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The Carbon Conundrum — Fire and Fuel Management in Fire-prone Forests

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Key messages

- It is anticipated that as climate changes, fire seasons will become longer and result in more wildfire ignitions, larger wildfires, and increased fire severity and duration.
- There are ways of managing fire-prone forests to maintain and protect the carbon they store, protect people and their communities, and reduce the costs of firefighting, rehabilitating post-fire conditions, and regenerating new forests.
- When fuel hazards are reduced, numerous other forest values can be maintained or protected, including water and air quality, aesthetics, recreation, tourism, native vegetation, habitat, site productivity, and forest health.

Introduction and Background

Natural resource managers face a conundrum: when do fire management activities increase sources or sinks of greenhouse gases? This extension note describes forest carbon (C) dynamics and approaches for dealing with carbon stocks and flows while managing for fire and a full range of natural resource values.

In addressing climate change, we need to understand the relationships between fire management and carbon emissions and storage. Our focus is on fire-prone dry forests such as those in the British Columbia (B.C.) south-central interior.

Carbon dioxide (CO₂), one of the greenhouse gases, contributes to

climate change. When forests burn and decompose, they emit CO₂. Natural and human-caused fires ignite each summer.

In many dry B.C. ecosystems, fire has been a natural ecosystem process. In these settings, fire provides many benefits: reducing fuel hazards, creating diverse ecosystems and habitats that support large numbers of species, enhancing soil nutrients, helping keep insects and pathogens in check, and taking up and storing carbon.

Over recent decades in western North America, spring and summer temperature increases along with earlier snowmelts have been documented; this has contributed to longer fire seasons, more large wildfires, and fires of greater duration.¹ A southern interior B.C. study concludes that

¹Westerling et al. 2006.

Glossary

Carbon dioxide (CO₂): colourless, odourless gas produced when any substance containing carbon (C) is burned or decomposes. CO₂ is one of the greenhouse gases. 1 kg of CO₂ is the equivalent of 0.27 kg of carbon. C cycles between solid and gaseous forms (vegetation takes in C during the growing season and releases C during dormancy).

Carbon pool: a reservoir that has the capacity to accumulate or release carbon (e.g., forest biomass). Fossil fuels were at one time vegetation and continue to store C until burned.

Terrestrial forest C pools: above ground (e.g., vegetation biomass), surface (woody debris, branches, needles), below ground (soil organic matter such as roots, peat, fungi, soil animals).

C source: a C pool that is decreasing in size. A C pool can be a source for atmospheric C when more C is flowing out of it than into it (e.g., a forest burning). The opposite of a C sink.

C sink: a C pool that is increasing in size. A C pool can be a sink for atmospheric C when more C is flowing into it than out of it (e.g., a live tree). The opposite of a C source.

Photosynthesis: process by which green plants use light to synthesize organic compounds from CO₂ and water.

Decomposition or decay: breakdown of organic matter into simpler components (e.g., a dead tree turns into a downed log, which decays into the soil).

longer fire seasons may increase fire weather severity, risk of ignitions, and fire behaviour severity.² These circumstances challenge land and resource managers dealing with fire as well as those addressing climate change and carbon flows and stocks.

Carbon is cycled from the atmosphere into the forest through photosynthesis by converting CO₂ into the components of wood. When trees die, the wood, foliage, and roots decompose. Some of the carbon is released as CO₂ gas, and other forms become part of the forest floor and soil. During a forest fire, combustion of wood and the forest floor rapidly releases CO₂, methane, and nitrous oxide gases, all of which contribute to climate change.³

Forests play a major role in the global C cycle. Stored C in live biomass, dead plant material, and soils represents the balance between absorbing CO₂ from the atmosphere and releasing it through respiration, decomposition, and burning.⁴

Over time and across landscapes, forests release CO₂ (e.g., due to fire and insect mortality) (Figure 1). At the same time, unburned forests across the landscape (and areas regenerating after fires) take in CO₂ from the atmo-

sphere as they grow. Basically, forests actively recycle CO₂.

Note that the use of fossil fuels releases CO₂ (and other gases) — however, underground deposits of coal, gas, methane, and oil have no such capacity for taking in atmospheric CO₂. This means that CO₂ from combustion of fossil fuels is the main contributor to greenhouse gases and climate change, not CO₂ from biological sources.

Aside from forests naturally recycling CO₂, fire management activities may add greenhouse gas emissions or enhance the uptake and storage of CO₂. All fuel reduction treatments emit carbon; for example, thinning a stand results in slash, which then either decomposes or is reduced by controlled burns.⁵ In addition, on-the-ground actions (e.g., skidding and hauling thinned merchantable timber) create fossil fuel emissions.⁶ Fire suppression actions also emit greenhouse gases through fossil fuel use in aircraft, trucks, pumps, etc.

Forest Management Actions

In dry, low-elevation ecosystems, some 20th century timber harvesting practices (e.g., high-grading the larg-

est trees) and fire suppression policies have resulted in increased small-tree density and/or altered tree and understory species composition. With a net loss of large trees and increase of small trees, above-ground carbon may have actually decreased in western U.S. forests.⁷ Most above-ground forest carbon is stored in the boles of the biggest trees. Removing smaller understory trees has a relatively minor effect on post-treatment carbon pools.⁸

A tool kit of management approaches can be applied to fire-prone ecosystems. These include fire suppression, fuel reduction and restoration treatments, and Modified Response Fire (Wildland Fire Use) techniques (Table 1).

The research findings summarized in Table 1 rely on methods for measuring and modelling forest carbon that have significant uncertainties. For example, U.S. Forest Service tools (tables and models) for estimating forest carbon stores rely on inventory data that were initially developed to quantify commercial timber volumes. These inventories do not provide direct measurements of carbon in other live and dead vegetation, on the forest floor, in soils, etc.⁹ However, traditional forest inventories can be

⁷Fellows and Goulden 2008; North et al. 2009.

⁸Fellows and Goulden 2008; Hurteau and North 2009; North et al. 2009.

⁹Ingerson and Loya 2008; Hurteau and North 2009; Zhang et al. 2009.

²Nitschke and Innes 2008.

³Mason et al. 2006, Wiedinmyer and Neff 2007; Dymond and Spittlehouse 2009.

⁴Krankina and Harmon 2006.

⁵North et al. 2009.

⁶Healey et al. 2009.



FIGURE 1 Forest fires quickly release CO₂ during combustion. Trees not consumed but killed by the fire emit carbon more slowly as they decay. However, in many ecosystems, fire is an important natural process that provides many benefits.

TABLE 1 The relative effects of fire and fuel management on carbon dynamics, specifically for fire-prone ecosystems. These systems naturally experience extended periods of drought.^a

Fire suppression ^b	Fuel reduction or ecosystem restoration ^c	Modified Response Fire ^d (also known as Wildland Fire Use ^e)
Effects on carbon (C)		
<ul style="list-style-type: none"> • Continued C uptake and storage in the unburned ecosystem • Increased: <ul style="list-style-type: none"> – short-term C emissions from fossil fuel use when suppressing fire – long-term C emissions from the ecosystem (as biomass accumulates, eventually a disturbance, likely more severe, will release C) – mortality of large trees (the main pool of above-ground C) 	<ul style="list-style-type: none"> • Increased: <ul style="list-style-type: none"> – short-term C emissions from ecosystem – short-term C emissions from fossil fuel use while thinning the forest – C uptake and storage in restored areas • Decreased: <ul style="list-style-type: none"> – mortality of large trees (the main pool of above-ground C) – C emissions possible if a fire occurs during the period of time the treatment remains effective 	<ul style="list-style-type: none"> • Continued C uptake and storage in unburned portions within fire perimeter • Increased: <ul style="list-style-type: none"> – short-term C emissions from ecosystem during fire – short-term C emissions from fossil fuel use when monitoring the fire (but considerably less C emitted than during fire suppression actions) – mid- and long-term C emissions after the fire, resulting from fire-induced tree mortality – mid- and long-term C uptake and storage in burned area as forest regenerates

Net benefit on C storage across the landscape: In all three cases the net benefit remains unknown because it depends, in part, on the timing of future fires relative to management actions, fire behaviour and fire effects, and the size of the fire relative to the area treated.

a Sources: Lippke et al. 2007a; Black et al. 2008; Bosworth et al. 2008; Hurteau et al. 2008; Dymond and Spittlehouse 2009; ÉcoRessources 2009; Hurteau and North 2009; Meigs et al. 2009; Mitchell et al. 2009; North et al. 2009.

b Continued suppression response to natural and human-caused fires.

c May include a combination of cutting small trees, ladder fuels, and fire-sensitive trees; removing surface fuels; and disposing of the slash (chipping, burning, or removing) while retaining larger fire-resistant trees (as described in Agee and Skinner 2005).

d Modified Response Fire: A wildfire that is allowed to burn within set policy and management guidelines or may be managed in such a manner as to bring the wildfire back within those guidelines (adapted from Canadian Interagency Forest Fire Centre 2003).

e Wildland Fire Use: The application of the appropriate management response to naturally ignited wildland fires to accomplish specific resource management objectives in pre-defined designated areas outlined in Fire Management Plans (U.S. National Wildfire Coordinating Group 2008).

used to estimate the carbon in forests through the use of models. There are now models to estimate whole-tree,¹⁰ stand,¹¹ or forest ecosystem carbon¹² and the impact of management activities or natural disturbances. Furthermore, recent changes to Canadian forest inventories include measurements of carbon in the whole ecosystem.¹³

Analysis and management of forest and grassland carbon emissions and uptake are multi-faceted and complex. In spite of the complexities, for droughty, fire-prone forests similar to those in B.C.'s interior, established scientists and agency senior managers have put forth carbon-related conclusions and recommendations, such as:

*"If we just keep managing forests based on our scientific understanding of the processes that promote a fully functioning system, we are going to end up in the best position with regards to carbon storage.... If you have a fire-prone forest and you thin the forest, the carbon stock is better protected."*¹⁴

*"In order to maintain resilient forests with lower risk of catastrophic carbon loss, it is sometimes necessary to undertake management practices that lower carbon stocks (e.g., fuel reduction thinning in fire-prone forests)."*¹⁵ (Figure 2).

*"Fuel reduction measures such as prescribed burns reduce carbon stores... (at least temporarily), but they can reduce the burning intensity in future fires and thus maintain higher carbon stores in forest landscapes in the long run."*¹⁶ (Figure 3)

"Strategies like using prescribed fire, reducing fuels, and changing the distribution of fuels across the land-



FIGURE 2 A stand that has been thinned from below while leaving the larger fire-resistant trees can help stabilize carbon stocks on the site.

*scape are essential strategies to reduce losses in long-term productivity, lower greenhouse gas emissions, and improve carbon storage ability."*¹⁷

*"...focus on reducing surface fuels, actively thinning the majority of small trees, and removing only fire-sensitive species in the merchantable intermediate size class. These changes would retain most of the current carbon-pool levels, reduce prescribed burn and potential future wildfire emissions, and favour stand development of large, fire-resistant trees that can better stabilize carbon stocks."*¹⁸

As noted above, several of the recommendations focus on planning and implementing fuel reduction treatments; fuel management actions pres-

ent a number of opportunities and challenges, described briefly below.

Opportunities and Challenges

Biomass for bioenergy One of the challenges to fuel treatments is cost. However, there are opportunities to use removed biomass material for heat (e.g., Fuels for Schools¹⁹), energy (in wood-fired boilers that generate electricity), or co-generation of a combination of heat and energy. Biomass used in these ways can offset fossil fuel use²⁰ and create "green jobs."²¹ Furthermore, long-term CO₂ emissions from use of bioenergy are offset by forest regrowth and the resulting carbon sequestration and storage—not so for fossil fuels.²²

¹⁹U.S. Fuels for Schools and Beyond Program. See www.fuelsforschools.info/

²⁰Krankina and Harmon 2006; Black et al. 2008; Bosworth et al. 2008; Fresco and Stuart III 2009; Mason et al. 2009.

²¹Bosworth et al. 2008; Mason et al. 2009.

²²Krankina and Harmon 2006; Wiedinmyer and Neff 2007; Fresco and Stuart III 2009.

¹⁰Ung et al. 2008.

¹¹Boudewyn et al. 2007.

¹²Kurz et al. 2009.

¹³Gillis et al. 2005.

¹⁴Hurteau quoted in McDaniel 2008.

¹⁵Tyrrell et al. 2009.

¹⁶Krankina and Harmon 2006.

¹⁷McDaniel 2008.

¹⁸North et al. 2009.



FIGURE 3 Reducing fuels through a controlled burn in the southern Rocky Mountain Trench.

Storing carbon in forest products

Fuel reduction treatments often include removing some merchantable trees (e.g., to reduce tree crown volume and thereby lower the risk of crown fires). Merchantable timber provides an opportunity to sequester carbon in building products.²³ The process of manufacturing thinned trees into wood construction materials produces fewer fossil fuel emissions than the manufacture of concrete, steel, and aluminum.²⁴ However, much CO₂ is released to the atmosphere during the wood product manufacturing process.²⁵

Carbon markets Some look to carbon offset markets as a new source

of revenue,²⁶ and to help pay for fuel reduction treatments.²⁷ However, fuel treatment projects are unlikely to be eligible in the regulated markets because they do not pay on futures—the reduction in carbon emissions has to have already occurred.²⁸ That means a wildfire would have to occur in a fuel reduction treatment area before a carbon credit could be claimed. Fire suppression activities in B.C. are also unlikely to qualify for carbon credits because they are part of normal business practice. Carbon markets are established to fund additional activities that go above and beyond “business as usual.”²⁹

On the other hand, because forests both release and take in carbon,

bioenergy may be considered carbon neutral in some offset markets. Thus, tradable credits might be obtained by substituting bioenergy for fossil fuels and may provide an ongoing stream of marketable carbon credits.³⁰

Other benefits of managing fuel hazards and fire risk

Market and non-market benefits can be attributed to fuel reduction investments when contrasted with the costs of fire suppression actions. Market benefits include avoided public costs of firefighting, post-fire rehabilitation, and regeneration; lost facilities and timber; and regional economic benefits (e.g., local employment and cost savings from substitution of forest biomass for fossil fuel). The non-market benefits associated with fuel reduction (when compared with fire suppression) include protection and restoration of native vegetation, habitat, water, long-term site productivity, aesthetics, air quality, recreation, tourism, and forest health, as well as safer firefighting, safer living conditions (resulting in fewer fatalities and community evacuations), and peace of mind resulting from reduced fire risk.³¹

“If the negative impacts that result from crown fires were fully reflected in the market, there would be much higher motivation to avoid them, providing the necessary incentive to remove high fuel loads in spite of the cost.... Land management decisions aimed at reducing the risk of fire can have a high benefit-to-cost ratio if all market and non-market costs and benefits are included.”³²

²³Mason et al. 2009; Bosworth et al. 2008; Lippke et al. 2007b; Krankina and Harmon 2006.

²⁴Dymond and Spittlehouse 2009; ÉcoRessources 2009; Mason et al. 2006, 2009; Bosworth et al. 2008.

²⁵Larson 2009.

²⁶For example, ÉcoRessources 2009; Greig and Bull 2009; Bosworth et al. 2008; Hurteau et al. 2008.

²⁷Hurteau et al. 2008; McDaniel 2008; Mason et al. 2006.

²⁸ÉcoRessources 2009; Pacific Carbon Trust 2009.

²⁹Dymond and Spittlehouse 2009; ÉcoRessources 2009; Pacific Carbon Trust 2009.

³⁰Fresco and Stuart III 2009; Pacific Carbon Trust 2009 (see Fuel Switching Protocol).

³¹Krankina and Harmon 2006; Lippke et al. 2007b; Bosworth et al. 2008; McDaniel 2008; Fresco and Stuart III 2009; Hurteau and North 2009; Mason et al. 2006, 2009.

³²Lippke et al. 2007b.

Public perception The social contract between the public and land and resource managers is important. If members of the public do not have a basic understanding of the benefits and risks of managing fire, fuels, and carbon (mentioned above), they may not support or accept proposed management actions. Thus, two-way community outreach is important to establish trust, find shared values, understand attitudes and opinions, and seek solutions.³³

Caveats

Other British Columbia forests This extension note is a summary of the literature related to forest carbon and fuel and fire management in fire-prone ecosystems. In B.C., some fuel reduction treatments are being implemented in the Montane Spruce, Sub-Boreal Spruce, and Sub-Boreal Pine—Spruce biogeoclimatic zones (to reduce fuel hazards created by trees killed by mountain pine beetle). However, for these areas, research related to fuels, fire, and carbon has not been published and therefore is not included here.

Dry forests – wet forests It is critically important to differentiate between dry, fire-prone ecosystems and wet ecosystems. Historically, in the dry forests of south-central B.C., fire has played important ecological and cultural roles. In dry ecosystems, fuel reduction may be essential to reduce accumulated understorey biomass and the risk of a stand-replacing fire,³⁴ restore ecosystems,³⁵ and potentially

stabilize carbon stocks.³⁶ On the other hand, wetter ecosystems (e.g., coastal) evolved in different ways; they tended to renew via different ecosystem processes (e.g., intense wind storms). However, over time, it is possible that climate change will result in more coastal fires, particularly in rain-shadow areas.

Less moisture – more fires In fire-prone forests, if the size and severity of wildland fires increase because of climate change,³⁷ fire-derived C emissions could accelerate global warming.³⁸

Conclusion

Fire and forest management decisions will never be made solely based on carbon emissions or storage. However, adding consideration of carbon to our decision-making processes will help ensure that societal support for forestry continues. In some instances, other objectives (e.g., human safety) will require decision makers to plan and implement forest actions that reduce threats to human lives, homes, and infrastructure.

It will be a challenge to weigh the trade-offs when striving for maximum carbon pools and minimizing carbon emissions while addressing fuel hazards and fire risk and considering other forest values and the impacts of climate change. Strategic application of management treatments will be required.

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³³For example, papers in Chavez et al., (2008) and McCaffery (2006) deal with social science findings related to fire and fuel management. These papers do not directly address forest carbon release or sequestration.

³⁴Hurteau et al. 2008; Mason et al. 2009.

³⁵Mitchell et al. 2009.

³⁶Lippke et al. 2007a; McDaniel 2008; North et al. 2009.

³⁷Westerling et al. 2006; Nitschke and Innes 2008.

³⁸Running 2006.

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