Forest Ecology and Management 324 (2014) 81–88

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Strategies for preventing invasive plant outbreaks after prescribed fire in ponderosa pine forest

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ARTICLE INFO

Article history:
Received 3 February 2014
Received in revised form 15 April 2014
Accepted 17 April 2014
Available online 10 May 2014

Keywords:
Cirsium arvense
Fire severity
Invasive plants
Pinus ponderosa forest
Prescribed fire
Verbascum thapsus

ABSTRACT

Land managers use prescribed fire to return a vital process to fire-adapted ecosystems, restore forest structure from a state altered by long-term fire suppression, and reduce wildfire intensity. However, fire often produces favorable conditions for invasive plant species, particularly if it is intense enough to reveal bare mineral soil and open previously closed canopies. Understanding the environmental or fire characteristics that explain post-fire invasive plant abundance would aid managers in efficiently finding and quickly responding to fire-caused infestations. To that end, we used an information-theoretic model-selection approach to assess the relative importance of abiotic environmental characteristics (topoedaphic position, distance from roads), pre-and post-fire biotic environmental characteristics (forest structure, understory vegetation, fuel load), and prescribed fire severity (measured in four different ways) in explaining invasive plant cover in ponderosa pine forest in South Dakota's Black Hills. Environmental characteristics (distance from roads and post-fire forest structure) alone provided the most explanation of variation (26%) in post-fire cover of *Verbascum thapsus* (common mullein), but a combination of surface fire severity and environmental characteristics (pre-fire forest structure and distance from roads) explained 36–39% of the variation in post-fire cover of *Cirsium arvense* (Canada thistle) and all invasives together. For four species and all invasives together, their pre-fire cover explained more variation (26–82%) in post-fire cover than environmental and fire characteristics did, suggesting one strategy for reducing post-fire invasive outbreaks may be to find and control invasives before the fire. Finding them may be difficult, however, since pre-fire environmental characteristics explained only 20% of variation in pre-fire total invasive cover, and less for individual species. Thus, moderating fire intensity or targeting areas of high severity for post-fire invasive control may be the most efficient means for reducing the chances of post-fire invasive plant outbreaks when conducting prescribed fires in this region.

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1. Introduction

Fire is a natural and important element of most ponderosa pine (*Pinus ponderosa*) ecosystems, including the Black Hills of South Dakota and Wyoming, USA (Brown, 2006; Brown and Sieg, 1996, 1999; Brown et al., 2008; Shinneman and Baker, 1997). Substantial human development in this region requires aggressive suppression of wildfires, so prescribed fire is an important tool for maintaining and restoring forest structure and health. Although natural resource managers recognize the importance of this tool, they are also concerned that prescribed fires provide opportune conditions for invasive plant species by increasing nitrogen, light, and water availability, as well as providing bare mineral soil for germination (Kucera and Ehernreich, 1962; Neary and Ffolliot, 2005; Vermeire and Rinella, 2009; Wan et al., 2001).

Effects of invasive plants are of particular concern when prescribed fires include areas of high fire intensity – a practice proposed as a means for restoring forests with long histories of fire suppression (Fulé et al., 2004; Miller and Urban, 2000). For example, exotic species comprised 26% of total understory cover 2 years after wildfires in northern Arizona ponderosa pine forest, with their highest cover being in areas that burned with high severity compared to moderate-severity or unburned areas (Crawford et al., 2001). In contrast, cover of exotic species in an intense prescribed fire in the same region remained below 1%, even in the most severely burned areas (Huisinga et al., 2005). The authors of the latter example attribute the difference in results between

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http://dx.doi.org/10.1016/j.foreco.2014.04.022
0378-1127/Published by Elsevier B.V.

the two examples to the general lack of anthropogenic disturbance – and therefore pre-fire invasive species – in their study area (a remote portion of Grand Canyon National Park) compared to that in the first example's location. Similarly, a recent review of fire effects on invasive plants concluded that, although there are many examples of invasive plants increasing with greater fire severity, the availability of propagules of these species is critical in determining the outcome of a specific fire (Zouhar et al., 2008). Furthermore, this review stressed that, "while generalizations are useful for describing and explaining fire's relationship to non-native invasive species, they have limited usefulness for predicting what will happen on a given site after a given burn" because local factors – traits and abundance of the local invasive species, topoedaphic and moisture characteristics, competition from native vegetation, and fire conditions – will trump these general patterns (p. 19, Zouhar et al., 2008).

Thus, local research, applicable within a region where invasive species, ecosystem type, and management history are fairly consistent, is needed to help natural resource managers minimize ecosystem impacts from invasive species after fire. Minimizing these impacts requires understanding what aspects of the environment and/or the fire are important in determining where the invasives will be most problematic. This would allow managers to avoid fire in areas prone to post-fire invasive plant outbreaks or to efficiently find and quickly respond to fire-caused infestations. To that end, we investigated the relationship between invasive plant species and environmental and prescribed fire characteristics in the central and southern Black Hills. Our goals were to determine which factors are associated with post-fire plant invasions and suggest strategies for reducing post-fire plant invasions.

2. Methods

2.1. Study area

The Black Hills of South Dakota and Wyoming, USA, are the isolated, easternmost extension of the Rocky Mountains uplift. Rising up to 1200 m above the surrounding plains, the Black Hills are characterized by ponderosa pine forest and woodlands that, prior to European settlement, experienced a variety of fire regimes (Brown, 2006; Brown and Sieg, 1999; Brown et al., 2008; Lentile et al., 2005; Lundquist and Negron, 2000; Shinneman and Baker, 1997; Stambaugh et al., 2008). Our work was conducted in the southern Black Hills, where frequent, low-severity, generally surface, fires dominated (Brown and Sieg, 1999). Fire suppression has resulted in increased tree density, particular in smaller size classes (Brown and Cook, 2006; Brown et al., 2008; Symstad and Bynum, 2007). Prescribed fire is used by land management agencies in the region to reduce the risk of high-intensity wildfire, reestablish pre-settlement fire regimes, and achieve forest structure that more closely resembles that of pre-settlement times. Consequently, the main objective of prescribed fires in the region often is to reduce seedling and small tree density while limiting mortality of larger trees. Some prescribed fires are used to reduce overstory density as well, to create relatively small patches of high severity in a larger, heterogeneous, mixed-severity landscape. This study was done in the context of prescribed fires whose burn objectives did not address invasive plant species (Swanson, 2010; unpublished burn plan for the Lithograph fire).

We evaluated fire effects in two National Park Service units in the central and southern Black Hills, Jewel Cave National Monument (JCNM; 43°44′N, 103°50′W) and Wind Cave National Park (WCNP; 43°37′N, 103°29′W). Most of the JCNM study area (78-ha) had burned in 1996 and 1999 prescribed burns and in the 2000 Jasper wild fire. The study area within WCNP (763 ha) had a more varied fire history. Approximately 3% burned in a 1992 wildfire, 18% burned in a prescribed fire in either 1997, 2006, or 2008, and <1% burned in various small wildfires. Thus, in contrast to the JCNM site, most of the WCNP site had not burned in the last 50 years. Invasive plant treatment was minimal within the study areas before the study began, and no treatment was allowed within 50 m of any established plot for the duration of the study (2010–2012).

2.2. Target invasive species

Twenty non-native species were chosen as target species for data collection (Table 1). Species included were either already the subject of invasive control efforts in the study parks or were on the parks' "watch-lists" because of their strongly negative impacts elsewhere in or around the region. With the exception of *Poa pratensis* and *Bromus inermis* (species the parks do not yet manage), the target list included all exotic species commonly encountered in the study plots.

2.3. Experimental design

We sought to maximize the range of environmental conditions represented and therefore used an "equal-stratified" random sampling approach (Hirzel and Guisan, 2002; Table 2). Strata and plot locations within them were delineated using ArcGIS 9.3.1 (ESRI, 2010). Strata were based on burn unit, and therefore prescribed fire implementation, a previous large disturbance, and environmental factors relevant to herbaceous plant growth and invasive plant propagule availability. Specific factors used in stratification were (1) burn unit (Lithograph at JCNM, American Elk at WCNP); (2) vegetation type, as mapped by the U.S. Geological Survey-NPS vegetation mapping program (Cogan et al., 1999), in which ponderosa pine forest types are separated by canopy cover class, for WCNP (vegetation at JCNM was mapped before the 2000 Jasper wildfire, which substantially altered forest cover); (3) north/east vs. south/west slope aspect derived from the February 2010 release of the 1-arc-second National Elevation Dataset (http://ned.usgs.gov/ accessed 12 May 2010); (4) soil type, as mapped by the NRCS soil survey program (data downloaded from http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx on 18 May 2010); (5) Jasper fire burn severity (JCNM only) from the NPS-U.S. Geological Survey National Burn Severity Mapping Project (http://burnseverity.cr.usgs.gov/, data provided to NPS June 2002); and (6) distance ($\leqslant$50 m vs. >50 m) from a road, well-used pedestrian trail, power line, or other development (Table 2). The sample area was limited to ponderosa pine vegetation types. Due to the high incidence of soil complexes (more than one soil type in a soil mapping unit), soil types were combined into a single category (JCNM) or two categories based on topographic position (WCNP). All possible combinations of all factors were not used because not all combinations occurred in the field and because some combinations produced areas that were very small. In the latter case, areas were combined into a single stratum using one or two variables consistent across the combinations.

A total of 88 plots (where a plot is the sample unit) were distributed among the two burn units (Table 2). Plots were established pre-treatment, in 2010.

2.4. Prescribed fires

The Lithograph burn unit, which was the same as the JCNM study area, was burned on 21 September 2010. Ignition was by hand with a mixture of backing, flanking, and short strip head firing techniques. Weather ranged from 14 °C and 45–49% relative humidity at the beginning and end of the fire to 18 °C and 37%