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Surface fuel changes after severe disturbances in northern Rocky Mountain ecosystems

Chris Stalling*, Robert E. Keane, Molly Retzlaff

USDA Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory, 5775 Hwy 10 West, Missoula, MT 59808, United States

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ABSTRACT

It is generally assumed that severe disturbances predispose damaged forests to high fire hazard by creating heavy fuel loading conditions. Of special concern is the perception that surface fuel loadings become high as recently killed trees deposit foliage and woody material on the ground and that these high fuel loadings may cause abnormally severe fires. This study evaluated effects of severe, exogenous disturbance events, namely fire and beetles, on future fuel conditions through biannual field collections. We measured surface fuel deposition and accumulation rates for a number of forest types after severe wildfires, Douglas-fir beetle outbreaks, and mountain pine beetle outbreaks to quantitatively describe fuel dynamics for up to 10 years after the disturbance. Fuel deposition was measured from semi-annual collections of fallen biomass sorted into six fuel components (fallen foliage, twigs, branches, large branches, logs, and all other material) from a network of seven, one meter square litter traps established on 15 sites across the northern Rocky Mountains USA. We also measured fuel loadings of the same six fuel components on each plot every year until the end of the study. Results show that most foliage material fell within the first one to two years after disturbance and surface fuel loadings did not appear to increase substantially at any point during the 10 years of this study. Large woody material greater than 75 mm diameter was found infrequently in the litter traps. Our results suggest that there is little increase in fire hazard during the first 10 years after severe disturbance in the study sites sampled for this study.

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1. Introduction

Conventional wisdom in fire management holds that stands with trees that are rapidly killed by insects, disease, or fire have increased future fire hazard because the dead foliage and fine woody material in the canopy is highly flammable (Axelson et al., 2009; Hicke et al., 2012), and, when this material falls to the ground, it creates heavy fuel loads that could result in faster fire spread and greater fire intensities (Gara et al., 1984; Jenkins et al., 2012). There is little doubt that the dying and dead needles are more flammable than green needles because of lower moistures and higher flammability (Jolly et al., 2012), but these needles only remain in the canopy for a short time (1–5 years). Of greater importance may be the rate at which the dead canopy material accumulates on the forest floor to increase surface fuel loadings and fire hazard. The dead foliage and woody material may fall quickly and create surface fuel conditions that could foster wildfires of high intensity and severity. What is needed is an in-depth analysis that describes the rate of fuel deposition and subsequent accumulation after severe disturbance events.

There are basically two field methods used to quantify fuel accumulation after disturbance: post-disturbance monitoring (Keane, 2008b) and chronosequence sampling (Pickett, 1989; Page and Jenkins, 2007; Jenkins et al., 2008). Monitoring involves continuous measurement of fuel conditions after disturbance on a site and it is the best method to describe temporal fuel changes (Busing et al., 2000). However, it is often difficult and costly to monitor surface fuel dynamics in the field because it requires extensive networks of litterfall traps that must be frequently visited over long time periods (5–10 years or longer) (Keane, 2008b). Chronosequence sampling essentially substitutes space for time by sampling fuels in many disturbed stands that have different time since disturbance (Pickett, 1989; Jeske and Bevins, 1979). Chronosequence sampling is perhaps the more popular but it has a major limitation in that the sampled stands that represent the time gradient often encompass a wide variety of biophysical conditions that result in high across-site variability in fuel loadings that may mask subtle fuel changes over time (Jenkins et al., 2012).

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* Corresponding author.
E-mail address: cstalling@fs.fed.us (C. Stalling).

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Wildland fuels change through the complex interaction of four basic ecological processes: vegetation development, deposition, decomposition, and disturbance (Keane, 2015). Plants become established and grow biomass that eventually gets deposited on the ground through mortality or shed plant parts. Decomposition then reduces the deposited biomass (Robertson and Paul, 2000). If deposition rates exceed decomposition rates, fuels accumulate on the ground. Many disturbance agents may increase deposition rates through full or partial plant mortality. Some disturbances, such as fire and grazing, may reduce live and dead accumulated fuel loadings through consumption. To fully understand fuel accumulation dynamics, it is important to quantify rates of all four of these processes, but especially deposition and decomposition. This study describes fuel dynamics by documenting fuel deposition and accumulation on forested sites following disturbance using a fuel monitoring method rather than chronosequence sampling.

Litterfall deposition rates have been monitored for many ecosystems of the world (Bray and Gorham, 1964; Harmon et al., 1986; Facelli and Pickett, 1991; Van Cleve and Powers, 1995) and in some forests of the United States Pacific Northwest (Keane, 2008b). Few studies, however, have quantified litterfall by those fuel components needed for fire management, and fewer still have monitored fuel dynamics after severe disturbance using fuel monitoring (Keane, 2015). Of this limited set of studies, most measured only the rate of foliage or coarse woody debris (CWD; woody fuel particles > 7.6 cm diameter) deposition (Harmon et al., 1986b, Vogt et al., 1986). Fine woody debris (FWD; woody fuel particles <7.6 cm diameter) additions to the forest floor, such as twigs and branches, are rarely reported even though they contribute to fire spread (Rothermel, 1972; Albini, 1976). There are some exceptions, such as Ferrari (1999) who measured twigfall in hardwood-hemlock forests and Meier et al. (2006) who measured fine woody material, along with other canopy litterfall, in an alluvial floodplain hardwood forest. Deposition rates for CWD are usually measured from historical tree mortality and snag fall rates over time, but this assumes tree fall is the only input to CWD buildup. Large branches and tree tops, however, may also contribute to CWD inputs to the forest floor in some ecosystems (Harmon and Hua, 1991). The objectives of this study were to determine if recently disturbed stands have high fire hazard due to increased deposition and accumulation of surface fuels.

2. Methods

In this study, biomass loadings (kg m^{-2}) of the major surface fuel components were monitored over a period of 5–10 years on 15 US northern Rocky Mountain sites that had experienced one of three severe disturbances – wildland fire (Fire), Douglas-fir beetle (DFB), and mountain pine beetle (MPB) – to document changes in fuel loadings over time. We also measured deposition (litterfall) rates of a subset of the same six fuel components to understand fuel accumulation dynamics. Information from this effort may help managers and researchers understand the complex changes in fuelbeds that can happen after severe disturbances by informing potential future fire behavior and effects prediction. This research may lead to new methods of prioritizing fuel treatments after major insect, disease, or fire events. Moreover, it should provide important parameters and values for fuel sampling and fire modeling efforts.

Six surface fuel components are recognized in this study. Freshly fallen leaves and needles from trees, shrubs, and herbaceous plants were considered *foliage* while all other non-woody material, such as fallen cones, bark scales, lichen, and bud scales, are lumped into a category called *other* fuels. These two fuel types composed the *litter* layer measured in this study. The fallen woody material was sorted into four diameter classes using definitions required by the fire behavior and effects models (Fosberg, 1970; Rothermel, 1972; Reinhardt et al., 1997). The smallest size class defines 1 h fuels with diameters less than 3 mm. Branches with diameters between 3–25 mm are 10 h fuels and large branches with diameters ranging from 25–75 mm are 100 h fuels. In this study, we combined all three of these size categories to describe fine woody debris (FWD). The logs (CWD-downed woody fuels greater than 75 mm in diameter) define the 1000 h fuel component; CWD does not include snags or stumps (Hagan and Grove, 1999). We use the term litterfall to describe the process of fuel deposition for all fuel components for simplicity and the devices used to measure fuel deposition are referred to as litter traps. In monitoring fuel loadings, we sampled the litter and duff layer as one fuel component for logistical reasons (it is difficult to distinguish between the two in the field).

2.1. Study sites

We selected sites in Montana and Idaho that were on flat ground, within 200 m of a road, and had the potential for high tree mortality (>70%) from a recent disturbance. Red needles had to be present on the recently killed trees. We attempted to target only stands that had 70% or greater mortality from the disturbance, but it was difficult to evaluate future mortality at the inception of an outbreak or burn. As a result, two selected stands had less than 70% mortality; 25% mortality was estimated for Merriwether 1 post-wildfire and Morgan Creek was estimated to have 50% DFB mortality. Efforts to find appropriate sites was challenging due to the specificity of our selection criteria; weeks were spent driving forest roads in search of potential study sites, often without any results. After an exhaustive GIS analysis and numerous reconnaissance trips, we finally established sites in four forest types after major mortality events from three different disturbance agents: Fire, DFB, and MPB (Table 1). We wanted to select sites in just one forest type but that was nearly impossible under our site and disturbance selection criteria and so we sampled across several forest types. Locations of the final 15 sites are shown in Fig. 1.

This study design was based on a previous study that explored the temporal dynamics of fuel deposition and decomposition for undisturbed mature forest stands in the US northern Rocky Mountains (Keane, 2008a, 2008b). In that study, three disturbed lodgepole pine sites near Red River, Idaho were established immediately after an MPB outbreak in 2002. At the close of that study, we found a number of other recently disturbed sites and established plots in those stands during field seasons beginning in 2007 with the last study sites located in 2010. Four forest types are represented in this study: (1) ponderosa pine (*Pinus ponderosa*) at the lower elevations; (2) mixed western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*), and lodgepole pine (*Pinus contorta*) at the montane elevations; (3) mixed lodgepole, subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engalmannii*) at subalpine elevations; and (4) whitebark pine (*Pinus albicaulis*) at the highest, upper subalpine areas. Site elevations ranged from 1429 m to 2828 m (Table 1).

2.2. Plot measurement

A circular, 400 m^2 plot was permanently located within close proximity of roads but with traps hidden from view to prevent vandalism. Traps were placed on slopes that were less than 10 percent to avoid littertrap movement downhill and located inside an area of at least 3 acres (1.2 ha) that represented the disturbed stand. A 1 m long iron rebar about 1 cm thick was driven in the ground for plot center (Keane, 2008b) (Fig. 2), photos and notes of the plot and surrounding area conditions were documented, and the plot coordinates were georeferenced using a GPS (Global Positioning system). We then measured topographic, vegetation,

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