Climate Change Impacts in Washington's Forests

A roadmap for adaptation and mitigation responses

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Abstract:
Research into the impact of climate change on forested ecosystems suggest that extreme disturbance events such as fires and insect outbreaks will be primary drivers of ecosystem change in the inland forests of the Pacific Northwest (PNW) Region. The loss of mature forest cover to insects and fire has implications far beyond the forest because of the linkages between climate change, carbon storage potential, sustainable ecosystems, living forests, renewable energy sources, and the forest product stream. Climate change is linked to elevated atmospheric concentrations of carbon dioxide (CO_2). Forests can increase or decrease atmospheric CO_2 through release (mortality and decay) or storage of carbon (growth). Dead and dying forests are subject to higher risk of fire releasing carbon to the atmosphere and sequestering less carbon than actively growing forests.

This paper integrates the issues emerging from current climate trends in eastern Washington. It considers forest health and ecosystem sustainability, identifies current climate change impacts, and explores mitigation and adaptation strategies that go beyond the boundaries of forest landscapes to integrate clean energy initiatives into an integrated carbon framework. Removing high fuel loads in the forest effectively transfers carbon storage to long-lived product pools or biofuels, that displace fossil fuels and energy intensive building materials while at the same time breaking the climate feedback of accelerated emissions. The combined effect of reducing wildfire risks and reducing reliance on fossil fuel intensive products and services provides the simultaneous benefits of reducing the carbon footprint and creating forest conditions that are more likely to be sustainable under changing climatic conditions.

Since 2000 eastern Washington has been experiencing warmer summer temperatures than at any time in the last 100 years. For the first 6 years of that period, precipitation shortfalls were severe, culminating in near record shortfalls by 2005. These extreme weather conditions are consistent with predicted climate change impacts for the Columbia basin as a whole (Mote 2004). Research into the impact of climate change on forested ecosystems suggest that extreme disturbance events such as fires (Gedalof et al. 2005, McKenzie et al. 2004) and insect outbreaks (Carroll et al 2003, Logan et al. 2003) will be primary drivers of ecosystem change in the inland forests of the Pacific Northwest (PNW) Region.

We can gauge how eastern Washington forests are responding to this climate trend by examining recent trends in fire, and insect activity. The most alarming trend is a substantial spike in pine mortality from mountain pine beetle (*Dendroctonus ponderosae*) (MPB). There were 20 times more pine trees killed from 2000-2004, than in the prior 20 years combined. Mortality trends from MPB were shown to be highly correlated with increasing summer temperatures and record low moisture levels (Oneil 2006). The record fires of 2006 were at least partially attributable to the presence of these recently killed pine stands, but extremely hot, dry conditions were necessary to carry the fires across approximately 400,000 acres. The increase in insect outbreaks and the extent of fires we have seen in the past five years suggests that climate change is already dramatically affecting our forested ecosystems.

While forests can decrease atmospheric CO_2 by storing Carbon in trees and wood products, the established link between elevated atmospheric concentrations of CO_2 (IPCC 2001) and temperature increases provide feedback inducing ever more emissions from the forest. Dead and dying forests are subject to higher risk of fire which releases carbon to the atmosphere (Lynch et al. 2006) and sequesters less carbon than actively growing forests. To disrupt the magnitude of the feedback mechanism between climate change and extreme disturbance events, we present options for developing additional carbon storage sinks associated with forests, including long-lived products and the potential for displacement of fossil fuels with renewable energy from forest biomass. This paper integrates the issues emerging from current climate trends in eastern Washington. It considers forest health and sustainability, identifies climate change impacts and explores mitigation and adaptation strategies. We present options for developing additional carbon storage sinks associated with forests, including long-lived products and the potential for displacement of fossil fuels with renewable energy from forest biomass.

Changing Weather and Forests

Temperature and precipitation data for eastern Washington was obtained from the Western Regional Climate Center (www.wrcc.org) to generate five-year running averages for the last 110 years in Figure 1 (Oneil 2006). Since 1989, summer temperatures have been generally higher than any other time in the century and, since 1999, the warming trajectory has been beyond the historic range entirely. Summer temperatures have not been below the 110-year average since 1984. The five-year running average of pre-growing season precipitation (September through June) has been below the 110-year average for 14 of the past 18 years. These temperature increases and precipitation shortfalls in eastern Washington are consistent with predicted climate change impacts in the Columbia basin (Mote 2004).

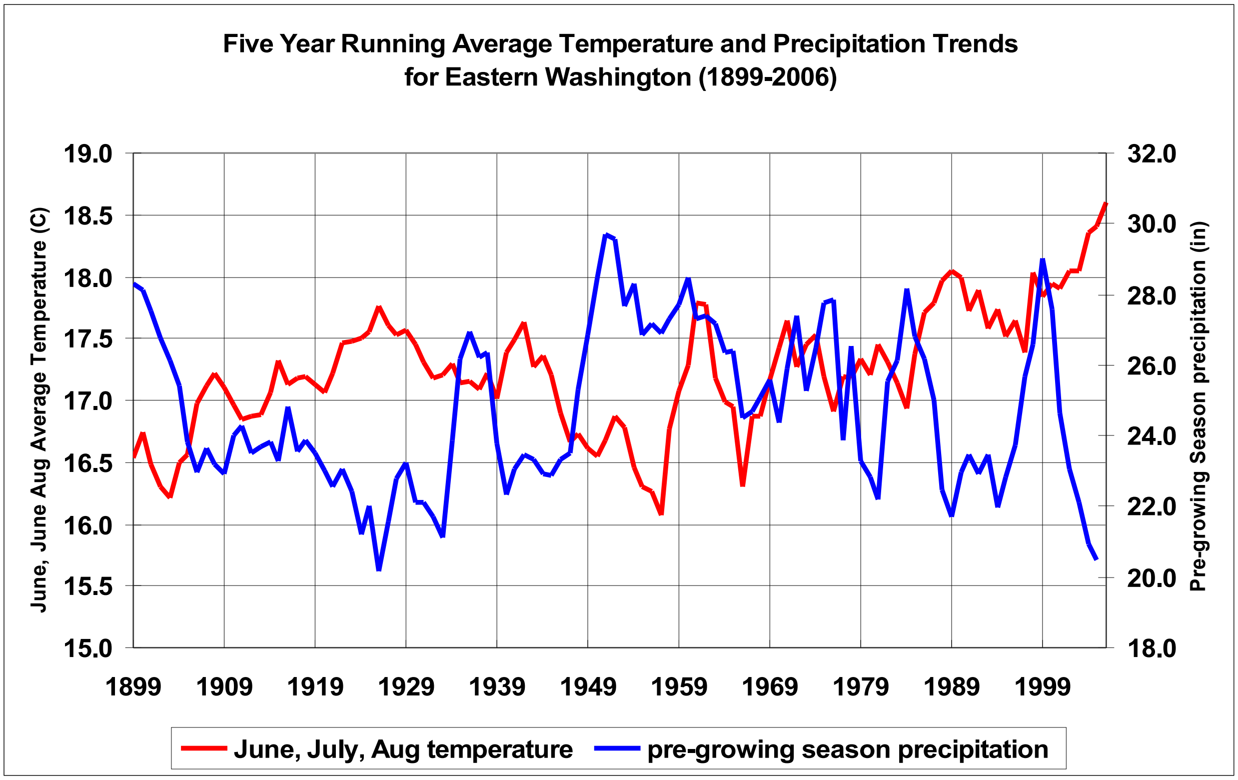

Figure 1: Temperature and precipitation trends for eastern Washington

The five-year running average of summer month temperatures (Figure 1) is correlated to the annual acreage of MPB outbreaks in lodgepole pine (*Pinus contorta*) and ponderosa pine (*Pinus ponderosa*) (Figure 2) (Oneil, 2006). The MPB outbreak data was collated from aerial surveys flown from 1954-2005 (data from PNWFHP, 2006). The large increases in acreage attacked by MPB that appear in the mid-1980's and since 2000, positively correlate with five-year average temperature trends and negatively correlate with precipitation trends for the same periods.

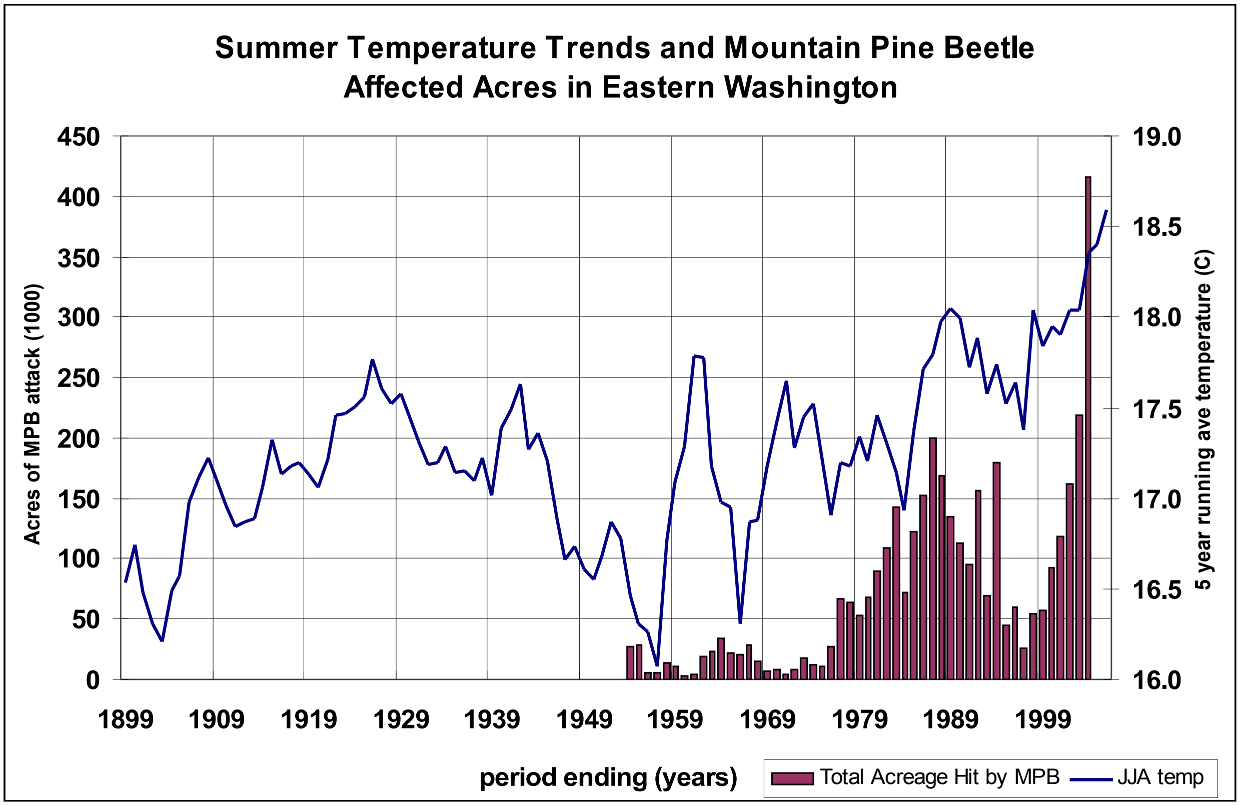

Figure 2: Temperature trends and MPB activity in eastern Washington on PP and LLP forests.

The same aerial survey data (PNWFHP 2006) was used in Figure 3 to depict a time series of mortality per acre from MPB infestations in ponderosa pine (PP) and lodgepole pine (LP) across all of eastern Washington for 1979 to 2004 (Oneil, 2006). The average mortality rate for the 1980-2000 reporting period was relatively stable at approximately 2.2 trees per acre. Coincident with the rise in substantial increase in average summer temperature from 2000 onward, for the 2001-2005 reporting period the average MPB induced mortality rate increased to 8.4 trees per acre. In 2004, MPB affected over 415,000 acres of LP and PP forests in eastern Washington, resulting in mortality of over 4 million pine trees (DNR FH 2006), representing an increase in the mortality equivalent to about 20 times the average for the previous 20 years. Lodgepole pine mortality from MPB attacks since 2000 is more than 70% of total mortality for the entire 25-year period from 1979-2004 (Oneil, 2006b). Elevated mortality rates for pine species have the greatest impact on the 30% of eastern Washington forest types that are dominated by pine. However, the percentage of non-Federal acres that would be potentially impacted is much higher as a pine component is found on almost 87% (3.3 million acres) of state and private timberlands in eastern Washington.

The increase in MPB attacks is most strongly correlated with changes in average summer vapor pressure deficit (VPD) (Oneil 2006) reflecting a regional climate change impact on sensitive pine species. However, the role of pine as the “canary in the coal mine” for eastside forests arises for several reasons. In comparison to other tree species, pines are host to the most aggressive native insect predator of eastside forests (USFS 2007). Pines are more sensitive to shifts in atmospheric dryness as measured by VPD than other tree species (Delucia et al 2000) and VPD increases exponentially relative to temperature increase (Waring and Running 1998), therefore even small shifts in temperature can generate substantial stress. Pines tolerate fewer years of stress than more shade tolerant species before succumbing to mortality (Keane et al, 1996). And finally, it is likely that the average VPD for the growing season months of June, July and August has reached a threshold value at which most tree species begin to exponentially decrease their stomatal conductance and shut down respiration to maintain water status (Waring and Schlesinger 1985).

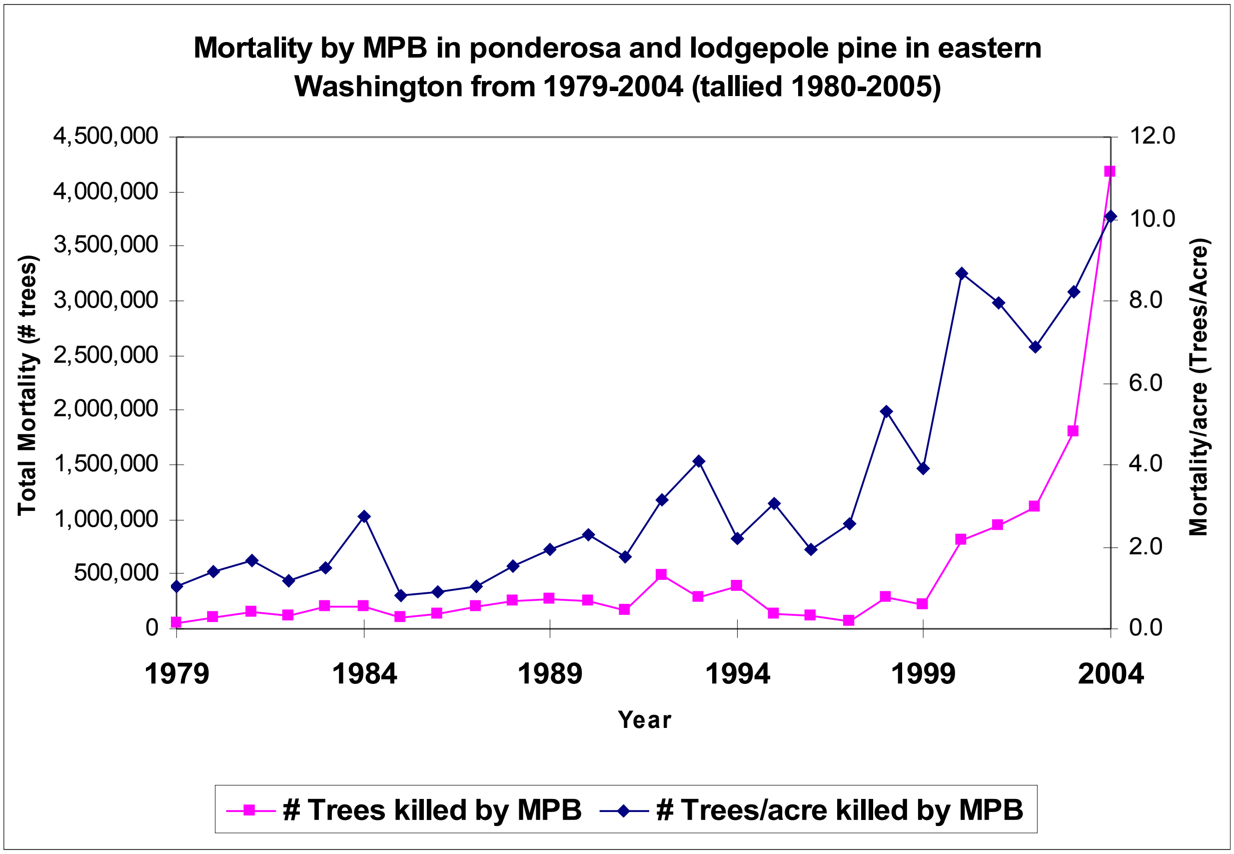

Figure 3: Tree mortality from MPB in eastern Washington 1979-2004.

Addressing insect outbreaks

Under historical climate conditions, controlling insect outbreaks involved reducing forest density, removing at-risk species or stand cohorts, or harvesting the forest while the insects are present to remove pest populations. Under current climatic conditions and presumably future conditions, the equilibrium state between the host trees and their insect predators is no longer clearly defined, as eastside forest managers have experienced numerous occurrences of recently thinned stands being killed by MPB in the past five years of hot dry conditions. In this state of climate flux, prior thinning and stocking recommendations can serve as a baseline to work forward from, but likely will not be sufficient to build the necessary resilience to climate change into eastside forests.

Much like the situation with wildfire, once insect and disease populations reach epidemic proportions, control options become limited or non-existent. Such is the case in British

Columbia where the MPB epidemic has impacted 9.2 million hectares in 2006 for a cumulative impact of 14 million hectares (34.5 million acres) (Carroll, 2007). Impacts from the MPB epidemic in central British Columbia have defied all control efforts and provided many surprises to managers. Whereas MPB typically hit stressed trees over 80 years of age, it is now killing 30 year old plantations of widely spaced, vigorous trees (Grainger, 2006). Whereas stands in close proximity to an existing outbreak were historically considered at high risk for infestation, now stands 200-400 km (125-250 miles) distant are succumbing to attack (Carroll, 2007). And finally, though MPB was known to prefer large diameter trees and especially target them during an epidemic, now small diameter trees are experiencing high mortality (Grainger, 2006). In British Columbia's epidemic, management agencies are no longer aiming for control, but for mop-up and mitigation of cascading environmental, economic, and social impacts (Shultz, 2006). Avoiding such high cost, high impact outcomes such as those presented by the British Columbia example requires a concerted effort on several fronts.

While we know thinning treatments must occur to maintain sustainable forest conditions, we also recognize that there are many challenges in identifying which areas will provide the greatest return on investment in terms of reducing insect spread, sustaining forest health, developing defensible space and reducing costs of mitigation. Identifying the best choices for treatment and designing effective treatments begins with having extensive, current, and spatially explicit inventory data. Analysis of the inventory data will determine treatment regimes that incorporate the many at risk values in our forests.

Fire Risk

Increase in the incidence, magnitude, and intensity of forest fires in inland forests have been attributed to a combination of changes in forest composition and structure from fire suppression, grazing, and past harvest practices (Sampson and Adams 1994, Pyne 1997, Arno 2000) and shifts in summer weather conditions that make more and hotter fires more likely (Gedalof et al. 2005, Westerling et al. 2006). Westerling et al. (2006) also found that spring snow melt is occurring earlier as a result of warming trends which adds to summer moisture shortfalls that increase wildfire hazard. Their analysis found that the number of large wildfires in the West was four times greater since 1986 than in the 16 years prior and that these fires affected 6.5 times more area across the entire region. Since 1995, approximately 1.1 million acres of forests have burned in eastern Washington. Approximately 1/3 of that acreage burned in 2006 in the most severe fire season since 1994, producing the largest fires since the 1903 Yacolt Burn (Christiansen 2007). The amount of dead and dry timber greatly exacerbated the effect of the extremely hot summer conditions, rendering the fires largely uncontrollable using all conventional means at our disposal (Christiansen 2007).

Historically, fire likely impacted approximately 82% of the forests (Camp 1995) over any given 100 year period in the East Cascades region and would have impacted virtually all of the forests in the southeast corner of the state (Olson, 2000). Similar fire impacts are likely for northeastern Washington, but detailed fire histories have not been compiled for that region. Since 1995, approximately 1.7%/year of the area in National Forests and 0.4%/year of the area under Washington Department of Natural Resources (DNR) fire protection have burned in eastern Washington (DNR fire statistics). At this 12 year rate, an area equivalent to that of the entire eastern Washington national forest system would burn within 58 years or 2.1 times more area than the historical extent found by Camp (1995). McKenzie et al. (2004) and Gedalof et al. (2005) indicate that the extent and severity of wildfires in Washington State are predicted to increase in size by 2-3 times under the most optimistic climate change scenarios and they conclude that summer temperature is the major driver in producing extreme wildfire events in Washington. To understand what a doubling of extent and severity might entail in terms of costs, ecological impact, and community and social disruption, we can start by examining the trends in these variables since 1995. Because wildfire activity is correlated with forest condition and our forests are under increasing stress from climate change and insect and disease outbreaks, the impacts we can estimate from the 1995-2006 data may be substantially lower than the impacts we may experience in the future.

Addressing Fire Risk

Historical studies and demonstrations have shown that treatments to remove surplus fuel loads and reduce forest density are successful at minimizing fire impacts. Reducing forest densities has the additional benefit of increasing the resiliency of live trees in the face of climate change. Improving the resilience of live trees can help to reduce the positive feedback that occurs when insect mortality increases the amount of dead biomass available when a fire is ignited.

Thinning forests to reduce their vulnerability to fire requires that the cut biomass be removed to effectively reduce fuel loads (Raymond and Peterson, 2005). The removal costs can be substantial if the thinned material is too small for the existing product stream. Mason et al. (2003), justified investing in treatments that can mitigate fire impacts by developing an avoidance of future costs approach. The avoided cost approach compares the future costs that would be saved by thinning forests now in order to reduce wildfire risk against the cost of thinning. These costs include avoided fire fighting costs, fatalities avoided, facility losses avoided, timber losses avoided, regeneration and rehabilitation costs avoided, community value of fire risk reduction, increased water yield and regional economic benefits. Considering the high cost of fighting fires, with the DNR spending $63 million last year alone, assessing the benefit of thinning in comparison to fire fighting costs is the first place to start. If even a fraction of the areas were thinned and became defensible space in which to control fire spread, and thus reduce fire risk, there may be a substantial monetary benefit from applying treatments as insurance against the expected cost of fighting fires on overstocked forests carrying large amounts of dead and dying biomass. This approach to justify greater investments in treatments to reduce future costs was recommended by the Washington Department of Natural Resources Forest Health Strategy Work Group which was convened by the Governor in 2004.

In the longer term, approaches and policies that promote forest biomass use as liquid fuel or as a renewable source of electrical energy may create sufficient market demand to make removal of small diameter wood economically feasible at market prices. Whether the wood is removed using the avoided cost approach or eventually provides positive economic returns, both its use as a renewal energy source and the reduction in fires could substantially improve the carbon footprint of the Inland West.

Forests, Carbon, and the Atmosphere

Global warming is linked to increasing concentrations of greenhouse gases, but fully 60 percent of total global impact is a result of increased atmospheric CO_2 (IPCC 2001). Forests increase or decrease atmospheric CO_2 through growth and mortality (Sampson and Hair 1992). One ton of CO_2 contains 0.27 tons of carbon. One ton of carbon is equivalent to 3.7 tons of CO_2. There are approximately 0.47 tons of carbon per cubic meter of wood and combustion of one cubic meter of wood results in release to the atmosphere of 1.7 tons of CO_2 (Innes and Peterson 2004). Dead and dying forests are subject to higher risks of fire which accelerates the release of carbon to the atmosphere (Lynch et al. 2006) and warmer summer temperatures are linked to increased wildfire activity (Gedalof et al. 2005, McKenzie et al. 2004).

Pacala et al. (2001) found that 20-40% of all terrestrial carbon sequestration in the United States occurred in western forests. Increases in wildfire frequency and intensity that release stored forest carbon could reverse that relationship such that forests would become a carbon source rather than a sink (Westerling et al. 2006). For example, in 2006, wildfires in eastern Washington consumed close to 400,000 acres of forestland generating smoke plumes that released volumes of CO_2 to the atmosphere equivalent to the annual emissions of 1 million Sport Utility Vehicles (SUV's) (Mason 2006). Much of the area burned in the 2006 fires contained dense forests with elevated mortality levels caused by MPB attacks. Since 1995, approximately 1.1 million acres of state and federal forestlands have burned in eastern Washington. Average annual volumes of CO_2 released by forest fires in eastern Washington have equaled the emissions equivalent of 250,000 additional SUV's every year since 1995. Forest management strategies that remove surplus fuel loads in overly-dense eastern Washington forests can help to reduce annual CO_2 emissions with the additional benefit of restoring forest health and resiliency and avoiding catastrophic forest fires.

Life-Cycle Analysis

Forest ecosystems absorb large quantities of carbon which is stored in solid wood, vegetation, litter, and soils thereby reducing atmospheric CO_2. Young healthy forests take up carbon at high rates, while the net carbon uptake in older forests ultimately slows with age followed by release from mortality, decay, and/or wildfire. The end-use of timber harvested from forests is a factor in evaluating the net consequences of forestry to the global carbon cycle. Forest products that are durable goods, such as building materials or furniture, store embodied carbon for the life of the product. Short-term products, such as paper and cardboard, once used and allowed to decay or burn, release stored carbon to the atmosphere. Carbon embodied in milling residuals and discarded wood products may be sequestered in landfills for long periods of time. When forest products are used in place of non-wood products such as steel and concrete, that are much more energy-intensive in their manufacture, releases of atmospheric carbon are avoided. When forest biomass is used to generate energy as a substitute for fossil fuels, releases of fossil carbon are avoided (Birdsey 1992).

The Consortium for Research on Renewable Industrial Materials (CORRIM), has recently released reports covering full life cycle assessment of the environmental performance of using wood products in residential construction (Bowyer et. al. 2004, Lippke et. al. 2004). Included in this research is accounting for four major carbon pools: 1) carbon in the forest; 2) carbon in products that leave the forest; 3) carbon associated with the use of forest biomass and product residuals as an energy source; and 4) the carbon offsets from the substitution that occurs when wood building materials displace products like steel or concrete. A major finding in the CORRIM report is that forests that are periodically harvested, planted, and re-grown to produce a continuing series of short- and long-lived products and energy feedstocks, sequester and offset more cumulative carbon than forests that are left unharvested. This finding is illustrated by the graphs below that depict comparative examples of carbon accounting associated with an even-aged managed forest (Figure 4) and an unmanaged forest (Figure 5) in western Washington. Figure 4 characterizes the time dynamic nature of carbon storage as quantified in metric tons per hectare for a 45-year commercial rotation as a cumulative sequence of carbon storage and release in the forest, in products, and the impact of product substitution for non-wood alternatives. Figure 5 shows the accumulation over time of carbon for the same beginning forest inventory, but with no treatments, no disturbances, and no products and hence no substitution for fossil fuels or energy intensive product alternatives.

While the carbon in the forest in Figure 4 is shown to cycle with each rotation around a steady state trend line, the carbon in product pools, net of energy used in harvesting, processing and construction, gradually increases over time. When the avoided carbon emissions from the displacement of fossil fuels and fossil fuel intensive building products are included, there is a substantial increase in total stored and offset carbon that can be seen to surpass the cumulative carbon storage in forest biomass when there is no harvest activity as displayed in Figure 5. While carbon stored in the forest reaches a steady state, the use of wood in construction displaces fossil fuel intensive products, thereby storing carbon while also reducing carbon emissions. Increasing the acreage under forest provides a one-time increase in forest carbon. If the forests are harvested and reforested, additional carbon storage is provided by the periodic production of long-lived products, and by displacement of fossil fuels for energy and substitution of energy intensive building materials with carbon neutral wood products.

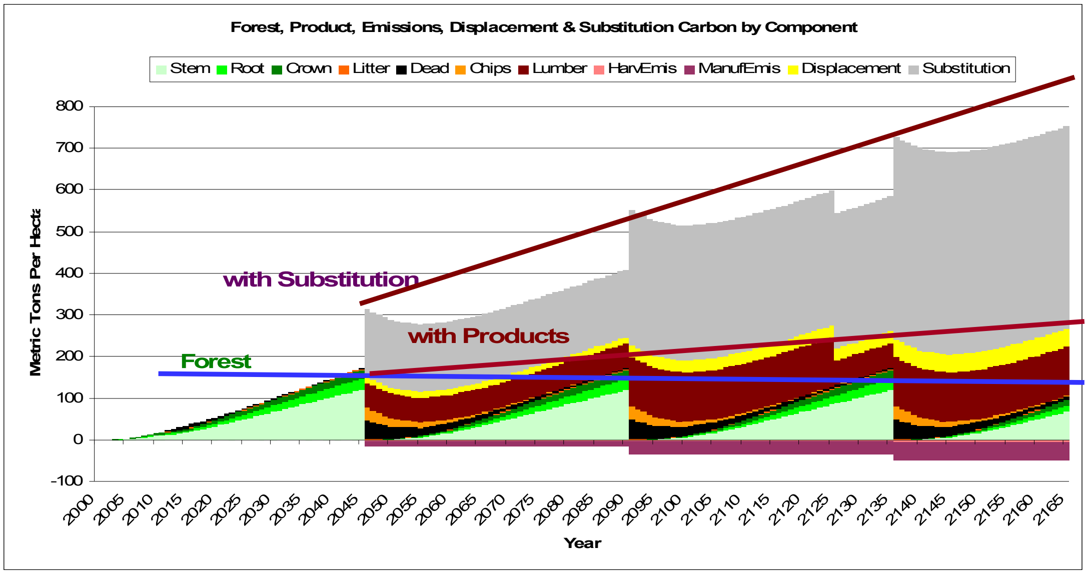

Figure 4: Carbon pools for a single acre of commercial forest under a 45-year rotation.

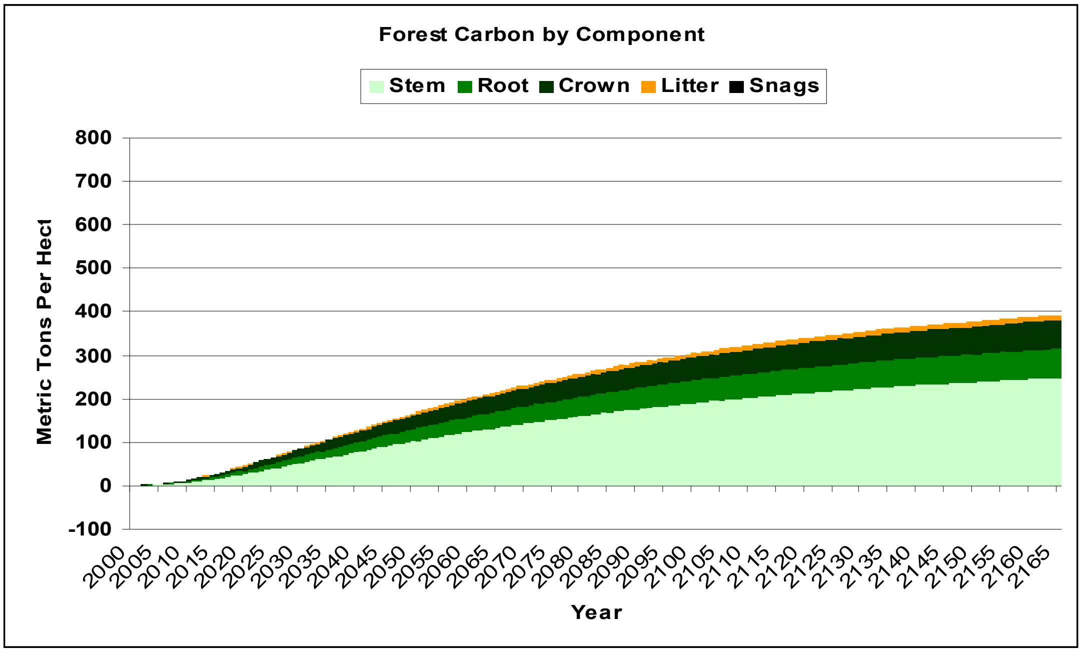

Figure 5: Carbon pools for a single acre of forest with no harvest and no disturbance.

Phase II CORRIM research has applied the same life cycle assessment principles, displayed in Figures 4 and 5, to eastern Washington forests where slower growth, uneven-aged management, and more diverse silvicultural pathways make analysis more complex. To accommodate variability in eastern Washington forests, summaries of cumulative carbon pools through time have been developed for the entire landscape rather than as a single-stand example. Figure 6 displays simulated estimates of the weighted-average amount of carbon produced per year per hectare in the forest, product, displacement, and substitution pools for all non-federal forests in eastern Washington (Johnson et al. in prep). These simulations assume that these forests will continue to produce timber volumes approximately equal to the volumes removed from 1980-2002 and also assumes that the forest products and co-products include lumber, chips, and hogfuel. The product streams do not account for anticipated increases in biomass removal associated with the current focus on using forest residuals as bioenergy and biofuel. How clean energy policy initiatives alter the relative mix of energy, co-product and product outputs from industrial production will alter the relative importance of the product, displacement, and substitution carbon pools depicted in these graphs, but will not alter the relative importance of these pools relative to the forest pool.

Figure 6 indicates that after 100 years the average carbon per hectare stored in the forest is only one third of the total carbon benefit accrued on non-federal eastern Washington forests. While eastside forests produce less biomass carbon per hectare than Westside forests, effective management of eastside forests for fuel removal can reduce the amount, intensity, and duration of wildfire and related carbon release. The extent of wildfire risk reduction based largely on management strategies developed prior to climate is uncertain. What is clear is that the risk exposure to wildfire is reduced with less carbon left on the landscape. Reducing this risk, in combination with increased carbon storage in products and displacement of fossil intensive products, offers the potential for managed forests to mitigate global warming trends while producing historically significant product mixes.

Federally managed forests produce a different set of carbon related issues. If we assume no harvest, no fire and no insect and disease impacts on national forests in eastern Washington, the carbon sequestration potential of these forests is approximated by Figure 7. However, McKenzie et al. (2004) indicates that we can expect at least a doubling of fire frequency and extent in eastern Washington. Linking this research to work done by Camp on the historic levels of fire refugia (i.e. the area that didn't burn under historical fire conditions) suggests that under the most optimistic climate change scenarios approximately 1.7% of the acres of national forest's in eastern Washington would burn in each decade. Using this 1.7% as a 'back of the envelope' calculation would generate the forest carbon footprint given in Figure 8. Figure 8 gives what we would hope is an upper bound of the carbon release potential if these forests burn at rates predicted by recent climate change research. If the forests burn at rates higher than anticipated under climate change scenarios, then there would be more emissions from these forests. In this rough approximation, regeneration is not estimated as regeneration delays and failure rates would need to be more accurately estimated. That 'black' component would be residual burned wood that decays, and thus releases carbon, at a rate of approximately 0.5 tons/carbon/acre/year. The grey component is the equivalent emissions released from the burned forest based on 6 tons/acre emitted for every acre burned (Mason et al. 2003). While this is a very cursory examination of potential impacts which is in need of much refinement, it does highlight how unmanaged forests are likely to become a source of carbon emissions rather than a sink.

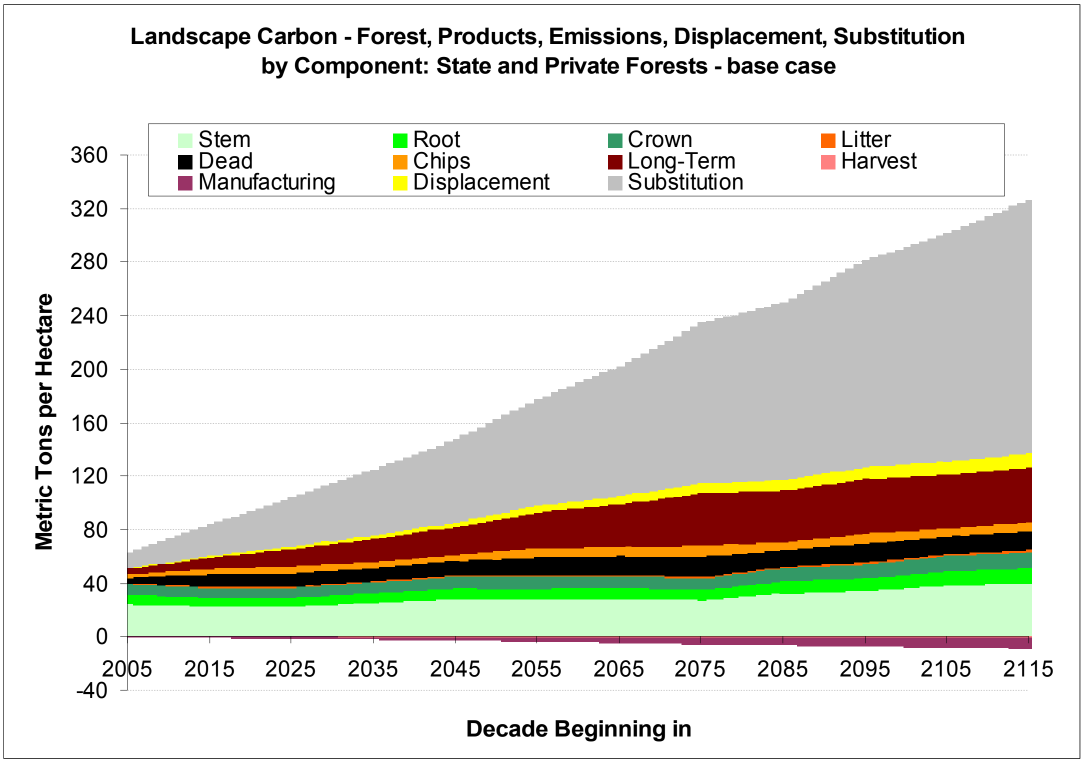

Figure 6: Tons per hectare carbon pools for non-federal forests in eastern Washington

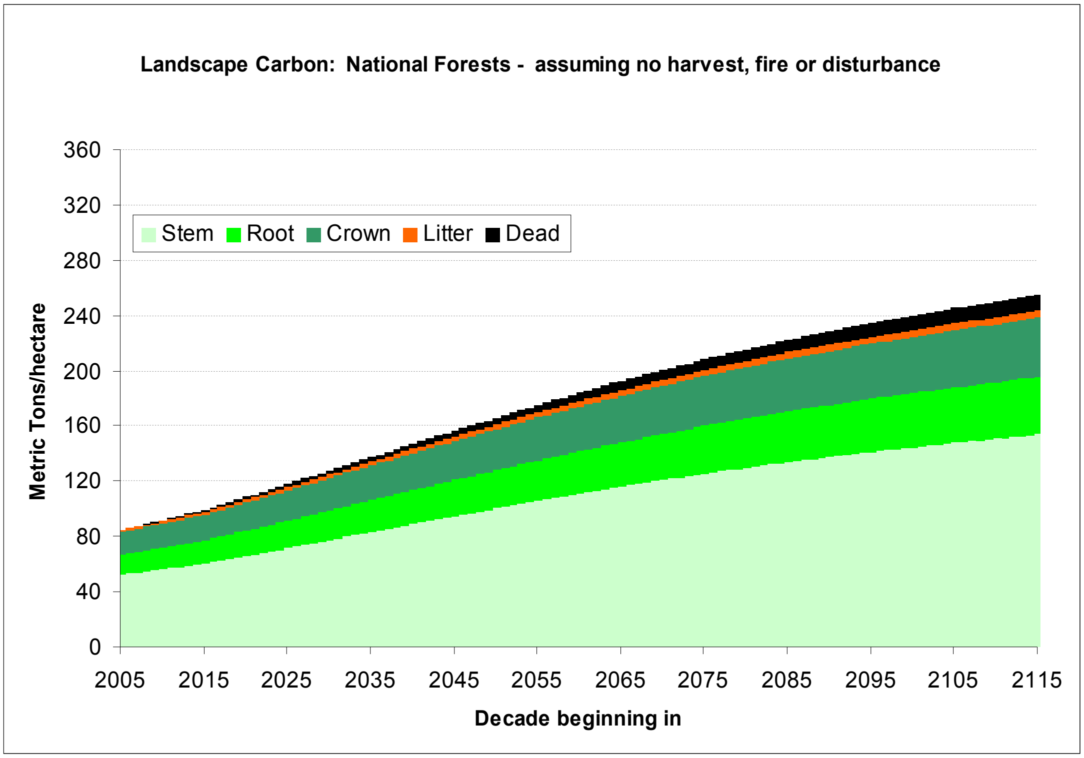

Figure 7: Tons per hectare carbon pools for national forests in eastern Washington assuming no management

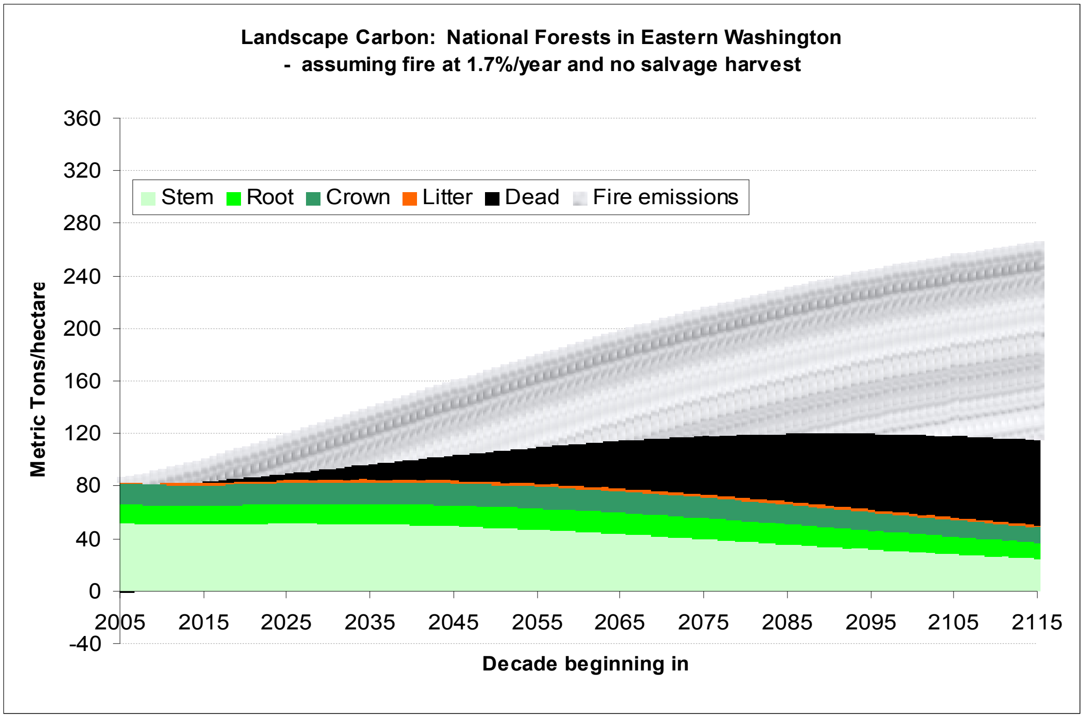

Figure 8: Tons per hectare carbon pools for national forests in eastern Washington assuming a 1.7% burn rate based on climate change estimates

Simulations of treatments on dry and mesic forest types within the national forests that are potentially available under a restoration scenario produces carbon impacts reflected in Figure 9. Treatments on national forests (Figure 9) produce fewer long-lived products than those on private lands because of the retention of large diameter trees on treated areas and the large number of acres left untreated. A comparison of Figures 6 and 9 (assuming no carbon releases from wildfire) reveals that non-federal forests in eastern Washington can provide a greater carbon benefit than federal forests (up to 100 metric tons per hectare) when substitution, displacement and product carbon storage is considered.

In the face of current and anticipated loss of eastside forests to insect infestations and fire under a changing climate, management strategies that increase the carbon stored in non-forest pools could lead to reduced CO_2 emissions. Active management could also produce more acres with mature forest components that are better suited to emerging climate conditions. Gains could include greater overall carbon sequestration accompanied by healthier forest conditions where fire, insects, and disease hazards have been reduced. Without such management actions, wildfire seasons such as those that occurred in eastern Washington in 2006 result in CO_2 emissions that negate carbon emission reductions achieved elsewhere.

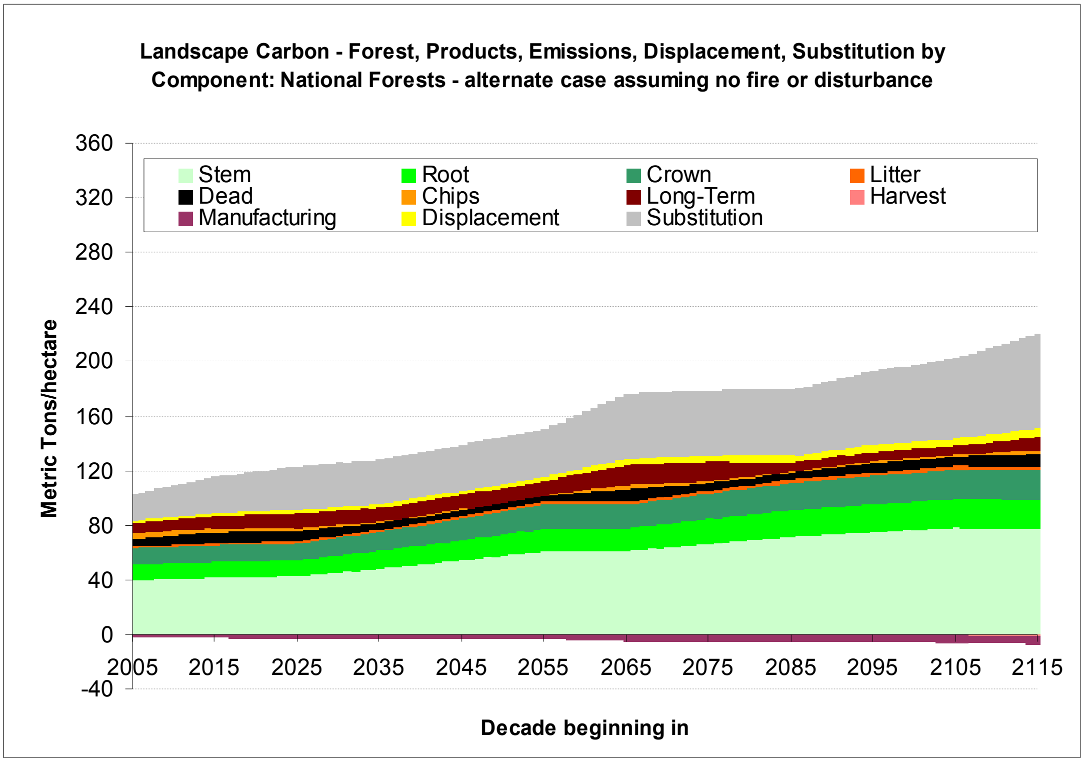

Figure 9: Tons per hectare carbon pools for National Forests in eastern Washington with thinning treatments on dry and mesic forests.

Carbon Accounting and Emission Caps

Carbon registries and accounting techniques are being considered to increase the incentive to reduce carbon emissions. As the above examples suggest, carbon accounting is complex and must be viewed from a systems perspective across many boundaries. For example, a cap on the emissions from utilities has received considerable attention yet would not lower the carbon in the atmosphere; it would only serve to slow the rate of future atmospheric carbon increases. Even given this limitation, the carbon offset that a utility would need would not logically come from pre-existing carbon stores in unmanaged forests. Greater benefit could be achieved from the avoidance of existing uses of fossil fuels or fossil fuel intensive products thereby reducing future releases of carbon to the atmosphere. This approach effectively extends the carbon stored in the forest to products that displace fossil fuel intensive products and their emissions. Further reductions of atmospheric carbon could also come from afforestation that with continued management would create additional product streams. Forest management, products manufacture, and use of residuals for energy can make unique contribution to global carbon strategies.

The Role of Forest Biomass

Forest management residues, typically burned in piles after timber harvests, represent a large source of woody biomass that is currently underutilized and could be available as a carbon neutral energy feedstock as a replacement for fossil fuel. Forest thinnings aimed at reducing fuel loads in eastern Washington forests can also provide woody biomass for clean renewable energy with an added benefit of reducing the risks and costs associated with forest fires. Residuals from the manufacture of forest products have proven to be a readily available and cost-effective source of biomass for energy generation (Perlack et al 2005). An evaluation of organic material resources for bioenergy production in Washington State concluded that forestry and wood product residues represent the greatest potential feedstock contributor; equivalent to all municipal and agricultural wastes combined (Frear et al. 2005). Wood biomass is uniquely versatile in that it can be a source of firm electrical power with steam and heat as valuable byproducts or it can be used to produce liquid and gaseous fuels to reduce reliance on fossil fuels for transportation applications.

Conclusions

In 1997, the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC 1997) identified forests and forestry specifically as important to the global carbon cycle. However, climate change mitigation protocols established by the Kyoto Protocol assume that carbon storage associated with forestry is limited to afforestation, reforestation, and deforestation. This narrow view of forest carbon mitigation is not without controversy. The carbon benefit of product substitution associated with displacement of fossil fuel energy and energy-intensive non-wood building materials has been well-documented (Perlack et al. 2005, Perez-Garcia et al. 2004, Boman and Turnbull 1997, Schlamadinger and Marland 1996, Buchanan and Honey 1995). Naburrs et al. (2000) examined the importance of broadening the Kyoto Protocol and found that more than 50 percent of potential additions to forest carbon storage in the United States could accrue from pest and fire management. Lippke et al. (2006) demonstrated that, primarily as a result of reduced forest fire emissions and increased long-lived product production, 56 percent more carbon was stored over a 50-year period in a managed rather than an unmanaged eastern Washington forest.

Fire-prone forests of eastern Washington can be managed to reduce atmospheric carbon in four basic ways:

- Absorption of atmospheric carbon through photosynthesis to storage in vegetation.
- Extension of carbon storage in long-lived products.
- Reduction of fossil fuel emissions through substitution for energy and building products.
- Reduction of carbon releases associated with forest mortality, decay, and wildfire.

In 2001, the Intergovernmental Panel on Climate Change (IPCC) issued a report that acknowledged forest growth, products, substitution, and disturbance avoidance as integral components of managed forest ecosystems and the global carbon cycle. Recognition of carbon boundary conditions that include all forest flows represents a choice for comprehensive versus selective environmental accounting with implications for improvement in forest health and climate change adaptation effectiveness.

Factors contributing to climate change are likely to persist through the near future. Forest management responses must consider climate impacts in order to reduce undesirable consequences of insect attacks, increased mortality and uncharacteristic fires. Monitoring of changing forest health trends combined with research on the broader implication of treatment alternatives, given that the climate is already outside the range of past experience, will be essential for development of adaptive response. A new understanding of changing forest management options and societal priorities will be needed to align strategies for effective forest health and climate change mitigation.

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