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Perspectives

Advancing Fire Science with Large Forest Plots and a Long-Term Multidisciplinary Approach

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Abstract: Large, spatially explicit forest plots have the potential to address currently understudied aspects of fire ecology and management, including the validation of physics-based fire behavior models and next-generation fire effects models. Pre-fire forest structures, fire-mediated mortality, and post-fire forest development can be examined in a spatial context, and value can be added to current multidisciplinary approaches by adding a long-term perspective. Here we propose that the fire science community begin to build a collaborative network of fire-related large forest dynamics plots to examine explicit spatial patterns of surface fuels, tree mortality, and post-fire regeneration throughout ecosystems with frequent-fire forests.

Keywords: large forest plots; fire severity; Smithsonian ForestGEO; Yosemite Forest Dynamics Plot

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One of the central challenges in fire ecology and management is to validate next-generation models at ecologically and operationally relevant scales. This includes physics-based fire behavior models and physiologically informed fire effects models, as well as integration of outputs from such models with measurements of fire effects and post-fire ecosystem development. Meeting this challenge will require large field sites in which surface and canopy fuels are mapped in three-dimensional (3D) space at high resolution [1] and where medium- and long-term fire effects on community composition, structure, and fuel accumulation are measured. Here, we suggest that large, spatially explicit forest plots modeled after the Smithsonian ForestGEO network [2] are a key investment needed to meet one of the most pressing research challenges in fire science.

The high-frequency, low- and moderate-severity fire regime forest types are the most appropriate ecosystems for investment in large, spatially explicit forest plots. Recent modeling studies illustrate the effects of fine-scale differences in stand structure on fire behavior (e.g., [3]), with the finding that aggregated fuel patterns (i.e., arising from spatially aggregated tree patterns) increase the variability of fire behavior. These initial results suggest a promising pathway for testing conceptual models for forest dynamics and the generation of spatial heterogeneity in frequent-fire forests [4,5]), and for the design and evaluation of fuel reduction, restoration, and climate change adaptation treatments in frequent-fire forests [6,7].

Large plots in which pre-fire measurements are comprehensive and long-term fire effects are monitored can fill gaps in fire research. Potential improvements extend from the scale of ecophysiological measurements of fire on seedlings [8] to socio-ecological "firescapes" [9] and to large landscapes [10].

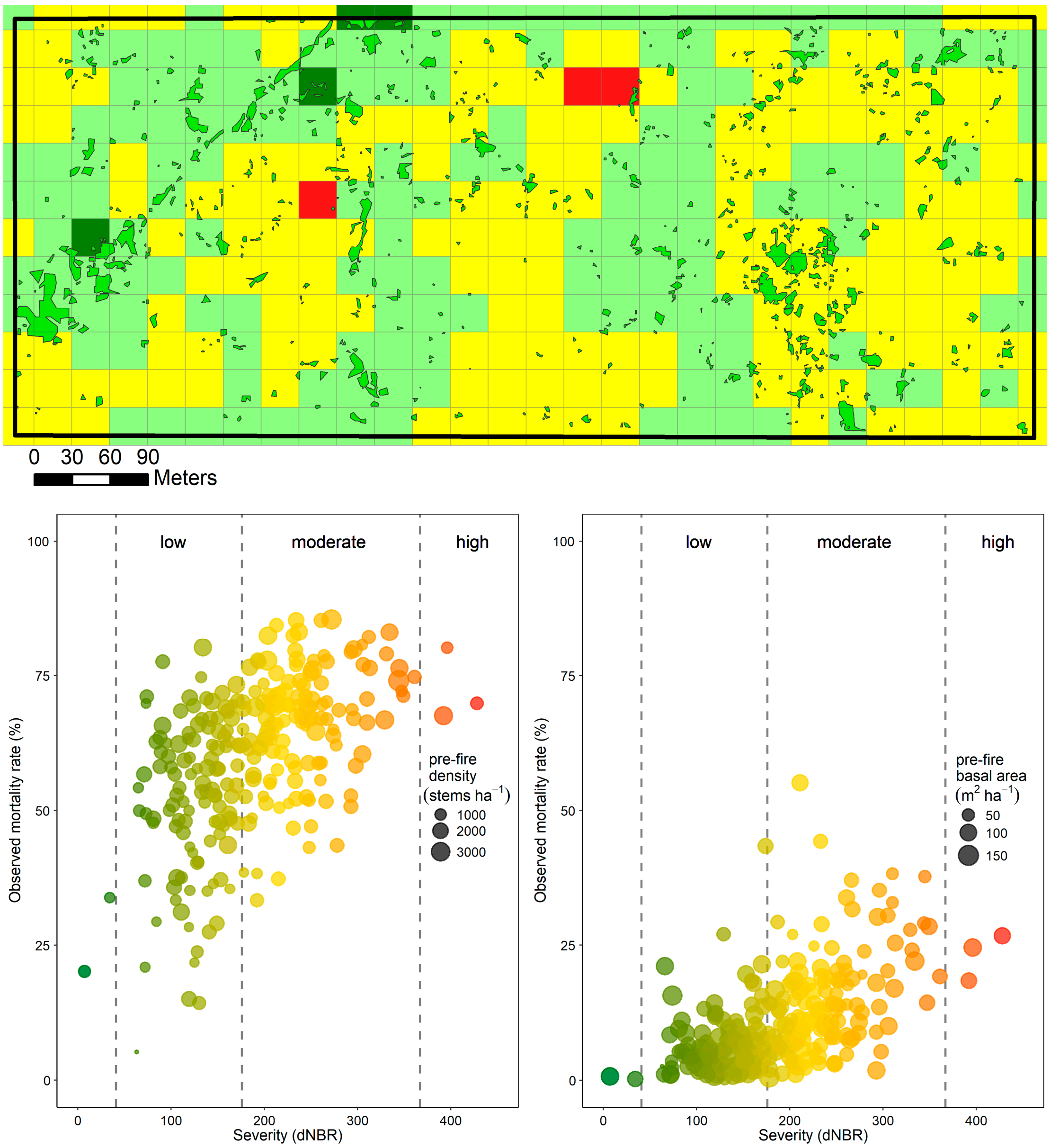

Figure 1. Spatial variation in burn severity at multiple scales within the Yosemite Forest Dynamics Plot. The YFDP contains 238 contiguous Landsat pixels. There were 24,305 immediate fire mortalities, with 7408 trees surviving two years post-fire within these 238 Landsat pixels. Fire severity measured by the differenced Normalized Burn Ratio (dNBR) [11] (unchanged [dark green], <41; 41 ≤ low severity [light green] < 176; 176 ≤ moderate severity [yellow] < 367; high severity [red] ≥367). Patches of unburned ground surface ≥1 m^2 (mapped six months post-fire) shown in medium green. One-year post-fire tree mortality per Landsat pixel by tree density and tree basal area is shown, but the relationship between dNBR spectral change does not have a simple correlation with observed mortality.

We suggest that large (≥10 ha) forest dynamics plots can help answer some unaddressed questions in fire ecology. Example phenomena include the spatial aggregation of tree mortality events, the spatial distribution of fuel strata (e.g., surface fuels [12], shrubs [13,14], and coarse woody debris) and the consequences of burn heterogeneity for post-fire succession [15] and snow hydrology [16] at a wide range of spatial scales (Figure 1).

Fire is a dominant governing process of spatial patterns of tree mortality and residual forest spatial pattern [17], either directly as a result of physical damage to trees or indirectly as a predisposing agent to other biotic or abiotic agents of mortality [18,19]. Fine-scale spatial pattern plays an important role in mediating post-fire effects, either through density-dependent mortality or aggregated post-fire forest development [20,21]. The importance of spatial heterogeneity to the correct calculation of landscape carbon [22–24] and remnant forest patches (e.g., refugia [25–28]) has been well established, but the spatial distribution of fire-caused mortality remains understudied. When spatial patterns of fire mortality are considered, they are usually inferred from Landsat-derived spectral changes at a 900 m^2 grain [29–32], but this scale is almost certainly too coarse to determine causes and consequences of tree mortality (Figure 1). The reason that fine-scale spatially explicit post-fire mortality has been understudied is the requirement for a study site of sufficient size where the trees and fuel have been mapped pre-fire, where the trees' fate can be determined after fire, and where measurements of tree mortality (or survival) are repeated post-fire. Examining spatial neighborhoods of tree mortality and the heterogeneity of fire effects requires large, mapped plots, almost certainly >1 ha [33], with sizes ≥10 ha more likely to elucidate subtle spatially explicit phenomena [34] and to provide information at operationally relevant scales [35]. There has been considerable success with 4 ha plots [24,36], which seem to constitute a practical minimum from the perspective of the requirements of point pattern analysis [37] or actual forest structural heterogeneity [38].

The Smithsonian Forest Global Earth Observatory (ForestGEO, http://www.ctfs.si.edu [2,39]) provides a framework for establishing large forest plots and using spatially explicit data across diverse forest types. As of 2017, there are 63 plots worldwide, 55 of them ≥10 ha. In the United States, four plots are co-located with the National Ecological Observation Network (NEON): at the Smithsonian Conservation Biology Institute, Virginia [40], the Smithsonian Environmental Research Center, Maryland [41], Harvard Forest, Massachusetts [42], and Wind River, Washington [43]. However, these plots are unlikely to burn (unless in a high-severity, stand replacement fire). Globally, three of the ForestGEO plots have experienced some recent low- to moderate-severity fire: Mudumalai, India [44], Huai Kha Khaeng, Thailand [45], and Yosemite, California [46]. The extent of these 63 plots makes them ideal for studying the effects of disturbance of all kinds—from large treefall to hurricanes and fire—and the uniform field protocols [47] and data representations [48] can facilitate collaborations. Of these ForestGEO plots, the Yosemite Forest Dynamics Plot (YFDP; 25.6 ha [46]) is located on a generally north facing slope in the lower mixed-conifer forests of Yosemite National Park (pre-1900 fire return interval of 29.5 years [49]). The YFDP experienced a relatively characteristic burn for this vegetation type (Figure 1) when it was burned in an unmanaged backfire [14] set in the path of the Rim Fire of 2013 [50]. Along with data from spatial pattern, these large forest plots provide high numbers of mortalities (Table 1) useful for calibrating fire effects models [51].

Table 1. Background levels of mortality in the Yosemite Forest Dynamics Plots and immediate and delayed consequences of fire. The Rim Fire occurred in August–September 2013, and field sampling took place in May–June of each year. The 25.6 ha extent of the plot allows for statistically significant inference of the effects on sub-populations of concern, such as large-diameter trees.

Diameter Class (cm)	Mortalities (Stems)						
	Pre-Fire			Fire	Post-Fire		
	2011	2012	2013	2014	2015	2016	2017
1 cm ≤ dbh < 10 cm	340	341	463	18,698	665	128	84
10 cm ≤ dbh < 30 cm	173	145	121	5241	1644	540	273
30 cm ≤ dbh < 60 cm	18	28	19	319	285	307	192
60 cm ≤ dbh < 90 cm	6	7	6	23	27	87	56
dbh ≥ 90 cm	5	11	4	24	17	130	64
Total	542	532	613	24,305	2638	1192	669

Implicit in suggestions for large plots is the concomitant suggestion for collaborating across multiple fire science disciplines, with respect to sampling designs, as well as analysis and publication of the large data sets generated. The success of the multidisciplinary RxCADRE study [35] provides a template for incorporating large, spatially explicit, long-term forest plots into fire science research.

We envision combining the large spatial extent, high-resolution, and long-term approach of the ForestGEO network [2] with the multidisciplinary approach and focus on generating data to validate process-based models of RxCADRE [35]. Logistical constraints make it unlikely that any one principal investigator would manage more than 2–3 large plots, and the strengths of the approach are strongest with a culture of cooperation [2,35]. Additionally, the time-appropriate release of uniformly collected data in purely open access venues would allow better synthesis across forest types.

The Western Forest Initiative program (http://westernforestinitiative.org) has released data on fire effects [52], shrub allometry [53] and multiple consistently produced remote sensing metrics, [54,55] as well as portions of the tree spatial data [24]. The existence of one such large fire effects plot in the Western United States may encourage others to establish compatible plots in other forest types, which together would provide a foundation for advancing fire science and addressing currently unsolved problems.

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