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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Introduction

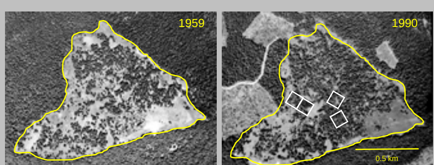
We are studying the consequences of conifer encroachment and the potential for restoration of dry, montane meadows in the western Cascade Range of Oregon. In a region dominated by coniferous forests, montane meadows contribute greatly to landscape diversity, wildlife habitat, and other important ecological functions. However, in many areas, suppression of fire and changes in climate and grazing pressure over the last century have led to rapid succession of meadow to forest. Faced by gradual loss of these habitats, resource managers are experimenting with prescribed fire as a tool for meadow restoration, but with limited knowledge of their ecology and dynamics. To better guide these efforts, we have designed a program of research and adaptive management at Bunchgrass Ridge. Our goals are to increase understanding of the history, dynamics, and variability of these systems, and to evaluate the potential for restoration. Three studies contribute to these goals:

- **Study 1.** A retrospective analysis of vegetation change along a transition from open meadow to old forest.
- **Study 2.** An analysis of the soil seed bank and its potential to contribute to restoration of the meadow flora.
- **Study 3.** An experiment to examine vegetation responses to tree removal and prescribed fire, and how responses vary with initial composition and structure.

The Study Site – Bunchgrass Ridge

Bunchgrass Ridge lies on a broad, gently sloping plateau at ~1300 m elevation in the central, western Cascade Range of Oregon. It supports a 100-ha mosaic of dry meadow and coniferous forest. Meadows are dominated by graminoids (*Festuca idahoensis* and *Carex pensylvanica*) and a diversity of forbs. Forests are comprised primarily of grand fir (*Abies grandis*) and lodgepole pine (*Pinus contorta*) with understories in older stands dominated by mesic-site herbs (*Achlys triphylla*, *Anemone oregana*, and *Smilacina stellata*).

Summers are warm and dry; winters are cool and wet. Annual precipitation is >2100 cm and winter snow can accumulate to ~2 m depth. Soils are deep (>170 cm), fine to very fine sandy loams derived from andesitic basalt and tephra. Soil profiles suggest development under grassland for centuries, even in locations that support old (>130 yr) forest.



Meadows have experienced recent and rapid encroachment by conifers. To sample the full history of invasion, study sites were selected to include areas of old forest, recent recruitment, and open meadow. From a set of nine, 1-ha experimental plots (**Study 3**), four (white squares in 1990 photo) were chosen for retrospective studies of ground vegetation (**Study 1**) and soil seed banks (**Study 2**).

Methods

- **Sampling design:** Four 1-ha "intensive plots" (**Fig. 1**), with 10 x 10 m subplots used as sampling units for vegetation and seed bank analyses.
- **Trees:** All live stems (≥1.4 m tall) and snags (≥5 cm dbh) mapped and measured for dbh. All live stems aged (increment core or basal section).
- **Canopy cover:** Hemispherical photo at the center of each subplot.
- **Ground vegetation:** Cover of species in four 1-m^2 quadrats/subplot (n = 356 subplots).
- **Species classification:** All species were classified *a priori* by habitat preference as "meadow", "forest", or "ruderal".
- **Soil seed bank:** Three 10-cm deep x 6-cm diameter soil cores/subplot (n = 209 subplots). Germination observed for 7 mo in the greenhouse.

A Chronosequence Approach

Conifer encroachment has occurred over many decades (**Fig. 2**), creating a mosaic of forest patches of varying age and structure in close proximity. This provides an ideal setting for a retrospective study of vegetation response to forest development. Stages along the developmental sequence were obtained with an agglomerative hierarchical clustering of subplots (Ward's linkage method with Euclidean distance; PC-ORD v. 4). The number of trees in each of eleven 20-yr age classes served as variable scores for each subplot. This produced seven classes (**Fig. 3**) representing a continuum from **open meadow** (class 0) to **old forest** (class 6).

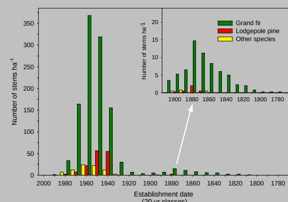
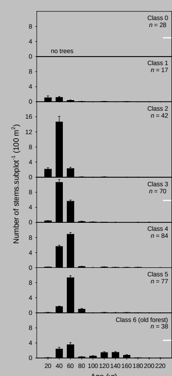


Fig. 2. Composite age structure of trees ≥1.4 m tall in the four 1-ha "intensive plots" illustrating two broad periods of encroachment at Bunchgrass Ridge. The age structure of the initial "cohort" is reproduced in the upper right for clarity (note the change in scale).



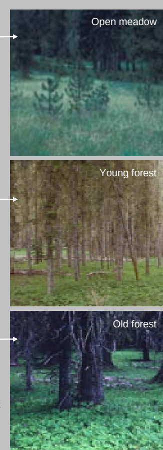


Fig. 3. Age structures of the seven developmental stages (encroachment classes). n is the number of subplots in a class.

Sampling Design

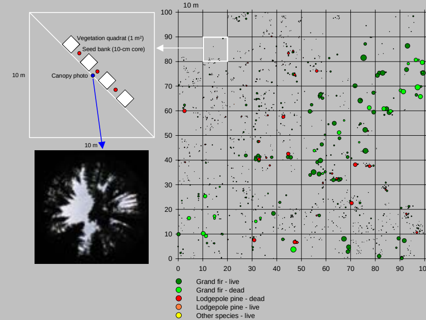


Fig. 1. One of four, 1-ha "intensive plots" with locations of all live and dead stems. Symbols size is scaled to dbh (approximate). Subplots (10 x 10 m) served as sampling units for ground vegetation (four 1-m^2 quadrats/subplot) and the soil seed bank (three 10-cm deep x 6-cm diameter cores/subplot). A hemispherical photograph was taken at the center of each subplot and analyzed for total annual transmitted light using the software Gap Light Analyzer (GLA 2.0; Frazer et al. 1999).

Study 1. Vegetation Responses to Conifer Encroachment

Questions: How do the abundance, richness, and composition of ground species change during the transition from open meadow to old forest? Are compositional trends correlated to changes in forest structure?

Conifer encroachment leads to dramatic changes in the ground flora (**Fig. 4**). Cover of meadow species declines steeply once tree density reaches a threshold (Class 2); richness of meadow species declines more gradually. Forest species recruit early (Class 1) and continuously through stand development.

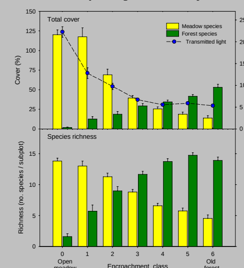
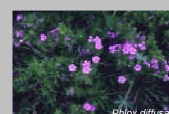


Fig. 4. Trends in transmitted light and total cover and richness of meadow and forest species among the seven encroachment classes. Values are means ±1 SE.



Indicators of open meadow (*Phlox diffusa*) and old forest (*Smilacina stellata*).

Compositional gradients in ordination space show strong correlations to changes in overstory structure (structural vectors in **Fig. 5**). Turnover in species composition along NMS1 reflects gradual replacement of lodgepole pine (Class 2,3) by grand fir (Class 4-6).

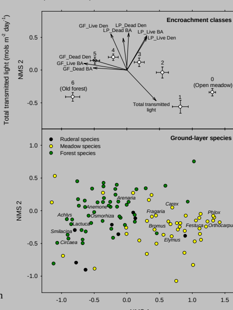
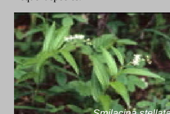


Fig. 5. NMS ordination of encroachment class centroids (±1 SE) and ground species (coded by habitat preference). Vectors portray the direction and relative strength of Spearman-rank correlations between structural variables and ordination axes. Names are shown for the most frequent species.



Study 2. Dynamics of the Soil Seed Bank

Questions: To what extent do meadow species contribute to the soil seed bank? Do the density and diversity of their seeds decline as meadow is replaced by forest?

Soils in general support a well developed seed bank. 4,130 germinants emerged from 94% of subplots (mean of 2,332 m^{-2}). Ruderals comprised 71% of germinants (15 species); meadow species comprised 21% of germinants (11 species). For seedbank analyses, encroachment classes were grouped as "open meadow" (classes 0-1), "young forest" (classes 2-5), and "old forest" (class 6).

Richness and density of meadow species did not vary significantly among open meadow, young forest, and old forest subplots (**Fig. 6**).

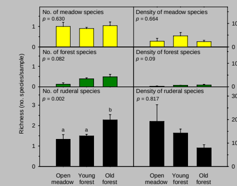


Fig. 6. Richness and density of meadow, forest, and ruderal species in the seed bank among three structural stages. Values are means ±1 SE. P values are from one-way ANOVA or Kruskal-Wallis tests.

DCA ordination showed gradual transition in seed bank composition from open meadow to old forest, but variability was high within each stage (**Fig. 7**). Germinant species associated with open meadow included common meadow taxa, *Danthonia intermedia* and *Achillea millefolium*. Species associated with old forest included ruderal exotics, *Lactuca muralis* and *Senecio sylvaticus*.

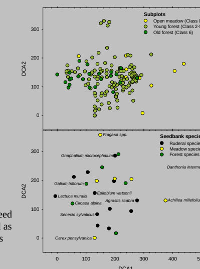


Fig. 7. DCA ordination of subplots and seed bank species. Germinant density was used as the measure of species abundance. Names are shown for the most frequent species.

Study 3. The Restoration Experiment

The experiment addresses three questions:

1. Is restoration of meadow communities possible following conifer encroachment?
2. Is prescribed fire necessary or is tree removal sufficient?
3. How do responses to treatments vary with initial structure and composition?

The experimental design consists of three replicates of three treatments (**Fig. 8**):

1. **Control**: no treatment
2. **Cut + no burn**: tree removal with slash burned locally in piles
3. **Cut + burn**: tree removal with broadcast burning of logging slash

Experimental units include the four plots used in retrospective studies and five additional plots sampled similarly for vegetation. Contrasts will be made at two scales: among **experimental units** to address overall treatment effects, and among **subplots** representing different stages of encroachment to understand how initial structure and composition shape responses to treatments.

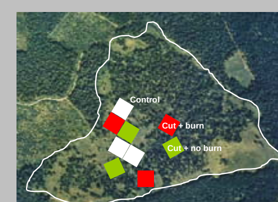


Fig. 8. Design of the restoration experiment. Experimental units are 1-ha in area; treatments were assigned randomly.

The results of our retrospective studies point to a number of factors that may limit the potential for restoration of dry, montane meadows: (1) significant declines in abundance and progressive loss of species diversity with time, (2) absence of a seed bank for most meadow taxa, and (3) potential competitive interactions with forest herbs and ruderal species that respond positively to overstory removal or soil disturbance. These limitations are likely to be most evident where forests have been present the longest.