Annie Merritt
Instructors Sarah Yarnell and Carson Jeffres
GEL 136
8 June 2018

Restoring vegetation in Sierra Nevada subalpine meadows: Case study of Tuolumne Meadows

Introduction

Sierra Nevada subalpine meadows comprise only a small fraction of the Sierra Nevada region, but they play an important role as areas of high biodiversity, providing habitat for many species as well as essential ecosystem services such as water filtration, flood attenuation, and aesthetic and recreational values (Drew et al. 2016). Sierran subalpine meadows are landscape features that occur in places with shallow water tables, with water sources primarily from snowmelt, direct precipitation, overland water flow, and surface flow from streams and springs (Lord et al. 2011). However, human activities have adversely affected many of these meadows, mainly due to livestock grazing pressures, diversions and ditching, culverts from roads, and railroad grades (Viers et al. 2013). About half of Sierra Nevada meadows are considered highly degraded, most commonly from streambed incision (Drew et al. 2016). Streambed incision results in the drainage of water normally stored in the rooting zone soil, which lowers the water table and ultimately can lead to conversions from mesic (wet) to xeric (dry) vegetation (Drew et al. 2016). In many subalpine meadows of the Sierra Nevada, this drying out of the meadow leads to woody plant encroachment, with woody plants—including conifers—invading the herbaceous meadow vegetation (Lubetkin et al. 2017). Various techniques are currently being used to restore Sierran subalpine meadows, including direct channel restoration techniques (e.g. "pond-and-plug," or partial channel infill, and beaver dam analogues), as well as techniques focusing on active restoration of herbaceous meadow vegetation and the removal of conifers.

While direct channel modifications have the goal of restoring meadow processes and associated herbaceous meadow vegetation, in some contexts more direct restoration of vegetation is needed. In this paper, I discuss vegetation restoration techniques applicable to Sierra Nevada subalpine meadows, ending with a brief discussion of Tuolumne Meadows as an example. Tuolumne Meadows presents a somewhat different case than most Sierra Nevada subalpine meadows, as its main issue is not channel incision so much as vegetation conversion, an increase in bare patches, and lodgepole pine encroachment, problems most likely due to impacts from historical and current grazing in conjunction with climate change (Wolf 2017).

Restoration of Herbaceous Meadow Vegetation

The goal of restoration in meadows is to reestablish the hydrologic, soil, and plant processes of the meadow, which work in harmony in undisturbed meadows but which have been disrupted in many cases by human activities (Wolf 2017). Because meadow hydrology and ecology are so tightly linked, restoring hydrologic processes is one method for maintaining or restoring specific vegetation communities (Lowry et al. 2011). However, in certain contexts, restoring native meadow vegetation may require active restoration of meadow flora, as can be the case with meadows experiencing conifer encroachment, where native vegetation often cannot reestablish using its natural seedbank (Lang and Halpern 2007). Such direct vegetation restoration techniques include vegetation removal (Berlow et al. 2003; Sundberg 2011); seeding and planting of native grasses, sedges, and rushes (Steed and DeWald 2003; Wolf and Cooper 2011); herbivore exclusion to limit grazing pressure (Wolf 2017); and prescribed burning and/or tree removal to limit or reverse conifer encroachment into meadows (Swanson et al. 2007; Halpern et al. 2010; Austin et al. 2007).

Conifer Encroachment

Conifer encroachment is a widespread problem in many Sierra Nevada subalpine meadows (Lubetkin et al. 2017). While the process of conifer encroachment is still not fully understood, studies indicate that it can result from fire suppression (Norman and Taylor 2005) and that it is exacerbated by climate change, which will continue to increase conditions favorable for conifer recruitment (Lubetkin et al. 2017). One approach to reducing or reversing conifer encroachment in meadows is the use of prescribed burning, which the Forest Service has experimented with (Stillwater Sciences 2012). Prescribed burning has also been applied in combination with tree removal and scattering: in meadows in Oregon, Swanson and co-authors (2007) found that tree removal increased recovery rates of herbaceous meadow vegetation whether or not the removal was followed by prescribed burn. Their results also indicated that conifer encroachment that is relatively recent can be reversed more easily than older conifer encroachment (as is the case in Tuolumne Meadows), which probably necessitates active restoration of the herbaceous meadow vegetation because in cases of older conifer encroachment soil conditions have been altered and the herbaceous vegetation seedbank depleted (Swanson et al. 2007).

However, tree removal and prescribed burning may not always produce the desired effects. Conifers can re-invade the meadow after treatment, indicating that the processes that historically deferred conifer establishment have been altered, and/or that disturbances from tree removal and prescribed burning treatments might increase conditions favorable for conifer establishment (Kremer et al. 2014).

Vegetation Restoration in Tuolumne Meadows

An iconic meadow in Yosemite National Park and the biggest subalpine meadow in the Sierra Nevada, Tuolumne Meadows receives many visitors and scientists today and historically experienced immense grazing pressure from sheep in the 19th Century (Wolf 2017). The main problems facing Tuolumne Meadows today include invasion by lodgepole pine, wetland vegetation conversion, and an increase in bare patches without vegetation, changes that have caused the meadow to have a net loss of carbon (Wolf 2017). These issues may be the result of historical livestock grazing, which could have altered soil rhizome structure, leading to erosion and subsequent establishment of woody upland plants (Cooper et al. 2006). Changes in fire frequency in Tuolumne Meadows due to fire suppression beginning after 1891 may be another factor in meadow vegetation community changes and lodgepole pine encroachment (Cooper et al. 2006).

In their report on the effects of Tioga Road on hydrologic processes and lodgepole pine encroachment in Tuolumne Meadows, Cooper and co-authors (2006) suggest that human-aided techniques are needed to restore vegetation, including deer exclusion to limit grazing, and the seeding and planting of native sedges, grasses, and rushes. Indeed, Tuolumne Meadows has lower sedge cover and more bare ground than similar meadows near it, problems that are most likely a result of extensive livestock grazing during the 19th century and that are believed to be maintained today by native herbivory (Wolf 2017). Wolf (2017) used herbivore exclusion plots to assess the impacts of native rodent and deer herbivory over the past century on the sparse, low-production wetland vegetation and riparian willows in Tuolumne Meadows. Results showed that bare ground decreased, aboveground biomass increased, and planted sedge and lodgepole pine (*Pinus contorta* var. *murrayana*) survival was higher in meadow plots protected from native herbivory (Wolf 2017).

Lodgepole pine invasion has been much studied in Tuolumne Meadows, where encroachment has been occurring since the 19th century but the processes governing it are not thoroughly understood (Cooper et al. 2006). It is known that lodgepole pine invaded Tuolumne Meadows during periods of both low precipitation and low annual variability in moisture conditions (Cooper et al. 2006). Because the National Park Service (NPS) carried out periodic manual removal of lodgepole pine saplings in Tuolumne Meadows from about 1933 until recently (National Park Service 2014), researchers do not know whether lodgepole pines that established prior to these removal activities would have survived if the removal activities had not taken place (Cooper et al. 2006). In 2010, the NPS discontinued the mechanical removal of conifer saplings, as it waits for the results of studies that will provide more site-specific information on conifer encroachment (National Park Service 2014). More research is needed to understand lodgepole pine invasion in Tuolumne Meadows, specifically, to better understand how past land uses have influenced conifer seedling establishment (National Park Service 2014).

Conclusion

While Sierra Nevada meadows are of critical importance as areas of high biodiversity that provide various essential ecosystem services and habitat for many species, about half of these meadows are currently degraded. Main drivers of Sierran meadow degradation include impacts from land use changes (e.g. the construction of roads and reservoirs), historical and current grazing, and climate change, while the most common degradation in these meadows is streambed incision, which ultimately leads to the drying of the meadow and associated vegetation conversions. With such pervasive degradation of Sierra Nevada meadows, restoration of meadow processes is essential. Restoration techniques that have been applied to Sierra Nevada meadows include direct channel modification methods as well as more direct techniques for restoring herbaceous meadow vegetation and limiting or reversing conifer encroachment. Tuolumne Meadows mainly faces the problems of vegetation conversion, an increase in bare cover, and encroachment by lodgepole pines. Restoration techniques most relevant to Tuolumne Meadows include human-aided techniques to reestablish herbaceous meadow vegetation (e.g. grazing exclusion, seeding and planting of native sedge, grass, and rushes) and techniques to limit or reverse lodgepole pine encroachment (such as tree removal and prescribed burning). Future research is needed in particular on the processes governing lodgepole pine invasion, a phenomenon that is not thoroughly understood.

Literature Cited

Austin, J.E., R.K. Keough, and W.H. Pyle. 2007. Effects of habitat management treatments on plant community composition and biomass in a montane wetland. *Wetlands* **27**(3):570-587.

Berlow, E.L., C.M. D'Antonio, and H. Swartz. 2003. Response of herbs to shrub removal across natural and experimental variation in soil moisture. *Ecological Applications* **13**:1375-1387.

Cooper, D.J., J.D. Lundquist, J. King, A. Flint, L. Flint, E. Wolf, F.C. Lott, and J. Roche. 2006. Effects of the Tioga Road on hydrologic processes and lodgepole pine invasion into Tuolumne Meadows, Yosemite National Park. Report prepared for Yosemite National Park.

Drew, W.M., N. Hemphill, L. Keszey, A. Merrill, L. Hunt., J. Fair, S. Yarnell, J. Drexler, R. Henery, J. Wilcox, R. Burnett, K. Podolak, R. Kelley, H. Loffland, R. Westmoreland, and K. Pope. 2016. Sierra Meadows Strategy. Sierra Meadows Partnership Paper 1: PP 40.

Halpern, C.B., J.A. Antos, J.M. Rice, R.D. Haugo, and N.L. Lang. 2010. Tree invasion of a montane meadow complex: temporal trends, spatial patterns, and biotic interactions. *Journal of Vegetation Science* **21**(4):717-732.

Kremer, N.J., C.B. Halpern, and J.A. Antos. 2014. Conifer reinvasion of montane meadows following experimental tree removal and prescribed burning. *Forest Ecology and Management* **319**:128-137.

Lang, N., 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**:557-56.

Lord M.L., D.G. Jewett, J. R. Miller, D. Germanoski, and J.C. Chambers. 2011. Hydrologic processes influencing meadow ecosystems. USDA Forest Service General Technical Report RMRS-GTR258, 44-67.

Lowry, C.S., S.P. Loheide II, C.E. Moore, and J.D. Lundquist. 2011. Groundwater controls on vegetation composition and patterning in mountain meadows. *Water Resources Research* **47** W00J11.

Lubetkin, K.C., A.L. Westerling, and L.M. Kueppers. 2017. Climate and landscape drive the pace and pattern of conifer encroachment into subalpine meadows. *Ecological Applications* **27**:1876-1887.

National Park Service. 2014. Tuolumne Wild and Scenic River Final Comprehensive Management Plan and Environmental Impact Statement. United States Department of the Interior.

Norman, S.P., and A.H. Taylor. 2005. Pine forest expansion along a forest-meadow ecotone in northeastern California, USA. *Forest Ecology and Management* **215**(1–3):51-68.

Steed, J.E. and L.E. DeWald. 2003. Transplanting sedges (*Carex* spp.) in southwestern riparian meadows. *Restoration Ecology* **11**:247-256.

Stillwater Sciences. 2012. A guide for restoring functionality to mountain meadows of the Sierra Nevada. Prepared by Stillwater Sciences, Berkeley, California for American Rivers, Nevada City, California.

Sundberg, S. 2011. Quick target vegetation recovery after restorative shrub removal and mowing in a calcareous fen. *Restoration Ecology* **20**:331-338.

Swanson, F. J., C.B. Halpern, and J.H. Cissel. 2007. 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: 63.

Viers, J.H., S.E. Purdy, R.A. Peek, A. Fryjoff-Hung, N.R. Santos, J.V.E. Katz, J.D. Emmons, D.V. Dolan, and S.M. Yarnell. 2013. Montane meadows in the Sierra Nevada: Changing hydroclimatic conditions and concepts for vulnerability assessment. Center for Watershed Sciences Technical Report (CWS-2013-01), University of California, Davis. 63 ppd.

Wolf, E.C. and D. Cooper 2011. Restoration of geomorphic structure, hydrologic regime, and vegetation in Upper Halstead Meadow. Colorado State University, Fort Collins, CO.

Wolf, E.C. 2017. Ecosystem function, degradation, and restoration in wetlands of the Sierra Nevada, California. PhD dissertation, University of California, Davis. Retrieved from https://search.proquest.com/docview/2020852803?accountid=14505.