Restoration of dry, montane meadows through prescribed fire, vegetation and fuels management: A program of research and adaptive management in western Oregon

Project 01C-3-3-10

Final Report to the Joint Fire Science Program

Frederick J. Swanson
USFS, PNW Research Station
Corvallis, Oregon

Charles B. Halpern
College of Forest Resources
University of Washington
Seattle, Washington

John H. Cissel
Joint Fire Science Program
Boise, Idaho

29 September 2007

Executive Summary

Mountain meadows in the Pacific Northwest, as in much of western North America, have experienced recent and rapid invasion by conifers. Changes in climate, cessation of sheep grazing, and long-term suppression of wildfire likely contribute to the observed replacement of meadow by forest. Faced by gradual loss of these habitats, land managers in the western Cascades of Oregon are using tree removal and prescribed burning as tools for restoration. However, these efforts have been undertaken with limited understanding of the historical role of fire in these meadow ecosystems, of the range of current vegetation conditions, and of the potential for restoration.

Through a collaborative effort of the research community and the Willamette National Forest in western Oregon, we have developed a program of research, education, and outreach at Bunchgrass Ridge — a complex of dry, montane meadows and coniferous forests of varying age and structure.

We have designed our research as an integrated series of observational field studies and experiments. Through retrospective analyses we explore the history of conifer encroachment — covering nearly two centuries of invasion — and its consequences for vegetation change. These provide the historical and ecological contexts for a large-scale experiment that addresses the following questions: (1) Is restoration of dry, montane meadows possible with tree removal and prescribed burning? (2) Is fire necessary for restoration or is tree removal sufficient? (3) Does the potential for restoration depend on the stage of conifer encroachment? (4) How do our experimental results bear on operational alternatives?

Retrospective Studies: Ecology and Dynamics of Montane Meadows

Detailed reconstructions of forest age structures at Bunchgrass Ridge provide insight into the timing and spatial patterning of invasion, the importance of facilitation and positive feedbacks in driving this process, and the consequences of tree encroachment for loss of meadow diversity and extent.

- Lodgepole pine and grand fir have established in meadows at Bunchgrass Ridge during two broad intervals that span nearly two centuries. Most invasion has occurred adjacent to existing edges, but occasional establishment in open meadow has led to new foci for expansion. Spatial-pattern analysis suggests that facilitation may drive the conversion of meadow to forest as early recruits (often lodgepole pine) modify the local environment for subsequent establishment (typically grand fir). This result underscores the importance of biological processes — in addition to the well-appreciated roles of climate and fire — in the dynamics of these systems. It also suggests that positive feedbacks can allow for invasion of meadow at times when climate might otherwise be unfavorable for tree establishment.
- Tree establishment is accompanied by rapid changes in ground vegetation. These reflect two simultaneous processes: displacement of meadow species and colonization by forest herbs. Both occur rapidly: within 60-80 yr of initial tree establishment, the understory is dominated by forest plants.
- Lodgepole pine and grand fir differ markedly in their facilitation of forest herbs. Under grand fir, abundance and richness of forest herbs are positively related to tree age (and

size). Under pine, there is no direct effect of age. Instead the effect of pine on understory vegetation appears to be indirect, i.e., through its facilitation of grand fir.

- Rapid replacement of meadow by forest species, as well as modification of soil chemical and biological properties by conifers, may pose barriers to restoration of these systems. Our results suggest that removing grand fir (of any age) should be a higher priority than removing pine. Clearly, however, removing trees during the earliest stages of encroachment is the most effective strategy for maintaining these systems.
- Studies of the soil seed bank suggest a limited potential for reintroduction or recovery of most meadow species via buried, viable seed. Nearly three-quarters of the species that characterize these meadows are absent from the seed bank. As a consequence, without further intervention, reestablishment of meadow species will require dispersal of seed, or gradual vegetative spread from adjacent openings. At the same time, seed banks are dominated by ruderal (early successional) grasses and herbs that may compete with target species during restoration efforts.

Experimental Studies: Restoration of Meadows by Tree Removal and Prescribed Burning

The experiment includes three replicates of three 1-ha (2.5 ac) treatments: (1) a control (no harvest), (2) tree removal with slash piled and burned (leaving most of the ground surface unburned), and (3) tree removal with the slash broadcast burned. Tree removal was conducted in winter on deep, compacted snow. Broadcast and pile burning were completed the following fall.

Replication and the untreated control enable us to make strong inferences about the effects of the restoration treatments across the backdrop of natural variation in vegetation composition in space and time. Treatments 2 and 3 allow us to test whether tree removal is sufficient to achieve restoration goals, or whether fire is also necessary. Within experimental units, a range of habitats, including areas with few trees, recent invasion (<75 yr), and older forest (95-200 yr) allows us to test whether potential for restoration depends on the stage of encroachment.

Delays in implementation of the experiment have limited initial post-treatment sampling to a single growing season. Nevertheless early results point to some striking differences in response among treatments, and to how these may be conditioned by pre-treatment forest structure. They also bear on some of the operational limitations and ecological consequences of alternative approaches to fuel reduction.

- Broadcast burning led to significant exposure of mineral soil and to increases N availability. In contrast, in the absence of fire, harvest over snow resulted in minimal soil disturbance. Similar outcomes would not have been possible if snow cover had not been present during yarding.
- Greater soil disturbance and short-term increases in N availability in broadcast burned treatments should promote greater establishment of ruderals. Surprisingly, however, in the first growing season, ruderals contributed minimally to the vegetation in either treatment, despite their prominence in the seed bank.
- Disposal of slash through pile burning represents a tradeoff between the extent and intensity of disturbance. Although burn scars covered only 10% of the ground surface their centers were characterized by significant exposure of mineral soil and

concentrations of NH_4^+-N, greatly exceeding those in broadcast burned treatments. Vegetation recovery may be problematic within burn scars; these intensely disturbed sites may also serve as foci for future invasion of weedy species.

- Gathering of slash in piles can be effective at reducing ground fuels, but hand piling can be labor intensive. At the same time, piles can be burned during late fall or early winter at a time when fire risk, as well as cost and effort associated with containment, is low. By comparison, weather conditions for broadcast burning are more restrictive, and fire containment requires greater effort and cost.
- In the short term, tree removal, with or without burning, appears to benefit meadow species at the expense of forest herbs. Changes in the abundance and diversity of meadow taxa were small relative to forested controls. In contrast, forest herbs declined significantly, particularly after burning, potentially allowing for future recruitment or spread of meadow species.
- Meadow species show potential for recovery across a wide range of forest structures. Even in old forest, where abundance and diversity of meadow species were low, responses to overstory removal and burning were neutral or positive. Persistence through disturbance, dramatic reductions in the abundance of forest herbs, and limited recruitment of ruderal species suggest potential for meadow recovery across a broad range of forest ages and structures.
- For taxa that have been lost from the system, long-term recovery will require reintroduction through seed dispersal or vegetative expansion from adjacent edges. In our system, these processes may be aided by the mosaic of residual meadow openings that occur among areas of encroachment. Focusing future restoration efforts along ecotonal areas or on small tree islands will maximize the potential for seed dispersal or vegetative spread.

Clearly, longer term observations are needed to determine whether tree removal and fire can be used to reverse the effects of encroachment, and the conditions under which restoration is possible. They may also suggest possible alternative approaches.

We see great potential for existing and future studies at Bunchgrass Ridge to inform the management and restoration of western Cascade meadows. We have invested heavily in education and outreach and expect these activities to expand as we learn more from these and additional studies.

Table of Contents

1. Overview

Mountain meadows comprise a small portion of the western Cascade landscape, but serve many important ecological and societal functions. In a region dominated by dense coniferous forest, meadows create natural fire breaks, support distinctive plant and animal communities (Hickman 1976, Halpern et al. 1984), provide habitat and forage for wildlife, and offer unique recreational opportunities.

Throughout the Pacific Northwest — as in much of western North America — mountain meadows have experienced recent and fairly rapid encroachment by conifers. Numerous factors have contributed to invasion — changes in climate, cessation of sheep grazing, and long-term suppression of wildfire (e.g., Vale 1981, Rochefort et al. 1994, Woodward et al. 1995, Rochefort and Peterson 1996, Miller and Halpern 1998, Hadley 1999).

Faced by gradual loss of these valuable habitats, land managers have begun to use prescribed fire as a tool for restoration. However, these efforts have been undertaken with limited understanding of the historical role of fire in these systems, of the current range of ecological conditions, and of the potential for restoration where encroachment has led to significant loss or degradation of native meadow communities.

With funding from the Joint Fire Science Program (JFSP), we have developed a program of research and adaptive management at Bunchgrass Ridge in the Willamette National Forest of western Oregon. We have brought together scientists and resource specialists with a long, successful history of collaboration through what is now called the Central Cascades Adaptive Management Partnership based at the H.J. Andrews Experimental Forest/Long-Term Ecological Research (LTER) site.

We identified two primary goals in our original proposal: to improve our understanding of the ecology and dynamics of mountain meadows in this region, and to assist land managers in designing strategies for meadow restoration and maintenance. We suggested that successful restoration would require:

- improved understanding of the history of conifer encroachment and its consequences for meadow composition and structure
- experimental studies to quantify the range of potential responses to fuel reduction treatments including prescribed fire
- collaboration and information sharing among researchers, managers, and the public
- a process of adaptive management by which experimental outcomes would guide new approaches to restoration.

We have been successful in achieving these goals. In this final report to the JFSP, we review our achievements and findings to date. These are also available on our Web site: http://depts.washington.edu/bgridge/index.htm.

We acknowledge the contributions of many researchers and field staff who have assisted with these studies, and especially the productive collaboration with resource managers on the Willamette National Forest. Treatment implementation was made possible with financial support from the Rocky Mountain Elk Foundation and in-kind contributions from the Confederated Tribes of the Grand Ronde and the McKenzie River Ranger District. Funding from the Willamette National Forest supported supplemental studies of treatment effects on soils. Finally, many students have pursued research and training opportunities supported by a diversity of federal

and international programs. Through these synergies, it has been possible to build a broader program of research and education than envisioned in our original proposal.

As with many complex field manipulations — particularly those that involve timber harvest and prescribed fire on federal lands — the experimental portion of our work has experienced significant delays. Turnover in key management staff during merger of the Blue River and McKenzie Ranger Districts, associated delays in the EA process, and an inability to implement harvest during winter 2005 due to lack of snow have resulted in a 30-month delay in completion of the treatments relative to the original, proposed schedule.

We reported these delays in annual progress reports to JFSP and received a one-year extension. However, termination of this grant in September 2007 constrains our ability to report on early, post-treatment responses; the timing of treatment permitted only a single post-treatment measurement (August 2007). Nevertheless, we have completed a first analysis and synthesis of early responses to treatments.

With supplemental funding from the Willamette National Forest, we have also added two complementary studies to the experiment: effects of restoration treatments on soil chemistry and local effects of burn piles on vegetation and soils.

We see great potential for this program of research to increase understanding of montane meadow ecosystems and to inform future attempts at restoration. Bunchgrass Ridge now serves as a center for research, adaptive management, and outreach — one that provides opportunities for long-term study, experimentation, and education.

2. Study Area

Environment. Bunchgrass Ridge forms a broad, gently sloping plateau in the Cascade Range of western Oregon. It lies along the boundary of the older, steeply dissected western Cascade Range and the younger, high Cascade peaks. Elevations range from 1220 to1375 m (4000 to 4500 ft) and slopes are gentle (<5%), facing primarily southwest. Climate is maritime, with warm dry summers and cool, wet winters. Most precipitation falls during winter, with >1000 cm of snowfall. Snowpacks can exceed 2 m and persist into late May.

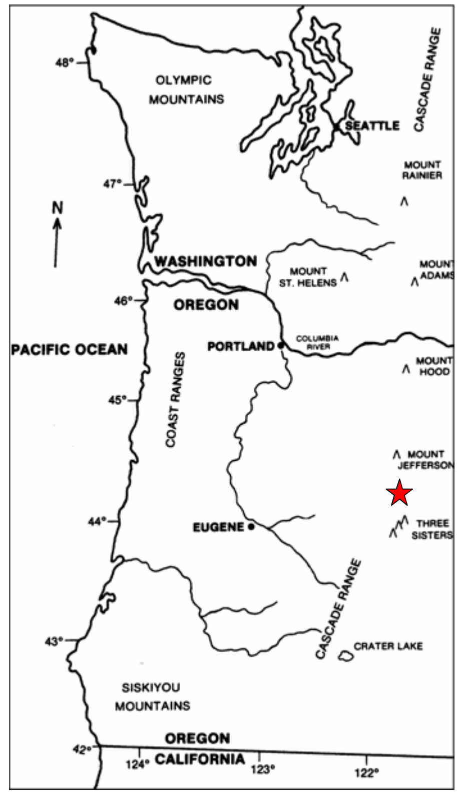


Fig. 1. Western Cascade landscape with Bunchgrass Ridge (below arrow) as seen from the north. Location map (right).

Vegetation. The plateau supports a mosaic of dry meadows, areas of recent encroachment (<75 yr), and older forests (>100-200 yr). Meadows are dominated by graminoids (mainly *Festuca idahoensis* and *Carex pensylvanica*) and forbs, and forests by grand fir (*Abies grandis*) and lodgepole pine (*Pinus contorta*). Forest understory species are typical of rich, mesic sites (e.g., *Smilacina stellata, Achlys triphylla*, *Galium oreganum*, and *Anemone oregana*) (Hemstrom et al. 1987). For a full list of plant species at Bunchgrass Ridge, see Appendix 1 (section 8.1).

The study area is surrounded by mature and old-growth forests and by regenerating stands that originated from clearcut logging in the 1970s and 1980s.

Soils. Soil profiles beneath meadow and older forest suggest centuries of development beneath grassland vegetation (see Appendix 2). Soils are deep (>170 cm), fine to very-fine-sandy loams derived from andesitic basalt and deposits of tephra with variable amounts of glacially derived cobbles, stones, and boulders.

Disturbance history. Information on fire and grazing history are lacking for Bunchgrass Ridge. At this elevation in the western Cascades, fires are likely to have been infrequent (>100 yr; Teensma 1987) and episodic, driven by variation in climate and human activity (Weisberg and Swanson 2003). Native Americans are thought to have used fire to maintain open habitats throughout the Northwest (Boyd 1999). However, stumps within experimental plots do not show evidence of fire and archeological surveys have failed to produce artifacts from human use of the meadow prior to Euro-American settlement.

Grazing by sheep is likely to have occurred during the early part of the 20th century, synchronous with widespread grazing in the Cascades (Burke 1979, Johnson 1985, Rakestraw and Rakestraw 1991). However, data on the timing or intensity of local grazing are not present in Forest Service archives.

Recent conifer encroachment. Recent encroachment of conifers into meadows has been dramatic (Fig. 2). The study area supported a mix of forest and meadow for much of the 20th century, but many open areas have since been filled by trees.

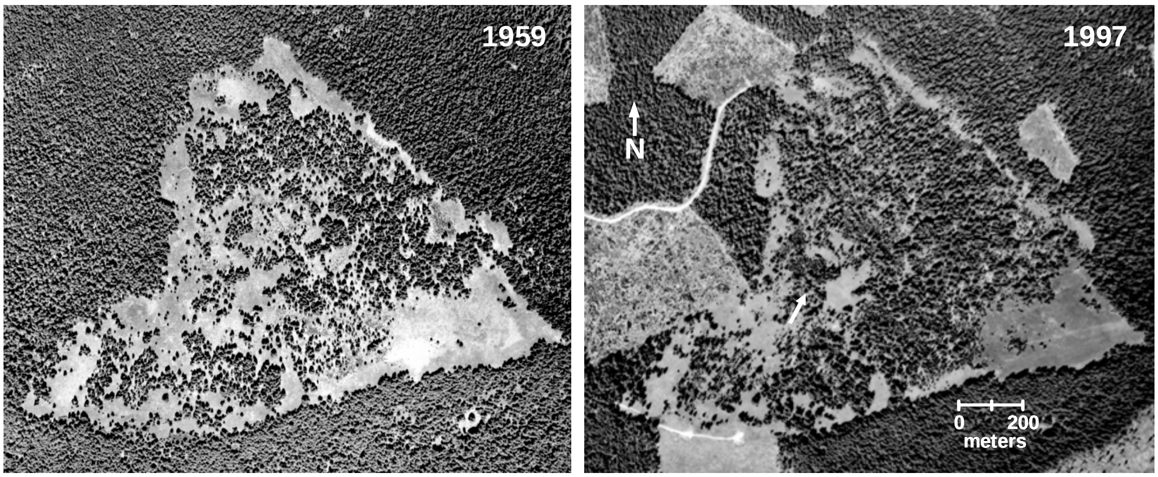


Fig. 2. Aerial photos of the study area illustrating the rapid closure of meadows during the latter half of the 20th century. Forests in the 1959 photo are now >100 yr old. Clearcuts are apparent in the 1997 photo.

Designation as a Special Habitat Area. Bunchgrass Ridge was designated as a Special Habitat Area in the 1990 Willamette National Forest Land and Resource Management Plan and was targeted as high priority for restoration during the 1995 Upper McKenzie Watershed Analysis. The primary objectives of restoration included: (1) improving wildlife use by enhancing forage quality and abundance, (2) reducing excessive fuel loadings, (3) maintaining and restoring grass- and forb-dominated communities and associated ecological processes, and (4) protecting and preserving historic and prehistoric heritage resources (Wilson et al. 1999).

3. Research Program

We have designed our research as an integrated series of observational, retrospective, and experimental studies. We began by examining the history of conifer encroachment at Bunchgrass Ridge and its consequences for biological diversity. The results of these studies provide the historical and ecological contexts for a large-scale experiment in which we are testing the potential for restoration through tree removal and prescribed fire. Here we briefly review the major findings and implications of these studies.

3.1. Ecology and dynamics of montane meadows: retrospective and observational studies

3.1.1. History of conifer encroachment

3.1.1.1. Spatial and temporal patterns of conifer invasion

Manuscript in preparation. Antos, J. A., C. B. Halpern, J. Rice, R. D. Haugo, and N. L. Lang. Tree invasion of a montane meadow: a spatial and temporal analysis. Ecology.

Knowledge of the timing and spatial structure of conifer invasion into meadows is critical to understanding the natural dynamics of forest-meadow boundaries and to establishing a baseline for assessing future change. In this study, we addressed the following questions:

- Has tree invasion at Bunchgrass Ridge been chronic or episodic?
- Are invading trees spatially aggregated?
- Has tree invasion been concentrated along edges or do isolated trees invade open meadow forming foci for subsequent invasion?
- Does initial establishment facilitate further recruitment?
- How do lodgepole pine and grand fir differ in their invasion patterns and potential interactions?

Methods. We used historical aerial photographs and extensive field reconnaissance of Bunchgrass Ridge to select study areas that included open meadow, recent encroachment, and old forest. From nine, 1-ha (2.5 ac) plots that would serve as experimental units in our restoration experiment, we selected four for intensive dendrochronological analysis. We mapped and measured all live and dead stems (n = 5,486 and 1386, respectively) taller than 1.4 m (4.6 ft) (Fig. 3). All live stems were then aged from increment cores or basal sections.

Age structures were developed and uni- and bivariate spatial statistics were computed to characterize temporal and spatial patterns of invasion.

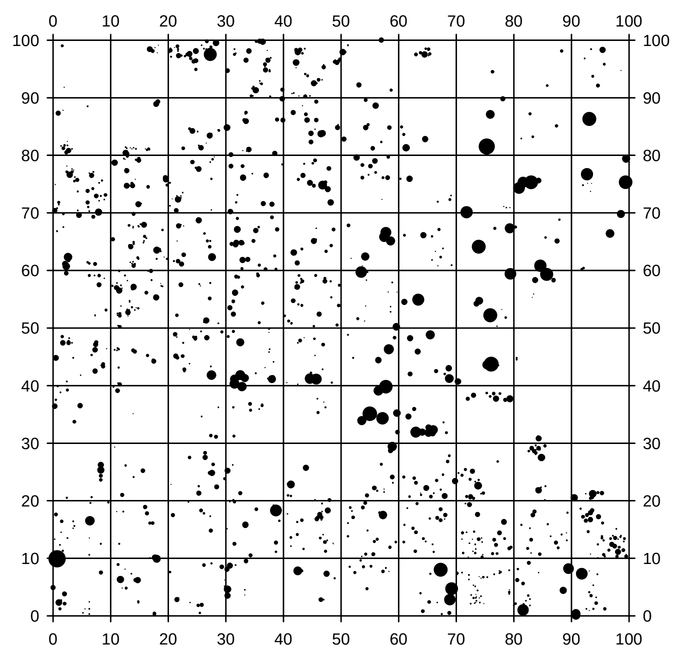


Fig. 3. Stem map of a 1-ha (2.5 ac) plot with trees scaled to diameter.

Results

- Establishment occurred during two broad intervals separated by a period of limited recruitment. During both intervals, establishment of lodgepole pine often preceded that of grand fir (Figs. 4, 6).
- Most individuals in the more recent, massive wave of invasion established in open meadow, but grand fir also recruited beneath its own canopy (Fig. 5).
- Most invasion occurred adjacent to existing edges (grand fir), but occasional establishment in open meadow (lodgepole pine) led to new foci for expansion.

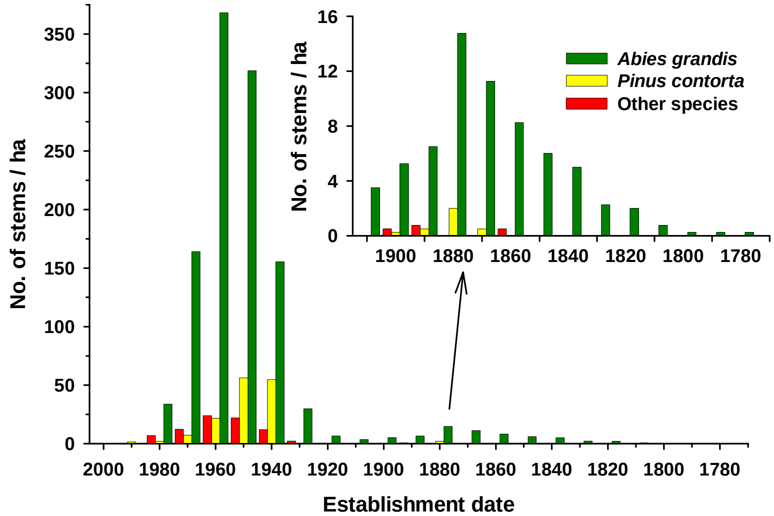


Fig. 4. Composite age structure of trees. The initial period of recruitment is enlarged for clarify. Many pine that established in the original cohort still persist as snags, but are not present in the live age structure.

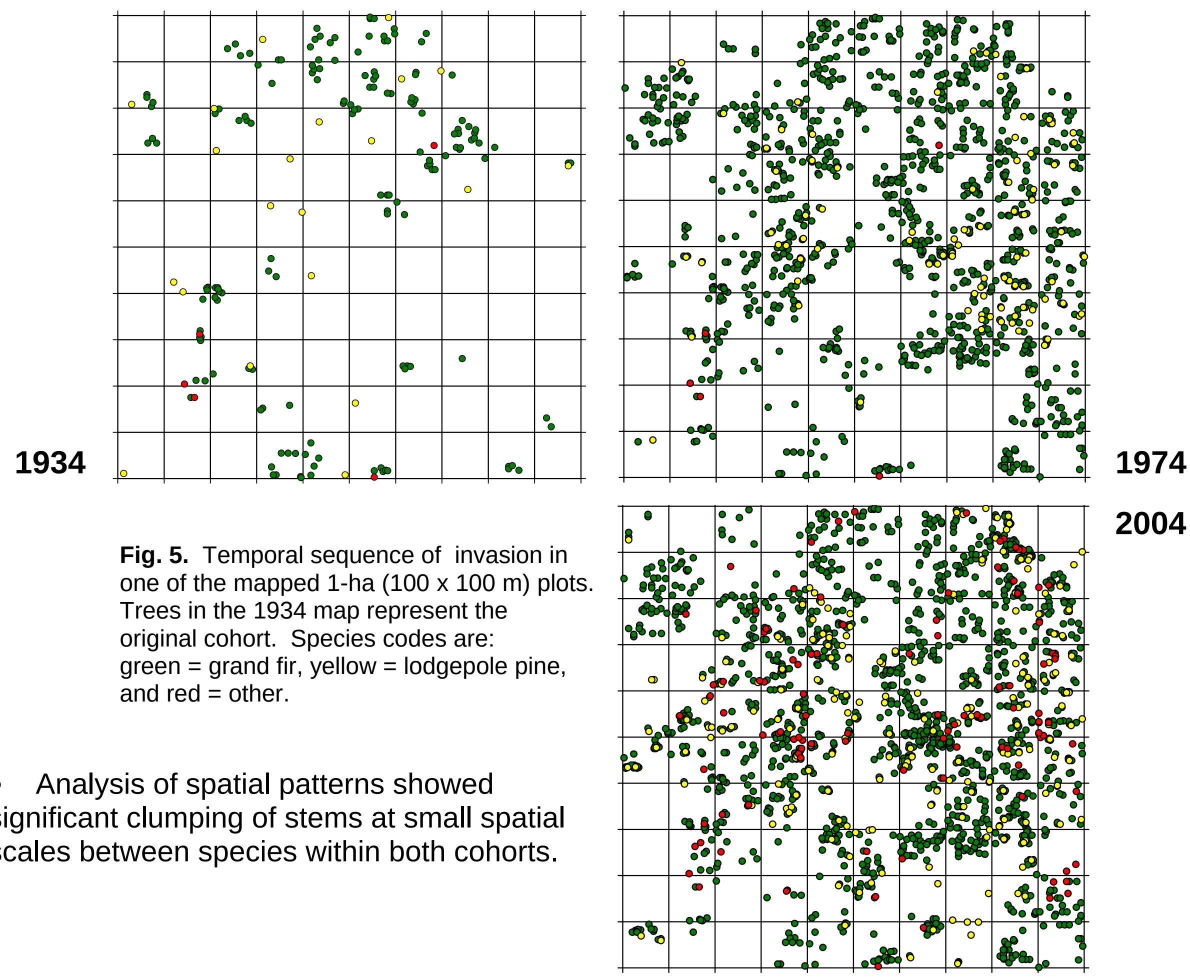


Fig. 5. Temporal sequence of invasion in one of the mapped 1-ha (100 x 100 m) plots. Trees in the 1934 map represent the original cohort. Species codes are: green = grand fir, yellow = lodgepole pine, and red = other.

- Analysis of spatial patterns showed significant clumping of stems at small spatial scales between species within both cohorts.

Conclusion. Facilitation appears to be an important driving force in conversion of dry, montane meadows to forest as early recruits modify the local environment for subsequent establishment. This underscores the importance of biological processes — in addition to climate and fire — in the long-term dynamics of these systems. It also suggests that positive feedbacks can lead to continuous invasion of meadows at times when climatic conditions might otherwise be unfavorable for establishment.

Fig. 6. Examples of recent and past facilitation of grand fir by lodgepole pine. Taller pines in the left photo are ~50 yr old and the small grand fir are ~20 yr old. The pine snag in the center of the right photo established in the mid-1800s; it is surrounded by mature grand fir.

3.1.1.2. Detecting change in meadow extent through analysis of aerial photography

Using GIS analyses of historical aerial photographs of Bunchgrass Ridge, Janine Rice, doctoral student at Oregon State University, is quantifying rates and environmental correlates of transitions from meadow to forest (and forest to meadow) (Fig. 7). She is addressing the following questions:

- At what rates have meadows been lost since the mid 1900s?
- What proportion of the study area remains in open meadow?
- Do rates of loss vary with slope and aspect?
- Do changes in rates of loss correlate with variation in climatic conditions during different periods of invasion?

This work comprises one chapter of her dissertation, *Forest-meadow dynamics of the western Oregon Cascades: patterns of change and environmental causes.*

The results of this work will be made available once the dissertation has been completed (November 2007).

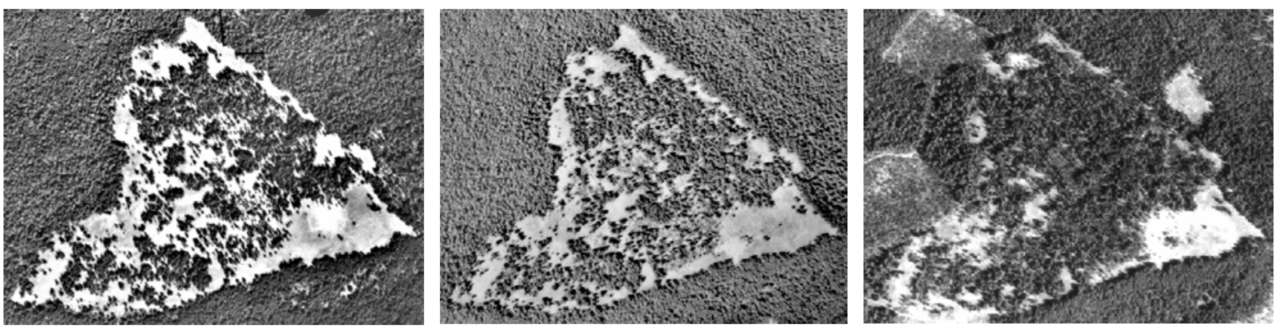


Fig. 7. Changes in the forest-meadow mosaic at Bunchgrass Ridge. Photo used in this analysis are from 1946, 1967, and 2000. Clearcuts are apparent in the 2000 photo.

3.1.2. Vegetation responses to conifer encroachment

Our detailed analyses of encroachment history provide a powerful tool for understanding patterns of vegetation change as meadows are replaced by forest. We have devoted several studies to quantifying these changes and how they may influence the potential for meadow restoration. We review the major findings and implications of these studies below.

3.1.2.1. Vegetation responses to conifer encroachment: a chronosequence study

For full paper see Haugo and Halpern (2007).

- How do the abundance and richness of meadow and forest understory species change during the transition from open meadow to old forest?
- How rapidly, and to what extent, are meadow species lost from these systems?
- How quickly do forest species colonize and how does composition change with forest age?
- Which attributes of forest structure (light availability, tree density, basal area) exhibit the strongest controls on meadow and forest species?

Methods. Subplots (10 x 10 m) within each of the 1-ha plots were used as sampling units for this study. Within each subplot we quantified forest structure (density and basal area by tree species), measured light availability, and estimated the abundance of all plant species.

We grouped subplots into seven encroachment classes by similarity in age structure, using an agglomerative, hierarchical classification. These groups describe stages in a chronosequence from open meadow to old forest (Fig. 8). For each class we calculated total cover and richness of two groups of species based on habitat affinity: meadow (n = 43) and forest understory (n = 48) (see Appendix 1).

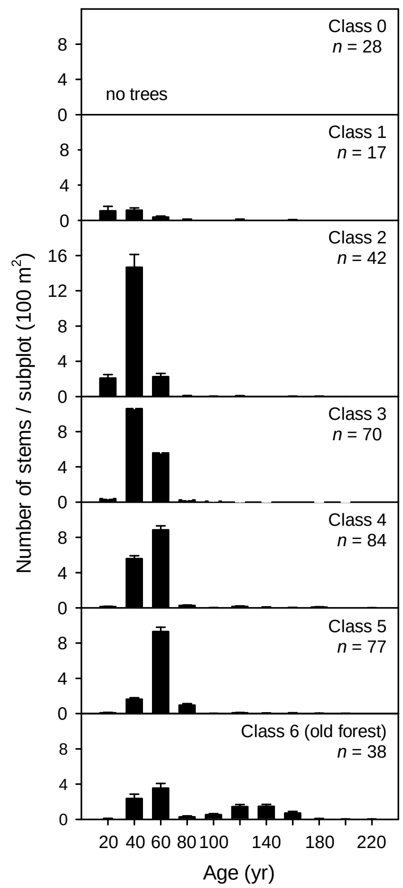
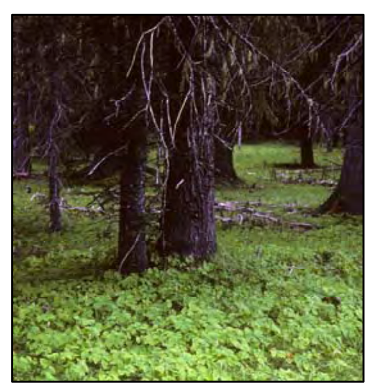


Fig. 8. Age structures of the seven encroachment classes: 0 = open meadow, 2-5 = young forest, and 6 = old forest, with illustrations below.



Results

- Cover of meadow species declined steeply with density of *Abies* and with associated reductions in light. Richness of meadow species declined more gradually.
- Forest herbs colonized rapidly and within 60-80 yr dominated the understory (Figs. 9, 10).
- Richness and cover of forest understory species showed weaker relationships with overstory structure than did richness and cover of meadow species (regression model r^2 for forest species: 0.34 - 0.42; model r^2 for meadow species: 0.48 - 0.54).

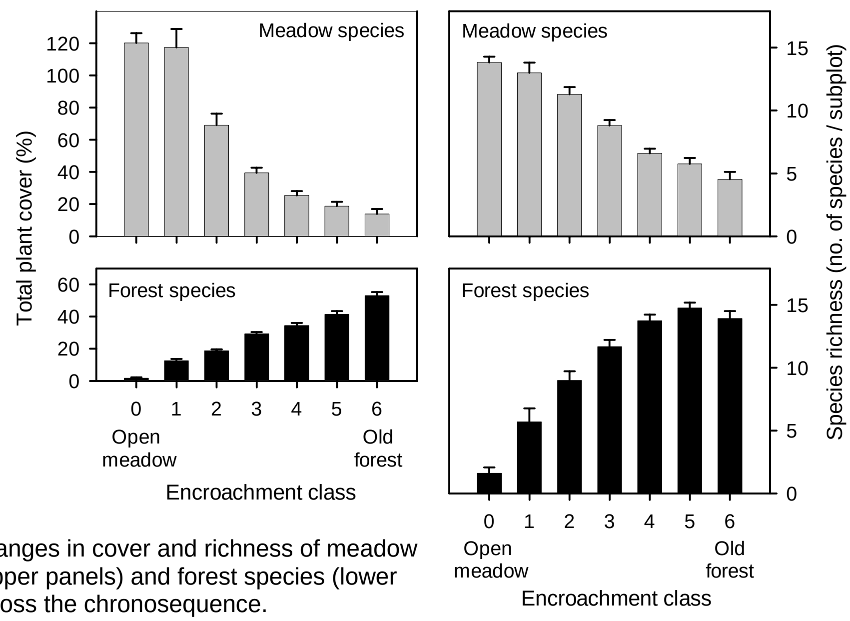


Fig. 9. Changes in cover and richness of meadow species (upper panels) and forest species (lower panels) across the chronosequence.

Fig. 10. Forest understory plants rapidly colonize beneath young stands of grand fir.

Conclusion. Rapid replacement of meadow by forest species may be indicative of a shift to an alternative stable state, reinforced by positive feedbacks between trees and soils. Loss of cover and richness of meadow species (and a limited seed bank, see Section 3.1.2.3) may pose barriers to restoration of native meadows. Removing trees during the earliest stages of encroachment is clearly the most effective strategy for maintaining these ecosystems.

3.1.2.2. Vegetation responses to tree establishment: effects of tree age and species

Manuscript in preparation. Haugo, R. D., and C. B. Halpern. Vegetation responses to tree establishment: effects of tree age and species. Ecology.

Individual trees establishing within meadows can exert significant effects on local vegetation. In a companion study to the chronosequence analysis, we posed the following questions:

- At what age do conifers cause displacement of meadow species or facilitate recruitment of forest herbs?
- Are effects of individual trees more pronounced on meadow or forest species?
- Lodgepole pine and grand fir have contrasting canopy structures and levels of shading. Do they have different effects on ground vegetation?
- Do responses to shading vary with position under the canopy (SW vs. NE exposures)?

Methods. From areas of open meadow, we selected 39 lodgepole pine and 46 grand fir (>1.4 m tall) of a range of sizes and ages (20-70 yr). From the base of each tree, ground vegetation was sampled with a transect extending to the SW and NE. Each transect was sampled in two equal lengths, under the canopy and in open meadow (Fig. 11), using a series of 20 x 50 cm quadrats (Fig. 12). Within each quadrat, we estimated cover of each plant species.

The effect of a tree was expressed as the mean difference between under-canopy and open meadow quadrats. Response variables included total cover and richness of meadow and forest species (as in section 3.1.2.1; also see Appendix 1).

General linear models were used to test the hypothesized effects of tree age, tree species, and orientation, as well as their interactions.

Fig. 11. Sampling transect extending from the base of a young grand fir into open meadow.

Fig. 12. Estimating plant cover in a sampling quadrat under a young grand fir.

Results

Mixed effects on meadow species

- As expected, there were significant negative effects of tree age on cover and richness, but no effects of tree species or orientation (Fig. 13, Table 1).
- Surprisingly, in 40% of transects, cover was greater under the canopy than in open meadow (Fig. 13). This occurred more frequently under pine than under grand fir (53 vs. 22% of transects), but less frequently with age. Partial shading by pine may reduce physiological stress in meadow plants during summer months. Under older trees, however, root competition and reduced light may become detrimental.

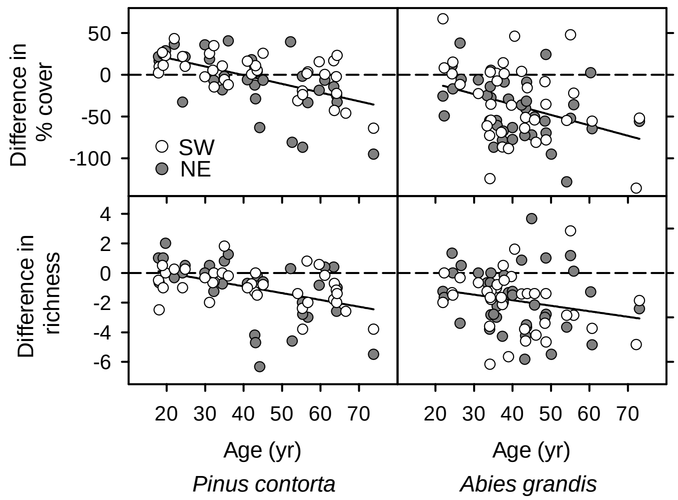


Fig. 13. Effects of tree age and tree species on meadow taxa. Negative values indicate lower cover (or richness) under the tree canopy than in open meadow.

Facilitation of forest species

- There was no effect of pine on forest species, but for grand fir, there were significant increases in cover and richness with age (Fig. 14, Table 1)

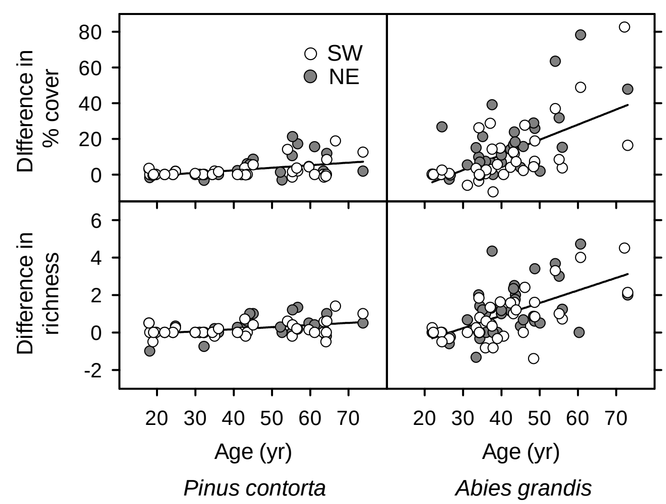


Fig. 14. Effects of tree age and tree species on forest understory taxa. See Fig. 13 for other details.

Conclusions

- Our methods and results suggest an approach to prioritizing tree removal as part of meadow restoration efforts. In this system, removing grand fir of any age is a higher priority than removing pine. More generally, our approach can be employed in other invaded systems to detect the tree species with the strongest effects, and the age(s) at which these effects become apparent.

Table 1. Levels of significance (*p* values) for predictors of meadow and forest understory species cover and richness. Significant terms are in bold.

		Meadow species		Forest species	
		Cover	Richness	Cover	Richness
	Adjusted R^2	0.33	0.13	0.31	0.40
Predictors	Full model (*p*)	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Tree age		**0.003**	**0.03**	0.19	0.13
Tree species		0.13	0.17	**0.005**	**0.001**
Transect orientation		0.99	0.43	0.69	0.68
Age x species		0.55	0.86	**<0.001**	**<0.001**
Age x orientation		0.45	0.26	0.91	0.93
Age x species x orientation		0.57	0.36	0.91	0.58

3.1.2.3. Dynamics of the soil seed bank: consequences of conifer encroachment and implications for restoration

For full paper see Lang and Halpern (2007).

Soil seed banks contribute to the diversity and dynamics of many plant communities. In some systems they are critical for maintaining species' populations or restoring native plant communities. We examined the composition of the soil seed bank at Bunchgrass Ridge to determine whether meadow species maintain viable seeds in the soil, and by implication, whether the seed bank can contribute to meadow restoration if conifers are removed. We addressed the following questions:

- Do meadow species maintain viable seeds in the soil?
- Do the density and diversity of seeds decline as meadow is replaced by forest?
- What types of species dominate the seed bank?
- What is the potential for seed banks to contribute to meadow restoration if trees are removed?

Methods. Samples for seed bank analysis were collected from subplots sampled for forest age structure and ground vegetation. 209 subplots were randomly selected. These represented three distinct stages of forest development: open meadow (Class 0), young forest (Classes 2-5), and old forest (Class 6). In May 2004, three soil cores (6 cm in diameter, 10 cm deep) were extracted from each subplot and combined. Above-ground vegetation was then sampled in the same subplots between July and August.

Soil samples were mixed with sterile potting soil and placed in germination flats in the greenhouse (Fig. 15). Seedling emergence was monitored for 7 months.

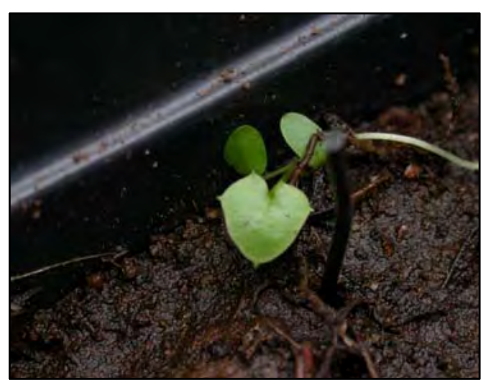


Fig. 15. Collecting soil samples in May (upper right); germination flats in the University of Washington greenhouse (left); and a seedling of the exotic herb, *Lactuca muralis* (lower right).

Results

Meadow and forest soils supported well-developed and diverse communities of viable seeds. However:

- Ruderal taxa dominated the seed bank in density (71% of germinants) and richness (Fig. 16).
- Meadow taxa comprised 21% of germinants. However, most of these were of a single species, *Carex pensylvanica*, the dominant sedge.
- Nearly 75% of meadow species present in the vegetation were absent from the seed bank.
- Density and richness of meadow species did not change predictably with stage of encroachment (Fig. 16).

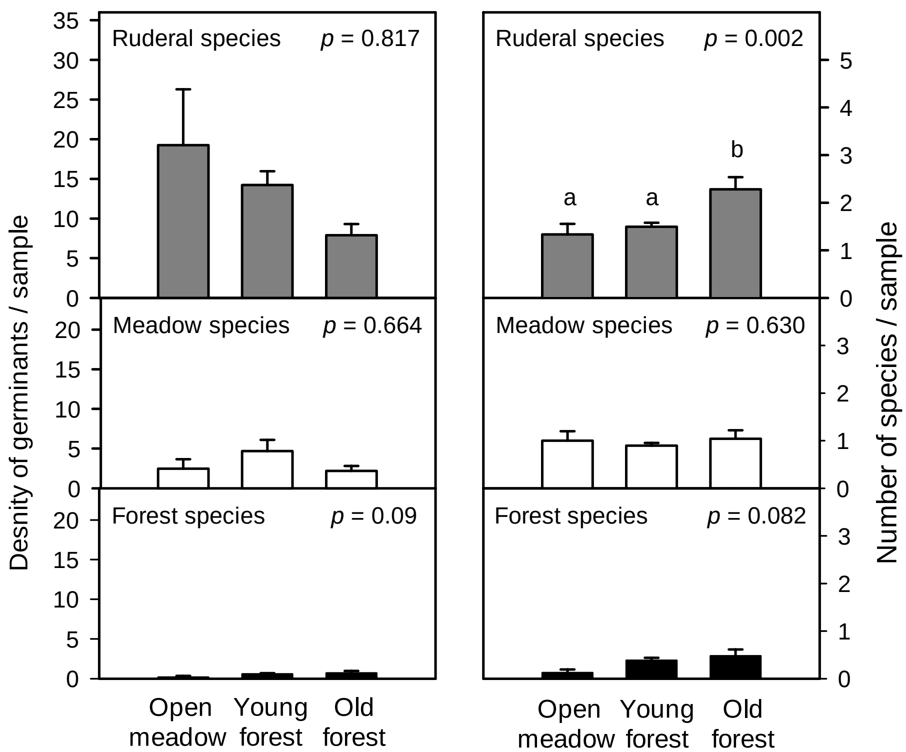


Fig. 16. Density and richness of ruderal, meadow, and forest species germinating from soil samples collected in open meadow, young forest, and old forest. *P* values are from one-way ANOVA or its non-parametric equivalent. Different letters indicate a significant difference between stages of encroachment.

Conclusion. Our results suggest that following tree removal, reestablishment of most meadow species will not occur through germination from a viable seed bank. Some species, such as *Carex pensylvanica*, may germinate in profusion. However, without further intervention, reestablishment of most species must occur through dispersal from adjacent sources. Dominance of the seed bank by ruderal species may also pose a challenge to restoration, particularly where soil disturbance stimulates germination of these species. Surprisingly, however, ruderals have contributed minimally to the first-year vegetation in our experimental treatments (see section 3.2.4).

3.1.3. Other studies of meadow ecology

Our broader program of research and the proximity of Bunchgrass Ridge to the Andrews Experimental Forest/LTER has afforded many opportunities for collaboration, independent research, and training. Here we describe the results of a study funded through an NSF-sponsored Research Experiences for Undergraduates (REU) fellowship to Jessica Niederer, a student at Cornell University. Subsequent collaboration with Chad Jones, a post-doctoral researcher in the Halpern lab led to publication of this work (Jones et al. *in press*).

3.1.3.1. Gopher disturbance in meadows: effects on species diversity and heterogeneity

For full paper see Jones et al. (*in press*).

Pocket gophers play important roles in structuring grassland ecosystems. Gopher mounds can initiate succession, ensuring persistence of less competitive species and providing sites for establishment of disturbance-dependent taxa. Knowledge of the relationships between gopher disturbance and community structure comes largely from studies of low-elevation prairies and grasslands in central and eastern North America. Studies from mountain ecosystems are rare. Mound formation by the western pocket gopher, *Thomomys mazama*, is conspicuous at Bunchgrass Ridge and in meadows throughout the western Cascades. We asked the following questions:

- How do plant abundance and species diversity change as mounds undergo succession?
- Are mounds more heterogeneous than adjacent undisturbed meadow and do these differences change over time?
- Do mounds provide safe sites for species that are absent from or uncommon in undisturbed meadow?
- How do mounds affect larger scale patterns of diversity and heterogeneity?

Methods. Mounds were assigned to one of three age classes (Fig. 17):

- new, formed in the current growing season with no plant cover
- young, formed 1-2 yr before sampling
- old, formed at least 3 yr before sampling, with pronounced compaction and weathering

Fig. 17. Examples of mound age classes: new, young, and old (from left to right).

A series of three quadrats (10 x 10 cm) was used to sample vegetation on mounds and in adjacent meadow. Within each quadrat we recorded presence of all species and estimated total cover of forbs and graminoids. Analyses of cover, richness, and heterogeneity were conducted at two spatial scales: quadrats and quadrats combined (i.e., plots: 10 x 30 cm).

Results

- Plant cover and species richness increased with mound age, but old mounds had lower cover and were less diverse than adjacent meadow (Figs. 18, 19).
- Forbs benefited by mound formation relative to graminoids (Fig. 18).

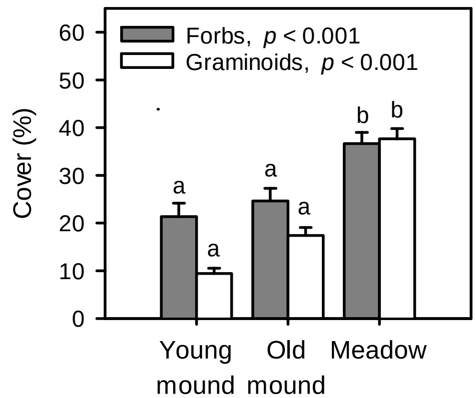


Fig. 18. Total cover of forbs and graminoids on young mounds, old mounds, and adjacent meadow. *P* values are from one-way ANOVA. Different letters among age classes indicate significant differences in cover.

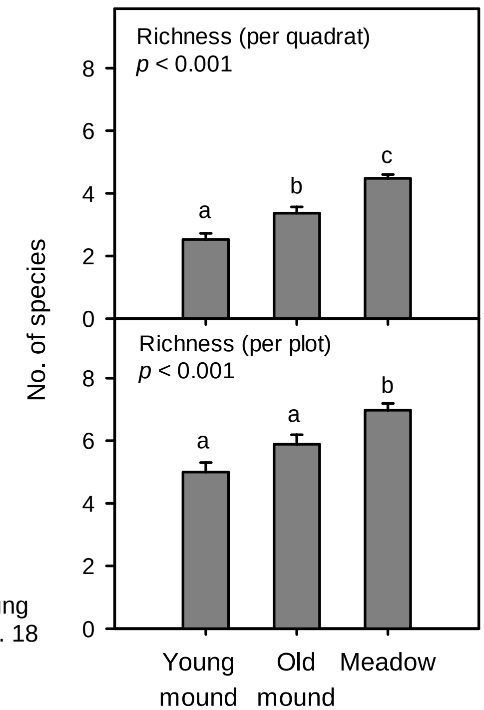


Fig. 19. Species richness at two spatial scales on young mounds, old mounds, and adjacent meadow. See Fig. 18 for other details.

- Species heterogeneity was greatest in young mounds and declined with age (Fig. 20).
- Mounds did not support "fugitive" species absent from undisturbed meadow. This is surprising given the abundance of ruderals in the soil seed bank (see section 3.1.2.3).

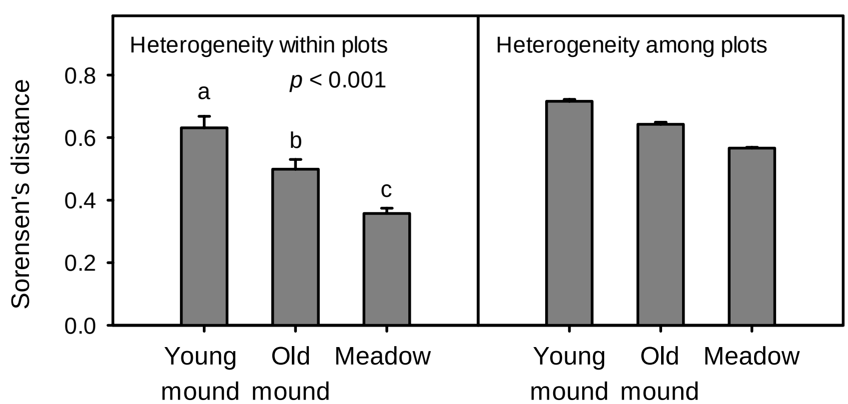


Fig. 20. Changes in species heterogeneity (Sorensen's distance) within and among mounds.

Conclusion. Succession on gopher mounds is rapid, achieved through resprouting of buried plants and vegetative growth from adjacent meadow. Although mounds do not enhance species diversity, they serve two important functions: (1) reducing dominance of graminoids that outcompete forbs in the absence of disturbance, and (2) resetting succession, enhancing local variation in species composition. In the absence of gophers, these meadows would become increasingly dominated by grasses.

3.2. The restoration experiment

The centerpiece of our research is an experiment that explores the potential for restoration of meadows through tree removal and prescribed burning. It addresses the following questions:

- Is restoration of meadows possible with tree removal and prescribed burning?
- Is fire necessary for restoration or is tree removal sufficient?
- Does the potential for restoration depend on the stage of conifer encroachment?
- How do these results bear on operational alternatives?

3.2.1. Experimental design

The design consists of three replicates of three treatments randomly assigned to nine 1-ha (2.5 acre) experimental units (Fig. 21). Replication and the untreated control enable us to make strong inferences about the effects of the restoration treatments across the backdrop of natural variation in vegetation composition in space and time. Treatments include:

- Control (C): no treatment
- Tree removal with slash piled and burned (PB) leaving most of the ground surface unburned
- Tree removal with slash broadcast burned (BB)

Comparisons between unburned (PB) and burned (BB) treatments allow us to address our second question: Is fire necessary for restoration or is tree removal sufficient?

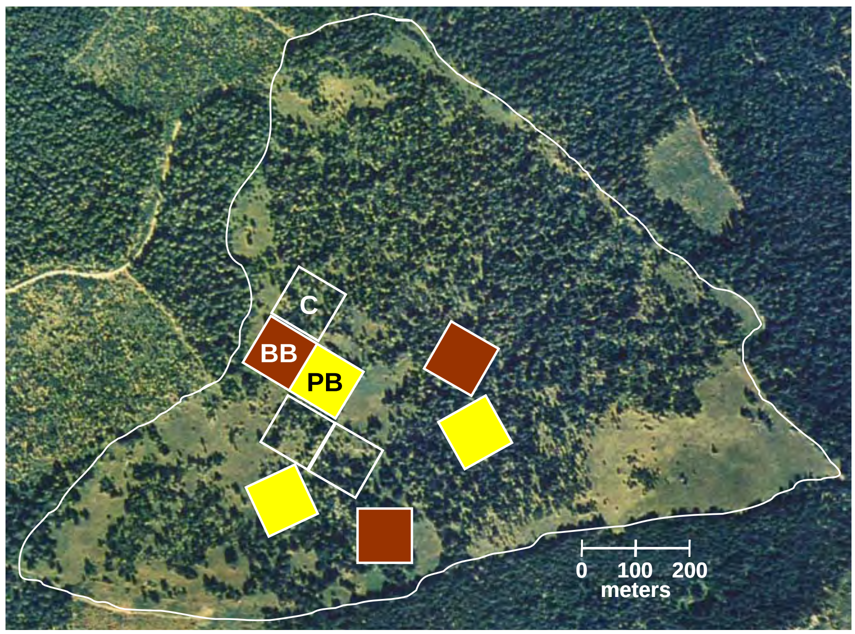


Fig. 21. Arrangement of the experimental treatments at Bunchgrass Ridge.

Within experimental units, a range of habitats including areas with few trees, recent invasion (<75 yr), and older forest (95-200 yr) allows us to address our third question: Does the potential for restoration depend on the stage of encroachment? (Fig. 22).

Fig. 22. Responses to treatments may differ in areas with few trees, in dense young forests, and in older forests.

3.2.2. Treatment implementation

Logging. Logging was conducted in January-February 2006 on deep, compacted snow to minimize damage to soils. Road access was maintained by a commercial snow blower. Harvest had been scheduled for the previous winter, but was delayed by record drought and virtual absence of snow.

Larger trees were felled with chainsaws and smaller trees were cut with a Timco mechanical faller (John Deer 653E). Directional felling was required to avoid disturbance to control plots. If possible, tree canopies were yarded while attached to boles to reduce fuel loadings, however, most limbs were broken during falling and yarding.

Rubber-tired and tracked skidders (John Deer 550) were used to yard boles to a road-side landing, ~250 m (~820 ft) west of the study area.

A hydraulic log loader (John Deer 690ELC) was then used to delimb and cut logs to length at the landing.

Fuel reduction treatments

Pile and burn treatments (PB)

Fig. 23. Areas between slash piles remained unburned.

Logging slash was piled by hand to create conditions where most of the ground surface was not burned (for comparison with broadcast burned treatments) (Fig. 23). Piles were located external to areas that would be sampled for vegetation and soils.

Piles were constructed in June 2006 and were covered with polyethylene film to shed water. They ranged in height from 1.8-3.0 m (6-10 ft) and in diameter from 2-4 m (6.5-13 ft).

Following an extended period of dry weather in October, piles were ignited on 2 November (Fig. 24) and burned to completion the next day (95-100% consumption). At 09:30 hr, temperature was 5ºC (41ºF), relative humidity was 100%, winds were SW at 3.2 km/hr (2 mph), and cloud cover was complete. Two-day rainfall (2-3 November) at the McKenzie Bridge Ranger Station (451 m, 1480 ft elevation) totaled 3.3 cm (1.3 in).

Fig. 24. A pile and burn unit before (27 Sep 2006), during (2 Nov 2006), and after treatment (28 Jun 2007).

Broadcast burn treatments (BB)

Fire lines (~50 cm, 20 in wide) were constructed around each broadcast burn unit (Fig. 25). Within these lines, duff was removed to mineral soil.

A hose lay with multiple pumping stations was used to distribute water. Hoses extended as far as 0.9 km (~0.6 miles) to the most distant treatment, requiring significant coordination of effort as demand changed from holding to mop-up among treatment units.

Water was hauled by fire engines from a distance of 4.8 km (3 miles) and used for pre-burn wetting of areas adjacent to experimental units, holding, and mop-up operations.

Fig. 25. Broadcast burn treatment units showing fuel loadings prior to burning.

Fig. 26. Broadcast burning on 28 September 2006.

Slash was burned on 28 September 2006 (Fig. 26). Burning occurred between 11:15 and 14:30 hr. Air temperatures were 70-75ºF (21-24ºC), relative humidity 25-27%, and wind speeds 0-5 km/hr (0-3 mph), with no cloud cover. Fuel moisture prior to ignition averaged 12% (10-hr), 16% (100-hr), and 28% (1000-hr).

Individual experimental units burned to completion within one-half to two hours of ignition. Flame lengths averaged 1-2 m (3-6 ft) with maxima of 2.4 m (8 ft) (Fig. 26).

Consumption of fine fuels averaged 67-87% among experimental units (Fig. 27). Areas that were shaded by forest edge burned less intensively, as did areas lacking woody debris (Fig. 27, middle right).

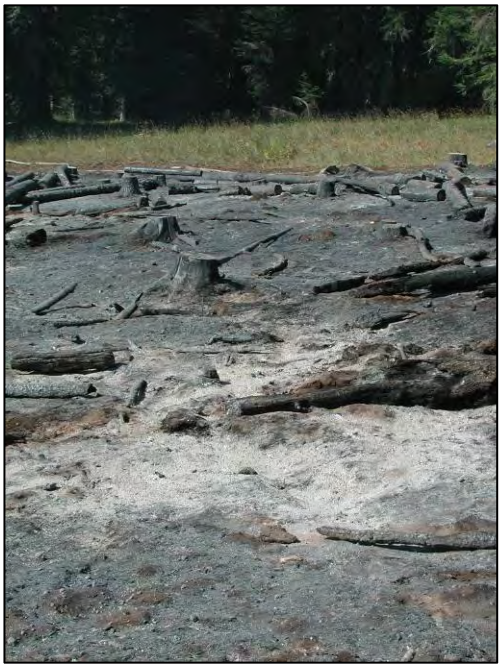


Fig. 27. Variation in ground-surface conditions following broadcast burning, including areas with exposed mineral soil and unburned vegetation (29 September 2006).

3.2.3. Sampling design and analysis

3.2.3.1. Tree removal with and without burning

Overall treatment effects: Is fire necessary for restoration or is tree removal sufficient?

Field measurements. Ground conditions, fuels, vegetation, and soil properties were sampled within 32 - 64 subplots (10 x 10 m) per experimental unit (Fig. 28, Table 2).

Table 2. Response variables measured before (2004) and after treatment (2006 = post-logging, 2007 = post-burning).

Variable	Before	After
Ground conditions: cover of mineral soil, CWD, fine litter, and burn severity	2004	2007
Fine fuels: 1-, 10-, and 100-hr	2006	2007
Cover of all species; cover and richness of meadow, forest, and ruderal species (see Appendix 1).	2004	2007
Conifer seedlings (density)	2004	2007
Soil properties (0-10 cm): total C and N, available N, and pH		2007

Statistical analyses. For all response variables, subplot values were averaged to generate means for each experimental unit. Analysis of variance (ANOVA) was then used to assess treatment effects (*n* = 3 replicates per treatment). Nonmetric multidimensional scaling (NMS) was used to examine changes in plant species composition.

Fig. 28. Sampling of fuels (July 2006) and ground vegetation (July 2007).

Variation in response to treatments: Does the potential for restoration depend on the stage of conifer encroachment?

To test whether responses to treatment depend on the stage of encroachment (i.e., forest age and structure), subplots within each experimental unit were assigned to one of three structural classes: (1) meadow or few trees, (2) young forest, or (3) old forest (see section 3.1.2.1.). Subplot values were averaged for each structural class and responses to treatments were assessed separately by class.

3.2.3.2. Effects of burn piles

Although slash piles covered only 10% of the ground surface within pile and burn (PB) treatments, intensive burning may have severely altered soil properties and vegetation. Further, burn scars also have the potential to serve as foci for establishment of native and exotic ruderal species that benefit from greater soil disturbance and nutrient availability. With support from the ESA SEEDs program (see section 4), Sheena Hillstrom (Washington State University) designed a study to quantify the magnitude and spatial extent of these effects (Fig. 29).

Ten piles were chosen from each treatment unit. Ground conditions, vegetation, and soils were sampled along transects oriented in a random direction from the center of each pile (C), across the edge (E), into adjacent unburned vegetation (U1 and U2).

Fig. 29. Left column: Sampling design to assess effects of burn piles. PVC posts mark the corners of 0.1 m^2 quadrats. Right column: Quadrats at the center (C) and edge (E) of a burn scar, illustrating the difference in consumption of litter and exposure of mineral soil.

3.2.4. Early results

3.2.4.1. Tree removal with and without burning

Ground-surface conditions

- Ground-surface conditions were unchanged in pile and burn (No burn) treatments (Figs. 30, 31).
- In contrast, broadcast burning (Burn) resulted in significant exposure of mineral soil and loss of fine litter (Figs. 30, 31).

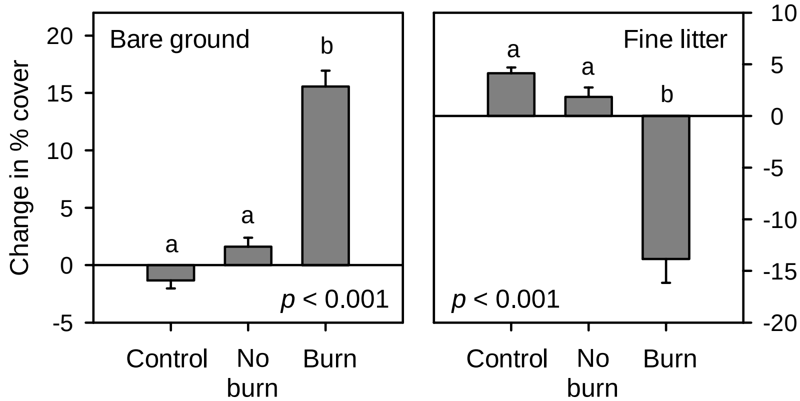


Fig. 30. Differences in cover of bare ground (mineral soil) and fine litter among treatments.

Fig. 31. Differences in exposure of mineral soil in pile and burn (left) and broadcast burn (right) treatments.

Extent and severity of burning

- In broadcast burned plots, burning was extensive, but variable. Half of all subplots had >80% cover of blackened ground (Fig. 32).
- Intensive burning was less common: >80% of subplots had <10% cover of white ash or reddish mineral soil (Fig. 32).

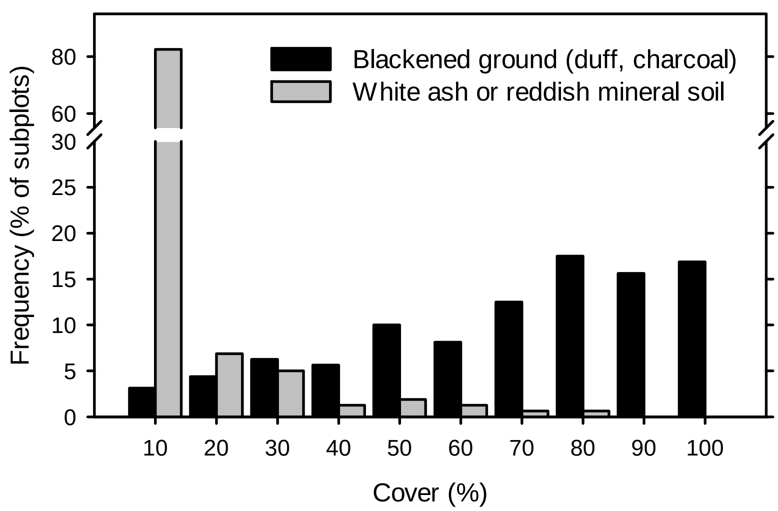


Fig. 32. Frequency of subplots with increasing cover of blackened soil or white ash (indicative of more intensive burning).

Initial effects on soil properties

Total C and N, C:N ratio, and pH

- Ten months after broadcast burning we were unable to detect significant effects of logging or burning on soil pH, total C, or total N (Fig. 33).

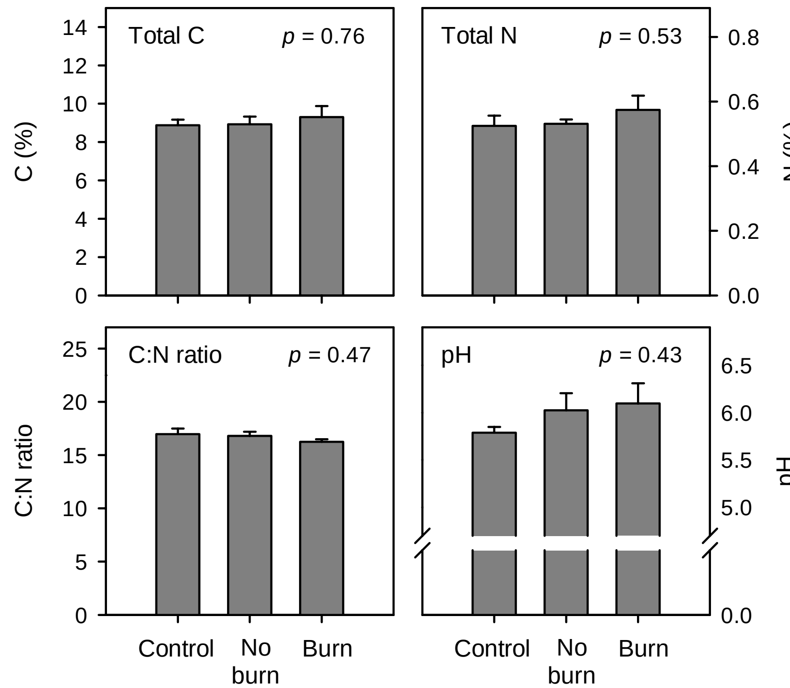


Fig. 33. Total C, Total N, C:N ratio, and pH of soil samples (0-10 cm) collected in Aug 2007, 10 months after broadcast burning. *P* values are from one-way ANOVA (n = 3 replicates).

Available N

- However, concentrations of NH_4^+-N and NO_3^--N were two to three times greater in broadcast burn than in pile and burn (No burn) treatments (Fig. 34).

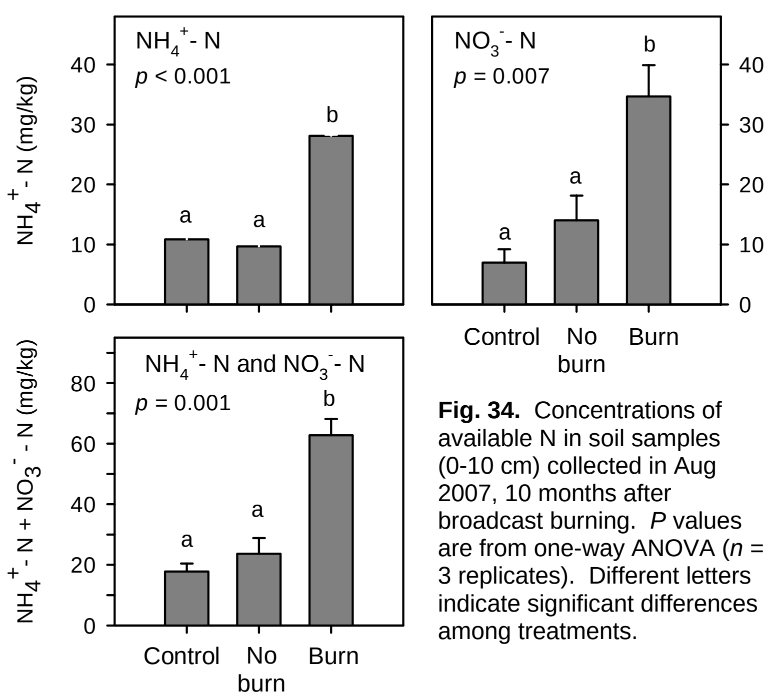


Fig. 34. Concentrations of available N in soil samples (0-10 cm) collected in Aug 2007, 10 months after broadcast burning. *P* values are from one-way ANOVA (n = 3 replicates). Different letters indicate significant differences among treatments.

Initial responses of vegetation

First-year responses to treatments offer a limited view of the long-term potential for restoration. However, they offer some insights into the initial effects of fire and its interaction with vegetation structure.

Is fire necessary for restoration or is tree removal sufficient?

Plant richness and cover. Removal of the overstory resulted in large declines in plant richness and cover (Fig. 35). Declines were significantly larger in burned than in unburned treatments.

Forest and meadow species. Declines in richness and cover were largely attributable to forest species; meadow species were less sensitive to fire (Figs. 36, 37).

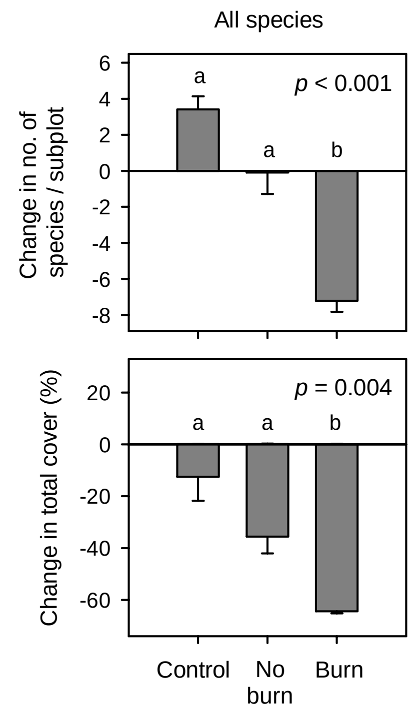


Fig. 35. First-year changes in richness and total plant cover among treatments. *P* values are from one-way ANOVA (*n* = 3 replicates). Different letters indicate significant differences in means among treatments.

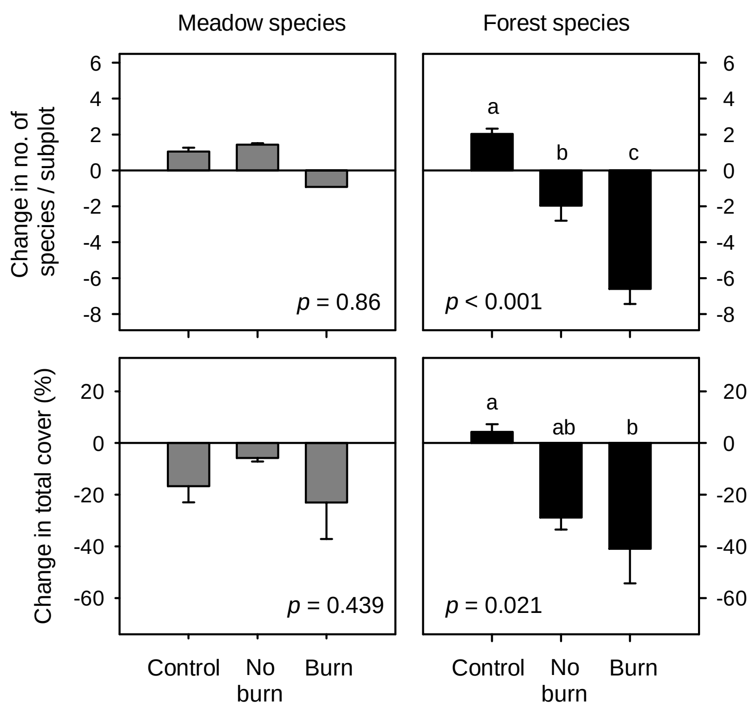


Fig. 36. First-year changes in richness and total cover of meadow and forest species among treatments. See Fig. 35 for other details.

Fig. 37. Persistence of a large clone of the forest herb, *Smilacina stellata*, in a pile and burn (No-burn) treatment where it had dominated the understory. Survival was poorer in broadcast burned treatments.

Ruderal species. Ruderal species, including native and exotic herbs and grasses, contributed minimally to plant diversity and cover (mean <0.2%) in the first growing season (Fig. 38).

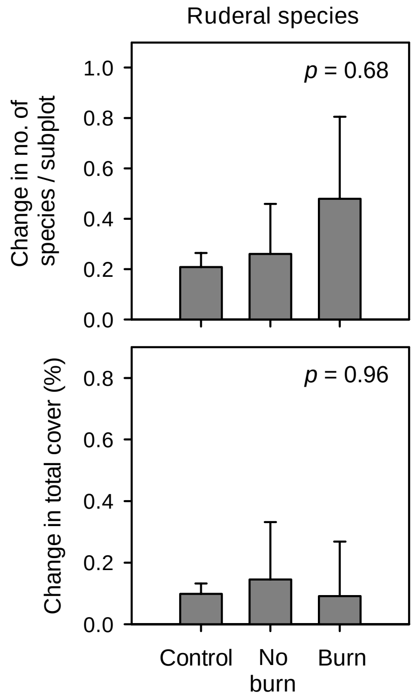


Fig. 38. First-year increases in richness and cover of ruderal species among treatments. See Fig. 35 for other details.

Conifer recruitment. Conifers recruited at greater density in burned than in unburned treatments (Fig. 40), consistent with the greater exposure of mineral soil by burning.

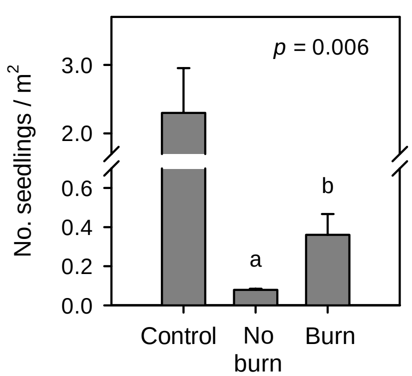


Fig. 40. Density of conifer seedlings (<1 m tall). The *p* value is from a t-test between no-burn and burn treatments. Densities in the controls are shown for comparison.

Changes in composition. Compositional change as expressed in ordination (NMS) space, was consistently greater in burned than in unburned treatments (Fig. 39). Movement along NMS2 coincided with a shift in dominance from forest (F) to meadow species (M).

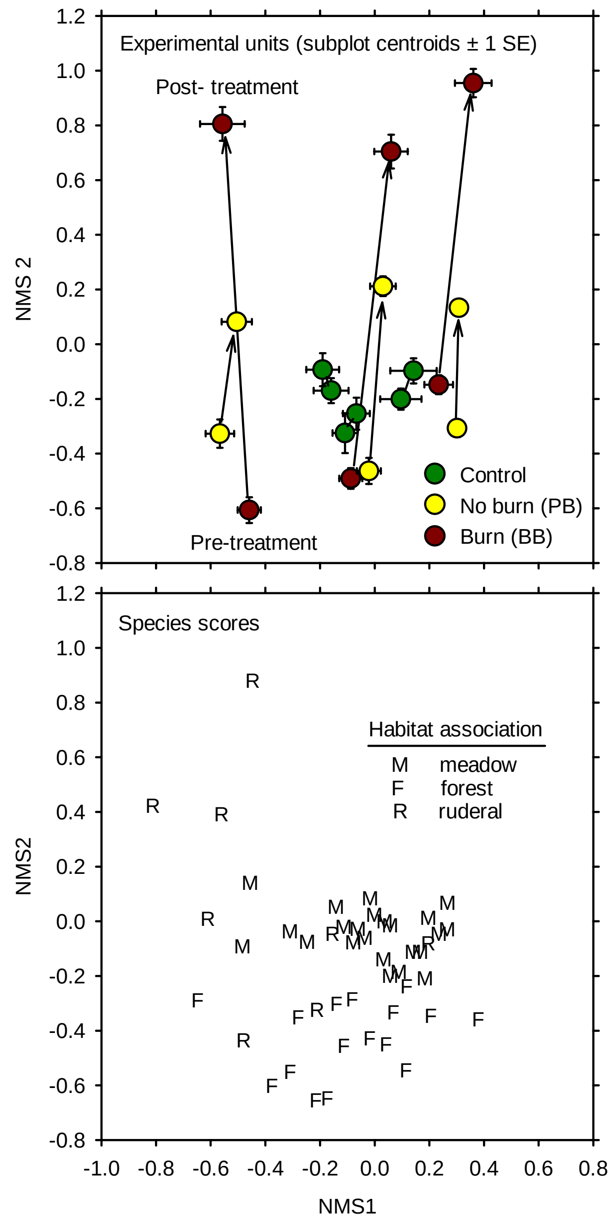


Fig. 39. NMS ordination of the nine experimental units showing average responses to treatments (subplot centroids ±1SE). Arrows connect pre- and post-treatment samples. Common taxa shown in the species ordination are coded by habitat association. Note the shift in No-burn units toward greater dominance of meadow (M) species.

Does the potential for restoration depend on the stage of conifer encroachment?

Open areas with relatively few trees. In relatively open areas, meadow species declined markedly after burning. Nevertheless, they remained the dominant plant group (Fig. 41).

Young and old forest. In areas of young and old forest, where forest understory species had been dominant, meadow species showed:

- neutral or positive responses to overstory removal (No burn), and
- neutral or negative responses to burning (Burn) (Fig. 41).

In contrast, forest understory species showed:

- large and significant declines after overstory removal (Figs. 41, 42), and
- greater loss in burned than in unburned areas (Figs. 41, 42).

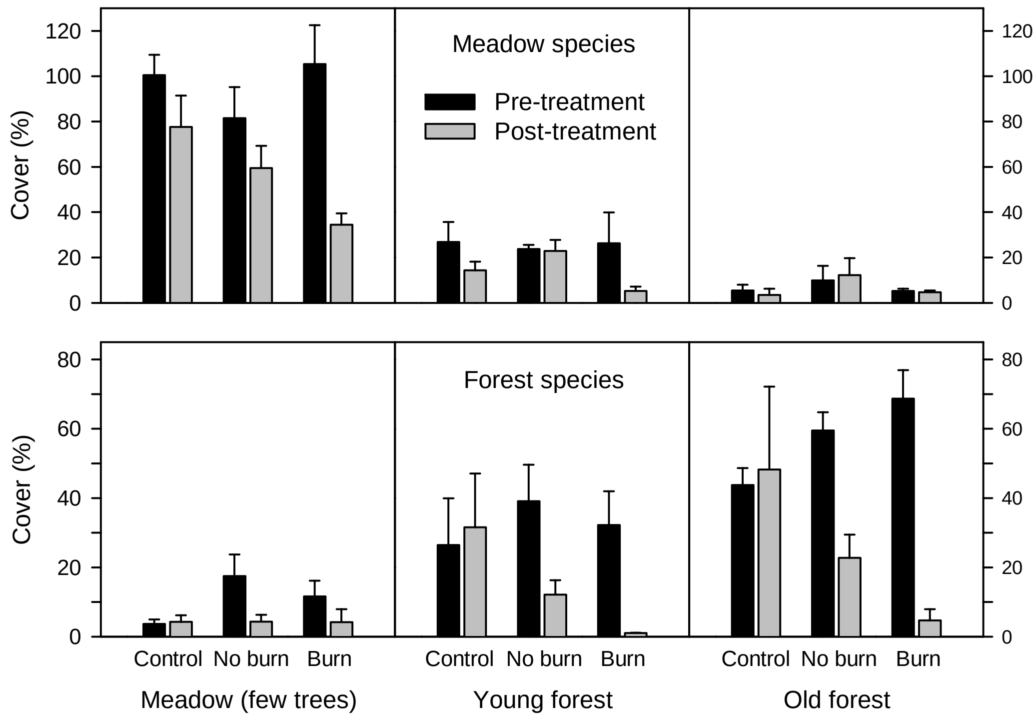


Fig. 41. Responses of meadow and forest species to experimental treatments in subplots representing different stages of encroachment: meadow (few trees), young forest, and old forest.

Fig. 42. Old forest understories in control, pile and burn, and broadcast burn treatments. Note the persistence of *Achlys triphylla* in the no-burn treatment and dominance of meadow species (*Vicia americana*) in the burn treatment.

Potential for establishment of ruderals

Although populations of ruderal species were generally sparse, first-year responses suggest greater potential for establishment in previously forested areas and greater diversity of species after burning (Figs. 43, 44).

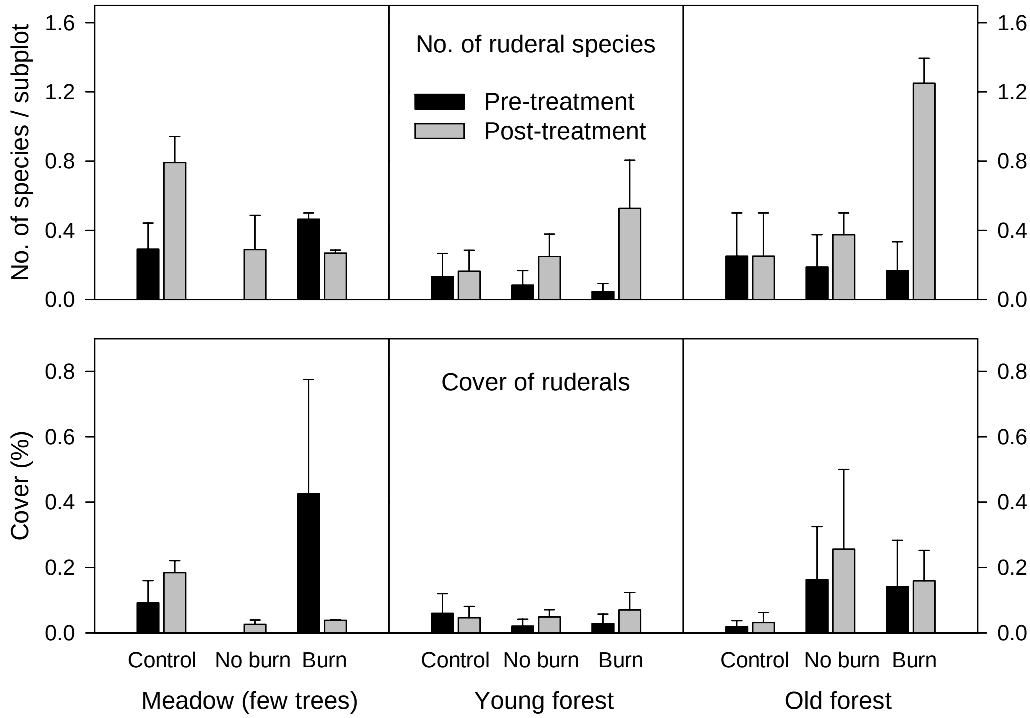


Fig. 43. Variation in the number and cover of ruderal species in subplots representing different stages of encroachment: meadow (few trees), young forest, and old forest.

Fig. 44. Ruderal species at Bunchgrass Ridge. *Phacelia heterophylla* (left) and *Ceanothus velutinus* (right) emerged from the soil seed bank; *Ceanothus* was most frequent in burned areas. *Rumex acetosella* (center) was most frequent in areas of former meadow (where it was present prior to treatment).

Conclusion. Dramatic shifts in the abundance of meadow and forest species and limited recruitment of ruderals suggest strong potential for restoration through tree removal. Short-term responses to broadcast burning indicate that there are tradeoffs in the use of fire. Although burning greatly reduces the abundance of forest species, exposure of mineral soil may also lead to greater recruitment of ruderals and greater germination of conifer seedlings.

3.2.4.2. Effects of burn piles

Total area in burn piles. Burn scars covered an average of 10% of the ground surface in pile and burn units (range of 8 to13%).

Fig. 45. Transect from the center of a burn-pile scar (C, white ash) across the edge (E, blackened duff) into unburned vegetation (U1, U2).

Ground surface conditions

- Most scars had a central area (C) where soil heating was intense, leaving white ash or reddened mineral soil. This was surrounded by an edge (E) of blackened duff or charcoal, with significantly less exposure of mineral soil (Fig. 45).
- Burning had no effect on ground conditions adjacent to the scar (U1 vs. U2) (Fig. 46).

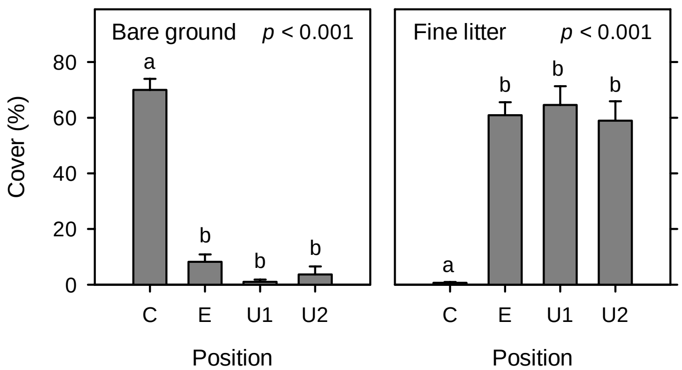


Fig. 46. Cover of bare ground (mineral soil) and fine litter from the burn scar center (C), across the edge (E), into unburned vegetation (U1, U2) (see Fig. 45). *P* values are from one-way ANOVA (*n* = 15). Different letters indicate significant differences among positions.

Initial effects on soil properties

- Concentrations of soil C and N were comparable inside and outside of burn-pile scars. Variation in C:N ratio was small but significant (Fig. 47).
- pH was significantly elevated (0.4 -0.5 units) at the center, but not at the edge (Fig. 47).

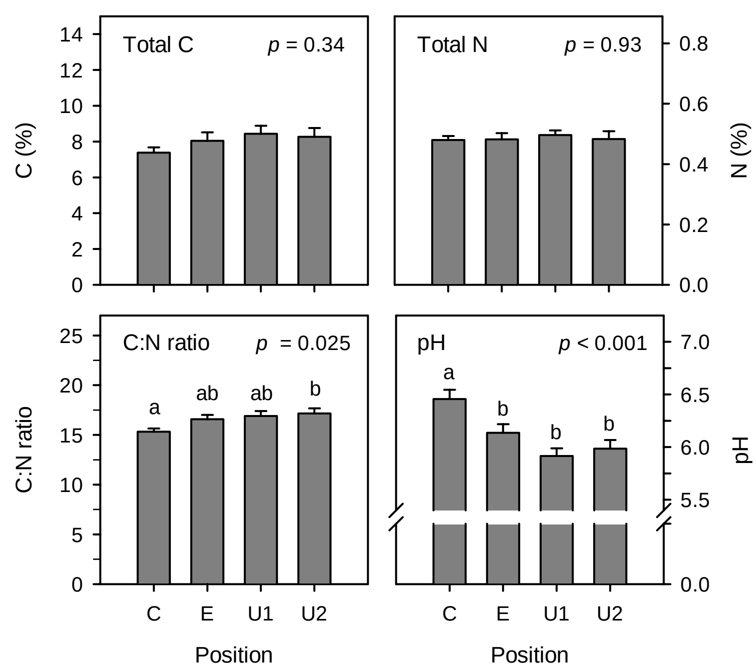


Fig. 47. Concentrations of soil C and N, C:N ratio, and pH from the burn scar center (C), across the edge (E), into unburned vegetation (U1, U2). See Fig. 46 for other details.

Initial effects on soil properties (cont.)

- Burn-pile scars were characterized by highly elevated concentrations of NH_4^+-N at the center (C), and elevated concentrations of $N0_3^-$-N at the edge (E) (Fig. 48).
- Effects of burning on available N were not apparent in adjacent vegetation (U1 vs. U2) (Fig. 48).

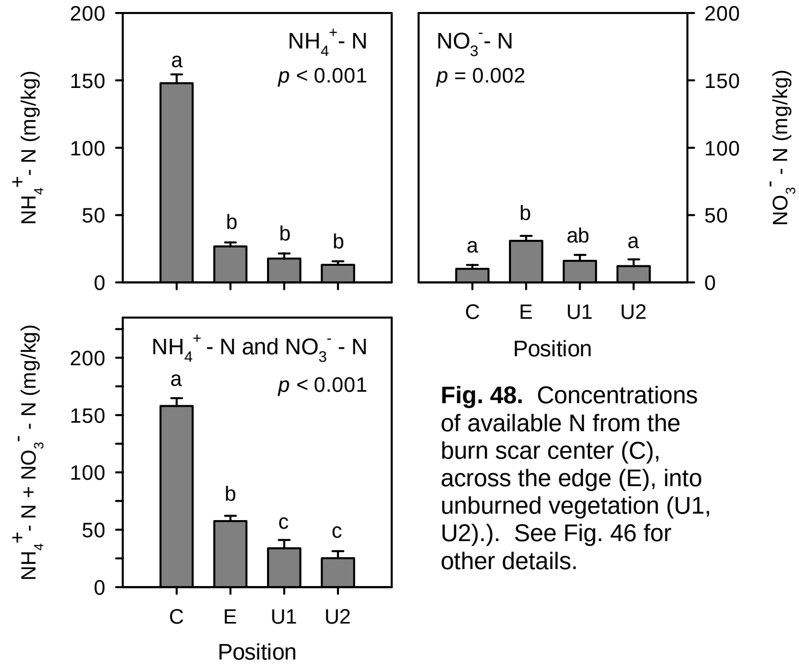


Fig. 48. Concentrations of available N from the burn scar center (C), across the edge (E), into unburned vegetation (U1, U2).). See Fig. 46 for other details.

Initial responses of vegetation

- Plants were virtually absent from the centers (C) of burn scars and greatly reduced in diversity and cover at the edge (E) (Fig. 49).
- However, effects of burning were not apparent beyond the edge (U1 vs. U2) (Figs. 49, 50).

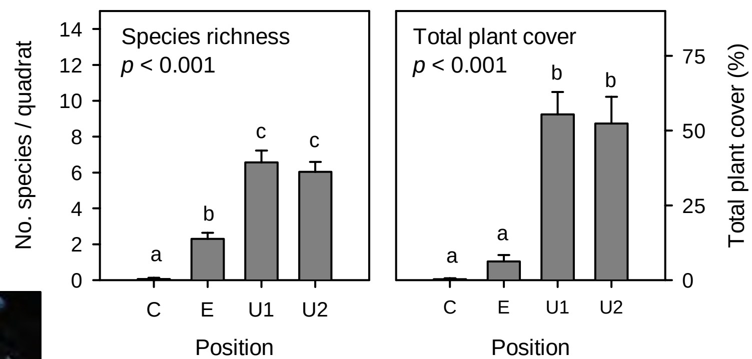


Fig. 49. Richness and total plant cover from the burn scar center (C), across the edge (E), into unburned vegetation (U1, U2). See Fig. 46 for other details.

Fig. 50. Plant cover at the edge of a burn-pile scar. Note the sharp transition to dense meadow vegetation (*Bromus carinatus*) beyond the burn scar.

Conclusion: The immediate effects of burn piles on soil chemistry (available N) and vegetation are dramatic, but localized. Plant survival within the burn scar and vigorous growth outside the edge suggest that natural ingrowth and healing may be possible over time. Although ruderals were uncommon in the first growing season, future establishment of these species may limit potential for recovery. Additional monitoring of permanent transects is planned and further experimentation (e.g., seedling and addition of litter) is being considered.

Aerial view of Bunchgrass Ridge on 29 September 2006, one day after experimental units had been broadcast burned (whitish patches). Slash piles visible in the pile and burn units were ignited on 2 November 2006.

3.2.5. Conclusions

Nearly two centuries of conifer encroachment at Bunchgrass Ridge have led to major loss or degradation of native meadows. Distinctive communities of grasses, sedges, and forbs have been replaced by forests of lodgepole pine and grand fir whose understories are dominated by shade-tolerant herbs. Significant changes in vegetation occur at the earliest stages of encroachment, and the transition to a ground flora dominated by forest herbs can occur within decades of initial tree establishment.

Is restoration of meadows possible with tree removal and prescribed burning? Is fire necessary for restoration or is tree removal sufficient? Does the potential for restoration depend on the stage of conifer encroachment? How do our experimental results bear on operational alternatives?

Tree removal is obviously a necessary first step in the process of restoration. However, the results of our retrospective and experimental studies suggest that several additional factors can pose barriers to recovery. These include:

- the degree to which meadow species have been lost from the local flora
- the absence of a viable seed bank for most meadow species
- distances to local seed sources and possible dispersal limitations
- establishment of weedy species that are promoted by disturbance, including fire
- modification of soil properties by conifers or fire in ways that facilitate ongoing recruitment of tree seedlings

Clearly, long-term observations of recovery are required to adequately answer these questions. However, first-year trends point to some striking differences in response among treatments and how these are conditioned by pre-treatment forest structure. They also bear on some of the operational limitations and ecological consequences of alternative approaches to fuel reduction.

- **Broadcast burning results in significant soil disturbance and increased nutrient availability.** As expected, broadcast burning led to significant exposure of mineral soil and to increased available N. As in most forest ecosystems fire-induced increase in N availability is likely to be short-lived (e.g., Wan et al. 2001), and differences between burned and unburned treatments should quickly disappear.

- **Harvest over snow resulted in minimal soil disturbance in the absence of fire.** An important result of the pile and burn treatment was the virtual absence of harvest-related soil disturbance. Tree removal over snow led to no greater exposure of mineral soil than in untreated controls — the original duff layer was left largely intact. Similar outcomes would not have been possible if snow cover had not been present during yarding.

  At the same time, there are limits and challenges to operating on snow. Lower elevation systems are unlikely to support sufficient snowpack. Even at higher elevations, the amount and timing of snowfall, and the extent to which compaction is sufficient to permit yarding can be highly unpredictable. Finally, winter hauling requires that access roads are plowed, increasing the cost of operations.

- **Potential for establishment of ruderal species.** It is possible that through greater soil disturbance and short-term increases in N availability, broadcast burning will promote greater establishment of ruderals than in unburned treatments (e.g., Halpern 1989). Surprisingly, ruderals have contributed only minimally to the vegetation in either treatment, despite their prominence in the seed bank (Lang and Halpern 2007).

- **Localized effects of burn piles.** Despite low levels of ground disturbance in the pile and burn treatments, disposal of slash through pile burning represents a tradeoff between the extent and intensity of disturbance. Although burn scars covered only 10% of the ground surface, their centers were highly disturbed, with significant exposure of mineral soil. Concentrations of NH_4^+-N greatly exceeding those in broadcast burned treatments. Vegetation recovery in these areas may be problematic.

  Although ruderals had not established in the first growing season (intense fall burning is likely to have consumed viable seed), it is possible that burn scars will serve as foci for future invasion and possible spread into surrounding areas. In addition, tree seedlings may preferentially colonize these areas. Old burn scars associated with overstory thinning in the1980s at Bunchgrass Ridge now support small patches of grand fir saplings.

  Operationally, although construction of burn piles can be effective at reducing ground fuels, hand piling can be labor intensive. At the same time, piles can be burned during late fall or early winter at a time when fire risk, as well as cost and effort associated with containment, is low. By comparison, broadcast burning is highly dependent on weather conditions and successful implementation is inherently less predictable. Moreover, fire containment requires considerably greater effort and cost.

- **Tree removal and burning benefit meadow species at the expense of forest herbs.** Tree removal, with or without burning, appears to benefit meadow species at the expense of forest herbs. Changes in the diversity and abundance of meadow taxa were no greater following tree removal (and burning) than in the controls. In contrast, forest herbs showed significant declines after tree removal, particularly in burned units.

  On balance, these results have two important implications. First, these grassland species appear tolerant of fairly high intensity burns. Timber harvest, particularly in areas of old forest, resulted in fuel loadings that are likely to have been greater than those associated with historic burning of these meadows. Second, significant reductions in the abundance of forest herbs may allow for future recruitment or spread of meadow species.

- **Meadow species show potential for recovery across a wide range of forest structures.** Low initial abundance and absence from the soil seed bank constrain the short-term responses of most meadow species. However, even in old forest, responses to overstory removal and burning were neutral or positive. Persistence through disturbance, dramatic reductions in abundance of forest herbs, and limited recruitment of ruderal species suggest potential for meadow recovery across a broad range of forest ages and structures.

  For taxa that have been lost from these systems, long-term recovery will require reintroduction through seed dispersal or vegetative expansion from adjacent edges. At Bunchgrass Ridge, these processes may be aided by the fine-scale mosaic of residual meadow openings that occur among areas of encroachment.

4. Education, Training, and Outreach

Beyond our JFSP-sponsored research, Bunchgrass Ridge has served as a nucleus for related studies of meadow ecology and a catalyst for broader implementation of meadow restoration practices in the western Cascade region. As a result, our restoration experiment was the focus of this year's Forest Plan Monitoring Review by the Willamette National Forest (WNF) Supervisor's Office (details below).

Many individuals have taken advantage of research, training, or educational opportunities at Bunchgrass Ridge through the Central Cascades Adaptive Management Partnership (http://www.reo.gov/ama/locations/cencas.html), the Andrews Forest-LTER (http://www.fsl.orst.edu/lter/), and other institutional relationships. Cheryl Friesen, Research Liaison on the Willamette National Forest, has coordinated communication among individuals from numerous meadow-related projects on the Forest — projects that draw from or contribute to studies at Bunchgrass Ridge.

Through these and other mechanisms, it has been possible to support a much larger research and outreach effort than would be possible with JFSP funding alone. Here we list the research, training experiences, outreach activities, and external connections that have developed, at least in part, through activities at Bunchgrass Ridge. We expect these outreach activities to expand substantially in the coming years as effects of treatments become more apparent and additional papers are published.

Research at Bunchgrass Ridge

Graduate students directly funded through the Joint Fire Science Program

- Ryan D. Haugo. M.S. thesis (2006), University of Washington. *Vegetation responses to conifer encroachment in a dry, montane meadow: a chronosequence approach.* Haugo is pursuing doctoral research at the University of Washington and continuing studies at Bunchgrass Ridge.
- Nicole L. Lang. M.S. thesis (2006), University of Washington. *The soil seed bank of an Oregon montane meadow: consequences of conifer encroachment and implications for restoration.*

Graduate students with external funding

- Janine Rice. Ph.D. dissertation (pending), Oregon State University. *Forest-meadow dynamics of the western Oregon Cascades: patterns of change and environmental causes.* NSF-IGERT Fellowship.

Additional collaborators and related research

- Joseph Antos. Collaborating faculty, University of Victoria. *Tree invasion of a montane meadow: a spatial and temporal analysis.* Antos has assisted with all aspects of the study including site reconnaissance and experimental design, critical review of retrospective studies, and analysis of spatial and temporal trends of tree invasion.
- Eric Seabloom and Elizabeth Borer. Faculty, Oregon State University. Bunchgrass Ridge now serves as an experimental site in the global network of grassland sites that comprise the Nutrient Network (NutNet) Experiment. NutNet investigates the effects of soil resources and herbivory on ecosystem processes, http://web.science.oregonstate.edu/~seabloom/nutnet/

International exchange students

- Ziyu Ma. Independent research (2005), Sichuan University (Chengdu). *Vegetation dynamics in a montane meadow: effects of conifer encroachment.* University of Washington-Sichuan University Undergraduate Exchange Program Fellowship.
- Michael Frank and Marcus Koch. Undergraduate research internships (2003), University of Applied Sciences, Department of Forest Science and Forestry, Freising, Germany.
- Florian Steer, Tina Volkl, and Katrin Wendt (2004). Undergraduate research internships (2004), University of Applied Sciences, Department of Forest Science and Forestry, Freising, Germany.

Independent undergraduate research

- Nina Griffin. Independent research (2007), University of Maine. *Plant diversity in bunchgrass meadows: an analysis of the intermediate disturbance hypothesis through gopher mounds.* NSF Ecosystem Informatics – OSU EcoInformatics Summer Institute.
- Sheena Hillstrom. Independent research (2007-2008), Washington State University. *Effects of burn treatments on vegetation and soil following conifer removal from a montane meadow*. Ecological Society of America SEEDs Program.
- Jessica Niederer. Independent research (2004), Cornell University. *Gopher disturbance in meadows: effects on species diversity and heterogeneity.* NSF Research Experience for Undergraduates (REU) Fellowship.
- Kyle Smith. Senior thesis (2005), University of Washington. *Effects of conifer encroachment and changes in forest structure on understory light*. College of Forest Resources.

Outreach

Outreach has taken a diversity of forms, including workshop presentations, field trips, publications, and the creation of key institutional links that provide opportunities for research, training, and education. We share examples below.

Workshops. In April 2006, we were invited to share the results of our JFSP-sponsored research at a regional information-sharing workshop sponsored by the Northwest Oregon Ecology Group: *The Ecology of Openings*. Attendees included university and PNW Research Station scientists, and natural resource managers from federal, state and private agencies, including NCASI, ODF, USFS, USFWS, and others. We have made additional presentations at regional scientific meetings (see section 5. Crosswalk table of project deliverables).

Field tours. In June 2007, we hosted a field tour of the Bunchgrass Ridge restoration experiment for a review team from the Willamette National Forest Supervisor's Office. The team is charged with evaluating the planning process, implementation, and outcome of management projects on each Ranger District. Summary comments from the review team and the Forest Supervisor were highly complimentary, noting in particular the successful implementation of treatments, the opportunities for future research, the strong research-management partnership, and the potential for developing management plans for the larger landscape that build on this research.

Publications. In June 2007 we completed a key publication that will have wide circulation — an issue of PNW Science Findings — a series devoted to disseminating current research that has relevance to land managers, policy makers, and the public (see PNW_Science_Findings_ no94_2007.pdf; http://www.fs.fed.us/pnw/publications/scifi.shtml). We review the current state of knowledge on extent, condition, and trends in mountain meadows, the causes and ecological consequences of conifer encroachment, and the potential for restoration. Retrospective and experimental studies at Bunchgrass Ridge are prominent in this work.

Educational and training opportunities. Through affiliation with the Andrews Forest-LTER, Oregon State University, and other groups, we have formalized several institutional relationships that have, and will continue to provide students with financial and educational resources to pursue independent research and training at Bunchgrass Ridge. These include:

- The National Science Foundation:
  Research Experiences for Undergraduates (REU), which funds summer programs for undergraduates via supplements to existing NSF grants, http://www.nsf.gov/crssprgm/reu/,
  Integrative Graduate Education and Research Traineeships (IGERT), which fund Ph.D. students, http://www.nsf.gov/crssprgm/igert/intro.jsp, and
  The Ecosystem Informatics Summer Institute (under IGERT), which funds advanced undergraduates from around the U.S. for summer education and research at the Andrews Forest, http://eco-informatics.engr.oregonstate.edu/
- The Ecological Society of America's SEEDs Program. SEEDs' mission is "to diversify and advance the profession of ecology through opportunities that stimulate and nurture the interest of underrepresented students", http://www.esa.org/seeds/
- University of Washington-Sichuan University Undergraduate Exchange Program, which engages undergraduates in a year of independent research with a faculty mentor, http://depts.washington.edu/uwww/UEP/overview.php

Details on the research activities of the students are provided above.

Related research and management in the central Cascades of Oregon

Graduate student research

- Michele Dailey. M.S. thesis (pending), Oregon State University. *Conifer encroachment into montane meadows, Chucksney-Grasshopper Complex, Oregon*. Michele's research has two components: (1) a remote-sensing based classification of non-forest openings in the Willamette National Forest; and (2) a change-detection analysis of meadows in the Chucksney-Grasshopper Complex using aerial photography in combination with tree-age and vegetation data from selected edges.
- Harold Zald. Ph.D. dissertation (pending), Oregon State University. Associated with the Forest Inventory and Analysis program of the Forest Service, Harold is examining sampling methods to document long-term changes in forest-meadow dynamics in the subalpine zone of the Mt. Jefferson Wilderness, Oregon.

Additional collaborators and related research

- Sadao Takaoka. Collaborating faculty, Senshu University, Japan. *Change in extent of meadows and shrub fields in the central western Cascade Range, U.S.A.* Takaoka and Swanson collaborated during a sabbatical visit to examine historical changes in the extent of meadows and shrub fields in the central western Cascades of Oregon. Aerial photography, fire records, and other archival data were used to examine possible influences of wildfire and sheep grazing on rates of meadow closure. A manuscript is in review at Professional Geographer. This work is also described in the June 2007 issue of PNW Science Findings (see above).

Management activities in the Willamette National Forest (selected examples)

- Meadow restoration in the Chucksney-Grasshopper Complex (Chucksney Mountain Roadless Recreation Area, McKenzie River Ranger District, Willamette National Forest). Tree removal and prescribed burning are under way; additional treatments are proposed to restore the aerial extent of this once large meadow complex.

- Restoration of natural meadows through mechanical and hand treatment of lodgepole pine at Lodgepole Flat Meadow, Lost Prairie, and Tombstone Prairie (Sweet Home Ranger District).

5. Crosswalk Table of Project Deliverables

For proposed items, see our original proposal, Table 3. Schedule of … communications/outreach products and Section 5. Deliverables and technology transfer.

Proposed	Delivered	Status/Availability
Scientific papers		
History of conifer encroachment in montane meadows.— Includes analyses of spatial and/or temporal patterns of invasion.	Haugo, R.D. 2006. Vegetation responses to conifer encroachment in a dry, montane meadow: a chronosequence approach. M.S. thesis. University of Washington, Seattle. 52 p.	Completed. See: Haugo_MS_thesis_2006.pdf Haugo_MS_defense_presentation_2006.pdf (powerpoint presentation)
	Haugo, R.D., and C.B. Halpern. 2007. Vegetation responses to conifer encroachment in a dry, montane meadow: a chronosequence approach. Canadian Journal of Botany 85:285-298.	Published. See: Haugo_&_Halpern_2007_CJB.pdf
	Antos, J.A., C.B. Halpern, J. Rice, R.D. Haugo, and N.L. Lang. *In prep.*. Tree invasion of a montane meadow: a spatial and temporal analysis.	Draft manuscript for Ecology; planned submission, winter 2008.
	Rice, J. *In prep*. Forest-meadow dynamics of the western Oregon Cascades: patterns of change and environmental causes. Ph.D. thesis. Oregon State University, Corvallis.	Planned completion, Nov 2007.
	Rice, J., J. Jones, C.B. Halpern, and J.A. Antos. *In prep*. Spatial and temporal patterns of conifer establishment during early invasion of a western Cascade meadow.	Draft manuscript; planned submission 2008.
Effects of encroachment on native plant communities.— Includes theses and papers on vegetation and soil seed bank responses to conifer encroachment.	Haugo, R.D. 2006. Vegetation responses to conifer encroachment in a dry, montane meadow: a chronosequence approach. M.S. thesis. University of Washington, Seattle. 52 p.	Completed. See: Haugo_MS_thesis_2006.pdf Haugo_MS_defense_presentation_2006.pdf (powerpoint presentation)
	Haugo, R.D., and C.B. Halpern. 2007. Vegetation responses to conifer encroachment in a dry, montane meadow: a chrono-sequence approach. Canadian Journal of Botany 85:285-298.	Published. See: Haugo_&_Halpern_2007_CJB.pdf
	Lang, N.L. 2006. The soil seed bank of an Oregon montane meadow: consequences of conifer encroachment and implications for restoration. M.S. thesis. University of Washington, Seattle. 58 p.	Completed. See: Lang_MS_thesis_2006.pdf Lang_MS_defense_presentation_2006.pdf (powerpoint presentation)

Proposed	Delivered	Status/Availability
Scientific papers (cont.)		
	Lang, N.L., and C.B. Halpern. 2007. The soil seed bank of a montane meadow: consequences of conifer encroachment and implications for restoration. Canadian Journal of Botany 85:557-569.	Published. See: Lang_&_Halpern_CJB_2007.pdf
	Haugo, R.D., and C.B. Halpern. *In prep*. Vegetation responses to tree establishment: effects of tree age and species.	Draft manuscript for Ecology; planned submission, winter 2008.
Initial responses to restoration treatments.	Draft manuscripts on vegetation and soils responses are pending. Experimental treatments were delayed for >2 yr and post-treatment measurements were completed in Aug 2007.	Planned submissions, June 2008.
Role of gopher disturbance in montane meadows (not initially proposed, but facilitated by JFSP).	Jones, C.C., C.B. Halpern, and J. Niederer. *In press*. Plant succession on gopher mounds in western Cascade meadows: consequences for species diversity and heterogeneity. American Midland Naturalist.	To be published April 2008. See: Jones_et_al._2008_Amer_Midl_Nat.pdf
Annual web reports and communiqué		
	Comprehensive web site describing retrospective studies and early responses to experimental restoration treatments.	Completed. See: http://depts.washington.edu/bgridge/index.htm
	Halpern, C.B., R. Haugo, N. Lang, J. Antos, and F. Swanson. 2005. Restoration of montane meadows in western Oregon: research and adaptive management at Bunchgrass Ridge. Pg. 4-5 *in* Northwest Oregon Ecology Group Newsletter 4.	Completed. See: NW_Oregon_Ecology_Newsletter_2005.pdf
	Thompson, J. 2007. Mountain meadows — here today, gone tomorrow? Meadow science and restoration. Science Findings Issue 94. Pacific Northwest Research Station, Portland, OR.	Completed. See: PNW_Science_Findings_no94_2007.pdf

Proposed	Delivered	Status/Availability
Workshops, presentations, and field tours		
Workshops and presentations		
	Halpern, C.B., R.D. Haugo, N.L. Lang, J.A. Antos, K.M. Smith, F J. Swanson, and J.H. Cissel. 2005. Restoration of dry, montane meadows through prescribed fire, vegetation and fuels management: A program of research and adaptive management in western Oregon. 2005 Joint Fire Science Program Principal Investigator Workshop, San Diego, CA. Poster.	Completed. See: JFSP_2005_workshop_poster.pdf
	Haugo, R. D. 2005. Hey, where'd all those tree comes from? Causes and consequences. 2005 Graduate Student Symposium, College of Forest Resources, Seattle, WA. Presentation.	Completed. See: Haugo_CFR_grad_student_symposium_2005.pdf (powerpoint presentation) http://www.cfr.washington.edu/cfrgss/gss_streaming.htm (video presentation)
	Haugo, R.D, and C.B. Halpern. 2005. Conifer encroachment in a dry, montane meadow, western Cascade Range, OR. 78th Annual Meeting of the Northwest Scientific Association, Corvallis, OR. Presentation.	Completed.
	Haugo, R.D., N.L. Lang, and C.B. Halpern. 2006. Conifer encroachment of montane meadows: effects on vegetation, seed banks, and potential for restoration. Ecology of Openings: Northwest Oregon Ecology Group Information-Sharing Workshop, Salem, OR. Presentation.	Completed. See: Haugo_NW_Oregon_Ecology_Group_workshop_presentation_2006.pdf
	Haugo, R.D., and C.B. Halpern. 2006. Vegetation dynamics following conifer encroachment in a dry, montane meadow, western Cascade Range. Northwest Scientific Association, 79th Annual Meeting, Boise, ID. Presentation.	Completed.
	Lang, N. L. 2005. Seed bank dynamics of an Oregon montane meadow: consequences of conifer invasion. 2005 Graduate Student Symposium, College of Forest Resources, Seattle, WA. Presentation.	Completed. See: http://www.cfr.washington.edu/cfrgss/gss_streaming.htm (video presentation)

Proposed	Delivered	Status/Availability
Workshops, presentations, and field tours (cont.)		
Workshops and presentations (cont.)		
	Lang, N.L., and C.B. Halpern. 2005. Soil seed bank dynamics of an Oregon montane meadow: implications of conifer encroachment. 78th Annual Meeting of the Northwest Scientific Association, Corvallis, OR. Presentation.	Completed.
	Ma, Z. 2005. Vegetation dynamics in a montane meadow: effects of conifer encroachment. Eighth Annual Undergraduate Research Symposium, University of Washington, Seattle, WA. Poster.	Completed.
Field tours		
	Oregon Natural Resources Council (10 Sep 2004). Field tour with ONRC staff to review research objectives and experimental treatments.	Completed.
	Willamette National Forest (WNF) Supervisor's Review Team (28 June 2007). Field tour of the Bunchgrass Ridge restoration experiment as part of a programmatic review of the McKenzie River District's Forest-Plan monitoring.	Completed.
JFSP annual progress reports		
	JFSP annual progress reports (2003-2006).	Completed.
A long-term ecological database		
	Retrospective, pre-, and post-treatment data are accessible through the Oregon State University Forest Science - LTER Databank.	Completed. See: http://www.fsl.orst.edu/lter/data/abstract.cfm?dbcode=TP112&topnav=97
A system of permanent experimental plots		
A system of permanent experimental plots for future research and monitoring, demonstration, and public education.	Nine permanent 1-ha (2.5 ac) experimental plots have been established for long-term study. Plots are marked with a permanent grid system (10-m spacing) and corners are surveyed with GPS.	Completed.

6. Literature Cited

Boyd, R. Editor. 1999. Indians, fire and the land in the Pacific Northwest. Oregon State University Press, Corvallis, Oregon.

Burke, C. J. 1979. Historic fires in the central western Cascades, Oregon. M.S. thesis, Oregon State University, Corvallis, Oregon.

Hadley, K. S. 1999. Forest history and meadow invasion at the Rigdon Meadows Archaeological site, western Cascades, Oregon. Physical Geography 20:116-133.

Halpern, C. B. 1989. Early successional patterns of forest species: interactions of life history traits and disturbance. Ecology 70:704-720.

Halpern, C. B., B. G. Smith, and J. F. Franklin. 1984. Composition, structure, and distribution of the ecosystems of the Three Sisters Biosphere Reserve/Wilderness Area. Final report to the United States Department of Agriculture. Pacific Northwest Research Station, Forestry Sciences Laboratory, Corvallis, Oregon.

Haugo, R. D., and C. B. Halpern. 2007. Vegetation responses to conifer encroachment in a dry, montane meadow: a chronosequence approach. Canadian Journal of Botany 85:285-298.

Hemstrom, M. A., S. E. Logan, and W. Pavlat. 1987. Plant association and management guide, Willamette National Forest. United States Department of Agriculture Forest Service PNW Region R6-Ecol 257-B-86.

Hickman, J. C. 1968. Disjunction and endemism in the flora of the central western Cascades of Oregon: An historical and ecological approach to plant distributions. Ph.D. dissertation, University of Oregon, Eugene, Oregon.

Hitchcock, C. L., and A. Cronquist. 1973. Flora of the Pacific Northwest. University of Washington Press, Seattle, Washington.

Johnson, R. R. 1985. Historical records inventory for the Willamette National Forest: Forest grazing permits. Forest Service Warehouse, United States Department of Agriculture Forest Service, Willamette National Forest, Eugene, Oregon.

Jones, C. C., C. B. Halpern, and J. Niederer. *In press*. Plant succession on gopher mounds in western Cascade meadows: consequences for species diversity and heterogeneity. American Midland Naturalist.

Lang, N. L., and C. B. Halpern. 2007. The soil seed bank of a montane meadow: consequences of conifer encroachment and implications for restoration. Canadian Journal of Botany 85:557-569.

Miller, E. A., and C. B. Halpern. 1998. Effects of environment and grazing disturbance on tree establishment in meadows of the western Cascade Range, Oregon, USA. Journal of Vegetation Science 9:265-282.

Rakestraw, L., and M. Rakestraw. 1991. History of the Willamette National Forest. United States Department of Agriculture, Willamette National Forest, Eugene, Oregon.

Rochefort, R. M., R. L. Little, A. Woodward, and D. L. Peterson. 1994. Changes in subalpine tree distribution in western North America: A review of climatic and other causal factors. The Holocene 4:89-100.

Rochefort, R. M., and D. L. Peterson. 1996. Temporal and spatial distribution of trees in subalpine meadows of Mount Rainier National Park, Washington, USA. Arctic and Alpine

Research 28: 52-59.

Teensma, P. D. A. 1987. Fire history and fire regimes of the central western Cascades of Oregon. Ph.D. dissertation, University of Oregon, Eugene, Oregon.

Vale, T. R. 1981. Tree invasion of montane meadows in Oregon. American Midland Naturalist 105:61-69.

Wan, S., D. Hui, and Y. Luo. 2001. Fire effects on nitrogen pools and dynamics in terrestrial ecosystems: a meta-analysis. Ecological Applications 11:1349-1365.

Weisberg, P. J., and F.J. Swanson. 2003. Regional synchroneity in fire regimes of western Oregon and Washington, USA. Forest Ecology and Management 172:17-28.

Wilson, N., E. Bergland, P. Ford, S. Kamrath, and J. Phillips. 1999. Bunchgrass Meadow Special Habitat Area Management Plan. United States Department of Agriculture Forest Service, McKenzie Ranger District, Willamette National Forest, Oregon.

Woodward, A., E. G. Schreiner, and D. G. Silsbee. 1995. Climate, geography, and tree establishment in subalpine meadows of the Olympic Mountains, Washington, USA. Arctic and Alpine Research 27:217-225.

7. List of Products Accompanying This Report

The following publications and presentations accompany this report as pdf files.

Full Title	**Pdf Name**
Refereed publications	
Haugo, R. D., and C. B. Halpern. 2007. Vegetation responses to conifer encroachment in a dry, montane meadow: a chronosequence approach. Canadian Journal of Botany 85:285-298.	Haugo_&_Halpern_2007_CJB.pdf
Jones, C. C., C. B. Halpern, and J. Niederer. *In press*. Plant succession on gopher mounds in western Cascade meadows: consequences for species diversity and heterogeneity. American Midland Naturalist.	Jones_et_al._2008_Amer_Midl_Nat.pdf
Lang, N. L., and C. B. Halpern. 2007. The soil seed bank of a montane meadow: consequences of conifer encroachment and implications for restoration. Canadian Journal of Botany 85:557-569.	Lang_&_Halpern_CJB_2007.pdf
Other Publications	
Halpern, C. B., R. Haugo, N. Lang, J. Antos, and F. Swanson. 2005. Restoration of montane meadows in western Oregon: Research and adaptive management at Bunchgrass Ridge. Pages 4-5 *in* Northwest Oregon Ecology Group Newsletter 4.	NW_Oregon_Ecology_Newsletter_2005.pdf
Thompson, J. 2007. Mountain meadows — here today, gone tomorrow? Meadow science and restoration. Science Findings Issue 94. PNW Research Station, Portland, OR.	PNW_Science_Findings_no94_2007.pdf
Theses	
Haugo, R. D. 2006. Vegetation responses to conifer encroachment in a dry, montane meadow: a chronosequence approach. M.S. thesis. University of Washington, Seattle. 52 p.	Haugo_MS_thesis_2006.pdf
Lang, N. L. 2006. The soil seed bank of an Oregon montane meadow: consequences of conifer encroachment and implications for restoration. M.S. thesis. University of Washington, Seattle. 58 p.	Lang_MS_thesis_2006.pdf
Powerpoint Presentations	
Haugo, R. D. 2005. Hey, where'd all those tree comes from? Causes and consequences. 2005 Graduate Student Symposium, College of Forest Resources, Seattle, WA.	Haugo_CFR_grad_student_symposium_2005.pdf
Haugo, R. D. 2006. Vegetation responses to conifer encroachment in a dry, montane meadow: a chronosequence approach. M.S. thesis presentation. University of Washington, Seattle.	Haugo_MS_defense_presentation_2006.pdf
Haugo, R.D., N.L. Lang, and C.B. Halpern. 2006. Conifer encroachment of montane meadows: effects on vegetation, seed banks, and potential for restoration. Ecology of Openings: Northwest Oregon Ecology Group Information-Sharing Workshop, Salem, OR. Presentation.	Haugo_NW_Oregon_Ecology_Group_workshop_presentation_2006.pdf

Full Title	Pdf Name
Powerpoint Presentations (cont.)	
Lang, N. L. 2006. The soil seed bank of an Oregon montane meadow: consequences of conifer encroachment and implications for restoration. M.S. thesis presentation. University of Washington, Seattle.	Lang_MS_defense_presentation_2006.pdf
Posters	
Halpern, C. B., R. D. Haugo, N. L. Lang, J. A. Antos, K. M. Smith, F. J. Swanson, and J. H. Cissel. 2005. Restoration of dry, montane meadows through prescribed fire, vegetation and fuels management: A program of research and adaptive management in western Oregon. 2005 Joint Fire Science Program Principal Investigator Workshop, San Diego, CA.	JFSP_2005_workshop_poster.pdf

8.1. Appendix 1. Plant species of Bunchgrass Ridge

Species[1]	Habitat[2]	Origin[3]
Grasses		
Agropyron repens	M	E
Agrostis scabra	M	N
Bromus carinatus	M	N
Bromus vulgaris	F	N
Dactylis glomerata	R	E
Danthonia intermedia	M	N
Deschampsia atropurpurea	M	N
Elymus glaucus	M	N
Festuca idahoensis	M	N
Festuca occidentalis	F	N
Melica subulata	F	N
Poa pratensis	M	E
Stipa occidentalis	M	N
Trisetum canescens	F	N
Sedges and Rushes		
Carex deweyana	—	N
Carex hoodii	M	N
Carex pachystachya	M	N
Carex pensylvanica	M	N
Luzula campestris	R	N
Ferns		
Athyrium filix-femina	F	N
Dryopteris austriaca	F	N
Polystichum munitum	F	N
Pteridium aquilinum	M	N
Herbs and sub-shrubs		
Achillea millefolium	M	N
Achlys triphylla	F	N
Actaea rubra	F	N
Adenocaulon bicolor	F	N
Agoseris aurantiaca	M	N
Agoseris glauca	M	N
Anaphalis margaritacea	M	N
Anemone deltoidea	F	N
Anemone lyallii	F	N
Anemone oregana	F	N
Antennaria microphylla	M	N
Aquilegia formosa	—	N
Arabis sp.	M	N
Arenaria macrophylla	F	N
Asarum caudatum	F	N
Aster ledophyllus	M	N

[1] Nomenclature from Hitchcock and Cronquist (1973)
[2] Primary habitat: F = forest, M = meadow, R = ruderal, — = not classified
[3] Origin: E = exotic, N = native

Species	Habitat	Origin
Herbs and sub-shrubs (cont.)		
Aster occidentalis	M	N
Aster radulinus	M	N
Calochortus subalpinus	M	N
Campanula scouleri	F	N
Cerastium arvense	M	N
Cerastium vulgatum	M	E
Chimaphila menziesii	F	N
Chimaphila umbellata	F	N
Circaea alpina	F	N
Cirsium callilepis	M	N
Cirsium vulgare	R	E
Claytonia lanceolata	M	N
Clintonia uniflora	F	N
Comandra umbellata	M	N
Corallorhiza maculata	F	N
Corallorhiza mertensiana	F	N
Corallorhiza striata	F	N
Cornus canadensis	F	N
Delphinium menziesii	M	N
Disporum hookeri/D. smithii	F	N
Epilobium angustifolium	R	N
Epilobium minutum	R	N
Epilobium watsonii	R	N
Erigeron aliceae	M	N
Fragaria vesca/F. virginiana	M	N
Galium oreganum	F	N
Galium triflorum	F	N
Geum macrophyllum	—	N
Goodyera oblongifolia	F	N
Hackelia micrantha	M	N
Hieracium albiflorum	F	N
Hieracium gracile	M	N
Iris chrysophylla	M	N
Lactuca muralis	F	E
Lathyrus nevadensis	M	N
Lilium columbianum	—	N
Linnaea borealis	F	N
Listera spp.	F	N
Lomatium triternatum	M	N
Lupinus latifolius	M	N
Microsteris gracilis	M	N
Montia sibirica	R	N
Orthocarpus imbricatus	M	N
Osmorhiza chilensis	F	N
Penstemon procerus	M	N
Penstemon sp.	M	N
Phacelia heterophylla	R	N
Phlox diffusa	M	N
Polygonum douglasii	M	N
Polygonum minimum	M	N
Prunella vulgaris	R	E
Pyrola picta	F	N

Species	Habitat	Origin
Herbs and sub-shrubs (cont.)		
Pyrola secunda	F	N
Ranunculus uncinatus	—	N
Rubus lasiococcus	F	N
Rubus ursinus	F	N
Rumex acetosella	R	E
Satureja douglasii	—	N
Senecio triangularis	M	N
Smilacina stellata	F	N
Stellaria sp.	M	—
Taraxacum officinale	R	E
Tiarella trifoliata	F	N
Trientalis latifolia	F	N
Trillium ovatum	F	N
Veronica americana	M	N
Veronica sp.	M	N
Vicia americana	M	N
Viola glabella	F	N
Viola nuttallii	M	N
Viola orbiculata	F	N
Xerophyllum tenax	—	N
Shrubs and broadleaved trees		
Acer circinatum	F	N
Amelanchier alnifolia	F	N
Berberis aquifolium	F	N
Berberis nervosa	F	N
Castanopsis chrysophylla	—	N
Ceanothus velutinus	R	N
Haplopappus greenei	M	N
Holodiscus discolor	—	N
Prunus emarginata	—	N
Rhamnus purshiana	—	N
Ribes cereum	—	N
Ribes lobbii	—	N
Rosa gymnocarpa	F	N
Rubus parviflorus	—	N
Sambucus racemosa	—	N
Sorbus sitchensis	—	N
Symphoricarpos mollis	F	N
Vaccinium caespitosum	M	N
Vaccinium membranaceum	F	N
Vaccinium parvifolium	F	N
Conifers		
Abies amabilis	—	N
Abies grandis	—	N
Abies procera	—	N
Juniperus communis	—	N
Libocedrus decurrens	—	N
Pinus contorta	—	N
Pinus monticola	—	N

Species	Habitat	Origin
Conifers (cont.)		
Pseudotsuga menziesii	—	N
Taxus brevifolia	—	N
Tsuga heterophylla	—	N
Tsuga mertensiana	—	N

8.2. Appendix 2. Descriptions of soils profiles at Bunchgrass Ridge

Courtesy of Duane Lammers and Ted Dyrness, USFS PNW Research Station, 15 October 2004

Old forest near Plot 8

Pedon Number: S04OR039-001

Date described: August 12, 2004
Described by: T. Dyrness, D. Lammers

Slope gradient: 5 percent
Aspect: NNW, 320 degrees
Elevation: 1357 meters

Landform: glaciated mountain ridge
Parent material: Mazama ash over till; andesitic basalt

Vegetation: Trees: *Pseudotsuga menziesii, Abies grandis, Abies amabilis*
Understory: *Clintonia uniflora, Achlys triphylla*, *Chimaphila umbellata*, *Fragaria* spp., *Rubus lasiococcus*, *Anemone deltoidea, Viola glabella*, *Osmorhiza chilensis*

Location: UTM Zone 10; Northing: 4903374, Easting: 582912

Taxonomic Class (as sampled): ashy, amorphic Aquic Vitricryands

Pedon description (colors are for moist soil unless otherwise noted, texture and percent clay are by field estimate)

Oi—0 to 2 cm; undecomposed needles and twigs [S04OR039-001-001]

A1—2 to 17 cm; very dark brown (10YR 2/2) ashy fine sandy loam (7 percent clay), very dark grayish brown (10YR 3/2) dry; weak fine granular structure; soft, very friable, nonsticky, nonplastic and smeary; many very fine and fine, common medium and few coarse roots; 10 percent fine gravel; few fine and medium charcoal fragments; clear wavy boundary [S04OR039-001-002]

A2—17 to 46 cm; very dark grayish brown (10YR 3/2) ashy fine sandy loam (7 percent clay), brown (10YR 4/3) dry; weak fine granular structure; soft, very friable, nonsticky, nonplastic and smeary; common very fine and medium, few fine and coarse roots; few fine irregular pores; 5 percent fine gravel; few fine and medium charcoal fragments; upper 60 percent of horizon is bioturbated by rodents; clear wavy boundary [S04OR039-001-003]

Bw—46 to 62 cm; dark brown (7.5YR 3/2) ashy fine sandy loam (9 percent clay), brown (10YR 4/3) dry; weak coarse subangular blocky structure that parts to weak fine granular; soft, very friable, nonsticky, slightly plastic and weakly smeary; few very fine, fine, medium, and coarse roots; few very fine tubular pores; 5 percent fine gravel; gradual wavy boundary [S04OR039-001-004]

2Bwb—62 to 94 cm; dark brown (7.5YR 3/2) ashy fine sandy loam (9 percent clay), brown (10YR 4/3) dry; weak coarse subangular blocky structure that parts to weak fine granular; soft, very friable, nonsticky, nonplastic and weakly smeary; few very fine, fine, and medium roots; few very fine and fine tubular pores; 20 percent gravel, 35 percent cobbles, and 15 percent stones; gradual wavy boundary [S04OR039-001-005]

2Btb—94 to 103 cm; dark grayish brown (10YR 4/2) sandy loam (12 percent clay), brown (10YR 5/3) dry; moderate medium subangular blocky structure that parts to weak fine granular; slightly hard, firm, slightly sticky, slightly plastic and weakly smeary; common clay bridging between sand grains; common faint coarse patches of reduced matrix and few very fine faint oxidized iron masses; few very fine and fine roots; many fine tubular pores; 50 percent gravel; clear wavy boundary [S04OR039-001-006]

2C—103 to 157 cm; dark grayish brown (10YR 4/2) sandy loam (6 percent clay), brown (10YR 5/3) dry; massive; soft, friable, nonsticky and nonplastic; few very fine and fine roots; 45 percent gravel [S04OR039-001-007]

Diagnostic horizons and features in this pedon:

reduced matrix and redox concentrations (Aquic subgroup): 94 to 103 cm; 2Btb
argillic horizon (Alfic subgroup): 94 to 103 cm; 2Btb
umbric epipedon (Humic subgroup): 2 to 94 cm; A1, A2, Bw, 2Bwb
zone with andic soil properties: 2 to 94 cm; A1, A2, Bw, 2Bwb
particle-size control section: 2 to 102 cm
   ashy family: 2 to 62 cm; A1, A2, Bw -- thickest part
   ashy-skeletal family: 62 to 94 cm; 2Bwb
   loamy-skeletal family: 94 to 102 cm; 2Btb

Young forest between Plots 2 and 3

Pedon Number: S04OR039-002

Date described: August 12, 2004
Described by: T. Dyrness, D. Lammers

Slope gradient: 6 percent
Aspect: SW; 300 degrees
Elevation: 1341 meters
Landform: glaciated mountain ridge
Parent material: Mazama ash over till; andesitic basalt

Vegetation: Trees: *Abies grandis (tall), Abies procera* (understory), many dead *Pinus contorta*
Understory: *Rubus lasiococcus, Galium oregana, Hieracium gracile, Fragaria* spp., *Anemone deltoidea, Osmorhiza chilensis, Campanula scouleri, Achlys triphylla*

Location: UTM Zone 10; Northing: 4903305, Easting: 582447

Taxonomic Class (as sampled): ashy, amorphic Humic Vitricryands

Pedon description (colors are for moist soil unless otherwise noted, texture and percent clay are by field estimate)

Oi—0 to 2 cm; undecomposed needles and twigs [S04OR039-002-001]

A1—2 to 15 cm; very dark brown (10YR 2/2) ashy fine sandy loam (9 percent clay), very dark grayish brown (10YR 3/2) dry; weak fine granular structure; soft, very friable, nonsticky, nonplastic and weakly smeary; few very fine, fine and medium roots; common very fine and fine, and few medium and coarse irregular pores;10 percent fine gravel; clear wavy boundary [S04OR039-002-002]

A2—15 to 34 cm; very dark brown (10YR 2/2) ashy fine sandy loam (9 percent clay), dark brown (10YR 3/3) dry; weak medium subangular blocky structure that parts to weak fine granular; soft, very friable, nonsticky, nonplastic and weakly smeary; few very fine, fine and medium roots; common very fine and fine, and few medium and coarse irregular pores;10 percent fine gravel; clear wavy boundary [S04OR039-002-003]

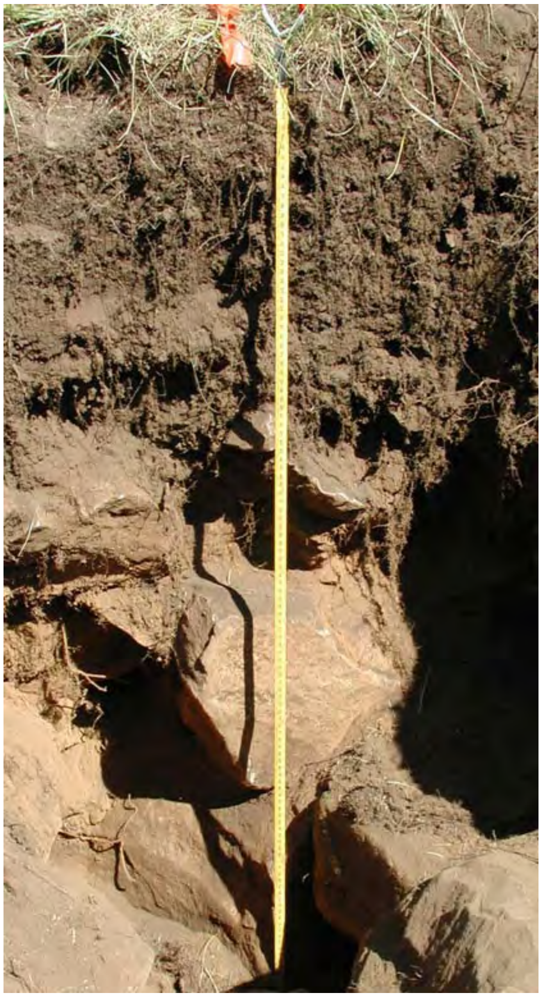
Bw1—34 to 72 cm; very dark brown (7.5YR 2.5/2) ashy fine sandy loam (11 percent clay), brown (7.5YR 4/3) dry; weak medium subangular blocky structure that parts to weak fine granular; soft, very friable, nonsticky, nonplastic and weakly smeary; common very fine, fine and medium, and few coarse roots; few medium and coarse tubular pores; 15 percent gravel and 5 percent cobbles; gradual wavy boundary [S04OR039-002-004]

2Bw2—72 to 102 cm; brown (7.5YR 4/3) ashy fine sandy loam (12 percent clay), dark yellowish brown (10YR 4/4) dry; weak medium subangular blocky structure that parts to weak fine granular; soft, very friable, nonsticky, nonplastic and weakly smeary; few very fine, fine and medium roots; few medium and coarse tubular pores; 20 percent gravel, 25 percent cobbles and 10 percent stones; gradual irregular boundary [S04OR039-002-005]

2C—103 to 129 cm; brown (10YR 4/3) sandy loam (12 percent clay), dark yellowish brown (10YR 4/4) dry; massive; soft, very friable, nonsticky and nonplastic; few fine and medium roots; 15 percent gravel, 35 percent cobbles, 35 percent stones and 2 percent boulders [S04OR039-002-006]

Diagnostic horizons and features in this pedon:

umbric epipedon (Humic subgroup): 2 to 72 cm; A1, A2, Bw1
zone with andic soil properties: 2 to 102 cm; A1, A2, Bw1, 2Bw2
particle-size control section: 2 to 102 cm
   ashy family: 2 to 72 cm; A1, A2, Bw1 -- thickest part
   ashy-skeletal family: 72 to 100 cm; 2Bw2



Lower section of *Holodiscus* Meadow

Pedon Number: S04OR039-003

Date described: August 13, 2004
Described by: T. Dyrness, D. Lammers

Slope gradient: 11 percent
Aspect: SW; 220 degrees
Elevation: 1338 meters
Landform: glaciated mountain ridge
Parent material: Mazama ash over till; andesitic basalt

Vegetation: Trees: none; Understory: *Festuca idahoensis, Cirsium callilepes, Lupinus latifolius, Carex pensylvanica, Erigeron aliceae*

Location: UTM Zone 10; Northing: 4903230, Easting: 582563

Taxonomic Class (as sampled): ashy, amorphic Vitric Melanocryands

Pedon description (colors are for moist soil unless otherwise noted, texture and percent clay are by field estimate)

A1—0 to 7 cm; very dark brown (10YR 2/2) ashy very fine sandy loam (7 percent clay), very dark grayish brown (10YR 3/2) dry; weak very fine granular structure; soft, very friable, nonsticky, nonplastic and smeary; many very fine and fine, and few medium roots (thick root mat); 5 percent fine gravel; clear smooth boundary [S04OR039-003-001]

A2—7 to 31 cm; very dark brown (10YR 2/2) ashy very fine sandy loam (7 percent clay), dark grayish brown (10YR 4/2) dry; weak coarse subangular blocky structure that parts to weak fine granular; soft, very friable, nonsticky, nonplastic and smeary; common very fine and fine, and few medium roots; many very fine irregular pores; 10 percent gravel; clear irregular boundary [S04OR039-003-002]

A3—31 to 51 cm; very dark brown (10YR 2/2) ashy very fine sandy loam (7 percent clay), dark grayish brown (10YR 4/2) dry; weak medium subangular blocky structure that parts to weak fine granular; soft, very friable, nonsticky, nonplastic and smeary; common very fine, and few fine and medium roots; common very fine and fine irregular pores; 10 percent gravel, 10 percent cobbles and 5 percent stones; clear irregular boundary [S04OR039-003-003]

2Bw—51 to 113 cm; dark reddish brown (7.5YR 3/3) ashy very fine sandy loam (10 percent clay), yellowish brown (10YR 5/4) dry; weak fine subangular blocky structure; soft, friable, nonsticky, nonplastic and weakly smeary; few very fine, fine and medium roots; common very fine and fine irregular pores; 10 percent gravel, 10 percent cobbles,10 percent stones and 50 percent boulders; clear irregular boundary [S04OR039-003-004]

3Bqm—113 to 126 cm; reddish brown (7.5YR 4/3) loam (12 percent clay), pale brown (10YR 6/3) dry; moderate medium subangular blocky structure; slightly hard, firm, nonsticky and slightly plastic; slightly brittle and extremely weakly cemented; common fine vesicular pores; 5 percent gravel and 5 percent cobbles [S04OR039-003-005]

Horizons A1, A2 and A3; 65 percent of soil matrix is bioturbated by rodents

Diagnostic horizons and features in this pedon:

melanic epipedon (Melanic greatgroup): 0 to 113 cm; A1, A2, A3, 2Bw
umbric epipedon (Humic subgroup): 0 to 113 cm; A1, A2, A3, 2Bw
zone with andic soil properties: 0 to 113 cm; A1, A2, A3, 2Bw
particle-size control section: 0 to 100 cm
  ashy family: 0 to 51 cm; A1, A2, A3 -- thickest part
  ashy-skeletal family: 51 to 100 cm; 2Bw
  duripan: 113 to 126 cm; 3Bqm

Upper section of *Holodiscus* Meadow

Pedon Number: S04OR039-004

Date described: August 13, 2004
Described by: T. Dyrness, D. Lammers

Slope gradient: 7 percent
Aspect: SSW; 260 degrees
Elevation: 1345 meters
Landform: glaciated mountain ridge
Parent material: Mazama ash over till; vesicular andesite

Vegetation: Trees: none; Understory: not described, similar to lower meadow: *Festuca idahoensis, Cirsium callilepes, Lupinus latifolius, Carex pensylvanica, Erigeron aliceae*

Location: UTM Zone 10; Northing: 4903254, Easting: 582623

Taxonomic Class (as sampled): ashy, amorphic Vitric Melanocryands

Pedon description (colors are for moist soil unless otherwise noted, texture and percent clay are by field estimate)

A1—0 to 18 cm; very dark brown (10YR 2/2) ashy very fine sandy loam (7 percent clay), dark grayish brown (10YR 4/2) dry; weak medium subangular blocky structure that parts to weak fine granular; soft, very friable, nonsticky, nonplastic and smeary; many very fine and fine, and few medium roots; few very fine and many fine tubular pores; 5 percent fine gravel; clear smooth boundary [S04OR039-004-001]

A2—18 to 44 cm; very dark brown (10YR 2/2) ashy very fine sandy loam (7 percent clay), dark grayish brown (10YR 4/2) dry; weak medium subangular blocky structure that parts to weak fine granular; soft, very friable, nonsticky, nonplastic and smeary; many very fine and fine, and few medium roots; common fine and medium tubular pores; 10 percent gravel; clear wavy boundary [S04OR039-004-002]

AB—44 to 61 cm; very dark brown (7.5YR 2.5/2) ashy very fine sandy loam (9 percent clay), brown (10YR 4/3) dry; weak medium subangular blocky structure; soft, friable, nonsticky, nonplastic and weakly smeary; common very fine, and few fine and medium roots; common very fine, fine and medium tubular pores; 10 percent gravel; gradual wavy boundary [S04OR039-004-003]

Bw1—61 to 82 cm; very dark brown (7.5YR 2.5/2) ashy very fine sandy loam (8 percent clay), yellowish brown (10YR 5/4) dry; weak medium subangular blocky structure; soft, friable, nonsticky, nonplastic and weakly smeary; common very fine and fine, and few medium and coarse roots; few very fine and fine irregular pores; 5 percent gravel, 5 percent cobbles and 20 percent stones; gradual wavy boundary [S04OR039-004-004]

Bw2—82 to 116 cm; dark reddish brown (7.5YR 3/3) ashy very fine sandy loam (11 percent clay), yellowish brown (10YR 5/4) dry; weak medium subangular blocky structure; soft, friable, nonsticky, slightly plastic and weakly smeary; few very fine, fine and medium roots; common very fine and fine irregular pores; 20 percent gravel, 5 percent cobbles and 20 percent stones; clear irregular boundary [S04OR039-004-005]

2Bqmb—116 to 139 cm; dark grayish brown (10YR 4/2) coarse loamy sand (4 percent clay), light brownish gray (10YR 6/2) dry; moderate medium subangular blocky structure; hard, firm, nonsticky, nonplastic and smeary; weakly cemented, brittle and dense; few fine faint irregular iron masses on ped faces; few fine roots, many very fine and fine vesicular pores; 60 percent gravel, 15 percent cobbles and 5 percent stones; clear irregular boundary [S04OR039-004-006]
[Note: coarse sand and very fine gravel-size fragments appear to be silica cemented concretions that do not slake in water.]

2Bwb—139 to 160 cm; brown (10YR 4/3) fine sandy loam (11 percent clay), yellowish brown (10YR 5/4) cry; weak medium subangular blocky structure; soft, friable, nonsticky and slightly plastic; few fine and few medium roots; 25 percent gravel, 30 percent cobbles and 10 percent stones [S04OR039-004-007]

Diagnostic horizons and features in this pedon:

melanic epipedon (Melanic greatgroup): 0 to 61 cm; A1, A2, AB
umbric epipedon (Humic subgroup) : 0 to 116 cm; A1, A2, AB, Bw1, Bw2
zone with andic soil properties: 0 to 116 cm; A1, A2, AB, Bw1, Bw2
particle-size control section: 0 to 100 cm
  ashy family: 0 to 82 cm; A1, A2, AB, Bw1 -- thickest part
  ashy-skeletal family: 82 to 100 cm; 2Bw
  duripan: 116 to 139 cm; 2Bqmb
  redox concentrations: 116 to 139 cm; 2Bqmb

Old-growth forest adjacent to Bunchgrass Ridge study area, west of Plot 2

Pedon Number: S04OR039-005

Date described: August 13, 2004
Described by: T. Dyrness, D. Lammers

Slope gradient: 5-6 percent
Aspect: 305 degrees
Elevation: 1345 meters
Landform: glaciated mountain ridge
Parent material: Mazama ash over till; andesitic basalt

Vegetation: Trees: *Pseudotsuga menziesii, Abies grandis, Abies amabilis*
Understory: *Clintonia uniflora*, *Achlys triphylla*, *Chimaphila umbellata*, *Fragaria* spp., *Rubus lasiococcus*, *Anemone deltoidea*, *Viola glabella, Osmorhiza chilensis*

Location: UTM Zone 10; Northing: 4903403; Easting: 582293

Taxonomic Class (as sampled): ashy-skeletal, amorphic Humic Vitricryands

Pedon description (colors are for moist soil unless otherwise noted, texture and percent clay are by field estimate)

Oi—0 to 3 cm; undecomposed needles and twigs [S04OR039-005-001]

A1—3 to 11 cm; dark brown (7.5YR 3/2) ashy fine sandy loam (8 percent clay), brown (10YR 4/3) dry; weak fine granular structure; soft, very friable, nonsticky, nonplastic and weakly smeary; common very fine, few fine and medium roots; common very fine irregular pores; 10 percent gravel; few fine and medium charcoal fragments; clear smooth boundary [S04OR039-005-002]

A2—11 to 26 cm; dark brown (7.5YR 3/2) ashy fine sandy loam (8 percent clay), brown (10YR 4/3) dry; weak medium subangular blocky structure; soft, very friable, nonsticky, nonplastic and weakly smeary; common very fine, few fine, medium and coarse roots; few very fine and common fine irregular pores; 10 percent gravel; few fine and medium charcoal fragments; gradual wavy boundary [S04OR039-005-003]

2Bw1—26 to 73 cm; dark brown (7.5YR 3/3) ashy fine sandy loam (8 percent clay), yellowish brown (10YR 5/4) dry; weak medium subangular blocky structure; soft, very friable, nonsticky, nonplastic and weakly smeary; common very fine, fine and medium, and few coarse roots; common fine and medium, and few coarse; tubular pores; 10 percent gravel, 10 percent cobbles, 20 percent stones and 15 percent boulders; few fine and medium charcoal fragments; gradual wavy boundary [S04OR039-005-004]

2Bw2—73 to 113 cm; dark brown (7.5YR 3/3) ashy fine sandy loam (11 percent clay), yellowish brown (10YR 5/4) dry; moderate medium subangular structure; slightly hard, friable, nonsticky, slightly plastic and weakly smeary; few very fine, fine, medium and coarse roots, few very fine and fine irregular pores; 20 percent gravel, 10 percent cobbles, 15 percent stones and 20 percent boulders; few fine charcoal fragments; abrupt irregular boundary [S04OR039-005-005]

3Bqmb1—113 to 129 cm; brown (10YR 4/3) fine sandy loam (11 percent clay), light yellowish brown (10YR 6/4) dry; moderate medium angular blocky structure; moderately hard, firm, nonsticky, slightly plastic, weakly cemented and brittle; few fine faint irregular iron masses between peds; no roots; few fine irregular pores; 30 percent gravel; abrupt irregular boundary [S04OR039-005-006]

3Bwb—129 to 151 cm; brown (10YR 4/3) loam (14 percent clay), yellowish brown (10YR 5/4) dry; weak medium subangular blocky structure; soft, friable, nonsticky, slightly plastic and moderately smeary; few very fine, fine and medium roots, common fine, few very fine and medium tubular pores; 10 percent gravel and 15 percent stone; gradual wavy boundary [S04OR039-005-007]

4Bqmb2—151 to 173 cm; brown (10YR 5/3) sandy loam (15 percent clay), pale brown (10YR 6/3) dry; strong medium subangular blocky structure; hard, firm, nonsticky, slightly plastic, nonsmeary and brittle; few fine distinct dendritic iron masses on faces of peds; many fine prominent threads of silica on ped faces and on surfaces along pores; 10 percent gravel [S04OR039-005-008]

Diagnostic horizons and features in this pedon:

umbric epipedon (Humic subgroup): 3 to 113 cm; A1, A2, 2Bw1, 2Bw2
zone with andic soil properties: 3 to 113 cm; A1, A2, 2Bw1, 2Bw2
particle-size control section: 3 to 103 cm
  ashy family: 3 to 26 cm; A1, A2
  ashy-skeletal family: 26 to 100 cm; 2Bw1, 2Bw2
  buried silica cemented layers: 113 to 129 cm and 151 to 173 cm; 3Bqmb1, 3Bqmb2