Final Report
Sierra Meadows: Historical Impact, Current Status and Trends, and Data Gaps

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Introduction

The Sierra Nevada Mountains are prized for their majestic views of roaring rivers and snowcapped peaks. The Sierra landscape supports a diverse set of natural communities with many endemic species and extraordinary habitats. However, the Sierra is subject to some the largest drivers of change of any rural region in the United States including population growth, recreational visits, changing land use, and climate change. Human alterations of California's waterscape have exploited the rivers and wetlands of the Sierra Nevada for 145 years. A century of intensive logging, mining, railroad building, development, fire suppression, and grazing have left approximately 25 percent of the natural habitat intact (SNEP). Much of this intact habitat occurs at higher elevations.

Mountain meadows are often overlooked as dormant space between the prized high peaks and roaring rivers, when in fact meadows are keystone to the mountain ecosystems and to the watershed as a whole. The ecological and hydrologic role that mountain meadows play has been largely overlooked by scientists and land managers and therefore has largely remained an unknown resource.

The purpose of this report is to present the results of a multi-partner project titled "Sierra Mountain Meadow Wetlands," a two year project in which existing information on the current condition and function of meadows in the Sierra was synthesized and new information was collected in order to better characterize the role that they play in terrestrial and aquatic ecosystems. The project area included all or part of three river basins that flow down the north western slope of the Sierra: the Yuba River, Bear River and American River, as well as portions of four river basins that flow east towards the Great Basin: Little Truckee River, Truckee River, West Fork of the Carson River and East Carson River. The project team developed a Mountain Meadow Health Database where spatial information relevant to meadows can be stored and analyzed using geographical information systems (GIS). This information was used, in addition to field data on aquatic and terrestrial conditions, to develop an integrated Meadow Health Rating System and to assess the status and trends of mountain meadows in the Sierra.

This report begins by explaining the important role that meadows play as habitat and as part of the physical processes of a watershed. This section is followed by the historical and current land and water uses that impact mountain meadows. Then new findings on meadow health and assessment derived from aquatic and terrestrial field surveys conducted by University of California at Davis are presented. These findings are integrated with the known impacts of land and water uses on meadow function using a landscape scale spatial analyses. In the conclusion, the data gaps are summarized and recommended next steps are presented. It is our hope that by understanding the specific functions that meadows provide to the mountain ecosystem and to the watershed as a whole, better management decisions for their preservation, restoration and utilization can be made.

Meadows of the Sierra Nevada

The Sierra Nevada Mountains run northwest to southwest and are approximately 400 miles long and 50 mile wide. The range is highest towards the south with several peaks over 14,000 feet. The number of mountain meadows in the Sierra Nevada is largely unknown, as is the location, size, physical and aquatic characteristics of these meadows. However, it is known that meadows support some of the greatest plant biodiversity in the Sierra Nevada region, and provide forage and habitat that is crucial to many mammals, birds, and amphibians (Graber 1996).

Meadows and the niches they create are biodiversity hotspots, in that many animal species, particularly birds and amphibians, use or are dependent upon meadow ecosystems. Meadows of the Sierra Nevada are particularly important habitat for birds and amphibians. In fact, during summer months, montane meadows are considered the single most important habitat in the Sierra Nevada for birds (Graber 1996). Streams flowing through these meadows are important habitat for aquatic biota including trout and other native fishes and contribute in a major way to fisheries in the Sierra Nevada.

Recent studies indicate that mid-elevation meadows are critical habitat for several amphibian, mollusk, and invertebrate species (Kattelmann 1996). Generally, soil arthropod and microorganism communities are highly diverse and complex in meadow ecosystems. The number of arthropod species in meadow soils conservatively represents more than three-quarters of all species of higher life forms (plants, invertebrates, and vertebrates) found in meadows, openings, ridges, streams, and springs (Lattin 1990).

Meadow species can be grouped as dependant or partially dependant on meadow ecosystems. Some of the focal animal species that are dependant on meadow ecosystems in Sierra Mountain meadows are great gray owls, willow flycatcher, and the Yosemite toad.

Habitat for Threatened or Endangered Species: The Role that Meadows Play

Great Grey Owl

Great gray Owl (*Strix nedulosa*), designated as a threatened Species by the State of California and a sensitive species by Region 5 of the U.S. Forest Service requires special management emphasis to avoid federal listing. Great Gray Owls (GGOW) are dependant on dense forests and on meadows in the medium to high seral condition. These habitats are diminishing because of forest and range practices. Green tree and salvage harvest activities can eliminate nest trees and grazing practices remove cover necessary for grass-forb habitat. Prescribed burning can remove potential nest snags and downed woody material needed for small mammal habitat.

Virtually all GGOW recorded in California are of birds found in or near montane meadows. Only 17 natural nests have been found in California, and 16 of those were in large, broken-topped conifer snags (Green 1995). Of the known GGOW pairs in California most nested within 280 yards of a meadow (Winter 2000). Meadows appear to be their preferred foraging habitat in California because their preferred prey inhabit grass-forb habiat, which do not occur under the dense canopies of the Sierran forests (Winter 1996). Grass-forb habitats rarely exist outside of meadows in the Sierra Nevada, except in stands that have been thinned. Clear-cuts and recent burns, where they exist in the Sierra, provide some structural similarity to a meadow ecosystem for a few years before the trees or brush shade out the grasses and forbs. Such sites can provide foraging for nesting GGOWs but only on a short-term basis (Greene 1995).

Willow Flycatcher

The Willow Flycatcher (*Empidonax traillii*) is a Forest Service sensitive species and is listed as a California endangered species by the state. Currently, half of the California breeding population of the Willow Flycatcher is in the Sierra Nevada. The population dwells along higher elevation streams and wet meadows.

Natural, free-flowing rivers and healthy meadows provide nesting cover and foraging habitat for Willow Flycatcher. Willow flycatcher populations across the West are facing serious declines based largely upon habitat loss and destruction. Fencing stream and meadow areas to prevent the entry of cattle on these sensitive lands, coupled with monitoring and restoration, and in some cases removal of cows, are sound protection measures to help Willow Flycatcher populations survive.

Yosemite Toad

Yosemite Toads (*Bufo canorus*) are small olive green toads with black spotting, endemic to the Sierra Nevada Mountains. Their primary habitat consists of ponds used as breeding areas and nearby meadows that provide food. The Yosemite Toad has experienced a sharp decline in population over recent years. On December 10, 2002, the U.S. Fish and Wildlife Service concluded that it may warrant protection under the Endangered Species Act. Unfortunately, budgetary constraints precluded the Service from listing the toad as threatened or endangered at the time. It is currently a Forest Service Sensitive Species and a California State Species of Special Concern.

Nineteen other species of high vulnerability, including Swainson's thrush, long-eared owl, and western red bat, are also dependent upon meadow ecosystems. Twenty-seven animal species of moderate vulnerability are dependent on meadows and an additional 75 species of moderate vulnerability are known to use meadow ecosystems either sometime during the lifecycle or when meadows are accessible. Over half of the 30 native Sierra Nevada amphibian species have experienced population declines and are in need of protection to survive. In addition, several species of Threatened, Endangered, and Sensitive (TES) species of fishes occur in streams flowing through meadows.

Watershed Function: The Role that Meadows Play

Meadows occur in areas where topography and/or geology encourage sediment deposition and water collection. These areas are hydrologic convergence points in the watershed, where shallow soils or low permeability soil layers result in high water tables. High moisture is maintained in some meadows by local springs or seeps. Thus, meadows represent areas of high moisture availability in what can be an otherwise water limited landscape.

Along the west slope of the Sierra Nevada, the unique hydrology and soil conditions in mountain meadows support lush vegetation cover of gramenoids, forbs and deciduous shrubs, such as willow and alder. Mountain meadows can play an important role in stabilizing streambanks, regulating water quality, attenuating flood flows, and by acting as natural water storage reservoirs. The way in which meadows perform these hydrologic functions depends on the interaction of physical and biological characteristics of the meadow.

Meadow ecosystems can be characterized by the interaction of: 1) vegetation, 2) landform and soils, and 3) hydrology, (USDI-BLM 1993, 1994). The combination of land form and soil moisture regime is the considered to be the most significant property that determines the existence and characteristics of a meadow (Wood 1975). Meadow vegetation is also important to the hydrologic function of meadows because it stabilizes streambanks, controls nutrient cycling, reduces water velocity during flood events, and provides cover and food for vertebrates and invertebrates. If the water table drops or fluctuates greatly, the abundance and type of vegetation may change significantly.

In general, hydrologically functional meadows require a shallow water table and fine textured soil to draw water to shallow rooted meadow plants by capillary rise. Landform combinations that favor the establishment of shallow water tables include: 1) relatively impervious bedrock, 2) an upper drainage area of sufficient size to supply seepage, 3) a gentle gradient or, 4) favorable drainage area-to-slope relationship.

Hydrologically functional meadows with perennial and intermittent streams 1) dissipate stream energy from high flows, reducing erosion and improving water quality; 2) filter sediment and capture bedload, aiding floodplain development; 3) enhance floodwater retention and groundwater recharge; and 4) support root masses that stabilize streambanks against cutting action (USDA Forest Service 2001a).

The degradation of a meadow's hydrologic function results not only in habitat loss but also in the loss of the meadows physical ecological services. It is thought that meadows in the headwaters of watersheds contribute to the function of the source of the watershed, the effect of which can be traced to the valley. Source watersheds are critical to maintaining the quantity and quality of California's water supply. Stable, well vegetated streams with functioning meadows, aquifers and uplands are critical to reducing erosion and modifying potentially destructive runoff patterns.

It is logical to assume that the natural storage capacity of headwater meadows impacts the hydrologic response of the watershed to large precipitation events. Hydrologically functional meadows in the headwaters may significantly increase the storage capacity of the watershed and therefore buffer the impact of intense rain events by attenuating the flood flows and reducing peak flows. Functioning meadows moderate runoff patterns by storing water in soils, vegetation, streambanks and subsurface aquifers, which reduces peak flows and extendes late season flow (Ponce and Lindquist 1990). The role of meadows in modifying hydrologic function is not well quantified. Preliminary results from pilot studies conducted by the Feather River Coordinated Resource Management Group indicate that restored meadows attenuate peak flows reflecting a greater storage capacity. However, there is a real need for basin specific assessments of the storage capacity of hydrologically intact meadows as compared to degraded meadows.

History of Misuse

Historic and current land and water use practices have impacted Sierra Mountain Meadows ecosystem function across the Sierra Nevada. The major human activities that have affected the health of mountain meadows began with domestic livestock grazing by the Spaniards beginning in the 17th century. This was soon followed by mining practices during the gold rush in the mid-nineteenth century and associated acceleration of logging practices. Many of the very destructive methods used in the nineteenth century were stopped or vastly improved during the 20th century; however the legacy of misuse remains a reality that limits ecosystem functions throughout the Sierra Nevada. Below we discuss in more detail the history of each of these uses, their impact on meadow health and what is being done to assess the effects of current land uses.

The History of Grazing and Meadows

Overgrazing in the late 1800's and early 1900's resulted in widespread deterioration of meadows (SNEP). Prior to 1900, sheep outnumbered cattle in the 'upper pastures'. In response to many drought years, sheepherders in the 1860's and 1870's greatly increased their use of Sierra Meadows for forage since these areas supported lush vegetation even in years of drought (Menke et al. 1996, Ratliff 1985). Demands for sheep and cattle products increased during the gold rush period; ranchers responded by increasing the number of animals above what the foothill grasslands could support during the dry season (Ratliff 1985). In an analysis of the historical perspectives, McKelvey and Johnston (1992) found that Sierran travelers from the late 1800's often remarked on the scarcity of forage left for their pack animals due to intensive and extensive livestock grazing:

> *The great obstacle to the explorer is not the danger of crag or chasm, but the starvation threatening his animals, through the destruction of the fine natural meadow pasturage by sheep (Russell Dudley 1898, professor of botany, as quoted by Vankat 1970 p.20 in McKelvey and Johnston 1999)*

> *The soil being denuded of grass is broken up by thousands of sheep tracks, and when the rains come this loose soil is washed down the mountainsides into the valleys, covering up the swamps and meadows, destroying these natural reservoirs (1894 report by Acting Superintendent of Sequoia and General Grant National Parks as quoted by Vankat 1970 p.20 in McKelvey and Johnston 1999)*

During the late 19th and early 20th centuries the United States Forest Service (USFS) and the Bureau of Land Management (BLM), began recording use and numbers of livestock with the formation of the National Parks. (Menke et al. 1996). However, a quote from the 1933 Annual Grazing Report of the Modoc National Forest reveals that the managers felt responsibility towards the well-being of the livestock ranchers over meadow health and protection:

> *The proper thing to do is to reduce the number of stock to meet forage conditions. This we have been planning to do for several years, but because of … the precarious condition of all the stockmen*

concerned we feel that it is a most inopportune time to make reductions (as quoted in Menke et al. 1996).

In 1934, the Taylor Grazing Act established 'grazing districts' and dictated a permitting system to be used by all federal land management agencies. The Bureau of Land Management was charged with halting overgrazing and soil deterioration (National Research Council 1994). Grazing use was reduced by over 50 percent of the pre -1920 stocking rates in the 1930's and 1940's (Menke et al. 1996). During the 1950s and 1960's, livestock use fell even more due to economic reasons.

Beginning in the 1960's, recognition of the damage done by past grazing led to many vegetation 'improvement' projects, such as plowing and planting with exotic perennial grasses, post burn broadcast seeding (exotics), and herbicide treatments to reduce sage brush (Menke et al. 1996). During the 1970's and 1980's these improvement projects became more ecologically oriented, and included exclosures, rest-rotation systems, erosion control structures, and replanting of native riparian species (Menke et al. 1996). The Forest Service began making protection of meadow resources a primary focus in the 1980's and 1990's; actual reductions in meadow use in the central and southern Sierra meadows were first recorded during this period (Menke et al. 1996).

In the 1950's, the Forest Service began collecting data to assess range condition and trends using the Parker three-step method in which plant species were recorded within ¾ inch loops along permanently marked transects that were revisited at various intervals. This methodology was largely abandoned in the 1980's due to problems with representation within such a small sampling area (3/4" loops). However, the large number of repeated measures taken along these transects in rangelands across the American West make this unique set of historic data very valuable.

Since retiring the Parker three-step method in the mid 1980's, Region 5 of the Forest Service had no commonly used method for monitoring range condition and trends until 2002. In 2002, Region 5 of the Forest Service initiated a long-term monitoring study for meadows in the Sierra Nevada as part of the Sierra Nevada Forest Plan Amendment (a.k.a. the Framework). Two years of data were collected for this effort before funding ended. Data from the Framework monitoring project, titled the "Aquatic Conservation Strategy Meadow Study Plan," is included in the Sierra Meadows Health Database created as a part of this project and is being integrated with other sources of new and existing data on meadow health and trends from various governmental and academic institutions as part of this Mountain Meadow Wetlands project.

Currently, information on historic grazing resides with the Heritage Resource Managers associated with Forest Service District Offices throughout the state. Files on current grazing allotments (e.g. 1990's through today) are held by Range Conservationists in National Forest District offices. These historic and current files include several folders. One folder contains administrative information, such as permit applications, dates, and correspondence; a second folder includes planning and management agreements, such as the Allotment Management Plan (AMP) developed with the application, operating instructions, and site maps; a third folder includes data from monitoring of vegetation, soils, and hydrology; and a fourth folder includes information on structural (e.g. fences, trough additions, ect.) and nonstructural (e.g.

channel restoration) improvements that have been made and are planned to be executed (pers. com. Leigh Sevy, Tahoe National Forest Range Specialist). Furthermore, each National Forest within the Project Area should have a GIS data layer available that includes information on current grazing allotments. The Region 5 Range program has several projects underway to gather historic and current information on grazing allotments as well as soils and vegetation monitoring data. Meeting with the Region 5 Range Conservationists about these efforts early in the fall of 2007 would be a step towards gaining a better understanding of the historic effects of grazing on meadows in the Project Area.

Livestock overgrazing affects meadow health and leads to erosive conditions which in turn destroys habitat. Livestock grazing in the Sierra Nevada causes a host of threats including non-native species invasion, predation, meadow and stream degradation, and changes in prey abundance. Grazing allowed in habitat of the Willow Flycatcher has led to its drastic population decline. Many studies concluded that livestock grazing has detrimental impacts on Yosemite toads through trampling, alteration of meadow habitat, changes in-stream hydrology, siltation of springs, bacterial increase from livestock fecal matter, and impaired water quality.

Overgrazing compacts and disturbs the soils. The increased soil compaction from hoofs can lower infiltration and reduce the water holding capacity of meadows, which in turn reduces soil moisture and rooting density and leads to erosive conditions. Once erosion has started, it can trigger a series of hydrologic changes that leave meadows disconnected from their original hydrologic function. Eroding stream channels typically downcut, resulting in a lowering of the local water table. Water stored in the meadow quickly drains down to the lowered water table and is released from storage more quickly through the eroded channel banks, resulting in reduced summer streamflows. Downcut channels are then no longer connected to their historic, wide meadow floodplains but are confined within narrow, incised channels. When streams no longer flow on top of meadows, meadow bottomland soils are not replenished with fine silt particles transported by the stream. In addition, the energy of the stream during high flows is confined to the smaller, incised channel and is not slowed by flowing across the meadow, resulting in faster in-channel flow velocities and more streambank erosion. Water passes through the meadow area more quickly and is resident on the meadow for shorter periods, if at all. This reduction in the amount of water stored in the meadow and streambank often results in the loss of many meadow species.

The History of Mining and Meadows

The Sierra Nevada was the location of extensive gold mining from 1848-1942. Mining activities have affected creek geomorphology and continue to impact water quality across watersheds. It is estimated that between 20-40,000 abandoned mine sites exist throughout the Sierra Nevada region (Abandoned Mine Lands, Department of Conservation).

The advent of hydraulic gold mining in the 1850's was followed by rapid and voluminous sediment production and widespread channel aggradation (James 1991, Gilbert 1917). While much of the material produced in 19th and 20th century mining has been distributed far downstream from the source area, significant amounts of sediment are still stored in main channels and their tributaries (Curtis et al 2005). In many systems, storm events mobilize and transport these sediments, which impact water quality and habitat characteristics for numerous aquatic organisms (Curtis et al 2005).

As a result of mining practices numerous toxic chemicals were released into the environment. For example, mercury was used to amalgamate gold in both hydraulic and hard rock mining. It has been estimated that 30 million pounds of mercury was utilized in the process of extracting gold in the Sierra Nevada. Annual mercury losses at mine sites ranged from 10 to 30 percent of the amount used to recover gold, with an estimated total loss in the Sierra Nevada of 11-12 million pounds of mercury into the environment (Churchill, 2000).

Recent data show that sediment bound mercury from mine tailings are still being worked through the watershed during storm events (Curtis et al 2005). New research is being done on the fate and transport of mercury in the watersheds and on the factors that control the methelation of mercury, which affects the bioavailability of mercury to the food chain.

The legacy of mine tailings and the toxic chemicals that they contain (such as lead, mercury and asbestos) has directly affected the quality and distribution of aquatic species habitat. The impact of mining activities on meadow health has not been assessed to date. However, the biochemical cycling such as the transformation of mercury to methyl-mercury and its uptake by the food chain in anoxic environments should not be overlooked when considering the health of meadows and selecting appropriate restoration techniques in meadows that are downstream from mine sites.

The History of Fire Management and Meadows

Sierra Nevada forests and meadows were altered by burning patterns associated with sheep grazing in the late 1800s. Sheepherders were known to set large fires in the fall to maintain open space and select for ruderal species, plant species that are first to colonize disturbed lands (Menke et al. 1996, Allen-Diaz et al. 1999). Consequently, sheep herders gave special attention to burning large, downed fuels and to burning mesic areas to stimulate forage production (McKelvey and Johnston 1992).

Since the beginning of the 20th Century, fire suppression has been a guiding policy for the Forest Service and other federal land management agencies. Intense fire suppression has produced forests which are denser with generally smaller trees. These changes have increased the levels of fuel, both on the forest floor and "ladder fuels," small trees and brush which carry the fire into the forest canopy. Increases in fuel, coupled with efficient suppression of low and moderate intensity fires, led to an increase in fire severity. Surface erosion related to high intensity wildfires is much greater than that associated with low intensity ground fires (Robichaud, P.R. and R.E. Brown, 1999, Sugihara et al. 2006). Similarly, moist areas such as meadows and riparian areas are more likely not to burn when ground fires burn surrounding uplands than when a high intensity wild fire burns adjacent lands (Sugihara et al. 2006). In the latter case, very high temperatures and low humidity associated with intense wild fires can desiccate meadow grasses and make them more combustible. Thus, through both indirect (erosion in surrounding uplands) and direct means, intense wildfires have greater negative effects on mountain meadows than do low intensity (more frequent) ground fires. The recent history of fire suppression, drought, and bark beetle attacks increase the likelihood that the fire regime in the Sierra Nevada is shifting from one in which intense crown wild fires were rare to one in which they are increasingly common (Regents of California 1996b, Sugihara et al. 2006).

The History of Timber Harvesting and Meadows

During the 19th Century, timber harvesting was used mainly to support mines in the growing towns of the Sacramento and San Joaquin Valleys. Timber was used to keep tunnels from collapsing, as fuel for processing ore, and as rail beds used to transport processed ore to the market by train (McKelevy and Johnston 1992). Large mines consumed between 2,000 and 3,500 cords annually. Fuel needs of stamp mill-machines, mills for pulverizing ore, were great. For example, the Empire Mine in Grass Valley had a 30-stamp mill that consumed 11 cords of wood in a 10-hour period or, assuming constant operation, 9,600 cords a year (McKelevy and Johnston 1992). Before the 1900's most logging occurred at low elevations on lands adjacent to mines due to the limitations associated with transporting timber by horse-drawn wagons.

There were several waves of intensive logging in the 20th Century. Logging increased during World War I and included returns to many areas that were still recovering from the 19th century harvests, as well as harvesting from large areas that had not yet been logged. Many new logging roads were constructed during this time. The post World War II boom and increase in housing construction resulted in high demands for lumber and timber harvest in the Sierra Nevada. Another wave of timber harvest occurred in the mid 1980's through the early 1990's before lawsuits were brought against the Forest Service related to the spotted owl and other management issues which significantly slowed the rate of timber harvest on federal lands. Since the mid-1990's, intensive logging has been most active on private lands; however salvage logging may also become increasingly common on Federal lands (Pegg 2006).

Early 19th century timber harvests were restricted to relatively low elevations due to physical limitations of logging operations therefore, their impact on high elevation meadows was likely limited. However, as logging practices became more agile it became possible to log areas that were previously inaccessible. The literature on the erosion, soil fertility, nutrient cycling, and hydrologic effects of timber harvest in forested watersheds is well established and quite complete (e.g. Likens and Bormann 1995). However research on the direct effects of timber management on associated or adjacent meadows is very sparse. Indirect effects of timber harvest on meadows include channel gullying and channel downcutting due to increased rates of runoff and erosion associated with upslope harvested areas. Indirect effects on the aquatic habitat are associated with increased fine sediment input to the stream and associated reduction in spawning gravels and diversity of aquatic habitat as well as increased water temperatures resulting from shade canopy removal.

The effects of human activities and land and water management projects during the 20th century were added to the set of impacts from earlier times. As the state population and agricultural economy grew, the need for water in agricultural areas of the Central Valley and elsewhere, as well as in coastal urban areas, inspired water districts to construct elaborate and extensive water transportation and hydro-electric facilities throughout the water-rich Sierras. Diversion and irrigation ditches formed a vast network that altered local and regional stream hydrology. Additional waves of timber harvesting and associated road construction further affected erosion and sediment delivery patterns in rivers and meadow streams. Invasive exotic plant and animal species often proliferate in the wake of road construction and other forms of disturbance. The changes in the natural fire regime, first fire suppression followed by an increase in the frequency of large wildfires due to excessive fuel build-up, introduce an added layer of disturbance pressure to meadow health in the Sierra Nevada.

The work described below is the most comprehensive assessment of meadow health conducted to date. Unlike previous efforts, it is not focused on the impacts of a single land management activity, such as grazing. It includes an assessment of both the terrestrial and the aquatic ecosystems which together determine the health of a meadow.

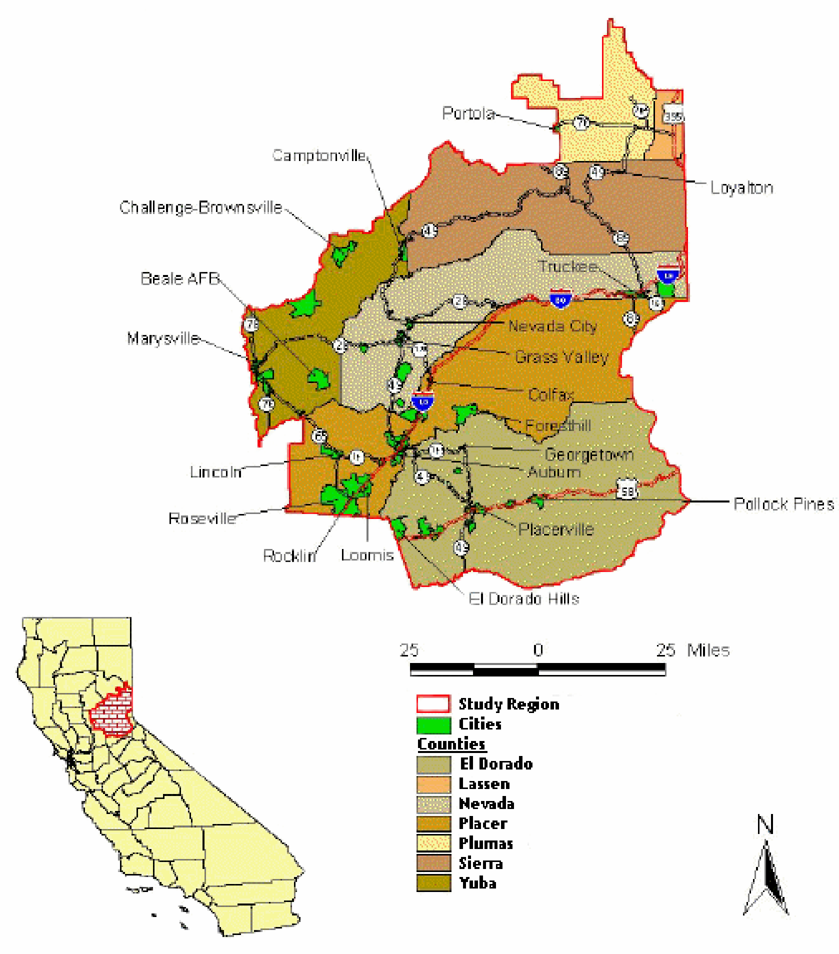
Meadow Health Rating System

At the University of California at Davis, Dr. Peter Moyle and his team compared various measures of assessing the ecological condition ("health") of meadows in the project area. Existing data from previous vegetation surveys, which are often used as the principal method to assess meadow conditions, were combined with newly collected data on streams flowing through wet meadows, and integrated to develop meadows health assessments. In this way, the methods commonly used for terrestrial assessment of meadows were compared to the results of aquatic assessments to see if they produced similar results (i.e., were meadows likely to be assessed as being in good or bad condition by all methodologies or did different methods produce different results?) The condition of the streams and the biotic communities they support was determined by measuring the diversity and abundance of fish, amphibians, aquatic insects, and riparian vegetation as well as by characterizing physical habitat and water quality.

Study Area

Meadows in the northern Sierra Nevada mountain range, California, in Plumas, Sierra, Nevada, El Dorado, Alpine, and Placer Counties were sampled by the UC Davis team (Figure 1). The meadows were located on public land, mainly on national forest lands (Tahoe, El Dorado, Stanislaus, Humboldt/Toiyabe, Plumas), at elevations between 4,900 and 8,200 ft. The meadows used in the analysis were mainly classified as Moist Meadow Foothill Zone Ecological Type or Moist Meadow Montane Zone Ecological Type by Weixelman et al. (2003). These meadows are dominated by grasses and sedges with patches of willows and other riparian shrubs; they have wet to moist soils through most of the summer. Most had streams flowing through them with perennial flows, with some streams becoming intermittent by late summer. The meadows were typically surrounded by mixed coniferous forest. All had a history of grazing by cattle and sheep, as well as of logging in surrounding forests, although most of the meadows sampled were in varying degrees of recovery from past heavy use. A total of 88 meadow sites were sampled; 40 were in drainages on the western side of the Sierra Nevada (Sacramento-San Joaquin drainage), and 48 on the eastern side (Lahontan drainage).

Figure 1. Map of general study area.



Field Methods

The streams were sampled by two teams of five people. One team, from the University of California, Davis, sampled mainly streams in meadows with recent vegetation surveys from the US Forest Service (Weixelman et al. 2003). The other team, from the California Department of Fish and Game (DFG), sampled meadow streams of special interest to DFG, which often did not have vegetation surveys associated with them (J. Brown, DFG, pers. comm.). Between the two teams, 88 meadow streams were sampled; of which 42 had associated vegetation surveys located within 500 meters of the stream sampling site (Appendix 1). Of these 42 sites with associated vegetation surveys, 37 contained fish. The entire database was used for evaluating overall status of aquatic systems in the meadows, while the database from sites with vegetation surveys was used for comparing results of terrestrial and aquatic surveys.

Surveys were conducted between June 21 and September 18, 2005. Sites chosen were all wet to moist meadows with reasonable accessibility. For the most part accessibility was based on a combination of public ownership and access from nearby roads, although crews sampled sites accessible by hiking up to three miles as well. In addition, two streams (Sagehen and Martis Creeks) dominated by meadow systems with long-term data sets available on fish numbers were sampled.

Before sampling, reconnaissance of each reach was made to ensure it fit the study criteria and was actually possible to sample, meaning that it had low enough flows to maintain blocknets across the reach, had access by road or foot (< 7 km), had vegetation densities that allowed access to the stream itself, and was permanent enough to support fish or invertebrate populations. We sampled ~50 meter reaches at each site and tried to include a representative sample of the hydrologic regimes found in the stream. Once the site, was chosen, surveys were conducted in the following order: (1) amphibians. (2) aquatic invertebrates, (3) fish, (4) riparian vegetation, and (5) physical habitat and water quality.

Amphibian and Reptile Surveys

Day-active amphibians (mainly frogs)were surveyed in the riparian zone, using Visual Encounter Surveys (Crump and Scott 1994). Reptiles (mainly two species of garter snakes) were also recorded. The amphibian surveys started as soon as the crew arrived on the site, before other sampling began. Two observers, one on each side of the stream, walked upstream along the stream bank over the length of the stream reach counting all amphibians within 5 m of the stream bank and in any side channels or pools along the stream bank. All amphibians observed were identified and recorded on a standardized form (Crump and Scott 1994, p. 91, Appendix 2). Amphibians observed or captured during the fish sampling were recorded in a total abundance score for the site. The final data consisted of (1) a species list and (2) abundance score for each species, where 0 = none observed, 1 = rare (single individual encountered), 2 =common (2-10 individuals encountered), and 3 = abundant, more than 10 individuals encountered. Few reptiles were found during our surveys. Amphibians abundance was also low but higher than reptiles. Their numbers were insufficient to support an index of their own so their presence was quantified in the joint fish and amphibian index.

Aquatic Invertebrate Sampling

Benthic macroinvertebrates (BMI) were sampled using modified Level 2 protocols from Harrington and Born (2000). We took three total samples from within each fish sampling reach, using a D-net, taking one sample in each riffle, or other suitable habitat. Each sample was then placed in a white enamel pan and the major debris removed. Samples were sorted and invertebrates identified to the lowest possible taxon in the field, a departure from the Harrington and Born (2000) protocol which assumes collectors have only minimal skills in identifying aquatic invertebrates and so requires that preserved samples of invertebrates be sorted in a laboratory setting. We identified the first ~100 invertebrates in each sample (300 minimum) to the lowest taxonomic group possible by eye or with a field microscope to order, noting number of families in the orders Ephemeroptera, Plecoptera, and Trichoptera. Invertebrates with questionable identification were preserved in 70% ethanol for later identification in the laboratory. Three entire samples were brought back for traditional laboratory processing to ensure field sorting accuracy.

Fish Sampling

Basic fish sampling procedures followed those of Moyle et al. (2002). A block net was placed at the upper and lower end of each section. A single pass with a Smith-Root type 12 backpack electrofisher was made, with fish captured by two or three people using dip nets. The fish were kept alive in buckets until they were measured (fork length and standard length) and weighed (most through volumetric displacement, with some on an electronic balance); then they were returned alive to the water. At some sites, three pass electrofishing was performed for a more quantitative comparison with past surveys. All data was recorded on standardized forms (Appendix 3).

Vegetation Sampling

Riparian plant communities were classified using fifteen categories (non-woody plants, sedges, grass, forbs, shrubs, willows along stream, willows at site, alders along stream, alders at site, sagebrush, other shrubs, number of trees, tree coverage, aspen, white alder, cottonwood, lodgepole pine, white fir, other tree species); the percentage cover of each category was noted with a score of 1 equal to <5% of the total area, 2 = 5-20%, 3 = 21-50%, 4 = 51-80%, and 5 = 81-100% (Appendix 5). In addition, we estimated average willow height and noted moisture regime by determining if there was standing water on the surface of the soil, if the soil was saturated, if the soil was moist on the top 2 -5 centimeters, or if the soil was dry to touch).

We used the results of Weixelman et al. (2003) as the botanical component for determining vegetation health in the meadow (Appendix 6). Health status in this case was defined as successional status, which represents the degree of recovery from a past disturbance. The assessment first determines meadow type based on soil saturation, depth to soil mottling, presence of soil organic or peat layer, presence of indicator species, and elevation (Appendix 5). Then the relative frequency of plant species on a line transect is quantified. Plant species are divided into three seral categories (1) early seral; (2) mid-seral; (3) late seral. Weixelman et al. (2003) equate seral status with ecological condition, so early seral status corresponds with low ecological function, mid-seral status with moderate ecological function and late-seral with high ecological function. Estimates of extent of bare soil cover and rooting depth are included to further determine "ecological status." Weixelman et al. (2003) determined scores for the meadows using the vegetation successional scorecard (Appendix 5).

Physical Habitat and Water Quality Sampling

At each site, 20 environmental variables were measured or estimated (Table 1), following USFS (Overton et al. 1997) and Moyle et al. (2003).

Table 1. Environmental variables determined at each site during surveys.

1. Stream Name, County, GPS coordinates
2. Date, beginning time, ending time
3. Description of site including human impacts
4. Presence of birds, reptiles, and amphibians
5. Elevation (m)
6. Gradient of stream section (m/km)
7. Air temperature (C, beginning, end, time taken)
8. Water temperature (C, beginning, end, , time taken)
9. Water Clarity (1-5)[1]
10. Turbidity (NTU)
11. Conductivity (units)
12. Section Length (m)
13. Length (m) of riffles, runs, pools
14. Width (m), 10 transects
15. Average depth (cm) from depth measures at 25%, 50%, and 75% the width at 10 transects
16. Maximum depth (cm)
17. Aquatic vegetation: estimated % of section covered with emergent plants, floating mats, filamentous algae, and macrophytic vegetation
18. Substrate: estimated % clay, mud, sand, gravel, cobble, boulders, and bedrock
19. Silt: % flocculent material covering bottom
20. Flow (m^3/sec) [2]

Turbidity (NTU) was determined with an HF Scientific DRT-15 CE Turbidimeter, while conductivity and temperature (□ C) were measured with a Hanna HI 991300 Multimeter. Current speed was measured with a Marsh-McBirney Model 2000 flow meter. Physical habitat was also characterized using the Physical/Habitat Quality parameters from Barbour et al. (1999) which scores 10 parameters on a 20 point system (Appendix 7).

Analyses

Indexes of Biotic Integrity:

As a part of the data analyses multiple IBI, or Index of Biotic Integrity were developed. These are extremely helpful tools in assessing the ecological condition ("health") of Sierra Mountain Meadows.

The Indices of Biotic Integrity were based on Karr (1981) and Moyle and Marchetti (1999). The IBIs developed were as follows:

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[1] Clarity measures based on 1-5 scale, 5 being most clear, 1 being most turbid

[2] Flow in m^3/sec taken in a cross-stream transect broken into 10 sections whose individual flow is then averaged and combined to get total flow.

1) Fish and Amphibian Index of Biotic Integrity
2) Fish-only Index of Biotic Integrity
3) Macroinvertebrate Index of Biotic Integrity
4) Habitat Quality Index and
5) Index of Biotic Function.

1) Fish-Amphibian IBI
Fish and amphibians were placed together in one IBI following Moyle and Randall (1998). The justification for not building an index just for amphibians is that they were uncommon at our sites and their absence is part of a documented Sierra-wide decline of amphibians. This decline is well documented, particularly amongst *Rana muscosa* and is at least partly related to fish predation (Vredenburg 2004) though evidence that UV-B radiation, air pollution, pollution and habitat loss also play a role in their statewide decline (Blaustein and Wake 1995, Davidson et al. 2001). Their lack of abundance probably says less about the health of each meadow system than about the overall state of amphibian populations in the region. The IBI included eight metrics: 1) number of trout species, 2) percentage of native species, 3) the number of native species present, 4) number of age classes in all fish, 5) total fish abundance, 6) total number of species present, 7) number of amphibians, and 8) number of amphibian species present (Appendix 8). Only rainbow trout were counted as native to west-side streams, while only cutthroat trout were counted as native of east-side streams.

2) Fish IBI
The fish IBI used all of the same metrics as the Fish-Amphibian IBI (Appendix 9); however, trout are treated as trout/meter^2 without regard to whether they are native or introduced species. No amphibian data is included in this IBI. We decided to treat all trout the same because there is so much historical alteration in the fish fauna throughout the state. Native trout were not historically planted in meadow streams or have been displaced by non-native trout through biotic interactions (competition, predation, disease) (Moyle 2002) that do not reflect meadow conditions. In fact, many of the streams with trout, especially at higher elevations on the west side of the Sierras, were probably historically fishless (Moyle 2002), so fish represent a disturbance in themselves. Unfortunately, records are lacking for determination of the historic fish presence in most of the meadows studied.

3) Macroinvertebrate Indices and IBI
Five macroinvertebrate metrics were generated: 1) EPT index (percentage of individuals in Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) taxonomic groups from the total sample. EPT species are generally considered indicative of high water quality. 2) total number of taxa (an indicator of diversity), 3) tolerance value of dominant taxa (a determination of a taxon's sensitivity to pollutants or water quality), 4) percent dominant taxa, and 5) percent stoneflies. Stoneflies (Plecoptera) are the most sensitive of the EPT species; therefore a higher percentage in the sample indicates better stream health. These five metrics were combined to create a macroinvertebrate IBI (Figure 6).

4) Habitat Quality Index
The HQI was based upon ten metrics which were scored on a 0 to 20 basis (Appendix 11), from Barbour et al. (1999). A score of 16-20 (Optimal) for the metric indicated it contributed to high habitat quality, while a score of 11-15 (Sub-Optimal) indicated moderate habitat quality with some impairment, a score of 6-10 (Marginal) indicated considerable

impairment of habitat quality, and 0-5 (Poor) indicated severely compromised habitat quality. The scores of these ten metrics were converted into a Habitat Quality Index on 100 point scale by the following equation ([total score/10]*5).

5) Index of Biotic Function (IBF)
The fish, fish and amphibian, macroinvertebrate and habitat indices were combined to create an overall IBF for meadow streams. This score is an average of the four metrics and provides an overall look at the stream health when all factors are considered. Due to the structure of the Habitat Quality Index, its scores were consistently higher than the other indices and therefore increases the overall IBF score for each meadow (Table 7).

Vegetation Analysis
An index of vegetation health (VHI) was created based on the percentages of each seral category in the meadow as defined by Weixelman et al. (2003). We assigned the low ecological function species a 1 score, the moderate ecological function species a 3 score, and a 5 score for the high ecological function species. Each score was multiplied by the percentage of species found in that ecological function group, and then the scores were added together and adjusted to a 0 to 100 scale (Table 2).

	Ecological Function		
	Low	Moderate	High
Percent Functional Group	25	25	50
Multiplier	1	3	5
Score	25	75	250
Sum of Function Scores (SFS)	350		
Total Possible Score (TPS)	500		
Final score (SFS/TPS)	0.7		
Adjusted Final Score	70 out of 100		

Table 2. Example of index to determine vegetation health scores.

For example, in the table above, a site that had 25% low, 25% moderate, and 50% high ecological function would be scored 25 low, 75 moderate, and 250 high for a total score of 350 out of a possible 500 points. We then divide the total score by 5 in order to adjust the score to a 0 to 100 scale and we get a score of 70 for this site. Our own measures of vegetation cover were too descriptive for statistical analysis and so were not used in Vegetation Health Index.

Statistical Analysis
Standard descriptive analysis was performed to establish mean, variance, standard deviation, standard error, minimum, maximum, range, skewness, and kurtosis for measured physical parameters, and average, range, and standard error for indices. HQI scores, fish-amphibian IBI scores, macroinvertebrate indices, IBI scores and VHI scores were analyzed for linear relationships using Pearson product moment correlations (N = 37, the total number of sites that had both fish and vegetation data out of the total number of sites sampled between both crews). Comparisons were made for all sites containing data for fish (N= 76) as well, without the VHI comparison. Data analysis was performed using the program Statgraphics 5.0.

Quality control
In order to provide replication and ensure that both the UC Davis and the DFG crews were sampling consistently with one another, both crews sampled the same sites at nine locations. The replicates took place both on different days or sampled adjacent sites on the same days, and some sites were sampled using mixed teams from both crews. To compare matched sites we compared IBI score means using t-tests assuming the differences between the means was equal to 0 at a 0.05 significance (Appendix 12). The paired samples were also checked for normality, because it is assumed that the data is normal when using tests that compare standard deviations. We also assumed that variances of the compared site IBIs were equal, so an F-test to compare standard deviations was performed. No significant differences were found between the mean IBI scores and all assumptions of normality and equal variances were met (Appendix 12).

Results
Each of the final indices is based on a possible score of 100. We broke the indices up into discreet categories with an index score of 0-25 being in poor ecological condition, 26-50 being in fair ecological condition, 51-75 being in good ecological condition, and 76-100 being in very good ecological condition. The habitat quality metric from the EPA (Barbour et al 1999) is broken into the same numerical categories, but is given the terms poor, marginal, sub-optimal and optimal as per the EPA format.

Fish and Amphibian IBI
Of the 89 montane meadow sites sampled by the two crews, 11 were fishless. From the 78 containing fish, 3940 fish were captured representing 18 species, nine of them native to California (Table 4). Only 21 sites (24 %) contained amphibians. Only two sites contained ranid frogs, both mountain yellow-legged frogs (*Rana muscosa*). Fifteen sites contained Pacific tree frogs (*Hyla regilla*), three sites contained western toads (*Bufo boreas*), and one site contained long-toed salamanders (*Ambystoma macrodactylum*) (Table 3). In addition, six sites contained Western aquatic garter snakes (*Thamnophis atratus*), and one a western terrestrial garter snake (*Thamnophis elegans*). Because of this lack of amphibian abundance, we were unable to build an index on amphibians alone and instead combined them with fish in the fish-amphibian IBI (Figure 2). Fish-amphibian IBI scores ranged from 23.00 to 90.00 with an average of 47.01 (SE = 1.68).

Table 3. Records of amphibians and garter snakes from sample sites

Place	Common Name	Scientific Name	Stage (number)
Childs Meadow	Pacific Treefrog	*Pseudacris regilla*	Adult (1)
Willow Creek	Aquatic Garter Snake	*Thamnophis elegans elegans*	Adult (1)
Howard Creek	Mountain Yellow-Legged Frog	*Rana muscosa*	Adult (2)
Church Creek	Pacific Treefrog	*Pseudacris regilla*	Adult (1)
Upper Yuba	Western Toad	*Buffo boreas*	Adult (1)
Bear Flat	Pacific Treefrog	*Pseudacris regilla*	Adult (1) Larvae (1000)
Independence	Aquatic Garter Snake	*Thamnophis elegans elegans*	Adult (1)
French Meadows	Western Toad	*Buffo boreas*	Adult (1)
Willow Creek	Pacific Treefrog	*Pseudacris regilla*	Adult (1)
Big Meadow Creek	Pacific Treefrog	*Pseudacris regilla*	Adult (2)
Tryon Meadows	Western Toad Pacific Treefrog Long Toed Salamander	*Buffo boreas* *Pseudacris regilla* *Ambystoma macrodactylum macrodactylum*	Larvae (250) Larvae (250) Larvae (50)
Wet Meadow	Pacific Treefrog	*Pseudacris regilla*	Adult (2)
Silver Creek	Pacific Treefrog	*Pseudacris regilla*	Adult (4)
Stanislaus Meadows	Mountain Yellow-Legged Frog Pacific Treefrog	*Rana muscosa* *Pseudacris regilla*	Adult (4) Adult (2)
Upper Truckee	California Mountain Garter Snake	*Thamnophis elegans elegans*	Adult (1)
Scott Meadow	Pacific Treefrog	*Pseudacris regilla*	Adult (1)
Lower Barker Meadow	California Mountain Garter Snake	*Thamnophis elegans elegans*	Adult (1)
Pacific Creek	Pacific Treefrog	*Pseudacris regilla*	Adult (2)
Stanislaus Creek	Mountain Yellow-Legged Frog Pacific Treefrog	*Rana muscosa* *Pseudacris regilla*	Adult (4) Adult (3) Larvae (35)
Sagehen Creek III Sagehen Creek VII	Terrestrial Garter Snake Pacific Treefrog Pacific Treefrog	*Thamnophis elegans* *Pseudacris regilla* *Pseudacris regilla*	Adult (1) Adult (1) Adult (1)
Martis Creek III	Pacific Treefrog	*Pseudacris regilla*	Adult (1)
Macklin Creek	Pacific Treefrog	*Pseudacris regilla*	Adult (1)
Little Truckee River	California Mountain Garter Snake	*Thamnophis elegans elegans*	Adult (1)

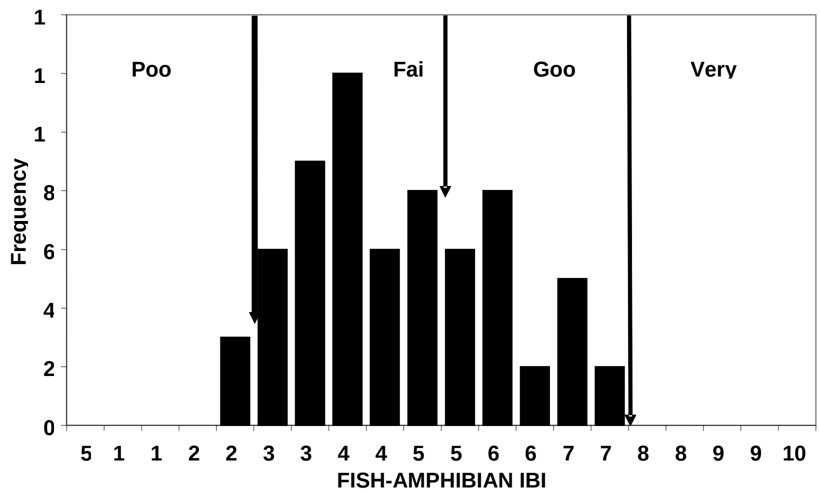


Figure 2. Frequency graph of Fish-Amphibian IBI scores

Fish IBI

Rainbow trout and cutthroat trout are native to California, but they were not native to many of the sites where they were collected. A majority (65%) of the fish captured were trout (Salmonidae), especially brook trout (38% of fish, 48% of sites) and rainbow trout (16% of fish, 44% of sites). Trout regardless of species were found in most (83%) of the streams containing fish. Usually just one species of trout was present or dominant at a site. Because of the prevalent mixing of native and non-native trout throughout the study area, all trout were treated the same and were quantified as trout/m^2. The scores for the fish-only IBI ranged from 20 to 100, mean, 59.73 (SE = 2.18) (Figures 2, 3).

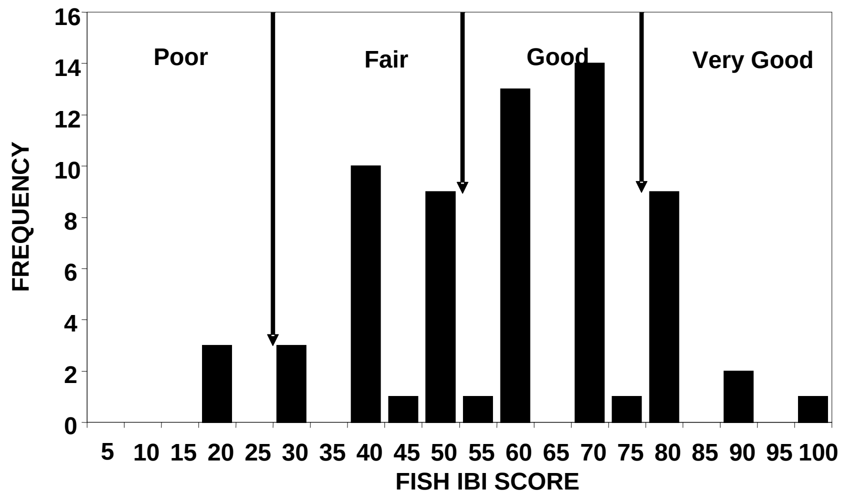


Figure 4. Frequency graph of Fish-only IBI scores

Table 4. Species percentage of the total caught, on east or west side * indicates non-native species. Rainbow trout and cutthroat trout were both found in streams outside their native range as well as within their native range.

Fish Species	N	No. sites with fish	% Total	East	West
Golden shiner* ***Notemigonus crysoleucas***	5	1	0.1		X
Speckled dace ***Rhinichthys osculus***	144	7	3.7	X	X
Lahontan redside ***Richardsonius egregius***	14	4	0.4	X	
Tui chub ***Siphateles bicolor***	40	2	1.0	X	
Mountain sucker ***Catostomus platyrhynchus***	8	3	0.2	X	
Tahoe sucker ***Catostomus tahoensis***	31	3	0.8	X	
Sacramento sucker ***Catostomus occidentalis***	39	1	1.0		X
Mountain whitefish ***Prosopium williamsoni***	3	1	0.1	X	
Brook trout* ***Savelinus fontinalis***	1483	48	37.6	X	X
Brown trout* ***Salmo trutta***	242	15	6.1	X	X
Cutthroat trout ***Oncorhynchus clarki***	112	6	2.8	X	X
Rainbow trout ***Oncorhynchus mykiss***	646	44	16.4	X	X
Kokanee* ***Oncorhynchus nerka***	7	1	0.2	X	
Green sunfish* ***Lepomis cyanellus***	3	1	0.1	X	
Bluegill* ***Lepomis macrochirus***	1	1	<0.1	X	
Smallmouth bass* ***Micropterus dolomieu***	14	1	0.4	X	
Pauite sculpin ***Cottus beldingi***	1120	17	28.4	X	
Riffle sculpin ***Cottus gulosus***	28	4	0.7		X

Total	3940	76	100	15	7

Macroinvertebrate IBI

The average number of macroinvertebrates identified in three kick-net samples from all sites (n = 89) was 337.00, range = 80.24, SE = 15.42, average taxa richness in the subsamples was 12.00, range = 16, SE = 0.32 (Figure 4), average EPT index was 50.18, range = 80.25, SE = 2.42 (Figure 4A), mean tolerance 4.51, range = 7.00, SE = 0.18, and percent dominant taxa averaged 49.41, range = 55.6, SE = 1.57, Macroinvertebrate IBI scores ranged from 20 to 84, averaging 50 (SE = 1.75) (Figure 5).

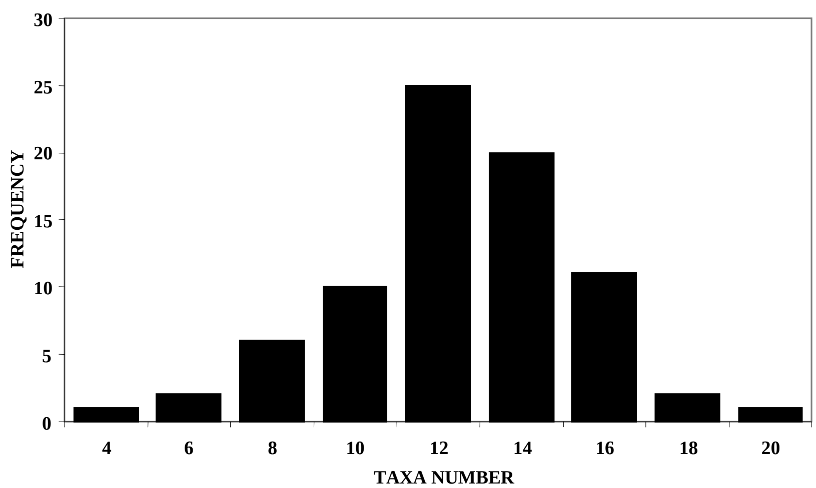


Figure 4. Frequency graph of the invertebrate taxa richness

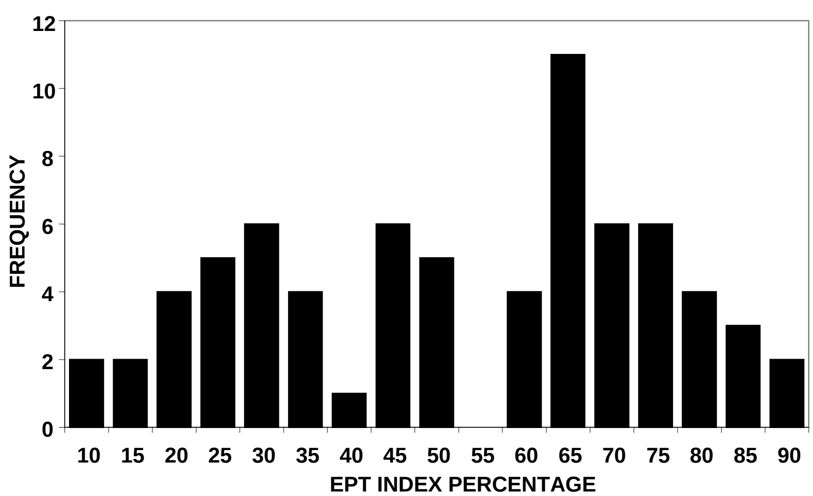


Figure 4A. Frequency graph of EPT index results.

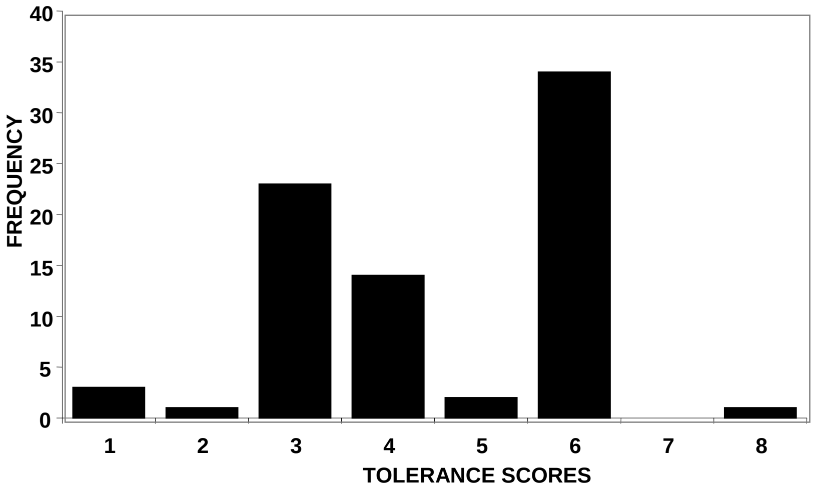


Figure 4b. Frequency graph of dominant invertebrate taxa tolerance values according to Harrington and Born (2000). Higher values indicate taxa are more tolerant to pollutants, sediment or water quality. Therefore a stream dominated by tolerant taxa is indicative of lower water quality and decreased stream health.

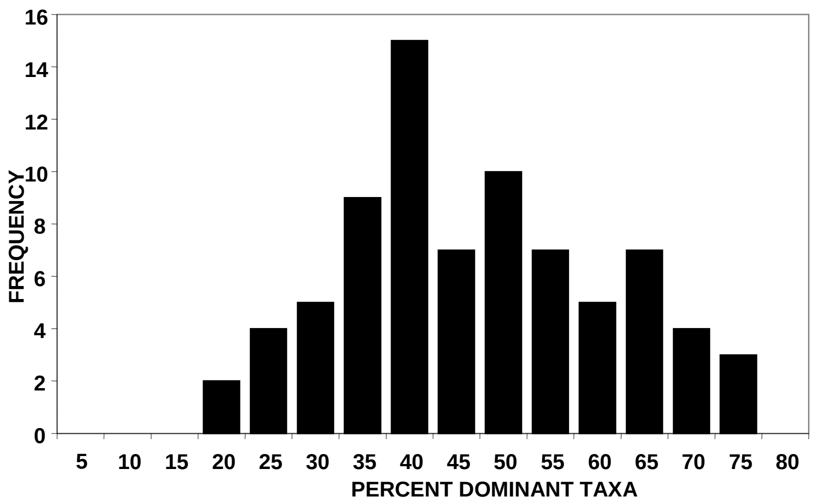


Figure 4c. Frequency graph for the percentage of dominant invertebrate taxa.

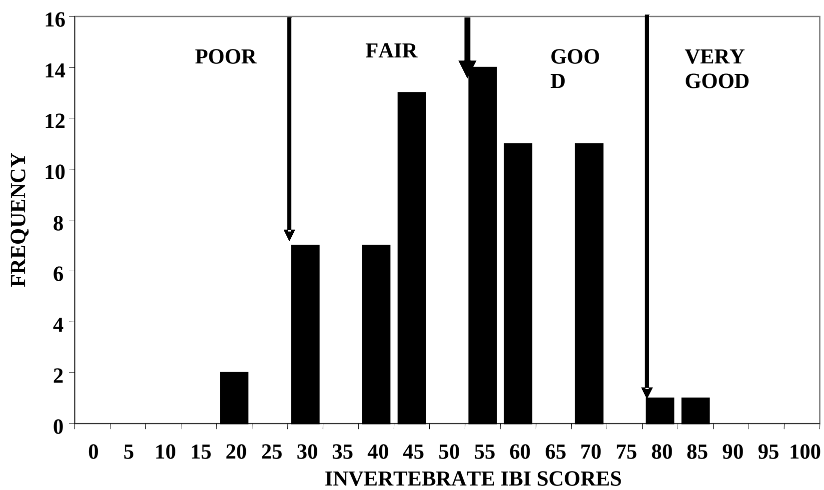


Figure 5. Frequency graph of five combined invertebrate metrics to make a final IBI.

Index of Biotic Function

The mean score for the stream IBF (n = 66) was 57.4 (SE = 1.1, range = 42). The IBF was statistically normal with IBF skewness = 0.75, and kurtosis = -0.10.

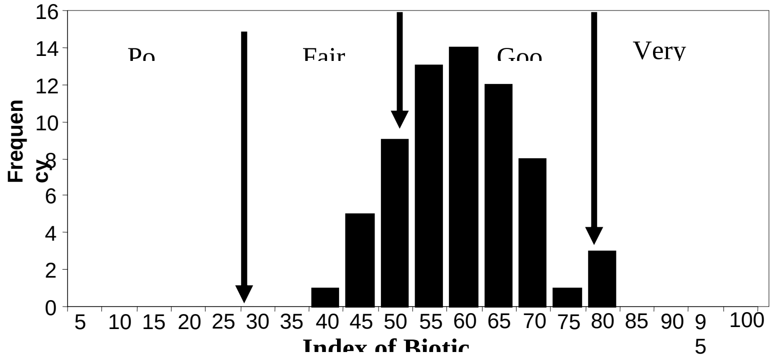


Figure 6. Frequency graph of the scores of the Index of Biotic Function. This score is a combination of the Fish-Amphibian IBI, the Fish IBI, the Macroinvertebrate IBI and the Habitat Quality Index.

Habitat Quality Index

HQI scores ranged from 47 to 92 (mean 72, SE = 1.13), for all 78 sites surveyed, indicating that habitat quality was mostly in the suboptimal to optimal range, although some meadows (mostly those with heavy grazing) were in marginal condition (Figure 7).

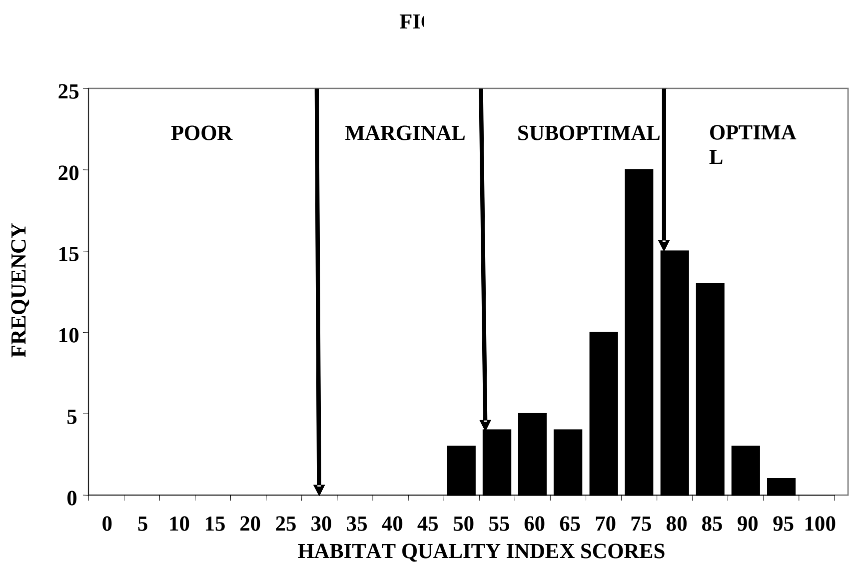


Figure 7. Frequency graph for Habitat Quality Index.

Vegetation Health Index.
The VHI values were generally high to moderate (mean, 80.8, range 33-100, SE = 3.1) (Figure 8).

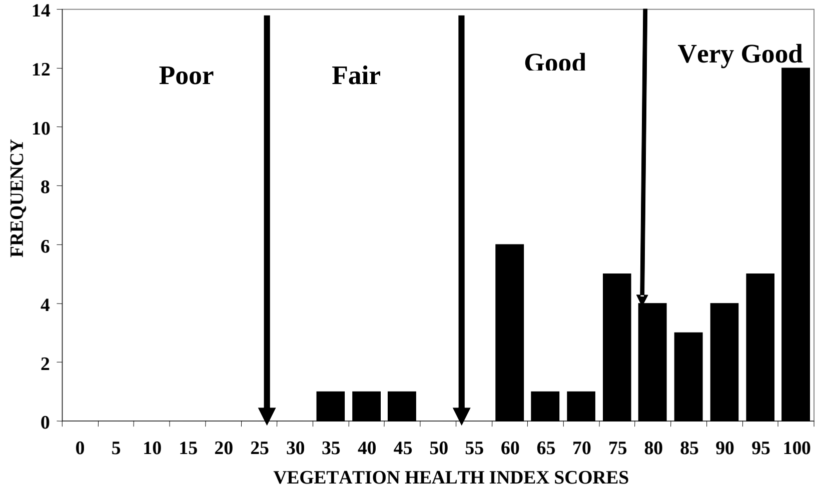


Figure 8. Distribution of vegetation health scores for meadows assessed by Weixelman et al.

Correlation analysis

In order to relate the various measures of meadow health, the indices were correlated to each other using Pearson product moment correlations. We found that for combined UC Davis and CDFG surveys (n = 66) that the Invertebrate IBI had a significant correlation (p<0.05) to the Fish IBI and the Index of Biotic Function (p<0.001). The Fish IBI correlated with the Fish and Amphibian IBI (p<0.001) and both Fish IBIs correlated with the Index of Biotic Function (p<0.001). The Habitat Quality Index correlated significantly with the Index of Biotic Function (p<0.001) (Table 5). We found that for sites having USFS vegetation surveys (n = 37), the Fish IBI was significantly correlated (P<0.05) to the Fish and Amphibian IBI and the Vegetation Health Index (p<0.1). The Macroinvertebrate IBI was significantly correlated to the Vegetation Health Index (p<0.05) and the Index of Biotic Function (p<0.05). The Habitat Quality Index was not significantly correlated to any other health measurement and Vegetation Health Index was significantly correlated to the Macroinvertebrate IBI (p<0.05) and the Fish IBI (p<0.1) (Table 5a).

Table 5. Pearson product moment correlations of IBI scores for fish, macroinvertebrates, habitat assessment the 66 sites from both UC Davis and the CDFG that had information for all five metrics. The top number is the correlation coefficient and the bottom number is the p-value. *** Signifies a significant correlation at the 0.001 level, ** Signifies a significant correlation at the 0.05 level, * Signifies a significant correlation at the 0.1 level.

Correlations	INVERTEBRATE IBI	HABITAT IBI	FISH IBI	FISH and AMPHIBIAN IBI	INDEX OF BIOTIC FUNCTION
Invertebrate IBI		0.1861 0.1326	0.3064 0.0124^{**}	0.1170 0.3496	0.6353 0.0000^{***}
HABITAT INDEX	0.1861 0.1346		0.0723 0.5642	-0.0788 0.5294	0.3308 0.0067^{**}
FISH IBI	0.3064 0.0124^{**}	0.0723 0.5642		0.5605 0.0000^{***}	0.8488 0.0000^{***}
FISH and AMPHIBIAN IBI	0.1170 0.3496	-0.0788 0.5294	0.5606 0.0000^{***}		0.6685 0.0000^{***}
INDEX OF BIOTIC FUNCTION	0.6353 0.0000^{***}	0.3308 0.0067^{**}	0.8448 0.0000^{***}	0.6685 0.0000^{***}	

Table 5a. Pearson product moment correlations of IBI scores for vegetation, fish, fish and amphibians, macroinvertebrates, habitat assessment and the IBF for the 37 sites from UC Davis that had information for all six metrics. The top number is the correlation coefficient and the bottom number is the p-value. *** Signifies a significant correlation at the 0.001 level, ** Signifies a significant correlation at the 0.05 level, * Signifies a significant correlation at the 0.1 level

Correlations	VEGETATION IBI	INVERTEBRATE IBI	HABITAT IBI	FISH IBI	FISH and AMPHIBIAN IBI	INDEX OF BIOTIC FUNCTION
VEGETATION INDEX		0.3330 0.0440**	0.1974 0.2416	-0.2874 0.0846*	-0.1131 0.5050	-0.0363 0.8310
INVERTEBRATE IBI	0.3330 0.0440**		-0.0904 0.5948	0.1129 0.5058	0.1336 0.4306	0.4927 0.0019**
HABITAT INDEX	0.1974 0.2416	-0.0904 0.5948		0.0160 0.9253	-0.1518 0.3698	0.2012 0.2324
FISH IBI	-0.2874 0.0846*	0.1129 0.5058	0.0160 0.9253		0.5286 0.0008***	0.8418 0.0000***
FISH and AMPHIBIAN IBI	-0.1131 0.5050	0.1336 0.4306	-0.1518 0.3698	0.5286 0.0008***		0.6730 0.0000***
INDEX OF BIOTIC FUNCTION	-0.0363 0.8310	0.4927 0.0019**	0.2012 0.2324	0.8418 0.0000***	0.6730 0.0000***	

Table 6. Individual index scores by meadow.

Location	Invertebrate IBI	Habitat Quality Index	Fish IBI	Fish/Amphibian IBI	Index of Biotic Function
Childs Meadow	52	73	50	68	61
Willow Creek	68	79	70	60	69
Butt Creek	44	61	75	65	61
Butt Creek	44	72	60	60	59
Boulder Creek	20	73	30	45	42
Willow Creek	68	71	40	40	55
Charity Valley Creek	60	47	20	23	37
Big Meadow Creek (Sher meadow)	44	71	60	33	52
Little Jamison Creek	44	75	20	40	45
Jamison Creek	36	74	50	55	54
Hot springs creek)	28	73	45	49	49
Graeagle Creek	36	76	40	40	48
Church Creek	44	80	70	48	60
Church Tributary	20	86	40	30	44
Tributary to Pauley Creek	52	82	60	35	57
Foster Meadows	60	83	60	35	59
Red Lake Outflow	28	77	55	60	55
Pierce Creek	44	82	60	60	61
Forestdale Creek	76	83	50	30	60
Trib to Indian	44	77	20	40	45
Upper Yuba (Lake Van Norden inflow)	44	71	60	51	57
Indian Creek B	56	83	50	50	60
Indian Creek A	36	77	50	55	55
Clarks Creek	44	60	70	66	60
Church Creek	28	72	80	40	55
Tributary to Independence Creek	60	70	40	30	50
Independence Creek	60	83	70	60	68
Haypress Meadows	68	77	70	40	64
Tributary to Haypress Meadows Creek	52	69	50	35	51
Tributary to San Jacquin	52	84	70	45	63
Austin Meadows	52	69	40	30	48
French Meadows	68	73	80	53	68
Cold Stream	60	92	70	40	66
West fork of the Carson	52	81	60	40	58
Charity Creek	44	77	50	35	51
Willow Creek	52	74	30	25	45
Willow CreekA	36	82	40	38	49
Grass Lake CreekB	28	60	60	54	51
Big Meadow Creek	52	66	70	50	60

Forestdale	52	76	40	30	50
Silver Lake Spring	52	75	40	50	54
Schneider Creek	52	64	40	50	51
North Fork of the Mokulmne River	52	73	70	50	61
Silver Creek	44	71	80	63	64
Woods Creek	60	69	60	50	60
Hot Spring Creek	44	62	60	35	50
Mokelumne River	36	68	70	45	55
Gardener Meadow	44	79	30	25	45
Silver Creek	60	83	60	35	60
Angora Creek	52	54	90	54	63
Upper Truckee River	68	75	70	60	68
Big Meadow Creek	68	87	80	40	69
Big Meadow Creek	28	83	40	30	45
Upper Barker Meadow	60	71	60	35	56
Lower Barker Meadow	68	79	60	35	60
Ward Creek	68	70	70	40	62
Walker Creek	28	68	80	45	55
Pacific Creek	36	48	50	45	45
Sagehen IV	68	87	100	60	79
Martis Creek I	60	75	90	66	73
Sagehen VII A	68	80	80	74	76
Sagehen VII B	52	73	80	66	68
Loney Meadow	36	71	80	45	58
Prairie Creek	60	77	70	40	62
Macklin Creek	84	85	80	68	79
Little Truckee	68	60	70	71	67

Table 7. Comparison of IBI scores results separated by number and percentage of sites (n = 66) in each of the five stream indices.

Category	Index Score	Invertebrate IBI	Percent	Habitat Quality Index	Percent	Fish IBI	Percent	Fish/Amphibian IBI	Percent	Index of Biotic Function	Percent
Poor	0-25	2	3	0	0	3	4.5	3	4.5	0	0
Fair	26-50	26	39.4	2	3	22	33.3	41	62.1	15	22.7
Good	51-75	36	54.5	35	53	29	43.9	22	33.3	48	72.7
Very Good	76-100	2	3	29	43.9	12	18.2	0	0	3	4.5

Discussion

Fish and Amphibian IBI

The near-absence of amphibians from our samples is disturbing, reflecting the general problem of Sierra-wide amphibian declines. Their rarity indicates that a once-significant component of meadow ecosystems in now missing and that biotic integrity is lower as a consequence. We believe that their rarity is more a reflection of conditions outside the meadow systems than within the systems. The presence of non-native fish in most streams is well-documented as the primary cause of amphibian decline (Knapp and Matthews 2000, Vredenburg 2004) but the rarity of amphibians even in fishless streams suggests that there may be a problem beyond fish predation. Because of this, measures of amphibian diversity and abundance are best not used to evaluate the condition of mountain meadows, particularly not in systems with large trout populations. When amphibian presence is used in metrics, their absence brings overall scores down. This may be appropriate but it presumably reduces the ability of an IBI to detect change.

Fish IBI

Fish are an important part of ecosystem health; however, their presence in meadow streams often confounds analysis because of the degree of alteration of the fish community by humans. Many of the fish are non-native species and arguably a disturbance in themselves, especially trout in meadow streams that were historically fishless. Presumably their presence alters both amphibian and invertebrate diversity and abundance. However, meadow streams supporting large and diverse trout populations are clearly functioning well, because trout require the cold, clear, highly oxygenated water typical of montane streams, reflecting a high degree of ecological function of the surrounding ecosystems and limited pollution problems. The two fish IBIs we use are normally distributed, correlate strongly to one another ($p<0.001$), with the invertebrate IBI and the IBF. They can thus be used as an effective tool to gauge overall ecological health of meadow streams.

Macroinvertebrate IBI

Macroinvertebrates are widely used for determining ecological condition in streams and the results from our study confirm their utility in the study of mountain meadow systems. The macroinvertebrate IBI correlated with both fish IBIs as well as being the only metric to correlate with the terrestrial vegetation ($p<0.05$). This ability to tie together both terrestrial and aquatic systems makes macroinvertebrates the most powerful means available to measure aquatic ecosystem health. They are of further importance because many of the invertebrates themselves begin life as aquatic nymphs but then emerge as terrestrial adults that play a significant role in the food web gradient from riparian to upland communities. Invertebrate metrics have the advantage over fish metrics in that invertebrates are native to the sites and have many species and families with widely differing physiological and habitat tolerances. However, the interactions among fish and invertebrates do have to be recognized as factors that can affect invertebrate IBIs. Other factors that affect stream macroinvertebrate IBIs include seasonal changes in invertebrate community composition and short term impacts such as storm events, high flows, or other perturbations. Therefore, it is ideal to sample multiple times throughout the year to get the most pertinent data or else consistently sample at the same time of year. The drawback of using macroinvertebrates to measure stream health is that they require a high level of expertise and can be expensive and time consuming to sort. This problem is widely acknowledged and more and more material is available in the form of guides and keys to macroinvertebrates.

Habitat Quality Index

The Habitat Quality Index (HQI) showed that most of the streams we sampled were in fairly good condition, with nearly all of them falling into the optimal or sub-optimal range. In our samples, the HQI correlated with the IBF. However, there was no statistically significant correlation between the HQI and any of the other indices we measured when vegetation was included in the analysis. The likely reason for this is that the HQI combines metrics that are on a different scale than the metrics we developed for the other indices. The EPA's Habitat Quality metrics represent the entire spectrum of possible habitat quality ranging from severely impaired streams that have been completely altered, channelized and paved, to pristine streams with no obvious anthropogenic changes. This differs from our other metrics that are based on the mean score within the total sample sites and the construction of the IBI is a function of standard deviations away from the mean. Certainly, we anticipate a strong relationship between habitat quality and stream health metrics such as species abundance, diversity, and richness for the biotic indices. The lack of correlation in this analysis is an indicator of the difficulty of using different scales for statistical comparisons. It also illustrates the necessity of developing regional reference sites to have a basis of comparison on which to judge system health. There is currently impetus amongst the bioassessment community to provide comprehensive regional reference sites and numerous statistical methods are being developed to infer what conditions would be like previous to human disturbance, as the EPA habitat quality assessment does (Barbour et al. 1999, Rehn, pers. comm. 2007). We also need access to raw data on streams that are in poor condition to build more accurate IBIs. In further analysis of these data, we intend to develop a set of reference conditions specific to meadow habitats in order to provide the benchmark against which all Sierran meadow streams can be measured.

Vegetation Health Index

The terrestrial botanical surveys and our aquatic surveys show statistically weak relationships to one another. The Weixelman et al (2003) data for the sites we sampled is not normally distributed and is heavily skewed towards high ecological function. This positive assessment of ecosystem health did not necessarily characterize the streams associated with these meadows. There are several possible explanations for this discrepancy between the botanical and stream surveys, the most fundamental being that many of the vegetation studies took place at sites a considerable distance from the actual stream and conditions there did not reflect the conditions of the meadow around the stream. These meadow systems are extremely heterogeneous in regards to the hydrology, soil type, and plant community. While the upland portion of the meadows may be adversely impacted by heavy grazing, road building, logging or other extractive uses, the riparian corridor may be affected even more strongly because of the dynamic processes and eroding power inherent in the moving water of the stream. The two areas may have had the same amount of initial impact, but the riparian area and stream might take significantly more time to recover. Impacts to the stream may ultimately impact the upland, particularly if there is a major alteration of the stream hydrology, such as bank erosion or incision that causes the water table to drop, thus depriving the upland meadow of moisture. It is also possible that the two systems operate on different time scales, with some plant communities recovering quickly following removal of disturbance (mostly grazing) moving into later successional stages in 10-20 years. In contrast, aquatic systems may take longer if the hydrology of the stream has been significantly damaged with the streams having become incised and the banks destabilized (Micheli and Kirchner 2002). Essentially full recovery of the plant communities within the riparian corridor is needed before the streams are fully on a trajectory back to good condition, defined as having complex habitat capable of supporting a high richness of insect life and abundant and diverse aquatic vertebrates (fish and/or amphibians). A further concern is that the terrestrial measures of health are based upon very small percentages (mean = 2.61) of the entire meadow that was actually measured and are therefore not representative of the ecological condition of the entire meadow. We have attempted to rectify that with data collected during our 2006 field season.

Caveats

We have done only a preliminary statistical analysis on these data. Future plans include developing reference conditions and setting IBI scores in statistical quartiles or using floor and ceiling wedges. Our invertebrate metric is the most in need of reworking to be specific to meadow systems. The metrics used are valid metrics, but they were developed for stream sections with rocky riffles and have not been tested to see if they are the best ones for lower-gradient meadow systems. Pearson product correlations show basic relationships, but multimetric regression analysis or other analyses are needed to further tease out statistical relationships in the data. The small number of sites for which we were able to collect all of the relevant data for in 2005 make it difficult to draw strong conclusions about relationships. There are also some befuddling relationships like a negative correlation between vegetation health index scores and the Fish-only IBI (Table 7). These types of results beg for deeper analysis which we hope to be able to accomplish in the analysis of the 2006 data, combined with the present data set.

Conclusions

Terrestrial and aquatic evaluations of meadow health did not prove to have a strong statistical relationship; however, together they did suggest that many meadow systems in the Sierras are in reasonably good condition and have improved markedly from their historic degraded conditions. Despite this result, many meadows still suffer from over-grazing, logging, and other factors (Ratliff 1985) and our small sample size cannot definitively reflect the overall condition of Sierran meadows. While botanical surveys are currently the dominant tool used to define ecological health conditions, the results of this study and the markedly lower health scores associated with stream surveys indicates that many important health factors are not being evaluated in botanical studies. This suggests terrestrial vegetation and aquatic ecosystems should be evaluated together. Of particular importance are measures of physical habitat quality--especially any measure of incision, erosion or sedimentation in the stream--and the most likely biological component to react to those habitat changes, which is the invertebrate community.

Within the scope of this analysis, we recommend using the invertebrate and physical habitat assessment methods from the EPA (1999) and replicated in the Harrington and Born (2000) protocols as a minimum survey protocol. Groups hoping to survey meadows should attempt to do as much of the protocol presented here as possible because no single metric can fully explain the condition of a meadow stream, but taken together, these metrics provide an accurate overall picture of meadow health and a deeper understanding of management needs. Riparian vegetation surveys, amphibian visual encounter surveys and fish surveys are important factors in understanding community function but may not be feasible for certain groups to collect.

The problem of metric comparison remains. We cannot stress enough the need to develop criteria for reference conditions. There are countless valid metrics for ecological health assessment available, but they cannot be legitimately compared to one another with meaningful results until they are all scaled to one another and reference conditions are known. It is our belief that the metrics we have developed tend to score low because they were evaluated against one another, rather than the potential extremes of conditions that exist. Even the worst sites we surveyed did not reflect the levels of disturbance associated with urban or agricultural streams, but they might score quite low based on the range of sites we surveyed. Our surveys took place on public land at mid to high elevation and in general, these lands have been fairly well managed in the last decade. In order to create indices that represent the full spectrum of stream conditions, we need to survey sites that are highly impacted and build them into our IBIs. These predominantly occur in lower elevation streams that are generally on private land, which limits our access to them. As it stands, it is not surprising that there is no correlation between our indices and the habitat quality index, which has reference conditions built into it.

The next step in this analysis must establish benchmark reference conditions for meadow conditions in order to make these indices a valuable management tool. We have an excellent basis for developing reference site criteria because we surveyed so many high quality streams that had only minimal disturbance. From here we can begin to develop indices that reflect the true overall health gradients that exist and have the most descriptive results in useful indices that can be applied throughout the Sierras by managers, researchers and community groups alike. The work we have done here shows that it is important to look at the stream health as well as vegetation health when evaluating meadow systems because streams show a high degree of sensitivity to environmental perturbation. No one metric is truly representative of stream health and therefore it is important to conduct several different surveys to get a complete picture of ecosystem health.

Current Status and Trends of Mountain Meadows

The data collected in the field from the above described activities was combined with existing data to create a single comprehensive database. The process of bringing multiple databases together into a single geo-referenced database allowed the status of meadow health to be assessed with respect to the vicinity of these meadows to known land and water use impacts. This effort would not have been possible without the formidable work of the Department of Fish and Game in which meadows were delineated across the Sierra Nevada. This enabled the existing data and newly collected data to be geo-referenced to specific meadow sites. In addition, because of this effort the newly collected data on aquatic habitat could be compared to the existing vegetation data in order to better asses the status of mountain meadows. In order to assess the status and trends of meadows the terrestrial and vegetation data were combined in the geo-referenced GIS database so that trends could be defined with respect to landscape scale land and water uses. In this way, our analysis captures the current status and developing trends of mountain meadows in Sierra Nevada public lands.

Meadow Delineation

The California Department of Fish and Game (DFG) Resource Assessment Program delineated 1,948 mountain meadows within the study area by hand using aerial photography to identify areas void of vegetation. This information was combined into a single GIS layer to which site specific data could be associated. The delineated meadow area is comprised of meadows that currently exist as meadows and does not reflect areas that were historically meadows and may have been developed into towns.

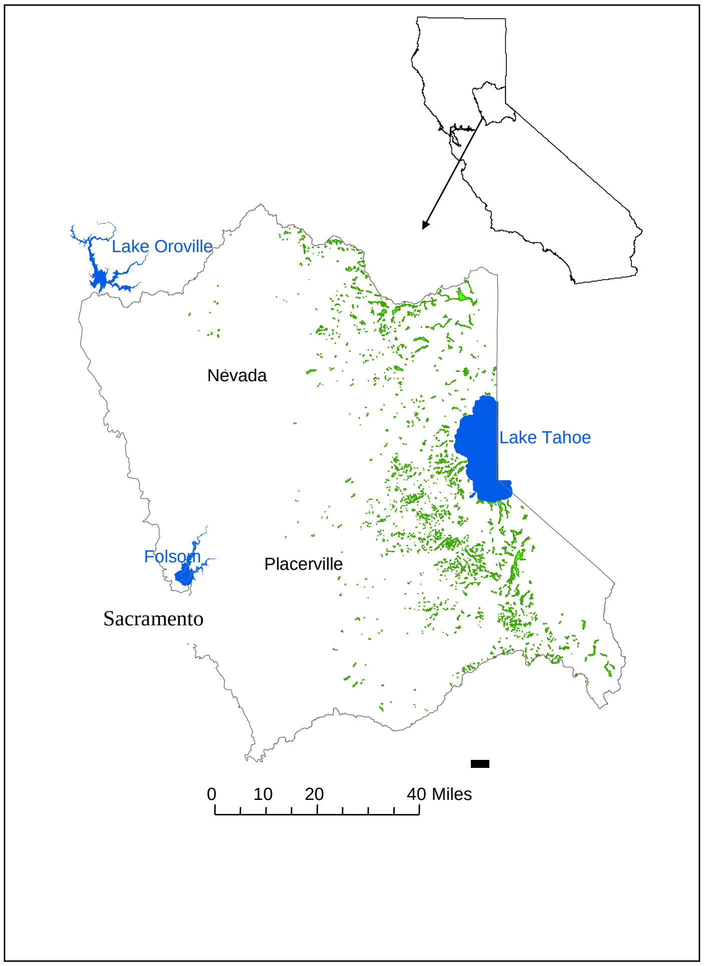


Figure 9. Project Area including delineated green polygons represent 1,948 mountain meadows that have been delineated in the area by CDFG.

Many of these meadows have no field data, and some meadows have field data collected by more that one agency. For example, of the 1,948 delineated meadows;
87 meadows have data from the US Forest Service Aquatic Conservation Strategy Meadow Study Plan for Sierra Nevada Forest Plan Amendment, 48 have data collected by US Forest Service Rangelands Program, 29 collected by the Aquatic Conservation Strategy Meadow Study Plan, 144 sites have data from the Department of Fish and Game Resources Assessment Program, 25 of which were collected by the Assessment of Aquatic Resources in Sierra Montane Meadows (DFG).

The USFS and DFG data are focused on terrestrial or vegetation characteristics, for grazing management purposes. The University of California at Davis team collected aquatic data at 30 meadow sites for a portion of the meadows that had existing vegetation data.

To asses the current status and trends affecting mountain meadows in the Sierra the data from these different sources were entered into the Sierra Meadows Health Database. Included in this GIS database are spatial layers relevant to the land and water uses that are likely to impact meadows. These include elevation, slope, roads, mine sites, and population.

The significance of mountain meadows in relationship to these landscape features and other on-going land and water uses is discussed below. We also describe ongoing or recommended possible steps for assessing these effects on meadow hydrology, vegetation, and habitat in a spatially explicit manner. We review existing information on the topics listed in Table 8 and summarize the findings of our analyses on the Status and Trends impacting meadows in the project area.

Table 8. Land and water uses that affect meadow health and function in the Project Area.

Land use pressures on Meadows	**Water use pressures on Meadows**
Grazing	Dams
Roads	Diversions and Irrigation
Invasive Species	
Recreation	
Fire and Fuels Management	
Mining	
Timber Management	
Residential and Commercial Development	

Meadow Location

Sierra Mountain Meadows range in size from a few square meters to several square kilometers. As seen in Figure 10, the majority of the meadows in our study area are at elevations between 6,500 to 8,500 ft.

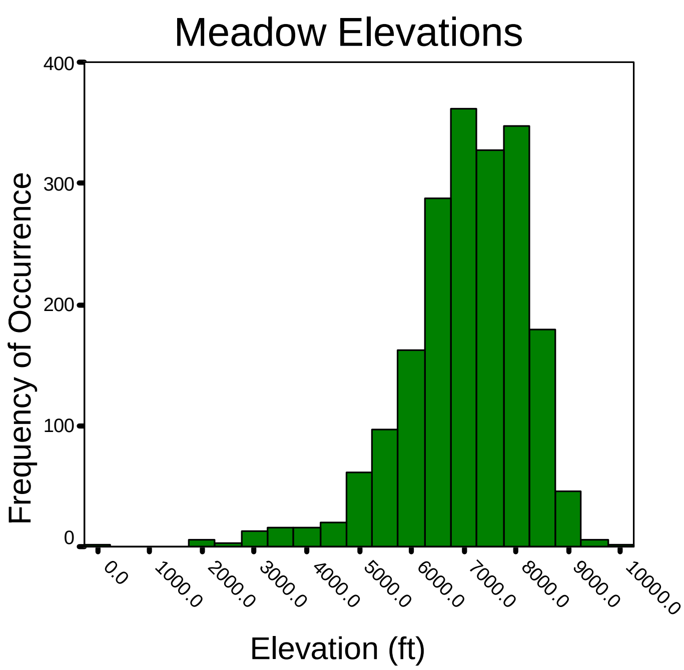


Figure 10: Histogram of meadow elevations.

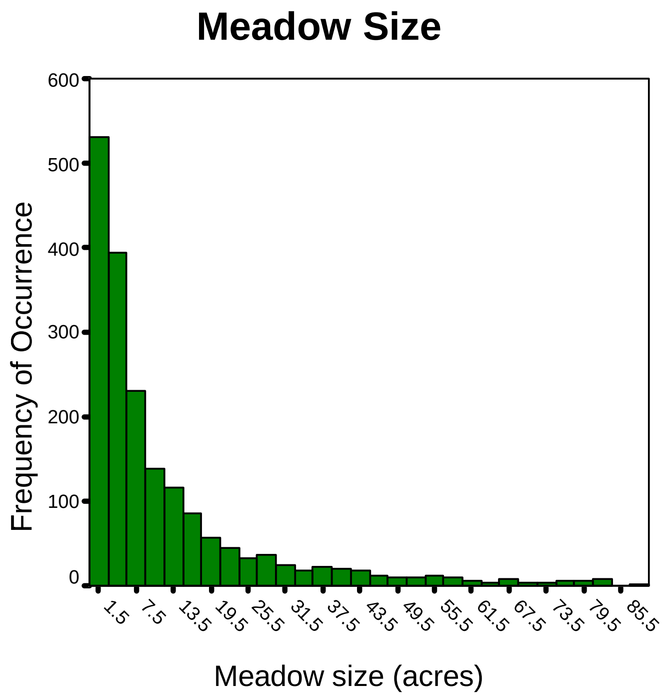


Figure 11: Histogram of meadow size in acres.

As seen in Figure 11, the majority of the meadows in our study area (62%) are 10 acres in size or less. This means that there are many small meadows that make up our data set and not very many large meadows. This is in contrast to the historical large meadow ecosystems that today are covered by urban centers such as Auburn, Quincy and Grass Valley or that still reside in the hands of private landowners. In this way, our analysis captures the current conditions of mountain meadows and their cumulative effect on ecosystem services on public lands.

Status of Knowledge of Grazing and Meadow Health

There is currently no GIS layer of information on grazing permits issued or the intensity of grazing that is occurring. As a result we had to rely on a review of the literature to determine the current state of meadows as a result of current grazing practices.

Menke et al. gathered and analyzed a subset of the Parker three-step data from the National Forests within the Project Area, including Tahoe, El Dorado and Plumas National Forests (1996). A summary of their findings regarding grazing effects on meadow community composition is presented in SNEP chapters 7 and 22 (Menke et al. 1996 and Regents of California 1996c). By comparing historic (1940's and 50's) Parker three-step data to current information, the SNEP team reports that Sierra Mountain Meadows are experiencing:

- Decreases in the ratio of sedge-to-grass without compensation by rushes, indicating loss or declines in water tables;
- Radical fluctuations in clover species in meadows due to exited nitrogen cycling and close grazing of taller vegetation that formerly buffered against such wide swings in botanical composition;
- “Red flag" indicators of more than 7%-10% bare soil in wet meadows, indicating severe

abuse beyond what burrowing rodents could account for;
- Exposed soil stabilized at around 5%, whereas before 1956 the average for all Sierran National Forests was about 11%.

Overall these findings depict a mixed picture. Exposed soil is generally considered an indication of disturbed conditions. On one hand, the area of exposed soil, averaged over all meadow types, has decreased since the 1950's. On the other hand, other indications such as lowered water tables, instability in nutrient cycling and plant species composition, and elevated bare soil in wet meadows (as opposed to all meadows), point to increasing instability and reduction of habitat quality since the 1950's. There is a project underway to gather and digitize historic data collected according to the old Parker 3-step procedure and to pair modern data (pers. com. Dave Weixelman, Botanist, Tahoe National Forest). This combined old and new dataset will be helpful for assessing meadow conditions in the past (e.g. back to the 1940's) and changes since that time.

Trends in Meadow Health Related to Grazing

Much of the damage to meadow ecosystems from grazing occurred during the late 1800's and early 1900's (Ratliff 1985). Changes to the meadows attributed to overgrazing during the late 19th century include gullying, desiccation, shrub encroachment, and changes in species composition and diversity (Wood 1975, Ratliff 1985, Allen-Diaz 1991, and Menke 1996). Livestock grazing along stream banks has been shown to increase bank erosion and channel incision. Channel incision lowers the water table in the surrounding meadow and results in a general reduction in moisture availability across the meadow (Odion et al. 1988, Schoenherr 1995). There is also evidence that grazing and the concomitant change in species composition from wet sedge and rush dominated communities to drier site species composed of non-native grasses and sagebrush has resulted in increased bank instability and channel migration rates (Micheli and Kirchner 2002). Today conditions and grazing use patterns in many meadows are improving; however channel down cutting from heavy historic use has permanently altered many meadows through lowered streambeds and ground water tables. These changes in meadow hydrology are believed to be the basis for several major shifts in plant community composition.

Livestock grazing can affect plant species composition through the following four mechanisms (Menke 1996, Berlow and D'Antonio 2002):

- Changes in site hydrology;
- Increases in soil disturbance which offers increased colonization sites for invasive or opportunist species;
- Increases in soil compaction which lowers infiltration and water holding capacity, which in turn, reduces soil moisture and rooting density; and
- Selective grazing, which alters competitive conditions for plant species.

Indications of possible broad changes in plant community composition due to hydrologic changes come from Dull (1999), who report results from a palynological (pollen analysis) study of meadows on the Kern plateau. Dull (1999) found that Riccia, a liverwort genus, dominated upper wet meadows prior to intense 19th century grazing and have been replaced primarily by Carex (sedge) species since then. In slightly drier meadow areas, willow (Salix) species abundance has diminished and been replaced by members of the Cyperaceae family (sedge, rush, and umbrella sedge; Dull 1999). Encroachment of sagebrush into dry and moist meadows has also been attributed to channel down cutting and lowering of the water table. This issue will be addressed in greater detail in the section entitled Invasive Species.

The direct effects of domestic grazers on plant species composition has also been documented for meadows in the Sierra Nevada. Species such as Nebraska sedge (*Carex nebrascensis*), which have long-lived shoots with primordia (tissue capable of producing new vegetative growth) that is close to the ground and not easily accessible to grazing animals (Ratliff and Westfall 1992), are most common in meadows with a history of heavy grazing (Menke et al. 1996). Selective grazing, in which species such as Baltic sedge (*Juncus balticus*) and bulrushes (*Scirpus*) are not preferred by livestock, results in greater abundance of these least palatable species (Menke et al. 1996, Ratliff 1985). Meadows with increased bare soil due to trampling and other disturbances show in increase in abundance of opportunistic species, such as Douglas's knotweed (*Polygonum douglasii*; Menke et al. 1996).

Status of Knowledge of Roads and Meadow Health

We acquired a GIS data layer of paved and unpaved roads for the project area from the California Spatial Information Library (CASIL). The data layer ("Roads") was developed by the Department of Fish and Game and is available for each county. This layer was integrated into the Sierra Meadows Health Database and GIS project. Since roads affect meadows either from above or indirect proximity to the meadow, we identified the contributing area for each meadow as the area in which roads could potentially affect meadow ecology and function. The roads data layer contains attribute information specifying whether or not a road is paved or unpaved. This layer was intersected with the data layer containing the meadow drainage areas to calculate the total length and density (miles of roadway per square miles of drainage) for unpaved, paved and all roads. We assumed that the unpaved roads were 16 foot wide logging roads (WEPP road website: http://forest.moscowfsl.wsu.edu/fswepp/docs/ wepproaddoc.html), and that the area of 'roaded influence' is twice the width of the actual road (Auerbach et al. 1997, Forman et al. 1997, Larson and Parks 1997). We then calculated the percent of area contributing to each meadow that is under 'roaded influence'.

Data on road density were available for 1,282 of the 1,948 meadows within the Project Area. Within the areas contributing to meadows in the Project Area, 85% of the roaded mileage recorded is unpaved, and 15% is paved. There is an average of 2.7 miles of total roaded area and 2.3 miles of unpaved road area per square mile of contributing area (Figure 12). On average, 2% of the area contributing to meadows in the Project Area is under 'roaded influence'. Three of the 1,282 meadows have 10% or more and 36 (or nearly 2% of the total) have 5% or more of the contributing areas under 'roaded influence' (Figure 13).

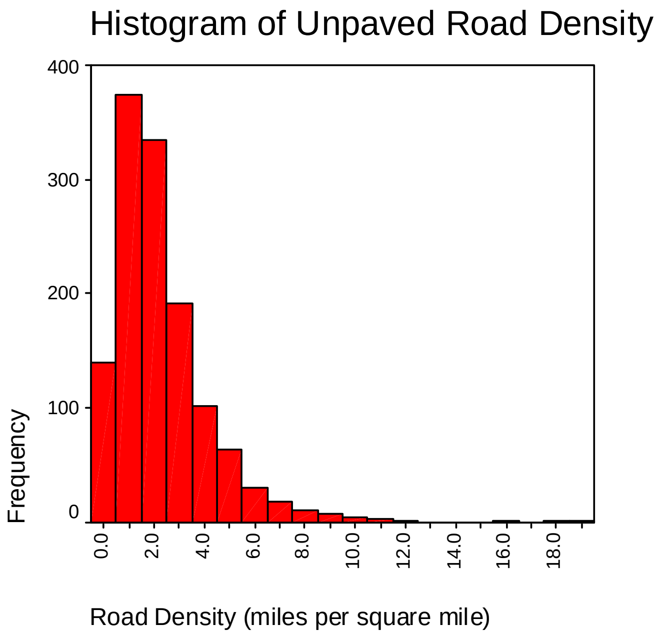


Figure 12. Histogram of unpaved road density in contributing area of meadows within the Project Area.

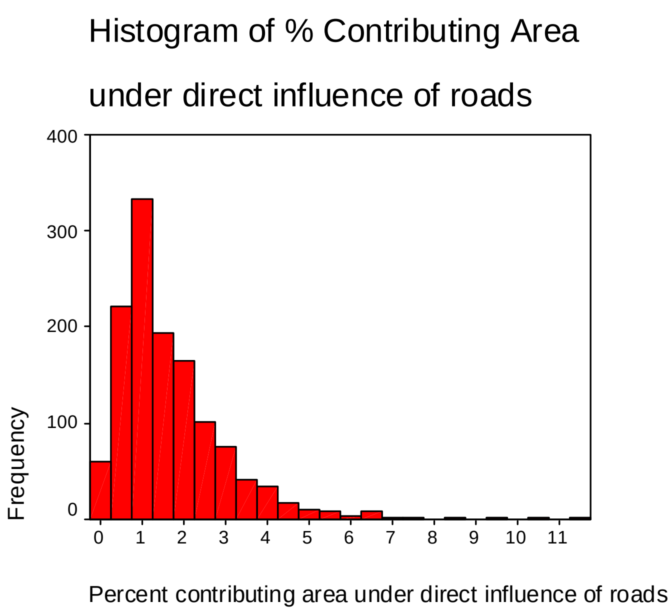


Figure 13. Histogram of percent contributing area under direct influence of roads for meadows contained within the Project Area.

The 36 sites with 5% or more of the contributing area impacted by 'roaded influence' are most likely to suffer some negative impacts to meadow health. However, none of these meadows were surveyed by UCD field crews and so we are unable to link the meadow health analysis with the landscape scale analysis.

Trends in Meadow Health Related to Roads

Based on the above discussion, roads in the contributing area to meadows are expected to affect the hydrology, water quality, sediment balance, and aquatic and terrestrial communities associated with meadow systems. There are no studies that specifically address the impact of roads on meadow health. However, is known that roads have an affect the physical and biological processes of the ecosystems they traverse. Local and downstream geomorphology is affected by roads through several processes (Gucinski et al. 2001):

- Accelerating mass and surface erosion from the road surface and cut and fill areas along the road edges;
- Directly affecting channel structure by filling over channels and through the construction of culverts; and
- Diverting surface flow into ditches and gullies along the road side, thereby increasing the channel density of the roaded area.

Hydrologic processes are similarly altered by the existence of roads. The hard surfaces of roads increase the rate at which precipitation moves into the channel – this can affect the timing and volume of event-related stream water flow (a.k.a. the storm hydrograph; King and Tennyson 1984, Wemple et al. 1996). Alterations in hydrology exacerbate geomorphic effects (Montgomery 1994, Furniss et al. 1998, Gucinski et al. 2001):

- Road surfaces and adjacent ditches concentrate surface flow, increasing incision and channelization in otherwise undisturbed parts of the landscape; and
- Culverts blocked by coarse woody debris and/or sediment can cause mass erosion events that introduce large deposits of sediment in the channel.

Water quality is also degraded in streams associated with roads. In addition to increases in fine sediment inputs, activities associated with roads, such as application of chemicals to the road surface and adjacent lands (salts and oils to reduce ice and dust and herbicides to reduce roadside weed encroachment), as well as leakage of oil, brake lining, and vehicle emissions increase pollutant inputs to nearby streams (Gucinski et al. 2001). Unpaved roads result in the greatest amount of surface erosion, particularly during the first five years after construction (Megahan and Kidd 1972). Although surface and mass erosion rates slow down as the road ages, other geomorphic effects, such as those related to culverts and channel stability, can become increasingly unstable with time (Montgomery 1994, Gucinski et al. 2001).

Gravel and dirt surfaced sloped roads with ditches are probably one of the largest sources of management-induced sedimentation in the Sierra Nevada. These types of activities have significantly altered the hydroscapes of the eastern Sierra region (Sierra Nevada Forest Plan Framework FEIS Volume 3, Ch 3. Affected Environment and

Consequences). Building roads can require that streams be relocated; one example of this is at Cottonwood Creek in the Feather River watershed, which led to extensive gully erosion (Lindquist and Wilcox, 2000).

Status of Knowledge of Invasive Species and Meadow Health

Species compositional change is the norm for plant composition in North America throughout the Pleistocene era (Davis 1986, Delcourt and Delcourt 1992). Even within the last few centuries, climate change is influencing vegetation change in the Sierra Nevada. Thus, the invasion of species into the Sierra (or range expansion of species already there) is not an unexpected phenomenon and should increase in intensity or rate as climate continues to change (D'Antonio et al. 2002). It should be noted that the changes in vegetation that are induced by climate change are difficult to separate from other factors in the environment that also impact vegetation.

We are lacking spatially explicit information on the distribution of invasive exotics. The influence of invasives is likely to become increasingly important in a large number of meadows. The California Native Plant Society maintains a database on invasive and exotic plant species that occur throughout the state. This database is publicly available and is the basis for part of the D'Antonio et al. (2002) study. However, the information in this database is rarely site specific, and therefore would not serve as a good basis for developing spatially explicit information on the occurrence and risks associated with invasive plant species. The Forest Service maintains information on changes in plant community composition (e.g. the Parker 3-step data) in meadows that fall within grazing allotments; however, this information is dispersed among Forest Service Range offices at the District level. Thus, the effects of invasive exotic plant species will be integrated into the analysis of the health and trends of Sierra Meadows for meadows that are identified as particularly valuable or threatened based on other characteristics.

Trends in Meadow Health Related to Invasive Species

Exotic plant species can directly and indirectly alter the aesthetic values, biological diversity and ecosystem services we gain from meadow ecosystems. Potential impacts include alteration of disturbance regimes, changes in the food base for wildlife species, soil erosion and loss of soil carbon storage, decreases in range or forest productivity, and altered recreational or aesthetic values.

Invasive, exotic plant species are often early invaders after soil disturbance, and most tend to out-compete and replace native vegetation. In turn, vegetation types affect which types of soil organisms predominate. Replacement of native plant communities with exotic species may change soil microbial populations and, thus, nutrient cycling processes. Many weedy annuals have shallow root systems that make them poor candidates for stabilizing soil surfaces and providing erosion protection.

D’Antonio et al. present preliminary results from a survey of invasive versus native plant species in 32 high elevation (2,200 to 3,400 m) meadows in the Sequoia and Kings Canyon National Park (2002). The authors report that exotic plants occurred in 12% of these meadows; and in all cases of occurrence, they were rare (<5% cover). The main non-native plant species present were the perennial grass *Poa pratensis*, and the forb *Taraxacum officinale*.

Interestingly, in contrast to the extremely low abundance of exotic species in these high-elevation meadows, 60% of the meadows surveyed contained saplings of the native lodgepole pine (*Pinus contorta* ssp. *murrayana*). These pine saplings were observed in a range of conditions, from trailside disturbances, dry disturbed soil, and de-watered meadow areas near erosion gullies, to relatively undisturbed areas and boggy meadows.

The work of Bauer et al. (2002) on large meadows of the Kern Plateau in the southern Sierra Nevada suggests that while exotic invaders were rare, native woody invaders (there largely *Artemisia rothrockii*) are widespread and can rapidly invade many high elevation meadows (Bauer et al. 2002, Berlow et al. 2002, 2003). They believed that these native woody species had greater potential to affect forage production, wildlife, native species diversity and other ecosystem characteristics than do the current suite of non-native plant species likely to enter most high elevation areas (D'Antonio et al. 2002).

Meadow sagebrush invasion is most frequently attributed to increased meadow aridity resulting from grazing associated with channel down cutting. Livestock grazing along stream banks has been shown to increase bank erosion and channel incision; channel incision lowers the water table in the surrounding meadow (Odion et al. 1988, Schoenherr 1995). Lower groundwater tables reduce water availability and promote success of drier site species such as sagebrush.

Berlow et al. (2002) found that while increased aridity might be the primary factor for increased sagebrush cover in upper terrace meadows, a more complex set of factors appear to control sagebrush invasion in lower terrace (e.g. wetter) meadows. Under 'background' conditions, wet meadows support continuous herb cover, which effectively excludes sage brush seedling establishment through competition. However, soil disturbance due to gopher activity resulted in large increases in sage brush establishment. Furthermore, simulated grazing (e.g. herb clipping) had similarly stunning, positive, effects on four year old sagebrush seedling survival (Berlow et al. 2002). The increases in sagebrush cover in moist meadow habitats appears contingent on seed source proximity, since sage species seed dispersal is limited (e.g. ~ 1m radius). Thus, sagebrush expansion into neighboring dry meadows might be a necessary precursor to sagebrush invasion into adjacent moist meadow areas. The authors suggest that sagebrush expansion into moist meadows is an important area for management efforts that extend beyond restoring meadow hydrology.

Status of Knowledge of Recreation and Meadow Health

The Tahoe National Forest Service conducts a recreation survey every four years. This is a forest wide monitoring survey where park visitors are interviewed as they leave the Park. Participation is voluntary and the survey is largely about user satisfaction. The last survey was conducted in August 2002, Tahoe National Forest ranked 11th in the Nation and 2nd in Region 5 for use. The survey found that the percent of visitors that:
1) Used designated off road vehicle areas was 0.7% which may reflect the population that participated in the survey more than anything else and that 2) the percent of visitors that spent their time viewing natural features such as scenery, flowers, etc on Natural Forest lands was 59%. A most recent survey was conducted in the Summer of 2006, but the results were not available at the time of this report.

Trends in Meadow Health Related to Recreation

Recreational use of meadow ecosystems has the potential to produce different types of disturbances than grazing. The pasturing of packstock increased at the turn of the century when tourism was developing in the Sierra Nevada (Ratliff 1985). Following World War II, pack trips became even more popular (Allen-Diaz et al. 1991), particularly in the most scenic subalpine and alpine meadows (Menke et al. 1996). In many of these higher elevation meadows, disturbance and grazing effects from packstock are believed to be greater than those due to feedstock (Menke et al. 1996). Although packstock meadow use has increased since WWI, there is no consistent program for monitoring packstock use or grazing impacts. In the high Sierra meadows, packstock grazing is believed to be the largest source of damage (Menke et al. 1996).

Since World War II, meadows have become popular destinations for hikers and backpackers. For some wild animal species, disturbances such as noise, human waste, and trails may be more detrimental than cattle (Graber 1996). Dispersed and developed recreation activities in meadows may affect willow flycatchers through disruption of nest contents and by trampling vegetation which removes nest cover and disrupts the insect community. Altered hydrology through soil compaction and streambank chiseling, modified plant community composition and structure, and habitat fragmentation from trails and campgrounds also influence the microclimate (Sierra Nevada Forest Plan Framework, FEIS Volume 3, Ch. 3 part 4.4, pg 156 Affected Environment and Environmental Consequences). Dispersed camping at popular destinations can also result in increased erosion, trampling of stream banks, noise and water pollution.

Off road vehicle use in meadow areas has had significant negative and long lasting effects on meadows. Off road vehicles are heavy and even single passes across organic meadow soils can result in long-lasting soil compaction. Compacted soils have different water holding capacities and infiltration rates than undisturbed soils. The Forest Service maintains information on damage and restoration of meadows that fall within grazing allotments; however this information is dispersed among Forest Service Range offices at the District level.

Recreational uses of the Sierra Nevada are expected to increase with the expected tripling of the Sierran population between 1990 and 2040 (Regents of California 1996a). Therefore, unless there are changes in rules and regulations controlling recreation, pressures on meadows related to packstock use, dispersed camping, and off road vehicle use can be expected to increase in the coming decades.

Status of Knowledge of Mines and Meadow Health

Information on the location of mines in the study area is difficult to obtain due the widespread presence of small, undocumented, abandoned mines. The best dataset that was found during this effort is the PAMP (Principal Areas of Mine Pollution; http://conservation.ca.gov/OMR/abandoned_mine_lands/pamp/index.htm) database created by the Office of Mine Reclamation in the California Department of Conservation. This database contains 2,422 mines statewide, all of which had production that exceeded $100,000.

A data layer with points representing these mines was intersected with the drainage areas to calculate the number of mines in each drainage area. Through this exercise, we found that the contributing areas of 14 of the 1,948 meadows (less than 1%) included between 1 and 3 PAMP mines (Figure 15). This very small percentage of meadows in the Project Area with documented large mines in their contributing area might indicates that overall impacts of mining and mine tailings on meadow function is minor in relation to other human use effects. However, the pervasive nature of mining impacts and the extensive number of abandoned mines, estimated to be between 20,000-40,000 in the Sierras, indicates there is not adequate information to rule out the potential negative impacts of mining activities on meadow health.

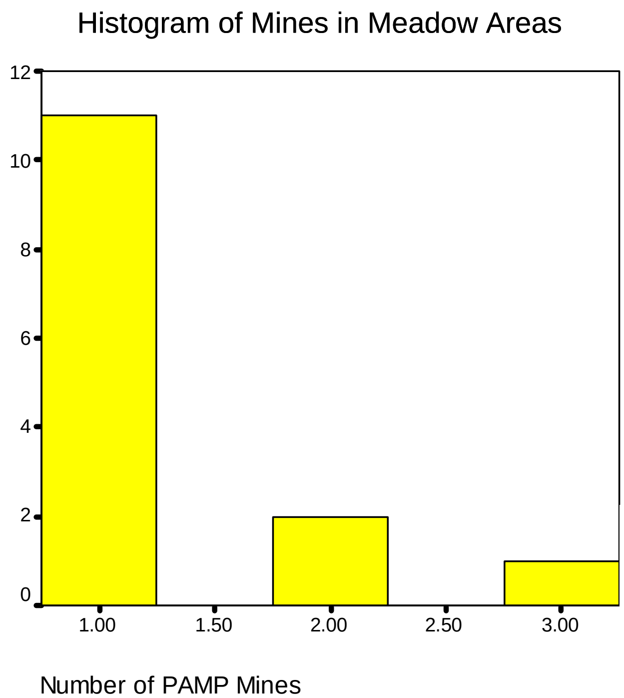


Figure 14: Histogram of the number of mines. Fourteen meadows have mines out of 1,948 meadows. Mine data from Principal Areas of Mine Pollution database created by the California Department of Conservation, Office of Mine Reclamation. All mines produced > $100,000 of oar.

Unfortunately, none of the meadows impacted by mines in the analysis above were surveyed by field crew from UCD and so we are unable to link the Meadow Health Assessment with the landscape scale GIS analysis.

Trends in Meadow Health Related to Mining

Water quality issues related to abandoned mines and downstream mine tailings can also be important since tailings and abandoned mines can leak Mercury and other toxic substances into the stream and groundwater (Domagalski 1998). Mercury enters the food chain as methyl-mercury. The biogeochemical conditions which favor the transformation of mercury into methyl -mercury are still being defined. However, anoxic environments where mercury laden sediment settle out are considered methyl-mercury hotspots. High levels of mercury have been recorded in fish downstream from leaking abandoned mines (Larry Walker Associates 1997, May et al. 1999); these contaminants can bioaccumulate and wipe out top predator species, thereby significantly altering the aquatic community food web (Krabbenhoft and Wickert 1995, Slotten et al. 1997, May et al. 1999). Toxins collected in aquatic organisms are also transported into the terrestrial community through aquatic/terrestrial predator prey relationships (e.g. birds eat emergent aquatic insects). Meadows associated with historic mining activity should be assessed for mercury prior to disturbing the soils further and potentially releasing mercury into the environment and foodchain.

Sediment issues related to abandoned mines is an area of recent research. There is new evidence for the large amount of mining debris that remains as fine sediment in the headwater streams and that this sediment is transported downstream during storm events (Curtis 2005, 2006). Suspended sediment is a water quality issue but it also impacts the geomorphology of stream channels and can cause them to degrade. There is no information specifically on the impact of historic mining sediment and meadow health.

Status of Knowledge of Fire Management and Meadow Health

Tahoe National Forest maintains a Fire history layer that indicates the extent of past fires as well as some information on fire intensity. As a next step in this project, we recommend requesting this data layer from the Forest Service so that this spatially explicit information can be analyzed using methods similar to those applied to estimate potential effects of roads and abandoned mines.

Status of Knowledge of Timber Harvesting and Meadow Health

Data layers on timber harvest sales and fuel reduction projects on Federal lands have been collected and maintained by resource managers in the Tahoe National Forest (Tim Biddinger, personal communication). We plan to request this data layer from Tahoe National Forest in order to perform an assessment of timber related activity within meadow contributing areas in the Tahoe National Forest and other National Forests in the Project Area. This effort could be part of the next phase of this investigation. Timber harvest plans (THPs) for private lands might also be available from private lands from the State Department of Forestry and could be pursued during the next phase of the project.

Status of Knowledge of Water Uses and Meadow Health

The Sierra Nevada generates approximately 20 million-acre feet of runoff each year. These waters support complex aquatic ecology resulting in the Sierra Nevada being ranked high among the world's ecological regions in terms of endemic aquatic invertebrates. The rivers and associated wetlands arising in the Sierra also form an immense natural and engineered water supply network which provides over half of the state's water supply. There are two major water delivery systems in California: the Central Valley Project and the State Water Project. Thirteen Sierra watersheds supply the Central Valley Water Project, while the State Water Project is highly dependent on the Sierra's Feather and Kern River watersheds. In addition, many local water projects supply other parts of the California, such as the Tuolumne River supplying San Francisco, the Truckee River supplying Reno and the

Mokelumne River supplying the East Bay. Overall, water is the most valuable natural resource produced by the Sierra Nevada (Regents of California 1996a).

There are 218 dams in the Project Area that exceed 6 feet in height and/or 15 cf in storage capacity (DWR, Division of Safety of Dams database). Some of the largest of these dams, including Folsom Dam on the American River and Pardee Dam on the Mokelumne River, generate a combined 220 kilowatts of electricity while also providing key flood control and water storage for residential and agricultural uses. Many of the reservoirs formed behind these dams also provide water recreation in a region that has few natural lakes below 7,000 feet. Numerous smaller dams in the Project Area divert water for local residential and agricultural uses.

Overall, dams serve the following functions in the Project Area:

- Hydropower ('clean energy')
- Recreation (lakes)
- Water supply for human consumption
- Water supply for farming (irrigation)
- Flood control

Spatially explicit information is available for moderate to large sized dams in the Project Area, but not for many of the large and small diversions and irrigation ditches. The presence of moderate to large sized dams in the drainage area for each meadow was determined using the database of dams kept by the Department of Water Resources (DWR) Division of Safety of Dams. This data layer was intersected with the meadow drainage area polygons to calculate the number of dams in the contributing area of each meadow polygon. Of the 1,948 meadows in the Project Area, 88, or 4.5%, have one to five dams in their contributing area. The actual distance of the dams upstream of the meadow could be calculated in the next phase of this project in order to further identify those meadows most subject to negative effects related to dams.

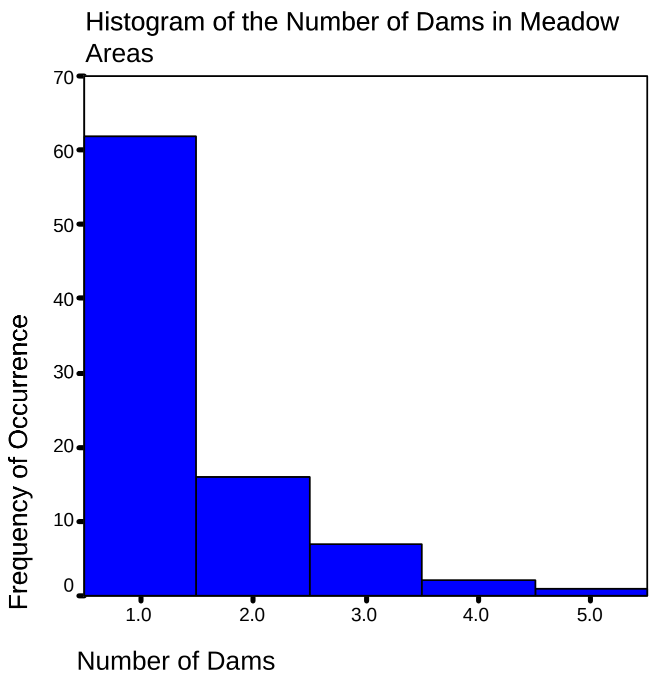


Figure 15: Histogram of number of dams in Meadow contributing area.

Trends in Meadow Health Related to Water Use

Dams and diversions impact downstream meadow streams and ecosystems. Dams and diversions severely compromise longitudinal connectivity of streams and radically alter the volume, timing, and intensity of downstream water flows and sediment. Dams radically alter river sediment transport processes that ultimately shape the downstream valley and riparian landscape through erosion and deposition. Sediment trapped behind dams leaves sediment deprived water below the dam. Thus, sediment that would be transported and deposited along the river downstream of the dam is withheld. Reduced sediment availability alters the development of depositional features, such as gravel and cobble bars, and depositional terraces, downstream of the dam (Knighton 1984, Rubin et al. 1990). In addition, water released below a dam has power and energy to transport more sediment since most of the sediment is withheld behind the dam. This 'sediment hungry water' can erode and armor downstream banks as the water tries to regain equilibrium between its power and sediment load (Kondolf 1997, Williams and Wolman 1984). For example, within nine years of completing Hoover dam, the river bed below the dam had lowered more than 4 meters. Deepening of the riverbed lowers the groundwater table, taking some local wells out of business, which can affect local agriculture, economics, and communities (IRN 2004). Depletion of river gravels and introduction of fines due to lower flows reduces habitat for spawning fish, for aquatic invertebrates, and for many riparian plant species (Larson 2006, Cordone and Kelley 1961, Lloyd 1987).

During flood events, streams scour floodplains and break through banks to form new meander bends. During these natural events, a stream destroys and recreates surfaces for new/regenerating communities. This process provides a constant source of new habitats and maintains the high biodiversity characteristic of riparian areas. Dam operators control water releases to minimize flooding events and to more evenly distribute water flows across the seasons. These controls on water and sediment flow mean that scouring events during floods are reduced or stopped, and that the river often loses its power to meander across the floodplain. Thus, habitat and species diversity is reduced downstream of dams (Ligon et al. 1995). Dams also affect the quality of downstream waters by keeping waters released from the bottom of the dam at low and constant temperatures (IRN 2004, Ligon et al. 1995) and by creating a break in the flow of nutrients and organic material that naturally flows down rivers and forms the basis of the aquatic food web (IRN 2004, Ligon et al. 1995). Changes in the physical habitat and hydrology of rivers are responsible for 93% of the decline in freshwater fauna in North America (IRN 2004).

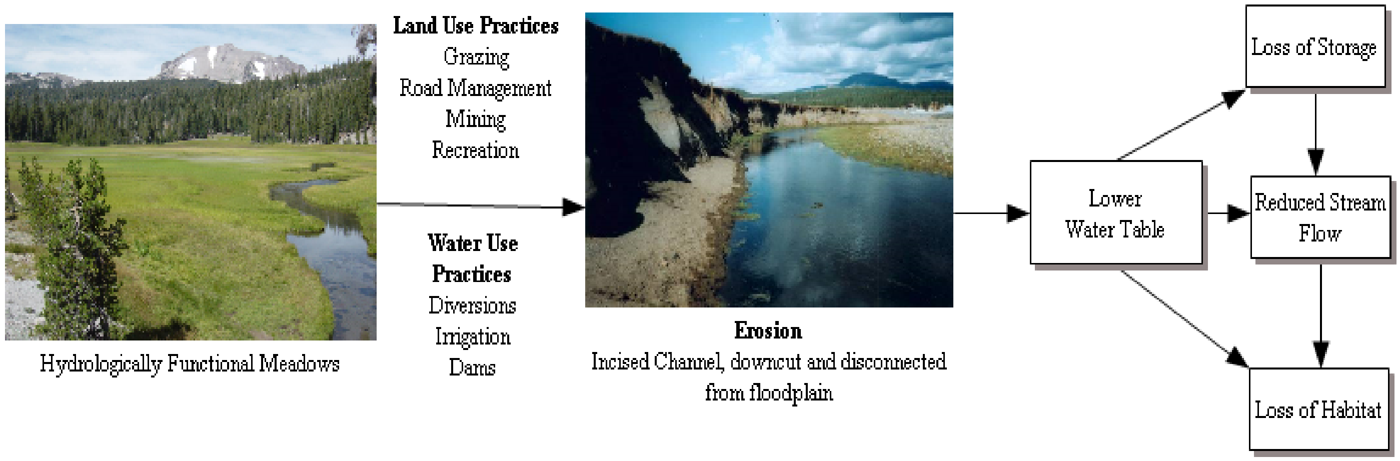
For meadows, the results of water flow controls imposed by dams and diversions can be dramatic. Reduced baseline flows and minimized flooding events reduce or remove the connectivity between the river channel and the associated meadow. As mentioned above, the reduction in sediment transport can lower the river bed, effectively lowering the local water table and thereby drying out associated meadows. Aquatic communities in mid-reaches are most dependent on nutrient, woody debris, and/or organic matter inputs from upstream (Vannote et al. 1980); therefore the dam-related reduction in organic inputs from upstream could negatively affect the meadow stream community. Plant biodiversity can also be affected, since propagules of many riparian plant species depend on water for downstream transport (Malanson 1993). Reduction in native propagule delivery and alteration in the water and sediment flow regimes disfavor native species and create gaps that can be filled by more generalist invasive species (Malanson 1993). In turn, changes in aquatic invertebrates and riparian vegetation can affect riparian and meadow associated birds and terrestrial vertebrates. For example, reduced flows along the Colorado River below Glen Canyon Dam have diminished the extent of native willow cover that provides key habitat for the southwestern willow fly catcher (USBR and USDOI 1996). Non-native fish species are often introduced into reservoirs for recreational fishing; these non-native fish species escape below the dam and can alter downstream aquatic communities (Cohen and Moyle 2004, Moyle 1976).

Trends in Meadow Health Related to Erosion

A pervasive trend affecting the ecological and hydrological health of Sierra Meadows are land uses and water uses that lead to erosive conditions. Once erosion has started, it can trigger a series of hydrologic changes that leaves meadows disconnected from their original hydrologic function. Eroding stream channels typically downcut, resulting in a lowering of the local water table. When the water table is lowered water stored in the meadow drains down to the lowered water table and is released from storage through the eroded channel banks, resulting in reduced summer streamflows. Downcut channels are no longer connected to their historic, wide meadow floodplains but are confined within narrow, incised channels.

When streams no longer flow on top of meadows, meadow bottomland soils are not replenished with fine silt particles transported by the stream. In addition, the energy of the stream during high flows is confined to the smaller, incised channel and is not slowed by flowing across the meadow, resulting in faster in-channel flow velocities and more streambank erosion. As a result water passes through the meadow and is resident on the meadow for shorter periods, if at all. This reduction in the amount of water stored in the meadow and streambank often results in the loss of many meadow species.

Figure 16: Conceptual model of erosion and loss of hydrologic function in meadows, leading to loss of habitat and watershed function



The desired future condition is meadows that are hydrologically functional (USDA Forest Service 2001a). Hydrologically functional meadows with perennial and intermittent streams perform the following functions:
1) dissipate stream energy from high flows, reducing erosion and improving water quality;
2) filter sediment and capture bedload, aiding floodplain development;
3) enhance floodwater retention and groundwater recharge; and
4) support root masses that stabilize streambanks against cutting action.

When land or water management activities cause channels to become incised and soil moisture or flood patterns to be reduced or altered, the types and proportions of plant communities in meadow areas change. In the most severe cases, upland plant communities replace meadow communities dominated by obligate wet-site species. Less obvious is the replacement or reduction in area of wet sedge or willow communities by moist or dry-site graminoid communities. Changes in plant species composition reflect changes in ecological function as well as changes in hydrologic conditions. Some general plant species, such as willows, sedges, and rushes, are common in functioning meadows but are sensitive to changes in hydrologic profile. These plants disappear if water tables are lowered or instream flows are altered. Approximately 30 rare vascular plants and bryophytes are found only in meadows or special aquatic habitats. Dramatic change in hydrology can diminish subsurface water storage and flood attenuation capacity. For example, Cottonwood Creek where the-channels erode and incise (like when they are relocated) caused the subsurface meadow aquifer to drain, and vegetation to convert from wet meadow species to xertic species, and surface flow patterns changed from perennial to intermittent.

Degradation of the hydrologic function as well as the aquatic habitat and biodiversity of meadows and meadow streams may be linked to multiple water uses and water management activities, including (1) dams for hydropower generation and/or water supply; (2) diversions for various uses including hydroelectric power, agricultural irrigation or residential use; and (3) irrigation ditches. In the early 20th century, the generation of hydroelectric power became the dominant private use of the Sierra Nevada water, and electricity was exported far beyond the mountains. For 145 years the development, manipulation, and use of the water resources has significantly modified the Sierra Nevada landscape and ecosystems.

Trends in Meadow Health Related to Climate Change

Climate change will significantly shift the way California water supply systems are operated because the largest natural reservoirs of water is the Sierra snow pack, which feeds many of California's major watersheds. Leading scientists agree that a rise in temperature will occur even under the best emission reduction scenarios. This warmer temperature will result in a 36% reduction of Sierra snow in fifty years and nearly half of its current amount by 2090. Looked at another way, the State of California predicts that there will be a 1500-foot rise in the snow level over the next 90 years.

Snow stores water over the winter and then melts and flows down from April through July to refill storage reservoirs. There is further evidence that the rising of the snow level will increase the incidence of "rain on snow" events at critical mid-elevation Sierra forests, increasing the peak flows and flooding associated with storms in the winter when we have no excess storage capacity. Furthermore, the increase in winter peak flows combined with the compounding effects of the planned clear-cutting in the region will make it difficult to gauge the timing of water releases from the headwaters. There is a real need for more research to quantify the water storage capacity of meadows under climate change scenarios, specifically the loss of storage in headwaters due to a rising snow level and how large hydrologically functioning meadows can act as a cumulative water storage/retention mechanism.

Restoration and Conservation actions to improve current Status and reverse Trends

The status of Mountain Meadows depends on the land and water uses occurring in and around the meadow especially in the "contributing watershed area" for each meadow. It is evident that from this analysis that grazing and roads have the greatest region-wide effect on mountain meadows, and that mines although few in comparison to roads may have a significant effect on meadow health by way of contamination and habitat destruction. Small dams and diversions are pervasive throughout the history of meadow management and have altered the hydrologic conditions in drastic but often reversible ways the effects of which change the hydrologic function of meadows upstream of the dam site as well downstream.

Sierra Mountain Meadows provide ecological services as habitat to rare and endangered species and serve important water storage and flood attenuation function for the entire watershed. In order for meadows to continue to provide these ecological services they need to be managed in a way that leaves the meadows connected to the shallow groundwater table. If a meadow is connected to the shallow groundwater table then the vegetation that grows in the meadow will be better suited as habitat to the species endemic to the riparian and wet land habitats of meadows. In addition, connection to the shallow groundwater table will ensure proper groundwater recharge and storage capacity of meadows in the headwaters as well as effective retention ponds during flood events.

Unfortunately, the current status and trends of Sierra Mountain Meadows indicate that there are a number of land and water uses that lead to erosive conditions which can begin a cascade of events that leaves meadows disconnected from the water table and unable to provide healthy aquatic and wetland habitat for the rare and endangered species that depend on them. And these erosive conditions will eventually limit the extent of viable grazing land if the meadow is allowed to regress to entirely xertic system. A priority should be creating a Integrated Watershed Management Plan specific to Mountain Meadows and preserving the ecological services meadows provide as well as selecting meadows for restoration.

Data Gaps Analysis and Recommended Next Steps

The greatest fractional loss of wetland area in all states has occurred in California where only 9 percent remains of an estimated unimpaired wetland area of about 5 million acres. Wetlands in mountain areas, particularly meadow wetlands, have received much less attention than their counterparts in lowlands and coastal areas despite significant degradation from forest management, dams and diversions, mining, overgrazing, and the introduction of invasive exotic species. Given the importance of Sierra mountain meadow wetlands for ecological services, it is important to gain a comprehensive perspective and utilize all of the information available regarding the status of these wetlands in order to prioritize effective conservation and restoration actions.

Based on this literature review, synthesis of available existing data, and collection of new data, the most important human impacts on Sierra meadows are those that lead to erosive events such as grazing. Unlike any other human use considered here, grazing has directly impacted nearly every meadow in the study area. Much is to be gained by gathering and analyzing existing spatially explicit data on 20th Century grazing practices and plant and soil monitoring, as is planned by the Region 5 Range program. Insights on vegetation and hydrologic responses of particular meadow ecosystem types to various grazing practices (number, timing, grazing species, distribution, etc.) could be crucial for developing restoration and grazing management plans in the Project Area. Organizing a meeting with Dave Weixelman (Botanist R5 Adaptive Management Services Enterprise Team) and Crispin Holland (R5 Range Program Manager) at the end of the 2007 field season would be the first step toward identifying ways in which the R5 Range Program and this project can work together toward similar goals.

Other human uses likely to have important impacts now and in the future include water use and recreational activities. Some information on recreation use in meadow areas is collected by the Range Program. Some initial inquiries into the type and extent of this information might be a first step to take to inform decisions on whether or not to invest in collecting and analyzing available information on meadow recreation use. Some or all of this available information might come as part of the above R5 Range Program's effort to collect range data from the various district offices in the Region.

Although we are lacking spatially explicit information on the distribution of invasive exotics, the influence of invasives such as sagebrush, is likely to become increasingly important in a large number of meadows. Regional trends and spatially explicit information on changes in invasive exotic species might be quantified by comparing current/recent vegetation data to the Parker 3-step data to be collected through the R5 Range Program. Spatially explicit information on current occurrences of invasive exotics could be assessed for the 208 plot subset of the 1,948 meadows in the Project Area that have associated vegetation data in the Meadow Health Database.

Impacts related to mining, roads, timber, and fire might also be important for particular meadows, and the importance of these impacts at a broader scale needs to be assessed based on the ecosystem services and ecological significance associated with each particular meadow in question. Spatially explicit data layers on fire and recent timber management history are available through the Forest Service and could be integrated into the Sierra Meadows GIS project in order to assess possible fire and timber history impacts on meadows of interest. Although the impacts related to roads appears to be less important than other uses based on this initial review, it would be helpful to calculate the number of road-stream intersections per unit area as part of a next step in this project, since it is a commonly used metric and could be used as a point of comparison to other systems.

Impacts and ecosystem services related to water use are also important. Although less than 5% of the meadows in the project area have dams greater than 6 feet in height and/or 15 acre feet in capacity within their contributing area, the effects of these dams on those meadow systems might be great. In order to identify meadows subject to significant dam effects, it would be useful to calculate the distance of dams in a meadow's contributing area from the meadow itself. Another possible useful step for the planning process might be to group those meadows affected by dams according to drainage and associated hydroelectric power. The data needed to quantify and spatially identify the impacts of diversions and irrigation ditches on water supplies to meadows in the Project Area are not readily available. Identification of several subset study areas in which these impacts could be mapped and quantified could be a part of the next phase of this project if information pointing to their importance is brought forward from local or other sources.

Future restoration actions should concentrate on restoring the hydrologic function of wet meadows, improving degraded habitat conditions and developing management regimes to reduce the land and water use impacts on meadows.

Known Data gaps include:

- Develop methods to quantify storage capacity and flood attenuation
- Determine groundwater sources
- Gather and analyze data on existing grazing practices, information on grazing intensity is lacking in that we only have record for permitted grazing rather than actual grazing that occurred
- Study health and conditions of naturally dry meadows, because we have selected for meadows with streams in them and therefore our data set in biased towards wet meadows
- Characterize the large meadows that were either developed or are on private lands, our data set mainly covers public lands and therefore our data set is biased towards smaller high elevation meadows on public lands

Recommended Next Steps: Informing Future Management Decisions

Gathering information, particularly spatially explicit information, on past and current land and water uses associated with Sierra meadows can be a time consuming and expensive process. Therefore the next steps taken should be weighed against the likelihood of that information providing useful insight into the management and restoration planning process. Some of this information might be most useful if gathered on a site by site basis, rather than over the entire Project Area. However, there are at least three strong arguments for developing an information base on past and current land and water uses related to Sierra Meadows:

1. This information can provide a history of disturbance sources and disturbance types that could be essential for interpreting current trends in vegetation and hydrology for any given meadow. Understanding the processes behind observed trends is central to effective management and restoration.

2. An analysis of current land and water uses in relation to their impacts on meadow processes and ecosystem services could provide important information so that the appropriate balance between meadow restoration and maintenance of ecosystem services can be explicitly weighed against other land and water uses. Explicit identification of potential conflicts may offer the best first step toward identifying 'win-win' solutions.

3. Finally, a region-wide information base on land and water uses can be used to assess current and future trends. Historic analysis of land and water uses in the Sierra indicates that uses are constantly shifting and that past uses do not necessarily indicate future uses or their associated impacts. Identification of new, developing trends and associated impacts could be used by land use/recreation planners to avoid or minimize such impacts.

Targeting meadows for restoration to re-establish the hydrological connection between the surface and groundwater is the primary goal of the Feather River Coordinated Resource Management Group located in the Feather River watershed using their pond and plug method of restoration. The pond and plug restoration technique involves digging several ponds and using the dirt that is excavated to fill in eroded gullies that rut the degraded meadow, with the intent that the following spring, the meadow will be saturated with the winter runoff that would have otherwise raced downstream. This technique allows surface water to find a way across the meadow in a natural, meandering channel and re-connects the meadow to the groundwater in essence returning the hydrologic function to the meadow. The applicability of this method to other regions should be determined and may enable this technique to be applied widely to reverse the erosive conditions that lead to dry hydrologically disconnected meadows.

In addition, identifying plant species for removal at an early stage of invasion is essential to their successful control. Hence early detection is a critical monitoring challenge. We need to know more about pathways of introduction and dispersal, including the roles (and effects) of logging, roads, trails, human visitation, cars, heavy equipment, pack animals, and livestock to aid in understanding where to look for incipient outbreaks and habitats that will be most vulnerable to full scale invasion. While programs such as weed free feed have been instituted (http://www.extendinc.com/weedfreefeed/ and http://pi.cdfa.ca.gov/weed/wff/) to reduce the potential entry of weeds into backcountry habitats, better documentation of pathways on a species-by-species basis will help target control efforts. Coordinated region-wide early detection and rapid response systems need to be developed. (D'Antonio et al.2002).

The successful implementation of these restoration actions and with the innovation of additional restoration and management techniques we can preserve, improve and protect Sierra Mountain Meadows as a viable terrestrial and aquatic resource for overall watershed function.

Outreach and Dissemination of Final Products

The Mountain Meadows final report will be used to inform the Mountain Meadows IRWMP in Northern California. The Mountain Meadows IRWMP will expand the meadow health database and the regional assessment of meadow health into the Feather and Pitt watersheds. In this way, the Mountain Meadows EPA work will be leveraged to inform this regional planning effort. The EPA Final Report will be distributed at IRWMP stakeholder meetings and at three IRWMP workshops which will be open to the public.

In addition, the Mountain Meadows Final Report will be disseminated to multiple watershed groups that are interested in monitoring meadow health for their watersheds. Watershed groups in the Yuba River watershed that have already expressed interest in monitoring meadow health include, the South Yuba River Citizens League and Friends of Deer Creek. It is our hope that as more watershed groups become interested in meadow health we will have ample opportunities to disseminate the Mountain Meadows Final Report to additional watershed groups. The Final Report will be posted on UCD's Center for Watershed Science website as well as the Natural Heritage Institute website. It will also be distributed on CDs at watershed group conferences, such as the Sierra Nevada Alliance Conference in August 2007.

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Appendix 1

Site Name	% of Polygon assessed	% Low	% Mod	% High	FISH IBI
Gardener Meadow	2.93	25	25	50	25
Mokolumne River	0.17	0	100	0	50
Silver Creek	5.54	0	50	50	62.86
Silver Creek	1.64	0	0	100	62.86
Forestdale Creek	3.12	0	14.291	85.71	30
Woods Creek	0.79	0	0	100	50
W.F. Carson River	0.79	0	14.301	85.719	40
Hot Springs Creek	6.81	5.95	52.385	41.667	48.57
Willow Creek B	3.39	0	33.333	66.667	37.5
Silver Lake Spring	7.16	11.11	11.111	77.78	50
Schneider Creek	5.104593	0	66.66	33.33	50
Big Meadow Creek	0.79	83.33	0	16.66	40
Upper Truckee River	1.74	0	0	100	60
San Joaquin Trib	3.18	0	13.16	86.841	45
Loney Meadow	0.08	0	100	0	45
Sagehen IV	4.67	0	62.5	37.5	60
Prarie Creek	6.53	0	20	80	40
Austin Meadows	2.69	0	38.464	61.54	30
Big Meadow Creek	4.67	10.53	34.213	55.26	50
Angora Creek	2.61	60.61	39.394	0	54.291
Grey Eagle	6.35	66.66	8.33	25	40
Little Jamison Creek	2.25	0	0	100	40
Clarks Creek	0.17	0	50	50	65.71
Boulder Creek	1.78	0	23.812	76.19	45
Peirce Creek	0.12	0	100	0	60
Indian Creek A	3.44	25	50	25	55
Indian Creek B	1.49	25	0	75	50
Willow Creek	4.29	0	0	100	40
Cold Stream	0.14	0	100	0	40
Independence Creek	0.13	0	0	100	60
Little Truckee	0.39	0	4	96	71.43
Haypress Meadows	0.08	0	0	100	40
Tributary to Haypress Meadows Creek	0.88	0	25	75	35
Pauley Trib	0.42	0	0	100	35
Church Trib	1.77	16	16	68	30
Church Creek	5.21	16.33	34.69388	48.989	40

Appendix 2

Form # 3: Visual Encounter Survey:

Date:__________ Site # :______________ Observers:________________

Stream:______________________ Length________________

Weather________________ Air Temp:________

Time Begin:_______End:_______ Habitat Description:_____________________________
____

Species	Number	SVL (est. cm)	Location: 1=water, 2=logs, 3=edge, 4=bank	Life Stage: Adult Juvenile Tadpole	Notes

Totals:
Species______________ No._______Abundance (1-5)______________
Species______________ No._______Abundance (1-5)______________
Species______________ No._______Abundance (1-5)______________
Species______________ No._______Abundance (1-5)______________
Species______________ No._______Abundance (1-5)______________
Species______________ No._______Abundance (1-5)______________
Species______________ No._______Abundance (1-5)______________
Species______________ No._______Abundance (1-5)______________

General Abundance:
1= 1 sited
2= 2-3
3= 4-10
4= 11-100
5= 101+

Appendix 3

Stream______________________________Site #.________Date_________
Seconds: Pass 1____________Pass 2_______________Pass 3_______________
Species Time Begin:____________ Time End:_______________

Pass #

FL	Wt.	FL	Wt.	FL	Wt.	FL	Wt.	FL	Wt.	FL	Wt.	FL	Wt.	FL	Wt.

Appendix 4

Invertebrate Survey: Stream Name___________________Site #__________Date_______

Invertebrates	Total #		Total #
Acari (mites)		Oligochaeta (aquatic worms)	
Amphipoda (scuds)		Ostrocoda (seed shrimp)	
Cladocera (water fleas)		Turbellaria (Flatworms)	
Decapoda (crayfish)		Diptera (Flies)	
Gastropoda (snails)		Coleoptera (Beetles)	
Hirudinea (leaches)		Odonata (Dragon/Damselflies)	
Isopoda (sowbugs)		Hemiptera (True Bugs)	
Nematoda (roundworms)		Lepidoptera (Aquatic moths)	
Nematomorpha (horsehair worms)		Megaloptera (hellgramites)	
Pelecypoda (clams)			

EPT Index

# Taxa total	#Mayfly taxa	# Stonefly taxa	# Caddisfly taxa
# EPT taxa	EPT Index (% total)	% Dominant taxa	% Stoneflies
Total # Organisms in sample	Notes (problems w/ ID, etc.)		

EPT Taxa (Family)		
Ephemeroptera (Mayflies)	Plecoptera (Stoneflies)	Trichoptera (Caddisflies)

Appendix 5

Vegetation Survey
Stream Name:__________________ Site #__________Date:__________

Form Basic Meadow Plant Data

Moisture Regime **(check one box)**	**y/n**
Standing water	
Saturated (water pools around feet)	
moist top 1-2 inches	
dry to touch	

Notes (plant height, species, % cover estimates)

Vegetation (Estimate percent cover category)	<5%	5-20%	21-50%	51-80%	>80
Non-woody plants					
Sedges					
Grass					
Forb					
Shrubs					
Willows present along stream only					
Willows					
Average willow height (feet)					
Alders present along stream only					
Alders					
Sagebrush					
Other shrubs					
Trees					
Trees cover >15% site					
Aspen					
White Alder					
Cottonwood					
Lodgepole pine					
White/Red Fir					
Other Tree species					

Appendix 6

Methods for Assigning 'Health Status' to Sierra Meadows based on Weixelman et al. (2003) approach. Health status in this case refers mainly to successional status, or degree of recovery from disturbance.

1. As best as possible, key out wetland using Weixelman key on next page. Criteria include:
- depth to soil saturation
- depth to soil mottling
- presence of soil organic or peat layer
- presence of indicator species (see key)
- elevation

2. Calculate Relative Frequency (percent of hits) of 3 groups of plant species for each site. Three groups are (1) early seral; (2) mid-seral; (3) late seral. For example, if 20 out of 100 hits were species in category (1), then the plot's early seral frequency would be 20%. Steps for doing this are:
- Assign early, mid, and late seral categories for each indicator species (these assignments are based on a database Dave W. sent me with assignments that have been agreed upon by the Region 5 Range Conservationists as of Winter 2005. – It will involve doing a database query or two.)
- Sum total number of hits per plot
- Sum number of early, mid, and late seral hits
- Calculate relative frequencies

For plots with only percent cover data (not frequency data based on 'hits'), use percent cover in place of relative frequency and make a note or column with a mark on whether this was based on frequency or percent cover.

3. Plot relative frequencies of early versus late seral groups on appropriate Score Card Triangle --- see attached triangles taken from Weixelman methodology.

4. Combine evidence on vegetation and extent of bare soil cover, and rooting depth -- if there is any evidence of this from data -- and designate 'Ecological Status' category based on Key— these keys are attached at end of this document.

Key to Region 5 meadow types (scorecard types)

1. Dry meadow sites dominated by drier grasses, forbs, and grass-like species. Depth to soil saturation greater than 100 cm. Depth to mottles (redoximorphic concentrations) generally greater than 100 cm. Some key indicator species are *Poa secunda*, *Achnatherum* spp., *Bromus tectorum*, *Carex douglasii*. 2

1'. Not as above. Moist to wet meadow sites dominated by grasses and grass-like species or mosses. Depth to soil saturation less than 100 cm in mid summer . Depth to mottles (redoximorphic concentrations) less than 100 cm. Soils with a peat layer or not. 3

2. Elevation 3,000 ft. to 6,000 ft. .**Dry meadow foothill type**.

2'. Not as above. Elevation 6,000 ft. to 8,000 ft. ..**Dry meadow montane type**.

3. Depth to soil sataturation between 40 and 100 cm in mid summer. Depth to mottles (redoximorphic concentrations) generally between 40 and 100 cm. Soils without a peat layer. Key indicator species are: *Poa pratensis*, *Juncus balticus*, and *Muhlenbergia richardsonis*. .... **Moist meadow foothill and montane type**

3'. Not as above. Sites wetter. Soils with or without a peatlayer. Key indicator plant species are: *Carex nebrascensis*, *C. jonesii*, *C. vallicola*, *C. simulata,* or *C. vesicaria*. 4

4. Soils with a layer of organic soil . *Sphagnum* mosses and *Drosera* sp. are often prominent. Typical vascular plant indicators are *Carex vesicaria*, *C. echinata*, and Carex capitata. .... **Peatland meadow montane type**

4'. Not as above. Soils without an organic layer. 5

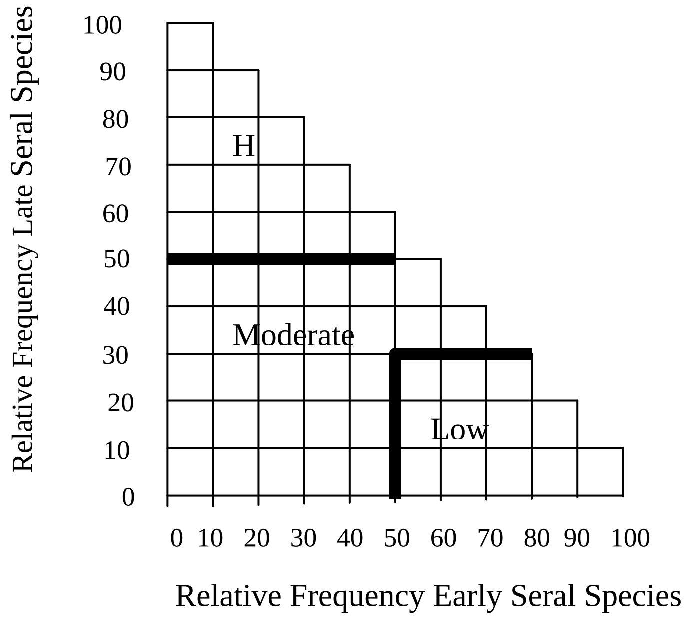
5. Elevation 3,000 – 6,000 ft. .... **Wet meadow foothill type**

5'. Not as above. 6

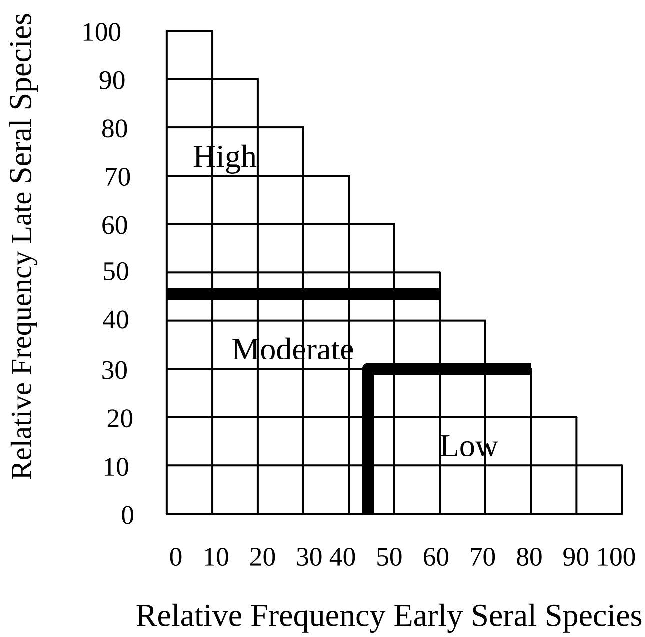
6. Elevation 6,000 ft. – 8,000 ft. .... **Wet meadow montane type**

6'. Not as above. Elevation 8,000 ft. – 9500 ft. .... **Wet meadow subalpine type**

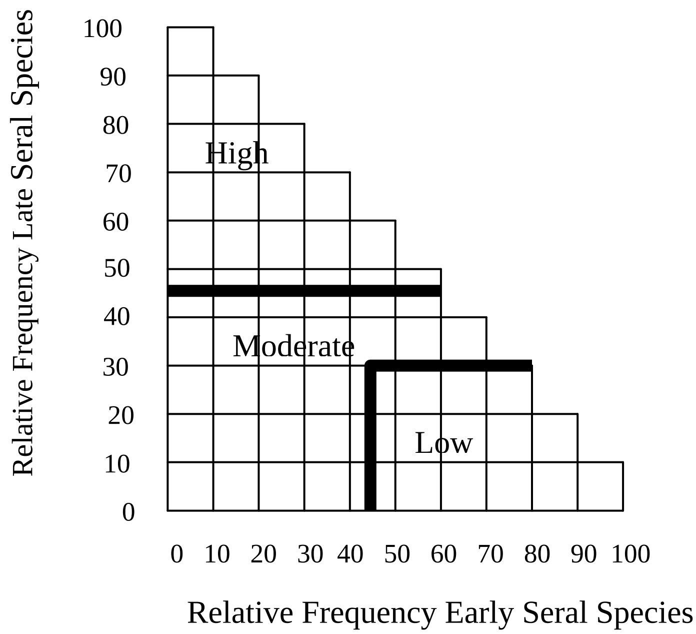
Vegetation successional stage scorecard for wet meadows.



Vegetation successional stage scorecard for moist meadows.



Vegetation successional stage scorecard for dry meadows.



Scorecared for assessing ecological function - Dry meadow foothills zone

Ecological Status	Species Composition	Root Depth (>100 roots/dm^2)	Bare Soil
High ecological status	Vegetation is in a late successional stage using the dry meadow triangle.	> 6 cm	< 7%
Moderate ecological Status	Vegetation is in a mid successional stage	4 – 6 cm	8 - 12%
Low ecological status	Vegetation is in an early Successional stage	0 - 3 cm deep	> 12 %

Scorecared for assessing ecological function –Dry meadow/ Montane zone

Ecological Status	Species Composition	Root Depth (>100 roots/dm^2)	Bare Soil
High ecological status	Vegetation is in a late successional stage	> 7cm	< 8%
Moderate ecological Status	Vegetation is in a mid successional stage using the Dry meadow triangle	4 – 6 cm	8 - 13%
Low ecological status	Vegetation is in an early Successional stage	0 - 3 cm deep	> 13 %

Scorecard for assessing ecological function - Moist meadow

Ecological Status	Species Composition	Root Depth (>100 roots/dm^2)	Bare Soil
High ecological status	Vegetation is in a late Successional stage	> 18 cm deep	0 - 6 %
Moderate ecological Status	Vegetation is in a mid successional stage using the Moist meadow triangle	10 - 17 cm deep	6 - 13 %
Low ecological status	Vegetation is in an early Successional stage	0 - 9 cm deep	> 13 %

Scorecard for assessing ecological function - Wet meadow/foothills zone

Ecological Status	Species Composition	Root Depth (>100 roots/dm^2)	Bare Soil
High ecological status	Vegetation is in a late Successional stage using the Wet meadow triangle	> 20 cm deep	0 - 4 %
Moderate ecological Status	Vegetation is in a mid successional stage	10- 19 cm deep	5 - 9 %
Low ecological status	Vegetation is in an early Successional stage	0 - 9 cm deep	> 10 %

Scorecard for assessing ecological function - Wet meadow/montane zone

Ecological Status	Species Composition	Root Depth (>100 roots/dm^2)	Bare Soil
High ecological status	Vegetation is in a late Successional stage using the Wet meadow triangle	> 19 cm deep	0 - 4 %
Moderate ecological Status	Vegetation is in a mid successional stage	10- 19 cm deep	5 - 9 %
Low ecological status	Vegetation is in an early Successional stage	0 - 9 cm deep	> 10 %

Scorecard for assessing ecological function - Wet meadow/subalpine zone

Ecological Status	Species Composition	Root Depth (>100 roots/dm^2)	Bare Soil
High ecological status	Vegetation is in a late Successional stage using the Wet meadow triangle	> 15 cm deep	0 - 4 %
Moderate ecological Status	Vegetation is in a mid successional stage	10- 15 cm deep	5 - 8 %
Low ecological status	Vegetation is in an early Successional stage	0 - 9 cm deep	> 8 %

Appendix 7

Rapid Bioassessment Data

Date:	Site #:	Observers:	Stream:	GPS Lat/Long	Time:	Water Temp

Habitat Quality (for each measure 20 is high, 0 is low)

Epifaunal Habitat	Embeddedness	Velocity/Depth regime	Sediment Deposition	Channel Flow Status	Channel alteration	Freq. of Riffles
Bank Stability	Veg. Protection	Riparian Width		Total Habitat Score:		
LB:	LB:	LB:				
RB:	RB:	RB:				

Rapid Bioassessment Data

Date:	Site #:	Observers:	Stream:	GPS Lat/Long	Time:	Water Temp

Habitat Quality (for each measure 20 is high, 0 is low)

Epifaunal Habitat	Embeddedness	Velocity/Depth regime	Sediment Deposition	Channel Flow Status	Channel alteration	Freq. of Riffles
Bank Stability	Veg. Protection	Riparian Width		Total Habitat Score:		
LB:	LB:	LB:				
RB:	RB:	RB:				

Appendix 8

Metrics for a Fish and Amphibian Index of Biotic Integrity for Montane Meadows of the Central and Northern Sierra Nevada

I. Native trout species (rainbow trout, western Sierra Nevada, Lahontan cutthroat trout, eastern Sierra Nevada)
  1. No native trout present (1)
  2. Native trout present with non-native trout (3)
  3. Native trout only (5)

II. Percentage of native species
  1. <25% (1)
  2. 26-75% (3)
  3. 75% + (5)

III. Number of native species present (or % expected)
  1. 0-1 (1)
  2. 2 (3)
  3. 3+ (5)

IV. Number of age classes, native species
  1. 0-1 (1)
  2. 2 (3)
  3. 3+ (5)

V. Total fish abundance
  1. <10 (1)
  2. 10-50 (3)
  3. >50 (5)

VI. Total number of species present (or % expected)
  1. 0-1 (1)
  2. 2-3 (3)
  3 4+ (5)

VII. Number of amphibians (larvae scored as 1% of total number present)
  1. 0 (1)
  2. 1-3 (3)
  3. 4+ (5)

VIII. Number of native amphibian species present
  1. 1 (1)
  2. 2 (3)
  3. 3+ (5)

IBI Score = [Total points/number of metrics] x 20

Appendix 9

Metrics for a Fish without native trout and amphibians Index of Biotic Integrity for Montane Meadows of the Central and Northern Sierra Nevada

I. Trout species biomass per square meter of area (gm/m^2)
  1. < .1 = (1)
  2. > .1 < .5 = (3)
  3. = .5 = (5)

II. Number of age classes, native species
  1. 0-1 (1)
  2. 2 (3)
  3. 3+ (5)

III. Total fish abundance
  1. <10 (1)
  2. 10-50 (3)
  3. >50 (5)

IV. Total number of species present (or % expected)
  1. 0-1 (1)
  2. 2-3 (3)
  3 4+ (5)

IBI Score = [Total points/number of metrics] x 20

Appendix 10

Metrics for macroinvertebrate Index of Biotic Integrity for Montane Meadows of the Central and Northern Sierra Nevada.

I. EPT index

1. < 25 (1)
2. > 25 < 65 (3)
3. > 65 (5)

II. Species richness

1. < 6 (1)
2. > 6 < 9 (2)
3. > 9 < 12 (3)

III. Tolerance

1. > 5 (1)
2. > 3 < 4 (3)
3. = 2 (5)

IV. Percent dominant species

> 39 (1)
>15 < 39 (3)
≤ 14 (5)

V. Percent stoneflies

1. < 5 (1)
2. > 5 < 25 (3)
3. > 25 (5)

IBI Score = [Total points/number of metrics] x 20, where 80-100 is excellent, 60-80 is good, 40-60 is fair and <40 is poor.

Appendix 11.
Montane Meadow Habitat Quality Assessment Metrics for Index of Biotic Integrity for Central and Northern Sierra Nevada.

Each of 10 habitat features was rated on a 0-20 point basis and then combined for a total score out of 200 possible. Each category is rated and put into one of four habitat quality categories. 1) Poor habitat 0-50 points; 2) Marginal habitat, 51-100 points; 3) Sub-Optimal habitat, 101-150 points; and 4) Optimal habitat, 151-200 points.

1. Epifaunal Substrate/Available Cover

    1. Poor: < 20 % stable habitat: lack of habitat is obvious; substrate is unstable or lacking.
    2. Marginal: 20–40% mix of stable habitat; less than desirable habitat availability; substrate frequently disturbed or removed.
    3. Sub-Optimal: 40-70% mix of stable habitat; can be fully colonized; will maintain population.
    4. Optimal: >70% of substrate favorable for colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other suitable habitat.

2. Embeddedness

    1. Poor: Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediments.
    2. Marginal: Gravel, cobble, and boulder particles are 50- 75% surrounded by fine sediments.
    3. Sub-Optimal: Gravel, cobble, and boulder particles are 25- 50% surrounded by fine sediments.
    4. Optimal: Gravel, cobble, and boulder particles are25- 50% surrounded by fine sediments. Layering of cobble provides diversity of niche spaces.

3. Velocity/Depth Regime

    1. Poor: Dominated by 1 velocity/depth regime (usually slow/deep).
    2. Marginal: Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).
    3. Sub-Optimal: Only 3 of the 4 regimes present (if fast-shallow missing score lower than if missing other regimes).
    4. Optimal: All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). Slow is < 0.3 m/s, deep is > 0.5m.

4. Sediment Deposition

    1. Poor: Heavy deposits of fine material, increased bar development; more than 50% (80% for low gradient) of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
    2. Marginal: Moderate deposition of new gravel, sand or fine sediment; on old and new bars; 30-50% (50-80% for low gradient) of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate

deposition of pools prevalent.

    3. Sub-Optimal: Some new increase in bar formation, mostly from gravel, sand or fine sediment; = 30% (20-50% for low-gradient) of the bottom affected; slight deposition in pools.
    4. Optimal: Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition.

5. Channel flow status

    1. Poor: Very little water in channel and mostly present as standing pools.
    2. Marginal: Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.
    3. Sub-Optimal: Water fills >75% of the available channel; or <25% of the channel substrate is exposed.
    4. Optimal: Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.

6. Channel Alteration

    1. Poor: Banks shored with gabion or cement; > 80% of stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
    2. Marginal: Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.
    3. Sub-Optimal: Some channelization present, usually in areas of bridge abutments; evidence of past chanelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.
    4. Optimal: Channelization or dredging absent or minimal; stream with normal pattern.

7. Frequency of riffles

    1. Poor: All flat water or shallow riffles, poor habitat; ratio of distance between riffles/stream width is >25.
    2. Marginal: Occasional riffle or bend; some habitat; ratio of distance between riffles/stream width is = 15 -25.
    3. Sub-Optimal: Riffles infrequent; ratio of distance between riffles/stream width is = 7 -15.
    4. Optimal: Riffles relatively frequent; ratio of distance between riffles/stream width is = < 7:1.

8. Bank Stability (score both banks individually on 1-10 scale)

    1. Poor: Unstable; many eroded areas; 60-100% of bank has erosional scars.
    2. Marginal: Moderately unstable; 30-60% of bank has erosional scars.
    3. Sub-Optimal: Moderately stable; small areas of erosion; 15-30% of bank has erosion.

4. Optimal: Banks are stable; erosion absent or minimal; <5% of bank has erosion.

9. Vegetation Protection (score both banks individually on 1-10 scale)

   1. Poor: Less than 50% of stream bank covered in vegetation; large areas of bare soil; stubble height = 5 cm.
   2. Marginal: Stream banks covered with 50-70% vegetation; patches of bare soil or closely cropped vegetation common; <50% of potential plant height remaining.
   3. Sub-Optimal: Vegetation coverage 70-90%; some disruption, but >50 potential plant height remaining.
   4. Optimal: Greater than 90% of stream bank and riparian zone covered; disruption minimal or not evident; most plants allowed to grow naturally.

10. Riparian Vegetation Zone (score both banks individually on 1-10 scale)

   1. Poor: Width of riparian zone <6 m; little or no riparian vegetation (from human activities).
   2. Marginal: Width of riparian zone 6-12 m; large human impact.
   3. Sub-Optimal: Width of riparian zone12-18 m; minimal human impact.
   4. Optimal:Width of riparian zone >18 m; no human impact.

Appendix 12

Statistical results from comparison testing of sites mutually sampled by UCD and the California Department of Fish and Game. In order to be normally distributed skewness must be between 1 and -1.

Site	Standard skewness	Standard kurtosis	t-statistics	P-value	F statistics	P-value
Big Meadow	-0.99	0.48	1.42	0.20	0.64	0.73
Big Meadow	1.44	1.26				
Butt Creek	0.43	0.20	-0.57	0.58	0.83	0.84
Butt Creek	-0.13	0.43				
Charity Creek	1.73	1.77	1.19	0.26	0.95	0.96
Charity Creek	0.04	-0.39				
Forestdale	1.32	1.20	-1.15	0.28	0.68	0.69
Forestdale	-0.34	-0.19				
Hot Spring	0.04	-1.01	0.50	0.63	0.51	0.47
Hot Spring	1.31	1.15				
NF Mokelumne.	0.38	-0.96	-1.05	0.32	2.00	0.46
NF Mokelumne.	0.47	-1.11				
Sagehen	-0.01	-0.62	1.95	0.08	0.24	0.14
Sagehen	0.43	-0.11				
Silver	-0.06	-0.11	0.56	0.59	0.63	0.62
Silver	0.29	0.58				
Stanislaus	-1.15	0.88	-1.47	0.19	0.68	0.76
Stanislaus	1.62	1.61				

Appendix 13

Environmental and Geomorphological Measurements

	Count	Average.	Variance	Standard deviation	Standard error	Minimum	Maximum	Range	Skewness	Kurtosis
Average depth	78	19.5	204.1	14.3	1.6	4.0	107.0	103.0	11.8	31.7
Average width	78	245.2	21628.1	147.1	16.7	60.0	665.0	605.0	3.7	0.5
Clarity	39	4.8	0.2	0.5	0.1	3.0	5.0	2.0	-5.8	6.3
Conductivity	35	33.6	294.1	17.1	2.9	9.0	76.0	67.0	2.2	0.4
Maximum depth	78	50.1	794.3	28.2	3.2	9.0	183.0	174.0	5.9	9.5
Percent Algae	78	6.6	179.3	13.4	1.5	0.0	75.0	75.0	11.7	21.2
Percent Bedrock	78	0.26	1.9	1.4	0.2	0.0	10.0	10.0	21.2	66.1
Percent Boulder	78	9.1	122.6	11.1	1.3	0.0	55.0	55.0	5.9	5.5
Percent Canopy	78	21.8	413.6	20.3	2.3	0.0	80.0	80.0	3.9	0.3
Percent Clay	41	4.4	202.7	14.2	2.2	0.0	75.0	75.0	10.1	21.1
Percent Cobble	78	28.5	380.7	19.5	2.2	0.0	70.0	70.0	0.3	-1.7
Percent Emergent Plants	78	18.0	425.0	20.6	2.3	0.0	90.0	90.0	6.8	6.0
Percent Floating mats	78	0.2	0.9	1.0	0.1	0.0	5.0	5.0	17.6	40.6
Percent Gravel	78	30.4	374.9	19.4	2.2	0.0	80.0	80.0	3.1	0.6
Percent Macrophytes	78	6.6	85.2	9.2	1.0	0.0	50.0	50.0	9.7	16.4
Percent Mud	78	12.9	363.1	19.1	2.2	0.0	90.0	90.0	8.6	10.1
Percent Pool	78	21.0	524.2	22.9	2.6	0.0	100.0	100.0	6.1	4.7
Percent Riffle	78	33.6	447.6	21.2	2.4	0.0	80.0	80.0	0.8	-1.3
Percent Run	78	44.9	720.7	26.8	3.0	0.0	100.0	100.0	1.0	-1.2
Percent Sand	78	17.2	271.7	16.5	1.9	0.0	75.0	75.0	5.9	4.5
Percent Silt	78	23.7	638.3	25.3	2.9	0.0	90.0	90.0	4.1	0.3
Section Length	78	52.1	62.8	7.9	0.9	32.0	89.0	57.0	7.3	13.1
Start H20 Temperature	78	11.7	12.5	3.5	0.4	5.4	25.6	20.2	3.9	4.3
Start Air Temperature	77	19.3	16.0	4.0	0.5	10.5	28.0	17.5	-0.3	-1.4
Turbidity	33	1.4	2.1	1.4	0.2	0.1	7.5	7.4	4.3	11.2