Draft Nez Perce–Clearwater National Forests Forest Plan Assessment

4.0 Baseline Assessment of Carbon Stocks

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4. Baseline Assessment of Carbon Stocks

4.1 EXECUTIVE SUMMARY

Forests substantially mitigate the climate effects of increasing atmospheric CO_2 concentrations by removing carbon from the atmosphere and storing it as biomass. Worldwide, forests offset about one-third of global CO_2 emissions from fossil fuel combustion. U.S. forests offset about 10–20% of U.S fossil fuel emissions.

Available information suggests that carbon stocks of the Nez Perce and Clearwater National Forests have been increasing over the last several decades as they recover from extensive fires in the late 19th and early 20th century. The Nez Perce and Clearwater National Forests store approximately 312 million metric tons (Mt) of carbon (excluding soil carbon stocks) and contain approximately 0.7% of total U.S. forest carbon stocks. Wood products harvested from the Nez Perce and Clearwater National Forests store an additional 6 Mt of carbon, although the size of the harvested wood products carbon pool has been declining since 2000 as a result of declining harvest levels. Net annual growth (gross annual growth minus losses due to mortality) on the two Forests combined is estimated to be 216 million cubic feet, which equates to an average annual increase in live aboveground carbon stocks of roughly 1.16 Mt.

The future trajectory of carbon stocks on the Nez Perce and Clearwater National Forests is uncertain and will depend on the spread of root diseases, the extent and severity of future fires, tree mortality caused by bark beetles and other forest insects, the rate of tree regeneration after disturbances, and potential changes in forest productivity. Projected changes in regional climate may exacerbate many of these change agents and thus reduce the carbon stocks on Nez Perce and Clearwater National Forests. Forest management activities that reduce the potential for uncharacteristically large and severe natural disturbances and promote rapid forest regeneration after disturbances may reduce some of these potential risks to forest carbon stocks.

4.1.1 *Introduction*

From 1990 to 2006, terrestrial vegetation absorbed approximately one-third of the annual global carbon emissions from fossil fuel combustion and land use change (Bonan 2008; Canadell, Le Quere et al. 2007; Denman et al. 2007). The feedback of carbon between the atmosphere and terrestrial ecosystems has a significant impact on rates of climate change.

Forests remove carbon from the atmosphere through photosynthesis and convert it into sugars used to grow leaves, wood, and roots. Forests also release carbon dioxide to the atmosphere through respiration and decay of dead wood, litter, and organic matter in soils. In addition, forest fires release some stored carbon to the atmosphere. Fires, insect outbreaks, pathogens, drought stress, and wind storms kill trees and increase the amount of biomass available for decomposition by microorganisms, and timber harvesting removes carbon from the forest although some of it is stored in wood products or used to produce energy, displacing fossil fuel use (Ryan et al. 2010) (Figure 1).

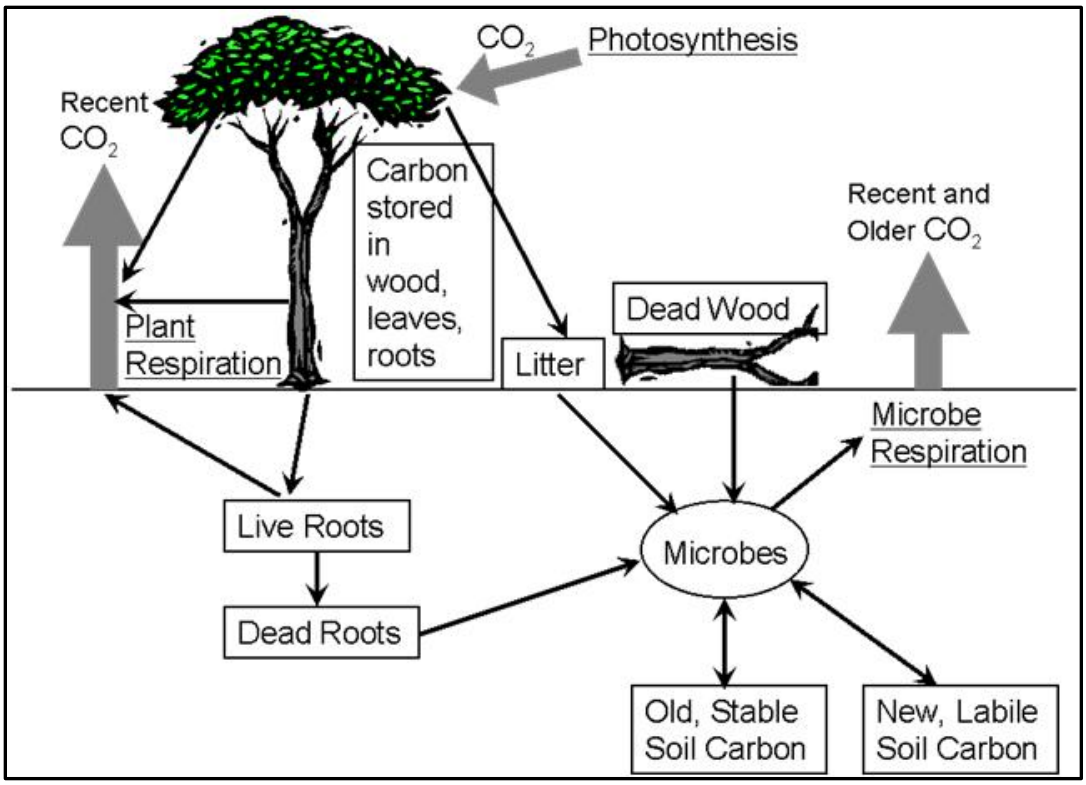

Figure 1. Flows of carbon from the atmosphere to the forest and back. Carbon is stored mostly in live and dead wood as forests grow (adapted from Ryan and Law 2005).

The rate of forest carbon gains and losses and total forest carbon stocks varies over a forest's life cycle. When forests are disturbed by fire, harvest, insect outbreaks, and other perturbations, forest carbon stocks will usually recover fully over the life-cycle of the forest (Kashian et al. 2006). Thus, over time, the net carbon change is often zero (Figure 2) (McKinley et al. 2011). Over large areas of forest comprised of a multitude of stands of different ages, carbon storage and sequestration rates are more stable because stands are in different stages of recovery from disturbance, with some stands providing a carbon "sink," while others act as net "sources," releasing more greenhouse gases than they sequester (Ryan et al. 2010). Changes in the frequency or severity of disturbance regimes over large areas compared to the historical baseline can increase or lower the average carbon stocks in forests over time (Kashian et al. 2006; Smithwick et al. 2007; McKinley et al. 2011). Over time, these processes can significantly affect the amount of atmospheric CO_2 and, thus, global climate (Sabine et al. 2004; Canadell, Pataki et al. 2007; Denman et al. 2007; Bonan 2008; McKinley et al. 2011).

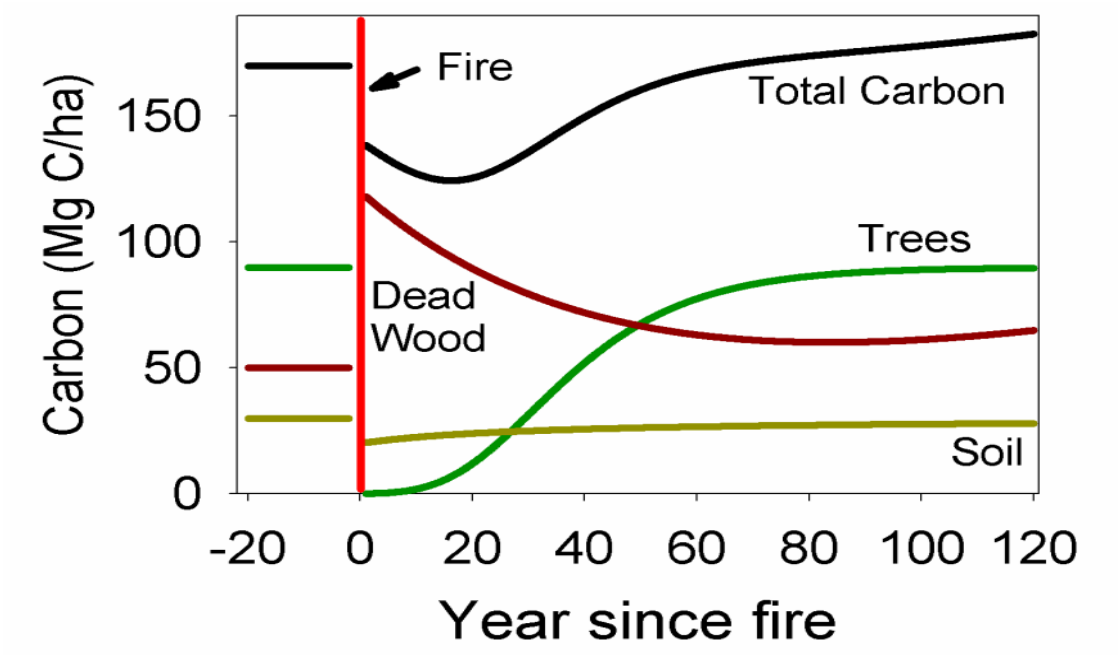

Figure 2. Post-fire forest c recovery over time showing total carbon that includes the decomposition of trees killed by fire (dead wood), tree regeneration (trees), and soil (soil).If A forest regenerates after a fire and the recovery is long enough, the forest will recover the carbon lost in the fire and in the decomposition of trees killed by the fire. Model output is from an analysis published in Kashian et al. (2006)

Most studies estimate that the terrestrial biosphere is currently a net sink, removing more carbon from the atmosphere than it is emitting; thus, mitigating the effects of CO_2 emissions from fossil fuel combustion and land use change (Denman et al. 2007; Le Quéré et al. 2009). Forests are the dominant contributors to the terrestrial ecosystem carbon sink, removing about 2.4 billion metric tons of CO_2 per year from the atmosphere from 1990 to 2007, offsetting about one-third of global CO_2 emissions from fossil fuel combustion (Pan et al. 2011)

It is clear that forests play a key role in mitigating global CO_2 emissions and, thus, the rate of climate change (Nabuurs et al. 2007). However, the future of this ecosystem service is uncertain. Converting forests to non-forest, particularly in the tropics, and the potential effects of climate changes on forests raise questions about the future strength of the global forest carbon sink, and whether it may convert to an additional source of carbon to the atmosphere. Ultimately, the answers to these questions will have a significant impact on global climate.

This section of the Assessment summarizes the best available scientific information on the carbon stocks and fluxes of the Nez Perce–Clearwater National Forests. It provides estimates of existing carbon pools of the forest sector (live and dead aboveground biomass, soil carbon, and harvested wood products). These estimates are derived from local data collected during soil surveys, systematic forest inventory (the Forest inventory and Analysis Program), and forest harvest records.

4.1.2 *Current Carbon Stocks of the Nez Perce–Clearwater National Forests*

4.1.2.1 Aboveground Forest Ecosystem Carbon

The Nez Perce–Clearwater National Forests store an estimated 312 Mt of carbon (Heath et al. 2011), which represents about 0.7% of the total of approximately 42,654 Mt of carbon in forests of the coterminous United States (EPA 2008). The average density of forest carbon is about 196 milligrams of carbon per hectare (mg C/ha) (approximately 216 U.S. tons). The average carbon density of the Nez Perce-Clearwater National Forests is among the highest in the Northern Rockies and interior western United States (Hicke et al. 2007; Potter et al. 2008).

4.1.2.2 Soil Carbon

This section is under development

4.1.2.3 Harvested Wood Products

In addition to the ecosystem carbon stocks described above, wood products produced with timber from the Nez Perce–Clearwater National Forests store approximately 6 Mt of carbon. Of this amount, an estimated 3.8 Mt are held by products currently is use and 2.2 Mt is stored in solid waste disposal systems (Table 1).

Table 1. estimated current carbon stocks of major forest carbon pools for the Nez Perce–Clearwater National Forests

National Forests	Total Aboveground Carbon (Tg C)[a]	Soil Carbon (Tg C)[a]	Harvested Wood Products Carbon in use (Tg C)[a]	Harvested Wood Products C in Solid Waste Disposal Systems (Tg C)[a]	Total (Tg C)[a]
Nez Perce and Clearwater National Forests	312	—	3.8	2.2	312

Note: Total above ground Carbon estimate is from Heath et al. (2011). Estimates of carbon stored in harvested wood products in use and in solid waste disposal systems are calculated with the methods described by Stockmann et al. (2012).
[a] All units are teragrams (Tg), which equate to million metric tons.

The reservoir of carbon stored in U.S. forests is approximately 42,700 to 66,600 Mt (Birdsey et al. 2007; EPA 2008). Public forestlands contain approximately 37% of this carbon reservoir (Smith and Heath 2004). National Forest System lands store an estimated 11,604 Mt of carbon, or 17%–27% of all forest carbon of the United States (Heath et al. 2011). The combined forest ecosystem (excluding soil carbon) and harvested wood products carbon pools of the Nez Perce–Clearwater national Forests store approximately 312 Mt of carbon, which represents approximately five tenths (0.00459) to seven tenths (0.00716) of 1% of the total U.S. forest carbon reservoir.

4.1.3 *Recent Carbon Stock Trends of the Nez Perce and Clearwater National Forests*

4.1.3.1 Aboveground Forest Ecosystem Carbon

The principal drivers of aboveground forest carbon stocks are forest growth and mortality. Forest Inventory and Assessment (FIA) surveys completed in 2001 on the Nez Perce National Forest, estimated that net annual growth (annual growth minus losses due to mortality) is 312 Mt of biomass (Disney 2010). FIA surveys completed in 1999 on the Clearwater National Forest estimated net annual growth is 2.3 Mt of biomass (Hughes 2011). The primary agents for decadal and longer-scale carbon changes on the Nez Perce and Clearwater National Forests are root diseases, wildland fire, bark beetles, and timber harvest. Root disease is the leading cause of tree mortality on both Forests (44% of all mortality on the Clearwater National Forest and 22% on the Nez Perce National Forest). Mountain pine beetle and other forest insects are the second leading cause of tree mortality on the Clearwater National Forest and Nez Perce National Forest (20% and 22%, respectively), followed by wildland fire (3% and 20%, respectively) (Disney 2010, Hughes 2011). Longer-term trends reflecting these change agents can be inferred from 20th century trends in forest age and structure classes.

Recent scientific literature documents the general pattern of changes in carbon stocks and net ecosystem productivity (NEP)[1] over the period of stand development in coniferous forests of the interior western United States (Smithwick et al. 2008; Bradford et al 2008; Dore et al. 2008; Luyssaert et al. 2008; Irvine et al. 2007; Hall et al. 2006; Law et al. 2003; Kashian et al. 2006; Law et al. 2001; Carey et al. 2001). Total carbon stocks decline from disturbance, and then increase rapidly during intermediate years, and then at a declining rate, over time until another significant disturbance (regeneration timber harvest or tree mortality resulting from drought, fire, insects, disease, or other causes) kills large numbers of trees (Figure 2) (Pregitzer and Euskirchen 2004; Canadell, Pataki et al. 2007). Carbon flux and NEP are lowest, and usually positive (a carbon source to the atmosphere) in young stands (0–30 years old) following disturbance because carbon emissions from decay of dead biomass exceed the amount of carbon removed from the atmosphere by photosynthesis within the stand. As the stand develops, NEP increases and the stand becomes a carbon sink. NEP and carbon sink strength generally peak at the intermediate stage of stand development (40–100 years old), and then decline with age but often remain negative (Pregitzer and Euskirchen 2004; Canadell, Pataki et al. 2007) (Figure 2). Over the long term (centuries), net carbon storage is often zero if stands regenerate after

[1] Net ecosystem productivity, or NEP, is defined as gross primary productivity (GPP) minus ecosystem respiration (ER) (Chapin et al. 2006). It reflects the balance between (1) absorbing CO_2 from the atmosphere through photosynthesis (GPP) and (2) the release of carbon into the atmosphere through respiration by live plants, decomposition of dead organic matter, and burning of biomass (ER). When NEP is positive, carbon accumulates in biomass. Ecosystems with positive NEP are referred to as a carbon sink. When NEP is negative, ecosystems emit more carbon than they absorb. Ecosystem with negative NEP is referred to as a carbon source.

disturbance because regrowth of trees recovers the carbon lost in the disturbance and subsequent decomposition of trees killed by the disturbance (Kashian et al. 2006).

On the Nez Perce and Clearwater National Forests, the distribution of forest age and structure classes has changed substantially since the early 20th century (Forest Service 2004). Intermediate age classes have increased in area while the amount of young stands has decreased. In most forest types, the abundance of older, late successional stands has declined. The cause of these changes varies by forest type and geographic location, but the most wide-spread agents of change are root disease, white pine blister rust, timber harvest, and the substantial decline in acres burned since 1935. A significant portion of the increase in intermediate age classes is the result of forest regrowth following large stand-replacing fires in the late 19th and early 20th centuries. Figure 3 displays the current age class distributions of the Nez Perce and Clearwater National Forests.

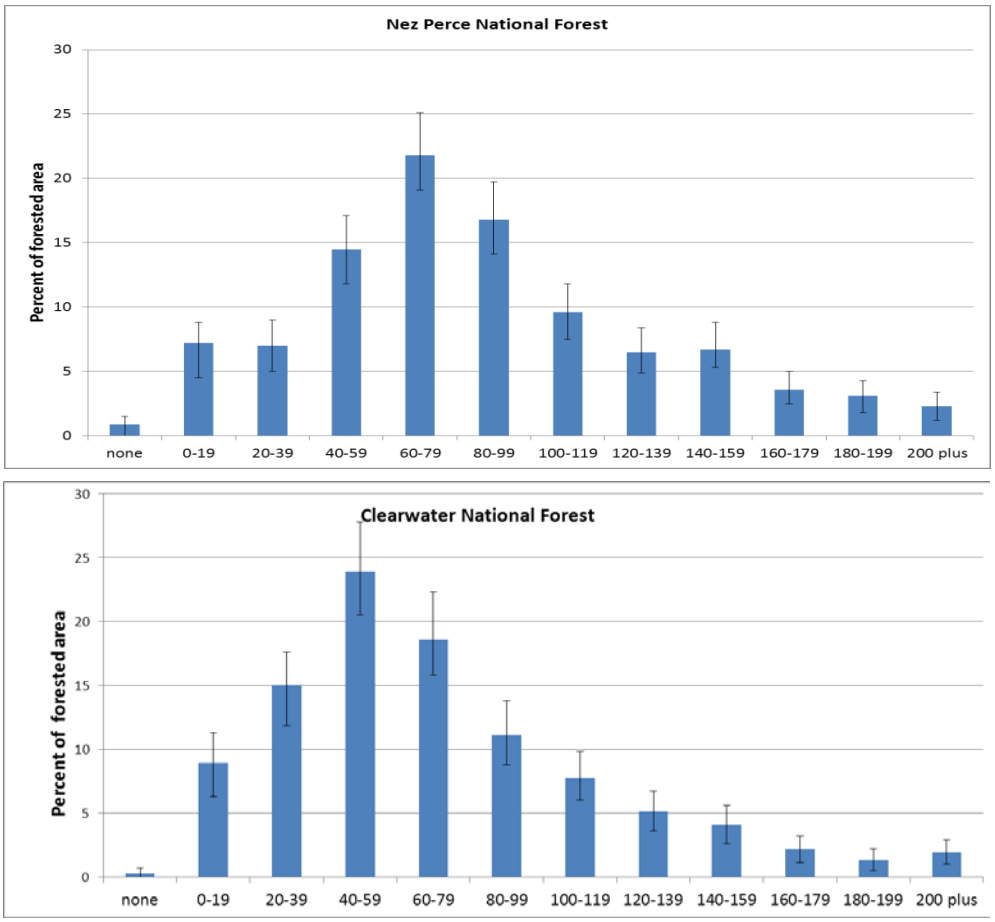

Figure 3. Estimated current age class distribution of the Nez Perce and Clearwater National Forests. Calculated values represent conditions at the time of inventory: 2000–2007 for the Nez Perce National Forest and 1998–2007 for the Clearwater National Forest. Narrow vertical lines represent the 90% confidence interval. The estimated means and confidence intervals are based on 324 Forest Inventory and Assessment field unit locations (1,246 subplots) from the Nez Perce National Forest and 293 Forest Inventory and Assessment field locations (1,127 subplots) from the Clearwater National Forest.

These observed trends in age and structure classes on the Nez Perce and Clearwater National Forests generally mirror those identified for much of the Inland Northwest (Hessburg and Agee 2003). Hessburg et al. (2000) constructed historical and current vegetation maps from 1932 to 1966 and 1981 to 1993 aerial photographs for sample subbasins within the interior Columbia River basin. Comparing historic and current vegetation maps, Hessburg et al. (2000) found that forests of central Idaho experienced a significant increase in area of intermediate structural classes. Stand initiation structures (new forests) declined significantly due to fire exclusion, despite timber harvest activity. This analysis found no significant change in the amount old forest structures (both single and multi-storied) in the Central Idaho Mountains "ecological reporting unit" (ERU) that contains most of the Nez Perce and Clearwater National Forests (Hessburg et al. 1999, 2000). However, they noted that timber harvest activities reduced

the abundance of medium- and large-sized trees distributed in other forest structures as remnants of stand-replacing fires.

These observations are supported by data on annual acres burned on the Nez Perce and Clearwater National Forest over the last 110–140 years (Figure 4). These records indicate that a relatively high number of acres burned in the late 19th and early 20th centuries, followed by an extended 4–5 decade period of comparatively few acres burned. Over the last 25 years (1985–2010), acres burned have increased over the mid-20th century, but less than the early 20th century.

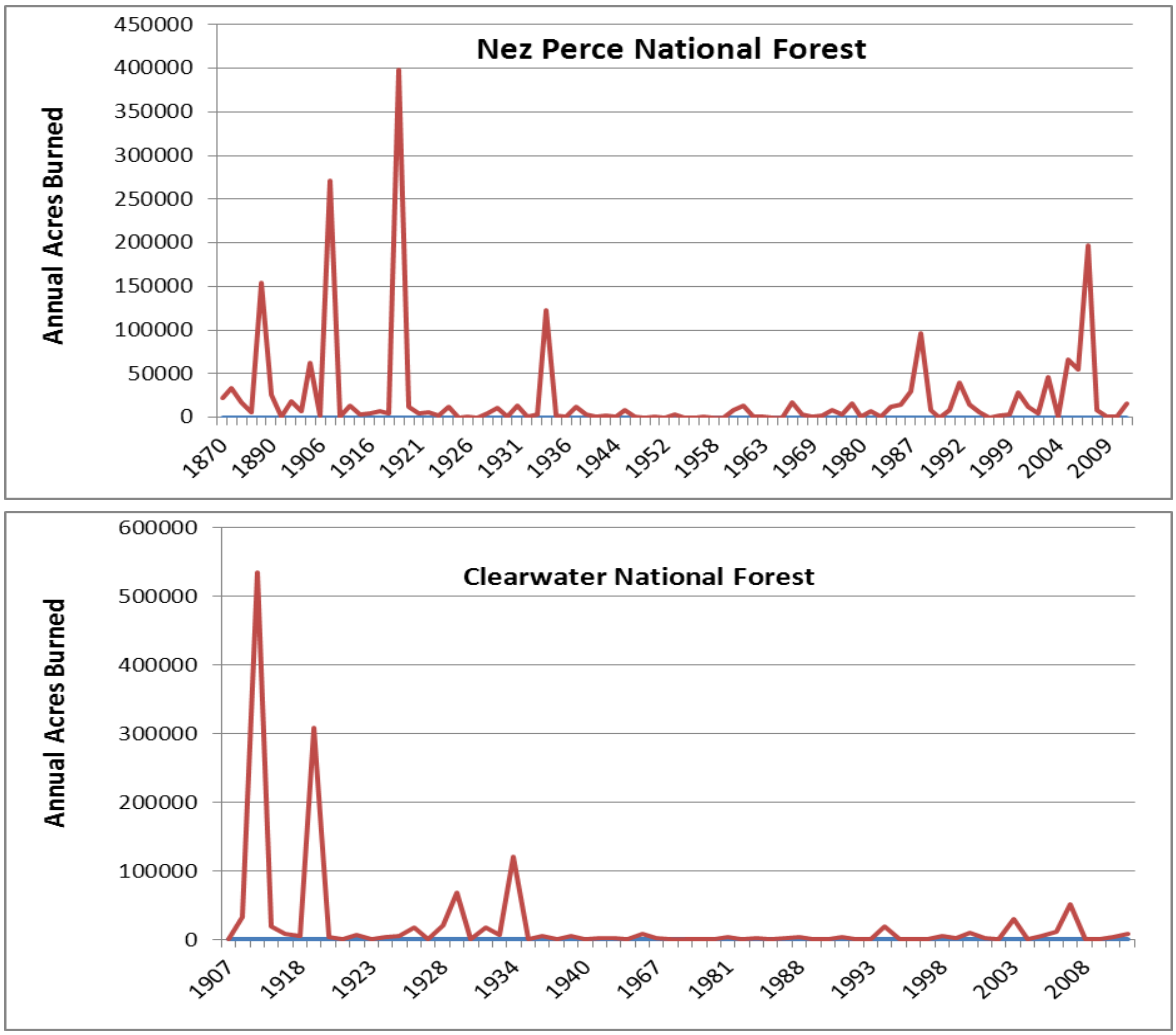

Figure 4. Annual acres burned on Nez Perce and Clearwater National Forests

Recently, bark beetle populations and resulting tree mortality have increased substantially in western North America. On the Nez Perce and Clearwater National Forests, beetle-caused tree mortality (Table 2 and Figure 5) has also been substantial although less severe than some other areas.

Table 2. Acres of bark beetle mortality 2001-2011

Trees Per Acre	1–5	6–15	15+
Nez Perce National Forest (acres)	292,236	138,748	61,194
Clearwater National Forest (acres)	217,740	42,175	5,276
Total (acres)	509,976	180,923	66,740

Note: Data are compiled from Aerial Detection Surveys. The following bark beetles are included in these data: Mountain Pine Beetle, Douglas-fir Beetle, Spruce Beetle, Western Pine Beetle, Western Balsam Bark Beetle, Pine Engraver, Douglas-fir Engraver, and Fir Engraver.

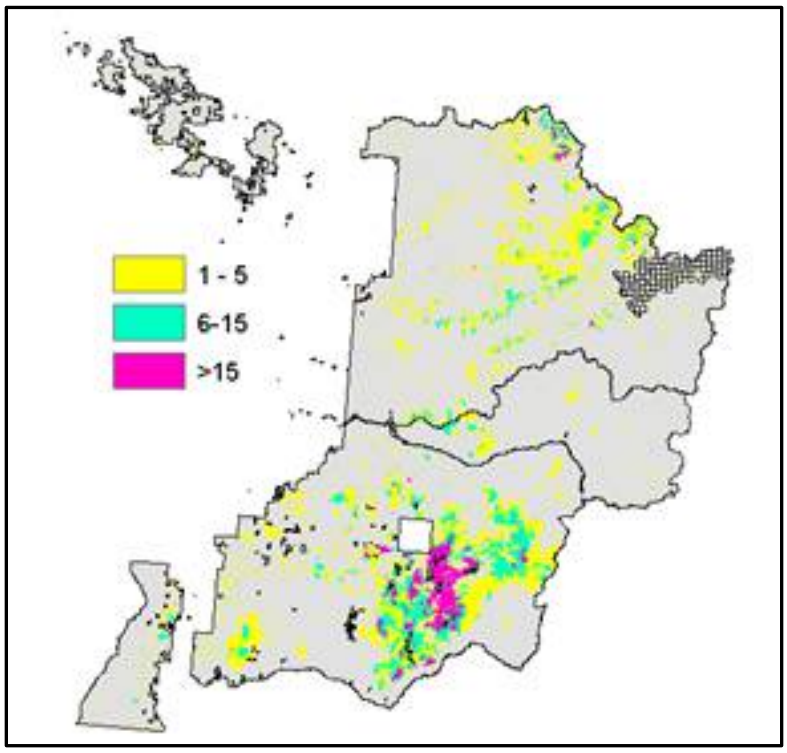

Figure 5. Areas of the Nez Perce and Clearwater National Forests with bark beetle-caused tree mortality 2001-2011. Tree per acre classes represent the number of trees per acre killed by bark beetles.

Root diseases have a substantial, and perhaps the most significant, effect on forest carbon stocks and flux on the Nez Perce–Clearwater National Forests. Root disease–caused tree mortality has long been common in Idaho forests. However, over the past century, disease-tolerant species such as western white pine, western larch, and ponderosa pine have decreased significantly in abundance due to white pine blister rust, wildfire suppression, and historical harvesting practices. These species have been replaced with Douglas-fir, grand fir, and subalpine fir, which are the species most susceptible to root diseases, resulting in substantially increased tree mortality and productivity losses in today's forests (Byler et al. 2000). Root diseases reduce stand densities, stall forest succession, result in smaller trees, and substantially reduce forest productivity

(Figure 6). Thus, moderate and high-severity root disease centers are a major source of forest mortality and a long-term constraint on forest carbon sequestration rates.

Figure 6. Typical root disease centers of moderate severity. Note the dead standing trees, reduced stand density, loss of crown cover, and substantially lower productivity. Because these effects persist for long periods until disease resistant tree species are able to occupy the site, root diseases limit forest carbon stocks and sequestration rates for longer periods than other disturbances.

Root disease is the leading cause of tree mortality on the Nez Perce National Forest (22% of all mortality) (Disney 2010) and Clearwater National Forest (44% of all mortality) (Hughes 2011) (Table 3). Root diseases affect more acres on these National Forests than wildland fire, bark beetles, and timber harvest combined. Because root diseases can reduce tree growth and stocking densities for many decades, their effects on forest carbon stocks and flux are more persistent than the effects from other disturbance agents.

Table 3. Estimated acres of low, moderate and high root disease effects on the Nez Perce and Clearwater National Forests

Root Disease Severity	Low (1–20 ft^2 basal area loss)	Moderate (21–80 ft^2 basal area loss)	High (>80 ft^2 basal area loss)
Nez Perce National Forest (acres)	864,119	338,639	15,976
Clearwater National Forest (acres)	609,280	469,787	21,795
Total (acres)	925,099	808,429	37,771

Source: National Insect and Disease Risk Map (Forest Service 2006)

Timber harvesting and other types of silvicultural practices remove biomass from the ecosystem, reducing carbon stocks. However, unlike other disturbance processes, timber harvesting continues to store some portion of the carbon removed from the ecosystem in the form of wood products. Since the time when FIA surveys were used to estimate existing forest ecosystem carbon stocks and age class distribution described above, timber harvest and other silvicultural practices have occurred on the Nez Perce–Clearwater National Forests (Table 4). These activities have affected substantially fewer acres than bark beetle–caused tree mortality, wildland fire, and root diseases.

Table 4. Acres of silvicultural treatments 2001–2011

Silvicultural Treatment	Even-aged Timber Harvest	Uneven-aged Timber Harvest	Intermediate Harvest	Precommercial Thinning	Prescribed Fire
Nez Perce National Forest (acres)	4,286	529	6,094	6,616	39,996
Clearwater National Forest (acres)	5,334	857	3,923	7,832	44,832
Total (acres)	9,620	1,386	10,017	14,448	84,828

Source: Northern Region FACTS database

4.1.3.2 Harvested Wood Products Carbon

Carbon stocks in wood products harvested from the Nez Perce and Clearwater National Forests peaked in the late 20th century and have declined since 1995 (Figure 7). This trend generally mirrors the trend in annual acres harvested. As of 2010, approximately 3.8 Mt of carbon are stored in harvested wood products currently in use and another 2.2 Mt are stored in solid waste disposal systems (i.e., landfills).

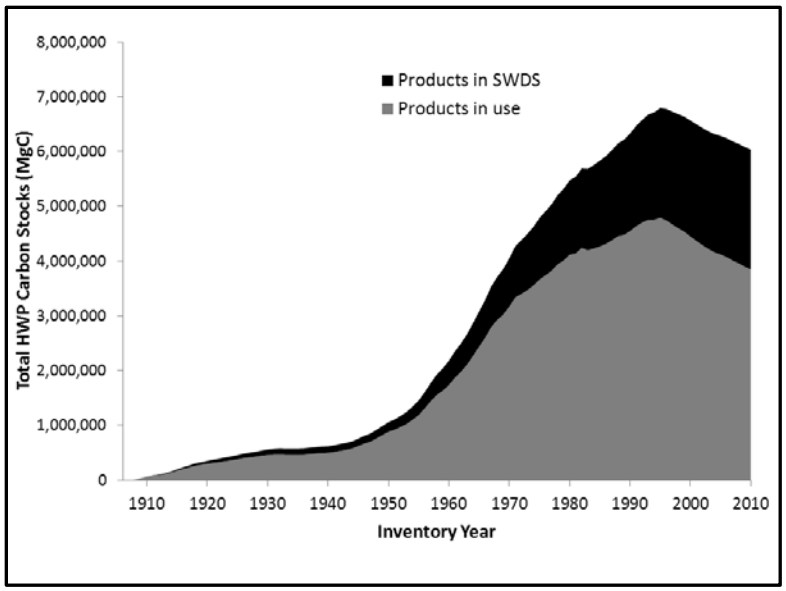

Figure 7. Cumulative total carbon stored in harvested wood products (HWP) manufactured from Nez Perce and Clearwater National Forests timber using the Intergovernmental Panel on Climate Change/Environmental Protection Agency approach. Carbon in HWP includes products that are still in use and carbon stored at solid waste disposal sites (SWDS), including landfills and dumps. Stockmann et al. (2012) describe the methods used to produce these estimates.

4.1.4 *Projected Trends in Forest Carbon Stocks and Flux*

The future of the terrestrial carbon sink of western U.S. forests is uncertain due to the uncertainty associated with the multiple interacting factors that influence carbon stocks and fluxes (Lenihan et al. 2008a; Ryan et al. 2008; King et al. 2007; Pacala et al. 2007; Birdsey et al. 2007). These factors include climate variability and change; potential positive effects of increased atmospheric CO_2 concentrations on plant productivity; frequency, duration, and severity of moisture stress; changes in the rate and severity of natural disturbances; and land management practices (Canadell, Pataki et al. 2007).

Projections of the future of the U.S. carbon sink based on national trends in land-use change and fire suppression indicate that the U.S. carbon sink will decline over the 21st century due a slowing of ecosystem recovery from 19th century land use and vegetation response to 20th century fire suppression (Hurtt et al. 2002). This analysis, which does not include projected climate changes, also concluded that U.S. forests would convert to a large carbon source if fire suppression is ineffective in the 21st century.

Modeling experiments based on projected changes in climate, but not land use, suggest that the future strength of the U.S. carbon sink is very sensitive to the degree of change in climate, particularly precipitation, and fire regimes (Bachelet et al. 2001; Lenihan et al. 2008a,b). If precipitation increases and temperature increases are small or moderate, net ecosystem productivity and carbon stocks are expected to increase. Conversely, if climate changes result in decreased precipitation and soil moisture during the growing season, net ecosystem productivity

is expected to decline due to drought stress and may result in a net carbon source to the atmosphere (Lenihan et al. 2008a,b). Increasing concentrations of atmospheric CO_2 may moderate these impacts by enhancing vegetation productivity and water use efficiency (Bachelet et al. 2001; Joyce and Nungesser 2000; Lenihan 2008a,b), at least up to a point where nutrient limitations and increasing temperatures overwhelm the beneficial effects of CO_2 concentrations (Fishlin et al. 2007). Increases in annual area burned may further reduce net ecosystem productivity and carbon stocks despite the potentially positive effects of increasing CO_2 concentrations (Lenihan et al. 2008a,b).

Empirical analyses of the growth rates of trees in the Pacific Northwest demonstrate the potential impacts of climate change on forest productivity and reveal that high-elevation and low-elevation forests respond differently to climate variability. Seasonal photosynthesis ("carbon uptake period") and annual growth rates of high-elevation forests (e.g., subalpine fir, mountain hemlock, and high-elevation lodgepole pine and Douglas-fir) are commonly limited by a relatively short growing season, low soil temperatures, and long periods of snowcover (Littell et al. 2008; Chinn et al. 2008; Case and Peterson 2007; Case and Peterson 2005; Peterson et al. 2002). Growth rates increase in these high-elevation forests during years with earlier spring snowmelt, abnormally warm annual temperatures, and longer growing seasons. These results suggest that projected changes in regional climate will likely result in increased productivity and carbon stocks of high-elevation forests.

Conversely, growth rates of lower and mid-elevation ponderosa pine, Douglas-fir, and lodgepole pine forests of the Pacific Northwest and Northern Rockies tend to be limited by low growing-season precipitation and high growing-season temperatures (Littell et al. 2008; Case and Peterson 2007; Case and Peterson 2005; Watson and Luckman 2002). During these conditions, the rate of water loss from evapotranspiration is greater than the rate of water absorption by roots, resulting in water stress (Case and Peterson 2007). Prolonged periods of water stress significantly reduce a tree's ability to photosynthesize (Kozlowskie and Pallardy 1997). As a result, climate projections with increased frequency of reduced snowpack, earlier spring snowmelt, increased temperatures during the growing season, and little or no significant increase in summer precipitation likely will result in reduced forest productivity and carbon sequestration in low and mid-elevation forests of the Pacific Northwest and Northern Rockies (Boisvenue 2007; Boisvenue and Running 2010). Recent research suggests that regional warming and water balance deficit trends over the late 20th century are contributing to rapid and widespread increases in mortality rates and slight decreases in forest density and basal area in old growth forest throughout the western United States (van Mantgem et al. 2009).

In addition to the gradual changes in forest productivity and carbon stocks resulting from directional climate change, episodic events such as large high severity fires and large-scale insect outbreaks can significantly affect carbon stocks and flux of forest ecosystems. In the short term (decades), disturbances can convert regional carbon sinks to a carbon source (Kurz, Stinson, and Rampley 2008; Kurz, Stinson et al. 2008; Kurz, Dymon et al. 2008). Over the long term

(centuries), the effects of disturbances on the regional carbon balance are neutral assuming similar vegetation regrows on the disturbed area and the long-term frequency and severity of disturbances does not change (Kashian et al. 2006; Canadell, Pataki et al. 2007). The potential fertilization effect of atmospheric CO_2 concentrations may influence the rate of terrestrial carbon recovery (Lenihan et al. 2008; Balshi et al. 2009). One recent study of ponderosa pine stands in western Montana and eastern Idaho concluded that recent increases in atmospheric CO_2 concentrations increased growth rates in older trees (Knapp and Soulé 2010).

On the Nez Perce–Clearwater National Forests, carbon stocks and flux rates of will vary over coming decades in response to complex and uncertain interactions between climate variability and change, forest age class distribution, disturbance–recovery processes, and possible effects of CO_2 concentrations on forest productivity (Hyvonen et al. 2007; Smithwick et al. 2008). The contribution of forest regrowth from past disturbances is expected to decline as the maturing forests grow more slowly and take up less CO_2 from the atmosphere. Projected climate changes for the region suggest that relatively high-elevation forests may increase in productivity and carbon sequestration, whereas these processes may decline in low-elevation forests and mid-elevation forests with south and southwesterly aspects. Potential increases in the frequency and size of high severity fires, bark beetle outbreaks, and root disease occurrence or severity could also significantly impact the carbon budgets of these forests over the 21st century. Extensive high severity fires, large scale tree mortality from bark beetles, and productivity losses due to root diseases could convert the Nez Perce–Clearwater National Forests from a net carbon sink to a carbon source for several decades (Bond-Lamberty et al. 2007; Kurz, Stinson et al. 2008; Kurz, Dymon et al. 2008). In addition, timber harvesting will affect the amount of ecosystem carbon stored and the short-term net flux of carbon within the atmosphere. However, the net contribution to atmospheric CO_2 concentrations resulting from fire, insect-caused tree mortality, and timber harvest is expected to be approximately zero over the long term as long as disturbed areas regenerate with similarly productive species and the disturbance frequency and intensity does not change (Kashian et al. 2006).

Using harvested forest biomass will continue to store carbon in wood products and landfills (EPA 2008; Skog 2008; Skog and Nicholson 2000; Skog and Nicholson 1998) and may reduce the demand for more fossil-fuel intensive products such as steel and cement (Perez-Garcia et al. 2005; Malmsheimer et al. 2008). In addition, emerging markets in forest biomass for use in energy production could offset fossil fuel emissions (Malmsheimer et al. 2008; Nicholls et al. 2009).

4.1.5 *Key Sources of Uncertainty*

4.1.5.1 Changes in Climate

Net ecosystem productivity is very sensitive to changes in temperature, precipitation, soil moisture and other climate characteristics (Angert et al. 2005; Paio et al. 2008; Paio et al. 2009). Climate change also has a significant impact on the extent and severity of wildland fires,

population dynamics of bark beetles and other forest insects, moisture stress on trees, and other disturbance processes. All global climate models project surface temperature warming in the Northern Rockies. Average annual temperatures are expected to increase by +1.5 degrees Fahrenheit (°F) to 5.9 °F by the 2040s, depending on the rate of greenhouse gas emissions. These projected temperature increases exceed observed 20th century year-to-year variability. Annual mean temperature could change by –10% to +20% by the 2040s. Many climate models project increases in precipitation during the winter and decreases in summer; however, projected precipitation changes are comparable to 20th century variability. These regional climate projections suggest increasing water deficits for forests, which increases tree stress and mortality, tree vulnerability to insects, and fuel flammability. The severity of these potential climate change effects remains somewhat uncertain at local scales.

4.1.5.2 Disturbance Regimes

High severity disturbance events have a substantial and rapid impact on forest carbon stocks and flux. Persistent changes in the frequency, extent, and severity of disturbances can alter long-term (decades or longer) regional net carbon balances. Yet, knowledge of the future trajectory of wildfires, insect outbreaks, drought severity and duration, and other major forest disturbances is limited. The available scientific evidence suggests the average annual area burned by wildfires is likely to increase in coming decades in the Pacific Northwest and Northern Rockies. Similarly, higher temperatures and water stress may increase the susceptibility of trees to bark beetles and other insect and pathogens. Available scientific information suggests that risks of bark beetle mortality may increase in higher elevation forests. However, there is greater uncertainty in these projections at finer spatial scales.

4.1.5.3 CO_2 Fertilization

CO_2 is a fundamental building block of photosynthesis. Trees and other plants grown in elevated CO_2 environments have increased growth rates, productivity, and water use efficiency compared to controls (Norby et al. 2005). Thus, some evidence indicates that increasing atmospheric concentrations of CO_2 may increase forest productivity. However, the results of these controlled experiments have not been widely confirmed in natural environments (see Knapp and Soulé 2010). Additional studies have suggested that the potential CO_2 fertilization effect is limited to young plants and by water and nutrient availability (particularly nitrogen) (Norby et al. 2010). In addition, some evidence exists that trees and other plants acclimate to elevated CO_2 concentrations over time, thus reducing the duration of the potential fertilization effect. In sum, considerable uncertainty exists about the potential of elevated CO_2 concentrations to increase net ecosystem productivity, carbon storage, and the carbon sink strength of forests.

4.1.5.4 Potential Changes in Forest Composition

Long-term projections of regional net carbon balances depend on assumptions about the future vegetation composition of currently forested areas (Kashian et al. 2006; Canadell et al. 2008). In coming decades, climatically suitable habitat for many tree species may shift from their current

locations (Rehfeldt et al. 2006). Some models suggest that changes in climatically suitable habitat combined with amplified disturbance regimes may result in some forests of the Northern Rockies converting to non-forest vegetation (Westerling et al. 2011). However, there is considerable uncertainty regarding the effects of climate change on the composition of forest vegetation. These uncertainties in future forest composition and structure contribute to the uncertainty in long-term projections of forest carbon stocks and flux and regional net carbon balances (Smithwick et al. 2008; Rhemtulla et al. 2009).

4.1.5.5 Biomass Utilization

Using woody biomass for energy production and as a substitute for more greenhouse gas intensive materials (e.g., steel and cement) has the potential to provide substantial global carbon benefits (Nabuurs et al. 2007). However, the capacity to realize these potential carbon benefits is uncertain due to current technological limitations, social and political issues, and reliability of feedstock supplies. At regional and local scales, limited and declining capacity in the wood products industry adds further uncertainty to projections of the size of the carbon pool in harvested wood products and the use of woody biomass to displace fossil fuels.

4.1.6 *Potential Mitigation Options*

The recent Intergovernmental Panel on Climate Change report identifies four general categories of options to reduce emissions by sources and/or increase carbon sequestration by sinks by forests: (1) maintaining or increasing forest area; (2) maintaining or increasing site-level carbon density; (3) maintaining or increasing landscape-level carbon density; and (4) increasing off-site carbon stocks in wood products and enhancing product and fuel substitution (Nabuurs et al. 2007).

4.1.6.1 Land Exchange

Occasionally, the Nez Perce–Clearwater National Forests have the opportunity to exchange lands with willing landowners. Where land exchanges result in a net increase in forest productivity or net forested acres within the National Forest System, they may maintain or increase the area of productive forests.

4.1.6.2 Prompt Regeneration of Disturbed Areas

Rapid tree planting in areas severely disturbed by wildfire can accelerate carbon accumulation, and thus increase stand- and landscape-level carbon density over time. An evaluation of management options to modify the net carbon balance of Canadian forests found that the potential for increasing the forest carbon sink strength was largest with reducing regeneration delays after natural disturbances (Chen et al. 2000). On the Nez Perce–Clearwater National Forests, natural regeneration is often, but not always, successful over time. The interior of high severity burn patches are most prone to long-delayed tree regeneration. In these areas, rapid post-fire tree planting may accelerate forest development and carbon accumulation. However, such treatments are costly and may be financially infeasible (Chen et al. 2000).

4.1.6.3 Extended Rotations

Several commentators have suggested that increasing timber harvest rotation length can produce global carbon benefits by increasing forest carbon storage (Birdsey et al. 2007; Nabuurs et al. 2007; Ingerson 2007; Leighty et al. 2006; Birdsey et al. 2000). In concept, increasing rotation ages can increase stand- and landscape-scale carbon storage by holding more carbon in forests and avoiding emissions from harvesting. However, several factors suggest that achieving carbon benefits from extended rotations may be problematic.

Extended harvest rotations focused on specific ownerships, forests, and regions will reduce annual timber harvest levels and wood products production in the affected area. Such local and regional reductions would likely be offset by market-driven harvest increases by other timberland owners and in other regions. For example, more than 85% of the reductions in timber harvest levels on western federal forests in the late 1980s and 1990s were replaced by increased harvest by other timberland owners and regions, including international imports (Wear and Murray 2004; Murray et al. 2004). As a result of this "leakage," little or no net effect would be likely on national or global terrestrial carbon balance, and no net effect on atmospheric concentrations of CO_2, as a result of increasing rotation lengths on the Nez Perce–Clearwater National Forests. In addition, increased lumber prices resulting from timber sale reductions (Wear and Murray 2004) could lead to increased use of more energy-intensive materials (e.g., steel and cement), and net increases in greenhouse gas emissions from fossil fuel combustion.

Extending rotation ages also increases exposure of landscape-scale carbon stocks to high severity disturbances, such as wildfires, (Kurz, Stinson et al. 2008) and may even increase the probability of bark beetle outbreaks (Kurz, Dymond et al. 2008). In fire-prone areas, such as the Nez Perce–Clearwater National Forests, the probability that the theoretical carbon storage benefits of extended rotations will be substantially reduced is increased. Thus, the carbon storage benefits may not persist or be sustainable for extended periods. Recent analysis indicates that the risk of carbon loss due to wildfire is higher on the Nez Perce–Clearwater National Forests than most other forested areas of the United States. (Hurteau et al. 2009).

4.1.6.4 Fire Suppression

Several authors have suggested that continued or increased fire suppression effort can help maintain or increase landscape-level carbon density and storage in U.S. forests (Birdsey et al. 2007; Nabuurs et al. 2007; Birdsey et al. 2000). However, fire management strategies to increase forest carbon storage must consider both the amount of carbon stored and the stability of that storage as climate and fire regimes change (Schimel 2004; Schimel and Braswell 2005).

Aggressive fire suppression can limit the number and size of large fires and, therefore, may increase forest carbon storage and sink strength, at least for the short term. However, these carbon storage gains are unlikely to be sustained over time. Since 1986, the number of large forest fires in the Northern Rockies increased more than tenfold (1,100%) and the area burned by

large fires increased more than threefold (350%) compared to the period 1970 to 1985 (Westerling et al. 2008). Numerous simulations of the effects of projected climate change on wildfire in western North America all indicate an increasing probability of increased annual area burned and increased frequency of high severity fires (Westerling and Bryant 2008; Nitschke and Innes 2008; Bachelet et al. 2007; McKenzie et al. 2004; Brown et al. 2004). If observed trends continue or if the projected changes in fire regimes are even partially realized, aggressive fire suppression is likely to lead to most acres burning in fewer, more extreme and unmanageable events with greater losses of forest carbon stocks (Hurteau et al. 2008). Thus, it is likely that, at best, the carbon benefits of aggressive fire suppression are temporary, not permanent, and may even result in greater greenhouse gas emissions from fires and loss of forest carbon stocks than would occur with less aggressive fire suppression (Kirschbaum 2006; Breshears and Allen 2002).

4.1.6.5 Using Biomass for Energy Production

According to the IPCC, “When used to displace fossil fuels, woodfuels can provide sustained carbon benefits, and constitute a large mitigation option” (Nabuurs et al. 2007 pg. 551). A recent study estimates that U.S. forests are capable of sustainably producing 368 million dry tons of wood per year, with 41 million dry tons from currently unused logging residues and 60 million dry tons from hazardous fuel treatments (Perlack et al. 2005). If applied to bioenergy production, this wood residue could offset a substantial percentage of U.S. CO_2 emissions from fossil fuels (Richter et al. 2009).

In addition to ongoing energy production from milling byproducts at area wood processing facilities, several opportunities exist to use wood residues from timber harvest, hazardous fuel reduction projects, and other silvicultural treatments on the Nez Perce–Clearwater National Forests. These opportunities include Avista Corporation’s Bioenergy Plant in Kettle Falls, Washington; several area pellet plants; and area schools and other facilities with high-efficiency wood heating systems. Potential exists for a substantial increase in wood energy production in central Idaho that could replace CO_2 emissions from fossil fuels while also reducing CO_2 emissions from pile burning and other forest residue treatments.

4.1.7 *Summary of Mitigation Options*

At the global scale, preventing large-scale conversion of forests to other land uses (deforestation), primarily in the tropics, provides the greatest opportunity to mitigate the trend of increasing atmospheric concentrations of CO_2 (Nabuurs et al. 2007). In the United States, the largest and most effective mitigation opportunity has already been taken—creating State and federal public forests that share the common objective of “keeping forests as forests” in perpetuity.

Within the context of public forests, individual land management actions are unlikely to have significant long-term effects on the atmospheric concentrations of CO_2 and other greenhouse gases. Without a substantial reduction in fossil fuel emissions, the impacts of projected climate

change on disturbance regimes and species composition will likely overwhelm the short-term effects of land management actions. From this perspective, the primary forest management action to mitigate increasing atmospheric CO_2 concentrations is the sustainable use of woody biomass to generate energy and biofuels and displace more fossil-fuel intensive construction materials (Nabuurs et al. 2007). As the IPCC concluded; “In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit” (Nabuurs et al. 2007, p. 543).

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