Effects of landscape-level fuel treatments on carbon emissions and storage over a 50 yr time cycle

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Abstract
We investigated how multiple fuel treatment types, organized in varying spatial arrangements, and at increasing proportions of a mixed-conifer forest in the Klamath Mountains of northern California (~20,000 ha) variably affect carbon sequestration and emissions over a 50 year time period. Preliminary analysis of three fuel treatment scenarios (fire only, mechanical only, and fire + mechanical) and an untreated landscape indicates that treating large areas with prescribed fire may increase carbon emissions in the short term but may be off-set by an increase in long term carbon storage.

Introduction

Fuel reduction projects are a common and proven means for protecting wildland-urban interface (WUI) communities and forest resources in the western US (Stratton 2004; Murphy 2007; Schmidt *et al*. 2008). However, removing vegetation from a landscape to reduce fire danger poses a possible conflict: vegetation stores close to half of the carbon on a landscape (Boerner 2008). By removing vegetation, fuel treatments can alter carbon sequestration and emissions at a given location (Dicus 2009, Dicus *et al*. 2009), a topic of growing concern in the fire management community.

The Eddy Gulch Late Successional Reserve (LSR) on the Salmon River and Scott River Ranger Districts of Klamath National Forest, in northwest California, is a large landscape consisting of mixed-conifer forests that provides potential habitat for spotted owls and borders multiple WUI communities. Like many regions in the western U.S. with understory and mixed-severity fire regimes, fire exclusion in the LSR have resulted in an increase in surface and canopy fuel loading and continuity, increasing fire danger to local communities and critical habitat. Increased fire danger is the impetus for many landscape level fuel reduction programs (Keane *et al*. 2002; Stephens and Ruth, 2005). The Forest Service has proposed such a fuel treatment project for the LSR, providing a location to test how landscape level fuel treatment alternatives influence potential carbon emissions from wildfires and carbon storage over a long term cycle. This manuscript provides preliminary results for how three alternative fuel treatment strategies impact these aspects of the LSR.

Study Site and Methods
The study site is the Eddy Gulch LSR of the Klamath National Forest in northwest California (123 4.72 W 41 1554 N). Vegetation consists largely of a multi-layered, multi-aged forest dominated by Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) in association with Pacific madrone (Arbutus *menziesii*), white fir (Abies concolor), and others.

Initial landscape vegetation data came from the forest inventory and analysis data for the Klamath National Forest. This initial vegetation was altered to represent three fuel treatment alternatives (Fig. 1) using the Forest Vegetation Simulator (FVS) within the ArcFuels (Ager *et al* 2010) workstation for ArcMap v. 9.3 (ESRI 2009). Alternative-1 is the complete treatment design proposed by the Forest Service for the Eddy Gulch LSR: it includes fuel reduction zones (FRZ's) that utilize mechanical treatments and prescribed fire, prescribed fire units, and mechanical treatments. Alternative-2 includes only areas designated for FRZ and mechanical treatments. Alternative-3 includes the portion of the initial design designated for prescribed fire.

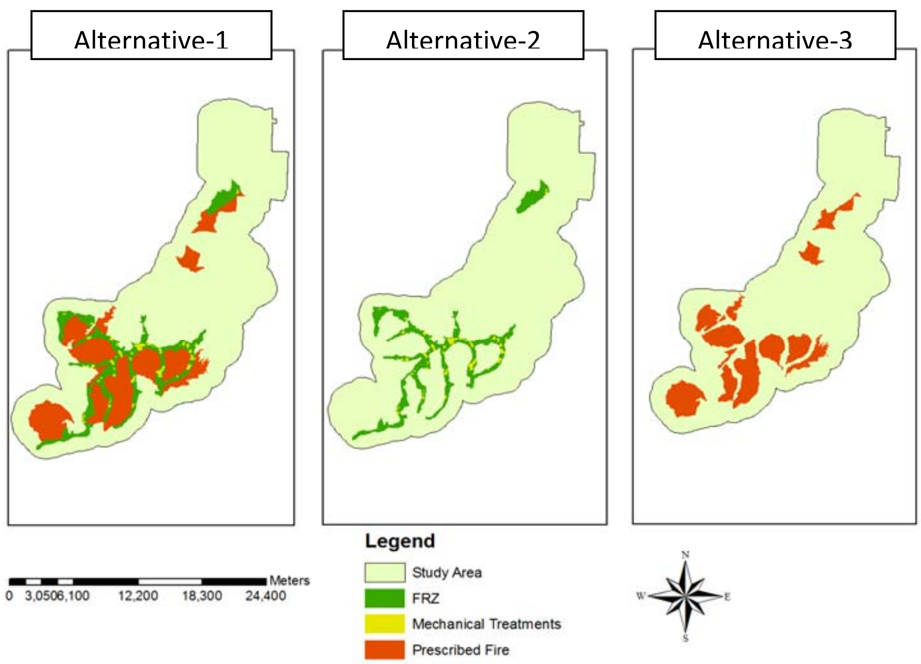

Fig. 1. Treatment alternatives within the Eddy Gulch LSR**.**

Each alternative was subsequently modeled for 50 years using the Fire and Fuels extension (FFE) within FVS (Reinhardt and Crookston 2003). Included in each FVS-FFE scenario was a wildfire simulated across the entire study area using 97th percentile weather conditions, 5 years after treatment implementation. An untreated landscape was also modeled for 50 years in FVS-FFE with the wildfire in year 5 for comparison to the treatment alternatives. The wildfire simulations provided potential carbon emissions for the entire landscape, not the potential spread or size of a wildfire as it moved across the study area. This is because FVS is non-spatial and fire behavior in any given stand is not influenced by the fire behavior in adjacent stands. In order to maintain consistency across all alternatives the wildfire was assumed to burn across the entire landscape, representing a worst case scenario for carbon emissions.

At the end of the 50 year cycle FVS-FFE generated a carbon report for each alternative and the untreated landscape. The carbon report contained yearly tons/acre values for emissions from fire (prescribed fire and wildfire) in years where fire occurred (year 1 for prescribed fire stands and year 5 for the entire landscape) and carbon storage. These tons/acre values were multiplied by the area of the study site to determine total values for tons of carbon lost via smoke emissions and total tons of carbon stored on the landscape in year 50.

Results and Discussion

Our results point to a contradiction: the treatment scenario with the largest standing stock of carbon 50 years post treatment (Alternative-1) is also the treatment strategy that lost the most carbon when prescribed fire and potential wildfire emissions were accounted for. However, increases in carbon storage appeared sufficient to off-set the higher emissions over the 50 simulation, meaning that the net change in carbon for Alternative-1 compared to no-treatment was positive (Fig. 2). A positive net change was also present in Alternative-3, but not as large as Alternative-1. Alternative-2 did not show this positive trend; the net change from no-treatment was negative.

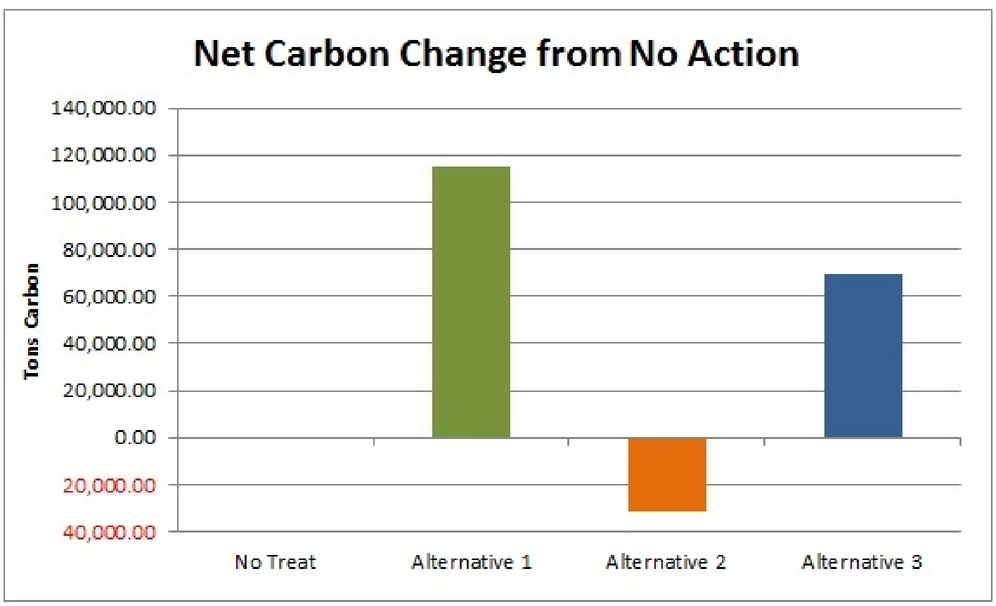

Fig. 2. Net C change derived from comparing carbon emissions and storage for each scenario to no-treatment and summing the values.

The increase in storage and emissions may stem from the same cause. Alternative-1 and Alternative-2 both had larger emissions than alternatives with smaller or no prescribed fire treatments. Simultaneously, the areas of prescribed fire treatment produced large areas resilient to catastrophic wildfire, allowing for the retention of more large trees when a wildfire was modeled. Because vegetation is a large pool of carbon (Boerner 2008), the alternative that created the largest area resilient to fire also retained the largest amount of carbon. Alternative-1 combines large prescribed fire units with mechanical units, creating the largest area resilient to catastrophic wildfire, resulting in this alternative having a slightly larger positive change in carbon than seen in Alternative-3.

Alternative-2 has small prescribed fire events as part of the FRZ units resulting in slightly larger carbon emissions than the no-treatment alternative. The area treated in this alternative is small compared to alternatives 1 and 3, resulting in much less area becoming resilient to high-severity wildfire. As a result, this alternative lost large amounts of carbon when the wildfire was simulated. The combination of prescribed fire emissions and large vegetation losses due to wildfire resulted in this alternative having a negative net change in carbon when compared to no-treatment.

Under the no-treatment scenario there were no emissions from prescribed fire so the emissions under this alternative are lower than any of the three other alternatives. However, because there are no fuel reductions, this alternative had no area resilient to wildfire, resulting in the largest loss of carbon during the wildfire in Year-5 of the simulation. The growth over the reaming 45 years was not enough to off-set the large amount of carbon lost in the form of vegetation during the wildfire event.

This work represents a worst case scenario in which the entire landscape experiences a wildfire even after fuel treatments. It is expected that the reduction in fire behavior and spread resulting from fuel treatments would realistically provide an even larger increase in carbon storage than was modeled here due to less area experiencing high intensity fire and larger areas retaining the large trees that account for much of the carbon storage.

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