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.

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 Distinctive communities of grasses, sedges, and forbs have been replaced by forests of lodgepole pine and grand fir whose understories are dominated by shade-tolerant herbs.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.