Forest Ecology and Management 259 (2010) 1255–1261

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Analyzing the effectiveness of alternative fuel reductions of a forested landscape in Northeastern China

Zhihua Liu [a,c], Hong S. He [a,b], Yu Chang [a,*], Yuanman Hu [a]

[a] Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China
[b] School of Natural Resources, University of Missouri, 203 ABNR Building, Columbia, MO 65211, USA
[c] Graduate School of Chinese Academy of Sciences, Beijing 100039, China

ARTICLE INFO

Article history:
Received 22 December 2008
Received in revised form 25 June 2009
Accepted 21 December 2009

Keywords:
Economic analysis
Fire risk
Forest
Fuel reduction
LANDIS
Northeastern China

ABSTRACT

Successful management of forest fire risk in the Northeastern China boreal forest ecosystem often involves trade-offs between fire dynamics, fire hazard reduction, and fiscal input. We used the LANDIS model to study the effects of alternative fuel reduction strategies on fire dynamics and analyzed cost effectiveness for each fuel reduction strategy based on cost–benefit theory. Five levels of fuel treatment area (2, 4, 6, 8, and 10% for each decade) and two fuel treatment types (prescribed burning [PB] and mechanical treatments in combination with prescribed fire [PR]) under current fire suppression simulated by LANDIS were compared in a 5×2 factorial design over a 300-year period. The results showed that PR scenarios are more effective at reducing the occurrence and burn area of catastrophic fires than PB scenarios. In addition, area burned by high intensity fire can be tremendously reduced by increasing low intensity fires with a higher level of treatment area under the various PR scenarios. The cost effectiveness of alternative fuel reduction strategies is strongly dependent on treatment area. In general, PB scenarios will be more cost effective in larger treatment areas and PR scenarios in smaller. We recommend mechanical treatments in combination with prescribed fire, with 4% of landscape treated in each decade (PR04) to be the optimal fuel reduction strategy in the study area based on risk control and cost efficiency analysis. However, the most challenging work in China is to make local forest policy makers and land managers accept the ecological function of fire on forest ecosystems.

1. Introduction

The boreal forests of Great Xing'an Mountains in Northeastern China cover the largest area and important source of timber and wood products in the country. They also encompass rather unique ecological and environmental settings in Northeastern China (Zhou, 1991; Xu, 1998). Forest fire is a key natural disturbance in shaping forest ecosystem dynamics, affecting species composition and regulating age structure in the region (Zhou, 1991; Xu, 1998). Historically, fire regimes in these systems were characterized by frequent, low intensity surface fires mixed with sparse stand-replacing fires on relatively small areas (Xu et al., 1997). Those historical fire regimes have been dramatically altered due to the effective fire suppression started in the early 1950s. Consequently, high fuel accumulation coupled with a warmer, drier climate in recent decades resulted in fires of greater intensities and extents than those that occurred historically (Tian et al., 2005). On 6th May 1987, a catastrophic fire occurred in the Great Xing'an Mountains and burned an area of 1.3×10^6 ha. The fire had sweeping effects on stands and led to severe soil erosion in post-fire flooding events, which made forest recovery difficult (Xiao et al., 1988; Shu et al., 1996; Wang et al., 2007).

Contrary to its intention, currently fire suppression policy may be counterproductive in preventing catastrophic fires in Great Xing'an Mountains in Northeastern China. Preliminary studies in this region suggest that fuel reduction should be incorporated into forest management to reduce the likelihood of catastrophic fires (Chang et al., 2007, 2008).

The primary fuel treatment types include prescribed fire to reduce surface fuel and mechanical removal of coarse woody debris and small diameter understory trees from forest. Prescribed fire is effective at reducing wildfire ignitions and can also significantly mitigate fire intensity in an actual wildfire by altering the fuel profile (Pollet and Omi, 2002; Skinner et al., 2004; Martinson and Omi, 2008). Mechanical treatment is effective at reducing the likelihood of high intensity stand-replacing fires (Agee and Skinner, 2005). However, mechanical treatment may potentially increase surface fine fuel load, surface fuel depth, and

---

* Corresponding author. Tel.: +86 24 83970350; fax: +86 24 83970351.
E-mail address: changyu@iae.ac.cn (Y. Chang).

0378-1127/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2009.12.022

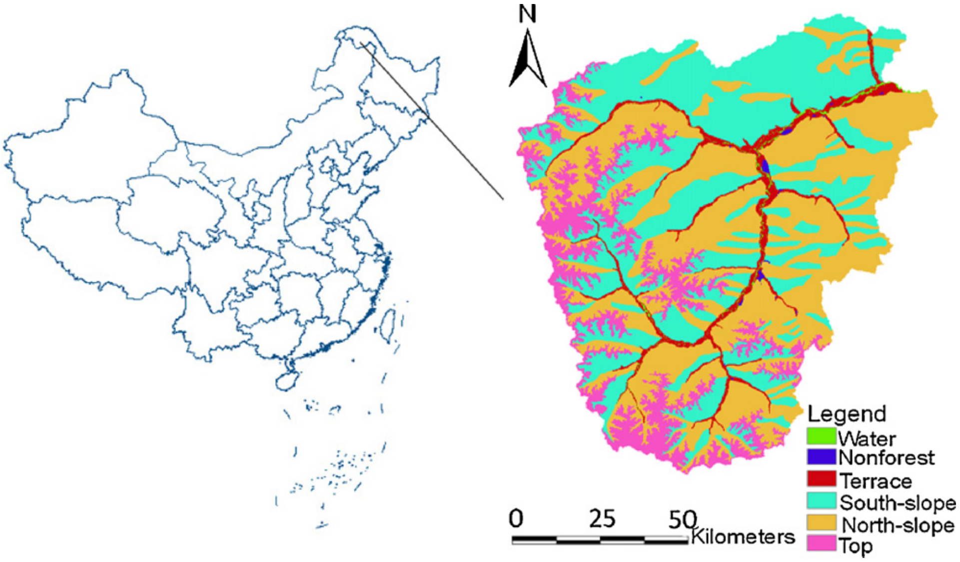

Fig. 1. The geographic location of the study area and different land types, among which water and non-forest land types are not simulated in the model.

continuity, which may be ineffective in reducing wildfire ignitions and contribute to greater surface fire intensity (Stephens and Moghaddas, 2005).

The effectiveness of fuel treatments is related to treatment type, treatment area (proportion of landscape to be treated), and frequency (Agee and Skinner, 2005). Numerous experimental studies have studied the effectiveness of alternative fuel treatments types, most at plot levels over relatively short time spans (Stephens, 1998; Pollet and Omi, 2002; Stephens and Moghaddas, 2005; Raymond and Peterson, 2005; Youngblood et al., 2007). Results from these studies suggest that mechanical plus prescribed fire treatments can effectively reduce fire intensity and tree mortality due to the reduction in surface fuel. Treatment area and frequency are also critical in reducing fire hazard. Reports showed that large and aggregated treatment units can be more effective than small and dispersed treatment units at reducing fire intensity and stopping the spread of wildfires (Agee and Skinner, 2005; Finney et al., 2007; Ritchie et al., 2007). Fuel treatment effects may last from a few years to two decades depending on fuel dynamics in forest ecosystems (Fernandes and Botelho, 2003). Thus, treatment frequency should be determined by the relationships between time of fuel accumulation and time of decomposition (Fernandes and Botelho, 2003; Keane, 2008).

Treatment cost is another key factor in designing and prioritizing fuel treatment. In general, fuel treatment cost varies with site conditions, treatment type, size, and frequency (González-Cabán, 1997; Hesseln, 2000; Calkin and Gebert, 2006; Hartsough et al., 2008), and cost–benefit analyses are needed to determine feasible fuel treatments. Designing a fuel treatment plan requires identifying the optimum combinations of treatment type, size, and frequency, while taking into account treatment costs and long-term effects.

Our goal was to evaluate the effectiveness of alternative fuel treatment plans and their costs in reducing fire hazard. Specifically, we (1) investigated how total burned area, area burned by different intensity fires, and frequency of catastrophic fires respond to alternative fuel treatments, and (2) determined the optimal fuel treatment strategy for this study area through cost–benefit analyses. Because conducting long-term experiments on fuel treatment for a large landscape is unfeasible, we used a stochastic, spatially explicit forest landscape model, LANDIS. We constructed fuel treatment plans by combining different levels of treatment area and treatment types under the current fire suppression policy. To capture the potential variation of treatment responses, increased area of treatment were also constructed to reflect potential treatment capability. We selected prescribed fire and mechanical treatment in combination with prescribed fire as treatment types to represent common fuel treatment options.

2. Methods

2.1. Study area

Our study area, Huzhong Forest Bureau (Fig. 1), encompassing approximately 937 244 ha of the Great Xing'an Mountains in Northeastern China (52°25′00″N, 122°39′30″E to 51°14′40″N, and 124°21′00″E). The area falls within the cool temperate zone (Zhou, 1991) affected by the Siberian cold air mass and has a terrestrial monsoon climate with a long and severe winter. Annual average precipitation and temperature is ~500 mm and 4.7 °C, respectively.

Vegetation of this area is cool temperate coniferous forests; the southern extension of eastern Siberian boreal forests (Zhou, 1991). The canopy species composition is relatively simple, including larch (*Larix gmelini*), pine (*Pinus sylvestris* var. *mongolica*), spruce (*Picea koraiensis*), birch (*Betula platyphylla*), and two species of aspen (*Populus davidiana* and *P. suaveolens*). With the exception of some portions of wetland near rivers, larch is widely distributed over 65% of the study area. Birch and pine are mixed with larch in most areas owing to fire disturbance and forest harvesting, with pine having a small area of distribution (1.8%). Aspen is confined to terraces along the rivers where water is plentiful. Spruce, being highly shade tolerant, occurs mostly in valleys and high elevation areas, and pine-p (*Pinus pumila*) occurs mostly in elevations >800 m (Xu, 1998).

2.2. The LANDIS model

LANDIS (version 4.0) is a raster-based, spatially explicit forest landscape model that simulates forest landscape change in response to disturbance, succession, and management at large spatial extents (10^3–10^6 ha) over long time spans (10–1000 years) in 10-year increment. Various components and processes simulated in LANDIS were described extensively elsewhere (He et al., 1999; He and Mladenoff, 1999a,b; Mladenoff and He, 1999; Gustafson et al., 2000; He et al., 2004; Mladenoff, 2004). The effectiveness of the model to simulate the forest landscape in