Forest Ecology and Management 343 (2015) 9–21

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Comparing historical and current wildfire regimes in the Northern Rocky Mountains using a landscape succession model

Feng Zhao [a,*], Robert Keane [b], Zhiliang Zhu [c], Chengquan Huang [a]

[a] Department of Geographical Sciences, University of Maryland, College Park, MD 20742, United States
[b] USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT 59807, United States
[c] US Geological Survey, 12201 Sunrise Valley Drive, Reston, VA 20192, United States

ARTICLE INFO

Article history:
Received 19 September 2014
Received in revised form 20 January 2015
Accepted 22 January 2015
Available online 14 February 2015

Keywords:
Fire regimes
FRCC
LANDSUMv4 model
MTBS
LANDFIRE
Northern Rocky Mountains

ABSTRACT

Wildland fire is a key ecosystem process that shapes the landscape of Western United States. Changes in fire regimes can therefore have profound impact on ecosystem functions and services, including carbon cycling, habitat conditions, and biodiversity. This study examined fire regime changes in the Northern Rocky Mountain region using a landscape succession model (LANDSUMv4). The objective is to report a new method to develop fire regime condition class (FRCC) maps by comparing historical reference conditions of fire regimes – simulated using historical fire record and the LANDSUMv4 model – with current fire regimes developed using 27 years remote sensing fire product and LANDSUMv4. Results of this study indicate that most forest ecosystems in the study region experienced less frequent but more severe fires during the contemporary time period compared to the historical conditions. Fire regimes have changed the most for montane forests which historically were dominated by frequent and nonlethal fires. Forest ecosystems characterized by infrequent stand replacement fires also experienced moderate departure from historical fire conditions. FRCC assessment method proposed in this study can be applied to other areas of U.S. The findings of this study will help reveal contemporary fire dynamics in this region and serve for future fire and fuel studies and other forest management applications.

1. Introduction

Fire is a key ecological process that recycles nutrients, regulates vegetation succession, controls plant regeneration, and maintains biodiversity in many forest ecosystems (Bowman et al., 2009; Scott et al., 2013). Fire regime is the temporal and spatial expression of fire for specific ecosystems, and often can be described and classified by fire frequency and severity (Heinselman, 1981; Brown and Smith, 2000; Morgan et al., 2001). Fire frequency is the number of fire events at a point (point frequency) or within an area and a time period (rotation period) (Morgan et al., 2001). Point fire frequencies, such as mean fire return intervals (Heinselman, 1973) represent patterns as aggregates of point samples. Fire rotation period, on the other hand, incorporates reconstructed or mapped fire perimeters and are defined as the length of time necessary to burn an area equivalent to a specific study area or landscape (Heinselman, 1981; Morgan et al., 2001). The severity of fire has been described by the degree of tree mortality (Morgan et al., 1996), degree to which fires consume organic biomass on and within the soil (Ryan and Noste, 1985; Lenihan et al., 1998), heat penetrating into the soil (Ryan and Noste, 1985; White et al., 1996), or a combination of these fire effects (Turner et al., 1994).

Assessing departure of current to historical (pre-EuroAmerican settlement) fire regimes is critical for fire and climate change research, fire management, prioritizing fuel treatment and policy making (Bowman et al., 2009). Previous studies suggest that historical fire regimes may have been altered as a result of increased anthropogenic activities including active fire suppression, land-use change, population increases and climate change (Covington and Moore, 1994; Keane et al., 2002c). Recent studies have also noted that changes in fire regimes may lead to major shifts in vegetation, landscape structure, and ecological functions including productivity (Baker, 1992). Effective wildland fire management is partly reliant on accurate and consistent comparison of historical and current fire regimes at multiple spatial and temporal scales (Hardy et al., 2001; Keane et al., 2003). Landscape fuel treatment can be prioritized, designed, and scheduled to restore and manage the forests by understanding the causal mechanisms creating historical and current fire regimes. For example, land managers use such information to quantitatively determine the condition of

---

* Corresponding author. Tel.: +1 2404856468.
E-mail address: fengzhao@umd.edu (F. Zhao).

http://dx.doi.org/10.1016/j.foreco.2015.01.020
0378-1127/

fire-dependent ecosystems and whether management actions designed to improve the health of the ecosystems are achieving their desired outcome (Hann and Bunnell, 2001; Hardy et al., 2001). For policy applications, fire regime calculations are useful and often necessary for measuring goals of federal wildland fire management policies such as consistent management standards across geography and land management units and guidance for fuel treatments or community assistance (Council, 2009). Informed fire management is also emerging as a critical tool for implementing climate change policies (such as the Climate Action Plan[1]) to adapt to and mitigate effects of climate change (Brown et al., 2004; Spittlehouse and Stewart, 2004). This study was conducted with these potential applications in consideration.

Recently, methods have been developed to compare characteristics of current and historical fire regimes across major ecosystems in North America. One measurement called fire regime condition class (FRCC) is, a classification based on the amount of change or departure by fire attributes and vegetation, developed to represent departure of present-day fire regime conditions from a defined reference period – that is, whether a landscape is still within the natural or Historical Range and Variation (HRV) (Hann and Bunnell, 2001; Hann et al., 2004). Directly estimating the departures of current to historical fire regimes over large areas has been difficult owing to discrepancies between historical fire records which tend to be simple-point records and contemporary observations, which tend to be remote sensing-based maps covering a relatively short time span. The LANDFIRE[2] project (Rollins, 2009) used vegetation departure as a surrogate for fire departure. Maps were produced for the U.S. depicting attributes of current vegetation such as successional patterns and trends that have departed from simulated historical vegetation reference conditions as the result of altered fire regimes. Despite continued efforts by the LANDFIRE project, a consistent FRCC calculation with a reasonable spatial scale and geographic scope is still difficult (Hann and Bunnell, 2001; Hardy et al., 2001).

Landscape fire succession models that spatially predict fire regimes have been demonstrated to be a suitable tool for developing fire regime maps (Keane et al., 2003). Several previous efforts have used landscape fire succession models (such as SEM-LAND and LANDIS) to compare historical and current fire regimes (Li et al., 2005; Chang et al., 2008). Although these studies have made substantial contribution to our understanding of fire regime departures simulated with landscape models, two gaps remain in the literature. First, contemporary fire records used in these studies for simulating current fire regimes were either incomplete or of short time interval (about 10 years of fire records), and therefore might not be sufficient to capture long-term variability of fire characteristics. Second, spatial ranges examined by these studies have tended to be at landscape level (several square kilometers) with extensive parameterization and computation efforts. For regional or national applications, landscape fire succession models are needed, with more simplified parameterization while retaining enough spatial and temporal information for forest management activities such as fire management and fuel treatment.

We present here the methods and results of a study on comparing current and historical fire regime conditions, with potential forest management applications. The specific objectives of this study were to (1) use time series (1984–2010) remote sensing product (Monitoring Trends of Burn Severity, MTBS) to quantify current fire characteristics in the study region; (2) introduce a new method that uses a landscape fire succession model to examine and compare current and historical fire regime conditions for a large study area in the Northern Rocky Mountains. With the availability of LANDFIRE and a remote sensing based fire product nationally, this method can be applied to other study regions in U.S.

2. Methods

2.1. Study area

This study used zone 10 of the LANDFIRE project mapping zones as the study region (Fig. 1), which comprises a large portion of the Northern Rocky Mountains. The study region covers a broad range of environmental gradients (Table 1) including significant variability in geology, landform, climate, vegetation, and land use (Habeck and Mutch, 1973; Weaver, 1980). In the order of increased elevation, major forest types include mid-Montane forest (e.g. Ponderosa Pine and Douglas Fir), high-Montane forest (e.g. Engelmann Spruce), and subalpine forest (e.g. Subalpine Fir and Whitebark Pine). Findings from fire history studies indicated that the Northern Rocky Mountains were dominated by fire regimes of 30–200 years frequency and varied severities (Arno et al., 2000). In Northern Rocky Mountains, mixed-severity regimes covered about 50 percent of the area, nonlethal regimes occupied about 30 percent of this area and stand replacement regimes included about 20 percent (Arno, 1980; Arno et al., 2000). Nonlethal regimes are primarily confined to forests where Ponderosa Pine was historically dominant. Mixed severity regimes were found across a broad range of forest types, including some of those dominated by Douglas Fir and Western Larch, Lodgepole Pine and Whitebark Pine, as well as some relatively moist Ponderosa Pine stands. Other areas of these same forest types were characterized by stand-replacement fire regimes (Arno et al., 2000).

2.2. Methods overview

We used the LANDscape SUccession Model version 4.0 (LANDSUMv4) (Keane et al., 2002a, 2006) to simulate both the historical and current fire regimes in the study region (Fig. 2). The historical time period was defined as 'pre-EuroAmerican settlement' (before 1900s), the same as it was defined in the LANDFIRE project. Current time range was defined as 1984–2010, which was the mapping period of the MTBS data.

LANDSUMv4 is a spatially explicit landscape vegetation dynamic model for simulating fire and succession on fine scale landscape for land management applications (Keane et al., 2002a, 2006). Two main components of the model are succession and disturbances. LANDSUMv4 model simulates succession within a polygon or patch using a multiple pathway succession modeling approach (Kessell et al., 1981; Keane et al., 2006). This approach simulates succession as a deterministic process and assumes all pathways of successional development would eventually converge to a climax plant community called a potential vegetation type (PVT) (Pfister and Arno, 1980). Disturbances, such as fires, are modeled in LANDSUMv4 as a stochastic process (Barrett, 2001; Keane et al., 2006; Steele et al., 2006). There are two phases of fire simulation: the initiation phase and the effect phase. Fires are initiated for a polygon using a stochastic approach based on fire probabilities specified for each PVT and succession class combinations in a Scenario Input File. The effects of an initiated fire disturbance are simulated as a change in succession age, succession class, or both (Keane et al., 2006).

LANDSUMv4 requires seven key tabular input files and two map files for its execution (Keane et al., 2006). Tabular input files include Simulation Input File, Attribute Input File, Disturbance

---

[1] http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

[2] LANDFIRE: LANDFIRE Vegetation Departure layer. U.S. Department of Interior, Geological Survey. <http://landfire.cr.usgs.gov/viewer/>.