Fire as a Restoration Tool in Pacific Northwest Prairies and Oak Woodlands: Challenges, Successes, and Future Directions

Authors: Hamman, Sarah T., Dunwiddie, Peter W., Nuckols, Jason L., and McKinley, Mason

Source: Northwest Science, 85(2) : 317-328

Published By: Northwest Scientific Association

URL: https://doi.org/10.3955/046.085.0218

Sarah T. Hamman[1], The Nature Conservancy of Washington, 120 Union Ave. SE #215, Olympia, Washington 98501

Peter W. Dunwiddie, School of Forest Resources, University of Washington, Box 354115, Seattle, Washington 98195

Jason L. Nuckols, The Nature Conservancy of Oregon, 87200 Rathbone Road, Eugene, Oregon 97402

and

Mason McKinley, The Nature Conservancy of Washington, 120 Union Ave. SE #215, Olympia, Washington 98501

Fire as a Restoration Tool in Pacific Northwest Prairies and Oak Woodlands: Challenges, Successes, and Future Directions

Abstract

In Pacific Northwest prairies and oak woodlands, cessation of anthropogenic burning in the mid-1800s resulted in large-scale degradation and loss of habitat due to tree and shrub encroachment. Widespread invasive species, deep thatch accumulations, and extensive moss cover now limit the ability of native plants to germinate and thrive. These changes in habitat structure and function have contributed to the decline of several plant and animal species. Over the past decade, prescribed fire has been increasingly applied throughout the Willamette Valley-Puget Trough-Georgia Basin Ecoregion and used in conjunction with other techniques (herbicide, seeding native species) to restore native habitat with variable results. This variability likely is a result of differential fire intensity, dictated by fuels, weather and application technique, all of which can be controlled for by altering fire season, fire frequency, pre-fire treatments and fire extent. In order to burn at the spatial and temporal scales necessary for effective habitat restoration, however, prescribed burn programs must overcome several socio-political, programmatic and economic challenges. This requires a collaborative approach to prescribed fire training, implementation and research. Future research on fire season, fire frequency, species-specific responses to fire and effects of fire surrogates on ecosystem structure and functioning will help to refine prescribed fire management for maximum effectiveness in prairie and oak woodland restoration.

Introduction

Fire has been a formative ecological process in grassland and woodland systems throughout the world for millennia. In the Pacific Northwest (PNW), prairies and oak woodlands were anthropogenically maintained for food and material resources with frequent, low severity fires (Boyd 1999, Weiser and Lepofsky 2009, Walsh et al. 2010). This management action maintained open landscapes dominated by camas (*Camassia quamash*), Garry oak (*Quercus garryana*) and other valuable native forbs and bunchgrasses. With Euro-American settlement to this region in the mid 1800s, fire was largely lost from the system. Throughout the late 19th and early 20th centuries, many native prairies were used for grazing livestock and some were seeded with pasture grasses or converted and amended for agricultural production. In areas that weren't used for agriculture or grazing, fire exclusion led to large-scale invasion by native Douglas-fir (*Pseudotsuga menziesii*), non-native, invasive fruit trees, shrubs (primarily Scotch broom, *Cytisus scoparius*) and grasses (Foster and Shaff 2003, Gedalof et al. 2006). Since that time, 95-99% of the intact, native prairie and oak woodlands throughout the original range have been lost to development, invasive species and agriculture, leaving approximately 16,200 ha of the original 845,000 ha of native prairie and oak woodlands scattered throughout their former range (Crawford and Hall 1997, Lea 2006, Vesely and Rosenberg 2010). This landscape-scale conversion from continuous native prairie and oak woodland to highly fragmented low-quality patches has led to an increasing number of threatened and endangered species associated with this disappearing habitat (GOERT 2002, Gedalof et al. 2006). Within the prairies and oak woodlands of the Willamette Valley – Puget Trough – Georgia Basin (WPG) Ecoregion (Figure 1), there are seven critically imperiled (G1), 14 imperiled (G2) and 25 vulnerable (G3) high fidelity (prairie or oak woodland-specific), fire-adapted or fire-dependent plant species (Table 1). Most current management and conservation efforts within the Ecoregion are geared towards restoring

[1]Author to whom correspondence should be addressed. Email: shamman@tnc.org

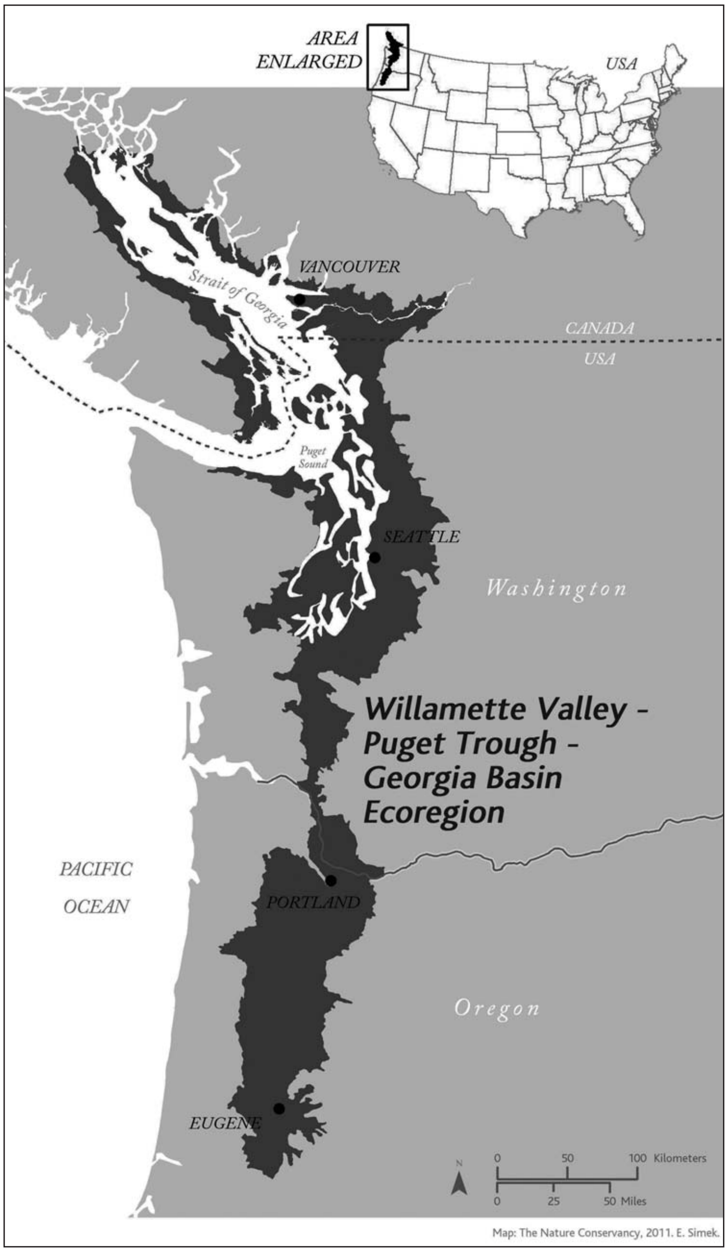

Figure 1. The focus area of this paper is the Willamette Valley – Puget Trough – Georgia Basin Ecoregion, defined by its distinct climate, geology and native species.

native habitat for these species, and restoring greater functionality to the systems where key ecological processes, such as fire, have been lost.

Managers have identified prescribed fire as a key approach for restoring habitat attributes that many of the rare prairie and oak woodland species depend upon. However, as is the case for fire practitioners working throughout the U.S., managers in PNW prairies and oak woodlands must consider the legacy of previous management actions and current habitat fragmentation on fire behavior and ecosystem response. Despite this added challenge, use of prescribed fire for restoration has expanded considerably in the WPG Ecoregion over the last decade. Over this time, managers have learned that implementing prescribed burns on a scale that is necessary for restoration requires clearly defined and prioritized ecological objectives, an extremely knowledgeable, collaborative burn team, sufficient programmatic and political backing to encourage supportive regulatory guidelines, and accurate information on fire effects to help develop burn plans that meet the ecological objectives. We explore these issues here by discussing: 1) ways to tailor prescribed fire to meet ecological objectives; 2) socio-political and programmatic challenges land managers in the Ecoregion have faced with prescribed fire implementation, and how these obstacles are being overcome; and 3) future areas of research that will further enhance the effectiveness of prairie and oak woodland fire management for rare species habitat.

Tailoring Prescribed Burning to Meet Ecological Objectives

History, research, and management have shown that there is no one burn prescription that can be effectively applied across ecosystems (Brown and Smith 2000). Even within the same ecosystem type, fire can have drastically different effects on ecosystem structure and function due to variable fire intensity and initial vegetation composition and structure. Fire intensity, defined as the energy released during a fire, encompasses several metrics for grassland systems, including rate of spread, surface temperature and flame length (Keeley 2009). It is dictated by weather, fuel moisture, topography, slope, fuel load and type and, in prescribed fire situations, ignition pattern. Many of these components can be manipulated or utilized by fire practitioners to achieve specific ecological objectives (Agee 1996). In the prairies and oak woodlands of the WPG Ecoregion, managers have identified several ecological objectives that they hope to meet by strategically manipulating prescribed fire as a restoration tool (Table 2). Due to the nature of the fuels and habitat needs of the rare species present in these systems, these objectives encompass targets for the substrate (litter, duff, moss, soil), the vegetation (grasses, forbs, shrubs and some trees), and the overall community structure. The objectives listed within each

TABLE 1. Globally At-Risk vascular plant species of the prairies and associated habitats of the WPG Ecoregion. G-Rank (Global Rank) is a standardized conservation status rank developed by NatureServe, based on rarity, trends, and threats (1=critically imperiled; 2=imperiled; 3=vulnerable). WV=Willamette Valley, PT=Puget Trough, GB=Georgia Basin.

Common Name	Scientific Name	G-Rank	WV	PT	GB
Elegant brodiaea	*Brodiaea elegans ssp. hooveri*	3	X		
Rosin weed	*Calycadenia truncata ssp. scabrella*	3	X		
Small camas	*Camassia quamash ssp. azurea*	3		X	X
Small camas	*Camassia quamash ssp. intermedia*	2	X		
Golden Paintbrush	*Castilleja levisecta*	1	X	X	X
Giant red Indian paintbrush	*Castilleja miniata var. dixonii*	3		X	X
Victoria paintbrush	*Castilleja victoriae*	1			X
Four spot	*Clarkia purpurea ssp. purpurea*	2	X		
Large godetia	*Clarkia purpurea ssp. viminea*	3	X		X
Sticky blue eyed Mary	*Collinsia rattanii ssp. glandulosa*	3	X		
White-rock larkspur	*Delphinium leucophaeum*	2	X	X	
Willamette Valley larkspur	*Delphinium oreganum*	1	X		
Peacock larkspur	*Delphinium pavonaceum*	1	X		
Beautiful shooting star	*Dodecatheon pulchellum ssp. monanthum*	3	X		
Willamette Valley daisy	*Erigeron decumbens*	1	X		
Barestem buckwheat	*Eriogonum nudum var. nudum*	3	X		
Wayside aster	*Eucephalus vialis*	3	X		
Shaggy horkelia	*Horkelia congesta ssp. congesta*	2	X		
Gorman's iris	*Iris tenax var. gormanii*	1	X		
Kellogg's Rush	*Juncus kelloggii*	3	X		X
Seaside juniper	*Juniperus maritima*	3		X	X
Thin leaved pea	*Lathyrus holochlorus*	2	X		
Macoun's meadowfoam	*Limnanthes macounii*	2			X
Bradshaw's desert parsley	*Lomatium bradshawii*	2	X		
Spurred lupine	*Lupinus arbustus ssp. arbustus*	3	X	X	
Kincaid's lupine	*Lupinus sulphureus var. kincaidii*	2	X		X
White Meconella	*Meconella oregana*	2		X	X
Cismontane sandwort	*Minuartia cismontana*	3	X		
Willamette navarretia	*Navarretia willamettensis*	1	X		
Baby blue-eyes	*Nemophila menziesii var. atomaria*	3	X		
Rosy owlclover	*Orthocarpus bracteosus*	3	X	X	X
Close flowered knotweed	*Polygonum polygaloides ssp. confertiflorum*	3	X		
Imbricate sword fern	*Polystichum imbricans ssp. imbricans*	3	X	X	X
Racemed goldenweed	*Pyrrocoma racemosa var. racemosa*	3	X		
Thompson's mistmaiden	*Romanzoffia thompsonii*	3	X		
Gorman's saxifrage	*Saxifraga gormanii*	3	X		
Rigid white topped aster	*Sericocarpus rigidus*	3	X	X	X
Bristly-stemmed Sidalcea	*Sidalcea hirtipes*	2		X	
Nelson's Sidalcea	*Sidalcea nelsoniana*	2	X		
Bell shaped catchfly	*Silene campanulata ssp. glandulosa*	3	X		
Hitchcock's blue-eyed-grass	*Sisyrinchium hitchcockii*	2	X		
Idaho blue-eyed grass	*Sisyrinchium idahoense var. macounii*	2		X	X
Idaho blue-eyed grass	*Sisyrinchium idahoense var. segetum*	3		X	
Tolmie's goldenrod	*Solidago missouriensis var. tolmieana*	3		X	
Howell's triteleia	*Triteleia grandiflora var. howellii*	3	X	X	X
Small-flowered trillium	*Trillium parviflorum*	2	X	X	

TABLE 2. Summary of potential ecological objectives, ways that fire behavior can be manipulated to achieve objectives, and important monitoring variables that can inform future management in prairies and oak woodlands of the WPG Ecoregion. These ecological objectives serve as an example of overall goals for prairie and oak woodland burn programs. Specific objectives for a particular burn unit should have values attached to each objective (i.e., consume 50% litter, kill 100% Scotch broom) and be geared toward the explicit restoration needs of that landscape.

Ecological Objectives	Ways to manipulate fire behavior	Monitoring variables
Substrate: • Consume litter • Consume moss • Create bare ground for germination of native seeds • Consume non-native grass seeds and rhizomes **Vegetation:** • Top kill shrubs, vines and young trees • Kill Scotch broom • Stimulate germination and fecundity of fire-adapted native grasses, forbs and trees (Garry oak) • Kill target Douglas-fir trees **Community structure:** • Increase habitat heterogeneity • Leave unburned refugia for invertebrates and other wildlife • Create open savanna-like conditions	**Fire Season/Fuel conditions:** • Burn during high / moderate / low relative humidity • Burn when fuel moisture is high / moderate / low • Burn when litter or moss moisture is high / moderate / low • Burn in appropriate phenological window **Fire Frequency:** • High (annual) • Moderate (3-5 years) • Low (6+ years) **Pre-fire treatments:** • Apply targeted herbicide • Rake/dethatch litter or moss • Mow to cure or decrease stature of vegetation • Masticate woody fuels and either disperse, pile or remove **Fire Application Techniques:** • Apply backing fires • Apply head fires • Apply flanking or strip fires • Protect sensitive areas	**Pre-burn:** • Vegetation community metrics of interest • Bare ground • Litter depth and cover • Moss depth and cover **During the burn:** • Weather variables • Relative humidity • Temperature • Wind speed and direction • Rate of spread • Flame length • Surface temperature **Post-burn:** • Fire Severity – % litter consumption – depth of soil char – % ground scorch – vegetation consumption • Vegetation community metrics of interest • Bare ground • Litter depth and cover • Moss depth and cover

of these categories represent overarching goals for the burn programs throughout the Ecoregion; individual burns require much more explicit and prioritized goals to fit the specific ecological condition of the landscape. Once those explicit and prioritized objectives are set, detailed burn plans can be developed that are geared toward achieving the objectives by altering fire season, fire frequency, pre-fire treatments and/or fire application technique.

Fire Season

The climate of the WPG Ecoregion provides a fairly tight window for effective ecological burning. Average annual precipitation ranges from approximately 1109 mm in the Willamette Valley to 1292 mm in the Puget Trough to 690 mm in the Georgia Basin, with most of it occurring as rain during winter months (November – March). The primary fire season for PNW prairies and oak woodlands typically ranges from early-August to mid-October, depending on the duration of the spring rains, the duration and intensity of the summer drought, and the onset of the fall rainy season. Storm and Shebitz (2006) and Sprenger and Dunwiddie (2011) suggest most Native American burning took place in the fall; Tveten and Fonda (1999) reported that fall fires were preferable to spring burning for sustaining native species in the Puget Trough prairies.

When deciding on appropriate fire season, managers must consider the phenological windows for species they want to both control and enhance with fire. In the Willamette Valley, fire application is often pushed to the latter portion of the seasonal burn window to allow for full maturation and senescence of many high fidelity prairie and savanna herbaceous species that are still setting seed in September and October, such as *Perideridia montana* (common yampah), *Symphiotrichum hallii* (Hall's aster), *Sericocarpus rigidus* (Columbian white-top aster) and *Pyrrocoma racemosa* (clustered goldenweed). Land managers and researchers in the central U.S. tallgrass prairie have found that burning at different times can select for vastly different vegetation communities (Engle 2000, Engle and Bidwell 2001). In addition to phenological variability, vegetative responses to fire season depend on pre- and post-burn precipitation (Augustine and Milchunas 2009), fire behavior as dictated by day-of-burn weather conditions (Bidwell et al. 1990, Bidwell and Engle 1992), fire frequency (Blair 1997, Emery and Gross 2004) and topography (Abrams et al. 1986). To understand how some of these interacting factors affect ecological objectives, managers in the WPG Ecoregion have been expanding the burn window to accommodate more burn days and to experiment with earlier season fire effects. It is currently unknown how early season (July) or very late season (late October, after fall rains have begun) burns might influence invasive species cover and native species composition and structure. These types of burns may encourage heterogeneous fire severity and, therefore, help to achieve some ecological objectives related to community structure by leaving unburned resource patches from which fire-sensitive species may more readily recolonize burned areas (Schultz and Crone 1998, Panzer 2002, Schultz et al. 2011).

Fire Frequency

Replicating the frequency of historical burning in PNW prairies and oak woodlands might help to develop a prescribed burn schedule that more closely matches the conditions to which the target species are best adapted. However, the frequency with which a particular patch of prairie burned is difficult to reconstruct. Even if fires were lit every year or two, as suggested by Storm and Shebitz (2006), the fire rotation for the prairie could be several years longer, depending on the patchiness of each burn. Tveten and Fonda (1999) suggested that most native species were negatively impacted by annual burning, and that a 3-5 year frequency was optimal for maintaining prairie and oak woodland habitat. Peterson and Reich (2001) also found that a 3-5 year fire return interval was optimal for restoration and maintenance of oak stand structure in Midwestern oak savannas. Current frequency goals within the Puget Trough are to burn individual units (on average) every 3-4 years, but restrictions on smoke emissions and, in some cases, insufficient resources, currently limit the ability to burn all sites on this rotation. Priority for restoration burning is given to sites based on the following criteria: 1) they support critical ongoing fire research; 2) they contain priority rare species; 3) they are slated for reintroduction of rare species; 4) they require time-sensitive burn treatments; 5) they contain high or mid-quality habitat; and 6) they contain low quality habitat and may pose a threat to adjacent lands (i.e., large Scotch broom seedbank).

When burning is not an option, managers typically utilize fire surrogates such as mowing, herbicide and/or dethatching (to remove moss and heavy litter) to achieve certain ecological objectives on unburned sites. Although these treatments are often not preferable, due to increased cost per unit land treated and lower conservation benefit than strategically applied prescribed fire (Harrington and Kathol 2009, Roony and Leach 2010), they do often provide reasonable short-term maintenance of invasives and fuel loads until fire can be used.

Pre-Fire Treatments

Many native plants in PNW prairies and oak woodlands are adapted to conditions created by frequent, low- to moderate-intensity fires (Stanley et al. 2008). However, solely reintroducing fire to these systems when the fuel type and load is outside the historical range, due to invasion by non-native shrubs or dense pasture grasses, may not benefit recovery of native species. In PNW prairies and oak woodlands, altered fuel type and loading includes everything from deep litter, duff and moss layers with no woody vegetation, to 1-10 hour fuels dominated by invasive shrubs and small trees, to 100-hour fuels dominated by Oregon white oak and Douglas-fir (Agee 1996). To manage fuel loads for low- to moderate-intensity fires, pre-fire herbicide or mowing treatments are often necessary (Tveten and Fonda 1999).

In the Willamette Valley, significant woody invasion by rose (*Rosa* spp.), blackberry (*Rubus* spp.), Scotch broom, ash (*Fraxinus latifolia*), and feral fruit trees into wet prairie can occur in as few as five years if no management actions are taken. This woody component does not burn safely and effectively under the same conditions preferred for prairie and savanna fires. Thus, *in situ* mastication or shearing and removal of the woody material may be necessary so that subsequent controlled burns can be reintroduced with less intense effects. Similar mechanical and chemical treatments are often applied to Puget Trough and Georgia Basin sites to remove encroaching Douglas-fir trees, large Scotch broom infestations, and to kill non-native, invasive grasses and shrubs prior to burning. If the ecological objectives for a burn unit call for patches of high intensity fire (to create bare ground or kill certain invasives), it is also often possible to strategically add fine woody fuels in piles or rows around the area of interest to increase localized fire intensity for resource benefit. Research conducted throughout the WPG Ecoregion has shown that the most effective way to remove invasive grasses and shrubs and restore native prairie species to low- or moderate-quality sites involves a combination of restoration treatments including pre-fire grass-specific herbicide, frequent (1-3 years) late season prescribed fire, post-fire broad spectrum herbicide, and native seed addition (Stanley et al. 2008, 2011).

Fire Application

One of the most easily manipulated factors influencing fire intensity during a prescribed fire operation is fire extent. Determining the area burned dictates the fuel types involved (including just open native grassland or incorporating dense pasture grasses, dense shrub or woodland fuels), and can lead to variable fire intensity and, hence, fire effects. Due to the fire exclusion of the past 100 years and current management and restoration actions, most prairie and oak woodland burns involve more than one fuel type, leading to more complex fire behavior and effects (Foster and Shaff 2003). One way to accommodate these various fuels and manipulate fire intensity is to strategically use fire application techniques. Backing fires (burning against prevailing winds), flanking fires (burning perpendicular or at an angle to prevailing winds) and head fires (burning with prevailing winds) all have different implications on fire intensity and, often, fire severity, by influencing the rate of spread (Pyne et al. 1996). Backing fires have the slowest rate of spread and therefore, lowest fire intensity, but can lead to the highest fire severity by slowly consuming available fuels down into the soil organic layers (due to the high residence time). Backing fires are often used in PNW prairies and oak woodlands to consume accumulated moss and litter to expose soil for subsequent native seeding. Head fires often have the greatest fire intensity, but due to the fuel structure in prairies and grasslands, may have the lowest fire severity (Bidwell et al. 1990). Because the rate of spread is so high with head fires, the fuels are often not fully consumed and certain ecological objectives (i.e., moss and litter removal) may not be met; however, this method is often effective at top-killing invasive shrubs.

Exclusion areas within burn units can also be created to protect targeted resources and further vary the mosaic effects. Maintenance of permanent non-fire refugia in several Midwestern tallgrass prairies has been successful in protecting fire-sensitive butterfly species within a fire-managed landscape (Swengel and Swengel 2007). Exclusions are typically created using a variety of ignition and holding techniques. Utilizing ignition patterns to achieve ecological objectives in variable fuels throughout a burn unit may help to advance management goals for the system. For instance, in a high-quality prairie site in the Puget Trough, fire practitioners deployed ignition and holding teams within the burn unit to protect certain trees and restrict burning in previously mapped, fire-sensitive butterfly resource areas (Figure 2).

Adaptive Management

To optimize the use of all of these methods for ecological burns, managers must be willing to utilize adaptive management in developing and refining their prescribed burn plans, and use ecological and management objectives to direct their actions (Owen and Rosentreter 1992). It is not sufficient, and may not even be desirable, simply to return fire to a site that has been left unburned for decades. Setting, prioritizing and communicating clear short- and long-term ecological and management objectives early for each site encourages practitioners to consider these issues while administering the burn. To assess ecological impacts (fire effects) of the burns, most programs monitor basic pre- and post-fire conditions for vegetative parameters of interest (i.e., native plant diversity, non-native vegetation cover, oak seedling density). Real learning opportunities about prescribed fire application, however, often come from strategic, hypothesis-driven research that incorporates multiple components of the fire regime (fire season, frequency, intensity, severity, and extent), which, in turn, may require monitoring a variety of other variables (fuel loads, litter consumption, scorch height). Fire managers and restoration teams throughout the WPG Ecoregion have begun expanding their monitoring efforts to address specific questions related to fire intensity, severity and effects on ecosystem structure and function (Table 2), based on recent advances in knowledge from complementary studies. For instance, recent research on mardon skipper (*Polites mardon*) habitat preferences suggests that this rare butterfly species prefers small fescue (*Festuca roemeri*) bunches over large bunches for oviposition sites (Henry 2010). Incorporating this metric (fescue bunch size) into the monitoring plan will help us understand how we can manipulate prescribed fire to select for optimum mardon skipper habitat.

Challenges and Successes with Prescribed Fire Implementation

Intensive efforts to restore the structure and function of native prairies and oak woodlands using prescribed fire have been growing throughout the WPG Ecoregion over the past decade. These efforts have involved cross-agency and cross-border collaborations that

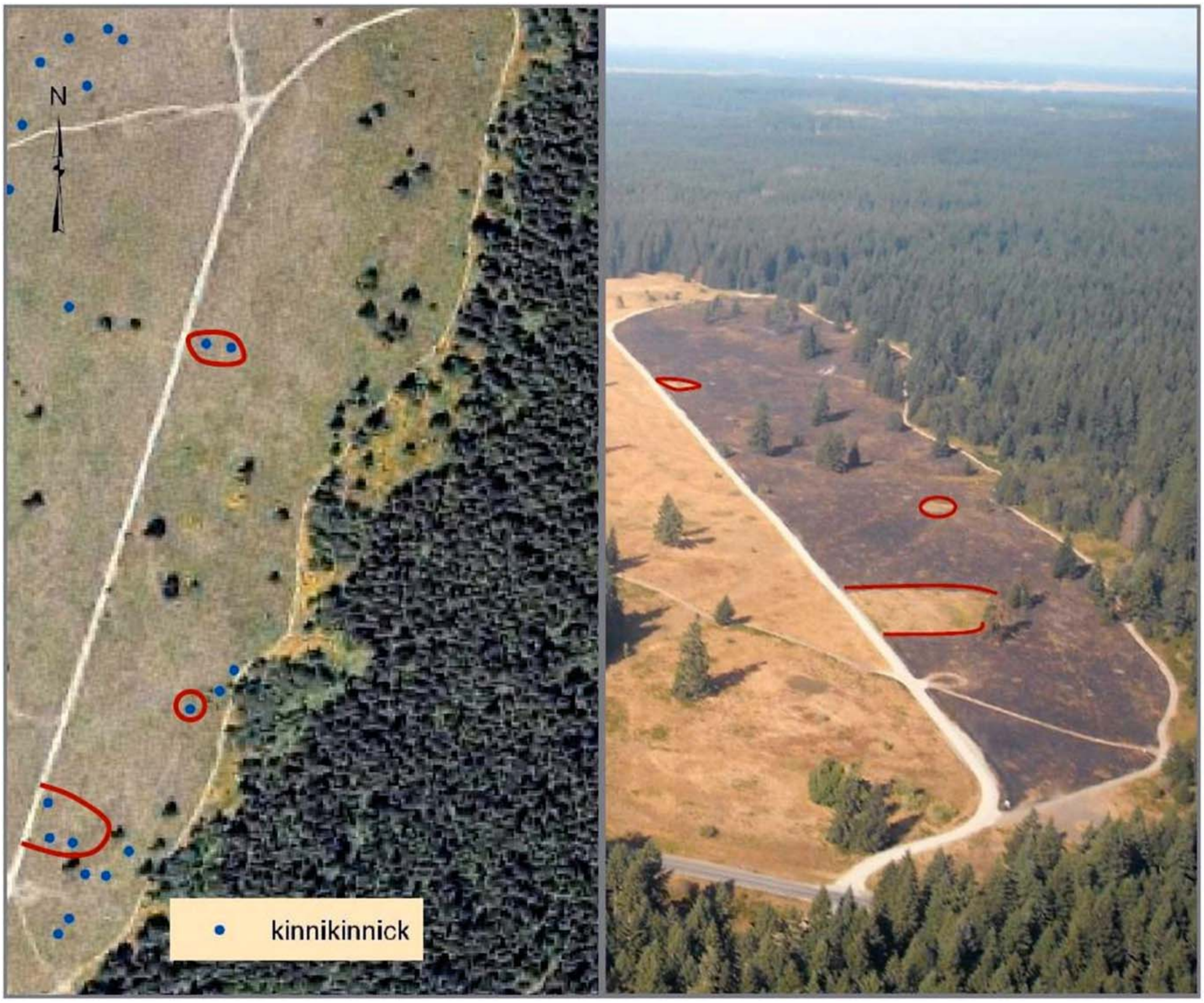

Figure 2. Aerial photo on the left shows locations of kinnikinnick (*Arctostaphylos uva-ursi*), an important larval host plant and nectar source for the hoary elfin butterfly (*Incisalia polia obscura*), within a proposed burn unit on Johnson Prairie, a high quality prairie site within the Puget Trough. This photo was used to help direct fire application at this site, as evidenced by the fire exclusions (marked in red) in the photo on the right. *Photo credit: Bob Wilken.*

provide mutually beneficial gains in knowledge and appreciation of the role of fire as a restoration tool. The successful application of prescribed fire at individual sites, however, depends on several socio-political and programmatic factors (Black et al. 2008).

Socio-political Challenges and Successes

In order for prescribed burns to be conducted at times and in ways that meet ecological objectives, supportive local, state and federal policy and regulations must exist. Air quality regulations, fire hazard ratings and statewide burn bans can all create major obstacles to burning if not considered and addressed. Air quality is often a public concern, and justifiably so, with research showing clear links between increased smoke pollution and asthma (Bowman and Johnston 2005). To develop a burn plan that supports public health, meets agency regulations, and achieves ecological objectives, burn managers must work with regulators early in the planning process to ensure that smoke can be introduced into the atmosphere when air quality is good and transport winds are adequate. Oregon state regulations actually require that burn managers get their burn plans approved early in the year by the appropriate state regulatory agencies to avoid any penalties (Oregon Administrative Rules, DEQ 266).

County and statewide burn bans are set throughout the year to decrease the risk of wildfire. If enacted during the prime 'burning window' (July-October), these burn bans can constrain or even prohibit safe prescribed burn programs, limiting the window of opportunity to the shoulders of the burn season when it may not even be possible to burn, or it may be impossible to meet ecological objectives. Therefore, it is often essential for burn programs throughout the WPG Ecoregion to secure or take advantage of existing exemptions to any late summer or early fall burn bans for ecological burning, as has been done in the Willamette Valley and Puget Trough regions.

Further concerns arise when considering how climate change and future land use change may influence the available burn window. Climate models for the PNW predict warmer, drier summers and wetter falls and winters (Mote and Salathé, 2010, Bachelet et al. 2011). These changes may decrease the available burn window due to increased and potentially earlier fall precipitation, while simultaneously shifting species phenologies, which could have large implications on fire effects. Predicted synergistic interactions between climate, land use change (increased fragmentation and proximity to the wildland-urban interface) and fire in California have shown dramatic population shifts for several fire-adapted species (Lawson et al. 2010, Hurteau and North 2009).

Programmatic Challenges and Successes

Training and retaining sufficient personnel for an effective prescribed fire program is a difficult and on-going problem. There are several challenges facing the current fuels management workforce: 1) Much of the workforce is at or near retirement age; 2) The type of training needed for fire professionals has expanded to include fire ecology, fire behavior and effects, technological advances (remote sensing, geographical information systems (GIS), models), and social sciences; 3) Very few universities provide educational opportunities in wildland fire management and fire ecology; and 4) There is a lack of a common vision and coordinated approach between educational institutions and fire management agencies to provide appropriate training opportunities (Kobziar et al. 2009). Tackling these challenges to develop a skilled workforce requires a new model for fire professional development that provides access to education, experience, and training for a variety of fire management career paths (Kobziar et al. 2009), most of which are vital for successful prescribed fire programs.

A skilled prescribed fire crew, consisting of a certified burn boss, firing boss, holding boss, engine bosses and operators, ignition crew and holding crew (up to 25-30 crew members for larger, more complex burns) must be available to carry out each burn. Crew size is dependent upon the size of the burn unit, ignition strategy required to meet burn objectives, fuel complexity, number and type of available communication tools (i.e., radios), terrain, quality and length of fuel breaks, and proximity to the wildland-urban interface. Each of these components affect the overall complexity of a burn and can increase the need for resources. Acquiring sufficient numbers of trained personnel for a productive burn program can take years, especially in prairie and oak woodland systems where burn teams are often needed 3-4 days per week during the burn season.

Within the WPG Ecoregion, fire managers have been making a concerted effort to expand the trained workforce available for prescribed fire application. Although the number of trained firefighters available for ecological burning has increased 33% in the Willamette Valley and over 500% in the Puget Trough over the past five years, the actual number of personnel is still small (Figure 3a) and needs to increase to make these prescribed burn programs more efficient and effective. Political hurdles and several extremely wet years have limited development of the prescribed burn program infrastructure and resource base in the Georgia Basin. However, clear communication, education and outreach over the past decade have slowly allowed fire managers in the Georgia Basin to develop the trust and understanding of local fire authorities, making it possible to now discuss and plan prescribed burning within a restoration context (Irvin Banman, Nature Conservancy Canada, personal communication). Interagency training, which has been a strong component of the growth of the Willamette Valley and Puget Trough programs, has helped to overcome many similar socio-political hurdles. By providing opportunities for networking and learning across agency lines, this type of coordination allows for various agencies to work together to achieve shared goals, typically at lower cost and greater mutual benefit. Additionally, local and regional fire departments may be able to provide local support to prescribed fire programs. These crews are often required to respond to calls about smoke columns arising from controlled burns, even if they are aware of the burn plan. Turning these potentially demanding situations into training opportunities for fire department personnel creates a mutually-beneficial partnership and increases available resources for the burn team.

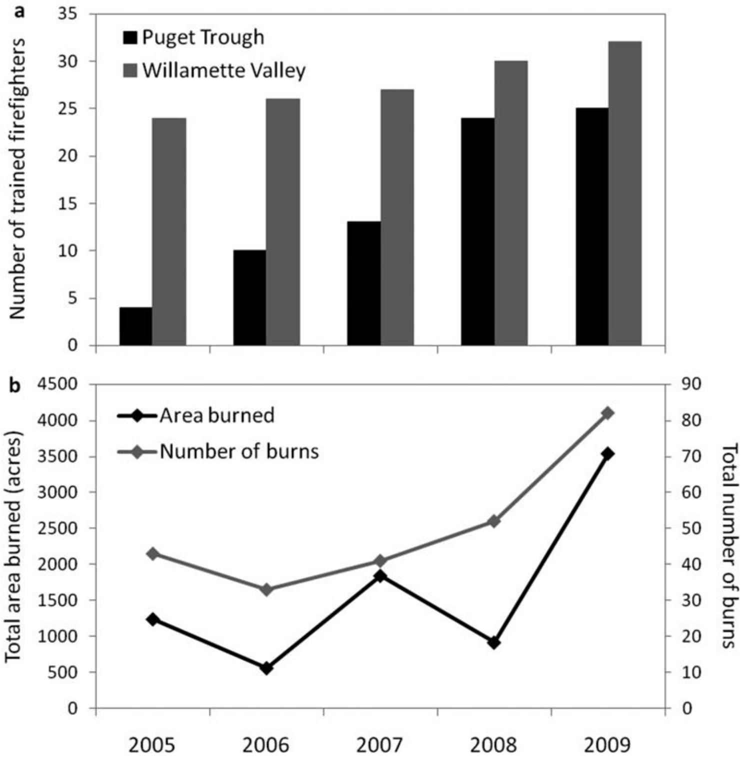

Figure 3. Over the past five years the total number of (a) trained firefighters and (b) acres burned and burn projects in the prairies and oak woodlands of the WPG Ecoregion have substantially increased.

Along with the growth of the trained workforce, there has been a substantial increase in the total number and extent of prescribed burns throughout the Ecoregion over the past five years (Figure 3b). This shift to more and larger burns reflects a growing skill level, improved partner integration and ability to accommodate greater risk and complexity in the application of fire. However, fire application is still ultimately limited by weather patterns, as exemplified by the fewer hectares burned in 2006 and 2008 due to extremely wet weather in the Willamette Valley. If the prescribed burn programs within the WPG Ecoregion continue on the same general trajectory as over the past 5 years, and burn at the target return interval of 3-4 years, acreage burned for restoration of prairies and oak woodlands throughout the Ecoregion should total around 4,000 – 6,000 ha in 2015. This total represents nearly one-third of the remaining intact prairies and oak woodlands throughout the Ecoregion.

Future Directions

Fire can help achieve certain ecological objectives, particularly restoration targets for WPG prairies and oak woodlands. These targets are based on both overall habitat structure (i.e., open, savanna-like habitat, bunchgrass prairie) and specific services these landscapes provide (i.e., nectar and oviposition resources for butterflies, nesting cavities for rare birds and mammals) (Table 2). For scientists and managers to fully understand and utilize fire as a restoration tool, its complexity must be embraced by application, research and monitoring efforts. Based on current knowledge gaps surrounding fire in PNW prairies and oak woodlands, we recommend future research efforts focus on: 1) altered fire season effects on prairie and oak woodland habitat, 2) effects of repeated fires on ecosystem structure and function, 3) species-specific responses to fire, and 4) effects of fire surrogates on ecosystem structure and functioning. Answers to these questions will help to refine prescribed fire management for maximum effectiveness in prairie and oak woodland restoration. Because short-term and long-term fire effects are often very different (Pendergrass et al. 1999, Dunwiddie 2002), it will be important to evaluate these questions over appropriate time scales before incorporating results and lessons learned into management plans.

Many native grassland species have been found to benefit from fire, but only when it is applied during a particular season and paired with other restoration treatments (herbicide, mowing, native seeding) (Engle and Bidwell 2001, Suding and Gross 2006, Brudvig et al. 2007, Simmons et al. 2007, Stanley et al. 2011). Because fire alone can also benefit several non-native invasive species, the current restoration challenge in many fire-adapted systems involves creating habitat for native prairie species while excluding or prohibiting invasion by non-natives. Tveten and Fonda (1999) determined that both spring and fall burns were equally effective at reducing fuel loads in fescue-dominated WPG prairies, but fall burning was much more effective at removing Scotch broom and promoting native species. Stanley et al. (2008, 2011) identified that a combination of seasonal restoration treatments (spring grass-specific herbicide application, fall burning, post-burn broad spectrum herbicide application and fall native seeding) was the most effective at removing invasives and restoring natives to disturbed prairie sites. Little is currently known, however, about how burns conducted very early or very late in the season might influence habitat structure and functioning in these systems. For example, late-season burns conducted under moister conditions may result in much more patchy burns, with far less consumption of moss, litter and woody fuels, than burns conducted during the peak of the summer drought, creating a heterogeneous landscape capable of hosting a more diverse set of species.

Fire return interval plays a large role in prairie and oak woodland community structure and composition (Engle and Bidwell 2007, Gross and Romo 2010). Similar to dry forests and shrublands of the western United States, many of the prairies and oak woodlands of the WPG Ecoregion have experienced fire exclusion over the past century, leading to altered species composition, fuel loading and fuel type (Foster and Shaff 2003, Walsh et al. 2010). It is unrealistic to expect that these sites will re-establish a reasonable trend toward fire-adapted native species dominance after only one or two burns. Furthermore, it may not be appropriate to extrapolate the impacts of one or two burns to how a system may respond over decades of repeated burning (Dunwiddie 2002). It may well take numerous burns, in combination with other management strategies, to successfully restore diverse and resilient grassland and woodland systems. Understanding how multiple fires and the frequency of those fires, when applied over several decades, influence the attainment of ecological objectives will be a valuable contribution to developing sound fire management plans into the future.

When deciding on application method, species-specific responses must also be considered. Because there are so many rare, vulnerable and imperiled species in this ecosystem, specific knowledge about response to fire can help to conserve rare species habitat and even particular life history traits (i.e., germination rates, fruiting, flowering, seedling establishment, timing of larval diapause and use of host plants, phenology of emergence, etc.) (Barker and Williamson 1988). Kaye et al. (2001) found that biennial fall burning increased growth rates and decreased the extinction likelihood of Federally endangered Bradshaw's desert-parsley (*Lomatium bradshawii*) populations, despite significant environmental stochasticity, relative to unburned populations. However, Dunwiddie (2002) found that multiple burns on a prairie resulted in responses by individual species that differed widely in magnitude, direction and duration between burns. Streaked horned lark (*Eremophila alpestris strigata*), a Federal candidate species, benefits from open and very sparsely vegetated habitat, so frequent fire may improve conditions for these birds (Pearson et al. 2005), but this prescription may not be appropriate for certain butterfly species (Schultz et al. 2011). Providing detailed knowledge about fire regime impacts on high fidelity prairie and oak woodland species will inform fire management plans and help to improve the utility of fire as a restoration tool.

Fire cannot always be utilized as a restoration tool on certain sites due to greater risk to surrounding properties, smoke management issues, property regulations or presence of fire-sensitive species. Other restoration methods can potentially be used to achieve ecological objectives in the WPG Ecoregion. McDougall and Turkington (2007) found fire surrogate treatments (mowing and weeding) to be just as effective as prescribed fire for exotic species control and native plant growth in Garry oak savannas of the Georgia Basin. However, evidence from Midwestern prairies suggests that mowing is not as effective as fire and herbicide at controlling invasive grasses (Simmons et al. 2007), but if applied in the appropriate season, may help enhance certain rare native species (Howe 1999). When evaluating fire surrogates, we need to carefully consider what effectiveness metrics are most appropriate to measure to evaluate attainment of our ecological objectives. For instance, while certain methods may successfully reduce exotic species cover, they may not reduce moss or litter cover, thereby limiting native establishment. As we develop a better understanding of the role of different types of fires on prairie and oak woodland structure and functioning, it will be important to investigate potential surrogate treatments to mimic fire effects.

Conclusions

Restoring fire to prairies and oak woodlands is a complex process that must incorporate past knowledge, current challenges and changing future conditions. As has been observed in other ecosystems throughout the western U.S., simply applying practices used by indigenous cultures may not return systems to an earlier state, given today's altered fuel loads, invasive species and the risks associated with burning in the wildland-urban interface (Moore et al. 1999, Swetnam et al. 1999). Tackling present-day challenges surrounding prescribed fire application requires a collaborative, interdisciplinary, adaptive management approach that can be best served by working across agency and political boundaries. Working throughout the WPG Ecoregion to answer some of the highest priority questions surrounding altered fire regimes, species responses to fire and fire surrogate effects on ecological objectives will provide widely applicable findings with local significance, and it will generate opportunities for the different prescribed burn programs to learn from each other. Lessons learned about overcoming certain social, political and programmatic obstacles related to prescribed fire implementation can be shared and implemented across borders. As more regional and national agencies recognize the need for safe application of fire for restoration and fuel reduction purposes (WDNR 2008, USFWS 2010), the prescribed fire programs developed here in the WPG Ecoregion can serve as models of successful, large-scale, science-based fire management programs that embrace and utilize the complexity of fire for effective habitat restoration.

Acknowledgements

We gratefully acknowledge Shyanne Smith and Irvin Banman for helpful information about fire program history and development in the Georgia Basin, Ed Alverson for information on rare species of the WPG Ecoregion, Erica Simek for the WPG Ecoregional map and Cheryl Fimbel for the butterfly resource photos. We also thank Jeremy Bailey for providing information on both regional and national fire program planning and development. This work was supported by The Nature Conservancy.

Literature Cited

Abrams. M. D., A. K. Knapp, and L. C. Hulbert. 1986. A ten-year record of aboveground biomass in Kansas tallgrass prairie: Effects of fire and topographic position. American Journal of Botany 73:1509-1515.

Agee, J. K. 1996. Achieving conservation biology objectives with fire in the Pacific Northwest. Weed Technology 10:417-421.

Augustine, D. J., and D. G. Milchunas. 2009. Vegetation responses to prescribed burning of grazed shortgrass steppe. Rangeland Ecology and Management 62:89-97.

Bachelet, D., B. R. Johnson, S. D. Bridgham, P. V. Dunn, H. E. Anderson, and B. M. Rogers. 2011. Climate change impacts on western Pacific Northwest prairies and savannas. Northwest Science 85:411-433.

Barker, N. G., and G. B. Williamson. 1988. Effect of winter fire on *Sarracenia alata* and S. *psittacina*. American Journal of Botany 75:138-143.

Bidwell, T. G., D. M. Engle, and P. L. Claypool. 1990. Effects of spring headfires and backfires on tallgrass prairie. Journal of Range Management 43:209-212.

Bidwell, T. G., and D. M. Engle. 1992. Relationship of fire behavior to tallgrass prairie herbage production. Journal of Range Management 45:579-584.

Black, A., M. Williamson, and D. Doane. 2008. Wildland fire use barriers and facilitators. Fire Management Today 68:10-14.

Blair, J. M. 1997. Fire, N availability, and plant response in grasslands: A test of the transient maxima hypothesis. Ecology 78:2359-2368.

Bowman, D. M. J. S., and F. H. Johnston. 2005. Wildfire smoke, fire management and human health. EcoHealth 2:76-80.

Boyd, R. 1999. Indians, Fire, and the Land in the Pacific Northwest. Oregon State University Press, Corvallis.

Brown, J. K., and J. K. Smith. 2000. Wildland fire in ecosystems: effects of fire on flora. USDA

Forest Service General Technical Report RMRS-GTR-42-vol. 2. Rocky Mountain Research Station, Ogden, UT.

Brudvig, L. A., C. M. Mabry, J. R. Miller, and T. A. Walker. 2007. Evaluation of central North American prairie management based on species diversity, life form and individual species metrics. Conservation Biology 21:864-874.

Crawford, R. C., and H. Hall. 1997. Changes in the south Puget prairie landscape. *In* P. V. Dunn and K. Ewing (editors), Ecology and Conservation of the South Puget Sound Prairie Landscape. The Nature Conservancy, Seattle, WA. Pp. 11-15.

Dunwiddie, P. W. 2002. Management and restoration of grasslands on Yellow Island, San Juan Islands, Washington, USA. *In* P. J. Burton (editor), Proceedings of the Third Annual Meeting of the B.C. Chapter of the Society for Ecological Restoration, University of Victoria. B.C. Chapter of the Society for Ecological Restoration, Victoria, British Columbia. Pp. 78-87.

Emery, S. M., and K. L. Gross. 2004. Effects of timing of prescribed fire on the demography of an invasive plant, spotted knapweed *Centaurea maculosa*. Journal of Applied Ecology 42:60-69.

Engle, D. M., M. W. Palmer, J. S. Crockett, R. L. Mitchell, and R. Stevens. 2000. Influence of late season fire on early successional vegetation of an Oklahoma prairie. Journal of Vegetation Science 11:135-144.

Engle, D. M., and T. G. Bidwell. 2001. The response of central North American prairies to seasonal fire. Journal of Range Mangement 54:2-10.

Foster, J. R., and S. E. Shaff. 2003. Forest colonization of the Puget Lowland Grasslands at Fort Lewis, Washington. Northwest Science 77:283-296.

Gedalof, Z., M. Pellatt, and D. J. Smith. 2006. From prairie to forest: three centuries of environmental change at Rocky Point, Vancouver Island, British Columbia. Northwest Science 80:34-46.

Gross, D. V., and J. T. Romo. 2010. Temporal changes in species composition in Fescue Prairie: relationships with burning history, time of burning, and environmental conditions. Plant Ecology 208:137-153.

Garry Oak Ecosystem Recovery Team (GOERT). 2002. Recovery strategy for Garry oak and associated ecosystems and their associated species at risk in Canada 2001-2006. Garry Oak Ecosystems Recovery Team. Victoria, BC.

Harrington, J. A., and E. Kathol. 2009. Responses of shrub midstory and herbaceous layers to managed grazing and fire in a North American savanna (oak woodland) and prairie landscape. Restoration Ecology 17:234-244.

Henry, E. H. 2010. A first step towards successful habitat restoration and reintroduction: understanding oviposition site selection of an imperiled butterfly, Mardon skipper. M.S. Thesis, Washington State University, Vancouver.

Hurteau, M., and M. North. 2009. Response of *Arnica dealbata* to climate change, nitrogen deposition, and fire. Plant Ecology 202:191-194.

Kaye, T. N., K. L. Pendergrass, K. Finley, and J. B. Kauffman. 2001. The effect of fire on the population viability of an endangered prairie plant. Ecological Applications 11:1366-1380.

Keeley, J. E. 2009. Fire intensity, fire severity and burn severity: a brief review and suggested usage. International Journal of Wildland Fire 18:116-126.

Kobziar, L. N., M. E. Rocca, C. A. Dicus, C. Hoffman, N. Sugihara, A. E. Thode, J. M. Varner, and P. Morgan. 2009. Challenges to educating the next generation of wildland fire professionals in the United States. Journal of Forestry 107:339-345.

Lawson, D. M., H. M. Regan, P. H. Zedlers, and J. Franklin. 2010. Cumulative effects of land use, altered fire regime and climate change on persistence of *Ceanothus verrucosus*, a rare, fire-dependent plant species. Global Change Biology 16:2518-2529.

Lea, T. 2006. Historical Garry oak ecosystems of Vancouver Island, British Columbia, pre-European contact to the present. Davidsonia 17:34-50.

MacDougall, A. S., and R. Turkington. 2007. Does the type of disturbance matter when restoring disturbance-dependent grasslands? Restoration Ecology 15:263-272.

Moore, M. M., W. W. Covington, and P. Z. Fulé. 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications 9:1266-1277.

Mote, P. W., and E. P. Salathé, Jr. 2010. Future climate in the Pacific Northwest. Climate Change 102:29-50.

Oregon Administrative Rule (OAR). Department of Environmental Quality, Division 266: Field burning rules (Willamette Valley). DEQ 8-2010, f. & cert. ef. 8-27-10.

Owen, W. R., and R. Rosentreter. 1992. Monitoring rare perennial plants: techniques for demographic studies. Natural Areas Journal 12:32-39.

Panzer, R. 2002. Compatibility of prescribed burning with the conservation of insects in small, isolated prairie preserves. Conservation Biology 16:1296-1307.

Pearson, S. F., H. E. Anderson, and M. Hopey. 2005. Streaked horned lark monitoring, habitat manipulations and a conspecific attraction experiment. Washington Department of Fish and Wildlife, Olympia, WA.

Pendergrass, K. L., P. M. Miller, J.B. Kauffman, and T. N. Kaye. 1999. The role of prescribed burning in maintenance of an endangered plant species, *Lomatium bradshawii*. Ecological Applications 9:1420-1429.

Peterson, D. W., and P. B. Reich. 2001. Prescribed fire in oak savanna: fire frequency effects on stand structure and dynamics. Ecological Applications 11:914-927.

Pyne, S. J., P. L. Andrews, and R. D. Laven. 1996. Introduction to Wildland Fire. John Wiley and Sons, Inc. New York, NY.

Rooney, T. P., and M. K. Leach. 2010. Replacing hay-mowing with prescribed fire restores species diversity and conservation value in a tallgrass prairie sampled thrice: a 59-year study. The American Midland Naturalist 164:311-321.

Schultz, C. B., and E. E. Crone. 1998. Burning prairie to restore butterfly habitat: a modeling approach to management tradeoffs for the Fender's blue. Restoration Ecology 6:244-252.

Schultz, C. B., E. Henry, A. Carleton, T. Hicks, R. Thomas, A. Potter, M. Collins, M. Linders, C. Fimbel, S. Black, H. E. Anderson, G. Diehl, S. Hamman, R. Gilbert, J. Foster, D. Hays, D. Wilderman, R. Davenport, E. Steel, N. Page, P. L. Lilley, J. Heron, N. Kroeker, C. Webb, and B. Reader. 2011. Conservation of prairie-oak butterflies in Oregon, Washington, and British Columbia. Northwest Science 85:361-388.

Simmons, M. T., S. Windhager, P. Power, J. Lott, R. K. Lyons, and C. Schwope. 2007. Selective and non-selective control of invasive plants: The short-term effects of growing-season prescribed fire, herbicide and mowing in two Texas prairies. Restoration Ecology 15:662-669.

Sprenger, C. B., and P. W. Dunwiddie. 2011. Fire history of a Douglas-fir–Oregon white oak woodland, Waldron Island, Washington. Northwest Science 85:108-119.

Stanley, A. G., T. N. Kaye, and P. W. Dunwiddie. 2008. Regional strategies for restoring invaded prairies: observations from a multisite, collaborative research project. Native Plants Journal 9:247-254.

Stanley, A. G., P. W. Dunwiddie, and T. N. Kaye. 2011. Restoring invaded Pacific Northwest prairies: Management recommendations from a region-wide experiment. Northwest Science 85:233-246.

Storm, L., and D. Shebitz. 2006. Evaluating the purpose, extent, and ecological restoration applications of indigenous burning practices in southwestern Washington. Journal of Ecological Restoration 24:256-268.

Suding, K. N., and K. L. Gross. 2006. Modifying native and exotic species richness correlations: the influence of fire and seed addition. Ecological Applications 16:1319-1326.

Swengel, A. B., and S. R. Swengel. 2007. Benefit of permanent non-fire refugia for Lepidoptera conservation in fire-managed sites. Journal of Insect Conservation 11:263-279.

Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications 9:1189-1206.

Tveten, R. K., and R. W. Fonda. 1999. Fire effects on prairies and oak woodlands on Fort Lewis, Washington. Northwest Science 73:145-158.

U.S. Fish & Wildlife Service (USFWS). 2010. Wildland Fire Management: Keeping fire on our side. Fire Management Branch, National Interagency Fire Center, Boise, ID.

Vesely, D. G., and D. K. Rosenberg. 2010. Wildlife Conservation in the Willamette Valley's Remnant Prairie and Oak Habitats: A Research Synthesis. Oregon Wildlife Institute, Corvallis, OR.

Walsh, M. K., C. A. Pearl, C. Whitlock, P. J. Bartlein, and M. A. Worona. 2010. An 11,000-year-long record of fire and vegetation history at Beaver Lake, Oregon, central Willamette Valley. Quaternary Science Reviews 29:1093-1106.

Weiser, A., and D. Lepofsky. 2009. Ancient land use and management of Ebey's Prairie, Whidbey Island, Washington. Journal of Ethnobiology 29:184-212.

Washington State Department of Natural Resources (WDNR). 2008. Recommendations of the Forest Fire Prevention and Protection Work Group. Resource Protection Division, Olympia, WA.

Received 1 October 2010
Accepted for publication 4 February 2011