

**MOUNTAIN MEADOW MONITORING ACROSS THE WESTERN UNITED
STATES:**

**A SYNTHESIS WITH IMPLICATIONS FOR THE MONITORING OF VITAL
SIGNS IN DEVILS POSTPILE, KINGS CANYON, SEQUOIA AND YOSEMITE,
NATIONAL PARKS**

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EXECUTIVE SUMMARY

Mountain meadows have been identified as key ecosystem elements in the Sierra Nevada Network (SIEN) (Devils Postpile, Sequoia and Kings Canyon, and Yosemite vital signs workshops 2001-2002; SIEN vital signs prioritization March 2005). While this habitat represents a relatively small percentage of total land area, meadows concentrate energetic resources and provide critical habitat for both resident and transient animals, including a diverse array of invertebrate species and the vertebrate fauna that feed upon them. Meadows also are one focus for visitor use, especially by those visitors who rely on packstock to access wilderness areas. For these reasons, preliminary rankings of ecological indicator prioritization efforts put the structure and function of meadow systems and the organisms that rely on them in the top tier of the current vegetation, wildlife, and human use lists.

Although the Sierra Nevada parks have a well-documented history of research, inventory and monitoring activities related to mountain meadow systems, most of this work has been conducted within the limited context of grazing impacts to vegetation resources. For example, the current meadow monitoring program at Sequoia and Kings Canyon evolved in response to issues surrounding the impacts of packstock on ecosystem structure and function as well as on the experience of other visitors. Because the objectives of past and current monitoring programs within SIEN Parks are so different from the aim of the Inventory and Monitoring program, new methodologies are being developed to capture changes in species composition, hydrology, and soils within montane and subalpine meadows. Sampled attributes need to be sensitive to changes in ecological function as a response to anthropogenic stressors and impacts. This includes but is not limited to rapid anthropogenic climatic change, altered fire regimes, invasion by exotic species, air pollution (NO_x and SO₄), and habitat fragmentation and human use.

This project is intended to provide information on the long-term monitoring of meadow vegetation and associated physical attributes from a synthesis of strategies included in current and past monitoring efforts specific to mountain meadow ecosystems. Monitoring plans selected for this analysis represent a cross-section of plans and plan components from the Bureau of Land Management, the US Forest Service, the National Park Service, the EPA, and in some cases, independent researchers. Included plans primarily focus on mountainous regions of the western United States, with special attention on monitoring efforts in the Sierra Nevada. Past and current monitoring in the SIEN Parks is summarized as a point of reference.

Information on monitoring plans and monitoring plan components was acquired through interviews of regional ecologists and other federal employees who contributed to the development and or implementation of long-term monitoring plans in their respective Forests, Parks, or Field Units. In addition to interviews, we searched on-line databases that focused on academic journals or federal documents. Electronic versions of monitoring plans and academic articles focusing on key components of monitoring plans were named and archived in a MS Access database. Finally, we gathered information on the steps being taken by other NPS Networks in the development of monitoring plans for wetland vital signs.

This paper is divided into four sections. In *Current Monitoring Programs across the Western U.S.*, individual monitoring plans are compared to one another where possible; otherwise a discussion of the method, along with advantages, disadvantages, and limitations with respect to specific monitoring objectives is presented. *Creating a Long-Term Monitoring Plan for Meadow Ecological Integrity in the Sierra Nevada National Parks* synthesizes the lessons learned from analysis of individual monitoring plans into a discussion of long-term monitoring plans by component parts. *Summary of Recommendations* provides suggestions for component parts of a tractable long-term monitoring program. Finally, *Appendix A* provides a detailed summary of objectives, methodology, data collected, analysis, and key contacts for individual monitoring plans discussed in *Current Monitoring Programs across the Western U.S.*

Key findings indicate that long-term monitoring efforts should be tied to specific testable questions. Selecting questions that are ecologically relevant and that you can afford to answer within the constraints of available budget and personnel will encourage the efficient collection of data and the robust statistical analysis necessary to detect change over time. Sites should be stratified based upon the most significant ecological drivers for your study area. Geological substrate, regional climate, presence/absence of glaciation, stream gradient and temperature would be expected drivers for mountainous regions such as those found in the Sierra Nevada National Parks.

Stratification by wetland types and elevation should follow watershed-scale stratifications to reduce the natural variability within meadow ecosystems and to make the detection of anthropogenic impacts more feasible. In order to account for the presence/absence of packstock grazing at the meadow scale, dose response curves could be created to arrange meadows of the same type along a disturbance gradient based on past and current use. Meadows within each type could then be sampled in the low, mid-, and high regions of the disturbance gradient for packstock use.

Decisions about plot layout and location, as well as choice of monitoring attributes, should be tailored so that data can be collected efficiently and in such a way as to provide adequate information to answer specific monitoring questions (hypotheses). Monitoring attributes should be ecologically relevant and should respond to changes in management and/or impacts by anthropogenic stressors over an appropriate time scale.

Monitoring wells or piezometers should be installed to monitor inter-annual and seasonal variation in the water table. Monitoring wells should be specifically tied to vegetation plots that are small enough to be representative in species composition for the particular hydrologic regime at that microsite. Other hydrologic data such as annual precipitation, annual snowpack and timing of snowmelt, flood frequency analysis, and flow regime (perennial or ephemeral) in meadows containing streams, should be collected as well.

Soil measures should be tied to specific cover plots, and a basic soil profile described at the time of well installation would go a long way in clarifying the soil attributes at a given site. A more complete soils analysis may be necessary, depending on specific monitoring questions. Geomorphological attributes should be selected based upon specific monitoring questions. Minimally, slope and aspect should be measured for all meadows, and channel cross-sections with photo point documentation should be included for meadows occurring along perennial streams.

For plant species composition, we recommend that frequency be measured for herbaceous species in 100 systematically placed quadrats (25 x 25 cm each), and that percent

cover be measured for herbaceous species in four to five systematically placed 2 x 2 m subplots. Plots should be located within a 400 sq. m macroplot that is randomly located within one or more of the wetland types found in the sampled meadow. Percent cover by shrub species could be measured by a line or point-line intercept method around the perimeter of the macroplot in one 80m transect or two 40 m transects. Presence/absence of trees should be counted within the macroplot according to species and size class. Additional measurements should be added carefully to answer specific questions while preventing the sampling protocols from becoming too cumbersome. Most importantly, the site-specific sampling design should be simple to set up and sample, and should be located within a single wetland type.

In setting up a long-term monitoring program, it is important to choose strategies for managing inter-annual, seasonal, site-based, and observer-based variability. Managing error increases the power with which you can detect trend without making type I and/ or type II errors. Since the variation associated with year cannot be effectively reduced by choices in sampling design, long-term monitoring plans must account for seasonal and inter-annual variability in temperature and precipitation, modeling the effects of these factors on target variables. Site-based variability can be managed by increasing the duration of the study and by sampling a fixed number of sites each year. Data on season and inter-annual variability that are collected from sites sampled each year can be extrapolated to sites sampled on a rotational basis within the study area. The selection of highly repeatable methods and the collection of quality assurance data will help in managing observer-based variability.

Power can be achieved by managing sample size, number of factors in the design, and duration of the study. The inclusion of intensively sampled sites which will be resampled each year with extensively sampled sites which will be sampled on a standard rotational basis (e.g. every five years) will help balance the statistical requirements for power with the ecological requirements for extrapolation to the entire NPS network.

Data reduction techniques can also be used to increase the power associated with the analysis of plant species composition traits. Data reduction techniques include the use of seral stages or functional groups, multimetric indices, wetland evaluation technique for wetland condition, and the Integrative Biological Indicator (IBI) indices for bioassessment. The last three in the above list fall under the broad heading of multimetric indices, which have been applied to wetland vegetation with mixed results. Multimetric indices should be adopted with caution, as they may require considerable time and resources to create and test.

INTRODUCTION

Background

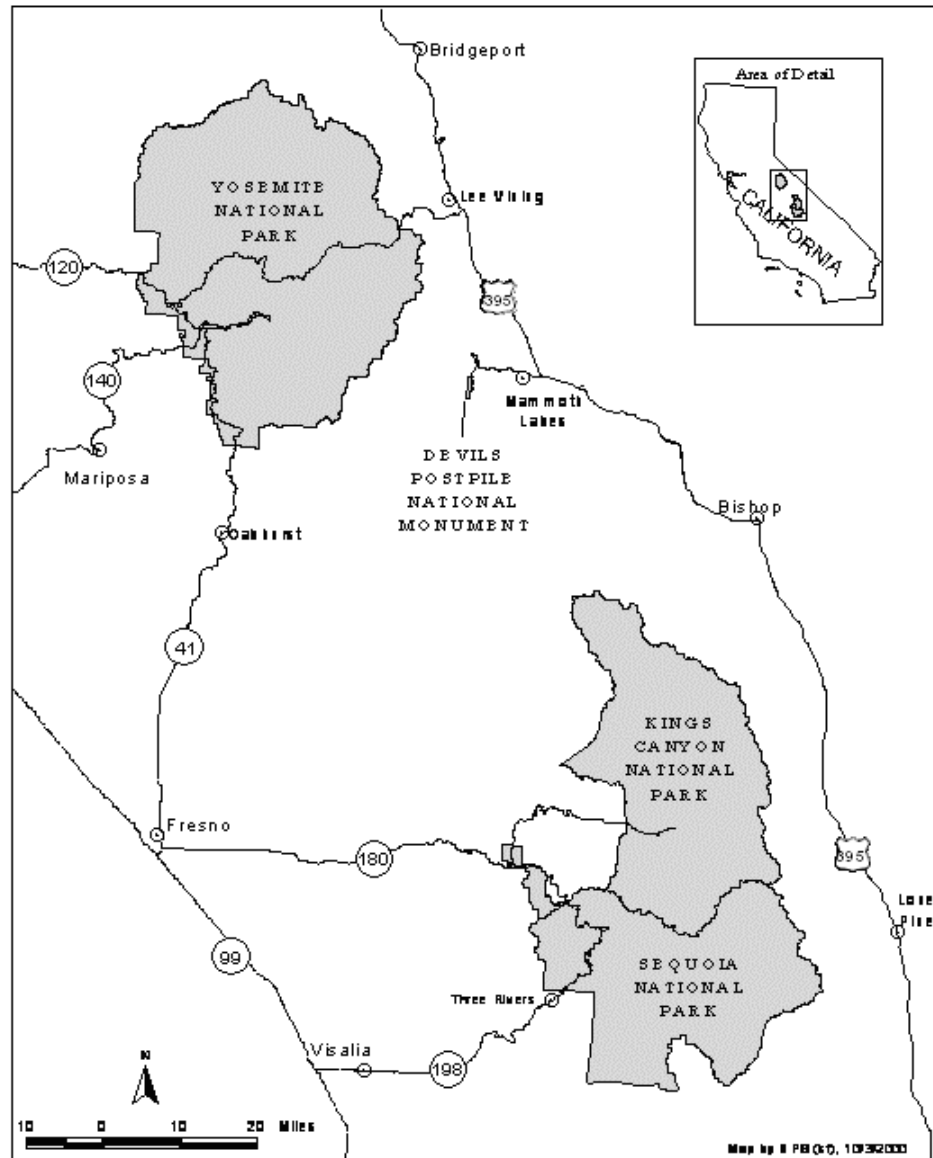
National Park Service (NPS) Management Policies (National Park Service 2001a) and recent legislation (National Parks Omnibus Management Act of 1998) require that park managers know the condition of natural resources under their stewardship and monitor long-term trends in those resources in order to fulfill the mission of conserving parks unimpaired. The NPS has developed an Inventory & Monitoring (I&M) program to fill in knowledge gaps in baseline data about natural resources in parks and to design and implement long-term monitoring protocols that will enable managers to develop broad-based, scientifically sound information on the current status and long term trends in the composition, structure and function of park ecosystems (National Park Service 2006).

Individual resources chosen to be monitored as part of the Inventory and Monitoring Program have been termed “vital signs”. Vital signs are akin to ecological indicators, as they are intended to represent “the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values” (National Park Service 2006). The elements and processes that are monitored include “water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources” (National Park Service 2006). Because the National Park Service (NPS) acknowledges that the vital signs chosen represent only a subset of physical, chemical, and biological elements that the NPS manages, considerable effort has been taken in their selection (Mutch et al. 2004, 2005).

To improve the efficiency of an inventory and monitoring program, the NPS created networks of parks linked by geography and shared natural resource characteristics. There are 32 networks nationwide. The Sierra Nevada Network includes the following NPS administered units in California: Devils Postpile National Monument, Sequoia and Kings Canyon National Parks, and Yosemite National Park, all on the west slope of the Sierra Nevada (Figure 1). The parks cover approximately 658,000 ha and are largely federally-designated Wilderness. Land ownership around the parks is predominantly United States Forest Service, resulting in a large expanse of federally managed lands. The network includes a wide elevation range (400-4417 m) that supports a diverse and abundant assemblage of plants and animals along this gradient.

Mountain meadows have been identified as key ecosystem elements in the Sierra Nevada Network (SIEN) (Devils Postpile, Sequoia and Kings Canyon, and Yosemite vital signs workshops 2001-2002; SIEN vital signs prioritization March 2005). While this habitat represents a relatively small percentage of total land area, meadows concentrate energetic resources and provide critical habitat for both resident and transient animals, including a diverse array of invertebrate species and the vertebrate fauna that feed upon them. Meadows also are one focus for visitor use, especially by those visitors who rely on packstock to access wilderness areas. For these reasons, preliminary rankings of ecological indicator prioritization efforts put the structure and function of meadow systems and the organisms that rely on them in the top tier of the current vegetation, wildlife, and human use lists.

Figure 1. Sierra Nevada Network parks. The Sierra Nevada Network (SIEN) includes Yosemite and Sequoia and Kings Canyon National Parks, together with Devils Postpile National Monument.



Objectives

Although the Sierra Nevada parks have a well-documented history of research, inventory and monitoring activities related to mountain meadow systems, most of this work has been conducted within the limited context of grazing impacts to vegetation resources. For example, the current meadow monitoring program at Sequoia and Kings Canyon evolved in response to issues surrounding the impacts of packstock on ecosystem structure and function as well as on the experience of other visitors.

The objective of the Inventory and Monitoring program is to know the condition of natural resources under NPS stewardship and to design and implement long-term monitoring of vital signs that will enable managers to develop broad-based, scientifically sound information on the current status and long term trends in the composition, structure and function of park ecosystems (National Park Service 2006).

Because the objectives of past and current monitoring programs within SIEN Parks are so different from the aim of the Inventory and Monitoring program, new methodologies are being developed to capture changes in species composition, hydrology, and soils within montane and subalpine meadows. Sampled attributes need to be sensitive to changes in ecological function as a response to anthropogenic stressors and impacts. This includes but is not limited to rapid anthropogenic climatic change, altered fire regimes, invasion by exotic species, air pollution (NO_x and SO₄), and habitat fragmentation and human use (Mutch et al. 2005).

This project is intended to provide information on the long-term monitoring of meadow vegetation and associated physical attributes from a synthesis of strategies included in current and past monitoring efforts specific to mountain meadow ecosystems. Monitoring plans selected for this analysis represent a cross-section of plans and plan components from the Bureau of Land Management, the US Forest Service, the National Park Service, the EPA, and in some cases, independent researchers. Included plans primarily focus on mountainous regions of the western United States, with special attention on monitoring efforts in the Sierra Nevada. Past and current monitoring in the SIEN Parks is summarized as a point of reference.

General Approach and Project Scope

Information on monitoring plans and monitoring plan components was acquired through several different search avenues. We conducted interviews of regional ecologists and other federal employees who contributed to the development and or implementation of long-term monitoring plans in their respective Forests, Parks, or Field Units. In each interview, we asked about the plan's objectives, chosen methods, data collected, and perceived strengths and weaknesses of the program. Through the interview process, electronic versions of plans were collected. These plans were named and archived with the help of a bibliographic database. In addition to interviews, we searched on-line databases that focused on academic journals (e.g. Biosis and Web of Science), as well as databases that focused on federal documents (e.g. NatureBib). Electronic versions of academic articles focusing on key components of monitoring plans were named and archived in the same database. Finally, we gathered information on the steps being taken by other NPS Networks in the development of

monitoring plans for wetland vital signs. These included the Rocky Mountain and Klamath Networks.

Because the focus of the I & M program is on preserving the ecological integrity through the monitoring of vital signs, we give more attention to monitoring plans whose objectives are geared towards the preservation of ecosystem components, functions, and processes. In general, we avoided projects that focused on vegetation classification, except where they provided specific information on past or current research and monitoring efforts within the SIEN Parks. Similarly, we avoided methods focusing on vegetation utilization by cattle, except where they provided specific information on SIEN Parks. Finally, while the monitoring of invertebrate populations will be a substantial component of the SIEN meadow ecological integrity monitoring program, protocol development of these taxa is being spearheaded by Dr. Jeff Holmquist of the White Mountain Research Station and is therefore outside of the scope of this project (see Holmquist 2004, Holmquist and Schmidt-Gengenbach 2006).

This paper is divided into four sections. The first section entitled *Current Monitoring Programs Across The Western U.S.* focuses on four groups of monitoring plans: 1) plans adapted from the greenline method (mostly U.S. Forest Service methods), 2) BLM plans, 3) past and current monitoring within the SIEN Parks, and 4) plans being developed for wetland vital signs by other NPS networks in fulfillment of the I & M monitoring program. Plans are compared to one another within these groups, and where that is not possible, a discussion of the method, along with advantages, disadvantages, and limitations with respect to specific monitoring objectives is presented. The second section entitled *Creating a Long-Term Monitoring Plan for Meadow Ecological Integrity in the Sierra Nevada National Parks* synthesizes the lessons learned from analysis of individual monitoring plans into a discussion of long-term monitoring plans by component parts. Section four provides a summary of recommendations for component parts of a tractable long-term monitoring program. Finally, Appendix A provides a detailed summary of objectives, methodology, data collected, analysis, and key contacts for individual monitoring plans discussed in *Current Monitoring Programs across the Western U.S.*

CURRENT MONITORING PROGRAMS ACROSS THE WESTERN US

Monitoring plans selected for this analysis represent a cross-section of plans and plan components from the Bureau of Land Management, the US Forest Service, the National Park Service, the EPA, and in some cases, independent researchers. Plans are compared to one another in four groups: 1) plans adapted from the greenline method (mostly US Forest Service methods), 2) BLM plans, 3) past and current monitoring within the SIEN Parks, and 4) plans being developed for wetland vital signs by other NPS networks in fulfillment of the I & M monitoring program. Some plans are more conceptual in nature, focusing on sampling design, stratification, and sampling methods, while others focus more on the nuts and bolts of data collection and analysis. When methods can not be directly compared to one another, a discussion of the method, along with advantages, disadvantages, and limitations with respect to specific monitoring objectives is presented. For each plan discussed below, a detailed summary of objectives, methodology, data collected, analysis, and key contacts is presented in Appendix A.

Sampling Methods

Relevés, transect sampling, and quadrat methods have all been used for vegetation sampling in meadow environments. These methods can be combined or used in isolation, depending upon the sampling objectives. What follows is a brief description of each type, along with generalizations about how each is used in the sampling of mountain meadows.

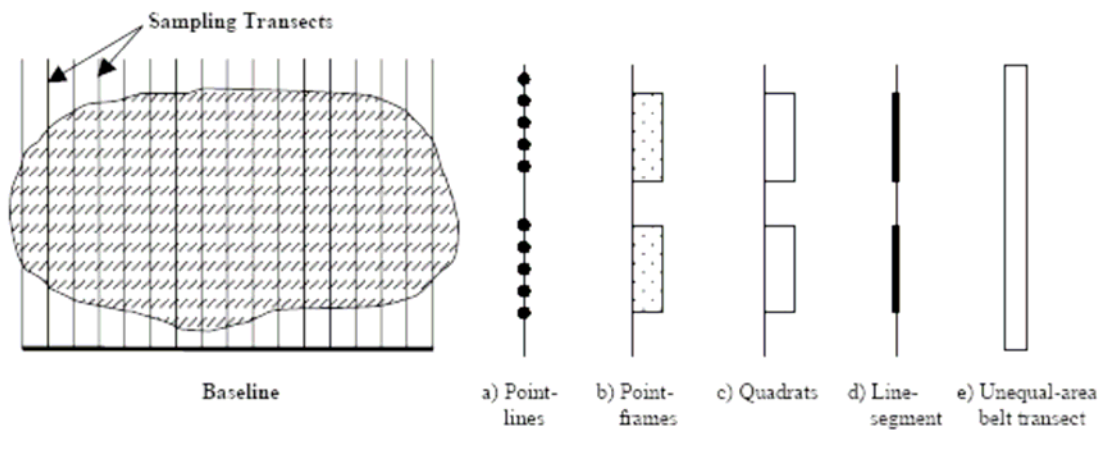
The relevé method was developed by Braun-Blaunquet and is typically used by phytosociologists and others interested in classifying plant community types (Mueller-Dombois and Ellenberg 1974). Relevés are subjectively placed in homogeneous areas of vegetation that are representative of a given community type. Percent cover by species is generally estimated for all species by ocular estimation. Phytosociologists favor this technique because it is generally easy to use and time-efficient. A trained botanist with an assistant can usually complete a relevé within two hours, as long as the botanist is familiar with the regional flora. Relevés vary in size based on vegetation type.

A number of transect sampling methods have been used to sample meadows and other wetland types. In open basins, transects are generally located at either random or systematic intervals perpendicular to a baseline (Figure 2). A stratified random approach is sometimes used to randomly sample within targeted areas along the hydrologic gradient or within different vegetation types (US EPA 2002c). Line-intercepts or belt transects are often used to capture percent cover by shrubs, while point-intercepts or evenly spaced quadrats along the transect provide data on herbaceous components of the vegetation (Barbour et al. 1998).

Quadrat methods involve sampling frequency or cover within a regularly shaped plot with a fixed size. Quadrats vary in size and range from small plots like Daubenmire plots (Daubenmire 1959, Barbour et al. 1998) and the nested frequency plots (Weixelman and Bakker 2005) to larger multi-scale plots and macroplots (Stohlgren et al. 1997). A macroplot refers to a relatively large sampling area in which sub-sampling will be conducted, often using quadrats, line-segments or point-lines (Elzinga et al. 1998.). Quadrats are sometimes placed randomly within homogeneous stands of vegetation or along transects at regular intervals. Nested plots are favored for estimating frequency, as this attribute is especially

sensitive to quadrat size. Most of the monitoring plans evaluated have chosen many small quadrats (up to 200 per meadow) to sample frequencies of herbaceous species, and a smaller number of larger plots to sample trees, snags, and saplings.

Figure 2. Transects of different types arranged perpendicular to a baseline in a wetland complex, reproduced from Barham et. al (2004). The diagram on the left depicts a general representation of transects arranged perpendicular to a baseline in a wetland complex. A-e are graphical representations of different ways to sample along a transect. Point-line, quadrats, line-segment, and belt transects are all used by various monitoring programs summarized in this report.



In a summary of inventory and monitoring methods by Weixelman and Durham, sampling methods were lumped into two broad groups: “1) those that used a macroplot or a number of macroplots to sample meadow vegetation within a homogeneous area; and 2) those that used cross sectional transects running perpendicular to the stream or baseline in order to sample vegetation” (Weixelman et al. 2002). Relevés are included in the first category.

Both sampling methods used permanently-placed plots to reduce variability associated with change in sampling location. A tally of protocols summarized by Weixelman and Durham confirmed that among the plans included, classification projects are more likely to use macroplot (including relevé) methods, whereas monitoring projects are more likely to use transect/ quadrat methods. Benedict’s and Halpern’s classification projects in Sequoia and Kings Canyon are included due to their regional significance and as a representation of classification efforts. Otherwise, this report avoided the selection of classification projects, focusing instead on monitoring frameworks. For this reason, more of the projects described here are of the transect/ quadrat variety, rather than of the relevé camp. Another reason for the preponderance of transect/quadrat methods may be the publication of Winward’s greenline method (Winward 2000), which seems to have had a large impact on monitoring protocols developed by the USFS, and to a lesser extent by the BLM, over the last six years. The first set of summarized protocols, therefore, focuses on plans that are the children and

stepchildren of this methodology. Each one presents a few alterations, improvements, or unique modifications.

PLANS BASED ON THE GREENLINE METHOD

Greenline Method (Winward 2000)

The greenline method was developed by Al Winward to evaluate the health of vegetation in basin-type meadow complexes, especially with respect to the impacts of grazing. The design works easily for meadows which include a dominant perennial stream but has been successfully used for other meadow types as well. Winward has defined the greenline as “the first perennial vegetation that forms a lineal grouping of community types on or near the water’s edge. Most often it occurs at or slightly below the bankfull stage” (Winward 2000). The greenline sampling design includes three sampling methods. (1) The vegetation cross-section method identifies community types, based on one or two dominant species, across the valley floor. These data are converted into relative frequency of each community type within a single meadow complex. According to Winward, this method describes six to twelve community types per riparian complex and “evaluates the health of vegetation across the valley floor”. (2) The greenline method provides a similar measurement of the streamside vegetation. (3) Finally, the woody species regeneration method measures the density and age class structure of any shrub or tree species that may be present in the sampling area. The dominant species named in community types are assigned to successional classes, and the relative frequency of each seral class in the meadow is used to help ascertain meadow condition. The greenline methods are collectively attractive in that they are simple and seemingly straightforward to use. In fact, many other USFS protocols have been based on these methods, usually with some additions, and in all cases with small to major changes (Weixelman et al. 2002, Weixelman and Bakker 2005).

The three methodologies created by Al Winward were designed as a rapid assessment of range health in relation to the range of community types, bank stability, and health of a shrub layer along riparian zones where they would be expected. The application of this approach to long-term monitoring efforts has several limitations. First, community classifications are not always available for sampled meadows, and the availability of reference sites with unaltered vegetation and potential natural communities (PNC) are difficult to find. If they are available, they are typically determined by percent cover of various species. To determine if you were actually in those ranges, you would normally need a plot, within which you would determine cover by species. So accurately determining community type in a repeatable way would be a challenge with this method, or any other method based on the cross-sectional and greenline vegetation approaches. Second, a successional status rating and a bank stability rating are assigned to each community based on the expertise of local experts, and in a few cases, research on those particular species. The USFS has since developed a more transparent process of classification based on functional groups, instead of successional status of dominant plant species. This makes sense, especially as linear and directional succession is atypical in these communities. Third, this methodology does not attempt to capture the floristic diversity of the meadow; nor does it attempt to capture species composition in plots or across the meadow as a whole. Community type is

based on the most dominant species, or in a few instances, the two most dominant species. The vegetation cross-section and greenline methods do not tell you how total species composition is changing with respect to grazing. This is unfortunate, as less common species are usually more sensitive to grazing (Murrell Stevenson 2004c, a). Finally, quality assurance testing of this method found that although monitoring with community types allows for the rapid assessment of vegetation, there was subjectivity in determining community type of the ground. Even with completed vegetation classifications for the areas tested, and twelve days of training at the beginning of the field season on how to use the classifications and sampling methods, observer agreement for community type data was low. In fact, the variation from one observer to the next was almost as much as the variation from one site to the next, making differences among sites difficult to detect with this method (Coles-Ritchie et al. 2004a).

USFS Region 5 Range Monitoring Project (Weixelman and Bakker 2005)

Building substantially upon the components of the greenline method, the range monitoring protocol was developed to provide long-term monitoring of USFS meadows grazed by cattle, determining trends within permanently established plots and providing a quantitative estimation of meadow condition. Most of the meadows sampled as a part of this project were below 2743 m.; emphasis was placed on mesic portions of meadows, as it was assumed that this was where grazing-related disturbance would be concentrated. Because this protocol was geared towards the effects of grazing, meadows with >20% cover by willows were excluded from sampling. Otherwise meadows were divided into wet, mesic, and dry meadows, with fens being treated separately. Wet meadows are defined as being dominated by some percent of hydric species, and or water table within 50 cm of the surface throughout the growing season, and or anaerobic soil conditions. Plant composition was sampled using rooted frequency (angiosperms and gymnosperms only), as this measure is objective, easy to sample, and less sensitive to inter-annual variation than estimates of canopy cover (Weixelman and Bakker 2005). According to Weixelman, a meadow could be sampled in about three hours assuming the use of data loggers that already had species lists available.

Instead of analyzing the successional status of community types, as in Winward (2000), plants are analyzed in terms of functional groups, based on measured traits (life form, life history, wetland rating, rooting characteristics, vegetative lateral spread mechanism, and nitrogen fixing capability). Based on the combination of traits, plants were assigned to one of three functional classes (low, moderate, or high). Based on the suite of measured traits, deep-rooted graminoids would fall into the “high” functional class, whereas non-hydric forbs fall into the “low” functional class. Percent frequency by species across a set of three transects was summed across three condition classes (high, moderate, and low) to determine the relative frequency of each functional group within the meadow. Overall condition ratings in meadows were based on the predominant condition class for vegetation, percent bare ground, and rooting depth.

While this methodology presents some significant and beneficial additions to the greenline method, including the establishment of permanent plots, estimates of frequency for all species, and the inclusion of functional groups based on measured traits, there are some inherent limitations. (1) Because transects were usually located in mesic sites within meadows, plots did not represent the meadow as a whole. (2) Soil-water measurements were

linked to transects rather than plots and were not representative of all of the plots along the transect. (3) Analysis of data from two years suggested that wet meadow types had the highest percentage of high-condition sites. While functional status was established primarily for wet types, it was used in the analysis to describe the condition of wet, mesic and dry types, although each has different inherent capabilities. To adequately rate the condition of all three community types within a meadow complex, different criteria would be needed for high, moderate and low condition classes within each type. (4) There is no measurement in this protocol to capture change in woody vegetation, an omission that Weixelman would like to correct in future sampling efforts. (5) “These preliminary findings indicate that there may be a need to consider changes in water table when interpreting the condition and trend of mountain meadows. Future work will include more analyses on the relationship of water table to condition assessment”(Weixelman and Bakker 2005). Annual rates of precipitation should also be included as a covariate in the analysis to make it more meaningful. (6) “Future work will need to include other aspects of hydrologic influence as well, such as the source of groundwater, duration of groundwater influence, and potential soil nutrient availability as well as other soil factors in a classification”(Weixelman and Bakker 2005) (7) “For management considerations, these categories of condition classes and transitions likely do not follow a pathway of linear succession and retrogression. A next step in the process of describing condition for a meadow site is to incorporate the assessment of condition into a state and transition model. In order to do this, data are needed that describe changes in process and function associated with species composition, and relates those changes to hydrologic characteristics and management. The detection of thresholds (biotic and abiotic) between stable states of vegetation is of key importance in describing the function and processes unique to meadow and riparian areas (Leonard et al. 1992)”(Weixelman and Bakker 2005). (8) Because rooted frequency is highly sensitive to frame size, a nested plot is favored when studying trends in specific species, rather than functional groups. Even with a nested plot, a large sample size is necessary to pick up changes in uncommon species.

Sierra Framework Methodology (Aquatic Conservation Strategy Meadow Study Plan)

Like the Range Monitoring Plan (Weixelman and Bakker 2005), the Sierra Framework methodology (Weixelman et al. 2002, 2004) was an adaptation of Al Winward’s Greenline method (Winward 2000), encompassing a vegetational cross-section of community types, greenline sampling along the primary stream channel, and a protocol to capture the recruitment and regeneration of woody vegetation. Development of this program began in 1990. The plan was implemented for two years (2003 and 2004) and then discontinued due to a change in funding priorities within the US Forest Service. Through the implementation of the Sierra Framework methodology, between 60 and 80 sites within the Sierra Nevada Forest Plan Amendment (SNFPA) study area were visited. This area comprised all or parts of eleven National Forests that lay within the boundaries of the Sierra Nevada Ecosystem Project (SNEP): Inyo NF, Toiyabe NF, Sequoia NF, Sierra NF, Stanislaus NF, Eldorado NF, Tahoe NF, Plumas NF, Lassen NF, and Modoc NF. If three crews were involved in sampling in both years, as the budget suggested, a maximum of thirteen sites/ crew/ season were sampled. This is plausible given the tremendous amount of travel time associated with covering eleven National Forests.

This plan is different from the Range Monitoring Plan or the Greenline method in that it was not geared towards grazing but rather was designed to be a long-term monitoring strategy for capturing a 20% change in vegetation, soils and hydrology attributes with an alpha of 0.20 and a power of at least 80% (sample size ~ 162 meadows per hydrologic type over a ten-year sampling period). Data were collected on vegetation composition, size of meadow complex, count by diameter class of hardwoods and softwoods, recruitment of woody species, count by diameter class of snags, total cover of vegetation, shrub height and percent cover by genus, ground cover by class, frequency of noxious weeds, frequency of sensitive plant species, total rooting depth, and depth to redoximorphic features. Like the Range Monitoring Plan, meadows are rated based on a condition class. This method was more complex and time-consuming than the Range Monitoring plan, taking 1-2 days for a three- person crew, as opposed to 3 hours with a two person crew and a data logger with species already entered.

Prior to beginning fieldwork, meadows were stratified into categories through interpretation of aerial photographs. Meadows were divided by geomorphic position: (1) spring-fed sloping (mostly fens), (2) fluvial (floodplain or stream-terrace), or (3) basins. Fens occurred mostly on spring-fed slopes or at the toe-slope of basins. Meadows were further stratified by elevation. Minimum site size was 0.4 ha. Riparian areas were excluded from this study, as they were addressed separately by a different study plan.

Those components of meadow-riparian complexes that are dominated by herbaceous vegetation are addressed...along with meadow systems occurring in non-riparian settings. Meadows are dominated by herbaceous vegetation, supporting less than 10 percent canopy cover by woody vegetation. They include the montane meadow habitat, subalpine meadow habitat, alpine habitat, Darlingtonia series, and multiple sedge series designations in the California Native Plant Society classification (Sawyer and Keeler-Wolf 1995) but do not include the montane wetland shrub habitat nor the subalpine wetland shrub habitat designations. This treatment of meadows is consistent with California wildlife habitat relationship (WHR) types (Mayer and Laudenslayer 1988). WHR meadows have no or sparse shrub layers (Weixelman et al. 2002).

Authors of this plan initially wanted to be completely unbiased in their selection of sites. They did not have a good meadow GIS layer from which to work and so instead used FIA grids and randomly selected some number of meadows, making sure that some were in the north, central, and southern ends of the project area. The upper end of the baseline was based upon a point from USFS classified dataset, not the centroid of the FIA hectare. Crews searched within a certain radius and chose the nearest meadow that was at least 0.4 ha in size on USFS land. USFS crews used 1:24000 aerial photographs in stereo pairs to help locate sites and drew the meadows they found over the Digital Ortho Quarter Quadrangle (DOQQ).

There were several pitfalls encountered in the implementation of this study plan. (1) The site selection method often produced false positives, meaning that many times crews were directed to places that were not really meadows. Because Sierra Nevada Ecosystem Project (SNEP) boundaries were used, the Lassen and Modoc National Forests, which are ecologically different than the other forests in the Sierra Nevada region, were included. According to Susan Durham (pers. Comm.), most of the false positives were in these two forests. (2) Wet areas were easier to recognize than drier meadows. If the project had

continued, meadows would have been stratified after the fact by hydrologic type. In the end, data collected as part of the Sierra Framework initiative were not analyzed. According to Durham, sampling points were too few to draw any statistically-relevant conclusions. (3) The baseline was originally split into thirds and then transects were randomly selected within each third. Susan thought the random placement of transects within each third added a substantial time to set-up and for the relocation of plots. In addition, rebar easily sinks in wet ground and is lost. Therefore, in the last year they were switching to a more systematic design: instead of 3 stratified random transects, each with 20 nested plots, they switched to 5 transects placed evenly across baseline, each with 12 nested plots. This change in design created a more even distribution of plots which were easier to relocate, while preserving the number of plots per meadow. (4) Durham suggested that the characterization of community types across the meadow cross-section was not useful in the field without a completed plant community classification for the area. According to Durham, even within field crews, assigning community types to areas was cumbersome and not very repeatable. This portion of the protocol also proved labor intensive. (5) Proceeding to a randomly placed point for the top of the baseline using GPS was time intensive. Crews were not trying to capture any specific type of vegetation, but were trying to capture the variety of communities that exist in the meadow complex. According to Durham, more information could have been gained by sacrificing some of the randomness, and sampling within homogenous patches of vegetation. (6) Susan thought that sampling water level with a one-time auguring did not provide as much information as would be gained having sites where wells were sampled every year to capture regional patterns in the inter-annual variation of the water table. (7) The complete random design of sites, combined with the avoidance of sampling sites near one another in the same year (to avoid the problems of separating out the variation attributed to proximity versus inter-annual variation in the absence of sentinel sites) greatly increased the travel time and reduced the number of sites that could be visited within one season. Selecting some proportion of sites near roads would have reduced travel time within a season.

PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program

The PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program was developed to address monitoring requirements for bull trout and steelhead in twenty National Forests and nine Bureau of Land Management (BLM) field units within the Interior Columbia River Basin. There are two protocols associated with this program, the stream habitat protocol and the riparian vegetation protocol. Both are designed to determine how well the implementation of conservation and management plans affect the desired outcome of maintaining or restoring the structure and function of riparian ecosystems (Coles-Ritchie et al. 2004b, PACFISH/INFISH (PIBO) Effectiveness Monitoring Program Staff 2004, Henderson et al. 2005).

The stream habitat protocol includes a variety of methods for assessing various attributes of stream habitat including channel cross-sections, gradient, habitat units, large wood, sinuosity, streambed substrate, streambank parameters, water temperature, and aquatic macroinvertebrates. While many of these methods are specific to documenting the breeding habitat for steelhead and bull trout, other methods are appropriate for gauging the change in physical properties of basin wetlands associated with perennial streams. Hydrological and geomorphological methods focusing on attributes that might be adapted to SIEN objectives

include bankfull elevation, gradient, and sinuosity (Harrelson et al. 1994); streambed particle counts (Wolman 1954); bank stability (Platts et al. 1987, Bauer and Burton 1993); bank angle and undercut banks (Platts et al. 1987); channel cross-sections (Rosgen 1996); and the presence or absence of large wood (Hankin and Reeves 1988). All of the above methodologies were adapted for the specific objectives of this program and are summarized in *Effectiveness Monitoring For Streams And Riparian Areas Within The Upper Columbia River Basin: Sampling Protocol For Integrator Reaches, Stream Channel Parameters* (PACFISH/INFISH (PIBO) Effectiveness Monitoring Program Staff 2004).

The riparian vegetation protocol is based on the greenline and vegetation cross-section methods devised by Winward (Winward 2000). Modifications were made to collect data on species composition at a reach scale and to decrease the variation attributed to the difference in observer (Coles-Ritchie et al. 2004a). Reach lengths are defined as being at least 20 bankfull channel widths in length, ranging from 160 to 480 m. Sampled reaches were not deeper than could be waded by observers. Like the Sierra Framework methodology, changes from Winward's methods include the establishment of permanently placed plots. The sierra framework methodology uses nested plots, while this method uses Daubenmire plots and places species in traditional Daubenmire cover classes (Daubenmire 1959). Plots were arranged along the greenline (at least 20 plots per side of channel along a given reach) and perpendicular to the valley bottom at 3m, 6m, and 9m on either side of the channel at 5 locations for a total of 30 plots (5 x 2 sides of channel x 3 plots per side at each location). The riparian vegetation protocol was designed to take six hours with a field crew of three and the availability of a hand-held data logger loaded with data forms.

While data analysis showed measurable differences between managed and unmanaged sites in terms of physical attributes and macroinvertebrates, there were no significant differences in measured attributes of riparian vegetation. The authors used this result to underscore the importance of physical attributes in sampling methodologies. Additionally, changes to the vegetation sampling protocol could improve the strength of vegetation data. The use of cover classes, the elimination of unknown species with less than five percent cover, and or the presence of multiple observers may have compromised the precision and accuracy of vegetation data.

BLM MONITORING PLANS

The BLM monitoring plan reviewed was *Riparian Management: A Process for Assessing Proper Functioning Condition of Wetlands* (Prichard 1998a, b). This plan is a qualitative rather than quantitative assessment. Other qualitative assessments we found include the *NRCS Riparian Assessment* and the *Montana Rapid Assessment of Wetland Condition*, both of which present a useful scorecard for streambank erosion due to gully and headcuts (NRCS version 3.2, Apfelbeck and Farris 2005). Other monitoring methods used by the BLM include Cowley and Burton's adaptation of the greenline methodology (Cagney 1993, Cowley and Burton 2005), and range management methods focusing on utilization by cattle.

BLM Process for Assessing Proper Functioning Condition of Wetlands

The BLM has a goal of restoring and/ or maintaining at least 75% of their wetlands in proper functioning condition (PFC). Wetlands are in proper functioning condition when “vegetation, landform, or large woody debris is present to dissipate stream energy associated with high waterflows, thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid floodplain development; improve flood-water retention and ground-water recharge; develop root masses that stabilize streambanks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; and support greater biodiversity” (Prichard 1998a, b). Because the BLM has so much area to cover, they elected to use a qualitative method of assessing PFC. This method uses a checklist to answer yes, no, or not applicable to a series of questions. Responses then guide the observer in assigning a functional rating of PFC, functional-at risk, nonfunctional, or unknown. Functional-at risk sites are then prioritized for restoration or change in management strategy. Separate checklists are provided for lentic and lotic areas (Appendix A).

Concepts of successional status underlay the PFC methodology. By achieving PFC, Prichard states that wetlands and riparian areas are able to achieve an “advanced ecological status”, which combines the potential of the site with its practical capability given political, social, or economic constraints. Potential is defined as the highest ecological status that could be achieved with none of the above constraints, and it is tied to the concept of potential natural community. The BLM then uses the PFC qualitative assessment to get an idea of how a site is functioning with respect to natural ecological processes. BLM then chooses to manage that site at one of several seral states based on the use objectives and the ability of the site to withstand that level of use (Prichard 1998a, b).

There are several primary limitations associated with this methodology: (1) the lack of quantitative data precludes any analysis of trend, (2) a high level of professional expertise may be necessary to make some of the required evaluations, and (3) this method may not be repeatable among different observers. Instead of using trend analysis, this methodology calls for observers to determine if site conditions have improved, degraded, or remained constant since the last visit. There is an unknown category in cases where this evaluation can not be determined by the observer. This methodology is probably fairly effective at providing a first-cut decision as to which sites need more attention and monitoring. The BLM has other methods for evaluating functional-at risk sites in a more quantitative manner (e.g. Cowley and Burton 2005).

PAST AND CURRENT MONITORING PROGRAMS FOR SIEN PARKS

Projects in the SIEN Parks to date have focused on vegetation classification and mapping (Benedict 1982, Benedict 1983, Halpern 1985, Halpern 1986) or on the impacts of packstock grazing on residual biomass (National Park Service 1986, McClaran and Neuman 1989, Neuman 1990, McClaran and McDougald 1994, National Park Service 1999). Methodologies have been based on relevé or macroplot methods in the first case, and on

grazing methodologies such as the comparative yield method, step-point sampling method, and frequency sampling in the second case.

Because the objectives of past and current monitoring programs within SIEN Parks are so different from the aim of the Vital Signs Monitoring Program, new methodologies are being developed to capture changes in species composition, hydrology, and soils within montane and subalpine meadows. Sampled attributes need to be sensitive to changes in ecological function as a response to a host of anthropogenic stressors and impacts (see subsequent section on stressors). This section includes descriptions of classification and packstock monitoring projects from the SIEN network as a point of reference (Appendix A).

Classification of Meadows in Sequoia and Kings Canyon National Parks

Benedict classified sub-alpine meadows in Sequoia and Kings Canyon National Parks, while Halpern focused on the classification of montane meadows (Benedict 1983, Halpern 1985, Halpern 1986). To lay the groundwork for the early meadow monitoring program, DeBenedetti assigned meadow vegetation in the parks meadows to twelve key plant associations (National Park Service 1982); this system was also used by Neuman (1990). Together, these projects provided an early and substantial contribution to the classification of meadows in the southern Sierra Nevada.

Benedict sampled 134 relevés in seven subalpine meadows (Benedict 1983). Sixteen environmental factors were recorded at each site. Five of the meadows had vegetated margins and two had sandy margins, and therefore both of Benedict's major types (Benedict 1982) were included. Results further grouped relevés into hydric, mesic and xeric meadows. Meadows were further subdivided into 19 plant associations that were consistent with earlier classification efforts (Ratliff 1982). Soil moisture, depth to ground water, and depth of standing water were the environmental attributes most closely associated with variation in plant species composition (Benedict 1983).

Halpern used the relevé method of vegetation sampling and monitoring wells to measure depth to water table (Halpern 1985). Eight monitoring wells each were installed in Log and Crescent Meadows, arranged perpendicular to the long axis of the meadow. Locations were chosen subjectively to represent unique plant associations. In addition to depth to water table, soil-water oxygen was measured in both meadows. Results showed that soil-water oxygen decreased with increasing depth of measurement. Depth to water table decreased from early July through August and then increased again through November. These results were consistent with other estimates of water table drawdown during the growing season (Allen-Diaz 1991).

Classification efforts such as those described above, in combination with information presented by Ratliff and Potter (Ratliff 1985, Potter 2003) would be very helpful if frequency of community type is chosen as an attribute in the SIEN Vital Sign Monitoring Plan. This attribute should be selected with caution, however, as it has been applied with mixed results in the field (Coles-Ritchie et al. 2004a, Durham 2006).

Monitoring of Packstock Use in SIEN National Parks

The objective of the packstock monitoring program in Sequoia and Kings Canyon National Parks is to characterize the impact of packstock use on meadow systems (National

Park Service 1999). Packstock use is documented through a formal reporting system imposed on administrative, commercial, and private users. The number of animals, kind of packstock, and number of nights spent in each meadow are included on standardized reporting forms. Packstock use is then evaluated in terms of animal units per acre. Impacts are characterized by the comparative yield method for estimating residual biomass, the step-point sampling method for estimating bare ground (Evans and Love 1957), and the frequency sampling method for detecting changes in species composition (McClaran and Neuman 1989). A description of the data collected by each method is included in Appendix A.

Between 24 and 38 meadows are monitored yearly for residual biomass by Wilderness rangers and a roving ecologist. Because use is usually concentrated in specific areas of meadows, residual biomass in core areas is compared against reference areas in each meadow complex. Core areas are chosen to represent areas with moderate and regular use, while reference areas are assumed to have no use. Since packstock use varies spatially by visit and by year, this assumption may or may not be met. Plant species composition is sampled on a five-year rotational basis in five pairs of meadows (grazed vs. ungrazed), so that one meadow pair is sampled each year. Species composition is collected in 100-200 quadrats per meadow, using a nested frequency frame that permits 100 frequency sampling plots to be sampled by a two-person crew in 7 hours.

Abbott et al (2003) performed an analysis of residual biomass and other methods included in this program (Appendix A). Recommendations based on the results involved the inclusion of absolute biomass as an indicator of meadows with lower-than-expected production values. In addition, the authors recommended an assessment of the ecological status for each meadow so that biomass values could be addressed in the context of each meadow's condition, and that species composition should be characterized using the dry-weight rank method, a method that uses biomass to estimate species composition (Smith and Despain 1997). Because the 10x10 cm frequency plot contributed relatively little additional information, it was recommended that the 25x25 cm plot be used exclusively instead of the nested plot. The establishment of permanent plots was recommended to reduce sampling error. Finally the author suggested guidelines be developed with respect to grazing frequency, intensity, and distribution.

A similar program was developed by McClaran and McDougald for monitoring the impacts of packstock use in Yosemite National Park (McClaran and McDougald 1994). Methodologies used include the comparative yield method for residual biomass (Catchpole and Wheeler 1992), and the point-intercept method for ground cover (Cook and Studdendieck 1986). As part of this program, permanent plots were established in 14 meadows that had moderate to heavy use by packstock and that occurred within areas of uniform species composition. Permanent plots were recommended to ensure that change over time was actually due to packstock rather than a change in monitoring location (McClaran and McDougald 1994). These meadows were sampled in 1994 but according to Mark Fincher (pers. Comm.), they were not sampled again as a group in subsequent years. From 1994 to 2003, five of the original 14 meadows were monitored on a semi-regular basis. This monitoring program will soon be replaced or supplemented by a revised method based on data from monitoring efforts currently used in the Inyo National Forest to rate grazing suitability through intensive field sampling and a subsequent scoring process (Peggy Moore, pers. Comm). Apparently, analysis of this method by Eric Berlow, of the White Mountain Research Station, has found that meadow status can be reduced to a few key variables (e.g.

bare ground and hoof punches) (Peggy Moore, pers. Comm). This new transect methodology is being tested in one meadow this year. The updated protocol was not available at the time of this report.

Peggy Moore (U.S. Geological Survey), worked with other researchers on a parallel study, beginning in 1994 and ended in 2000, to examine meadow response to varying intensities of packstock grazing (Moore et al. 2000). Experimental grazing was conducted in each of three vegetation types: xeric shorthair sedge (*Carex filifolia* var. *erostrata*), a high-elevation type, shorthair reedgrass (*Calamagrostis breweri*), a more mesic type, and tufted hairgrass (*Deschampsia cespitosa*), a type found in upper montane wet meadows (Moore et al. 2000). After two years of grazing in all three types, bare ground increased significantly and plant foliar cover decreased, although this decrease was only significant ($p < 0.05$) in the tufted hairgrass type. The largest and most consistent result across all meadow types was a decrease in productivity (Cole et al. 2004). The proportion of biomass that could be removed each year and the resulting reductions in productivity were estimated. Authors concluded that residual biomass could be used as an indicator of intensity if mean annual productivity levels by meadow type were used as a proxy for utilization and were associated with specific monitoring measures (Moore et al. 2000).

PROTOCOL DEVELOPMENT OF WETLAND INDICATORS BY OTHER NPS NETWORKS

The Rocky Mountain and Klamath National Park networks have begun collecting baseline data to inform the development of their vital signs monitoring programs. Both programs have chosen wetlands as one of the vital signs to be included as part of their I & M long-term monitoring programs. Each network has a slightly different focus, which is reflected in the way in which baseline data is being collected and in which protocols are being developed. The Rocky Mountain Network (ROMN) is focused on the use of bioassessment tools such as multimetric indices, whereas the Klamath Network has focused to date on the development of models which predict wetland types, and the definition of reference conditions for each wetland type found within Klamath Parks. ROMN is focused on preserving wetland ecological integrity (defined below), whereas the Klamath Network is focused on determining wetland condition and laying the groundwork for restoration efforts in degraded wetland environments. The two programs are summarized below. Supplementary information for each program can be found in Appendix A.

Monitoring of Wetland Ecological Integrity within the Rocky Mountain Network

The Rocky Mountain National Parks Network (ROMN) is developing a monitoring plan for a component of their vital signs program called *Wetland Ecological Integrity* (National Park Service 2005). The goals of this program are to establish biometrics for wetland ecological integrity and to monitor trend over time, in order to prioritize additional monitoring, diagnose the causes of degradation, and provide data to inform management decisions about protecting and restoring ROMN wetlands. The authors' definition of ecological integrity follows Karr and Dudley, where ecological integrity is defined as the ability to "support and maintain a balanced adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural

habitats within a region” (Karr and Dudley 1981). As the authors indicate, biological metrics can be effective and integrative factors for monitoring change in wetland condition. When sampled in conjunction with important physical and chemical properties of the ecosystem, these metrics have the potential to detect trends with higher power. Therefore, their monitoring program highlights the selection of pre-existing indicators of biological integrity (IBI) or the development of IBIs that are suitable for their particular types of wetlands. The development and testing of IBIs and other multi-metric indices are discussed under Data Reduction Techniques in the Recommendations section of this report (Karr and Chu 1999, Wilcox et al. 2002, Jones 2004, Larsen et al. 2004). In addition, research by Jones (2004) and Wilcox (2002) are summarized in Appendix A as individual components of monitoring plans. Sampling units will be stratified by wetland type. Measurements of atmospheric deposition (NO_x and SO_4), ground water, and surface moisture regime will serve as explanatory variables.

Wetland Assessment within the Klamath Network

In an effort to collect baseline data for the Klamath Network Vital Signs Monitoring Program, Paul Adamus of the College of Oceanic and Atmospheric Sciences, Oregon State University, was asked to provide an assessment of wetland types within the network. The aims of the project were to create and test a model to predict which wetland type(s) would be found at a given location and to provide baseline data of value to future monitoring efforts of wetland condition, future restoration efforts, and future classification of wetland vegetation for national parks in the Klamath Region. It was hoped that these efforts might help the Klamath Network determine “best management practices” for each wetland type and identify which native plant species might best exclude exotic invaders (Adamus 2005).

GIS was used to determine important functional variables such as geologic type, elevation, annual precipitation, stream presence/absence, and several topographic variables (slope, compound topographic index, curvature, plan curvature, profile curvature), which were in turn used to create a “hydrogeomorphic (HGM) context profiling” Bedford (1996) of potential wetland sites. Logistic Regression and a recursive-partitioning (“tree”) algorithm called CHAID (Chi-square Automatic Interaction Detection) were used for HGM wetland profiles. The CHAID model was preferred, as it “yielded a series of 16 decision rules that were easily converted to GIS queries of the spatial data” (Adamus 2005, Adamus and Good 2005).

Field sites were selected by a combination of random and targeted methods (Adamus 2005). First, GRTS algorithm was employed to select 50 wetlands for field data collection in a spatially-balanced statistically random manner, and they were mapped. Cluster analysis was then used to detect wetlands with unusual combinations of attributes that would be undersampled by use of the GRTS algorithm alone. An additional 25 wetlands were identified through cluster analysis, and these sites were targeted for field sampling, in addition to the 50 randomly selected sites (Adamus 2005, Adamus and Good 2005).

Field methods were based upon the California Rapid Assessment Method (Collins et al. 2004) and synthesis methods used at Point Reyes National Seashore (Parsons and Donovan 2005). Degraded wetlands in need of restoration were highlighted. Data were compiled to determine what reference areas existed for each wetland type, and what each “type ‘should’ look like, in terms of the range of plant diversity, species

composition, functions, and potential habitat for selected species” (Adamus 2005). Wetlands were scored relative to other wetlands within the same hydrogeomorphic class (Brinson 1993) and Cowardin class (Cowardin et al. 1979). The best examples were selected based on data from the biological metrics measured during the first field season. Preliminary wetland types, based solely on field observations, included *Veratrum californicum* var. *californicum* dominated meadows, graminoids-dominated meadows, wet depressions, pond and pond margins, and *Alnus incana* var. *tenuifolia* dominated shrublands. Descriptions of each of these types can be found in the 2005 status report (Adamus and Good 2005).

While we did not have enough information to evaluate how well the chosen models predicted wetland types visited in the field, Adamus’ overall approach can be considered in terms of inherent strengths and weaknesses. Reference sites are often employed as a model for monitoring and restoration efforts, but the selection of “reference” conditions can be challenging, as each site within an individual wetland type is likely to have a unique site history, and as reference conditions often represent a snapshot in time rather than the dynamic quality inherent in a naturally functioning ecosystem. This exercise is necessary, however, if wetlands are to be placed along a gradient of disturbance, and especially if dose response curves are being used in the analysis of wetland condition (US EPA 2002a). Likewise, the combination of randomly chosen and targeted sites was necessary to adequately represent both ends of the disturbance gradient, which otherwise would likely have been undersampled (US EPA 2002c, a). The use of algorithms to select a set of spatially-balanced random sites was a good idea. It could easily be applied in such a way as to improve sampling feasibility by weighting the probability of selecting a large number of sites too far from roads and trails. Overall what we liked best about this approach was the pragmatic focus on monitoring as a tool for improving wetland management: finding the “best management practices” for each wetland type that would restore degraded wetlands and reduce the possibility for successful invasion by exotic species. The inclusion of a baseline inventory of wetland types can provide valuable information for the development of a long-term monitoring protocol.

CREATING A LONG-TERM MONITORING PLAN FOR MEADOW ECOLOGICAL INTEGRITY IN THE SIERRA NEVADA NATIONAL PARKS

An analysis of monitoring plans provides a great deal of insight on the components of a good monitoring plan. According to one group, the development of a long-term monitoring plan includes seven sequential steps:

- 1) Prepare clear monitoring questions and objectives;
- 2) Create a tractable sampling design;
- 3) Develop sampling protocols for data collection;
- 4) Prepare the data management systems, including GIS;
- 5) Plan the methods for analysis and interpretation of data;
- 6) Create an plan for the type and frequency of reporting; and
- 7) Develop a monitoring sustainability plan (Pacific Analytics 2001).

The last step involves building an institutional commitment to the program to ensure its long-term success. Keeping the project simple enough to be cost-effective, yet complete enough to provide a meaningful data set with enough power to establish trends is the goal of any project. The following components of a long-term monitoring plan are discussed below: (1) monitoring objectives; (2) components of the sample design, including stratification and site selection; (3) types of data to collect with respect to hydrology, soils, and vegetation; (4) strategies for managing power and data reduction; and finally (5) a summary checklist of components essential to the success of any long-term monitoring program.

Monitoring Objectives

The SIEN Parks Meadow Ecological Integrity workgroup has identified several monitoring objectives related to change in categories related to biota, hydrology, geomorphology and small mammals:

- 1) Determine temporal changes in species composition of meadow vascular and non-vascular flora;
- 2) Determine temporal changes in the composition of above-ground meadow invertebrate populations at the level of Order (or Family) except for ant Genera (or Species);
- 3) Determine temporal changes in hydrology to include the duration, depth, and timing of surface and ground water;
- 4) Determine temporal changes in wet meadow geomorphic process to include sediment flux into meadows, meadow soil density and moisture, carbon flux of fens, exposed bare ground within meadows, and morphology and flood frequency of meadow streams; and
- 5) Determine temporal changes in the type, frequency and spatial distribution of small mammal signs.

While this group is not necessarily interested in linking change to specific environmental processes or stressors, they do expect that measured attributes be sensitive to changes in ecological integrity. This includes but is not limited to climate change, nitrogen deposition and other contaminants, suppression of naturally-caused fires, invasion by exotic species (vertebrates, invertebrates, plants, and pathogens), recreational and administrative packstock grazing, and other impacts associated with recreation (e.g. trails, roads, trampling, anthropogenic wildfire). Analysis by the Inventory and Monitoring team found the five important systemic stressors posing the greatest threat to Sierra Nevada network parks included rapid anthropogenic climatic change, altered fire regimes, invasion by exotic species, air pollution (including nitrogen deposition), and habitat fragmentation and human use. Packstock use, localized dams, and mines were considered to be more localized impacts (Mutch et al. 2004, 2005). While some effort has been made by the SIEN Meadow Ecological Integrity Workgroup to link specific stressors to possible impacts on dependent variables (see Table 1), more work should be done to create testable hypotheses about how each of these might modify physical and or biological components of the meadow ecosystem. Most of the information needed to generate hypotheses for each of the five systemic stressors can be found in Phase II of the I & M Monitoring Plan report (Mutch et al. 2005). Sampling protocols should then be adjusted to ensure that analyses of those impacts will be possible based on the data collected.

An example might be something like this: we expect that temperature increases due to global warming might cause a draw-down in the water table earlier in the season, thus creating a drying trend in the meadow and providing an opportunity for the encroachment of trees into the meadow. To detect such a change, counts and measurements of trees in several age categories and snags along the meadow-forest ecotone should be included. If tree encroachment is not of interest, tree sampling may be excluded from the protocol, depending on the wetland types under consideration. In sum, monitoring should be tied to specific questions (e.g. US EPA 2002c). Those questions should be related to monitoring objectives and management goals and where possible should provide information to which management can actively respond. “Clearly defining the question being asked (identifying the hypothesis) encourages the use of appropriate statistical analyses, reduces the occurrence of false-positive (Type I) errors, and increases the efficient use of management resources (Leibowitz et al. 1992, Kentula et al. 1993, Suter 1993, US EPA 2002b).

Sampling Design

Sampling design focuses on the overall setup for stratification and site selection. Sampling designs generally fall under one of the following three categories: random, stratified-random, or targeted. Although one of the reviewed plans followed a complete random sampling approach (Weixelman et al. 2002), stratified random or a combination stratified random and targeted approaches were more common. A stratified random design calls for the random sampling of sites within each of several categories, whereas targeted sampling focuses on sites where known impacts occur. When attempting to capture sites along a specific disturbance gradient, a random sampling approach will cause both ends of the disturbance gradient to be undersampled, and therefore a random or stratified random approach is generally selected, with targeted sites being added to ensure the inclusion of the

Table 1. Draft Summary of Potential Meadow Stressors and Consequences. This table was created by the SIEN Meadow Ecological Integrity Workgroup. It represents their thinking about direct and indirect consequences. As a work in progress, it is not considered complete.

Meadow Integrity Stressors	Consequences	
	Direct	Indirect
Climate Change	phenology, surface water duration, soil moisture, soil and air temperature	plant species (including lodgepole pine) composition, invertebrate & vertebrate species composition & density
Nitrogen Deposition	plant biomass and species composition	invertebrate species composition & density
Contaminants	altered physiology, aquatic invertebrate species composition and density	amphibian, bird & reptile density
Invasive Plants	plant species composition & biomass	invertebrate species composition & density
Invasive Vertebrates	plant and bird species composition and abundance	
Invasive Invertebrates	invertebrate and plant species composition and abundance	
Recreational and Administrative Packstock Grazing		
Consumption	plant biomass, stream cover, animal disturbance	plant species composition & structure, small mammal and bird species composition & density, invertebrate species composition & density; aquatic/fish habitat
Trampling	plant structure, stream cover, animal disturbance,	plant biomass & species composition, small mammal and bird species composition & density, invertebrate species composition & density; aquatic/fish habitat
Denudation	% bare ground, erosion	
Chiseling	soil surface profile, stream bank profile, erosion, turbidity, water temperature	
Compaction	soil density	plant biomass & species composition, invertebrate species composition & density
Defecation/Urination	nutrient enrichment, plant mortality	plant and invertebrate species composition
Recreation		
Trails/roads	habitat fragmentation, erosion, litter accumulation, surface flow obstruction, noise	invertebrate species composition & density, road kills, animal disturbance
Trampling	plant structure	plant biomass & species composition
Noise	soundscape	animal disturbance
Anthropogenic Wildfire	plant biomass & structure, invertebrate & vertebrate species composition & density, soil depth, evapotranspiration	plant, small mammal and avian species composition & abundance; hydroperiod; water/soil chemistry; water physical characteristics (conductivity, turbidity, temperature, color)
Human Waste	nutrient enrichment, pathogen dispersal	plant biomass, surface water quality
Water Withdrawal	water table lowered, loss of soil moisture	plant biomass & species composition, invertebrate species composition & density
Loss of Natural Fire Regime	reduced sediment, reduced nutrient input, reduced water input	altered soil and water chemistry, plant biomass & species composition, invertebrate species composition & density

extreme cases at both ends of the disturbance gradient (US EPA 2002c, a). If monitoring questions do not specify the need to sample the full range of variation along a disturbance gradient, a stratified-random approach is preferable, as it reduces the variation among sites by grouping sites of a particular type together, while preserving the ability to make statistical inferences that require random, rather than arbitrary, sampling.

The SIEN Meadow Ecological Integrity Workgroup has decided to use a combination of sites that will be monitored every year with sites that will be monitored on a rotating schedule, to be revisited every five years. Sites visited every five years will be chosen using a stratified-random approach, whereas sites that will be visited every year will be chosen from a subset of the stratified-random sites that are relatively easy to access. Sites monitored every year will be more intensively sampled and may require the use of more equipment, so it makes sense to locate these sites within reach of drivable roads. For some trend analyses, it will be useful to look at responses of intensively monitored sites as a group, since among-site variation will be reduced in sites monitored each year. The presence of intensively monitored sites will also provide information on inter-annual and seasonal variability, which can then be extrapolated to extensively monitored sites. Strategies for stratification and site selection are presented below, followed by a summary of recommendations for this portion of the long-term monitoring plan.

Stratification

Condition analysis of meadows is generally accomplished by a stratification of environmental characteristics and species composition. The stratification of environmental characteristics is sometimes called the analysis of ecological drivers and begins at the watershed scale. Drivers are aptly named for their importance in controlling hydrologic, geomorphic, and ecological processes within watersheds (Welker 2006). The combination of drivers in a watershed enables us to predict the number and type of wetlands that are likely to be found. A selection of similar watersheds, then, is the first step in site selection. According to Welker (2006), drivers in mountainous environments can be divided into several tiers of importance. At the watershed scale, geology and climate (snowmelt, rain and snow, or rain) should be evaluated first, followed by presence/absence of glaciation, stream gradient, and temperature. The data from these analyses can then be used to predict the distribution and extent of meadows, their physical and chemical properties, and their estimated productivity and community characteristics. In a case study from Bighorn National Forest, stratification was simplified to include geology, glaciation, and climate regime, as these were the drivers which had the greatest influence over water chemistry, landscape heterogeneity and gradient, and variation in hydrology within the study area (Welker 2006).

As part of the stratification process, an ecological driver matrix can be created to depict the process of identifying driver combinations that are important in predicting wetland type and the sensitivity of watersheds to anthropogenic disturbance (Welker 2006). Indirect ordination can be used as a tool for determining which driver combinations are controlling group structure; then cluster analysis can be used to identify groups of similar watersheds. Stressors can then be evaluated separately to determine the appropriate scale and measurement to be used for the analysis.

After the appropriate scale has been determined, watersheds can be evaluated based on their risk for individual stressors. Components of risk include environmental sensitivity, scale of the negative consequences from activity, and the relative rarity of resources;

measures of risk should be identified by incorporating landscape drivers and impacts from stressors currently and historically occurring on the landscape. For the purposes of stratification, stressors can be grouped into categories based on their relative impact to hydrology, channel condition, water quality, biotic condition, or other aspects of meadow condition (see Table 2). According to Welker's methodology (2006), stressors can then be evaluated according to the following four-step process: 1) ranking each watershed according to percentile assignment for that particular metric; 2) grouping percentiles into four categories representing similar potentials for impact by stressors; 3) using GIS to create a visual representation of the analysis; and 4) synthesizing the data into an additive effects analysis for the specific impact category as well as for all impacts.

Table 2. Stressors can be grouped by their impacts to meadow structure and function.

Stressor Group	Description of Impacts from Welker (2006)
Hydrology	"Anthropogenic activities that remove or alter water flow from wetlands and stream systems influence a variety of different components of aquatic, riparian, and wetland resources, including sediment transport, channel and vegetation maintenance, life-history timing, and habitat quantity and quality."
Channel Condition	"Direct and indirect alterations of stream channels influence different components of aquatic, riparian, and wetland resources, including sediment transport, channel and vegetation maintenance, life-history timing, and habitat quantity and quality, and can alter hydrology, habitat conditions, channel confinement, sediment dynamics, and biological communities related to aquatic, riparian, and wetland resources."
Water Quality	"Water quality concerns are realized directly from effluent from mining audits, road salting, and other activities, as well as indirectly from changes in attributes such as water temperature resulting from alteration in riparian shading."
Biotic Condition	"The introduction of non-native flora and fauna has been shown to have significant effects on native communities, as well as effects on water quality, channel stability, and hydrology."
Riparian and Wetland Condition	"Anthropogenic activities have a variety of effects on riparian and wetland soil and vegetative characteristics. These effects in turn have a number of influences on other associated characteristics of the physical and biological characteristics of these environments."

Site Selection

Once watersheds have been grouped into similar types, based on ecological drivers and sensitivity to impacts, a secondary stratification by species composition may be important due to the variation in the meadow flora and environmental attributes across a large study area (Klickoff 1965, Pemble 1970, Burke 1980, Benedict and Major 1982, Ratliff 1985, Allen-Diaz 1991, Manning and Padgett 1995, Weixelman and Bakker 2005). By grouping meadows that are similar in terms of structure and function, the natural variability

within meadows ecosystems is reduced, making detection of variability caused by anthropogenic impacts easier. “This leads to more meaningful comparisons between wetlands and creates a more sensitive tool for decision makers”(US EPA 2002c).

At this more localized scale, meadows of the southern Sierra Nevada have been divided into two main types, those with vegetated margins, and those with sandy margins (Benedict and Major 1982). This distinction represents underlying differences in geology and hydrologic regime that correspond with the age and weathering of substrata and indirectly, with the distribution of plant species (Benedict 1982). These two groups are further divided into meadows occurring in basins, springs and seeps (mostly peat-accumulating), and meadows occurring along perennial streams. The US Forest Service Sierra Framework Project Region followed this geomorphic stratification including meadows that are 1) spring-fed sloping (mostly fens), 2) fluvial (floodplain or stream-terrace) or 3) basins. Sites were further divided by elevation classes (Weixelman et al. 2002).

Recently, the distinction between peat-accumulating and non-peat accumulating meadows has been given considerable attention (Chimner et al. 2002, Cooper and Arp 2002, Chimner and Cooper 2003, Cooper et al. 2005) David Cooper (pers. Comm.) has suggested the following as a possible stratification for meadow types in SIEN National Parks: basin, slope x peat accumulating, non-peat accumulating at low, mid- and high elevations. The resulting types would include fens, marshes, and wet meadows.

	Peat-Accumulating	Non-Peat Accumulating
Basin	FENS	WET MEADOW or MARSH
Slope	FENS	WET MEADOW

Marshes are depressional wetlands characterized by herbaceous, emergent species rooted in hydric non-peat-accumulating soils. Marshes occur along the margins of lakes or alone in open basins where deep standing water collects at least seasonally. In mountains, marshes reach a maximum depth from 20 to 200 cm after spring snowmelt and then become shallower over the course of the growing season, due in part to evapotranspiration. Some marshes become completely dry by the end of summer, and during drought years, marshes may remain dry. Depending on the current and previous years’ hydrologic regimes, standing water depth and groundwater flows to or from marshes will vary (Rosenberry and Winter 1997), causing subsequent changes in the distribution and abundance of individual plant species (Van der Valk and Davis 1978, Weller 1987, Rejmankova et al. 1999, Welker 2006).

Wet meadows are characterized by hydric species including sedges, rushes, and grasses; seasonally saturated soils and a water table within 50 cm of the surface throughout the growing season; and anaerobic soil conditions. Unlike marshes, wet meadows do not have perennially high water tables or seasonally deep water. Tuolumne Meadows, in Yosemite National Park, is a good example of a wet meadow complex in the SIEN Park study area (Weixelman and Bakker 2005, Welker 2006).

Fens are peat-accumulating wetlands fed by perennial groundwater discharge, and are typically dominated by grasses and sedges. Fens are often found on mountain toe-slopes and on alluvial fans where there is little erosion or mineral sediment deposition, and where the water table remains at the soil surface (Cooper 1990). Fens provide many ecological functions including water filtration, carbon storage, forage for native mammals, and where shallow pools are present, habitat for aquatic invertebrates and amphibians (Chimner et al. 2002, Welker 2006). Fens vary in pH, hydrologic regime, and plant species composition according to elevation and other environmental attributes. Extreme rich fens are basic in pH and have high concentrations of calcium ions (Cooper 1996), whereas transitional rich fens are acidic and iron fens are strongly acidic (Cooper and Andrus 1994, Cooper et al. 2002). Cooper's preliminary classification of fens in the Sierra Nevada (unpub. Data) divides fens into types occurring in basins and types occurring on slopes. Sloping fens are further divided into rich, transitional, and poor types based on nutrient availability. Smaller subdivisions within each type are based upon species composition.

Fens should be mapped for several reasons. Studies of fens in the Sagehen Creek Basin, Sierra Nevada, found that the topographic position of fens influenced peat depth, a major factor of habitat condition (Erman 1976, Bartolome et al. 1990). On steeper slopes, gravity pulled peat masses downward, increasing the extent of the mass but reducing the maximum depth (Erman 1976). Because some substrates are more fractured, allowing for higher infiltration rates, differences in geology affect the timing and amount of water discharge to fens, and therefore their vulnerability to hydrologic disturbance (Thompson et al. 1992, Pacific Analytics 2001).

Bogs and fens differ in water chemistry, peat depth, and source of water. Bogs typically have a deeper layer of peat than fens (Keddy 2002). In addition to this distinction, bogs are more influenced by direct precipitation whereas fens are fed by seeps and other sources of ground water. Bogs are always nutrient-poor and acidic, while fens vary widely in pH and typically have a higher nutrient availability. Unlike fens, which are typically dominated by grasses and sedges, bogs are dominated by *Sphagnum* spp. and woody ericaceous shrubs, like *Vaccinium* spp., which are adapted to nutrient-poor, acidic conditions (Archibold 1995). Sites in the Sierra Nevada with floating *Sphagnum* mats, *Vaccinium* spp., *Drosera* spp., and other plants characteristic of bogs have been described as "Poor Fens" by David Cooper (unpublished classification of Sierra Nevada Fens), due to their limited nutrient availability and lower rates of annual precipitation than bogs in other parts of the world. Wetlands of this type may need to be analyzed separately from other fens because of their similarity to bogs in terms of species composition, hydrology, chemistry, and rates of peat accumulation.

After sites are grouped by wetland type, they should also be stratified by elevation. In the Kings River area, for example, the transition from montane to subalpine occurs near 2400 m. Montane and subalpine wet meadows differ in terms of hydrology, vegetation, and geomorphic processes. Hagberg (1995) found that within sampled meadows of the Kings River area, meandering channels with entrenched gravel or sandy substrates were characteristic of subalpine meadows, while braided networks of wide, shallow channels hidden under a blanket of vegetation were more characteristic of meadows in the montane zone. Unlike in the montane zone, subalpine streamflow remained confined to entrenched channels except during flood events, when surface flows spread out over the floodplain (Hagberg 1995). Because elevation often integrates differences in hydrology, vegetation, and

geomorphology across the montane and subalpine zones, stratifying sites by elevation will reduce overall site-based variability. To further minimize variability, elevation should be corrected for differences in latitude.

Sampling Protocols

After the specific monitoring questions have been formulated and stratification is complete, the next step in developing a long-term monitoring plan involves the creation of sampling protocols. Sampling protocols focus on which attributes will be sampled and how those attributes will be measured. In addition, sampling protocols include an overall site-level sampling design. At this scale, sampling can occur at random locations within the meadow (random), at random locations within broad plant community types (stratified random), along a grid (systematic), or in specific areas where an impact or plant community occurs (targeted). Final decisions about plot layout and location, as well as choice of monitoring attributes, should be tailored so that data can be collected efficiently and in such a way as to provide adequate information to answer specific monitoring questions (hypotheses).

Monitoring Attributes

The choice of monitoring attributes is an important one, as the best sampling protocol will collect data on variables that are ecologically meaningful, relating to a particular ecological function or process, and indicating change for the system or a significant component part. In addition, attributes must be measured easily and accurately and must be sensitive to the types of impacts being addressed by the monitoring program. For a successful long-term monitoring program, it is important to select variables which respond (hopefully quickly) to changes in management [and/ or impacts by anthropogenic stressors], and for which data can be efficiently gathered” (Pacific Analytics 2001, Keddy 2002). Following is a discussion of attributes related to hydrology, geomorphology, soils, and plant species composition, including the ways in which these attributes have been incorporated into the reviewed monitoring plans.

Hydrology

At the meadow-complex scale, the hydrologic gradient is arguably the most important ecological driver, both in terms influencing the physical structure of meadows and in terms of determining the distribution of plant communities in meadow systems (Wood 1975, Heady and Zinke 1978, Benedict 1983, Halpern 1985, Sarr 1995, Castelli et al. 2000, Fraser and Kindscher 2003, Murrell Stevenson 2004b). Stressors such as cattle grazing can have a profound impact on the interaction of physical (e.g. channel structure) and hydrological properties (e.g. depth-to-water table). Overgrazing can lead to an increase in channel incision and degradation, followed by a drawdown of the water table and a change in the relative distribution of meadow habitats, with dry habitats increasing in abundance and wet habitats decreasing (Allen-Diaz 1991, Berlow et al. 2002). Maintenance of the water table, by contrast, allows for the persistence of diverse meadow communities (Odion et al. 1988), while healthy streambank vegetation provides the root mass and root length density necessary to reduce channel erosion and downcutting (Kleinfelder et al. 1992, Dunaway et al. 1994, Clary and Kinney 2002). For these reasons, the inclusion of hydrologic attributes is

paramount to a successful long-term monitoring project focused on maintaining the ecological integrity of meadow systems.

Hydrologic attributes that could be measured in meadow environments include duration, extent, timing, and depth of surface and subsurface flows. Additional attributes include annual snowpack and timing of snowmelt. Flow regime (perennial, intermittent, ephemeral) can be summarized in meadows containing streams.

Monitoring wells or peizometers have been used in many areas to measure depth-to-water table (Benedict 1983, Halpern 1985, Halpern 1986, Allen-Diaz 1991, Sarr 1995). In Sequoia and Kings Canyon National Parks, water wells were installed in Log and Crescent meadows in 1983, eight in each meadow, perpendicular to the long axis of the meadow. Locations were chosen subjectively to represent particular plant associations, and water table depth was monitored bi-weekly throughout the growing season (Halpern 1985).

Weixelman (pers. Comm.) stated that one main weakness of the hydrologic sampling associated with the Range Monitoring and Sierra Framework protocols was that soil-water sampling was not tied to specific vegetation plots. Preliminary findings from his 2004 Range Monitoring Report indicated that changes in the water table should be considered when interpreting the condition and trend of mountain meadows, and that more analyses on the relationship of water table to condition assessment should be added in the future (Weixelman and Bakker 2005). This would include additional aspects of hydrologic influence, such as the source of groundwater, duration of groundwater influence, and potential soil nutrient availability (Weixelman and Bakker 2005).

For the SIEN monitoring program, wells can be installed so that they are flush with the ground surface and do not detract aesthetically from views provided in mountain meadows. In addition, the installation of monitoring wells is more accurate and less destructive than holes made by hand augurs on repeat visits (Durham, pers. Comm). Monitoring wells should be specifically tied to vegetation plots that are small enough to be representative in species composition for the particular hydrologic regime at that microsite. The number and location of monitoring wells per site should be determined based on overall sampling design and specific monitoring questions. It may be appropriate to install more wells in sites which have been chosen for intensive sampling and which can be visited more than once over the course of the growing season. Sampling a subset of sites every year is necessary to capture regional patterns in the inter-annual variation of the water table (Durham, pers. Comm).

Geomorphology

As described above, meadows are likely to be stratified based on a hydro-geomorphic approach. A description of site geomorphology should be included in the sampling protocol (e.g raised convex, normal, hanging, lotic, xeric, and sunken-concave) (Pacific Analytics 2001). Many wetland monitoring plans also include slope and aspect; sites with perennial streams generally include some description of stream morphology and estimates of flood frequency (Rosgen 1994). The *NRCS Riparian Assessment* and the *Montana Rapid Assessment of Wetland Condition* both provide a scorecard for streambank erosion due to gullyng and headcuts (Apfelbeck and Farris 2005). The PACFISH protocols, which are focused on preserving fish habitat, provide extensive measurements of attributes in perennial streams (Coles-Ritchie et al. 2004b, Henderson et al. 2005). Attributes that might be adapted to SIEN objectives include bankfull elevation, gradient, and sinuosity (Harrelson et al. 1994);

streambed particle counts (Wolman 1954); bank stability (Platts et al. 1987, Bauer and Burton 1993), bank angle and undercut banks (Platts et al. 1987); channel cross-sections (Rosgen 1996) and the presence or absence of large wood (Hankin and Reeves 1988, Moore et al. 2000). In addition, photo points can be helpful in documenting change in channel morphology at specific locations. Whatever descriptors are selected for geomorphology, a pictorial reference for or key to each type should be included where possible in the data forms. These are available in many of the referenced monitoring plans (e.g. see Weixelman et al 2002, 2004 descriptions of valley bottom shapes and for a key to meadow hydrogeomorphic types). Minimally, slope and aspect should be measured for all meadows, and channel cross-sections with photo point documentation should be included for meadows occurring along perennial streams.

Soils

Soil and soil-water attributes that are often measured include soil moisture, texture, rooting depth, color, peat depth, carbon accumulation, density, and bare ground. Of these methods, soil moisture is related to the timing and length of inundation and therefore can impact the distribution of species (Pacific Analytics 2001, Murrell Stevenson 2004b). Pacific Analytics, who did an analysis of attributes being considered for the Sierra Framework Monitoring Plan (Appendix A), found that geological substrate was more informative than soil texture, and that rooting depth is generally correlated with extent of inundation and is therefore a redundant and potentially destructive measure (Pacific Analytics 2001). Although soil color provides information about the chemical composition of the soils, it was not recommended unless a complete soil evaluation was included in the protocol (Pacific Analytics 2001). The Sierra Framework protocol included the following soil and soil-water attributes: depth to restrictive horizon, compaction, field texture, rooting depth (after Weixelman), depth to water table, depth to surface water, depth to soil saturation, depth to redoximorphic features or mottles, and depth of peat layer (Weixelman et al. 2002, 2004, Weixelman and Bakker 2005). Minimally, bare ground, soil moisture, depth to mottling features, peat depth, and carbon accumulation should be measured in fens (Pacific Analytics 2001); bare ground, soil moisture, and depth to mottling should be measured in wet meadows and marshes (Pacific Analytics 2001). A more complete soils analysis may be necessary, depending on specific monitoring questions.

Plant Species Composition

Plant species composition is a valuable indicator of environmental change in wetland systems. Plants are sensitive to changes in temperature, soil-water oxygen, and changes in depth to water table. Virtually all monitoring plans use some traits associated with plant species composition in the assessment of wetland condition. With that said, plant composition in mountain meadows is heterogeneous within meadows and across landscapes (Murrell Stevenson 2004c). According to Winward (2000) individual meadows within the Sierra Nevada typically contain anywhere from six to twelve different plant communities.

There are some broad generalizations that can be made about the relationship between plants and stressors. In general, the presence and distribution of exotic species are good indicators of current or past stress (Keddy et al. 1993). Rare species can be good indicators of meadow ecological integrity as they are more sensitive to change (Keddy et al. 1993, Murrell

Stevenson 2004c). Common species, however, are more likely to impact ecosystem function, and therefore may better indicate meadow functional integrity (Keddy et al. 1993, King 1993). A decrease in the presence or abundance of small, short-lived plants is more likely to serve as early warning indication of stress, whereas the distribution of longer-lived plants, like lodgepole pine, can provide information on the accumulation of impacts over time (Keddy et al. 1993).

Although there is information on the general tolerance of many species to anthropogenic change (US EPA 2002c), the response of individual plant species to specific stressors is not well-documented. Perhaps less than twenty percent of all wetland plant species have been studied for their response to individual stressors (Adamus and Gonyaw 2000). For this reason, groups of species are generally analyzed in terms of sensitivity to anthropogenic impacts (see section on data reduction techniques below). Species are generally grouped by seral stage, wetland functional status, or some other combination of life form and life history traits. Other important monitoring attributes include primary production and decomposition rates, which are good indicators of nutrient loading and sedimentation rates, and the proportion of exotic and invasive species (Pacific Analytics 2001, Keddy 2002).

Reviewed monitoring plans tended to have separate methodologies for measuring the herbaceous, shrub, and tree layers. Even plans that restricted their sampling units to meadows dominated by herbaceous perennials and with less than 20% cover by shrubs had some protocol for sampling cover and height of shrub species. In meadows that occur along perennial streams, woody species such as willows provide an important ecological function in protecting and strengthening streambanks, and in providing stream shading, structural and species diversity, and wildlife habitat (Winward 2000). As willows in particular are vulnerable to grazing impacts and as they provide a canopy for a diverse understory (Sarr 1995, Murrell Stevenson 2004c, a), measures of their presence and abundance should be included in any long-term monitoring plan of meadows.

Most plans reviewed in this document used some combination of frequency, abundance, and biomass as measurements of species contribution. There is no panacea for measuring change in plant species composition, as each of the above attributes has a number of advantages and disadvantages (see Table 3). Frequency measurements are commonly used because they are easy to collect. Large sample sizes are required to detect changes in uncommon species, however, and frequency estimates are sensitive to plot size. A plot size that generates 60-70% of the most frequent species is chosen as a rule of thumb (Mueller-Dombois and Ellenberg 1974). Cover estimates tend to be more variable among different observers but provide more information than frequency estimates. Whatever measures are chosen, they should be sensitive to changes in management, be repeatable among different observers, be efficient in terms of time, effort, and money, and finally should not be affected by seasonal changes in foliage, especially in grazed environments (McClaran and Neuman 1989).

In a review of attributes being considered for the Sierra Framework Monitoring plan, it was suggested that as many attributes be measured that are practical and economical, as “biological integrity is the presence and abundance of these components and the only way to measure integrity is to measure [them]” (Pacific Analytics 2001). We recommend that frequency be measured for herbaceous species, and that percent cover be measured for herbaceous species, shrubs, and sub-shrubs. Since frequency is a stand-alone method for

trend detection, and cover can be associated with specific monitoring wells, is useful for detecting changes in species abundance, and is commonly used as a metric in multi-metric indices (described below), both measures will be valuable to a long-term monitoring program focused on detecting changes in species composition related to anthropogenic impacts and changes in management. Additional measurements may be necessary to answer specific monitoring questions, but keep in mind that if too many questions are trying to be answered, sampling protocols may become unwieldy and impractical.

Table 3. A summary of plant species composition attributes measured in the field. This table summarizes the advantages and disadvantages of various methods of capturing change in plant species composition. This primarily summarizes a discussion by McClaran and Neuman (1989) but highlights arguments made by many others in their defense of chosen methods (e.g. Weixelman et al. 2002, Abbott et al. 2003, Weixelman and Bakker 2005).

Method	Advantages	Disadvantages
Frequency	1) Easy to collect (involves only a P/A decision) (Weixelman and Bakker 2005) 2) Limits variation among observers and therefore increases repeatability 3) Is not affected by changes in foliage over the course of a season (Hironaka 1985)	1) Requires large sample sizes to detect changes in uncommon species (Abbott et al. 2003) 2) Sensitive to quadrat size 3) No value to relate the frequency of one species to another or to summarize the frequency of all species (Grieg-Smith 1983) 4) May lack desired sensitivity in detecting change as it does not measure any quantity (number, weight or cover) of plant species (Abbott et al. 2003).
Cover	1) Relatively time efficient 2) Provides a summary value for all species and the relative contribution of each species 3) Is an indirect measure of removal of vegetation by grazing (McClaran and Neuman 1989)	1) Relatively high variation among observers, thus reducing repeatability 2) Sensitive to seasonal changes due to grazing or natural phenology 3) Inability to measure what proportion of change is due to density or dispersion of plants (Grieg-Smith 1983)
Above-ground Biomass	1) Provides a summary value for all species and the relative contribution of each species 2) Is a direct measure of removal of vegetation by grazing (McClaran and Neuman 1989) 3) Is a good indicator of nutrient availability over time (Pacific Analytics 2001).	1) Requires more time than cover or frequency methods 2) Relatively high variation among observers, thus reducing repeatability 3) Sensitive to seasonal changes due to grazing or natural phenology 4) Inability to measure what proportion of change is due to density or dispersion of plants (Grieg-Smith 1983)
Shoot Density	1) The most direct measure used to detect changes in plant species composition over time (McClaran and Neuman 1989)	1) The most time-intensive and is therefore used mainly for specific research efforts (McClaran and Neuman 1989)

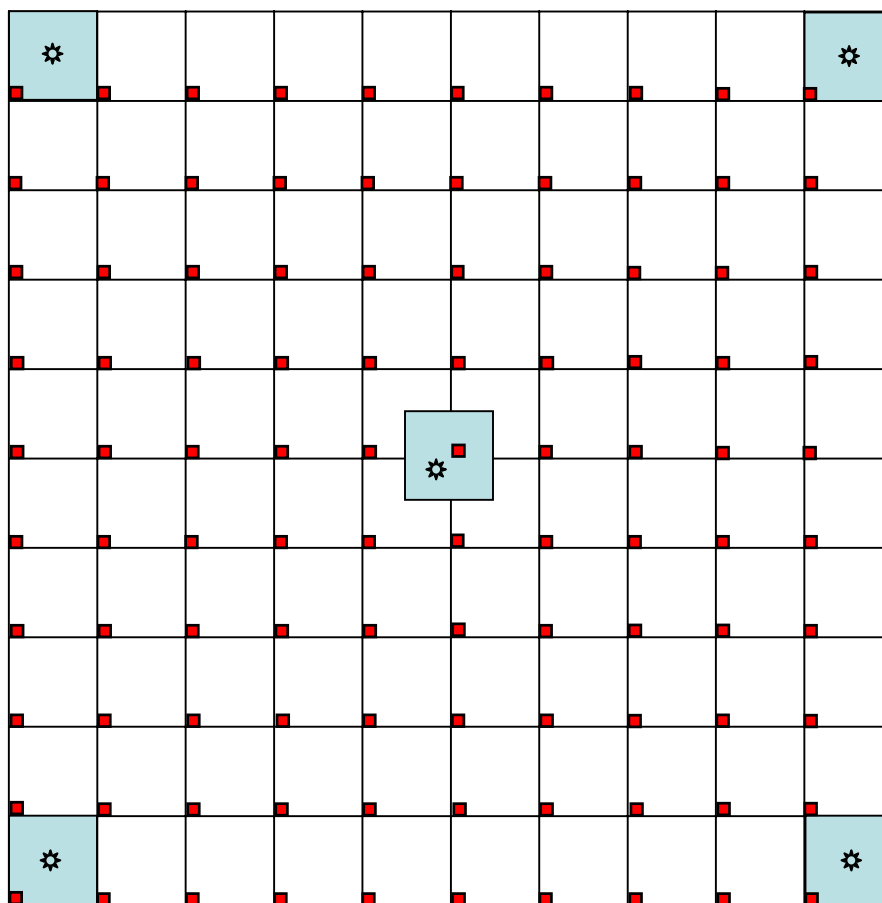
Suggestions for a Basic Sampling Protocol for Plant Species Composition

Methods currently in use by the Sequoia and Kings Canyon National Parks provide a good springboard for a discussion of a basic sampling design at the meadow scale. We suggest that meadows be stratified by wetland type, and that a macroplot be placed randomly in one of the available patches for one or more types. Current protocols in use by the Sequoia and Kings Canyon Packstock Monitoring Protocol use a macroplot that is 100 paces by 40 paces in size (McClaran and Neuman 1989). For ease of analysis, we suggest a standardized macroplot size of 400 sq m (Figure 2). 2 x 2 m cover plots could be placed in each of the four corners of the 400 sq m macroplot, and a hydrologic monitoring well could be installed in the middle of each of these subplots. If necessary, an additional 2 x 2 m cover plot could be installed at the center of the macroplot, for a total of five cover plots per macroplot (Figure 2). Frequency could be measured in 25 x 25 cm plots, a size known to capture the majority of the species found in Sierra Nevada montane and subalpine meadows (McClaran and Neuman 1989). 100 frequency plots could be sampled along a grid to measure the frequency of herbaceous species with statistical adequacy (Figure 2).

The 2 x 2 m plot could be made of pvc pipes or lightweight fiberglass rods that could be disassembled for transportation to and from sites. Stripes could be painted on quadrat frames to assist in the estimation of percent cover by species. Alternatively, a portable frequency frame, similar to those used by the Gloria Mountaintop Monitoring Program (Pauli et al. 2004), could be used instead (see Figure 3). This frame is comprised of two sets of two thin strips of wood connected by ten evenly spaced strings (2 m long each for a 2 x 2 m plot). The two sets are laid on top of each other, in opposite orientations, and attached together by wing nuts at each of the four corners. This creates a grid with one hundred squares that would guide field botanists in making more accurate cover estimations. Cover could be assigned by species at <1%, 1-5%, and thereafter to the nearest 5%. Estimates could be later lumped into cover classes for analysis. Soils and hydrologic data should be specifically tied to one or more cover quadrats, while other physical parameters could be tied to the macroplot or meadow as a whole. Information from cover plots could be analyzed to fit macroplots into pre-existing plant community classifications, if any monitoring questions are tied to the response of individual plant associations to specific impacts or management activities.

Percent cover by shrub species could be measured by a line or point-line intercept method around the perimeter of the macroplot in one 80m transect or two 40 m transects. Coles-Ritchie et al (2004a) suggest that identification of shrubs to genus would reduce between-observer variability associated with the misidentification of species within challenging taxa. If members within the same genus are fulfilling similar functions, and if this level of precision is sufficient to answer identified monitoring questions, this would certainly be a valid approach.

Figure 2. Schematic of basic macroplot with subplots. This figure shows one strategy for sampling trees, shrubs, and herbaceous plants in meadow environments. The largest square represents a 400 sq m macroplot (20 m on a side) randomly placed within a particular wetland type. Diameter at breast height (dbh) and height could be measured for mature trees within the macroplot. Seedlings and saplings could be counted according to species and size class and identified to species. Shrub cover could be sampled along two line transects around the perimeter of the plot, or along several gridlines within the plot. Shrubs could be identified to species or in some cases to genus, where appropriate. Cover of herbaceous plants could be measured in four to five 2 x 2 m quadrats, placed in the corners and possibly the center of the macroplot. A monitoring well or peizometer should be installed in the center of each cover plot. One hundred 25 x 25 cm frequency frames could be sampled at a standard corner of each grid cell.



⚙ monitoring well or peizometer

■ 25 x 25 cm frequency frame

□ 2 x 2 m quadrat for cover of herbaceous species

Figure 3. Picture of frequency frame used by GLORIA Mountaintop Monitoring volunteers on Barcroft Mountain, 2004. Although the quadrat depicted was designed to sample percent frequency, a similarly constructed 2 x 2 m quadrat with gridlines could be helpful in producing more accurate estimates of cover by herbaceous species.



Presence/absence of trees could be counted within the macroplot according to species and size class. In addition, diameter at breast height (dbh) and height could be measured for mature trees. The study of tree/ sagebrush invasion in meadows would require a separate protocol where plots are placed along the forest/ meadow ecotone. As these invasion processes could be directly related to global climate change (Vale 1981, de Valpine and Harte 2001, Shaw and Harte 2001, Berlow et al. 2002, Inouye et al. 2002, Dunne et al. 2003, Millar et al. 2004, Norman and Taylor 2005), establishing a protocol for these measures should be considered.

As the development of specific protocols is outside of the scope of this project, the above are meant to serve as general suggestions that could be adapted to the specific monitoring questions being developed by the SIEN Meadow Ecological Integrity Workgroup. Most importantly, the site-specific sampling design should be simple to set up and sample, should be located within homogenous patches of vegetation (Mueller-Dombois and Ellenberg 1974), and should be far less cumbersome than those suggested by the Sierra Framework Methodology (Weixelman et al. 2002, 2004).

Managing Sources of Variability

Seasonal and Inter-Annual Variability

The variation associated with year cannot be effectively reduced by choices in sampling design, and therefore long-term monitoring plans must account for seasonal and inter-annual variability in temperature and precipitation (Larsen et al. 2004). In addition, the variation in physical and biotic attributes caused by periodic disturbances such as fire, insect infestations, disease, and floods must be distinguished from changes caused by stressors such as grazing (Leonard 1997). Modeling these controlling factors with their effects on target variables will reduce the variance attributed to inter-annual variability, increasing the power to detect trends over time (Larsen et al. 2004). Not surprisingly, a review of existing monitoring plans reiterated the importance of accounting for inter-annual variability. For example, in an analysis of species composition in Sequoia and Kings Canyon National Parks, data on annual precipitation, together with the inclusion of grazed and ungrazed sites, allowed researchers to conclude a >15% decrease in the frequency of *Muhlenbergia filiformis* in grazed and ungrazed meadows was due to several years of drought rather than the impact of packstock (McClaran and Neuman 1989). The importance of tracking seasonal and inter-annual variability, then cannot be underestimated, and even integrative measures such as Integrative Biological Indicator (IBI) indices for bioassessment (see data reduction techniques below) should not be used unless they are calibrated for the precipitation and snowpack predating any sampling year (Wilcox et al. 2002).

Site-Based Variability

Site-based variability generally accounts for the largest portion of the error term when it comes to statistical analysis. While this variability can be managed in part by proper stratification of sites (discussed above), there are other aspects of sampling design to consider. Because the magnitude of site variance is greater than the variation in and residual variation among individual surveys, a survey design that specifies a random selection of sites each year would be a “worst-case scenario”, lowering trend detection sensitivity, especially when relatively few sites are monitored (Larsen et al. 2004). The addition of years to a study increases the number of repeated measures for a given plot, thus increasing the ability to detect trends and minimizing type I error. For sites where permanent plots are resampled through time, the variance between sites is greatly reduced (Roper et al. 2003), and sample size calculations become primarily a function of observer-based variability (Coles-Ritchie et al. 2004a). Therefore, smaller sample sizes are needed to detect change for sites resampled annually (Coles-Ritchie et al. 2004a).

Observer-Based Variability

In addition to considerations of inter-annual and season variability, a long-term monitoring plan will include strategies for minimizing the variation between observers. By collecting quality assurance data on observer-based variability associated with a particular monitoring program, scientists can reduce the probability of making incorrect conclusions about how changes in vegetation are linked to impacts by stressors or specific management actions. Without these data, changes may be detected that in actuality did not occur but were instead an artifact of observer-based variability (type I errors), while changes that did occur may not be detected (type II errors) (Coles-Ritchie et al. 2004a).

Information from reviewed monitoring plans echoes some of the above concerns. Several years after Winward's publication on the Greenline methods (Winward 2000), an analysis of between observer difference showed that even with substantial training, the variation from one observer to the next for community type data was almost as much as the variation from one site to the next, making differences among sites difficult to detect with this method (Coles-Ritchie et al. 2004a). A comparison of the vegetation cross-section widths and the wetland ratings for the same observers suggested that precision was sometimes affected by differences in defining the edge of the riparian area, underscoring the importance of using methods that result in a consistent sampling area (Coles-Ritchie et al. 2004a).

In a quality assurance study by Kercher et al. (2003), two highly skilled and trained teams varied considerably in terms of cover estimates, with one team consistently giving higher estimates of cover than the other. In addition, pseudoturnover was almost 20% per plot, a number mostly attributed to the identification of rare or uncommon species with less than eight percent cover. In a case like this, eliminating uncommon species from the analysis and collapsing cover estimates into presence/ absence data might be necessary to reduce between-observer variability.

Because of the between-observer variability associated with cover estimates (Nilsson and Nilsson 1983, Nilsson and Nilsson 1985, Leps and Hadincova 1992, Kercher et al. 2003), most of the reviewed monitoring plans included frequency data instead (e.g. Weixelman et al. 2002, 2004, Weixelman and Bakker 2005). Frequency data avoid problems associated with seasonal changes in cover due to grazing by cattle or packstock, as well as changes in cover due to inter-annual variability. While frequency data are more repeatable than cover estimates, they do require more intensive sampling, which can be expensive (McClaran and Neuman 1989).

Quality assurance data should be collected irrespective of the chosen method(s) for collection of species composition data. After field crews have been trained and calibrated, two crews should sample the same plots in the same year and on or near the same date to estimate between-observer variability associated with the protocols. Examples of quality assurance studies include Kercher et al. (2003) and Coles-Ritchie et al. (2004a).

The selection of highly repeatable methods, and the collection of quality assurance data will help ensure that long-term monitoring data collected as part of the SIEN Meadow Ecological Integrity Monitoring Program will effectively detect change.

Achieving the Appropriate Level of Power

When setting up a long-term monitoring program, it is important to determine a plan for achieving the appropriate level of power for analyses. Managers generally evaluate trend data by looking for $X\%$ change over the course of Y years with a certain level of power and probability of making a type I error. Sample size, number of factors in the design, and number of years all contribute to the degrees of freedom available for the analysis and effect sizes for a given attribute. McClaran and Neuman found that for the analysis of frequency data, a measured change in the range of 22-27% was necessary to statistically detect a 15% change with a type I error probability of 0.05 (McClaran and Neuman 1989). Larsen et al (2004) evaluated effects of spatial and temporal variation useful for evaluating and controlling trend detection power: site, year, the interaction of site and year, and residual

variation. They emphasized the importance of survey duration for trend detection sensitivity, as the power to detect trends improves substantially as the number of years a site is sampled increases. That said, the greatest variation in plant species composition is usually attributed to site differences. The error associated with site can be decreased for plant composition attributes if wetlands are stratified by plant community or wetland type. The Sierra Framework monitoring project elected to choose a random design for the first year of their monitoring project. Their initial idea was that they would perform sample size tests with the data collected, would group meadows after the fact, and would then add meadows if necessary to achieve the desired power (Weixelman et al. 2002, 2004). We advise stratification by wetland type in advance of sampling to ensure an even design and ease of analysis for plant attributes.

Most discussions of power recommend sampling a smaller number of sites over more years to obtain a dataset that is complete for the sites visited, as opposed to increasing the number of sites visited with the end result of a dataset with large data gaps. The EPA recommends using species/area curves or the plot of cumulative coefficient of variation against number of samples to help gauge sample adequacy for vegetation (US EPA 2002a). The use of integrative multi-metric indices can also increase the power in bioassessments of wetlands, as can the use of a combination of assemblages (e.g. plants and macro-invertebrates) in the indices (see data reduction techniques) (Gernes and Helgen 1999, US EPA 2002a). We recommend a study design that combines intensively sampled sites which will be resampled each year with extensively sampled sites which will be sampled on a standard rotational basis (e.g. every five years). This approach will balance the statistical requirements for power with the ecological requirements for extrapolation to the entire NPS network. The inclusion of data reduction techniques will also be instrumental in managing power.

Data Reduction Techniques

Data reduction techniques have been employed by many groups to increase the power associated with the analysis of plant species composition traits. Community and species based metrics have been formulated for vegetation, and a number of these have been applied to wetland ecosystems. The simplest data reduction techniques use the seral or functional status of individual species to determine the relative abundance of early and late successional groups (or low, middle and high functional status) in meadows (For a description of functional status, see the above section entitled *USFS Region 5 Range Monitoring Project* (Weixelman and Bakker 2005)). This can reduce sampling error associated with the misidentification of plants (Coles-Ritchie et al. 2004a), as plants mistaken for one another generally share the same seral or functional rating (Winward 2000). Multimetric indices linking vegetation responses to stressors (Jones 2004), wetland evaluation technique for wetland condition (Adamus 1983, Adamus et al. 1987, Wilcox et al. 2002) and the Integrative Biological Indicator (IBI) indices for bioassessment (Wilcox et al. 2002) are all data reduction techniques which use a variety of attributes to help assess the condition of wetlands.

The use of seral status in the analysis of wetland vegetation requires that each species is assigned to one of several seral classes (e.g. early, mid-, or late successional) (Winward 2000). Assignments generally depend on the professional judgment of those conducting the

analysis and relate to the resistance of a plant species to stress. Since the process of succession in meadows is rarely linear, and since seral stages can be “arbitrary and difficult to quantify” (Pacific Analytics 2001), region 5 of the US Forest Service has shifted over to analysis of plants in terms of functional groups, based on measured traits (life form, life history, wetland rating, rooting characteristics, vegetative lateral spread mechanism, and nitrogen fixing capability). Based on the combination of traits, plants are assigned to one of three functional classes (low, moderate, or high). Overall condition ratings in meadows are then based on the predominant condition class for vegetation, percent bare ground, and rooting depth (Weixelman and Bakker 2005). Functional status then may be available for some of the more common species found in the southern Sierra Nevada.

Multimetric indices can be valuable components of monitoring programs, as they link complex responses of vegetation to multiple stressors, reduce data complexity, and increase the ability to detect trends with a high degree of power. For example, in the SIEN Parks, multimetric indices could be developed for plant and or invertebrate taxa. Metrics would be developed separately for each community. For plant species composition, some combination of community-based metrics, plant functional group metrics, and species-specific metrics that changed predictably along a disturbance gradient would be chosen and combined into a multimetric index for each wetland type: marshes, fens, and wet meadows. Community-based metrics include species richness and dominance, while plant functional group metrics include the number of perennials, annuals, or intolerant species, and species-specific metrics include the dominance of individual species (Jones 2004). Dose-response curves are used to group wetlands into disturbance classes along the gradient from least to most disturbed (US EPA 2002a).

The Rocky Mountain Network (NPS) is developing a multi-metric approach to the analysis of vegetation and invertebrates as part of their monitoring plan for the ecological integrity of wetland in the ROMN Parks. A summary of their work to date on protocol development, as well as Jones technique for creating multimetric indices linking vegetation responses to stressors and Wilcox’s method for creating and testing IBI indices are summarized in detail in Appendix A.

The Integrative Biological Indicator (IBI) method was developed for the analysis of fish in streams, but it has been successfully implemented for the analysis of macroinvertebrates and algae (Karr and Chu 1999). Related approaches have been tested for plants in wetland environments with mixed results (Jones 2004). To use IBI metrics, wetlands are classified into broad types for the purposes of stratification. Reference conditions are then defined for each wetland type. Wetlands of the same type are compared against reference conditions for that type. Wetlands are selected to represent the full range of disturbance along the gradient. Since random sampling will produce sites that under-represent the extremes of the gradient, targeted sites are added to capture both ends of the disturbance gradient. After sites are chosen, standard field sampling methods are selected and attributes of plant composition are selected for inclusion into metrics for biological assessment. Each attribute is tested for performance along the disturbance gradient, and the metrics which show the best response are kept for the integrative index. Finally individual metrics are scored and total IBI scores are calculated for each site. Data interpretation and summary reports conclude the process (Karr et al. 1986, US EPA 2002c, a).

The development of multi-metric indices like IBI may require considerable time and resources. If no regional IBI methods exist for a given study area, metrics must be developed

and tested with real-world data before they are used (US EPA 2002a). In addition, not all metrics translate well across wetland types. Therefore individual metrics must be tested when they are applied to a new wetland type (Keddy et al. 1993, US EPA 2002c). Wilcox suggested that because the adaptation of these methods to wetland situations has met with mixed results, especially with respect to inter-annual changes in hydrologic regime, any such adaptation should be successfully tested prior to implementation (Wilcox et al. 2002). Jones cautions against the use of large-scale land use patterns as a surrogate for site-level measures of disturbance, and the EPA recommends the development of a disturbance gradient integrating several anthropogenic stressors to provide the best dose-response curve (US EPA 2002a, Jones 2004).

SUMMARY OF RECOMMENDATIONS

Long-term monitoring efforts should be tied to specific testable questions. Selecting questions that are ecologically relevant and that you can afford to answer within the constraints of available budget and personnel will encourage the efficient collection of data and the robust statistical analysis necessary to detect change over time. While some effort has been made by the SIEN Meadow Ecological Integrity Workgroup to link specific stressors to possible impacts on dependent variables, more work should be done to create testable hypotheses about how each of these might modify physical and or biological components of meadow ecosystems. Sampling protocols should then be created to ensure that analyses of those impacts will be possible based on the data collected.

After questions are formulated that are tied to specific monitoring objectives, sites should be stratified based upon the most significant ecological drivers for your study area. Geological substrate, regional climate, presence/absence of glaciation, stream gradient and temperature would be expected drivers for mountainous regions such as those found in the Sierra Nevada National Parks. While creating complicated models based on the interaction between ecological drivers and stressors may seem tempting, this should only be attempted if funding allows, and if accurate information is available for each stressor at the appropriate scale. Because it is the ecological drivers, and not the stressors, which in general will predict the distribution and extent of meadows, their physical properties, and their community characteristics, we recommend that the drivers be the focus of stratification at the watershed scale. Stressors such as climate change and nitrogen deposition can then be used as explanatory variables in the data analysis phase of the project. Stratification by wetland types and elevation should follow watershed-scale stratifications to reduce the natural variability within meadow ecosystems and to make the detection of anthropogenic impacts more feasible. In order to account for the presence/ absence of packstock grazing at the meadow scale, dose response curves could be created to arrange meadows of the same type along a disturbance gradient based on past and current use. Meadows within each type could then be sampled in the low, mid-, and high regions of the disturbance gradient for packstock use.

Decisions about plot layout and location, as well as choice of monitoring attributes, should be tailored so that data can be collected efficiently and in such a way as to provide adequate information to answer specific monitoring questions (hypotheses). Monitoring attributes should be ecologically relevant and should respond to changes in management and/or impacts by anthropogenic stressors over an appropriate time scale.

Monitoring wells or peizometers should be installed to monitor inter-annual and seasonal variation in the water table. The installation of monitoring wells is less destructive than holes made by hand augurs on repeat visits, and will be flush with the ground so as not to detract aesthetically from views provided in mountain meadows. Monitoring wells should be specifically tied to vegetation plots that are small enough to be representative in species composition for the particular hydrologic regime at that microsite. It may be appropriate to install more wells in sites which have been chosen for intensive sampling and which can be visited more than once over the course of the growing season. Other hydrologic data such as annual precipitation, annual snowpack and timing of snowmelt, flood frequency analysis, and flow regime (perennial or ephemeral) in meadows containing streams, should be collected as well.

For soils, bare ground, soil moisture, depth to mottling features, peat depth, and carbon accumulation could be measured in fens; bare ground, soil moisture, and depth to mottling could be measured in wet meadows and marshes (Pacific Analytics 2001). Soil measures should be tied to specific cover plots, and a basic soil profile described at the time of well installation would go a long way in clarifying the soil attributes at a given site. Some of the more invasive measures could be minimized or avoided using this approach. A more complete soils analysis may be necessary, depending on specific monitoring questions.

Geomorphological attributes should be selected based upon specific monitoring questions. Minimally, slope and aspect should be measured for all meadows, and channel cross-sections with photo point documentation should be included for meadows occurring along perennial streams.

For plant species composition, we recommend that frequency be measured for herbaceous species in 100 systematically placed quadrats (25 x 25 cm each), and that percent cover be measured for herbaceous species in four to five systematically placed 2 x 2 m subplots. Plots should be located within a 400 sq. m macroplot randomly located within one or more of the wetland types found in the sampled meadow. Hydrologic monitoring wells should be installed in the middle of each cover plot. Percent cover by shrub species could be measured by a line or point-line intercept method around the perimeter of the macroplot. Species identification to genus could be considered as a way to reduce error associated with misidentification of species, as long as this level of precision is sufficient to answer the specific monitoring questions. Presence/absence of trees should be counted within the macroplot according to species and size class. The study of tree/ sagebrush invasion in meadows would require a separate protocol where plots are placed along the forest/ meadow ecotone. Additional measurements should be added carefully to answer specific questions while preventing the sampling protocols from becoming too cumbersome. Most importantly, the site-specific sampling design should be simple to set up and sample and should be located within a single wetland type.

In setting up a long-term monitoring program, it is important to choose strategies for managing inter-annual, seasonal, site-based, and observer-based variability. Managing error increases the power with which you can detect trend without making type I and/ or type II errors. Since the variation associated with year cannot be effectively reduced by choices in sampling design, long-term monitoring plans must account for seasonal and inter-annual variability in temperature and precipitation, modeling the effects of these factors on target variables. Site-based variability can be managed by increasing the duration of the study and by sampling a fixed number of sites each year. Data on season and inter-annual variability that are collected from sites sampled each year can be extrapolated to sites sampled on a rotational basis within the study area. The selection of highly repeatable methods and the collection of quality assurance data will help in managing observer-based variability.

Power can be achieved by managing sample size, number of factors in the design, and number of years in a study. Most discussions of power recommend sampling a smaller number of sites over more years to obtain a dataset that is complete for the sites visited, as opposed to increasing the number of sites visited with the end result of a dataset with large data gaps. Stratification by wetland type in advance of sampling will help ensure an even design and ease of analysis for plant attributes. The inclusion of intensively sampled sites which will be resampled each year with extensively sampled sites which will be sampled on

a standard rotational basis (e.g. every five years) will help balance the statistical requirements for power with the ecological requirements for extrapolation to the entire NPS network. Data reduction techniques can also be used to increase the power associated with the analysis of plant species composition traits.

Data reduction techniques include the use of seral stages or functional groups, multimetric indices (Jones 2004), wetland evaluation technique for wetland condition (Adamus 1983, Adamus et al. 1987, Wilcox et al. 2002), and the Integrative Biological Indicator (IBI) indices for bioassessment (Wilcox et al. 2002). The last three in the above list fall under the broad heading of multimetric indices, which have been applied to wetland vegetation with mixed results. While the use of multimetric indices is attractive, as they link vegetation responses to stressors, they should be adopted with caution, as they may require considerable time and resources to create and test. New indices must be created and tested for each study region and wetland type. Large-scale land use patterns have not been effectively used as a surrogate for site-level measures of disturbance, and disturbance gradients should integrate several anthropogenic stressors to provide the best dose-response curve. Finally data should be calibrated for the hydrologic regime of the current and previous years.

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APPENDIX A

Summaries of Individual Monitoring Plans

Greenline Monitoring Method

Winward, Alma H. 2000. **Monitoring the vegetation resources in riparian areas.** Gen. Tech. Rep. RMRS-GTR-47. Ogden, UT: U.S.D.A Forest Service, Rocky Mountain Research Station. 49 p.

Objective 1	-Evaluate the health of vegetation across the valley floor, especially with respect to the impacts of grazing. The valley floor is the cross section that cuts perpendicularly across the meadow grade and extends from the upland vegetation at one lateral edge across to the upland vegetation at the other lateral edge. The valley bottom shape can vary from flat to U-shaped to V-shaped, and is a geomorphological meadow trait.
Objective Significance	"Human-caused influences normally involve changes in specific water table features or damaging impacts on certain plant species. These influences normally show up in changes in the community type composition within a complex. If there is a set kind and composition of community types within a complex in undisturbed conditions, and if new types develop within that complex when unnatural disturbance factors are present, such as livestock grazing and trampling or damages from recreational or other land disturbing activities (fig. 4f), changes in kinds and amounts of community types can be measured to determine the degree of impact" (Prichard 1998a, b, Winward 2000)
Methodologies Used	Vegetation Cross-Section method
Data Collected	a. Line intercept method used to capture community type cover and composition on at least 5 transects (permanently marked) and placed "perpendicular to the grade of the riparian complex". b. Transects are marked by paces instead of a measuring tape. A hand-held counter is used to help count steps. c. Transects are placed to best represent the entire complex. The author recommends using an aerial photograph to help place transects. d. Output is a percentage of total steps taken in all 5 transects for each community type, approximating relative cover by each community type. e. Community types are named by dominant species. *** Use of this method requires pre-existing classification of local community types.*** f. Spatial extent of communities is mapped based on aerial photography after types are determined (or in the field). Analyses focus on the comparison of a grazed site to some reference site in an unaltered condition, using similarity indices to ascertain percent similarity in community type between the two sites to discover the seral stage of the grazed site and if grazed sites are at least 75% similar in community type to reference sites, an indication that they are meeting desired conditions.
Monitoring Interval in years	3-5 years
Objective 2	-To describe vegetation along stream channels.

Objective Significance	The type of vegetation encountered along the greenline is a measure of bank stability and therefore the ability of the bank to withstand the erosive power of hydrologic events. The objective of this method is to determine successional status of vegetation along banks and to determine bank stability. The greenline is defined as “the first perennial vegetation that forms a lineal grouping of community types on or near the water’s edge. Most often it occurs at or slightly below the bankfull stage”.
Methodologies Used	Greenline Method
Data Collected	a. A similar line intercept method (described in the Vegetation Cross-section method) is used to describe plant communities along the greenline. *** Use of this method requires pre-existing classification of local community types.*** b. The minimum distance to be covered on each greenline is 363 lineal feet on each side of the stream. c. “Percent composition of each community type from the greenline measurements is used to make both the successional status and bank stability ratings.”
Monitoring Interval in years	3-5 years
Objective 3	To determine regeneration of woody species along greenline.
Objective Significance	This method acknowledges that grazing by cattle reduces the establishment and survival of willow seedlings and possibly other shrubs. It assumes that in grazed meadows, recruitment and regeneration indicate a recovering or healthy and naturally-functioning ecosystem. The author acknowledges that not all stream channels would naturally be dominated by shrubs and gives examples.
Methodologies Used	Woody Species Regeneration Method
Data Collected	a. Density counts of woody species by specified age classes, or in specific cases, patch sizes. b. Data is collected in a 6 ft. wide belt along greenline transects, using a center-marked 6 ft. long pole. The center mark is placed above greenline. Aerial extent for a 363 ft greenline would be 0.1 acre. c. Four age classes (Sprout, young, mature, and dead) are used based on growth rings and unbrowsed height. Patch sizes are used for rhizomatous species that occur in more or less continuous clumps. d. A qualitative estimate of browsing is provided in the comments section and is based on ranges of percent utilization.
Monitoring Interval in years	3-5 years
Key Contacts	

USFS Region 5 Range Monitoring Project

Weixelman, D. and Bakker, G. 2004. USFS Region 5 range monitoring project, 2004 report.
U.S.D.A. Forest Service, Adaptive Management Services. Nevada City, CA. 36p.

Objectives	1) To provide long-term monitoring of range condition by analyzing discrete portions of meadows (mesic) and treating each meadow separately to determine trend within plots. 2) To provide an "ecological classification (vegetative, soils, and hydrologic) and quantitative condition scorecards for meadows" (Weixelman et al. 2004).
Objective Significance	Permanent plots were used to determine trend within meadows. Augur holes provide "an effective measure of the plant vigor, soil stability, and the ability of a plant community for stabilizing streambanks. In addition, a number of studies have shown that rates of water infiltration are directly related to root density and depth in riparian soils". "The rooting depth is often the first parameter that responds to a management change."
Methodologies Used	1) Rooted frequency of plant species in quadrat frames in riparian areas 2) Greenline Method along streambanks (Winward 2000) including all three components of Winward's methodology (Greenline, Vegetation Cross-Section method, and Woody Species Regeneration Method)
Data Collected	Rooted frequency of plant species in quadrat frames in riparian areas: a) 20 quadrats were laid out along each of 3 25-m transects, for a total of 60 plots per meadow. 10x10 cm frames in mesic sites, or nested quadrats in drier sites (capturing 5x5, 10x10 and 20x20 cm frames) were used. Quadrats were read every meter, starting at 1m, and with a break between 10 and 15 m. The break provided space for auguring at 12.5 m. b) Transects were permanently marked at each end and in the middle with rebar. The first transect was located randomly within a homogeneous plant community with homogenous landforms and hydrology. Subsequent transects were laid out parallel to the first with a 5 m spacing. c) At each quadrat, vegetated rooted frequency (P/A) of all species and bare ground category (determined by four points at the quadrat corners) were recorded. d) Other attributes collected on each transect included slope, aspect, GPS location, elevation, topographic position, hydromorphic category. e) One 3 in diameter augur hole was made near the middle of each transect to determine rooting depth (the maximum depth where there are at least 100 roots (< 2 mm diameter) per square decimeter of soil). Depth to saturation, depth to water table, and depth to mottles were also noted. f) A minimum of 11 photographs were taken at each site, using photo boards and chalk.
Analysis of functional groups	Vegetation: Instead of analyzing the successional status of community types, as in Winward 2000, plants are analyzed in terms of functional groups, based on measured traits (life form, life history, wetland rating,

	rooting characteristics, vegetative lateral spread mechanism, and nitrogen fixing capability). Based on the combination of traits, plants were assigned to one of three functional classes (low, moderate, or high). By looking at the abundance of different functional groups over time, one can get a sense of the functioning of a meadow and predict what groups might be found given specific environmental and disturbance conditions. "Generally, hydric, deep-rooted graminoid species are considered high functional status for wet meadows, while non-hydric, forb species are considered low status". Percent frequency by species across a set of three transects was summed across functional classes to determine the relative frequency of each functional group within the meadow.
Analysis of meadow condition	CCA was used to develop a scorecard for meadow condition. Relative frequency of each functional group was plotted in multidimensional space, together with rooting depth and percent bare ground. Macroplots (comprised of three adjacent transects) appeared in relation to these traits and were then rated according to their condition (low, moderate, or high). Rooting depth and percent bare ground were also broken up into the three classes; the final score for the macroplot was based on the predominant class from all three response variables. Paired t-tests were used to see if a plot was significantly different from itself in terms of vegetation condition and overall condition class after a five year reread. Bar graphs (no error bars) were used to display the number of sites that were stable, "trending" upwards, or "trending" downwards. Transect = su for this analysis. T tests were used to examine the mean change (and se) in depth to water table over a five year period. Transects within the same meadow were assumed to be independent sampling units. These measurements were not correlated with annual precipitation and therefore are not very valuable.
Monitoring Interval in years	5 years
Key Contacts	Dave Weixelman Adaptive Management Services US Forest Service Nevada City, CA email: dweixelman@fs.fed.us phone: 530-478-6843

Sierra Framework Plan (Aquatic Conservation Strategy Meadow Study Plan)

Weixelman, D., S. Durham, C. Brown, and T. Frolli. 2002. Aquatic conservation strategy meadow study plan, draft. Prepared for the Sierra Framework Initiative, U.S.D.A. Forest Service.

Objectives	To capture the status and change of meadow vegetation condition and key attributes reflecting habitat condition and ecological functioning in meadow complexes.
Objective Significance	
Methodologies Used	Vegetation Cross Section- Modified. "Nested plots were placed systematically on the cross sectional transect for measuring vegetation and soil attributes. The sizes of the nested plots were chosen to conform as closely as possible to FIA nested plots while allowing for adequate sampling of most meadow attributes" (Weixelman et al. 2002).
Data Collected	1) 3 80m transects, crossing the baseline 2) 2 subplots per transect, measuring live trees >5 in dbh and snags. A densitometer was used to read tree cover. Recruitment and % cover by species were recorded in each subplot. 3) In 2 circular microplots per transect, each with a 2.1 m radius, tree seedlings and saplings <5 in dbh were recorded 4) 20 nested quadrats (10x10, 20x20, 20x50, 50x50 cm) per transect were used to estimate rooted frequency of herbaceous species in one of three hydrologic types (wet, moist, or dry). 5) Ground cover was measured at the four corners of each quadrat. 6) Soil data was collected along the sampling line, outside the subplot and outside of the baseline (3 locations per transect). 7) Soil attributes included depth to restrictive horizon, compaction, field texture, rooting depth (after Weixelman), depth to water table, depth to surface water, depth to soil saturation, depth to redoximorphic features or mottles, dept of peat layer. 8) A line-intercept method was used along each transect to capture height and cover by shrubs. 9) Percent community composition (plant communities approximated by dominant plant species) of the meadow complex were determined along three cross sectional transects (after Winward). 10) *** In the last year of the study, 5 equally spaced transects were used, each with 12 nested quadrats, instead of the original 3 transects randomly located within each third of the baseline, each with 20 nested quadrats.
Analysis	
Monitoring Interval in years	Intended to be read every 5 years, with 15% read every year.
Key Contacts	Dave Weixelman, Adaptive Management Services US Forest Service, Nevada City, CA email: dweixelman@fs.fed.us phone: 530-478-6843 Susan Durham, Sierra Ecosystem Associates Phone: (530) 622-8740 Susan@sierraecos.com

PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program

- Henderson, Richard C.; Archer, Eric K.; Bouwes, Boyd A; Coles-Ritchie, Marc S.; Kershner, Jeffrey L. 2005. PACFISH/INFISH biological opinion (PIBO): effectiveness monitoring program seven-year status report 1998 through 2004. Gen. Tech. Rep. RMRS-GTR-162. Fort Collins, CO: U.S.D.A. Forest Service, Rocky Mountain Research Station. 16 p.
- Coles-Ritchie, M., A. Kelly, and R. Henderson. 2004. Effectiveness monitoring for streams and riparian areas within the Upper Columbia River basin: sampling protocol, vegetation parameters. U.S.D.A. Forest Service, PIBO Effectiveness Monitoring Program, Logan, UT.

Objectives	1. To “determine whether a suite of biological and physical attributes, processes, and functions of upland, riparian, and aquatic systems are being degraded, maintained, or restored across the PIBO landscape.” 2. To “determine the direction and rate of change in riparian and aquatic habitats over time as a function of management practices.” 3. To “determine if specific Designated Management Area practices related to livestock grazing are maintaining or restoring riparian vegetation structure and function” (Henderson et al. 2005).
Objective Significance	This program was developed in response to monitoring needs addressed in the Biological Opinions for bull trout and steelhead. This project aims “to determine whether the aquatic conservation strategies within PACFISH and INFISH, or revised land management plans, are effective in maintaining or restoring the structure and function of riparian and aquatic systems” (Henderson et al. 2005).
Methodologies Used	1) stream habitat protocol (not included here, as focus is on fish) 2) riparian vegetation protocol (based on greenline and vegetation cross-section methods) modified initially to describe each attribute at a reach scale and to increase repeatability among observers. . “Reach lengths are a minimum of 20 bankfull channel widths in length, range from 160 to 480 meters, and are wadeable” (Coles-Ritchie et al. 2004b).
Data Collected	1) “vegetation—species, cover, and height—at the reach scale. The vegetation sampling area corresponds to a reach length that is 20 bankfull widths (160 m to 480 m). All reaches are within unconstrained valley bottoms with gradients < 3% and have wadeable channels with bankfull widths between 1 and 15 meters. We feel strongly that it should not be used in other stream types without additional review and testing.” 2) A 50 cm x 20 cm quadrat frame (Fig. 2) of Daubenmire (1959) is used to determine the vegetation cover over the quadrat. Plots were concentrated along the greenline (at least 20 plots per side of channel along a given reach) and perpendicular to the valley bottom at 3m, 6m, and 9m on either side of the channel at 5 locations for a total of 30 plots (5 x2 sides of channel x 3 plots per side at each location). 3) Six cover classes were used to assess vegetation in plots (0 to 5, 5 to 25, 25 to 50, 50 to 75, 75 to 95, and 95 to 100 percent). 4) Collect species cover data for a 0.5 m x 0.2 m area associated with each channel transect, on both sides of the stream For each quadrat record the species and canopy cover using the Daubenmire cover classes, for all species that can be identified,

	or for unknown species over 5% cover. 5) Record the height of woody plants with cover over the quadrats, using the following 3 categories: < 1 m; 1 - 2 m; or > 2 m tall. Consider only the greatest height of that species over the quadrat. 6) For each quadrat determine whether the quadrat is in the valley bottom (generally flat and including terraces or in the uplands (sloped)). 7) Collect information on trees within a belt 9.5 m long (from greenline along cross-section plots) and 3m wide (1.5 m on either side of cross-sectional line). Record trees that are at least 4 cm in diameter and 1.4 m tall. For each tree record the species, dbh, and distance from greenline. 8) Protocol is provided for species collection and treatment of unknown species at each site (Coles-Ritchie et al. 2004b).
Analysis	"In the first analysis, riparian vegetation was evaluated in relation to environment, management, and stream variables. Similarity indices and ordinations were used to compare all sites based on the relative cover of community types. Stream reaches were grouped into four riparian types: (1) conifer-alder forests, (2) wet sedge-willow sites, (3) dry-grazed sites, and (4) steeper-shrub sites. The dry-grazed sites were more impacted by management than the other riparian types. Precipitation and elevation explained the greatest amount of variance. These techniques found little difference between managed and reference sites across the entire study area (Coles-Ritchie 2004, chapter 3). ... These analyses show that the effects of land management activities can be detected at the large scale for many physical stream habitat attributes and macroinvertebrates but not for riparian vegetation" (Coles-Ritchie et al. 2004b).
Monitoring Interval in years	Each site revisited on a 5 year rotational basis.
Key Contacts	PIBO Effectiveness Monitoring Program Forestry Sciences Lab 860 N. 1200 E., Logan, Utah 84321 Phone: 435-755-3560 Fax: 435-755-3563 Web site: http://www.fs.fed.us/biology/fishecology/emp.html Email: PIBO@fs.fed.us Marc Coles-Ritchie Riparian Ecologist US Forest Service, PIBO Effectiveness Monitoring 860 North 1200 East Logan, UT 84321 (435) 755-3597 mcolesritchie@fs.fed.us http://www.fs.fed.us/biology/fishecology/staff/mritchie.html

Creation of Integrative Multimetric Indices Linking Vegetation Responses to Stressors

Jones, W.M. 2004. Using vegetation to assess wetland condition: a multimetric approach for temporarily and seasonally flooded depressional wetlands and herbaceous-dominated intermittent and ephemeral riverine wetlands in the northwestern glaciated plains ecoregion, Montana. Report to the Montana Department of Environmental Quality and the U.S. Environmental Protection Agency. Montana Natural Heritage Program, Helena, MT. 34 pp. plus appendices.

Objectives	"This study attempted to evaluate wetlands by measuring vegetation response to anthropogenic stressors for temporarily and seasonally flooded depressional and herbaceous-dominated intermittent and ephemeral riverine wetlands in the northwestern glaciated plains ecoregion in north-central Montana" (Jones 2004).
Objective Significance	"Biological assessments can be accurate and cost-effective tools to assess wetland condition and measure impairment (Karr and Chu 1999). Because biota integrate multiple physical and chemical parameters, directly measuring the biotic community's response to anthropogenic stressors can be the most direct means to evaluate the effect of those stressors on wetland condition and function (Danielson 2002)."
Methodologies Used	Site Selection: 1) Watersheds were ranked by 12 factors relating to degree of human disturbance including stream density, road density, number of road/ stream crossings per 10 sq. miles, percent federal land, percent wilderness and percent land cover. Sample watersheds were selected based on mean overall rank in each of three categories: most impacted, least impacted, and moderately impacted. 2) "Depressional wetlands were stratified by inundation period using the zones described by Stewart and Kantrud (1971) (i.e., wet meadow and shallow marsh, corresponding to temporarily and seasonally flooded, respectively). Riverine wetlands were stratified by geomorphology (i.e., depositional bar, channel shelf, floodplain (<i>sensu</i> Hupp and Osterkamp 1985))." Sampling Method: Randomly placed quadrats (1.0m x .5 m) in each inundation zone or fluvial surface.
Data Collected	1) Percent canopy cover of vascular species in each quadrat. Within each stratification, sampling continued until no more species were found. Then one additional plot was sampled. 2) Additional information was recorded on "hydrologic and geomorphic modifications (e.g., presence and extent of ditches, dikes, tiles, revetment, slumped or unstable banks), physical site disturbances (e.g., presence and extent of pugging and hummocking), and land use within the wetland and adjacent uplands."
Analysis	1) Watershed disturbance ranking was measured against several scales of disturbance at individual sites to determine what if any correlations existed. Relationships between watershed disturbance categories and other disturbance measures were analyzed using Kruskal-Wallis tests (SYSTAT 2002). 2) A multimetric approach was used to combine metrics reflecting diverse biotic responses to anthropogenic stressors into an integrative measure of biological condition (Karr and Chu 1999, Teels and Adamus 2002). "Examples

	of metrics include changes in species richness and dominance (community-based metrics), changes in the number of perennials, annuals, or intolerant species (plant functional group metrics), and dominance of individual species (species-specific metrics)." Plant functional group metrics used in this study were native perennials and C-value, a value subjectively assigned by experts describing the tolerance to disturbance and fidelity to habitat integrity for a given species. 3) "Vegetation attributes that changed predictably along the disturbance gradient were identified and combined into a multimetric index for each wetland type. These indices were significantly related to wetland condition, as measured by the human disturbance gradient, for both depressional and riverine wetlands. When wetlands were divided into three disturbance categories (reference condition, moderately disturbed, and severely disturbed), vegetation metrics were able to correctly classify 73% of depressional and 86% of riverine wetlands sampled. The multimetric index for depressional wetlands responded primarily to on-site agricultural disturbance and was comprised of four metrics: the floristic quality index and relative cover of native perennials, species with a coefficient of conservatism ≥ 4, and exotic species. The riverine multimetric index responded primarily to on-site grazing intensity and included the richness of native perennials, Simpson diversity index, proportionate richness of tolerant species, relative cover of intolerant species, and floristic quality index." "The composition and abundance of the whole plant community sampled at a site was not predictably associated with disturbance category." Indicator species analysis (McCune and Grace 2002) was used to determine which species were indicative of severely disturbed or reference condition in temporarily or seasonally flooded depressional wetlands. "Watershed disturbance rankings did not correlate with either small-scale disturbance measures or vegetation metrics, and this finding argues against the use of large-scale land use patterns as a surrogate for site-level measures of disturbance."
Monitoring Interval in years	N/A
Key Contacts	Marc Jones 2004 Montana Natural Heritage Program P.O. Box 201800 1515 East Sixth Avenue Helena, MT 59620-1800 406-444-5354

Application of Index of Biotic Integrity Metrics to Wetlands

Wilcox, D. A., J. E. Meeker, P. L. Hudson, B. J. Armitage, M. G. Black, and D. G. Uzarski.
2002. Hydrologic variability and the application of index of biotic integrity metrics to
wetlands: A Great Lakes evaluation. *Wetlands* 22:588-615.

Objectives	to develop and evaluate an Index of Biotic Integrity (IBI) for wetlands that could be used to categorize the level of degradation. A secondary aim was to see how well these data met several criteria critical to wetland IBI development: 1) determine if this approach is valid for wetlands within the study region; 2) explore the limitations that constrain this approach caused by the effects of natural disturbance, variability in disturbance types among wetlands, restricted numbers of comparable wetlands, and potential lack of pristine reference sites; 3) propose alternative approaches, and 4) extend our findings to other wetland types.
Objective Significance	Both land management and regulatory agencies identified a need to use biological indicators as a tool for detecting wetland condition and degradation.
Methodologies Used	Plant, fish, and invertebrate communities in wetlands at the Lake Superior sites were sampled from 20 July to 20 August 1993. Lake Michigan sites were sampled from 10 July to 18 August 1995. Sampling in 1994 was conducted at the Lake Huron sites. Vegetation Sampling: 1) Aerial photography was used to map vegetation communities within each wetland. 2) Plant communities were characterized by sampling randomly placed 1-m x 1-m quadrats in each vegetation type (variable number of quadrats per type). 3) Species identified to lowest possible taxonomic level. Ocular estimation was used to determine cover by species within quadrats. Invertebrate Sampling: 1) Funnel traps (Swanson 1978) were used to sample invertebrates in daily sets. 2) In addition, adult caddisflies (Trichoptera) were sampled using ultraviolet blacklight traps placed in overnight sets at each site for two nights (Armitage et al. 2001).
Data Collected	Mapping Scale: 1) % of wetland in individual mapped vegetation types 2) sum of %wetland in invasive vegetation types Quadrat Scale: 1) total number of taxa 2) number of native taxa 3) number of invasive taxa in each specific vegetation type 4) total number of taxa, number of native taxa, and number of invasive taxa across all vegetation types 5) mean percent cover of various dominant taxa and individual invasive taxa in specific vegetation types 6) mean percent cover of all submersed aquatic plants and individual turbidity-tolerant taxa in submersed aquatic vegetation types (SAV); 7) sum of mean percent cover of all invasive taxa in specific vegetation types and of all turbidity-tolerant taxa in SAV vegetation types 8) % of all taxa that are obligate wetland plants 9) Floristic Quality Index (FQI) scores for each wetland

	Invertebrates: Invertebrate data were evaluated using attributes selected from those recommended by others for use in streams and wetlands (e.g., DeShon 1995, Burton et al. 1999).
Analysis	1) Dose-response curves were used to plot biological attribute values against a number of human disturbance gradients at the local or watershed scale. 2) Dose-response curves that demonstrated an obvious response to increasing human disturbance in various forms when displayed graphically were used to select potential metrics 3) From the graphic display of the dose-response curves, scores of 1, 3, or 5 were assigned to various ranges of attribute data, generally according to natural breaks in the data, to reflect poor conditions, moderate conditions, and minimally impacted conditions, respectively (Karr 1981, Karr et al. 1986, USEPA 1998, Karr and Chu 1999). 4) Collective IBI scores, not individual metric scores, were used to compare sites. Collective scores were evaluated separately for plant, fish and invertebrates. Findings: 1) The IBI method requires stratification by geographic, geomorphic, and hydrologic features. 2) The IBI method is better-suited for wetlands with relatively stable hydrology. 3) Wetlands with unpredictable yet recurring types of natural disturbance, such as climate-induced, long-term high water periods, droughts, or drought-related fires, require an additional scaling to capture time since disturbance. 4) IBI scores should not be used “unless the scoring ranges are calibrated for the specific hydrologic history pre-dating any sampling year” (Wilcox et al. 2002). 5) Other candidate wetlands include wet meadows or wet prairies in the proper setting and some expansive peatlands. However, fens often differ in ground-water source, resultant water chemistry, and associated vegetation (Boelter and Verry 1977, Vitt and Chee 1990, Gorham and Janssens 1992, Vitt et al. 1995), so a fen IBI might require segregation of wetlands based on inherent water chemistry differences.
Monitoring Interval in years	N/A
Key Contacts	Douglas A. Wilcox U. S. Geological Survey Great Lakes Science Center 1451 Green Road Ann Arbor, Michigan, USA 48105 E-mail: douglaspwilcox@usgs.gov

BLM Process for Assessing Proper Functioning Condition of Wetlands

Prichard, D. 1998. Riparian management: process for assessing proper functioning condition, Technical Reference 1737-9. U.S. Department of the Interior, Bureau of Land Management, Denver, CO.

Prichard, D. 1998. Riparian management: process for assessing proper functioning condition for lentic riparian-wetland areas, Technical Reference 1737-11. U.S. Department of the Interior, Bureau of Land Management, Denver, CO.

Objectives	To determine the condition of wetlands with regards to proper functioning, with the desired goal of reaching restoring and/or maintaining riparian-wetland areas so that 75 percent or more are in proper functioning condition (PFC), and where possible achieving an “advanced ecological status, except where resource management objectives, including PFC, would require an earlier successional stage, thus providing the widest variety of vegetation and habitat diversity for wildlife, fish, and watershed protection.” The BLM defines wetland/riparian resources as the interactions between vegetation, soils/ landform, and hydrology. “Proper Functioning Condition - Riparian-wetland areas are functioning properly when adequate vegetation, landform, or large woody debris is present to dissipate stream energy associated with high water flows, thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid floodplain development; improve flood-water retention and ground-water recharge; develop root masses that stabilize streambanks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; and support greater biodiversity”(Prichard 1998a, b)
Methodologies Used	Qualitative Assessment of wetland condition.
Data Collected	For each of the following questions, observed checks the appropriate box, answering yes, no or n/a. Observer then assigns a Functional Rating of Proper Functioning Condition, Functional—At Risk, Nonfunctional or Unknown and makes a call on whether functional-at risk sites are trending Upward, downward, or in an unknown direction. Lotic Wetlands: 1) Floodplain above bankfull is inundated in “relatively frequent” events 2) Where beaver dams are present they are active and stable 3) Sinuosity, width/depth ratio, and gradient are in balance with the landscape setting (i.e., landform, geology, and bioclimatic region) 4) Riparian-wetland area is widening or has achieved potential extent 5) Upland watershed is not contributing to riparian-wetland degradation 6) There is diverse age-class distribution of riparian-wetland vegetation (recruitment for maintenance/recovery) 7) There is diverse composition of riparian-wetland vegetation (for maintenance/recovery) 8) Species present indicate maintenance of riparian-wetland soil moisture characteristics 9) Streambank vegetation is comprised of those plants or plant communities that have root masses capable of withstanding high streamflow events 10) Riparian-wetland plants exhibit high vigor 11) Adequate riparian-wetland vegetative cover is present to protect

	banks and dissipate energy during high flows 12) Plant communities are an adequate source of coarse and/or large woody material (for maintenance/recovery) 13) Floodplain and channel characteristics (i.e., rocks, overflow channels, coarse and/or large woody material) are adequate to dissipate energy 14) Point bars are revegetating with riparian-wetland vegetation 15) Lateral stream movement is associated with natural sinuosity 16) System is vertically stable 17) Stream is in balance with the water and sediment being supplied by the watershed (i.e., no excessive erosion or deposition) Lentic wetlands have a different set of questions: 1) Riparian-wetland area is saturated at or near the surface or inundated in “relatively frequent” events 2) Fluctuation of water levels is not excessive 3) Riparian-wetland area is enlarging or has achieved potential extent 4) Upland watershed is not contributing to riparian-wetland degradation 5) Water quality is sufficient to support riparian-wetland plants 6) Natural surface or subsurface flow patterns are not altered by disturbance (i.e., hoof action, dams, dikes, trails, roads, rills, gullies, drilling activities) 7) Structure accommodates safe passage of flows (e.g., no headcut affecting dam or spillway) VEGETATION 8) There is diverse age-class distribution of riparian-wetland vegetation (recruitment for maintenance/recovery) 9) There is diverse composition of riparian-wetland vegetation (for maintenance/recovery) 10) Species present indicate maintenance of riparian-wetland soil moisture characteristics 11) Vegetation is comprised of those plants or plant communities that have root masses capable of withstanding wind events, wave flow events, or overland flows (e.g., storm events, snowmelt) 12) Riparian-wetland plants exhibit high vigor 13) Adequate vegetative cover is present to protect shorelines/soil surface and dissipate energy during high wind and wave events or overland flows 14) Frost or abnormal hydrologic heaving is not present 15) Favorable microsite condition (i.e., woody debris, water temperature, etc.) is maintained by adjacent site characteristics EROSION/DEPOSITION 16) Accumulation of chemicals affecting plant productivity/composition is not apparent 17) Saturation of soils (i.e., ponding, flooding frequency and duration) is sufficient to compose and maintain hydric soils 18) Underlying geologic structure/soil material/permafrost is capable of restricting water percolation 19) Riparian-wetland is in balance with the water and sediment being supplied by the watershed (i.e., no excessive erosion or deposition) 20) Islands and shoreline characteristics (i.e., rocks, coarse and/or large woody debris) are adequate to dissipate wind and wave event energies (Prichard 1998a, b)
Monitoring Interval (years)	?
Key Contacts	U.S. Department of the Interior Bureau of Land Management, Service Center P.O. Box 25047 Denver, CO 80225-0047

Meadow Monitoring of Packstock Use in Sequoia and Kings Canyon National Parks

- National Park Service. 1999. Meadows and grazing. *in* Natural and cultural resources management plan, Sequoia and Kings Canyon National Parks. National Park Service, U.S. Department of the Interior.
- Abbott, L. B., R. D. Piper, and K. E. Young. 2003. Analysis of residual biomass monitoring program in Sequoia and Kings Canyon National Parks. New Mexico State University, Las Cruces, NM.
- McClaran, M. P., and M. J. Neuman. 1989. Developing and testing a system to monitor species composition change in backcountry meadows of Sequoia and Kings Canyon National Parks. National Park Service, U.S. Department of the Interior.

Objectives	• Residual biomass at the end of the growing season meets standards established to maintain naturally functioning ecosystems • Plant species composition and diversity is maintained within the natural range of variation • Soil and fluvial processes are maintained such that unnatural losses are prevented (National Park Service 1999)
Objective Significance	Given that it is not possible to allow grazing in wilderness meadows without sustaining some level of environmental impacts (Archer and Smeins 1991), we must determine in which meadows grazing should be allowed to occur, and under what conditions. Managers are thus faced with the challenge of setting standards for acceptable impacts that will allow for continued packstock use while maintaining naturally functioning meadow ecosystems (National Park Service 1999).
Methodologies Used	1) Comparative yield method for residual biomass (Haydock and Shaw 1975, Catchpole and Wheeler 1992, Abbott et al. 2003) "Comparative yield is a non-destructive method that estimates residual biomass by placing biomass in classes and then developing an on-site relationship between actual biomass and the biomass classes" (McClaran and McDougald 1994). 2) Step-point sampling method for Bare ground (Evans and Love 1957) 3) Frequency sampling for species composition (McClaran and Neuman 1989) using nested quadrats (10x10 cm nested within 25x25 cm) with 100-200 quadrats per meadow. Quadrats are located randomly on transects perpendicular to a 100 pace transect line within a mapped, broad vegetation type (National Park Service 1986). Frequency sampling can be accomplished at the rate of 6.9 plots/ person/ hour, or 7 hours for a 2-person crew to complete 100 plots. 4) Packstock Use. Number of animals, kind of livestock, and number of nights spent in each meadow are reported by private, commercial and administrative users. Packstock use is evaluated in terms of animal units per acre.
Data Collected	1) Residual biomass (production) and groundcover data are collected at the end of the growing season from approximately two dozen (up to 38) wilderness meadows that consistently receive moderate to heavy use. 2) Species composition is monitored on a five-year cycle in five meadow pairs (grazed and ungrazed) selected to represent a range of meadow types. 3) Gross changes in meadow vegetation and structure are captured through an extensive collection of repeat photographs. 4) Packstock use levels and patterns are tracked through a system of ranger observations, wilderness permits, and self-reporting forms submitted by private, commercial and administrative users of site specific grazing within the parks (National Park Service 1999).

	5) Evidence of bare ground, soil compaction, gully, sheet erosion, and rill erosion are recorded in a qualitative manner (National Park Service 1986). 6) Although plots are not permanently marked in the field, they are approximately relocated using aerial photographs and field maps each year. Frequency is analyzed for the total number of randomly-located frequency plots.
Analysis	1) T-test statistics were used to determine if there was a 15% difference in mean frequency for a given species between one sampling date and the next. For species that changed significantly, the authors looked for species that changed in grazed but not ungrazed meadows (McClaran and Neuman 1989). 2) Sorenson's similarity index (McCune and Grace 2002) was used to see how the similarity in species lists changed between a grazed/ ungrazed pair from one sampling date to the next. The change could not be evaluated using statistical inference methods, however (McClaran and Neuman 1989). 3) Average biomass was compared between core (areas of moderate to heavy packstock use) and reference (areas with no packstock use) area at the end of the growing season (Abbott et al. 2003). 4) Regression analyses were used to determine if the number of animal unit nights was directly related to residual biomass on core areas, if core biomass relative to reference biomass would be explained by packstock use, if reference biomass less core biomass was significantly related to packstock use, and if percent bare ground was correlated to packstock use (Abbott et al. 2003). 5) Simple linear regression was also used to determine the relationship of maximum water content of snow pack to 1) biomass and 2) bare ground (Abbott et al. 2003). 6) Species from frequency sampling were given seral ratings. Relative proportion of early, mid-, and late seral species for each meadow were compared in terms of similarity to Potential Natural Community ratings (% similarity) (Abbott et al. 2003).
Monitoring Interval (years)	Yearly for biomass data; 5 years for species composition data
Key Contacts	Sylvia Haultain Plant Ecologist Sequoia and Kings Canyon National Parks Three Rivers, California 93271 (559) 565-3769

Monitoring Packstock Grazing in Yosemite National Park

McClaran, M. P., and N. McDougald. 1994. Monitoring packstock grazing in Yosemite National Park. National Park Service, U.S. Department of the Interior.

National Park Service. 1997. Protocols for monitoring packstock grazing in Yosemite National Park. Wilderness Office, National Park Service, Yosemite National Park, and Yosemite Field Station, Biological Resources Division, U. S. Geological Survey.

Objectives	To monitor 1) grazing impacts in meadows, 2) campsite impacts, and 3) the spatial distribution and total amount of packstock use (McClaran and McDougald 1994, National Park Service 1997).
Objective Significance	Given that it is not possible to allow grazing in wilderness meadows without sustaining some level of environmental impacts (Archer and Smeins 1991), we must determine in which meadows grazing should be allowed to occur, and under what conditions. Managers are thus faced with the challenge of setting standards for acceptable impacts that will allow for continued packstock use while maintaining naturally functioning meadow ecosystems (National Park Service 1999).
Methodologies Used	1) Point-Intercept Method for Ground Cover (Cook and Studdendieck 1986) Ground cover is described by the percentages of hits in each of the following categories: live plants, bare ground, plant litter, and rocks. 2) Comparative Yield Method for Residual Biomass (Catchpole and Wheeler 1992). “Comparative yield is a non-destructive method that estimates residual biomass by placing biomass in classes and then developing an on-site relationship between actual biomass and the biomass classes” (McClaran and McDougald 1994). 3) Plots are placed every foot along a 100 ft transect. At each biomass plot a pin-point is recorded for ground cover.
Data Collected	1) Permanent plots were to be established in 14 meadows that had moderate to heavy use by packstock and that occurred within areas of uniform species composition. 2) Data collected includes residual biomass and percent vegetation, bare ground, plant litter, and rock on each transect. Dry weight is determined for a subset of biomass samples.
Analysis	Average biomass rank is converted to residual biomass weight by calculating the relationship between ranks and the weight of biomass in the plots using linear regression analysis. Other analyses were not included in this report.
Monitoring Interval (years)	According to Mark Fincher, all 14 meadows were not sampled again after 1994. From 1998 to 2003, 5 meadows were monitored on semi-regular basis.
Key Contacts	Lisa Acree, Botanist Office of Vegetation and Ecological Restoration Resources Management and Science Yosemite National Park 5083 Foresta Road, P.O. Box 700 El Portal, California 95318 (209)379-1217 (209/379-1116 fax) lisa_acree@nps.gov

ROMN Vital Sign #3; Wetland Ecological Integrity Protocol Development Summary

National Park Service. 2005. ROMN vital sign #3; wetland ecological integrity protocol development summary- draft. National Park Service, U.S. Department of the Interior.

Objectives	To establish biometrics for wetland ecological integrity in the Rocky Mountain National Network, NPS. 2) To monitor trend in biological metrics over time in order to prioritize additional monitoring, diagnose the causes of degradation, and provide data to inform management decisions about protecting and restoring ROMN wetlands.
Objective Significance	As the authors indicate, biological metrics can be effective and integrative factors for monitoring change in wetland condition. When sampled in conjunction with important physical and chemical properties of the ecosystem, these metrics have the potential to detect trends with higher power.
Methodologies Used	Sampling Design Sampling design will target select, high-priority or at risk wetland types and will include a combination of sentinel and randomly-selected sites. Sentinel sites will be sampled more intensively. Visits to non-sentinel sites will be completed in one day by a crew of two. Site visits will be less frequent, with valid inference to the park possible after several years. Sentinel sites may require more involved instrumentation that operates on a continuous or episodic basis and thus more frequent sampling events. Inference from the sentinel sites will be restricted to the site itself (without complex modeling), but robust description of temporal patterns and possible mechanisms will be possible. We will account for temporal (e.g., annual) variability via revisits to a subset of sites across years (e.g., Larsen et al. 2004). Monitoring Strategy: 1) Wetland types will be classified so that sampling and analysis may occur within each important wetland type. 2) Indices of Biotic Integrity (IBI; Karr and Chu 1999) will be developed for each wetland type. The IBI combines multiple individual metrics (e.g., species richness, % annuals, % invasive, etc.) each referenced to and scaled by an ecoregions or park-specific expectation into a summary score of the integrity of a specific sampled wetland. An IBI exists for vegetation in Montana (Jones 2004) and is being developed (in part) via a Floristic Quality Index in Colorado. 3) The chemical and physical (especially hydrology; Cooper et al. 1998, Cooper 1990) context of a wetland will be considered across multiple spatial and temporal scales. 4) Trend in a given measure or IBI metric will be defined as an X% change / Y year period, with a Type I error of 0.10 at 80% power. Trend will be calculated for IBIs and for physical and chemical factors. 5) The relative impacts of atmospheric deposition (NO_x, SO₄) and changes in ground-water and surficial hydrology on physicochemical and biological characteristics of select sensitive wetlands of the ROMN will be assessed. 6) Scoring ranges will be calibrated for the specific hydrologic history pre-dating any sampling year in any wetlands with unpredictable but recurring variation in climatic factors (Wilcox et al 2002).
Data Collected	1) properties of one or more classes of biological assemblages (vegetation and possibly benthos and algae) 2) certain chemical and physical aspects of wetlands (primarily ground and surface water hydrology, water and soil physiochemical attributes, and landscape-scale structure and composition of wetlands and their matrix) . 3) Atmospheric deposition (NO_x, SO₄)

Analysis	N/A
Monitoring Interval (years)	N/A
Key Contacts	

Wetland Assessment within the Klamath Network

Adamus, P. R., and J. Good. 2005. Assessment of wetlands in Lassen Volcanic National Park (LAVO), summer 2005. Prepared for I & M Coordinator, Klamath Region, National Park Service, Ashland, OR.

Adamus, P. R. 2005. Implementation plan for summer 2005 assessment of wetlands in Lassen Volcanic National Park. Prepared for I & M Coordinator, Klamath Region, National Park Service, Ashland, OR.

Objectives	“Project will provide (1) corrections and additions to existing NWI maps, (2) management recommendations specific to individual wetlands in the park, (3) strategies for addressing larger scale wetland conservation issues (e.g., non-native species), (4) a quantitative baseline essential for future monitoring of wetland condition, (5) classifications of wetland site potential, and (6) location of degraded wetlands in need of restoration” (Adamus 2005).
Objective Significance	“The synthesis of information proposed in this project will help managers take a strategic rather than reactive approach to mitigating threats to park wetlands, will better determine the spatial and temporal scales at which to attack the problem(s)” (Adamus 2005).
Methodologies Used	Predictive Modeling: Hydrogeomorphic Classification (HGM) (Bedford 1996) 1) Using GIS, the geologic type, elevation, annual precipitation, stream presence/absence, and several topographic variables (slope, compound topographic index, curvature, plan curvature, profile curvature) were determined for each of 1000 points that might have been wetlands. 2) Logistic Regression and recursive-partitioning (“tree”) algorithm called CHAID (Chi-square Automatic Interaction Detection) were used in order to predict wetland occurrence. Both yielded models that explained 70-80% of the variance, but the CHAID model was far more informative. It yielded a series of 16 decision rules that were easily converted to GIS queries of the spatial data (Adamus 2005, Adamus and Good 2005). Ground Truthing (Fieldwork): Field collection included, but exceeded in extent: 1) the California Rapid Assessment Method (CRAM, Collins et al. 2004) • For plots that are primarily herbaceous, the contiguous area must be exactly 100 square meters (e.g., 10m x 10m, or 20m x 5m, etc.). For plots that are primarily shrub or tree, the plot must cover exactly 400 square meters. Every shrub/tree plot must contain a 100 square meter herb plot within its boundaries, but not every herb plot will conversely include a shrub/tree plot. 2) synthesis methods used at Point Reyes National Seashore (Parsons and Donovan 2005) 3) Opportunities for restoring degraded wetlands in particular were highlighted (Adamus 2005, Adamus and Good 2005).
Data Collected	Data Collection: 1) Relevé-style surveys were completed within plots (described above). All species possible were identified and assigned to a cover class within each height stratum. 2) For shrub/tree plots, the spherical densiometer was used to estimate canopy shade at 3 representative points within the plot.

	3) Soils data were collected from at least two 12 in deep soils pits. 4) Three channel cross-sections were completed when streams were present. 5) Additional species were recorded in unique microhabitats until species-area curve leveled out. 6) Additional hydrologic features were recorded (Adamus 2005, Adamus and Good 2005).
Analysis	1) Regression, ordination, and recursive-partitioning procedures were used to identify environmental factors most strongly associated with the occurrence of individual wetland species or species associations. 2) Relative levels of potential wetland functions were assessed by assigning scores to metrics and indices derived from the data (all data forms). These indices represented the following: • Potential Capacity for Natural Water Storage & Slow Infiltration • (for streamflow support and fire hazard reduction) • Potential Capacity for Intercepting and Stabilizing Suspended Sediments • Potential Capacity for Processing Nutrients, Metals, and Other Substances • Potential Capacity for Carbon Sequestration • Potential Capacity for Supporting Invertebrate Communities Characteristic of the Wetland Type • Potential Capacity for Supporting Native Fish Characteristic of the Wetland Type • Potential Capacity for Supporting Amphibians Characteristic of the Wetland Type • Potential Capacity for Supporting Birds & Mammals Characteristic of the Wetland Type • Potential Capacity for Supporting Plant Species & Associations Characteristic of the Wetland Type • Potential Capacity for Supporting Levels of Primary Production Characteristic of the Wetland Type 3) According to this protocol, wetlands were scored relative to others within the same hydrogeomorphic class (Adamus 2005, Adamus and Good 2005).
Monitoring Interval (years)	N/A
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A Classification of Hydric Montane Meadows of Sequoia National Park, California

Halpern, C.B. 1985. Hydric montane meadows of Sequoia National Park, California :a literature review and classification. USDI Cooperative National Park Service Resources Study Unit, Western Region, University of California., Davis. Technical Report No. 20. 87 pp.

Halpern, Charles B. 1986. Montane meadow plant associations of Sequoia National Park, California. Madrono. 33(1): 1-23.

Objectives	To provide an inventory and classification of montane meadows in Sequoia and Kings Canyon National Parks.
Objective Significance	This study, together with Benedict's research (Benedict 1982, Benedict and Major 1982, Benedict 1983), provided an early and substantial contribution to the classification of meadows in Sequoia and Kings Canyon National Parks.
Methodologies Used	Relevé method for vegetation sampling. 81 relevés were sampled in 1982. Relevés were assessed in circular plots 250-500m ² (Halpern 1985, Halpern 1986). Sampling was conducted in a total of 22 meadows. Monitoring wells were used to determine the depth to water table in Log and Crescent Meadow, Eight wells were installed in each meadow, perpendicular to the long axis of the meadow. Locations were chosen subjectively to represent particular plant associations. Water table depth was monitored bi-weekly from July 6 to Nov 8.
Data Collected	1) Ocular estimation was used to provide data on vegetative cover by species. 2) Cover estimates were made of the various substrate types: bedrock, loose rock, mineral soil, coarse and fine litter, moss and lichen. 3) Elevation, slope, aspect, landform, topography, and hydrologic features were recorded. 4) Depth to water table was recorded in two meadows. Soil water oxygen and water temperature measurements were taken in both meadows in early July.
Analysis	Cluster analysis and ordination were used to classify plant communities. TWINSpan was used to provide information on indicator species. DECORANA was used for Detrended Correspondence analysis (DCA).
Monitoring Interval (years)	N/A
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Monitoring of Special Aquatic Habitats in the Sierra Nevada, California

Pacific Analytics, L. L. C. 2001. Literature synthesis and recommendations for the categorization and monitoring of special aquatic habitats in the Sierra Nevada, California- final report. Prepared for the USDA Forest Service, IBET Province, Eldorado National Forest, Albany, OR.

Objectives	To evaluate the division of special aquatic habitats of the Sierra Nevada into (1) springs/seeps, (2) bogs/fens, (3) small ponds, and (4) vernal pools, and to evaluate the preliminary monitoring variables for each habitat category.
Objective Significance	The Sierra Framework Project Monitoring Team of the USDA Forest Service had divided special aquatic habitats into the four groups described above. This classification scheme was based predominantly on water quality and vegetation characteristics (Pacific Analytics 2001). This report was intended to serve as an independent assessment of the classification scheme and monitoring attributes for each class.
Methodologies Used	Monitoring attributes were chosen and recommended based on their utility in the following three categories: 1) mapping and inventory, 2) basic explanatory variables (condition), and 3) biotic attributes (integrity) (Pacific Analytics 2001).
Data Collected	Authors gave recommendations for monitoring attributes for each of the four habitat types. Here is a summary of the recommendations: 1) basic environmental factors such as average and minimum/ maximum temperatures, rainfall, and humidity. 2) hydrological factors: water depth, area or extent, and timing of inundation, and water persistence. 3) Peat depth 4) Water temperature, conductivity (fens only), dissolved oxygen, pH, and turbidity 5) Calcium concentration (fens only) 6) frequency, intensity and extent of disturbances such as fire, grazing, mining, and visitors. 7) presence/absence of all vascular plant species 8) populations of both exotic and sensitive species. 9) All invertebrate species that are listed by the U.S. Fish and Wildlife as Threatened or Endangered, all proposed and candidate species, and all invertebrates listed by the California Department of Fish and Game as rare, threatened, or endangered 10) non-indigenous invertebrates (Pacific Analytics 2001)
Analysis	A short evaluation of the appropriateness of a given attribute was provided for each of the preliminary monitoring attributes being considered by the Sierra Framework Project Monitoring Team.
Monitoring Interval (years)	None was recommended
Key Contacts	Pacific Analytics, L.L.C. P.O. Box 219 Albany, Oregon 97321 541-926-0117 www.statpros.com

USFS RNA Monitoring Protocol, Oregon

PNW Forestry Sciences Lab. 1993. RNA monitoring protocols, Oregon. USDA Forest Service, Corvallis, OR.

Objectives	To describe and monitor the transition zone between vegetation types
Objective Significance	The RNA protocol calls for a circular plot in terrestrial systems where vegetation is more homogeneous. The ecotone method is used to cover situations (like wet meadows and other wetland types) that are more heterogeneous and whose habitats occur along a gradient from aquatic to terrestrial.
Methodologies Used	Ecotone Transect- In meadow-type situations, we have set up transects across ecotones, thus from the interior of a meadow into a forest, from the interior of a wetland into the forest, etc. The transects are generally about 100m long. We measure herbs, shrubs and trees (Greene 2006). 1) 2-3 transects are placed, randomly, and perpendicular to the ecotone. 2) Variable-width belt transects (5-10 m) are used to measure trees ≥ 5 cm dbh, snags and saplings. 3) Saplings are also tallied in a belt which may or may not be the same width as the tree/snag belt. Species and meter mark are noted for each sapling in the breast height to 4.9cm dbh category. 4) Line-intercept is used to measure shrubs and coarse woody debris. Species, where possible, decay class and meter mark are noted. 5) For coarse woody debris, the intercept diameter (minimum 10 cm) is measured for volume estimates 6) Daubenmire microplots (0.5 x 0.2 m) are used to characterize ground vegetation and substrate. They are located to and on the left side of the transect. A minimum of 40 microplots are used, but more are used in ecotones with more abrupt changes in vegetation (Daubenmire 1959, PNW Forestry Sciences Lab 1993).
Data Collected	1) Count of trees by species which are ≥ 5 cm dbh and within transect 2) Percent cover of shrubs by species 3) Number of saplings encountered along transect 4) Number of snags encountered along transect 5) Percent cover of vascular plants by species, mosses and lichens as a group. "Herbs, grasses and grass-like plants are tallied by species in the microplots. The two seedling classes are both tallied (estimated if numerous) and given a per cent cover. Mosses and lichens are done as groups unless field personnel are trained in their identification. 6) Exposed substrate characteristics are also taken by category: rock (≥ 8 cm), gravel, bare ground, erosion pavement, coarse litter (≥ 10 cm), fine litter (<10 cm). Rock or coarse litter covered by moss or lichen is tallied under both categories. Moss and lichen may optionally be sub-sampled by substrate as well" (PNW Forestry Sciences Lab 1993).
Analysis	None provided
Monitoring Interval (years)	?
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EPA's Method of Using Vegetation to Assess Environmental Conditions in Wetlands

US EPA. 2002. Methods for evaluating wetland condition: study design for monitoring wetlands, EPA-822-R-02-015. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

US EPA. 2002. Methods for evaluating wetland condition: developing metrics and indexes of biological integrity, EPA-822-R-02-016. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

US EPA. 2002. Methods for evaluating wetland condition: using vegetation to assess environmental conditions in wetlands, EPA-822-R-02-020, Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Objectives	States will need to develop monitoring programs to monitor water quality and condition of wetlands. This document outlines three sampling approaches that may be used either in isolation or in concert to meet specific monitoring objectives. "Stratified random sampling might be good for ambient monitoring programs, BACI for evaluating restoration, and targeted sampling for developing an Index of Biological Integrity or nutrient criteria thresholds. In fact, some State programs will likely need to use a combination of approaches" (US EPA 2002b).
Objective Significance	The methods below, from the Study Design for Monitoring wetlands, are best considered within the context of the other listed EPA modules: Developing Metrics and Indices of Biological Integrity (IBI) (US EPA 2002a) and Using Vegetation to Assess Environmental Conditions in Wetlands (US EPA 2002c). The former has been referenced by authors who have developed and tested IBIs for specific wetland systems; the latter discusses specific sampling strategies (quadrat, relevé and transect methods) and an overview of steps leading up to the selection of metrics for IBIs. These documents together present guidelines and various components of monitoring plans from which States can choose and tailor to fit their unique monitoring questions. Although these documents fall outside the scope of monitoring plans for the Western United States, they are included because many programs have been directly or indirectly influenced by EPA's recommendations.
Methodologies Used	Suggestions for Sampling Design: Stratified random sampling 1) Random selection of wetland systems from entire population within a region. 2) System characterization for a class of wetlands is more statistically robust. 3) Rare wetlands may be underrepresented or absent from sampled wetlands. 4) This design is potentially best for regional characterization of wetland classes, especially water quality conditions are unknown. Targeted/tiered approach (recommended for IBI development) 1) Targeted sampling is a specialized case of random stratified sampling and is based on problematic (wetland systems known to have problems) and reference wetlands. 2) A stressor (or disturbance) gradient is defined, and then wetlands are grouped into classes (e.g. most, moderately, and least impaired). The EPA uses the following categories: degraded, high-risk, low-risk, and reference site (US EPA 2002b).

	3) Wetlands are then randomly selected within each class and risk category for monitoring. 4) This design may miss important wetland systems if they are not selected for the targeted investigation. 5) This design is potentially best for site-specific and watershed-specific criteria development when water quality conditions for the wetland of interest are known. Before/after, control/impact (BACI) 1) Selection of wetlands based on a known impact. 2) An ideal impact survey has several features: The type of impact, time of impact, and place of occurrence should be known in advance; the impact should not have occurred yet; and control areas should be available (Green 1979)(US EPA 2002b). In practice, impacts are rarely known in advance. 3) "BACI designs modified to monitor impacts during or after their occurrence can still provide information, but there is an increase in the uncertainty associated with the results, and the likelihood of finding a statistically significant change caused by the impact is much less probable" (US EPA 2002b). 4) A specific example of this type of set-up is the area-by-time factorial design (e.g. Two wetlands are sampled, one adjacent to clearcut and the other not. Both wetlands are sampled before and after the clearcut) (US EPA 2002b). In this example, a lack of replication precludes extrapolation to other areas. 5) "The simple BACI design was extended by Stewart-Oaten et al. (1986) by pairing surveys at several selected time points before and after the impact to help resolve the issue of pseudoreplication (Hurlbert 1984). This modification of the BACI design is referred to as the BACI-paired series (PS) design" (US EPA 2002b). In this case, time-series analyses or repeated measures analysis must be used to avoid type I errors associated with a lack of independence between samples. 6) The information gained in this type of investigation is not transferable to wetland systems not included in the study. 7) This design is potentially best for monitoring restoration or creation of wetlands and systems that have specific known stressors. Creation of IBI Indices: 1) Classify wetlands into broad types for the purpose of stratification. 2) Define reference conditions against which other wetlands of the same type can be compared. 3) Select wetlands that represent the full range of human disturbance. 4) Establish standard field sampling methods. 5) Choose metrics (attributes of plant composition) to include in index for biological assessment (US EPA 2002c). 1) Evaluate attribute performance across disturbance gradient 2) Select metrics from best-performing attributes 3) Score individual metrics (e.g. 5,3,or 1; several schemes provided) 4) Calculate total IBI scores for each site 5) Interpret IBI scores and report data (after Karr et al 1986)
Data Collected	N/A
Analysis	N/A
Monitoring Interval (years)	N/A
Key Contacts	http://www.epa.gov/ost/standards http://www.epa.gov/owow/wetlands/bawwg

