Sharing the Road: Managers and Scientists Transforming Fire Management

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Abstract—The Nature Conservancy and the Forest Service, Department of Agriculture have long-term goals to reintroduce fire into U.S. ecosystems at ecologically relevant spatial and temporal scales. Building on decades of collaborative work, a Master Participating Agreement was signed in March 2017 to increase overall fire management capacity through training and education. In October 2017, The Nature Conservancy hosted a cross-boundary fire training, education, research, and restoration-related event for 2 weeks at Sycan Marsh Preserve in Oregon. Eighty people from 15 organizations applied prescribed fire on over 1,200 acres (490 ha). Managers and scientists participated in the applied learning and training exercise. The exercise was a success; operational and research objectives were met, as indicated by multiagency, multidisciplinary fire research, and effectiveness monitoring. This paper describes a paradigm shift of fire-adapted, cross-boundary, multiagency landscape-scale restoration. Participants integrated adaptive management and translational ecology so that applied controlled burning incorporated the most up-to-date scientifically informed management decisions. Scientists worked with practitioners to advance their understanding of the challenges being addressed by managers. The model program has stimulated an exponential increase in landscape-scale and ecologically relevant dry forest restoration in eastern Oregon. Collaboration between managers and scientists is foundational in the long-term success of fire-adapted restoration. Examples of effects of prescribed fire on ecosystem services in the project area, such as increased resilience of trees in drought years, are also provided.

Keywords: active fire regime, all-lands, cross-boundary, fire training, forest restoration, interorganization

INTRODUCTION

Fire has shaped human societies. Conversely, societies have shaped fire regimes. Fire defines the persistence of carbon in nature and the distribution of resources. Inherent in the use of fire are some social feedback mechanisms through which these fire-use practices include adaptations for the generation, accumulation, and transmission of knowledge; the use of local institutions to provide leaders and stewards and rules for social regulation; mechanisms for cultural internalization of traditional practices; and the development of appropriate world views and cultural values. How people relate to fire—the observable effects of their beliefs—can be seen live on the land.

Conditions in forests have become more hazardous due to accumulation of abundant flammable vegetation, in many cases a result of disrupted traditions of indigenous fire management, practices of

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fire exclusion and suppression, establishment of weeds and other flammable plants, and a warming climate (Moreira et al. 2011; Nagel et al. 2017; Williams 2013). Length of fire seasons and extent of land area burned with high severity have increased, as have economic losses from wildfire and expenditures on fire suppression (Jolly et al. 2015). Population change has also affected fire risk. In some regions, such as the western United States, expansion of exurban areas has increased the probability of ignitions and placed more assets at risk in forested fire-prone areas. Accompanying demographic shifts have engendered new social values, policies, and decisions that favor reduction of short-term fire risk to homes and other structures at the expense of long-term risk to forest landscapes (Williams 2013).

Ongoing research into the complex interactions between forest ecosystems, socioeconomic changes, land uses over space and time, and ongoing climate change has demonstrated major alterations in large-scale disturbance patterns (Allen 2007; Barbier et al. 2010; Lambin and Meyfroidt 2010; Ravenscroft et al. 2010; Spies et al. 2014). Wildfires are out of control. Many lack appreciation of the changes in fire use that have brought us to this situation. Social and ecological regimes have undergone a subtle transition from fire adapted, to fire excluded, to fire-intolerant so that today we have a high wildfire risk for people and the environment (Fischer et al. 2016; Spies et al. 2014). The nearly intractable problem of wildfire risk in forests can be characterized as a socioecological pathology (Fischer et al. 2016): the science of the causes and effects of a set of interrelated social and ecological conditions and processes that deviate from what is considered healthy or desirable.

Most often we seek to solve societal problems through governance (Canton-Thompson et al. 2008; Fischer et al. 2016). Acknowledging the remedy to the wildfire risk pathology is a governance system that transforms maladaptive feedbacks into adaptive feedbacks (Duit and Galanz 2008). Creating such a governance system requires policies that influence human–land–forest and fire-management behaviors and that account for socioecological interactions at multiple scales: spatial (ownership, landscape, ecoregion), temporal (short- and long-term), and organizational (individuals, groups, institutions).

Components of a framework for addressing the pathology of wildfire risk in fire-prone temperate forests include broad human engagement in complex thinking about multiscalar policies, and adaptive planning and management. The Fire Learning Network is an example of network that has built connectivity among land management organizations to further the restoration of fire-dependent ecosystems through landscape-scale collaborative planning (Butler and Goldstein 2010). The Network process has identified institutional innovations to reduce temporal and spatial scale mismatches. Risks of social exchange mismatch can best be resolved through trust.

In 2009, the National Cohesive Wildland Fire Management Strategy was developed as a strategic push to work collaboratively among all stakeholders and across all landscapes, using best science, to make meaningful progress toward three goals: 1) resilient landscapes, 2) fire adapted communities, and 3) safe and effective wildfire response. The National Strategy establishes a vision for wildland fire management, defines three national goals, describes the wildland fire challenges, identifies opportunities to reduce wildfire risks, and establishes priorities focused on achieving these goals.

Objectives

In the Big Coyote Fuels Reduction project, the goals of the partnership between the Forest Service, Department of Agriculture (hereafter, Forest Service) and The Nature Conservancy (TNC) were exemplified when TNC hosted a collaborative training, education, research, and restoration-related event for 2 weeks at Sycan Marsh Preserve in Oregon. The objectives of the workshop were to 1) increase overall fire management capacity, through training, research, and education; 2) increase knowledge of prescribed burning techniques targeted at achieving specific effects; 3) build trust, and facilitate communication between managers, citizens, and scientists; and 4) provide the means to promote an increase in landscape-scale ecologically relevant restoration. Outside of the agreement, TNC and the Forest Service would continue monitoring the effectiveness of fuels reduction monitoring begun in 2014 for fire behavior and forest health. The objectives of this paper are to document strategies of the Big Coyote project that have provided social acceptance of prescribed fire use through cutting-edge scientific understanding of fire behavior and that have contributed to successful and long-lasting collaborations between managers and scientists. Effectiveness monitoring has revealed how implementation may be improved. In combination, and with national-level support, these concepts have contributed to an increase in cross-boundary projects in eastern Oregon.

BACKGROUND

The Nature Conservancy and the Forest Service have long-term goals to reintroduce fire into U.S. ecosystems at ecologically relevant spatial and temporal scales. Both the Forest Service and TNC have recognized that excluding wildland fire from fire adapted ecosystems, once thought to protect valuable natural resources as well as people and communities, has instead often had detrimental effects. The lack of fire as a natural disturbance has also contributed to uncharacteristic fuel loadings and fuel profiles. These conditions, coupled with management activities, changing climatic conditions, and drought, as well as the ever-increasing wildland-urban interface, very likely contribute to higher complexity fires and more extreme fire behavior. As a result, many fires are having catastrophic effects. Building on decades of collaborative work, a Master Participating Agreement (MPA) (FS Agreement No. 17-PA-11132543-013) was entered into in March 2017 to increase overall fire management capacity, through training and education. The MPA was intended to enhance the longstanding relationship, particularly around prescribed fire. The purpose of this agreement was for the parties to cooperate and exchange resources in various aspects of prescribed fire management and fuels management, including training and development, planning, and implementation of prescribed fire and mechanical fuel treatments. The MPA will help to enhance training and educational opportunities; increase overall fire management capacity; facilitate restoration of fire adapted ecosystems; improve community safety; enhance training and education opportunities; facilitate sharing of science, traditional ecological knowledge related to fire in a contemporary context, expertise; and increase overall fire management capacity. The projects performed under the MPA will work to restore, protect, or enhance natural resources and make communities safer.

A national Cooperative Agreement, "Promoting Ecosystem Resilience and Fire Adapted Communities Together" (PERFACT), #14-CA-11132543-094, has been executed between the parties. Supplemental project agreements under this MPA will round out the field element of the project described in the PERFACT Cooperative Agreement. In October 2017, TNC and the Forest Service began the Big Coyote Fuels Reduction project, FS Agreement No. 18-PA-11060200-001, completing the administrative means to implement PERFACT through cross-boundary fuels treatments.

To conduct cross-boundary fire management, the two parties agreed to follow standard operating procedures outlined in national, regional and local dispatch center mobilization guides for dispatching of resources and equipment. We complied with standard planning and implementation procedures as described in the Interagency Prescribed Fire Planning and Implementation Procedures Guide (National Wildfire Coordinating Group 2017 www.nwcg.gov/tags/pms-484). One burn plan was written for the cross-boundary burn area. There was one Burn Boss each day, with an overall Incident Command for the burn operations. Monitoring plans included pretreatment and post-treatment monitoring, evaluation of activities, and an ongoing assessment of ecosystem services.

Past Collaboration and Research with the Forest Service

In 2002, TNC and the Forest Service began a before-after-control-impact (BACI) study (Green 1979; Stewart-Oaten et al. 1986) to evaluate the effects of fuels reduction on habitats and populations of birds in ponderosa pine (*Pinus ponderosa*) forests throughout the Interior West. Due to the dependence of bird responses on fire severity, effects of prescribed fires on bird communities may differ from the effects of wildfire. Low severity fire, such as prescribed fire, generally consumes the ground-layer vegetation and duff without killing large overstory trees, while leaving the structure of the dominant vegetation intact (Saab et al. 2005). In contrast, high severity fires cause changes in forest structure by killing the aboveground vegetation (Smith et al. 2000). Sycan Marsh Preserve had two study-site pairs, which were formed by splitting a large area into control and burned units. The current project was one of the control sites of the Birds and Burn research project initiated in 2002.

SITE DESCRIPTION

Sycan Marsh Preserve is in the Modoc Plateau and East Cascades Ecoregions in the headwaters of the Klamath Basin, on the divide between the Great Basin and Klamath Basin. The Upper Sycan Watershed is composed of seven watersheds (six field Hydrologic Unit Codes) from Sycan Marsh to the headwaters (84,511 ha). Average annual precipitation at the marsh is 47.8 cm, with 90 percent of the total falling between October and May. Mean annual air temperature is 5.6 °C.

There are 15 different soil series found in the Big Coyote Fuels area. The most common soil type is Andyfan (60A–64A), followed by the Andyfan-Shakecreek series (66A–67A). These soils occupy much of the dry prairie and marsh area. Most of the forested areas occur on soil series 016B, Lapham. This series consists of very deep, somewhat excessively drained soils that formed in volcanic ash over lacustrine deposits derived from volcanic rocks, such as basalt and tuff-breccia. Lapham soils are on lake terraces.

The Upper Sycan Watershed is a mixed ownership of Forest Service lands (56 percent), TNC (15 percent), and industrial forest lands (29 percent). Three streams, Coyote, Long, and Pole, traverse the project area from west to east, transmitting water from forested areas west of the marsh. Pole Creek rises as a spring within the project area, then flows east.

Low elevations are predominantly ponderosa pine and lodgepole pine (*Pinus contorta*), while higher elevations on and around Yamsae Mountain contain mixed conifer stands consisting of ponderosa pine, white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), and an occasional western white pine (*Pinus monticola*). Smaller inclusions of aspen (*Populus tremuloides*) clones and juniper (*Juniperis occidentalis*) woodlands also exist in the project area. Historically, most of the Big Coyote forested areas consisted of ponderosa pine that averaged 12 trees ha^{-1}, with 24 percent of the trees in clumps with more than 15 trees, and 20 percent as isolated trees. Clump spacing was based on 6 m between trees. The single-storied stands had small openings between the clumps. Average tree diameter was over 68 cm diameter breast height (d.b.h.). The natural fire interval ranged from 3 to 37 years, with a median of 10.7 years over the past 400 years based on fire scars (Bienz, unpublished).

In 2005, we treated 142 ha of forest land with mechanical harvest (fig. 1). Pretreatment density was 10.1 m^2 ha^{-1} (71 trees [>10 cm d.b.h.] ha^{-1}), plus 103 saplings ha^{-1} (59 percent). Ponderosa pine was dominant (66 percent) and structure was uneven-aged. Harvest yielded 17.8 m^3 ha^{-1}. We included 71 ha of the mechanical harvest area in prescribed burns in 2006, 2013, and 2017. In 2008, another 162 ha, consisting of 130 ha of forest land and 32 ha of grassland, was treated with prescribed fire only. Forest structure in these two areas was uneven-aged, with lodgepole pine being the predominant tree (51 percent). Average gross volume was 39 m^2 in lodgepole pine and 70 m^2 in ponderosa pine. The density was 5.3 m^2 ha^{-1}; there were 42 trees ha^{-1} with d.b.h. greater than 10 cm and 16 saplings ha^{-1} (29 percent of the number of trees). In 2016, 110 ha was restored to historical spatial patterns, and a basal area of 6 m^2. Tree density post-harvest was 17 trees ha^{-1} (fig. 2). Harvest was 20.6 m^3 ha^{-1}.

METHODS

Cooperation (e.g., jointly planning and implementing fire management) has the potential to increase the economy of scale of operations and, potentially, the collective impact of practices. The Nature Conservancy received a grant (March 28, 2017) under the authority of the Cooperative Forestry Assistance Act of 1978 for the Big Coyote Fuels Reduction project 17-DG-10062765-705. Despite the potential ecological and social benefits of cooperating on forest management on landscape scales, and over 15 years of prescribed fire treatments with resource monitoring and research, we have found that such approaches are uncommon in practice among public and private land managers.

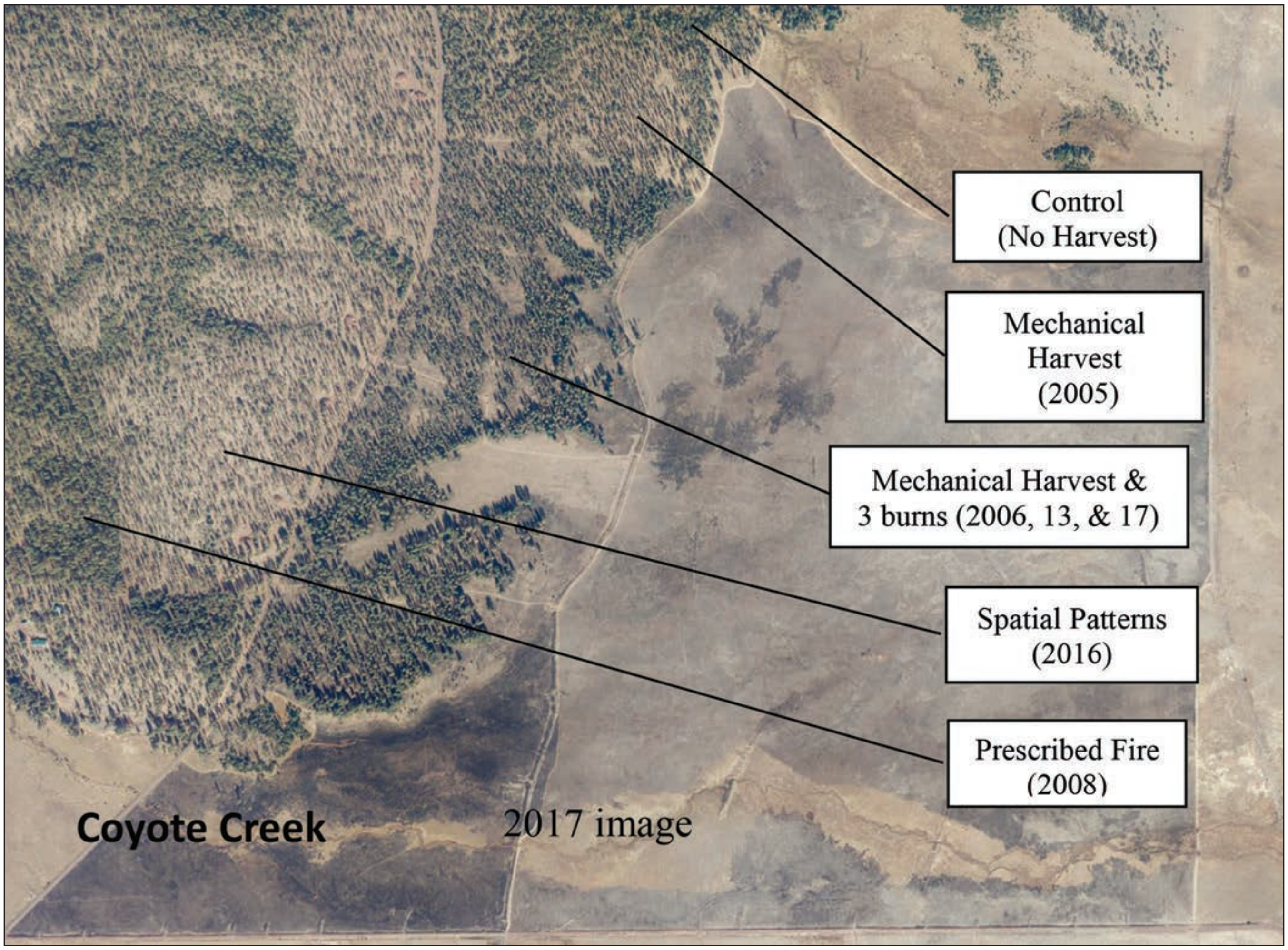

Figure 1—Image of the Big Coyote Fuels Reduction area in Oregon, post-burn, October 2017. Labels identify the types of project activities and years by area.

Figure 2—Before (left) and after (right) a prescribed burn to reduce basal area, increase quadratic mean diameter (QMD), retain fire- and drought-resistant trees, and establish plant architecture (spatial heterogeneity). Pretreatment basal area was 24.4 m^2 ha^{-1}; posttreatment basal area was 9.9 m^2 ha^{-1}, with 12 trees ha^{-1} and a QMD of 149 cm^2. The arrows point to the same tree pre- and post-treatment.

In anticipation of cross-boundary prescribed burning, TNC and the Forest Service began coordination in January 2017 to develop burn plans, identify contractors and collaborators, and proposed schedule of activities. Contractors were employed to prepare fire lines. In addition, contractors were hired to participate in the burn activities. Perhaps one of the most vital contractors was the caterer. Good food is critical to the success of a multiday fuels reduction project. The Fire Learning Network (FLN) provided logistical and financial support. The research team, composed of faculty and students, and Federal agencies, made several visits to the preserve to coordinate and plan for their activities. Monthly phone calls facilitated coordination.

On October 11, 2017, 80 people from 15 organizations engaged in constant two-way communication between the fire cadre and scientists. Unique to this project was the goal of advancing knowledge and application of fire science. Participants had the opportunity to learn lessons from their peers in TNC's FLN cadre, and advance their skills by completing task book requirements. The application of these skills has enhanced their knowledge of fire behavior, and fire use skills were advanced, and provided enthusiasm to apply prescribed fire.

RESULTS

The ways in which individuals observe and experience environmental change, including hazardous conditions and wildfires, have bearing on their responses. To understand the factors that shape values, beliefs, and behaviors of individuals across the full spectrum of stakeholders in wildfire risk mitigation within our region, we must include resource users, landowners, members of community organizations, and participants in task forces, as well as decisionmakers in nongovernmental organizations, Federal and State agencies, and other formal organizations.

Our objective to reduce wildfire risk, and significantly expand the area restored through collective actions, is dependent on sound science, case studies that illustrate ecosystem services and how well we can identify appropriate collaborators, work out collaborative agreements, and ensure that the behaviors of others are beneficial. Our scientific understanding of the processes and impacts is essential to guide our discussions. We also recognize how these activities impose transaction costs on collaboration, which may vary depending on how well individuals can draw upon their experiences or social and organizational network affiliations. Likewise, transaction costs may depend on characteristics of the surrounding natural environment, which may influence the difficulty of observing whether a partner follows through on risk mitigation agreements.

In one example, one of the neighbors adjacent to this project was opposed to the use of controlled burning in early October 2017. This landowner's institutional knowledge and the increased fear from extensive wildfires ongoing in California made our proposed controlled burning unacceptable to her (or him; gender not disclosed to protect the landowner's privacy). After extensive discussions over a 4-day period, the level of fear moderated. Mostly based on our history of working as neighbors, our listening to this individual's concerns, and trust in our scientific approach, this person provided endorsement. Upon reflecting on the methodical process that we followed and seeing the positive ecological benefits after the fire, the landowner asked whether we would include her (or his) lands when next we applied controlled burning.

In our situation, the value of cross-boundary fuels treatments expands beyond restoring ecological process to the human relations developed. During our training, participants learn from each other and share experiences while conducting controlled burns. The FLN cadre experiences the world of fire with a diversity of people along the spectrum of individuals, agencies, experience, and wonder. Participants are able to climb the professional ladder more quickly as more highly skilled resources and have greater opportunities because of cross-boundary training.

Collaboration in Fire and Forest Science

Understanding fire ecology and management and managing adjustments in our existing applications are essential to our learning processes. Current methods of data collection and the process to validate next-generation models that are relevant at operational and ecological scales are foundational. Working with the Forest Service's Missoula Fire Sciences Laboratory and the University of Montana, provided the most up-to date, physics-based fire behavior models. The Nature Conservancy's work with the Forest Service's Western Wildlands Environmental Threats Assessment Center, led by the third author of this paper, has provided needed information on the physiological basis of tree and stand health, and the net long-term effects of fuels reduction treatments, including fire effects, on forest health. Results from the research team have contributed to documentation of effects of fire on ecosystem services.

Ecosystem Services

Fuels reduction treatments are prioritized on public lands to reduce wildfire hazard and spread, while improving forest health, wildlife habitat, aesthetics, and other cultural values. The projects being implemented as part of the Big Coyote Fuels Reduction effort were initiated with an emphasis on BACI research design, so we have continued to monitor results and report here some of the other findings. Ecosystem services, the benefits that nature provides to people, are one approach for emphasizing the importance of conservation and restoration. These benefits can be defined in a variety of ways but are often categorized as provisioning services, regulating services, cultural services, and supporting services (Millennium Ecosystem Assessment 2015).

Provisioning services are goods directly enjoyed or consumed, such as food, water, medicines, timber products, and nontimber forest products. Through the Big Coyote Fuels project and associated cross-boundary treatments, provisioning services have been enjoyed in food, water, timber, and recreation. Timber harvest has provided local employment and forest products to sustain local mills. Mule deer (*Odocoileus hemionus*) populations are an important resource for recreation and Klamath Tribal subsistence. Populations were monitored throughout the year to determine animal density, annual production, and physiological condition for specific habitat conditions. Multiple regression analysis found a significant relationship between carrying capacity and annual production and animal condition ($r^2 = 0.94$, $P < 0.001$). The relationship between carrying capacity and animal density and annual production was also significant ($r^2 = 0.76$, $P = 0.01$) (Bienz and Dunsmoor 1992).

Monitoring of populations by using radiotelemetry was conducted in 2006 and 2007 by the Oregon Department of Fish and Wildlife and the Klamath Tribes. Does with fawns used the treatment areas disproportionately to other habitats (fig. 3).

Regulating services are recognized as beneficial outcomes from regulation of processes such as flood control, water storage, erosion prevention, air and water purification, and climate stabilization. Without forest resilience, all other ecosystem components and values are not sustainable, at least over the long term. We have provided discussion on the merits of incentives and agency structures that facilitate

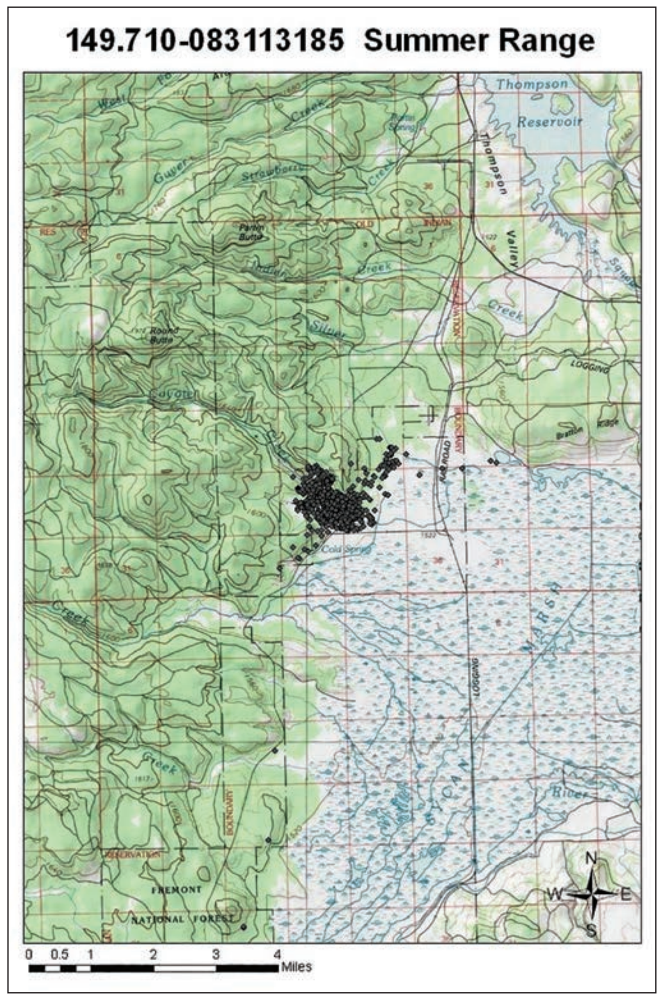

Figure 3—Locations of one female mule deer with radio transmitter 149.710 near Sycan Marsh Preserve, Oregon. Locations of the transmitter are concentrated in the areas of the Big Coyote Fuels Reduction project. This deer successfully raised two fawns each year during the radiotelemetry study conducted by the Oregon Department of Fish and Wildlife.

restoration of wildland fire and ecologically based fuels treatment to forest landscapes. Here we provide an example of forest resilience to fire, insects, and climate change.

We investigated the responses of ponderosa pine to stand basal area manipulations at Sycan Marsh. Stand basal area was manipulated to four replicated levels in 2005, and additional stands in 2008 and 2016 (see Site Description). Three treatments with prescribed fire were applied in 2006, 2013, and 2017 in one of the stands that received mechanical harvest in 2005. We measured basal area increment (BAI) to assess the response and sustainability of wood growth, carbon isotope discrimination inferred from annual rings to assess the response of crown gas exchange, and ratios of leaf area to sapwood area to assess longer term structural acclimation. We assessed aboveground productivity from tree ring analysis of BAI. After trees were felled, we removed stemwood cross-sections from a height of 1.3 m from each stump with chainsaws. Ring widths were converted to BAI from 1980 to 2017 using tree-specific cross-sectional radii (inside bark) and assuming concentric circularity. We found that mechanical harvest and mechanical harvest with three treatments of prescribed fire had similar increases in growth following treatments. Results for BAI are presented at the individual plot level (fig. 4). Treatments of reducing basal area and prescribed fire increased tree resilience during drought years, and increased carbon sequestration (see also Supporting Services).

Cultural services include intangible or spiritual connections with nature, including heritage, sense of place and recreation experiences. In our location, members of the Klamath Tribes exercise treaty-protected subsistence use on public lands. Their continued use of subsistence resources maintains their health and well-being physically and spiritually. In 2016 and 2017 tribal members were included in the fire training. Members of the tribes have been included in other forest restoration working sessions, and trainings.

Supporting services are foundational building blocks of ecosystems, including nutrient cycling, pollination,

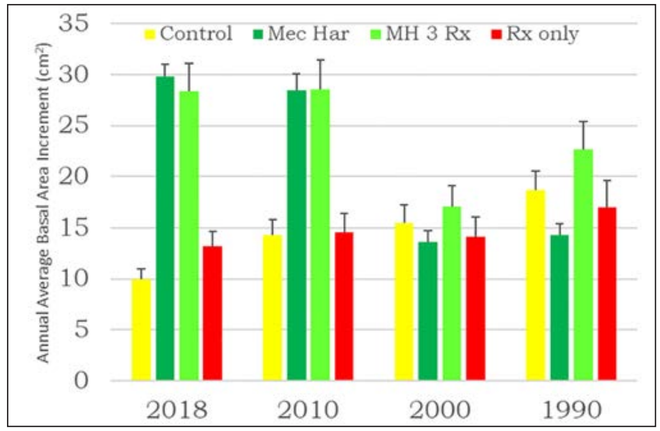

Figure 4—Annual average basal area increment (BAI) (cm^2) for the period 1980 through 2018 by decade in the Big Coyote Fuels Reduction project at Sycan Marsh Preserve, Oregon. Growth in the control was generally the same as the treatment areas for decades 1980 to 1990 and 1991 to 2000, and with prescribed fire (Rx) only through 2010. Mechanical harvest (Mec Har) in 2005 released the residual stand to more than double rates of growth through 2017. Prescribed fire applied in 2006, 2013, and 2017 to an area with mechanical treatment in 2005 (MH 3 Rx) had similar growth to the Mec Har. Prescribed fire (Rx only) in 2008 has led to a general downward trend in BAI, but not as significant as in the control. Data are averaged for 30 trees per treatment.

and photosynthesis. Whole-tree and canopy attributes (measured from the ground) were used to assess the level of tree drought stress and health in the current year. Tree condition is categorized as above average, average, or below average. Average age of trees and tree diameters were not significantly different between treatment types. In general, above-average trees had the largest diameters; the exception was the mechanical harvest with two prescribed fires (now three fires), where the above-average trees had an average diameter of 40.3 cm, and average-condition trees had an average diameter of 42.7 cm. In the control area, tree diameters averaged 48.6 cm for above-average trees, 36.9 cm for trees in average health, and 38.3 cm for trees in below-average health. We concluded that 1) fuels reduction treatments not followed by prescribed fire had a greater proportion of trees in poor health than unmanaged stands; 2) harvest followed by prescribed fire eliminated all poor-health trees; and 3) harvest followed by three prescribed fires within 11 resulted in 62 percent of the population in above-average condition (fig. 5).

Figure 5—Comparison of proportion of sampled trees in each of three health conditions after fuels reduction treatments conducted in the dry pine forest type. Treatments: No treatment (control), mechanical harvest with no fire (Harvest, nF), mechanical harvest with prescription to create spatial complexity (Heterogeneous, nF), and Mechanical Harvest with prescribed fire in 2006, 2013, and 2017 (Harvest, 2xF). Tree health was quantified within each treatment aspoor, average (ave), or above average (AA). Fuels reduction treatments followed by three prescribed fires in 11 years improved the proportion of above-average trees by 60 percent. Harvest with three fires had 1.4 times greater diameter growth than other treatments, and diameter growth in the control and harvest with no fire were similar. Managing forest structure by increasing spatial heterogeneity increases resilience in drought; 62 percent of the trees were in above-average condition. Source: Grulke and Bienz (2014–2017).

Water supply has been quantified for the Upper Sycan Watershed through rate and timing of streamflow collected by TNC starting in the summer 2000 field season. The data have been used to determine the surface flow components of a hydrologic budget. Data collection by the Forest Service had begun at some of these sites in 1993, with some changes and data gaps occurring over time. The Klamath Tribes, and Oregon Water Resources Department (OWRD 2019) continue to collect and report on streamflow data. We have found an immediate, short-term increase in streamflow following prescribed fire during each treatment. This has allowed more continuous surface flow and longitudinal connectivity, which also can help establish subsurface pathways (Ward and Stanford 1995).

Water supply is enhanced by increased connectivity, given that it is expected to drive groundwater supply recharge. Information on groundwater elevations is used to assess seasonal changes in groundwater levels at Sycan Marsh, rate and direction of groundwater fluxes, and relationships to annual precipitation and evapotranspiration. Beginning in 1995, piezometers (groundwater wells) were installed at the preserve, and more wells were added each year through 2012. We observed an immediate response in groundwater elevations following prescribed fire. Wells located within burn areas have increased in elevation as much as 1 cm within 24 hours of burning. Groundwater level is important for attenuation and base flow maintenance, which in turn offsets climatic water deficits (Mayer and Naman 2011).

Several streams at Sycan Marsh have been listed on the Clean Water Act 303(d) list for failing to meet State water quality standards for stream temperature. Data are collected to: 1) validate the influence of restoration management on water temperature with respect to Clean Water Act regulations; 2) provide a baseline of environmental conditions on aquatic species (habitat quality vs. degree-days); and 3) guide adaptive management for future restoration projects.

CONCLUSIONS

Sycan Marsh Preserve provides the facilities and environmental conditions needed to address landscape-scale implementation and analysis. Watershed-scale treatments and evaluation of the responses require large field sites in which surface and canopy fuels are mapped in three-dimensional space at high resolution (Parsons et al. 2018) and where medium- and long-term fire effects on community composition, structure, and fuel accumulation are measured. Prior to this project we collected data on large, spatially explicit forest plots referenced to historical reconstruction plots. Collection of these historical collection was a key investment needed to meet one of the most pressing research challenges in fire science.

Historical forest conditions based on extensive forest inventory plots (Hagmann et al. 2013), along with data collected shortly after initiation of the fire-prevention era combined with 5-ha reference plots (Churchill et al. 2013), provided historical reference information. Management that incorporates ecological processes as well as spatial patterns requires inventory plots greater than 5 ha (Churchill et al. 2013, 2018). Our large plots with tree health data provide consistent methods to accurately assess impacts from treatments, fire, and climate (fig. 5). These types of data may assist in guiding future research and management.

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 (Parsons et al. 2017), with the finding that aggregated fuel patterns, which may be established from spatially aggregated tree patterns (Larson and Churchill 2012), increase the variability of fire behavior (Churchill et al. 2018). These initial results suggest a promising pathway for testing conceptual models for forest dynamics and the generation of spatial heterogeneity in frequent-fire forests (Platt et al. 1988), and for the design and evaluation of fuels reduction, restoration, and climate change adaptation treatments in frequent-fire forests (Churchill et al. 2013; Ziegler et al. 2017).

Active management in the form of forest thinning, prescribed fire, and the combination of the two has been shown to increase forest resilience (Clyatt et al. 2016; D'Amato et al. 2011; Nagel et al. 2017) and decrease wildfire severity in dry forests (Hessburg et al. 2016; Lyderson et al. 2017; Moritz et al. 2014). To restore ecological resilience to significant areas of national forests and ensure socioeconomic viability of communities, the pace and scale of restoration projects need to significantly increase. The Fremont-Winema National Forest developed an Accelerated Restoration and Priority Landscape Plan (Lehman and Markus 2015) and a Ten Year Integrated Natural Resource Plan which provides a strategy to double restoration on the forest over the next 10 years. We have taken steps to exceed the goals, as the current schedule will restore over 1 million Federal forest acres (405,000 ha) by 2028. And the all-lands approach will achieve the National Cohesive Strategy objectives.

Reforming the approach to amend the socioecological interactions to expedite forest restoration was addressed at multiple scales: spatial (ownership, landscape), temporal (short- and long-term), and organizational (individuals, groups, institutions). We provided leadership, administration of programs, and people, training, and feedback from the learning experiences. Our model was flexible in both engagement and implementation, making necessary adjustments daily. One example was when the test fire exceeded the comfort level of the Burn Boss, who then called off that day's burn. The experience was perhaps most valuable to the cadre members who were eager to begin the day's fire activities, only to learn that each situation needs careful and experienced evaluation of fire response to environmental conditions. Though this call was not popular with the cadre members, who were prepared to burn, the decision was a necessary step to illustrate the precautions required for using controlled fire.

Prescribed fire science tools help managers understand how different types of fire behaviors may affect ecosystem services and resulting negative effects, such as smoke movement. Information on wildfires may not apply to prescribed fire situations. Fire managers need better fire models to predict fire behaviors under moderate conditions. We are still learning how the fire will behave in different ignition scenarios and with backing and flanking fires.

Quantifying the importance of fire to ecosystem services provides a framework to better understand values and interconnected services. We have included a framework to advance the discussions on how to incorporate these values into future forest restoration programs.

Providing a landscape where individuals can observe and experience a resilient forest and its myriad ecosystem services changes perceptions and opinions. In the social engagement of discussing these systems, people experienced new avenues for scientific discovery that expand the scope of the social–ecological system under inquiry. Ultimately this engagement enriches understanding of how biophysical processes play out in today's world. This points out many of the social and psychological processes that influence the communication and implementation of science in practice. Our results show the importance of considering predominant wildfire experience types in a community before developing a wildfire mitigation program. The findings of this study may have relevance for other communities that have experience with wildfires.

Support garnered from the training has exceeded expectations for outcomes. Commitments have been made from agencies, contractors, universities, and research associates to continue to participate in future burning projects at Sycan Marsh Preserve. Through our collaborative learning process, team concepts, and increased capacity, we have found individuals and agencies accepting the importance of fire for nonindustrial and commercial forest lands. Data and teamwork have been valuable to evaluate impacts on tree health and seedling establishment (Smith et al. 2016b). A Prescribed Fire Council Chapter has now been formed for Klamath and Lake Counties in Oregon to provide for the socioecological "firescapes" (Fischer et al. 2016; Smith et al. 2016a). Cross-boundary fuel and wildfire risk reduction are being developed in these two counties of Oregon. A manual to guide future cross-boundary projects has been published through collaboration with the Forest Service's Pacific Northwest Research Station (Leavell et al. 2018).

Data collected during the fuels treatments have been used to adjust plans for future burning (fig. 1). The benefits of hazardous fuels reduction are being increasingly recognized, and the importance of expanding fuels reduction activity across property lines has achieved valuable social acceptance. Collaborative groups such as the Klamath Lake Forest Health Partnership have now developed cross-boundary projects for over 30,000 acres (12,000 ha) (Leavell et al. 2018). This is in addition to the 10,000 acres (4,000 ha) associated with the Big Coyote Fuels Reduction project. Within Klamath and Lake Counties, non-Federal forest restoration is being planned on over 100,000 acres (40,000 ha) to increase human safety and reduce risks of severe wildfire. Since the Master Participating Agreement was signed in 2017, cross-boundary forest restoration has been implemented on more than 4,000 acres (1,600 ha). The Klamath Lake Prescribed Fire Council has been formed. Over $2 million has been secured to expanded community engagement with Learning Networks for Fire, Forests, and Community Risk Reduction and Resilience.

There is still a lack of holistic understanding of how fire management enables the provisioning of ecosystem services in a range of forested ecosystems. We have briefly discussed the types of ecosystem services and the value of incorporating them into planning and management. We will continue to incorporate these values into future restoration discussions. The extension of research into the measurements of fire behavior, forest health response, effects on water and nutrient balance and dynamics, and long-term interactions over time and space will be critical to understanding how vertical connectivity relates to priority ecosystem services. However, the Sycan Marsh model has provided a community of learning that has the training and space to apply ecological insights more effectively in improving forest resilience and meeting societal needs.

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