

Contemporary patterns of burn severity heterogeneity from fires in the Northwestern U.S.

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Introduction

Historically, frequent, low-severity fires maintained open-grown structure of dry ponderosa pine forests (Hessburg and Agee 2003). Thus, an open forest structure may be a reasonable template for ecological restoration in those particular forest types (Allen and others 2002). In contrast, setting goals for ecosystem management and restoration targets in the vast majority of forests that are typified by mixed-severity fire, where forest structure historically varied across time and space, has proven more difficult (Halofsky and others 2011; Perry and others 2011).

Mixed-severity fire regimes historically maintained landscape heterogeneity in fuels and ecological conditions, which both limited fire spread and supported diverse species assemblages (Figure 1; Hessburg and others 2005). Fire historically produced significant heterogeneity (Hessburg and others 1999), which likely maintained high beta diversity (i.e., different species compositions among local sites) while creating landscape feedbacks limiting the spread or severity of subsequent fires (Parks and others 2013). Interactions between fires whereby fire reduces the spread or severity of subsequent fires have been referred to as fire's self-limitation (Collins and others 2008), can give rise to patterns consistent with theories of self-organized criticality (Pueyo and others 2010), and have been termed "landscape memory" by some ecologists (Peterson 2002). In mixed-severity fire regimes, one hypothesis is that landscape memory has been lost through fire exclusion that created a contagious landscape prone to biologically homogenizing patterns of burn severity (Figure 1).

Whether forests historically characterized by mixed-severity fire have been altered through fire exclusion and timber harvesting to the point where active intervention is needed to sustain biological diversity and ecosystem function remains uncertain and controversial (Schoennagel and Nelson 2011; Williams and Baker 2011; Fulé and others 2013; Larson and others 2013a). If forested landscapes have become more contagious and prone to homogenization by fire, then the heterogeneity of burn severity within fires may have decreased over time, theoretically shifting fires toward proportionally higher severity burns.

While it is difficult to compare historical burn severity composition and heterogeneity to contemporary patterns, remotely-sensed estimates of burn severity can be used to

investigate patterns of recent fires, which should provide insights into patterns of fire across the landscape. I used Monitoring Trends in Burn Severity (MTBS, Eidenshink and others 2007) data to evaluate patterns fire severity from 1984 to 2008 in the Northwestern United States. I investigated the composition of burn severity among and within different vegetation cover types, and also explored how the relative and total composition of burn severity scaled with fire size.

Methods

I obtained tabular MTBS data for years 1984-2008 that included classified burned severity area within fire perimeters for the northwestern U.S. (including Washington, Oregon, parts of Northern California and Nevada, Idaho, and western Montana). I calculated the composition of burn severity for each fire as the relative proportion of area within each severity class (high, moderate, low, low or unburned, increased greenness). The analysis was conducted for all LANDFIRE land cover types recorded within each fire perimeter, as well as three separate vegetation cover types including evergreen and mixed forests, shrub and herbaceous vegetation, and deciduous forests. To display and easily quantify how burn severity composition varied across a gradient of relative high severity, I rank ordered fires by proportion high-severity fire, and then ranked those fires with zero high-severity fire by proportion of moderate-severity fire, and then ranked those with zero high- or moderate-severity fire by proportion of low-severity fire (Figure 2). To investigate how patterns of burn severity varied across fire size, I plotted and regressed the relative and total area of high- and low-severity fire against total fire perimeter size for all fires.

Results

The composition of burn severity is highly heterogeneous irrespective of dominant vegetation cover types considered (Figure 2). Few fires were dominated by high-severity burn regardless of vegetation type. For instance, less than 2 percent of fires were characterized by ≥ 50 percent high severity and only about 14% of fires experienced $\geq 25\%$ high severity across all vegetation types (Figure 2, Table 1). The proportion of each fire characterized by high-severity burn varied slightly by cover type (Table 1), and forests experienced relatively more high-severity fire compared to other cover types.

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Historical condition



Existing condition + Climate change



Figure 1—Conceptual figure describing the hypothesized historical role of mixed-severity fire (top box and arrow diagram) compared to the existing condition including the role climate change may play in driving contemporary fires (bottom diagram). Historically, mixed-severity fire created diverse landscape conditions that influenced high levels of beta diversity (i.e., variability in species composition among sites) across landscapes. These heterogeneous conditions gave rise to landscape-level feedbacks (i.e., ecological memory) whereby patches of past fires created barriers to subsequent fires, which maintained diverse conditions among sites. Through fire suppression and timber harvesting, forest conditions have been homogenized by removing patch-creating fires, reducing beta diversity and removing diversity-maintaining landscape feedbacks. Existing landscape-scale forest conditions may be contagious to spatial processes, such as fire and insect spread. These contagious conditions across landscapes lacking old, large fire-resistant trees may be at risk of being homogenized by large drought-influenced fires.

Figure 2—Relative composition of burn severities across all cover types and three vegetation cover types in fires that burned between 1984 and 2008 in northwestern states of the U.S. rank ordered on amount of fire burned under high severity (top panel). Fires are shown as stacked bar graphs next to each other to highlight the variability in burn severity across fires. Number of fires for each panel including some statistics on proportion high severity are shown in Table 1.

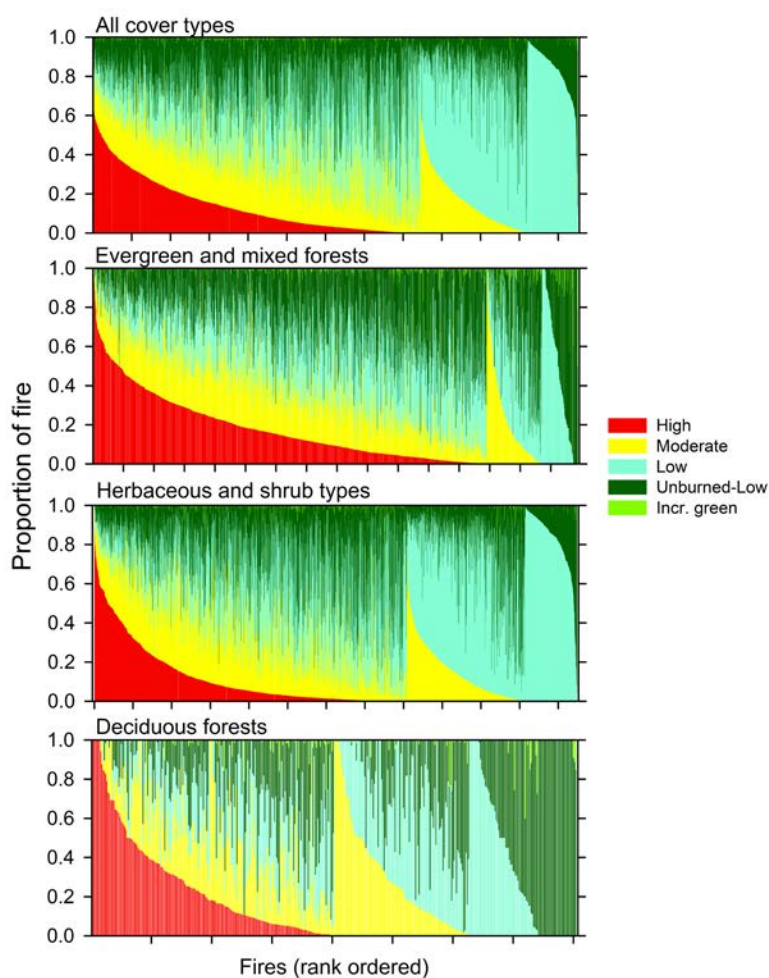


Table 1. Number and percentage of total fires characterized by at least 50% or 25% area of high burn severity for all cover types and broken down by dominate vegetation. Data are shown in Figure 2.

	Number of fires with ≥ 50% high severity burn area	Number of fires with ≥ 25% high severity burn area	Total number of fires with each cover type	Percent of fires with ≥ 50% high severity burn area	Percent of fires with ≥ 25% high severity burn area
All cover types	44	342	2501	1.8	13.7
Evergreen and mixed forests	87	372	1587	5.5	23.4
Herbaceous and shrub types	70	278	2497	2.8	11.1
Deciduous forests	32	81	403	7.9	20.1

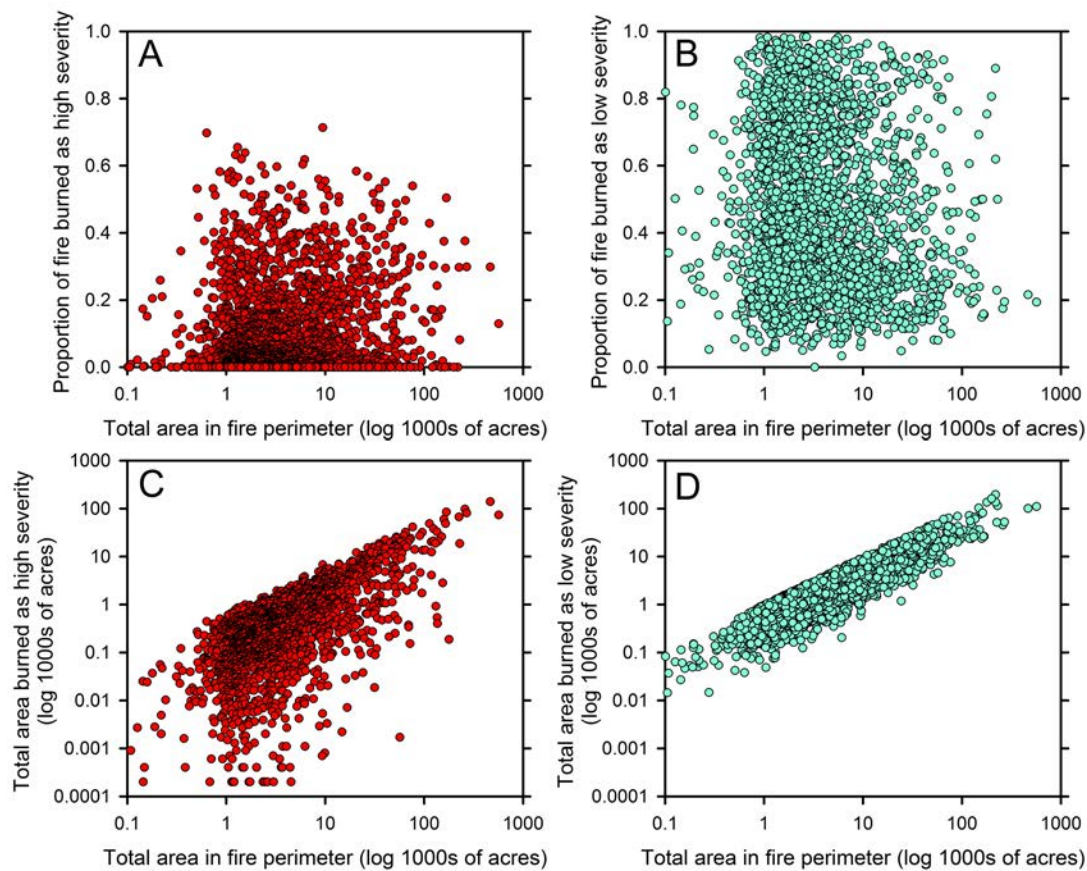


Figure 3—Relationships between log total area within fire perimeters and the proportion of fires and log total area burned under high (A and C, respectively) or low (B and D, respectively) severity.

The proportion of either high (Figure 3A) or low severity (Figure 3B) burn with a fire event was unrelated to fire size, suggesting that larger fires are not compositionally different than small fires in terms of the relative area of different burn severities. However, the total area burned under high (Figure 3C) and low (Figure 3D) severity did scale with increasing fire size. In other words, larger fires produced greater total (but not relative) area of high- and low-severity fire. Total high-severity burn area was less tightly correlated with total area burned with a less steep slope compared to how total low-severity burn increased with total fire area (compare Figure 3C-D). This pattern suggests that larger fires

predictably produce more area of low severity burns compared to areas of high severity burn.

Discussion and Conclusions

Most contemporary fires in the northwestern U.S. produced a mixture of burn severities covering the full gradient from high severity to unburned areas (cf., Kolden and others 2012). This heterogeneity makes traditional categorical classification of fire regimes unrealistic. Agee (1993) represented this well by depicting the continuously variable proportions of all fire severities across fire regime classes. Classification

of fire regimes may be relatively simple for forests at the extremes in terms of the proportion of high- and low-severity fire (e.g., low-severity ponderosa pine forests, Allen and others 2002, vs. high-severity lodgepole pine forests, Turner and others 2003). However, most forest types actually fall within some kind of mixed-severity fire regime (cf., Schoennagel and Nelson 2011). Rather than thinking of a mixed-severity classification as a “holding place” for ecosystems that do not clearly fall into one of the two extreme classes of fire regimes, research and management should focus on mechanisms that give rise to variability in burn severity and landscape feedbacks (e.g., self-limitation of fire through landscape memory).

Quantifying patterns of burn severity in contemporary fires is an important step in understanding mechanisms that create mixed-severity fire, such as climate and biophysical drivers of fire severity and pattern (Cansler and McKenzie 2014). Understanding mechanisms governing fire severity, and how burn severity may be conditioned upon interactions among various factors (e.g., wind speeds, topography, species composition, climate, previous fire mosaic) should inform questions about whether, where, and how to actively restore forested landscapes historically characterized by mixed-severity fire.

Large fires create ecological, economic, social, and political challenges, which may be exacerbated by climate change (Westerling and others 2006). While the relative composition of fires does not appear to change with fire size, the amount of area burned under different severities does increase with fire size. Large fires produce large areas of high burn severity, but they also produce significant heterogeneity with more area of low-severity burn that may result in desired forest structure and fuel loadings resilient to subsequent fires (Cansler and McKenzie 2014). Even patches of high-severity fire can be desirable for the maintenance of many plant and animal species populations (Swanson and others 2011).

While contemporary fires have clearly produced significant heterogeneity in burn severity, whether the heterogeneity is within the historical range of variability is more difficult to determine. Have fires of the past 3 decades produced more severe and homogeneous conditions following decades of fire exclusion, timber harvesting, and climate change compared to historical fires? If so, questions remain about whether prescribed fuels reduction can actually reduce the risks of homogenizing high-severity burn areas. Despite the high levels of compositional heterogeneity shown here, contemporary fires may produce larger and more severe and homogeneous patches of high-severity fire now compared to historical conditions (Figure 1).

Heterogeneity is often stated as a goal of restoration in some mixed conifer forests, but goals of forest restoration should be explicit about the kinds of desirable and ecologically-informed heterogeneity across scales. Goals of forest management should be described in terms of patch size distribution and arrangement of patches, in addition to compositional landscape heterogeneity. Determining desired conditions for these types of landscape metrics may be complex and challenging, but methods do exist for some areas

historically dominated by mixed-severity fire regimes (e.g., Churchill and others 2013; Hessburg and others 2013). More research should also investigate how various measures of heterogeneity produced by fires influences native biological diversity.

In the southwestern Crown of the Continent of western Montana, a collaborative supported with the Collaborative Forest Landscape Restoration Program (CFLRP), has worked to embrace the uncertainty about what kind of heterogeneity is desirable, whether existing conditions have been altered and are at risk of homogenizing landscape feedback (Figure 1), and which treatments might help set the landscape up to burn in a way that restores ecological patterns and processes, while also increasing the decision space for managers to allow some fires to burn. Given the uncertainty associated with restoration in forests characterized by mixed severity fire regimes, the collaborative is working toward applying a rigorous experimental design to projects that will set up an active adaptive management program to shed light on some of these questions (Larson and others 2013b). Ultimately, restoration forestry must focus on social, economic, and ecological considerations about how to restore fire’s role as a sculptor of landscape heterogeneity.

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References.

- Agee, J.K. 1993. Fire ecology of Pacific Northwest Forests. Island Press, Washington, DC.
- Allen, C.D., M. Savage, D.A. Falk, K.F. Suckling, T.W. Swetnam, T. Schulke, P.B. Stacey, P. Morgan, M. Hoffman, and J.T. Klingel. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: A broad perspective. *Ecological Applications*. 12: 1418-1433.
- Cansler, C.A., and D. McKenzie. 2014. Climate, fire size, and biophysical setting control fire severity and spatial pattern in the northern Cascade Range, USA. *Ecological Applications*. doi: <http://dx.doi.org/10.1890/13-1077.1>
- Churchill, D.J., A.J. Larson, M.C. Dahlgreen, J.F. Franklin, P.F. Hessburg, and J.A. Lutz. 2013. Restoring forest resilience: from reference spatial patterns to silvicultural prescriptions and monitoring. *Forest Ecology and Management* 291: 442-457.
- Collins, B.M., J.D. Miller, A.E. Thode, M. Kelly, J.W. van Wagtenonk, and S.L. Stephens. 2009. Interactions among wildland fires in a long-established Sierra Nevada natural fire area. *Ecosystems* 12:114-128.

- Eidenshink, J., B. Schwind, K. Brewer, Z.-L. Zhu., B. Quayle, and S. Howard. 2007. A project for monitoring trends in burn severity. *Fire Ecology* 3:3-21.
- Fulé, P.Z., T.W. Swetnam, P.M. Brown, D.A. Falk, D.L. Peterson, C.D. Allen, G.H. Aplet, M.A. Battaglia, D. Binkley, C. Farris, R.E. Keane, E.Q. Margolis, H.D. Grissino-Mayer, C.I. Miller, C.H. Sieg, C. Skinner, S.L. Stephens, and A. Taylor. 2013. Unsupported inferences of high-severity fire in historical dry forests of the western United States: responses to Williams and Baker. *Global Ecology and Biogeography* 21: 1042-1052.
- Halofsky, J. E., D. C. Donato, D. E. Hibbs, J. L. Campbell, M. Donaghy Cannon, J. B. Fontaine, J. R. Thompson, R. G. Anthony, B. T. Bormann, L.J. Kayes, B.E. Law, D. L. Peterson, and T. A. Spies. 2011. Mixed-severity fire regimes: lessons and hypotheses from the Klamath-Siskiyou Ecoregion. *Ecosphere* art40. <http://dx.doi.org/10.1890/ES10-00184.1>
- Hessburg, P.F. and J.K. Agee. 2003. An environmental narrative of Inland Northwest United States forests, 1800–2000. *Forest Ecology and Management* 178: 23-59.
- Hessburg, P.F., B.G. Smith, R.B. Salter. 1999. Detecting change in forest spatial patterns from reference conditions. *Ecological Applications* 9: 1232-1252.
- Hessburg, P.F., J.K. Agee, and J.F. Franklin. 2005. Dry forests and wildland fires of the inland Northwest USA: Contrasting the landscape ecology of the pre-settlement and modern eras. *Forest Ecology and Management* 211: 117-139.
- Hessburg, P.F., K.M. Reynolds, R.B. Salter, J.D. Dickinson, W.L. Gaines, and R.J. Harrod. 2013. Landscape evaluation for restoration planning on the Okanogan-Wenatchee National Forest, USA. *Sustainability* 5: 805-840.
- Kolden, C.A., J. A. Lutz, C. H. Key, J. T. Kane, and J. W. van Wagendonk. 2012. Mapped versus actual burned area within wildfire perimeters: characterizing the unburned. *Forest Ecology and Management* 286:38-47.
- Larson, A.J., R.T. Belote, C.A. Cansler, S.A. Parks, and M.S. Dietz. 2013a. Latent resilience in ponderosa pine forest: effects of resumed frequent fire. *Ecological Applications* 23: 1243-1249.
- Larson, A.J., R.T. Belote, M.A. Williamson, and G.H. Aplet. 2013b. Making monitoring count: project design for active adaptive management. *Journal of Forestry* 115: 348-356.
- Parks, S.A., Miller, C., Nelson, C.R., Holden, Z.A. 2014. Previous fires moderate burn severity of subsequent wildland fires in two large western US wilderness areas. *Ecosystems* 17: 29-42.
- Perry, D.A., P.F. Hessburg, C.N. Skinner, T.A. Spies, S.L. Stephens, A.H. Taylor, J.F. Franklin, B. McComb, and G. Riegel. 2011. The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California. *Forest and Ecology Management* 262: 703-717.
- Peterson, G.D. 2002. Contagious disturbance, ecological memory, and the emergence of landscape pattern. *Ecosystems* 5: 329-338.
- Pueyo, S., P. Mauricio Lima de Alencastro Graça, R. Imbrozio Barbosa, R. Cots, E. Cardona, and P.M. Fearnside. 2010. Testing for criticality in ecosystem dynamics: the case of Amazonian rainforest and savanna fire. *Ecology Letters* 13: 793-802.
- Schoennagel, T. and C. R. Nelson. 2011. Restoration relevance of recent National Fire Plan treatments in forests of the western United States. *Frontiers in Ecology and the Environment* 9: 271-277.
- Swanson, M.E., J.F. Franklin, R.L. Beschta, C.M. Crisafulli, D.A. DellaSala, R.L. Hutto, D.B. Lindenmayer, and F.J. Swanson. 2011. The forgotten stage of forest succession: early-successional ecosystems on forest sites. *Frontiers in Ecology and the Environment* 9: 117-125.
- Turner, M. G., W. H. Romme, and D. B. Tinker. 2003. Surprises and lessons from the 1988 Yellowstone fires. *Frontiers in Ecology and the Environment* 1:351–358
- Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and early spring increase western U.S. forest wildfire activity. *Science* 313: 940-943.
- Williams, M.A. and W.L. Baker. 2012. Spatially extensive reconstructions show variable-severity fire and heterogeneous structure in historical western United States dry forests. *Global Ecology and Biogeography* 21:1042-1052.