Impacts of Climate Change and Invasive Plants in Sierra Meadows: Overview and Recommendations

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The Sierra Nevada region is treasured for its natural beauty as well as its importance to California's water supply. Photo by Bob Case.

The value of Sierra meadows

The Sierra Nevada, John Muir's "Range of Light," is a celebrated part of our natural heritage. Among the iconic craggy peaks and sweeping forests are meadows, where snowmelt keeps streams flowing year-round and supports diverse grasses, wildflowers, and shrubs. These meadows play a vital role in the lives of almost every wildlife species in the region, from songbirds to frogs to bears. The resiliency of these meadows to environmental change is critical to protecting the region's wildlife. Most of California's 10,000 meadows, covering 300,000 acres, are found in the Sierra Nevada and Cascade ranges. With a warming climate, the Sierra Nevada will see increasing pressure from invasive plants, even at high elevations. Because meadows often have water availability and lack of shade, they are particularly vulnerable to invasive plants, which can degrade habitat by replacing native plants on which wildlife depends. Some invasives also alter hydrology and other abiotic processes. California's Wildlife Action Plan identifies both climate change and invasive plants as top threats to wildlife in the Sierra Nevada (CDFW 2015).

Sierra Nevada meadow complexes are wetland habitats with great ecological importance despite their limited extent (Manley et al. 2009). They are biological hotspots for birds and amphibians, providing habitat for species that include the federally-endangered willow flycatcher, federally-endangered great gray owl, and federal candidate Yosemite toad, as well as nine species of trout and salmon (Ratcliff 1985, NFWF 2010). Meadows promote lower stream temperatures, higher plant productivity, and increased insect prey availability (NFWF 2010). During summer months, montane meadows are considered the single most important habitat in the Sierra Nevada for birds (NFWF 2010).

How climate change affects the weather in the Sierra Nevada will be result of several processes interacting at global, regional, and local scales. These include the Pacific Decadal Oscillation and El Nino Southern Oscillation events that influence patterns of temperature and precipitation, including whether precipitation occurs more as rain or snow (Millar et al. 2004). Models based on future climatic conditions predict that snowpack will decrease in the Sierra, causing reduced spring and summer stream flows (PRBO Conservation Science 2011). This will decrease the water that feeds meadows. Meadows provide important shade and water for wildlife during the three to six month summer drought, which is expected to increase in duration as California's climate changes (PRBO Conservation Science 2011). When this occurs, meadows will become even more important for wildlife and water storage.

Invasive plant threat to Sierra meadows

Like many vegetation communities, mountain meadows may be caught between increased stress on native plants and increased colonization by invasive plants. Suitable habitat for many native plants may shrink, with some areas becoming refugia for particular species (Kueppers et al. 2005, Loarie et al. 2008). Plants may shift to higher or lower elevations in response to climate change (Kelly and Goulden 2008, Rapacciuolo et al. 2014). At the same time, invasive plants, which tend to be generalist species with broad ecological tolerances, may be able to colonize new locations (Pauchard et al. 2009). Of course, many invasive plants are still expanding their distribution regardless of climate change.

As climate change progresses, meadows may be impacted by changes in the four stages of invasive plant establishment: transportation, colonization, establishment, and spread (Ad Hoc Working Group 2014). In the past, the Sierra Nevada, especially higher elevations, was relatively protected from invasive plants. Meadows above 5900 ft. elevation in Sequoia-Kings Canyon National Park in the southern Sierra had few invasive plants in meadows (D'Antonio et al. 2004). Cold temperatures at higher elevations may have prevented weeds from establishing. It was believed that yellow starthistle (*Centaurea solstitialis*) could not survive at higher elevations but the species has been found in flower at Tuolumne Meadows in Yosemite National Park at 8500 ft. elevation (D'Antonio et al. 2004). In response to this and other sightings, the California Department of Food and Agriculture established a "Yellow Starthistle Leading Edge Project" across 14 counties in the Sierra to stop the species' spread to higher elevations. (The project has since lost funding).

Temperature and precipitation are not the only abiotic factors changing. Increased nitrogen deposition can also change plant communities, possibly giving an advantage to weeds that can use nitrogen more efficiently and grow bigger. (Interestingly, in Cal-IPC's modeling, the species that showed the greatest projected expansion in suitable range by 2050 was Spanish broom (*Spartium junceum*)(Cal-IPC 2012), a nitrogen-fixing shrub in the legume family

Some invasive plants are well-known ecosystem transformers that increase fires. Two examples are medusahead and cheatgrass. Even if these species are not in the actual meadows, their presence nearby may increase the spread or intensity of fire. If fire frequency and intensity are already increasing, invasives could make them even worse, and can colonize areas opened up by fires, creating a positive feedback loop that can lead to ecosystem type conversion, as occurs in pinyon-juniper woodlands in the Great Basin (Brooks and Pyke 2001).

Perennial pepperweed (*Lepidium latifolium*) is present in the eastern Sierra. It is extremely abundant in wet habitats elsewhere in California, where it can form monocultures, alter soil chemistry, and be extremely difficult to control (D'Antonio et al. 2004). Its invasion into Sierra meadows could have severe consequences.

Recreational users can inadvertently spread invasive plant seeds. Photo by Bob Case.

Some shallow-rooted invasive plants increase soil instability and erosion, thereby reducing resiliency of wildlife habitat. These include cheatgrass (*Bromus tectorum*), yellow starthistle (*Centaurea solstitialis*) and other thistles, orchard grass (*Dactylis glomerata*), timothy (*Phleum pratensis*), perennial pepperweed

(*Lepidium latifolium*), and purple loosestrife (*Lythrum salicaria*) (NFWF 2010).

Increasing population and changes in recreation patterns could spread invasive plants. The population of the Sierra in 2040 is expected to be three times what it was in 1990 (NFWF 2010). Increased population combined with warming temperatures may encourage more hikers, bikers, hunters, horses, and other recreationists to venture into areas that currently receive little human traffic. Because some invasive plant seeds can stick to shoes, equipment, or animals, recreationists have potential to spread invasive plants from populations at lower elevations along trails and into more remote areas.

In addition to non-native invasive plants, woody plant encroachment is a problem worldwide, raising concerns that meadows will be converted into shrub or forest areas. This encroachment may be assisted by drops in water tables in meadows due to channel incision. In the Southern Sierra Nevada, a native sagebrush (*Artemisia rothrockii*) is encroaching into semi-arid riparian montane meadows (Darrouzet-Nardi et al. 2006). Conifers are encroaching on meadows in many areas of the Sierra Nevada. Lodgepole pine (*Pinus contorta*) is moving into subalpine meadows, with pulses of encroachment corresponding to regional variation in temperature and precipitation. In particular, lodgepole pine encroachment appears to follow the Pacific Decadal Oscillation, increasing during periods when the PDO is in a phase that creates warmer, drier conditions that allow pine seeds to germinate at depths where they can escape competition with grass and forbs (Millar et al. 2004). Multiple factors may contribute to these patterns, including lack of fire, climate change, and overgrazing.

Increased atmospheric CO_2 may make invasive plants harder to kill by changing their physiology or their response to particular control methods. For example, Canada thistle, yellow starthistle, and spotted knapweed (invasive plant species found in the Sierra) increased in biomass under experimental conditions of increased carbon dioxide (Ziska 2003). The resulting increase in biomass made Canada thistle harder to control with glyphosate herbicide (Ziska et al. 2004).

Impacts of invasive plants on wildlife

Invasive plants can harm wildlife in two principle ways. First is the change in vegetation composition that can reduce availability of food or the structure needed for cover, foraging, and nesting. Some invasive plants are unpalatable or even toxic to wildlife. Others can create dense infestations that block passage, especially for larger animals such as deer.

The second way invasive plants can harm wildlife is by changing abiotic conditions. For example, stream temperature can increase (which is not favorable for many fish species) if an invasive plant like arundo replaces native riparian trees and thereby reduces shade.

Barbed goatgrass is a poor forage plant for livestock or wildlife. Photo by Bob Case.

In most cases, it is difficult to isolate impacts that a particular invasive plant species will have on a particular wildlife species, and the effect of invasive plants on wildlife is an area that needs more study. In the case of Sierra meadows, we know that they provide important habitat for many types of wildlife, both resident and migrating species, and that many species need a particular combination of biotic and abiotic factors in order to live and reproduce in an area. Meadow birds need shrubs, dense sedge cover, and intact hydrology (H. Loffland, pers. comm.). Fish need specific temperatures and water chemistry. Thus it is a solid inference that invasive plants that could change vegetation and abiotic conditions are a significant concern for those working to protect wildlife.

Below are some specific impacts of invasive plants in the region:

- Yellow starthistle, which grows in dense patches and has sharp spines, might impede foraging by the federally-endangered great gray owl (H. Loffland, pers. comm.).
- Russian knapweed is avoided by grazing animals due to its bitter taste (Whitson 1999).
- Canada thistle reduces forage for animals and its spines can injure them (Bayer 2000).
- Spotted knapweed was found to severely reduce elk foraging compared to sites with native bunchgrasses in one study, and likely would have the same effect on deer. It has low palatability to livestock and wildlife (Sheley et al. 1999).
- Barbed goatgrass reduces forage for livestock by up to 75% due to its sharp projections and is likely to have the same effect on wildlife such as deer (Peters et al. 1996).
- Perennial pepperweed (a.k.a. tall whitetop) outcompetes grasses that provide better food for waterfowl (Howald 2000).

One piece of good news is that bird species associated with meadows and riparian areas may be less vulnerable to climate change than birds that depend on other habitats in the Sierra (Siegal 2014). This means that improving the habitat by removing (or keeping out) invasive plants can be a successful management activity – the birds are not expected to simply depart due to climate change.

Impacts of invasive plants on water

Changes in hydrology can affect invasive plants and invasive plants can change hydrology. Though more study is needed, some invasive plants have been shown to consume significant amounts of groundwater. For instance yellow starthistle in the Central Valley is estimated to consume 1 million acre-feet of water a year more than the annual grasses it displaces (Cal-IPC 2014).

Controlling perennial pepperweed at the Truckee River State Wildlife Area. Photo by Jeannette Halderman, Truckee River Watershed Council.

The National Fish & Wildlife Foundation (NFWF 2010) estimates that meadow restoration in the Sierra Nevada could increase groundwater storage between 50,000 and 500,000 ac-ft per year. If a water-intensive invasive plant species takes over a meadow, it could offset the gain in water storage that is expected from such meadow restoration projects.

Impacts of invasive plants on soil carbon

Alluvial wet meadows in the Sierra Nevada store substantially more carbon than surrounding uplands, and the impacts of factors such as grazing have been studied (Norton et al. 2011, Norton et al. 2014). The impact of invasive plants on soil carbon in meadows has not yet been studied. Increased invasive plants could lead to decreased soil moisture, which leads to increased soil oxidation and plant decomposition and reduction of soil carbon storage (W. Horwath, UC Davis, personal communication). More study is needed, because dynamics of litter drop and decomposition play an important role in determining whether different vegetation stores more or less carbon in the soil (Tamura and Thayaril 2014).

Redox fluctuations due to moisture changes can lead soils to be either sinks or sources for methane (CH_4) and nitrous oxide (N_2O), both powerful greenhouse gases. Depending on seasonal soil moisture status, mountain meadows in Colorado ranged from being a sink in a dry meadow to a source in a wet meadow (Wickland et al 1999). Generally, the more productive the plant species in the meadow under wet conditions, the more CH_4 is emitted (Bhuller et al 2014). As invasive species are often more competive and express more biomass production, they may lead to greater CH_4 emissions. Estimates for N_2O emissions from meadows are sparse and source/sink relationships are not well defined (Mummey et al 2000). Generally, N_2O emissions are low but increase with dry periods (as well as the extent of nitrogen deposition from human activities.

Goals for invasive plant management in the Sierra

Natural resource management in the face of climate change requires choosing among options of resistance, resilience, and realignment (Peterson et al. 2011). Adapting a realistic management approach that accepts some invasive species rather than attempting a zero-tolerance policy may be most effective in the long term. Using an "Early Detection/Rapid Response" approach to locate and remove new species can often provide more effective adaptation than focusing on widespread invasive plants.

Surveying for invasive plants at Kirkwood Meadow in the Lake Tahoe Basin. Photo by LeeAnne Mila, El Dorado County Agriculture Department

Cal-IPC works with partner groups across California to support strategic prioritization and to design landscape-level projects for effective invasive plant management. Te following recommendations are based on the fundamental principles used in these efforts. For invasive plants already found in a meadow site, land managers should:

- Remove small invasive plant populations before they spread.
- Remove populations near vectors of spread, such as roads and streams. (The meadow connectivity study by UC Berkeley (Morelli 2015) can also be used to chart likelihood of spread; while habitat connectivity is good for wildlife, it also poses vulnerability for invasive plant spread.)
- Focus on meadows that have the most intact habitat and that are particularly important for wildlife.
- Delay addressing invasive plants in meadows where hydrologic restoration is scheduled, and plan to work after restoration is completed. This ensures that you can remove any invasive plants that have taken advantage of the construction disturbance. Make sure restoration work includes Best Management Practices (BMPs) for preventing the spread of invasive plants into (or out of) the site during construction (Cal-IPC 2012).

For invasive plant species not yet invading meadows, we recommend that land managers:

- Identify species that (1) have the highest potential to invade meadows based on proximity, habitat preferences, and pathways for spread, and (2) are likely to cause the greatest impacts.
- Focus early detection efforts on likely pathways of introduction and points of entry.

- Design public education materials and campaigns with those species and pathways in mind.
- Write BMPs for preventing invasive plant spread into construction contracts for projects in the area, especially restoration projects.
- Work with road and highway maintenance agencies to use prevention BMPs and to report new infestations.
- Work with wildfire crews to use prevention BMPs and to keep staging areas weed-free.
- Use weed-free forage for grazing or pack animals that travel near meadows.

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A Boy Scout pulls barbed goatgrass from Eldorado National Forest. Photo by Eldorado NF.

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