Carbon

Introduction

Research strongly suggests that global average temperature is increasing. Most of the observed 20th-century increase is related to rising atmospheric concentrations of greenhouse gases, including carbon dioxide. Forests worldwide contribute greatly to the global carbon cycle by taking up and storing about 1.4 billion metric tonnes of carbon every year (McKinley et al. 2011), and forests already store over one trillion metric tonnes of carbon [1] in plants and soil (Domke 2018). Forest management can play an important role in moderating the amount of carbon dioxide that enters and leaves the atmosphere (Ryan et al. 2010; McKinley et al. 2011; Skog et al. 2014).

In response to this evidence, the Nantahala-Pisgah National Forest (N-PNF) has identified carbon uptake and storage and accompanying potential climate regulation as a key ecosystem service. This section of the environmental impact statement (EIS) analyzes past, present, and future conditions and factors influencing carbon dynamics on the N-PNF.

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Carbon uptake and storage are among the many ecosystem services provided by forests. Through photosynthesis, growing plants remove carbon dioxide (CO_2) from the atmosphere and store it in forest biomass, such as in plant stems, branches, foliage, and roots. Some of this organic material is eventually stored in forest soils through biotic and abiotic processes. This absorption and storage of carbon by plants from the atmosphere modulates GHG concentrations in the atmosphere. The rate of carbon removal by plants from the atmosphere is influenced by many factors, including natural disturbances, management, forest age and successional pathways, climate and environmental factors, and availability of nutrients and water.

Forests both take up carbon and release it into the atmosphere. Forests are dynamic systems that naturally undergo ebbs and flows in carbon storage and emissions as trees establish and grow, die with age or disturbances, and re-establish and regrow. Management activities, such as timber harvests and prescribed fire, tend to approximate and promote natural processes that would also release carbon to the atmosphere. Many management activities initially remove carbon from the forest ecosystem, but they can also result in long-term maintenance or increases in forest carbon uptake and storage by improving forest health and resilience to various types of stressors. Carbon can also be transferred and stored outside of the forest system in the form of wood products, further influencing the amount of carbon entering the atmosphere. Wood fiber can substitute for products that generate more GHG emissions to produce, such as concrete and steel, and it may be used as a renewable energy source ("substitution effect"). Substitution of wood for fossil-fuel intensive materials and energy can lower net carbon emissions.

Regulatory framework

No applicable legal or regulatory requirements or established thresholds exist for management of forest carbon or GHG emissions. The 2012 Planning Rule and Final Directives requires an assessment of

[1] Carbon mass is used here, not CO_2 mass, because carbon is a standard unit and can easily be converted to any other unit. To convert carbon mass to CO_2 mass, multiply by 3.67 to account for the mass of the O_2.

baseline carbon stocks and a consideration of this information in management of the national forests (Forest Service Handbook 1909.12.4).

Methodology and analysis process

Key indicators:

- Carbon pools (carbon stocks) and carbon uptake
- Natural and human-caused influences on carbon stocks and carbon uptake

Analysis process and information sources

This section summarizes the Forest Carbon Assessment for the Nantahala-Pisgah National Forest (Dugan and McKinley 2018). The carbon assessment draws largely from two recent U.S. Forest Service reports: the Baseline Report (USDA Forest Service 2015) and the Disturbance Report (USDA Forest Service, in review). Together they provide the best available quantitative assessment of forest carbon stocks, harvested wood products stocks, and the factors that influence carbon dynamics on the N-PNF. The primary sources to evaluate potential future conditions and the impacts of climate change on forest carbon dynamics were the Resource Planning Act (RPA) assessment (USDA Forest Service 2016) and a regional vulnerability assessment (McNulty et al. 2015).

The RPA and regional vulnerability assessments used here characterize the affected environment and assess potential environmental consequences of management alternatives on carbon dynamics. They incorporate advances in data and analytical methods and collectively represent the best and most relevant scientific information available for the N-PNF. These resources were explicitly selected for their consistent reliance on Forest Inventory and Analysis (FIA) data, which contains statistically valid sampling of ground-truthed monitoring data. They also use validated (peer-reviewed) modeling tools that integrate current remotely sensed and high-resolution products (e.g., Healey et al. 2018) with FIA data (Dugan et al. 2017; Dugan and McKinley 2018).

Analysis area and scale

The spatial scale of this analysis includes the forested lands of the Nantahala-Pisgah National Forest. The N-PNF was administratively combined with the Uwharrie and Croatan National Forests to form a single administrative unit, the National Forests in North Carolina (NFs in NC). Therefore, some of the model results presented here, including estimates of carbon stocks and impacts of disturbances and other factors, are available only for combined NFs in NC or at the regional scale. The N-PNF accounts for about 80 percent (about one million acres) of the forested area in the NFs in NC. [2] Thus, the available information is a reasonable representation of the carbon trends and factors impacting carbon on the N-PNF.

Relative to the contribution of all the world's forests to carbon flux, the influence of the N-PNF is extremely small, so a meaningful analysis at the global scale is not practical. However, national and regional factors related to forests' influence on carbon dynamics are included here to provide context for the nature of the local effects of N-PNF.

The temporal scale for analyzing carbon socks and emissions focuses on the expected lifespan of the plan (10-15 years). However, this report includes analysis and discussion beyond this expected lifespan to

[2] This estimate is derived from the most recent FIA survey data available in FIA EVALIDator (https://apps.fs.usda.gov/Evalidator/evalidator.jsp).

provide context for potential forest carbon dynamics and factors influencing these dynamics in the future. Considering factors beyond the plan period is important because this plan covers only part of the life cycle of the forest.

The Forest Service is committed to using the best available information to support management decisions. In general, this means relying upon sources that are data-driven, locally calibrated, and consistent over both time and space. However, estimates of future carbon stocks (i.e., stored carbon) and their trajectory over time remain unclear because of uncertainty from the multiple interacting factors that influence carbon dynamics. These factors include environmental changes and changes in climate that affect the health, productivity, and diversity of forests. Although advances in research have helped to account for and document the relationship between GHG and global climate change, it remains difficult to reliably simulate observed temperature changes and distinguish between natural or human causes at smaller than continental scales (IPCC 2007).

Affected Environment

Carbon Stocks and Influences

Forests in the NFs in NC are maintaining a carbon sink; carbon stocks increased by 15 percent from 1990 (79.1±7.1 teragrams of carbon [Tg C])[3] to 2013 (91.1±11.3 Tg C) (Fig. 1). This increase indicates that negative impacts on carbon stocks caused by disturbances and environmental conditions have been modest and exceeded by forest growth. Most forest carbon stocks in the NFs in NC, About 47 percent, are stored in the aboveground portion of live trees. The second largest carbon pool is soil carbon, storing another 32 percent.

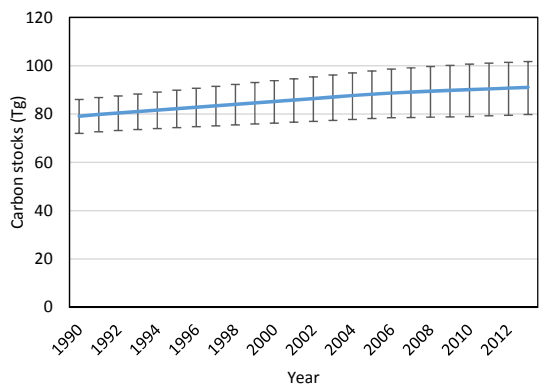

Figure 1. *Total forest carbon stocks for the baseline period 1990 to 2013 for National Forests in North Carolina bounded by 95 percent confidence intervals (error bars).*

The N-PNF contains about 73 Tg of carbon.[2] Forest carbon trends on the N-PNF were influenced by were timber harvesting, fire, legacy effects of historical management, as well as climate and environmental factors. According to satellite imagery, the most prevalent disturbance during this period was timber harvesting. However, harvests were relatively small, affecting on average just 0.07 percent of the N-PNFs forested area annually (Fig. 2). About half of all timber harvests since 1990 were characterized as

[3] This report uses carbon mass, not CO_2 mass, because carbon is a standard unit and can easily be converted to any other unit. To convert carbon mass to CO_2 mass, multiply by 3.67 to account for the mass of the O_2.
1,000 teragrams (Tg) =1 petagram (Pg)
1,000 teragrams = 1 billion metric tonnes
1,000 teragrams = 1 gigatonne
1 teragram = 1 million metric tonnes
1 megagram (Mg) = 1 metric tonne
1 metric tonne per hectare = 0.4 U.S. long tons per acre
carbon (C) mass * 3.67 = carbon dioxide (CO_2) mass

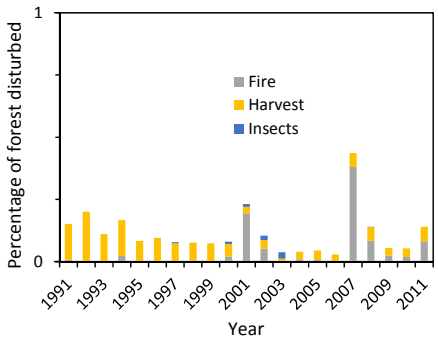

Figure 2. *Percentage of the forested area disturbed in the Nantahala-Pisqah National Forest by harvests, insects, and fire.*

low-intensity, resulting in less than a 25 percent reduction in canopy cover. Forest carbon losses associated with harvests have been small compared to the total amount of carbon stored in the NFs in NC, resulting in a loss of about 0.57 metric tonnes per acre (2.5 percent) of non-soil carbon from 1990 to 2011 (Fig. 3). However, these estimates do not account for either continued storage of harvested carbon in wood products or the effect of substitution. Carbon storage in harvested wood products (HWPs) and landfills has increased across all national forests in the southeastern United States since the early 1900s. However, recent declines in timber harvesting have slowed the rate of carbon accumulation in the product sector.

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The second most common disturbance on the N-PNF during 1990-2011 was fire, affecting on average 0.06 percent of forested area annually. The area affected by fires (wildfires and prescribed) increased over this period (Fig. 2). Some prescribed fires may have been undetected because they did not cause a change in canopy cover and instead just burned along the forest floor with very low intensity. Overall, fires detected over this 21-year period resulted in the loss of approximately 0.21 metric tonnes per acre (0.96 percent) of non-soil carbon (Fig. 3).

The greatest influence on current carbon dynamics on the N-PNF is the legacy of intensive timber harvesting and land clearing for agriculture throughout the 19th century, followed by a period of forest recovery in the early to mid-20th century. As a result, stands on the N-PNF are mostly middle-aged and older (Fig. 3). Although older forests store more carbon and can continue to take up significant amounts of carbon even as they age, the rate of carbon uptake generally declines as forests age. Therefore, in coming decades, aging stands on the N-PNF may have lower rates of carbon accumulation, although stocks are projected to continue to increase above current levels. Projections from the RPA assessment also indicate that forests under all land ownerships in the Southern region are experiencing a potential age-related decline in the rate of carbon accumulation that will continue through 2060.

Climate and environmental factors, including elevated atmospheric CO_2 and nitrogen deposition, have also influenced carbon accumulation on the N-PNF. Of the disturbance and non-disturbance factors assessed during 1990-2011, climate had both the least and most variable impacts on forest carbon accumulation. Recent warmer temperatures and precipitation variability may have stressed forests, causing climate to have a negative impact on carbon accumulation since the 1990s. Conversely, increased atmospheric CO_2 and nitrogen deposition have potentially enhanced growth rates and helped to counteract ecosystem carbon losses from disturbance, aging, and climate.

The effects of future climate conditions are complex and uncertain. However, under changing climate and environmental conditions, forests of the N-PNF may be at increasing risk of many stressors, including moisture stress, extreme temperatures and weather events, insects and diseases, and the spread of invasive species. These potentially negative effects might be offset somewhat by the positive effects of longer growing season, more precipitation, and elevated atmospheric CO_2 concentrations. However, it is difficult to judge the effects of these factors and their interactions on future carbon dynamics of the N-PNF.

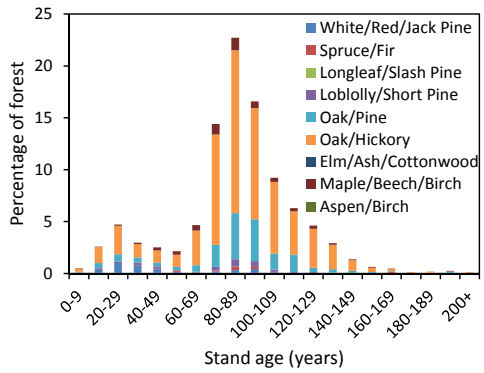

***Figure 3**. Stand age distribution in 2011 by forest type groups in the Nantahala-Pisgah National Forest.*

The population in the region is growing, and some conversion of forested lands to non-forest purposes is likely to occur on private lands adjacent to and near the N-PNF. Converting forest land to a non-forest use removes a very large amount of carbon from the forest and inhibit future carbon storage, because regrowth is inhibited. However, national forests tend to experience low rates of land-use change, and thus, forest land acreage is not expected to change substantially within the N-PNF in the future. Forested area on the N-PNF will be maintained as forest into the foreseeable future, which will allow a long-term continuation of carbon uptake and storage.

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Environmental Consequences

Background

The forests on the N-PNF take up and store more carbon than they lose through disturbances and management activities combined (see Affected Environment). All of the proposed management activities would initially reduce carbon stocks on the forest. However, these short-term losses and emissions are very small relative to both the total carbon stocks on the forest and national and global emissions. Further, the proposed activities would generally maintain and improve forest health and supply wood for forest products. The initial negative carbon effects would be mitigated or even reversed with time, reducing the potential for negative cumulative effects. The N-PNF will continue to be managed to maintain forests as forests to maintain many ecosystem services and co-benefits, including carbon uptake and storage.

All plan alternatives, including the no-action alternative, use the same suite of management tools and silviculture treatments to achieve desired conditions. These alternatives consist of the following treatments: 1) harvests – to regenerate specific stands and create new age classes; 2) thinning – to reduce stand densities; 3) prescribed fires – to reduce fuel loads, generate young forests conditions, and promote more natural fire-return intervals. Although management strategies are designed to support a wide array of ecosystem services and conditions (e.g., wildlife habitat, resilience to environmental change), they can also have secondary, and often desirable, consequences for carbon. The following

management strategies are incorporated into forest plan direction under all alternatives that also influence carbon uptake and storage potential:

- Manipulate the forest to provide for new young forest conditions to support wildlife habitat. This can cause a decline in carbon stocks, but compared with older stands, doing so promotes relatively high rates of carbon uptake over time as forests regrow (Pregitzer and Euskirchen 2004).
- Enhance or accelerate the development of old-growth conditions to support higher carbon stocks in mature forests compared with younger stands (Harmon et al. 1990).
- Decrease forest densities and fuel conditions to reduce the risk of large, stand-replacing disturbance from insect, disease, and fire. Although this strategy initially reduces carbon stocks, it can lower risk for greater carbon stock losses and emissions in the future (Wiedinmyer and Hurteau 2010).
- Ensure successful reforestation after harvest or mortality-inducing disturbances to ensure continued carbon uptake and storage (IPCC 2014).
- Promote desired composition, structure, function, and pattern (ecological integrity) to support long-term carbon uptake and storage in the face of changing environmental conditions (Millar et al. 2007).
- Use harvested wood for valuable and renewable products to store carbon over the long-term and substitute for energy-intensive materials or fuels, reducing the net amount of carbon emissions into the atmosphere (Lippke et al. 2011).

All action alternatives provide the same desired conditions for terrestrial ecosystems, and the standards and guidelines that help achieve or maintain those conditions. Specifically, all plan alternatives seek to do the following: maintain existing grass, forb and shrub openings, establish young forest conditions, provide for open forest woodland, develop old-growth conditions, improve composition, structure, and function of forest stands, restore fire-adapted ecozones, restore and enhance spruce fir and mesic ecozones, and provide for stable and improved forest health conditions. Using management activities to achieve this desired mix of conditions will enhance the overall ecological integrity of the forest ecosystems, improving their ability to adapt to potential stressors. These proposed activities will help maintain critical ecosystem functions into the future, in part by balancing the maintenance of carbon stocks and rates of carbon uptake.

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Potential effects

In a global atmospheric CO_2 context, even the maximum potential management levels described by the plan alternatives would have a negligible impact on national and global emissions and on forest carbon stocks, for reasons described below. As in this case, when impacts on carbon emissions (and forest carbon stocks) are small, a quantitative analysis of carbon effects is not warranted and thus is not meaningful for a reasoned choice among plan alternatives (USDA Forest Service 2009).

Carbon fluxes resulting in forest carbon accumulation and loss from forested ecosystems are difficult to measure because of ecological complexity and many sources of uncertainty. Even more difficult is the ability to quantify potential carbon consequences of management alternatives in the future; this is because of variation in possible future climatic conditions, stochasticity in disturbance and weather events, and limitations in data and modeling tools. The result of such variability is often a very low signal-to-noise ratio: small differences in carbon impacts among management alternatives, coupled with

high uncertainty with estimates of carbon stocks and fluxes, make the detection of statistically meaningful differences among alternatives highly unlikely.

Therefore, rather than focus here on a strict but uncertain quantification of potential future changes in carbon stocks and emissions, potential carbon impacts are discussed qualitatively, with supporting estimates where possible. This is accomplished by drawing on the quantitative analysis of the effects of past management activities on forest carbon stocks and fluxes, as well as through future-looking analysis where available (see Affected Environment).

Description of potential management effects on carbon

Forest management activities, such as the harvests, thinning, and prescribed fires proposed in the plan alternatives, are used to achieve a number of desired conditions. One goal is to make stands and associated carbon stores more resilient to environmental change. This is done by managing forests to approximate natural processes and disturbances that reduce stand density and promote regeneration (McKinley et al. 2011). Both natural and human-caused disturbances tend to reduce carbon stocks and increase carbon emissions for some time following the disturbance. Generally, the goal of the plan is to create heterogeneous forests with a mix of both younger and older stands. Doing so would further enhance ecological integrity by providing for more diverse ecosystem services and a more natural ecosystem structure and function.

The actions proposed by the plan have different effects on carbon over time. The proposed actions will initially decrease carbon stocks and cause carbon emissions. However, these effects will be very small and transitory. The initial small adverse effects on carbon by these proposed actions will likely be balanced, and possibly eliminated or reversed, in a relatively short time. Negative effects will be offset when the forest stands in the proposed managed area regenerate and recover, as well as by facilitating carbon storage in HWPs. The plan also describes goals to restore natural forest structure, improve forest health, maintain and promote ecosystem services, and enhance adaptation to more severe disturbances, which will help sustain carbon uptake and continued carbon storage over the long term (Millar et al. 2007; D'Amato et al. 2011).

One management goal is to enhance the development of old-growth conditions. This would be accomplished through activities such as retaining downed woody debris and snags, creating woodlands by thinning or prescribed burning, and enhancing native species by removing nonnative vegetation and using it in wood products. Older forest stands are desirable because they provide a range of ecosystem services, including storing more carbon than do younger stands. However, depending on forest type, rates of carbon uptake are typically lower than in younger to middle-aged stands. The current stand-age structure on the N-PNF indicates that these forests are mostly middle-aged and older (Fig. 3). If disturbance and management regimes follow the same trends since 1990 (Fig. 2), the forests of N-PNF will continue to age. As the forests age, rates of carbon uptake may decline after several decades, but carbon stocks will continue to increase. The RPA assessment projects a similar trend in net carbon sequestration for all land tenures in the southeastern United States. However, in the central and southern Appalachian region, stands treated with periodic low-intensity harvests and thinnings can have higher productivity and carbon uptake due to growth releases (Davis et al. 2009, Keyser and Zarnoch 2012, McNulty et al. 2017), indicating a positive cumulative effect.

Another management goal is to create young forest conditions to produce early successional habitat. This would be accomplished through silvicultural practices that can be used in tandem, such as

harvesting, thinning, and prescribed burns. In the absence of thinning and harvesting, the forest will thin from natural disturbances and other processes associated with natural succession (e.g., age-related mortality, competition). The resulting dead trees will continue to store carbon, and they will also decay over time, emitting carbon into the atmosphere. In the southern and central Appalachian region, clear-cuts and higher-intensity harvests typically result in lower carbon stocks in the short-term but have higher rates of carbon uptake as forest regrow and reach productive ages (Davis et al. 2009, McNulty et al. 2017). However, the plan also includes lower-intensity harvests that will maintain higher forest carbon stocks and promote higher rates of carbon uptake (Keyser and Zarnoch 2012).

Management activities involving timber harvesting and thinning can result in both long-term carbon storage off site and substitution effects through the use of HWPs. Carbon can be stored in wood products for days to centuries, depending on the commodity produced and end use. Just over half of timber sourced from the North Carolina is used for saw and veneer logs (Gray et al. 2017). These types of logs are typically used for longer-lived wood products like building materials and furniture that result in long-term storage of carbon. As more commodities are produced and remain in use, the amount of carbon stored in products increases, creating a cumulative benefit when considered with forest regrowth. Even as more wood products are discarded, the carbon stored in solid waste disposal sites also increases. Harvested wood products can also substitute for more fossil fuel-intensive materials like steel, concrete, and plastic, resulting in a net decline in emissions (Gustavsson et al. 2006, Lippke et al. 2011, McKinley et al. 2011, Dugan et al. 2018). Likewise, harvested wood and discarded wood products can be burned to produce heat or electrical energy (including about 4 percent of roundwood removals in North Carolina), also producing a benefit by substituting for more carbon-producing energy sources. The IPCC recognizes wood and fiber as a renewable resource that can provide lasting climate-related mitigation benefits that with active management can accrue over time (IPCC 2000).

The plan alternatives also propose to continue to use prescribed fire to produce young stand conditions, reduce hazardous fuels, promote fire-adapted species, and encourage natural fire-return intervals. Historical fire suppression has allowed these fire-dependent forests to become unnaturally dense and surface fuels to build up in some areas of the southeast, possibly increasing the risk for wildfires in the N-PNF (Fowler and Konopik 2007). As climate conditions change in the Southeast, warmer temperatures and more frequent and severe droughts are expected to increase, and they may also contribute to increased wildfire risk across forests (McNulty et al. 2015). Consequently the fire-dependent forests (e.g., shortleaf pine, dry mesic oak, pine/oak/heath) in the plan area may be more at risk to more frequent and severe wildfires, resulting in the loss of ecosystem services and potentially increasing carbon emissions and lowering carbon stocks. High-severity fires can also cause the permanent transition of forests to non-forest ecosystems in some circumstances (Roccaforte et al. 2012; Anderson-Teixeira et al. 2013).

Prescribed fires proposed in the plan typically target surface and ladder fuels and are less severe than wildfires (Agee and Skinner 2005), because they are conducted within predetermined conditions. Fire-dependent forest types that are targeted for prescribed burning also typically contain species with thicker bark, which offers protection from heat-related damage. Thus, in some situations, prescribed fires and thinning can lower overstory tree mortality (Carter and Foster 2004, Hurteau and North 2009), potentially reducing amounts of carbon emissions that might be emitted if the same area were to burn in a high-severity wildfire (Wiedinmyer and Hurteau 2010). By promoting natural fire-adapted ecozones through the use of thinning and prescribed burns, thereby reducing the threat of wildfire, the proposed

plan alternatives might create more advantageous conditions to support long-term forest health in a changing climate (adaptation) and reduce carbon emissions and maintain carbon stocks (mitigation) (IPCC 2007).

The proposed alternatives will not convert forest land to non-forest uses. The largest source of GHG emissions in the forestry sector globally and within the United States is deforestation, defined as the removal of all trees on forested land to convert it other land uses. Maintaining forest land is necessary to ensure carbon storage over time and to realize potential carbon benefits from management activities through regrowth. The population of the Southern Appalachian region is growing rapidly, and the conversion of forested lands to non-forest purposes is likely to occur to some degree on private lands adjacent to and near the Forest. However, under all plan alternatives, the forests on the N-PNF would remain as forests. Forests would not be converted to other land uses but rather would be retained and managed to maintain a vigorous and healthy condition. This management goal supports tree growth and productivity, which contributes to long-term carbon uptake and storage. Consequently, the plan alternatives for the N-PNF will not result in major sources of GHG emissions relative to local, national and global emissions and can be important in maintaining forest carbon uptake and storage and other ecosystem services in the region.

Environmental change introduces additional uncertainty about how forests—and forest carbon uptake and storage—may change in the future. For example, over the coming decades, the southeastern United States may experience more intense tropical storms, more extreme heat events, decreased water availability, and larger and more frequent wildfires. Although some environmental conditions might hinder the ability of forests to continue to uptake and store carbon, some might also enhance forest growth and carbon uptake (e.g., CO_2 fertilization, longer growing season).

Potential effects of the no-action alternative (Tier 1)

All proposed plan alternatives focus on achieving the same condition-based objectives to attain specific ecosystem outcomes. Tier 1 seeks to achieve these objectives with the same management capacity and intensity as under the existing plan, which includes about 800 acres treated by timber harvests and thinning and about 2,000 to 4,000 acres of prescribed fire per year. Although less comprehensive as the action alternatives described in Tier 2, this direction would support the N-PNF towards continued resilience at both the stand and landscape scales. Tier 2 would increase the likelihood of sustaining the ability of the N-PNF to take up carbon at higher rates and continue to store carbon in the near and long term.

The effects of actions under Tier 1 would result in a similar pattern of carbon storage and flux as described in the section on Affected Environment, because Tier 1 represents the status quo. For instance, in 1990-2011, harvesting affected about 0.07 percent of the total forested area of the N-PNF per year, mostly in the low-intensity category (0-25 percent change in canopy cover). Ecosystem carbon losses from harvests in 1990-2011 across the NFs in NC totaled 0.57 metric tonnes per acre (0.0271 Tg C acre yr^{-1}) by 2011, or about 2.5 percent of vegetation (non-soil)[4] carbon stocks. Losses of carbon are even smaller, perhaps less than 1 percent, when considering the total ecosystem carbon stocks, which includes soil carbon. For context, during about this same period (1990-2013), total ecosystem stocks in

[4] Estimate is for all National Forests in North Carolina. The N-PNF accounts for about 80 percent of the forested area in the NFs in NC, but only about 41 percent of the harvesting from 1990 to 2011. Thus the effect of harvests on carbon storage on the N-PNF alone likely causes less than a 2 percent decline in non-soil carbon stocks.

the NFs in NC, including the N-PNF, increased by about 15 percent (or 12 Tg C) (Fig. 1), indicating that carbon removed from the ecosystem through harvesting and fires was more than offset during this period by an increase in carbon stocks from forest growth. N-PNF contains about one million acres of forest land. Ecosystem carbon losses from harvests have been about 27,100 metric tonnes (0.027 Tg C) of carbon annually from 1990 to 2011, which is a small fraction of the estimated 73 million metric tonnes of carbon stored on the landscape. When considering product streams and stand regeneration over time, the net effects of harvesting on carbon storage and emissions are likely even more minimal.

The Tier 1 alternative would also achieve the desired conditions of restoring fire-adapted ecozones and lowering hazardous-fuel loads through the use of prescribed fire treatments. Between 1990 and 2011, fires (prescribed and wildfire) on the N-PNF resulted in the estimated loss of about 10,000 metric tonnes of carbon per year, a tiny fraction of the total carbon stocks on the forest. Furthermore, this carbon loss due to fires may represent the upper bounds of estimated carbon losses, because the historical analysis covering 1990-2011 may have included a greater proportion of wildfires (relative to prescribed fires), which typically burn at higher severities and result in greater carbon losses.

Potential effects of action alternative (Tier 2)

Under all action alternatives, the forest management strategies incorporated into the plan direction focus on the goal of maintaining or increasing forest resilience to changing environmental conditions. These action alternatives (Tier 2) seek the same ecosystem outcomes as the no action alternative (Tier 1), but they assume that additional capacity or resources would be available, thus increasing the land base on which to accomplish this work compared with Tier 1. Refer to section XX.XX for a full discussion of the changes in vegetation conditions and treatment areas under each of the action alternatives.

Commented [MDC-5]: References other chapters

Management activities described in Tier 2 represent elevated levels of influence on carbon dynamics compared to what the N-PNF experienced in 1990-2011 (Fig. 3). The maximum treatment area for harvests and thinning under Tier 2 would be about 3,000 to 4,000 acres per year, or about 0.3 to 0.4 percent of total forested area on the N-PNF. This is about a four- or five-fold increase in annual harvest area compared to both Tier 1 (800 acres annually) and past harvest levels in 1990-2011. Assuming that the annual carbon impact also increases up to five times, harvest treatments may result in a maximum removal of about 135,500 metric tonnes (0.13 Tg C) of carbon per year from aboveground pools.[5]

Tier 2 also includes an increase in prescribed burning of up to 17,000 acres annually, or about a four- to nine-fold increase compared to Tier 1. If maximum levels of prescribed burning are achieved, this would result in a potential loss of about 40,000 to 90,000 metric tonnes of carbon annually.[6] However, by reducing hazardous fuels, additional prescribed burning up to maximum levels described in Tier 2 may further reduce the risk of more severe wildfires and greater carbon losses in the future.

Considering the maximum area treated with harvesting and prescribed fire, the amount of carbon that might be removed is small relative to the approximately 73 million metric tonnes (Tg) of carbon stored in the forest ecosystem of N-PNF.[2] With maximum intensification, potential management actions would

[5] Estimate assumes that harvesting in the Tier 2 results in about five times the carbon lost from Tier 1 harvesting. Tier 1 is equivalent to historical levels and realizes a loss of approximately 27,100 metric tonnes of carbon annually. Values are estimated from model results (USDA Forest Service, in review).

[6] Estimate assumes that prescribed burning in Tier 2 results in about four to nine times the carbon lost from prescribed burning under Tier 1. Tier 1 is equivalent to historical levels and realizes a loss of about 10,000 metric tonnes of carbon annually. Values are estimated from model results (USDA Forest Service, in review).

affect up to about 2 percent of the forested area and much less than 1 Tg C annually. Tier 2 alternative will not significantly or adversely affect forest carbon storage, but rather would achieve a more resilient forest condition that will improve the ability of the N-PNF to maintain carbon stocks and enhance carbon uptake, possibly reducing potential carbon emissions in the future.

Discussion of effects

Climate change is a global phenomenon, because major greenhouse gases mix well throughout the planet's lower atmosphere. Estimated emissions of GHGs in 2010 were 13,336 ± 1,227 teragrams carbon globally (IPCC 2014) and 1,881 teragrams carbon nationally (US EPA 2015). All of the plan alternatives are projected to contribute negligibly to overall GHG emissions. The action alternatives are directed at a very small percentage of the total forest land on the N-PNF; even in the near-term, these alternatives would have a minimal direct effects on carbon emissions and carbon stocks relative to total carbon stocks in the N-PNF. Furthermore, considering the proposed actions in a global atmospheric CO_2 context, even the maximum treatment levels would contribute infinitesimally to GHG emissions and therefore would have a negligible effect on GHG emissions and climate change. Moreover, because local GHGs emissions mix readily into the global pool of GHGs, it is difficult and highly uncertain to ascertain the indirect effects of emission from multiple, generally small projects that make up these action alternatives on global climate. At the global and national scales, each of the plan alternatives direct and indirect contribution to GHGs would be negligible.

Because the potential direct and indirect effects of Tier 1 and Tier 2 alternatives would be negligible, the contribution of the plan's proposed actions to cumulative effects on global atmospheric GHG concentrations and climate change would also be negligible. The proposed activities under both Tier 1 and Tier 2 generally maintain and improve forest health and provide for the supply of wood for forest products. Potential negative effects are mitigated and may be completely reversed with time, reducing or eliminating potential negative cumulative effects on carbon. Carbon emitted during the initial implementation of the management actions (e.g., harvest, thinning, prescribed fire) would have a temporary influence on atmospheric carbon concentrations, because carbon would be removed from the atmosphere over time following management as the forest regrows. Over the longer term, the activities proposed in the plan are likely to increase carbon storage and reduce emissions. These net outcomes would be the cumulative result of forest regrowth, enhanced productivity of young stands and growth releases from lightly thinned stands, reduction in the risk of high-severity wildfires, carbon storage off-site in products, and substitution benefits of wood products and wood-based energy (IPCC 2007, McKinley et al. 2011, Keyser and Zarnoch 2012, Bergman et al. 2014, Skog et al. 2014). The management mechanisms applied in all plan alternatives are consistent with internationally recognized climate change adaptation and mitigation practices identified by the IPCC (IPCC 2000, IPCC 2007).

Carbon stocks on the N-PNF will likely continue to increase or remain stable under all plan alternatives in the foreseeable future. Natural ecosystem processes on the N-PNF, including forest growth (succession) and small-scale disturbances (e.g., fire, insects, harvests) will continue to influence carbon stocks and emissions, but they are not expected to significantly change current trends in carbon over the span of the plan. The plan alternatives seek to increase the Forest's resilience to climate change, improve adaptive capacity, and utilize timber for wood products; doing so will also maintain the capacity of forest ecosystems and HWPs to store carbon. All plan alternatives would preserve existing forest lands

and forests by improving forest conditions and retaining forest characteristics by maintaining current land use. Given the likely changes in land use in coming decades on adjacent lands, this is a critical goal.

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