California's Mountain Meadows: The Effects of Historic and Modern Grazing and Adaptive Management and Restoration Strategies

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Abstract

Sierra Nevada Mountain wet meadows are an important part of California's hydrology, ecology and water supply. They are increasingly subject to adverse effects, including cattle grazing, which leads to their degradation and a decrease in the functions and services that they perform. The historic and modern effects of grazing can affect hydrology, essential habitat, and vegetation, but restoration and mitigation measures can be used to help reverse these effects. By adopting adaptive management strategies and new governmental policies, as well as by integrating traditional ecological knowledge, Sierra Nevada wet meadows can be improved, and their functions and services can provide benefits throughout California.

Introduction

The Sierra Nevada mountain meadows of California are are integral part of the state's ecology, hydrology, and water supply. Their vegetation and soils filter and store fresh water from seasonal melting snowpack. They also aid in flood abatement by decreasing flow velocity downstream, allowing fresh water to flow at a manageable pace to reduce flood forces, including velocity and volume of water. Mountain meadows are an essential habitat for numerous types of plants and animals, including many rare or endangered species, despite covering a small area. They can also be beneficial for low flow augmentation via stream headwaters, especially during the summertime.

As important as all of these functions are, Sierran mountain meadows face an increasing amount of adverse impacts, putting them at risk for severe degradation. A changing climate, infiltration of invasive species, intensive grazing patterns, ineffective forest management systems, and the elimination of traditional resource management, are some of the largest threats that these meadows face. Meadow degradation results in increased floods, reduced water storage capacities, reduced biodiversity, reduced grazing capacity, and lower late season flows in downstream rivers. These environmental impacts impart not only ecological problems, but human struggles. It is for these reasons that the maintenance of Sierran wet meadow functions and health is critical.

Improved meadow restoration and adaptive management strategies would be instrumental in protecting wet meadows as a valuable resource. Current management strategies, regulations, and restoration practices may not be enough, and increased understanding of the issues which contribute to meadow degradation would help to protect them. Cattle grazing, in specific, has the potential for significant ecological and hydrological impacts on Sierran meadows. Improving

Sierra Nevada Mountain meadow ecology by more thoroughly addressing grazing and its impacts, and by ensuring restoration and adaptive management strategies are adequate in mitigating for it, would have numerous benefits on California's water supply and natural resources.

Background - Sierra Nevada Mountain Meadows

The Sierra Nevada's mountain meadows are a vital part of the watershed ecology and native ecosystems of California. They offer valuable habitat for many different species and have a significant amount of wetland biodiversity. They are also instrumental in flood abatement as they not only store large amounts of groundwater but slow the flow of melting snowpack. Sierran meadows act as natural water filters thanks to their herbaceous plants; these wetland or semi-wetland plants use water within the top 1 meter of soil and remove nutrients for their use, which helps to clean and purify the water (American Rivers 2012). Most of these plants are mesophytes or emergent hydrophytes, but they can also be alpine or subalpine species (Ratliff 1982). These plants rely on specific wetland soil characteristics to thrive.

Mountain meadows require consistent soil moisture for their wetland vegetation; meadow plants rely on certain kinds of soils in order to hold or draw up specific amounts of water. Typically, meadows have four main depositional units: a buried soil, stratified sand, pre-Holocene alluvium, and layers of grus, peat, and sandy loam (Ratliff 1985). It's estimated that around 4.7 centimeters of wetland soil accumulate annually. Because of its unique needs, wetland vegetation may not be able to adapt to other soil types, which makes soils and specific levels of moisture necessary for meadows to carry out their functions and maintain biodiversity. Fine-textured soil supports plants with shallow roots which use capillary action and a shallow water table to survive. This is something that can develop through long-term or historic soil transformations, when peat materials from large water bodies form floating rafts which support the growth of sphagnum moss or other plants (Ratliff 1985.) Because this process happens over several hundreds of years, it is difficult if not impossible to restore severely-degraded peat-dependant wetlands.

The ecotonal areas between Sierran wet meadows and the surrounding upland areas can house more upland-oriented species of animals and plants which may use the meadow intermittently for reproductive or feeding purposes. There are several terrestrial vertebrates that require meadow areas and their riparian areas to survive, including many different types of mammals and birds. Though mountain meadows compose less than a tenth of the total region of the Sierras, they're a critical resource to maintain biodiversity by contributing to habitat and foraging area (Ratliff 1985, Merrill 2012).

Classification

Sierra Nevada mountain meadows are typically classified based on their hydrology. Dry, moist, and wet are the three characteristics that tend to be broad starting points for meadow classification. Meadow water sources can be groundwater-based, like springs or seeps, or they can come from sources such as precipitation, downstream runoff, subsurface flow, or internal flow. They could also be classified based on their altitude, hydrology, or the type of vegetation that they support, such as grasses, rushes, sedges, mosses, etc. Range type is yet another way of classifying mountain meadows, and includes the dominant species and type of vegetation present (U.S. Dpt. Agric., Forest Serv. 1969). Sierra Nevada meadows are considered to be either wetlands or semiwetlands (Ratliff 1985).

The California Native Plant Society has established the CNPS Manual of California Vegetation, which is a standard vegetation classification used across numerous environmental disciplines (Sawyer and Keeler-Wolf 1995). This system, based on 14 years of surveying, analysis, mapping, and description, is used by agencies like the California Department of Fish and Game, United States Forest Service, National Park Service, and United States Geological Survey. This manual is effective at identifying over 450 vegetation types and includes their life history and regional distribution, making it an effective tool for wetland classification.

The California Rapid Assessment Method, or CRAM, is a method of classification used to monitor conditions of wetlands in California. It is designed to be a cost-effective solution that provides scientifically-defensible results, with teams of 2-3 trained practitioners completing assessments in no more than 3 hours (Collins et al. 2007). CRAM is most beneficial for assessing ambient conditions in watersheds throughout the state, and can also be used to assess how well mitigation and restoration projects perform over time (Collins et al. 2007).

Background - Cattle Grazing in Mountain Meadows

Cattle ranching was first introduced in California in 1769 and was the first major industry in California (Ratliff 1985). It began with around 200 cattle, and the industry has expanded as missions were established in the West. Eventually, missions each had numerous ranches for sheep, cattle, and other types of livestock. The amount of land claimed for raising animals took up about one-sixth of today's California (Ratliff 1985). Cattle were primarily raised for their tallow and hides between 1769 and 1850.

Cattle were raised for large-scale meat production beginning in the 1850s, and this is when cattle grazing in remote parts of the Western United States became commonplace. Many parts of far-removed rural landscapes were deemed unsuitable for settlement or cropland due to the harsh climate, inaccessible terrain, and unique soil types (Derlet et al. 2010). It was possible, though, to graze animals, which meant that otherwise-unusable land could be purposeful as cattle rangeland in the early development of the West. The gold rush of 1849 was one of the biggest contributing events to a rise in cattle grazing; with a need for more animal products to support miners, cattle and sheep were increasingly grazed for their hides, wool, and meat (Ratliff 1985). Summer grazing in California's mountain meadows began most significantly during periods of drought in the 1860s and 1870s, and sheep grazing became meadows' most dominant use (Ratliff 1985). By 1862, about 3 million cattle were spread throughout the state, with around 40% living in the Sacramento and San Joaquin valleys (Ratliff 1985).

Prior to 1890, the federal government did not make any attempts to control grazing on public lands, making them open to exploitation and creating an "era of tacit consent" (Ernst 1949). Even after this period, though, thousands of sheep and cattle were illegally brought onto federal land for grazing. Groups of sheep and cattle were routinely driven into Sierran high meadows because of the quality summer forage (Micheli 2002). One of the first major successes in managing these livestock was the development of the National Forest System in the Department of Agriculture, which required grazing permits for sheep, cattle, and other livestock. This was established between 1905 and 1906 (Ratliff 1985).

Intensive grazing patterns have been a stressor in meadows since the 1800s, and the problem has resulted in massive deterioration of meadow health. Some of these effects include unfavorable changes in plant species composition, incising of meadow channels, desiccation, shrub encroachment, and lowering of groundwater tables (Merrill 2012.) Even with decreased livestock grazing in the 20th century, historic use has already changed many Sierran meadows (Menke et al. 1996). Specifically, channel incision from early cattle grazing habits has altered a number of meadows in the Sierras (Menke et al. 1996).

Livestock grazing is still the most significant land use of the meadow (Micheli 2002). Cattle grazing in Sierra Nevada meadows gradually declined from the 1920s into the 1970s, but began increasing again after that period (Ratliff 1985). Today, regulated numbers of cattle graze meadows during the summer months, and may continue to have effects on meadow structure and health.

Overall, the effects of grazing are significant. If historical analyses and accounts of grazing are correct, the majority of Sierra Nevada meadows likely reflect that history of use and its impact (Kattelmann 1996). Because grazing was so widespread for so long, systems that are actually highly-altered may be perceived as being natural. In reality, pristine areas should be expected to have denser vegetation and wider, shallower streams (Kattelmann 1996). The effects of grazing on riparian areas have only recently been recognized as a concern worthy of addressing, and meadow management will be a challenge not only due to historic conditions, but also because of current cattle use.

Three notable examples of affected meadow regions include Bear Creek Meadow, meadows in the Last Chance Watershed, and Tuolumne Meadows. These meadows serve as good case studies in the discussion of cattle grazing's impacts on meadow ecosystems (see figures 1, 2).

Background - Meadow Case Studies

Bear Creek Meadow

Bear Creek is a meadow at the bottom of the Bear Creek Watershed in the Fall River Valley's northwest. It rests at the southern portion of the Cascade region, just north of the Sierra Nevadas in what is called the Sierra-Cascades. Its water supply comes from large springs originating from volcanic rock formations (Meinzer 1927). It sits at an elevation of 1,010 meters and has a semi-arid climate, receiving an annual average of 501mm precipitation (Loheide 2008). The meadow is overlain by sands and gravels of deltaic origin as well as silty loam soils (NCRS 2003).

Surface-water inflow acts as an intermittent hydrologic input to Bear Creek. Water is perennially supplied through Fall River spring discharge; precipitation and seasonal subsurface recharge from a nearby pasture also contribute. The Fall River hydrologic system as a whole is precipitation-fed from the Medicine Lake Highlands. Water from the highlands flows south and discharges to form the Fall River headwaters and perennial tributaries (Loheide 2008).

Bear Creek was severely degraded prior to 1999, when it was rehabilitated using a strategy intended to re-water it.

Last Chance Watershed Meadows

The Last Chance Watershed, in the Feather River Basin of Plumas National Forest, is a semiarid environment. It is located along the eastern slope of the Sierra Nevada between 1,680-2,350 meters and has mean annual precipitation of 410mm. The majority of precipitation is winter snow, and spring snowmelt contributes to meadow runoff and recharge. Meadows experience a summer dry period annually (Loheide II 2009). The watershed's riparian floodplains form one of the longest meadow systems in the Sierra Nevada (Loheide 2008).

In ideal conditions, meadows in the Last Chance are habitat for hydric and mesic vegetation, specifically sedges, rushes, and other herbaceous species. Xeric communities are common and dominant on hillslopes (Loheide II 2009). The meadow system was, historically, a hydrological buffer. Streams would meander through the meadows and flood during seasonal periods of snowmelt. The resulting floods infiltrated meadow sediments, feeding wet meadow vegetation through shallow groundwater during the summer dry period (Loheide II 2009).

Tuolumne Meadows

Located in Yosemite National Park, the Tuolumne Meadows is 186km2 and located at 2,600m, making it one of the Sierra Nevada's largest high-elevation meadows. Its basin is made up of mostly granitic rock. In lower elevations it is covered with glacial till, which forms localized groundwater aquifers (Loheide 2008). In the 1800s, the meadows were very popular for sheep and cattle as summer pastureland. Sheep grazing was historically more popular than cattle grazing in the Tuolumne, and twelve to fifthteen thousand sheep are pastured there today, but cattle are also grazed during the summer (Cooper 2006).

Currently, the Tuolumne Meadows and surrounding areas support six major plant communities which all have their own dominant species, soils, and unique hydrology. During summertime, the water table can be at or close to the ground's surface, but dries as the soils do. Tuolumne River drainage is typical of other Sierra Nevada rivers and has high and cold drainages, a Mediterranean climate, and quick snowmelt seasons (Cooper 2006). Infiltration of water into underlying rock occurs more slowly due to the meadows being underlain mostly by intrusive rocks like granodiorite. Some parts of bedrock are made up of metamorphic rocks, but around 90% of bedrock is intrusive (Cooper 2006).

A range of human uses affect the meadows. Historically, indigenous persons lived in and travelled throughout the Tuolumne, including Miwok and Yokut people (Barrett 1933, Guzman 2015). Today, fire suppression, extensive human development, and the role of Yosemite National Park as a tourist destination subjects the meadows to a different set of adverse impacts than they faced in the 1800s (Cooper 2006). These modern effects may be exacerbated by the influence of seasonal grazing.

<u>Meadow Functions and Adverse Impacts of Grazing</u>

Sediment Control and Hydrologic Function

Mountain meadows commonly form in places where the downstream bedrock is deposited in a basin or wide valley bottom. The meadows experience sediment accumulation from erosion of the meadow channel; sediment may also be brought from gullying or rilling, or wasting from adjacent hills. Though a meadow ecosystem's sediment might change in the short-term, such as during storms, sediment storage as a whole usually isn't affected long-term without significant force (Merrill 2012.) They are, though, easily influenced by improper sediment supplies, loads, and transports, which can cause channel avulsion, aggradation, or incision. These effects in turn contribute to impaired groundwater and sediment storage and transport as well as degradation of the meadow ecosystem overall.

Sediment control is an important function that Sierran mountain meadows perform, so the loss of this ability can be significant. Slope meadows, especially, catch water from surrounding areas and can remove sediment prior to the water infiltrating groundwater or flowing into stream systems. This mechanical filtering action contributes to ecosystem health and also provides clean water for both human and animal use (Ratliff 1985).

Meadows must have a well-functioning channel and floodplain to perform effective water and sediment control. Grazing cattle, especially in more intensive operations, alter channel structure because the cattle are naturally drawn to the water, where they can cool off, have more palatable foraging material, and an increase in forage in general. Their movement through and across meadow channels contributes to erosion, which can change channel structure, the amount of sediment entering the channel, or the types and amount of surrounding vegetation (Menke et al. 1996).

The removal of certain types of vegetation by foraging cattle also contributes to erosion, which can then affect meadow channels and hydrologic function (Kattelmann 1996). This has a cascading effect that changes the sediment load and transport over both the short- and long-term. Vegetation normally acts as a buffer to flowing water and prevents it from washing away soil, and underground structures, like roots, add structural strength to soil (Kattelmann 1996). In an open floodplain, native vegetation improves sediment deposition above the active channel (Kattelmann 1996). Riparian vegetation also enhances stream bank stability (Micheli and Kirchner 2002). Degraded alluvial channels that don't have the benefit of vegetative protection on their banks have both increased width and downcut, and deliver higher amounts of sediment downstream. For example, in a part of the North Fork Feather River, up to 60% of delivered sediment is attributed to bank erosion alone (Wills and Sheehan 1994). This sediment affects local and regional water supplies and contributes to further degradation downstream.

Along with degraded channels comes a lowered water table. When a meadow channel becomes incised, subsurface flow is reduced, and the normally shallow water table declines (Ratliff 1985). In a functional wet meadow, the water table is almost always at or near the surface, and provides groundwater storage for adjacent snowmelt (Ratliff 1985). Degraded meadow channels fundamentally alter the system's ability to hold and move water, leading to higher volumes of water moving downstream more quickly and causing flood events (National Fish and Wildlife Foundation 2010). Late-season water flow is also affected by degraded meadow channels, as temporal distribution of streamflow is dependent on intact meadow channels with a healthy water table (National Fish and Wildlife Foundation 2010). A high water table is thus necessary not only to prevent flood events, but to provide fresh water downstream, especially during otherwise dry summer months (National Fish and Wildlife Foundation 2010).

The potential groundwater storage capacity of Sierra Nevada wet meadows is also comparable to numerous human-made alternatives, including new reservoirs. It's estimated that meadow restoration in the Sierras could increase groundwater storage by 50,000 to 500,000 acre-feet annually, with the wide variation due to uncertainties in existing channel depths (National Fish and Wildlife Foundation 2010). This is comparable to proposed projects like new reservoirs in Colusa County and the Inland Empire Regional Water Recycling Initiative, which are estimated to contribute 470,000-640,000 acre-feet and 100,000 acre-feet of water storage, respectively, per year (National Fish and Wildlife Foundation 2010). Addressing the issue of cattle grazing and related meadow channel degradation would increase this potential.

In Tuolumne Meadows, the Tuolumne River appears to be widening, which is causing a lower river water level that's anticipated to have an effect on surface-subsurface flow interactions (Cooper et al. 2006). The Tuolumne was also subject to historic cattle grazing, and today grazing still occurs in the meadows occurs during summer. The current lack of establishment by willows and other buffering vegetation will contribute to further degradation of the river channel. (Cooper et al. 2006). Following this will come in a drop in river stage and the associated water table. Modern cattle grazing has the potential to contribute to this issue by causing further channel erosion and preventing the re-establishment of buffering plants.

In the Last Chance Watershed, the water table has already declined from historic grazing, logging, and construction that caused channel incision (Loheide 2009). This has caused encroachment of sagebrush and xeric vegetation and has affected the meadows' ability to filter sediment and prevent further channel incision and erosion. Like in the Tuolumne, this may be exacerbated by grazing if it isn't adequately accounted for and mitigated, as cattle's preferential grazing habits, and the way they move through and along channels, worsens existing channel degradation.

Bear Creek Meadow has been mostly rehabilitated, but its meadow channels were degraded due to heavy livestock use and severe channelization (Loheide 2009). Bear Creek's primary channel had become incised and widened by the mid 1990s and this made it entirely disconnected from its floodplain except for in the largest flood events (Loheide 2009).

Soils and Vegetation

Soils can be easily altered or damaged by cattle grazing. As livestock tramples the soil, they make way for invasion of opportunistic plant species that can survive in the resulting lowered water table and poorer soil conditions. Trampling causes soil compaction and can lower pH of the soil solution; when there is more stress than the soil's resistance can accommodate, the soil deforms, and this can change how it reacts with oxygen (Ratliff 1985). In turn, this degradation removes habitat for species of plants which depend on the meadow, and can reduce plant biomass overall as well as change plant communities.

Preferential grazing is another major cause of range deterioration. The use of the same areas during the same season each year, and preferential treatment that favors or neglects one or more species, can cause disruption of others (Ratliff 1985). Their grazing can replace rushes and sedges with other types of plants, like legumes and grasses, which changes species composition (Menke et al. 1996). Cattle also tend to graze more heavily in wet meadows because of the abundance of water and shade; this combined with the general preference for wetland plants as forage is a contributor to intensive grazing habits (Kattelmann 1996).

Same-area-usage also contributes to redistribution of nutrients, as livestock animals move and concentrate nutrients where they tend to gather. Nutrients accumulate in urine spots and dung pats, and can lead to long-term effects on species composition (Ratliff 1985).

In the Tuolumne, most tussocks of *Carex filifolia*, a dominant species in the meadow's critical *Carex filifolia - Antennaria corymbosa* community, are degraded. Typically, *Carex filifolia* is a strongly-tufted plant which contributes to dense sods rich in organic matter. The tussocks are currently separated from others due to heavy gravel soils, and their tussocks have eroding edges (Cooper 2006). Historic livestock grazing is thought to be the most likely reason for degradation of *Carex filifolia* tussocks, and they are reportedly difficult and very time-consuming to rebuild (Ratliff 1982). Another community, the *Gentian-Aster community,* has been described as a disturbance community caused by excessive grazing (Ratliff 1982).

Also in the Tuolumne, the invasion of lodgepole pines into the meadow has occurred at ten recorded sites. The invasion of current lodgepoles corresponds with historic ecological response to invasion between 1945-1976 and suggests that a change in regional climate and anthropogenic disturbance, including domestic grazing, was causal (Cooper 2006).

It is estimated that, overall, livestock grazing in the late 1800s have had long-term impacts on Tuolumne Meadow's vegetation. The meadow's primary vegetation types, including the *Aster alpigenus – Carex subnigricans*, *Calamagrostis breweri – Vaccinium caespitosum*, and *Carex filifolia – Antennaria corymbosa* communities, have been affected. These communities have lower cover of densely-tufted and long-lived plants, as well as more bare soil, than is expected for a more intact meadow. Historic trampling impacts are visible in dry parts of the Tuolumne Meadow, with degraded *Carex filifolia* and invasion of tap-rooted plants in areas where rhizomatous vegetation would be expected (Cooper 2006). The meadow's organic-rich soils, but low below-ground vegetation content, suggests that current vegetation was not responsible for creation of the modern soils, but rather that the vegetation is the result of intensive historic grazing disturbance (Cooper 2006).

In the Last Chance watershed, prior to restoration, native wet meadow vegetation had been replaced by xeric vegetation partially due to historic cattle grazing (Loehide 2009). Stream incision was a large contributing factor and caused sagebrush (*Artemisia tridentata*) to encroach. Sagebrush and other woody plants had modified the type and volume of supporting root systems, changed leaf evapotranspiration, and altered the ratio of plant transpiration to total evapotranspiration (Huxman et al. 2005). Recent restoration efforts have helped to rehabilitate the meadow, helping to raise stream water levels and the water table.

In Bear Creek Meadow, the lowering of the water table due to channel degradation caused a replacement of native wet and moist vegetation by annual grasses more suited to upland environments (Loheide 2009). The largest effects were on *Carex nebrascensis, Carex athrostachya, Juncys balticus, Juncus vocillei,* and *Juncus nevadenses*. These plants were essentially replaced by *Poa bulbosa, Bromus tectorum,* and *Bromus japonicus,* which are considered invasive in the wet meadow environment. (Loheide 2009).

With a change in vegetation also comes a change in the animals that it supports. Many different species of animals rely on wet meadow ecosystems for their reproductive cycle or as annual or seasonal feeding grounds. A change in meadow hydrology, and the resulting shift from wet to dry vegetation, also leads to altered animal habitat.

Essential Habitat and Animal Ecology

Sierra Nevada mountain meadows offer the necessary food, cover, and water for all types of wildlife (Loffland et al. 2011). The degraded soil and altered plant species composition has a cascading effect on the ecosystem; animals which need meadow-specific plants to survive may not be able to get adequate food or use the meadow for reproductive purposes. One example is ground-nesting birds; they cannot nest in a degraded meadow ecosystem, as they require adequate cover from species like sedges and rushes to keep their nests safe from predation (Menke et al. 1996). In Tuolumne Meadows, willow stands are a critical nesting area for passerine birds (Cooper et al. 2006). A large portion of wildlife species are only found in riparian habitats, including 25% of California's mammals, 80% of amphibians, and 40% of reptiles (Wills and Sheehan 1994). At least 135 bird species require or prefer riparian zones (Wills and Sheehan 1994).

Fish production in grazed streams is generally highly decreased due to changes to channel width, absence of undercut banks, lack of vegetation and cover, decreased streamflow, and warmer water (Behnke and Zarn, 1976). In the grazed portions of streams, channels have primarily shallow riffle areas and no deep pools, which are necessary for fish habitat, especially wild brown trout, *Salmo trutta* (Behnke and Zarn, 1976). Cattle grazing can also have an effect on type and numberfish species; in one instance, there were more mountain whitefish, *Prosopium williamsoni*, in the grazed stream portions than the ungrazed portions. Mountain whitefish may be more adapted to the disturbed habitat than trout, which could affect species interaction and competition (Behnke and Zarn, 1976). Additionally, the removal of vegetative cover by cattle favors the replacement of native trouts by other forms which are more suited to the degraded environment (Behnke and Zarn, 1976). Erosion and sedimentation in the Feather River, in part due to grazing, has been linked to the impairment of native fisheries (Wills and Sheehan 1994).

The presence of domestic livestock, including cattle, affects amphibians in all life stages. Trampling by cattle affects larvae and juvenile stages of toads, and can can have cumulative effects on toad abundance (Jennings 1996). The effects of livestock can also be cumulative, and this is the case with long-term cattle grazing, which removes plants that provide cover for amphibian species in both their aquatic and terrestrial stages. Specific examples of the effects of cover removal include dehydration of salamanders and increased predation on California red-legged frogs, *Rana draytonii*, a threatened species (Jennings 1996). Grazing that is too frequent, or too intense, for the recovery of an amphibian population results in a reduction of that population (Jennings 1996).

In one study which included cattle and sheep, grazing livestock in general was found to have a negative effect on peak biomass of small mammals (Schmidt et al. 2003). This effect increased with grazing intensity. However, intermediate grazing seemed to be a benefit to small mammals; grazing at intermediate levels reflected biomasses and population sizes that were larger than or similar to control conditions. These effects were even greater when compared to heavily-grazed areas, and voles, in specific, had more offspring in the intermediate setting (Schmidt et al. 2003). This may be due to the livestock's effect on vegetation; intermediate grazing removed some cover which resulted in patches of high, dense vegetation in rejuvenated areas (Schmidt et al. 2003). This intermediate disturbance effect suggests that moderate levels of grazing may not be harmful to small mammal populations, and that the intensity of the grazing is the more important factor.

Overall, the ecological costs of livestock grazing in Sierra Nevada meadows can be significant. Cattle grazing can result in a loss of biodiversity from altered hydrology and vegetative cover, it can lower population densities for many taxa, it can disrupt ecosystem functions, and can change characteristics of terrestrial and aquatic habitats (Fleischner 1994). Cattle congregate in riparian areas, and the effects of their grazing can be magnified in these habitats due to them having such high biodiversity (Fleischner 1994). Sierra Nevada meadows are especially sensitive to the effects of grazing, as it has the potential to have a cascade effect on hydrology, vegetation, and animals.

Adaptive Management and Restoration Strategies

Because wet meadow ecosystems are so important, the development of practical restoration methods, with focused project goals, is critical for improving California's water resources. The state's hydrology, water quality, and biodiversity is highly dependent on Sierran meadow health, and improvements would offer numerous benefits, including but not limited to improved flood abatement, increased groundwater storage, and better sediment control. Restoration ecologists can create goals that are based on historic, present, and future meadow stressors, including cattle grazing. Then, they can determine the best course of action in order to meet those goals. As an example, a goal of increased biodiversity could come from actions like allowing meandering channels, increasing connectivity between meadow flooding and groundwater, and making the groundwater table higher (Merrill 2012).

Adaptive management and monitoring strategies should also be used in long-term restoration projects. If monitoring is not performed, management decisions can only be based on educated guesses. This could create unexpected changes in the environment, especially when compared to fact- and measurement-based solutions. Restoration ecologists can use monitoring to encounter potential problems or challenges before they become too large or complex to correct or handle; this allows them a greater opportunity to prepare for or prevent anticipated problems rather than to have to deal with them after they've already occurred.

Monitoring and adaptive management programs should be developed as a part of the overall project, and not be created after the fact. By creating these systems at the same time as the project, they have a greater guarantee of being successfully used, and there is less of a chance for a system to be abandoned due to only being an undeveloped afterthought. Additionally, restoration goals are a good starting point for creating the management program, so creating them at the same time encourages the development of more meaningful and effective strategies. Monitoring and management programs, if closely-tied with project goals, are an important tool for restorationists as they allow them to see whether meadow processes are changing as expected and desired (Merrill 2012).

Wet meadow vegetation and ecology is directly linked to hydrologic patterns and processes, which makes these the most important focuses for Sierra Nevada meadow restoration (Loehide et al. 2008). The major effect of cattle grazing is altered hydrology, either through direct effects such as channel incision and degradation, or indirect, like preferential grazing on supportive wetland vegetation. Because they so severely affects meadow function, restoring hydrology and vegetation should be the primary goals of Sierra Nevada meadow projects.

One important part of this is the creation and maintenance of a shallow water table. A modern restoration method that could be beneficial for the water table is "pond-and-plug," which focuses on re-watering meadows. The process involves filling incised stream channels with intermittent "plugs" of alluvial material gathered from the surrounding environment. The unfilled portions of the channels become ponds (Loehide et al. 2008). In Bear Creek, this method created significant changes to the meadow's hydrology. It raised groundwater levels and the volume of subsurface storage, decreased baseflow and annual runoff, increased evapotranspiration, and increased the frequency of floodplain inundation (Loehide et al. 2008). Because the mean water table depths of spring and summer improved, wet-meadow vegetation was favored.

For long-term meadow restoration success, it is important to quantify the water requirements of the wet meadow vegetation, and to identify inflows of water and the related geologic and physical controls (Loehide et al. 2008). Identifying these factors, and how they differ between meadow systems, will provide restorationists and resource managers with the ability to draw on past results from reference conditions and apply them to new projects.

The use of geographic information systems (GIS) is another technique for restoration of meadow hydrology. It can provide a useful framework for determining the changes of stream channels over time by identifying rates of meander migration (Micheli and Kirchner 2002). These migration rates can then be related to the environment through GIS analysis. The resulting GIS data can be used by resource managers as a baseline for future monitoring (Micheli and Kirchner 2002). Similarly, aerial photography can be used to map vegetation and stream channels. Aerial photos can be digitized and used with image processing tools, then processed in a raster grid format. Then, they can be georeferenced to historic images and data for comparison (Micheli and Kirchner 2002).

The impact of cattle on riparian areas in general depends on their behavior and how they utilize streamside vegetation (Marlow and Pogacnik 1986). One study indicated a seasonal trend in the usage of upland and riparian areas, with upland being used more often than riparian in June and July, except when there were low levels of upland forage; from August to September, the riparian zone was favored (Marlow and Pogacnik 1986). Additionally, the use of shrubs seems to be inverse to the use of herbaceous plants; when herbaceous plants are the most palatable and available, they are the preferred forage, but when they become a limiting factor, cattle graze shrubs instead (Roath and Krueger 1982). Based on these trends, precise timing of cattle grazing periods in meadows could be beneficial for maintaining desired meadow vegetation during or after rehabilitation. Ranchers could try to match the timing of cattle grazing with timing of the least-sensitive vegetative group; early-season grazing could minimize the impact on herbaceous riparian plants, while late-season grazing would minimize it for upland species. This could be beneficial in environments where a particular type of vegetation has yet to become fully rehabilitated.

Policy

Cattle grazing is currently limited and managed based on numerous governmental policies, including grazing permits issued by the Forest Service and Bureau of Land Management. Currently, fees for grazing are very low; it costs $1.41 per animal unit month to graze cattle on public land (Bureau of Land Management.) Ranchers graze livestock over around 155 million acres of BLM land, with around 18,000 renewable permits administered. These permits generally cover a 10-year period (Bureau of Land Management.)

Low fees and wide usage of lands incentivizes grazing throughout the year. Existing policies could be changed to more actively work with restoration and management efforts by limiting grazing during sensitive times of year. In doing this, the adverse impacts of cattle grazing on meadow vegetation could be more easily avoided.

Traditional ecological knowledge, TEK, also plays an important role in restoration and monitoring, but unfortunately, its use and application is currently limited. Integrating traditional and local ecological knowledge into conservation and restoration practices can be very beneficial, especially for the maintenance of biodiversity, but the application is not easy (Charnley, Fischer, and Jones 2007). The value of TEK is widely recognized; for example, fire was a traditional hunting aid and management strategy used by indigenous peoples throughout the Sierra Nevadas. Though fire did not directly influence meadow vegetation, it did facilitate more open meadow conditions, as it had the effect of keeping out invasive trees (Ratliff 1985). Though TEK is known to be valuable, social, economic, and policy constraints currently prevent this knowledge from being fully integrated into restoration and monitoring practices (Charnley et al. 2007).

A change in policy to support traditional knowledge would help to facilitate its use across broad environmental scopes, including Sierra Nevada meadows. TEK cannot be implemented if practitioners lack access to and influence on the related resources, and so it is necessary that policies are put in place to allow for this. This should include incentives and benefits for traditional knowledge holders, who should be allowed to share the results of their efforts with western scientists and managers. Traditional engagement in management practices has the potential to suit multiple needs and stakeholders, including the economic and cultural needs of indigenous peoples, and should be encouraged (Charnley et al. 2007).

Conclusion

Sierra Nevada Mountain wet meadows vital to California's hydrology as well as its biodiversity and water supply. Adverse effects, like cattle grazing, has unfortunately led to their degradation. Despite this, restoration and mitigation measures focused on restoring meadow hydrology and vegetation can be used to help reverse these effects. Adopting adaptive management strategies meaningful governmental policies and integrating traditional ecological knowledge would allow Sierra Nevada wet meadows to perform their functions and services throughout California.

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Appendix

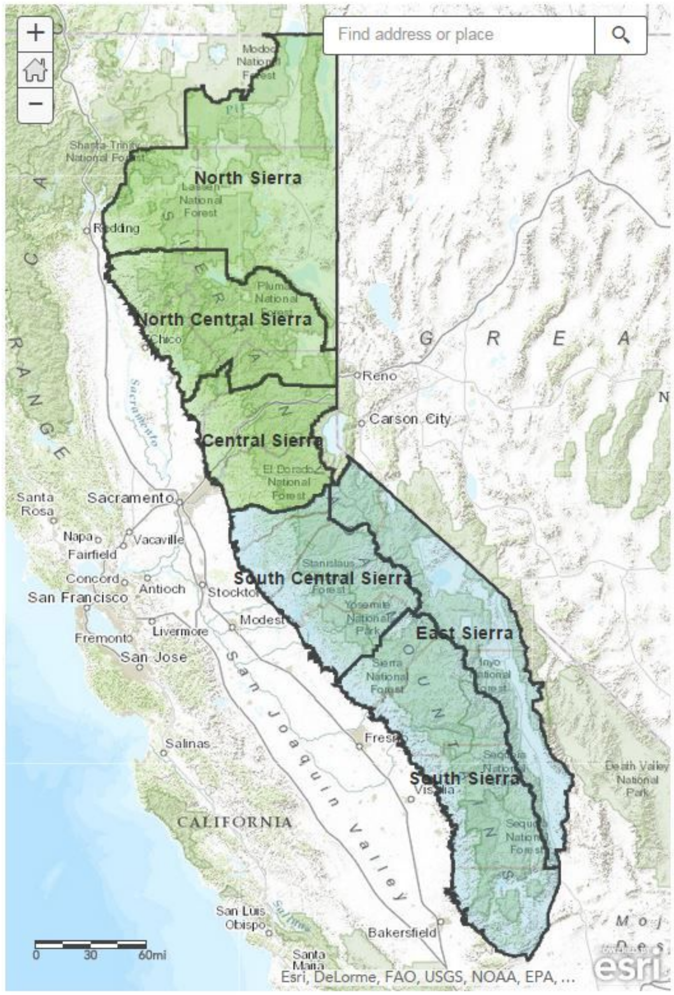

Figure 1: Regions of California's Sierra Nevada (Sierra Nevada Conservancy.)

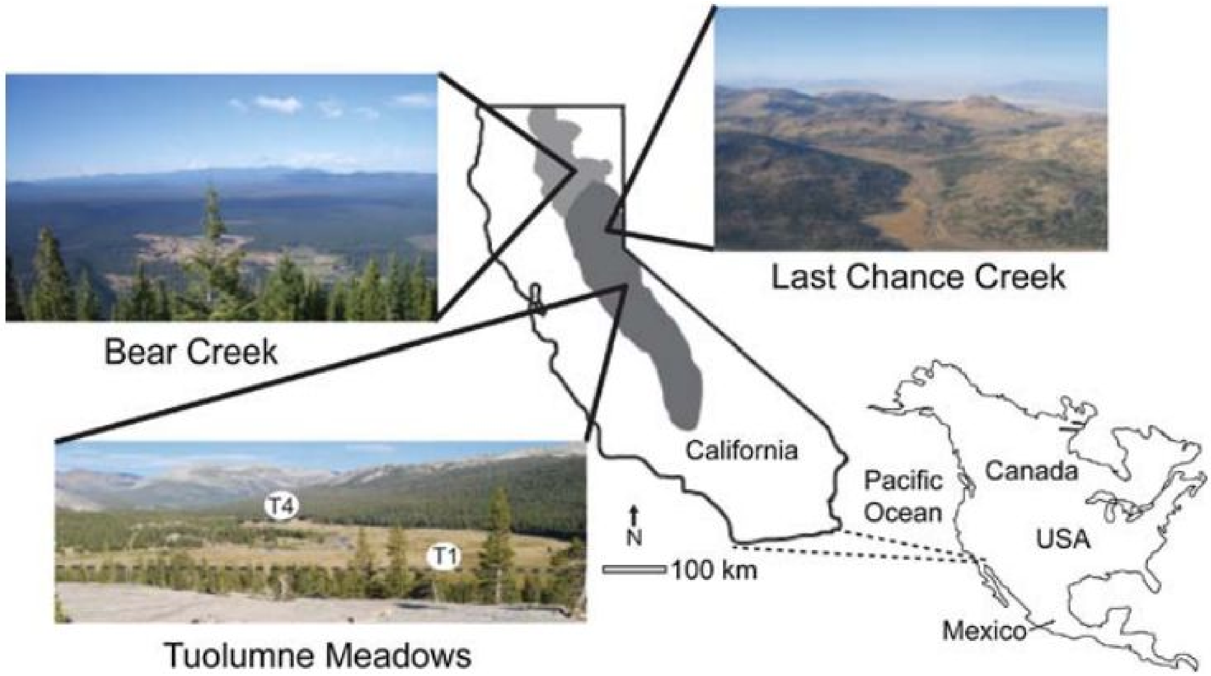

Figure 2: The locations of Bear Creek, Last chance Creek, and Tuolumne Meadows

(Loehide et. al 2008.)