

PROJECT TITLE:**DISTURBANCE ECOLOGY OF ROCKY MOUNTAIN PINE FORESTS: CONSERVATION IMPLICATIONS****Principal Investigators:**

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Project Summary

Large, high-severity fires in southwestern ponderosa pine forests have raised concerns about the viability of these conservation target systems. Recognizing that disturbance regimes vary in response to many factors, we must determine how large disturbances change communities, and understand the implications of these changes for conservation strategies at multiple scales. Our heuristic approach to addressing this problem utilizes extensive research on the patterns and consequences of high-severity fires in lodgepole pine forests to develop hypotheses regarding the influence of fire size and patterns of burn severity on post-fire regeneration and trajectories of change in ponderosa pine forests. To test our hypotheses, we will map present-day plant communities in areas affected by high-severity fire during the past 50 years using remote sensing and field data, describing communities across a gradient of time-since-fire in relation to the spatial heterogeneity of burn severity. We will determine the quantitative and qualitative differences in older and newer burns of similar and different sizes and evaluate the cumulative effects of high-severity burns on biodiversity within the regional landscape. Our research will be used to describe the area affected by high-severity fire and the range of ecological outcomes associated with variations in the spatial heterogeneity of high-severity burns. Our results will be applied to all four steps of the Conservation by Design approach, and provide important information to conservation practitioners and public agency decision-makers through the interagency/TNC Fire Learning Network, other professional forums, and peer-reviewed publications.

Statement of Problem

Ponderosa pine (*Pinus ponderosa*) communities have been identified as conservation target systems in most western U.S. ecoregional assessments, and the recent occurrence of large, severe fires in southwestern ponderosa pine forests has raised concerns because the effects of these events on ecosystem viability are unknown (McCarthy and Yanoff 2003). The critical problem is how to define ecosystem-level conservation targets—the biotic associations that we value in a particular place and time—while recognizing that these systems are dynamic at multiple spatial and temporal scales. Ecosystems that experience large disturbance events present an especially difficult challenge because the plant communities that we usually identify in ecoregional assessments may fluctuate widely in composition and structure in response to these events. Conservation practitioners commonly assume that fire regimes in these systems are severely out of balance, and that these altered regimes threaten both human and natural communities (TNC Fire Initiative 2004). Accordingly, agencies and private organizations are planning large-scale programs to prevent large disturbance events from creating these new mosaics at particular places and times. Recognizing that disturbance regimes vary in response to many interacting factors, including climate, we must first determine how large disturbances change communities and processes and second, increase our understanding of the implications of these changes for conservation strategies at multiple scales.

Background Information

Historical data show that severe fires rarely occurred in ponderosa pine forests of the southwestern U.S. because frequent low-severity fires maintained low levels of surface fuels, thereby discouraging the movement of fire into the forest canopy (Swetnam and Baisan 1996). Crown fires have been more common than predicted by the historical record in the past several decades, leading to concern that ponderosa pine regeneration, which is limited by a narrow window of required climatic conditions, may not continue at levels that are sufficient for persistence of the ponderosa pine community at broad spatial and temporal scales (Savage et al. 1996). Further, dramatic plant community shifts have been observed following severe wildfires (Allen et al. 2002), with unknown ramifications for the spatial and temporal dynamics of plant and animal habitats.

In contrast to ponderosa pine forests, high-severity fire is recognized as a natural component of lodgepole pine (*Pinus contorta*) forests (Romme and Despain 1989). The fires of 1988, as well as more recent fires, provided important opportunities for examining the role of spatial patterning in forest regeneration and other ecological processes. In both lodgepole and ponderosa pine systems, the spatial variability of fire intensity (*i.e.*, magnitude of heat) interacts with vegetation, soils, and topography and leads to spatially heterogeneous patterns of burn severity (*i.e.*, degree of environmental change) across the landscape (Turner et al. 1997, Kotliar et al. 2003). Post-fire landscapes are often complex mosaics comprised of low severity surface burns where soils are largely intact, high-severity areas with extensive tree mortality and consumption of soil organic layers, moderate or mixed effects, and islands of unburned vegetation. Important consequences of the spatial patterns of burn severity include resulting patterns of surviving organisms that dictate initial succession patterns (Turner et al. 1998) and differential responses of animal species in relation to post-burn habitats (Kotliar et al. 2002).

Striking spatial patterns of burn severity, and differential responses of the plant community to variation in burn severity have been documented in lodgepole pine forests of Yellowstone National Park (*e.g.*, Turner et al. 1994). It is possible that similar patterns follow large severe fires in

ponderosa pine forests. However, there may be important differences in patterns of burn severity and community response between lodgepole and ponderosa pine forests because the two systems had very different historical fire regimes and grow under different climatic conditions. Because a substantial body of work already exists on the patterns and consequences of heterogeneous burn severity in lodgepole pine, but not in ponderosa pine, our heuristic approach in this new study is to develop a series of predictions from the lodgepole pine system, and to test how well they apply (or do not apply) to large severe fires in the ponderosa pine system.

Methods and Work Schedule

We hypothesize that fire size and the pattern of burn severity strongly influence post-fire regeneration and trajectories of change in ponderosa pine forests. The objectives of our research are to:

1. Determine the persistent and ephemeral effects of the spatial heterogeneity of burn severity in areas affected by high-severity fire over decadal time frames.
2. Determine the differences in spatial heterogeneity in older and newer burns of similar and different sizes and, using our findings from Objective 1, evaluate the cumulative effects of high-severity burns on biodiversity within the broader regional landscape.

To meet these objectives, we will adopt a framework that was developed to understand the effects of post-fire spatial heterogeneity on trajectories of change after high-severity fire in lodgepole pine forests (Turner et al. 1994, 1997). We will adapt and test hypotheses developed for the lodgepole pine system to the ponderosa pine system, examining burns of different sizes, ages, and spatial configurations in the southwestern U.S. We will share interim and final research results and determine conservation implications of this project with conservation practitioners and public agency decision-makers through the interagency/TNC Fire Learning Network, other professional forums, and peer-reviewed publications.

Study Design: Objective 1

We will map present-day plant community distributions in areas affected by high-severity fire over decadal time frames using remote sensing and field data. These data will enable us to test the following hypotheses, which were modified from hypotheses and findings of Turner et al. (1997) to reflect our expectations in the ponderosa pine community:

H₁: Ponderosa pine density and cover will decrease with increasing distance from unburned/low severity areas and patch size. These elements of spatial heterogeneity are important because they determine the distance from seed source and its interaction with wind direction and microclimate

H₂: Herb and shrub cover and diversity will decrease with increasing burn severity at the local (sample plot) scale, but will be greater when the landscape context includes patches of unburned/low severity. Response will differ depending on species life forms and life histories.

H₃: Opportunistic species cover (including early successional and non-native species) will increase with increasing burn severity, and these effects will be more pronounced in more recent burns (along the 30 to 50 year gradient) because of more abundant regional seed sources. Large patches of high burn severity are expected to favor opportunistic species because of availability of full sunlight and exposed mineral soil and decreased competition with other species.

H₄: Species richness will be greatest in transitional zones between different severities, and will decrease with increasing distance to low severity/unburned forest. Greater diversity of habitats is created within these zones when fire interacts with increased local variation in vegetation structure, moisture, and subtle differences in topography.

Our research sites will be chosen within areas of biodiversity significance identified in ecoregional assessments to maximize the relevance of our research. We will select as many sites (≥ 6) and replicates (≥ 3) within sites as possible, given logistical and practical constraints. Our selection will be based on several criteria: location in New Mexico or Arizona ponderosa pine dominated areas that burned in high-severity fire between 30 and 50 years ago, availability of aerial photos within 2-5 years post-fire (to maximize our ability to differentiate burn severities), and availability of fire perimeter data. Sites will be preferred in National Parks (Grand Canyon and Bandelier), to minimize effects of management practices (*e.g.*, logging, planting and cattle grazing). Potential sites we have identified fall into two size ranges; 400 to 2,000 ha (occurring between 1950 and 1980) and 3,000 to 6,000 ha (occurring between 1960 and 1980). These burns represent the high end of the size range for burns recorded in this older time period. We will seek to maximize the number of sites along a gradient in the range of variability in composition and configuration of surface cover of present-day landscapes based on analysis of spectral characteristics of satellite reflectance data (Landsat, 30-m resolution) and recent aerial photos.

Burn Severity Mapping: Using aerial photos taken within 2 to 5 years post-fire, we will interpret and digitize severity polygons for selected sites with a minimum mapping unit (mmu) that includes small groups of unburned trees. These remnant trees may have provided important seed sources for ponderosa regeneration. Severity classes will include: high (areas of tree mortality, including crown fire and high-severity surface burns that also resulted in tree mortality), moderate/mixed (areas of mixed severity within the mmu), unburned/low (areas with minimal tree mortality—either no or only occasional torched trees within the mmu).

Field Sampling: Field sampling will be conducted along a minimum of 3 transects within each study site. The transects will vary in length, and will represent a gradient from unburned/low severity outside the burn perimeter into the largest high-severity patches identified from aerial photos. Transects will run adjacent to unburned/low severities that occur within high-severity patches and will be positioned to capture effects of variation in wind direction on seed dispersal.

Sample point intervals along the transects will vary, with increased density in transition and edge zones where higher variability is expected. Within small plots at each sample point, we will characterize topographic position, slope, and aspect; soils (nitrogen, carbon, phosphorus, texture); plant species richness and percent cover; cover type (exposed mineral soil, unburned litter, charred litter, pebble, cobble, or boulder). We will focus our field sampling on selected species of shrubs and herbs that exhibit the full range of post-fire responses. The particular species may differ among study areas, because of regional floristic differences, but the representative life forms and life histories will be similar among all sites. At each site we will sample native (i) annual species that reproduce exclusively by seed (*e.g.*, the herbs *Polygonum spp.*, *Gayophytum diffusum*, *Collinsia parviflorum*), (ii) perennial species that reproduce primarily by sprouting from surviving roots and root collars (*e.g.*, the shrub *Quercus gambelii*, plus the herbs *Antennaria spp.* and *Achillea lanulosa*), (iii) perennial species that are easily killed by fire and reproduce primarily by seed (*e.g.*,

the shrub *Purshia tridentata*), and (iv) species that are expected to reproduce through a variable mix of sprouting and seedling recruitment (e.g., the herbs *Lupinus spp.*, *Geranium caespitosum*, and *Senecio spp.*). Forest composition and structure will be quantified for focal trees in each plot, and pine seedlings will be counted by age (in years) to estimate recruitment.

Statistical Analysis: Statistical analyses will compare tree, shrub, and understory characteristics among sites in relation to spatial composition and configuration of burn severity and time-since-burn (either as a treatment effect, if the dates comprise older and less old categories, or along a gradient of age). Because we expect that interactions among burn severity, succession, and other processes will result in heterogeneous responses, quantile regression will provide a valuable approach to estimating functional relations (Cade and Noon 2003). Quantile regression estimates multiple rates of change across response distributions, and can be used to identify limiting factors in the presence of unmeasured and interacting variables (Haire et al. 2000, Cade and Noon 2003). To increase our ability to predict seed dispersal after high-severity fire events, we will conduct a kernel analysis (Silverman 1986, Worton 1989) based on our findings in which a decay function is used to develop a model of burns as a cumulative dispersal surface for ponderosa pine seeds, with shape determined by wind direction.

Study Design: Objective 2

We will use remotely sensed and field data from recent burns to (1) determine the quantitative and qualitative differences in older and newer burns of similar and different sizes, and (2) based on our findings from Objective 1, evaluate the cumulative effects of high-severity burns on biodiversity within the broader regional landscape. We will test the following hypotheses, derived from Turner et al. (1994) and modified to reflect our expectations in the ponderosa pine community:

H₁: Recent large burns are qualitatively and quantitatively different from older burns. Because of hotter, faster burning conditions associated with recent large burns, these areas will tend to have greater percentages of high severity, and the spatial configuration of high severity within the burns will be more aggregated, with less interspersion of burn severities.

H₂: Recent burns of approximately the same size as older burns differ in terms of composition of high severity as well as spatial configuration, influenced by increased fuel loads resulting from fire suppression and hotter burning conditions. These recent burns are expected to exhibit more similarity in spatial pattern to recent large burns than to older burns of the same size.

To test the above hypotheses, we will select approximately six study sites in Arizona or New Mexico, based on their location in ponderosa pine dominated areas that have experienced high-severity fire over the past 3 to 6 years. Sites located in proximity to those selected for Objective 1 will be preferred. Three of the sites will be approximately equal in size to the older burns selected for Objective 1, and 3 will be larger. Based on exploration of available records, large fires during this recent time frame range from 5,000 to 14,000 ha in size. All sites selected for study will have available recent aerial photos and Landsat TM imagery.

Mapping Burn Severity: Recent burns that are comparable in size to older burns will be mapped using the same burn severity categories described for Objective 1, but with a combination of aerial photos and satellite imagery (Landsat TM; Kalkan *et al.* 1998); this will enable interpretation of existing burn severity maps based on satellite imagery alone for new, larger burns in terms of the

differences in representations created by differing spatial and spectral resolutions, and their effect on subsequent analyses.

Field Sampling: We will assess and modify burn severity maps in the field when necessary. We expect that our own field data from several recent large burns (Kotliar and Haire, unpubl.data) and National Park Service fire effects data will provide sufficient information for this purpose.

Statistical Analysis: Using the burn severity maps created to address Objectives 1 and 2, we will conduct statistical comparisons of landscape heterogeneity in older and newer burns of similar and different size. Specifically, we are interested in the relative degree of isolation of high severity (cumulative distributions of distance to unburned edge), proportion of high severity, and amount of edge between patches of different severities. Given the contemporary (1950-present) fire history of the landscapes containing our study sites and our findings (from both objectives), we will quantify the percent area affected by high-severity fire and the possible ecological outcomes associated with variations in spatial heterogeneity. Using simple models, we will develop a series of maps that will enable evaluation of the persistence of the ponderosa pine community as well as community shifts and novel landscape elements that may result from high-severity fire.

Work and Product Schedule (Begin May 2004, end June 2006)

| Task | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Identify study sites, prepare preliminary maps | | | | | | | | |
| Site visits, final site selection, testing and refinement of field data collection methods | | | | | | | | |
| Complete mapping | | | | | | | | |
| Field season | | | | | | | | |
| Provide maps, yearly reports and data summaries. Meet with FLN and collaborators to present results. | | | | | | | | |
| Manuscript preparation for journal submission. | | | | | | | | |

Significance and Impact of the Work

Ponderosa pine forests cover millions of acres in the western United States and northern Mexico. Through the ecoregional assessment process, the ponderosa pine system has been named as a conservation target at hundreds of areas of biodiversity significance throughout its range. These forests also provide habitat for a wide variety of target and/or federally-listed species, including the Kaibab squirrel, Mexican spotted owl and northern goshawk. Ponderosa pine forests, where they lie within portfolio conservation areas, are frequently at risk of loss of ecosystem components or processes because their keystone ecological process – fire – has been so widely and radically altered. Altered fire regime is perhaps the foremost threat to the viability of ponderosa pine forests. Approximately 91% of the ponderosa pine forests within portfolio areas is in Fire Regime Condition Classes 2 or 3 (that is, moderately or significantly altered and at risk of losing key ecosystem components) (McCarthy and Yanoff 2003).

This study will answer several questions of critical importance to the fire managers and conservation practitioners who direct the many fuel reduction and ecological restoration projects authorized by the federal Healthy Forests Restoration Act and other new programs. Among these are:

- How have patterns of burn severity changed over the past several decades?
- Are recent burns more homogeneous than older burns?
- How does the spatial patterning of burn severity influence habitat diversity?
- How do burn-influenced patterns of diversity change over time?
- How do anomalous severe burns affect the size and distribution of landscape patches?
- What are the effects of severe burns on stand- and landscape-scale species richness and on distribution and abundance of native and non-native opportunistic plants?
- What are the cumulative effects of high-severity burns on regional and local forest diversity and spatial patterning?
- Do these cumulative effects threaten the viability of ponderosa pine forests and the species that they support?

In the context of Conservation by Design, our research results could be applied to all four steps of the conservation approach. New information about current forest condition, for example, could be used to develop new criteria for selecting ponderosa pine occurrences for portfolio assembly in ecoregional assessments. (Selection has been based to date primarily on areal extent and degree of fragmentation.) New knowledge about post-fire vegetation development could help us construct more accurate ecological models, for conservation area planning; these, in turn, would help us perform more accurate and informed viability assessments for ponderosa pine systems and nested targets. Finally, the research results could also help practitioners develop conservation measures by providing assessments of cumulative impacts, identifying “key ecological attributes” and indicators, and identifying viability thresholds. Measures of patch size and distribution, for example, could provide an alternative to the widely accepted but largely untested Fire Regime Condition Class assessment framework.

A third objective of our work is to share interim and final research results with conservation practitioners and public agency decision-makers through the interagency/TNC Fire Learning

Network (FLN), other professional forums, and peer-reviewed publications. We are particularly motivated to work with scientists and public and private land managers to determine and disseminate the conservation implications of our findings. To that end, we will present the study design, first-year findings and final report at regional FLN workshops, scientific meetings, and both internal and peer-reviewed publications. We will also use our findings to explore how high-severity fires, whether these events are novel disturbances that create long-term community shifts or events that function in creating a longer-term dynamic equilibrium, may be used to frame future research questions and develop methodologies to gain additional knowledge in both ponderosa and lodgepole pine systems.

Key Personnel

Patrick McCarthy, Director of Conservation Programs for The Nature Conservancy in New Mexico, will oversee and administer the work. He will also serve as liaison to TNC's Fire Initiative, Fire Learning Network (FLN), program staff in Arizona, Colorado, Utah and northern Mexico, and to regional public agency fire managers. Patrick will assist with site selection and field logistics and will play a lead role in sharing and interpreting the study's findings with members of the regional academic and fire management communities through the Fire Learning Network and other forums. He will be responsible for ensuring that the study's findings are widely disseminated and understood in the fire management community, and that managers have opportunities to help shape the study's final recommendations. Patrick is well-suited for the role of project manager and liaison because of his 12 years of project management experience with the Conservancy, his understanding of fire ecology and fire management issues, and his experience working with the Fire Initiative and the FLN. He currently directs TNC's Jemez Mountains FLN demonstration project.

Sandra Haire, Ecologist, U.S. Geological Survey, Biological Resources Division, Fort Collins Science Center. Ms. Haire will work with Dr. McGarigal in overseeing all aspects of the study design and all quantitative analyses. She will take responsibility for burn severity mapping with aerial photos and satellite imagery. Ms. Haire will work with Dr. McGarigal on statistical and spatial analyses, contributing experience in statistics, remote sensing, global positioning systems, and geographic information systems to the project design and completion. She is currently developing products and co-authoring research papers focusing on the relationships between the spatial heterogeneity of burn severity and post-fire ecological communities and processes in western coniferous forests.

Kevin McGarigal, Ph.D., Professor and Director of Landscape Ecology Program, Department of Natural Resources Conservation, University of Massachusetts, Amherst. In cooperation with Sandra Haire, Dr. McGarigal will be responsible for overseeing all aspects of the study design, including site selection, sampling layout, field data collection and all quantitative analyses. Dr. McGarigal has extensive skills in the quantitative sciences, including computer modeling and statistical analysis of ecological data. He is considered a leader in the field of landscape pattern analysis and is the developer of the popular software, FRAGSTATS, for categorical map pattern analysis. In addition, he and Dr. Romme have been working closely with land managers in the southern Rocky Mountains to develop and apply a landscape disturbance-succession simulation model to quantify the historic range of variation in landscape structure, with an emphasis on the role of fire and insects/pathogens on forest dynamics.

Bill Romme, Ph.D., Professor of Forest Ecology, Department of Forest, Rangeland, and Watershed Stewardship, College of Natural Resources, Colorado State University. Dr. Romme will be

responsible for providing general oversight of all research activities. In particular, he will work in cooperation with Haire and McGarigal to ensure proper sampling layout and the use of appropriate methods of field data collection, and he will assist in the interpretation of results, especially with respect to any observed similarities and differences between ponderosa pine and lodgepole pine systems. Dr. Romme has extensive research experience in ponderosa and lodgepole pine forests and has published numerous papers on the ecology and dynamics of these forests. In addition to recent studies on the disturbance history and ecology of pinyon juniper woodlands, mountain shrublands, and ponderosa pine forests in southwestern Colorado, he has studied lodgepole pine forest dynamics in the Greater Yellowstone Ecosystem for more than 25 years, and has published seminal papers on the history and role of fire in this system.

Melissa Savage, Ph.D., professor emerita at the University of California–Los Angeles and executive director of the Four Corners Institute in Santa Fe, New Mexico, will serve as technical advisor. Dr. Savage will assist with study design, site selection and liaison to the southwestern U.S. fire ecology community. She will also review and provide scientific guidance on the project's reports and publications. Melissa is an extensively published fire ecologist with many years of academic and practical conservation science experience. She is also actively and widely engaged in conservation practice, having recently coordinated and completed an ambitious multi-year ecological restoration project on Rowe Mesa in the southern Sangre de Cristo Mountains, among other projects.

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