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Meadows in the Sierra Nevada of California: state of knowledge

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Retrieval Terms: meadow classification, meadow productivity, meadow management problems, meadow conditions and trends, mountain meadows, Sierra Nevada, California

Management of mountain meadows in the Sierra Nevada of California to maintain or restore geologic and biologic stability, while providing amenities, is a common goal of managers and users. Meadows are wetlands or semiwetlands supporting a cover of emergent hydrophytes and mesophytes and dry herblands of the subalpine and alpine zones. These meadows are concentrated use points which, once destroyed, are not quickly replaced.

American Indians had little adverse effect on meadows of the Sierra Nevada. Moderate to light grazing by native animals was probably common. Ranching—the first industry in California—expanded as the Spanish missions became established. Cattle were valued for their hides and tallow. Sheep numbers remained low during the Spanish and Mexican periods. Then, the gold rush of 1849 ushered in a shift toward beef production, and large numbers of sheep as well as cattle were used for meat. As mining decreased, sheep ranching for wool increased; by the 1870's, California led the nation in wool production.

Summer grazing in the mountains began during droughts in the 1860's and 1870's. Sheep grazing soon became the dominant use of the meadows. Today, however, cattle have all but replaced sheep in the National Forests.

Overgrazing of meadows in the late 1800's and early 1900's resulted in widespread deterioration. Early attempts by the National Parks and Forest Reserves to regulate grazing were mostly fruitless. Effective control in the Forest Reserves began when grazing permits were required by the Forest Service, U.S. Department of Agriculture. Meadows have improved, but local abuse can still be found.

Recent concern over the conditions of meadows has resulted in studies by the Forest Service, U.S. Department of Agriculture; the National Park Service, U.S. Department of the Interior; and colleges and universities. Although much is yet to be learned, a body of technical knowledge focused on meadows of the Sierra Nevada is now available, serving as a source for guides to meadow management.

The basic unit for meadow classification is meadow site—an area of homogeneous species composition having a general species composition different from that of adjacent areas. Meadow sites are grouped by physiographic properties; hydrologic or major floristic properties, or both; and close floristic similarity into meadow subformations, meadow series, and meadow site associations.

Conditions favorable to accumulating fine-textured materials and establishing a shallow water table are prerequisite to meadow development. A characteristic condition is a favorable drainage area-to-slope relationship: large drainage areas with steep stream gradients do not contain meadows.

True pedogenic soil horizons are rarely found in soils of Sierra Nevadan meadows. Four main depositional units are present: pre-Holocene alluvium; a buried soil; stratified sand; and interstratified layers of grus, peat, and sandy loam. Layers of known age in the fourth unit indicate a soil accumulation rate of about 1.8 inches (4.7 cm) per century.

Herbage produced on Sierra Nevadan meadows in California ranges from less than 300 lb per acre (336 kg/ ha) to over 4,000 lb per acre (4,484 kg/ha). High-elevation meadows in poor condition generally produce less herbage than low-elevation meadows in better condition. Mesic meadows are usually more productive—although production varies more from year-to-year—than meadows at the extremes of the moisture gradient.

Meadows respond to fertilization. Nitrogen can increase yields dramatically. Phosphorus, however, has been more consistent in increasing yields. Usually, nitrogen favors grasses and grasslikes and phosphorus favors legumes.

Poor sites respond proportionally more to fertilization than good sites.

Carbohydrate storage cycles of meadow species appear to follow the natural pattern: gradual decline in winter, sharp decline at the start of spring growth, and buildup during maturation. Defoliation in early spring or at flowering is detrimental to many meadow species. Late defoliation, preventing carbohydrate accumulation in developing shoots, may damage some species.

The need to leave some herbage ungrazed has long been recognized. For meadow sites in the Sierra Nevada, the rule of "graze half, leave half" is unsafe. Use of very wet or dry meadow sites should not exceed 35 percent; 45 percent use of more mesic sites is satisfactory.

Some of the more common conditions that can adversely affect meadows are:

- Defoliation of meadow plants. If too severe, too frequent, and at the wrong time, defoliation can deteriorate meadows. When properly coordinated with the requirements for growth and reproduction of a given species, grazing does not usually harm the ability of that species to produce herbage and survive.
- Preferential grazing. This major cause of range deterioration is caused when animals and humans use specific areas about the same time each season, and a treatment that favors one species may eliminate another from the stand. Breaking the use pattern by modifying frequency and timing of use is the only effective way to counter the harmful effects of preferential grazing.
- Trampling. This condition compacts the soil and cuts the sod. Even when the sod is not cut, trampling may lower the pH of the soil solution. Damage occurs when the stress applied exceeds the resistance of the soil to deformation. The most obvious signs of trampling damage are holes punched in meadows and multiple trails.
- Redistribution of nutrients. Nutrients become concentrated in certain areas. Livestock redistribute nutrients within and among meadows and closely associated ecosystems. People redistribute nutrients from distant ecosystems to meadows. Short-term effects of nutrient redistribution are evident as dung pats and urine spots. Long-term effects gradually become evident as changes in species composition.
- Rodent activities. Although rodent activities can markedly affect species composition and may induce erosion by channeling water, cultivation of the soil by rodents is beneficial. Overgrazing emphasizes the negative effects of rodents, but rodents inflict little harm to meadows in good condition.
- Invasion by lodgepole pine. This autogenic process is both aided and hindered by livestock disturbance. A mineral seedbed in a well-lit, warm, moist environment favors lodgepole pine seed germination. Early snowmelt and long snow-free periods favor seedling establishment. Deep, long-lasting snowpacks favor young trees.
- Fire. A critical element of meadow history and maintenance is fire. Major fires in their watersheds affect Sierra Nevadan meadows. Sediment depositions from major fires are evidenced by charcoal in many meadow soils. Light fires, which burn only the current growth, do little harm to trees or meadows. Hot fires, which burn mulch and peat, may kill well-established trees and greatly damage meadows.
- Erosion. This condition occurs naturally and as a result of overgrazing. Maintaining or restoring its hydrologic characteristics is essential to maintaining or restoring a meadow. Erosion control in meadows is designed to check gully progress, refill gullies, and restore the water tables. Good erosion control includes assessing meadow stability and causes of erosion, grazing management, building properly designed structures, planting appropriate vegetation, and controlling rodents.

Vegetal cover, including litter, is the characteristic most used to indicate soil condition. Species composition and ecological position are preferred to indicate vegetative condition. Meadow sites in excellent condition have a dense, even herbaceous cover (about 100 percent) and are composed mostly of decreaser species.

How a meadow site measures up is indicated by its condition. How management measures up is indicated by trend in condition. Management of meadows must be based on trust, agreement, and commitment of managers and users. The products to be produced from a given area and the actions needed to produce them must be decided. Good range management must be practiced and must include proper use, restoration efforts, monitoring condition trend, and user education.

INTRODUCTION

Meadows of the Sierra Nevada of California provide the bulk of forage on many grazing allotments, park preserves, and wilderness areas. And yet they comprise only 10 percent of the land area there. An abundance of rodents, insects, and reptiles provides food for many species. Ecotones—timbered edges—between meadows and forests contain many other animal species. Mountain meadows, therefore, are valuable for the production of livestock products, the maintenance of wildlife populations, and the grazing of recreation stock. Furthermore, they provide scenic vistas, and their timbered edges and grass carpets are favored campsites of forest, park, and wilderness visitors. Meadows filter sediment from water flowing from surrounding slopes, and in so doing provide clean water for human use and for maintaining suitable fish habitat in streams and lakes.

The diversity and richness of habitats available in meadows and their associated vegetations draws people as well as animals. Repeated high or untimely concentrations of use can cause damage to the resource. Interest in maintaining existing meadows, restoring deteriorated meadows, and managing all meadows properly is increasing. This interest is expressed in movements for more wilderness areas, and in concerns about wildlife, fish, and the quality of life. All these developments have led to the need to know more about mountain meadows.

This state-of-knowledge report summarizes available information about the meadows of the Sierra Nevada of California—how meadows are classified, the development of meadow soils, the productivity of meadows, problems in management, and ways to evaluate range conditions and trends.

BRIEF HISTORY

Livestock grazing and meadows of the Sierra Nevada have a common history of more than 100 years. And that history is well documented (Burcham 1957, Vankat 1970). Before the arrival of Spanish and Mexican colonists, only native grazing animals were present in California. Deer, elk, pronghorn antelope, and bighorn sheep were the only large ungulates. Except locally, deer, elk and antelope were not abundant in the Sierra Nevada. Meadows of the Sierra Nevada, therefore, probably existed under a regime of moderate or light grazing—mainly by deer, bighorn sheep, and small mammals.

American Indians of the area were hunters and gatherers. Their main influence on the native vegetation was through use of fire as an aid in hunting game. They did not much influence meadow vegetation. Use of fire by American Indians may, in some instances, however, have served to keep out invading trees and, thereby, an open meadow condition was maintained.

Grazing by Livestock

Cattle ranching was the first industry in California. It started in 1769, at San Diego, with about 200 head. As missions were established, the cattle industry expanded. At their zenith, the missions each had several ranches—some for cattle and others for sheep and other livestock, and claimed about one-sixth of present-day California. In addition to mission livestock, individually owned herds of livestock on ranches and great numbers of feral stock grazed the land.

Cattle were valued chiefly for their hides and tallow during the Spanish and Mexican periods (1769 to 1850). Emphasis toward meat production changed markedly as an outgrowth of the gold rush. To help meet the demand, cattle numbers were increased from about 250,000 in 1850 to about 1 million in 1860. A shift in cattle population centers also occurred and about 40 percent were located in the Sacramento and San Joaquin valleys. By 1862, the number of cattle in the State was about 3 million head.

The first flock of sheep was brought to San Diego in 1770. In 1783, the sheep numbered 188 head. By 1831, however, sheep at the missions numbered 153,455 head. Although sheep were important to the Spanish and Mexican economies of California, intensive labor requirements and predation problems tended to keep the flocks at minimum levels.

With the gold rush, local sheep were used to feed the miners, and large numbers of sheep were imported. Some 551,000 head, for example, were brought in from New Mexico from 1852 to 1860. As the mining boom declined, attention was turned from mutton production to wool production. Sheep numbers peaked in the 1870's with about 6.4 million head and, for a time, California led the Nation in sheep and wool production.

Damage to Resources

Forage needs precipitated the period of overstocking and overgrazing mountain meadows. High precipitation and floods in 1861-62 were followed by drought in 1862-63 and 1863-64. It was during these and subsequent drought periods, such as 1876-77, that the practice of summer grazing in the mountains began.

Cattle may have grazed the mountain meadows as early as 1861. In 1864, some 4,000 head were reported on the Big Meadow Plateau (King 1902), which is part of the Sequoia National Forest.

Sheep grazing rapidly became the dominant use of the meadows. Tales of damage to resources were to become legendary. Evidently, few, if any, passes between meadows in the Sierra Nevada were not crossed by flocks in search of greener pasture. Sheep grazing was blamed for reduced wildlife populations. Not only did sheep consume forage, which would have been available for wildlife, but diseases carried by sheep were transmitted to wildlife, particularly bighorn sheep (*Ovis canadensis*). Also, herders took a toll of native predators in defense of their flocks.

Early efforts by the National Parks and Forest Reserves to regulate grazing were mostly fruitless. Within the National Parks, control was gradually gained, and the period of heavy sheep use was over by 1900. In the Forest Reserves, however, effective control did not begin until after the National Forest System in the Department of Agriculture was established in 1905-06 and grazing permits were required.

After the peak period, sheep grazing declined in significance. And today, cattle have all but replaced sheep in the National Forests. Except for a few situations associated with private holdings, grazing for livestock production is not allowed in the National Parks. From the 1920's into the 1970's, grazing for cattle production generally declined on the National Forests. That trend has now reversed in response to need and the mandate for public land managers to increase red meat production. Nevertheless, pressure from special interest groups to reduce or to eliminate livestock grazing as a forest use continues.

Although grazing of meadows for livestock production has declined, other uses have increased. The large pack trips of the early 1900's, with as many as 100 head of stock, are gone. But considerable horse and mule grazing still occurs, and in some areas is considered a problem. Use of meadows and meadow edges by backpackers has dramatically increased. Evidence of people damage to meadows and surrounding vegetation is increasing. Such damage is observed on bands of meadow around high-elevation lakes where trampling by fishermen has made trails.

Abuse has so damaged the meadow resource that general, widespread deterioration of mountain meadows in California has been indicated (Bailey and Connaughton 1936). For Sequoia and Kings Canyon National Parks, meadow deterioration has been well documented (Bennett 1965, Sharsmith 1959, Sumner 1941, Vankat 1970). Nevertheless, little effort was expended to study and understand meadows of the Sierra Nevada until the 1960's.

In June 1965, the Pacific Southwest Forest and Range Experiment Station and Sequoia and Kings Canyon National Parks started a joint meadow research program with a study of Funston Meadow on the Kern River (Hubbard and others 1965). After completing that study, they turned their attention to meadows of the Rock Creek drainage southwest of Mount Whitney in Sequoia National Park. Work was done by the University of California under a cooperative agreement with the Station, and was funded by the National Park Service. That research continued until 1972.

Since then, the Station has continued to study mountain meadows through its Range Research Work Unit, headquartered in Fresno. The National Park Service has continued to support meadow research by universities and individuals. The Sierra Club sponsored a wilderness impact study (Stanley and others 1979).

CLASSIFICATION OF MEADOWS

Meadows in the Sierra Nevada of California are wetlands or semiwetlands supporting a cover of emergent hydrophytes and mesophytes and dry herbland of the subalpine and alpine zones (Ratliff 1982). They may be classified in a number of ways, including by wetness, range type, altitude, physiography, vegetation, and sites. A single classification is usually applied to an entire meadow, with little if any recognition given to different sites. Wet, moist, or dry meadows can be further classified, however, by range type, which indicates the vegetation type and dominant species (U.S. Dep. Agric., Forest Serv. 1969).

Meadows of Gaylor Lake Basin in Yosemite National Park were classed as wet, moist, and dry (Klikoff 1965). The wet type is the shorthair (*Calamagrostis breweri*) type of Sumner (1941), and the dry type corresponds to the short-hair sedge (*Carex exserta*) type described by Bennett (1965). Similarly, in Yosemite Valley, meadow sites were classified in relation to a drainage gradient (Heady and Zinke 1978). Sedges (*Carex* species) decreased in percentage of species composition from depression bottoms to sites excessively drained. Grasses generally increased in the composition, becoming more prevalent than sedges on the better drained sites.

Kings Canyon National Park meadows have been classified into wet, woodland, and shorthair types (Sumner 1941). The wet meadow type consists of sphagnum, coarse-leaved sedge, fine-leaved sedge, and grass subtypes, and division of the woodland meadows into broad-leaved and coniferous subtypes was suggested (Bennett 1965).

Meadows have been classed as montane (midaltitudinal) and subalpine and alpine (high altitudinal) (Sharsmith

1959). Three classes—level meadows, hanging meadows, and stringer meadows—have been used along Rock Creek in Sequoia National Park (Harkin and Schultz 1967).

A physiographic classification with two classes in the top category was proposed (Benedict 1981). The classes were meadows with vegetated margins (type 1) and meadows with sandy margins (type 2). A lower level category contained topographic classes (basin, slope, and stream), and within these were classes of a geological category. The classification, like most others, dealt with meadows as the individual units to be classified.

At the Blodgett Forest Research Station in California, rush (*Juncus*), forb, and dry grass meadow vegetation classes were identified (Kosco 1980). A fourth class contained rushes, sedges, grasses, and forbs in about equal proportions.

Sites within meadows are considered individual units (Ratliff 1979, 1982). Fourteen meadow site classes are described on the basis of current vegetation. The classes are viewed as approximations to series within meadow subformations (Hall 1979).

In developing the classification scheme provided in this guide, I have drawn from the authors cited, classifications of meadows from other areas, and my experience. The scheme follows the basic concepts of Hall (1979). The basic units of classification are meadow sites. I have defined a meadow site as an area of meadow with a homogeneous species composition and a general species composition different from that of adjacent areas (Ratliff 1979). Major categories of the system are subformations, series, and associations.

Although the classification is still largely heuristic, I believe it will serve as a vehicle for communication between land managers and between managers and researchers.

Subformations

A subformation is an aggregation of series with a given physiognomic character. Meadow sites are classified by subformations which, in turn, are divided into series and associations. The physiography of a meadow defines its subformation. Categories used to describe the physiography are margin type and topographic position (Benedict 1981) and plant belt (Sharsmith 1959). Codes for the classes here and in following sections are provided for use on maps, data records, or where more detailed descriptions are not required:

Category:	Class	Code
Margin type	Vegetated	A
	Sandy	B
Plant belt	Subalpine	A
	Montane	B
Topography	Basin	A
	Slope	B
	Stream	C

With this system, 12 broad meadow subformations are possible. If we use the letter codes above, the six subformations with vegetated margins are: A-A-A (vegetated margin-subalpine-basin), A-A-B (vegetated margin-subalpine-slope), A-A-C (vegetated margin-subalpine-stream), A-B-A (vegetated margin-montane-basin), A-B-B (vegetated margin-montane-slope), and A-B-C (vegetated margin-montane-stream). The six subformations with sandy margins are the same as above, except that the first code will be a B, meaning sandy margin.

Vegetated margin meadows have a herbaceous cover that extends unbroken, except by rocks or trees to or into the timbered slopes. Sandy margin meadows have a zone of sand and gravel that separates areas of meadow from each other or from the timbered slopes. The montane and subalpine plant belts in the Sierra Nevada extend from lower elevations of 1,968-4,921 ft (600-1,500 m) to upper elevations of 9,842-11,483 ft (3,000-3,500 m) (Rundel and others 1977). They include lodgepole pine forest as part of the "upper montane" zone. I include the upper reaches of lodgepole pine forest in the subalpine, however, and so I more closely follow Storer and Usinger (1963). True alpine meadows have not been included in my studies and, therefore, the alpine belt is not included at this time. Basin meadows are formed in old lakes or behind terminal moraines. Streams passing through them will usually have distinct meanders. Slope meadows are formed below seeps or springs, and they may or may not be strongly sloping. Stream meadows, formed along either permanent or intermittent streams, are commonly called stringer meadows.

Series

A series as used here is a group or cluster of meadow sites that have the same kind of margins, occur in the same plant belt, occupy equivalent topographic positions, and possess similar vegetative and hydrologic properties. Within subformations, series can be defined according to hydrological properties and vegetation. I view the hydrologic and vegetative categories as being on the same level of abstraction. Either alone or combined they may be considered to define meadow series.

Hydrology

There are 72 theoretical hydrologic series (2 by 2 by 3 by 6).

The six hydrologic classes are:

• (A) raised-convex—a site (with an enclosed open water surface) occuring [sic] as a mound above the surrounding meadow.

• (B) hanging—a site that occurs on a slope and is constantly watered by flows from springs and seeps.

• (C) normal—a site that obtains water from the water table, is recharged by precipitation, and may dry in the surface during summer.

- (D) lotic—a site that is characterized by moving water and constantly watered by flows from upstream.
- (E) xeric—a site that occurs on a slope or bench, is seasonally recharged by precipitation, and becomes quite dry during summer.
- (F) sunken—concave-a site that is characterized by ponded water and is seasonally recharged by flows from upstream.

The hydrologic category has its basis in an intuitive consideration of meadow hydrology and an adaptation of the classification described by Gosselink and Turner (1978).

Hydrology of a meadow or meadow site is the variable controlling potential vegetation. Chemistry of the incoming water affects the nutrient availability and cycling. Velocity of the flows affects the particle size of materials transported to and from a meadow. Seasonality and reliability of the flows largely determine the vegetational stability. Alteration of a meadow's hydrology will change its species composition. Only by maintaining or reestablishing the natural hydrology of a meadow or meadow site is it possible to maintain or recover its potential or stable-state vegetation.

The concept of a hydrologic classification of meadows or meadow sites is certainly not new (Hall 1979; Harkin and Schultz 1967; Heady and Zinke 1978; Hormay 1943; Klikoff 1965; Sumner 1941; U.S. Dep. Agric., Forest Serv. 1969). The classification of Gosselink and Turner (1978), however, is probably the first to use the dynamics of meadow hydrology for classification. They used four groups of characteristics to describe the classes: water inputs, type of flow, water outputs, and hydro-pulse. I have added xero-pulse to their list, added or removed some individual characteristics, and revised the classes to fit conditions of the Sierra Nevada. Also, I have attempted to judge the significance of each characteristic to each hydrologic class.

Input Flows—The sources of water for meadow sites are input flows (*table 1*). Capillarity is considered to be a major source for the raised-convex (bog) class (Gosselink and Turner 1978). Although capillary water is needed for sites of that class in the Sierra Nevada, hydrostatic water is of equal or greater need. Development of subsurface aquifers within a meadow system has been discussed (Leonard and others 1969). Water carried in a layer of coarse sediment between layers of peat may surface downslope. At that point, peat deposits may build up, restricting the flow of water. A raised mound with an open water surface above the water table of the surrounding meadow develops to give a site of the raised-convex class. Such aquifers also supply water to other parts of a meadow.

Hydrostatic flows from springs and seeps are the main water sources for hanging meadow sites. The water is either forced to surface by bedrock or emerges from the base of lateral moraines (Benedict 1981). On peat, much of the water movement is at or near the surface (Heinselman 1970). Down slope from the water source, therefore, the older more compressed peat may act to prevent downward flow of the water. The peat layers of aquifers are less porous than the coarse material (Leonard and others 1969). And, in my studies of the Sierra Nevadan meadows, relatively dry soil frequently has been found below a water saturated surface, especially below a seep or spring.

Precipitation is necessary for all meadow sites, but more directly so to some than to others. Normal meadow sites obtain water mainly by capillarity from the water table. They depend, however, on precipitation, upslope flows, or both, to recharge the upper soil layers with water. Xeric

Table 1—*Hydrodynamic classification of meadow sites in the Sierra Nevada, California*[1]

Classification variables	Hydrologic class: Raised convex	Hanging	Normal	Lotic	Xeric	Sunken concave
Input flows						
Capillary	*		*			
Hydrostatic	*	*		o		
Precipitation	o	+	+	+	*	+
Upstream or upslope			+	*	+	*
Internal flows						
Capillary	*	+	+			
Subsurface	*	*	*	*	*	*
Surface sheet		+	o	*	*	+
Surface rill		o	+		+	
Output flows						
Evapotranspiration	*	*		*	*	*
Percolation	o		*		+	o
Downstream runoff		*	*	*	*	
Hydro-pulse			o			
Seasonal				*	*	*
Seasonal/ constant	*	*	*	+		
Xero-pulse						
Seasonal			*		*	*
None	*	*		*		

[1]Key: o = minor importance, + = moderate importance, and * = major importance.

sites are recharged mainly by precipitation, but upslope flows may influence them. Xeric sites occur on slopes and benches and may be subjected to inundation during snowmelt from barren, rocky areas above.

Lotic and sunken-concave meadow sites depend more upon upstream water than on-site precipitation. In the Sierra Nevada, such sites are usually found in topographic basins or flooded areas along streams. Lotic sites are characterized by moving water. Velocity and depth of water during spring runoff affect their species compositions. Sunken-concave sites are characterized by ponded water. Their species compositions are influenced by the depth of ponding after spring runoff.

Internal Flows—Those flows, occurring once water reaches a site, are internal flows. Subsurface flows occur on all sites. Maintaining the water table by subsurface flows is of major importance to all meadow sites. Capillary rise of water is important to both the raised-convex and the hanging meadow classes. In an invasion of "bog forest" by sphagnum moss, the sphagnum advanced uphill into climax forest to a height of 15 ft (4.5 m) above the bog (Cooper 1912). Water held in the capillary pores of sphagnum peat is necessary for such a phenomenon to occur. Mosses of some kind are usually found in hanging and raised-convex meadow sites.

The surface sheet type of internal flow is represented by surface water of variable depth covering the entire site. The water is usually moving. This movement is especially apparent in normal, lotic, and xeric meadow sites. Except for overflow, water is stagnant on sunken-concave sites. Water depth at flowering time is a key variable controlling species composition (Hormay 1943). Depth of the surface sheet flows, therefore, primarily determines the species of lotic sites, as does depth of standing water on sunken-concave sites.

Surface rill flows are akin to rill washing (Gustafson 1937). After a rainstorm, rill flow is evidenced as shallow puddles in small depressions or slight movements of litter. Rill flows can be valuable to hanging meadow sites, especially when surface water is gone. Except for the usually dry summers in the Sierra Nevada, rill flows would be of major significance on normal and xeric meadow sites.

Output Flows—Water lost or removed from a meadow site constitutes an output flow. Although evapotranspiration occurs regardless of the kind of meadow site, as an output flow it is of greatest significance on raised-convex and sunken-concave sites. In both, losses to percolation are relatively minor because of the presence of head pressure on raised-convex sites and an impermeable or slowly permeable layer on sunken-concave sites. Because both are ponded, downstream runoff does not occur.

Percolation flow is important on normal and xeric sites. On normal meadow sites, water may percolate to the water table and eventually emerge downstream. A generally shallow soil means that deep percolation will not occur on xeric sites, except when water enters fissures in the underlying rock. Thus, although percolation occurs, the soil is quickly saturated and most output becomes downstream runoff.

Downstream runoff is a major output flow of hanging and lotic meadow sites. Owing to the saturated or slowly permeable nature of the underlying materials, percolation is slow.

Hvdro-pulse—The regularity of additions of water to the meadow site system is reflected by its hydro-pulse. Conditions of fairly constant moisture regimes from year to year have been considered the key to developing and maintaining meadows in northeastern California (Hormay 1943). The same may be assumed for meadows of the Sierra Nevada.

Although subsurface flows may continue throughout summer in the Sierra Nevada, water input is mainly snowmelt and spring and early summer rains. Normal, lotic, xeric, and sunken-concave meadow sites largely depend upon those inputs. Raised-convex and hanging sites are also affected by seasonal regularity of snow and rain. After the flush of water early in the season, a fairly constant input of water is maintained. Depending upon its location in the watershed, size of the watershed, and mount of precipitation, lotic sites may also receive rather constant additions of water through the summer.

Xero-pulse—The regularity with which a meadow site dries is reflected in its xero-pulse. Raised-convex, hanging, and lotic sites have high soil water-content, except in the situation of extreme prolonged drought over a number of years. Soils of xeric sites are usually quite dry by about the first of August. Having deeper soils and possible access to the water table, normal meadow sites usually have some moisture at depth. They may, however, be fairly dry in the surface layer. Surface water is usually gone from sunken-concave sites by mid-August, and the soil may dry to considerable depth before fall.

Vegetation

The 14 vegetation classes (Ratliff 1979-1982) and the 19 associations (Benedict 1981) have been combined to give 21 vegetative series (*table 2*). These are general classes intended to reflect species abundance in the community. They are based on current, rather than potential or climax, vegetation. The list of series may be enlarged or condensed as new information is brought into the system.

Associations

Associations are composed of sites of the same hydrologic and vegetative series and have close floristic similarity. They comprise the lowest category of classification. The most extensive and intensive work to define meadow associations in the Sierra Nevada has been that of Benedict (1981).

The same species are expected to grow together on sites having similar environments. Nonsalient differences in the environments, however, can affect the species present, their abundance, or both. As a result, differences between associations of the same series may not be immediately obvious, and intensive study is usually necessary to identify different associations. For most administrative purposes, therefore, classification of meadow sites to the association level would likely

Table 2—*Vegetative series and associations of meadow sites in the Sierra Nevada, California*

Series		Association	
Code	Name	Code	Name
A	*Agrostis* (Bentgrass)		
B	*Artemisia rothrockii* (Rothrock sagebrush)	1	*Artemisia rothrockii*
C	*Calamagrostis breweri* (Shorthair)	1	*Calamagrostis breweri-Oryzopsis kingii*
		2	*Calamagrostis breweri-Aster alpigenus*
		3	*Calamagrostis breweri-Vaccinium nivictum*
		4	*Calamagrostis breweri-Trisetum spicatum*
D	*Calamagrostis canadensis* (Bluejoint reedgrass)	1	*Calamagrostis canadensis-Dodecatheon redolens*
E	*Carex exserta* (Short-hair sedge)	1	*Carex exserta*
F	*Carex heteroneura*	1	*Carex heteroneura-Achillea lanulosa*
G	*Carex nebraskensis* (Nebraska sedge)		
H	*Carex rostrata* (Beaked sedge)	1	*Carex rostrata*
		2	*Carex rostrata-Mimulus primuloides*
I	*Deschampsia caespitosa* (Tufted hairgrass)	1	*Deschampsia caespitosa-Cardamine breweri*
		2	*Deschampsia caespitosa-Senecio scorzonella*
		3	*Deschampsia caespitosa-Senecio scorzonella-Achillea lanulosa*
J	*Eriogonum* (Buckwheat)	1	*Eriogonum-Oreonana clementis*
K	*Gentiana newberryi* (Newberry gentian)		
L	*Heleocharis acicularis* (Slender spikerush)		
M	*Heleocharis pauciflora* (Fewflowered spikerush)	1	*Heleocharis pauciflora*
		2	*Heleocharis pauciflora-Mimulus primuloides*
N	*Hypericum anagalloides* (Tinkers penny)		
O	*Juncus* (Rush)	1	*Juncus orthophyllus*
P	*Muhlenbergia filiformis* (Pullup muhly)		
Q	*Muhlenbergia richardsonis* (Mat muhly)	1	*Muhlenbergia richardsonis*
R	*Penstemon heterodoxus* (Heretic penstemon)	1	*Penstemon heterodoxus-Achillea lanulosa*
S	*Poa* (Bluegrass)		
T	*Trifolium longipes* (Longstalk Clover)		
U	*Trifolium monanthum* (Carpet Clover)		

be impractical. When known, however, the association to which a site belongs should be identified as part of its classification.

Classification to the association level may be required to assess range condition and trend in condition and for some research programs. Because the associations are based on current vegetation, identification of the association present on a site may provide a clue to its potential. A site of vegetative series C (shorthair) with association 2 *(Calamagrostis breweri—Aster alpigenus)* may represent a degraded stage from association 1 *(Calamagrostis breweri—Oryzopsis kingii*) of that series, for example. And, perhaps, a change in the association of a site could even be taken as an indication of the presence of trend in condition.

Meadow Soils

Development

Soil moisture regime is the single most significant property that determines the existence and characteristics of a meadow (Wood 1975). The characteristics of a meadow depend upon consistency in the moisture regime from year to year (Hormay 1943). Situations favorable to accumulating fine-textured materials and establishing shallow water tables are prerequisite to meadow development. A fine-textured soil is needed to draw water to shallow rooted meadow plants by capillary rise. A shallow water table is needed so that water does not have to be raised too far. A favorable situation has (1) a relatively impervious bedrock floor; (2) an upper drainage area of sufficient size to supply seepage to maintain a shallow water table well into the growing season; (3) a gentle gradient; and (4) a favorable drainage area-to-slope relationship, perhaps the most valuable characteristic.

Drainage area above a meadow affects the volume of annual water input. Slope affects water velocity, sediment load, and deposition. Above a critical slope threshold, an alluvial valley floor is usually unstable (Schumm 1977). As valley floor slope increases so does valley instability. Meadows with drainage areas larger than 512 acres (207.2 ha) and with slopes greater than two percent are likely to be unstable (Wood 1975). Usually, such meadows have well-defined stream channels through them. Meadows with drainage areas smaller than 512 acres or with slopes less than two percent, or both, are likely to be stable. Meadows with gentle slopes and small drainage areas do not usually have well-defined stream channels. Steeply sloped meadows with small drainage areas tend to contain straight stream channels. Gently sloped meadows with large drainage areas tend to contain sinuous stream channels. Large drainage areas with steep stream gradients do not contain meadows.

Peatification and Marshification— Some meadows of the Sierra Nevada have developed through the typical successional pattern from glacial or montane lakes. Many Sierra

Nevadan meadows, however, were created abruptly [sic]because of changes in the moisture regime (hydrology) brought about by major changes in climate (Wood 1975). Others have developed by aggrading of surfaces and lifting of the water table with the land.

Bodies of water transform into peat in the process of being filled with peaty materials due to the growth of vegetation in them. The materials are deposited as strata, with the type of material deposited related to water depth and the organisms present. This process is called peatification (Vilenskii 1957). The five steps in the process are:

1. Deposition of lake marl—lake silt rich in lime;
2. Deposition of sapropelite—sedimentary peat consisting mainly of minute animal and plant remains;
3. Deposition of remains of rooted shore vegetation—the type of material deposited largely depends upon the depth of water;
4. Gradual reduction in depth and surface area, with zones of shore vegetation moving farther out;
5. Finally, the complete filling of the pond or lake with plants and peat and the development of a marsh.

The peatification process may follow different routes. Under favorable conditions vegetation may grow out over the surface of the water forming a raft upon which other plants grow. Materials dropping from the bottom of the raft settle to the bottom. At the same time, the raft becomes thicker. Peat materials, therefore, build up from both the top and the bottom. This is probably the manner in which sites of the raised-convex hydrologic class are gradually filled.

Another process through which peat accumulates is marshification, or the swamping of dry lands, which occurs at some northern and moderate latitudes (Vilenskii 1957). This process is driven by a rise in the water table because of decreased evapotranspiration. A weed stage generally follows, as after the harvest of timber, and lasts for one year or so. The weed stage is succeeded by a meadow stage composed largely of rhizomatous grasses. After about two years in the meadow stage, sphagnum moss begins to invade the meadows. Mosses other than sphagnum may first become established in the grass meadow providing conditions more suitable for sphagnum. Alternately, reedgrasses (*Calamagrostis* spp.) and sedges become established and these are followed directly by sphagnum.

Meadows have sometimes developed after logging in the Sierra Nevada. Conditions favorable for marshification occur where surface runoff is poor, where the parent material is from rock types with mineral compositions favorable to clay formation, where subsurface drainage is poor, and where fine-textured material that effectively prevents or slows the outflow of seepage water is deposited.

Poor subsurface drainage may result from a compact, impermeable illuvial B horizon or by bedrock. But an irreversible loss of moisture from peat (Pons 1960, Schelling 1960) during periods of drought or because of draining may produce a slowly permeable layer that acts to keep incoming water at or near the surface. These two conditions combine to keep water at or near the surface. On sites of the hanging hydrologic class, drought and drainage frequently produce the anomaly of a relatively dry soil beneath a wet meadow surface. These same two conditions may also permit marshification in uncut forest—especially near existing marshes. The invasion of the "bog forest" by sphagnum moss has been described (Cooper 1912). The sphagnum advanced uphill into climax forest to a height of 15 ft (4.5 m) above the original level of the marsh. The process of marshification appears to be active around some seeps and springs in the Sierra Nevada, but the particular mosses involved may not be sphagnum.

Stratigraphy and Chronology—Four main depositional units are recognized in montane meadows of the Sierra Nevada (Wood 1975). A unit of coarse pre-Holocene alluvium several feet thick rests upon the bedrock. The next unit is a paleosol (old soil), which shows profile development and in some meadows a gleyed (intensely reduced, with ferrous iron and neutral gray colors) condition. This buried soil unit extends into the alluvium and in places to the bedrock. It was developed between 8,705 and 10,185 years B. P. (before present). The third unit is composed of stratified sand deposits, dated from 8,700 to 1,200 B.P. and as much as 20 ft (6.1 m) thick. It represents a period of forest development with well-drained soils. Evidence of profile development was not found, implying geologic instability. The fourth depositional unit is 2 to 12 ft (0.6 to 3.7 m) thick and is made up of interstratified layers of sorted grus, peat, and organically rich sandy loams. This unit represents development of open, wet meadows and has been deposited since 2,500 years B.P. Repetition of sand-sod-peat layers has effectively prevented soil profile development. Continued geological instability in the drainage area of a meadow is indicated. Present sand and gravel depositions on meadows, therefore, may be continuations of a natural process.

I have frequently observed the fourth depositional unit described by Wood (1975). One profile, an extreme situation perhaps, had 10 separate well-delimited layers in the first foot (30 cm) of soil. But not all montane meadows of the Sierra Nevada have the four soil unit sequence. Some meadows have well-developed soils and have evidently been stable for up to 10,000 years. One study concluded that "meadow ecosystems are as stable as the surrounding vegetation" (Benedict 1981, p. 80). What occurs on the drainage area above it, therefore, greatly affects what occurs on a meadow.

Many subalpine meadows of the Sierra Nevada are not infilled glacial lakes, and differ somewhat in their stratigraphy from montane meadows (Wood 1975). Glacial till, fluvial deposits of gravel and sand, and a topsoil comprise the basic stratigraphic sequence. Accumulation of topsoil at Tuolumne Meadow, Yosemite National Park, has occurred during the last 2,300 years. On glacial till hummocks, the beginnings of genetic soil horizon development occurs and A, B, and C horizons can be recognized. Topsoils of low areas range to 3 ft (0.9 m) thick. In some, thin sandy lenses indicate minor, but continued, deposition of materials from the drainage area.

Bands of meadow around high-elevation lakes, as hypothesized, developed through growth of moss and Sierra bilberry (*Vaccinium nivictum*), alpine laurel (*Kalmia polifolia* *microphylla*), or both, over and around boulders at waters edge (Ratliff 1973). The shrubs serve to anchor the moss. In turn, the moss acts to raise the water table and support extension of shrub branches between boulders. This shrub-moss base (with trapped dust and sand) constitutes the parent material of the soil. Eventually, other plants become established and a more typical A horizon is produced.

One, and often two, layers of a white pumiceous volcanic ash (tephra) were found in several meadow soil profiles examined by Wood (1975). Source of the tephra was found to be the Mono-Inyo craters. The more recent layer was named "tephra 1" and the older layer "tephra 2." Times of deposition, determined by radiocarbon techniques, were 720 years B.P. for tephra 1 and 1,200 years B.P. for tephra 2 (Wood 1975).

Presence of these tephra layers and their ages are significant. They serve as check points for estimating the deposition rates of materials above them. About 10 inches (25 cm) of meadow soil have been deposited above tephra 1, and about 22 inches (56 cm) of meadow soil have been deposited above tephra 2 (Wood 1975, fig. 3-29). Those amounts of soil translate into 1.4 inches (3.4 cm) per century for tephra 1 and 1.8 inches (4.7 cm) per century for tephra 2. For the 480 years between 1,200 and 720 B.P., the rate of accumulation was about 2.5 inches (6.5 cm) per century. It appears that the rate of accumulation has slowed since tephra 1 was deposited. Erosion or decomposition rates, or both, however, may have accelerated.

Classification

Little real effort has been expended toward classification of meadow soils in the Sierra Nevada. Some soils appear to be of organic origin, others are clearly of mineral origin. The earliest classification effort of which I am aware was that of the U.S. Department of Agriculture, Soil Conservation Service (1962). Four kinds of soils from 12 meadows on the Sierra National Forest were described: normal meadow, drained meadow, alluvial timber, and peat meadow. All were said to have effective depths of 3 to 5 ft (0.9 to 1.5 m). The first three overlay weathered granitic material, the peat meadow overlays decayed organic material. Surfaces of normal meadow soils vary from peat-like to silt loam in texture, have gravel to silt loam subsoil, and are slightly alkaline to moderately acid. The water-holding capacity of these soils is high, with moderately slow to very slow runoff. They are poorly to imperfectly drained with very slow to moderate permeability, and have a seasonally high water table.

Drained meadow soils have loamy, coarse sand to loam surfaces and coarse sand to silt loam subsoils. They are slightly to moderately acid and have low to moderate water-holding capacities with slow to moderate runoff. They are slowly to moderately permeable and are imperfectly to well drained.

Alluvial timber soils have slow surface runoff, moderate to rapid permeability, and are imperfectly to well drained. Their surfaces vary from coarse sandy loam to loam over coarse sandy loam to sandy loam subsoils. Surface runoff is slow, with water-holding capacity ranging from low to high. Reaction is slightly to moderately acid.

Peat meadow soils have peat surfaces and subsoils and high water-holding capacities. They generally have water within 1 ft (30 cm) of the surface and are slowly permeable and slowly drained but with slow runoff. Their reaction is slightly acid.

Recently, the soil taxonomy system (Soil Survey Staff 1975) was applied to meadows of the Sierra Nevada (Wood 1975). Meadow soils, not classed as Histosols, are considered either udic or perudic cryofluvents. *Udic* and *perudic* refer to the soil moisture regime, *cryo* refers to the soil temperature regime, *fluv* refers to water-deposited sediments, and *ent* refers to Entisol. Entisols are dominated by mineral soil materials; they do not have distinct pedogenic (related) soil horizons.

In general, a soil is considered a Histosol when more than one-half of the upper 80 cm of the soil is organic, or if organic material of any thickness rests on rock or fragmented material, the interstices of which are filled with organic materials (Soil Survey Staff 1975). The first situation is likely in infilled lakes. The "typical peaty" meadow soil (Aliev 1964) appears to generally express such conditions. The second situation is found at seeps, springs, and along some lake shores. "Dern-peaty" and "peaty-dern" soils have been described (Aliev 1964). These have thin surface layers high in organic matter.

Histosols saturated for long periods have a minimum of 12 to 18 percent organic carbon, depending upon the amount of clay in the mineral fraction (Soil Survey Staff 1975). The more clay (up to 60 percent), the more organic carbon is required for the soil to be a Histosol. Histosols not saturated for long periods have at least 20 percent organic carbon. The presence of large amounts of organic matter therefore distinguish the Histosols from the orders of mineral soils. Histosols have "histic epipedons" (a kind of diagnostic surface horizon). Certain Entisols and Inceptisols, however, also may have histic epipedons. Presence of a histic epipedon, therefore, does not automatically signify a Histosol.

Meadow soils of the Histosol order are fluvaquentic borofibrists or borohemists (Wood 1975). *Aqu* of fluvaquentic refers to water; therefore, such soils are like water-deposited wet Entisols. *Boro* soils have a frigid temperature regime. The *fibrists* are Histosols that consist largely of recognizable plant remains, which are not easily destroyed by rubbing between the fingers. The *hemists* are Histosols that are far more decomposed; most of the material is easily destroyed by rubbing. Here the water table fluctuates appreciably permitting more rapid decomposition than with fibrists.

Characteristics—Meadow soils in the Sierra Nevada cannot be characterized by soil horizon. Many of the layers in organic soils do not meet the definition of a soil horizon, and it is not always possible to distinguish true soil horizons when they are present (Soil Survey Staff 1975). It is frequently difficult to determine the boundaries between fabric, hemic, and sapric soil materials. Variation in textures frequently represent different depositional events (Hubbard and others 1966). One study found that meadow soils in Yosemite Valley did not approach maturity (Heady and Zinke 1978). And

Table 3—*Average values of some soil characteristics on 82 meadow sites of the Sierra Nevada, California by depth segment*

	Depth segment		
Soil characteristic	0 to 10 cm	10 to 20 cm	20 to 30 cm
pH	5.0	5.1	5.1
Composition (pct[1])			
Sand	54	56	58
Silt	34	31	30
Clay	11	12	13
Organic matter	21	13	10
Gravel	6	6	7

Source: Ratliff (1979)

[1]Values are for the 2-mm soil fraction, except for percent for gravels, which is calculated on the basis of bulk sample weight.

whether the soil is of organic or of mineral origin, it has been shown that true pedogenic soil horizons are rare in modern meadow soils (Wood 1975).

Sampling and describing meadow soils by depth segment seems a viable alternative. From the surface, the first 10-cm soil segment is the most heavily affected by grazing and other activities. Frequently, it is the zone of maximum root concentration and is highly organic. From 10 to 20 cm, organic matter is usually moderately reduced, but plant roots are usually abundant. Sufficient mineral matter is present for particle size determination, and the segment is affected by surface disturbances. The 20- to 30-cm segment frequently is well below the zone of maximum root concentration, is usually relatively low in organic matter, and is below most surface activity influences. Deeper segments, although significant for understanding meadow genesis, are little influenced by current management activities.

I have used and suggest use of the 10- to 20-cm depth segment as a standard for comparing and characterizing meadow sites. For study of meadow response to management activities, the top segment should also be used. The lower segments should be used when fuller understanding of meadow development is required.

Detailed and specific information on soil characteristics of meadow sites and site classes are available (Benedict 1981; Bennett 1965; Heady and Zinke 1978; Hubbard and others 1966; Ratliff 1979, 1982).

Soils of Sierra Nevada meadows generally tend to be strongly acid to very strongly acid with a pH of about 5.0 (*table 3*). A low pH of 3.4 and a high pH of 8.0 have been reported. Textures of meadow soils range from coarse sands to an occasional clay. Most soil textures are loamy sands, sandy loamy, and loamy. The average texture by depth segment to 30 cm is sandy loam.

Organic matter content of meadow soils (estimated by gravimetry and ignition) has ranged between 4 and 90 percent. The organic content usually decreases with depth. The average organic matter content in the 10- to 20-cm segment (*table 3*) was 38 percent less than at 0 to 10 cm. Between the middle and lower segments the rate of decrease is much less. The depositional sequence may, however, result in organic matter at depth being more than in the surface segment. In one soil, for example, organic matter contents were 25, 16, and 31 percent in the respective depth segments from the surface. The effect appears related to more sand and less silt in the 10- to 20-cm segment than in the other two.

Sequences of deposition and erosion determined where and how much gravel was in each soil, but it appears that gravels were deposited in about equal amounts in the three depth segments (*table 3*). Because the soil samples were extracted with a ¾-inch-(1.9-cm) diameter sampling tube, only pebbles of finely gravelly size (Soil Survey Staff 1975) or slightly larger were included in my samples. Nevertheless, gravelly meadow soils are frequently observed. Eleven of the 82 soils contained 15 percent or more gravels in one or more depth segments, and meadow soils with cobblestone size fragments have been reported.

Series Descriptions

A series, as used here, is a group or cluster of meadow sites that have the same kind of margins, are found in the same plant belt, occupy equivalent topographic positions, are influenced in the same way hydrologically, and have similar vegetations.

The classification presented in this paper provides for 1,512 (2 x 2 x 3 x 6 x 21) theoretical meadow series. Of course, not all are biologically possible. Among the 126 theoretical hydrologic-vegetative combinations, 32 have been identified in the field (*table 4*). Few, if any of these, are found under all combinations of margin type, plant belt, and topographic position. Even so, a large number of possible series are obvious.

Only in a few situations have enough sites been studied to adequately define the series. Therefore, rather than attempt to provide modal class concepts, my aim is to enable the manager to use the classification scheme. For that purpose, each series discussed is represented by a single site (one that I personally have studied). The site in each situation reflects as nearly as possible my concept of sites that belong to the series.

The code for a meadow series includes five letters representing, in order, the nature of the margin, the plant belt, the topographic location, the hydrologic series, and the vegetative series. The association to which a site belongs may be identified in the classification code by adding the association number to the vegetative series.

Series A-B-C-B-G (fig. 1) is represented in John Brown Meadow, Minarets Ranger District, Sierra National Forest. The meadow has vegetated margins, is in the montane belt at 6,791 ft (2,070 m), and is a stringer along an intermittent stream. Seeps in the upper reaches of the meadow feed the stream, but it was dry some distance below the site in mid-August 1979.

The site has a slope of 4 percent. Above the site, water is well distributed over the meadow so that there is no distinct channel. As a result, the site receives some flow from upstream. Its main input flow is from seepage at the upper side. Water flows slowly across the site to join the stream.

Table 4—*Hydrologic-vegetative series relationships common in the Sierra Nevada, California*

Vegetative series,	Hydrologic series					
	A Raised convex	B Hanging	C Normal	D Lotic	E Xeric	F Sunken concave
A *Agrostis* (bentgrass)		X	X			
B *Artemisia rothrockii* (Rothrock sagebrush)					X	
C *Calamagrostis breweri* (Shorthair)			X			
D *Calamagrostis canadensis* (Bluejoint reedgrass)		X				
E *Carex exserta* (Short-Hair sedge)					X	
F *Carex heteroneura*			X			
G *Carex nebraskensis* (Nebraska sedge)		X	X	X		
H *Carex rostrata* (Beaked sedge)				X		
I *Deschampsia caespitosa* (Tufted hairgrass)		X	X			
K *Gentiana newberryi* (Newberry gentian)			X			
L *Heleocharis acicularis* (Slender spikerush)				X		X
M *Heleocharis pauciflora* (Fewflowered spikerush)	X	X	X			
N *Hypericum anagalloides* (Tinkers penny)	X	X				
O *Juncus* (Rush)			X			
P *Muhlenbergia filiformis* (Pullup muhly)		X	X			
Q *Muhlenbergia richardsonis* (Mat muhly)					X	
R *Penstemon heterodoxis* (Heretic penstemon)			X			
S *Poa* (Bluegrass)					X	
T *Trifolium longipes* (Longstalk clover)		X	X			
U *Trifolium monanthum* (Carpet clover)		X	X			

Figure 1—Meadow series vegetated magin (A), montane (B), stream (C), hanging (B), and Nebraska sedge (G) in John Brown Meadow, Minarets Ranger District, Sierra National Forest.

Table 5—*Species composition for nine meadow sites of the Sierra Nevada, California*

Classification variable	Site classification								
Margin type	A	A	A	A	A	A	B	A	A
Plant Belt	B	B	B	A	B	A	B	B	A
Topographic	C	A	A	A	B	A	B	A	B
Hydrologic series	B	C	D	D	E	C	N	F	E
Vegetative series	G	G	G	H	S	C		L	E
Species	Percent composition[1]								
Agrostis lepida								5.7	
Aster alpigenus			0.3			12.0			
Aster occidentalis		15.3							
Calamagrostis breweri						36.3			1.0
Carex athrostachya		6.7						0.7	
Carex exserta									80.3
Carex nebraskensis	81.7	54.3	55.3						
Carex rostrata		0.3		57.3				T	
Carex simulata	6.3	0.7	36.3			T			
Dodecatheon jeffreyi			2.3				8.3		
Gentiana newberryi			0.3			5.7			
Heleocharis acicularis	2.3	1.3	16.0					69.7	
Heleocharis palustris							4.3	12.7	
Heleocharis pauciflora	2.7	3.3	7.0				0.3		
Horkelia fusca capitata					14.7				
Hypericum anagalloides			0.7			T	19.0		
Juncus nevadensis				6.0					
Lupinus breweri bryoides									5.3
Marsilea vestita								10.0	
Muhlenbergia filiformis			13.0			1.3	11.7		
Oxypolis occidentalis							19.3		
Perideridia species		6.0					T		
Phalacroseris bolanderi							8.0		
Poa pratensis					60.7				
Senecio species						7.3			
Solidago canadensis					6.7				
Solidago multiradiata						9.0			1.7
Stipa occidentalis					9.0				
Trifolium longipes		9.7							
Vaccinium nivictum						10.7			

[1]Percent composition is calculated on the basis of nearest shoot-to-point frequency. T = Trace.

Here, water depth is not enough to permit a lotic classification. And although the slope is considerably less than usual for hillside bogs, the site must be assigned to the hanging hydrologic series.

Nebraska sedge (*Carex nebraskensis*) is the vegetative series, and the species makes up 82 percent of the composition here (*table 5*). Analogne sedge (*Carex simulata*) is the next most frequent species on the site.

Organic matter content of the soil (26 percent) is high (*table 6*). The soil texture is a sandy loam with pH 5.6. A recent overwash of sand on the site is evidenced by a high (95 percent) basal frequency of bare soil.

Some similar sites may have much less Nebraska sedge. The amounts of Nebraska sedge may not be enough to keep such sites in that vegetative series. It will likely be replaced by the fewflowered spikerush (*Heleocharis pauciflora*) vegetative series. Such a result may be a response to overuse, and such sites may have a Nebraska sedge potential.

Series A-B-A-C-G is represented by a site in Cannell Meadow, Cannell Meadow Ranger District, Sequoia National Forest (*fig. 2*). Cannell Meadow is a large montane, basin meadow at 7,600 ft (2,316 m). A few bare spots occur where the margins are not vegetated. These may be people-caused, however, and the meadow is classed as having vegetated margins.

The site is in the normal hydrologic series. Although it is subject to sheet flows in the spring, depth of the water does not approach that of lotic sites. The water table may be at considerable depth by mid- to late summer. Nebraska sedge is the vegetative series and on this site makes up 54 percent of the species composition. Western aster (*Aster occidentalis*) and longstalk clover (*Trifolium longipes*) are the next most frequent species.

Soil on the site is a sandy loam with pH 5.7 and 8 percent organic matter. Bare soil makes up about 6 percent of the surface, and 87 percent is covered by litter. Less than 2 percent of the surface cover is moss.

Species composition on sites of this series appears to be influenced considerably by the regime of grazing. A fence separated this site (which is generally used late in the grazing season) from a site of the same series that is grazed season long. On that site, Nebraska sedge makes up 24 percent,

Table 6—*Surface cover and soil properties on nine meadow sites of the Sierra Nevada, California*

Classification variable	Site classification								
Margin type	A	A	A	A	A	A	A	A	A
Plant belt	B	B	B	A	B	A	B	B	A
Topographic	C	A	A	A	B	A	B	A	B
Hydrologic series	B	C	D	D	E	C	B	F	E
Vegetative series	G	G	G	H	S	C	N	L	E
Surface cover	Percent cover[1]								
Soil	94.7	5.7	26.7	63.0	21.3	8.0	19.0	43.0	34.0
Litter	0.3	87.3	59.7	34.0	73.7	77.3	28.3	53.7	38.7
Gravel	1.0				0.3				13.0
Rock									1.7
Wood							0.7	1.3	
Moss	1.3	1.7	9.0	0.3		2.7	50.0		
Higher plants	2.7	5.3	4.6	2.7	4.7	12.0	2.0	2.0	12.6
Soil property[2]									
Texture (Percent)									
Sand	57.1	61.0	43.2	20.6	52.8	72.4	62.0	19.8	56.4
Silt	35.4	31.9	47.6	39.7	28.9	16.6	32.2	42.2	33.1
Clay	7.5	7.1	9.2	39.7	18.3	11.0	5.8	38.0	10.5
Organic matter (Pct)	26.5	8.0	22.2	33.3	9.5	4.7	28.9	5.8	7.4
Acidity (pH)	5.6	5.7	5.0	5.2	5.5	4.9	5.2	6.0	5.1

[1]Percent surface cover is calculated on the basis of frequency of actual basal point contacts.
[2]Soil values are for the 10- to 20-cm depth segment.

Figure 2—Meadow series vegetated margin (A), montane (B), basin (A), normal (C), and Nebraska sedge (G) in Cannell Meadow, Cannell Meadow Ranger District, Sequoia National Forest.

straightleaf rush (*Juncus orthophyllus*), 19 percent, and fewflowered spikerush, 17 percent of the composition. Also, litter was reduced to 65 percent of the surface, and soil was increased to 9 percent and moss to 24 percent.

Series A-B-A-D-G is represented by a site in Jackass Meadow, Minarets Ranger District, Sierra National Forest (*fig. 3*). Jackass Meadow has vegetated margins, lies at 7,000 ft (2,134 m) in the montane belt, and is a basin meadow. The site is lotic-water flows over it with some depth and velocity, and the water table is almost always at or near the surface. The vegetative series is Nebraska sedge, which makes up 55 percent of the species composition. Other species of significance on the site are slender spikerush (*Heleocharis acicularis*), fewflowered spikerush, and pullup muhly (*Muhlenbergia filiformis*). Some Jeffrey shooting-star (*Dodecatheon jeffreyi)* and Bolanders clover (*Trifolium bolanderi*) are present. Frequently, longstalk clover is the main clover on these sites.

The soil is a loam with 22 percent organic matter and pH 5.0. Litter covers 60 percent, soil, 27 percent, and moss, 9 percent of the surface.

Figure 3—Meadow series vegetated margin (A), montane (B), basin (A), lotic (D), and Nebraska sedge (G) in Jackass Meadow, Minarets Ranger District, Sierra National Forest.

Water depth and velocity are the main variables controlling species composition of sites in this series. A depth of surface flow in spring of 10 to 15 cm is usual. On one site of this class, flow velocity for 30 consecutive days during spring runoff averaged 0.36 ± 0.04 ft sec^{-1} (11.0 ± 1.2 cm sec^{-1}). Where water is less deep, sites of this class tend to merge with sites of the tufted hairgrass (*Deschampsia caespitosa*) series. Where water is deeper and velocities are reduced, sites of this class tend to merge with sites of the beaked sedge *(Carex rostrata)* series.

Sky Parlor Meadow *(fig. 4)* on Chagoopa Plateau, Sequoia National Park, contains a representative of *series A-A-A-D-H.* The meadow has vegetated margins, lies at 8,976 ft (2,736 m) in the subalpine belt, and is in a basin.

The hydrologic series of the site is lotic. Usually surface water is found on the site even in September, and the water table is always above or near the surface. Although I have not measured flow velocity, it should be less and water depth should be greater than on lotic Nebraska sedge sites.

The vegetative series is beaked sedge and constitutes 57 percent of the composition. Analogne sedge is a codominant, and Nevada rush *(Juncus nevadensis)* is frequently seen.

Soil texture is clay loam with 33 percent organic matter and pH 5.2. Because of fairly rapid decomposition at the site (Ratliff 1980), the amount of soil (63 percent) is almost twice that of litter (34 percent).

In the subalpine belt, beaked sedge sites tend to merge with open water as water becomes deeper and with grass dominated vegetative series as water becomes more shallow. Montane sites with the same hydrologic and vegetative series tend to merge with those of ephemeral-lakes in deeper water and with those of the Nebraska sedge series in more shallow water.

Crane Flat Meadow in Yosemite National Park contains an example of *series A-B-B-E-S (fig. 5).* The meadow has vege-

Figure 4— Meadow series vegetated margin (A), subalpine (A), basin (A), lotic (D), and beaked sedge (H) in Sky Parlor Meadow, Sequoia National Park.

Figure 5—Meadow series vegetated margin(A), montane (B), slope (B), xeric (E), and bluegrass (S) in Crane Flat Meadow, Yosemite National Park.

Figure 6—Meadow series vegetated margin (A), subalpine (A), basin (A), normal (C), and shorthair (C) in Delany Meadow, Yosemite National Park.

tated margins and lies at 6,430 ft (1,960 m) in the montane belt. It is a slope meadow. The site is somewhat elevated above the main meadow area and has a 3.5 percent slope. Hydrologically, the site must be considered in the xeric series. The soil is well drained with a sandy loam texture. It receives no moisture other than normal precipitation. The water table, if present, appears quite deep and likely has little influence on the site.

Floristically, the site is in the bluegrass *(Poa)* series. More than 60 percent of the composition is Kentucky bluegrass *(Poa pratensis)*. A forb, dusky horkelia *(Horkelia fusca)*, is the next most frequent species.

Soil organic matter is about 10 percent and pH is 5.5. Litter covers 74 percent and bare soil, 21 percent of the surface. Gopher mounds are abundant on the site. This situation occurs on many xeric sites, especially where dryness has resulted from a lowered water table due to erosion.

The site described here shows no evidence of recent erosion, and it has been ungrazed for many years. Under grazing, some reduction in bluegrass may occur, and other species of forbs will become more abundant.

Series A-A-A-C-C is represented by a site *(fig. 6)* one-half mile North of Dog Lake in Yosemite National Park. The meadow has vegetated margins, lies at 9,400 ft (2,865 m) in the

Figure 7—Meadow series vegetated margin (A), montane (B), slope (B), hanging (B), and tinkers penny (N) in McKinley Grove, Kings River Ranger District, Sierra National Forest.

Figure 8—Meadow series vegetated margin (A), montane (B), basin (A), sunken-concave (F), and slender spikerush (L) near Clover Meadow, Minarets Ranger District, Sierra National Forest.

subalpine belt, and is in a basin. An intermittent stream meanders the length and is tributary to Delaney Creek, which passes through the lower reaches of the meadow.

The hydrologic series of the site is normal. It receives water from upslope in the spring. Soil texture at the site is a sandy loam with pH 4.9. The water table in mid-July was at a depth of 78 cm. At that depth, a layer of coarse sand appears to serve as an aquifer carrying water under the meadow. Shorthair is the vegetative series of the site. Shorthair and Sierra ricegrass *(Oryzopsis kingii)* make up 36 percent of the composition. On this site, however, Sierra ricegrass is the main species. On the drier side, sites of this series tend to merge with sites having short-hair sedge. On the more moist side, sites of this series tend to have more shorthair. The caespitose grasses form large bunches, which account for much of the 12 percent cover of higher plants. Litter covers 77 percent of the surface. Alpine aster *(Aster alpigenus)* and Sierra bilberry are the two next most important species.

A meadow in the McKinley Grove of Sequoias on the Kings River Ranger District, Sierra National Forest, contains a fine example of *series A-B-B-B-N (fig. 7).* The meadow has vegetated margins, lies at 6,480 ft (1,975 m) in the montane belt, and has a 15 percent slope.

Hydrologically, the site is in the hanging series. Seeps

Figure 9—Meadow series vegetated margin (A), subalpine (A), slope (B), xeric (E), and short-hair sedge (E) in Dana Meadow, Yosemite National Park.

provide a constant supply of water for the site and the meadow as a whole. Water appears to be retained near the surface by a slowly permeable zone in the 10- to 20-cm soil layer. Soil texture is a sandy loam with pH 5.2 and 29 percent organic matter. Below about 20 cm, the amount of sand and gravel increase. The dominant surface characteristic, with 50 percent cover, is moss. Floristically, the site is in the tinkers penny *(Hypericum anagalloides)* series—the hillside bog class of Ratliff (1979, 1982). Sites of this series vary markedly in species composition. Tinkers penny, American bistort *(Polygonum bistortoides),* and violet (*Viola* spp.) should, however, be found. Here, tinkers penny and Pacific cowbane *(Oxypolis occidentalis)* together comprise 38 percent of the nearest shoot-to-point composition.

An ephemeral-lake site *(fig. 8)* on the Minarets Ranger District, Sierra National Forest, represents *series A-B-A-F-L.* The meadow has vegetated margins, is in the montane belt at 7,140 ft (2,176 m), and is a basin type. Hydrologically, the site is classed as sunken-concave, and water may stand on it until mid-summer. By fall, the water table may be at a considerable depth, and the surface soil may be dry and hard.

Slight changes in normal water depth alter species composition from point to point in an ephemeral-lake. The slender spikerush vegetative series is typical of ephemeral-lake sites. Here slender spikerush and creeping spikerush *(Heleocharis palustris)* are the predominant species. Other species characteristic of the class include clover fern *(Marsilea vestita)* and *Porterella carnosula.*

Bare soil on this site occupies 43 percent of the surface and litter occupies 54 percent of the surface. Soil pH is 6.0 and soil texture is a silty clay loam.

Dana Meadow in Yosemite National Park contains several examples of *series A-A-B-E-E.* The meadow has vegetated margins, is in the subalpine belt, and is slope type in its upper reaches. The representative site *(fig. 9)* lies at 9,860 ft (3,005 m) and occupies a ridge with a general slope of 5 percent. The soil is a sandy loam with pH 5.1 and 7 percent organic matter. Hydrologically, the site is xeric—the expected hydrologic series for sites of the short-hair sedge vegetative series. Short-hair sedge makes up 80 percent of the composition, and its patches of dense sod largely account for the high plant cover. Several species, including Brewer's lupine *(Lupinus breweri),* Heretic penstemon *(Penstemon hetrodoxus),* and skyline bluegrass *(Poa epilis),* occupy the spaces between sod patches.

Meadows with sandy margins in the subalpine belt at an elevation of 10,800 ft (3,293 m) are represented in Sequoia National Park at Siberian Outpost *(fig. 10).* Specific data on sandy margin meadows is not available. Their occurrence appears to be correlated with the southern limits of glaciation (Benedict and Major 1982). Siberian Outpost contains basin, stream, and slope meadow sites. A few hanging and lotic sites are found, but most are normal or xeric. Floristically, the main series are shorthair, beaked sedge, fewflowered spikerush, and short-hair sedge. The sandy areas contain the *Eriogonum-Oreonana clementis* association (Benedict 1981) of the buckwheat *(Eriogonum)* series. In some places, western needlegrass *(Stipa occidentalis)* and bottlebrush squirreltail *(Sitanion hystrix)* are abundant.

PRODUCTIVITY OF MEADOWS

Productivity of meadows is related to site elevation, vegetation type, range condition, fertilization, and degree of utilization. Productivity of meadows generally decreases as elevation increases. Vegetation of mesic meadow sites tends to be the most productive, but it may also be the most variable from

Figure 10 — Siberian Outpost, Sequoia National Park, with sandy margin (B) meadows.

year to year. As range conditions decline, meadow productivity generally declines. Productivity usually peaks when vegetation is at or near climax. Nitrogen fertilization at rates of 90 to 150 lb N per acre (100 to 168 kg/ha) and phosphorus fertilization at 40 to 80 lb P_2O_5 per acre (45 to 90 kg/ha) frequently increase production many times over that of unfertilized meadows. Responses to phosphorus have been more consistent than responses to nitrogen. When used to reduce soil acidity, lime may increase meadow productivity. With fertilization, species composition may change and the resulting increases in productivity will be temporary.

Elevation

Productivity of meadows in excellent condition decreased as elevation increased (Crane 1950). Cow months (a month's tenure by one cow) per acre declined from 3.4 at 5,500 to 6,000 ft (1,676 to 1,829 m) to 1.7 at elevations of 8,500 to 9,000 ft (2,591 to 2,743 m). Similar trends were found along Rock Creek in Sequoia National Park (Giffen and others 1970). At 9,450 ft (2,987 m) elevation meadow productivity across vegetation types was about 1,695 lb per acre (1,900 kg/ha). At 11,600 ft (3,536 m) productivity was only 312 lb per acre (350 kg/ ha).

On the Sierra National Forest, elevation of Markwood Meadow is 5,800 ft (1,768 m) and of Exchequer Meadow 7,280 ft (2,219 m). At Markwood Meadow, forage production was estimated at 3,739 to 4,508 lb per acre (4,191 to 5,053 kg/ ha) (Clayton 1974, Pattee 1973). At Exchequer Meadow, forage production was estimated at 1,280 to 2,963 lb per acre (1,435 to 3,221 kg/ha).

The general trend to lower productivity with increased elevation should be considered in arriving at grazing capacities and in considering meadow condition and trend. Low production at high elevations does not indicate poor condition, nor does high production at low elevations indicate good condition.

Vegetation

Series

Data on meadow productivity are of more value when they are related to vegetative series. Such data are scant and available for only a few series. Sources of the data provided *(table 7)* include Sanderson (1967) and Ratliff (1974). Data for the slender spikerush series comes from similar sites on the Lassen National Forest (Reppert and Ratliff 1968). Other data were collected from 1971 to 1981 in the Sequoia and Kings Canyon National Parks and the Sierra National Forest.

Maximum productivity is achieved by those vegetative series that occur on more mesic sites (Giffen and others 1970). Slender spikerush and beaked sedge sites generally are wetter than sites with Nebraska sedge and tufted hairgrass. Sites with short-hair sedge are the most xeric. The effects of elevation are also evident *(table 7)*; the last three series generally are found at higher elevations than the others.

Table 7—*Estimates of herbage production for seven meadow vegetative series of the Sierra Nevada, California*

Vegetative series	Sites studied	Herbage production		
		gm/m²	*kg/ha*	*lb/acre*
Beaked sedge	7	185	1,850	1,650
Slender spikerush	2	113	1,130	1.010
Tufted hairgrass	5	270	2,695	2,405
Nebraska sedge	3	314	3,145	2,805
Fewflowered spikerush	1	128	1,280	1,145
Shorthair	28	119	1,195	1,065
Short-hair sedge	11	32	325	285

Table 8—*September standing crops at five meadow sites in Sequoia National Park, California*

Site	Vegetative series	Standing crops 1972	1973	1974
			gm/m²	
Hair Sedge	Short-hair sedge	45.2a[1]	33.8a	50.6a
Lake Shore	Shorthair	199.8a	182.2a	296.8a
Chagoopa	Shorthair	132.0b	164.2b	274.8a
Big Arroyo	Tufted hairgrass	467.3a	378.6ab	303.2b
Sky Parlor	Beaked sedge	227.5a	195.0a	260.5a

[1]Values, within rows, followed by the same letter do not differ significantly (P = 0.95) by Tukey's w-procedure.

Data on yearly variations in productivity are available from two studies in Sequoia National Park (Ratliff 1976, 1980). Among the five sites in these studies, standing crops differed significantly between years at two: Chagoopa and Big Arroyo *(table 8).* These two sites are the more mesic of the five. The results suggest that year-to-year variations in productivity may be greater on mesic than on drier or wetter meadow sites.

Standing crops at four of these five meadow sites approximated the maximum values found elsewhere in Sequoia National Park. The values *(table 7)* for the beaked sedge, fewflowered spikerush, shorthair, and short-hair sedge vegetative series fall within the ranges DeBenedetti (1983) found elsewhere in the park *(table 9).* It is acceptable to assume, therefore, that productivity on sites of those series will usually fall within those values. But the differences among the values from different sources show that it is unacceptable to assume a standard productivity for a given vegetative series.

Species

Estimated production per unit of composition times the observed composition provides an estimate of productivity of a particular species on a site. The sum of the species productivities estimates site productivity. This type of information is expensive to obtain, however.

The only published information on individual species production for meadows of the Sierra Nevada is given by Sanderson (1967). He reported average production from two meadows for Nebraska sedge (123 lb per acre or 138 kg/ ha), pullup muhly (239 lb per acre or 268 kg/ ha), California oatgrass *(Danthonia californica americana)* (24 lb per acre or 27 kg/ ha), and Idaho bentgrass *(Agrostis idahoensis)*(6 lb per acre or 7 kg/ ha). Legumes as a group produced 30 lb per acre (34 kg/ha). Grasslike plants as a group (other than Nebraska sedge) produced 582 lb per acre (652 kg/ha).

In meadows of the Sierra Nevada, I have observed more than 200 herbaceous and shrubby plant species. But the listings provided in this section do not exhaust the possibilities *(table 10).* Each new meadow site should be considered a resource of new species.

Plant species can be categorized as decreasers, increasers, and invaders (Bell 1973, Dyksterhuis 1949, Range Term Glossary Committee 1974, Stoddart and others 1975). Categorization of the species in this report is based on my experience and on information in the literature (Dayton 1960; Hayes and Garrison 1960; Hermann 1966, 1970, 1975; Hitchcock 1950; Munz and Keck 1959; U.S. Dep. Agric., Forest Serv. 1937; Weeden 1981). Decreaser species, present in climax vegetation, decrease in the stand with overgrazing. Increaser species, present in climax vegetation, increase in the stand — at least initially — with overgrazing. Invader species, absent in climax vegetation, increase in the stand with overgrazing.

Decreasers and Increasers — Decreaser species are usually major constituents of the composition at climax. Increaser species are usually minor constituents of the composition at climax. Under certain conditions, however, some such species are probably true decreasers — *Habenaria dilatata* (white bogorchid), for example. Also, some increaser species indicate a greater departure from climax than others — *Cirsium drummondii* (dwarf thistle) compared with *Danthonia intermedia* (timber oatgrass), for example. Species believed to represent both situations are indicated in the tables.

The presence or even abundance of various species may or may not indicate overgrazing (Sharsmith 1959). The lists, therefore, should be used only as guides. The land manager must decide, on a site-by-site basis, which species are the decreasers, increasers, and invaders.

Carbohydrate Storage — Carbohydrate storage cycles in meadow species need to be considered in determining proper use. Carbohydrate storage patterns are probably related to a particular species' pattern of growth and reproduction (Hyder and Sneva 1959). The responses of one species cannot, therefore, always serve to explain those of another species (Smith 1972).

The level of carbohydrate reserves in plants is affected by rates of photosynthesis, respiration, and growth (Cook 1966). Carbohydrate reserves in grasses gradually decline during winter because of continued, though slight, respiration. A sharp decline usually occurs at the start of spring growth. And reserves build up during maturation (Heady 1975). Defoliation will cause a temporary drop in carbohydrate reserves.

I know of only one study specifically on carbohydrate storage cycles of meadow plant species in the Sierra Nevada (Steele 1981, Steele and others 1984). Seasonal variation in total nonstructural carbohydrate (TNC) levels in rhizomes

Table 9—*Ranges in herbage standing crops and average standing crops at quiescence for five vegetative series in Sequoia National Park, 1977-1981*

Vegetative series	5-Year range[1]	Average standing crop		
	gm/m²	*gm/m²*	*kg/ha*	*lb/acre*
Beaked sedge	55 to 367	167	1668	1488
Fewflowered spikerush (≤8 cm tall)	12 to 97	53	532	475
Fewflowered spikerush (≥ 8 cm tall)	113 to 415	238	2379	2122
Shorthair	18 to 292	74	742	662
Short-hair sedge	6 to 46	22	222	198
Brewer sedge[2]	15 to 68	29	288	257

Source: DeBenedetti (1983)

[1]Low- and high-plot values observed during study.

[2]*Carex breweri.* Not listed in *table 2.* Hydrologically, sites of the series are xeric.

Table 10 — *Ecological groups of meadow species in the Sierra Nevada. California*

Code[1]	Scientific name[2]	Common name	Plant belt[3]
	Decreaser or primary meadow species		
AGSU	*Agropyron subsecundum*	Bearded slender wheatgrass	M
AGDI	*Agrostis diegoensis*	Thin bent	M
AGEX-1	*Agrostis exarata*	Spike bent	M
ALL-2	*Allium* sp. herbaceous perennial	Wild onion	M-S
ALAE	*Alopecurus aequalis*	Shortawn foxtail	M
BOMU	*Botrychium multifidum*	Broadleaf grape-fern	M
BOSI	*Botrychium simplex*	Little grape-fern	S
CABR-1	*Calamagrostis breweri*	Shorthair	S-A
CACA-1	*Calamagrostis canadensis*	Bluejoint reedgrass	M-S
CAAB-2	*Carex abrupta*	Abruptbeak sedge	M-S-A
CAAQ	*Carex aquatilis*	Sand sedge	M-S
CAAT-2	*Carex athrostachya*	Slenderbeak sedge	M
CAEX-1	*Carex exserta*	Short-hair sedge	S
CAFI-2	*Carex fissuricola*	—	M-S
CAFR-1	*Carex fracta*	—	M-S
CAHA-3	*Carex hassei*	—	M
CAHE-3	*Carex heteroneura*	—	M-S-A
CAJO	*Carex jonesii*	Jones sedge	M-S
CALA-3	*Carex lanuginosa*	Wooly sedge	M-S
CALE-2	*Carex lemmonii*	—	M-S
CAMI-1	*Carex microptera*	Small-wing sedge	M-S
CAMU-2	*Carex multicostata*	Manyrib sedge	M-S
CANE-1	*Carex nebraskensis*	Nebraska sedge	M-S
CANE-2	*Carex nervina*	—	M-S
CANI	*Carex nigricans*	Black alpine sedge	S-A
CAOR	*Carex ormantha*	Star of David sedge	M-S
CARO-2	*Carex rostrata*	Beaked sedge	M-S
CASC-2	*Carex scopulorum*	—	M-S
CASE-1	*Carex senta*	Rough sedge	M
CASI-1	*Carex simulata*	Analogne sedge	M-S
CASP-2	*Carex spectabilis*	Showy sedge	M-S-A
CASU-3	*Carex subnigricans*	—	S-A
CAVE-2	*Carex vesicaria*	Blister sedge	M-S
CACU-2	*Castilleja culbertsonii*	Indian paint-brush	S-A
DECA-1	*Deschampsia caespitosa*	Tufted hairgrass	M-S
GLEL	*Glyceria elata*	Tall mannagrass	M
GLLE-1	*Glyceria leptostachya*	Slimleaf mannagrass	M
GLST	*Glyceria striata*	Fowl mannagrass	M
HADI	*Habenaria dilatata*	White bogorchid	M
HEPA-2	*Heleocharis palustris*	Creeping spikerush	M
JUBA	*Juncus balticus*	Baltic rush	M
JUEN	*Juncus ensifolius*	—	M
JUME-2	*Juncus mertensianus*	Merten's rush	M
JUME-3	*Juncus mexicanus*	Twisted baltic rush	M-S
JUNE	*Juncus nevadensis*	Nevada rush	M
JUOR	*Juncus orthophyllus*	Straightleaf rush	M-S
JUOX	*Juncus oxymeris*	Pointed rush	M
LUCO-1	*Luzula comosa*	Maryflowered wood-rush	M

Table 10 — *Ecological groups of meadow species in the Sierra Nevada, California (continued)*

Code[1]	Scientific name[2]	Common name	Plant belt[3]
	Decreaser or primary meadow species (continued)		
LUOR	*Luzula orerstera*	Common wood-rush	S-A
MAVE	*Marsilea vestita*	Clover fern	M
MOCH	*Montia chamissoi*	Chamisso miner's lettuce	M-S-A
ORKI	*Oryzopsis kingii*	Sierra ricegrass	S
OXOC	*Oxypolis/is occidentalis*	Pacific cowbane	M
PEPRF	*Penstemon procerus formosus*	Small-flowered penstemon	M-S
PEBO	*Perideridia bolanderi*	Bolander yampah	M-S
PEPA-5	*Perideridia parishii*	Parish's yampah	M-S
PHAL-1	*Phleum alpinum*	Alpine timothy	S-A
POAMS	*Polygonum amphibium stipu/aceum*	Ladys thumb knotweed	M
SAL-11	*Salix* sp.	Willow	M-S-A
SIPR	*Sibbaldia procumbens*	—	S-A
SIRE	*Sidalcea reptans*	Spike checker-mallow	M
SIEL	*Sisyrinchium elmeri*	Elmer's yellow-eyed grass	M
SPRO	*Spiranthes romanzoffiana*	Hooded ladies tresses	M
TRWO-2	*Trifolium wormskioldii*	Cow clover	M
TRSP-1	*Trisetum spicatum*	Spike trisetum	S-A
TRWO-1	*Trisetum wolfii*	Beardless trisetum	M-S
VANI	*Vaccinium nivictum*	Sierra bilberry	S-A
	Increaser or secondary meadow species		
ACLA-2	*Achillea lanulosa*	Western yarrow	M-S-A
AGTR-1	*Agropyron trachycaulum*	Slender wheatgrass	M
AGID	*Agrostis idahoensis*	Idaho bent	M
AGLE	*Agrostis lepida*	Sequoia bent	M-S
AGSC-2	*Agrostis scabra*	Rough bent	M
AGVA	*Agrostis variabilis*	Mountain bent	S-A
ANCO-1	*Antennaria corymbosa*	Flattop pussytoes	M-S
ANRO	*Antennaria rosea*	Rose pussytoes	M-S-A
ASAD	*Aster adscendens*	Long-leaf aster	M
ASALA	*Aster alpigenus andersonii*	Alpine aster	S-A
ASOC	*Aster occidentalis*	Western aster	M
ATFIC	*Athyrium filix femina californicum*	Common lady-fern*	M
CAMI-2	*Calochortus minimus*	Lesser star tulip	M
CAHO-2	*Caltha howellii*	Twinflower marshmarigold*	M
CACA-3	*Carex canescens*	Silvery sedge	M-S
CADO	*Carex douglasii*	Douglas sedge	M-S-A
CAFE-2	*Carex feta*	Western sedge	M
CAIN-3	*Carex integra*	Smoothbeak sedge	M-S
CALE-5	*Carex leptopoda*	Short-scale sedge	M
CALU-1	*Carex luzulaefolia*	—	M
CIDR	*Cirsium drummondii*	Dwarf thistle	M
CITI	*Cirsium tioganum*	Tioga thistle	S
DACA-1	*Danthonia californica americana*	California oatgrass	M
DAIN	*Danthonia intermedia*	Timber oatgrass	M-S
DOAL	*Dodecatheon alpinum*	Alpine shooting-star	S-A
DOJE	*Dodecatheon jeffreyi*	Jeffrey shooting-star	M

Table 10—*Ecological groups of meadow species in the Sierra Nevada, California (continued)*

Code[1]	Scientific name[2]	Common name	Plant belt[3]
	Increaser or secondary meadow species (continued)		
DORO	*Drosera rotundifolia*	Roundleaf sundew	M
ELGL	*Elymus glaucus*	Blue wildrye	M
EPBR	*Epilobium brevistylum*	Sierra willow-herb	M
EPGL-1	*Epilobium glaberrimum*	Glaucous willow-herb	M-S-A
EPOR	*Epilobium oregonense*	Oregon willow-herb	M-S-A
EQA R	*Equisetum arvense*	Field horsetail*	M
ERCO-5	*Erigeron coulteri*	Coulter fleabane	M-S
ERPEH	*Erigeron peregrinus hirsutus*	Peregrine fleabane	M-S
FRPL-1	*Fragaria platypetala*	Broad petal strawberry	M
GATRS	*Galium trifidum subbiflorum*	Sweet scented bedstraw	M
GEAM	*Gentiana amarella*	Annual gentian	M-S
GEHO	*Gentiana holopetala*	Tufted gentian	M-S
GENE-1	*Gentiana newberryi*	Newberry gentian	S-A
GESI	*Gentiana simplex*	Hikers gentian	M-S
GNPA	*Gnaphalium palustre*	Lowland cudweed*	M
HAAP	*Haplopappus apargioides*	Alpine flames	S-A
HEBI	*Helenium bigelovii*	Bigelow sneezeweed*	M
HEHO	*Helenium hoopesii*	Orange sneezeweed*	M
HEAC	*Heleocharis acicularis*	Slender spikerush	M
HEPA-4	*Heleocharis pauciflora*	Fewflowered spikerush	M-S-A
HEPU-3	*Hesperochiron pumilus*	Meadow centaur	M
HOBR	*Hordeum brachyantherum*	Meadow barley	M
HYAN	*Hypericum anagalloides*	Tinkers penny	M
HYFOS	*Hypericum formosum*	Southwestern St. Johnwort	M
IVLY	*Ivesia lycopodioides*	Club moss ivesia	S
1VPU	*Ivesia purpurascens*	Purple ivesia	M
JUDR	*Juncus drummondii*	Drummond rush	M-S
JUPA-1	*Juncus parryi*	Parry rush	S-A
KAPOM	*Kalmia polifolia microphylla*	Alpine laurel*	S-A
LENE-2	*Lewisia nevadensis*	Nevada lewisia	M-S
LOOB	*Lotus oblongifolius*	Stream deervetch	M
LUPR	*Lupinus pratensis*	Inyo meadow lupine*	M-S
MECIS	*Mertensia ciliata*	Mountain bluebells	M
MIMO-3	*Mimulus moschatus*	Musk monkeyflower	M
MIPR	*Mimulus primuloides*	Primrose monkeyflower	M-S
MITI	*Mimulus tilingii*	Mountain monkeyflower	M-S-A
MUFI	*Muhlenbergia filiformis*	Pullup muhly	M-S
MURI-1	*Muhlenbergia richardsonis*	Mat muhly	M-S
NOAL	*Nothocalais alpestris*	Alpine lake-agoseris	M-S-A
OESA	*Oenanthe sarmentosa*	Pacific water-drop-wort	M
PEAT	*Pedicularis attolens*	Little elephant heads	M-S
PEGR-1	*Pedicularis groenlandica*	Elephant heads	M-S
PEHE-2	*Penstemon hetrodoxus*	Heretic penstemon	S-A
PEOR-1	*Penstemon oreocharis*	—	M
PHBO-2	*Phalacroseris bolanderi*	Bolander's sunflower	M
PHBR-4	*Phyllodoce breweri*	Mountain-heather*	S-A
POEP-1	*Poa epilis*	Skyline bluegrass	S-A
POPR-1	*Poa pratensis*	Kentucky bluegrass	M

Table 10—*Ecological groups of meadow species in the Sierra Nevada, California (continued)*

Code[1]	Scientific name[2]	Common name	Plant belt[3]
	Increaser or secondary meadow species (continued)		
POBI-3	*Polygonum bistortoides*	American bistort	M-S
POCA-7	*Porterella carnosula*	—	M-S
POBR	*Potentilla breweri*	Brewer cinquefoil	M-S-A
POFL-1	*Potentilla fabellifolia*	Fanleaf cinquefoil	M-S-A
POGL-2	*Potentilla glandulosa*	Sticky cinquefoil	M
POGR-4	*Potentilla gracilis nuttallii*	Fivefinger cinquefoil	M
PUER	*Puccinellia erecta*	Upright alkali grass	S-A
PUPA-2	*Puccinellia pauciflora*	Fewflowered alkali grass	M
RAAL-l	*Ranunculus alismaefolius*	Plantainleaf buttercup	M
RAFLO	*Ranunculus flammula ovalis*	Spearwort buttercup*	M
RHOC	*Rhododendron occidentale*	Western azalea*	M
ROCU	*Rorippa curvisiliqua*	Western yellow cress	M
RUCA-1	*Rudbeckia californica*	California coneflower	M
SASAH	*Sagina saginoides hesperia*	Arctic pearlwort	M-S-A
SAAP-2	*Saxifraga aprica*	Sierra saxifrage	M-S-A
SAOR-1	*Saxifraga oregana*	Oregon saxifrage	M
SAPUA	*Saxifraga punctata arguta*	Dotted saxifrage	M-S
SCCL	*Scirpus clementis*	Slender club-rush	S-A
SCCO	*Scirpus congdoni*	Congdon's bulrush	M
SCCR	*Scirpus criniger*	Fringed bulrush	M-S
SCMI	*Scirpus microcarpus*	Panicled bulrush	M
SECL-1	*Senecio clarkianus*	—*	M
SEINM	*Senecio integerrimus major*	Lambstongue groundsel*	M
SOCAE	*Solidago canadensis*	Canada goldenrod	M
SOMU	*Solidago multiradiata*	Alpine goldenrod	S-A
STLO-1	*Stellaria longipes*	Long-stalked starwort	M
STCO—1	*Stipa columbiana*	Subalpine needlegrass	M-S
THA-1	*Thalictrum sp.*	Meadow rue	M-S
TOGLO	*Tofieldia glutinosa occidentalis*	Western tofieldia*	M-S
TRBO	*Trifolium bolanderi*	Bolanders clover	M
TRLO	*Trifolium longipes*	Longstalk clover	M
TRMO-1	*Trifolium monanthum*	Carpet clover	M
TRCEP	*Trisetum cernuum projectum*	Nodding trisetum	M
VECA-1	*Veratrum californicum*	Western false-hellebore*	M
VEALA	*Veronica alpina alterniflora*	Alpine speedwell	M-S
VEAM	*Veronica americana*	American speedwell	M
VESC-2	*Veronica scutellata*	Marsh speedwell	M
VIMA-2	*Viola macloskeyi*	Western sweet white violet	M-S
	Invader or low-value meadow species		
ACMI	*Achillea millefolium*	Common yarrow	M
ANDI	*Antennaria dimorphs*	Low pussytoes	M-S
BRLA-2	*Brodiaea laxa*	Grassnut brodiea	M
BRTE	*Bromus tectorum*	Cheatgrass brome	M
CAUM-2	*Calyptridium umbellatum*	Pussy paws*	M-S
CARO-1	*Carex rossii*	Ross sedge	M-S
CIALP	*Circaea alpina pacifica*	Enchanter's nightshade	M
CIAN	*Circium andersonii*	Anderson's thistle	M

Table 10—*Ecological groups of meadow species in the Sierra Nevada, California (continued)*

Code[1]	Scientific name[2]	Common name	Plant belt[3]
	Invader or low-value meadow species (continued)		
DAGL-l	*Dactylis glomerata*	Orchardgrass	M
DECA-4	*Dentaria californica*	California toothwort	M
DEDA	*Deschampsia danthonoides*	Annual hairgrass	M
FEOC-1	*Festuca occidentalis*	Western fescue	M
FRCA-1	*Fragaria californica*	California strawberry	M
GANU-1	*Gayophytum nuttallii*	Nuttal groundsmoke	M
HIAL	*Hieracium albiflorum*	White hawkweed	M
HOFUC	*Horkelia, fusca capitata*	Dusky horkelia	M
HOFUP1	*Horkelia, fusca parviflora*	—	M-S
HOLA-1	*Holcus lanatus*	Velvet grass	M
IRHA	*Iris hartwegii*	Foothill iris	M
IVUN	*Ivesia unguiculata*	Yosemite ivesia	M
JUBU	*Juncus bufonius*	Toad rush	M
JUTE-1	*Juncus tenuis*	Poverty rush	M
JUTEC	*Juncus tenuis congest us*	—	M
LETR-2	*Lewisia triphylla*	Three-leaf lewisia	M-S
LONE-3	*Lotus nevadensis*	Nevada deervetch	M
LOPU-2	*Lotus purshianus*	Porsh deervetch	M
LUBRB	*Lupinus breweri bryoides*	Brewer's lupine*	S-A
LUCO-5	*Lupinus covillei*	Coville lupine*	M-S
MAGL-1	*Madia glomerata*	Cluster tarweed	M
MIPE	*Mitella pentandra*	Fivestamen miterwort	M
MUMI-2	*Muhlenbergia minutissima*	Annual muhly	M
NESP	*Nemophila spatulata*	Sierra nemophila	M
PHPR-1	*Phleum pratense*	Timothy	M
PHDI-4	*Phlox diffusa*	Spreading phlox	M-S-A
PLHI-1	*Plagiobothrys hispidulus*	Hairy popcorn flower	M
PODO-3	*Polygonum douglasii*	Douglas knotweed	M
POKE-2	*Polygonum kellogii*	Kellogg knotweed	M-S-A
PRVU	*Prunella vulgaris*	Common self-heal	M
RORA	*Rotala ramosior*	Common toothcup	M
RUAN	*Rumex angiocarpus*	Sheep sorrel	M
SIHY	*Sitanion hystrix*	Bottlebrush squirreltail	M-S
STAL	*Stachys albens*	Whitestem hedge nettle	M-S
STOC-1	*Stipa occidentalis*	Western needlegeass	M-S
TAOF	*Taraxacum officinale*	Common dandelion	M
TRMI-2	*Trifolium microcephalum*	Littlehead clover	M
TRRE	*Trifolium repens*	White clover	M
VESE	*Veronica serpyllifolia*	Thymeleaf speedwell	M
VIAD	*Viola adunca*	Hookedspur violet	M

[1]Codes from Reed and others (1963). Decreaser species whose codes are italicized are expected to comprise a relatively small percentage of the composition at climax, but they are expected to decrease with overgrazing. When in abundance, increaser species whose codes are italicized may indicate a greater degree of deterioration from climax than other increaser species.

[2]Scientific names from Munz and Keck (1959).

[3]M = montane; S = subalpine; A = alpine.

*These. species are known to be or are suspected of being poisonous to some classes of livestock.

and shoots of a natural population of Nebraska sedge were studied at Tule Meadow on the Sierra National Forest. The TNC cycle for Nebraska sedge follows closely the generalized cycle characterized earlier (Humphreys 1966). TNC in rhizomes decreased to 7.5 percent of the dry weight during early shoot growth, and reached a peak level of 17.4 percent in fall. TNC levels in shoots ranged from a low of 10.6 percent in spring to a high of 16 percent in late summer after flowering. TNC levels in emerging shoots average 16.4 percent in September and 19.1 percent at the end of October. Carbohydrates appear to have been transferred from mature shoots to emerging shoots serving as storage locations or sinks.

In Sequoia National Park, reductions of 20 percent to 40 percent in reserves of TNC in roots of short-hair sedge, shorthair, and Carex *scopulorum* one year after clipping the herbage to a one-inch (2.5-cm) stubble height were reported (DeBenedetti 1980). And near Carson Pass, decreases in the carbohydrate content of roots and rhizomes of American bistort, *Sibbaldia procumbens*, and twinflower marshmarigold *(Caltha howellii)* when plants were transplanted from 9,000 to 6,000 ft (2,743 to 1,829 m) elevation were reported (Mooney and Billings 1965). Naturally growing pussy paws *(Calyptridium umbellatum)*, however, had about 50 percent more carbohydrate at the lower than higher elevation.

Naturally growing American bistort in Wyoming showed the same general response to elevation as did pussy paws at Carson Pass (Mooney and Billings 1965). The reduced carbohydrate levels of the transplanted plants were attributed to higher respiration rates at the lower, warmer elevations. Naturally growing plants of high-elevation species at lower elevations apparently compensate for the higher respiration by being able to store relatively high amounts of carbohydrates.

Underground organs of herbaceous alpine species in the Medicine Bow Mountains, Wyoming, contained abundant reserves of carbohydrates (Mooney and Billings 1960). Many of the species apparently use much of their reserves for growth before and immediately after snowmelt. Because of rapid development, it appears that the reserves are restored quickly and maintained during most of the growing season. Shoot and root reserves, however, may experience a depression associated with the period of flowing and fruit set. Carbohydrates in rhizomes of American bisort declined sharply from when leaves were expanding to when plants were in bud. The reserves then rapidly rebuilt to early bloom followed by a lower rate of buildup to dormancy. These findings suggest that American bistort could be most easily damaged by defoliation when it is in bud. Each species studied throughout the season showed somewhat different trends in its carbohydrate cycle. Mooney and Billings consider that slower developing species (such as species of *Gentiana)* may depend more upon current photosynthesis than upon a reserve of carbohydrates.

Rhizome reserves of *Carex bigelowii* on Mt. Washington, New Hampshire, were 61 percent depleted during initial growth (Fonda and Bliss 1966). The reserves were fully recovered during flowering but dropped by about 30 percent immediately afterwards. By seed dispersal, however, the reserves were again fully recovered. Although the rhizomes of grasslikes are important, roots of grasslike species are considered to be relatively unimportant as storage organs. A species of cinquefoil *(Potentilla)* and a species of huckleberry *(Vaccinium)* both showed lower carbohydrate levels after full bloom than before flowering.

Maximum carbohydrate storage in timothy *(Phleum pratense)* occurred between anthesis and the seed-in-dough stage (Reynolds and Smith 1962). With smooth bromegrass *(Bromus inermis),* a drop in carbohydrate storage occurred as the heads emerged from the boot, after which carbohydrates increased to maturity. With both species of grass and with alfalfa *(Medicago saliva),* the peaks were followed by slight drops, but total available carbohydrates (TAC) generally remained high to the end of the season.

Timothy is often cut for hay. Carbohydrate trends in timothy and other "northern grasses" were studied (Okajima and Smith 1964). For timothy, total available carbohydrates decreased with growth of new shoots in early spring and were minimum when tillers started to elongate. Carbohydrates then accumulated and were high at heading when timothy was cut. It was cut twice during the season, and with each cutting the general cycle of TAC depletion and storage was repeated.

Higher levels of carbohydrates in timothy were obtained with two cuttings than with three cuttings (Reynolds and Smith 1962). And timothy stored higher percentages of carbohydrates with all cutting treatments than either alfalfa or smooth bromegrass.

Two groups of perennial grasses can be distinguished by the type of carbohydrates stored in overwintering organs (Okajima and Smith 1964). One group accumulates fructosan and sucrose; the other accumulates starch and sucrose. The first group contains grasses native to temperate latitudes. The second group contains grasses native to semitropical or tropical latitudes. Timothy, smooth bromegrass, orchardgrass *(Dactylic glomerata),* reed canarygrass *(Phalaris arundinacea),* and Kentucky bluegrass were all found to store fructosan. Smooth bromegrass had, however, mostly sucrose. *Agrostis alba, A. tenuis,* and *Bromus marginatus* also store fructosan (Ojima and Isawa 1968).

These results suggest that most meadow grasses in the Sierra Nevada store fructosan. Whether this is true for the grasslikes is not known. For clovers (*Trifolium* spp.), the main carbohydrate reserve is starch (Ojima and Isawa 1968). American bistort apparently stores starch, also (Mooney and Billings 1960). At least some meadow forbs, therefore, appear related to semitropical or tropical grasses in the type of carbohydrates stored.

Among other species of range plants, the carbohydrate reserves of lambstongue groundsel *(Senecio integerrimus)* were studied (Donart 1969). This and other species of the genus grow in meadows of the Sierra Nevada. When the plants were in full leaf — just prior to formation of flower buds, the root reserves were at their seasonal maximum. When the flower buds began to develop, the reserves dropped 69 percent. With flowering, the reserves rose to about one-half the maximum, declined slightly in the late flowering stage, and then increased to the end of the growing season. The plants were generally more advanced phenologically at given dates than other species studied (Donart 1969). Management of *Senecio* species may require therefore a different treatment than grasses and various other forbs.

The studies on carbohydrate cycles and reserves suggest that grazing is detrimental when reserves are being spent to produce spring growth or near the time of heading. I suggest that the range readiness standards (U.S. Dep. Agric., Forest Serv. 1969) are adequate for montane meadows. The range is considered ready for grazing when Kentucky bluegrass, Nebraska sedge, and/or tufted hairgrass growth is 6 inches (15 cm) tall. By then, carbohydrate reserves should be sufficient for plants to withstand moderate defoliation.

A late grazing that prevents carbohydrate accumulation in emerging shoots could be damaging. I suggest that grazing should therefore cease in fall in time to permit regrowth sufficient to store carbohydrates for winter respiration and initial spring growth.

Accumulation of carbohydrate reserves in plants depends upon the balance between respiration and photosynthesis (White 1973). After grazing or clipping, the leaf area left and the age of the leaf tissues largely control a plant's photosynthetic capacity. Leaf blades older than about 28 days generally have a much reduced photosynthetic capacity. A grazing treatment that maintains an abundance of young leaves may therefore give as great or greater carbohydrate storage and herbage production as protection from grazing.

Growth and Development — Along with carbohydrate storage patterns, the developmental morphology of a species may largely determine how and to what degree it may safely be grazed. But aside from work on the phenology of alpine plants (Holway and Ward 1965), little is known about the way meadow species grow.

The apical meristems of vegetative grass shoots retain the capacity to produce new leaves. Such shoots may live from one to several years. When the apical meristems become modified to produce seed, no additional leaf material is produced. Reproductive grass shoots die after seed matures.

Two general groups of grasses— culmless species and culmed species (Hyder 1972) — have been classified on the basis of the developmental morphology of vegetative shoots. If the basal internodes of vegetative shoots show no or little elongation through the season, the species is culmless; if the internodes elongate and thereby elevate the shoot apex, the species is culmed. Other clues help to determine if a species has culmed or culmless vegetative shoots: its growth pattern over the year compared with that of species of known character, and the ratio of reproductive to vegetative shoots. For two culmless grass species, blue grama *(Bouteloua gracillis)* and buffalograss *(Buchloe dactyloides),* the ratio of reproductive to vegetative shoots was about 1:6 (Rechenthin 1956). For a culmed species, switchgrass *(Panicum virgatum),* the ratio of reproductive to vegetative shoots was about 2:1.

Culmless species have the apical meristems of vegetative shoots at or near ground level throughout the growing period. The sources of leaf material, therefore, are generally below the level of normal defoliation resulting from grazing. Culmed species, however, elevate the apical meristems of vegetative shoots (as well as of reproductive shoots) at some point in the growing season, thereby exposing them to grazing animals.

These characteristics of grasses influence the appropriate kind of management. Culmless species can often be grazed season long if the degree of use is not excessive. Culmed species may require specialized grazing treatments for highest sustained productivity (Hyder 1972).

Some grasses with culmed vegetative shoots elevate the growing points upon emerging (Rechenthin 1956); in others (Hyder 1972), a number of leaves reach maturity before the apex is elevated. In the latter, the leaves can be grazed before elevation of the apex without stopping leaf growth or development of new leaves. In the early stages, therefore, such species respond similarly to, culmless species.

Among the culmless species of grass listed by Heady (1975), only Kentucky bluegrass is common to Sierra Nevada meadows. Bottlebrush squirreltail, which occasionally grows in xeric meadows, is listed as a culmless species also. The growing points of broad-leaved species are in the terminal bud, which is elevated immediately (Rechenthin 1956). Even among forbs, however, differences exist. Common dandelion *(Taraxacum officinale)* has basal leaf primordia that are never elevated (Hyder 1972). This characteristic provides for leaf replacement after removal of the growing points.

Comparatively little is known about the culmless-culmed nature of grasslike plants. We do know that Nebraska sedge is a culmless species (Ratliff 1983). Overwintering mature vegetative shoots of Nebraska sedge have a core of live tissue, and the growing points of vegetative shoots are not elevated during the growing season. Only about one-half of the overwintered shoots become reproductive; including the emerging spring shoots that remain vegetative the first year, the ratio of reproductive to vegetative shoots is about 1:2.

Overwintering shoots of beaked sedge also have a central core of live tissue (Bernard 1973, 1974). All these shoots presumably flower in the following growing season; yet it appears that their growing points are not greatly elevated, if at all, during the previous growing season. Shoots of river sedge *(Carex lacustris)* live for 1 year or less (Bernard and MacDonald 1974). New shoots begin to emerge in July and continue into fall. The overwintered and early shoots of the growing season mature and die. Only late emerging shoots overwinter. Older shoots of river sedge do not have the central core of live vegetation (Bernard 1973). If these two species are compared with Nebraska sedge, it seems likely that beaked sedge is a culmless species and river sedge is a culmed species.

Range Condition

Range condition is defined as "the current productivity of a range relative to what that range is naturally capable of producing" (Range Term glossary Committee 1974, p. 21). Range productivity and forage value are both generally highest when vegetation approaches climax, and lowest when vegetation is far from climax (Sampson 1952).

Forage production and grazing capacity are therefore reflections of range condition— the worse the condition, the lower meadow productivity. Forage depletion was judged to be moderate on 40 percent, material on 42 percent, severe on 15 percent, and extreme on 3 percent of the open forest type in the Western United States (U.S. Dep. Agric., Forest Serv. 1936). Meadows originally produced a large part of the better forage in that type. Depletion on meadows was therefore as great or greater than in the type as a whole.

For the Sierra Nevada, relative reduction in grazing capacity with poorer meadow conditions is approximately constant for all elevations (Crane 1950). Average reductions over seven elevational zones were 35 percent from excellent to good condition, 56 percent from excellent to fair condition, and 75 percent from excellent to poor condition. Given these relationships, a meadow in excellent condition producing 2,500 lb (2,802 kg/ ha) of available forage per acre would provide only 1,625 lb (1,821 kg/ha) of available forage per acre in good condition, 1,100 lb per acre (1,233 kg/ha) in fair condition, and 625 lb per acre (700 kg/ha) in poor condition.

Using those differences, reductions from good condition to fair were 32 percent and from good to poor were 62 percent. From fair to poor condition, the reduction was 43 percent. Once damage occurs, reduction of productivity accelerates and is proportionally greater between the lower condition classes. If high livestock production is a goal, it seems essential to manage for excellent meadow conditions.

Fertilization

Fertilization is one means of increasing the productivity of mountain meadows. Improved fertility may increase the more desirable plant species and thereby result in better range condition. Although not usually practiced in National Forests or in National Parks, selected meadows in the Sierra Nevada are fertilized. To my knowledge, only two studies on the effects of fertilization on Sierra Nevada meadows have been reported (Evans and Neal 1982, Leonard and others 1969). Other studies reported are about fertilization of meadows elsewhere, and these are mostly related to hay meadow production. The information, nevertheless, suggests kinds and amounts of fertilizer, methods of application, and is useful in planning fertilization on Sierra Nevada meadows. Major conclusions from meadow fertilization studies have been:

- In general, less productive meadow sites show the greatest proportional quantitative responses.
- Botanical composition may change because of differences in species requirements for various nutrients. Grass and grasslike species generally respond well to nitrogen fertilizer, but legumes increase with application of phosphorus.
- Ammonimum nitrate applied at rates of 270 to 450 lb per acre (303-504 kg/ha) are adequate for most situations and provide about 90 to 150 lb N per acre (100-168 kg N/ha).
- High rates of nitrogen do not appear to result in nitrate buildup to toxic levels, at least on saturated meadow soils.
- Treble-superphosphate applied at rates of 95 to 190 lb per acre (106-213 kg/ ha) are adequate for most situations and provide 40 to 80 lb P_2O_5 per acre (45-90 kg P_2O_5/ha).
- Applications of lime may be effective on acid meadow soils; large amounts may, however, be needed to produce a significant response.
- Lower rates of nitrogen application are usually more cost efficient in terms of forage units produced per unit of N applied. But higher rates may be more efficient in terms of units of energy or crude protein produced.
- Cost and return considerations govern whether it is profitable to fertilize a meadow for grazing of livestock.
- Method and timing of fertilizer application may have some effect on subsequent production.

In a meadow along Rock Creek in Sequoia National Park, herbage production on an unfertilized site was 1,205 lb per acre (1,350 kg/ha) (Giffen and others 1970, Leonard and others 1969). With 250 lb per acre (280 kg/ha) of ammonimum nitrate, the site produced 2,185 lb per acre (2,450 kg/ha). And with a like amount of gypsum, the site produced 1,338 lb per acre (1,500 kg/ha). In addition, 100 lb per acre (112 kg/ ha) of copper sulfate applied as a foliar spray produced greener vegetation on peat soils, suggesting that application of minor elements may increase production in some situations.

Phosphorus alone or in combination with nitrogen or nitrogen and sulfur increased yields of Blando brome *(Bromus mollis)* grown in soil from two meadows on the Sierra National Forest (Evans and Neal 1982). Sources of nutrients were ammonium nitrate, phosphoric acid, and sodium sulfate.

At rates of 50 lb per acre and 200 lb per acre (56 kg/ ha and 224 kg/ ha) nitrogen did not significantly increase Blando brome yields. Phosphorus at 50 lb per acre did not increase yield over the control, but at 200 lb per acre the yield was increased 6 to 12 times. Combined, the low rates of nitrogen and phosphorus produced yields equal to those from the high rate of phosphorus alone. The same result occurred with the low rate of nitrogen and the high rate of phosphorus and with the high rate of nitrogen and the low rate of phosphorus. Maximum yields were obtained with high rates of nitrogen and phosphorus on one of the meadows soils. Maximum yields from the other meadow soil were obtained when sulfur at 100 lb per acre (112 kg/ ha) was included with the high rates of nitrogen and phosphorus. Maximum yields from both meadow soils were 24 times greater than those from the controls.

In British Columbia, yield on a Kentucky bluegrass site was increased an average of 1,100 lb per acre (1,233 kg/ha) by applying 100 lb N per acre (112 kg N/ ha) (Mason and Miltmore 1969). Ammonium nitrate fertilizer was used.

On another British Columbia meadow, seven of nine fertilizer treatments produced greater yields than the controls (McLean and others 1963). Botanical composition of that meadow was largely sedges with beaked sedge as a primary component. Although the seven treatments did not differ significantly, the data provided some valuable information. A 10-20-10 fertilizer formulation applied at a rate of 400 lb per acre (448 kg/ ha) produced 920 lb per acre (1,031 kg/ ha) more forage than the control, which produced 860 lb per acre (964 kg/ha). Treatments containing phosphorus produced an average of 700 lb per acre (785 kg/ ha) more forage. Hydrated lime alone produced 640 lb per acre (717 kg/ ha) more forage than the control. The total amount of lime applied was 3,000 lb per acre (3,362 kg/ ha). The response to lime was thought to result from its neutralizing effect on acid soil. The 16-20-0, 0-19-0, and 11-48-0 formulations produced 627, 600, and 200 lb per acre (703, 672, and 224 kg/ha) more forage than the control. The two treatments containing potassium produced the highest average yields (1,700 lb/ acre or 1,905 kg/ ha). The conclusion was that application of lime, phosphate, or complete fertilizers increases yields.

In the Nebraska Sandhills, ammonium nitrate was applied at rates of 0, 40, and 80 lb N per acre (0, 45, and 90 kg/ ha); and treble superphosphate at rates of 0, 40, 80, and 160 lb P_2O_5 per acre (0, 45, 90, and 180 kg/ha) (Russell and others 1965). Alone, nitrogen had little effect on production but interacted with phosphorus. At the highest rates of phosphorus, the average yields with 40 lb and 80 lb N applications ranged from 18 to 50 percent higher than without nitrogen. The greatest relative response was on the lowest yielding site. Actual yield increases ranged from about 500 lb per acre (560 kg/ha) to 800 lb per acre (897 kg/ ha), with the lowest yield from the poorest site. Phosphorus alone increased yields. Average increases in yields over the controls were about 18, 28, and 24 percent (320, 505, and 440 lb/acre or 359, 566, and 493 kg/ha) for the 40-, 80-, and 160-lb rates.

Ammonium nitrate was applied at rates of 0, 20, 40, and 60 lb N per acre (0, 22, 45 and 67 kg/ha) and treble superphosphate was applied at rates of 0, 40, 80, and 120 lb P_2O_5 per acre (0, 45, 90, and 135 kg/ha), on meadows in eastern Oregon (Cooper and Sawyer 1955). No significant interactions between nitrogen and phosphorus levels were found. The 60 lb per acre rate of N increased yields by a ton (2,000 lb or 907 kg) over the control, which produced 3,500 lb per acre (3,923 kg/ ha). Nitrogen at that rate had no carry-over effect. Phosphorus increased yields 660 lb per acre (740 kg/ ha). Rates of P_2O_5 greater than 40lb per acre had no significant advantage. A carryover effect was observed with phosphorus. The second year after fertilization, yields were 400 lb per acre (448 kg/ha) higher than those of the control. In the same area, applications of 50, 100, 150, and 200 lb N per acre (56, 112, 168, and 224 kg N/ha) produced yields 43, 67, 82, and 100 percent greater than the controls (Nelson and Castle 1958).

Ammonium sulfate was applied on a native flood meadow in Oregon (Gomm 1980). Application rates were 0, 98, 196, and 393 lb N per acre (0, 110, 220, and 440 kg N/ ha). All three levels of nitrogen resulted in greater yields than the control. The yields were 3,745, 6,218, 7,179, and 8,571 lb per acre (4,198, 6,969, 8,046, and 9,607 kg/ ha).

A meadow at 10,200-ft (3,109-m) elevation in Utah was fertilized for 3 consecutive years with ammonium sulfate and treble superphosphate (Browns 1972). Treatments in pounds per acre of N and P were 30 N, 60 N, 30 P, 60 P, 30 N + 30 P, and 60 N + 60 P. The greatest production was given by the combined high-rate treatment, followed by the combined low-rate treatment and the high-rate nitrogen treatment. Increases in production over the control (965 lb/ acre or 1,082 kg/ha) for those treatments were 628, 525, and 519 lb per acre. Significant carryover effects were not found the third year after fertilization. Visual differences were, however, still apparent between the control and treatment plots.

Ammonium nitrate at rates of 0, 80, and 160 lb N per acre (0, 90, and 179 kg N/ ha) was applied annually to meadows in Wyoming (Lewis and Lang 1957). Average yields for all eight grasses studied were 1,600, 5,800, and 7,400 lb per acre (1,793, 6,501, and 8,294 kg/ ha) for the 0-, 80-, and 160-lb rates. Some effect of the 160-lb rate was observed in regrowth after harvest, but no such effect was observed for the 80-lb rate.

The percent of calcium and phosphorus in the grasses was increased by nitrogen fertilizer. Fertilized plants had more seedstalks than did the controls and were darker green. Plants fertilized at the 160-lb (179-kg) rate, however, had fewer seedstalks than those fertilized at the 80-lb (90-kg) rate and were later in maturing. And at the higher rate, plants were more easily lodged or beat down (Lewis and Lang 1957).

Large variations in yield exist between meadows, and manuring has an equalizing effect on average yields (Klapp 1962). In assessing responses to manuring, effects on species composition need to be assessed. Hay yields of more than 8,900 lb per acre (9,975 kg/ ha) are possible with manuring on farm meadows in Europe. On wild meadows, the relative effect of manuring is even greater. Marked changes in species composition are, however, associated with the effect.

Changes in botanical and chemical composition of forage plants and yield responses should be measured for evaluating the effects of fertilization (Russell and others 1965). Alone, nitrogen fertilizer stimulated grasses and grasslikes, causing a reduction in the amount of clover. Phosphorus when used alone stimulated the legumes. Combined, nitrogen and phosphorus stimulated the grasses, grasslikes, and legumes to produce the greatest yields. Increases in clover with phosphorus applications also were reported (Cooper and Sawyer 1955).

Nitrogen applied in fall was profitable when the forage was harvested for hay (Workman and Quigley 1974). When the forage was harvested directly by livestock, fertilization was not profitable. Small differences in prices could, however reverse the latter conclusion. The 50-lb N per acre rate (Nelson and Castle 1958) was the most efficient in increased hay production—32 lb (14.5 kg)— per pound of fertilizer. Although the return in forage per dollar of N was greater at the 80-lb N per acre rate (Lewis and Lang 1957), the return in crude protein was greater at the 160-lb N per acre rate of application.

Compared to surface application, drilling treble superphosphate to depths of 3 or 4 inches (8-10 cm) reduced yields on subirrigated meadows in Nebraska (Moore and others 1968). The differences were largely attributed to the killing of plants from drilling rather than to fertilizer placement. In the year of treatment, yields were 2,500 lb per acre (2,802 kg/ ha) by drilling and 2,950 lb per acre (3,306 kg/ha) by surface application. The differences were less the next year, and one site produced greater yields on the drilled treatment. That result was thought to result from fixation of phosphorus applied to the surface.

Nitrate concentrations as low as 0.21 percent can kill cattle (Gomm 1979). When meadow plants are grown in saturated soil, the tissues apparently do not accumulate toxic nitrate concentrations. When grown in unsaturated soil, however, nitrate can accumulate to toxic levels. At normal application rates, toxic level accumulations are unlikely.

Although fertilization of meadows appears to be an attractive way to increase productivity, a few cautions are advisable:

• Decide the purpose of the fertilization and state it clearly. If the purpose is to increase red meat production, plan for the efficient, full use of the increased forage. If the purpose is to add organic matter to the ecosystem for range improvement, plan to protect the meadow from grazing.

• Test the soil to determine which fertilizer components and how much is most effective. Do not waste money and effort by applying the wrong fertilizer mix or by using more than is needed.

• Consider the micronutrients. Low meadow productivity may be associated with deficient or toxic levels, or both, of the micronutrients.

• Fence and manage a fertilized meadow apart from the rest of a grazing allotment to prevent overuse by livestock and wildlife.

• Continue fertilization to maintain the fertility level. Permanent increases in permitted use should not be based on the increased forage, unless a continuing fertilization program is assured.

Utilization

Mountain meadows of the Sierra Nevada historically have been grazed by domestic and wild herbivores. Continued overuse has resulted in and can be expected to result in meadow deterioration. The key to continued productivity of mountain meadows is proper utilization —"a degree and time of use of current year's growth which, if continued, will either maintain or improve the range condition consistent with conservation of other natural resources" (Range Term Glossary Committee 1974, p. 21).

A most reliable indicator of range condition is the amount of mulch or residue on the ground (Sampson 1952). Residue must be left after grazing for the range to sustain production (Stoddart and others 1975). For grassland vegetation, several authors have reported benefits from leaving some amount of the current herbage (Bement 1969, Bentley and Talbot 1951, Heady 1956, Hooper and Heady 1970, Hormay 1944). The 50-50 rule (graze half—leave half) is a good guide to conservative range use (Frandsen 1961). Implicit in such findings and statements is the idea that some herbage must be left to decompose. But the key question is this: What proportion of the current herbage production should be left to decompose (left unconsumed by the herbivore component) to maintain or improve meadow ecosystems?

I have suggested that the amount left should equal the average proportion that decomposes annually (Ratliff 1976, 1980). Yet I have no evidence to support that suggestion. If it is valid, then to maintain meadow productivity, utilization cannot (on the average) exceed $[(A - AK)/A]\ 100$, where A represents annual production or inputs to the mulch layer, and K represents the proportion decomposing in one year (Jenny and others 1949). The concept is this: when annual inputs exceed decomposition, the mulch layer increases and soil organic matter content stabilizes. When annual inputs are less than decomposition, the mulch layer and soil organic matter is consumed by the decomposers, resulting in instability.

For five sites in Sequoia National Park (Hair Sedge, Lake Shore, Chagoopa, Big Arroyo, and Sky Parlor), the K values were estimated to be 64, 51, 57, 55, and 66 percent (Ratliff 1980). Respective degrees of proper utilization at those sites would be 36, 49, 43, 45, and 34 percent. The lower values are for the driest and wettest of the five sites. It seems possible that sites having extreme environmental influences may not be able to sustain as heavy utilization as sites having more moderate environments. And the 50-50 rule cannot be considered a safe utilization guide for all meadow sites of the Sierra Nevada.

Given that a site is not deteriorated I suggest that utilization of meadow sites in the raised convex, hanging, lotic, and xeric hydrologic series should not exceed 35 percent of the average annual herbage production. An average utilization of 45 percent for meadow sites of the normal and sunken-concave hydrologic series should maintain productivity. These suggestions compare with actual utilizations at Markwood (44 percent) and Exchequer (37 percent) meadows on the Sierra National Forest (Clayton 1974). Average utilization of about 59 percent was reported for meadows at Blodgett Forest (Kosco 1980). Because no change in productivity was observed over the study period on Blodgett Forest, either the current level of utilization was acceptable or production had stabilized at a level lower than in pristine times (Kosco 1980).

MANAGEMENT PROBLEMS

Four major problems can plague a meadow manager: animal activities, lodgepole pine, fire, and gully erosion. In creating problems, use of meadow resources for livestock production stands out. Livestock grazing creates problems when defoliation, preferential grazing, trampling, and mineral redistribution are not in harmony with plant needs for growth and reproduction. Overgrazing may accentuate the ill effects of rodent use, create conditions favorable to lodgepole pine invasion, alter meadow-fire relationships, and accelerate erosion. Well-managed livestock grazing of meadows should produce no lasting negative effects.

Many acres of meadow appear to have been lost to forest since about 1900—after the period of heavy use by sheep. The loss has put added pressure on the remaining meadow area to produce what humans want from meadows. Fire in dry, ungrazed meadows may be a significant influence in maintaining stable forest-meadow boundaries. Fires on the watershed, however, are likely of more frequent influence to meadow ecology through increased water flow and subsequent sedimentation. Lowering the water table induces change in meadow vegetation. The breaking up or depletion of the protective sod cover and activities on the watershed may alter the threshold levels of erosive forces, resulting in erosion and gully formation. Gully erosion must be controlled and the water table raised to maintain or restore a meadow.

Animal Activities

The effect of a lone animal—or person—crossing a meadow is insignificant. But multiply the crossing tenfold, a hundredfold, or a thousandfold, and the net effect on the meadow could be highly significant.

When an external influence (a stress) results in a measurable and lasting change (a strain) to a meadow community or its soil, or both, the effect is significant (Sharma and others 1976). A strain may be elastic (reversible) or plastic (irreversible). Effects associated with elastic strains last for relatively short periods and are usually nondestructive. Effects associated with plastic strains may last for many years and usually are destructive. Recovery to the original plant community may be unlikely because of altered conditions.

An occasional season of overuse usually produces an elastic strain. An effect that is obvious at the close of the grazing season should be undetectable the next season. Continued overuse resulting in an overgrazed condition produces a plastic strain. Climax species may be replaced by less desirable plants, eroded soil, or both.

Wildlife and humans can be agents of stress. But livestock are the agents of stress that come to mind when effects on meadows are discussed. Nine "grazing factors" (intensity, season, and frequency of defoliation; selectivity in grazing; plant, mineral, and animal redistribution; mineral cycling; physical impacts; and animal behavior) interact to affect decisions about range use (Heady 1975). Effects of defoliation, preferential grazing, trampling, mineral redistribution, and burrowing by rodents on meadows are discussed here.

Defoliation

Defoliation of meadow species by grazing animals is regarded as a major cause of meadow deterioration and of rangeland in general. The degree, frequency, and timing of grazing or other defoliation affects a plant's ability to produce herbage, reproduce, and survive. Those factors, therefore, are fundamental to determining proper use for herbivore production and setting utilization standards. "Any factor affecting photosynthesis or utilization of carbohydrates for respiration or growth will affect the level of plant reserves" (Cook 1966). Effects of defoliation are associated also with removal of meristematic tissues (Heady 1975), and for most species, defoliation reduces root growth (Younger 1972).

Although a large body of literature is available on the effects of defoliation on plants, information about such effects on meadow plants is scant. To my knowledge, the only published work on defoliation effects for meadow species of the Sierra Nevada is that of DeBenedetti (1980). He found that clipping the herbage to a 1-inch (2.5-cm) stubble height reduced total nonstructural carbohydrates in roots of shorthair sedge, shorthair, and *Carex scopulorum* by 20 to 40 percent.

Although restricted to a single intensity of clipping, DeBenedetti's study involved four clipping regimes continued over a 3-year period. Herbage yield data from the study is still being analyzed.

The response of western false-hellebore *(Veratrum californicum)* to cutting at ground level during early spring emergence was studied (McDougald 1976). Three years of such treatment virtually eliminated the species from the study plot. Two years later the plants had recovered only slightly. We know that defoliation is generally most damaging to a plant when carbohydrate reserves are at their low point, and that carbohydrate reserves are generally lowest after growth begins. The response of western false-hellebore to early spring cutting may be associated with a low carbohydrate reserve at that time and perhaps early elevation and removal of the growing point.

Reductions in hay yields from native flood meadows in eastern Oregon were blamed on loss of soil fertility rather than on time or height of cutting (Cooper 1956). After 4 years of cutting, no significant differences owing to treatment were found in either yields or species composition.

Plots on three meadows of the Bighorn National Forest in Wyoming were clipped to either a 1-inch (2.5-cm) or 3-inch (7.6-cm) stubble height every 2 weeks (Pond 1961). The controls were clipped to a 1-inch (2.5-cm) stubble at seasons end, to estimate total production. Kentucky bluegrass density increased with all treatments, except the control on one meadow which showed a slight decrease. Tufted hairgrass decreased in all meadows with clipping to 1 inch (2.5 cm) every 2 weeks, but remained the same or increased with the other treatments. These findings support the placement of tufted hairgrass as a decreaser and Kentucky bluegrass as an increaser. On the two meadows where it grew, redtop *(Agrostis alba)* either disappeared or was greatly reduced by the most severe treatment. It decreased slightly or remained the same under the other treatments. Alpine timothy *(Phleum alpinum)* was reported for one meadow, where it remained the same on the control and with the 3-inch (7.6-cm) cutting treatment. Beaked sedge disappeared with the I-inch (2.5-cm) cutting treatment on two of the meadows. It was reduced by the 3-inch (7.6-cm) treatment but remained the same on the control plots. On the other meadow, beaked sedge disappeared even with the control treatment, but little of it was growing to start with. Ovalhead sedge *(Carex festivella)* decreased with both cutting treatments, but showed a slight increase on the control plot in one meadow. Baltic rush *(Juncus balticus)* density declined with all treatments, including the control. Density of forbs declined with all three treatments on two of the meadows, but increased with all treatments on the third meadow. All or most species mentioned grow on meadows of the Sierra Nevada, and it is obvious that a cutting or grazing intensity favorable to one species may not be favorable to another.

Beaked sedge was among the species in a study of six frequencies of clipping to a stubble height of 2 inches (5.1 cm) in British Columbia (McLean and others 1963). The clipping schedules were every 2, 4, and 8 weeks; every 6 weeks with a 2-week delay into the grazing season; every 4 weeks with a 4-week delay; and at the end of the grazing season. Individual species' responses were not reported, but no visual changes in composition were seen. Frequent clipping (every 2 to 4 weeks from the start of grazing) lowered subsequent forage yields. In some instances, plots not clipped late in the season owing to insufficient regrowth gave their highest yields the next year. This suggests that resting the meadow near the end of the season allows the sedge species to build their carbohydrate reserves and is in agreement with what we now know about Nebraska sedge (Steele 1981, Steele and others 1984).

Preferential Grazing

Grazing preference is "selection of certain plants over others" and selective grazing is "grazing of certain plant species on the range to the exclusion of others" (Range Term Glossary Committee 1974, p. 12, 25). I use the term "preferential grazing" (Ratliff 1962) to describe the grazing of certain range areas and certain plants or plant species, or both, in similar yearly patterns. Because of changing palatabilities as the season advances, most plant species are grazed more heavily at one time than another. And preferential grazing is a major cause of range deterioration (Hormay and Talbot 1961). This practice, when combined with too severe or too frequent defoliation, eventually reduces abundance of the preferred species. The only sure way to counter the effects of preferential grazing is to restrict grazing by livestock under some form of rotation. The rotation scheme must be keyed to the growth and reproduction requirements of the preferred species. The land manager therefore needs information on meadow site and plant preferences of grazing animals.

Grazing preferences by animals have been reported by Bell (1973), Heady (1975), Sampson (1952), and Stoddart and others (1975). Horses are the most selective among domestic animals, eating more rough forage than other classes of livestock. Cattle prefer grasses, browse, and forbs, in that order. Sheep use grass in quantity but make fuller use of forbs than cattle. Goats and sheep are best adapted to browse ranges. Elk prefer sedges and grasses but will graze forbs in summer. Grass and grasslike plants are necessary in the diet of bighorn sheep as well, although they use forbs in spring and summer. Forbs and browses constitute the primary food year around in the diet of deer.

Fertility, topography, and wetness help determine preferences. Fertilized and burned areas are preferred by all kinds of grazing animals; consequently, small fertilized areas may be overused and damaged. Cattle and horses tend to prefer level or rolling range. Sheep and goats are well adapted to steep topography. Such preferences may be related to where the animals were raised. Animals raised in rough country frequently make better use of steep areas than those raised in flat country. Sheep tend to avoid the wetter portions of meadows. Cattle graze farther out on a meadow as it dries and wade to graze selected species.

Preferential grazing in the Sierra Nevada has been studied, but only a few studies concern meadows. Deer selected sedges and rushes of "seepages" on winter range (Evans 1976). They browsed most heavily from late summer through early winter and during the spring growth period (Bertram 1982). Grasses were the principal food in fall on winter ranges and during spring migration. Forbs were eaten primarily from midwinter through early fall.

Counts of bites were used to study deer food habits at Markwood Meadow on the Sierra National Forest (Chesemore and others 1976). Tame yearling deer were observed from June 16 to August 18, 1975. The yearlings ate 80 food items. Forbs dominated the diet. Of the total diet, 75 percent was forbs, 12 percent grasses and grasslikes, 10 percent shrubs, and 3 percent other species. Among the forbs, sheep sorrel *(Rumex angiocarpus)* was predominant and was most important in the total diet as well. Sheep sorrel made up 25 percent of the diet at the start of the study, reached a peak of 29 percent in early July, and declined to 13 percent in mid-August. Other forbs contributing significantly to the diet were sticky cinquefoil *(Potentilla glandulosa)* (14 pct), American bistort (11 pct), and Yosemite ivesia *(Ivesia unguiculata)* (9 pct). American bistort and Yosemite ivesia were preferred by cattle and deer (Chesemore and others 1976). American bistort and sticky cinquefoil are considered increaser species. Sheep sorrel and Yosemite ivesia are considered invaders of meadows. Pointed rush *(Juncus oxymeris),* the most significant of the grasses and grasslike species, made up 6 percent of the total diet. Sedges comprised 4 percent and grasses 0.6 percent of the diet. The sedges, rushes, and grasses were grazed by cattle and deer.

Initially, cattle preferred the drier portions of Markwood and Tule meadows on the Sierra National Forest (Pattee 1973). As the meadows dried, cattle used the other portions. Tule meadow has a wet center and relatively dry edges. Markwood meadow has a dry center and relatively wet edges. Cattle spent 91 percent of their time in the center of Markwood meadow and 100 percent of their time on the edges of Tule meadow.

Species preferences by cattle and deer grazing on meadows could not be determined by direct observation because of vegetation density (Pattee 1973). Although dealing mainly with forage utilization, Clayton (1974) provided data on preferences. His study included three meadows—Markwood, Exchequer, and Three Springs—on the Sierra National Forest. In each meadow, each of 10 plots were sampled two or three times with 150 points. Total numbers and grazed numbers of plants or shoots of selected species were given. Using chi-square, I tested the hypothesis that the ratio of grazed to ungrazed plants or shoots was independent of species. This is equivalent to saying that the species are grazed in proportion to their abundance in the sample. Each set of data was tested separately. For each meadow and sampling for which independence was rejected *(table 11),* I computed chi-square for the individual species. Only species with one or more significant chi-squares are presented *(table 12).* The species names are as given by Clayton (1974). Although, the sedges he names can grow in meadows of the Sierra Nevada, what he has called sand sedge *(Carex aquatilis) is* Nebraska sedge according to Chesemore and others (1976). And I suggest that C. *vernacula is* abruptbeak sedge *(C. abrupta).*

In general, use of the sedges, tufted hairgrass, and tinkers penny was either less than or the same as expected by chance *(table 12).* Use of California oatgrass, *Deschampsia elongata,* Jeffrey shooting-star, *Rumex acetosella,* and cow clover *(Trifolium wormskioldii)* was either more than or the same as expected by chance. The numbers of plants or shoots observed were small; nevertheless, those species were evi-

Table 11—*Chi-square values for tests of independence between the ratio of grazed to ungrazed plants and plant species at three meadows in the Sierra Nevada, California, by sampling dates*

Sampling dates	Meadow		
	Markwood	Exchequer	Three Springs
	Chi-square values[1]		
1971:			
July	2.17 (3)		
August			24.25 (8)
1972			
June	44.86 (7)		
July		38.55 (9)	73.57 (14)
August	53.17 (12)	31.05 (11)	11.68 (8)

Source: Clayton 1974
[1]Degrees of freedom (df) are in parentheses.

dently selected by grazing animals. American bistort, elephant heads *(Pedicularis groenlandica),* and pointed rush belong to this group also. But they were relatively abundant. Bolander's sunflower *(Phalacroseris bolanderi)* shows the effects of palatability changes. It was not selected at the July 1972 sampling but was selected by the August sampling.

Cattle had not grazed Markwood Meadow at the June 1972 sampling. The results from that sampling, therefore, represent early use by wildlife. Again, the sedges were not selected. The other species were grazed more than or the same as expected.

Preference by horses and mules is related to degree of hunger (Strand 1979a). As the length of the grazing period increased they became more selective. Mules were observed to show greater degree of preference than horses. One mule repeatedly moved some distance to obtain *Elymus glaucus* (blue wildrye). During trips into the Minarets Wilderness Area in late August of 1978 and 1981, 1 observed that horses select and closely graze Sierra bilberry.

Trampling

Trampling refers to "the damage to plants or soil brought about by movements or congestion of animals" (Range Term Glossary Committee 1974, p. 28). As used here, trampling also refers to damage to plants or soil by movements or congestion of people. Its effects are of great concern to land managers because of damage to the resource. Trampling damage to meadows results from two main effects: compaction that alters soil structure, and cutting of the sod that leaves bare spots or mud holes. Both effects can result in soil loss and changes in species composition.

Although certain meadow areas have not been noticeably altered after many years of heavy use, others cannot tolerate even light use without being adversely affected (Strand 1979a). The major meadow characteristics that determine the degree or extent of trampling damage are elevation, slope, and hydrology. Generally, as elevation increases, meadow recovery rate decreases; as slope increases, meadow fragility increases; and, the hydrologic regime largely determines the species composition and soil properties. The species present influence the kinds of animals using the meadow and when they use it.

The primary effect of compaction is to alter the surface structure of the soil, thereby encouraging conditions favorable for erosion. Compaction increases bulk density, reduces total and noncapillary pore space, and lowers infiltration and percolation rates (Lull 1959).

Compaction is governed by the degree that stress overcomes soil resistance to deformation (Lull 1959). As resistance is overcome, soil particles and aggregates become packed—reducing pore space, increasing bulk density, and increasing resistance. When resistance and stress are in equilibrium, compaction ceases. Counterstresses of swelling and shrinking, with changes in soil moisture and temperature, largely determine how long a soil remains compacted.

Soil resistance to deformation is governed by the relationships among moisture content, texture, structure, density, and organic content (Lull 1959). Generally, resistance to stress and compaction lessens as soil moisture content increases. But maximum bulk densities are produced by compaction at a moisture content midway between the wilting point and field capacity. Maximum bulk densities are lower in clays than in gravely soils, but soils with widely different size grains compact more than soils with more uniform size grains. Soils with strong structures have durable peds, natural soil aggregates. They have lower bulk densities, are more permeable, and are more resistant to compaction than like-textured soils with weak structures. Although freezing and thawing tend to loosen compacted soils, they tend to compact soils by destroying soil structure. Resistance becomes stronger as compaction increases the bulk density. Organic matter increases resistance by raising the moisture content needed for compaction. Also, organic matter binds soil particles into aggregates and cushions the mineral soil surface.

Livestock and humans can exert sufficient pressure to compact meadow soils. Static ground pressures exerted by livestock were estimated (Lull 1959):

	Weight		Static ground pressures	
	lb	*kg*	*lbs / inch*^{2}	*kg / cm*^{2}
Livestock:				
Sheep	120	54	9.2	0.6
Cattle	1350	612	23.9	1.7
Horses	—	—	20.0 to 57.0	1.4 to 4.0

A 150-lb (68-kg) person whose shoes have a bearing surface of 24 inch^2 (155 cm^2), exerts a static ground pressure of 6.2 lb per inch^2 (0.4 kg/cm^2). During normal movement, the pressures exerted may be doubled or quadrupled because all the weight may be put on one hoof or foot. Presumably, when running, the pressures exerted are greater. Unless the soil is dry, or otherwise firm enough to support these pressures, the soil structure deforms and compaction results.

A compacted soil restricts root penetration. On a highly compacted meadow, the fibrous roots of perennial grasses and rhizomes of grasslike plants may not be able to develop normally. Plants with strong taproots or shallow rooted annuals may therefore become dominant.

Table 12—*Preferences of grazing animals for individual plant species on three meadows in the Sierra Nevada, California, at four sampling dates*[1]

Species and meadow	August 1971				June 1972				July 1972				August 1972			
	N	O	E	χ^2	N	O	E	χ^2	N	O	E	χ^2	N	O	E	χ^2
Carex aquatilis:																
Markwood					56	1	9.9	9.7					170	68	102.0	28.4
Exchequer									56	7	11.6	NS	61	12	12.7	NS
Three Springs	44	17	20.6	NS					67	15	25.1	6.5				
Carex teneraeformis:																
Exchequer									3	3	0.6	11.4				
Carex vernacula:																
Markwood					44	2	7.8	5.2					15	7	9.0	NS
Exchequer													78	9	16.3	4.1
Three Springs	16	8	7.5	NS					24	4	9.0	4.4				
Danthonia californica:																
Markwood													55	38	33.0	NS
Three Springs									4	4	1.5	4.2				
Deschampsia caespitosa:																
Markwood					22	7	3.9	NS								
Exchequer									7	3	1.5	NS	48	11	10.0	NS
Three Springs	56	18	26.3	4.9					42	19	15.7	NS				
Deschampsia elongata:																
Markwood					6	2	1.1	NS								
Three Springs									3	3	1.1	5.0				
Dodecatheon jeffreyi:																
Exchequer													2	2	0.4	7.6
Three Springs									6	4	2.2	NS				
Hypericum anagalloides:																
Exchequer													5	1	1.0	NS
Three Springs									17	1	6.4	7.2				
Juncus oxymeris:																
Markwood					9	4	1.6	4.4					339	216	203.5	NS
Exchequer									48	20	10.0	12.7	140	39	29.2	4.2
Three Springs	34	25	16.0	9.7					39	32	14.6	33.1				
Pedicularis groenlandica:																
Markwood													24	22	14.4	10.0
Three Springs									2	1	0.8	NS				
Phalacroseris bolanderi:																
Markwood													11	5	6.6	NS
Exchequer									49	2	10.2	8.3	22	10	4.6	8.1
Polygonum bistortoides:																
Markwood					30	11	5.3	7.5								
Exchequer													34	25	20.4	NS
Three Springs	5	1	2.4	NS					3	1	0.6	NS				
Rumex Acetosella:																
Markwood					1	1	0.2	4.7								
Trifolium wormskioldii:																
Markwood					2	2	0.4	9.3								

Source: Clayton (1974).
[1]N = Number of shoots or plants encountered in sample.
O = Observed number of shoots or plants which had been grazed.
E = Expected number of shoots or plants grazed.
NS = Not significant-chi-square < 3.84 ($\chi^2_{0.05}$ with 1 degree of freedom).

Compaction may not be apparent in meadows having a high content of organic matter in the surface layer. In such meadows, owing to the resistance of organic matter, the surface layer may show little or no compaction. But soil below the surface may be compacted and restrict water movement and roots. Such compaction must in time become evident through changes in composition of the vegetation and breakdown of the sod.

Trampling can alter the chemistry of the soil. In Sequoia National Park, the soil solution at the surface was more acid in and adjacent to the trail tread through a wet meadow than in the undisturbed portions (Leonard and others 1968). The pHs at the junction of the John Muir and Crabtree Meadow trails showed effects of trampling:

Location or material:	pH
Slurry at bridge (trampled)	5.2
Muddy water in trail (trampled)	5.4
Below trail (undisturbed)	6.2
Forb meadow between trails	5.4
Water in trail tread	5.4
Mud in trail bottom	5.4
Carex seep (undisturbed)	5.8
Carex seep (trampled)	5.4
Incoming water to area	6.2

Also, the pH could be dropped as much as one unit by trampling the meadow surface. The pHs in Rock Creek and Crabtree meadows were different before and after trampling (Leonard and others 1968):

	pH	
Meadow and site:	Before trampling	After trampling
Rock Creek		
Near rock	6.1	4.3
Rusty sedge area	5.2	4.4
Crabtree		
Seepage at Cabin Spring	6.8	6.5
Eroded muddy area in seepage	6.4	5.4
Sphagnum moss patch	7.0	5.8

One effect of pH change associated with trampling may be to favor species that tolerate more acid conditions over those species that are less tolerant. Trampling, however, affects vegetation in other ways as well. The most obvious signs of trampling are holes punched in meadows by livestock. This effect of trampling cuts the sod and, if concentrated, kills the vegetation, resulting in a trail or a large mud hole.

Generally, as the number of passes over an area increase, compaction will increase up to a point of maximum density (Lull 1959). This, along with damage to the sod, is why trails develop across meadows.

For the most part, low levels of people trampling do not permanently affect meadow vegetation (Palmer 1979). Height growth of a shorthair site, however, was reduced the year after 600 tramplings. And a *Phyllodoce breweri* (red mountain heather) community showed no recovery 2 years after being trampled 210 times. Low trampling levels (only five passes) will crush and flatten most plants, making somewhat of a path. This can lead others to follow the same route and, therefore, eventually damage the vegetation and produce a trail. People, like cattle, tend "to follow the leader."

The degree and persistence of trampling damage by packstock are related to soil wetness at the time of trampling and the amount of trampling (Strand 1979b). On a short-hair sedge site (xeric hydrology), 100 passes by horse and rider made a ring that was visible 1 but not 2 years later. On a wet meadow site (with standing water), only 25 passes were enough to trample 90 percent of the vegetation into the mud. Foliar cover was reduced 75 percent 1 year later and 30 percent 2 years later.

Cattle create trails between meadows. They make lengthwise trails in long meadows. Seldom is a cow trail built across a meadow: on reaching a meadow, cattle normally disperse for grazing; on leaving a meadow, they gather to the trail from dispersed points. I suggest, therefore, that trails across meadows are made by people. Many such trails likely originated when people on foot or horseback followed a game, sheep, or cow trail to a meadow edge and then proceeded across to pick up a trail on the other side.

This is not to deny that free-to-roam livestock cause trampling damage. They can and do. Such damage may be especially obvious on hillside bogs where hoof cuts may not heal for several years. Sphagnum rich meadows like Charlotte Lake Meadow in Kings Canyon National Park are especially subject to this kind of damage (Strand 1979a).

To reduce compaction and trails in meadows, I suggest:

- Adjusting use, particularly of high-elevation meadows and soft meadow edges, to periods when the soil is firm enough to support grazing livestock.
- Closing (fencing) sensitive sites to livestock grazing and other people uses.
- Fertilizing meadows or sites most resistant to trampling damage to attract livestock and wildlife from sensitive sites.
- Locating salt grounds well away from meadows to improve livestock distribution.
- Routing trails to keep transient livestock and people off meadows.
- Instructing people to walk abreast rather than in line if they must cross a meadow.
- Instructing people to use a different route from camp each time they cross a meadow to get water. Moderate grazing to reduce the height of the vegetation may be needed to achieve this in some situations.

Trampling of meadows, at least in moderate degree and in some situations, may not be all bad. Animals and people may transport rhizomes and seed in mud adhering to their hooves or boots and effectively replant a disturbed or degraded meadow. Some compaction may reduce frost damage to meadow vegetation.

Trampling to some degree will occur so long as livestock and people are allowed on meadows. For practical purposes, therefore, trampling cannot be prevented. But the land manager needs to take measures to reduce its damaging effects.

Mineral Redistribution

Redistribution of minerals is a natural consequence of grazing. It is the least likely of the nine grazing factors (Heady 1977) to be altered by management practices. Nevertheless, it is frequently considered to have adverse effects on meadows.

Relatively small amounts of mineral nutrients consumed by herbivores are actually lost to the ecosystem (Pieper 1977). Of the minerals consumed, these amounts are estimated to be returned to the ecosystem in feces and urine: nitrogen (89.7 pct), phosphorus (61.9 pct), potassium (96 pct), calcium (86.5 pct), and magnesium (89 pct). Mineral losses resulting from livestock grazing a meadow, pasture, or allotment are therefore of little significance.

Redistribution of minerals may be of greater significance. "The net effect of herbivores on nutrient cycling is to remove nutrients from some areas and to concentrate them in others" (Pieper 1977, p. 266). Mineral nutrients are redistributed when animals consistently feed in one place and deposit excreta some distance away at "focal points ... water, salt, feeding areas, bed-grounds, and shade" (Heady 1975, p. 91). Percentages in dung of the total amounts in cattle and rodent dung and urine were estimated to be nitrogen (12 pct), phosphorus (77 pct), potassium (6 pct), calcium (72 pct), and magnesium (85 pct) (Pieper 1977). Each cow dung pat covers from 0.4 ft^2 to 0.8 ft^2 (372 cm^2 to 743 cm^2), but the total area affected is about 2.6 ft^2(0.25 m^2) (Castle and MacDaid 1972).

Cattle defecate 10 to 16 times per day and urinate 8 to 12 times per day (MacLusky 1960). Together, the dung and urine voided per day affects about 8 m^2 (Heady 1975). Unless livestock defecate and urinate on meadows in direct proportion to the amount of herbage consumed there, some redistribution of minerals will occur.

Conditions conducive to rapid decomposition — warm, moist environments — are usually present in meadows during the grazing season. Dung on seeded and fertilized pastures crumbled in 59 days and disappeared in 114 days (Castle and MacDaid 1972). Dung deposited in July disappeared more quickly than that deposited in June. Fertilization did not affect rates of crumbling or disappearance. On arid rangeland, however, dung decomposition was accelerated by nitrogen fertilization and irrigation (Lussenhop and others 1982). Mineral redistribution within a meadow shows up as short-term localized effects of dung pats and urine. The effects will be at a maximum one to two months after deposition and gradually decline over a period of about 18 months (Castle and MacDaid 1972).

Minerals are put into meadows through precipitation, fixation, mineral and organic matter decomposition, and runoff and sediments from surrounding slopes. Long-term effects of mineral redistribution from grazing likely become apparent only over many years. These effects show up as general changes in species composition, with increases in those animal and plant species best able to utilize the altered mineral state.

Mineral redistribution by people is potentially more of a problem than mineral redistribution by livestock. People redistribute minerals from distant ecosystems to meadows and their associated ecosystems. Livestock redistribute minerals within and among closely associated ecosystems.

An adult human will produce about 2.2 lb (1 kg) of dung and urine per day (Reeves 1979). Water makes up about 90 percent of the excrement; on a dry-weight basis, the daily production is 0.22 lb (100 g). From 1,000 visitor days, therefore, 220 lb (100 kg) of fecal material are deposited.

Decomposition rates of human dung in the Sierra Nevada are slow (Reeves 1979). The variables affecting decomposition rates of human and cow dung are basically the same, however. And decomposition rates of human dung may possibly be increased (at least on dry sites) by nitrogen fertilization, as was found effective on cattle dung (Lussenhop and others 1982).

Vegetation responses on and around small dung pits or "cat-holes" have not been studied. We cannot say, therefore, how human waste affects the vegetation of meadows. But meadows evidently do affect what happens to minerals and organisms in the dung and urine: meadows act as filters. Soils of the Sierra Nevada generally have a low degree of filterability (Reeves 1979). But soils of meadows were reported to be relatively efficient buffers against pollution of lakes and streams, possibly because of the organic matter content of meadow soils. Presence of a meadow between the place of fecal deposition and a lake or stream is therefore most desirable.

Burrowing

High rodent populations, particularly mice and pocket gophers, can considerably damage a meadow. The species composition may change through preferential grazing, and erosion may increase by channeling of water in burrows. Presence of rodents and their activities are not all bad, however. They are certainly a source of food for other animals (carnivores) and thus play a significant role in the functioning of meadow ecosystems. Also, their cultivation of the soil is often considered beneficial.

In 1965, high-elevation meadows in Sequoia National Park were much disturbed by rodents (Hubbard and others 1965). Most of the disturbance was caused by meadow mice (*Microtus* spp.); pocket gopher (*Thomomys monticola monticola*) activity was found only on a small scale. The mouse population was thought to have rapidly declined in late winter or early spring 1965 after reaching a high in 1964. It was thought that the population would prove cyclic, reaching a new high in 3 or 4 years. But followup study showed low mouse populations through 1969 (Giffen and others 1970).

Rodents in Gaylor Lake Basin, Yosemite National Park, were not distributed in either a random or uniform fashion (Klikoff 1965). Rodent activity was absent in wet meadows, but tended to be locally concentrated in dry meadows. Disturbance in moist meadows was intermediate. Belding ground squirrels (*Spermophilus beldingii beldingii*) and pocket gophers were causing most of the disturbance. The yellow-bellied marmot (*Marmota flaviventris sierrae*) was thought to cause less disturbance because it burrows under large rocks. Herbage consumption by the rodents was not considered a critical factor in plant distributions. But reduction of seed was thought to be a significant action of the rodents.

Pocket gophers in two meadows at Huntington Lake on the Sierra National Forest frequently cached food, used underground plant organs at all times, and used herbage mostly in winter by burrowing under the snow (Ingles 1952). Mound building began in May and reached a maximum in August and September. An estimated 7.5 tons (6.8 metric tons) of dirt for mounds were moved in one year on the two meadows. Gopher activities were, however, beneficial in building soil and conserving water (Ingles 1952).

"On wild land the burrowing rodent is one of the necessary factors in the system of natural well-being" (Grinnell 1923, p.149). Gophers aid soil formation and water conservation, and together with ground squirrels help to reverse the effects of soil compaction. The effects of pocket gophers on meadows and grasslands have received considerable study in other areas (Bronson and Payne 1958, Ellison 1946, Moore and Reid 1951). Through preferential grazing, gophers reduce some desirable forage plants. They also reduce some undesirable plants and thereby benefit some good forage plants. Gopher diggings make a relatively poor seedbed where the soil and vegetal cover are intact. But where plants are sparse, gopher diggings make a relatively good seedbed. They may provide a suitable environment for Sierra Nevada lodgepole pine (*Pinus murrayana*) seedlings in otherwise dense meadow vegetation. On meadows in good condition, gophers use a relatively small portion of the vegetation and are not a serious problem. But on meadows in poor condition, a few gophers may use such a high proportion of plants that improvement is prevented. Most gopher activity is seen in those areas where livestock grazing has reduced the plant cover and where the soil displaced thereby is most liable to be exposed to erosion. Livestock grazing — at least overgrazing — appears to reduce the good, and to accentuate the bad, effects of gophers.

Rodents influence meadow decomposition by loosening the soil and mixing organic matter with it (Vilenskii 1957). They thereby improve conditions for decomposer activity and help to speed the recycling of nutrients.

Lodgepole Pine

Invasion of Meadows

Sierra lodgepole pine is listed as *Pinus contorta* var. *murrayana* (Krugman and Jenkinson 1974). It is also considered a separate species (Munz and Keck 1959). Common names for the species are Sierra lodgepole pine, lodgepole pine, and tamarack pine (Little 1979). Other varieties of lodgepole pine — *P contorta* var. *contorta* and *P. contorta* var. *latifolia — are* in close kinship with Sierra lodgepole pine; available information on them should be considered. For convenience, this report uses *lodgepole* or *lodgepole pine* to refer to all varieties.

Lodgepole pine's remarkable physiological adaptability and its occurrence around and in mountain meadows make it a focus of concern to land managers. It has invaded many meadow sites. The trees reduce the area of open meadow, alter light and moisture available for herbaceous plants, and produce undesirable changes in species composition and productivity.

Invasion of meadow sites by lodgepole pine has been documented primarily by observations spanning many years. A sharp transition from open meadow to large, older trees gives the impression of a stable relationship between forest and meadow. A transition from open meadow to scattered small trees to larger trees to large mature trees suggests instability and change.

The best quantified data on invasion are provided by Vankat (1970). He determined ages of trees in and around meadows and dated the invasion by lodgepole pine as 1900 to 1905. Lodgepole pine reproduction was scarce between 1865 and 1900-the period of heavy grazing by sheep,

The following hypotheses related to invasion of meadows by lodgepole pine have been proposed (Leonard and others 1969):

> The establishment of lodgepole pine seedlings is inhibited or prevented at the germination stage by sod, dense meadow vegetation or dense organic surface material, and by saturated soil. Seedlings are inhibited from rooting by saturated soil and are highly susceptible to trampling on grazing sites free of exposed rocks. Growth and development beyond the vulnerable seedling stage are further inhibited by constantly saturated soil, and by trampling and browsing.
>
> A lodgepole pine that has developed beyond the seedling stage on a meadow site can be expected to follow a normal course of development and to grow relatively rapidly even in seasonally saturated soil, or constantly wet but well aerated soil. The development of a stagnant, constantly saturated root environment is one exceptional circumstance that can lead to the decline and death of a sapling or mature tree over a period of several years.

Assuming that these hypotheses are true, in order to stop or reverse the invasion process, we need to understand the requirements of lodgepole pine for seed germination and seedling establishment. And we need to understand how management can modify the meadow environment to prevent occurrence of those requirements.

Growth and Establishment

Lodgepole pine can become established, grow well, and reproduce in soil environments that apparently are unfavorable to other conifers. It also grows under conditions in which the other conifers grow, including near tree-line environments. Although not always the dominant tree species, lodgepole pine probably grows in most montane and subalpine meadow edges of the Sierra Nevada.

Sierra lodgepole pine grows in an elevational range of about 5,000 to about 11,000 ft (1,525 to 3,353 m). the trees grow from 50 to 130 ft (15 to 40 m) tall. They produce pollen in May and June (Krugman and Jenkinson 1974), and cones ripen and disperse seed in September and October. Sierra lodgepole pine does not have serotinous cones; rather, the cones open soon after maturity and do not persist long on the trees. Seed production can start at 4 to 8 years of age, and normally a large seed crop is produced each year. The average number of cleaned seeds is 117,000 per lb (257,938/kg). About 200 lb (91 kg) of cones are required to obtain a pound of seed. Stratification of fresh seed is not needed to induce germination; however, for stored seed, stratification at 33° to 41° F (0.6° to 5° C) in a moist medium is recommended. Germinative capacity averages about 75 percent. A 70 percent germination of lodgepole pine seed collected at Rock Creek in Sequoia National Park was reported (Harkin and Schultz 1967).

Lodgepole pine regenerates best on mineral soil or disturbed duff free of competing vegetation and in full sunlight (Tackle 1961). The seed of lodgepole pine requires a small amount of light for germination, but the seedlings require considerable light to ensure satisfactory reproduction (Mason 1915). The best seedbed is a mineral soil with plenty of heat and available moisture; layers of needles or undecomposed humus may dry out before roots can reach the mineral soil. In Oregon, seedbeds of mineral soil supported about twice the number of seedlings as undisturbed litter (Trappe 1959). In summary, lodgepole pine needs a mineral seedbed in well-lit, warm, moist environments.

One study reported on effects of low temperatures and compared lodgepole and ponderosa pine seedlings (Cochran and Berntsen 1973). Thirty-six-day-old seedlings suffered greater mortality from night temperatures of 18°F (-7.8°C) than did 22-day-old seedlings. Younger seedlings of lodgepole pine can therefore stand lower night temperatures in spring than older seedlings. If a period of warm temperatures (just above freezing) is followed by temperatures of 20°F (-6.7°C) or less, mortality is reduced. Also, seedlings grown until fall under natural photoperiods can withstand minimum night temperatures of 15°F (-9.4°C), showing that shortening photoperiods are conducive to hardiness. It appears that only extremely cold night temperatures in spring could prevent lodgepole pine establishment in meadows. Such temperatures may occur in some meadows because of cold air drainage.

If other conditions are suitable, abundant germination of lodgepole pine seed may be expected in meadows soon after soil warms in spring. A study of the effects of temperature on germination of lodgepole pine seeds found that the optimum temperature was about 70° F (21.1°C) (Bates 1930). Temperatures above 82°F (27.8°C) or below 60°F (15.6°C) reduced germination. Fluctuating temperatures with the daily mean at 65° to 70° F (18.3° to 21.1 ° C) gave the best rates of germination. The response to fluctuating temperatures was considered to be linked with the species' habit of reproducing in exposed areas with great daily extremes in temperatures. The maximum and minimum temperatures of 48° and 38°F (8.9° and 3.3°C) at one centimeter from the south side of rocks (Leonard and others 1968) approximate the fluctuation stated earlier.

At 50 percent full light intensity, lodgepole pine seed germination was 22 percent (Boerker 1916). At 16 percent of full light intensity, germination was 7.5 percent; at 2 percent of full light, 3.5 percent. These data indicate lodgepole pine's need for light.

Moisture Effects— Physiological responses of lodgepole pine to soil moisture were studied along Rock Creek in Sequoia National Park (Leonard and others 1968, 1969). Pressure chamber readings on cut branches were taken as measures of physiological response. A branch (with its cut end protruding through a stopper) was sealed in a pressure chamber. The chamber was gradually pressurized with dry nitrogen gas; the pressure was recorded when water became visible at the cut surface.

Except on a porous moraine (dry site) in 1968, lodgepole pines under all site and seasonal conditions registered pressures almost entirely below 200 pounds per square inch (psi) (14/kg/cm^2). Diurnal pressures in September, however, peaked at about 225 psi (16 kg/cm^2). Pressures on the dry site approached 250 psi (18 kg/ cm^2) toward the end of summer. A pressure of 200 psi (14 kg/cm^2) represents a level of stress of significance for lodgepole pine. That pressure was exceeded only under circumstances of depleted soil moisture, excessively high evaporative stress, fungal infection of the needles, or an obviously poor crown condition.

Midwinter pressure readings showed that soil moisture was readily available. Except for a few surface centimeters, the soil was not frozen. Water and nutrients are therefore available for metabolic processes of lodgepole pine even in the dead of winter. Water movement in the trees is normal, at least when leaf tissue is not frozen.

Lodgepole pine is tolerant of soil saturation, thus able to survive and grow in meadows. No differences in physiological response were found among trees along a gradient from saturated meadow soils to porous moraine soils. Soil saturation did not appear detrimental to lodgepole pine. Deliberately flooded trees had low pressures and high rates of transpiration, indicating efficient water absorption by the flooded roots.

Continuous saturation lasting for several years could nevertheless contribute to tree mortality. Mortality of lodgepole pine in some normally saturated situations was observed. Long-term saturation of the trees may result in preferential attack by fungal infections of the needles. Characteristic fungal reproductive structures in needle specimens indicated that damage was caused by *Hypodermella montana.* Crowns of weakened trees were sparser than uninfected trees and showed some yellowing. Severely affected branchlets had shed all but the current crop of needles and their terminal buds were often-dry and brown. Although such fungal infections may not kill the trees, they can weaken them. These trees may then become susceptible to secondary attack by bark beetles. Evidence of bark beetle attack was observed in dead trees.

Disturbance by Livestock and Rodents— disturbance by livestock is the usual reason given for the invasion of meadows by lodgepole pine. Grazing— especially sheep grazing— and its influences on the vegetation and soil modified the meadow environment creating a suitable niche for lodgepole pine (Vankat 1970), and I believe that statement to be true. However, I also believe the proposition must be accepted that meadow invasion by lodgepole pine can be autogenic— the result of plant succession— and not always the result of allogenic effects.

On biologically and geologically stable meadows, the opportunities for invasion by lodgepole pine are few (Benedict 1981, 1982). Instability can result both from natural causes and from human activities.

If geologic or climatic change can induce instability in a meadow system by permitting lodgepole pine invasion, geologic or climatic change can induce instability in a forest system by permitting meadow invasion. That such events occur in the Sierra Nevada has been well demonstrated (Wood 1975). Over geologic time, meadows have developed, disappeared, and redeveloped at the same geographical locations.

From studies of stand age structure of trees contiguous with meadows, it has been hypothesized that sheep grazing and fires set by sheepherders to facilitate the movement of their flocks prevented regeneration of lodgepole pine, thereby stopping the process of invasion (Vankat 1970). This situation was photographed at Jackass Meadow on what is now the Minarets Ranger District of the Sierra National Forest (Sudworth 1900). The picture shows a fence line situation. The caption states that within the fenced area lodgepole pine reproduction was abundant, but outside, where sheep grazed heavily, only scattered large trees grew but did not reproduce. Grazing pressure and recurrent fires set by sheepherders were responsible for the lack of tree regeneration in the Rock Creek area of Sequoia National Park (Sudworth 1900).

Certainly, we can associate overgazing with soil disturbance and loss of vegetative cover. Sheep grazing during one 9-year period (1864-1873) was blamed for creating "a gray sea of rolling granite ridges, darkened at intervals by forest, but no longer velveted with meadows and upland grasses" on the Kern Plateau (King 1902, p. 351). Sheep, through trampling and grazing, can destroy fragile sods and effectively denude some meadows.

Although it prevented or checked the invasion of meadows by lodgepole pine, heavy grazing may have provided bare mineral soil and reduced mulch and competition, thereby predisposing meadows to invasion. We know that large areas of meadow were invaded by lodgepole pine soon after 1900, and that this invasion coincides with the end of heavy concentrations of sheep. We can therefore hypothesize that human activities, within historic times, have both impeded and encouraged lodgepole pine invasion.

Probably, lodgepole pine invasion of meadows is most strongly related to sheep grazing; however, cattle can cause severe disturbance to meadows. That continued invasion by lodgepole pine into meadows can be ascribed to forces set in motion during the time of sheep grazing is difficult to determine. We know that the current invasion has been occurring on ungrazed meadows and on meadows grazed continually since about 1900.

Grazing may indirectly cause invasion by lodgepole pine by affecting gopher activity and populations of some seed-eating rodents. Overgazing often aggravates the normal effects of gophers. And overgrazing may expose other rodents to greater predation, thereby reducing the amount of lodgepole pine seed consumed and improving changes for seedling establishment.

Although he did not fully evaluate the effects of pocket gophers, Buchanan (1972) suggests that they may play a role in lodgepole pine invasion. Surface soil deposits may benefit survival of lodgepole pine seedlings. These deposits provide the mineral seedbeds apparently required. Gopher mounds are slightly raised, not as deeply shaded by herbaceous vegetation as the undisturbed soil surface, and are relatively free of competing vegetation. Pocket gopher mounds covered about 5 percent of the meadow and 4 percent of the meadow-forest ecotone, providing a sizable area of suitable seedbed (Buchanan 1972). Where livestock no longer graze— as well as where they do— gopher activities may contribute to meadow invasion by lodgepole pine.

Snow Depth— In the Sierra Nevada, most lodgepole pine seedlings become established in years of low snowpacks (Wood 1975). Length of the snow-free period may be the most critical variable in tree invasion of subalpine meadows (Franklin and others 197 1). Tree invasion is related to periods of below-normal snowpacks and earlier snowmelt or to a long snow-free period after melt. A good seed crop followed by an early melt of snow can be expected to result in significant tree establishment. Where snow is deep, conifers do not usually reproduce (Billings and Bliss 1959). In the "ribbon forests" of the Rocky Mountains, tree seedlings were protected by snowpacks on their windward side (Billings 1969). Deep snowpacks resulted from the ribbon of trees immediately to windward. Adjacent to and in the lee of that ribbon, snowpacks were generally too deep and melted too late to permit tree establishment.

From these reports, we may expect that deep, long-lasting snowpacks tend to inhibit lodgepole pine invasion of meadows. But studies have not proven this to be fact.

A weather modification that increases snowpack could enhance conditions for lodgepole invasion (Buchanan 1972). Lodgepole pine seedlings, 2-0 stock, were planted in meadows, forests, and forest-meadow ecotones of the Bridger Range, Montana. Survival of the seedlings was lowest in the meadows and increased with increasing snow depth up to 7.9 ft (240 cm). Naturally occurring lodgepole, 1.7 to 6.7 ft (0.5 to 2 m) tall, increased in frequency with increasing snow depth ($r = 0.7$). Frequency of small seedlings was significantly correlated ($r = 0.36$) with snow depth on the meadows. Survival of planted lodgepole pine and presumably natural reproduction was explained by the relationship of snow and availability of late-season moisture. From this, we may expect the greatest invasion activity at the forest-meadow ecotones where snow accumulates to depths of not over 8 ft (244 cm) and melt is slow.

It seems reasonable that periods of low snowpack and early melt may be necessary for seedling establishment. Once established, the young trees are protected from cold temperatures, wind, physiological drought, and browsing by a deep, long-lasting blanket of snow. If the snowpack is deep enough and lasts long enough, survival of invading lodgepole pines should be reduced.

In the Sierra Nevada, lodgepole pine is frequently cut, piled, and burned to enlarge or reclaim a meadow. Although cut for lumber, it is not usually considered prime timber for manufacture. It is cut commercially for fence posts and firewood. Size and orientation of the openings from harvest or other removal of lodgepole pine influence snowpack depth and melt. General references on forest-opening effects on snow accumulation and melt are available (Anderson 1956, 1967, Berndt 1965, Gary 1980, Niederhof and Dunford 1942).

The largest snowpacks are observed on southern edges of openings shaded by trees, a few meters immediately to the lee of bordering trees, or where opening width is about equal to the height of the trees around it. Snowpacks on large forest openings disappear before the pack in long, narrow openings with an east-west orientation. Because of reduced radiation, the pack melts more slowly in openings with a north aspect and on well-shaded openings. Northern edges of openings usually accumulate less snow because of direct solar radiation and back radiation from trees. Where meadow reclamation is an objective, lodgepole pine harvest should be planned to take full advantage of these relationships.

Soil Conditions—The nature of the soil may influence whether lodgepole pine is able to invade a meadow. Lodgepole pine grows in shallow depressions (Howell 1931). There, clay pans form resulting in a perched water table. Lodgepole has been observed growing on two general soil types—well and excessively well-drained, moderately coarse to coarse-textured soils; and poorly and very poorly drained, organic soils (Stephens 1966). Medium to moderately fine textured soils, and moderately well drained, but moderately coarse to coarse textured soils lacked lodgepole pine. Lodgepole pine is considered a pioneer species on droughty, low fertility soils and on wet, organic soils (Stephens 1966). It is also considered a pioneer on bars of cobbles, rocks, and sand along the Kern River (Hubbard and others 1966).

A relationship of seedling, sapling, and larger trees with rocks in meadows has been observed (Leonard and others 1968). Higher maximum soil temperatures immediately adjacent to rocks and absorption of energy by the rocks could provide a more favorable environment for lodgepole pine than meadows away from rocks. Other microenvironmental conditions near rocks that may favor lodgepole establishment include exposed mineral soil, better soil texture, better aeration and drainage, and early snowmelt.

Soil moisture near rocks was 143.3 percent. But 4 ft (1.2 m) away from rocks, soil moisture was 351.3 percent. Soil particles 2 mm or less averaged 83.5 percent of the bulk sample near rocks and 96.3 percent of the bulk sample four feet (1.2 m) away from rocks (Giffen and others 1970). Moisture content is not independent of the percentage of fine soil particles.

Lodgepole pine roots have an affinity for rocks (Preston 1942). Roots tend to group adjacent to a large rock and some roots may penetrate the rocks. This affinity may be a nutrient reponse in an otherwise rather sterile soil.

In my studies of mountain meadows, I observed an apparent affinity of lodgepole pine for rocks in some, but not all, meadows. Where the soils are mainly of organic origin, rocks may provide a better habitat. On mineral soils, texture and drainage may be the controlling characteristics.

Fire

Fire as a part of the natural environment of many vegetation types in California has been receiving greater recognition during the last several years (Botti and Nichols 1980, Gordon 1967). Evidence strongly suggests that fire plays a significant role in the evolution and maintenance of meadows of the Sierra Nevada (Sharsmith 1959). Fire has been thought to influence the forest-meadow boundary (DeBenedetti and Parsons 1979, 1984; Parsons 1981).

Fire has a role in meadow evolution and maintenance in other mountain regions as well. In the Cascades of Washington and Oregon charcoal and rotting wood are uncommon in meadow soils and fire is not an important variable (Franklin and others 1971). In the Olympic Mountains of Washington, however, fire is a major variable in meadow creation and maintenance (Kuramoto and Bliss 1970). Between 1870 and 1880 fire destroyed much of the subalpine forest around James Peak, Colorado, permitting downward extension of alpine vegetation (Cox 1933). Destruction of ribbon forest by fire could result in new snowdrift patterns and replacement of forest by alpine or subalpine meadows in the Rocky Mountains (Billings 1969). And old records show fire is a natural ecosystem component of "Crex Meadows" in northwestern Wisconsin (Vogl 1964).

Meadows are not likely to burn when the herbage is grazed or in years of normal precipitation. Meadows may burn when herbage is tall and dry and during droughts. A fire crossing a meadow having high soil moisture usually consumes only current growth and some mulch. With very dry conditions, fire may damage the meadow considerably (DeBenedetti and Parsons 1979, Parsons 1981). To understand how fires affect meadows, we need to know how fire frequency and fire incidence relates to meadows and their watershed.

Fire frequency is the time between fires at particular points; fire incidence is the time between fires within a particular area (Kilgore and Taylor 1979). The larger the area considered, the greater the fire incidence. A higher fire incidence may be expected on its surrounding watershed than on a particular meadow. And, with their normally drier fuels, points in forests may be expected to burn more frequently than points in adjacent meadows. Fires in their watersheds are therefore apt to influence meadow ecology more often than fires directly on meadows. Increased water flows and sedimentation are likely the most significant effects of fires in the watershed. Fires that directly burn meadows will, of course, have greater and immediate effects on meadow ecology.

Fire History

Brush and forest fires have prevailed in California since the earliest recorded times (Sterling 1904). Fire frequency in portions of Kings Canyon National Park and Sequoia National Forest was 8 to 18 years between 1478 and 1875 (Kilgore and Taylor 1979). Fire incidence in the watershed areas was 1.7 years during that period.

Particular forest sites burned more often than expected from lightning alone (Kilgore and Taylor 1979). Burning by American Indians also augmented fire frequency. After 1875, fire frequency decreased markedly. Only 5 percent of all fire scars dating back to 1478 dated between 1875 and 1939. During 10 years (1865 to 1875), burning by herdsmen and others replaced burning by American Indians (Kilgore and Taylor 1979). American Indians regularly burned the mountains and sheepmen came and continued the practice (Sterling 1904). Setting fires apparently was declining as a regular practice even before fire suppression became effective.

Fuel conditions at higher elevations are lighter and fire crowning is currently not as serious a problem as at lower elevations (Kilgore 1971). Fire scars at the higher elevations were less frequent than at the lower elevations (Kilgore and Taylor 1979). Above about 7,500 ft (2.286 m), any role played by fire in meadow development diminished in importance (Sharsmith 1959). Lower elevation meadows are likely more often affected by forest fires than are higher elevation meadows.

Major fires (or at least fires of more than a few acres) may be required to produce geologic effects on meadows. Evidence of fire is frequently found in profiles of meadow soils. Five layers of charcoal were deposited in one meadow (Wood 1975). The deposits were all less than 1200 years old. These layers support that idea that major fires in the watersheds normally occur at intervals of 250 to 300 years.

Fire associated with the history of meadows along Rock Creek in Sequoia National Park was on approximately that time scale (Leonard and others 1969). Charcoal was found in the 7 to 15 inch (18 to 38 cm), 21 to 24 inch (53 to 61 cm), and 29 to 33 inch (74 to 84 cm) layers of the soil profile. The charcoal was found mainly in sand and gravel sediments, indicating that it came from slopes above the meadow. Evidence of the most recent fire was found on the slopes, and older trees seemed to correspond to earlier charcoal deposits. Ages of the trees dated the last two major fires in the Rock Creek area at 1900 and between 1700 to 1670.

Because of its relatively thin bark, lodgepole pine is more susceptible to fire damage than other pines (Mason 1915). Fire is most destructible to dense young stands. Higher mortality of lodgepole pine than of red fir (*Abies magnifica*) due to fire has been reported (Kilgore 1971). Although many mature lodgepole pines were killed, burning appeared to provide conditions favorable to lodgepole pine seedling establishment.

Evidence of two fires along Rock Creek was found (Harkin and Schultz 1967). The oldest was judged to be about 70 years old and would correspond with the 1900 fire cited to earlier. A younger, 1962 fire was thought to have been caused by a fisherman. That fire spot burned over a beaked sedge site and a hanging meadow that contained willows (*Salix* spp*.).* Upon leaving the meadow, the fire burned upslope and killed most trees on drier areas. Trees and willows within the meadow were not killed, but patches and stringers of trees outside the meadow boundaries were killed (Giffen and others 1970).

Part of a meadow along Rock Creek was intentionally burned in late fall 1969 (Giffen and others 1970). The burn was reportedly light because of low fuel volumes. Small trees in the path of the fire were not killed. In 1970, no visible differences between burned and unburned portions of the meadow were evident.

Prescribed burns to improve deer habitat on the Sierra National Forest have affected some meadows (Bertram 1982). Although not actually crossing the meadow, fire destroyed some down logs in Three Springs Meadow. Destruction of these natural check dams could have resulted in accelerated erosion and gullying. At Cabin Meadow, some areas had become dry enough to allow white fir *(Abies concolor)* to establish. Dead lodgepole pines in those areas were felled to provide ground fuel. The burn produced substantial kills of lodgepole pine trees up to sawlog-size and of sapling-size white fir. Meadow vegetation in the burned areas had expanded by the next. year.

The only documented instance of a wildfire burning a meadow in the Sierra Nevada is that reported by DeBenedetti and Parsons (1979, 1984) and Parsons (1981). Started by a lightning storm, the fire reached Ellis Meadow, Kings Canyon National Park, at 8,800 ft (2,682 m) in early August 1977. By the end of September, the meadow was still burning and about 60 percent of its 30 acres (12 ha) had been burned. Intensity of burning and depth of burning varied from place-to-place in the meadow. Areas with wideleaf sedges burned most intensively, and the ash layer reached a depth of 15 inches (38 cm) in some places. One year after the fire, grass and grasslike species made up only 8 percent of the ground cover; by 1981, they had increased to about 75 percent. The most serious aspect of this fire appears to be the loss of the deep peat layers built up over many, many years. The species composition reported the year after was mostly what one could expect to find on heavily grazed meadows. In 1981, vegetation was thought to be succeeding toward species characteristic of the prefire state. Catastrophic change had not occurred.

Fire Management

Not enough is known about fires in meadows to prescribe their use as a management tool. We have much to learn about the use of fire in the meadow environment, and it must be used with proper safeguards. A few observations are available, however.

A light fire across a meadow appears to affect vegetative composition only slightly. But changes in herbaceous vegetation that would result after a hot fire in a meadow appear undesirable. Because of this, any prescription for the use of fire must consider the soil moisture condition.

Because it is unlikely that fire crosses a meadow until the vegetation is mature and dry, fire affects the forage available only slightly. On grazing allotments, however, a season of nonuse may be needed to provide enough herbage to carry a fire.

Fire on a watershed can have marked effects. Probable changes in runoff and sediment loads need to be considered—especially if a large area is to be burned. A large increase in runoff through a meadow may result in gully formation. But a sediment load in the runoff is necessary if gullies are to be filled in behind check dams. Logs in meadows are natural check dams, and care should be taken not to burn them.

Years of low snowpack and early snowmelt may favor lodgepole pine seedling establishment. Unless followed by late spring and summer rains, these conditions are also likely to be conducive to fire. Fire-caused mortality of lodgepole pine has been reported, but fire has also been reported to stimulate lodgepole seedling establishment.

It appears possible to use fire to manipulate succession on the edges of meadows. Succession to forest was set back at Cabin Meadow on the Sierra National Forest (Bertram 1982). Tree invasion at Ellis Meadow in Kings Canyon National Park had been slowed by fire and no trees were established in burned areas through 1981 (DeBenedetti and Parsons 1979, 1984; Parsons 1981). Trees growing in hummocks in the meadow, however, survived the fire. Light fires may kill some seedlings. Fires hot enough to kill trees established in the meadow proper will likely do great damage to the meadow itself. And under conditions suitable for a hot fire, restriction of the fire to the target area may be almost impossible.

Gully Erosion

Prevention or control of erosion is the key to maintaining or restoring the hydrologic characteristics of a meadow, thereby maintaining or restoring the meadow itself. Erosion removes the protective sod and productive topsoil, and subsequent gully formation alters meadow hydrology by lowering the water table. Poorer soil and altered hydrology induce change in the vegetation—usually toward a less desirable plant community.

Erosion control in mountain meadows has a threefold purpose: to check the progress of active gullies, to bring about a refilling of the deeper gullies, and to restore the water tables. The objective is not only control, but rehabilitation.

Erosion is the transporting of soil by the actions of wind or water. It is a natural geologic process whereby disintegrated rock and soil are picked up and, if transported by water, moved to and deposited at a lower elevation. Sheet erosion is the removal of layers of soil from continuous areas. In mountain meadows, the natural sod of sedges, grasses, and forbs usually protects the soil from sheet erosion, but it does not always offer adequate protection against gullying. Gully erosion is the cutting of channels, and on-site erosion in meadows is most apparent as gullies.

A gully characteristically works up a stream from the lower end. A common example is where a main stream bed is quickly cut down by abnormal erosion, leaving undisturbed tributary channels perched at the former level. Such tributary channels cut back rapidly and in mountain meadows often form deep gullies where only shallow swales existed before. Where a break in the channel gradient occurs, a waterfall is formed. Breaks in the channel gradient designate a gully as a discontinuous type (Heede 1960). The falling water churns against the bare earth behind the falls and erodes the soil rapidly at this point. This is called "plunge-pool action" (Emmett 1968). An alternate erosive action is "sapping." Groundwater flows from the face of the gully head, washing away friable material below the sod. At the top of the gully head, the soil—held together by the roots of the meadow sod—is able to resist erosion. As undercutting proceeds by plunge-pool action, sapping, or both, the sod-crest begins to overhang the subsoil. From time to time, chunks of this overhanging sod break off and fall into the gully. The rate a gully head works upstream therefore depends on the soil structure and texture, the amount of root binding material, the maximum flow of the gully, the flow of groundwater, and the gradient of the channel. Its progress is steady until mea-sures are taken to stop the undercutting. As erosion of the gully heads proceeds, individual segments of a discontinuous gully join to form a continuous gully (Heede 1960).

Most meadow gullies have vertical sides with rims of overhanging sod. Unless corrected, this condition continues by constant undercutting of the sides. This situation should not be confused with the overhanging sod along permanent streams. There, the overhang is considered beneficial as fish habitat.

Erosion Control

Gully control is an effort to restore a stable condition in an intrinsically unstable situation where natural forces are seeking to establish a new stability. On the other hand, it lowers the effects of extrinsic variables to below their threshold levels in order to achieve stability.

The concept of meadow stability has been discussed (Benedict 1981, 1982, and Benedict and Major 1982). A meadow may be geologically and biologically stable, geologically stable and biologically unstable, or geologically and biologically unstable. The situation of a geologically unstable and biologically stable meadow is untenable. As long as the geologic conditions favorable for meadow formation persist, biological instability can eventually be overcome. Biologic stability has to do with condition trend rather than the ability of a meadow to withstand and recover from abuse.

Geologic stability depends on favorable conditions for meadow formation and maintenance. As such, the concept of geologic stability includes stability in intrinsic and extrinsic factors.

Presence of a dissecting gully has been taken as evidence of a meadow's instability (Wood 1975). Wood attributed meadow instability largely to damage to the sod by livestock grazing. Under the protection of undamaged sod, most gullied meadows had previously built up steeper slopes than allowed by their watershed areas.

And that is the concept of geomorphic thresholds (Schumm 1977). As material from the watershed is deposited, the valley (meadow) slope progressively increases until a threshold slope is reached and erosion of the valley (meadow) fill occurs. "Large infrequent storms can be erosionally significant, but only when a geomorphic threshold has been exceeded are major permanent changes the result" (Schumm 1977, p. 81). Variables intrinsic to landform development can induce erosion, and a change in an extrinsic variable is not necessary for the geomorphic threshold to be exceeded. On the basis of geomorphic threshold, then, livestock grazing or other disturbances should result in significant gully formation only after a meadow has evolved a slope-to-watershed relationship at which erosion, rather than deposition, can occur. But once slope is at or near threshold, the intrinsic process of erosion may be accelerated by extrinsic variables (Wood 1975).

Extrinsic variables also have thresholds (Schumm 1977). Grazing by livestock, for example, is an extrinsic variable. If the grazing effect is above the threshold level, the density of the vegetative cover may be reduced. In turn, though volume is constant, the hydrologic threshold of flow velocity may be exceeded because less vegetation is available to dissipate the energy. Soil erosion and possibly gully formation are the result.

Other extrinsic variables which may cause intrinsic variables to exceed their threshold values include denudation of the surrounding hills by logging, fire, or both; construction of highways and roads where roadway drainage concentrates water flow into a meadow; and destruction of the protective sod for crop agriculture.

Control Measures

There are no recent guides for erosion control specific to meadows of the Sierra Nevada. Instructive, up-to-date procedures for erosion control are, however, available (Heede 1965, 1966, 1977). And his discussion of early erosion control structures is excellent (Heede 1960).

The handbook on erosion control in mountain meadows (Kraebel and Pillsbury 1934) is directly applicable to meadows of the Sierra Nevada. It covers materials, design, and construction of control structures that are useful where costs or esthetics limit machinery, such as in wilderness areas. Unfortunately, the handbook is not generally available. But, as appropriate, parts of it are summarized below.

A complete control project includes an initial assessment, proper range management, rodent control, building of proper structures, and planting of appropriate vegetation. The initial assessment aims to determine if the meadow slope is over the geomorphic threshold, if erosion is occurring at an accelerated rate, and if accelerated erosion results from human activities on the meadow or other activities in its watershed. Proper range management aims to restrict grazing until the gully has been stabilized, followed by a regime that maintains the stabilized condition. Elimination of grazing is not called for if the meadow is geologically and biologically stable. Proper grazing management can improve meadow condition in a situation of geologic stability but biologic instability. Elimination of grazing may slow the demise of a meadow but, in a situation of geologic instability, will not restore a meadow. Rodent control aims to prevent excessive burrowing and consumption by rodents of young plants artificially introduced as part of the gully control. Building proper structures is designed to fill gullies and control erosion until natural or introduced vegetation becomes vigorous enough to make control permanent. The focus must be on the watershed mouth (Heede 1960, 1981), representing the base level of the watershed: what happens there affects the entire upstream area. The key is to first control that point. Work can than proceed upstream. Planting appropriate vegetation makes control measures more effective and permanent.

Materials Specification—The criterion for selecting materials for gully control structures is that satisfactory materials be readily and cheaply available.

Dam brush—chaparral is a satisfactory material, although tree branches are easier to handle. The brush should be somewhat flexible, preferably green, and heavily leaved. Dry, brittle brush is difficult to handle and does not make a satisfactory dam. The brush should be cut small enough to pile easily into a dense mass. The maximum convenient length is 3 or 4 ft (0.9 or 1.2 m). **Apron brush—**the requirements for apron brush are the same as for dam brush, except that it must be long and flexible. Willow and branches of various evergreen trees are excellent. **Litter—**any finely textured vegetative material can be used beneath aprons and against the upstream faces of dams. The best and most readily available material is the forest litter or leaf mulch that may be raked up from beneath the trees. **Trees—**where specified, trees should be freshly cut and have a dense foliage. Only evergreen trees should be used. **Logs—**these should be straight, sound, and of the sizes specified. **Posts—**any good fence post material is satisfactory. **Stakes—**any sound coniferous wood that does not rot quickly is recommended. If possible, use willow stakes, which may take root and grow. **Poles—**these should be straight and of sound wood. **Rock—**flat or angular rocks are far superior to round cobbles, since they have less tendency to roll during floods. Never take rocks from gully bottoms or other places where rocks provide a natural pavement. **Poultry netting—**commonly called "chicken wire," any convenient width is suitable. **Wire—**galvanized iron wire (No. 9 to No. 12) is recommended.

Gully Head Control—Plugs or mattresses constructed against a gully head have the immediate effect of stopping the plunge-pool action in undermining the head. They may not be effective against sapping action, however. A compact layer of litter must be packed against the head itself to stop undercutting, against the side near the head to prevent side cutting, and along the bottom to serve as cushioning apron. The litter must be firmly held in place to prevent being washed out during floods. This usually entails placing good-sized tree branches or brush over the fine material which, in turn, must be secured with posts, stakes, rocks, or other large material. The catch basin behind a check dam placed a few yards or meters downstream from the gully head will fill with sediment within a few years. This reduces the height of any drop in the stream bed level between the dam and the gully head and minimizes the danger of a new gully starting.

If the channel carrying runoff immediately above the gully head is heavily sodded, and if, as a consequence, a definite overhang of the crest is at least 6 inches (15 cm), it is practical to plug the head without modifying the slope. If the gully head has no definite overhang and slopes slightly upstream, it is advisable to cut the slope back so that runoff has a gradual, rather than vertical, drop. To protect this bare slope until the catch basin behind the downstream dam has become silted, the headslope must be covered with a mattress that extends along the bottom of the gully for 4 ft (1.2 m) or more to serve as an apron. Where gully head plugs or mattresses are not feasible, gully heads should be sloped back to the natural angle of repose of the soil and permanently stabilized with appropriate vegetation.

Flumes have sometimes carried water over a gully head. But the expense and care of their construction is ordinarily prohibitive. Spreading water—diverting it away from the gully above the head by a system of ditches—is preferable. Unfortunately, sites where water spreading is feasible are uncommon in the Sierra Nevada. In some situations, however, meadow-edge trees can be felled above gully heads to effectively spread the water. Trees falling into meadows is a natural process as evidenced by the presence of logs in the profiles of most montane meadows in the Sierra Nevada. And, frequently, trees falling across drainages will result in the development of a kind of hanging meadow.

Gully Channel or Bank Control—Mountain meadow channel control requires stabilizing the banks of well-established gullies and stream channels that traverse or border the meadows. Meandering streams that need control with jetties, riprap, and similar structures are seldom, if ever, observed in mountain meadows.

Channel control consists of breaking the current, filling washes, and bank fixation. Light structures, such as hog wire or chicken wire fences, can be constructed to break the force of water. Such structures, where effective, result in the deposi-tion of materials suspended in the water. Logging slash or similar material—tree tops, branches, and trash from cutting posts—can be placed in the channels. Such materials tend to slow the current and cause silt to be deposited. Bank fixation requires that banks of gullies and streams be sloped to the natural angle of repose of the soil. The aim is to make the bank sufficiently stable to support a cover of either natural or introduced vegetation. Normally, banks of about 70 percent slope are stable, but some soils may be stable at steeper angles. Most meadow gully banks become naturally overgrown when sloped back. If revegetation is required, sod should be planted or the slopes seeded. If the channel banks become loose and erode during rain, wattles should be constructed to stabilize them.

Once cut back, the slope usually requires protection until vegetation becomes fully established. A system of contour wattle construction, as on road slopes, can be adapted to control gully banks. A wattle is a continuous bundle of vegetation intended to hold the soil and interrupt the water flow down the slope. Wattles are usually spaced every 2 to 4 ft (0.6 to 1.2 m) along a slope. They can be effective on banks that have been sloped, where side gullies have started or are apt to start, on banks or gully heads that have a loose soil and little vegetative cover and are sloped to the natural angle of repose of the soil, and on wide or deep gully heads too large for practical use of normal gully head controls.

Several types of wattles are used. Sod strips 10 to 12 inches (25 to 30 cm) wide should be spaced about 30 inches (76 cm) apart. Terraces need not be made. The strips must be bedded firmly into the slope. Continuous hay or pine needle rope wattles are constructed by filling small trenches cut around the slopes on the contour or by using willow stakes to hold the ropes in place. Similar wattles can be constructed of brush.

The method of wattle construction depends on soil type, looseness of the slope, soil moisture conditions throughout the year, and anticipated flood flow. Normally, a combina-tion of wattle types provides the best slope protection at the least cost.

On a soil moist enough all year to grow a heavy sod, the following wattles are recommended:

• Where the soil is not subject to rapid erosion, use sod strip wattles only. This condition frequently exists along a main channel through a meadow where the banks are slowly receding and broadening the stream bed. The sod eventually covers the entire slope and protects against floods along the channel parallel to the wattles.

• Where the soil is not subjected to a heavy flow, but erodes easily, alternate sod strip with staked rope wattles. Usually, staked rope wattles can be spaced 4 to 5 ft (1.2 to 1.5 m) apart, with sod strip wattles planted midway between.

• Where erosion is relatively rapid and the soil is light, alternate sod strip with brush wattles. Brush wattles can be spaced 3 to 5 ft (0.9 to 1.5 m) apart with sod strip wattles midway between.

On a soil too dry to grow a good sod, the following wattles are recommended:

• Where erosion is slow, space trenched rope wattles 30 to 40 inches (0.8 to 1.0 m) apart.

• Where erosion is expected to be faster, alternate trenched and staked rope wattles.

• Where conditions are most severe, use staked brush wattles.

Check Dams—Reclaiming a gully with check dams stops headward erosion (especially when check dams are combined with head controls), stops deepening and widening of the gully, and stops or minimizes formation of side gullies. The area of the gully itself is reclaimed and the water table is raised.

For the purpose of erosion control, check dams in gullies decrease the velocity of the water down the gully. By decreas-ing velocity, silt is deposited in the gully. With enough prop-erly designed check dams, the gully stops eroding and becomes filled with the deposited material. For the gully to fill, however, erosion must be taking place somewhere above the point of deposition.

Because of poor foundation conditions generally found in meadow gullies, check dams in mountain meadows should be keyed into the channel bottom and channel banks and should be able to carry the maximum expected flow (Heede 1960). Numerous low dams along a gully are preferable to a few high dams. Low check dams are 3 to 4 ft (0.9 to 1.2 m) high. Low check dams do not usually wash out; but if they do, less flood damage results. A series of low dams should first be con-structed along the gully. When the catch basins behind these dams have filled, another series of dams can be built on top of or just upstream of the original dams. Check dams should be semipervious rather than impervious. However, erosion may start again when check dams made of brush, forest litter, and other such materials rot away.

Proper spacing between dams depends upon the gradient of the gully. The minimum interval used should make the crest of one dam level with the apron of the one above. Heede (1960) refers to this as the "head-to-toe rule." But this may be an inefficient rule, since deposits behind a check dam possess a gradient. A more proper interval positions the apron of the next higher dam at the highest point expected to be reached by deposits behind the lower dam. The criterion is the gra-dient of the deposits, some ranging from 5 to 6.5 percent (Heede 1960).

Dams are more economically built, more effective, and more stable if placed in key locations (Heede 1960). Continu-ous and discontinuous gullies should have check dams at the gully mouth where the gully slope merges with that of the meadow. Discontinuous gullies should also have check dams immediately below the gully heads. Placed immediately below the juncture of two or more gullies, one dam can provide two or more catch basins, thereby increasing its effectiveness. Narrow points of a gully allow a dam of certain height to be built with less material than where the gully is wide. Other key locations for check dams are points of least rapid erosion in the gully owing to a gentle gradient, better foundation material—rock, for example—in the gully bottom, or a protective cover of vegetation.

Check dams should be built as cheaply as possible to realize the greatest investment return. They must be well built to avoid causing additional damage to the meadow. The structure must provide safe passage of flood flows over the dam. This necessitates a low center that draws the overflow toward the middle of the channel, preventing the water from cutting around the dam. In high mountain meadows without large watersheds, making the sides 1 to 3 ft (0.3 to 0.9 m) higher than the center is usually sufficient. An apron below the downstream face of the dam is essential to prevent falling water from undercutting the dam. Check dams are not intended to be impervious. Material fine enough and stable enough to prevent large cracks or pipes opening through the dam should be placed against the upstream face. Such cracks or pipes may pass sufficient water to undercut the dam. The control value of vegetation should be applied to the fullest possible extent. But the catch basin above a check dam should not be filled with loose brush; it tends to remove litter and silt which would otherwise aid in sealing the dam.

Newer check dam designs are now available (Gray and Leiser 1982; Heede 1965, 1966, 1977). Also, computer programs are available (Heede and Mufich 1973, 1974) that specify check dam design, materials, and costs with a minimum of survey work. A prime reason for failure of gully control structures is inadequate attention to design. These new designs and computer programs hold promise of minimizing check dam failure.

Planting Vegetation—A quick and effective means of securing a vegetative cover for the control of soil erosion is the planting of willow cuttings. Willow stakes that hold brush in place may take root, grow, and hold the soil long after the brush has decayed (Gustafson 1937). Undercutting of banks and widening of gully bottoms may occur, however, if channels become choked with willows (Heede 1960).

A significant physiological characteristic of willows is the ability to produce abundant roots from cuttings (Massey and Ball 1944). Freshly cut willow stakes generally take root and grow when set in rich moist soil, as on stream sides and in wet meadows. Twigs broken off are also often able to become established and enlarge the stand. Several willow species grow from cuttings in new road fills and in bare, denuded gullies. Even on unfavorable sites, willow cuttings often grow vigorously for a few years before dying out.

In California, willows are used almost exclusively for cuttings. An ample supply of willow cuttings is usually available in the vicinity of the meadow to be controlled. This is significant in terms of cost as well as the assurance that the species is suited to the locality.

Wherever possible, vigorous native willow species should be used. Species with long, straight stems are easier to cut and drive into the ground than those with crooked stems.

Stakes should be cut and planted when the willows are dormant. This period extends from fall, when the leaves start to turn yellow, to spring, when growth starts. In moist soils, willow stakes are sometimes successfully planted during summer, but this is not recommended.

Little is known of the ability of other woody plants to grow from cuttings without care in mountain meadows. Also, availability may limit the use of other species, even if grown readily from cuttings. Some possible alternatives to willow are mountain alder (*Alnus tenuifolia*), quaking aspen (*Populus tremuloides),* western azalea *(Rhododendron occidentalis)*, and huckleberries. These species may be better to plant in some situations, even if it means starting from seed. Huckleberries, for example, inhabit acid soils, but willows cannot tolerate strongly acid soils (U.S. Dep. Agric., Forest Serv. 1937). Where the meadow soil is strongly acid, therefore, huckleberries may grow better .than willows.

In general, species that have browse value are preferred. But a plantation of palatable species may be quickly destroyed by livestock. Unpalatable and palatable species should be mixed where the meadow is subjected to livestock grazing or high deer or elk use. Observations should identify the palatable and unpalatable species growing in a locality.

The heavy sod found in mountain meadows is an excellent protection against erosion. Strips of such sod planted in key spots or in contour strips soon spreads and forms a strong cover for the soil. Care should be exercised to dig sod from level places in the meadow where no danger of new erosion exists.

Sods should be planted immediately before or during wet seasons. Where the soil is always damp, sod may be planted anytime. As a rule, obtain sod from the locality where it is to be planted. Plant the sod as soon as possible after cutting. If it is necessary to delay planting for one or two days, keep the sod moist. Sod should be placed with its surface slightly below ground level.

The effects of cuttings and sod plantings can be supplemented by sowing grass or cereal grain. Such stands may last one year only, or become replaced with native species that recapture the site.

EVALUATING RANGE CONDITIONS

Evaluating or classifying range condition is difficult. The methodology is still evolving. A range condition class is "one of a series of arbitrary categories used to classify range condition and usually expressed as either excellent, good, fair, or poor" (Range Term Glossary Committee 1974, p. 21). A fifth class—very poor—has frequently been used. I suggest that a four-class system is adequate for evaluating most meadows in the Sierra Nevada.

Evaluating range condition—current productivity relative to natural capability—includes a subjective evaluation. Evaluations of range condition will therefore vary. To some, condition is excellent only if herbage production and species composition are near climax. To others, condition is excellent only if calf or steer weight gains produced are maximum.

Equally difficult is detecting condition trend and determining trend direction. Range condition trend is defined as "the direction of change in range condition" (Range Term Glossary Committee 1974, p. 21). Trend is long-term progressive or regressive change. Without change there is no trend. Four main reasons explain the difficulty of determining trend in condition (Reppert and Francis 1973). Trend is evaluated over a period of many years. Different people frequently measure condition trend plots from one measurement to the next. Cause of trends in condition are unnoticed or not documented. And frequently, condition trend is interpreted by persons other than skilled range examiners.

Primary to evaluating range condition and condition trend are the characteristics needed to sustain production of a desired product mix. Range condition methodology aims to detect departure from those characteristics. Condition criteria aim to properly and accurately rate the degree of departure. Trend methodology aims to detect differences between times of observations in the degrees of departures, accurately indicate trend direction, and assess the cause of trend.

The characteristics basic to high range condition, regardless of the desired product mix, are geological and biological stability (Benedict 1981, 1982).

Geologic stability implies a static situation as related to trend in soil condition. Yet, as evident in meadow soil profiles, the stability is dynamic. Geologic instability implies a downward trend in soil condition. A downward trend in soil condition is possible with geologic stability but, unless halted may lead to geologic instability. If a meadow is not geologically stable, biologic stability is unattainable and management can do little to halt the downward trend in condition.

Biologic stability may occur at a stage below the climax potential and therefore does not necessarily connote excellent or good condition. Biologic instability implies condition trend toward or away from the potential. Directing condition trend to attain biologic stability with those characteristics required to meet management goals or objectives is the task of the land manager. For the most part, management goals or objectives are served well if biologic stability is attained and maintained in an open meadow environment with herbaceous vegetation composed mostly of climax perennials.

Established Methods

Certain methods field tested over many years can guide managers evaluating meadow condition and condition trend. The three-step method and the species composition method are two of these.

Three-Step Method

The three-step method of range condition and trend analysis (Parker 1954) has been widely applied on Forest Service grazing allotments throughout the Western United States. It has also been used by the Bureau of Land Management and the National Park Service, U.S. Department of Interior.

The studies that led to the development of the three-step method of assessing condition and trend were carried out by the Forest Service's Division of Range Research, Division of Range Management, six western Regions, and the Forest and Range Experiment Stations. The studies were started in 1948. In 1949, the three-step method was first tested; subsequently, the method was revised and retested in 1950. In both years, the method was tried on various types of ranges and in varying degrees of condition.

The persons first testing the three-step method—Kenneth W. Parker and his colleagues (Parker 1954)—were skilled range examiners. And the three-step method was intended for persons of similar skill.

The three-step method consists of the following:

Step one—Establish permanent line transects and record and summarize the data obtained from them. Establish transects only on the primary range and on sites representative of major condition classes; do not establish transects at random. Lay out each transect so that it is 100 ft (30.5 m) long in the center of a 150-ft by 100-ft (45.7-m by 30.5-m) plot.

Place transects in clusters to obtain a larger sample, a measure of variation, and more useful information per man-hour. A cluster should contain a minimum of three transects when the plant density index is less than 30, two transects when the index is 30 to 60, and one transect when the index is more than 60. Use a minimum of two clusters for each major condition.

When the majority of plant species are easily identified—usually in the growing season—make observations at 1-ft (30-cm) intervals along a transect. Use a 3/4-inch (1.9-cm) diameter loop, and classify the area that the loop delimits as erosion pavement, bare soil, vegetation, litter, or rock. Record observations on a specially designed form. Classify plant species as desirable or primary, intermediate or secondary, and undesirable or low value. The form is designed to separate low-value species from the more desirable ones.

Plant density index is the total of all hits within the 3/4-inch loop with established perennial vegetation. Forage density index is the total hits with either primary or secondary species. Ground cover index is the number of hits on bare soil subtracted from 100. Record the number of hits on each plant species.

Measure plant vigor randomly by recording the leaf length on 10 plants of valuable species within the plot.

Step two—Summarize and analyze the data for the cluster, classify the current condition, and estimate current trend. Record data on a "cluster summary" form-primary, secondary, low value.

Record the average number of hits, and the average percentage of total plant density (species composition) for the key species of the three vegetative classes.

Determine current vegetative condition from the sum of the forage density index, composition, and vigor ratings. Determine the condition from a score card prepared for the specific range type.

Rate erosion hazard and current erosion factors. Sum the ratings, then match the sum against ratings for soil condition classes to assess soil stability. Determine erosion hazard from the ground cover index that is rated from 0 to 15. The rating increases with the number of nonsoil hits. Determine current erosion from five defined erosion classes that rate erosion from 0 to 15, depending upon severity.

Determine current trend in forage condition from trend standards (prepared for each condition class) for the particular range type. The standards are based upon plant vigor and forage utilization. Vigor is given twice the weight of utilization. Record trend as up, down, or static.

Determine the current trend in soil stability from standards for condition classes. The variables used for determining trend in soil stability include the amount of litter being replaced each year, visible erosion, trampling displacement, rodent activity, and healing in gullies. As with trend in forage condition, record trend as up, down, or static. The information obtained in steps one and two can be used in subsequent years to determine the long-term trends in vegetation and soil conditions.

Step three—Take two key photographs. Take one general type from one end of the transect. Compare this photo with photos taken from the same position in past or future years to show general changes. Take an oblique close-up photo of a 3-ft2 (0.9-m2) plot. Take this photo and subsequent oblique close-up photos from the same point as the general one.

Species Composition Method

The Soil Conservation Service, U.S. Department of Agriculture, has developed and used the species composition or climax method (Bell 1973, Dyksterhuis 1949) of range condition analysis most extensively. Condition trend is not directly determined as in the three-step method. Compositional changes over time, however, are indicators of trend and trend direction.

Primary to the species composition method is recognition of range sites (Range Term Glossary Committee 1974). A range site is a kind of land or a class. In terms of the classification given in this paper, a range site is similar to a meadow site association. The difference is the definition of range sites by potential vegetation and definition of meadow associations by current vegetation. As potential vegetations of meadow sites are defined, the difference is eliminated.

Conceptually, each range site has the potential to produce a unique combination of species and amounts of them, provided physical characteristics have not deteriorated. Condition of a range site individual (Ratliff and Pieper 1982) can be determined if the potentials of the class to which it belongs are known.

Species are categorized as decreasers, increasers, or invaders. As condition deteriorates, the decreasers decrease and the increasers increase in percentage of the composition. With further deterioration, the increasers decrease and the invaders increase significantly. Range site individuals with the composition consisting of 75 to 100 percent climax decreaser and increaser species are considered in excellent condition. The percentage of increasers allowed is limited. The limit depends upon the percentage of a species expected in the climax stand. Any excess of increasers counts against condition and is included as part of the invader percentage. When decreasers and allowable increasers together comprise between 50 and 75 percent of the composition, condition is considered good. Fair condition sites contain 25 to 50 percent decreasers and increasers, poor condition sites contain less than 25 percent decreasers and increasers. The idea of the species categories is defined in the three-step method as primary, secondary, and low-value species.

Stability of the soil is implicit in the species composition method. A specific range site individual must have the potential of the range site to which it is assigned. It loses that potential if the soil is gone.

Condition Standards

Standards of meadow condition should at least be specific to meadow series, and preferably specific for meadow site associations. Attaining either appears distant, and managers need standards. Based on data available on standards and other research results, I suggest that the following conservative, generalized standards are applicable to meadow sites of the Sierra Nevada.

Soil Condition

Given that a meadow is not past the geomorphic slope threshold, and that maintaining or improving its condition is a reasonable expectation, geological stability on specific sites is related to soil stability. Condition is satisfactory if the site potential, as judged by soil characteristics, is maintained (Smith 1979). And soil condition has been given more weight than vegetative condition in assessing condition.

Four condition classes have been described (Ellison and others 1951, pp. 23, 24):

Condition:	Description
Satisfactory condition	"Soil stable under a normal or near-normal amount of vegetal cover; a high proportion of desirable forage plants."
Unsatisfactory condition (a)	"Soil stable under a normal or sub-normal amount of vegetal cover; a low proportion of desirable forage plants."
Unsatisfactory condition (b)	"Soil unstable under a subnormal amount of vegetal cover; a high proportion of desirable forage plants."
Very unsatisfactory condition	"Soil unstable under a subnormal amount of vegetal cover; a low proportion of desirable forage plants."

Vegetal cover includes litter (Ellison and others 1951). The third condition can occur with a good stand of desirable species but with little of the yearly production left. Presence of a good or excellent vegetative condition with a poor soil condition is therefore possible. That situation was frequently encountered on meadows of Sequoia and Kings Canyon National Parks (Bennett 1965). At least in those situations, his evaluations of meadow conditions more strongly reflected soil condition than vegetative condition.

For meadows in satisfactory or good condition, foliar and litter cover should combine so that no bare soil can be seen (Ellison and others 1951).

In Oregon, foliar cover on good condition meadows was 68 percent; on fair, 47 percent; on poor, 31 percent; and on very poor, 12 percent (Reid and Pickford 1946). Amounts of litter and bare soil were not included in the data. However, one excellent condition meadow was reported to have 17 percent bare ground, the suggestion being that surface not covered by foliage was bare. I suspect, nevertheless, that most of the remaining surface, at least on good and fair meadows, had abundant litter.

Excellent condition meadows on the eastern slope of the Sierra Nevada had minimum foliar cover of 70 percent; good condition meadows, 50 percent; fair condition meadows, 40 percent; and poor condition meadows, 25 percent (Crane 1950). Very poor condition meadows had less than 25 percent foliar cover. Litter covered at least 22 percent of the surface of excellent condition meadows, 30 percent of good condition meadows, and 27 percent of fair condition meadows.

Nonplant area was defined as hits on "erosion surfaces, rocks, manure, erosion pavement, bodies of water, and organic litter" (Bennett 1965, p. 24); "an area with no visible plant life within a one centimeter radius of the transect point" (Strand 1979a, p. 79). Strand remeasured several transects originally established by Bennett on meadows in Sequoia and Kings Canyon National Parks. Nonplant areas found by Bennett ranged from 6.4 to 52.6 percent *(table 13).* Foliar covers therefore ranged from 47.4 to 93.6 percent. By the foliar cover criteria of Reid and Pickford (1946) or Crane (1950), all 11 meadow areas were in fair or better condition.

Table 13— *Condition, foliar cover, and nonplant cover at II meadow sites in Sequoia and Kings Canton National Parks, California*

Meadow site	Condition	Cover		
		Foliar	Nonplant	Erosion[1]
		Percent		
Zumwalt	Very good	87.8	12.2	1.2
Upper Paradise	Fair	82.9	17.1	8.7
Arrowhead Lake	Good	79.2	20.8	9.4
Cotter	Good	55.5	44.5	12.5
Fjord Stringer	Fair to good	47.4	52.6	5.3
Charlotte Lake	Very poor	75.5	24.5	8.9
Vidette	Good	93.0	7.0	2.8
East Lake	Fair	81.8	18.2	11.2
Junction(Bubbs)	Fairly good	87.8	12.2	5.6
Junction (Kern)	Very poor	72.5	27.5	4.8
Upper Funston	Poor	93.6	6.4	1.0

Source: Bennett (1965)
[1]Percent of erosion surface included in nonplant cover.

Among the variables comprising nonplant area (Bennett 1965), only the amount of erosion surface was reported. Amounts of erosion surface ranged from 1.0 to 12.5 percent of the surface areas. Assuming that the remaining amounts of nonplant areas were mostly litter, it becomes evident that both Bennett (1965) and Crane (1950) require nearly 100 percent cover as defined by Ellison and others (1951) for a condition classification of excellent.

That same basic standard is adhered to by the U.S. Forest Service, Pacific Southwest Region (U.S. Dep. Agric., Forest Serv. 1969). A maximum of 5 percent bare soil and erosion pavement combined is permitted for excellent soil condition. Amounts may not exceed 25 percent for good condition, 45 percent for fair condition, and 79 percent for poor condition. On that basis, Zumwalt, Vidette, Junction (Kern), and Upper Funston meadows (Bennett 1965) *(table 13)* would be considered excellent in condition. All others would be classified as good.

Other indicators were included in assessing conditions on meadow areas (Bennett 1965): percentage of area trampled, invasion by lodgepole pine, and herbaceous vegetative condition. In effect, these indicators serve the same function as the classification of site damage to determine the soil condition score (U.S. Dep. Agric., Forest Serv. 1969). Damage resulting from all previous causes is classed as severe, moderate, or light. That classification, with the amount of bare soil and erosion pavement, determines the soil condition class.

The standards of Reid and Pickford (1946) and those of Crane (1950) have a foliar cover base. Cover is expressed as the percentage of surface area hidden from view by foliage. The surface area not covered by foliage is proportioned among soil, litter, and other surface variables. The Forest Service's Pacific Southwest Region uses a basal cover base (U.S. Dep. Agric., Forest Serv. 1969). Hits on herbaceous vegetation are recorded at the soil surface. The three-step loop procedure is used, and only one species or surface variable is recorded per loop. Basal cover is expressed as frequency of point (plot without size or shape— a sharp point) hits (Ratliff 1979). Hits on plants are recorded only when actual contact of the point is made with a plant where the plant emerges from the substrate.

I prefer basal cover to foliar cover as a measure of soil condition. Basal cover is affected by compositional changes. Grazing tends to stimulate short plant and moss growth, but basal composition should be little influenced by the current level of grazing, especially if the treatment has been of long duration. Foliar cover is better related to productivity than is basal cover determined by either loops or points. Grazing, however, alters the relationships between foliage and the surface. Except when indicating herbage utilization or preference, therefore, use of a foliar cover standard should be restricted to ungrazed meadows.

The standards for bare soil (U.S. Dep. Agric., Forest Serv. 1969) used by the Pacific Southwest Region appear adequate for nonxeric meadows. Of course, the three-step loop method must be used. The remaining area should be covered by plants, litter, and moss. Minor amounts of gravel, rocks, and wood are acceptable. Minimum herbaceous plant cover allowed for excellent condition wet meadows is 68 percent; for good, 51 percent; and for fair, 35 percent. For dry meadows the amounts are 56 percent for excellent, 36 percent for good, and 21 percent for fair.

The wet meadow standard may be reasonable for sites of the hanging, lotic, and sunken-concave hydrologic classes. They may also be reasonable for montane meadows with a xeric hydrology. For raised-convex and normal meadow sites, however, the wet meadow standards appear low. The dry meadow standards seem low for montane xeric meadows. But they are likely too severe as cover standards for the xeric short-hair sedge sites of the subalpine. Much effort is required to confirm or reject these hypotheses. I suggest, therefore, that to assess soil condition, the current standards (U.S. Dep. Agric., Forest Serv. 1969) be used until more specific standards can be developed.

Vegetative Condition

The following observations can serve as general guides to meadow vegetative conditions (Reid and Pickford 1946). Meadows in excellent or good condition appear to have a dense, even stand of vegetation. After grazing, such a meadow should give the impression of having been mowed because of the rather uniform forage value of the plant species present. Fair condition meadows appear dense, but unevenly, covered. Poor condition meadows have a distinct patchy appearance. Good condition meadows are not particularly colorful during flowering—scattered forb blossoms are not conspicuous. Fair condition meadows are colorful during flowering-clumps of brightly colored forb blossoms blend with green. Poor condition meadows are very colorful during flowering—patches of green occur among dense colonies of conspicuous, brightly colored forbs.

Because a meadow full of wildflowers is beautiful, these general guides may seem reversed. The first test of a climax is that the dominants belong to the same major life form; and in grasslands, the climax dominants are all grasses or sedges (Weaver and Clements 1929). Grasses have an advantage over subdominant forbs, such that the composition shifts away from grasses only by severe disturbance (Clements 1920). Better condition meadows should have fewer forbs to produce flowers than poorer condition meadows. Such was the situation on subalpine grasslands in Washington and Oregon (Pickford and Reid 1942). Also, free choice or season-long grazing did not decrease the abundance of meadow wildflowers (Ratliff 1972).

The second condition class of Ellison and others (1951) is encountered in mountain meadows where the soils are stable. With stable soil,-an evaluation of condition depends upon the relative biologic departure of the site from a standard. The frequently accepted standard for excellent condition is biologic stability at or near climax. Species composition is the usual indicator for departure from climax. Species evaluations used in the three-step method generally tend, however, to reflect grazing values. Even with the species composition method, the terms frequently have reflected grazing value more than ecological position (Smith 1979). Although some species of high ecological position also have high grazing value, when grazing value is used, that fact must be made clear to avoid confusion about the meaning of the standard.

Table 14— *Percentages of composition for primary, secondary, and low-value species by vegetative condition*[1]*—averages, from 11 meadow sites in Sequoia and Kings Cannon National Parks, California*

Species class	Vegetative condition			
	Excellent	Good	Fair	Poor
		Percent		
Primary	61.9	55.1	41.0	53.0
Secondary	25.2	10.7	10.0	0.7
Low-value	12.9	34.2	49.0	46.3

Source: Bennett (1965)

[1]Standards used were those of the U.S. Department of Agriculture, Forest Service (1969).

The three-step method uses the concept of the species composition method. For a rating of excellent condition, when low value species are absent, primary species must make up at least 75 percent of the composition (U.S. Dep. Agric., Forest Serv. 1969). The maximum allowable amount of secondary species in a climax community must therefore be 25 percent. Minimum combined amounts of primary and secondary species allowed are 68.6 percent for excellent condition wet meadows, 54.6 percent for good, and 25 percent for fair. Allowing 25 percent secondary species, minimum acceptable amounts of primary species for the condition classes, therefore, are 43.6 percent for excellent, 29.6 percent for fair, and 0.0 percent for poor. The species composition method accepts 50 percent primary species for excellent, 25 percent for fair, and 0 percent for poor.

I evaluated the vegetation and cover data from the 11 meadow sites studied by Bennett (1965) and rated their vegetative conditions. The standards for wet meadows (U.S. Dep. Agric., Forest Serv. 1969) were used. My evaluations did not agree fully with those of Bennett (1965). The results provided a useful comparison.

The average percentage composition for primary species *(table 14)* decreased from excellent to fair condition. And the percentage of low-value species increased. Bennett (1965) clearly stated his use of species' grazing values, and many of his low-value species are increasers rather than true invaders. Were the ecological classification used, it is probable that the secondary species would show a marked increase with declining condition—at least through fair condition.

The meadow sites that were classed as excellent had 87 percent primary and secondary species, good had 66 percent, and fair had 51 percent. I suggest, therefore, that excellent condition meadows will indeed have high percentages of primary or decreaser species. The maximum of 25 percent secondary or increaser species appears adequate, at least with the three-step method.

Percentages of decreaser, increaser, and invader species *(table 10)* were determined for the 90 meadow sites referred to

Table 15— *Vegetative condition class*[1] *and vegetative series for 90 meadow sites of the Sierra Nevada, California*

Vegetative series	Sites, by vegetative condition			
	Excellent	Good	Fair	Poor
Agrostis (Bentgrass)	—	2	1	
Calamagrostis breweri (Shorthair)	7	1	—	—
Carex exserta (Short-hair sedge)	4	—	—	—
Carex nebraskensis (Nebraska sedge)	3	2	—	—
Carex rostrata (Beaked sedge)	5	—	—	—
Deschampsia caespitosa (Tufted hairgrass)	2	3	3	—
Gentiana newberryi (Newberry gentian)	—	2	1	—
Heleocharis acicularis (Slender spikerush)	1	—	1	—
Heleocharis pauciflora (Fewflowered spikerush)	—	3	10	—
Hypericum anagalloides (Tinkers penny)	2	8	9	—
Muhlenbergia filiformis (Pullup muhly)	—	1	7	—
Poa (Bluegrass)	—	1	2	—
Trifolium longipes (Longstalk clover)	—	—	4	—
Trifolium monanthum (Carpet clover)	—	—	5	—
Total	24	23	43	00

[1]Assigned on the basis of species composition method.

by Ratliff (1982). Vegetative conditions of the sites were evaluated using the standards for the species composition method. A maximum of 25 percent increasers was allowed.

Excellent conditions *(table 15)* were found for 24 of the sites, good for 23, and fair for 43. Two vegetative series, beaked sedge and short-hair sedge, occurred on nine sites, all in excellent vegetative condition. Two common characteristics are responsible for that result. The series represent the environmental extremes. Beaked sedge sites are largely lotic and short-hair sedge sites are largely xeric in hydrology. Both tend to be monospecific, with beaked sedge and short-hair sedge making up at least 50 percent (and usually a much higher proportion) of the composition. Sites of other series tend to have many species. On the sites in excellent condition, the combined amounts of two or three primary species make up more than 50 percent of the composition.

The species composition method was inefficient in separating fair from poor condition sites. None of the sites rated poor in vegetative condition *(table 15)*, owing to the relative lack of invader species. The greatest amount of invaders on a site was 24.3 percent. The average amount of invaders on the 90 sites was 2.1 percent. Where the proportion of the composition made up by decreaser species was low, the proportion of increaser species was at least 25 percent, thereby giving a rating of fair condition. Also, when the percentage of decreaser species was at or just above 25 percent, the increaser species percentage was usually enough to give a good condition rating.

The percentage of increasers allowed is based on the concept that an amount equal to the maximum expected in the climax is normal. Regardless of the amount of decreaser species present, therefore, an amount up to the percentage of increasers normally expected is added to the decreaser percentage in determining condition. I propose that where invader species are few, as in Sierra Nevadan meadows, the percentage of increaser species allowed should be reduced for good and fair conditions *(table 16)*. This has the effect of raising the minimum amount of decreaser species acceptable while keeping the usual condition standards. The proposed standards were used to rate the 90 meadow sites (Ratliff 1982), with these results: 24 rated excellent, 20 rated good, 24 rated fair, and 22 rated poor in vegetative condition.

For rating vegetative condition, I have used nearest shoot-to-point (or closest individual) species composition. But I found the technique biased and suggest actual basal hits instead. Basal hits are affected less by current grazing than species composition or cover based on foliar hits. Foliar composition is, however, the better measure on ungrazed meadows.

Trends

Current condition tells only how a meadow site measures up to a set of standards. Assessment of condition trend tells how well management measures up.

Table 16— *Proposed generalized vegetative condition standards for meadow sites of the Sierra Nevada, California*

Vegetative condition	Minimum decreasers[1]	Maximum increasers[2]	Decreasers and increasers[3]
Excellent	50	25	75 to 100
Good	30	20	50 to 75
Fair	10	15	25 to 50
Poor	—	—	0 to 25

[1]Minimum percentage of composition allowed.
[2]Maximum percentage of composition allowed; excess percentage contributes to amount of invader species.
[3]Range in percentage of the composition of decreaser and allowed increaser species permitted for the condition class.

Condition trend is frequently rated as up, down, or static. An upward trend in meadow condition or static trend with an excellent condition is the usual goal. But detection and prevention of a downward trend in meadow condition is usually emphasized.

A downward trend in condition is first indicated by overuse in association with seven additional variables (Bell 1973):

1. Weakened condition and lowered vigor of decreaser species;
2. Decrease in the size and abundance of decreaser species;
3. Appearance of invader species;
4. Subdominance of climax plants in the stand;
5. Reduction in range productivity and livestock production;
6. Appearance and dominance of woody plant species;
7. Deterioration and erosion of soil.

Indicators of an upward trend in conditions are the reverse.

A meadow site may be considered static in trend or biologically stable when significant change no longer occurs under a specific management regime. The regime of management is significant. Altering management—the grazing system, for example—likely requires a series of biological adjustments to balance the site with its altered environment. Until the adjustments are made, change will occur—there will be trend in condition.

Measurement of change is the key to detection of trend. A score of 30 is the maximum potential for either soil or vegetative condition as determined by the Forest Service's Pacific Southwest Region (U.S. Dep. Agric. Forest Serv. 1969, sec. 480). "The magnitude of change required to indicate a real trend, upward or downward, must be one-quarter or more of the difference between the original (or previous) measurement and the maximum potential." That standard was derived from the fact that the standard deviation of a normal distribution is approximately equal to the range in values divided by 4 (Dixon and Massey 1957). A site with a score of 1 (very poor condition) at the original measurement, therefore, would need a score of $[(30 - 1)/4] + 1 = 8.25$ at a later measurement for trend to be present. A site in good condition with a score of 26 would need a change in its score of 1 for trend to be present. As condition improves, trend is indicated by smaller changes in scores. That feature reflects the need to quickly detect downward trend and correct management.

It may be possible to use that standard to decide when trend is indicated by the species composition method. If the sum of decreaser and increaser percentages were 40 percent on the first reading, at the next reading their percentage would need to be $[(100 - 40)/4] + 40 = 55$ for an upward trend to be declared. The statistical correctness of the standard needs to be investigated, however.

A five-phase procedure for determining trend from data obtained by the three-step method has been suggested (Reppert and Francis 1973). Whether the three-step or some other method is used, I recommend careful study and use of the procedure as follows:

- Correctly execute the three-step or other method at each observation.
- Determine current condition and tentatively assess trend in the field.
- Statistically compare plant group and species data and relate the results to changes visible in photographs.
- Compare statistical and photographic evidence with the trend assessments made in the field.
- Consider all available information and assign a cause for the trend.

MANAGEMENT CONCEPTS

My basic concept of meadow management is that good meadow management demands good range management. There are six requirements that must be satisfied.

(1) Good range management for meadows requires trust, agreement, and commitment.. Mutual trust among managers and users, agreement between them on actions to be taken, and commitment of all involved to accomplishing the actions are essential to success of any management plan. Without trust, there will be no agreement. Without agreement, there will be no commitment. And without commitment, nothing will be done.

(2) Good range management for meadows requires establishing reasonable, attainable objectives or goals. Prerequisite is deciding what the basic goal of meadow management should be. Based on the cooperation of persons concerned and knowledgeable about meadows and meadow problems, a basic goal has emerged. Mountain meadows of the Sierra Nevada should be managed in a manner that maintains or restores their ecological integrity while providing products for mankind. Ecological integrity means biologic and geologic stability (Benedict 1981, Benedict and Major 1982) rather than climax equilibrium.

(3) Good range management for meadows requires proper use (Range Term Glossary Committee 1974). Proper use of meadows may be defined as a degree and time (period and frequency) of use of meadow and watershed resources which, if continued, either maintains or restores meadow ecological integrity and is consistent with conservation of other natural resources. Use here is not restricted to livestock grazing but includes all herbivority and all direct activities of mankind.

To attain proper use, managers and users must decide upon the product mix wanted from and the degrees of use acceptable on a given management unit (allotment) or natural land unit (watershed). They must also decide the period(s) during which the product(s) are produced and the frequency of production.

The degree, period, and frequency of use are extrinsic factors controllable by man. When they are correctly coordinated, use of meadow resources will not exceed threshold levels that could cause damage. And the potential for damage from other extrinsic factors is lowered.

The product mix produced may include livestock, timber, big game, small game, songbirds, rest and relaxation, and flowers—anything people want from the unit. A definable carrying capacity exists for each product desired. The carrying capacity for livestock depends upon the resources available to produce that product. When needs for resources overlap, as for cattle and deer, they must be allocated among the products that require them. The optimum carrying capacity for a management unit "expresses the greatest return of combined products without damage to the physical resources" (Heady 1975, p. 115).

Increasing production of one product without decreasing production of other products dependent upon the same resources results in overstocking. Overstocking, in turn, results in overuse of resources needed for production of dependent products. Continued overuse (overgrazing) induces change by altering threshold levels of other extrinsic factors and threshold levels of intrinsic factors, thereby resulting in meadow deterioration.

Nature sets the periods and frequencies of use for wildlife. Man, within limits imposed by nature, sets the periods and frequencies of use for, himself and his domestic animals. Improper periods of use by livestock are often manifested as trampling damage which breaks the meadow sod. Calendar dates when conditions are suitable for individual uses vary from year to year. They should be used only as guides.

Unless livestock movements are restricted, their developed patterns of use will continue and be similar from year to year. Where possible, specialized grazing systems (such as two- and three-unit deferred rotations) should be employed. But many grazing allotments on National Forests in the Sierra Nevada have rough terrain and elevations that vary greatly. Those conditions make fencing for, and management of, specialized grazing systems very difficult. Under such situations, attention to animal distribution and stocking should be stressed.

(4) Good range management for meadows requires restoration efforts, where they are likely to succeed. Without geologic stability, restoration efforts may fail to give expected recovery. Therefore, geologic stability should be assessed during planning. Possible effects of present management should also be assessed. Degrees of use, periods of use, and frequencies of use that are not compatible with planned actions make success of restoration efforts improbable.

(5) Good range management for meadows requires determination of condition and monitoring of condition trend. Meadow productivity declines with decreasing condition, and reduction in productivity is proportionally greater between the lower condition classes. Therefore, management and individual user goals or objectives will generally be well served if a stable herbaceous vegetation composed mostly of climax perennials is maintained in an open meadow environment.

(6) Good range management for meadows requires user education. People disturb meadows. Users should learn how to properly use meadows and their associated ecosystems for the product(s) they desire. They should learn to work with other users and managers to attain the basic management goal.

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The Forest Service, U.S. Department of Agriculture, is responsible for Federal leadership in forestry. It carries out this role through four main activities:

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- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands.
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas.
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Forest and Range Experiment Station

- Represents the research branch of the Forest Service in California, Hawaii, and the western Pacific.

Ratliff, Raymond D. **Meadows in the Sierra Nevada of California: state of knowledge.** Gen. Tech. Rep. PSW-84. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1985. 52 p.

This state-of-knowledge report summarizes the best available information on maintenance, restoration, and management of meadows of the Sierra Nevada, California. Major topics discussed include how to classify meadows, meadow soils, productivity of meadows, management problems, and how to evaluate range conditions and trends. Current methods and standards are reviewed, and revised standards for evaluating conditions and trends are suggested. A primary conclusion is that proper meadow management requires proper range management, including the watershed above meadows and control of user populations.

Retrieval Terms: meadow classification, meadow productivity, meadow management problems, meadow conditions and trends, mountain meadows, Sierra Nevada, California