CALIFORNIA FIRE SCIENCE CONSORTIUM

JOINT FIRE SCIENCE PROGRAM

Joint Fire Science Program Knowledge Exchange

Research Synthesis for Resource Managers

Release:	Contact:	Phone:	Email:
August 2011	Lindsay Chiono	510-642-4934	lchiono@berkeley.edu

Wildland Fire Science Laboratory, UC Berkeley, 137 Mulford Hall MC #3114, Berkeley CA 94720

Balancing the Carbon Costs and Benefits of Fuels Management

The following review summarizes the growing body of scientific literature on the carbon balance of fuel treatments (i.e. the ability of treatments to achieve net carbon offsets.) The purpose of this review is to highlight and synthesize research relevant to forest managers and policymakers interested in the potential for forest management to contribute to climate solutions.

Introduction

Land management activities in many western forests, including efficient wildfire suppression and livestock grazing, have led to an accumulation of biomass and sequestered carbon along with high fire hazards. Wildfires are a significant source of carbon emissions in the U.S., equal to 4-6% of annual anthropogenic emissions (Wiedinmyer and Neff, 2007). In the West, a changing climate appears to be exacerbating conditions, lengthening fire seasons and promoting large fires (Westerling et al., 2006). Strategies that forest managers have used for decades to reduce fire hazard, improve forest health, and support wildfire suppression activities are now being contemplated as a means to protect forest carbon stores. These strategies, which include thinning and prescribed fire, can decrease the quantity and continuity of fuels and reduce the risk that a future high-severity wildfire could cause the release of accumulated carbon.

Management Implications

- Fuels reduction treatments for wildfire hazard mitigation can protect tree-based carbon.
- Cumulative emissions from fuel treatment maintenance activities, which often include prescribed fire, may exceed avoided wildfire emissions.
- Achieving a net carbon gain appears more likely when the quantity of carbon removed during treatment is minimized, when harvested biomass is converted to long-lived wood products, and where the risk of wildfire occurrence is high.

Recent interest in including the U.S. forest sector in carbon markets has sparked research to investigate the potential for forest management to contribute to climate change mitigation. Modeling efforts suggest that unmanaged forests, in the absence of disturbance, sequester more carbon than managed forests (Harmon and Marks, 2002; Hurteau and North, 2009; Mitchell et al., 2009). Yet dry western forests are adapted to frequent burning, and even an extensive and well-funded fire suppression network cannot fully control wildfires. The risk of losing stored carbon due to disturbance is an important consideration in valuing forest carbon for offset projects (Hurteau et al., 2009). The potential for fuel treatments to moderate wildfire behavior and effects is well known (e.g. Graham et al., 2004); at issue is whether reduced wildfire emissions are sufficient to balance the direct carbon costs of treatment activities.

By reducing the quantity of biomass killed and combusted, fuel treatments can be expected to reduce wildfire emissions of carbon. In assessing the overall carbon balance of treatments, however, the benefits in reduced wildfire emissions must be evaluated against the emissions arising from treatment activities themselves. Forest thinning and other fuels reduction activities release carbon in fossil fuel consumption during harvesting and transport, decay of logging slash left on site, broadcast or pile burning, and in the eventual decomposition of fuel wood and other wood products. Whether a given fuel treatment will yield a net benefit to the atmosphere depends upon a host of factors, many of which are not easily quantifiable. These include harvest efficiency, lifespan of harvested wood products (if applicable), the effect of treatment on future carbon sequestration, impacts to belowground carbon, and interactions between treatments and carbon-emitting disturbances like wildfire and bark beetle attack. Assessing the net carbon impact of fuel treatments is further complicated by the probabilistic nature of wildfire occurrence and the impermanence of post-treatment stand conditions, which must be maintained over time.

Carbon offset potential

Several studies have suggested that there is reason to expect that forest management might yield net carbon gains. But since treatment activities produce an immediate carbon emission while future wildfire emissions are uncertain, benefits may be only marginal, and can be difficult to estimate accurately. Treatment gains may be contingent on the specifics of treatment prescriptions, such as the utilization of harvested forest biomass, or on local disturbance regimes, which influence the likelihood that avoided emissions from future wildfires will be realized.

As a first step in evaluating the potential for prescribed fire to reduce wildfire emissions, Wiedinmyer and Hurteau (2010) estimated the reduction in emissions that could result from substituting prescribed burning for wildfire. From data on wildfire occurrence in 11 western states, they estimated wildfire emissions over an 8-year period in dry forest types deemed suitable for prescribed fire (those with historical high frequency, low-to-mixed severity fire regimes). By assuming that hypothetical prescribed fires burned in the same locations and under the same conditions as their wildfire counterparts, the authors estimated that emissions produced by these simulated prescribed fires were 52-68% lower than wildfire emissions. This study was intended to provide an upper estimate for the carbon emission reduction potential of prescribed fire and did not consider emissions from subsequent repeat burning, which would be necessary in order to safeguard against high-severity wildfire in the long term.

The carbon balance of fuel treatments may be conditional on the end use of forest biomass removed from a stand. Finkral and Evans (2008) assessed the carbon consequences of a restoration treatment in Arizona. Trees removed in the thin-from-below treatment were sold as firewood, and logging slash was burned on site. Emissions associated with harvest, transport, firewood processing, activity fuel burning, and a simulated post-treatment wildfire were included in the calculation of treatment costs and benefits. By shifting fire type from active crown fire (crown fire coupled with surface fire) to passive crown fire (surface fire with some torching activity), the thinning treatment reduced estimated potential wildfire emissions from 3.7 to 2.6 tons C $acre^{-1}$. Though wildfire emissions were reduced, the treatment resulted in a net release of 1.4 tons C $acre^{-1}$. When the analysis was repeated with the assumption that harvested biomass was used in longer-lived wood products (pallets and construction), the treatment achieved a net carbon benefit.

Depending on the intensity of treatment, the quantity of carbon removed may be substantial enough to negate gains from avoided wildfire emissions. East of the Cascade crest in Oregon, a modeling study of carbon dynamics that included modeled wildfires found that while understory removal treatments slightly enhanced carbon storage over the long term, higher levels of biomass removal reduced mean ecosystem carbon (Mitchell et al., 2009). Hurteau and North (2010) similarly found that forest carbon removed during treatment was recovered quickly (within 7 years) when the focus of treatment was reducing surface and ladder fuels. Removing large overstory trees greatly increased the period of time required for stands to recover the carbon contained in harvested timber.

Mitchell and others (2009) caution against indiscriminate application of fuel treatments without regard for natural fire regimes. They used a forest ecosystem simulation model to evaluate carbon storage in treated and untreated stands in the Pacific Northwest. A variety of treatments were modeled at varying frequencies, and wildfires were simulated within the documented range of their historic variability. Though fuels reduction treatments were shown to reduce wildfire severity, the net effect of treatment was typically to reduce average carbon stocking. This is partly because wildfires do not actually consume a large proportion of forest biomass. The carbon removed during treatment can surpass avoided wildfire emissions, especially when treatments must be repeated in the interim between wildfires in order to maintain low hazard conditions. Similarly, when wildfire frequency is low, the quantity of carbon removed in treatments over time can overwhelm likely wildfire losses. Net emissions were most pronounced in the west Cascades where historical fire return intervals were very long (143-500 years), and more ambiguous in the east Cascades, where return intervals were relatively short (<20 years). These findings suggest that the role of treatments in maintaining high levels of carbon stocking may align with widely held views of ecologically guided forest management. That is, fuel treatments are warranted in forests where fire suppression has led to some deviation from historic fire return intervals, causing fire hazard to increase as surface fuels accumulated and stand density increased. Treatments may instead be counterproductive in systems whose long historical fire return intervals exceed the period of active fire suppression.

Trade-offs in protected and emitted carbon

Prescribed burning, unlike mechanical treatment, causes the direct emission of carbon contained in surface fuels. Impacts to this large pool of forest carbon and the trade-offs between the carbon costs and benefits of treatment are important factors when considering whether to incorporate fire in a treatment prescription. Hurteau and North (2009) compared the ability of several treatment methods to protect tree-based carbon stocks in the southern Sierra Nevada. Simulated treatments included prescribed fire only, three thinning treatments that varied in post-treatment structure and species composition, and the addition of prescribed fire to each thinning treatment. Management activities, stand growth, and wildfire effects were modeled using the FFE-FVS system (Reinhardt and Crookston, 2003). For all treatment regimes that included burning, multiple prescribed fires were implemented over the 100-year modeling period. In order to compare the treatment effects on wildfire emissions, a wildfire was simulated under extreme fire weather conditions after 50 years of simulated growth and management. At the end of the simulation, those stands subject to prescribed fire had retained the most tree-based carbon. While thinning treatments supplemented with prescribed fire achieved the greatest reductions in wildfire carbon emissions, cumulative emissions from repeated prescribed burns exceeded emissions produced by the one-time wildfire.

Incorporating future carbon dynamics

In addition to protecting on-site carbon, silvicultural and prescribed burn treatments influence post-fire stand development and carbon dynamics. Reinhardt and Holsinger (2010) assessed treatment impacts on wildfire emissions and subsequent carbon recovery during post-fire growth. For stands representing several northern Rocky Mountain habitat types, they simulated prescribed burning alone and in combination with whole tree thinning from below. The lifespan of carbon contained in harvested timber was estimated in this study; however, the carbon emitted during harvest, transport, and the processing of wood products was not assessed. Simulated wildfires took place 4 years after completion of scheduled treatments. Total carbon stocks in treated stands were lower than in untreated stands immediately following wildfire, though there was more live-tree carbon in the treated stands (fig. 1). Over time, carbon stocks first declined as killed biomass decomposed. Eventually stand regeneration began to offset emissions from decomposition and the stands again became carbon sinks. Treatment hastened this transition in part by, in effect, removing preemptively the small trees that would have been killed by the wildfire.

Though treatment moderated wildfire impacts, at the end of the 95-year simulation period, carbon stocks in the treated and untreated stands were generally similar. The authors concluded that fuel treatments conducted solely in the interest of retaining carbon stocks or reducing potential wildfire emissions are not justified by these results.

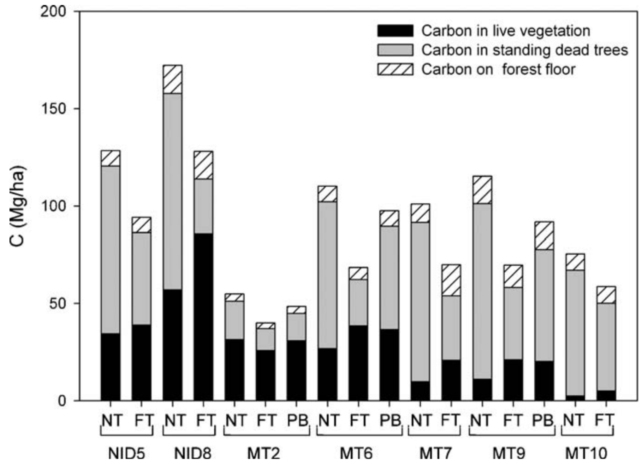

Figure 1. Mean carbon after wildfire by forest type (NID5…MT10) and method of treatment: no treatment (NT), mechanical fuel treatment (including post-harvest prescribed fire in some forest types) (FT), prescribed burn only (PB). The total height of the bar represents carbon. Carbon in live vegetation includes carbon in live trees, including live roots, herbs and shrubs. Carbon in standing dead trees includes the carbon in dead roots as well as above ground. Carbon on the forest floor includes carbon in litter, duff, and dead and down woody material. (Reinhardt and Holsinger, 2010)

In a similar long-term simulation study of the carbon balance of fuel treatments implemented in southern Oregon and northern California, Goslee and others (2010) took an approach that incorporates the stochastic nature of wildfire occurrence. Rather than scheduling a wildfire event soon after fuel treatment, a calculation that maximizes treatment benefits, they used an estimate of the local fire return interval for the period of 2001 to 2008 -- an annual burn probability of 0.6% -- to assess carbon emissions. Partly owing to this low wildfire risk, they found that fuel treatments, which included commercial timber harvest and pile burning of noncommercial biomass, produced an effective immediate net emission of 10-20.8 tons of carbon per acre. Even when modeled wildfires burned within one year of treatment, treatment activities still resulted in net carbon emissions. Treatment was shown to increase tree growth rates and reduce wildfire-caused mortality, but at the end of the 60-year simulation period, carbon stocks in treated stands had not recovered to the level of untreated stands.

Landscape level treatment effects

The studies discussed to this point have been stand-level investigations of fuel treatments, wildfire, and carbon. However, as several authors noted, treatments may have off-site impacts whereby fire behavior and effects in untreated stands are influenced by treated areas (Finney et al., 2005). If these off-site impacts, or "shadow effects," are significant, they could improve the carbon balance of treatment activities. Exploring this question, Cathcart and others (2010) incorporated wildfire risk in their landscape-level analysis of a southern Oregon watershed. The authors used burn probability modeling based on thousands of simulated wildfire scenarios to account for the influence of treatments on the likelihood of burning at a given location. Treatments on the landscape reduced the probability that wildfire would burn in treated and untreated stands alike, and reduced average fire intensities and sizes as well (fig. 2). However, given only a single ignition on the landscape, the carbon costs of treatments greatly exceeded the benefits in avoided emissions. Treatments exacted a net carbon cost of 23.7 tons per treated acre, and, while off-site effects were observed, they amounted to a savings of only 0.027 tons per untreated acre. Totaled over the landscape, treatments produced a net carbon emission of 2.13 tons of carbon per forested acre. In reality, though, the study landscape experiences multiple ignitions in a single year. Furthermore, fuel treatments represent an investment that can be expected to influence wildfire behavior for multiple years. When these factors were incorporated, the authors estimated that the avoided emissions benefit of treatments would balance the carbon cost in 9 years' time.

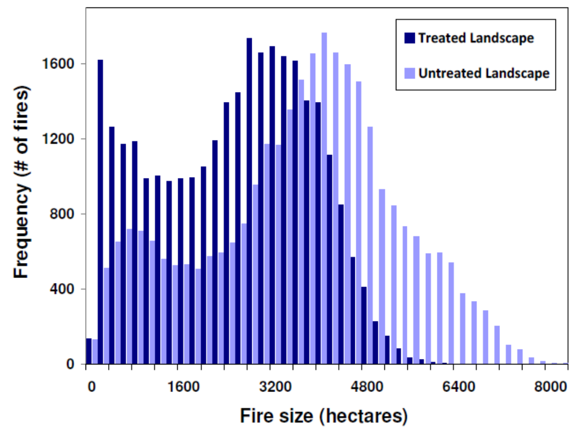

Figure 2. Frequency histogram of simulated fire sizes for untreated and treated scenarios for a southern Oregon watershed study area. (Adapted from Cathcart et al., 2010.)

Summary

While the fuel treatments investigated in these studies consistently reduced modeled wildfire severity and emissions, the net carbon impacts of treatment were more nuanced. In general, the hypothesis that fuels reduction treatments can protect tree-based carbon is well-supported in the literature (Hurteau and North, 2009; Stephens et al., 2009). Achieving a net carbon offset, however, may be contingent on utilization of harvested biomass (Finkral and Evans, 2008) or the forest type in which treatment occurs (Mitchell et al., 2009). Others have found that the carbon released as a result of treatment is not fully offset by avoided wildfire emissions even when the scale is tipped in favor of treatment benefits (e.g. a wildfire scheduled immediately post-treatment) (Reinhardt and Holsinger, 2010).

Some of the variability in these findings is no doubt due to decisions made by researchers regarding modeling and scope. Simulation of fuels reduction treatments and natural disturbances requires a number of choices and assumptions on the part of modelers including the method, location, and frequency of simulated treatments, the likelihood of burning by wildfire, and the time scale of analysis. These choices greatly impact study results. Because the full carbon accounting picture is large and complex, out of necessity, researchers often must restrict the scopes of their analyses. As a result, important factors in the carbon balance equation may be omitted. For example, the studies cited here have variously excluded the carbon costs associated with treatment activities, carbon emissions from the decomposition of fire-killed vegetation, and impacts of treatment and wildfire on future stand development. Though forest insects and pathogens are known to respond to wildfires and fuel treatment activities, to date no study relevant to this question of fuel management, wildfire, and carbon emissions has addressed interactions with these disturbance agents.

This active area of research has not yet yielded consensus on the question of whether fuel treatments have the potential to play a significant role in climate change mitigation. Even so, some general principles have begun to emerge. Achieving a net carbon gain appears more likely when the quantity of carbon removed during treatment is minimized, when harvested biomass is converted to long-lived wood products, and where the risk of wildfire occurrence is high (Hurteau and North, 2009; Hurteau and North, 2010; Mitchell et al., 2009; Reinhardt and Holsinger, 2010). Conversely, cumulative emissions from fuels reduction activities repeated in order to maintain low hazard conditions over time can overwhelm avoided wildfire emissions, resulting in a net carbon loss (Hurteau and North, 2009).

Though the climate benefit of fuel treatments may turn out to be marginal at best, the fire safe principles of Agee and Skinner (2005) are borne out by the studies discussed here: treatments that reduce horizontal and vertical fuel continuity in stands and promote large-diameter trees of fire-resistant species are effective in mitigating wildfire hazard. Carbon sequestration is one among many potential forest health goals of fuels management. In addition to reducing fire hazard, treatment activities may be conducted to promote resilience in the face of climate change, to reduce competition and concentrate growth in remnant trees, to support biodiversity, and to restore historic stand structures and species composition. Hurteau and Brooks (2011) speak of a spectrum of management options, a trade-off between maximizing carbon stocks and maximizing carbon stability. In the short term, heavily stocked, carbon-dense stands may contain more carbon than stands treated to maintain their carbon stocks in the event of a disturbance. Fuels management can sustain carbon stores along with the multitude of values and services provided by healthy forests.

Literature Cited

Agee JK, Skinner CN. Basic principles of forest fuel reduction treatments. Forest Ecology and Management (2005) 211:83-96. http://www.fs.fed.us/psw/publications/skinner/psw_2005_skinner%28agee%29001.pdf

Cathcart J, Ager AA, McMahan A, Finney M, Watt B. Carbon benefits from fuel treatments. In: Integrated management of carbon sequestration and biomass utilization opportunities in a changing climate: Proceedings of the 2009 National Silviculture Workshop--Jain TB, Graham RT, Sandquist J, eds. (2010) Boise, ID. http://www.fs.fed.us/rm/pubs/rmrs_p061/rmrs_p061_061_079.pdf

Finkral AJ, Evans AM. The effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest. Forest Ecology and Management (2008) 255:2743-2750.

Finney MA, McHugh CW, Grenfell IC. Stand- and landscape-level effects of prescribed burning on two Arizona wildfires. Canadian Journal of Forest Research (2005) 35:1714-1722.

http://ddr.nal.usda.gov/handle/10113/1267

Goslee K, Pearson T, Grimland S, Petrova S, Walls J, Brown S. Final Report on WESTCARB Fuels Management Pilot Activities in Lake County, Oregon. In: Catalogue No. CEC-500-XXXX-XXX (2010). http://www.winrock.org/ecosystems/files/WestcarbRPT/WESTCARB%20II_Winrock_LakeCountyReport.pdf

Graham RT, McGaffrey S, Jain TB. Science basis for changing forest structure to modify wildfire behavior and severity. In: Gen. Tech. Rep. RMRS-GTR-120 (2004) Fort Collins, CO: Department of Agriculture, Forest Service, Rocky Mountain Research Station. 43. http://www.fs.fed.us/rm/pubs/rmrs_gtr120.html

Harmon ME, Marks B. Effects of silvicultural practices on carbon stores in Douglas-fir-western hemlock forests in the Pacific Northwest, USA: results from a simulation model. Canadian Journal of Forest Research (2002) 32:863-877. http://ir.library.oregonstate.edu/xmlui/handle/1957/14632

Hurteau M, Hungate B, Koch G. Accounting for risk in valuing forest carbon offsets. Carbon Balance and Management (2009) 4:1. http://www.cbmjournal.com/content/4/1/1

Hurteau M, North M. Fuel treatment effects on tree-based forest carbon storage and emissions under modeled wildfire scenarios. Frontiers in Ecology and the Environment (2009) 7:409-414. http://www.treesearch.fs.fed.us/pubs/36882

Hurteau MD, Brooks ML. Short- and Long-Term Effects of Fire on Carbon in US Dry Temperate Forest Systems. BioScience (2011) 61:139-146. http://oak.ucc.nau.edu/mdh22/Publications/Hurteau%20and%20Brooks%202011.pdf

Hurteau MD, North M. Carbon recovery rates following different wildfire risk mitigation treatments. Forest Ecology and Management (2010) 260:930-937. http://www.treesearch.fs.fed.us/pubs/36883

Mitchell SR, Harmon ME, O'Connell KEB. Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems. Ecological Applications (2009) 19:643-655. http://www.fs.fed.us/pnw/pubs/journals/pnw_2009_mitchell001.pdf

Reinhardt E, Crookston NL. The Fire and Fuels Extension to the Forest Vegetation Simulator. In: General Technical Report RMRS-GTR-116 (2003) Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209. http://www.treesearch.fs.fed.us/pubs/5593

Reinhardt E, Holsinger L. Effects of fuel treatments on carbon-disturbance relationships in forests of the northern Rocky Mountains. Forest Ecology and Management (2010) 259:1427-1435. http://www.treesearch.fs.fed.us/pubs/34995

Stephens SL, Moghaddas JJ, Hartsough BR, Moghaddas EEY, Clinton NE. Fuel treatment effects on stand-level carbon pools, treatment-related emissions, and fire risk in a Sierra Nevada mixed-conifer forest. Canadian Journal of Forest

Research (2009) 39:1538-1547. http://nature.berkeley.edu/stephens-lab/Publications/Stephens%20et%20al.%20FFS%20Carbon%20CJFR%208-09.pdf

Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW. Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. Science (2006) 313:940-943. http://www.treesearch.fs.fed.us/pubs/24813

Wiedinmyer C, Hurteau MD. Prescribed fire as a means of reducing forest carbon emissions in the Western United States. Environmental Science & Technology (2010) 44:1926-1932.

Wiedinmyer C, Neff J. Estimates of CO_2 from fires in the United States: implications for carbon management. Carbon Balance and Management (2007) 2:10. http://www.cbmjournal.com/content/2/1/10