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Pack Stock Grazing Capacity for Wilderness Meadows in Yosemite National Park

Natural Resource Report NPS/YOSE/NRR—2018/1647





ON THIS PAGE
Photograph of a pond with cloud reflection in a subalpine meadow, Dorothy Lake, in Yosemite National Park
Photograph courtesy of the National Park Service

ON THE COVER
Photograph of pack stock (horses and mules) grazing in a subalpine meadow, Dorothy Lake, Yosemite National Park
Photograph courtesy of the National Park Service

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Natural Resource Report NPS/YOSE/NRR—2018/1647

Laura J. Jones, Joy S. Baccei, Erin E. Dickman,

National Park Service
Vegetation and Ecological Restoration
Division of Resources Management and Science
Yosemite National Park
P.O. Box 700
El Portal, CA 95318

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Contents

Page

Figures....v

Page....v

Tables....vi

Appendices....vi

Executive Summary....vii

Acknowledgments....ix

List of Terms....ix

Introduction....11

The need for grazing management....11

Project goals and objectives....12

Background....12

Meadows of the Sierra Nevada....12

Reported pack stock use....13

Elements of grazing capacity....15

Methods and Model Inputs....21

Field data collection....21

Forage area....25

Meadow area....25

Forage species....25

Forage production....26

Elevation....26

Meadow type....27

Meadow condition....27

Annual climatic factors....28

Estimates of allowable use....28

Consumption rate....30

Contents (continued)

Page

Grazing efficiency 30

Results and Discussion 32

Preliminary grazing capacities 32

Monitoring 39

Model validation 41

Feedback on grazing levels 41

Feedback on meadow condition 41

Ground-truth remote sensed productivity data 42

Relationship to annual variation in climatic factors 42

Conclusions 43

Future directions 44

References 45

Figures

Page

Figure 1. Conceptual model of the factors to consider in grazing capacity establishment; forage area, forage production, allowable use, consumption rate, and grazing efficiency. 15

Figure 2. Forage Area sub-model; area of interest (meadow) and proportion forageable area (in meadow)..... 15

Figure 3. Forage production conceptual sub-model; meadow type, elevation, meadow condition, and annual climatic factors. 16

Figure 4. Photographs of Yosemite "meadow types" that are driven by hydrologic regime—hydric (left photograph of sedges in wet meadow area), mesic (center photograph of grasses in moist meadow area) and xeric (right photograph of grasses in dry meadow area)..... 16

Figure 5. Diagram of theoretical allocations of annual primary productivity for systems without (left) and with (right) stock grazing (not to scale) 20

Figure 6. Map of study meadows in the Tuolumne River Watershed of Yosemite National Park 24

Figure 7. Map of study meadows in the Merced Watershed of Yosemite National Park 25

Figure 8. Graph of predicted annual plant productivity (lbs./acre) by elevation (ft.) for three moisture classes and four condition classes. 26

Moisture classes are dry (xeric), moist (mesic), wet (hydric), and the four condition classes are excellent, good, fair, poor 26

Figure 9. Photograph of grazed meadow vegetation (grasses). Monitoring can provide feedback to evaluate meadow management 39

Tables

Page

Table 1. Ratliff et al. (1987) allowable utilization percentage recommendations (ranging from 20% to 45%) for meadows based on moisture types (hydrologic type); moist (mesic), dry (xeric), wet (hydric) and ecological conditions; excellent, good, and fair. 18

Table 2. Utilization standards (allowable use % ranging from 10 to 40%) for herbaceous perennial vegetation in wilderness meadows of the Sierra and Inyo National Forests, based on landscape zone (montane, subalpine, and alpine), and seral ecological state (high, and mid to low)..... 18

Table 3. Tuolumne River watershed subalpine meadows characterized from 2008-2012..... 21

Table 4. Merced River watershed subalpine meadows characterized from 2008-2012..... 23

Table 5. Utilization levels (as a percentage of total aboveground annual production measured post-utilization) that correspond to defined amount of change, including standard error (shown as value after ± symbol) associated with estimated % change 29

Table 6. Preliminary grazing capacities for graable meadows in the Tuolumne River watershed 34

Table 7. Preliminary grazing capacities for grazable meadows in the Merced River watershed 37

Appendices

Page

Appendix A. Relationships between percent utilization and meadow characteristics..... 53

Appendix B. Draft Residual Biomass Monitoring Protocol 59

Appendix C. A Process for Including Understory Grazing in Site Capacity..... 63

Executive Summary

Pack stock (horses and mules) support recreational and administrative use in Yosemite National Park (Yosemite) and are permitted to graze in meadows. Grazing capacities are needed in Yosemite as one critical tool of an overarching management framework to address questions of appropriate spatial arrangement, timing, duration, and intensity of pack stock grazing in meadows within designated Wilderness and Wild & Scenic River corridors. The Wilderness Stock Use Framework outlines best practices for pack stock use management and monitoring that will guide where (site suitability), when (meadow opening dates), how (handling practices), and how much (site grazing capacity) use could occur at a given site in order to avoid, reduce, or mitigate impacts. In the Sierra Nevada, development of meadow grazing capacity models specific to pack stock use in a Wilderness context are limited, and current grazing capacity guidance specific to livestock may not sufficiently protect meadow ecological integrity. Hence, grazing capacities specific to Yosemite are needed. The park developed a preliminary grazing capacity for a high-use meadow in the Tuolumne River corridor (Ballenger 2013) which was applied to calculate Yosemite-specific pack stock grazing capacity for two high-use meadows, as outlined in the Tuolumne and Merced River Plans (NPS 2014a, b). This report builds on that work to develop a process of estimating preliminary grazing capacity more widely. This report does not determine grazing necessity in designated Wilderness areas, nor does it assess grazing appropriateness for particular sites. However, both of these topics are addressed in the Wilderness Stock Use Framework report. We explored several model inputs including forage area, forage production, allowable use, consumption rate, and grazing efficiency. We included most of these as explicit inputs to our resultant model, but excluded grazing efficiency. However, we show how grazing efficiency is implicit in forage production estimates. We carried over some model inputs as previously presented by Ballenger (2013), such as meadow area and pack stock consumption rates. In other cases, we modified metrics to incorporate new information or to facilitate broader application to a greater number of sites. We tailored a Yosemite-specific approach leveraging a unique dataset characterizing 77 meadows, 57 of which are available to grazing, with 44 of those in the Tuolumne River watershed and 13 in the Merced River watershed. Of these 57 meadows, a total of 47 meadows have stock camps associated with them: 35 of 44 meadows in the Tuolumne River watershed, and 12 of 13 meadows in the Merced River watershed.

The dataset contained spatial cover values for dominant plant species, bare soil extent, total vegetation and plant litter obtained from plots spaced on a grid sampling approach across the meadow (Ballenger et al. 2010). We determined meadow hydrologic types—hydric, mesic, or xeric—based on wetland indictor ratings and an estimate of forage availability based on the proportion of forage species dominating a site. Additionally, we obtained data for meadow size and elevation from a Geographical Information System GIS. Therefore, we were able to estimate site-specific productivity values as an input to preliminary grazing capacities. Given variability in meadow elevation, size, type, and species composition, application of these data allow us to highly refine site specific grazing capacity among meadows.

We applied a range of utilization rates (i.e. 5%, 25%, and 35% of total biomass productivity) to be allocated for pack stock consumption to an empirical relationship from a Yosemite-based study that

correlated levels of pack stock use with levels of acceptable ecosystem change in meadows (Cole et. al. 2004). We formulated how the grazing management goal can be framed in terms of acceptable level of changes in meadow characteristics. This report does not prescribe a level of allowable use, or management standard, as that decision takes into account both ecosystem health and park policy. However, the discussion of allowable use levels may inform those decisions.

We developed an automated ArcGIS® model to calculate preliminary capacities and generated capacities for 35 grazable meadows within the Tuolumne watershed and 12 within the Merced River watershed. Resulting site-specific capacities based on the range of biomass values for allowable utilization rates ranged widely from only 1 stock use night per year at Benson Lake-NE (0.4 acres) to 1,881 stock use nights per year at Middle Kerrick Meadow (156 acres). However, the capacity at Middle Kerrick, is almost twice as high as the second highest capacity—Upper Kerrick-South (89.5 acres) at 953 stock use nights—and driven by its large size. The median modeled stock use nights for each utilization rate were 16, 82 and 113. The real value in the determination of these capacities for adaptive management is in comparison with reported pack stock use to understand how use at each site is relative to its specific grazing capacity.

We generated grazing capacities for meadows for which we had existing plant species and soil data and in which grazing may be allowed. These include meadows with higher known levels of pack stock use. Adaptive management may seek to reduce the range of calculated grazing capacities for specific locations, such as those with resource concerns (i.e., the presence of listed species, sensitive habitats, or cultural resources). We also note that the calculated grazing capacities are specific to the meadow area of a given site, and do not include estimates for forested understory that is known to occur at some locations. In these cases, adaptive management may choose to increase the calculated capacities if pack stock animals are known to also utilize available forage in forested habitat as well. We provide additional suggestions for management of such sites.

Lastly, we present the comparative yield method (also used by Sequoia-Kings Canyon National Parks) as a protocol for monitoring grazing consumption, using residual biomass sampling, which can provide critical feedback for validating and adjusting modeled grazing capacities. This approach allows for sampling with negligible destructive sampling and requires no installations. In particular, using residual biomass as a proxy for production will allow for validation of the production sub-model and comparison of measured utilization against actual utilization based on pack stock use reporting. A dataset of residual biomass over several years at many sites could be a powerful tool for adaptive management. This dataset could also be explored for correlation with remote sensed data, such as the Normalized Difference Vegetation Index (NDVI), whereby the development of grazing capacities at sites are currently lacking plant species and soils data. A grazing monitoring program would be most effective if complimented by previously developed indicators and standards of meadow ecological condition (i.e. streambank stability, meadow fragmentation and bare soil cover) to inform management actions for sites below management standards, as defined in the Merced and Tuolumne Wild & Scenic River Plans (NPS 2014a, b, c).

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List of Terms

Terminology follows that of, or is adapted from the following sources, in chronological order: Crane (1950), Cowan (1958), Bedell (1998), Coulloudon et al. (1999), and (Cole et. al. 2004).

Available forage: The portion of forage production that is accessible for use by a specified kind or class of grazing animal.

Ecological change: The overall change in the state of an ecosystem's structure, function, services, and integrity (i.e. a meadow), based on the magnitude of changes in biotic and abiotic ecological factors (i.e. floristic composition, plant productivity, plant cover, bare soil, plant litter, erosion).

Ecological Condition: 1) The overall state of an ecosystem's structure and function (i.e. a meadow), based on integrity, as determined by biotic and abiotic ecological factors (i.e. floristic composition, plant productivity, plant cover, extent bare soil, plant litter, and degree of accelerated erosion). 2) a relative measure of meadow health, informed by multiple metrics of meadow and streambank (when present) condition, and relating to ecosystem processes, function, and services.

Forb: 1) Any herbaceous flowering plant other than those in the *Poaceae* (true grasses), *Cyperaceae* (sedges), and *Juncaceae* (rushes) families—i.e., any non-grass-like plant having little or no woody material on it; or 2) a broad-leaved flowering plant with an above-ground stem that does not become woody and persistent.

Forage: Browse and herbage which is available and can provide food for animals or be harvested for feeding.

Forage area: The area associated with a site containing forage, which may include both meadow and adjacent habitats. For the purposes of this report, forage area refers to meadow habitats.

Graminoid: Grass or grass-like flowering plant of the *Poaceae, Cyperaceae*, or *Juncaceae* families.

Grassland: An area dominated by grass or grass-like vegetation of the *Poaceae*, *Cyperaceae*, or *Juncaceae* families.

Graze: 1) The consumption of standing forage by livestock, pack stock or wildlife. (2) To put livestock or pack stock to feed on standing forage.

Grazing behavior: The foraging response elicited from an herbivore (such as a pack stock animal including horse or mule) by its interaction with its surrounding environment.

Grazing efficiency: The relationship between the amount of available forage and the forage that is consumed by stock animals (such as horses and mules) and that the amount lost to all other sources such as wildlife and insect herbivores, decomposition, and spoilage due to trampling and defecation.

Meadow: 1) A tract of grassland, typically located in a low lying landscape position, such as a valley or canyon bottom, where forage is different from surrounding uplands due to characteristics of the landscape position, soils, and/or hydrology. 2) An ecosystem which supports mainly herbaceous plants that use surface water and/or shallow groundwater, where the soil surface often remains wet or moist for a portion of the growing season. Plant communities are primarily dominated by graminoid plant families, intermixed with less dominant forb species.

Pack stock use: Commercial, administrative, or private use of horses and mules for transport.

Plant community type: An assemblage or population of dominant plants in a common spatial arrangement, such as hydric, mesic, or xeric hydrologic regime.

Productivity: The rate of plant biomass production per unit area, usually expressed in terms of weight or energy. For the purposes of this report, productivity is expressed in pounds per acre per year ($lbs*ac^{-1}$/year).

Rangeland: Land supporting vegetation that either is grazed or that has the potential to be grazed, and is managed as a natural ecosystem. Rangeland includes grassland, grazable forestland, shrubland and pastureland.

Rangeland condition: Usually defined in one of two ways: (a) a generic term relating to present status of a unit of range in terms of specific values or potentials. Specific values or potentials must be stated. (b) The present state of vegetation of a range site in relation to the climax (natural potential) plant community for that site. It is an expression of the relative degree to which the kinds, proportions, and amounts of plants in a plant community resemble that of the climax plant community for the site.

Residual biomass: The total amount of forage (above-ground herbaceous biomass) remaining on the land at the time of measurement (ideally, after the grazing season). Although residual biomass can be measured regardless of whether utilization has occurred, for the purpose of this report residual biomass was measured following utilization (following grazing).

Stocking rate: The relationship between the number of animals and the grazing management unit utilized over a specified time period. May be expressed as animal units per unit of land area (animal units over a described time period/area of land).

Stock Use Nights: Stock Use Nights (SUN) is used to express the number of overnight stays by a single head of stock at a given site (in this report, refers to pack stock animals; horses and mules).

Utilization: The proportion or degree of the current year's forage production that is consumed or destroyed by animals (including insects). The term may refer either to a single plant species, a group of species, or to the vegetation community as a whole. It should be noted that that timing of the measure relative to the potential for regrowth after defoliation is critical to the estimate of utilization

.

Introduction

The need for grazing management

The Organic Act (1916) mandates the National Park Service (NPS) to protect resources for future generations while providing for public enjoyment and the Wilderness Act of 1964 compels the NPS to maintain wilderness character, including "naturalness." The biological integrity of meadows within the Merced and Tuolumne Wild and Scenic River corridors, within Yosemite National Park (Yosemite) have been identified as "outstandingly remarkable values" to be protected and enhanced under the Merced and Tuolumne Wild and Scenic River Comprehensive Management Plans (MRP and TRP; NPS 2014a, b). Furthermore, Yosemite has prioritized meadow conservation in its strategic vision (NPS 2014d). Best management practices, including the application of grazing capacities, are needed in Yosemite's wilderness areas to balance preservation and protection of meadows with recreational and administrative pack stock use. Grazing capacities are also needed in Yosemite as one critical tool of an overarching management framework to address questions of appropriate spatial arrangement, timing, duration, and intensity of pack stock grazing in meadows within designated Wilderness and Wild & Scenic River corridors. The Wilderness Stock Use Framework (Kuhn et al. 2017, in review), outlines best practices for pack stock use management and monitoring to guide where (site suitability), when (meadow opening dates), how (handling practices), and how much (site grazing capacity) use should occur at a given site in order to avoid, reduce, or mitigate impacts.

Appropriate grazing intensity has long been recognized as an important consideration for best management of meadows subject to stock use (including use by pack stock). Studies have shown that when grazing is un-managed, or intensity is inappropriate, herbivores have negatively influenced and altered vegetation communities in Mediterranean regions around the world, such as California (Holmgren 2002, Milchunas 2006). The majority of grazing literature has focused on ecological impacts of non-native ungulates on vegetation, related to intensive use of grasslands by livestock (Ostoja et. al. 2014). However, limited research has linked pack stock grazing activities to increased bare soil, decreased plant cover, altered height structure, decreased primary productivity, and shifts in species composition in meadows (Miller and Donart 1981, Trimble and Mendel 1995, Olson-Rutz et al. 1996a, b, Fahnestock and Detling 2000, Glab 2007). Few studies have specifically addressed potential pack stock impacts to meadows in the Sierra Nevada, existing literature suggests that pack stock can alter water quality, soils, vegetation and wildlife in these ecosystems, depending on timing, intensity and duration of use (Ostoja et al. 2014, Kuhn et. al. 2015).

Research in the Western U.S. has included several observational studies on the effects of livestock grazing (primarily sheep and cattle) on meadow vegetation (Ratliff 1985, Menke et al. 1996, Allen-Diaz et al. 1999, Roche et. al. 2014). In England, experimental simulations of cattle and sheep grazing over a four year period demonstrated negative grazing effects on vegetation communities (Smith and Rushton 1994).When examined in combination with drought, intense mowing (which approximates high-intensity grazing) decreased resistance of grassland communities to disturbance (Vogel et al. 2012). Studies specific to meadows in the Sierra Nevada, suggest that unregulated, heavy grazing of sheep, along with fire suppression, were likely major drivers in the decline of native herbivore populations at the time of European occupation (Dull 1999, Snyder 2003). While

there is a long history of studies done on the effects of livestock grazing on vegetation, few studies have examined ecological response to pack stock grazing in meadows, specific to plant species composition, productivity, and bare soil extent (Cole et al. 2004, Holmquist et al. 2013, Ostoja et al. 2014, Dickman et. al. 2014, Kuhn et. al. 2015, Lee et. al. 2017).

Ecological responses associated with trampling in meadows and other grasslands (either by humans, livestock, or pack stock) can exhibit similar outcomes as those to grazing (Liddle and Grieg-Smith 1975, Liddle 1991, Cole 1995). Trampling by livestock or pack stock can alter vegetation, increase bare soil extent and can potentially lead to meadow instability (Benedict 1982). Additionally, trampling can lead to soil disaggregation, compaction, and reduced infiltration and drainage (Gilman et al. 1987, Olson-Rutz et al. 1996a, McClaran 2000, Cole et al. 2004, Pietola et al. 2005, Glab 2007, DeBenedetti 1983). Trampling can compromise root growth and decrease plant productivity as a result of altered soil structure and hydrology (University of California at Davis et al. 2007). On a broad-scale, this could result in greenhouse gas emissions due to loss of carbon and nitrogen storage from increased soil decomposition (Norton 2014). On a local scale, altered hydrology in meadows can also result in reduced water availability and reduced water storage, which is critical for local and downstream communities (Russo 2012, Stillwater Sciences 2012).

Because of the potential for ecological effects, it is important to develop a comprehensive science-based pack stock management and monitoring framework for Yosemite (Kuhn et. al. 2017). Grazing capacity is one key element of this framework that will facilitate adaptive management.

Project goals and objectives

Our main goal was to develop preliminary pack stock grazing capacities for Yosemite's Wilderness meadows that receive regular pack stock use as one component of a comprehensive pack stock management framework. Our secondary goal was to articulate how to apply these capacities in conjunction with monitoring in a management context. Our specific objectives were to 1) Present a process for establishing grazing capacities in Yosemite 2) Produce preliminary capacities for meadows in the Tuolumne River (n=35) and Merced River (n=12) watersheds; and 3) Present a residual biomass (RB) sampling protocol for grazing monitoring and discuss potential applications of monitoring results.

Background

Meadows of the Sierra Nevada

Meadow ecosystems occupy a very limited areal extent of less than 1% of the Sierra Nevada and Cascade Ranges (Viers et. al. 2013), and only 3% of Yosemite (Keeler-Wolf et. al. 2012, Moore et al. 2013). Despite their relatively small contribution to the landscape, mountain meadows provide essential habitat for a wide range of flora and fauna (Kattelmann and Embury 1996, University of California at Davis et al. 2007). Like other wetlands, meadows are governed by spatial and temporal variability in soils, vegetation, and hydrology (Weixelman 2011), which makes them differentially resistant to or resilient from stressors. Sierra Nevada meadows are snow-melt driven, groundwater dependent systems with seasonally saturated soils, as a result of direct connections to surface and ground water (Loheide 2009). These conditions often support wet-meadow vegetation dominated by

sedges, rushes, grasses, and other herbaceous species, with high plant diversity (Ratliff 1985, Loheide 2009).

The unique combination of resources available in meadows creates hotspots for biodiversity that support a multitude of species, especially in California's dry summer season when suitable conditions are less available elsewhere. For example, in addition to several special status plant species, meadows provide critical habitat for two species listed under the Federal Endangered Species Act: the endangered mountain yellow legged frog (*Rana mucosa*) and the threatened Yosemite toad (*Bufo canorus*) (Bakker et al. 2006). Meadows also provide valuable ecosystem services such as nutrient cycling and capture, carbon and nitrogen storage, retention of spring runoff, sediment filtration, and flood attenuation (Roche 2012, Norton 2014). These ecosystem services also support high water quality, which is essential for local ecosystems and downstream communities (Russo 2012).

While Sierra Nevada meadows are recognized as important for the numerous ecosystem services they provide, livestock, such as cattle and sheep, has historically heavily grazed them throughout the range. In Yosemite, livestock grazing was prohibited upon its establishment as a park in 1890 (Greene 1987) although cessation did not occur until 1905 (Kinney 1996, Menke et al.1996).

Reported pack stock use

Use of pack stock for support of administrative and recreational (commercial and private) purposes is a permitted use and continues today. Spatial and annual variation exists in timing, duration, and intensity of use at various meadow sites frequented by pack stock users. In this report *Stock Use Nights* (SUN) is used to express the number of overnight stays by a single head of stock at a given site. For instance, 12 SUN reported for a site conveys that a site had been utilized by 12 animals for one night. All pack stock users in the park, including administrative, report their level of use by location to the Yosemite Wilderness Office (Visitor and Resource Protection Division).Total SUN has fluctuated over the past decade. For example, total reported SUN among all types (administrative, commercial, and private) within Yosemite Wilderness was 28,021 SUN between 2004 and 2016. In 2011, Acree et al. suggested that commercial and administrative use levels were roughly equal (i.e., 50% and 45%), while private use accounted for roughly 5%, between 2004 and 2009. Since 2012, improvements in reporting indicate that the total amount of SUN was 12,638, with an average of 632 SUN per year between 2012 and 2016. During this five year period, commercial and concessioner use were roughly equivalent, accounting for 42% (5,336 SUN) and 40% (5,066 SUN) of the total reported SUN, while administrative and private use accounted for 12% and 6% (1,536 and 700 SUN) (Kuhn et. al. 2017, in review). Locations of permitted private pack stock use were generally non-specific (i.e. by canyon), therefore applying these numbers to site specific grazing capacities is challenging. Reported concessioner use occurred primarily at the High Sierra Camps but has only been recorded since 2012.

History of grazing capacity management in the Sierra Nevada

In the context of Sierra Nevada livestock production outside of Yosemite, land managers have long recognized the importance of grazing management in order to maintain ecological integrity in meadows, leading to guidelines for grazing capacity (e.g., Crane 1950, Ratliff et al. 1987, Bartolome

et al. 2002). Grazing capacity establishment in livestock production systems and park ecosystems have similarities, such as calculation of range productivity and forage consumption rates, however there are several marked differences that preclude direct application of livestock production guidelines in a park context. First and importantly, the NPS dual mission is to protect resources for current and future generations, while providing for visitor enjoyment, (i.e. use of pack stock), which differs from the goals of livestock production. Range management for livestock production aims to optimize animal production without compromising the ability of the range to sustain livestock and healthy ecosystems in future years. Hence, to be successful in rangeland management for livestock, there must be some measure of sustainability to maintain the resource (forage). However, implementation and interpretation differs by rangeland manager. While some may want to maximize production while maintaining a high degree of ecological function and biodiversity on the range, others may focus more on maximization of animal production at the expense of ecological function and biodiversity. Given the mission of the NPS and Yosemite, and governing laws and regulations, park goals are to protect and enhance the meadow ecological function, water quality, and wilderness character, while also providing for visitor enjoyment to these areas. Meadows in Yosemite have been, and continue to be, popular destinations for pack stock users, due to their forage availability, proximity to water, and scenery. Therefore, rangeland management standards may not sufficiently protect meadows to achieve desired ecological condition, while also providing for visitor enjoyment.

Effective grazing management in the Sierra Nevada and on NPS land requires development of strategies to address differences in grazing systems—namely the species of grazing animal and ecosystem type. Livestock grazing occurs in grasslands, chiefly by cattle and sheep while grazing in Yosemite occurs mainly in meadows by horses and mules. Grasslands differ from meadows, in that meadows typically support more diverse vegetation (both graminoid and forb species), and occur in typically low lying landscape positions, such as valley or canyon bottoms, which often have wetland conditions, such as longer periods of water inundation and saturation. Grazing behavior is also different between livestock animals and pack stock animals, thus we cannot infer pack stock forage and habitat preferences based on livestock literature. One recent study in Yosemite found that horses and mules forage mainly on graminoid species, but do not typically browse on shrubs or forbs, such as willows and flowering plants (Walden-Schreiner et. al. 2015).

Several land managers have pioneered grazing management specific to meadows (Crane 1950, Ratliff et al. 1987) but their focus was on livestock. Subsequently, studies assessed pack stock grazing and the effects of trampling in Sequoia and Kings Canyon National Parks (SEKI) with an emphasis on aligning management to achieve NPS objectives (Neuman 1994, Abbott et al. 2003). McClaran and Cole (1993) and Acree et al. (2010) underscored the need for grazing management guidelines for Yosemite. Yosemite recently began to approach grazing management (Abbe and Ballenger 2012), which included the development of a pilot grazing capacity model (Ballenger 2013). Park ecologists used this model to calculate Yosemite-specific pack stock grazing capacity for two high-use meadows, as outlined in the MRP and TRP (NPS 2014a, b).

Elements of grazing capacity

A general approach to establishing grazing capacities is: 1) Estimate available forage at a given site (annual above-ground production of forage species), 2) Determine what portion of that to allocate to stock consumption, and 3) Calculate the number of stock that could be fed with that amount of forage (Figure 1). Additionally, some approaches include a grazing efficiency term, which incorporates inefficiencies due to grazing behavior and losses to other sources. We discuss each of the model components in further detail below.



Figure 1. Conceptual model of the factors to consider in grazing capacity establishment; forage area, forage production, allowable use, consumption rate, and grazing efficiency.

Forage Area

The forage area sub-model is composed of an area that is then constrained by the proportion of that area deemed "forageable " or dominated by forage species (Figure 2).

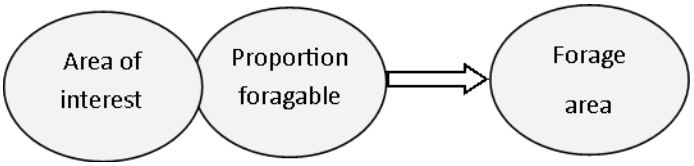


Figure 2. Forage Area sub-model; area of interest (meadow) and proportion forageable area (in meadow).

The area of interest (typically a meadow) is usually in close proximity to the campsite at which the group using the pack stock will spend the night and where pack stock will be released to graze, and contains herbaceous vegetation (forage).

Sierra Nevada meadows host a diverse assemblage of plant species. Pack stock animals do not graze uniformly but rather demonstrate preferences while grazing, particularly for graminoids (Ratliff 1985, Mayes and Duncan 1986, Olson-Rutz et al. 1996a, Cole et al. 2004). A recent pilot study on pack stock behavior in Yosemite meadows corroborates this (Walden-Schreiner et. al. 2015), where the study found that horses and mules prefer select graminoid forage species to others when grazing.

Ballenger (2013) determined apparent preferred forage species for two meadows that receive pack stock use in Upper Lyell Canyon via more intense study on grazed vegetation in those meadows from 2007-2009. As a result, Ballenger designated the forage area as the proportion of the meadow dominated by the four most commonly grazed species, all of which are graminoids, with the rationale that setting the grazing capacity based on the proportion of meadow dominated by these species would ensure that meadows would not become overgrazed.

Forage production

Several factors influence annual forage production, which is synonymous with aboveground net primary production (ANPP) for our purposes (Figure 3). Annual net plant production is the amount of energy fixed from photosynthesis minus the energy used by the plants, for one year (Gurevitch et al. 2002). Major factors known to influence plant production in meadows are vegetation composition, elevation, and climatic drivers that influence interannual variability in soil moisture, such as annual precipitation, snow pack accumulation, runoff, and annual temperature. These combined climatic drivers also influence meadow (or "range") condition (Ratliff 1985) where literature has formulated processes on how to incorporate these environmental factors into estimates of plant production for Sierra Nevada meadows (Crane 1950, Ratliff 1985, Ratliff et al. 1987, Weixelman and Zamudio 2001, Abbott et al. 2003, Moore et al. 2013).

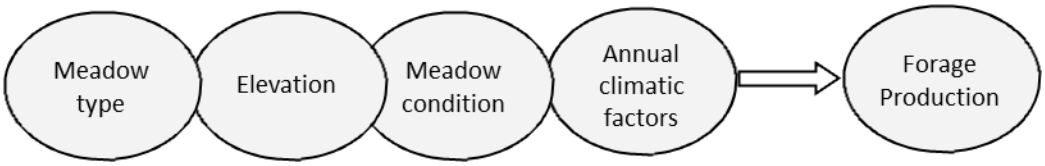


Figure 3. Forage production conceptual sub-model; meadow type, elevation, meadow condition, and annual climatic factors.

In Sierra Nevada meadows, plant production depends on meadow type and generally decreases with increasing elevation. Ratliff et al. (1987) estimated production for plant communities broadly classified as hydric ("wet"), mesic ("moist"), or xeric ("dry"), meadow types (Figure 4) and incorporated effects of both elevation and meadow condition. Mesic communities were the most productive and xeric the least. Abbott et al. (2003) interpolated these data by generating regression equations to estimate forage production by meadow type and range condition and reported these in 100' elevation increments. Moore et al. (2013) found that mean production estimates in *Calamagrostis muiriana* and *Deschampsia cespitosa* meadow types subalpine meadows of Yosemite were similar to ranges expressed in Ratliff et al. (1987) while estimates in the *Carex filifolia* type were higher than those in Ratliff et al.



Figure 4. Photographs of Yosemite "meadow types" that are driven by hydrologic regime—hydric (left photograph of sedges in wet meadow area), mesic (center photograph of grasses in moist meadow area) and xeric (right photograph of grasses in dry meadow area).

Ecological condition and production in meadows are related. Crane (1950) demonstrated that reduction in productivity for meadows was associated with a decline in ecological condition. Crane classified meadow condition into condition classes—excellent, good, fair, poor and very poor—based on density of plant cover, floristic composition, plant litter and degree of accelerated erosion. Meadows in excellent condition are assumed to have the maximum productivity. Productivity for other condition levels is given in reference to maximum productivity: good condition produces 65%, fair condition 44%, and poor condition 25%.

In addition to variation in productivity by site characteristics, productivity also depends on annual climatic conditions. Aboveground net primary production (ANPP) in high elevation meadows systems is limited by both temperature and moisture and constrained by short growing seasons, patchy resource availability, and soil moisture (Berdanier and Klein 2011). Subalpine meadow plant productivity in Yosemite has demonstrated high interannual variation, in which variability was driven by spring snow water content in mesic plant communities, and by both snow water content and cumulative growing season warmth in the xeric plant community (Moore et al. 2013). These authors found no strong climatic signal explaining variation in the hydric type. Contrasting results were found in a study at Niwot Ridge in the Rocky Mountain alpine in which ANPP was most strongly influenced by *this year's moisture* in mesic and hydric meadow types and precipitation from *previous year* in xeric meadows (Walker et al. 1994). However, the study system of Walker et al. was at 12,000 ft. and measured moisture was from a summer precipitation regime dominated by orographic thunderstorms. Therefore, consideration of spatial and temporal variability in moisture and temperature is important for better understanding variation in meadow plant productivity.

Allowable use

Allowable use (also referred to as "utilization") is defined as the maximum percentage of annual plant production allocated to stock consumption and is expressed as percent of available forage biomass. Guidelines for appropriate utilization rates for Sierra Nevada meadows have evolved over time. Consistent with range standards at the time, Crane (1950) suggested that utilization guidelines of 60-70% were appropriate for Sierra Nevada meadows used for livestock production. Ratliff (1976, 1980) measured decomposition rates of filter paper and natural herbage to estimate how much biomass decomposed annually; he proposed this as the minimum that should be retained as residual biomass (RB) to maintain a meadow at a given condition, and that more could be retained to increase the condition of meadows in degraded condition (Ratliff et al. 1987, Table 1). They found that decomposition rates were highest at intermediate moisture levels, and suggested that utilization guidelines of 20-45% would be appropriate to either maintain or improve condition of Sierra Nevada meadows. Neuman (1994) proposed reducing the utilization limits in Ratliff (1985, 1987) by 10 percentage points to reflect more conservative grazing levels in an NPS wilderness area. The reasoning behind this suggestion was likely that NPS wilderness areas need to maintain higher ecological condition and wilderness character.

Table 1. Ratliff et al. (1987) allowable utilization percentage recommendations (ranging from 20% to 45%) for meadows based on moisture types (hydrologic type); moist (mesic), dry (xeric), wet (hydric) and ecological conditions; excellent, good, and fair.

Moisture	Condition	Allowable Use (%)
Moist (Mesic)	Excellent	45
	Good	40
	Fair	35
	Poor	30
Dry or Wet (Xeric or Hydric)	Excellent	35
	Good	30
	Fair	25
	Poor	20

The US Forest Service (2001) adopted utilization limits of 30-40% for montane and subalpine meadows and 10-20% for alpine meadows in the Ansel Adams, John Muir and Dinkey Lakes Wildernesses, within the Inyo and Sierra National Forests (Table 2). The higher number is for meadows in high-seral stage, characterized by well-established plant communities, and the lower is for meadows in mid- to low-seral stage, characterized by pioneering species typically establishing post-disturbance. High seral stage would roughly correspond to Crane's (1950) excellent condition, and mid to low seral stage would roughly correspond to good to low conditions (David Weixelman, pers. comm. 2014). For example, Crane (1950) stated that meadows in excellent condition (high seral stage) had at least 70% cover of palatable forage species (30% utilization), whereas meadows in good condition (mid seral stage) has at least 50% cover (50% utilization), and meadows in fair (low) condition (low seral stage) had at least 35% cover (65% utilization).

Table 2. Utilization standards (allowable use % ranging from 10 to 40%) for herbaceous perennial vegetation in wilderness meadows of the Sierra and Inyo National Forests, based on landscape zone (montane, subalpine, and alpine), and seral ecological state (high, and mid to low).

Landscape Zone	Seral Ecological State	Allowable Use (%)
Montane and subalpine	High	40
	Mid to Low	30
Alpine	High	20
	Mid to Low	10

Cole et al. (2004) studied the effects of pack stock grazing in three meadow types in Yosemite to understand the relationships between grazing utilization and changes in vegetation and soil characteristics. The authors found that pack stock use resulted in reductions in basal vegetation cover, relative graminoid cover, litter cover, and plant productivity, and increases in floristic dissimilarity and bare soil cover. Cole and others also found a linear relationship between percent utilization and the magnitude of change in basal vegetation cover, productivity, and relative

graminoid cover. That is to say, as utilization level increased, there was a predictable and greater degree of change in these response variables. These findings provide a useful means of relating allowable utilization levels to a tangible management goal for level of acceptable change.

Consumption Rate

The consumption rate by pack stock likely varies by animal type, animal size, and specific individual needs, but has been estimated at14.8 kg (32.5 lbs.) per animal per night (Ratliff et al. 1987). This consumption rate value was adapted from equivalents of "animal use nights" (Society for Range Management 1998) and is defined as the vegetation biomass that one horse or mule consumes per night of grazing. To arrive at this consumption rate value for pack stock, an assumption was made that their forage consumption rate is typically 1.25 times the estimate for a cow. For example, if a cow consumes 780 lbs per month (standard value for a 1000 lb cow) then a horse or mule would consume 975 lbs per month. When this value is divided by 30 days, the resulting value is a consumption rate of 32.5 lbs per animal per night.

Grazing efficiency

Some range managers suggest applying a *grazing efficiency* term to utilization values. Grazing efficiency describes the relationship between the amount of forage that is consumed by stock and the amount lost to all other sources such as wildlife and insect herbivores, decomposition, and spoilage due to trampling and defecation (Figure 5). Other factors that affect grazing efficiency include stocking density, distance to water and slope of the foraging area. Smart (2010) demonstrated that grazing efficiency at moderate stocking rates is only 50% and that grazing efficiency *increases* with increasing grazing pressure. That is to say, less forage is lost to "other sources" when stocking rates per amount forage increases. Similarly, Stuth (1981) showed that as daily herbage allowance increased (i.e., stocking rates decreased), efficiency decreased. The authors presumed this was due to higher rates of decomposition and senescence. Grasshoppers alone consume a substantial portion of available forage—an estimated 6-12% annually—in the Western U.S. (Cowan 1958), which is often expressed as forage losses for livestock (Hewitt 1977). Forage utilization by grass hoppers has been compared to that of livestock, where Drake and Deckler (1937) estimated that 12 to 24 grass hoppers (depending on size) will consume as much forage daily as a cow, per square meter in a 0.4 ha area of blue grass pasture in Iowa. Grazing efficiency appears not to exceed 50% (Vallentine 2001) and decreases with increasing slope, with efficiency as low as 10% on steep slopes (Becchetti 2011).

For example, if just one horse were set out to graze in a meadow, the ratio of mass of foliage consumption by the horse compared to consumption by other herbivores and lost to senescence and decomposition would be very small and therefore represents "inefficiencies" in the system. In that same meadow with 100 head of stock set out to graze, a larger portion of the foliage would be consumed by these horses with less remaining for loss to natural processes, thereby resulting in a more "efficient" system. In a livestock production context in which an overarching goal is to maximize the animal weight gain per unit area, losses to these natural processes are generally considered undesirable. In contrast, in an NPS setting where objectives are to preserve natural processes low grazing efficiency helps achieve park objectives.

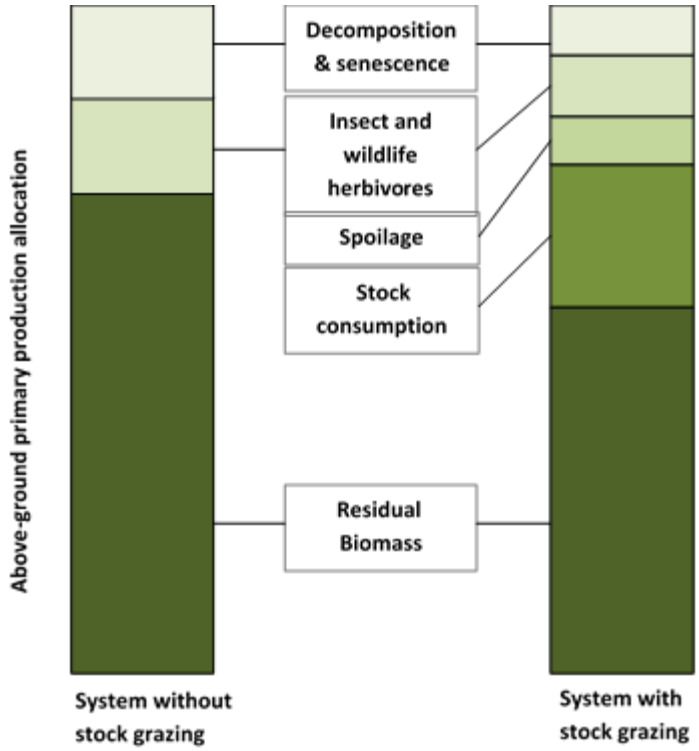


Figure 5. Diagram of theoretical allocations of annual primary productivity for systems without (left) and with (right) stock grazing (not to scale). The full bar represents annual aboveground primary production. Plant production in systems with pack stock grazing goes to stock consumption, losses to spoilage (i.e., trampling, defecation), and losses to natural processes (i.e. decomposition, wildlife and insect consumption).

Methods and Model Inputs

Field data collection

We applied field methodology described in Ballenger et al. (2010) and Kuhn et al. (2015). These methods are abbreviated here for clarity (see reports for additional detail). From 2008-2012 we characterized 77 meadows in Yosemite, 57 of which could be grazed by stock under current management guidelines (greater than 4 miles from a trailhead, within ¼ mile of the trail, and having no site-specific closures; tables 3 and 4, figs. 6 and 7). Of these 57 meadows, a total of 47 meadows have stock camps associated with them: 35 of 44 meadows characterized in the Tuolumne River watershed, and 12 of 13 meadows characterized in the Merced River watershed.

Table 3. Tuolumne River watershed subalpine meadows characterized from 2008-2012. Meadow names were given to each meadow unit at a given site, where suffixes indicate direction meadow is located in at a given site (N,E,W,S,NE,NW,SE,SW). Camp ID indicates commercial stock camp number, and Mdw ID indicates meadow ID number used for a meadow at a given site. Meadows with a Camp ID of "n/a" indicate no commercial stock use camp nearby. Meadow easting, northing, elevation, and area were derived from GIS, where meadow area was updated in GIS, based on field verification. Sample year and sample size indicate year field data were collected and number of sample plots used in capacity analysis.

Site Name	Meadow Name	Camp ID (Mdw ID)	Easting	Northing	Elev. (ft)	Area (ac)	Sample Year	Sample Size
Benson Lake	Benson Lake-NE	95 (3570)	278355	4211211	7,595	0.4	2008	19
	Benson Lake-NW	95 (3561)	278430	4211328	7,595	2.7	2008	6
Cold Canyon	Cold Canyon-N	147 (3207n)	289091	4204657	8,699	22.4	2011	42
	Cold Cyn-Smokey Jack	147 (3207s)	288707	4203720	8,699	39.1	2008	96
Dorothy Lake	Dorothy Lake-NW	100 (4694)	272712	4228179	9,394	19.7	2008	61
	Dorothy Lake-W	101 (4702)	273053	4228190	9,394	12.6	2008	3
Elbow Hill	Elbow Hill	n/a (3227)	289446	4205358	8,763	3.7	2011	16
Grace Meadows	Grace-North	n/a (3227)	270978	4225293	8,766	3.2	2011	13
	Grace Meadows	47 (4472)	270705	4224444	8,717	43.0	2011	79
Hook Lake	Hook Lake	97 (3414)	288692	4208425	9,384	8.3	2008	44
Jack Main Canyon	Tim's Camp-N	132 (3869e)	267355	4215728	7,695	4.6	2012	50
	Tim's Camp-S	132 (3869w)	267163	4215570	7,695	4.9	2012	33
Kerrick Canyon	Jose's Camp	88 (3915)	279407	4215390	9,109	10.2	2011	33
	Lower Kerrick-S	41 (3875)	280082	4216271	8,941	24.8	2010	49
	Upper Kerrick-N	90 (4324n)	282509	4221912	9,299	53.0	2008	163
	Upper Kerrick-S	138 (4324s)	300904	4185452	8,971	89.5	2012	51
	Middle Kerrick	89 (4136)	280688	4218468	9,151	156.0	2012	39
Lake Vernon	Lake Vernon-SE	9 (3555)	261196	4211009	6,570	9.3	2011	25
Lyell Canyon	Upper Lyell-N	61 (2040)	300753	4186383	8,971	17.3	2008	99
	Upper Lyell-S	84 (1987)	300904	4185452	8,977	32.8	2008	123
Matterhorn Canyon	Matterhorn-S	91 (3466)	287195	4209190	8,426	26.4	2008	77
	North of Middle Matterhorn	n/a (3664)	288773	4212677	8,828	11.7	2012	18
	Middle Matterhorn	n/a (3599)	288796	4211564	8,673	12.1	2012	21
	South of Matterhorn	n/a (3360)	282024	4210104	8,479	5.0	2008	16

Table 3 (continued). Tuolumne River watershed subalpine meadows characterized from 2008-2012. Meadow names were given to each meadow unit at a given site, where suffixes indicate direction meadow is located in at a given site (N,E,W,S,NE,NW,SE,SW). Camp ID indicates commercial stock camp number, and Mdw ID indicates meadow ID number used for a meadow at a given site. Meadows with a Camp ID of "n/a" indicate no commercial stock use camp nearby. Meadow easting, northing, elevation, and area were derived from GIS, where meadow area was updated in GIS, based on field verification. Sample year and sample size indicate year field data were collected and number of sample plots used in capacity analysis.

Site Name	Meadow Name	Camp ID (Mdw ID)	Easting	Northing	Elev. (ft)	Area (ac)	Sample Year	Sample Size
McCabe Lakes	McCabe-North	78 (3457)	294078	4209067	9,653	29.7	2012	71
Macomb Ridge	West of Macomb Ridge	na (3964)	270729	4217146	8,670	26.3	2012	72
Miller Lake	Miller Lake-N	96 (3400)	287621	4208020	9,456	8.6	2008	44
	Miller Lake-S	96 (3342)	287292	4207487	9,506	9.1	2008	43
Paradise Meadow	Paradise-N	136 (2427n)	265455	4214312	7,665	13.7	2011	22
	Paradise-S	121 (2427s)	265211	4214139	7,665	6.3	2011	6
Pate Valley	Pate Valley-N	69 (3061)	272277	4201740	4,389	1.6	2011	14
Rock Island Pass	Rock Island Pass	n/a (4161)	283712	4219453	10,145	16.1	2011	57
Rodgers Meadow	Rodgers Meadow	94 (3331)	278938	4206837	8,744	36.1	2011	76
Smedberg Lake	Smedberg-S	92 (3501)	286407	4207727	9,223	9.1	2008	44
Tilden Lake	Tilden Lake-N	46 (4321)	272645	4221957	8,920	9.7	2008	32
	Tilden Lake-NE	46 (4342)	273056	4222497	8,920	9.7	2008	24
	Tilden Lake-SE	85 (4145se)	271454	4219839	8,908	3.8	2008	7
	Tilden Lake-SW	46(4145sw1)	270711	4219691	8,908	1.7	2008	7
	Tilden Lake-W	46 (4145w)	271048	4219987	8,908	1.1	2008	4
	West of Tilden	n/a (4295)	270013	4221584	8,393	14.5	2008	65
Twin Lakes	Twin Lakes-South	49 (4413)	267641	4223792	8,899	6.8	2011	36
Slide Canyon	Upper Slide	n/a (4075)	286665	4218747	9,191	11.4	2011	48
Virginia Canyon	Castle Camp	39 (3519)	293048	4210568	8,784	5.6	2008	25
Wilma Lake	Wilma Lake	65 (3945)	268128	4217106	7,944	4.8	2011	28

Using ESRI ArcGIS® software, we randomly generated a grid with points spaced 20-30 m apart, depending on meadow size, using the Hawth Tools and X Tools Pro packages. During the growing season, we established temporary 5m X 5m vegetation plots at these grid points. Metrics collected that we applied to this effort include ocular estimates of dominant species cover, total vegetative cover using Daubenmire cover classes, plant litter cover and bare soil cover. We recorded whether pack stock sign (manure, hoof punching or grazing) was present at each plot. For analyses and incorporation into our findings, we removed one site with < 6 sample points (McCabe-South) and one site that had incomplete field data collection (Middle Kerrick).

Table 4. Merced River watershed subalpine meadows characterized from 2008-2012. Meadow names were given to each meadow unit at a given site, where suffixes indicate direction meadow is located in at a given site (N,E,W,S,NE,NW,SE,SW). Camp ID indicates commercial stock camp number, and Mdw ID indicates meadow ID number used for a meadow at a given site. Meadows with a Camp ID of "n/a" indicate no commercial stock use camp nearby. Meadow easting, northing, elevation, and area were derived from GIS, where meadow area was updated in GIS, based on field verificaton. Sample year, sample size indicate year field data were collected and number of sample plots used in capacity analysis.

Site Name	Meadow Name	Camp ID (Mdw ID)	Easting	Northing	Elev. (ft)	Area (ac)	Sample Year	Sample Size
Babcock	Babcock-North	54 (1754)	296473.9	4176074	9,332	11.81	2010	39
Lyell Fork of Merced River	Doc Moyle's-East	130 (1487)	296016.8	4176167	9,302	4.23	2010	56
	Doc Moyle's-West	130 (1489)	296017	4176167	9,302	6.9	2010	25
Echo Lake	Echo Lake	n/a (2146)	287978	4188481	9,341	17.3	2010	51
Emeric Lake	Emeric Lake	34 (1888)	290212	4184049	9,345	22.07	2010	94
Long Meadow	Long Meadow-North	79 (2147n)	286060	4188200	9,607	29.49	2008	69
	Long Meadow-South	79 (2147s)	286060	4188200	9,607	16.65	2008	48
Merced Lake	Merced Lake-East	145 (1163e)	289055	4179088	7,305	1.55	2010	41
	Merced Lake-Shore	145 (1665)	287688	4179479	7,200	6.19	2010	42
	Merced Lake-West	145 (1163w)	288400	4179609	7,268	2.54	2010	20
Triple Peak-South	Triple Peak-South	131 (1164s)	293567	4171164	9,059	4.85	2010	26
Turner Lake	Turner Lake	133 (942)	293070	4168240	9,542	8..24	2010	52
Washburn Lake	Washburn Lake	35 (1507)	291060	4176604	7,613	1.95	2011	24

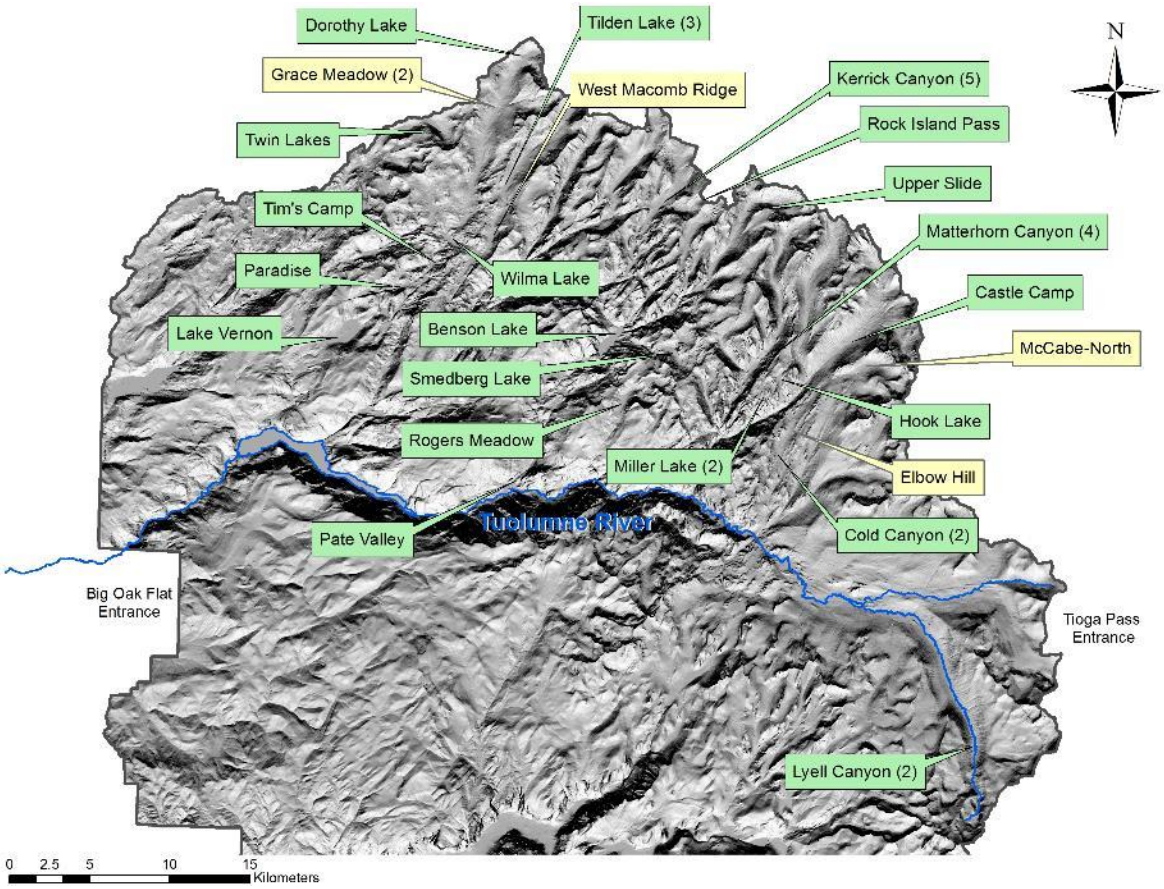


Figure 6. Map of study meadows in the Tuolumne River Watershed of Yosemite National Park. Numbers in parentheses indicate the number of meadows when more than one polygon is present at a general location. Meadow with green labels (20 total) indicate meadows with reported pack stock use since 2004, and yellow labels (4 total) indicate meadows without reported stock use since 2004.

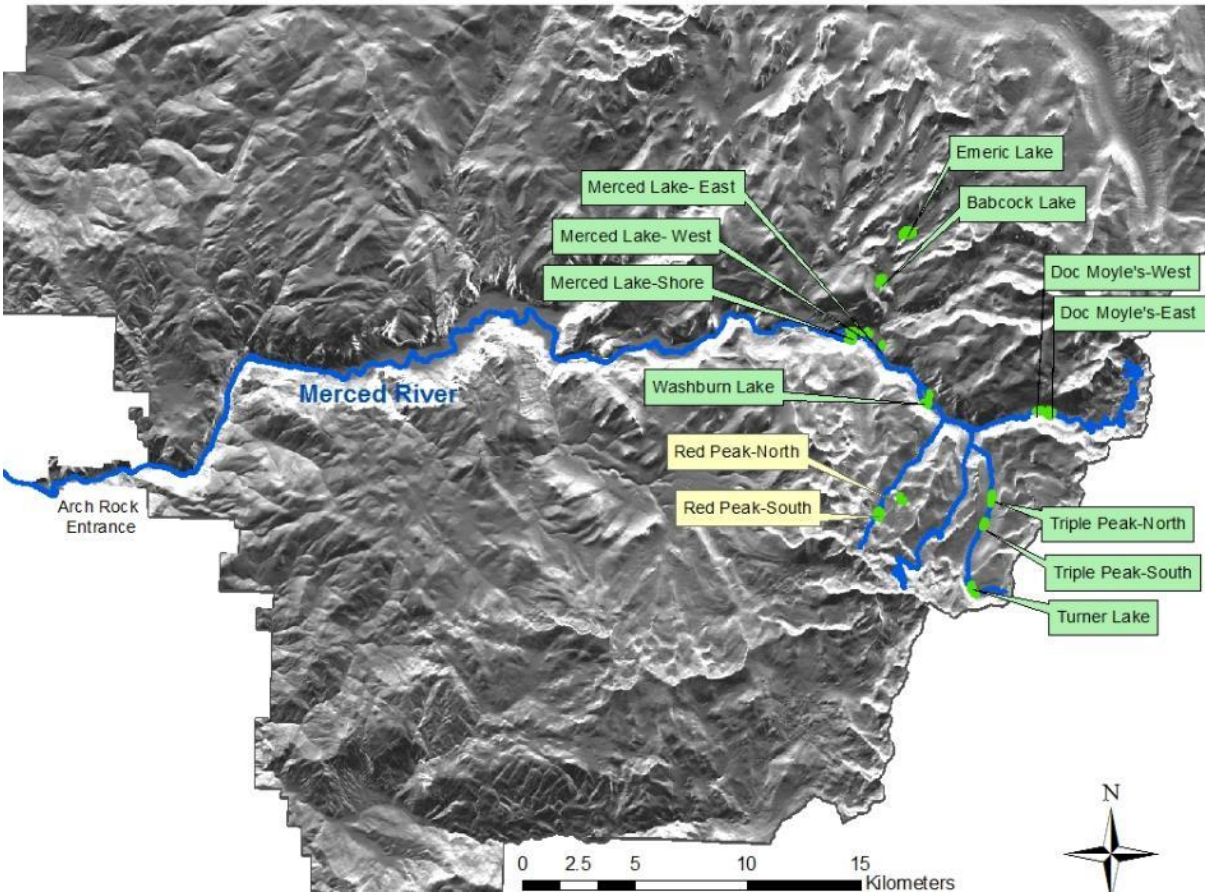


Figure 7. Map of study meadows in the Merced Watershed of Yosemite National Park. Meadow with green labels (11 total) indicate meadows with reported pack stock use since 2004, and yellow labels (2 total) indicate meadows without reported stock use since 2004.

Forage area

Meadow area

For the purposes of this report, forage area refers to meadow habitats that can be grazed. Meadow perimeters were initially delineated in ArcMap 10.1® software using an ArcGIS® shapefile of the Yosemite National Park 1997 vegetation map (Keeler-Wolf et al. 2012). These meadow areas were then overlaid on National Agricultural Imagery Program (NAIP) aerial imagery to identify rivers, large ponds, or forested areas that were excluded from mapped meadows to refine estimates of meadow area. Meadow boundaries were further refined according to field observations.

Forage species

For grazing capacities in Upper Lyell Canyon, Ballenger (2013) analyzed actual grazing observations to ascertain preferred forage species. These data were available for Upper Lyell Canyon but species composition varies among meadows, precluding inference outside that site. To establish grazing capacities for all meadows for which we have data, we chose to define the meadow forage area more generally as the proportion of sample plots dominated by graminoids, where species dominance within a plot equated to the highest percent vegetation cover of a species (Ballenger et. al. 2010). In

contrast, forbs, subshrubs and trees were not considered forage for the purpose of this work. In Yosemite, meadows are generally dominated by graminoids, with lesser representation by forbs, shrubs and subshrubs.

Forage production

We incorporated elevation, meadow hydrologic type, and rangeland condition to predict annual plant productivity using relationships developed by Ratliff et al. (1987) and as applied by SEKI (Figure 8).

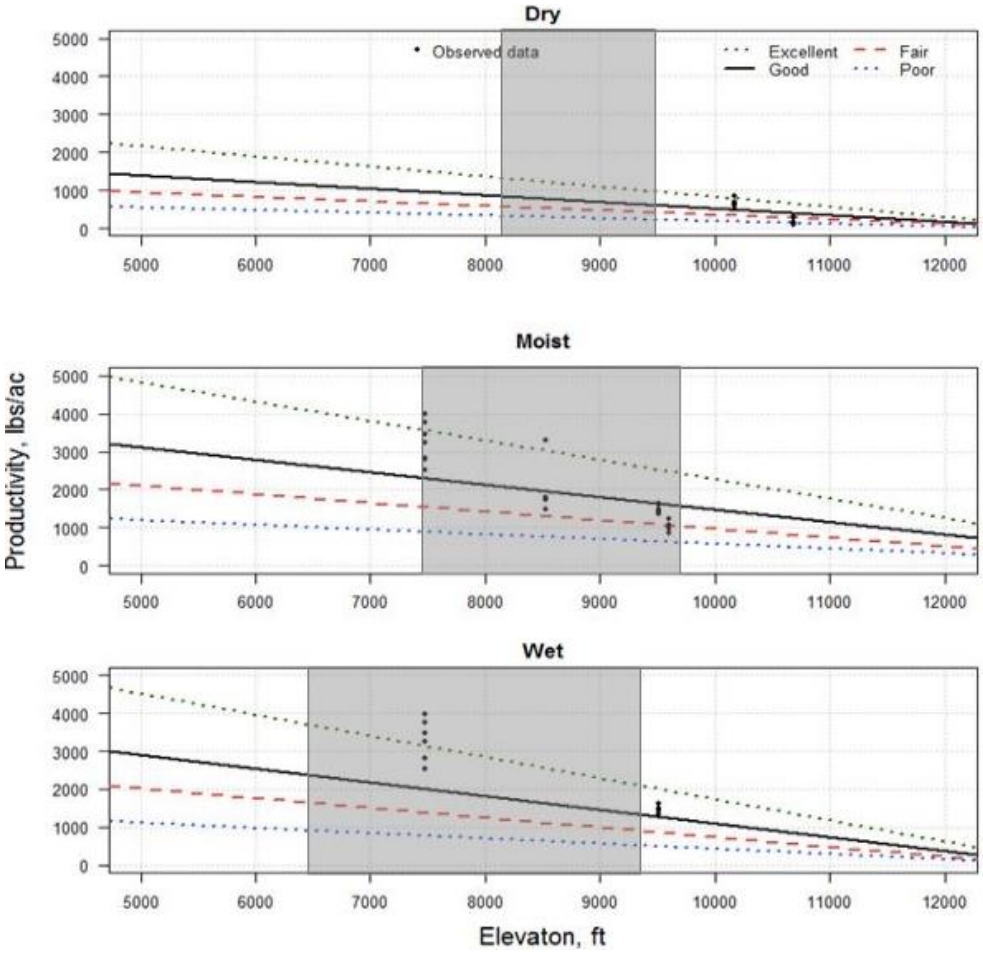


Figure 8. Graph of predicted annual plant productivity (lbs./acre) by elevation (ft.) for three moisture classes and four condition classes. Moisture classes are dry (xeric), moist (mesic), wet (hydric), and the four condition classes are excellent, good, fair, poor. These relationships were described in (Ratliff et al. 1987). Black dots represent observed data from SEKI. Shaded grey boxes represent elevation range extents for YOSE meadows that were used for estimation of grazing capacity.

Elevation

To obtain elevation, we extracted values from the center of meadows (centroid) using a digital elevation model (DEM) in ArcGIS® software.

Meadow type

Following Ratliff et. al. (1987) and Abbott et al. (2003), we recognized three meadow hydrologic types—hydric (wet), mesic (moist) and xeric (dry). For each meadow, the amount of forageable area belonging to each type was determined (% hydric, % mesic, % xeric). This was based on the proportion of dominant species belonging to each wetland hydrologic regime, as indicated by wetland indicator status. To do this, we assigned dominant plant species to their wetland indicator ratings from the National Wetland Plant List (U.S. Army Corps of Engineers 2013) —obligate (OBL), facultative wetland (FACW), facultative (FAC), FACU (facultative upland) or upland (U). For species not listed, we assigned a U rating, following convention. For the purposes of classifying meadows into hydrologic types, OBL species dominance indicated the "hydric" type, FACW or FAC dominance indicated the "mesic" type and FACU or U dominance indicated the "xeric" type. For each meadow, we calculated the proportion dominated by indicator species of each class to calculate the area covered by each hydrologic type. Thus meadow sites were not distilled to one type but rather a compilation of the three types.

Meadow condition

To estimate meadow condition, we examined definitions of range condition described through myriad approaches (e.g., Dyksterhuis 1949, Crane 1950, Weixelman and Zamudio 2001, Pyke et al. 2002, O'Brien et al. 2003, Pellant et al. 2005). However, because Crane (1950) established the empirical relationship between meadow condition and productivity, we applied that relationship to our productivity sub-model. Thus, to adequately crosswalk his condition classification with our data, we approached the definition of meadow condition similarly. Crane (1950) described meadow condition in the context of livestock production whereby goals are reflected in descriptions of plant composition for each condition class. Meadows in "excellent" condition were those with a high percentage of "palatable grasses and weeds," which include species considered invasive in Yosemite such as *Holcus lanatus* (common velvetgrass). Meadows in "good" meadow condition had "palatable grasses and weeds that make up at least 45% of the plant cover….[and] no forbs except clover or sweet anise…normally over 60% of the ground is covered with litter." Meadows in "fair," "poor," and "very poor" condition were those meadows with missing litter and humus, broken sods, and soil erosion. These combined characteristics are relatively rare in Yosemite meadows and, where they occur, are limited to very small portions of the meadow. Hence, *meadow condition* as discussed in Crane (1950) is not necessarily synonymous with *ecological condition*, a term more broadly used to express the state of a meadow based on integrity of ecosystem structure and function. While we are using Crane's condition classes, we had to modify them slightly to be relevant to Yosemite. For example, we would not choose to include weedy species under "good" condition that are invasive.

In a general sense, Yosemite meadows fit the qualitative description for "fair" or "good" provided in Crane (1950). We reviewed our data on the composition of dominant species recorded during surveys and found that the mean relative graminoid cover was 73% relative cover of meadow vegetation—the upper end of "good". Yet mean litter cover was 40%, which is below the cover that Crane described as "fair" (above 45%).

Since an additional consideration is to maintain consistency within the Sierra Nevada region, we also looked at grazing capacity and rangeland condition work developed by Sequoia and Kings Canyon National Parks (SEKI). There, managers use "good" as a starting point for rangeland condition. Yosemite and SEKI share many vegetation, geographic and climatic features and, because both experience recreational pack stock use in similar meadow plant community types, consistency in grazing capacity approaches would be useful for implementing best management practices on a region-wide basis. For these reasons, we assigned "good" rangeland condition to all meadows as a starting point for this report with adjustments to be made as needed, following meadow monitoring.

Annual climatic factors

Currently, we do not have sufficient data to quantify the influence of soil moisture (precipitation, spring snow water content) and temperature on meadow productivity in the park. These variables are therefore not incorporated as an adjustment to the productivity factor within the model for grazing capacity. Nonetheless, we know that there can be interannual variation in productivity. For instance, years with above-average spring snow pack can have a significant negative impact on productivity in mesic and xeric meadow types and higher temperatures can negatively affect the xeric meadow type (Moore et al. 2013). Such factors could be considered by Yosemite managers for future model refinements. This may be important considering changing conditions induced by climate change, such as expected increase in drought occurrence (Diffenbaugh et al. 2015, Williams et al. 2015).

Estimates of allowable use

We chose to model our estimates of allowable use on Cole et al. (2004) due to their Yosemite-specific research that most closely matches our needs. The empirical relationships between changes in meadow characteristics and utilization levels developed by Cole et al. (2004) provides a useful approach to decision-making on allowable utilization (use) levels based on management goals for minimizing change. Here we illustrate three scenarios for varying levels of acceptable change—no detectable change; 10% change; and 20% change—in productivity, basal vegetation cover and relative graminoid cover (Table 5, Appendix A). We selected these levels of change as an illustration of a range; however, managers may elect and calculate other levels. It should be noted that some of the equations chosen based on Cole et al. (2004) still had fairly poor fits, of $r2 < 0.3$. This is especially the case for *C. muiriana* in productivity and graminoid cover. Some reasons for lack of fit in the regression equations could be that the magnitude of responses varied across ecological variables and plant community types, or that variation in the timing of sampling occurred. Hence, for the purposes of assigning grazing capacities to meadows, caution should be exercised in applying utilization values based on their relationship with the three levels of ecological change.We eliminated responses that were not significant (e.g., bare soil in the *Carex filifolia* and *Deschampsia cespitosa* types) and for which regression equations had a poor fit, which was the case for bare soil cover in the *C. muiriana* type ($r^2 = 0.03$) and relative graminoid cover for year 4 in the *C. muiriana* type ($r^2 = 0.01$). The magnitude of responses varies across these ecological variables and plant community types.

Table 5. Utilization levels (as a percentage of total aboveground annual production measured post-utilization) that correspond to defined amount of change, including standard error (shown as value after ± symbol) associated with estimated % change. Productivity is aboveground peak biomass. Vegetation cover is basal live vegetative cover. Relative graminoid cover is the sum of the cover of all vascular graminoid plant species. *Responses in the Calamagrostis muiriana (formerly C. brewerii) meadow type varied by year and the mean of 3 years is presented here.

Metric	Meadow Type	Hydro Type	No Change		10% Change		20% Change	
			Percent	SE (±)	Percent	SE (±)	Percent	SE (±)
Productivity	*Carex filifolia*	Xeric	27%	*4%*	35%	*4%*	43%	*4%*
	*Calamagrostis muiriana**	Mesic	5%	*2%*	24%	*2%*	43%	*2%*
	Deschampsia cespitosa	Hydric	10%	*0%*	24%	*0%*	38%	*0%*
Basal vegetation cover	*Carex filifolia*	Xeric	28%	*4%*	32%	*4%*	37%	*5%*
	Calamagrostis muiriana *	Mesic	39%	*4%*	43%	*5%*	47%	*5%*
Relative graminoid cover	*Calamagrostis muiriana* *	Mesic	12%	*3%*	31%	*3%*	50%	*4%*

The resulting utilization levels that correspond to a set level of change have a wide range. For example, if the desired state were "no change" in *productivity* in the *C. muiriana* type, then the use level would need to be less than 5% (± 2%). Yet if the desired state were "no change" in *basal vegetation cover,* then the use level could be up to 39% (± 4%). Therefore, if the management goal were to observe "no change" in any of the metrics in the *C. muiriana* community type, then the percent use level would be set to 5%. Percent utilization that corresponds to "no change", 10% change and 20% change are 5% (± 2%), 24% (± 2%), and 43% (± 2%), respectively.

This suggests that a small amount of grazing—5% utilization—could occur without detectable changes in plant productivity, vegetation cover and relative graminoid cover for all metrics. At use levels resulting in greater than 5% utilization, a reduction in productivity in the *C. muiriana* could be anticipated. At utilization levels of about 25%, we would anticipate a reduction (~10% change) in productivity in *C. muiriana* and *D. cespitosa* communities, and reduced relative graminoid cover in *C. muiriana*. Utilization of approximately 35% would be expected to result in a 10% change in vegetation cover in the *C. filifolia* meadow type and a 20% reduction in productivity of the *D. cespitosa* meadow type, as well as >10% change in basal vegetation cover metric in *C. filifolia* communities, and ~10% change in relative graminoid cover in *C. muiriana*. For the purposes of distilling this analysis, when the ecological response was year-dependent (e.g. productivity in the *C. muiriana* type), we took the mean of the 3 years. However, it is important to note that variation among years likely points to the influence of climate on meadow response to pack stock use, as discussed in the *forage production* section of this report.

To produce preliminary capacities for this report, we used 5%, 25% and 35% use levels, which correspond to "no change", 10% and 20% ecological change, respectively (and rounded to the nearest 5%) from Cole et al. (2004). This provides a range of capacity outputs. However, these starting points can be revised and capacities recalculated based on specific management goals and objectives.

Consumption rate

We incorporated a rate of 32.5 lbs./ac per SUN as estimated in (Ratliff et al. 1987). This is the apparent convention for stock consumption, which defines consumption rate in the context of the amount of biomass one horse or mule consumes per night of grazing. This is in line with Yosemite 's stock use reporting metrics, in which use is recorded in SUN

Grazing efficiency

Incorporation of a grazing efficiency factor could protect against potential forage availability over-estimation. To consider if grazing efficiency was needed in our model, we looked back to the source from which we derived our utilization values from the relationship between utilization and acceptable ecological change. Cole et al. (2004) measured aboveground peak standing biomass rather than true productivity estimates, which would have required excluding herbivores and accounting for herbage that senesces and decomposes during the growing season. Therefore, in measuring peak standing biomass, these losses were already accounted for in our calculated available forage starting point. To obtain utilization estimates, Cole and others calculated the difference in biomass before and after grazing. Again, this accounts for losses due to all other herbivores, trampling and manure and is

essentially a comparison of residual biomass of a grazed versus ungrazed system (Figure 5). Since we derived productivity values from Crane (discussed further below) and utilization values from Cole and others, grazing efficiency is already implied in our production sub-model.

However, grazing efficiency can also convey the meadow-scale patchiness with which stock graze. Previous grazing studies have suggested that grazing by pack stock is non-uniform, and may be biased towards preferred forage species. This can often incur localized impacts within meadows, even when use rates are low (Olson-Rutz et al. 1996a, Cole et al. 2004, Ballenger et al. 2010). Results from a pilot pack stock behavior study performed in Yosemite may inform *where* pack stock graze within a meadow and if utilization is uniform (i.e., distributed evenly over the site) or biased (i.e., patchy due to preferences for particular biotic or abiotic features, Walden-Schreiner et. al. 2016a, b *in prep*.). If pack stock do not graze uniformly within sites, actual utilization levels in some areas may be higher than the allowable utilization while other areas may be lower. With this information, an efficiency term could be generated and capacities could be recalculated. Because we already did eliminate area dominated by shrubs, sub-shrubs and forbs (see *forage species*), we have, at least in part, accounted for some spatial grazing preference. The concept of grazing efficiency needs to be revisited as new study findings become available. Monitoring results can also inform whether overgrazing is occurring as a result of non-uniform grazing.

Results and Discussion

Preliminary grazing capacities

We calculated grazing capacities in pack stock use nights for 47 meadows, and compared these values with mean and maximum reported stock use nights for these overall sites (Tables 6 and 7). The capacities noted here are for illustration purposes based on a range of allowable utilization values between 5%, 25% and 35%, based on the results of our grazing capacity model. . The reported stock use nights noted here are for comparative purposes based on pack stock use data synthesized by NPS Wilderness staff at Yosemite. If Yosemite were to adopt an allowable grazing utilization outside of that range (5-35%), capacities would be different and could be calculated using our grazing capacity model. In addition to estimated grazing capacities by % allowable use levels, we also determined site-specific meadow information, including meadow area by foreagable hydrologic types, total meadow acreage, elevation, and estimated annual forage production (lbs/acre). The NPS reported mean and maximum stock use night data we provide by overall site is for a 12 year period, from 2004 to 2016), for comparison with estimated grazing capacities by % allowable use level .

Applying the grazing capacity model to the existing data set, calculated capacities range widely by site. At the lowest utilization level (5%), capacities ranged from a minimum of 1 to a maximum of 269 stock use nights per year, or, based on the highest utilization level (35%) a range of 10 to 1,881 stock use nights. This illustrates the wide range of meadow sizes, meadow types and elevations that drive differences in capacity output. Under a 5% capacity, the median capacity was 16—signifying half of all sites would support 16 or fewer stock use nights. These include locations that have received relatively high use such as Hook Lake, Benson, Miller Lake-North, and Miller Lake-South. At 25% and 35% utilization, the median capacity was 82 and 113, respectively. Middle Kerrick had the largest capacity at 269 – 1,881 stock use nights—a capacity more almost double the second-largest capacity, which was Upper Kerrick-South at 136 – 953 stock use nights. Middle Kerrick is by far the largest meadow potentially available for pack stock grazing at 156 acres (but see, Superintendent's Compendium), while Upper Kerrick-South, for comparison, is 89.5 acres.

These grazing capacities could be applied before the grazing season as an annual planning tool to avoid overgrazing. For instance, if there were need for pack stock support for administrative work, managers could look at site capacities in the vicinity to aid in selecting camps. Similarly, it could also be applied for managing commercial stock trips to popular locations. If anticipated use would approach capacity, a plan could be in place for resource managers to visit the site during the season to assess whether the meadow condition were affected by that level or if the meadow could support more grazing. Such site visits may be an especially important validation tool, considering that pack stock selectively graze one patch of meadow over another, and often graze beyond meadow boundaries, such as nearby uplands or forested understory (Walden-Schreinder 2015).The current method for assessing site ecological condition in wilderness meadows includes annual monitoring of bare soil extent, as part of the Visitor Use and Impact Monitoring Program in the park, which is mandated in the Merced and Tuolumne Wild & Scenic River Plans (NPS 2014 a,b,c). The bare soil indicator was developed by park staff via academic collaboration (Dickman et. al. 2014). The current method for estimating forage utilization includes annual monitoring of RBin wilderness meadows.

The combination of these monitoring data, in addition to accurately reported stock use nights by meadow site, can aid in the validation of modeled grazing capacity estimates by site, and the determination of whether a meadow site has truly reached grazing capacity for the year.

Grazing capacity can be used as a monitoring tool by calculating the *percent of capacity* by site:

percent of capacity = reported use / grazing capacity

where reported use and grazing capacity units are *stock use nights*. Reported use includes only nights grazed while stock spending the night but not set out to graze (e.g., feed pellets instead) would not be included in the *reported use* estimate. This could be applied in real time, during the grazing season, or post-grazing as part of the monitoring evaluation. When *percent of capacity* nears 100%, ideally monitoring would occur to observe meadow condition. Post grazing season evaluation of percent of capacity may be an important factor contributing to understanding of meadow conditions.

These estimates are based on meadow area only. However, some sites have forage available in nearby non-meadow habitat such as forest understory. Pate Valley is one example where the meadow grazing capacity was calculated at 5 - 36 stock use nights but there is additional forage in the forest understory. Aside from Castle Camp, popular stock sites in Virginia Canyon have little to no associated meadow area and we therefore did not calculate capacities for this project. To establish preliminary grazing capacities at these sites, or to adjust capacities at meadow sites that have substantial non-meadow forage potential, we recommend site visits to estimate productivity specific to those sites. Residual biomass sampling following the monitoring design in Appendix B could be applied, which would contribute to our understanding of productivity in those environments. Additionally, results of Yosemite's pack stock behavior studies could improve our understanding of spatial patterns of pack stock grazing in non-meadow sites (Walden-Schreiner et. al. 2016a, b). With this information, we could develop more informed preliminary grazing capacities for non-meadow environments. We provided more detail on a suggested approach to calculate grazing capacities in non-meadow environments in Appendix C.

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Table 6. Preliminary grazing capacities for graable meadows in the Tuolumne River watershed. Meadow names were given to each meadow unit at a given site, where suffixes indicate direction meadow is located in at a given site (N,E,W,S,NE,NW,SE,SW). Camp ID indicates commercial stock camp number, and Mdw ID indicates meadow ID number used for a meadow at a given site. Meadows with a Camp ID of "n/a" indicate no commercial stock use camp nearby. Site specific attributes that influence production—elevation, areas of each meadow type and area of forage species—are given as well as resulting total site production for *good* meadow condition class. Resulting grazing capacities in stock use nights at three levels are derived from the percentage of total annual production (lbs./acre) allocated to stock divided by stock consumption (32.5 lb./night). *Values for Upper Lyell sites were carried forward from Ballenger (2013). Mean reported stock use nights indicate average reported private, administrative, and commercial use from 2004 to 2016. *Meadows with duplicate values had use reported for a larger area, rather than specific meadow, and meadows will null values had no reported use (does not always indicate no use occurred).

Meadow	Camp ID (Mdw ID)	Elev. (ft)	Meadow Area (ac)					Annual Production (lb./ac)	Grazing Capacity (Stock Nights based on % Allowable Use)			Reported Stock Use Nights 2004-2016 Mean (Max)
			non-forage	hydric	mesic	xeric	total		5%	25%	35%	
Benson-NE	95 (3570)	7,595	0.0	0.1	0.4	0.0	0.4	2,209	1	7	10	115 (299)
Benson-NW	95 (3561)	7,595	0.0	1.1	1.5	0.0	2.7	2,132	9	43	60	115 (299)
Castle Camp	39 (3519)	8,784	0.6	2.8	1.4	0.7	5.6	1,521	12	58	82	25 (74)
Cold Canyon-N	147 (3207n)	8,699	5.3	2.1	10.7	4.3	22.4	1,571	41	206	289	0 (0)
Cold Canyon-Smokey Jack	147 (3207s)	8,669	8.2	2.4	15.5	13.1	39.2	1,398	67	333	467	21 (85)
Dorothy-NW	100 (4694)	9,394	10.0	1.0	8.7	0.0	19.7	1,637	24	122	171	33 (77)
Dorothy-W	101 (4702)	9,394	8.4	0.0	4.2	0.0	12.6	4,725	31	153	214	34 (77)
Grace Meadows	47 (4472)	8,666	24.0	0.5	10.3	8.2	43.0	1,406	41	206	289	0 (0)
Hook Lake-N	97 (3414)	9,384	1.1	2.6	2.3	2.3	8.3	1,218	13	67	94	11 (76)
Jose's Camp	88 (3915)	9,056	3.7	1.5	4.3	0.6	10.2	1,598	16	80	112	23 (82)
Lake Vernon-SE	9 (3555)	6,570	0.4	7.8	1.1	0.0	9.3	2,371	32	162	227	32 (125)
Lower Kerrick-S	41 (3875)	8,941	6.6	0.5	4.0	13.6	24.8	978	27	137	192	0 (0)
Matterhorn-S	91 (3466)	8,426	7.9	2.7	5.5	10.3	26.4	1,281	36	182	255	114 (328)
McCabe-N	78 (3457)	9,653	2.9	3.8	22.1	0.8	29.7	1,506	62	310	434	7 (74)
Middle Kerrick	89 (4136)	9,151	36.0	16.0	76.1	28.0	156.1	1,454	269	1343	1881	0 (5)

Table 6 (continued). Preliminary grazing capacities for graable meadows in the Tuolumne River watershed. Meadow names were given to each meadow unit at a given site, where suffixes indicate direction meadow is located in at a given site (N,E,W,S,NE,NW,SE,SW). Camp ID indicates commercial stock camp number, and Mdw ID indicates meadow ID number used for a meadow at a given site. Meadows with a Camp ID of "n/a" indicate no commercial stock use camp nearby. Site specific attributes that influence production—elevation, areas of each meadow type and area of forage species—are given as well as resulting total site production for *good* meadow condition class. Resulting grazing capacities in stock use nights at three levels are derived from the percentage of total annual production (lbs./acre) allocated to stock divided by stock consumption (32.5 lb./night). *Values for Upper Lyell sites were carried forward from Ballenger (2013). Mean reported stock use nights indicate average reported private, administrative, and commercial use from 2004 to 2016. *Meadows with duplicate values had use reported for a larger area, rather than specific meadow, and meadows will null values had no reported use (does not always indicate no use occurred).

Meadow	Camp ID (Mdw ID)	Elev. (ft)	Meadow Area (ac)					Annual Production (lb./ac)	Grazing Capacity (Stock Nights based on % Allowable Use)			Reported Stock Use Nights 2004-2016 Mean (Max)
			non-forage	hydric	mesic	xeric	total		5%	25%	35%	
Miller Lake-N	96 (3400)	9,456	4.1	0.4	2.3	1.8	8.6	1,218	8	42	59	0 (0)
Miller Lake-S	96 (3342)	9,505	5.7	0.4	0.8	2.1	9.1	952	5	25	35	23 (123)
Paradise-N	136 (2427n)	7,665	0.0	1.2	5.2	0.0	6.3	2,182	21	106	149	12 (91)
Paradise-S	121 (2427s)	7,665	0.0	2.8	0.6	0.0	3.4	1,993	10	52	73	12 (91)
Pate Valley-N	69 (3061)	4,389	0.6	0.0	1.0	0.0	1.6	3,299	5	26	36	43 (218)
Rodgers Mdw	94 (3331)	8,744	14.3	7.6	8.6	5.7	36.1	1,473	50	248	347	0 (0)
Smedberg-S	92 (3501)	9,223	3.7	2.3	1.2	1.9	9.1	1,213	10	50	70	50 (177)
Tilden Lake-N	46 (4321)	8,920	1.5	0.3	6.4	1.5	9.7	1,608	20	101	141	54 (163)
Tilden Lake-NE	46 (4342)	8,920	0.8	0.0	3.6	5.2	9.7	1,169	16	80	111	54 (163)
Tilden Lake-SE	85 (4145se)	8,908	0.5	0.0	3.3	0.0	3.8	1,830	9	46	64	54 (163)
Tilden Lake-SW	46 (4145sw1)	8,908	0.0	0.0	1.7	0.0	1.7	4,725	12	62	87	54 (163)
Tilden Lake-W	46 (4145w)	8,908	0.6	0.0	0.6	0.0	1.1	1,829	2	8	11	54 (163)
Tim's Camp-N	132 (3869e)	7,695	1.5	1.4	1.8	0.0	4.6	2,096	10	51	71	0 (0)
Tim's Camp-S	132 (3869w)	7,695	1.5	0.3	3.1	0.0	4.9	2,199	12	58	81	0 (0)
Twin Lakes-S	32 (4413)	8,899	3.2	1.1	1.3	1.1	6.8	1,376	8	38	53	12 (44)

Table 6 (continued). Preliminary grazing capacities for graable meadows in the Tuolumne River watershed. Meadow names were given to each meadow unit at a given site, where suffixes indicate direction meadow is located in at a given site (N,E,W,S,NE,NW,SE,SW). Camp ID indicates commercial stock camp number, and Mdw ID indicates meadow ID number used for a meadow at a given site. Meadows with a Camp ID of "n/a" indicate no commercial stock use camp nearby. Site specific attributes that influence production—elevation, areas of each meadow type and area of forage species—are given as well as resulting total site production for *good* meadow condition class. Resulting grazing capacities in stock use nights at three levels are derived from the percentage of total annual production (lbs./acre) allocated to stock divided by stock consumption (32.5 lb./night). *Values for Upper Lyell sites were carried forward from Ballenger (2013). Mean reported stock use nights indicate average reported private, administrative, and commercial use from 2004 to 2016. *Meadows with duplicate values had use reported for a larger area, rather than specific meadow, and meadows will null values had no reported use (does not always indicate no use occurred).

Meadow	Camp ID (Mdw ID)	Elev. (ft)	Meadow Area (ac)					Annual Production (lb./ac)	Grazing Capacity (Stock Nights based on % Allowable Use)			Reported Stock Use Nights 2004-2016 Mean (Max)
			non-forage	hydric	mesic	xeric	total		5%	25%	35%	
Upper Kerrick-N	90 (4324n)	9,299	24.4	10.7	10.7	7.2	53.0	1,309	58	288	403	30 (91)
Upper Kerrick-S	138 (4324s)	9,299	24.6	26.3	26.3	12.3	89.5	1,363	136	681	953	30 (91)
Upper Lyell-N	61 (2040)	8,971	2.1	1.7	4.5	8.9	17.3	1,124	26	131	184	38 (221)
Upper Lyell-S	84 (1987)	8,977	3.5	6.1	13.9	9.3	32.8	1,386	63	313	438	248 (685)
Wilma Lake	65 (3945)	7,944	0.7	2.4	1.7	0.0	4.8	1,969	12	62	87	11 (44)

Table 7. Preliminary grazing capacities for grazable meadows in the Merced River watershed. Meadow names were given to each meadow unit at a given site, where suffixes indicate direction meadow is located in at a given site (N,E,W,S,NE,NW,SE,SW). Camp ID indicates commercial stock camp number, and Mdw ID indicates meadow ID number used for a meadow at a given site. Meadows with a Camp ID of "n/a" indicate no commercial stock use camp nearby. SSite specific attributes that influence production—elevation, areas of each meadow type and area of forage species—are given as well as resulting total site production for good meadow condition class. Resulting grazing capacities in stock use nights at three levels are derived from the percentage of total annual production (lb./acre) allocated to stock divided by stock consumption (32.5 lb./night). *Value for Merced Lake East was carried forward from Ballenger (2013). *Meadows with duplicate values had use reported for a larger area, rather than specific meadow, and meadows will null values had no reported use (which does not necessarily indicate that no use occurred).

Meadow	Camp ID (Mdw ID)	Elev. (ft)	Meadow Area (ac)					Annual Production (lb./ac)	Grazing Capacity (Stock Nights based on % Allowable Use)			Reported Stock Use Nights 2004-2016 Mean (Max)
			non-forage	hydric	mesic	xeric	total		5%	25%	35%	
Babcock-N	54 (1754)	8,902	3.6	1.9	4.4	0.8	10.7	1,614	18	89	124	6 (36)
Doc Moyle's-E	130 (1487)	9,332	0.6	7.4	1.7	2.1	11.8	1,265	22	109	152	0 (0)
Doc Moyle's-W	130 (1489)	9,302	0.0	2.9	1.4	0.0	4.2	1,467	10	48	67	13 (43)
Emeric Lake	34 (1888)	9,345	9.6	0.9	5.9	5.6	22.1	1,187	23	114	159	63 (135)
Long Meadow-N	79 (2147n)	9,607	10.3	2.6	14.5	2.1	29.5	1,443	43	214	299	3 (40)
Long Meadow-S	79 (2147s)	9,607	2.4	1.7	9.0	3.5	16.7	1,313	29	144	201	0 (0)
Merced Lake-E	145 (1163e)	7,305	0.0	1.5	0.1	0.0	1.6	2,088	5	25	35	310 (925)
Merced Lake-Shore	145 (1665)	7,200	0.6	4.4	1.2	0.0	6.2	2,170	19	93	131	0 (0)
Merced Lake-W	145 (1163w)	7,268	0.4	2.0	0.1	0.0	2.5	2,105	7	35	49	0 (0)
Triple Peak-S	131 (1164s)	9,059	1.1	0.6	1.1	2.1	4.9	1,130	6	32	45	4 (26)
Turner Lake	133 (942)	9,542	4.9	0.0	3.0	0.3	8.2	1,527	8	39	55	0 (0)
Washburn Lake	35 (1507)	7,613	0.0	1.9	0.1	0.0	2.0	1,976	6	30	42	13 (36)

Lyell Canyon estimated grazing capacity values calculated using our grazing capacity model differ from those that were based on the methods of Ballenger (2013). In fair condition at 25% utilization, Ballenger calculated capacity to be 41 and 126 stock use nights at Upper Lyell-North and Upper Lyell-South, respectively. This is lower than our model estimates, which were 131 and 313 stock use nights. The model Ballenger used was specific to Upper Lyell Canyon and included a smaller subset of the dominant graminoid species as "preferred forage". Therefore, she assigned fewer plant types to "forage species", resulting in a lower estimate. Because the model here is intended to cover all meadows for which we have vegetation data but not necessarily stock sign (grazing, manure and hoof-punching) data, we had to use a more generalized approach. Also, her approach to meadow condition differed where she based meadow condition on seral stage of plants. A higher frequency of late seral stage plants results in meadow condition classification nearer to "excellent" while higher frequencies of low seral stage plants edges the classification toward "poor". For this generalized model, we elected an alternative approach based on descriptions in Crane 1950. This lead to a discrepancy in outcome of ecological condition in which Ballenger assigned "fair" while we assigned "good" ecological condition. Therefore, those two inputs generate estimates in Ballenger (2013) that are more conservative than our model. Because of its popularity and use history, Lyell Canyon is a very high priority site for meadow monitoring where resulting data could inform whether capacities could be higher or lower for that location.

Merced Lake-East estimated grazing capacity values calculated using our grazing capacity model also differ from those calculated based on Ballenger (2013) and presented in the MRP, however, in contrast to the Lyell Canyon case, they were higher based on Ballenger's method than our model. Capacities set per the MRP are "up to 58 stock use nights" whereas our model generates a value at that same utilization level of 35. In this case, resulting capacity is lower in our model than calculated from the Ballenger model because of the meadow condition sub-model alone. Plant species composition data at Merced Lake shows one species dominating—*Carex vesicaria*. Because *C. vesicaria* is a high seral stage species, the meadow condition sub-model used by Ballenger results in an "excellent" rating. Ecologists who documented this *C. vesicaria* dominance noted that very monoculture, or lack of site diversity, as a concern for ecosystem structure and function. However, diversity did not play a role in meadow condition for the purposes of productivity estimates. In contrast, our model gave all sites a "good" starting point, which would result in lower capacities at Merced Lake—East. It is important to also note that Merced Lake – East has additional forage outside the meadow area that is not accounted for in either model. This site has been a logistically important site for administrative operations but per the MRP was closed to grazing to allow for improvement in condition. Monitoring will be particularly important for this site as it recovers, and if grazing resumes. For the Lyell and Merced Lake-East sites, Merced and Tuolumne Wild and Scenic River Plans established those preliminary capacities; they are not superseded here. On-site monitoring of residual biomass and meadow condition can help determine if capacities could be increased or decreased.

We generated capacities for all meadows that allow grazing for which we had data. Site suitability is another aspect of pack stock management and not discussed in this report. Managers may change site suitability designation resulting in closures or openings. The data collection process prioritized

higher use sites. Therefore, we believe that the current grazing capacity output covers the sites of highest concern. Because we do not have data for all potential pack stock use sites, some meadows may not have a preliminary grazing capacity. If pack stock use at a site without such data increases to a point of needing additional attention, ecologists could collect plant data during a site visit in order to generate a grazing capacity estimate using this model. Alternatively, in the absence of plant data, ecologists could consider using coarser inputs such as substituting a classification by meadow hydrologic type based on remote sensing methods. In other cases, some meadows listed may have little to no documented use, their presence in the dataset is more to provide reference for ungrazed conditions. This does not preclude them from being potential sites in the future, so we list them here.

The *allowable use* parameter is still to be decided and will be a major determinant of grazing capacities. In the three scenarios presented, the highest use level, 35%, is seven times greater than the lowest use level. This could have major implications at popular sites. Because managers often must explore a range of possible and reasonable scenarios, a.k.a., "alternatives" in an environmental planning context, a range of allowable use levels could be explored for their effects on other values identified in the planning effort. Another way that managers could vary allowable use is by site. Sites may be determined to be of high logistical value—meaning they are key sites for accessing a primary route—and allowable use may be higher for those sites. Conversely, management may strive for a lower level of acceptable change due to grazing utilization for meadows in lower ecological condition to facilitate passive recovery. Sites may also be of high resource value (e.g. harboring endangered amphibians or cultural resources) and—if deemed suitable—may warrant lower allowable use levels.

Monitoring

The preliminary grazing capacities presented in this report are meant to serve as an informed starting point for site-specific pack stock management. Although we have developed an approach for calculating grazing capacities, the many factors influencing inputs to the model result in capacities that are imprecise. In addition, there were other potential inputs that we did not include in this model such as grazing efficiency and annual temperature and snowpack. Thus there is potential to refine the model itself or to adjust site-specific capacities where needed. Monitoring is the best way to ensure meadow protection and determine whether capacities can be adjusted (Figure 9).



Figure 9. Photograph of grazed meadow vegetation (grasses). Monitoring can provide feedback to evaluate meadow management.

To obtain feedback to manage grazing, the park could implement a monitoring program with two facets: monitoring of meadow condition and monitoring of actual grazing. Meadow condition monitoring has been developed for the MRP and TRP through the use of indicators and standards: streambank stability, meadow fragmentation and bare soil cover (NPS 2014a, b, c). Monitoring of these already-developed indicators could be expanded to pack stock use sites of interest that are outside these Wild and Scenic river corridors. Meadow condition standards could be developed for this particular context and for corresponding management actions identified for sites below the management standard.

Feedback on grazing can be obtained through monitoring either utilization or residual vegetation. We can test whether the *observed utilization* (the level of grazing that actually occurred) exceeded the *allowable utilization* (the target threshold selected by park management). Utilization is the aboveground vegetation biomass removed by stock animals and other consumers (e.g., insect, deer, small mammal) while residual biomass is the remaining aboveground herbaceous vegetation after utilization. Although our term of interest is *utilization*, these measurements require comparison of herbage remaining to herbage produced by erecting exclusion cages (Coulloudon et al. 1999). Such installations may be inconsistent with minimum tool practices in designated Wilderness, which is where grazing in Yosemite occurs. Residual biomass (RB) monitoring is therefore more appropriate in this Wilderness context. The comparative yield method of estimating RB (Haydock and Shaw 1975) was modified and adopted for use in the wilderness meadows of Sequoia and Kings Canyon National Parks in 1993 (NPS 2014c) and we are now pilot testing this methodology in Yosemite. Applying the same methodology would facilitate comparison on a regional scale. Appendix B—Draft Residual Biomass Monitoring Protocol—provides more detail.

Residual biomass data could provide powerful information for several applications. It could be used to validate the production sub-model and grazing capacity model presented here while providing monitoring feedback for adaptive meadow management. Residual biomass observations in ungrazed sites also yield meadow-level productivity measurements. These measurements can be used spatially to ground-truth remote sensed data productivity values that could be applied as an alternative monitoring mechanism in the future, or temporally to assess annual variability in relation to climatic factors.

Timing of utilization measurements is also important for adequately detecting forage utilization. For RB monitoring at Yosemite, we aim to measure forage utilization at the end of the growing season, after peak biomass, and after the majority of summer season pack stock use has occurred. We recognize that late season monitoring can potentially result in regrowth after defoliation, which could result in utilization estimates that are lower than if the measurements were made before regrowth. In addition, because monitoring occurs late season, after plant senescence has begun (i.e.. potentially seeds and leaves have fallen off), utilization estimates could be greater than if measurement were taken immediately after grazing occurred. However, it should be noted that it is logistically challenging to sample RB in multiple meadows simultaneously, where it is often not possible to ensure that utilization measurements occur immediately after grazing. This is due to the numerous and remotely located Wilderness meadows that receive pack stock use, and the fact that there is often

a delay in stock use reporting from stock users to resource managers. Hence, given these constraints, we take measurements at the end of the growing season to promote consistency among sites.

Model validation

Production values

The grazing capacity model relies on an accurate production sub-model. We can test the fit of the model by comparing modeled production and observed production. In this case, RB is a proxy for plant production at an ungrazed site.

Utilization and grazing efficiency

We can validate the grazing capacity model by comparing actual utilization—based on stock use reporting—against observed utilization. Because (100 – RB) can also can be a proxy for utilization, such *observed utilization* (equation 1) can be related to *expected utilization* generated with the model. Expected utilization is found by solving the capacity model for utilization and inputting reported stock use nights (equation 2).

$$(1)\ \text{Observed utilization } (\%) = 100\% - \text{RB}$$

$$(2)\ \text{Expected utilization } (\%) = \frac{\text{actual stock use nights (stock night)} * \text{consumption rate (lb} * \text{stock}^{-1}\ \text{night}^{-1})}{\text{forage area (ac)} * \text{forage production (lb ac}^{-1})} * 100$$

These results could validate the grazing utilization model or call attention refinements needed in the model. For instance, a systematically high ratio of *observed* versus *expected* utilization may indicate that a grazing efficiency term could be added to the model to better reflect ecosystem processes and pack stock grazing behavior. Alternatively, the park could make adjustments on a site-by-site basis based on the apparent need to address grazing efficiency.

Feedback on grazing levels

If the goal were to utilize at no more than 25% (i.e., allowable utilization was set to 25%), the park could consider an RB threshold standard of 75% (100% of total production minus 25% utilized). Evaluation of a grazed site can be made as a comparison to an ungrazed site as a reference and/or to compare with productivity values presented in the literature such as in Abbott et al. (2003). Comparison with a ungrazed site could facilitate discernment of climatic factor influences such as snowpack, drought, and seasonal temperature variation from grazing effects. Management could be adapted based on these results in conjunction with ecological condition monitoring to better achieve the targeted allowable utilization.

Feedback on meadow condition

Residual biomass can also serve as an indicator of meadow condition when treated as a trend over time. Productivity is an indicator of meadow condition so a downward trend in RB could indicate site overuse by pack stock or changes in environmental or climatic factors, such as the effects of prolonged drought. However, RB at a grazed site is not a proxy for production (since the consumed component of production is not measured). Therefore, a reduction in production would be difficult to

observe at a site with variable annual utilization levels. Yet looking at the trend over time at sites operating at the fairly consistent pack stock use levels should not be dismissed. Climatic factors driving plant productivity would also need to be evaluated as potential cause for the trend. For example, interannual variation in snowpack and precipitation climatic data could be evaluated in comparison with interannual variation in plant productivity, to determine whether a correlation exists.

Ground-truth remote sensed productivity data

Residual biomass is a proxy for annual primary plant productivity (ANPP). Another means of collecting ANPP is through remote sensing using the Normalized Difference Vegetation Index (NDVI), which in an index that calculates relative productivity through reflectance of near infra-red and green spectrums. There is currently a 20+ year NDVI dataset for all of Yosemite with spatial resolution at the meadow scale, and several within-year measurements. However, these values are relative and need to be tied to ANPP measurements. RB data collected throughout Yosemite could provide that needed field data to generate a relationship between NDVI and ANPP to elevate the utility of the NDVI dataset. Subsequently, NDVI could potentially be used to estimate productivity of a large number of meadows remotely, thereby increasing monitoring efficiency. However, we recognize that more research is needed to verify the relationship between NDVI values and ANPP in meadows in Yosemite's wilderness. Therefore, a study would need to be conducted prior to utilizing NDVI values for estimating ANPP in meadows for informing grazing capacities.

Relationship to annual variation in climatic factors

Quantifying RB at reference sites paired to grazed sites can also help us understand biomass interannual variation and differentiate the influence between utilization and climatic factors such as precipitation and temperature on biomass production. Evaluating trend over time in reference sites may illuminate empirical relationships between production and climatic factors.

Conclusions

Park managers could apply the preliminary grazing capacities we present in this report as one component of the Wilderness Stock Use Framework (Kuhn et al. 2017, in review), which outlines best practices for pack stock use management and monitoring that will guide how much (site grazing capacity), where (site suitability), when (meadow opening dates), how (handling practices), use should occur at a given site in order to avoid, reduce, or mitigate impacts. To determine grazing capacities on how much allowable use should occur, park managers could select the target utilization threshold levels based on consideration of goals, objectives, and constraints for each site. If not one of the three utilization levels used for illustration purposes, other target thresholds can easily be calculated. For other model inputs, Yosemite Resources Management and Science staff made decisions regarding the most appropriate approach to employ using the best available science. This model is a useful tool for communicating within the park and between the park and pack stock users, especially when viewed against actual use or desired use for an upcoming season. This grazing capacity modeling tool may also be applicable to managers in the greater Sierra Nevada region.

Although we have developed an approach for calculating grazing capacities, the many factors influencing inputs to the model result in capacities that are imprecise. In addition, other factors that are not included in the model may be important. Interannual variability in productivity can be very high and is known to be driven by certain climatic variables. Yet we do not have enough data on their relationships to add them explicitly to the model. Extreme weather events—such as the drought that encompassed 2012 – 2015—could have profound effects on productivity that we do not understand at this time. Although we are beginning to understand stock behavior patterns in meadows based on pilot studies (Walden-Schreinder et. al. 2015), we still cannot determine whether preferential use in certain areas could be causing localized impacts that go un-detected when evaluating sites at the meadow-scale for prediction of grazing capacities. Therefore, meadow monitoring is a necessary component of proper park meadow management that aims to protect and preserve ecological condition and function of these sensitive ecosystems for current and future generations.

We outlined a meadow monitoring strategy that can provide feedback to these preliminary grazing capacities. Comparing residual biomass within a meadow that receives pack stock use after a season of grazing to that of a reference site, in conjunction with meadow condition monitoring (i.e. bare soil) and annual pack stock use reporting, is the means by which preliminary grazing capacities can be adjusted (increased or decreased). Adaptive management based on meadow monitoring requires knowledge of actual levels of annual reported pack stock use as part of the feedback process for adjusting capacities. Therefore, accurate annual pack stock use night reporting in the park is absolutely critical for proper meadow management that meets the goals and objectives of the NPS dual mission.

Application of these preliminary grazing capacities for pack stock use and corresponding residual biomass monitoring are critical elements of a comprehensive pack stock management framework (Kuhn et. al. 2017, in review). The ongoing refinement of grazing capacities in Wilderness will help

park management achieve both goals of preserving and protecting ecological integrity and wilderness values while allowing for use by pack stock users.

Future directions

- Apply grazing capacities to examine use levels as a percentage of capacity. Select a percentage level at which meadows would be listed for meadow condition and RB monitoring.
- Implement RB sampling for both grazed and ungrazed meadows; incorporate into a broader monitoring program
- Validate model using RB results to evaluate production estimates as well as overall model
- Evaluate RB monitoring dataset (to determine utilization) in comparison with bare soil dataset (to determine condition), and accurately reported stock use nights, to validate modeled grazing capacity estimates, and determine if a meadow has truly reached capacity.
- Conduct study to verify the relationship between NDVI values and ANPP values in meadows
- Use NDVI remote sensed to estimate productivity (ANPP) of a large number of meadows remotely, to increase monitoring efficiency
- Use RB dataset as ground-truthing method for NDVI remote sensed data, and estimates of ANPP.
- After several years of data are amassed, use RB dataset to examine the relationship of productivity and climatic variables (i.e. evaluate and compare interannual variation in snowpack and precipitation climatic data with ANPP to determine if correlation exists).



Photograph of a subalpine meadow, Emeric Lake, in Yosemite National Park

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Appendix A. Relationships between percent utilization and meadow characteristics

Table A-1. Relationship between percent utilization (as a percentage of total aboveground annual production) and change in ecosystem metrics by meadow type. Productivity is aboveground peak biomass. Basal vegetation cover is basal live vegetative cover. Relative graminoid cover is the sum of the cover of all graminoid species divided by the sum of the cover of all vascular plant species. Regression equations in which x is percent utilization and y is percent of pre-grazed measurement. NS represents relationships that were not statistically significant. SE represents standard error associated with r-squared (R2) values. Table below is adapted from Cole et al. 2004. Note: *Calamagrostis brewerii* reported in the paper has since been changed to *C. muiriana*.

Metric	Meadow type	Sampling Year	Common Name	Regression Equation	r^2 value	SE (±)
Productivity	*Carex filifolia*	1	Shorthair sedge	y = 133 - 1.23x*	0.41	0.04
	Deschampsia cespitosa	1	Tufted hairgrass	y = 107 - 0.72x	0.37	0.00
	Calamagrostis brewerii	2	Brewer's reed grass	y = 106 - 0.65x	0.34	0.02
	Calamagrostis brewerii	3	Brewer's reed grass	y = 99 - 0.49x	0.22	0.02
	Calamagrostis brewerii	4	Brewer's reed grass	y = 104 - 0.47x	0.17	0.02
Basal Vegetation cover	*Carex filifolia*	1	Shorthair sedge	y = 165 - 2.32x	0.38	0.04
	Deschampsia cespitosa	1	Tufted hairgrass	NS	NS	NS
	Calamagrostis brewerii	2	Brewer's reed grass	y = 166 - 1.93x	0.52	0.04
	Calamagrostis brewerii	3	Brewer's reed grass	y = 211 - 2.87x	0.62	0.04
	Calamagrostis brewerii	4	Brewer's reed grass	y = 250 - 3.35x	0.68	0.04
Relative graminiod cover	*Carex filifolia*	1	Shorthair sedge	NS	NS	NS
	Deschampsia cespitosa	1	Tufted hairgrass	NS	NS	NS
	Calamagrostis brewerii	2	Brewer's reed grass	y = 101 - 0.39x	0.19	0.03
	Calamagrostis brewerii	3	Brewer's reed grass	y = 118 - 0.83x	0.39	0.03
	Calamagrostis brewerii	4	Brewer's reed grass	NS	NS	NS
Bare soil cover	*Carex filifolia*	1	Shorthair sedge	NS	NS	NS

Table A-1 (continued). Relationship between percent utilization (as a percentage of total aboveground annual production) and change in ecosystem metrics by meadow type. Productivity is aboveground peak biomass. Basal vegetation cover is basal live vegetative cover. Relative graminoid cover is the sum of the cover of all graminoid species divided by the sum of the cover of all vascular plant species. Regression equations in which x is percent utilization and y is percent of pre-grazed measurement. NS represents relationships that were not statistically significant. SE represents standard error associated with r-squared (R2) values. Table below is adapted from Cole et al. 2004. Note: *Calamagrostis brewerii* reported in the paper has since been changed to *C. muiriana*.

Metric	Meadow type	Sampling Year	Common Name	Regression Equation	r^2 value	SE (±)
	Deschampsia cespitosa	1	Tufted hairgrass	NS	NS	NS
	Calamagrostis brewerii	1	Brewer's reed grass	NS	NS	NS
Basal litter cover	*Carex filifolia*	1	Shorthair sedge	NS	NS	NS
	Deschampsia cespitosa	1	Tufted hairgrass	NS	NS	NS
	Calamagrostis brewerii	1	Brewer's reed grass	NS	NS	NS
Floristic Dissimilarity)	*Carex filifolia*	1	Shorthair sedge	NS	NS	NS
	Deschampsia cespitosa	1	Tufted hairgrass	NS	NS	NS
	Calamagrostis brewerii	1	Brewer's reed grass	NS	NS	NS

The calculation for floristic dissimilarity is given below where *n* is the number of species and $p_{before^{(i)}}$ and $p_{after^{(i)}}$ are relative cover for species *i* on the same plots, before and after grazing.

$$\text{Floristic Dissimlarity} = \sum_{i=1}^{n} | p_{before^{(i)}} - p_{after^{(i)}} |$$

Table A-2. Estimated annual production remaining based on % change, % allowable use, and preliminary grazing capacities for meadows in the Tuolumne River watershed. Meadow site specific attributes include meadow names with directional suffix (N,E,W,S,NE,NW,SE,SW), Camp ID indicating commercial stock camp number, elevation, total area (acres), overall hydrologic type, and estimated annual production (pounds per acre). Grazing capacity conveys estimated stock nights, based on allowable use scenarios. (5%, 25%, 35%). Annual production remaining is shown for % ecological change scenarios (no change, 10%, 20% change) and the inverse of allowable use.

Meadow	Camp ID (Md)	Elev. (ft)	Total Area (ac)	Hydro Type	Annual Production (lb./ac)	Annual Production Remaining (lb/ac) Based on % Change			Annual Production Remaining (lb/ac) Based on % Allowable Use			Stock Nights based on % Allowable Use		
						0%	10%	20%	0%	10%	20%	0%	10%	20%
Benson-NE	95 (3570)	7,595	0.43	Hydric	2,209	1,988	1,679	1,370	2,099	1,657	1,436	1	7	10
Benson-NW	(3561)	7,595	2.7	Hydric	2,132	1,919	1,620	1,322	2,025	1,599	1,386	9	43	60
Castle Camp	39 (3519)	8,784	5.55	Hydric	1,521	1,369	1,156	943	1,445	1,141	989	12	58	82
Cold Canyon-N	147 (3207n)	8,699	22.4	Mesic	1,571	1,414	1,194	974	1,492	1,178	1,021	41	206	289
Cold Cyn-Smokey Jack	(3207s)	8,669	39.2	Mesic	1,398	1,258	1,062	867	1,328	1,048	909	67	333	467
Dorothy-NW	100 (4694)	9,394	19.7	Mesic	1,637	1,473	1,244	1,015	1,555	1,228	1,064	24	122	171
Dorothy-W	101 (4702)	9,394	12.6	–	4,725	4,253	3,591	2,930	4,489	3,544	3,071	31	153	214
Grace Meadows	47 (4472)	8,666	43	Mesic	1,406	1,266	1,069	872	1,336	1,055	914	41	206	289
Hook Lake-N	97 (3414)	9,384	8.3	Hydric	1,218	1,096	925	755	1,157	913	792	13	67	94
Jose's Camp	88 (3915)	9,056	10.2	Mesic	1,598	1,438	1,214	991	1,518	1,198	1,039	16	80	112
Lake Vernon-SE	9 (3555)	6,570	9.26	Hydric	2,371	2,134	1,802	1,470	2,252	1,778	1,541	32	162	227
Lower Kerrick-S	41 (3875)	8,941	24.8	Xeric	978	880	744	607	929	734	636	27	137	192
Matterhorn-S	91 (3466)	8,426	26.4	Mesic	1,281	1,153	974	794	1,217	961	833	36	182	255
McCabe-N	78 (3457)	9,653	29.7	Mesic	1,506	1,356	1,145	934	1,431	1,130	979	62	310	434
Middle Kerrick	89 (4136)	9,151	156	–	1,454	1,309	1,105	902	1,381	1,091	945	269	1343	1881
Miller Lake-N	96 (3400)	9,456	8.6	Mesic	1,218	1,096	925	755	1,157	913	791	8	42	59

Table A-2 (continued). Estimated annual production remaining based on % change, % allowable use, and preliminary grazing capacities for meadows in the Tuolumne River watershed. Meadow site specific attributes include meadow names with directional suffix (N,E,W,S,NE,NW,SE,SW), Camp ID indicating commercial stock camp number, elevation, total area (acres), overall hydrologic type, and estimated annual production (pounds per acre). Grazing capacity conveys estimated stock nights, based on allowable use scenarios. (5%, 25%, 35%). Annual production remaining is shown for % ecological change scenarios (no change, 10%, 20% change) and the inverse of allowable use.

Meadow	Camp ID (Md)	Elev. (ft)	Total Area (ac)	Hydro Type	Annual Production (lb./ac)	Annual Production Remaining (lb/ac) Based on % Change			Annual Production Remaining (lb/ac) Based on % Allowable Use			Stock Nights based on % Allowable Use		
						0%	10%	20%	0%	10%	20%	0%	10%	20%
Miller Lake-S	(3342)	9,505	9.09	Xeric	952	857	723	590	904	714	619	5	25	35
Paradise-N	136 (2427n)	7,665	6.34	Mesic	2,182	1,963	1,658	1,353	2,072	1,636	1,418	21	106	149
Paradise-S	121 (2427s)	7,665	3.42	Hydric	1,993	1,794	1,515	1,236	1,894	1,495	1,296	10	52	73
Pate Valley-N	69 (3061)	4,389	1.57	Mesic	3,299	3,134	2,507	1,880	3,134	2,474	2,144	5	26	36
Rodgers Mdw.	94 (3331)	8,744	36.1	Mesic	1,473	1,399	1,119	840	1,399	1,105	957	50	248	347
Smedberg-S	92 (3501)	9,223	9.1	Hydric	1,213	1,092	922	752	1,153	910	789	10	50	70
Tilden Lake-N	46 (4321)	8,920	9.68	Mesic	1,608	1,527	1,222	916	1,527	1,206	1,045	20	101	141
Tilden Lake-NE	46 (4342)	8,920	9.66	Xeric	1,169	853	760	666	1,110	877	760	16	80	111
Tilden Lake-SE	85 (4145se)	8,908	3.82	Mesic	1,830	1,739	1,391	1,043	1,739	1,373	1,190	9	46	64
Tilden Lake-SW	46 (4145sw1)	8,908	1.72	Mesic	4,725	4,489	3,591	2,693	4,489	3,544	3,071	12	62	87
Tilden Lake-W	46 (4145w)	8,908	1.12	Mesic	1,829	1,738	1,390	1,043	1,738	1,372	1,189	2	8	11
Tim's Camp-N	132 (3869e)	7,695	4.62	Mesic	2,096	1,991	1,593	1,195	1,991	1,572	1,363	10	51	71
Tim's Camp-S	132 (3869w)	7,695	4.93	Mesic	2,199	2,089	1,671	1,254	2,089	1,649	1,429	12	58	81
Twin Lakes-S	32 (4413)	8,899	6.78	Mesic	1,376	1,307	1,046	784	1,307	1,032	894	8	38	53
Upper Kerrick-N	90 (4324n)	9,299	53	Mesic	1,309	1,244	995	746	1,244	982	851	58	288	403
Upper Kerrick-S	138 (4324s)	9,299	89.5	Mesic	1,363	1,295	1,036	777	1,295	1,022	886	136	681	953
Upper Lyell-N	61 (2040)	8,971	17.3	Mesic	1,124	1,067	854	640	1,067	843	730	26	131	184

Table A-2 (continued). Estimated annual production remaining based on % change, % allowable use, and preliminary grazing capacities for meadows in the Tuolumne River watershed. Meadow site specific attributes include meadow names with directional suffix (N,E,W,S,NE,NW,SE,SW), Camp ID indicating commercial stock camp number, elevation, total area (acres), overall hydrologic type, and estimated annual production (pounds per acre). Grazing capacity conveys estimated stock nights, based on allowable use scenarios. (5%, 25%, 35%). Annual production remaining is shown for % ecological change scenarios (no change, 10%, 20% change) and the inverse of allowable use.

Meadow	Camp ID (Md)	Elev. (ft)	Total Area (ac)	Hydro Type	Annual Production (lb./ac)	Annual Production Remaining (lb/ac) Based on % Change			Annual Production Remaining (lb/ac) Based on % Allowable Use			Stock Nights based on % Allowable Use		
						0%	10%	20%	0%	10%	20%	0%	10%	20%
Upper Lyell-S	84 (1987)	8,977	32.8	Mesic	1,386	1,317	1,054	790	1,317	1,040	901	63	313	438
Wilma Lake	65 (3945)	7,944	4.8	Hydric	1,969	1,772	1,497	1,221	1,871	1,477	1,280	12	62	87

Table A-3. Estimated annual production remaining based on % change, % allowable use, and preliminary grazing capacities for meadows in the Merced River watershed. Meadow site specific attributes include meadow names with directional suffix (N,E,W,S,NE,NW,SE,SW), Camp ID indicating commercial stock camp number, elevation, total area (acres), overall hydrologic type, and estimated annual production (pounds per acre). Grazing capacity conveys estimated stock nights, based on allowable use scenarios. (5%, 25%, 35%). Annual production remaining is shown for % ecological change scenarios (no change, 10%, 20% change) and the inverse of allowable use.

Meadow	Camp ID (Md)	Elev. (ft)	Total Area (ac)	Hydro Type	Annual Production (lb./ac)	Annual Production Remaining (lb/ac) Based on % Change			Annual Production Remaining (lb/ac) Based on % Allowable Use			Stock Nights based on % Allowable Use		
						0%	10%	20%	0%	10%	20%	0%	10%	20%
Babcock-N	54 (1754)	8,902	10.7	Mesic	1,614	1,533	1,227	920	1,533	1,210	1,049	18	89	124
Doc Moyle's-E	130 (1487)	9,332	11.8	Hydric	1,265	1,139	961	784	1,202	949	822	22	109	152
Doc Moyle's-W	130 (1489)	9,302	4.23	Hydric	1,467	1,320	1,115	909	1,393	1,100	953	10	48	67
Emeric Lake	34 (1888)	9,345	22.1	Mesic	1,187	1,128	902	677	1,128	890	772	23	114	159
Long Meadow-N	79 (2147n)	9,607	29.5	Mesic	1,443	1,371	1,097	823	1,371	1,082	938	43	214	299
Long Meadow-S	79 (2147s)	9,607	16.7	Mesic	1,313	1,248	998	749	1,248	985	854	29	144	201
Merced Lake-E	145 (1163e)	7,305	1.55	Hydric	2,088	1,880	1,587	1,295	1,984	1,566	1,357	5	25	35

Table A-3 (continued). Estimated annual production remaining based on % change, % allowable use, and preliminary grazing capacities for meadows in the Merced River watershed. Meadow site specific attributes include meadow names with directional suffix (N,E,W,S,NE,NW,SE,SW), Camp ID indicating commercial stock camp number, elevation, total area (acres), overall hydrologic type, and estimated annual production (pounds per acre). Grazing capacity conveys estimated stock nights, based on allowable use scenarios. (5%, 25%, 35%). Annual production remaining is shown for % ecological change scenarios (no change, 10%, 20% change) and the inverse of allowable use.

Meadow	Camp ID (Md)	Elev. (ft)	Total Area (ac)	Hydro Type	Annual Production (lb./ac)	Annual Production Remaining (lb/ac) Based on % Change			Annual Production Remaining (lb/ac) Based on % Allowable Use			Stock Nights based on % Allowable Use		
						0%	10%	20%	0%	10%	20%	0%	10%	20%
Merced Lake-Shore	145 (1665)	7,200	6.19	Hydric	2,170	1,953	1,649	1,346	2,062	1,628	1,411	19	93	131
Merced Lake-W	145 (1163w)	7,268	2.54	Hydric	2,105	1,895	1,600	1,305	2,000	1,579	1,368	7	35	49
Triple Peak-S	131 (1164s)	9,059	4.85	Mesic	1,130	1,073	859	644	1,073	847	734	6	32	45
Turner Lake	133 (942)	9,542	8.24	Mesic	1,527	1,451	1,161	870	1,451	1,145	993	8	39	55
Washburn Lake	35 (1507)	7,613	1.95	Hydric	1,976	1,779	1,502	1,225	1,877	1,482	1,285	6	30	42

Appendix B. Draft Residual Biomass Monitoring Protocol

Introduction

The comparative yield approach is a residual biomass (RB) sampling method described by Haydock and Shaw (1975) and is well suited for estimating above-ground biomass in grasslands. The advantages to this method are that there is negligible destructive sampling, structures (grazing exclusion cages) are not required and sampling is time-efficient (Coulloudon et al. 1999). SEKI adapted this methodology (Haultain 2008) and integrated it into their Wilderness Stewardship Plan Meadow Monitoring Strategy (NPS, 2015). Several years of monitoring have shown this method to be effective, efficient and repeatable. Adoption of the same methodology at YOSE as SEKI allows us to maintain consistency within the region and will promote future comparisons.

Monitoring Objectives

The primary goal of RB monitoring at YOSE is to obtain an estimate of how much grazing has occurred at sites with pack stock use. RB refers to the amount of forage remaining after one growing season or ungrazed meadows, specifically, RB is the amount of above ground plant material present after the season of grazing. This monitoring also can contribute to our understanding of plant productivity, available forage, and grazing capacity in varied meadow environments. In remote areas, such as wilderness meadows, where the timing and duration of grazing is unpredictable and extensive botanical surveys are costly, monitoring of RB on ungrazed and grazed sites provides an efficient proxy measure of productivity and utilization (NPS, 2015).

Location and timing of sampling

Sampling occurs at stock use meadows with priority given to sites with the highest use level as a percentage of preliminary capacity (actual stock use nights/estimated capacity). At each site, a core (grazed) and reference (ungrazed) plot are established within the meadow. Core plots are subjectively located within the area of greatest grazing impact on the assumption that if the impacts there are considered acceptable, then the rest of the meadow will also fall within management standards (Schelz 1996). Whenever possible, ungrazed reference sites are located in areas that are both biotically and abiotically comparable with grazed core plots, within the same meadow (NPS, 2015).

Meadows are sampled in September in an effort to measure RB post-utilization by stock animals. For sites approaching estimated capacity before the end of the use season, RB monitoring can occur any time after peak production, which is typically in late July during an average water year. If production has not yet reached its peak, RB results must be interpreted with caution. In such cases, meadow condition monitoring would be informative. In all cases, meadow condition monitoring in conjunction with RB would best aid management.

Reference quadrat establishment

This method relies on relating a visual, or ocular, estimate of biomass to measurements of biomass. Established reference quadrats from which vegetation will be clipped and weighed for the purpose of establishing a relationship between biomass and ocular biomass estimation. Locate five reference 30 cm x 30 cm quadrats ranging from relatively low to high production yield. Place the first quadrat, reference 1, in a low-yielding area that represents the low yielding situations commonly encountered

on the site (avoid bare or nearly bare quadrats). Next, determine reference 5 by placing a quadrat on a high-yielding area, excluding unusually dense patches of vegetation that would have a rare chance of being sampled. After selecting references 1 and 5, locate reference 3 by placing a frame in an area considered to have a yield halfway between references 1 and 5. Finally, locate reference quadrats 2 and 4 similarly by selecting the midpoint yield between references 1 and 3 and references 3 and 5, respectively.

For each of the five quadrats, clip vegetation to one cm and weigh it. Plot the clipped reference quadrat weights against their ranking. If the relationship in not approximately linear, repeat the process by clipping additional quadrats until the weights of the five reference quadrats are approximately linear and observers are confident in their ability to rank quadrats relative to one of the five references. Before clipping, establish plots of the same apparent rank to serve as means of ongoing calibration for the next step, *ocular estimation of biomass.*

Ocular estimation of biomass

Within each plot, place transects up to 100 m long, five meters apart, as needed to obtain a desired sample size. Place quadrats at each meter mark along transects and score each biomass yield with a ranking relative to the reference quadrats. Intermediate scores to the half rank, such as 3.5 or 2.5, are permissible. If a quadrat greatly exceeded the yield of reference 5, you may assigned a higher rank. For example, if a quadrat was 50% greater than reference 5, record a rank of 7. If more than 5% of the quadrats were ranked above 5, references not properly. In this case, start over with reference quadrat selection.

Biomass calculation

To calibrate the rankings, clip and weigh *at least* one and optimally 2 quadrats representing each reference. Collected all standing above-ground biomass by clipping all herbaceous vegetation rooted in the quadrat to 1 cm and collecting leaves (only) from woody species. Do not collect litter, which is defined here as plant material no longer attached to the plant. Biomass collection may contain senesced portions of plants that may be from this year's production or that of a prior year. Some plant parts may become detached but still remain standing within bunch grasses. For practicality, these will be part of the clipping. The imperfect differentiation between this year's production and last year's will introduce some uncertainty into the measurement. To obtain mass, weigh biomass samples, dry in a drying oven and then reweigh. Generate a calibration curve to relate the ocular ranking with the measured dry mass.

Data analysis

The **predicted value of residual biomass** is calculated using a calibration curve constructed by simple linear regression of the dry weights of the clipped quadrats against the ranking scale (Equations 1 - 3).

Equation 1: $b = \frac{\sum(x_c - \bar{x}_c)(y - \bar{y})}{\sum(x_c - \bar{x}_c)^2}$

Equation 2: $a = \bar{y} - b\bar{x}_c$

Equation 3: $\hat{Y} = a + b\bar{x}_o$

Where:

$x_c = biomass\ rank\ for\ calibration$

$x_o = biomass\ rank\ for\ occular\ estimates$

$y = clipped\ vegetation\ biomass$

$\hat{Y} = predicted\ biomass\ for\ the\ site$

The **variance of the regression, $S^2_{y,x}$** is calculated according to equation 4.

Equation 4: $s^2_{y,x} = \frac{\sum(y-\bar{y})^2 - \frac{(\sum(x_c-\bar{x}_c)(y-\bar{y}))^2}{\sum(x_c-\bar{x}_c)^2}}{n-2}$

The **predicted mean yield for a plot**, $\hat{\bar{y}}$, for n' ratings is read off at the mean of the ratings, $\bar{x}'$:

Equation 5: $\hat{\bar{y}} = y + b\ (x' - \bar{x})$

The **variance of the mean yield**, $\mathrm{Var}(\hat{\bar{y}})$, is calculated following equation 2 from Haydock and Shaw (1975), adopted here:

Equation 6: $\mathrm{Var}(\hat{\bar{y}}) = s^2_{yx} \left\{\frac{1}{n} + \left(\frac{s^2_{\bar{x}}}{n'} + (A - \bar{X})^2\right)/B\right\} + b^2 \frac{s^2_{\bar{x}}}{n'} 0$

Where:

$n =$ number of points in the scale

$n' =$ number of ocular ratings

$A =$ the mean of the x's$(\bar{x}) = \frac{(n+1)}{2}$ for integer ratings .... $= 6/2 = 3$

$B =$ corrected sum of squares for the n ratings $= \frac{n(n+1)(n-1)}{12}$ ... $= 5(6)(4)/12 = 10$

$s^2_{\bar{x}} = \frac{1}{n-1}\sum_{i=1}^{n'}(X_i - \bar{X})^2$ = the variance of ocular ratings (along the x-axis of the calibration plot)

Where $X =$ the mean of all possible ratings within a site

$s^2_{yx} =$ the residual mean square for the calibration line

= Equation 4, displayed above.

$b =$ estimate of the population regression coefficient (slope of the line)

The 95% confidence interval is calculated from the variance of the mean yield ($\mathrm{Var}(\hat{\bar{y}})$), n and n':

Equation 7: $CI = \overline{X} \pm \frac{96 * \mathrm{t} \sqrt{\mathrm{Var}(\widehat{y})} * (n-2)}{\mathrm{n} * (\mathrm{n}-3)} + \frac{b^2 * s_x^2}{n\prime}$

Data reporting

Site-specific mean and 95% confidence intervals (95% CI) are reported. To calculate an estimate of the residual biomass of the grazed site relative to the reference site: RB_{grazed} / RB_{ref} * 100. An estimate of percent utilization can be also be calculated by (RB_{ref} - RB_{grazed})/ RB_{ref} * 100.

On an annual basis, compare RB at the grazed site to that of its reference site. The results can be viewed in the context of how much use the site received that year based on the stock reporting data. When several years of data have been collected for a site, look at data over time for trends.

Appendix C. A Process for Including Understory Grazing in Site Capacity

While meadows represent the bulk of forage availability at pack stock camp destinations, anecdotal evidence from administrative packers, our field observations and preliminary data from a park pack stock behavior study suggest that pack stock also forage in the forest understory ("understory" hereafter). The amount of understory grazing varies greatly from none—where meadow is the only habitat available—to exclusive—where a site is located with lush forest understory vegetation and no meadow habitat (such as in Virginia Canyon). The model we developed for meadow grazing capacity emerged from vegetation data and previous research specific to meadow ecosystems. While we could apply the same conceptual model to derive understory capacity, we lack input for some metrics. Namely, we do not have a base of literature nor data needed to estimate productivity. Despite this, managers have a desire to include understory forage because at some sites it represents a sizable portion of the grazing area at many sites. Thus, including understory forage could better estimate capacity at these sites than meadow forage alone.

In the absence of data for forest understory productivity in the Sierra Nevada montane and subalpine, we suggest a two-phase approach. First, prior to a field visit, the total grazing area can be delineated and the forest understory production could be roughly estimated by professional judgment. That is to say, ecologists and managers with in-depth site knowledge could estimate the perceived forage available in the understory relative to the adjacent meadow. This should only be used as a placeholder until the second phase can be achieved in the field. The second phase is to estimate productivity on-site by applying the same residual biomass protocol we developed for monitoring grazing. This method can be implemented in less than a day and would yield an actual estimate rather than modeled productivity.

A-priori productivity estimation

The principle upon which this can work is to visually compare standing aboveground biomass of herbaceous vegetation between meadow and forest understory. Productivity in herbaceous vegetation is this year's growth. Thus visual comparison of density at least gets us at a qualitative representation of understory growth.

1) Delineate grazing area
2) Calculate area of understory grazing area
3) Visually compare the forage available in the understory relative to the meadow area (for which we have already calculated productivity) and represent as a percentage. This would take into account 1. the density of vegetation and 2. its composition (graminoids, forbs) and 3. basal area of trees, subshrubs shrubs and unvegetated ground (these would be excluded).
    a) If no meadow is adjacent for comparison, one would need to relate it to a similar known area
4) Calculate understory productivity by multiplying area by the productivity ratio in step 3.
5) Plan for a field visit to measure productivity.

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525