Testing for wildfire feedbacks in forests of the US Northern Rockies

Initial Report

Brian J. Harvey

Ecosystem and Landscape Ecology Lab, Department of Zoology, University of Wisconsin

Abstract. Understanding the complex responses of forested landscapes to changing fire regimes is critical for predicting land-cover patterns under a warming climate. Using decades of existing NASA satellite imagery and extensive field-calibration data on burn severity I tested whether successive forest fires in the Northern Rocky Mountains interact through feedbacks, and identified factors that are more likely to lead to two successive high-severity (stand-replacing) fires. Feedbacks among wildfires depended on forest type and interval between the first and second fire. Feedbacks in wildfire severity shifted from negative to positive with increasing elevation and with interval between two fires. Areas characterized by two successive stand-replacing fires were in subalpine forests at higher elevations, shallower slopes, and northeasterly aspects where the interval between fires was longer. Further analyses are underway, and results will identify when and where fire-catalyzed shifts in vegetation are occurring or are likely to occur with continued climate change and altered fire regimes.

Introduction

Understanding regional wildfire patterns is becoming urgent as the climate continues to warm and worldwide fire activity steadily increases (Flannigan et al. 2009). In the western US, fire frequency and annual area burned have increased since the mid-1980s in association with a warmer and drier climate (Westerling et al. 2006), and trends are particularly strong in forests of the N. Rocky Mountains (Morgan et al. 2008) where qualitative shifts in fire regimes are projected by the mid-21st century (Westerling et al. 2011). Tracking changes to fire regimes is necessary to further understand global change (Turner 2010), forecast changes to ecosystem services (Adams 2013), and inform US resource management (Stephens et al. 2013). Because of the spatial and temporal extent of wildfires, remote sensing data acquired from NASA satellites provide the most consistent and comprehensive information about these changes, but regional studies of changing fire regimes are lacking.

For many forested regions, a major consequence of increased wildfire activity is a decrease in the fire rotation (the time required to burn an area equal to a landscape of interest; (Baker 2009)). Most N. Rockies forests are adapted to regenerate after stand-replacing fires that occur every 100-300 years (Romme and Despain 1989, Barrett et al. 1991, Barrett 1994, Higuera et al. 2011), and wildfire activity was historically limited by the frequency of climate conditions suitable for fire initiation and spread. Simulations predict that continued warming and drying of the region over the next century could decrease fire rotations to ~ 30 years by the year 2050 (Westerling et al. 2011), but a key unknown is whether sequential fires occurring over a short period (i.e.,

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“reburns”) may interact through feedbacks that affect subsequent fire activity. Reduced burnable fuel following one fire may impose a negative feedback on fire severity (impacts of fire on the ecosystem) in a second fire (Collins et al. 2009, Parks et al. 2014). Alternatively, abundant growth of flammable vegetation following fire may cause a positive feedback on fire severity, where severely burned areas in one fire may be prone to burning severely again in a second (Thompson et al. 2007, Holden et al. 2010, van Wagtendonk et al. 2012).

If a second stand-replacing fire occurs before the trees regenerating from the first fire reach reproductive maturity, vegetation may transition from forest to non-forest (e.g, shrubland or grassland) because of failed tree recruitment after the second fire (Brown and Johnstone 2012, Pinno et al. 2013) (Figure 1). The factors that contribute to severe reburns in the N. Rockies are unknown, but critical for understanding potential broad-scale changes across forested landscapes.

Unburned | Burned once | Regenerating | Burned twice

Unburned subalpine forest with many reproductively mature canopy trees | Subalpine forest, one year following a stand-replacing fire with high postfire seedling density | Subalpine forest, 19 years following a stand-replacing fire. Postfire trees are not reproductively mature. | Subalpine forest, one year following a second stand-replacing fire in 24 years; low postfire seedling density.

Figure 1. Chronosequence illustrating temporal progression from a mature forest that has not burned in 100-300 years (left) to a recently burned forest with abundant postfire seedling regeneration (middle left) to a regenerating forest 19 years after fire (middle right) that then burns again at high-severity before the regenerating trees are reproductively mature. Photo credits: Brian J. Harvey and Monica G. Turner.

Methodological advances over the last several decades have improved the ability to track burn severity and post-fire recovery over space and time (see Lentile et al. 2006 for a review). The widespread availability of satellite data through the Landsat Thematic Mapper (TM) archive and projects such as the Monitoring Trends in Burn Severity (MTBS; www.mtbs.gov) (Eidenshink et al. 2007) have enabled analyses of regional fire trends (Miller et al. 2008, 2011, Dillon et al. 2011), but many studies are limited in their regional inference because they lack field data to calibrate burn severity indices (Miller et al. 2009).

In this study, I use remote sensing and field data to test for feedbacks among recent forest fires in the Northern Rocky Mountains in areas that have burned twice between 1984 and 2010, to ask the following research questions: (1) Is the severity of successive forest fires (fires occurring in the same location within 24 years) related through positive or negative feedbacks? What combination of factors leads to two successive stand-replacing forest fires? In answering these two questions, I test two hypotheses. First, I hypothesize that negative feedbacks among wildfires will be strong in low-elevation forests where postfire fuels regenerate slowly, whereas feedbacks will be weaker in mid-elevation forests and positive in subalpine forests, where postfire fuels can quickly regenerate. Second, I hypothesize that successive stand-replacing fires will more likely occur in areas characterized by subalpine forests with adaptations to high-severity fire, cool/wet climate conditions following the first fire, and protected topographic positions.

Methods

Study Area. The N. Rockies study region follows the US EPA ecoregions 15,16,17 and 41 (http://www.epa.gov/wed/pages/ecoregions.htm), stretching from northwestern Wyoming to the US/Canada border at the northern tip of Idaho (Figure 2). Forests are conifer dominated and vary compositionally with elevation, moisture, and latitude (Baker 2009). Historical fire regimes include low-frequency, high-severity regimes in higher elevation and mesic forests to moderate-frequency, mixed-severity regimes in lower elevation forests (Arno 1980, Baker 2009). Between 1984 and 2010, a total of 733 named forest fires larger than 200 ha occurred in the study area, burning 3,872,568 ha in total. Out of this total, 438,075 ha have burned twice, with intervals between fires ranging from one to 23 years (Figure 2).

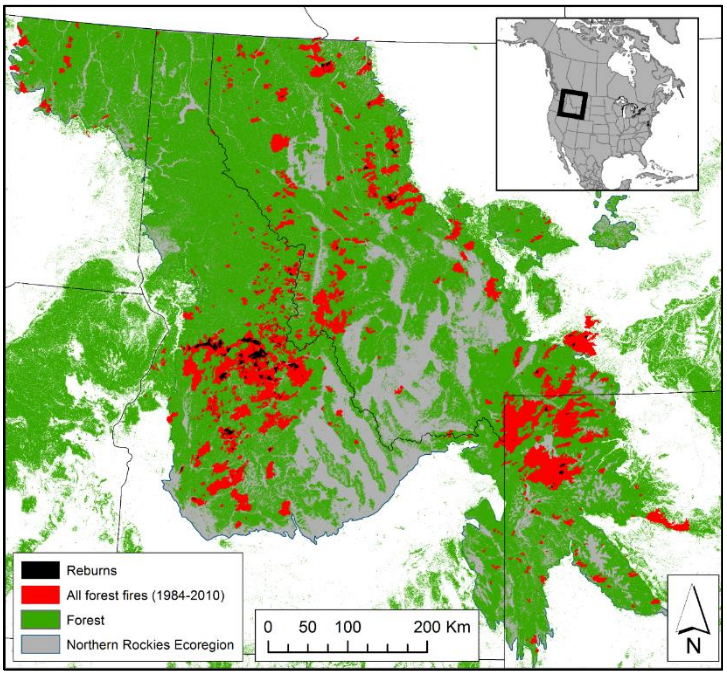

Figure 2. Map of study area with the Northern Rockies Ecoregion outlined in gray, forested areas shaded in green, all forest fires occurring in the study period in red, and all areas that burned at least twice during the study period in black.

Data acquisition and preparation. Fire-severity maps for all large fires (> 200 ha) burning in the study area (1984-2010) were extracted from the MTBS database (Eidenshink et al. 2007) and assembled into a regional fire severity atlas. To facilitate comparison of burn severity across multiple fires, the relative differenced normalized burn ratio (RdNBR; (Miller and Thode 2007)) that accounts for differences in pre-fire biomass was used to compare burn severity in the first and second fires for each location that has burned twice. Field data from 371 plots were used to calibrate burn-severity indices to field measures of burn severity using established protocols. Field measures of burn severity showed strong correlations (Pearson's *r* from 0.75 to 0.88) with RdNBR. Topographic data were acquired from the USGS National Elevational Dataset, forest type data were acquired from LANDFIRE (LANDFIRE 2014), and climate data were available from existing downscaled (12 km x 12 km) monthly data generated for the N. Rockies (Westerling et al. 2011). Using ArcGIS, I extracted the following variables from each of 2,249 systematically distributed points separated by at least 400m: burn severity in the first fire

(RdNBR), burn severity in the second fire (RdNBR), interval between fires (years), dominant forest type (subalpine, mid montane, lower montane), elevation (m), slope (deg.), NE Index (0-2, reflecting solar radiation), and regional moisture deficit (MD) (mm) in the year following the first fire and the year of the second fire. Field calibration data (Harvey et al., in prep) were used to determine areas of stand-replacing fire (greater than 90% tree mortality).

Data Analysis. To analyze feedbacks between successive fire events, I evaluated the relationship between burn severity in the first fire and burn severity in the second fire for two time intervals between fires (1-10 yrs or 11-23 yrs). Analyses were also separated for each forest type because of expected differences among forest types. Using all sampled pixels, I calculated the mean and 95% confidence interval for fire severity in the first and second fire in each forest type and interval combination. I interpreted negative feedbacks to be reflected by high severity in the first fire leading to low severity in the second fire, or vice versa. Positive feedbacks would be reflected by high severity in the first fire leading to high severity in the second fire, or vice versa.

To test for factors associated with two successive stand-replacing fires, I tested for significant differences between values for biophysical variables (forest type, elevation, slope, NE index, interval between fires, MD the year of the second fire, and MD the year after the first fire) between areas that burned twice where only the first fire was stand-replacing (i.e., second fire was lower severity) and areas that burned twice where both fires were stand-replacing. I used Chi-square tests to test for differences among forest types and non-parametric Wilcoxon signed-rank test for continuous variables. All analyses were performed using the R statistical software (R Development Core Team 2012).

Results and Discussion

Wildfire feedbacks in different forest types. Initial results suggest that feedbacks among successive fires differed depending on the forest type (Figure 3). Lower and mid-elevation forests were characterized by negative feedbacks, meaning that fire severity was higher in the first fire and lower in the second fire (Figure 3). For both forest types, the negative feedback was stronger with shorter intervals between fires (reductions in fire severity of 40% and 37%, in lower and mid-elevation forests, respectively) likely because of the time required to regenerate sufficient fuel following the first fire. Over longer intervals, negative feedbacks in low and mid elevation forests were weaker (reductions in fire severity of 21% and 11%, in lower and mid-elevation forests, respectively), as the effect attenuates when fuels are less limiting to fire severity. Contrasting this, subalpine forests exhibited positive feedbacks, where fire severity in the second fire was only 9% lower in short interval (1-10 yr) reburns but was 10% higher when intervals were 11-23 years (Figure 3).

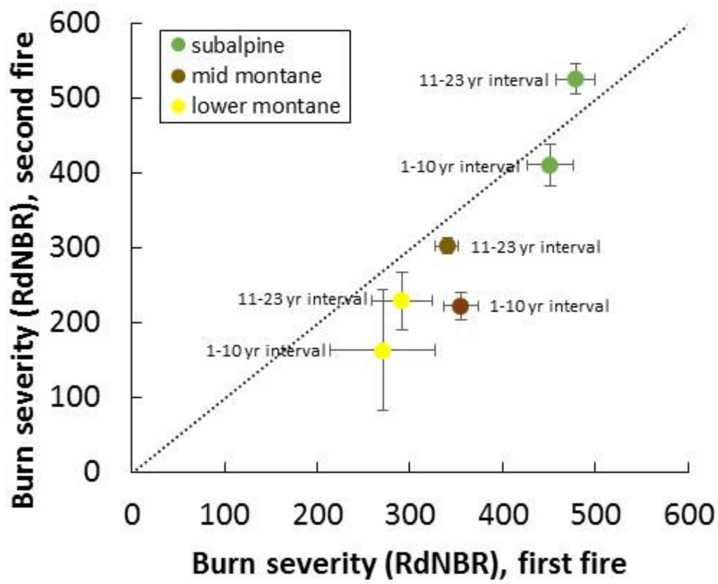

Figure 3. Relationship between fire severity in the first fire and fire severity in the second fire for all plots that burned twice during the study period. Points are means with 95% confidence intervals for all plots in each combination of forest type and interval between fires.

Factors leading to successive stand-replacing fires. Initial results suggest that vegetation and topographic setting both influenced the likelihood that an area that burned once as a stand-replacing fire, if burned a second time, would burn again as stand-replacing fire. Subalpine forests were more likely to burn as stand-replacing fire twice, whereas lower and mid-montane forests were less likely to experience two stand-replacing fires (Figure 4).

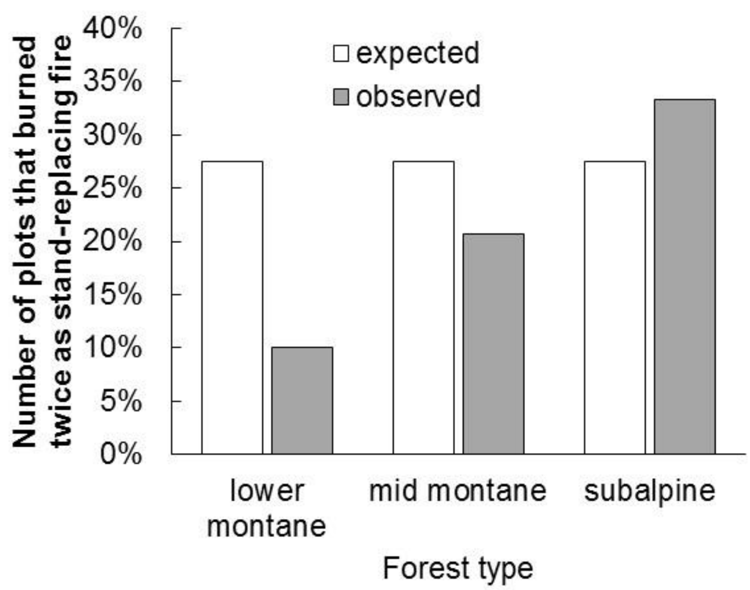

Figure 4. Observed vs. expected percentage of plots burning twice as stand-replacing fire in each forest type. Observed data deviated significantly from the expected under the null hypothesis of no difference among forest types (X^2 = 33.33, P < 0.001, Chi-square test of association).

Physical variables also influenced the likelihood that an area that burned once as stand-replacing fire, if burned again, would burn as stand-replacing fire in a reburn. Areas that burned twice as stand-replacing fire had higher elevation, shallower slopes, more northeasterly aspects, and longer intervals between fire events than areas that burned once as stand-replacing and then were not stand-replacing (i.e., much lower severity) in the second fire (Figure 5). Climate variables (MD) were not significantly different between areas that burned once at stand-replacing severity and those that burned twice as stand-replacing (Figure 5).

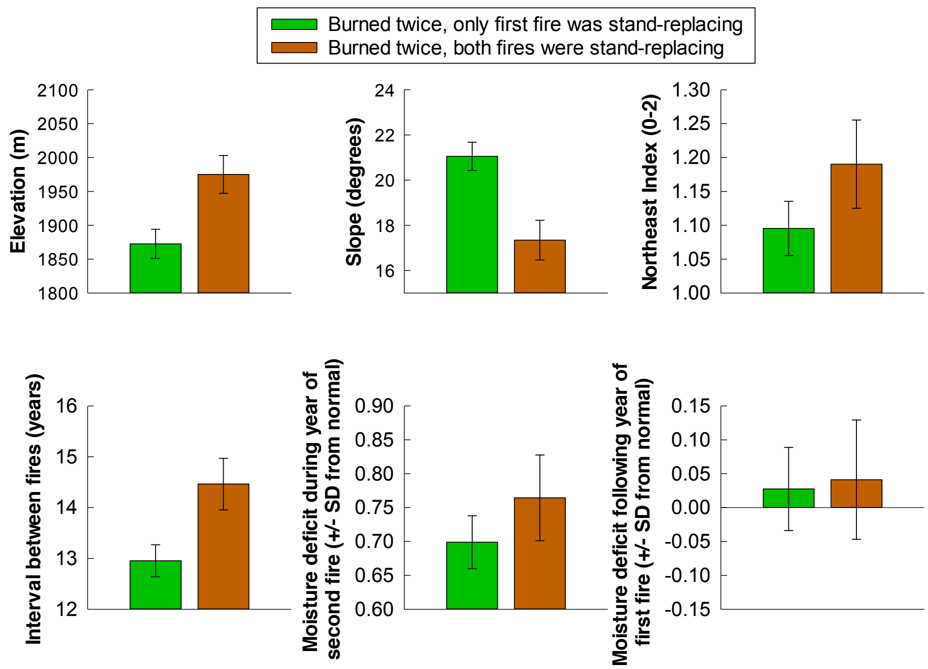

Figure 5. Comparisons for each biophysical variable among plots that burned twice as stand-replacing or burned twice, but only the first fire was stand-replacing. Bars are means and error bars are 95% confidence intervals.

Conclusion and ongoing work

The strength and direction of feedbacks among successive fires differed among forest types, with negative feedbacks in lower elevation and mid-montane forests and positive feedbacks in subalpine forests. Areas that were most likely to experience successive stand-replacing fires were subalpine forests at higher elevation, northeasterly aspects, gentler slopes, and where the interval between fires was longer. These factors all relate to high capacity for fuels to regenerate quickly after the first stand-replacing fire.

This report presents preliminary results, but research is continuing on this project. To determine whether successive, short-interval fires impair forest recovery, I will compare the normalized differenced vegetation index (NDVI) for the first three post-fire years in areas that burned twice at stand replacement to determine whether NDVI is lower in the first three years following the second stand-replacing fire than first fire. To control for differences among post-fire climate years, I will also compare areas within fires that burned twice at stand-replacement to areas that burned once at stand replacement (in the second fire only). I expect forest recovery will be impaired in areas experiencing two stand-replacing fires. This will be indicated by significantly lower NDVI values in the first three years following the second fire compared to areas that only experienced a single fire at stand-replacement, similar to findings in other systems (Malak and Pausas 2006).

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