Is spatial heterogeneity of burn severity changing with warming climate and increasing wildfire?

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I. Overview

In fire-prone regions, the resiliency of forested ecosystems is greatly influenced by spatial heterogeneity of burn severity. Fire frequency and area burned are increasing in most parts of the world (Flannigan et al. 2009), but little is known about how the spatial configuration of fire severity (the effects of fire on an ecosystem) may be changing with increasing wildfire. The frequency of large forest fires has increased in the western US since the mid 1980s in association with warmer temperatures and earlier spring snowmelt (Westerling et al. 2006). This trend is strongest in Northern Rocky Mountain (N. Rockies) forests (Westerling et al. 2006) where 5 of the 11 years with the most area burned in the last century have occurred since the late 1980s (Morgan et al. 2008), and qualitative shifts in fire regimes are projected by mid 21st century (Westerling et al. 2011). Recent research has examined changes in fire activity associated with warming climate, but the spatial resolution of broad-scale studies has been largely limited to characterizing fires as points or homogeneous polygons. Regional analyses of the spatial complexity of fires have so far focused on burn perimeters (shape) only (e.g., Rollins et al. 2001, Parisien et al. 2006). While informative, this resolution overlooks the significant spatial complexity that occurs within fire perimeters. Additional research has begun to examine regional-scale trends in burn severity (Miller et al. 2008), but almost no studies to date have examined potential changes in spatial heterogeneity of burn severity that may be accompanying non-spatial trends in severity.

Powerful analytic tools now exist to study spatial variability in burn severity over space and time. The multi-agency Monitoring Trends in Burn Severity project (www.mtbs.gov) provides valuable catalogued data of fire perimeters and severity indices for fires in recent years, but has significant limitations for comparing fires across broad temporal and spatial extents (see Meigs et al. [2011] for a discussion of limitations). Recent advances in burn severity indices have proven reliable over large regions and multi-decade time periods when coupled with extensive ground data (Miller et al. 2008) and landscape metrics that quantify ecologically important measures of spatial heterogeneity are well established.

I propose to examine recent temporal trends in spatial patterns of burn severity in large wildfires (> 200 ha) across the N. Rockies. Using field data and remote sensing to map fire severity and analyze burn-severity patterns, I will address two primary questions: *(1) How has spatial heterogeneity of burn severity changed during the last 25 years in the N. Rockies, and where are these landscape patterns changing most rapidly?(2) Do changes in spatial heterogeneity of burn severity vary (a) among forest types, (b) with topographic position or levels of complexity, (c) under different land management, and (d) with climate?*

1. Project Justification & Expected Benefits

Understanding how spatial patterns of burn severity may be changing under a warming climate is critical to predict broad-scale changes in forested ecosystems and the services they provide. **Postfire successional trajectories, carbon storage, nutrient cycling, wildlife habitat, and hydrology are affected not only by the amount of different burn severities, but also spatial heterogeneity of burn severity**. For example the amount and configuration of edge between burned/unburned forest patches in a fire influences distance to seed source (Turner et al. 1994, Donato et al. 2009). Assessing trends in fire severity is a top priority for informing policy in the US (Fleishman et al. 2011), and characterizing within-fire heterogeneity is important for federal fire policy (Stephens and Ruth 2005). Illustrating locations where the rate of change in disturbance severity is rapidly occurring can help forecast the potential for landscape traps (*sensu* Lindenmayer et al. 2011) - areas where landscapes can be shifted to an alternative state by disturbance feedbacks. Examining links between climate and changes in spatial heterogeneity of burn severity has considerable ecological and societal relevance and is critical for informing fire management in the US. My study will directly address the mission and goals of the Joint Fire Science Program by advancing knowledge about the relationship between climate change and fire effects.

2. Relation to Approved Thesis or Dissertation Research

My dissertation research examines and explains fire severity patterns in forests of the N. Rockies. During 2010 and 2011, I collected field data to determine how fire-severity patterns varied with severity of recent bark-beetle outbreaks in lodgepole pine and Douglas-fir forests of the Greater Yellowstone Ecosystem (GYE). I am also using remote sensing to analyze this disturbance interaction at the landscape scale. The proposed research will leverage my field data along with existing field and climate data for the study region, building on a foundation of long-term research in the GYE by my advisor and other researchers. Importantly, the proposed research will extend my focus beyond the GYE to the N. Rockies, and generate new understanding relevant for managing forested landscapes in the face of climate change.

3. Objective, Question, or Hypothesis

Question 1: *How has spatial heterogeneity of burn severity changed during the last 25 years in the N. Rockies, and where are these landscape patterns changing most rapidly?* Between 1984 and 2008, a total of 1,554 fires larger than 200 ha occurred in the N. Rockies, burning over 6,800,000 ha. However, little is known about how the spatial heterogeneity of burn severity may be changing. More frequent extreme burning conditions in a warming climate suggest that spatial heterogeneity could be decreasing, and burn severity increasing. I will address this knowledge gap by characterizing ecologically relevant landscape metrics of burn severity for each fire in the study period that burned in forested land and testing hypotheses about how these measures of heterogeneity may be changing over this period of warming climate and increased fire. Identifying areas where change is occurring most rapidly is important to further understand the mechanisms underlying observed patterns in burn severity over the last 25 years, and predict future changes to fire regimes in the N. Rockies. Over the period of 1984-2010, I expect the area-weighted mean patch size of high-severity patches and the proportion of fires burning as high severity will *increase*, while the area-weighted mean patch size of unburned islands and the proportion of unburned patches will *decrease.* The edge:area ratio for high-severity patches is expected to *decrease* as patches become larger and the edge:area ratio for unburned islands is expected to *increase* as patches become smaller, with a net decreasing trend in internal edge density at the whole-fire level. I expect the mean distribution of severity pixels in fires will shift toward a negatively skewed distribution, with the peak in the distribution moving toward higher severity. No *a priori* expectations exist for what locations will be characterized by high rates of change for spatial heterogeneity in burn severity.

Question 2: *Do changes in spatial heterogeneity of burn severity vary (a) among forest types, (b) with topographic position or levels of complexity, and (c) under different land management, and (d) with climate?* Within-fire spatial patterns in burn severity are driven by many factors including climate, weather, topography, and fuels (Turner et al. 1994, Collins et al. 2007) and can be further affected by prior disturbances and management (Collins et al. 2009). The El Niño Southern Oscillation and Pacific Decadal Oscillation are related to inter-annual changes in the occurrence of large fires (Schoennagel et al. 2005), but connections between climate and spatial heterogeneity of burn severity have not been examined to date. Depending on which factor(s) are most influential in generating heterogeneity, climate change in the N. Rockies may be significantly altering spatial patterns of burn severity. To address this gap, I will assess the degree to which climate is correlated with spatial heterogeneity of burn severity, and examine changes in burn heterogeneity among different forest types, topographic contexts, and land management. I expect stronger trends of decreasing heterogeneity and increasing severity in low-elevation conifers that historically burned with mixed-severity and in areas of less topographic complexity vs. high-elevation and high-latitude mesic forests that historically burned under high-severity regimes and areas of greater topographic complexity. I also expect that burn heterogeneity will decrease with increasing temperatures and decreasing precipitation.

II. Methods

1. Study Site(s)

The N. Rockies study region follows Westerling et al. (2011), stretching from the GYE in western Wyoming to the US/Canada border at the northern tip of Idaho. Forests are conifer-dominated and vary compositionally with elevation, moisture, and latitude (Baker 2009). Historical fire regimes range from low-frequency, high-severity (stand-replacing) regimes in higher elevation and mesic forests to more frequent, mixed-severity regimes in lower elevation forests (Baker 2009).

2. Sampling Design

This study will combine field measurements and remotely sensed indices of fire severity to analyze spatial heterogeneity of burn severity throughout the region, as described below.

3. Field Measurements, Remote Sensing, and Spatial Analysis

Question 1: Fire perimeters for all fires burning in forested land (1984-2010) will be extracted from the Monitoring Trends in Burn Severity website (mtbs.gov). Gridded topographic information will be acquired from the USGS National Elevation Dataset (NED) at ~30 m resolution to generate topographic variables (elevation, slope, aspect, topographic complexity) for each grid cell in a fire. Forest cover-type data will be acquired from LANDFIRE (landfire.gov) at 30-m resolution. Fire severity will be mapped for each fire using Landsat TM satellite imagery and the normalized burn ratio (NBR) as the raw measure of fire severity (Key and Benson 2005). Pre- and postfire images will be from near anniversary dates for each fire to minimize differences in solar zenith angle, phenology, and surface moisture, and calibrated to surface reflectance using the LEDAPS processing system (Masek et al. 2006). The average differenced NBR (dNBR) value for unburned pixels outside each fire perimeter will be subtracted from pixels in the fire to calibrate unburned areas, and the dNBR for each pixel in the fire will be used to assess the degree of change (Miller et al. 2008). To facilitate comparison of burn severity across fires in the study area, a relative ratio (RdNBR) will be computed for each grid cell in a fire (Miller and Thode 2007).

Landsat TM-derived measures of burn severity will be calibrated with field data from 1,730 existing plots on 30 fires in the GYE between 1988 and 2010 (Turner et al. 1994; Romme and Turner, unpublished; Abendroth 2008; author, unpublished). Data were collected in immediate postfire years using the Composite Burn Index (CBI) protocol (Key and Benson 2005) or more quantitative measures of burn severity (Turner et al. 1994). My preliminary analysis of fires in 2008 shows reliable correlations (Pearson's r from 0.75 to 0.88) between RdNBR and field measures of burn severity at the soil (litter and duff depth, %cover mineral soil, %cover charred material) and tree level (maximum bole char height, %circumference of bole scorch, %basal area mortality). RdNBR also distinguished crown fire from non-crown fire in two 2008 fires. During summer 2012, I will sample 350 additional plots randomly located within 7 recent fires (50 plots per fire) in the N. Rockies, using 30-m diameter circle plots with the CBI protocol (Key and Benson 2005). To expand spatial coverage of fires and augment forest composition in existing data that will be used for accuracy assessment, plots will be concentrated in the northern portion of the study region in low-elevation dry and mesic forests for which current data are limited.

Landscape metrics will be calculated on categorized burn-severity maps (high severity/stand replacing, less than high severity, or unburned/very low severity) for each fire in the study period. Patches of high severity and unburned islands will be defined using a smoothing filter window (3x3 grid cells) prior to computing landscape metrics. Frequency distributions of severity will be constructed for each year to test for significant changes in severity distribution shapes (Collins et al. 2009, Thode et al. 2011). To identify areas in the N. Rockies where spatial patterns of burn severity are changing most rapidly, region-wide maps will be produced illustrating directions and rates of change (relative to the mean over the study period) for each landscape metric. Maps will be evaluated using cross-validation by randomly partitioning plot data into training and validation sets and evaluating user's and producer's accuracy.

Question 2: Fires will be categorized by forest type, topographic context and land-management agency (US Forest Service, National Park Service, Bureau of Land Management, private lands). ANOVA will be used to assess how changes in spatial heterogeneity of burn severity (Question 1) vary among categories. Climate data are available from existing downscaled (12 km x 12 km) monthly temperature and precipitation data generated for the N. Rockies by my collaborators (Westerling et al. 2011). Each cell in the study area will be assigned monthly average temperature and precipitation values. Each fire will be assigned the temperature, precipitation, and burn index (Collins et al. 2009) values (mean and 95^{th} percentiles) from the underlying cell for a one-year time period preceding the fire, and for the duration of the fire. General linear models (with terms for spatial autocorrelation among fires) will be used to assess the relationship between climate variables and metrics of spatial heterogeneity of burn severity.

4. Data Management

All maps and data generated from this research will be made available on the Turner lab website (e.g., see http://landscape.zoology.wisc.edu/Data.html) and will comply with federal metadata standards.

5. **Data Analysis –** Described in Questions 1 and 2, above**.**

III. Project Duration and Timeline

Project Milestone	Description	Delivery Dates
Q1, field sampling	Field sampling in recent N. Rockies fires for RdNBR calibration	Summer 2012
Q1, remote sensing	Process Landsat images to generate burn severity maps for each fire	June 2013
Q1, Q2, spatial analysis	Statistical analyses of trends in spatial heterogeneity of burn severity; regional mapping of direction and rates of change	September 2013

IV. Deliverables and Science Delivery

Deliverable Type	Description	Delivery Dates
Refereed publication	Regional trends in spatial heterogeneity of burn severity (1984 to 2010) in the N. Rockies (for submission to ECOLOGY)	September 2013
Refereed publication	Pending observed trends (Q1/Q2) 2nd publication anticipated	June 2014
Conference presentation	Professional meeting (e.g., Ecological Society of America, Int. Assoc. of Wildland Fire, or Assoc. of American Geographers)	2013
Spatial dataset	Regional maps of rates of change in spatial patterns of burn severity across the N. Rockies	September 2013
PhD dissertation	Patterns and drivers of spatial heterogeneity of fire severity in the Northern Rocky Mountains, USA	May 2014

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