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

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Final Report to the Joint Fire Science Program

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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 1

2. Study Area 3

3. Research Program 5

3.1. Ecology and dynamics of montane meadows: retrospective and observational studies 5

3.1.1. History of conifer encroachment 5

3.1.1.1. Spatial and temporal patterns of conifer invasion 5

3.1.1.2. Detecting change in meadow extent through analysis of aerial photography 8

3.1.2. Vegetation responses to conifer encroachment 9

3.1.2.1. Vegetation responses to conifer encroachment: a chronosequence study 9

3.1.2.2. Vegetation responses to tree establishment: effects of tree age and species 11

3.1.2.3. Dynamics of the soil seed bank: consequences of conifer encroachment and implications for restoration 13

3.1.3. Other studies of meadow ecology 15

3.1.3.1. Gopher disturbance in meadows: effects on species diversity and heterogeneity 15

3.2. The restoration experiment 17

3.2.1. Experimental design 17

3.2.2. Treatment implementation 18

3.2.3. Sampling design and analysis 22

3.2.3.1. Tree removal with and without burning 22

3.2.3.2. Effects of burn piles 23

3.2.4. Early results 24

3.2.4.1. Tree removal with and without burning 24

3.2.4.2. Effects of burn piles 30

3.2.5. Conclusions 32

4. Education, Training, and Outreach 35

5. Crosswalk Table of Project Deliverables 39

6. Literature Cited 43

7. List of Products Accompanying This Report 45

8. Appendices 47

8.1. Appendix 1. Plant species of Bunchgrass Ridge 47

8.2. Appendix 2. Descriptions of soil profiles at Bunchgrass Ridge 49

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.

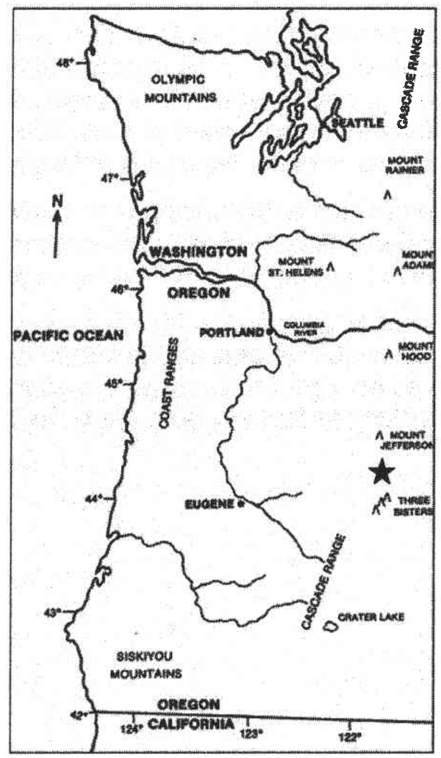


Fig. 1. Western Cascade landscape with Bunchgrass Ridge (below arrow) as seen from the north. Location map (right).

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.

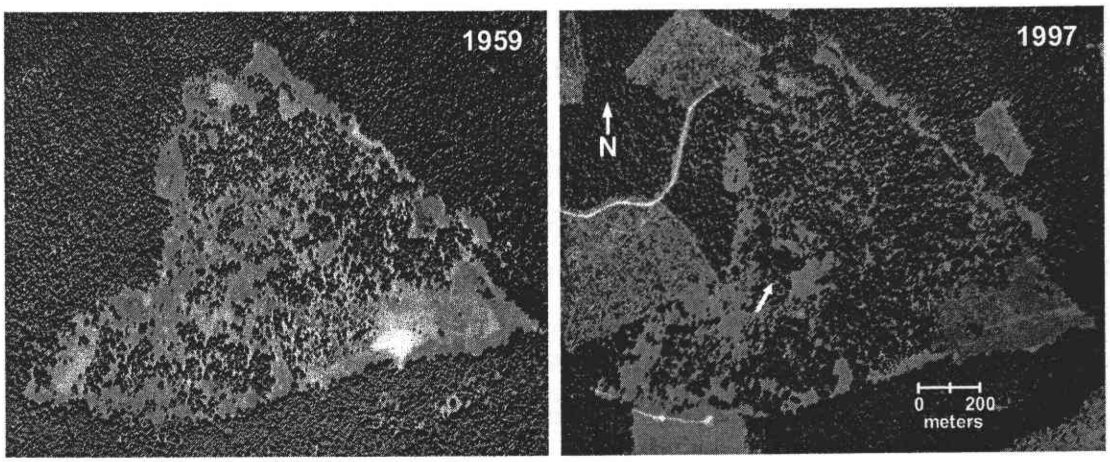


Fig. 2. Aerial photos of the study area illustrating the rapid closure of meadows during the latter half of the 20th century. Forests in the 1959 photo are now >100 yr old. Clearcuts are apparent in the 1997 photo.

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.

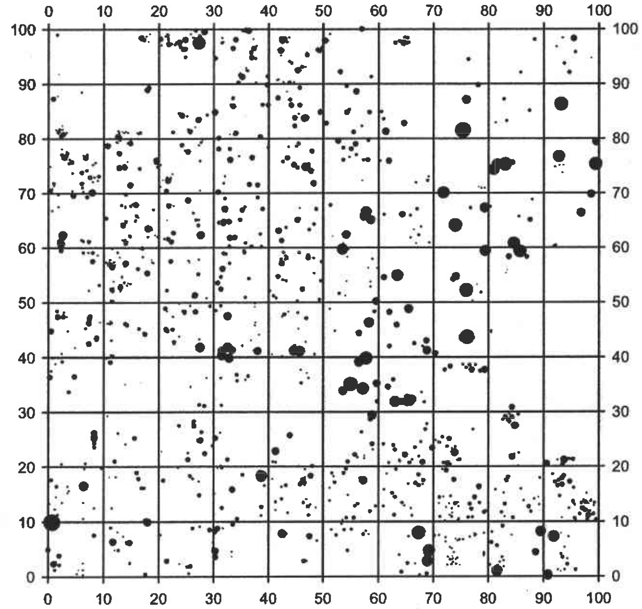


Fig. 3. Stem map of a 1-ha (2.5 ac) plot with trees scaled to diameter.

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.

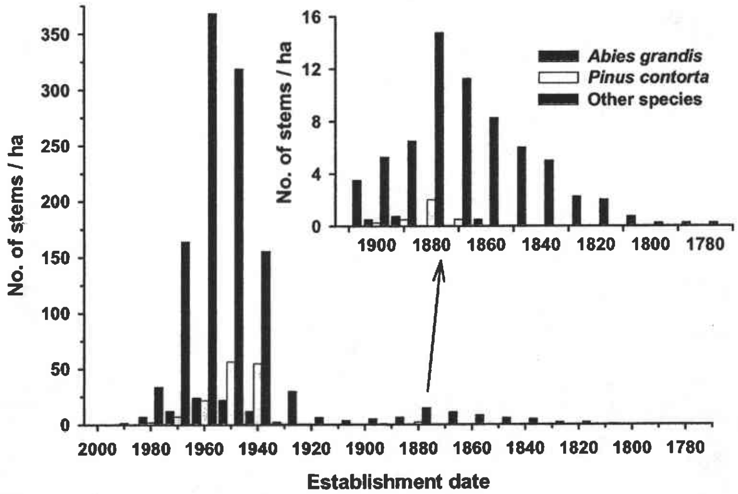
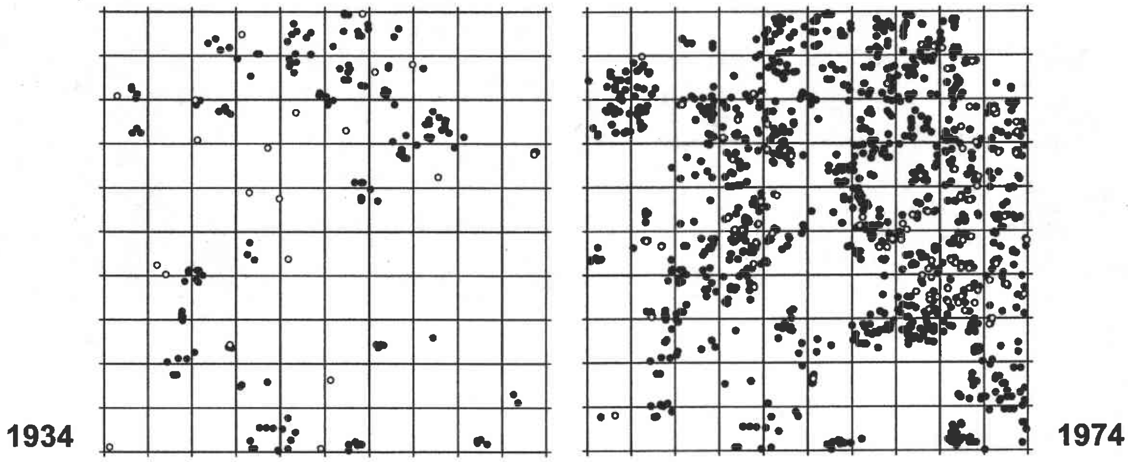


Fig. 4. Composite age structure of trees. The initial period of recruitment is enlarged for clarify. Many pine that established in the original cohort still persist as snags, but are not present in the live age structure.



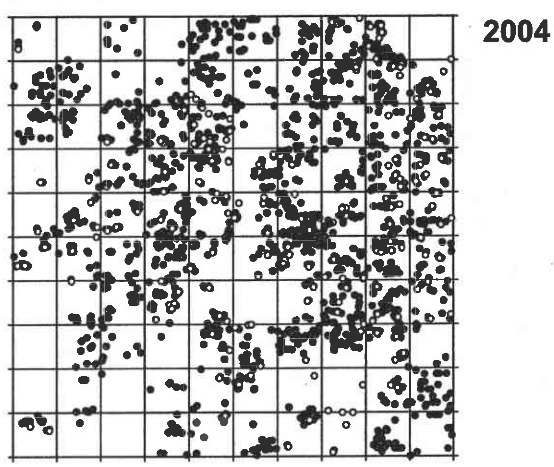


Fig. 5. Temporal sequence of invasion in one of the mapped 1-ha (100 x 100 m) plots. Trees in the 1934 map represent the original cohort. Species codes are: green = grand fir, yellow = lodgepole pine, and red = other.

- 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).

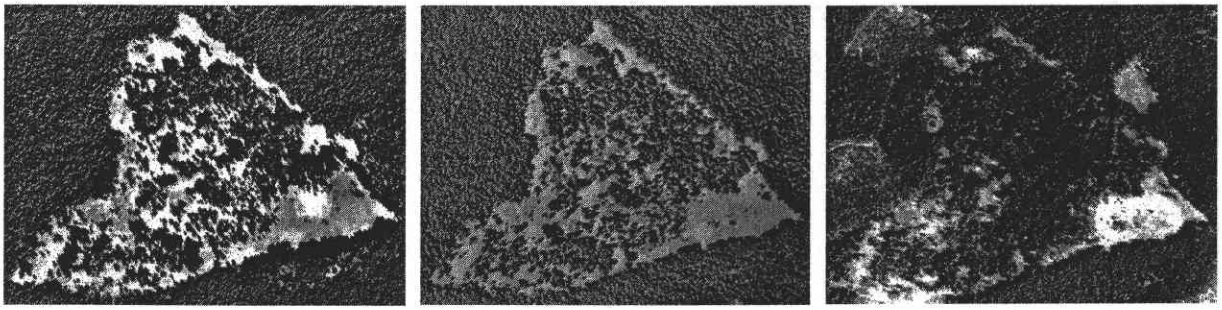


Fig. 7. Changes in the forest-meadow mosaic at Bunchgrass Ridge. Photo used in this analysis are from 1946, 1967, and 2000. Clearcuts are apparent in the 2000 photo.

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).

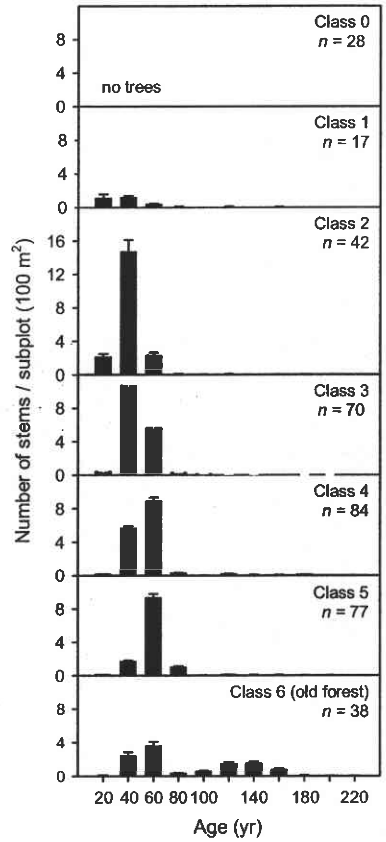


Fig. 8. Age structures of the seven encroachment classes: 0 = open meadow, 2-5 = young forest, and 6 = old forest, with illustrations below.

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).

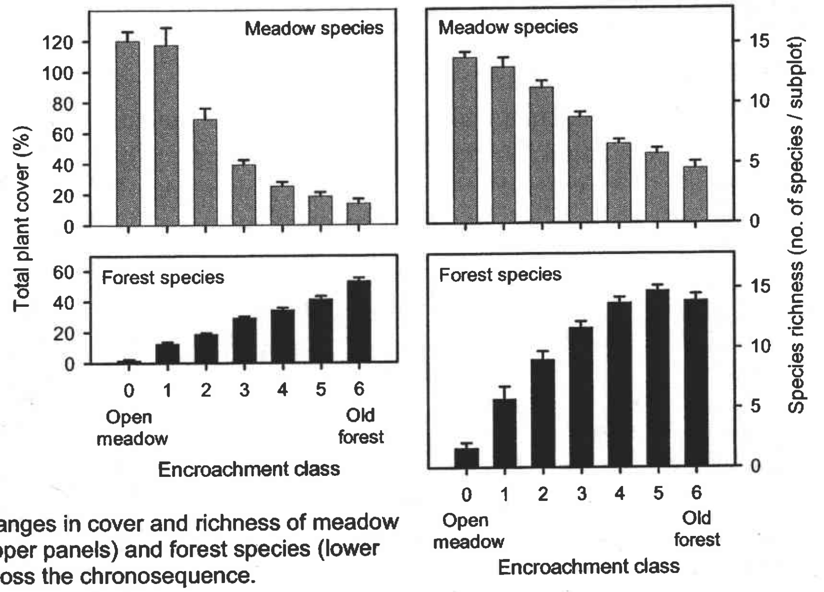


Fig. 9. Changes in cover and richness of meadow species (upper panels) and forest species (lower panels) across the chronosequence.

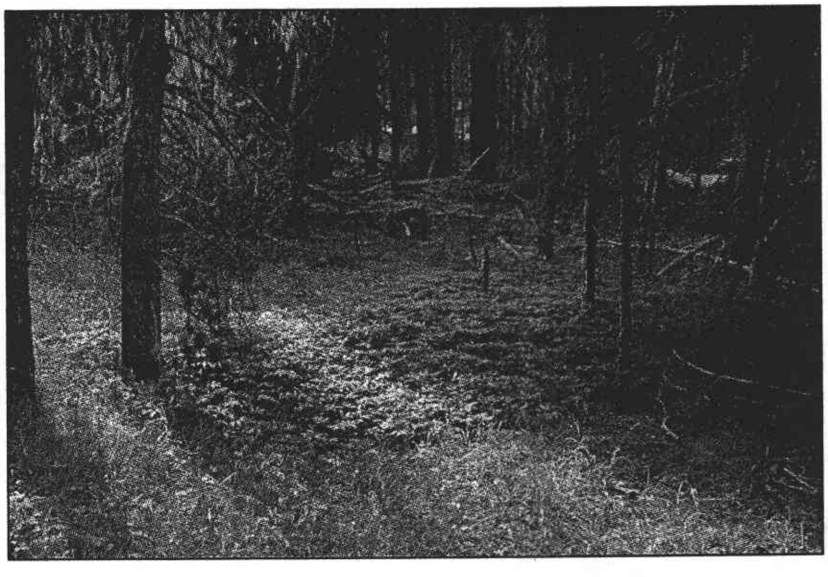


Fig. 10. Forest understory plants rapidly colonize beneath young stands of grand fir.

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.

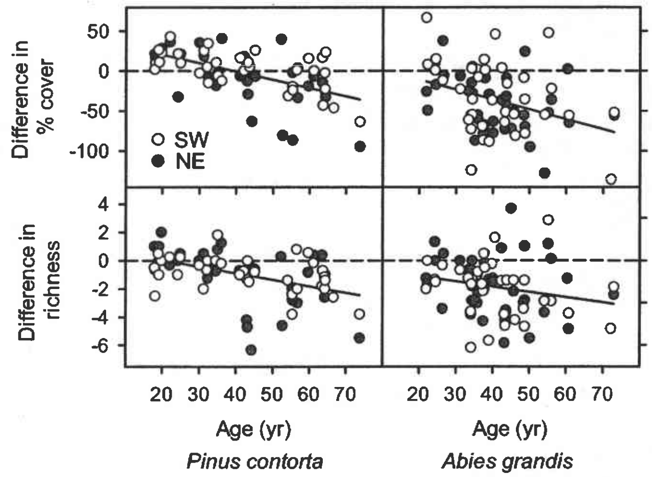


Fig. 13. Effects of tree age and tree species on meadow taxa. Negative values indicate lower cover (or richness) under the tree canopy than in open meadow.

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)

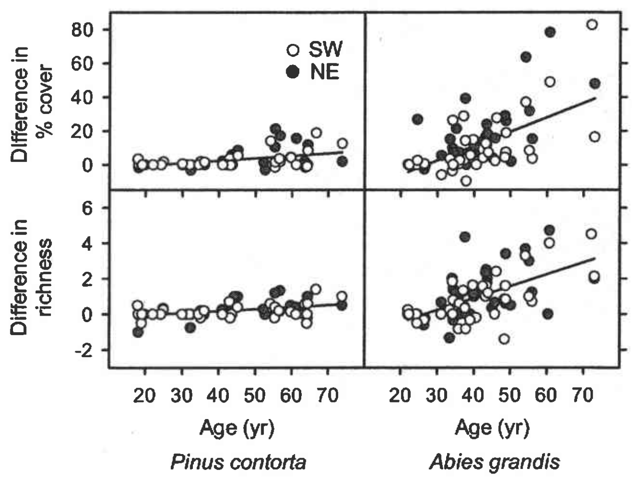


Fig. 14. Effects of tree age and tree species on forest understory taxa. See Fig. 13 for other details.

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