Ecological Engineering 81 (2015) 514–524

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Prescribed burning and mastication effects on surface fuels in southern pine beetle-killed loblolly pine plantations

Aaron D. Stottlemyer [a,*], Thomas A. Waldrop [b], G.Geoff Wang [c]

[a] Penn State University, One College Place, DuBois, PA 15801, USA
[b] USDA Forest Service, Southern Research Station, 261 Lehotsky Hall, Clemson, SC 29631, USA
[c] Department of Forestry and Natural Resources, 261 Lehotsky Hall, Clemson University, Clemson, SC 29631, USA

ARTICLE INFO

Article history:
Received 7 February 2014
Received in revised form 13 March 2015
Accepted 9 April 2015
Available online 21 April 2015

Keywords:
Forest disturbance
Site preparation
Hazard reduction
Fire behavior
Masticated debris

ABSTRACT

Surface fuels were characterized in loblolly pine (*Pinus taeda* L.) plantations severely impacted by southern pine beetle (*Dendroctonus frontalis* Ehrh.) (SPB) outbreaks in the upper South Carolina Piedmont. Prescribed burning and mastication were then tested as fuel reduction treatments in these areas. Prescribed burning reduced fuelbed continuity by consuming litter (Oi layer), duff (Oe + Oa), and woody surface fuels (1-, 10-, and 100-h timelag size classes) immediately after the treatment. Total loading of 1- and 10-h fuels in burned stands (3.1 Mg ha^{-1}) remained significantly lower than that in the control (no treatment) (5.6 Mg ha^{-1}) in the 2nd year post-treatment. However, 100- and 1000-h fuels increased post-burn due to accelerated failure of remaining pine snags and totaled 14.5 Mg ha^{-1} in the 2nd year post-treatment which was not significantly different than the control (17.3 Mg ha^{-1}). Mineral soil exposure averaged 73% of burned stands after consumption of the duff layer in many areas. Custom low, moderate, and high load fuel models were developed for SPB-killed stands and produced simulated fire behavior (flame length and rate of spread) similar to two standard slash-blowdown fuel models (SB2 and SB3) when input to the BehavePlus fire modeling system. Mastication resulted in a compacted (bulk density = 131.3 kg m^{-3}) and continuous layer of woody debris that averaged 15.1 cm in depth. Equations were developed for estimating masticated debris load and utilize fuelbed depth as input. The masticated debris load averaged 192.4 Mg ha^{-1} in the 1st year post-treatment and was significantly higher than total fuel loading in burned (16.3 Mg ha^{-1}) and control (24.3 Mg ha^{-1}) stands. The treatments tested in this study provide different options for preparing SPB-killed areas for reforestation activities and may produce short-term reductions in fire hazard.

1. Introduction

The southern pine beetle (SPB) (*Dendroctonus frontalis* Ehrh.) is native to pine (*Pinus* L. spp.) forests of the southeastern United States (Ward and Mistretta, 2002). During non-outbreak population levels, the SPB attacks storm-damaged, diseased, or lightning-struck pines (Hain et al., 2011) as well as low-vigor trees in overly dense, unthinned stands (Boyle et al., 2004). However, all trees are susceptible to attack when SPB populations reach outbreak levels (Hain et al., 2011). Major outbreaks occur in irregular cycles across the southern U.S., but may last several years and cause extensive tree mortality during these periods (Hedden 1978). The largest SPB outbreak on record lasted from 1999 to 2003 and caused the mortality of more than 28 million m^3 in tree volume (Pye et al., 2011) across more than 400,000 ha in eight southern U.S. states (Vose et al., 2009; Goelz et al., 2012), but was particularly widespread in Tennessee and South Carolina. In central America, an additional 90,000 ha of pine forest were affected by SPB during the same time period (Clarke and Nowak, 2009).

Southern pine beetle outbreaks have been particularly severe and recurrent in the Piedmont physiographic province (Ward and Mistretta, 2002) owing to a long legacy of agriculture and exploitative timber harvesting which reduced soil fertility (Callaham et al., 2006). Pines that are susceptible to SPB attack include loblolly (*Pinus taeda* L.), longleaf (*Pinus palustris* Mill.), shortleaf (*Pinus echinata* Mill.), and Virginia (*Pinus virginiana* Mill.) pines. Naturally regenerated and plantation loblolly pine stands, as well as mixed shortleaf pine-hardwood stands are the major forest types in the upper Piedmont region (Griffith et al., 2002) and are commonly attacked by SPB. When SPB infestations occur in pine plantations, a portion of the stand or nearly all of the trees may be killed in areas ranging from 0.5 to 2.5 ha in size (Stottlemyer, 2011)

* Corresponding author. Tel.: +1 814 375 4842; fax: +1 814 375 4784.
E-mail address: ads175@psu.edu (A.D. Stottlemyer).

http://dx.doi.org/10.1016/j.ecoleng.2015.04.076
0925-8574/

and are typically surrounded by unaffected pine-hardwood or mixed-hardwood forest. Woody debris that accumulates on the forest floor after pines die raises fire hazard concerns (Waldrop et al., 2007; Elliott et al., 2012) and may impede forest management activities.

Recent ecological research has been aimed at better understanding the influence of bark beetle outbreaks on fuels and fire behavior. To date, most of this work has been conducted following mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreaks in western U.S. coniferous forests which raise concerns about wildfire risk and have thus been the focus of various fuels and fire behavior studies (Page and Jenkins, 2007a,b; Jenkins et al., 2008, 2014; Simard et al., 2011; Schoennagel et al., 2012; Page et al., 2014). The terms "endemic," "epidemic," and "post-epidemic" have been widely used to describe phases of a bark beetle outbreak in relation to changes in fuels (Jenkins et al., 2014). During endemic population levels, bark beetles attack individual or small groups of trees injured or weakened by lightning, disease, or other insects and have a limited effect on fuels beyond localized increases in downed wood (Jenkins et al., 2008). The beetle population increases during the epidemic phase and needles and fine woody material from dead and dying trees increase to peak levels (Page and Jenkins, 2007a,b,b; Jenkins et al., 2008, 2014; Schoennagel et al., 2012; Page et al., 2014). In the post-epidemic phase, the majority of susceptible host trees has been killed, litter and fine fuel levels decrease and eventually return to background levels (Jenkins et al., 2008). Over the course of several years to decades post-epidemic, large surface fuels accumulate as dead trees fall and the fuelbed becomes deeper (Jenkins et al., 2008, 2014; Schoennagel et al., 2012). A couple of studies have examined fuels following SPB outbreaks in post-epidemic mixed pine-hardwood forests in the southern Appalachian Mountains containing varying abundance of pines (loblolly, shortleaf, and Virginia) and mixed hardwood species as the dominant overstory trees. In one study, Waldrop et al. (2007) found that approximately 2–4 years after an outbreak, SPB tree mortality led to increased loading of all size classes of woody surface fuels as well as depth of the fuelbed. This study, along with another in the same region (Elliott et al., 2012), provide detailed fuels information for post-epidemic pine-hardwood forests, but it is unclear whether these characterizations reflect fuel conditions following SPB outbreak in pine plantations and we are not aware of any studies in these areas.

Without intervention, SPB-killed stands may be at increased risk for catastrophic wildfire (Agee and Skinner, 2005) particularly during high fire danger periods (e.g., January through mid-April) or the heavy loading of woody debris may impede management activities, such as the establishment of a new pine plantation (Schultz, 1997). Prescribed fire can be an effective management tool for reducing fuel loads and preparing sites for regeneration in the southeastern U.S. (Waldrop and Goodrick, 2012), although we are not aware of any research evaluating the impacts of prescribed burning in SPB-killed pine plantations. Thus, it is not clear whether prescribed burning will sufficiently reduce heavy fuel loads or if severe fires will have deleterious effects on site productivity. One study involved prescribed burning in a pine-hardwood ecosystem following SPB tree mortality and heavy accumulations of woody surface fuels (Elliott et al., 2012). The burns consumed 50% of litter plus fine woody fuel mass and 18% of large woody fuel mass. However, the duff (Oe + Oa) layer, which is one factor involved in short-term site recovery and long-term site productivity (Clinton et al., 1996; Elliott and Vose, 2005; Waldrop et al., 2010), remained largely intact. These results suggest that burning may be effective for fuel reduction in SPB-killed pine plantations while having minimal impacts on site productivity.

Mechanical treatments have become increasingly common for fuels management particularly in the wildland–urban interface where the use of prescribed fire is constrained by public perception, risk to property, or concerns over effects of smoke emissions on air quality (Agee and Skinner, 2005). Mechanical methods are used in lieu of prescribed fire or as an initial treatment to moderate fire behavior (Stephens and Moghaddas, 2005). Mastication is a mechanical treatment where a machine equipped with a rotary drum with flailing knives or cleats shreds, grinds, or chips live and dead standing trees and shrubs, as well as down woody surface fuels (Kane et al., 2009). Larger fuels are fractured into smaller, irregularly sized particles and all masticated debris is deposited onto the forest floor (Battaglia et al., 2010) and typically left on-site (e.g., Fig. 2). Mastication has been used to achieve different fuels management objectives including the treatment of logging slash (Stephens and Moghaddas, 2005; Kane et al., 2009) and midstory sapling and shrub layers (Glitzenstein et al., 2006; Brockway et al., 2009; Kane et al., 2010; Outcalt and Brockway, 2010; Potts et al., 2010; Knapp et al., 2011; Kreye et al., 2013) as well as reducing canopy fuel loads (Stephens and Moghaddas, 2005; Reiner et al., 2009; Battaglia et al., 2010). These studies generally found that mastication results in a mixture of fuel particle shapes and sizes in a shallow, continuous fuelbed having high mass and bulk density (Kreye et al., 2014). The fractured nature of masticated fuels gives them high surface area to volume ratios (Knapp et al., 2011) which would be expected to decrease drying time (Anderson, 1990). While this characteristic might normally increase fire behavior in other types of activity fuels (Rothermel, 1972); masticated fuelbeds are compact which may slow drying time and suppress fire behavior (Kreye et al., 2011). For example, Glitzenstein et al. (2006) used mastication to treat large woody surface fuels and a continuous sapling and shrub understory post-Hurricane Hugo in South Carolina, USA. Masticated plots had lower flame lengths and rates of spread and less area burned compared to un-masticated plots, although slower wind speeds in the masticated plots may have contributed to the differences. We are not aware of any studies where mastication has been used for fuels management in areas where a severe insect outbreak caused near complete mortality of the overstory trees. Thus, information thought to be critical for modeling fire behavior and effects in masticated fuel is currently unavailable to forest managers. In particular, properties including depth, loading, and bulk density have been suggested to be critical to understanding fire behavior in masticated fuels (Kreye et al., 2014).

Forest managers have expressed interest in using prescribed burning or mastication as fuels treatments to simultaneously reduce the fire hazard and clear woody debris in SPB-killed stands to facilitate reforestation activities. Yet prudent management decisions require information about the fuel complex and how the treatments affect fuels which is currently unavailable. Therefore, the objectives of our study were to (1) characterize surface fuels; (2) compare custom fuel models to existing slash-blowdown fuel models for simulating fire behavior; and (3) examine impacts of prescribed burning and mastication as separate treatments on fuel loading and fuelbed structure in SPB-killed loblolly pine plantations.

2. Materials and methods

2.1. Site selection and plot establishment

This study was conducted in the Clemson Experimental Forest (CEF; latitude 34°40′, longitude 82°49′) which lies in the upper portion of South Carolina's physiographic Piedmont province (Myers et al., 1986). Maximum July temperature averages 31 °C in this region and total annual precipitation is 137 cm, on average (National Climatic Data Center). Soils in the study area are Cecil series and classified as fine, kaolinitic, thermic, Typic Kanhapludults. These