Meadow Response to Pack Stock Grazing in the Yosemite Wilderness: Integrating Research and Management

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Abstract—Management decisions on meadow preservation and allowable use are, ideally, based on scientific information that describes the relationship between levels of impact and levels of use. This information allows managers to provide the best protection of meadow systems while responding to demands for recreational use of mountain meadows. Monitoring and research activities can be coordinated to support management by gathering information on measurable levels of meadow use, meadow response to different levels of use and cause and effect relationships reflected in meadow response. Based on this information, wilderness managers can decide on the maximum acceptable impacts to meadows that still provide protection.

Meadows occupy less than 10 percent of the montane and subalpine regions of the Sierra Nevada, yet they support disproportionate amounts of biological diversity, ecosystem function and aesthetic interest. They contain high plant diversity, provide wildlife forage and habitat, filter organic inputs to streams and, from a human perspective, provide high aesthetic value. They have long been valued as well for livestock and pack stock forage that lasts late into the summer.

Meadows comprise over three percent of the area of Yosemite National Park. Ratliff (1982) classified central and southern Sierra Nevada meadows into 14 types. Two of the more extensive of these, shorthair sedge (*Carex filifolia* var. *erostrata*) and shorthair reedgrass (*Calamagrostis breweri*), also were recognized by Sumner (1941) and Klickoff (1965). Benedict (1981) described 19 associations from southern Sierra Nevada meadows, including Ratliff's (1995) tufted hairgrass (*Deschampsia cespitosa*) series, a mid-elevation meadow type. Grazing of mountain meadows in the Yosemite Wilderness is limited to pack animals used to support National Park Service administrative functions, transport small private parties, and conduct clients of permitted commercial pack stations. Currently, commercial outfits dominate use, followed by the Park's concessioner and private parties.

Several qualitative evaluations of meadow condition in the Sierra Nevada have been conducted (Briggs 1966; Ernst 1949; Guse 1969; Sharsmith 1961). Ernst provided a comprehensive picture of the Park's grazing situation in 1948, suggesting remedies for perceived overuse. Sharsmith evaluated selected heavy use areas and commented on "deteriorated conditions," including exotic annual grass invasion, erosion and lodgepole pine (*Pinus contorta* var. *murrayana*) encroachment associated with trampling and concentrated grazing. Guse commented on the lack of timely information on impacts and lack of a consistent mechanism for mitigating impacts in a responsive manner. He recommended meadow use monitoring, as well as research to determine meadow species composition and grazing capacities. Despite this periodic attention to meadow condition, few quantitative studies exist to support management decisions.

Mueggler (1967) documented a decline in herbage production after three successive years of defoliation in mountain grasslands of Montana. DeBenedetti (1980) found that clipping the herbage to a one-inch (2.5 cm) stubble height reduced total nonstructural carbohydrates in the roots of shorthair sedge, shorthair reedgrass and Rocky Mountain sedge (*Carex scopulorum*) by 20 to 40 percent. Stohlgren and others (1989) found a decrease in mesic meadow productivity following herbage removal but an increase in dry meadow productivity in each of four years of herbage removal. We hypothesized that applying different intensities of herbage removal could result in varying reductions in meadow productivity in subsequent years.

Olson-Rutz and others (1996) quantified the impact to meadow plant communities from four different durations of horse grazing over three summers. However, measurements were aimed at detecting the immediate effect of grazing on vegetation (changes in plant height) and not at describing meadow condition in subsequent years. Proulx and Mazumder (1998) found lower species richness in nutrient-poor ecosystems under heavy grazing by ungulates than

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under light grazing intensity. Olson-Rutz and others (1996) found that grass heights were reduced more than forb heights and that grasses were grazed more often than forbs for the four- and eight-hour durations. In this study, we hypothesized that such differential grazing pressure by plant type could result in species composition shifts in subsequent years.

McClaran and Cole (1993) noted that research is needed on the relationships between pack stock use and impacts, specifically how impacts vary among use levels. McClaran (1989) suggested that meadow management could benefit from additional information on how impacts vary among meadow types within use levels, as well as monitoring of current utilization.

Pack Stock Grazing Management

The goals of pack stock management in mountain meadows are to avoid adverse impacts to meadow structure, function, diversity and productivity and to allow access by pack stock users. Management decisions on meadow maintenance and allowable use are, ideally, based on scientific information that describes the relationship between levels of impact and levels of use. This information is needed to provide the best protection of meadow systems while responding to demands for recreational use of mountain meadows and the associated consumption of forage. These goals present a dilemma to managers because unlimited access may result in overuse, with adverse impacts on plant productivity, species composition and vegetative cover. One approach to resolving this conflict is to compromise each goal to some extent. Managers can set minimally acceptable standards for meadow condition. One such standard might be to maintain meadow productivity at no less than 90 percent of its ungrazed level. When minimal conditions are not met, managers must modify stock use levels or other use parameters to protect meadow integrity.

Supporting sound management requires four types of information: the measurable level of use of the system, the system response to different levels of use, the cause and effect relationships reflected in the response and the maximum acceptable impacts to the system that will still provide adequate protection. The first three are obtained through a combination of monitoring and research. The fourth is a judgment based on the available information. With this approach, monitoring assesses and tracks use intensity over time (along with some variables indicating meadow response), research identifies the effects of various use intensities on meadow condition, management sets maximum acceptable impact levels, and managers act on monitoring results to limit impacts on the system.

Various measures of levels of pack stock grazing include the number of animal nights per unit of time and the associated utilization or amount of plant material removed for each level of stock use. The inverse—the amount of meadow vegetation remaining after use by pack stock, termed residual biomass—has been used as a predictor of meadow response (McClaran and Cole 1993). Describing and tracking pack stock use levels is a primary task of meadow monitoring. Monitoring can also gather information on the system response to determine how meadows are responding to current grazing intensities (such as changes in productivity and ground cover).

Research can provide a systematically derived understanding of cause and effect, identifying what grazing intensities cause various degrees of impact. If the research integrates monitoring parameters into the research design, it can describe the relationship between monitoring measures, such as ground cover and residual biomass, and less efficiently measured but significant aspects of meadow structure and function, such as plant species composition and foliar cover.

Decisions by wilderness and resource managers and the public need to be made about minimally acceptable conditions and maximum acceptable impacts to meadows and to visitor experience. This task, out of the scope of research and monitoring, requires careful balancing of biological and political realities to make difficult decisions about wilderness management.

As an example of the interaction of research, monitoring and management, a maximum of 10% loss of productivity might be selected, based on wildlife needs, associated changes in species composition and soil retention capabilities over the long term. Research may determine that 20 percent utilization causes a 10 percent reduction in productivity for a certain meadow type. If monitoring estimates that current utilization is greater than 20 percent, management would respond by reducing pack stock use levels to allow the meadow to recover.

Management, then, is an iterative process of 1) recognizing research results that define meadow responses to different levels of use and 2) responding to unacceptable impacts exposed by ongoing monitoring aimed at detecting change. This model is applicable to most research and management relationships. In the following sections, we elaborate on the role of monitoring, research and management in this process.

Monitoring

The goals of monitoring include describing the condition of sites, intensity of use and range of variability (as influenced by weather variation, variations in use patterns, and other stressors) and detecting change and the direction of change in the variables measured. Establishing cause and effect is not a goal of monitoring but remains a responsibility of research.

The monitoring program at Yosemite is designed for maximum efficiency and simplicity because wilderness staff implement the monitoring as collateral duties in addition to all other responsibilities while on patrol. The program involves 14 different meadows in 12 areas, ranging in elevation from 1,300 to 3,050 m (4,400 to 10,000 ft). The rangers use permanently marked transects and collect data in two categories: late-season residual biomass to represent grazing intensity—the causal influence—and bare ground cover, representing meadow response to grazing over time.

Ground cover is measured at 150 points along the transects, and standing biomass is clipped from 15 quadrats arranged parallel to the transects. Quadrats are 25 x 25 cm, and plant material is clipped to a height of 1.0 cm. Only plant material produced in the current growing season is collected; litter from previous years is separated out and left on site. Quadrats

are located without repetition for eight years to avoid previously clipped sites.

Transects are relocated through the use of topographic maps, photographs, diagrams and permanent markers located at each end of the transects. Meadow transects are read annually, near the end of the season, to most closely represent the biomass remaining on sites after all of the season's use has occurred. Residual biomass is more practical to collect than the amount of forage removed, and it can be an indicator of use intensity if associated mean annual productivity is estimated.

It is important to monitor the amount of meadow use in terms of animal nights and forage removed before any standards are set. It provides information about when and to what degree any hypothetical standards have been exceeded and the magnitude of management adjustment that might be required. Detecting when the maximum allowable impacts have been exceeded is even more important after standards are established. This helps evaluate current use practices and allows managers to keep impacts below the acceptable standards. Despite the critical role of monitoring for grazing use levels and impacts, monitoring cannot establish cause and effect relationships, and monitoring alone is an insufficient basis for management.

Research

Research is critical to wilderness management because it defines the functional relationships between various levels of stress to natural systems and system responses to those stresses. Our research goal was to define the relationship between grazing intensity and associated changes in meadows. That is, we sought to describe changes in ground cover, meadow productivity, foliar cover and species composition from three different grazing intensities.

Study Design

We focused on three subalpine meadow types that are common and extensive in the Park. The first was a high-elevation, xeric shorthair sedge (*Carex filifolia* var. *erostrata*) type that occurs on well- drained, sandy, granitic soils between 2,600 and 3,300 m (8,500-11,000 ft). These meadows have early-season snowmelt, and they flower, set seed and senesce midway through the growing season. They produce little in the way of biomass (mean = 71 g/m^2) and have the lowest species diversity (we found 35 species in the 1,024 square meter study area) of the three types. The second meadow type was a more mesic shorthair reedgrass (*Calamagrostis breweri*) type. It occurs on sites where soils are saturated longer than shorthair sedge meadows, such as floodplains and near ponds. The type ranges in elevation from 2,400 to 3,050 m (8,000 to 10,000 ft) and exhibits moderate productivity (mean = 214 g/m^2) and species diversity (55 species on our study site) for a Sierra Nevada meadow. Tufted hairgrass (*Deschampsia cespitosa*) is the dominant species in the third type. These wet meadows are associated with upper montane mixed conifer forests, such as red fir (*Abies magnifica*), and have the greatest number of species (72 species on our study site) and the highest productivity levels (mean = 345 g/m^2) of all three types.

The study was designed to describe the changes in annual productivity, ground cover, plant foliar cover (both absolute and species specific) and species composition associated with recreational pack stock grazing at three different intensities. The experiment involved the three meadow types, three grazing intensities and four years of grazing. Within the shorthair sedge and reedgrass types, there were four sets of four plots each; there were three sets of four plots each in the tufted hairgrass type. Prior to grazing each year, ground cover, foliar cover, species composition and productivity measurements were made on 10 subplots (0.0125m^2 each) per plot. Then three plots within each block of four were grazed, each at a different intensity, with a fourth, ungrazed plot for comparison. This provided four replicates per grazing intensity and four control replicates. Immediately following grazing, we measured groundcover and then clipped for residual biomass, similar to the methods used for monitoring.

Ground cover data were analyzed using one-sample t-tests to compare post-grazing measurements with original condition. We analyzed productivity data by comparing values with original condition as well. We evaluated species composition changes using an index of floristic dissimilarity to compare conditions after grazing with original conditions, standardized for changes on the controls.

We measured groundcover and standing biomass immediately following grazing in order to estimate the grazing intensity achieved and to closely link the causal factor (grazing intensity), the resulting changes in meadows and monitoring variables. We provided this link to the research results within a fairly controlled setting, establishing the expected degree of change, by grazing intensity, for each meadow type.

Results

Our experimental grazing resulted in a number of statistically significant changes in meadow condition. One-sample t-tests showed that bare ground increased after two years of grazing in all three meadow types (table 1). Plant foliar cover decreased in a significant way only in the tufted hairgrass type ($p < 0.05$). While there was a measurable shift in species

Table 1—Number of years of grazing required to cause statistically significant[a] changes in various meadow attributes in three meadow types in the Sierra Nevada.

	Shorthair sedge	Shorthair reedgrass	Tufted hairgrass
	---------- *years* ----------		
Basal bare cover	1	2	2
Basal vegetative cover	2	>4[b]	>4[b]
Foliar cover	>4[b]	>4[b]	3
Species composition	2	2	2
Species richness	>4[b]	>4[b]	>4[b]
Productivity	2	2	2

[a]$p < 0.05$.

[b]No adverse impact was found, suggesting either that more than four years of grazing is needed or grazing at the intensities applied would not have an adverse impact.

composition after two years of grazing, as reflected in a similarity index, the most pronounced and consistent change across all meadow types was in productivity. Productivity declined by the second year of grazing in all three types.

The meadow productivity results are directly applicable to pack stock management if used to anticipate productivity reductions associated with observed levels of use. We graphed reduction in productivity after the third year of grazing against grazing intensity (proportion of biomass removed by grazing). These data allow us to estimate the proportion of biomass that could be removed each year by grazing and cause reductions in productivity of 10, 25, and 50 percent (fig. 1). If the maximum acceptable reduction in productivity is set at 10 percent for the shorthair sedge type, animals could remove 36 percent of standing biomass. If a 25 or 50 percent reduction in productivity is acceptable, animals could remove 45 or 57 percent of forage, respectively. Forage removal of 20, 49, and 99 percent in the shorthair reedgrass type would result in similar reductions in productivity (table 2). Limiting the decline in productivity to 10 percent for the tufted hairgrass type provides for up to 17 percent forage removal. Productivity declines of 25 and 50 percent are associated with 42 and 84 percent forage removal in this type.

A commonly used rule of thumb for grassland vegetation is to leave 50 percent of biomass at the end of the grazing period to maintain nutrient levels through decomposition (Frandsen 1961). This level of pack stock use would cause about a 30 percent loss of productivity in shorthair sedge meadows, a 25 percent decline in productivity in shorthair reedgrass meadows and a 28 percent decline in wet meadows dominated by tufted hairgrass. Ratliff (1985) concluded that utilization should not exceed 35 percent of average herbage production in drier types and 45 percent in more mesic types to maintain meadow productivity. He stated that the 50 percent rule cannot be considered a safe utilization guide for all meadows of the Sierra Nevada.

Although utilization—the amount of plant material removed by grazing—was the best predictor of meadow condition, it is difficult to measure. However, Park staff can monitor residual biomass and use it as an indicator of use intensity if they use mean annual productivity levels by meadow type to estimate utilization and associate these estimates with monitoring measures. Utilization can be estimated from

$$U = [(p-r)/p] \times 100$$

where U = utilization, p = mean annual productivity by meadow type, and r = residual biomass.

All three meadows used in this study had not been grazed for several decades. As such, they may be more representative of pristine conditions and support species that are more susceptible to grazing than meadows that were recently, periodically or continuously grazed during that time. Therefore, it is possible that grazed areas may have a different, possibly more conservative response to grazing intensity than ungrazed meadows. However, these results speak to the severity of impacts when grazing is introduced to previously ungrazed, pristine areas.

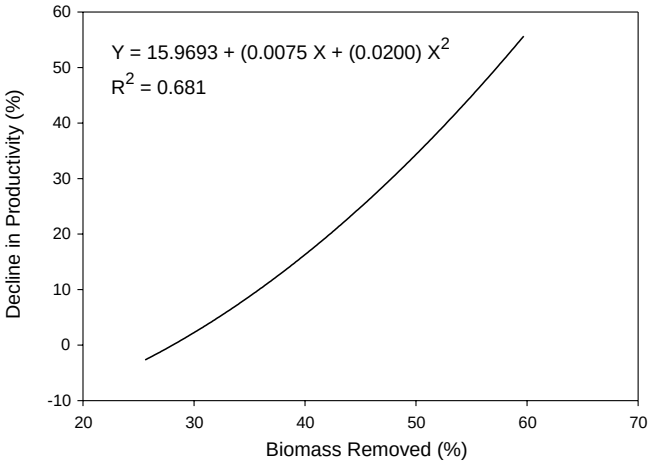

Figure 1—Proportional reductions in productivity associated with proportional amounts of forage removal by grazing in shorthair sedge meadows at Yosemite National Park, California.

Table 2—Maximum grazing intensity (proportion of biomass removed) that would cause specific levels of reduction in productivity.

Decline in productivity	Shorthair sedge	Shorthair reedgrass	Tufted hairgrass
	percent		
10	36	20	17
25	45	49	42
50	57	99	84

Management

Wilderness managers have responsibility for setting maximum acceptable impact levels and must decide what percent decline in productivity is acceptable. Research can only indicate the ramifications of such a decision. Managers must also set policy, communicate guidelines and implement restrictive actions when standards are not met. The monitoring component of the Yosemite program provides a consistent examination of Park meadows over time under actual use patterns. However, it is only through consistent monitoring that trends can be documented and change can be detected quickly enough for management to respond.

Research and monitoring, then, work in conjunction to provide managers with timely information on meadow condition and trends. They also provide a set of expected responses associated with different levels of use, which are in turn associated with meadow condition. Using this combined information, managers will be better prepared to set sound meadow use policies and protect wilderness meadows for the future.

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