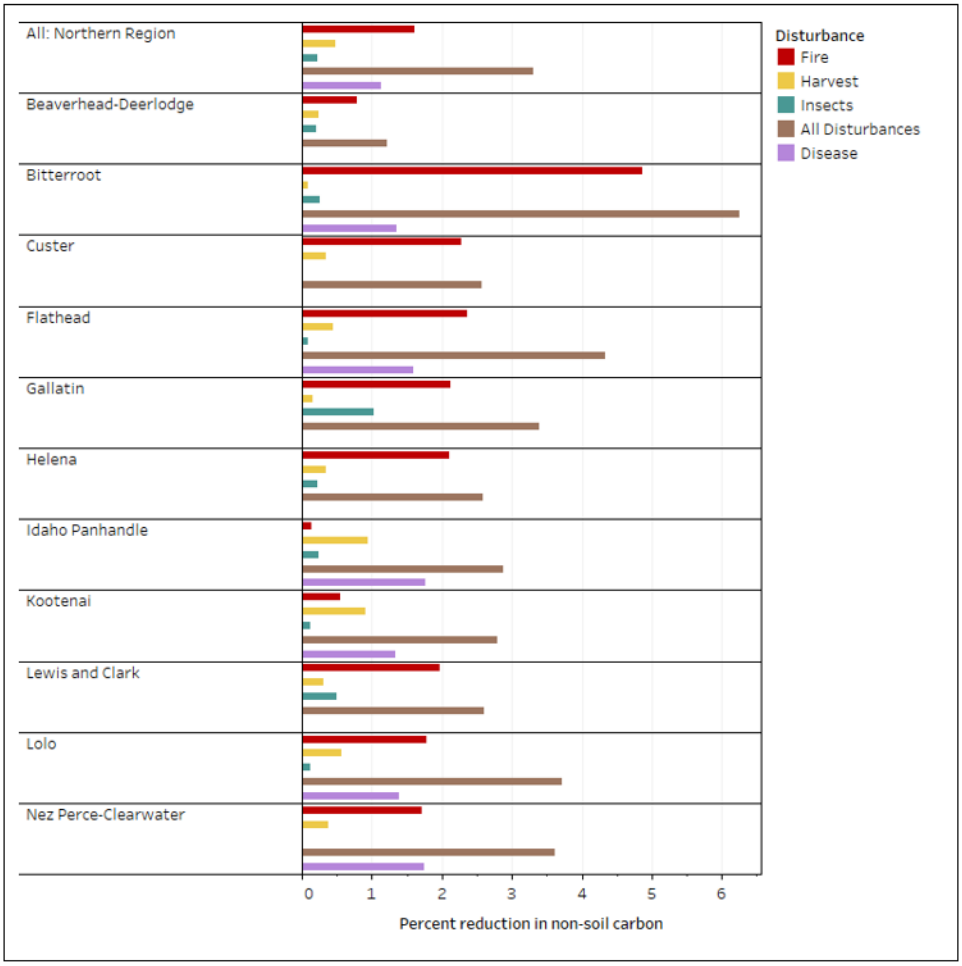


Figure 8. The percent by which 2011 carbon storage on each national forest in the Northern Region was reduced by disturbance from 1990 to 2011 relative to a hypothetical baseline with no disturbance. The brown line indicates the effect of all disturbance types combined.

Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); estimated using disturbance effects from the Forest Carbon Management Framework model and non-soil carbon stock estimates from the Carbon Calculation Tool.

Across all national forests in the Northern Region, with the exception of the Idaho Panhandle and Kootenai National Forests, fire has been the most significant disturbance affecting carbon storage since 1990, causing non-soil forest ecosystem carbon stocks to be 1.6 percent lower by 2011 (Figure 8) for the Region. Considering all national forests in the Northern Region, by 2011, disturbance accounted for total loss of 3.3 percent of non-soil carbon stocks, with fire contributing 1.62 percent, disease 1.13 percent, harvest 0.48 percent, and insects 0.22 percent (Figure 8). There were no non-soil carbon stock reductions caused by abiotic factors such as wind and ice storms.

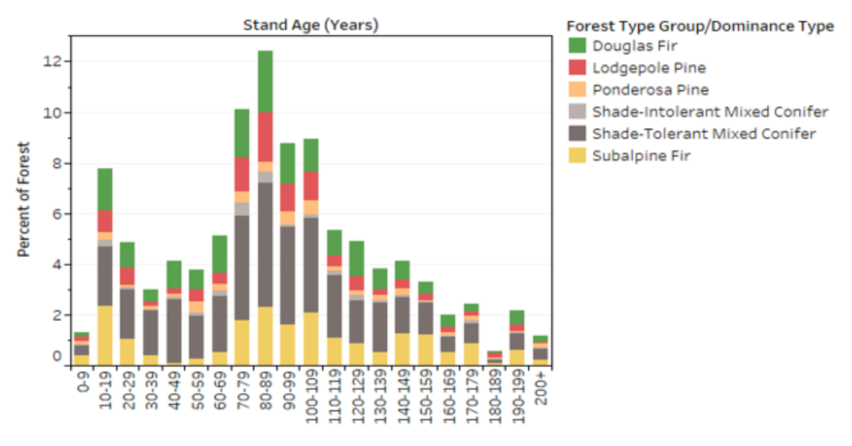
The ForCaMF analysis was conducted over a relatively short time. After a forest is disturbed, it will eventually regrow and recover the carbon removed from the ecosystem. However, several decades may be needed to recover the carbon removed depending on the type of the disturbance, as well as the conditions prior the disturbance (for example, forest type and amount of carbon) (Wear et al. 2013). The ForCaMF model also does not track carbon stored in harvested wood after it leaves the forest ecosystem. In some cases, removing carbon from forests for human use can result in lower net contributions of greenhouse gases to the atmosphere than if the forest was not managed, when accounting for the carbon stored in wood products, substitution effects, and forest regrowth (Lippke et al. 2011, McKinley et al. 2011, Skog et al. 2014, Dugan et al. 2018). Therefore, the IPCC recognizes wood as a renewable resource that can provide a mitigation benefit to climate change (Intergovernmental Panel on Climate Change 2000).

ForCaMF helps to identify the biggest local influences on continued carbon storage and puts the recent effects of those influences into perspective. Factors, such as stand age, drought, and climate, may affect overall carbon change in ways that are independent of disturbance trends. The purpose of the InTEC model was to reconcile recent disturbance impacts with these other factors.

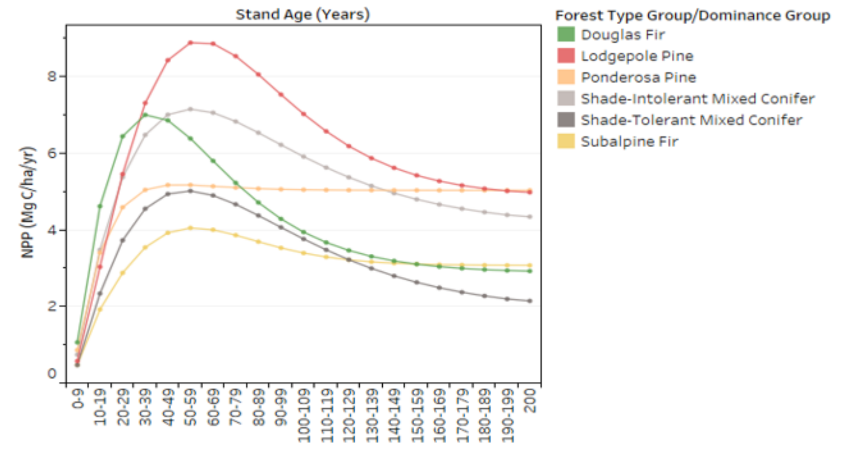
Effects of Forest Aging

InTEC models the collective effects of forest disturbances and management, aging, mortality, and subsequent regrowth on carbon stocks from 1950 to 2011. The model uses inventory-derived maps of stand age, Landsat-derived disturbance maps (Figure 6), and equations describing the relationship between net primary productivity and stand age. Stand age serves as a proxy for past disturbances and management activities (Pan et al. 2011). In the model, when a forested stand is disturbed by a severe, stand-replacing event, the age of the stand resets to zero and the forest begins to regrow. Thus, peaks of stand establishment can indicate stand-replacing disturbance events that subsequently promoted regeneration.

Stand-age distribution for the Nez Perce-Clearwater derived from 2011 forest inventory data indicates elevated stand establishment around 1890–1920 (Figure 9a). This period of elevated stand regeneration came after decades of intensive logging and large wildfires in the late 1800s and early half of the 1900s, as well as harvest activities associated with railroad and mining developments. From 1900 to 1939, fires burned approximately 2.3 million acres. The Nez Perce-Clearwater has also experienced a pulse in stand establishment following wildfires in the early 2000s. From 2000 to 2018, fire burned approximately 1.5 million acres. Stands regrow and recover at different rates depending on forest type and site conditions. Forests are generally most productive when they are young to middle age, then productivity peaks and declines or stabilizes as the forest canopy closes and as the stand experiences increased respiration and mortality of older trees (Pregitzer and Euskirchen 2004, He et al. 2012), as indicated by the in net primary productivity-age curves (Figure 9b), derived in part from Forest Inventory and Analysis (FIA) data.



(a) Stand age distribution in 2011



(b) net primary productivity-stand age curves by forest type group

Figure 9. (a) Stand age distribution in 2011 by dominance type in the Nez Perce-Clearwater and (b) net primary productivity-stand age curves (in megagrams of carbon per hectare per year) by forest type group in the Nez Perce-Clearwater

Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); derived from forest inventory data.

InTEC model results show that Nez Perce-Clearwater was accumulating carbon steadily at the start of the analysis in the 1950s through the mid-1980s (positive slope) (Figure 10) as a result of regrowth following disturbances and heightened productivity of the young to middle-aged forests (30-60 years old). As stand establishment declined and more stands reached slower growth stages around the 1980s, the rate of carbon accumulation declined (negative slope). Of all the factors modeled in InTEC, forest regrowth and aging following historical disturbances (early 1900s harvesting and land-use change), have collectively been responsible for the majority of carbon accumulation since 1950 in the Nez Perce-Clearwater (Figure 10).

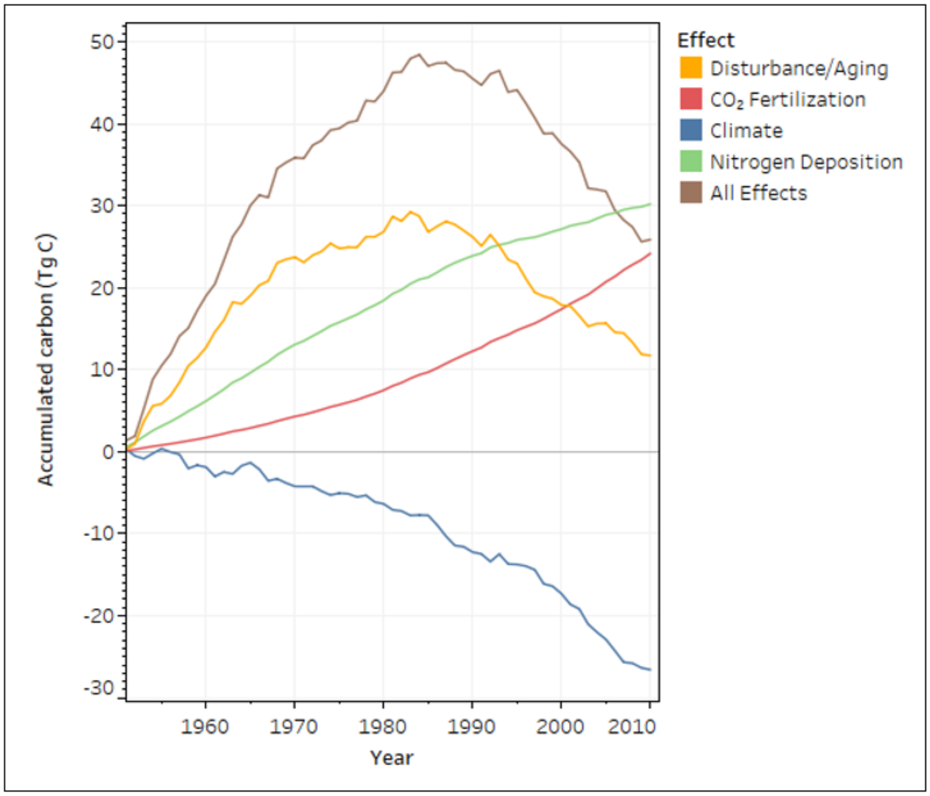


Figure 10. Accumulated carbon (in teragrams) in the Nez Perce-Clearwater due to disturbance and aging, climate, nitrogen deposition, carbon dioxide fertilization, and all factors combined (shown in brown line) for 1950–2011, excluding carbon accumulated pre-1950

Data Source: Nez Perce-Clearwater Carbon Dashboard Report, pulled 8/29/2019 (see the project record, USDA, 2019); estimated using the Integrated Terrestrial Ecosystem Carbon model.

Effects of Climate and Environment

The InTEC model also isolates the effects of climate (temperature and precipitation), atmospheric carbon dioxide concentrations, and nitrogen deposition on forest carbon stock change and accumulation. Generally annual precipitation and temperature conditions fluctuate considerably. The modeled effects of variability in temperature and precipitation on carbon stocks has varied from year-to-year, but, overall, climate since 1950 has negatively affected carbon stocks in the Nez Perce-Clearwater relative to other factors (Figure 10). Warmer temperatures can increase forest carbon emissions through enhanced soil microbial activity and higher respiration (Ju et al. 2007, Melillo et al. 2017), but warming temperatures can also reduce soil moisture through increased evapotranspiration, causing lower forest growth (Xu et al. 2013).

In addition to climate, the availability of carbon dioxide and nitrogen can alter forest growth rates and subsequent carbon uptake and accumulation (Caspersen et al. 2000, Pan et al. 2009). Increased fossil fuel combustion, expansion of agriculture, and urbanization have caused a significant increase in both carbon dioxide and nitrogen emissions (Chen et al. 2000, Zhang et al. 2012). According to the InTEC model, higher carbon dioxide has consistently had a positive effect on carbon stocks in the Nez Perce-Clearwater, tracking an increase in atmospheric carbon dioxide concentrations worldwide (Figure 10). However, a precise quantification of the magnitude of this carbon dioxide effect on terrestrial carbon storage is one of the more uncertain factors in ecosystem modeling (Jones et al. 2014, Zhang et al. 2015). Long-term studies examining increased atmospheric carbon dioxide show that forests initially respond with higher productivity and growth, but the effect is greatly diminished or lost within 5 years in most forests (Zhu et al. 2016). There has been considerable debate regarding the effects of elevated carbon dioxide on forest growth and biomass accumulation, thus warranting additional study (Korner et al. 2005, Norby et al. 2010, Zhu et al. 2016).

Modeled estimates suggest that overall nitrogen deposition had a positive effect on carbon accumulation in the Nez Perce-Clearwater (Figure 10). Like carbon dioxide, the actual magnitude of this effect remains uncertain. Elevated nitrogen deposition can also decrease growth in some species for a variety of reasons, such as leaching of base cations in the soil, increased vulnerability to secondary stressors, and suppression by more competitive species (Pardo et al. 2011). The InTEC model simulated that rates of carbon accumulation associated with nitrogen deposition decreased as deposition rates declined. Overall, the InTEC model suggests that carbon dioxide and nitrogen fertilization partially offset the declines in carbon accumulation associated with historical disturbance, aging, and regrowth, and climate.

Uncertainty Associated with Disturbance Effects and Environmental Factors

As with the baseline estimates, there is also uncertainty associated with estimates of the relative effects of disturbances, aging, and environmental factors on forest carbon trends. For example, omission, commission, and attribution errors may exist in the remotely sensed disturbance maps used in the ForCaMF and InTEC models. However, these errors are not expected to be significant given that the maps were manually verified, rather than solely derived from automated methods. ForCaMF results may also incorporate errors from the inventory data and the FVS-derived carbon accumulation functions (Raymond et al. 2015). To quantify uncertainties, the ForCaMF model employed a Monte Carlo-based approach to supply 95 percent confidence intervals around estimates (Healey et al. 2014).

Uncertainty analyses, such as the Monte Carlo, are not commonly conducted for spatially explicit, process-based models like InTEC because of significant computational requirements. However, process-based models are known to have considerable uncertainty, particularly in the parameter values used to represent complex ecosystem processes (Zaehle et al. 2005). InTEC is highly calibrated to Forest Inventory and Analysis (FIA) data and remotely sensed observations of disturbance and productivity, so uncertainties in these datasets are also propagated into the InTEC estimates. National-scale sensitivity analyses of InTEC inputs and assumptions (Schimel et al. 2015), as well as calibration with observational datasets (Zhang et al. 2012) suggest that model results produce a reasonable range of estimates of the total effect (for example, Figure 10, “all effects” line). However, the relative partitioning of the effects of disturbance and non-disturbance factors as well as uncertainties at finer scales (for example, national forest scale) are likely to be considerably higher.

Results from the ForCaMF and InTEC models may differ substantially from baseline estimates (CCT), given the application of different datasets, modeling approaches, and parameters (Zhang et al. 2012). The baseline estimates are almost entirely rooted in empirical forest inventory data, whereas ForCaMF and InTEC involve additional data inputs and modeling complexity beyond summarizing ground data.

Carbon on Non-forest Lands

The Nez Perce-Clearwater contains 132,457 hectares of non-National Forest System lands. Grasslands, shrublands, and riparian and wetland areas cover most of these lands, accounting for approximately 8 percent of the total area on the national forest. The vast majority of the carbon in these non-forest systems, such as grasslands and shrublands, is stored belowground in soil and plant roots (McKinley and

Blair 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.

Many grasslands are highly dependent on frequent fire and grazing, which temporarily remove above ground vegetation (Knapp et al. 1998). For example, fire suppression and overgrazing are implicated in allowing many grasslands to convert to shrublands with dense woody vegetation by altering wildfire regimes (Van Auken 2009). Replacement of grasslands with woody plants generally tends to increase total ecosystem carbon storage but can alter ecosystem function and structure (McKinley and Blair 2008, Van Auken 2009). Conversely, invasive species, such as cheatgrass (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).

The greatest lasting influence in non-forest ecosystem carbon stocks is land-use and land-cover change. For example, it is generally assumed that federal grassland areas have negligible changes in carbon due to limited land use and management change (U.S. Environmental Protection Agency 2019). Because soil carbon in grasslands is generally stable, substantial changes are typically a result of dramatic changes in land use or vegetation cover that persist indefinitely. The majority of grasslands in the Great Plains have been converted to agricultural use since European settlement, which has led to substantial losses of soil carbon. Like forests, managing the health of grasslands and other non-forest ecosystems and avoiding land use and land cover change are key concerns for maintaining carbon stocks. Land use change generally does not occur on Nez Perce-Clearwater, although there is increasing development on private lands in the region.

Grazing has long played an important role in plant composition and nutrient cycling in many non-forest ecosystems in the Great Plains (Knapp et al. 1998). Large grazing ungulates, including domesticated livestock and bison, produce a variety of greenhouse gas emissions. Livestock and wild ruminates produce methane from enteric fermentation, resulting from their digestive process. Nitrous oxide can be produced as a byproduct from soil microbial processes that chemically transform nitrogen in animal waste. The Environmental Protection Agency (2019) estimates that about 47 percent of the total greenhouse gas emissions in the agricultural sector are attributed to livestock. In turn, the agricultural sector contributes to about 9 percent of total greenhouse gas emissions in the United States. The USDA's National Agricultural Statistics Service estimated in January 2019 that the United States had about 94.8 million cattle (National Agricultural Statistics Service 2019). By comparison, the national forest maintains fewer than 6,000 cows (28,535 animal unit months). However, many of these animals are not typically present on Nez Perce-Clearwater year-round. Active livestock grazing allotments occur on about 15 percent of the Nez Perce-Clearwater.

Future Carbon Conditions

Prospective Forest Aging Effects

The retrospective analyses presented in the previous sections can provide an important basis for understanding how various factors may influence carbon storage in the future. For instance, 59 percent the forests of the Nez Perce-Clearwater are middle-aged and older (greater than 80 years) and 41 percent are younger (Figure 9a). If the national forest continues on this aging trajectory, more stands will reach a slower growth stage in coming years and decades (Figure 9b); however, with 41 percent of the forest containing younger stands, the Nez Perce-Clearwater may see an increase in carbon accumulation in the coming decades as the stands reach maximum productivity, potentially causing Nez Perce-Clearwater to eventually transition to a steady state in the future. Although yield curves indicate that biomass carbon stocks may be approaching maximum levels (Figure 9b), ecosystem carbon stocks can continue to increase for many decades as dead organic matter and soil carbon stocks continue to accumulate (Luyssaert et al. 2008). Furthermore, while past and present aging trends can inform future conditions, the applicability may be limited, because potential changes in management activities or disturbances could affect future stand age and forest growth rates (Davis et al. 2009).

The Resource Planning Act (RPA) assessment (U.S. Department of Agriculture 2016) provides regional projections of forest carbon trends across forestland ownerships in the United States based on a new approach that uses the annual inventory to estimate carbon stocks retrospectively to 1990 and forward to 2060 (Woodall et al. 2015, U.S. Department of Agriculture 2016). The RPA reference scenario assumes forest area in the United States will continue to expand at current rates until 2022, when it will begin to decline due to land use change. However, national forests tend to have higher carbon densities than private lands and may have land management objectives and practices that differ from those on other lands.

The Resource Planning Act's Rocky Mountain Region is equivalent to a combination of the Forest Service's Northern, Rocky Mountain, Intermountain West, and Southwest Region boundaries but includes all land ownerships. Their projections indicate that the rate of carbon sequestration will decline fairly rapidly in the 2020s mostly due to the loss of forestland (land-use transfer), causing the region's forests to shift to a carbon source. The net sequestration rate is also projected to decline slightly further, resulting in a shift to a carbon source (Figure 11). At the global and national scales, changes in land use—especially the conversion of forests to non-forest land (deforestation)—have a substantial effect on carbon stocks (Pan et al. 2011, Houghton et al. 2012). Converting forest land to a non-forest use removes a large amount of carbon from the forest and inhibits future carbon sequestration. National forests tend to experience low rates of land-use change, and forest land area is not expected to change substantially within the Nez Perce-Clearwater in the future. Therefore, on National Forest System lands, the projected carbon trends may closely resemble the "net sequestration" trend in Figure 11, which isolates the effects of forest aging, disturbance, mortality, and growth from land-use transfers and indicates a decline and then stabilization in the rate of net carbon sequestration through 2060.

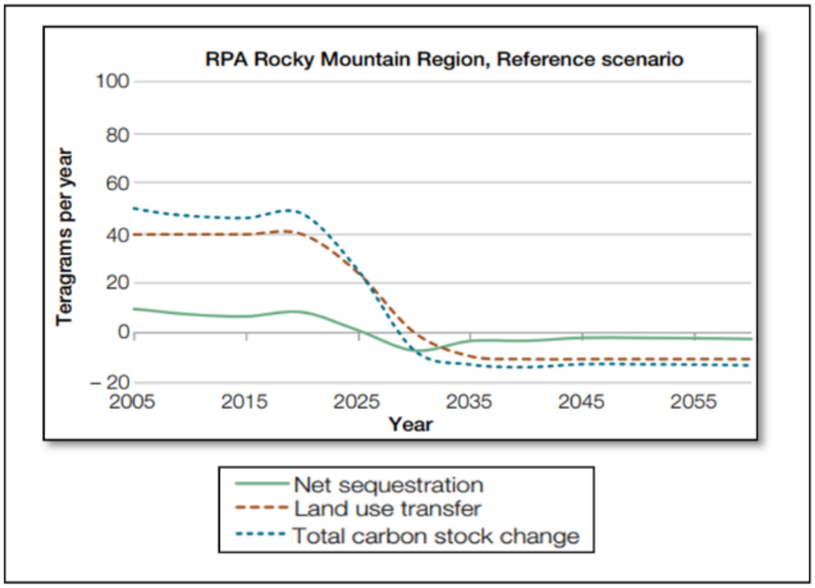


Figure 11. Projections of forest carbon stock changes in the North Region[1] for the RPA reference scenario[2]

1Equivalent to a combination of the Forest Service's Northern, Rocky Mountain, Intermountain West, and Southwest Region boundaries, but includes all land tenures.
2Net sequestration of forests is the total carbon stock change minus losses associated with land-use change.
Data Source: The Resource Planning Act (RPA) assessment (U.S. Department of Agriculture 2016)

Prospective Climate and Environmental Effects

The observational evidence described above and in previous sections highlights the role of natural forest development and succession as the major driver of historic and current forest carbon sequestration that is occurring on the Nez Perce-Clearwater and elsewhere across the region. Climate change introduces additional uncertainty about how forests—and forest carbon sequestration and storage—may change in the future. Climate change causes many direct alterations of the local environment, such as changes in temperature and precipitation, and it has indirect effects on a wide range of ecosystem processes (Vose et al. 2012). Further, disturbance rates are projected to increase with climate change (Vose et al. 2018), making it challenging to use past trends to project the effects of disturbance and aging on forest carbon dynamics.

A climate change vulnerability assessment for the Northern Rockies (Halofsky et al. 2018a;b), which encompasses the Nez Perce-Clearwater in the Western Rockies Subregion, describes projected changes in forest ecosystems through the end of the twenty-first century that could affect forest productivity and, ultimately, carbon sequestration and storage. Climate change is expected to cause temperatures to continue to rise in all seasons, increasing mean temperatures as well as the frequency of heat waves. Average warming across the five Northern Region Adaptation Partnership subregions is projected to be about 4 to 5 °F by 2050, depending on greenhouse gas emissions (Halofsky et al. 2018a;b). Growing season length is expected to increase by several weeks under various climate scenarios, and a longer growing season may enhance forest growth and carbon sequestration, where water supply is adequate and temperatures do not exceed biological thresholds (McMahon et al. 2010, Halofsky et al. 2018a;b). Seasonal precipitation is projected to be slightly higher in winter and spring, and slightly lower in summer than during the historical period of record (Halofsky et al. 2018a;b).

Elevated temperatures may increase soil respiration and reduce soil moisture through increased evapotranspiration, which would negatively affect growth rates and carbon accumulation (Ju et al. 2007, Melillo et al. 2017). Modeled results of recent climate effects using the InTEC model indicate that years with elevated temperatures have generally had a negative effect on carbon uptake in the Nez Perce-Clearwater (Figure 10). Although a longer growing season may increase annual biomass accumulation, droughts could offset these potential growth enhancements and increase the potential for other forest stressors, such as fires. Drought-stressed trees may also be more susceptible to insects and pathogens, which can significantly reduce carbon uptake (Kurz et al. 2008, D'Amato et al. 2011).

Changes in climate are expected to drive many other changes in forests through the next century, including changes in forest establishment and composition (Halofsky et al. 2018a;b). Altered temperature, precipitation, and growing season may affect the ability of some species to germinate and regenerate (Walck et al. 2011, Anderson-Teixeira et al. 2013, Petrie et al. 2017). Some northern tree species are expected to be particularly vulnerable in the future as climate conditions drive declines or failures in species establishment or habitat suitability (Halofsky et al. 2018a;b).

Vulnerability assessments suggest that many conifer species, including western white pine, western larch, whitebark pine, western red cedar, and western hemlock, are vulnerable to climate change. The potential for future declines may increase the risk of carbon losses in forest communities dominated by these species, particularly under scenarios of greater warming and increased fires (Halofsky et al. 2018a;b). Climate-driven failures in species establishment further reduce the ability of forests to recover carbon lost after mortality-inducing events or harvests. Although future climate conditions also allow for other future-adapted species to increase, there is greater uncertainty about how well these species will be able to take advantage of new niches that may become available (Duveneck et al. 2017, Iverson et al. 2017).

Carbon dioxide emissions are projected to increase through 2100 under even the most conservative emission scenarios (Intergovernmental Panel on Climate Change 2014). Several models, including the InTEC model (Figure 10), project greater increases in forest productivity when the carbon dioxide fertilization effect is included in modeling (Aber et al. 1995, Ollinger et al. 2008, Pan et al. 2009, Zhang et al. 2012). However, the effect of increasing levels of atmospheric carbon dioxide on forest productivity is transient and can be limited by the availability of nitrogen and other nutrients (Norby et al. 2010). Productivity increases under elevated carbon dioxide could be offset by losses from climate-related stress or disturbance.

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 to novel future conditions. The effects of future conditions on forest carbon dynamics may change over time. As climate change persists for several decades, critical thresholds may be exceeded, causing unanticipated responses to some variables like increasing temperature and carbon dioxide concentrations. The effects of changing conditions will almost certainly vary by species and forest type. Some factors may enhance forest growth and carbon uptake, whereas others may hinder the ability of forests to act as a carbon sink, potentially causing various influences to offset each other. Thus, it will be important for forest managers to continue to monitor forest responses to these changes and potentially alter management activities to better enable forests to better adapt to future conditions.

Summary

Forests in the Nez Perce-Clearwater are maintaining a carbon sink (see Figure 1 through Figure 4). Forest carbon stocks increased by about 17 percent for the Nez Perce-Clearwater between 1990 and 2013, and negative impacts on carbon stocks caused by disturbances and environmental conditions have been modest and exceeded by forest growth. According to satellite imagery, fires and disease, followed by timber harvest, have been the most prevalent disturbance detected on Nez Perce-Clearwater since 1990 (See Figure 6 through Figure 8). Fire disturbances during this time period were variable in terms of severity. Although, disturbance has played an important role for ecosystem integrity during this period forest carbon losses associated with the disturbances have been small compared to the total amount of carbon stored in the national forest, resulting in a loss of about 3.6 percent of non-soil carbon from 1990 to 2011 (See Table 3). These estimates represent an upper bound because they do not account for continued storage of harvested carbon in wood products or the effect of substitution. Carbon storage in harvested wood products sourced from national forests increased since the early 1900s. Recent declines in timber harvesting have slowed the rate of carbon accumulation in the product sector.

The biggest influence on current carbon dynamics on the Nez Perce-Clearwater is wildfire. If wildfire increases in frequency and in extent (as projected), it will keep forests in young age classes with less potential for carbon storage but higher potential for carbon uptake. Carbon will accumulate as forests age during the long intervals between disturbance events such as wildfire and disease outbreaks, however the probability of disturbance occurring increases over time. Thus, forests will eventually release stored carbon to the atmosphere, regardless of management activities designed to limit disturbance magnitudes. In disturbance prone forest such as the Nez Perce-Clearwater, the net carbon balance is zero over a long period of time, unless structural or functional ecosystem shifts occur, due to climate change influences (Halofsky et al. 2018a;b).

Climate and environmental factors, including elevated atmospheric carbon dioxide and nitrogen deposition, have also influenced carbon accumulation on the Nez Perce-Clearwater (See Figure 10). 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 due to historical disturbances, aging, and climate. The effects of future climate conditions are complex and remain uncertain. However, under changing climate and environmental conditions, forests of the Nez Perce-Clearwater may be increasingly vulnerable to a variety of stressors. These potentially negative effects might be balanced somewhat by the positive effects of a longer growing season, greater precipitation, and elevated atmospheric carbon dioxide concentrations. However, it is difficult to judge how these factors and their interactions will affect future carbon dynamics on the Nez Perce-Clearwater.

The forested area on the Nez Perce-Clearwater will be maintained as forest in the foreseeable future, which will allow for a continuation of carbon uptake and storage over the long term. Across the broader region, land conversion for development on private ownerships is a concern (Shifley and Moser 2016) and this activity can cause carbon losses (Chaplin-Kramer et al. 2015). The Nez Perce-Clearwater will continue to have an important role in maintaining the carbon sink, regionally and nationally, for decades to come.

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