# Helena and Lewis & Clark National Forests

# Forest Plan Assessment

## Chapter 4, Climate Change and Baseline Assessment of Carbon Stocks

2015

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# Climate Change and Baseline Assessment of Carbon Stocks

## Introduction

The 2013 proposed land management directives (FSH 1909.12.31) identify predominant climatic regimes as system drivers, and state that where there is available information the responsible official may consider the influence of changing climate on key ecosystem characteristics and their resulting vulnerability to likely future conditions (FSH 1909.12.32). **Climate change** is a non-random change in climate that is measured over several decades or longer, and may be due to natural internal processes or to external forcings such as changes in solar radiation, large volcanic eruptions, and changing concentrations of greenhouse gases in the atmosphere (FSH 1909.12). The HLC NFs lie at the boundary between the warm, wet, maritime airflows from the Pacific Ocean and the cooler, drier airflows from Canada (USDA Forest Service 2014a). Multiple climate models exist to predict the potential changes in climate. These models show that by the 2040's, mean annual monthly temperatures will likely rise and precipitation may slightly increase (USDA Forest Service 2014a). Natural climate cycles have occurred historically and continue to cause changes in climate. Human activities such as fuel burning, industrial activities, land-use change, animal husbandry, and agriculture lead to increases in ambient greenhouse gases, which contribute to the "greenhouse effect" and also cause temperatures to increase (Melillo et al. 2014).

**Carbon stocks** are the amount or quantity contained in the inventory of a carbon pool. The 2012 planning rule and proposed directives specify that the responsible official shall identify and evaluate available information relevant to the plan area for a baseline assessment of carbon stocks, and to evaluate the information available about current carbon stocks and recent changes in carbon stocks on the land and in harvested wood products (FSH 1909.12.4). The purpose of the carbon baseline assessment is to assess issues associated with climate change, and to assess the role of carbon in maintaining the long-term site productivity in the plan area (36 CFR 219.6(b); FSH 1909.12.4). Per FSH 1909.12.4, the responsible official should use the assessment to understand:

1. How the plan area plays a role in sequestering and storing carbon; and
2. How disturbances, projects, and activities influence carbon stocks in the past and may affect them in the future.

The primary relationship between forests, forest management, and climate change is the role forests play in the atmospheric carbon cycle, as displayed in Figure 4.1. Forests cycle carbon and are in continual flux. Forests remove carbon from the atmosphere through photosynthesis, and sequester it in the form of biomass. Forests emit carbon through respiration and the decay of organic matter. Wildfires release carbon into the atmosphere, and other mortality events such as windthrow and insects also influence the cycle. Soil carbon is linked with site productivity and influences the potential of a site to support vegetation. Carbon is added to the soil through decomposition of litter and woody debris, and may be lost through events such as wildfire or actions such as timber harvest. Over the long-term, through one or more cycles of disturbance and re-growth, net carbon storage is often zero because re-growth of trees recovers the carbon lost in the disturbance and decomposition of vegetation (Ryan et al, 2010; Kashian et al. 2006). Carbon storage and sequestration rates are more stable over large areas that comprise a multitude of forests of different ages; with multiple stands in different stages of recovery after disturbance, some stands provide a carbon "sink" while others act as net "sources" (Ryan et al. 2010). Changes in the frequency or severity of disturbance regimes over large areas can increase or lower the average carbon stocks in forests (Kashian et al. 2006).

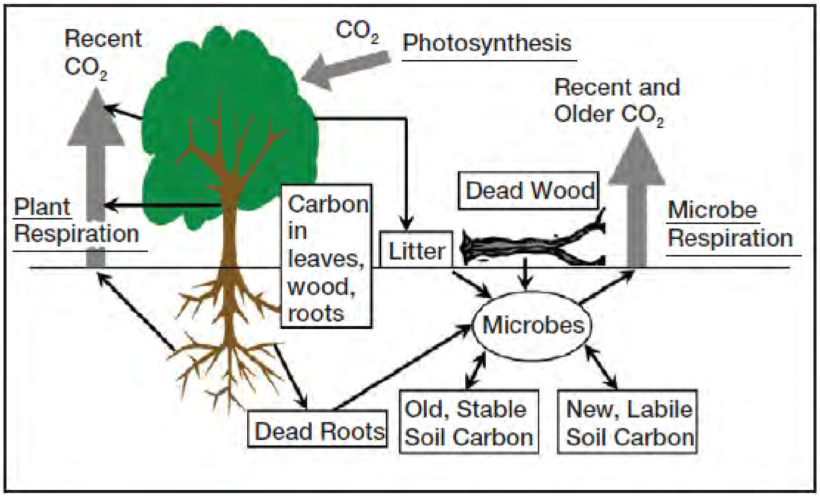

**Figure 4.1 Flows of carbon from the atmosphere to the forest and back in Ryan et al. 2010.**

Carbon sequestration is one way to mitigate greenhouse gas (GHG) emissions by offsetting losses through capture and storage of carbon; therefore, the Forest Service recognizes the vital role that our nation's forests and grasslands play in carbon sequestration (USDA Forest Service 2015).

Please refer to other chapters in this assessment for additional information regarding the effects of climate change to specific resources.

## Existing Information

An ever-increasing body of knowledge exists regarding climate change and carbon sequestration. The best available science is used to summarize conditions relative to the HLC NFs. The information sources available include the following:

- *Northern Rockies Adaptation Partnership (NRAP)*: The NRAP is a "science-management" collaboration with the goals of 1) assessing vulnerability of natural resources and ecosystem services to climate change and 2) developing science-based adaptation strategies that can be used by national forests to understand and mitigate the negative effects of climate change. The Northern Rockies region includes the U.S. Forest Service Northern Region 1 and the adjacent Greater Yellowstone area, spanning northern Idaho, Montana, northwest Wyoming, North Dakota, and South Dakota. Five subregions are identified and assessed; the HLC NFs plan area is in the Eastern Rockies subregion. The partners involved in NRAP include the U.S. Forest Service, National Park Service, Great Northern Landscape Conservation Cooperative, Plains and Prairie Potholes Landscape Conservation Cooperative, Department of Interior North Central Climate Change Center, Greater Yellowstone Coordinating Committee, Oregon State University, EcoAdapt, U.S. Bureau of Land Management, and the U.S. Geological Survey (http://adaptationpartners.org/nrap/). NRAP reports in draft form are referenced because final reports were not available at the writing of this assessment.
- *Intergovernmental Panel on Climate Change (IPCC)*: The IPCC is a scientific body under the auspices of the United Nations (UN). It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. Summary reports from this body are used in this assessment.
- *Coupled Model Intercomparison Project (CMIP)*: The Coupled Model Intercomparison Project began in 1995 to coordinate a common set of experiments for evaluating changes to past and future global climate. This approach allows for comparison of results from different global climate models around the world (USDA Forest Service 2014a). Results of these experiments are used by the IPCC and NRAP.

- *Forest Inventory and Analysis (FIA) data*: FIA data can be used to generate estimates of carbon stocks on National Forest System lands. The Climate Change Advisor's Office for the Forest Service recently conducted work to analyze and summarize carbon stock data for the Northern Region (USDA Forest Service 2015); although it is in draft form at the writing of this assessment, the report generated by this work is utilized for the assessment of baseline carbon stocks. This report provides a basic overall assessment of where carbon is stored at mid to broad scales, and provides basic information for forests that may lack more detailed data on carbon (USDA Forest Service 2015).
- *Forest Service Climate Change Resource Center* (CCRC): The CCRC is a web-based national resource that connects land managers and decision-makers with useable science to address climate change in planning and application. This website compiles educational resources, climate change and carbon tools, literature, and briefings (www.fs.usda.gov/ccrc).
- *Peer-reviewed literature and references*: A variety of literature and reference citations are utilized.

## Scale

Scale is important when assessing the broad concept of climate. Global and national scales are referenced to provide context, generally drawing upon work compiled by the IPCC. Global climate models are the principal source of future climate projections. However, because the spatial patterns of regional climate are far more heterogeneous than suggested by global climate model outputs, specific downscaling techniques are utilized to provide inputs for regional and sub-regional analyses (Daniels et al. 2012). This assessment draws upon work conducted by the NRAP to compile downscaled climate information to a regional (northern region) and sub-regional level to display information meaningful for the HLC NFs plan area. The Eastern Rockies subregion is the scale at which climate is summarized for the plan area, as shown in Figure 4.2.

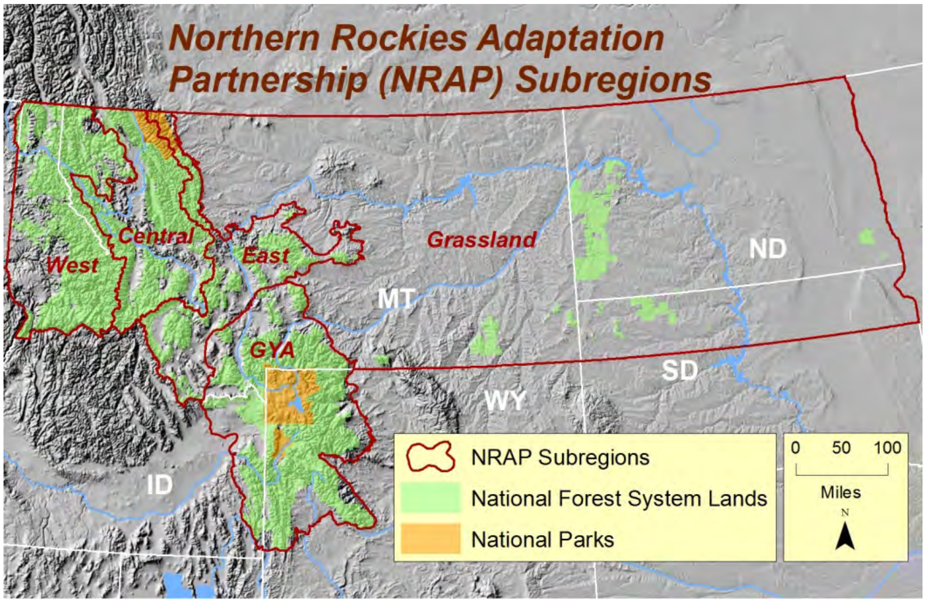

**Figure 4.2 Northern Rockies Adaptation Partnership (NRAP) Subregions**

The primary scale of carbon assessment is the national forest scale because FIA data may be summarized with statistical reliability at that scale. The contributions and trends of carbon sequestration at this scale are small in the context of global climate trends.

### *Key Sources of Uncertainty*

The future is uncertain, and so are predictions of future climate. Multiple global climate models exist. Sources of variability in these models include the uncertainty of future emissions driven by socioeconomic processes and unpredictable policy choices, variability internal to a given global climate model's simulation of weather and climate, variability related to parameterization and other model characteristics, and uncertainty or error in observed climate data used in downscaling outputs (Daniels et al. 2012).

The NRAP seeks to put global climate change information into a regional context to predict changes and identify vulnerabilities. This effort primarily uses CMIP5 climate scenarios. However, NRAP also utilizes information from multiple literature sources, some of which are based upon CMIP3. The primary difference in these is the set of emissions scenarios that force the simulations of future climate (USDA Forest Service 2014a). CMIP3 simulations were forced with emissions scenarios from the Special Report on Emissions Scenarios, which represent futures with different combinations of global population growth and policies. Conversely, CMIP5 simulations are driven by "representative concentration pathways", or RCP's, which do not define emissions but rather concentrations of greenhouse gases and other agents that influence climate (USDA Forest Service 2014a).

Uncertainty also exists regarding ecosystem carbon stocks. The source for carbon estimates used in this report are based on an analysis of Forest Inventory and Analysis (FIA) data with the Carbon Calculation Tool (CCT) conducted by the Climate Change Advisor's Office (USDA Forest Service 2015). CCT is the official reporting tool for interpreting historical FIA data to develop timelines of carbon stock estimates, and while there are uncertainties it is the best nationally available integration of historical and current inventory designs to identify trends in carbon storage (USDA Forest Service 2015). Research is underway to refine the modeling of forest floor carbon stocks; initial results of this work suggest that the existing model may be overestimating forest floor carbon. Refinements are planned in regard to the pools of soil organic carbon, belowground biomass, understory vegetation, and woodland-versus-forest delineations (USDA Forest Service 2015). The FIA data used include the most recent measurements for the national FIA grid, not including the intensification plots installed on the HLC. Most of these plots were measured before recent disturbances (large fires and the mountain pine beetle outbreak). Other sources of uncertainty with FIA data include sampling error, measurement error, and the lack of temporal sensitivity that results from the nature of the re-measurement cycle. The uncertainty of forest carbon stock change at the national scale often ranges between 20-30%, suggesting that uncertainty simulations at smaller scales should exceed 30% (USDA Forest Service 2015).

The critical sources of uncertainty in the analysis completed to estimate the carbon stored in harvested wood products include, but are not limited to, reported harvest, timber product ratios, primary product ratios, conversion factors, end use product ratios, product half-lives, disposition ratios, decay limits, landfill half-lives, dump half-lives, and burned with energy capture ratio (Stockmann et al. 2014). The range of actual values may differ from predicted values by +/- 5 to 30% based on analyses of uncertainty in estimating carbon stocks in harvested wood products (Stockmann et al. 2014).

In summary, current levels of uncertainty regarding carbon stocks are high – with ongoing research geared towards reducing these uncertainties – but this should not exclude managers from using initial carbon baselines to engage in learning more about forest carbon (USDA Forest Service 2015).

## Existing Condition

### *Climate*

The climate of this region fluctuates between cool and warm periods and is affected by multiple factors. The influences of sea surface temperature and atmospheric pressure are thought to directly influence drought in the western U.S. (Kitzberger et al. 2007). Multiple indices exist to measure sea surface temperatures, including:

- *El Niño Southern Oscillation (ENSO)*, which tracks seasonal and annual variation of sea surface temperature in the tropical Pacific (Kitzberger et al. 2007);
- *Pacific Decadal Oscillation (PDO)*, which tracks variations in sea surface temperature in the northern Pacific which tend to cycle approximately every 20 years (Zhang et al. 1997); and
- *Atlantic Multidecadal Oscillation (AMO)*, which tracks sea surface temperatures in the north Atlantic that tend to cycle approximately every 60 years (McCabe et al. 2004; Schlesinger and Ramankutty 1994; Sutton and Hodson 2003).

Potential correlations between these indicators of the climate cycle and disturbances such as wildfire are discussed in the *Terrestrial Ecosystems Chapter*. Monthly values for PDO from 1900 to 2009 are shown in Figure 4.3. The early 1900's reflects a relatively normalized period where warm and cool years were relatively equally represented and fluctuations fairly low. The following period until the late 1940's was dominated by warm conditions, while the period from about 1950-1980 was dominated by cool conditions. From 1980 to 2009, the Northern Region was subject overall to a warm PDO climate cycle. In the northern Rocky Mountains, the majority of the variability in peak and total annual snowpack and streamflow is correlated with the PDO (Pederson et al. 2010). Winters with high snowpack tend to be associated with negative PDO conditions (ibid).

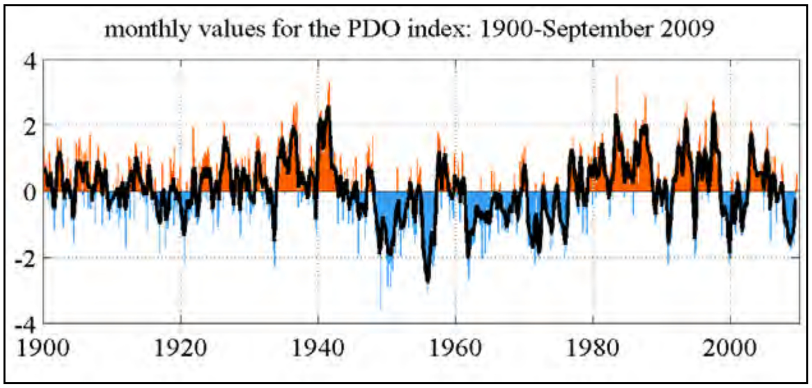

**Figure 4.3 Pacific Decadal Oscillation (PDO) 1900-2009 (USDA 2013)**

Climate data provides a measure of the historic trend and current climate in terms of temperature and precipitation. In the Eastern Rockies subregion from 1895 to 2012, the annual mean monthly maximum temperature increased by about 2.2 degrees Fahrenheit, while the annual mean monthly minimum temperature increased by about 1.8 degrees Fahrenheit with essentially no change in annual mean monthly precipitation (USDA Forest Service 2014a). The climate data summarized by NRAP shows the following conditions applicable to the HLC NFs:

- The annual mean monthly maximum temperature is between 53 and 54 degrees Fahrenheit.
- The annual mean monthly minimum temperature is approximately 30 degrees Fahrenheit.
- The annual mean monthly precipitation is just over 2 inches.

## Carbon Stocks

At the National scale, recent estimates of net annual storage indicate that forests are an important carbon sink (Pan et al. 2011). Forests generally act as carbon sinks because growing plants remove carbon dioxide and store it, causing these areas to absorb more carbon than they emit (USDA Forest Service 2015, Heath et al. 2011). In the U.S. in 2003, carbon removed from the atmosphere by forest growth or stored in harvested wood products offset 12-19% of U.S. fossil fuel emissions (Ryan et al. 2010). Forests in National Forest System lands feature greater carbon density, on average 28% more per forested hectare, than that of private land (Heath et al. 2011). In the U.S., land use conversions from forest to other uses (e.g. development or agriculture) are the primary human activities exerting negative pressure on the carbon sink (Ryan et al. 2010; Conant et al. 2007).

The Northern Region is estimated to store less carbon than some regions, such as the Pacific Northwest, because of the drier climate and lower productivity for growth. The Northern Region constitutes nearly 13% of the total U.S. National Forest System lands (Stockmann et al. 2014). Recent estimates of baseline carbon stocks on National Forest System land in the northern region from 1990-2013 for seven forest ecosystem carbon pools have been made (USDA Forest Service 2015). Carbon stocks are displayed in terms of *total forest ecosystem carbon*, *carbon density*, *carbon flux*, and *harvested wood products*. The carbon pools summarized include:

- Above-ground live tree
- Below-ground live tree
- Standing dead
- Understory
- Down dead wood
- Forest floor
- Soil organic

*Total forest ecosystem carbon* (the combination of all pools) stored in the Northern Region has steadily increased from 1990 to 2013; however, the stocks on the HLC NFs decreased slightly, as shown in Figure 4.4. The Lewis and Clark is estimated to store nearly 100 Tg of carbon and has experienced a decrease in the range of 0-8.4%, while the Helena National Forest stores just under 60 Tg and has experienced a decrease in the range of 8.4-28.3% (USDA Forest Service 2015). The decrease on the HLC may in part be due to recent insect-caused mortality and large wildfires.

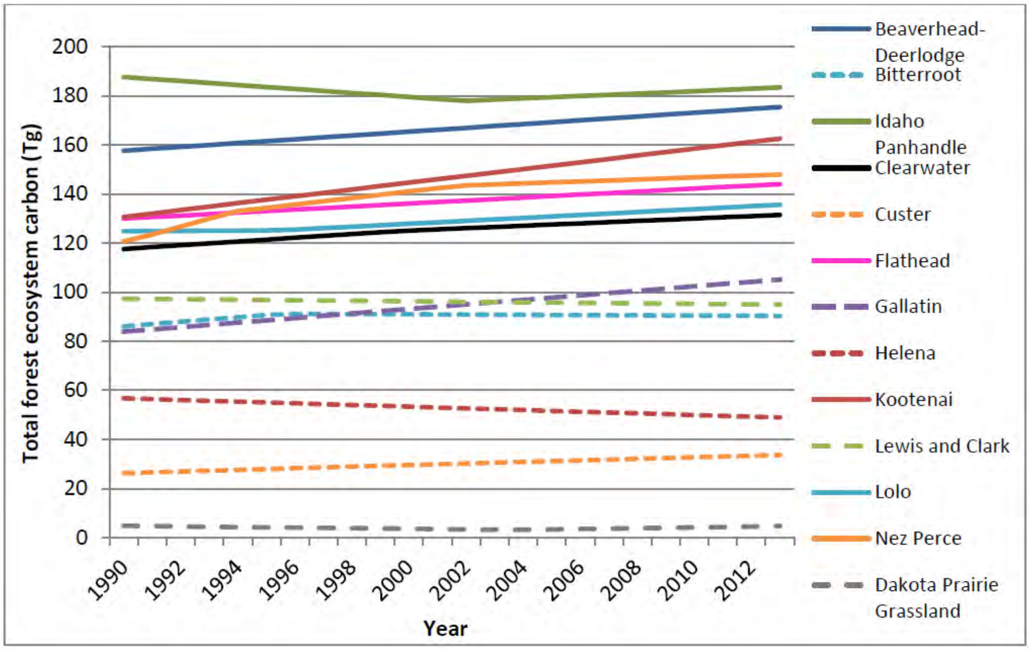

**Figure 4.4 Total forest ecosystem carbon (Tg) for national forests and grassland in Northern Region 1990 to 2013**
*(United States Department of Agriculture, Forest Service. 2015, Baseline Estimates of Carbon Stocks in Forests and Harvested Wood Products for National Forest System Units; Northern Region. 43 pp. Whitepaper.)*

*Carbon density* is an estimate of forest carbon stocks (tonnes) per unit area (acre). Carbon density increased slightly for the Northern Region from 1990 to 2013, but the densities on the Helena and Lewis and Clark National Forests decreased, as shown in Figure 4.5. Factors such as disturbances along with changes in land use, timber harvest, and site quality may be responsible for these trends (USDA Forest Service 2015).

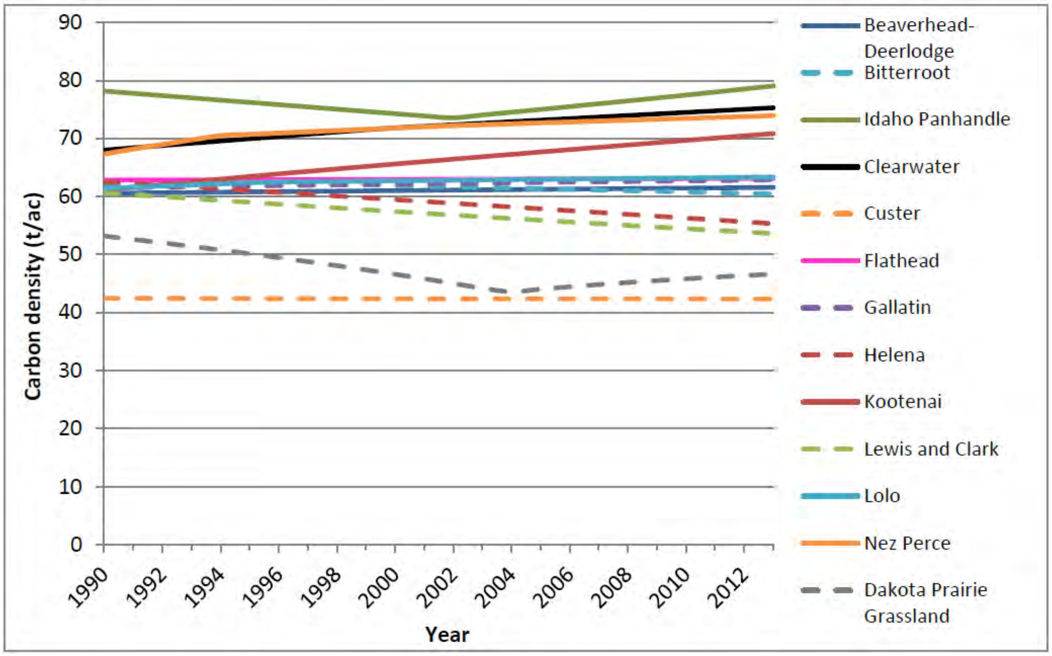

**Figure 4.5 Carbon density (tonnes/acre) for National Forests and Grasslands in Northern Region 1990 to 2013**

*(United States Department of Agriculture, Forest Service. 2015, Baseline Estimates of Carbon Stocks in Forests and Harvested Wood Products for National Forest System Units; Northern Region. 55 pp. Whitepaper)*

Regionwide, the above-ground live tree pool stores the most carbon, and the understory pool stores the least. The highest percent increase in carbon storage from 1990 to 2013 occurred in the standing dead pool (USDA Forest Service 2015); this may also be due to the disturbances that caused mortality of live trees.

*Carbon flux* is the change in carbon stocks over time, calculated by taking the difference between the inventories and dividing by the number of years between the inventories for each national forest (Woodall et al. 2013). A negative change means carbon is being removed from the atmosphere and sequestered by the forests (*carbon sink*), while a positive change means carbon is added to the atmosphere by forest-related emissions (*carbon source*) (USDA Forest Service 2015). While the carbon flux estimates for most timesteps on most national forests in the northern region are between 0 and -2, indicating that these forests balance as a carbon sink, the flux on the Helena National Forest is between 0 and +1, indicating that it is overall functioning as a carbon source. The flux on the Lewis and Clark National Forest is also slightly positive but very close to zero (USDA Forest Service 2015, Appendix A).

As shown by the carbon estimates, recent disturbances from bark beetles and fires may have weakened pre-disturbance sequestration rates. However, affected forests remain forests (not converted to other land uses). As forested stands develop, the strength of the carbon sink increases until peaking at an intermediate age and then gradually declining but remaining positive (Pregitzer and Euskirchen 2004). Carbon stocks continue to accumulate as stands mature, although at a declining rate, until impacted by future disturbances.

*Harvested wood products* are products made from wood including lumber, panels, paper, paperboard, and fuel wood (Skog 2008). The carbon pool of harvested wood products includes products in use and products at solid waste disposal sites. Additions to the pool are made through harvesting, and emissions result from decay and combustion (Stockmann et al. 2014). In the northern region, harvest levels prior to 1940 were low, began to increase in 1940, peaked in 1968, sharply declined in the early 1990's, and have remained relatively low since (USDA Forest Service 2015). The northern region's harvested wood product pool is in a period of negative net annual stock change because the decay of products harvested between 1906 and 2012 exceeds the additions of carbon to the pool through harvest (Stockmann et al. 2014). Harvested wood product carbon stocks represented roughly 2.16% of the total forest carbon storage associated with national forests in the northern region in 2012 (USDA Forest Service 2015). In the national context, harvested wood product carbon stocks in the northern region represent about 1.4% of the U.S. total. Forest-specific harvested wood product carbon stocks are not estimated for the Helena or Lewis and Clark National Forests. The levels of harvest on the HLC NFs generally mirror regional trends.

# Trends

## *Climate*

According to the climate modeling summarized for the Eastern Rockies subregion, the HLC NFs are expected to experience warmer conditions in the future (USDA Forest Service 2014a). There is potential for summer drought and early snow melt from the west that will affect changes in streamflow (USDA Forest Service 2014a). The potential significance of climate variability and change extends beyond changes in averages in that small changes in average conditions are likely to result in large changes in the frequency and magnitude of extreme conditions (USDA Forest Service 2013).Specific trends expected by the year 2100 for this subregion are summarized as follows (USDA Forest Service 2014a):

- Annual mean monthly maximum temperature is predicted to increase by 5 to 11 degrees Fahrenheit.
- Annual mean monthly minimum temperature is predicted to increase by 6 to 11 degrees Fahrenheit.
- The annual mean monthly precipitation is projected to increase 0.2 to 0.3 inches per month, although these projections have greater uncertainty than those for temperature.
- Seasonal mean monthly maximum and minimum temperatures are projected to increase in all seasons.
- The mean monthly minimum temperature in spring and autumn and/or the mean monthly maximum temperature in winter may rise above freezing for the first time.
- Seasonal precipitation projections call for winter and spring to be slightly wetter; fall to be the same; and summer to be slightly drier.

Climate models are unanimous in projecting increasing average annual temperatures over the coming decades in the northern region. Expected temperature increases exceed observed 20th century year-to-year variability, generally by the 2040's; however, projected precipitation changes are comparable to 20th century variability (USDA Forest Service 2014d). Beyond mid-century, climate change projections are less certain because they depend increasingly on assumptions for greenhouse gas emission rates. As a result of changes in long-term average trends, some weather conditions/events we now consider to be extreme will occur more frequently or with greater magnitude, while others will occur less (e.g., more unusually warm periods and fewer cold spells).

### Key Ecosystem Vulnerabilities to Climate Change

Climate change will have direct or indirect impacts to most, if not all, ecosystem characteristics. Research suggests that climate change may exacerbate stressors such as invasive species, drought, uncharacteristic wildfires, elevated insect and disease levels, and "stress complexes" will continue to manifest themselves (USDA

Forest Service 2013). Key vulnerabilities are identified and summarized for the northern region by the NRAP (USDA Forest Service 2014b).

### *Water and Soil Resources*

Climate change will likely have interdependent indirect and direct effects on forest water cycling (Vose et al. 2012). Indirect effects work primarily through effects on forest evapotranspiration (ET), the combination of evaporation of water from plant and ground surfaces and transpiration. Direct effects are associated with more rainfall and intense storms. These in turn increase base flows in streams (particularly intermittent streams), increase flood risk, accelerate erosion, and increase the potential for landslides, increased interstorm periods and drought, and changes in infiltration rates.

Water resources potentially vulnerable to climate change include snowpack and glaciers, and streamflow. Places with seasonally intermittent snowpacks will likely see snow more rarely, and some mid-to-low-elevation seasonal snowpacks may become intermittent. It is expected that most glaciers will be reduced in volume and area. Because warmer temperatures will likely reduce snowpack accumulation and advance snowmelt timing, it is expected that there will be an earlier streamflow center of timing and summer low flows are expected to be lower.

The carbon storage function of soil is defined as ability of the soil to store carbon. More carbon is stored in soil than in the atmosphere and above-ground biomass combined. Limiting factors of soil carbon storage are depth and rockiness. Carbon compounds are inherently unstable and owe their abundance in soil to biological and physical environmental influences that protect carbon and limit the rate of decomposition (Schmidt et al. 2011). Soil organic matter is formed by the biological, chemical, and physical decay of organic materials that enter the soil system from sources aboveground (e.g., leaf fall, crop residues, animal wastes and remains) or belowground (e.g., roots, soil biota). The organic compounds enter the soil system when plants and animals die and leave their residue in or on the soil. Immediately, soil organisms begin consuming the organic matter; extracting energy and nutrients; and releasing water, heat, and CO2 back to the atmosphere. Thus, if no new plant residue is added to the soil, soil organic matter will gradually disappear. If plant residue is added to the soil at a faster rate than soil organisms convert it to CO2, carbon will gradually be removed from the atmosphere and stored (sequestered) in the soil. Large quantities of soil organic matter accumulate in environments such as wetlands, where the rate of decomposition is limited by a lack of oxygen, and high-altitude sites where temperatures are limiting. Most carbon in mineral soil comes from root turnover (Schmidt et al. 2011), although some is moved from the forest floor into upper mineral soil layers (Qualls et al. 1991). Soil carbon stock in the plan area will be analyzed in the forest plan revision process.

### *Fisheries and Aquatic Wildlife*

As discussed in chapter 3, Watershed, Aquatic, Soil, and Air Resources, westslope cutthroat trout and bull trout populations are sensitive to increased water temperatures. Outputs from models which accurately back-predict historical temperatures were used in this assessment for analyzing climatic effects on aquatic wildlife populations. It appears that these are relatively consistent in predicting that local, average summer air temperatures are predicted to increase between 2 to 4 degrees Celsius by 2050 (Luce 2011, Barsugli 2009).

In the planning area, for every degrees Celsius increase in air temperature, a 0.44 degrees Celsius increase in average water temperature is predicted (Isaak et al. 2010, Mohseni and Stefan 1999, Mohseni et al. 2003). This would indicate that under constant catchment basin characteristics, an increase in summer water temperatures ranging from 0.88 to 1.76 degrees Celsius could be expected between now and 2050. One of the concerns for aquatic wildlife populations on the HLC NFs is whether these temperature increases could lead to mortality concerns. The term “mortality concerns” addresses temperature related fish-kill events that could reasonably be expected to occur during prolonged, extreme heat/drought events in the warmer sections of a stream. A fish-kill does not necessarily occur when temperatures exceed the critical thermal maximum for a species. The magnitude, duration, frequency of these events as well as the local microhabitat conditions are important factors. A weather event in which water temperatures slightly exceed a “reduced survivability threshold” for a few minutes on one day of the summer would be much less likely to create a fish-kill than a heat/drought event in which temperatures exceed the threshold by a higher magnitude, across multiple hours each day and persisting over the span of several days.

There are climatic factors in addition to maximum summer water temperatures that affect survival and lifecycle completion for fish and mussel species. Thermal regimes in other seasons can affect the timing of spawning and the success of egg incubation. Earlier snowmelt run-off could increase scour during critical time periods in the lifecycles of trout, char and mussels (Isaak et al. 2012). Earlier loss of snowpack also leads to lower summer flows which have been correlated within this plan area with decreased densities of westslope cutthroat trout (Moser 2011).

Groundwater influence and entry into surface water has been shown to both moderate temperature and be positively correlated with salmonid abundance (Ebersole et al. 2003). Perennial stream reaches in higher-elevation areas that have well-timbered valley bottoms and ground-water entry will be most resilient to warming conditions and earlier run-off. Lower elevation stream reaches, lacking riparian shade, containing high sediment loads, with impaired width-depth ratios, and losing flows to groundwater will be the least resilient reaches.

### *Tree Species and Vegetation Types*

Soil water balance largely determines what vegetation can survive on a specific site, and there are indirect effects based on climate’s influences on drivers such as wildfire, insects, disease, and site productivity. Fine-scale effects of topography and microclimate are also important. For most species and communities, the potential effects of climate change include both positive and negative effects. Highlights of potential effects to individual species and vegetation communities are summarized as follows (NRAP 2014b):

- Low elevation dry sites may become too dry for Engelmann spruce, but conversely warming conditions may allow its expansion in upper subalpine areas if snowpacks decrease.
- Due to shifts in streamflow and timing of peak flows, cottonwood establishment may decrease.
- Limber pine may gain a competitive advantage with warmer temperatures, but may also experience increased competition and lower germination rates. The potential effects will be interrelated to the responses of white pine blister rust.
- Ponderosa pine may experience an increase in its competitive advantage, especially on sites that were previously too cold, but the driest sites may become unsuitable and convert to a nonforested condition. In dry ponderosa pine/Douglas-fir forests, ponderosa may gain a competitive advantage at lower elevations while Douglas-fir may be favored on mesic sites, although cone worm and budworm effects on seed crops and Douglas-fir regeneration may be exacerbated. Patch size may increase due to increased wildfire extent and severity.
- The effects to lodgepole pine will be correlated to changes in wildfire extent and severity; it is well-adapted to fire, so increased wildfire extent may allow it to expand into subalpine areas if a seed source is present. However, lodgepole forests may be eliminated in areas that re-burn prior to reaching reproductive maturity.
- Impacts to Douglas-fir will vary; while it may lose a competitive advantage on dry sites to more drought tolerant associates such as ponderosa pine, it may expand on more mesic sites.
- Aspen may decrease on warmer and drier sites due to a water deficit, and due to pathogens and insects associated with sudden aspen decline; but conversely may expand in mesic areas where increased wildfire activity removes competitors and stimulates suckering.
- At high elevations, subalpine fir may decrease on sites that become too dry, but expand on sites with high productivity, although forest densities may not be resilient to disturbance. Trends will be interrelated with whitebark pine on some sites; blister rust and succession are expected to continue to reduce whitebark

pine. However, increased fire activity may allow for whitebark pine regeneration establishment where seed sources persist and kill shade-tolerant subalpine fir. Some whitebark pine/spruce-fir forests may be replaced by lodgepole pine in drier areas.

- Western larch is a small component on the HLC NFs, found only in the Upper Blackfoot Geographic Area on the eastern edge of its range. Spring frosts are one primary suppressor of reproduction; warmer spring temperatures may allow for more larch regeneration and increased fire activity could promote this shade intolerant species. Western larch may migrate to more northerly aspects and potentially become more common in the Upper Blackfoot. However, this may be offset by increased drought stress on dry sites.
- Nonforested communities such as big sagebrush, mountain big sagebrush, threetip sagebrush, and western grasslands may experience shifts in their distribution. For example, big sagebrush may expand northward and upslope as it gains a competitive advantage over other vegetation such as conifers, but may contract range-wide due to increased soil moisture stress. Wildland fire will also impact nonforested communities. Large burned areas may cause reductions in sagebrush where no live seed-bearing sagebrush are retained; however, shrub communities may re-seed fire areas that burn in a mosaic. In grasslands, species shifts may occur in that warm season grasses may expand and cool season grasses may decline. While increased fire frequency may promote grasslands, it may also allow for increased occurrence of invasive species.

### *Vegetation Resources and Landscape Function*

Vegetation resources and landscape functions potentially vulnerable to climate change include carbon sequestration, landscape heterogeneity, timber production, insect and diseases, invasive plant species, and wildfire regimes. The influences of climate change on these resources are summarized as follows (NRAP 2014b):

- The rate of carbon sequestration will largely depend on the rate and extent of wildland fire and the gains or losses of productivity in Northern Rockies ecosystems. It will also be influenced by the impacts of insects and diseases. Fire exclusion tends to push ecosystems into later successional stages where sequestration rates are minimal. Wildfires and prescribed burning will cause short-term carbon losses but may result in higher productivity and increased sequestration over the longer term. Carbon loss can be linked to fire severity, as high severity fires responsible for increased combustion of live and dead woody biomass alter the carbon source and sink ratios more than low and moderate severity fires that tend to retain greater amounts of live and dead woody biomass (Meigs et al. 2009). Dry sites, which are common on the HLC NFs, may experience decreases in productivity and carbon sequestration in the future, while more mesic sites may experience increases in productivity.
- Increased fire frequency or extent burned may create patchworks that increase landscape heterogeneity and resilience in some areas; conversely, wildfires that burn in fire-excluded landscapes may burn with high severity and cause atypical large patches that may decrease heterogeneity.
- There may be increases in timber production at mid and higher elevations due to warming. However, this may be offset overall by losses due to increased fire activity and decreased productivity on dry sites.
- Warming conditions may exacerbate bark beetle infestations by positively affecting reproductive rates and over-wintering survival, and exacerbating drought stress to suitable hosts which would allow for increased levels of mortality and infestations especially at higher elevations. However, temperature changes may also disrupt the synchronicity of bark beetle life cycles. Root diseases can also impact carbon sequestration; however, in general root diseases are not widespread or severe on the HLC NFs.
- Invasive plant species may expand into plant communities that in the past have been considered closed to invasion, including higher elevation moist forests that may burn more frequently.
- If fire season length increases, there is the potential for fire activity to increase and burn large areas. Fire severities may also increase due to decreased fuel moistures and longer summertime periods of hot, dry weather. This may be most noticeable at upper elevations if these fuels become more available to burn based on increased exposure to hot, dry weather.

### *Wildlife*

The wildlife species identified as potentially vulnerable to climate change on the HLC NFs include American pika, Canada lynx, flammulated owl, greater sage-grouse, pygmy nuthatch, and wolverine. Vulnerabilities are also identified specifically related to changes in snow cover/depth/condition. The potential influences of climate change on these species are summarized as follows (NRAP 2014b):

- In areas where warmer, dryer conditions cross critical thresholds, pikas are likely to experience local extirpations, and recolonization in many cases is unlikely.
- Loss of snow may shift the balance from lynx to other snow-adapted predators and may be destructive to snowshoe hare populations.
- Flammulated owls may be affected relative to the extent that large diameter dry forests are affected by climate change; increased disturbances that cause shifts to young forest may be detrimental.
- The effects of climate change to sage grouse are not straightforward, although it is strongly tied to the condition of sagebrush habitats. Climate caused changes to this species will interact with notable anthropogenic stressors in ways that are complex and hard to predict.
- Pygmy nuthatches prefer dry forests, and may expand into higher elevation areas with warmer temperatures. However, disturbances that cause shifts to young forests or shifts from forests to grass/shrublands may be detrimental.
- Trends to wolverine are strongly tied to the expected changes and losses to snowpack and snowy habitats.

### *Recreation*

The elements of recreation identified as potentially vulnerable to climate change applicable to the HLC NFs include activities where wildlife is an important part of the recreational experience, gathering of forest products, participation in recreation activities that occur in warm weather, snow-based activities, and water-based activities. The potential influences of climate change on recreation are summarized as follows (NRAP 2014b):

- While the effects to big game are expected to be relatively neutral, the desirability of hunting during established seasons may decline as warmer weather persists later in the fall and snow cover decreases.
- Vegetation changes caused by climate change may alter the distribution and productivity of targeted forest product species (such as huckleberries and Christmas trees). Increased wildfires may create short term increases in the availability of some products such as mushrooms and firewood.
- Overall demand for warm-weather activities, such as hiking and camping, is expected to increase due to longer seasons.
- Overall warming is expected to reduce expected season length and the likelihood of reliable winter recreation seasons for snow-based activities such as skiing and snowmobiling. Some areas may become unsuitable, and use may become concentrated in areas that remain suitable.
- Increasing temperatures, reduced storage of water as snowpack, and increased variability in precipitation are expected to increase the likelihood of reduced water levels and greater variation in water levels in lakes and reservoirs, which is associated with reduced site quality and suitability for water-based activities such as swimming, boating, and floating. However, demand for water-based recreation is likely to increase as the season lengthens and people seek relief from heat.

### *Ecosystem Services*

The ecosystem services identified as potentially vulnerable to climate change which are applicable to the HLC NFs include building materials/wood products, cultural and heritage values, erosion regulation, fuel (wood/biofuels), mining materials, viewsheds/clean air, water quality, and water quantity. The potential influences of climate change on ecosystem services are summarized as follows (NRAP 2014b):

- Increased wildfire activity may increase the demand for fuel treatments, which may increase the availability of building materials and wood products.
- Climate change may accelerate on-going effects to cultural resources, including potential degradation by wildfire and wildfire suppression tactics, post-wildfire flooding and other changes to runoff patterns, increased erosion associated with drought, vandalism, and changes in recreation use.
- Increased flooding in steep areas may increase erosion.
- Increased incidence of pests and wildfire may promote the use of fuel and biofuels.
- Mineral development is not sensitive to climate change and therefore may become more important if other economic drivers are impacted.
- Climate change and increased wildland fire can affect air quality by increasing air pollutants and potentially affect sensitive groups with existing health issues or the general public.
- Water quantity and quality may be impacted through climate influences on watersheds such as drought, increased wildfires, decreases in vegetation cover, less snowpack, and earlier snowmelt. These may lead to impacts such as increased water treatment costs or damage to municipal water infrastructure.

## *Carbon Stocks*

At the broad scale, the long-term ability of forests to persist as net carbon sinks is uncertain (Galik and Jackson 2009). Drought stress, forest fires, insect outbreaks and other disturbances may substantially reduce carbon stocks (Galik and Jackson 2009). Climate change threatens to amplify risks to forest carbon stocks by increasing the frequency, size, and severity of disturbances (Dale et al. 2001, Breashears and Allen 2002, Westerling and Bryant 2008, Running 2006, Littell et al. 2009, Boisvenue and Running 2010). Research indicates that these risks may be particularly acute for forests of the Northern Rockies (Boisvenue and Running 2010). Increases in the severity of disturbances, combined with projected climatic changes, may limit post-disturbance forest regeneration, shift forests to nonforested vegetation, and possibly convert areas from an existing carbon sink to a carbon source (Strom and Fule 2007, Kurz et al. 2008, Galik and Jackson 2009, Turner 2012).

Carbon stored in U.S. forests is projected to peak between 2020 and 2040, and then decline through 2060 primarily due to removal of trees as private forest lands are converted to urban and other developed land uses (USDA Forest Service 2012). Further, western forest ecosystems may emit greater amounts of carbon if wildfire area and insect disturbance increase as expected (Vose et al. 2012).

Because of the recent wide-spread mountain pine beetle outbreak and large fires over the last thirty years, the HLC NFs plan area may be a neutral or slight carbon source in the near future, at a similar level to the existing condition. Once the dead material has fallen to the ground, the ability to contribute to harvested wood products will be reduced in these areas until the new forests grow. Long-term, reforestation is expected unless repeated disturbances cause some areas to remain nonforested. The total carbon sequestered on the HLC NFs may continue on a downward trend based on potential increases in wildfires and decreases in site productivity. Overall, the carbon cycle in forested ecosystems is expected to be relatively neutral when considered over a long enough timespan which includes the flux and cycles of natural disturbances and regrowth.

## *Influence of Management on Climate and Carbon Trends*

Future climates will be influenced by natural cycles and human contributions to greenhouse gas emissions. The ability of forests to sequester carbon depends in part on their resilience to multiple stresses, including increasing probability of drought, wildfires and insect outbreaks. Management actions that maintain long-term productivity and reduce the likelihood of high severity disturbances may help maintain the capacity of a forest to sequester carbon; however the magnitude and overall potential impact of this is uncertain and depends greatly on the scale considered.

The capacity of a forest as a carbon sink can be evaluated against potential carbon emissions from a disturbance, such as wildfire. Stored carbon will eventually be lost to the atmosphere through the process of combustion when a forest burns, and the probability of a wildfire occurring tends to increase as years since fire increases (Loehman et al. 2014). Comparing potential carbon emissions from a wildfire in a mixed conifer forest that has been unmanaged versus treated with prescribed fire or understory thinning, the unmanaged forest has the potential for greater carbon emissions than the treated forest based on modeling (Hurteau and North 2009). In forests that burned in stand-replacing fires in four large wildfires in the western U.S. in 2002, silvicultural treatments such as understory thinning may have decreased the actual carbon emissions (Hurteau et al. 2008).

Meigs et al. (2009) and Campbell et al. (2007) found that litter, understory plant foliage, and small downed wood were readily consumed regardless of burn severity following wildfires in Oregon. Likewise, Stephens et al. (2009) observed that prescribed fires ignited with dry surface fuels as is typical within the historical wildfire season consumed more than 75 percent of the carbon stored in surface wood, litter, and duff. Dry fuels produce greater emissions of carbon monoxide (CO) and carbon dioxide (CO2) than fuels with higher fuel moisture (Loehman et al. 2014). There are also greater carbon monoxide and carbon dioxide emissions during the smoldering phase as compared to the flaming phase of combustion (Loehman et al. 2014).

To an extent, rates of net carbon sequestration in forests may be enhanced through management strategies that retain and protect forest land from conversion to non-forest uses, restore and maintain resilient forests that are better adapted to a changing climate and other stressors, and reforest lands disturbed by stand-replacing events (USDA Forest Service 2015). Millar and others (2007) identified two primary approaches for incorporating the uncertainty of climate change into ecosystem management:

- *Adaptation strategies* are actions that help ecosystems accommodate changes adaptively. Specific adaptation strategies may include options such as *resistance* (forestall impacts and protect highly valued resources), *resilience* (improve the capacity of ecosystems to return to desired conditions after disturbance), and *response* (facilitate transition of ecosystems from current to new conditions).
- *Mitigation strategies* include actions that enable ecosystems to reduce anthropogenic influences on global climate. Mitigation strategies include options to sequester carbon and reduce greenhouse gas emissions.

Each strategy that can increase forest carbon storage, prevent its loss, and reduce fossil fuel consumption has risks, uncertainties, and important tradeoffs (Ryan et al. 2010). For example, thinning, prescribed fire, and other silvicultural actions are often suggested as adaptation actions because they may increase resilience and increase the likelihood of sustaining carbon in the long-term (Millar et al. 2007; Joyce et al. 2008; Ryan et al. 2008). Timber harvest can reduce carbon stocks in the short term, but may improve sequestration over time by promoting growth and resiliency. Harvested wood is of additional importance; treatments that generate long-lived wood products such as lumber and furniture transfer ecosystem carbon to the harvested wood products pool (USDA Forest Service 2015). Forest vegetation treatments also generate excess material (woody biomass) which, if utilized, can be a renewable energy substitute for fossil fuels (ibid). Avoiding deforestation associated with land use changes and providing for prompt reforestation after disturbance ensures that forests remain carbon sinks over time; these actions have few risks. Strategies such as decreasing harvest can increase diversity and retain carbon, but there is risk in products being harvested elsewhere and potential carbon lost in disturbances (Ryan et al. 2010). Recognizing the tradeoffs is vital to promote forest carbon storage, and the other benefits offered by forests should be considered along with carbon storage potential (ibid).

Six principles have been identified for forest carbon management in the Northern Rockies which are intended to be refined, updated, and formally approved based on field experience, emerging science, and higher level policy revisions and interpretations across the full range of Forest Service programs and authorities (USDA Forest Service 2015). It is important to note that these principles are not meant to imply that maximizing forest carbon storage should be the objective of any forest plan or that carbon should be the most important or overriding purpose of forest plans or project actions (USDA Forest Service 2015).

- Emphasize ecosystem function and resilience
- Recognize carbon sequestration as one of many ecosystem services
- Support diversity of approach in carbon exchange and markets
- Consider system dynamics and scale in decision making
- Use the best information and methods to make decisions about carbon management
- Strive for program integration and balance

## Information Needs

One of the primary elements of uncertainty identified in this assessment relates to how soil carbon is estimated. The information provided in this report is based on FIA data because of the need for consistent Nation-wide data sources and methodologies (USDA Forest Service 2015). The limitation of this data source relative to soil carbon is in the coarse nature of the grid sample and limited depth of the soil measured. Better soil data is becoming available from several sources on the HLC (SSURGO and NASIS) which includes measurements to a greater depth represented in geospatial databases. In the short term, these data should allow for an improved analysis of the soil carbon pool for the planning area to be carried forward in the planning process.

There is uncertainty regarding the accurate representation of climate change, carbon, cycles, and the potential for forest management to influence them on a meaningful scale. Especially pertinent to a discussion of carbon storage goals is the natural role of disturbance in fire-prone ecosystems, such as those found on the HLC NFs, which would naturally generally promote carbon neutral systems over a long timescale as forests are in a continual state of flux. Assessments on forest carbon disturbances are currently being developed which may help inform managers and the public of the relationship between carbon storage, past management, and disturbances to begin considering the short and long-term carbon consequences of alternative forest management strategies (USDA Forest Service 2015). It is unclear how carbon storage goals may interact with other desired conditions or services such as biodiversity, sustainability, clean water and air, and wildlife habitat needs in dynamic and complex ecosystems.

The current forest plans on the HLC NFs do not include goals or standards related to carbon storage.

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