Literature Synthesis and Recommendations for the Categorization and Monitoring of Special Aquatic Habitats in the Sierra Nevada, California

Final Report

Prepared for

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TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

This report represents the deliverable product resulting from Task Order Number 1 of a Statistical and Ecological Services Agreement under Contract No. 53-91U9-1-1C15, made between the USDA Forest Service and Pacific Analytics, LLC.

In the initial phase of this project, Pacific Analytics reviewed the relevant literature on categorization and monitoring of special habitats available in several electronic literature databases. Special attention was paid to the Sierra Nevada region, although pertinent literature from other regions of North American and abroad were considered as well.

This report describes the process of literature selection and review. Discussion of the literature as it relates to the problem is provided. Literature regarding four special aquatic habitats was reviewed. In the discussion of the literature we present key attributes for each habitat, followed by a discussion of the important physical, floral, and faunal attributes of the habitats. Finally, where appropriate, a discussion of the major disturbance factors is included.

Following the habitat literature reviews is a narrative regarding the criteria for selecting monitoring attributes and an evaluation of the proposed habitat categories. Based on our preliminary assessment of literature, it appears that the habitat classification scheme proposed by the Sierra Nevada Framework Project Monitoring Team is appropriate, although more monitoring variables should be included.

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Monitoring Special Aquatic Habitats

I. Executive Summary

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Included in this report is an in-depth discussion of monitoring and monitoring recommendations, and a summary list of specific monitoring recommendations with brief justifications.

Acknowledgements and a complete bibliography follow the recommendations chapter.

II. INTRODUCTION

Water resources of the Sierra Nevada are vital to the economy and biological diversity of California. The water runoff from the Sierra Nevada Mountains supplies a major share of water and hydroelectric power to the California's agriculture, urban centers and industry, supports vast areas of wetland habitats, and ultimately sustains the estuary ecosystem of the Sacramento-San Joaquin Delta (Erman 1996, Jennings 1996, Kattelmann 1996, Moyle 1996). The Sierra Nevada ranks as a "globally outstanding" ecoregion due to its unusually high organismal species richness and endemism (DellaSala 1999). As much as 25% of species of some of California's aquatic invertebrates including stoneflies (Plecoptera), and mountain midges (Diptera), and 20% of mollusks are endemic to the Sierra Nevada (Erman 1996). Almost 50% of amphibians inhabiting the Sierra Nevada are endemic to this region (Jennings 1996). Diverse aquatic habitats of the Sierra Nevada also support a high number of sensitive species.

The biota of special aquatic habitats such as bogs, fens, springs, seeps, mountain ponds, small first- and second-order streams, and vernal pools forms a significant component of the overall biological diversity of the Sierra Nevada and the State of California. These habitats provide unique microhabitat environments for assemblages of sensitive species. For example, the habitat distribution of the California pitcher plant (*Darlingtonia californica*) is restricted by the availability of cool running water conditions found in perennially wet fen seeps (Coleman and Kruckeberg 1999, Nyoka and Ferguson 1999). *Senecio clevelandii* grows on serpentine spring seeps in the Sierra Nevada (Jepson 1957, Harrison et al. 1999) and the western lily (*Lilium occidentale*) can be found in bog habitats (Mize 1990). The highly endemic Yosemite toad (*Bufo canorus*), and the mountain yellow-legged frog (*Rana muscosa*) require high-elevation ponds as breeding habitats (Jennings 1996, Shaffer et al. 2000, Knapp and Matthews 2000). Vernal pool complexes scattered throughout the western foothills of the Sierra Nevada support numerous sensitive species of plants and animals including the Butte County meadowfoam (*Limnanthes floccosa californica*), Boggs Lake hedge-hyssop (*Gratiola heterosepala*), conservancy fairy shrimp (*Branchinecta conservatio*), or the California tiger salamander (*Ambystoma californiense*) (Anonymous 1997, Keeler-Wolf et al. 1998).

Special wetland habitats also have a great historical value. Native Americans frequently used vernal pools as food-gathering and ceremonial sites (Anonymous 1997), and the preserved vegetation remains in peatlands can serve as indicators of climate changes and the succession and evolution of surrounding habitats (Erman 1976, Klimanov and Sirin 1997, Weltzin et al. 2000). Fens in Sierra Nevada meadows also have significant recreational values (Bartolome at el. 1990).

Despite their great economic and biological values, aquatic habitats are the most threatened ecological communities in California (Jensen et al. 1990). The Sierra Nevada is no exception to this trend as indicated by a decline in the local populations of indigenous species of fish (Moyle and Williams 1990, Moyle et al. 1996), amphibians (Jennings 1996), and aquatic invertebrates (Erman 1996). For example, Jennings (1996) warns that small aquatic habitats of the Sierra Nevada such as springs, seeps and bogs are the most affected aquatic habitats that support imperiled amphibian taxa.

The Sierra Nevada Framework Project Monitoring Team of the USDA Forest Service has made preliminary decisions for monitoring special aquatic habitats in the Sierra Nevada, California as part of an effort to build a knowledge database to evaluate the integrity and sustainability of these biological resources. The Team has grouped special aquatic habitats into four major groups comprising (1) springs/seeps, (2) bogs/fens, (3) small ponds, and (4) vernal pools, and has selected preliminary monitoring variables for each habitat category. This current classification scheme is based predominantly on water quality and habitat vegetation characteristics. These and other attributes need review and evaluation as monitoring variables.

The USDA Forest Service, IBET Province – Eldorado National Forest has contracted with Pacific Analytics, LLC to provide statistical and ecological services to assist the Sierra Nevada Framework Project Monitoring Team. Services will be provided through a series of Task Orders that will be individually negotiated within the framework of Contract No. 53-91U9-1-1C15. In Task Order 1, the Forest Service has asked Pacific Analytics to provide literature review of special aquatic habitats. The primary objective of this review was to identify a sound ecological basis for categorization and monitoring attributes of these aquatic communities. Consequently, findings of this review should aid in evaluating the decisions made by the Sierra Nevada Framework Project Monitoring Team, and, if appropriate, provide suggestions for alternative monitoring attributes.

III. METHODS

We broadly searched the ecological literature for studies focusing on the description, functional role, conservation, monitoring and management of special aquatic habitats including peatlands, spring seeps, ponds and vernal pools using standard publication search engines (Agricola 1984-2001, CAB Abstracts 1984-2001, Biological Abstracts 1990 – 2001, and Zoological Records 1993-1999). Although the primary focus of the literature search was on the Sierra Nevada Region in California, we included studies from other geographic regions of North America, and the world. The search string was comprised of the names of special aquatic habitat categories and key words “monitoring” and “management.” The results of this search produced records from worldwide literature. To obtain records directly relevant to the Sierra Nevada, and California, we further crossed the original search string with these geographic names (Table 1).

The results of the electronic literature searches in individual databases (n = 467 records) were imported into a ProCite® (Version 5, ISI ResearchSoft 1999) database where the bibliography records were sorted alphabetically in an AUTHOR / TITLE / DATE hierarchy, and numbered in ascending order. A total of 112 duplicate records were removed from the database, thereby reducing the database holdings to a total of 355 unique records. We also extensively consulted our own bibliography databases, the OASIS database of the Oregon State University library, literature citation lists in published articles obtained during the electronic search, and those provided by aquatic monitoring experts to obtain additional records. All records were evaluated for their relevance to the research on special aquatic habitats in the Sierra Nevada. Attention was given primarily to unique habitat characteristics of special habitats that would create sound ecological basis for their categorization. General literature on monitoring and management of wetland habitats was also reviewed.

IV. RESULTS

The preliminary search of two sets of electronic bibliography media including AGRICOLA, CAB Abstracts, Zoological Records, and Biological Abstracts media produced a total of 13,155 and 8,858 bibliography records, respectively, on special aquatic habitats worldwide (Table 1). Each of these records contained reference to at least one special aquatic habitat keyword. These are surprisingly high numbers considering the fact that we reviewed only that fraction of the relevant literature published in the past 20 years. Although a large portion of these records focused on extraneous topics including aquaculture ponds, sludge treatment ponds, or marine cold seeps and vents, a major effort would was required to process this amount of literature.

A total of 467 records appeared to be applicable to special aquatic habitats in California. This number was further reduced to 355 records after the removal of 112 duplicates. Despite the vast amount of literature on special aquatic habitats reported worldwide, we found only 6 records that were relevant to the Sierra Nevada suggesting a general lack of information on these types of biological communities in this ecoregion (Table 1). Our search string did not include the key word "spring" in order to simplify the initial assessment of the literature. A literature search based on this keyword alone produced a total of 76,207 and 33,627 records in both sets of databases, respectively, and the results were highly ambiguous owing to the multiple meanings of this search term.

Table 1. Results of the preliminary literature search on special aquatic habitats in electronic bibliography media.

Main search term	Electronic database / No. retrieved bibliography records per region					
	AGRICOLA (1984 – 2001) CAB Abstracts (1984 – 2001) Zoological Records (1993-1999)			Biological Abstracts (1990 – 2001)		
	Worldwide	California †	Sierra Nevada †	Worldwide	California †	Sierra Nevada †
Pond	7296	251	2	5675	90	2
Bog	2690	22	1	1587	4	0
Fen	2161	14	1	1059	1	0
Peatland	1311	3	0	704	0	0
Seep	216	20	0	253	18	0
Vernal pool	35	27	0	38	22	0
Pond OR bog OR fen OR peatland OR seep OR vernal pool	13155	332	4	8858	135	2
[Pond OR bog OR fen OR peatland OR seep OR vernal pool] AND monitoring	205	15	0	189	5	0
[Pond OR bog OR fen OR peatland OR seep OR vernal pool] AND management	2125	73	0	2249	51	1

† The main search term combined with the name of the state or ecoregion.

V. DISCUSSION

The discussion of Special Aquatic Habitats is organized as follows:

(1) A discussion four habitat reporting unit categories proposed by the Sierra Nevada Framework Project Monitoring Team. Based on the information from the review, key distinguishing characteristics (physical, floral, faunal) of these habitats, and major types of disturbance that may affect their habitat integrity are identified and discussed,

(2) A discussion ecological criteria for selecting monitoring attributes,

(3) A summary of the major findings and with an evaluation of proposed categories and ecological justification for the separation. Comments on the rarity and conservation status of special habitat categories in the Sierra Nevada are also included.

V-1. Peatlands (Fens and Sphagnum Bogs)

Fens and bogs (peatlands) are small wet meadows that form a distinctive and uncommon habitat type in the Sierra Nevada. These habitats, typically surrounded by mixed conifer forests, are important recreations sites that support a specialized flora and fauna (Bartolome et al. 1990). Peatlands are also important because they can affect water and sediment yield to streams (Costin 1967, Bay 1969). In California, where they are associated with nearby perennial springs, peatlands can affect ionic balance and organic matter concentrations (Erman and Erman 1975). Plant succession and human disturbance have a strong impact on the quality of these meadows, and concern has been expressed about changes in these habitats caused by the invasion of pines and other plant species, and the impacts of human disturbance (Anonymous 1972).

Peatlands are also considered important because they are repositories of considerable ecological history (Erman 1976). The structure of ancient plant communities and the climate in which they occurred can be reconstructed from preserved plant remains. The chronology of their succession is also contained in peatlands. Interpretation of the information preserved in peatlands will require further understanding of the way peatlands grow, change and function (Walker and Walker 1961). Conservation of these habitats will preserve this information until such time that scientists have learned enough about the systems to interpret the data.

V-1.1. Classification of Bogs versus Fens

Peatland habitats (bogs and fens) generally develop in either topographically flat areas, river valleys, or surface depressions (Hofstetter 1983, Siegel 1988), where annual precipitation rates exceed the amount of evapotranspiration (Gorham 1957, Ivanov 1983). According to Moyle's (1996; p. 950) classification of aquatic habitats of the Sierra Nevada, Sphagnum bogs are marshy wetlands with carnivorous plants and ranid frogs, whereas fens are minerotrophic, spongy peatlands dominated by non-sphagnum mosses and sedges located on hillsides and fed by spring water.

The main source of water for bogs is from precipitation (ombrotrophic habitats), whereas the fen hydrology is regulated by a combination of flowing groundwater discharge and precipitation (minerotrophic habitats; Erman and Erman 1975, Erman 1976, Siegel 1988). As a result, the surface water of bogs is dilute, acidic), and poor in minerals, whereas the pH and mineral concentration of fen waters are similar are similar to those of groundwater (Erman and Erman 1975, Erman 1976, Glaser et al. 1981, Heinselman 1970, Siegel 1988).

All fens studied in the Sierra Nevada appear to be hydrologically connected with perennial springs and seeps (Erman and Erman 1975, Erman 1976), and thus identification, mapping and monitoring could be included in peatland surveys. Streamflow from fens are more uniform than from bogs, due to a constant input of ground water into the former (Verry and Boelter 1978, Siegel 1988).

Bogs and fens have fundamentally different plant community composition, hydrology, nutrient availability, and soil chemistry (Moore and Bellamy 1974, Gore 1983, Bridgham et al. 1996, 1998). Some research has presented evidence that bog and fen plant communities may change in different directions and magnitudes in response to warming and changes in water table elevation (Welzin et al. 2000). This information needs to be carefully understood and considered before lumping bogs and fens into a single category.

V-1.2. Peatland Attributes

The natural features of peatlands have received little attention in California (Erman 1976). Scientists around the world have studied both physical attributes (peat depth, area, topography, water chemistry), and biotic attributes (carnivorous plants, vegetation, vertebrates, and oligiochetes and other invertebrates) of peatlands in regions outside of California.

Physical Attributes

Peat cores have been used to investigate the evolution of fen habitats. In the fens of the Sierra Nevada for which information is available, average peat depth is 17.3 to 84 cm, with some peat deposits as thick as 416 cm (Erman and Erman 1975, Erman 1976). Changes in the peat depth can be an indication of down slope movement and extension of fens. The thickness of the peat layer buffer affects exogenous factors, protects the integrity of the habitat, and is also a good predictor of the biomass of associated invertebrate fauna (Erman 1976).

Increases in peat depth usually mean less contact of vegetation with mineral rich water and a succession toward bog (less productive, more acidic) conditions (Gorham 1957, Heinselman 1970). Oligochaete production increases with increasing peat depth at least over the range from 17.3 to 87.4 cm (Erman and Erman 1975). This may be due to the greater buffering capacity afforded by deeper than shallow peats. Chironomid and ceratopogonid production were not correlated with peat depth (Erman and Erman 1975).

Detailed ecological classifications of bogs and fens have used both water chemistry and vegetation as discriminating criteria (Siegel 1988, Chadde et al. 1998). Temperature, pH, conductivity, dissolved oxygen, alkalinity, hardness, total and orthophosphate, nitrate, and silica are some of the attributes measured (e.g. Main and Busch 1992, Chadde et al. 1998). Bog and fen vegetation very sensitive to changes in pH and concentrations of calcium and other nutrients (Clymo 1973). For example, a study of northern Rocky Mountains peatlands found poor fens had bog like conditions with low pH (4.2 to 5.8), and a calcium concentration of 2 to 10 mg/l. Rich fens had very high pH (>7), and calcium concentrations > 30 mg/l (Glaser 1987).

Floral Attributes

The predominant vegetation species of bogs are *Sphagnum* mosses and ericaceous shrubs adapted to acidic surface water conditions (Siegel 1988, Weltzin et al. 2000). Non-ericaceous shrubs, sedges (*Carex* spp.), and a variety of mosses such as *Drepanocladus aduncas* (Hedw.) and *Cratoneuron filicinum* (Hedw.) are also found in fen habitats (Erman 1976, Siegel. 1988, Weltzin et al. 2000). Since fens are small wet meadows, they show vegetation similarities to other Sierra Nevada meadows (Bartolome et al. 1990). In contrast to Sphagnum bogs, fens are fairly abundant peatlands in the Sierra Nevada (Erman and Erman 1975). Erman and Erman (1975) found a great overlap in faunal composition between fens and oligotrophic lakes. It is plausible that monitoring procedures for lakes could be partially applicable to fens. Charlet and Rust (1991) suggest that bogs can locally become critical habitats to some avian species including the Golden Eagles (*Aquila chrysaetos*).

In an extensive study of fans in Iowa, over 225 peatland plant species were identified (Pearson and Leoschke 1992). *Carex stricta* and *Eupatorium maculatum* were the most common graminoid and forb species, respectively, and *Solidago* spp. commonly occurred on disturbed sites. Several vascular plant species in the western United States have been identified as indicators of peatlands in Iowa (Holte 1966, Pearson and Leoschke 1992), in Minnesota and Wisconsin (Eggers and Reed 1987), Montana (Mantas 1993, Chadde and Shelly 1995), and the Northern Rocky Mountains (Chadde et al. 1998). The lists are extensive and the literature should be consulted for complete details.

Plants can be indicators of water quality, and habitat condition and integrity (Chadde et al. 1998). For example, dense stands of sedges, spike rushes, and other grasslike plants are believed to indicate nutrient rich soils in Rocky Mountain peatlands (Chadde et al. 1998). After comprehensive inventories of peatlands in California are complete, vascular plants are certain to be discovered that are good indicators of biotic integrity of these special habitats as well.

Diatoms are algae that have been shown to provide an excellent means of documenting water quality characteristics (Patrick 1968, Main and Busch 1992). The diatoms present in peatland habitats change in response to the chemical and physical properties of the water itself and are good monitoring attributes (Main and Busch 1992). Diatoms accurately reflect water conditions such as conductivity, alkalinity, and hardness, but do not respond quickly to pH (Main and Busch 1992).

Faunal Attributes

There is a limited life zone for invertebrates in the fen because oxygen extends down only a few centimeters (Erman and Erman 1975). During studies of peatland invertebrates, scientists have measured elevation, area, peat depth, July aerobic limit, dissolved oxygen, temperature, pH, Ca^{+2}, Mg^{+2}, and looked for correlations with invertebrate species presence and abundance (Erman and Erman 1975). Monitoring attributes will be difficult to select before comprehensive inventories of invertebrates in Sierra Nevada peatlands are made, and compared to studies in other regions.

While the fauna of European peatlands has been studied extensively (Harnisch 1929, Macfadyen 1952, Nielsen 1955, 1961, Cragg 1961, Banage 1963), little work done on fauna of bogs, fens and other peatlands in the United States (Erman and Erman 1975). The invertebrates of some peatlands in California have been studied in detail (Erman and Erman 1975), but much information remains to be collected about the species of insects that depend on peatland conditions for survival. Some of these invertebrates are important pollinators of some rare plants have been studied in detail (e.g. *Darlingtonia californica* Torr., Nyoka and Ferguson 1999). Others may serve ecological functions such as recycling nutrients and controlling invasive plants and be good indicators of processes and functions that contribute to habitat integrity (Karr et al. 1986).

In a detailed study of a Sierra Nevada peatland near Sagehen Creek, scientists recorded at least nineteen species of the macroinvertebrates (Erman and Erman 1975). Aquatic Oligochaetes were the most abundant invertebrate group, followed by flies (Chrinomidae and Ceratopogonidae) and nematodes. Nematode numbers were as high as 1,053 m^{-2} and sometimes had higher densities than chironomids. The results of this study showed that Oligochaete production generally increases with peat depth, but that dipteran production was not correlated with peat depth. The scientists concluded that Oligochaete survival probably declines in shallow fens but that Diptera species are probably less susceptible to extreme environmental changes.

Studies in northern Rocky Mountain peatlands found a large diversity of macroinvertebrates (Rabe and Savage 1977, Rabe et al. 1986, 1990, Rabe and Chadde 1995). This indicates that many more macroinvertebrates will be found associated with California peatlands. Inventories of peatland macroinvertebrates will probably be necessary before specific monitoring questions of interest can be developed.

V-1.3. Major Disturbance Factors

It has been suggested that wet meadows, including fens, are relatively stable ecological systems sensitive only to changes in their physical environment, primarily hydrology (Benedict 1982, Bartolome et al. 1990). Nevertheless, due to a paucity of studies on the hydrology of peatlands, it is very difficult to predict the cumulative effect of disturbances on their hydrologic functions (Siegel 1988). Some research has suggested that only a minute amount of groundwater input (a few percent by volume) may significantly alter the water chemistry of bogs, and trigger transgression of bog vegetation by fen species

(Siegel 1983, 1988). For example, Clymo (1973) suggests that fen vegetation can out compete *Sphagnum* mosses at levels of pH above 4.5.

Water levels and nutrient concentrations of incoming water are identified as the two most critical factors affecting the abundance and distribution of peatland species in the northern Rocky Mountains (Chadde et al. 1998). Factors like fire, drought, and beavers bring periodic changes in these two factors and consequent shifts in location and abundance of peatland species. Direct impacts that may threaten the integrity of peatland ecosystems and associated plant and animal populations include ditching and drainage, peat mining, livestock grazing, water flow regulation, and invasion by exotic plant species. Livestock grazing causes trampling and removal of vegetation and may result in soil compaction and altered hydrologic conditions.

Indirect effects may be changes in water chemistry. Removing beaver from peatlands may have negative impacts on the overall functioning of the ecosystem. Long-term static water levels can lead to the gradual depauperization of the flora in peatlands (Crum 1988, Chadde et al. 1998). System integrity may potentially be threatened by adverse alteration of hydrologic regimes and nutrient regimes. Off-site management activities like timber harvest, road building and livestock grazing that alter hydrologic and nutrient regimes may also adversely impact peatlands (Chadde et al. 1998).

Grazing appears to affect fens in two general ways: 1) by modifying the vegetational structure of the plant community through selective utilization of plant species and 2) by altering the physical structure of the wetland by trampling (Pearson and Leoschke 1992). Selective grazing of palatable grasses and forbs appears to increase the relative abundance of *Carex stricta* and *Helianthus grosseserratus*, both of which posses coarse, scabrous foliage of low palatability to cattle (Pearson and Leoschke 1992). Heavily grazed fens may become hummocky, often exhibiting pedestals crowned by coarse sedges and surrounded by trenches up to 1 m deep (Pearson and Leoschke 1992). Once established, extremely hummocky terrain may persist for many years, even after cattle are removed (Pearson and Leoschke 1992, Cicero 1997). Grazing has also been found to disturb nesting sites of the Montane Lincoln's Sparrow, because of their tendency to nest on or near swampy ground in boggy meadows (Grinell and Miller 1944, Austin 1968, Cicero 1997). This bird may be useful as an indicator of site wetness and excessive grazing.

During dry periods, cattle may walk into fens and bogs and considerable compaction can occur. The compaction may influence hydrologic patterns because pathways are worn into the peat that change permeability and alter the flow of water. The pathways can also develop into surface drainages when wetter conditions return, and act to drain the fen (Thompson et al. 1992). Livestock grazing can alter natural hydrologic regimes by increasing runoff and exacerbating erosion and gullying, and thereby lowering the groundwater table (Rauzi and Hanson 1966, Cicero 1997). Damage caused by sheep includes trampling of herbaceous vegetation and browsing of willows (Cicero 1997).

Woody plant expansion has been suggested as a potential threat to fens and bogs. Recommendations for the control of woody plants include prescribed burning (Wilhelm 1978, Kohring 1982, Schennum 1983, McGrath 1988, Skinner 1988, Warners 1989, Rooney 1990, Carpenter 1990a). While it appears to be effective in some cases, burning may have significant impacts on fens (Kohring 1982, Warners 1989, Carpenter 1990). Research on the effects of fire on rare plants, mosses, and invertebrates in fens is needed (Pearson and Leoschke 1992).

Although invasions of trees such as lodgepole pine (*Pinus contorta*) into peatlands are apparent in the Sierra Nevada, research has shown that tree invaders do not persist in the vicinity of peatlands and are natural components of vegetation dynamics in these systems

(Bartolome et al. 1990). While tree invasions could be monitored, no direct management decisions are likely to be necessary.

Impacts from mining are also a concern in the Sierra Nevada. Mining could conceivably impact fens by direct destruction through excavation or earthmoving or indirect destruction via disruption of the surrounding hydrological system (Pearson and Leoschke 1992).

V-2. Wetland Springs and Seeps

From a hydrological perspective, springs are regarded as concentrated points of natural groundwater discharge at a rate high enough to maintain surface flow (van Everdingen 1991, Williams and Williams 1999). Often, several springs combine to form a meadow stream (Moyle 1996). Some springs however, are associated with very shallow or small aquifers, which, when exhausted may result in intermittent or periodic surface flow. At peak flow, springs and seeps are commonly associated with zones of saturated soil and mosses that provide habitat for many aquatic and semiaquatic invertebrate species (Danks and Rosenberg 1987).

Scientists consider seeps as drainage components of fens (Verry and Boelter 1978, Erman 1984), or sources of mineral rich water for these peatlands (Erman 1976). Tiner (1999) refers to these aquatic habitats simply only as “conditions,” or precursors that favor the development of different palustrine wetlands such as bogs, fens and ponds. Sierra Nevada seeps and springs can emerge from porous serpentine rock and traverse areas of sandy or gravelly soil that retain moisture and create habitat for plants and animals (Harrison et al. 1999).

Spring discharge often represents rain or snowmelt that entered the ground years earlier at higher elevations, usually some distance from the spring. Discharge from freshwater springs is used for domestic water supply, irrigation, or as "mineral water". Any special plant or faunal associations that depend on the year-round water supply, constant temperature, microhabitat, or dissolved minerals provided by springs will be adversely affected if the discharge from springs is diverted for domestic uses or disturbed by human activities (Everdingen 1991). In the Sierra Nevada, grazing and off road vehicles disturb spring and seep habitats and a high proportion of exotic species found at a site may be the result of long-term disturbance (Fiedler and Leidy 1987).

V-2.1. Wetland Spring and Seep Attributes

Sierra Nevada springs and seeps occur in wetland habitats with clear and cold constant water temperature and flow. Large groundwater reservoirs buffer the conditions and help to maintain the stable conditions (Danks and Williams 1991). Scientists have found that these habitats can harbor endemic groups of invertebrates (Erman 1996, Moyle 1996). In Canada, a study was initiated in the 1980's to investigate invertebrates associated with springs and seeps (Williams 1983, Williams and Williams 1999), but, except for taxonomic and behavioral studies of a few plant and invertebrate taxa, the floral and faunal components of these habitats in California are little-known (Jewett 1966, Sheldon and Jewett 1967, Surdick 1981, Erman 1984, Fiedler and Leidy 1987, Erman 1989).

Physical Attributes

Regionally, the physical conditions in springs can vary greatly because many different geological and ecological conditions may intersect in any given spring (Danks and Williams 1991). In springs near Sagehen Creek, average water temperature of permanent, constant-temperature springs ranges from 3.5° to 9°C (Erman 1989). Erman (1984) reports that water temperature of spring seeps can vary seasonally, and reach temperatures as high as 10 to 14°C on a hot summer day with oxygen levels from 5.6 to 7.0 mg/l. The pH of spring water can vary from strongly acidic to alkaline (Everdingen 1991), but averages for the Sierra Nevada have not been established.

The rate of groundwater discharge is an indication of groundwater flow, and the chemical composition of spring water reflects the mineral composition of the rock with which the water has been in contact as well as the length of time the water has been underground (Everdingen 1991). Variations in flow rate, temperature, and chemical content can change suddenly during periods of heavy rainfall, when spring water may be diluted with infiltrating, cold, non-mineralized rainwater (van Everdingen 1984). Earthquakes can also cause changes in suspended-solids and discharge rates (van Everdingen 1991).

Springs in Canada have been classified on the basis of water temperature, such as coldwater springs and thermal (hot) springs (Everdingen 1991). Scientists have also measured ground slope, aspect, and topographic position to classify springs (Fiedler and Leidy 1987). Danks and Williams (1991) recommend source geometry, water supply, temperature, chemistry, and persistence as key descriptors of springs.

Floral Attributes

The flora associated with Sierra Nevada Springs and seeps is relatively unknown. In Canada, the vegetation surrounding springs has been shown to modify conditions by shading the water, and providing microhabitats for a variety of invertebrates (Danks and Williams 1991). Scientists that study spring and seep flora measure species composition, percent cover, frequency of occurrence, percentage of total flora, area cover of exotic species, tree and sapling composition, shrub species composition, herb species percent cover, percent of exotics, and percent total plant cover by exotic species (Fiedler and Leidy 1987). These criteria are useful to determine the condition and integrity of these special habitats.

Five habitat specialists of serpentine seeps are *Helianthus exilis, Senecio clevelandii, Astragalus clevelandii*, *Delphinium uliginosum,* and *Mimulus nudatus* (Harrison et al. 1999). Vegetation in spring seeps associated with the Sierra Nevada fens includes primarily *Equisetum arvense*, *Darlingtonia californica*, *Carex* spp., and *Salix* spp. (Harrison et al. 1999). All of these plants are on the California Native Plant Society's inventory of rare and endangered vascular plants (Smith 1981). Small populations may become locally extinct, but this is expected under metapopulation theory (Harrison and Taylor 1997). However, the destruction of even a modest number of populations or habitats may lead to regional extinction of these patchily distributed species (Hanski 1997, Hanski and Simberloff 1997, Harrison and Taylor 1997). Insects may be good indicators of pollination function and therefore biotic integrity of these habitats (Harrison et al. 1999). The plant species may exhibit strong synchronized population fluctuations that may be correlated with habitat conditions, although the conditions that influence population size remain to be described. The scientists studying serpentine seeps suggest that spatial distribution may be very important to the survival of these rare plants (e.g., Harrison et al. 1999).

Faunal Attributes

Spring-formed wetlands are hotspots of biological diversity (Shepard 1993, Sada et al. 1995). Overall, the insect fauna of springs are best represented by Diptera, Coleoptera, Trichoptera, with characteristic representatives from other aquatic groups such as Plecoptera, Odonata, and Emphemeroptera (Danks and Williams 1991, Williams and Williams 1999). In North America, distinctive spring faunas have been described for chironomids (Colbo 1991), empidids (Harper 1980), and caddisflies (Williams 1991b), water mites (Smith 1991), Crustaceans, including ostracodes (Forester 1991), amphipods (Gooch and Glazier 1991), Mollusca (Gooch and Glazier 1991), tricladid Turbellaria (Gooch and Glazier 1991), and other groups (e.g. Hynes 1970). The occurrence and biology of these taxa are less well-known in spring habitats in California, but it is reasonable to assume similar distinctive insect faunas will be discovered in Sierra Nevada springs and seeps (Erman 1984, Erman 1996). For example, 26 species of Caddisflies (Trichoptera) were found to be restricted to small bodies of water such as spring sources, seeps, spring streams, temporary ponds, and intermittent streams (Erman 1989). Because of their special adaptations to conditions, the fauna of springs and seeps may provide useful and meaningful, and relatively inexpensive, indicators for monitoring groundwater quality (Erman 1989, Williams et al. 1990, Williams 1991a).

Trichoptera show a strong affinity to habitat conditions such as water temperature and food availability. Differences in populations may also be due to elevation, groundwater source, and summer temperatures (Williams 1991b). At a regional level, factors such as vegetation, current, substrata particle size, microhabitat diversity, and pH influence Trichoptera assemblage structure (Williams and Williams 1999). Detritus-rich seeps contained species of *Frenesia*, *Lepidostoma*, and *Homophylax*. Scraper and predator species of Trichoptera were most abundant in springs with high microhabitat diversity and pH. Chironomid species also reflect substrata diversity and pH (Williams and Williams 1999).

Habitat conditions can limit the number of species found in springs (Myers and Resh 1999). Mean water depth, turbidity, temperature, ionic concentration, pH, conductivity, sediment organic matter, and redox potential were the most important variables identified that influence aquatic invertebrate distribution and abundance (Mackay 1993, De Szalay et al. 1999, Myers and Resh 1999). Calanoid copepods were more abundant in areas of high turbidity. Other taxa (i.e., cyclopoid copepods, cladocerans, midges, water boatmen, and damselflies) were strongly correlated with low turbidity (Mackay 1993, De Szalay et al. 1999). Odonates were prevalent in water with low sediment organic matter, while calanoid copepods, cladocerans, water boatmen, and Oligochaetes were more abundant when sediment organic matter was high (Mackay 1993, De Szalay et al. 1999). As water temperature increases, the number of aquatic invertebrate species decreases (Lamberti and Resh 1983, Pritchard 19991, Myers and Resh 1999). Many crenophilic mite species exhibit a very narrow tolerance range for environmental factors such as dissolved chemicals and pH, as well as temperature. These species have been suggests as potential biomonitors of environmental change (e.g. Schwoerbel 1959, Young 1969, Smith 1991). Burning is a wetland management technique often applied. De Szalay and Resh (1997) found that water boatmen, midges, and beetles increased in abundance with burning, although other taxa decreased in abundance.

V-3. Aquatic Pond Habitats

V-3.1. Aquatic Pond Attributes

No clear classification category currently exists for ponds. Generally, these aquatic habitats fall into a category of surface water depression wetlands filled with overland flows and precipitation, and the bottom of the depression normally located above the water table (Novitzki 1978). Moyle (1996) recognizes at least three categories of ponds in the Sierra Nevada: (1) mountain ponds, which are small (< 1ha), shallow (< 1.5 m deep) permanent or ephemeral alpine lakes in mountain meadows. In the winter these habitats can freeze solid and become deoxygenated. Ephemeral and permanent ponds studied in the Sierra Nevada range in size from 25 to 300 m^2. These ponds are up to 2 m deep (Soiseth 1992), and their water chemistry is similar to the surface water, with pH values ranging from 5.3 to 7.2 (Soiseth 1992). (2) alpine ponds comprising small oligotrophic lakes found at high elevations formed by glacial and volcanic activities, some of which may be connected to streams with fish, and (3) dystrophic ponds, which are acidic and fishless shallow alpine bodies of water with boggy edges that may become bogs. Cowardin et al. (1979) consider ponds as emergent wetlands. Although these habitats occupy a small proportion of the total acreage, they are some of the most valuable because they serve a concentration points for many floral and faunal species (California Department of Fish and Game 1965, Thomas et al. 1979).

Physical Attributes

Episodic acidification in the Sierra Nevada occurs in alpine wetlands during snowmelt and summer rainstorms (Dozier et al. 1987, Melack et al. 1988, Stohlgren and Parsons 1987). Sierra Nevada surface waters are sensitive to acid deposition because of their dilute chemistry (Melack et al. 1988). The pH is an important physical attribute to measure.

Other important physical attributes include pond maximum length, breath, surface area, and shoreline length maximum depth and percent relative depth, water permanence, sediment depth, temperature, dissolved oxygen, pH, conductivity, turbidity (Marcot 1990). Ultimately found water permanence and successional stage were best to classify ponds (Marcot 1990).

Floral Attributes

Classification based on vegetation characteristics alone was not sufficient to distinguish ponds from other wetlands (Marcot 1990). Typical pond vegetation includes species of *Typha*, *Carex* and *Juncus*, vegetation found in other wetland habitats.

Faunal Attributes

A variety of amphibian species such as the Yosemite toad (*Bufo canorus*), Pacific treefrog (*Pseudacris regilla*) and the mountain yellow-legged frog (*Rana muscosa*) breed in high-elevation ponds (Soiseth 1992, Jennings 1996, Shaffer et al. 2000, Knapp and Matthews 2000). Amphibians are sensitive to pH. Mortality of Pacific Treefrog (*Pseudacris regilla*) tadpoles occurs below pH 5.0 and early developmental stages are most sensitive to low pH (Pierce 1985, Freda 1986). Future emissions of compounds associated with acid deposition are likely to increase, which can influence the distribution and abundance of some Sierra Nevada amphibian species (Soiseth 1992).

Macroinvertebrates are abundant in ponds. They are important in diets of dabbling waterfowl that over-winter in California seasonal wetlands (Batzer and Resh 1992). (Batzer and Resh 1992) examined how temporal change and habitat manipulation influenced macroinvertebrate communities in experimental ponds. They found temporal trends of inverts were not significantly altered by manipulations of water depth or plant cover. Water depth did not significantly affect midge densities. More adult hydrophilid beetles and water boatmen in ponds with 50% less vegetation cover. Mowing and reducing plant cover by 50% increased the numbers of water boatmen, hydrophilid beetles, and possibly amphipods for waterfowl consumption.

Parker and Knight (1992) investigated aquatic invertebrates associated with evaporation ponds used to dispose of subsurface irrigation drain water. They found that the macroinvertebrate and zooplankton assemblage diversity has a negative correlation with salinity (Parker and Knight 1992). They concluded that dissolved minerals are the most likely factor determining biological characteristics of evaporation ponds (Parker and Knight 1992).

V-3.2. Major Disturbance Factors

Monitoring of exotic species, primarily fish is critical to the integrity of pond habitats. These vertebrates have a predominant influence on the structure and integrity of aquatic habitats (Carpenter et al. 1985, Power 1990, Moyle and Ellison 1991, Knapp and Matthews 2000) and some non-indigenous species may out-compete native fauna. For example, introductions of trout into naturally fishless lakes, or ponds connected to stream networks appears to have negative effects on population size of the mountain yellow-legged frog (Knapp et al. 2000). Lawler et al. (1999) documented adverse effects of introduced mosquitofish and bullfrog tadpoles on red-legged frog tadpoles.

Roads also impact pond floral and faunal populations. Road building often alters the physical environment, and soil adjacent to and under the road, soil density, temperature, water content, light levels, dust, surface waters, patterns of runoff, and sedimentation as well as adding heavy metals (especially lead), salts, organic molecules, ozone, and nutrients to roadside environments. Roads also promote the spread of exotic species and the use by humans (Trombulak and Frissell 1999).

V-4. Vernal Pools

V.4.1. Vernal Pool Attributes

Largely endemic to California, vernal pools are ephemeral wetland habitats that form in shallow depressions lined with impermeable soil layer (e.g. hardpan, claypan, volcanic basalt) that restricts the drainage of water and allows the pool to retain water longer than the adjacent upland areas. At the same time, the shallow profile of the vernal pool facilitates drying and thus does not permit permanent water retention. Vernal pools generally fill with water during the winter and remain flooded until spring or early summer. The cycle of inundation and drying can be repeated several times during the rainy season (Sawyer and Keeler-Wolf 1995, Anonymous 1997, Hobson et al. 1998).

Vernal pools are inhabited by assemblages of plant and animal species that can tolerate this extremely ephemeral environment (e.g. cyst-forming crustaceans), and in fact, the highly adapted and specialized flora and fauna, including a high proportion of threatened and endangered taxa, is the predominant characteristic that makes vernal pools a unique habitat category (Ahl 1991, Dawson 1991, Anonymous 1997, Black et al. 1997, Rogers 1997, Keeler-Wolf et al. 1998, Heise and Merenlender 1999, Belk and Fugate 2000).

These habitats are thus a result of a unique combination of Mediterranean (summer-dry) climate, topography, soil conditions, hydrology and a local highly specialized biota (Holland 1976, Dawson 1991, Sawyer and Keeler-Wolf 1995, Keeler-Wolf et al. 1998). Some of the most extensive California vernal pool areas are found along the western foothills of the Sierra Nevada and comprising the Northeastern and Southeastern Sacramento Valley and Southern Sierra Foothills. Additional areas that favor the development of vernal pools are located in the Sierra Valley and Modoc Plateau regions in the northeastern corner of California.

Many ecologist argue that vernal pools represent only one component in an environmental continuum of small ephemeral wetland habitats that share similar species of organisms and include vernal lakes, desert or semi-desert playas, tehajas, mountain snow melt and rockbound pools, and marshes. Keeler-Wolf et al. (1998) argue that the classification of ephemeral wetlands and the concept of vernal pools will require a fundamental revision as more information is accumulated on the biology and distribution of these habitats. Unfortunately, the current state of knowledge does not allow a comprehensive treatment of the entire habitat series, and most of the general discussion is presently restricted to a small subset of "true" vernal pools (Keeler-Wolf et al. 1998).

Keeler-Wolf and others (1998) provide an excellent and thorough assessment of vernal pools in California.

Physical Attributes

Pool depth and profile are two important factors that influence the flora and fauna found in California vernal pools (Heise and Merenlender 1999). Very shallow profile pools support a diverse mix of perennial wetland and vernal pool specialist taxa (Heise and Merenlender 1999). Steep-profiled pools with narrow margin topography did not support vernal pool specialist plants common on shallow-profiled pools (Heise and Merenlender 1999).

The length of the inundation phase (hydroperiod) is another important factor influencing vegetation structure and faunal components of vernal pools (King et al. 1996, Black et al. 1997, Heise and Merenlender 1999). Pools with longer periods of inundation support taxa, such as *Juncus, Eleocharis, and Carex*, more typical of perennial wetlands (Heise and Merenlender 1999). Invasion of weedy exotic plant species is correlated with changes in hydrology (Barry 1995, Bauder 1987). Weedy exotic species increase during drought years or other dry periods of (Barry 1995). Depth is correlated with hydropereiod, and therefore may be a good monitoring variable (Black et al. 1997).

In addition to hydroperiod, the time of year when soils became moist enough to promote germination (month), and the time between moistening and beginning of inundation are important factors for germination of vernal pool plants (Bliss and Zedler 1998, Heise and Merenlender 1999). Gallagher (1996) found that pool depth and duration are important to the occurrence of Brachiopoda, such as *Branchinecta lynchi, Linderiella occidentalis,* and *Lepidurus packardi*, in vernal pools in northern CA.

Water chemistry attributes are other factors measured in studies of vernal pools. These attributes include conductivity, total dissolved solids, alkalinity, salinity, pH, and dissolved oxygen, and temperature (King et al. 1996). There is a strong correlation between total dissolved solids (TDS) and conductivity and alkalinity that supports the collapse of these variables into TDS.

Floral Attributes

The floral attributes of vernal pools in California have been intensely studied. Several excellent inventories have been conducted and are a good source of information to evaluate monitoring attributes (Jain 1976, Holland and Jain 1987, Zedler 1987, Sawyer and Keeler-Wolf 1995, Bauder and McMillan 1998, Holland 1998). Almost 200 plant species are known to be restricted to or commonly occur in vernal pools (Holland 1976, Keeler-Wolf et al. 1998). The lists are extensive and cannot be repeated here, and the reader is directed to this literature for detailed information.

Vernal pools support a uniquely adapted flora that contains regional as well as localized components (Stone 1990). Although many species occur regionally, the number of species in individual pools may only reach 15-25 (Holland 1976). Basing inferences about habitat condition and integrity solely on the occurrence of native plant species may therefore, be of limited value. However, the introduction of exotic species is the major threat to vernal pool habitats (Barry 1995). Non-indigenous annuals can present a formidable obstacle to reestablishment of native plants (Menke 1992). Competition from exotic weeds such as Cocklebur (*Xanthium strumarium*), Bindweed (*Convolvulus arvensis*) in large pools threatens habitat for endangered plant species Hairy Orcutt Grass (*Orcuttia pilosa*) and Hoover's Spurge (*Chamaesyce hooveri*) (Stone et al. 1987). The introduction of perennial grass and Italian ryegrass (*Lolium multiforum*) in smaller swalelike pools is a problem for endangered vernal pool plant Greene's Tuctoria (*Tuctoria greeni*) (Stone et al. 1987).

Faunal Attributes

Vernal pools in California have a specialized suite of animal species (Cox and Austin 1990, Simovich et al. 1992, US Fish and Wildlife Service 1994, King et al. 1996). The fauna includes crustaceans (fairy shrimp, clam shrimp, and tadpole shrimp), insects, spadefoot toads (*Scaphiopus hammondii*), tiger salamanders (*Ambystoma californiense*), water birds such as avocet,, killdeer, greater yellowlegs, cinnamon teal, and mallard (Zedler 1987, Jokerst 1990, Thorp 1990, Thorp and Leong 1995, Keeler-Wolf et al. 1998)

Crustacean assemblages are strongly related to habitat type, and physical and chemical differences among pools, and with geologic/floristic habitat classifications (King et al. 1996). Species richness of crustacean assemblages is positively correlated with both depth and surface area of vernal pools (King et al. 1996). Because 44% of all crustacean species found in vernal pools in California are new to science, they may not be useful for monitoring if they cannot be identified (King et al. 1996). More taxonomic work needs to be completed before the potential of group of animals as useful indicators of habitat condition and integrity can be realized.

V-4.2. Major Disturbance Factors

Skinner (1996) considers agriculture, grazing and urbanization as the greatest threats to the integrity of vernal pools. These habitats are particularly vulnerable since the majority of them occur in relatively flat and accessible areas, which are attractive to farming and housing development (Cheatham 1976, Keeler-Wolf et al. 1998). For example, a common practice in some vernal pool areas is to excavate and dam existing vernal pools to develop cattle ponds (Keeler-Wolf et al. 1998). Modification of surrounding uplands alters vernal pool watershed habitat (Barry 1995). As a result, it is estimated that over 90% of vernal pool ecosystems have been lost, and these habitats are thus the most fragile and threatened types of wetlands in California (Holland 1976, Stoner 1990, Barry 1995, Keeler-Wolf et al. 1998). Some research, however, suggests that light grazing appears to be beneficial to vernal pools by maintaining species diversity (Anonymous 1997) likely through suppression of dominant highly competitive species similar to ecological processes in native prairies (Collins et al. 1998).

Since vernal pools contain a higher percentage of native, highly adapted species of crustaceans, grasses and wild flowers that the surrounding habitats, monitoring for exotic invaders is critical to the integrity of these habitats (Barry 1995, Keeler-Wolf et al. 1998). Prescribed burning can have negative effects on plant specie diversity of vernal pools by increasing the mineralization and flux of N and P, which may favor the invasion of exotic species (Cox and Austin (1990).

The management of vernal pools is currently consists primarily of their geographic mapping, and monitoring of rare species. Pool depth and area appear to be significant indicators and predictors of the faunal diversity (Gallagher 1996, King et al. 1996). Complete species inventories or at least suites of species are needed (Keeler-Wolf et al. 1998). Considering the unique metapopulation dynamics of dispersal and colonization of organisms within pool clusters (Skinner 1996, Keeler-Wolf et al. 1998), monitoring and conservation efforts should be given to as many pools as feasible within a particular area.

Grazing may be an important tool for managing vernal pool hydrology and prevent the invasion of exotic weeds (Barry 1995, Heise and Merenlender 1999). Moderate cattle or horse grazing does not seem to pose much of a threat to persistence of vernal pool plants despite the disruptive effect of trampling and grazing may help perpetuate vernal pool plants (Zedler 1987), although pools with heavy sheep use are often devoid of herbaceous vegetation (Heise and Merenlender 1999). Direct precipitation is the dominant input initially filing pools during the winter (Hanes et al. 1990), and surface runoff seems to be essential for maintaining as adequate inundation period (Barry 1995). Runoff decreases in proportion to an increase in the amount of vegetation cover (Blackburn 1975). Grazing animals help maintain the hydrology of the uplands surrounding vernal pools by preventing excessive accumulation of plant material (Barry 1995).

Grazing helps reduce the amount of plant residue surrounding vernal pools, and increase the diversity of plants including low-stature, spring-maturing forbs such as filaree (*Eridium spp*), and summer annuals such as turkey mullein (*Eremocarpus setigerus*). A livestock-grazing program can control plants such as medusahead (*Taeniatherum caputmedusae*), *Eleocharis palustris* (a sedge) and wild oats (*Avina fatua*) that can dominate the edges of vernal pools. Control of these plants help sustain vernal pool habitat for stands of endangered plants such as *Orcuttia* and *Neostaphia* (Crampton 1959, Stone et al. 1987).

Grazing may also influence the diversity of microecosystems within a vernal pool (Barry 1995). When vernal pools are wet, animal disturbances can cause microdepressions that provide habitat for vernal pool plants and animals generally found in deeper vernal pools (Barry 1995).

Fire did not exert an adverse effect on native vernal pool herbs, and appeared to mitigate the effects of natural dry basin conditions (Cox and Austin 1990, Menke 1992). Some vernal pool plant species declined immediately after burning,, including *Pogogyne abramsii and Psilocarphus brevissimus* (Cox and Austin 1990).

V-5. Evaluation of Proposed Habitat Categories

The review of the literature supports the current habitat classification scheme proposed by the Sierra Nevada Framework Project Monitoring Team. However, any categorization of wetland habitats has its limitation due to a great diversity of these habitats, and should be considered merely a working hypothesis (Keddy 2000). Our rationale is as follows. Bogs and fens are permanent wetlands that clearly warrant a placement in a unique habitat category due to the accumulation of peat, a process that does not occur in any other habitat types with the rare exception of dystrophic ponds. Although the surface water chemistry of fens is significantly different from that of bogs, in a sense, bogs and fens represent two states of the same bog-fen hydrobiological system, or complex. Bogs and fens may gradually replace each other under the influence of external factors affecting the water chemistry, and consequently the associated biota (Siegel 1988). The resulting intermediate bog-fen habitat state is termed a transitional poor fen, or semi-ombrotrophic bog with pH levels of 4.0 to 5.1, and calcium levels from 2.0 to 4.0 mg/L (Glaser et al. 1981, Heinselman 1970, Siegel 1988).

According to Moyle (1996), sphagnum bogs and fens are unique to rare (rarity level = 1 to 2) and unusual (3), respectively, habitat types in the Sierra Nevada (Table 2). Most of the peatlands in this region represent a mixture of disturbed or relatively undisturbed habitats (disturbance level = 3 – 4) that are declining in abundance and quality (overall rating = special concern) (Table 2). Thus, peatlands are a unique habitat category that deserves protection and monitoring in the Sierra Nevada.

The classification status of springs and seeps is currently ambiguous. Dependent on the scale of spatial resolution, springs and seeps could either be considered unique microhabitats, or be simply regarded as hydrological components of larger macrohabitats such as fens, ponds, or streams. Springs are more common (rarity score = 4) than peatlands (1 –3) in the Sierra Nevada (Table 2), which likely reflects their associations with more widespread aquatic habitats including ponds and streams. There is a possibility of collapsing the springs/seeps category as more information accumulates on their biology.

Sierra Nevada ponds are a rather diverse assemblage of aquatic bodies that can either be ephemeral or permanent, contain fish or be fishless, and have water chemistry similar to the surface water, or under the process of acidification (i.e. dystrophic ponds). Despite this heterogeneity, ponds are significantly dissimilar from peatlands, which display a higher degree of acidification and water permanence, and whose fauna is dominated by *Sphagnum* or non-*Sphagnum* mosses. Ponds also differ sharply from vernal pools, which are extremely ephemeral habitats with a unique biota. In particular, the ephemeral quality of vernal pools selects for highly adapted assemblages of organisms and generally excludes typical pond vegetation components such as *Typha*, *Carex* spp., or *Juncus* spp. In terms rarity, the Sierra Nevada ponds studied range from being infrequent (e.g. dystrophic, some alpine ponds; rarity = 3) to widespread (e.g. mountain ponds; rarity = 5) (Moyle 1996).

Without a doubt, vernal pools fall into an exclusive habitat category even though the heterogeneity of this habitat type will likely increase after similar habitats (e.g. mountain snow melts, rockbound pools, etc.) have been considered. Vernal pools are also distinctive by their increased sensitivity to mechanical destruction and grazing due to their frequent occurrence in relatively accessible areas. From the ecological and political perspective, vernal pools represent a highly unique and sensitive habitat category. Overall, monitoring recommendations for vernal pools should currently aim to support statewide conservation efforts to map and survey these habitats (Keeler-Wolf et al. 1998).

Table 2. Key distinguishing characteristics of special aquatic habitats in the Sierra Nevada.

	Peatlands		Springs & seeps	Ponds	Vernal Pools
	Sphagnum Bogs	Fens			
Habitat permanence	Permanent	Permanent	Permanent	Ephemeral / Permanent	Ephemeral
Endemism	Moderate	Moderate	Moderate	Low	High
No. sensitive species	Moderate (no. species?)	Moderate	Moderate	Low	High (no species?)
Rarity †	1-2	3	4	3-5	N/A
Disturbance †	3-4	3-4	3	3-5	N/A
Primary type of disturbance	Hydrologic alterations	Hydrologic alterations	Hydrologic alterations	Hydrologic alterations	Mechanical destruction, grazing, exotic species
Overall rating †	Special concern	Special concern	Special concern	Secure / Special concern	Highly sensitive ‡

† Follows the habitat rating system of Moyle (1996) for the Sacramento-San Joaquin and Great Basin Provinces of the Sierra Nevada. ‡ Vernal pools are not included in Moyle's (1996) treatment of aquatic habitats in the Sierra Nevada, and the rating of vernal pools here reflects the current state of knowledge of these habitats.

VI. RECOMMENDATIONS

VI-1. Monitoring Goals

The Forest Service has asked for monitoring attribute recommendations for the four classes of wetlands discussed above. Monitoring attributes are chosen in the context of the goal or purpose of the monitoring program. The most general purpose of environmental monitoring is to learn about the changes occurring in the natural world. This purpose may be subdivided into three more specific goals: to ***detect, predict,*** and ***understand*** those changes. Not all monitoring programs have all three of these goals, but all have at least one of them. We believe the goals of the Forest Service special aquatic habitats monitoring program encompass all three.

Every monitoring program has it's own set of unique purposes, as well. These are usually one or more of the following, ranked in general order of increasing complexity and sophistication:

- To detect threshold events, or critical levels, of environmental phenomena, attributes, and characteristics
- To detect hazards and risks, to valued ecosystem attributes and functions and/or to the human communities that depend on them
- To detect specific changes in the environment
- To provide historical records of change in environmental phenomena, attributes, and characteristics
- To detect trends, periodicities, cycles, and/or other patterns in those changes

- To associate auxiliary phenomena, attributes, and characteristics with trends and patterns of change in key phenomena, attributes, and characteristics
- To predict future changes in environmental phenomena, attributes, and characteristics
- To link environmental changes to their causes

All these purposes of environmental monitoring involve increasing our knowledge and understanding. A closely related purpose of monitoring is to modify management actions. The new knowledge gained through monitoring should be useful in evaluating past environmental treatments and in directing new treatments, management actions, and other human influences. The ultimate goal of environmental management is good stewardship. Monitoring should inform stewardship efforts and help us to protect, enhance, and care for the natural world.

The Forest Service has defined the purpose of their special aquatic habitat monitoring program as “monitoring the condition and integrity of four classes of aquatic habitats.” These are vague terms and need specific definitions before appropriate attributes can be recommended. We offer the following definitions and discussion as the context for our recommendations.

VI-2. Integrity and Condition

Ecological condition may be defined as mode or state of existence of the habitat. This may be as simple as the presence/absence of water, or as complicated as the level of all the measurable attributes present in the habitat (i.e., physical, chemical, hydrological, edaphic, floral, and faunal, etc.). Generally natural resource managers measure ecosystem conditions to predict the suitability of habitats for sustaining the ecosystem's biological components.

Considerations relevant to assessment of environmental condition include evaluation of the relationship of biological response to specific stressors. Managers need to know how the biotic components of these habitats respond when stressed by disturbance or change in their physical environment (Barbour et al. 1999). Another consideration is measurement of physical parameters as a means of holding those factors constant while evaluating the impacts of other stressors of interest, such as disturbance by fire, grazing, visitors, exotic species, and land use changes. Measurement of physical and biological attributes provides the Forest Service with a means to investigate change in the biota and its relationship with changes in the landscape.

Ecosystem integrity is a holistic property that applies to the entire ecosystem not just component taxa or functions (King 1993). Monitoring habitat integrity is, therefore, a complicated task. Before measurements are taken, managers must consider carefully their goals, and objectives, and their methodology. When selecting monitoring attributes, managers must:

1. define integrity in an operational way that can be measured,
2. select variables which indicate integrity,
3. identify levels of the variables that represent integrity or lack thereof,
4. develop a feedback system to modify the variables according to ecosystem responses to management activities designed to conserve the ecosystem and its components.

The regulatory goal of conservation and protection of threatened or sensitive habitats is the preservation of native biotic diversity at all levels in the hierarchy of ecological structure. Managers measure physical and biotic attributes to determine the condition and integrity of habitats. ***Biological integrit*y** is defined as the ability of a system to support and maintain biota diversity and function comparable to natural habitats of the region (Karr 1993), and refers to the plant and animal species that are characteristic of a region and their relative abundances in the absence of human intervention (Karr et al. 1986). A living system exhibits integrity if, when subject to disturbance, it sustains an organizing, self-correcting capacity to recover toward an end state that is normal for that system (Regier 1993). Systems with intact integrity have realized their potential, their conditions are stable, and they have the capacity to repair themselves when perturbed with minimal management (Karr 1993).

Integrity also refers to the soundness or completeness of an ecosystem (King 1993). An ecosystem with integrity has a set of living organisms, unique but always changing, within adapting populations. Ecosystems contain organisms that modify their surroundings by altering the abiotic features via nutrient recycling and primary production, and use other biota as food, but do not affect drastically the entire ecosystem in which they live so as to impair its self-organizing capabilities (Regier 1993). Healthy ecosystems exhibit complex trophic networks, interactions between organisms across levels or scales of organization, such that the system has relatively persistent structure that can exist in several states (Regier 1993). The biota, in essence, associate themselves with a balanced feedback system to stabilize the entire ecosystem.

A system is defined by its components (structure) and the interactions (functions) among them (King 1993). Loss of any component (species), change in interaction, or loss of function is a loss of integrity (King 1993). Ecological systems are amazingly resilient to alteration of structure without loss of function because of redundancy in the system (King 1993). However, while measurement of functional properties (conditions) like water quality, may be better indicators of functional integrity they are insensitive to species composition (structural integrity). Indicators of ecosystem integrity must be selected from as many perspectives and system descriptors as practical (King 1993).

Condition may also be defined as the state of plant and animal populations (growing, stable, or decadent), or the status of individuals of those populations (normal healthy, breeding, active individuals versus abnormal, sick, aged, lethargic individuals). Monitoring answers questions about the condition (state) of populations over time. Trends become obvious when analyzed in the context of time. Judgments about he conditions of individuals must be made by experts familiar with the biology of the taxon of interest, and may not be obvious from monitoring.

Selecting monitoring variables is a complicated task that should proceed in a logical manner. Monitoring variables should be ecologically meaningful, related to function or process (e.g. water level, primary production biomass), and indicate change for the entire community or some component part. Monitoring variables should be those that can be measured practically, and are sensitive to change or disturbance and respond quickly. Finally monitoring variables must be those that can easily be measured accurately (Keddy 2000).

VI-3. Key Questions of Interest

Monitoring is a kind of scientific investigation. Every investigation must begin with hypotheses, which we call questions of interest. The questions of interest define the purposes and scope of the investigation, and are used to judge the findings that result.

Asking the key questions is the first and most important step in systematic environmental monitoring. Without careful definition of the key questions, monitoring efforts are aimless. Monitoring programs can be successful only if clear, concise, well-considered, collaborative, quantified questions of interest are created at the outset.

VI-3.1. Key Questions Defined

Key questions are those with useful answers. Environmental monitoring is aimed at increasing knowledge about change in natural systems, but some facets of that knowledge are more useful than others. Key questions should be based on specific, prior goals of detection, prediction, and/or understanding. Development of key questions must be coordinated with management objectives, and with the potential of management to respond to the increased knowledge.

Key questions are those that can be investigated efficiently. No monitoring program is blessed with unlimited funding. Many questions are interesting; only a few can be investigated within the budget. Questions of understanding are inherently more expensive to answer than questions of detection. It is always more expensive to answer questions with a high degree of accuracy and precision, and always less expensive to answer questions with low accuracy and bias. Accuracy and precision, and their counterparts, inaccuracy and bias, are measures of inferential strength. Monitoring planners should evaluate the projected strength of the inferences, or answers, they hope to find, before environmental monitoring programs are implemented. More specifically, they should estimate the relative costs of achieving differing levels of inferential strength and chose the level that is most efficient for their monitoring purposes. This process of weighing inferential strength against costs is known as power analysis.

Utility and efficiency are important criteria to consider in development of key questions. Monitoring planners cannot, or should not, determine utility and efficiency in a vacuum.

Instead, they must collaborate and consult with management decision-makers. Decision makers should know what they are potentially going to get for their monitoring funds.

Acceptable key questions must be framed with an understanding of the entire monitoring process. Monitoring planners must be able to predict the utility and efficiency of each a proposed question to aid decision-makers in their determinations. Planners must have a comprehensive picture of all the systematic steps in environmental monitoring to do this.

VI-3.2. Time and Space

Monitoring is the investigation of change over time and space. Time is of the essence in monitoring. Ecosystems are dynamic, not static. Some changes occur rapidly. Some occur only over a period of decades or centuries. Some insect populations will hatch, mature, breed, and die within only a week or two each year. These same insect populations may also exhibit cyclical patterns that are decades long. In western deserts flash floods may rise and subside within a few hours. The landscapes they sculpt may have developed over millennia of relatively benign drought, punctuated by momentous, short-lived, flood phenomena.

Environmental monitoring planners must have a grasp of time. They must have a constant, even nagging, sense that measurement of time is crucial to the development of key monitoring questions of interest. They must concern themselves with time-oriented concepts, such as trends, cycles, periodicities, and short- versus long-duration phenomena. This overriding concern with the passage of time separates monitoring from many other types of scientific investigations. Most environmental monitors learn their scientific craft in universities. Graduate school is a short-lived phenomenon in most people's lives. Environmental monitoring investigations are typically too long-lived to be appropriate for most graduate students to undertake. Rapid development and completion of hypotheses, studies, analyses, and dissertation reports comprise the model most students learn. Often, they must unlearn this investigatory style to be good environmental monitors.

Location is also of the essence in monitoring. Ecosystems, (or their elements), are found in specific places, and their changes often involve movement across space. Many animals move or migrate: they are here today, somewhere else tomorrow. Some relatively small animals, like northern spotted owls, have huge home ranges covering thousands of acres. Even plants migrate, spreading to new places by vectors of wind, water, or faunal transport. Change across space, like time, also may exhibit trends, cycles, and periodicities.

Monitoring planners must always include measurement of location and locational change in their monitoring programs. The most common tools for this purpose are maps. Unfortunately, maps are much more complicated affairs than clocks or calendars. Time moves in one direction. Environmental phenomena may move in any or all spatial directions. Clocks tell time and only time. Calendars yield dates and only dates. Maps may have any number and manner of environmental attributes, characteristics, and phenomena symbolically placed upon them. Time data, as displayed on clocks and calendars, usually have a high degree of accuracy and are easily verified. Map data often have low levels of accuracy and are difficult to validate without expensive ground surveys. Despite their complexity and limited accuracy, maps are indispensable tools for environmental monitoring.

VI-3.3. Models

The answers to key monitoring questions are often couched in statistical models, mathematical descriptions of environmental changes. This is particularly true when the results of monitoring analyses involve detection of trends and cycles, prediction, or quantification of cause-and-effect relationships. In developing the key questions, monitoring planners should envision the types of analyses, and hence the types of models, that the monitoring program will utilize.

Models do not equal Truth. All models are estimates or approximations, and so cannot be said to have absolute accuracy and precision. Still, many models are useful tools. There are two separate, and usually mutually exclusive, uses of models: prediction and understanding.

Predictive models quantify probable changes in an environmental attribute, characteristic, or phenomena. The predicted changes are often based on a set of associated variables chosen using statistical principles. Accurate predictive time horizons are relatively short, and the inferential strength of prediction diminishes as time horizons lengthen.

Models for understanding are based on theoretical statements about ecosystem interactions. They yield insight into processes, but may be poor predictive tools. In some cases, models for understanding are not even quantifiable. The food chain pyramid is one such example. We theorize that in ecosystems there are more lower-food-chain animals (prey) than higher-food-chain animals (predators). This relationship may be generally true, and it is not considered necessary to test it with exacting measures. The dynamics of predator-prey ratios and population fluctuations may be much more complex in real world situations.

Models, whether for prediction or understanding, may be validated but never verified. Verification implies establishing the truth or reality of a model, which cannot be done. Models are mathematical descriptions many magnitudes simpler than the natural systems they symbolize. Models do not equal Truth, but models may be validated. Predictive models, in particular, may be shown to have measurable accuracy and precision through testing.

Regardless of their purposes, all monitoring models must include time as factor. Many must also include locational change; (all should at least include a description of the location of the attributes, characteristics, or phenomena under investigation). Monitoring is the investigation of change, and change always occurs in the temporal domain. Typical monitoring models include trend analyses, survival analyses, growth and mortality analyses, and population change analyses.

VI-3.4. Collaboration

Monitoring planning is a collaborative process. No single individual can successfully plan a monitoring program particularly when the scope includes the large set of environmental questions associated with National Forest management. Many natural resource specialists and managers must be involved and must make contributions to the planning effort.

There are two primary reasons for collaboration. First, collaboration is necessary for the monitoring program to be scientifically valid and comprehensive. Different disciplines, such as botany, zoology, hydrology, and ecology are too complex and rigorous for any one person to have full command of all of them. Moreover, important phenomena often include all of these differing aspects of the environment. Scientific collaboration helps monitoring planners develop programs that correctly identify the key questions, that is, programs that investigate all the important factors associated with key ecosystem attributes, characteristics, and phenomena.

Second, collaboration is necessary for monitoring programs to achieve sustainability and continuity. For monitoring programs to be successful, long-term **institutional commitment** must be developed at the outset. Developing institutional commitment requires collaboration at many levels in the bureaucracy. Monitoring is the investigation of change over time. Monitoring efforts must often extend for many years and decades. Data collected today must be compared to data collected many years in the future to detect, predict and understand environmental change. The individuals who design monitoring programs are often retired or reassigned long before the monitoring efforts are completed. The institution, in this case the Forest Service, must commit to a long-term schedule and budget outlay for monitoring program success. Without such commitment, it may be futile to begin monitoring. Collaboration helps to ensure the sustainability and continuity of monitoring programs.

VI-3.5. The Systematic and Comprehensive Approach

Consideration of all the points mentioned, efficiency, utility, inferential strength, time and space, models, collaboration, and institutional commitment are necessary when formulating the key questions of interest. Asking the right questions sets the stage for the entire monitoring planning process. Many other steps follow: design of the sampling system (including protocols), design of the data management system, planning the analyses, planning the reporting systems, and ensuring continuity. Monitoring planners must be able to foresee and evaluate all the future steps, so that the key questions ask are appropriate for the entire monitoring program.

To achieve this appropriateness, monitoring planners must prioritize potential key questions. There are many interesting environmental questions. So many, in fact, that they cannot all be investigated under one program. Some interesting questions may be very expensive to answer. Often, cause-and-effect questions fall into this category. It is necessary for monitoring planners to foresee the long-term costs of investigating monitoring questions, and the relative utility of the potential answers. To do this, the entire monitoring program must be understood and carefully planned. When the probable costs and utility are predicted for all interesting questions, planners may rank the potential key questions in terms of efficiency and importance.

There is no easy way to make difficult prioritization decisions. Future costs and utility are often hard to predict. Different scientific disciplines, and different special interest groups, usually have different priorities. Compromise and tradeoffs are often agreed to only after exhaustive and sometimes acrimonious debate.

Approaching monitoring planning systematically and comprehensively is one way to reduce contentiousness. It is not a cure, but can help to relieve some of the pain and uncertainty. The systematic and comprehensive approach means understanding and applying all the steps in monitoring planning.

We have identified the following seven-step process for planning of long-term monitoring:

1. Prepare clear statements of the questions of interest.
2. Design the sampling systems
3. Develop sampling protocols for data collection
4. Prepare the data management systems, including GIS

5. Plan the analysis and interpretation systems
6. Develop a reporting system
7. Develop a monitoring sustainability plan

Each of these seven steps must be undertaken and completed to develop a successful monitoring plan. Furthermore, the steps must be undertaken in a comprehensive manner. Planning decisions made in any one stage affect decisions at all the other stages.

The following review is provided to clarify and emphasize these critical planning steps:

1. Prepare clear statements of the questions of interest.

The first step in developing a monitoring plan requires clearly defining the questions of interest. Key questions are those with answers that can be efficiently estimated and that yield the information necessary for management decision-making. The monitoring program depends upon identifying the important issues and concerns, and reducing general problems to questions of specific, measurable factors. Much future effort will be spent investigating the key monitoring questions. They must be well considered and carefully elucidated at the outset.

2. Design the sampling systems

The second step in monitoring planning is designing the sampling systems. It is expected that many quantifiable questions of interest will be generated in the first step. Proposed questions of interest must be prioritized, based on the projected costs of collecting the data and the projected value of the knowledge to be gained. Expertise in statistics, biometrics, and cost/benefit analysis are required for sampling system design. Some of the design techniques that should be applied are power analysis, cost allocation analysis, sampling structure determinations, sample size determinations, scale evaluations, randomization, replication, blocking, and covariate determinations. Schedules of sampling efforts must also be developed. Monitoring is the investigation of change over time, so planning the frequency and timing of sampling is an essential element in sampling system design.

3. Develop sampling protocols for data collection

The third step in monitoring planning is to develop the data collection system(s). Sampling protocols are necessary to standardize data collection. Data gathered in the future must be comparable to data gathered today to statistically detect significant environmental changes. Protocols should include specific methods to be used for every habitat and each animal or plant type, descriptions of the tools necessary for data collection, and randomization schemes for determining trap placement, plant selection, or measurement device location. Protocols should be field-tested to assure feasibility and efficiency. Field data collection crews should then be trained and tested in the use of the sampling protocols.

4. Prepare the data management systems, including GIS

The fourth step in monitoring planning is the preparation of a data management plan. The data collected in each sampling exercise must be checked for errors and corrected. Data sets must be entered into a database for easy access and retrieval. Monitoring requires comparisons of attributes over sometimes-lengthy periods of time. The database must be properly archived to be retrievable many years in the future.

It is important to recognize that data sets are expensive to obtain, and hence have significant monetary value. Not only will the archived data contribute information for future management decisions in Sierra Nevada forests, they will also provide information potentially useful for natural resource management elsewhere in the West.

A geographic information system (GIS) is an important component of monitoring data management. The changes over time detected and predicted by monitoring must also be placed in spatial contexts. One aspect of environmental change is the movement of floral and faunal attributes through migration, displacement, reintroduction, and re-vegetation. A GIS allows monitoring data to be applied to maps in layers, such that information about spatial relationships is easily visualized.

5. Plan the analysis and interpretation systems

The fifth step in monitoring planning is the development of an analysis and interpretation plan. Statistical analysis and scientific interpretation are necessary to produce logical inferences and new knowledge from monitoring data. The sampling design and the statistical structure of the data must be accounted for in the analysis plan. Techniques of exploratory data analysis (EDA), graphics, statistical distribution tests, data transformations, and modeling should be developed in the plan. Much of the information gained through monitoring will be evaluated by means of mathematical models. Such models include time trend analysis, survival analysis, growth and mortality models, and population change models. The appropriate model forms should be specified in the planning process. Failure to specify analytical forms could cause gaps and inefficiencies in sampling design and data collection. Prior planning for analysis will help ensure completeness and timeliness of the sampling, and prevent wasteful effort.

6. Develop of a reporting system

The sixth step in monitoring planning is the development of a plan for the reporting the results. The new knowledge acquired through monitoring should be communicated to responsible Forest Service personnel and interested agencies and the public for use in making management decisions. Charts, tables, and maps may be the immediate products of analysis, but they do not stand alone. Associated reports should be carefully planned and clearly written, with consideration of the intended audience and the appropriate application of the findings. The reports should clearly explain the results of data analysis and the implications to natural resource management. Monitoring reports need to be produced on schedule and updated on a regular basis.

7. Develop a monitoring sustainability plan

The seventh step in monitoring planning is development of a monitoring sustainability plan. Institutional commitment must be developed to secure annual budgetary planning for future monitoring efforts. Monitoring happens in the context of time. Environmental changes, and trends in those changes, are often detected only after several years of data collection. The Forest Service must consider their monitoring programs to be permanent elements in future budgets. Involving other stakeholders, such as USGS/BRD, the BLM, the Park Service, universities, local environmental groups, and citizens will help to build community commitment to the program. Planning for sustainability and commitment is a necessary element in long-term environmental monitoring.

In summary, systematic monitoring of special aquatic habitats in the Sierra Nevada should be comprehensive, cost-effective, statistically designed, executed with analytical integrity, presented to decision makers by way of meaningful reports, charts, and maps, and updated regularly over many decades. Consideration and application of the seven steps will improve efficiency and effectiveness of knowledge acquisition, and guarantee managers, regulators, scientists, and citizens useful information on which rational management decisions may be based. Conscientious planning and implementation of a properly designed, systematic monitoring plan will provide the Forest Service with the necessary prerequisites for continued good stewardship of its properties.

VI-4. Monitoring Attribute Recommendations

We provide the following recommendations for monitoring attributes based on the desire expressed by the Forest Service to monitor status, condition and integrity of the four groups of special aquatic habitats in order to determine the status of these habitats. Monitoring attribute recommendations for each of the habitat groups are organized into three major kinds of recommendations; 1) mapping and inventory, 2) basic explanatory variables (condition), and 3) biotic attributes (integrity). Within each of these three groups, attributes are presented for in order of priority, and are accompanied by a rationale for each.

VI-4.1. Peatlands

VI-4.1.1. Mapping and Inventory

Recommendation VI-4.1.1: We recommend that Forest Service monitoring of peatlands begin with mapping the locations of bog and fen habitats within the management area.

Mapping may involve remote sensing such as satellite or aerial photographs, or ground searching in localities where these habitats are likely to occur. Identifying the locations of the individual fens and bogs will facilitate monitoring design planning, help determine adequate sample size, and allow for randomizations and other sampling selection criteria. It will also help the Forest Service determine the extent of these habitats over the landscape. The maps also provide a base layer for a GIS, upon which all other information will be organized.

Recommendation VI-4.1.2: We recommend that the Forest Service mapping include measurements at each site of the elevation, topographic position (slope and aspect), substrate type, the size (historic extent of inundation) and shape of the habitat, significant landmarks (e.g., large trees, boulders, buildings, etc.).

Information about these important attributes may help to explain variation of the biota in these habitats. For example, peatland research in the Rockies has shown that slope, aspect, and elevation have important influences on the distribution of vegetation (see Chadde et al. 1998). The same is probably also true for the Sierra Nevada. In the Sagehen Creek Basin, where the only detailed studies of fens in the Sierra Nevada have occurred (Bartolome et al. 1990), topographic position of fens was found to influence peat depth, a major factor of habitat condition (Erman 1976). Peat mass in fens on steeper slopes was sometimes pulled downward by gravity, elongating the mass and reducing the maximum depth (Erman 1976). Furthermore, geologic settings of fens are hypothesized to influence their vulnerability to hydrologic disturbance (Thompson et al. 1992). Some substrates are more fractured and allow water to penetrate quicker, changing the timing and amount of water discharge to fens (Thompson et al. 1992).

Recommendation VI-4.1.3: We recommend that the Forest Service photograph the sites upon the first and subsequent visits.

Photographs provide information about the location of major landmarks or features of morphology or orientation, vegetation zones, buildings, etc (Barbour et al. 1999). This information will be useful to those people evaluating and interpreting the monitoring information and can be a good reference record of environmental change.

VI-4.1.2. Basic Explanatory Variables (Condition)

Ecosystems are produced by multiple environmental factors acting simultaneously (Keddy 2000). These “conditions” explain some part of the variation in biotic populations over time, and therefore should be measured. Correlations between changes in environmental factors and changes in biotic populations of interest need to be investigated, and analyzed, to be understood. Knowledge of the nature of these relationships will allow analyses to be “adjusted” for environmental factors, filtering out "noise", so that the impacts from management and disturbance can be distinguished from the natural variability exhibited by the parameters.

Recommendation VI-4.1.4: We recommend that the Forest Service monitor basic environmental factors such as average and minimum/maximum temperatures, rainfall, and humidity.

Biologists have documented the effects of these environmental factors on plants and animals, and their ability to cause great variation in biological assemblages. It is against these basic explanatory variables that all other influences will be measured. Low-cost weather stations have made the collection of this kind of information easy and affordable. Data recorders can be used to store weather and climate information for download at convenient intervals.

Recommendation VI-4.1.5: We recommend that the Forest service monitor hydrological factors: water depth, area or extent, and timing of inundation, and water persistence.

Evaluation of habitat quality is essential in any assessment of ecological condition, and should be performed at each site at the time of biological sampling. An important physical attribute that reflects condition is hydrology. Hydrology accounts for more than 50% of the variation found in aquatic plant and animal populations (Keddy 2000). Hydrological factors include water depth, area or extent and timing of inundation, and water persistence. All are important factors that influence biotic assemblages found in special aquatic habitats. For example, in a study of bogs in Minnesota, Weltzin et al. (2000) concluded that Annual Aboveground Net Primary Production (ANPP) varied with available moisture. They found that wet sites had higher ANPP than dry sites, driven primarily by increases in the biomass of bryophytes. The same relationships between these factors could be expected in the Sierra Nevada.

Hydrology attributes, such as water flow rates and time in the ground are interesting and may influence the conditions of habitats, however, these attributes are more difficult to measure, and commitment of resources should be considered and evaluated before these measurements are undertaken.

Recommendation VI-4.1.6: We recommend that the Forest Service monitor peat depth.

Peat depth is an important attribute for monitoring condition in peatland habitats. Peat depth has been found to influence the number and kinds of invertebrate species in peatlands of the Sierra Nevada (Erman and Erman 1975, Erman 1976). Peat depth influences daily changes in water level, rates of change of water temperature, and the production of invertebrates and can buffer exogenous factors such as weather and disturbance (Erman and Erman 1975, Erman 1976, Siegel 1988). Erman and Erman (1975) found that peat depth was positively correlated with Oligochaete production, and was a good predictor of the biomass of some of the associated invertebrate fauna. Chironomids and ceratopogonids populations were apparently unaffected by the change in peat depth in bogs in Sagehen Creek Basin.

Recommendation VI-4.1.7: We recommend that the Forest Service monitor water temperature, conductivity, dissolved oxygen, pH, and turbidity.

Water quality and chemistry are other important factors influencing habitat condition and structure of biotic assemblages, and account for about 35% of the variation found in floral and faunal populations (Keddy 2000). Indicators of water quality are temperature, dissolved oxygen, turbidity, pH, conductivity, hardness and alkalinity, salinity, orthophosphate, nitrate, and mineral concentrations (e.g., Calcium and Magnesium per liter). We recommend water temperature measurements be included in monitoring of peatlands in the Sierra Nevada. In controlled experiments in Minnesota fens, scientists found that water temperature can influence the structure of biotic assemblages (Weltzin et al 2000). Varying temperature changed the species richness and composition of the flora of these fens. Water temperature is another of those abiotic attributes that should be considered basic explanatory variables against which the influence of other attributes can be measured.

Besides temperature, the measurement of conductivity, dissolved oxygen, pH, and turbidity is standard to many aquatic studies and allows some comparison among sites (Barbour et al. 1999). The measurement of these attributes is relatively simple and standardized kits are available. We recommend that these attributes be monitored in peatland habitats. Main and Busch (1992) found that pH and conductivity influence the structure of diatom assemblages in Iowa fens. These variables many also impact the condition of Sierra Nevada peatlands. In any case, the incorporation measurements of these water quality attributes into analyses will help distinguish signal from noise.

Recommendation VI-4.1.8: We recommend that the Forest Service monitor Calcium concentration of peatland water.

Nutrient levels influence plant and animal populations and have been called good indicators of habitat condition (Keddy et al. 1993, Chadde et al. 1998). Studies of fens in the Rocky Mountains indicate that fens with high concentrations of Calcium (>30mg/l) support more species than fens with lower concentrations of Calcium (Chadde et al. 1998). A positive correlation between pH and the concentration of cations such as Potassium (K^+), Sodium (Na^+), Calcium (Ca_2^+), and Magnesium (Mg_2^+) was discovered in Rocky Mountain and Minnesota fens (Siegel 1988, Chadde et al. 1998). This relationship can be hypothesized to prevail in the Sierra Nevada as well, although it has not been investigated. Because it an easy and inexpensive measurement to take, and the data collected will allow evaluation of its relationship to pH, we recommend that Calcium concentration be monitored.

Many other water chemistry attributes have been studied in peatland research. They include, alkalinity, hardness, total- and ortho-phosphate, silica, nitrates, organic and inorganic chemicals, heavy metals, and toxic substances (Siegel 1988, Bursik 1990, Main and Busch 1992, Chadde et al. 1998 and others) Some of these attributes are good indicators of human disturbance and pollution (Karr 1993). All are attributes that, when used as explanatory variables, help explain variation in biotic populations. However, because no clear relationships between these attributes and biological populations has been shown in the Sierra Nevada, these additional attributes should be measured in research oriented studies.

Recommendation VI-4.1.9: We recommend that the Forest Service monitor frequency, intensity and extent of disturbances such as fire, grazing, mining, and visitors.

Disturbance can account for up to 20% of the variation in biotic populations (Keddy 2000). We recommend that attributes (frequency, intensity and extent) of disturbances such as grazing, fire, mining, and visitors be measured. Grazing is thought to modify the vegetational structure of plant communities by selective consumption of plant species, especially grasses and forbs in peatland habitats (Pearson and Leoschke 1992). In a study of Iowa fens, Thompson et al. (1992) found that cattle grazing can change the permeability of soil and divert water flow, thereby changing the conditions on which aquatic life depends. In California and Oregon peatlands, grazing intensity was found to destroy Lincoln's sparrow habitat (Cicero 1997). Cattle trample vegetation, browse surrounding vegetation, exacerbate erosion and gullying, thereby eliminating potential nesting habitat. Mining activities may also change erosion patterns and the chemical composition of ground water. Fire can change the structure of the forests surrounding peatland habitats, and may potentially influence the conditions in this special aquatic habitat.

Recommendation VI-4.1.10: We recommend that the Forest Service monitor physical attributes using remote sensing techniques wherever practical to avoid unnecessary disturbance by monitoring personnel.

Frequent visits by monitoring personnel can inadvertently change the conditions at sampling sites. Monitors open trails that facilitate access by other visitors who are not aware of the sensitive nature of peatland habitats. Trampling and compaction is difficult to avoid and even the most knowledgeable visitor can leave a footprint in the bog.

VI-4.1.3. Biotic Attributes (Integrity)

The life supporting ability of a wetland system is dependent on the landscape mosaic (topographic position and geologic setting), climate, hydrology and water quality (chemical composition and fertility), and disturbance. We often assume species will persist if quality (condition) of habitat is maintained (Keddy et al. 1993). This often leads to the measurement of abiotic conditions that are believed to reflect integrity. However, when information about biological assemblages is required, it is better to measure those assemblages directly than relying on abiotic indicators (Paulsen and Linthurst 1994). In habitats such as peatlands of the Sierra Nevada, where few studies have been made, measuring the flora and fauna along with physical and chemical conditions is the only way relationships between these attributes may be established.

Monitoring physical attributes of special aquatic ecosystems will provide a good picture of the status of the condition of these habitats. However, monitoring condition is not the sole purpose of the Forest Service monitoring program. Monitoring integrity is another. Integrity is measured because we want to know about the existence and persistence of biotic components of ecosystems. We also want to know how impacts from natural and man-made disturbances affect biotic populations, and if management activities are effective at mitigating the disturbances. Following the National Water Quality Assessment (NAWQA) program goals, the Forest Service may want to know more about:

1) How biological assemblages differ among selected environmental settings in each study unit,

2) The primary physical and chemical factors influencing biological assemblages in selected environmental settings,

3) How biological assemblage characteristics are affected by physical and chemical characteristics at different temporal and spatial scales, and,

4) How biological assemblages affect physical and chemical characteristics spatially and temporally.

Using a multi-taxa approach adds additional power to the monitoring design, and agreement, or lack thereof, among these sets of taxonomic data can be very instructive and provide insights to the long-term persistence of these species and their habitats (Gurtz 1994).

There are several reasons for measuring biological attributes. Plants and animals respond to a variety of natural and anthropogenic environmental influences, including stress from use and management, and other disturbances. The biota integrates the impacts over time and populations respond as critical levels are reached. The biota may also integrate impacts over space. Pollution or other variables may enter the system at an undetected point source and the biota can manifest the impacts at some distance from that source. Biological components of ecosystems can provide sensitive indicators of environmental change. For example, chemicals may concentrate in plant and animal tissues at levels that are easier to detect than those that exist in water and sediment. Finally, persistence of biotic components is often the target of conservation and management of threatened ecosystems.

Many biotic attributes have been used as monitoring variables. Biological diversity and redundancy are equivalent to habitat integrity and stability. The number of species (species richness) and guilds are good metrics for measuring biotic integrity. Good guilds to measure in wetlands include carnivorous plants, filter feeding invertebrates, and dabbling ducks (Steedman and Haider 1993). The presence of guild taxa is a good indicator that the function is being carried out and maintained (Severinghaus 1981, Karr 1987, Keddy et al. 1993).

Biotic components are good surrogates for physical attributes that are difficult or expensive to measure. Vegetation biomass is a good indicator of nutrient availability over time. Exotic species are good indicators of stress (Keddy et al. 1993). Rare species are good indicators of integrity because they are sensitive to change and indicate a healthy system, however, their absence is not necessarily an indication of a lack of integrity because of their rarity (Keddy et al. 1993). Middle level consumers are good indicators because they eat lower on the food chain and their persistence is dependent on those components, and because they are food for higher up the food chain (Keddy et al. 1993). Biotic interactions like competition, predation, disease, and parasitism may also be good indicators of integrity (Karr 1993).

When species richness is high, managers need to pick those species that will meet their monitoring needs. Rare species are unlikely to have much of an impact on ecosystem function (although some may). Common species are more likely to do much of the work in ecosystem functions. Thus, while persistence of rare species is important for aesthetics or ethics, common species may be more crucial to ecosystem function persistence and therefore better indicators of ecosystem functional integrity (King 1993). Long-lived organisms provide information about accumulation of impacts while smaller, shorter-lived organisms give better “early warning” signals about integrity (Keddy et al. 1993).

There are other biotic factors that are important monitoring attributes. For example, primary production and decomposition rates are good indicators of nutrient loading and sedimentation rates (Keddy 2000). Other important considerations are the proportion of exotic and invasive species, the persistence of rare or ecologically important species (e.g., pollinators of rare plants), abundance and impacts of pests, and seasonal events such as emergence of mayfly mating swarms. The context of these attributes must be considered in light of the goals and purposes of the monitoring program.

Monitoring wetland habitats is complicated and difficult. Managers must use an integrated approach using both elements (species) and processes to achieve their goals (Karr 1993). The extent to which biological attributes are included in monitoring depends largely on available resources. Biological sampling can be expensive, and limited funding will restrict the number of biological attributes measured. The efficiency of measuring biological metrics must be considered in light of the comprehensive approach to monitoring discussed above.

Other considerations may be the resources available for personnel to collect samples and the availability of taxonomic experts to identify and count biological samples. Below we provide lists of plants and invertebrates that occur in the special aquatic habitats being monitored by the Forest Service. We recommend that as many of these species be included in the monitoring program as is practical and fits the monitoring budget. Without specific knowledge of the budget we can only make general recommendations and assume the Forest Service has sufficient resources to measure everything. More specific questions of interest must be developed within the framework of the comprehensive approach to monitoring.

After a period of monitoring, data analysis will clarify correlations between biotic changes and physical attributes. Inferences about threshold values for physical factors will supply managers with important information about management activities and natural processes.

The following two sections on Floral and Faunal attribute recommendations contain general discussions as an introduction to the subjects. The general discussion above and in the following sections pertain to each of the four habitat groups but will be discussed only in the Peatland section and not repeated for each habitat group. However, specific recommendations and special considerations for each group are provided in the appropriate habitat group sections.

Floral Attributes

Plants are important components of all ecosystems, first because they are the primary producers, making energy from the sun readably available to animals and other plants, and second because they can ameliorate conditions so they are more favorable to other biota. We recommend that as many floral attributes be measured that are practical and fit within the monitoring budget. Biological integrity is the presence and abundance of these components and the only way to measure integrity is to measure these components.

Recommendation VI-4.1.11: We recommend that the Forest Service monitor the presence/absence of plant species known to occur in peatlands of the Sierra Nevada.

Pearson and Leoschke (1992) evaluated the conservation status of fens in Iowa by making plant species lists for sites visited. They estimated that 1-2 hours were needed to compile a plant species list at each site. They classified those sites with intact vegetation (i.e., those sites that contained the plants usually found in Iowa peatlands), high species richness, and the presence of at least one rare species (i.e., endangered, threatened, or special concern species) as outstanding. Sites with at least one rare species were classified as significant. Sites that were cultivated, completely drained (or otherwise severely disturbed) were classified as destroyed. Standards for evaluating the status of peatlands in the Sierra Nevada have not been established, but adopting the above system could be a first step in developing those standards.

We have assembled a list of plants and their associated habitats (Table VI-4.1.1). The list is probably incomplete, but substantially represents information available from modern literature. Subspecies have not been identified except by common name.

Periphyton attributes could also be measured. These plants do not appear in Table VI-4.1.1, but are considered good indicators of condition and integrity (Barbour et al. 1999). There are many advantages to using periphyton such as algae and diatoms as indicators.

1) Algae have rapid reproduction rates and short life cycles, and react quickly to short-term impacts or conditions,
2) Relatively standard methods for collecting are easy to apply, and their collection does not greatly impact other resident biota,
3) Standard methods for analysis of functional and non-taxonomic classification are available,
4) Algal assemblages are sensitive to pollutants that may not be detected by changes in other biological components.

While periphyton species are important components of Sierra Nevada peatlands, monitoring them is time consuming and expensive. Taxonomic experts must be consulted for identification, and the results can be delayed for several months and years. We do not recommend monitoring periphytons unless sufficient budget exists to support the effort required to make it effective.

Recommendation VI-4.1.12: We recommend that the Forest Service monitor all plant species that are listed by the U.S. Fish and Wildlife as Threatened or Endangered, all proposed and candidate species, and all plants listed by the California Department of Fish and Game as rare, threatened, or endangered.

These plant species are of particular interest and information about changes in their abundance and distribution may potentially be useful in managing them and their special habitats. Measuring the populations of these plants provides information about the effectiveness of management systems. Only one of the plants in Table VI-4.1.1 fall into these categories, however, Forest Service personnel should be alert for other species that attain this status.

Recommendation VI-4.1.13: We recommend that the Forest Service monitor *Darlingtonia californica* populations.

Some plant species are considered as indicators of condition, and may have special interest besides those designated as rare, threatened, or endangered. For example, the California pitcher plant, *Darlingtonia californica*, while not designated as a threatened species, is important because of the habitat (bogs) they occupy. Populations of California pitcher plants can be reduced by fire suppression, over-collecting by horticulturalists, loss of habitat due to mining, property development, grazing, and other activities that interrupt water flow (Schnell 1976, Pietropaolo and Pietropaolo, 1986, Skinner and Pavlik 1994, Nyoka and Ferguson 1999). The species is thought to be a good indicator of disturbance to bogs and monitoring populations of this species will provide valuable information about the condition of bogs in the Sierra Nevada (Nyoka and Ferguson 1999).

Recommendation VI-4.1.14: We recommend that the Forest Service monitor populations of nonindigenous plant species.

Invasive, non-indigenous plants are a major concern. They can displace native species and overwhelm a habitat in a short period of time. Establishment of exotic species usually implies that habitats have been disturbed or are not healthy. We recommend that the Forest Service include non-indigenous species as part of their monitoring program.

Recommendation VI-4.1.15: We recommend that the Forest Service monitor other indicator plant populations as budgets permit.

Other plant indicator species that react to conditions or disturbance include Shore sedge (*Carex limosa*), sundew (*Drosera rotundifolia*) and spikerushes (*Elocharis* spp.). Table VI-4.1.1 includes a column "Indicates". This column contains information from modern literature regarding potential conditions represented by the presence of these species. Acronyms are based on the National List of Plant Species that occur in Wetlands: California (Region 0) (Reed 1988).

OBL = Obligate Wetland plant. Occur almost always (estimated probability > 99%) under natural conditions in wetlands.

FACW = Facultative Wetland plant. Usually occur in wetlands (estimated probability 67% - 99%), but occasionally found in non-wetlands.

FAC = Facultative plant. Equally likely to occur in wetlands or non-wetlands (estimated probability 34% - 66%).

FACU = Facultative Upland plant. Usually occur in non-wetlands (estimated probability 67% - 99%), but occasionally found in wetlands (estimated probability 1% - 33%).

Table VI-4.1.1. Plants Associated with Peatland Habitats. A list of plant species associated with peatland habitats, their common names, the habitats in which they occur, the attribute they may be an indicator for or, and references for information provided. The list contains plant species that appear in the modern literature. Red = Federal Threatened or Endangered, Purple = Federal proposed or candidate species, Green = CA Rare or Threatened

genus	species	common name	habitat	indicates	reference
Blechnum	spicant	Deer fern	bog/fen		Sawyer and Keeler-Wolf 1995
Carex	limosa	Shore sedge	bog/fen	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Chamaecyparis	lawsoniana	Port Orford-cedar	bog/fen	FACU+	Sawyer and Keeler-Wolf 1995, Guard 1995
Cyripedium	californicum	California lady-slipper	bog/fen		Sawyer and Keeler-Wolf 1995
Darlingtonia	californica	Darlingtonia	bog/fen	fire, grazing, water flow, pollinators	Sawyer and Keeler-Wolf 1995, Nyoka and Ferguson 1999
Drosera	rotundifolia	Sundew	bog/fen	hydroperiod, stable environment	Sawyer and Keeler-Wolf 1995, Erman 1976, Marcot 1990
Eriophorum	gracile	Cotton-grass	bog/fen		Sawyer and Keeler-Wolf 1995
Gaultheria	shallon	Salal	bog/fen		Sawyer and Keeler-Wolf 1995
Hypericum	anagalloides	Tinker's penney	bog/fen	OBL	Sawyer and Keeler-Wolf 1995, Guard 1995

Ledum	gladulosum	Labrador-tea	bog/fen	FACW+	Sawyer and Keeler-Wolf 1995, Guard 1995
Lilium	spp.	Lilies	bog/fen		Sawyer and Keeler-Wolf 1995
Menyanthes	trifoliata	Bog-bean	bog/fen	OBL	Sawyer and Keeler-Wolf 1995, Guard 1995
Mimulus	primuloides	Primrose monkeyflower	bog/fen		Sawyer and Keeler-Wolf 1995
Parnassia	palustris	Grass-of-Parnassus	bog/fen		Sawyer and Keeler-Wolf 1995
Pinguicula	macroceras	Butterwort	bog/fen		Sawyer and Keeler-Wolf 1995
Rhododendron	occidentale	Western azalea	bog/fen		Sawyer and Keeler-Wolf 1995
Rudbeckia	californica	Cone flower	bog/fen		Sawyer and Keeler-Wolf 1995
Rynchosposa	spp.	Rynchosposa moss	bog/fen		Sawyer and Keeler-Wolf 1995
Sphagnum	spp.	Sphagnum	bog/fen	pH	Sawyer and Keeler-Wolf 1995, Siegel 1988
Spiraea	douglasii	Spiraea	bog/fen	FACW	Sawyer and Keeler-Wolf 1995, Guard 1995
Vaccinium	uliginosum	Bog billberry	bog/fen		Sawyer and Keeler-Wolf 1995
Scirpus	spp.	Bulrushes	marsh, seep, bog/fen		Sawyer and Keeler-Wolf 1995
Eleocharis	spp.	Spikerushes	seep, Bog/fen	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999

Faunal Attributes

Invertebrates are the most numerous and diverse organisms that occur in wetland habitats, both in number of species and in numbers of individuals, and make up the vast majority of aquatic species in the Sierra Nevada. Their diverse functions as herbivores, predators, omnivores, pollinators, and detritivores make them key components of virtually all food webs. Thus it is important to include information about invertebrate species in aquatic habitat management decisions.

Local degradation of habitats is hypothesized to have led to significant impacts on aquatic invertebrates. The aquatic invertebrate fauna as a whole remains largely unknown, and only a fraction of the species diversity in the range has been identified or studied. In addition to more widely known aquatic habitats, such as streams and lakes, many invertebrate species occur in highly local places such as intermittent streams, ephemeral ponds, fens, bogs, springs, and small wetlands. Many species are known only from single sites. Due to food chain relationships, impacts to invertebrates have significant cascading effects on other animals.

From a conservation point of view, it is crucial to know how a plant population responds to a disruption in the population of its pollinator. Most plants rely on several arthropod species for pollination. Those that depend upon a small number of native pollinator species are at a greater risk when habitat is altered or disturbed. Small populations and sparse floral displays may cause rare and endangered plant species to attract fewer pollinators (Spira 2001). Habitat alteration may decrease pollinator populations and lead to a lower frequency of pollinator visits to threatened plants.

The measurement of all ecosystem attributes is virtually impossible; therefore, practical evaluation of the impacts of disturbance and change often depends on surrogate information (Faith and Walker 1996). Many criteria have been advocated for use in habitat assessment (Ratcliffe 1977, Margules and Usher 1981, Usher 1986). Invertebrates represent over 85% of all species (Asquith et al. 1990) and have been used successfully for monitoring in many ecosystem types (e.g., Nelson and Anderson 1994, Samways and Steytler 1996, Ruzicka and Bohac 1993, and others). Because of their small size, high diversity, and sensitivity to environmental perturbations, invertebrates are useful indicators of habitat heterogeneity, ecosystem biological diversity, and environmental stress (Pearson 1992, Pearson and Cassola 1992, Kreman 1994, Nelson and Anderson 1994, Weaver 1995, Samways and Steytler 1996).

Invertebrate information is often site specific and sensitive to time and space; therefore, it cannot be averaged over large, diverse areas. However, community composition at selected sites often reveals the health of the ecosystem at that location (Cooperrider et al. 1986). Because invertebrates participate in almost all ecological processes, they provide a better early warning system that rapidly and accurately reflects the relative intensity of impacts than longer-lived species whose populations react more slowly to environmental change (Pearson and Cassola 1992, Kreman 1994, Samways and Steytler 1996).

Some aquatic invertebrates occur in large numbers and are ubiquitous. They are not only sensitive, but also respond quickly to environmental changes. Monitoring aquatic invertebrates has become a standard measurement of water quality (EPA 1999). Aquatic invertebrates can be a gauge of the levels of ecological changes and are measurable links between microscopic organisms and fish populations. Besides being taxonomically well-known, functional feeding group identification has been well worked out and used extensively for environmental assessment (e.g., EPT index).

Recommendation VI-4.1.16: We recommend that the Forest Service monitor the presence/absence of invertebrate species known to occur in peatlands of the Sierra Nevada.

We recommend that invertebrate species be included in the Forest Service monitoring program of peatland habitats. We have assembled a list of invertebrates known to occur in peatland habitats in the Sierra Nevada (Table VI-4.1.2). The list is probably incomplete, but substantially represents information available from modern literature. The status of biological integrity is measured by the presence and abundance of these components. Monitoring these invertebrate species will provide the Forest Service with good data about the integrity of the peatland habitats.

Recommendation VI-4.1.17: We recommend that the Forest Service monitor 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 from peatland habitats.

These species are of particular interest and information about changes in their abundance and distribution may be potentially useful in managing them and their special habitats. Measuring the populations of these invertebrates provides information about the effectiveness of management systems. None of the invertebrates in Table VI-4.1.2 fall into these categories, however, Forest Service personnel should be alert for species that attain this status.

Recommendation VI-4.1.18: We recommend that the Forest Service monitor populations of nonindigenous invertebrate species in peatland habitats.

Many exotic species of arthropods have been introduced into wetland habitats. The most widespread is the honeybee (*Apis mellifera* L.). Although widely considered beneficial, honeybees can displace native pollinators and disrupt native-plant pollination systems. Studies have shown that while honeybees can remove up to 90% of the floral resources in an area, they are often poor pollinators of wild plants (O'Toole 1993). The decrease in food supply may also be correlated with a decrease in the number of native pollinator species (Ginsburg 1983, Pyke and Balzer 1985, Roubik et al. 1986, Paton 1993, Buchmann 1996). The disruption of natural pollination systems reduces seed production and may threaten the long-term survival of some plant species (Paton 1993, Spira 2001)

We recommend that the Forest Service monitor non-indigenous species. Exotic species have the potential to disrupt natural systems and their presence is often considered a measure of the condition of the habitat.

Recommendation VI-4.1.19: We recommend that the Forest Service monitor other indicator invertebrate populations as research uncovers valid relationships, and as budgets permit.

Invertebrates have been shown to be very useful as indicators of the status of aquatic habitats. Relationships between the presence/absence, or abundance of invertebrate species and habitat conditions have been well-studied for wadeable streams and rivers (Barbour et al. 1999), and for other wetland habitats (see Batzer et al. 1999), however, few studies have focused on invertebrates of peatland habitats in the Sierra Nevada. Information about invertebrate indicator species is preliminary and needs to be developed further. This is a useful goal for Forest Service research and while some information may be collected during monitoring, cause-and-effect relationships can only be studied in controlled experiments.

In the only study that reports a correlation between an invertebrate group, oligochaetes, and a peatland attribute, peat depth, in peatlands in the Sierra Nevada, Erman and Erman (1975) found that oligochaete annual production increased with peat depth. Other work suggests that species from the dipteran families Ephydridae, Culicidae, and Chironomidae may also function as indicators (Batzer & Resh 1992). Much work needs to be done before invertebrates can be used as indicators of habitat conditions. There is a lack of baseline inventory data, and few studies of the relationships between invertebrates of peatlands and ecological condition or conservation status (Marshall et al. 1999).

A word of caution: Invertebrate populations may be sensitive to sampling. In the past, entomologists have often sampled habitats under the assumption that their sampling does no harm to the population being studied. This assumption should be reexamined. During an ecological assessment in Hawaii in 1982, over 29,000 specimens of a U.S. Fish and Wildlife candidate species, Wekiu bug (*Nysius wekiuicola*), were collected (Howarth and Stone 1982). A second assessment in 1998 found that the population of these bugs had declined 99.7% (Howarth et al. 1999). While other factors may have caused the decline of this species, sampling certainly may have contributed. Brenner (2000) found that the population of some species of beetles declined after just two years of sampling with pitfall traps. We recommend that live traps be used where feasible and practical for sampling invertebrates, and that death traps be used only when no other alternative is available.

Table VI-4.1.2. Invertebrates Associated with Peatland Habitats in the Sierra Nevada. A list of invertebrate species associated with peatland habitats, the habitats in which they occur, the attribute they may be an indicator for or , and references for information provided. The list contains invertebrate species that appear in the modern literature.

family	genus	species	habitat	indicates	reference
Diptera					
Tipulidae			peatlands		Erman & Erman 1975
Tabanidae	Chrysops	spp.	peatlands		Erman & Erman 1975
Chrinomidae	Pentaneura	indecisa	peatlands		Erman & Erman 1975
Chrinomidae	Corynoneura	tarus	peatlands		Erman & Erman 1975
Chrinomidae	Metriocnemus	spp.	peatlands		Erman & Erman 1975
Chrinomidae	Paratendipes	spp.	peatlands		Erman & Erman 1975
Caratopogonidae			peatlands		Erman & Erman 1975
Oligochaeta					Erman & Erman 1975
Lumbriculidae	Kincaidiana	hexatheca	peatlands	peat depth, water temperature	Erman & Erman 1975
Lumbriculidae	Kincaidiana	freidris	peatlands	peat depth, water temperature	Erman & Erman 1975
Lumbriculidae	Lumbriculus	variegatus	peatlands	peat depth, water temperature	Erman & Erman 1975
Tubificidae	Limnodrilus	silvani	peatlands	peat depth, water temperature	Erman & Erman 1975

Tubificidae	Rhyacodrilus	coccineus	peatlands	peat depth, water temperature	Erman & Erman 1975
Tubificidae	Tubifex	kessleri americanus	peatlands	peat depth, water temperature	Erman & Erman 1975
Naididae	Slavina	appendiculata	peatlands	peat depth, water temperature	Erman & Erman 1975
Enchytraeidae	Mesenchytraeus	spp.	peatlands	peat depth, water temperature	Erman & Erman 1975
Enchytraeidae	Enchytraeus	spp.	peatlands	peat depth, water temperature	Erman & Erman 1975
Acari			peatlands		Erman & Erman 1975
Arachnida					
Aranidae	Araniella	displicata	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Aranidae	Cyclosa	conica	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Aranidae	Metapeira	grandiosa	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Clubionidae	Clubiona	pacifica	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Dictynidae	Mallos	pallidus	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999

Micryphantidae			Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Salticidae	Metaphidippus	aeneolus	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Tetragnathidae	Tetragnatha	versicolor	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Theridiidae	Theridion	differens	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Thomisidae	Xysticus	locuples	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Mollusca					
Sphaeriidae			peatlands		Erman & Erman 1975

VI-4.2. Springs and Seeps

VI-4.2.1. Mapping and Inventory

Recommendation VI-4.2.1: We recommend that Forest Service monitoring of springs and seeps begin with mapping the locations of spring and seep habitats within the management area.

Mapping may involve remote sensing such as satellite or aerial photographs, or ground searching in localities where these habitats are likely to occur. Identifying the locations of the individual springs and seeps will facilitate monitoring design planning, help determine adequate sample size, and allow for randomizations and other sampling selection criteria. It will also help the Forest Service determine the extent of these habitats over the landscape. The maps also provide a base layer for a GIS, upon which all other information will be organized.

Mapping would also provide information about the location of the nearest similar habitat. The distance to the nearest seep was found to have a strong influence on the presence of five serpentine seep habitat specialist plant species (Harrison et al. 2000). These plants are considered important because they appear on the California Native Plant Society's inventory of rare and endangered vascular plants (Smith 1981).

Recommendation VI-4.2.2: We recommend that the Forest Service mapping include measurements at each site of the elevation, topographic position (slope and aspect), substrate type, the size (historic extent of inundation) and shape of the habitat, significant landmarks (e.g., large trees, boulders, buildings, etc.).

Information about these important attributes may help to explain variation of the biota in these habitats. For example, spring research in Canada has shown that slope, aspect, and elevation have important influences on the penetration and discharge rates of spring water (see Everdingen 1991). These rates may influence the quality of the habitat and the ability of some species to survive (Dank and Williams 1991). Furthermore, geologic settings of springs tend to influence the chemical composition of dissolved solids in spring water (Everdingen 1991).

In a descriptive study of seeps in Marin County, California, Fiedler and Leidy (1987) hypothesized that slope, aspect, and topographic position may be an important factor influencing the distribution of seep-specialist plant species. Source geometry was hypothesized to be important in the persistence of some plant and animal species in seeps in Canada (Danks and Williams 1991).

Surrounding vegetation can have significant impacts on the plants and animals that occur in springs. Shade reduces the growth rates of aquatic vegetation, lowering primary productivity and reducing the species richness of invertebrate assemblages (Danks and Williams 1991). This is another important attribute to measure during mapping and monitoring.

Recommendation VI-4.2.3: We recommend that the Forest Service photograph the sites upon the first and subsequent visits.

Photographs provide information about the location of major landmarks or features of morphology or orientation, vegetation zones, buildings, etc (Barbour et al. 1999). This information will be useful to those people evaluating and interpreting the monitoring information and can be a good reference record of environmental change.

Photographs also provide information about vegetation adjacent to the habitats. In Canada, the vegetation surrounding springs has been shown to modify conditions by shading the water, and providing microhabitats for a variety of invertebrates (Danks and Williams 1991).

VI-4.2.2 Basic Explanatory Variables (Condition)

Ecosystems are produced by multiple environmental factors acting simultaneously (Keddy 2000). These "conditions" explain some part of the variation in biotic populations over time, and therefore should be measured. Correlations between changes in environmental factors and changes in biotic populations of interest need to be investigated, and analyzed, to be understood. Knowledge of the nature of these relationships will allow analyses to be "adjusted" for environmental factors, filtering out "noise", so that the impacts from management and disturbance can be distinguished from the natural variability exhibited by the parameters.

Recommendation VI-4.2.4: We recommend that the Forest Service monitor basic environmental factors such as average and minimum/maximum temperatures, rainfall, and humidity.

Biologists have documented the effects of these environmental factors on plants and animals, and their ability to cause great variation in biological assemblages. It is against these basic explanatory variables that all other influences will be measured. Low-cost weather stations have made the collection of this kind of information easy and affordable. Data recorders can be used to store weather and climate information for download at convenient intervals. Minimum/maximum temperatures is hypothesized to be an important factor determining the composition of biotic assemblages of seeps (Danks and Williams 1991).

Recommendation VI-4.2.5: We recommend that the Forest service monitor hydrological factors: water depth, area or extent, and timing of inundation, and water persistence.

Evaluation of habitat quality is essential in any assessment of ecological condition, and should be performed at each site at the time of biological sampling. An important physical attribute that reflects condition is hydrology. Hydrology accounts for more than 50% of the variation found in aquatic plant and animal populations (Keddy 2000).

Hydrological factors include water depth, area or extent and timing of inundation, and water persistence, and water discharge rate. All are important factors that influence biotic assemblages found in special aquatic habitats. Danks and Williams (1991) reported that higher discharge rates inhibit accumulation of detrital food materials, and may influence some biotic populations. High water discharge rates also increases habitat heterogeneity and can increase species richness (Danks and Williams 1991).

Seep size was determined to be a non-significant factor in the persistence of five serpentine seep habitat specialist plant species (Harrison et al. 2000), but this study was limited and we believe habitat size may be an important factor in the distribution of other species. The persistence of water at seeps was considered important in the differences of biotic assemblages between different seeps in Canada (Danks and Williams 1991). The same relationships may be expected to occur in Sierra Nevada seeps and springs.

Hydrology attributes, such as underground water flow rates and time in the ground are interesting and may influence the conditions of habitats, however, these attributes are more difficult to measure, and commitment of resources should be considered and evaluated before these measurements are undertaken. Everdingen (1991) found that Total Dissolved Solids (TDS) reflected the mineral composition of the rock strata and subsurface residence time. He did not include in his publication how these factors may influence the biota of springs, only that TDS was a measure of the condition of the spring habitats in Canada (see Recommendation VI-4.2.6).

Recommendation VI-4.2.6: We recommend that the Forest Service monitor water temperature, dissolved oxygen, pH, and TDS.

Water quality and chemistry are important factors that can influence habitat condition and structure of biotic assemblages, and account for about 35% of the variation found in floral and faunal populations (Keddy 2000). Indicators of water quality are temperature, dissolved oxygen, turbidity, pH, conductivity, hardness and alkalinity, salinity, orthophosphate, nitrate, and mineral concentrations (e.g., Calcium and Magnesium per liter).

Water temperature is one of those abiotic attributes that should be considered a basic explanatory variable against which the influence of other attributes can be measured. Water temperature influences the species of plants and animals found in Canadian springs, and the same relationship can be hypothesized to occur Sierra Nevada habitats (Danks and Williams 1991). As water temperature increases, the number of aquatic invertebrate species decreases (Lamberti and Resh 1983, Pritchard 19991, Myers and Resh 1999). We recommend water temperature measurements be included in monitoring of springs and seeps in the Sierra Nevada.

Besides temperature, the measurement of conductivity, dissolved oxygen, pH, and turbidity is standard to many aquatic studies and allows some comparison among sites (Barbour et al. 1999). The measurement of these attributes is relatively simple and standardized kits are available. Water chemistry (TDS) is hypothesized to be an important factor in the distribution of spring-specialist plants and animals (Danks and Williams 1991).

Water pH is considered an indicator of the concentration of metal ions which may have a detrimental effect on fish populations in streams receiving spring discharge. Research in Canadian springs found that low pH indicated a high metal concentration (Everdingen 2000).

We recommend that these attributes be monitored in spring and seep habitats. All but conductivity were attributes measured in descriptive studies of springs and seeps we evaluated for this report, although no direct information was found that related how the factors changed the biotic assemblages. However, these variables many also impact the condition of Sierra Nevada springs and seeps, and the incorporation of these water quality attributes into analyses will help distinguish signal from noise.

Because water is sometimes drawn from wells for use by humans and cattle, there is often concern about the condition of ground water. It has been suggested that monitoring the conditions of water in springs and seeps can be useful in extrapolating the conditions of ground water (Williams and Danks 1991). Little literature is available on this subject and more work needs to be completed before correlations are established between ground water and spring water conditions.

Recommendation VI-4.2.7: We recommend that the Forest Service monitor frequency, intensity and extent of disturbances such as fire, grazing, mining, and visitors.

Disturbance can account for up to 20% of the variation in biotic populations (Keddy 2000). We recommend that attributes (frequency, intensity and extent) of disturbances such as grazing, fire, mining, and visitors be measured. Grazing and off-road vehicular traffic are hypothesized to modify the vegetational structure of plant communities by trampling plant species in spring and seep habitats, leading to an increase in the presence of non-indigenous species (Fiedler and Leidy 1987). Also, cattle and off-road vehicles trample vegetation, browse surrounding vegetation, exacerbate erosion and gullying, thereby eliminating potential nesting habitat. Mining activities may also change erosion patterns and the chemical composition of ground water. Fire can change the structure of the forests surrounding peatland habitats, and may potentially influence the conditions in this special aquatic habitat.

Recommendation VI-4.2.8: We recommend that the Forest Service monitor physical attributes using remote sensing techniques wherever practical to avoid unnecessary disturbance by monitoring personnel.

Frequent visits by monitoring personnel can inadvertently change the conditions at sampling sites. Monitors open trails that facilitate access by other visitors who are not aware of the sensitive nature of spring and seep habitats. Trampling and compaction is difficult to avoid and even the most knowledgeable visitor can disturb sensitive habitats.

VI-4.2.3. Biotic Attributes (Integrity)

Floral Attributes

Plants are important components of all ecosystems, first because they are the primary producers, making energy from the sun readably available to animals and other plants, and second because they can ameliorate conditions so they are more favorable to other biota. We recommend that as many floral attributes be measured that are practical and fit within the monitoring budget. Biological integrity is the presence and abundance of these components and the only way to measure integrity is to measure these components.

Plant species may exhibit strong synchronized population fluctuations that may be correlated with habitat conditions, although the conditions that influence population size remain to be described. Scientists studying serpentine seeps suggest that spatial distribution may be very important to the survival of these rare plants (e.g., Harrison et al. 1999).

Recommendation VI-4.2.9: We recommend that the Forest Service monitor the presence/absence of plant species known to occur in springs and seeps of the Sierra Nevada.

Little information is available about the plants that occur in springs and seeps in the Sierra Nevada. In a recent publication about California vegetation, Sawyer and Keeler-Wolf (1995) offer only sparse information about the plants that occur in spring and seep habitats. We have assembled a list of plants and their associated habitats (Table VI-4.2.1) from available literature. The list is probably incomplete, and general inventories of spring and seep vegetation would expand the list.

Recommendation VI-4.2.10: We recommend that the Forest Service monitor all plant species that are listed by the U.S. Fish and Wildlife as Threatened or Endangered, all proposed and candidate species, and all plants listed by the California Department of Fish and Game as rare, threatened, or endangered.

These plant species are of particular interest and information about changes in their abundance and distribution may be potentially useful in managing them and their special habitats. Measuring the populations of these plants provides information about the effectiveness of management systems. None of the plants in Table VI-4.2.1 fall into these categories, however, Forest Service personnel should be alert for species that attain this status.

Recommendation VI-4.2.11: We recommend that the Forest Service monitor populations of nonindigenous plant species.

Invasive, non-indigenous plants are a major concern. They can displace native species and overwhelm a habitat in a short period of time. Establishment of exotic species usually implies that habitats have been disturbed or are not healthy (Fiedler and Leidy 1987). We recommend that the Forest Service include non-indigenous species as part of their monitoring program.

Recommendation VI-4.2.12: We recommend that the Forest Service monitor other indicator plant populations as budgets permit.

Some plant indicator species react to habitat conditions. Table VI-4.2.1 includes a column "Indicates". This column contains information from modern literature regarding potential conditions represented by the presence of these species. Acronyms are based on the National List of Plant Species that occur in Wetlands: California (Region 0) (Reed 1988).

Table VI-4.2.1. Plants Associated with Sierra Nevada Spring and Seep Habitats. A list of plant species associated with spring and seep habitats, their common names, the attribute they may be an indicator for, and references for information provided. The list contains plant species that appear in the modern literature.

genus	species	common name	habitat	indicates	reference
Carex	utriculata	Beaked sedge	marsh, seep	OBL	Sawyer and Keeler-Wolf 1995, Guard 1995
Scirpus	spp.	Bulrushes	marsh, seep, bog/fen		Sawyer and Keeler-Wolf 1995
Carex	scopularum	Rocky Mountain sedge	seep	FACW, hydroperiod	Sawyer and Keeler-Wolf 1995, Guard 1995, Heise and Merenlender 1999
Eriophorum	criniger	Cotton-grass	seep		Sawyer and Keeler-Wolf 1995
Pedicularis	groenlandica	Elephant's ears	seep		Sawyer and Keeler-Wolf 1995
Eleocharis	spp.	Spikerushes	seep, Bog/fen	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Carex	nebrascensis	Nebraska sedge	seep, wet meadow	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Juncus	spp.	Rushes	seep, wet meadow	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Oryzopsis	kingii	Sierra ricegrass	seep, wet meadow		Sawyer and Keeler-Wolf 1995
Eleocharis	palustris	creeping spikerush	wet meadow, seep, vernal marsh	OBL, hydroperiod	Tiner 1999, Guard 1995, Heise and Merenlender 1999

Faunal Attributes

Invertebrates are the most numerous and diverse organisms that occur in wetland habitats, both in number of species and in numbers of individuals, and make up the vast majority of aquatic species in the Sierra Nevada. Their diverse functions as herbivores, predators, omnivores, pollinators, and detritivores make them key components of virtually all food webs. Insects may also be good indicators of pollination function and therefore biotic integrity of these habitats (Harrison et al. 1999). Because of their special adaptations to conditions, the fauna of springs and seeps may provide useful and meaningful, and relatively inexpensive, indicators for monitoring groundwater quality (Erman 1989, Williams et al. 1990, Williams 1991a). Thus it is important to include information about invertebrate species in aquatic habitat management decisions.

Recommendation VI-4.2.13: We recommend that the Forest Service monitor the presence/absence of invertebrate species known to occur in springs and seeps of the Sierra Nevada.

We recommend that invertebrate species be included in the Forest Service monitoring program of spring and seep habitats. We have assembled a list of invertebrates known to occur in spring and seep habitats in the Sierra Nevada (Table VI-4.2.2). The list is probably incomplete, but substantially represents information available from modern literature. The status of biological integrity is measured by the presence and abundance of these components. Many crenophilic mite species, for example, exhibit a very narrow tolerance range for environmental factors such as dissolved chemicals and pH, as well as temperature. These species have been suggests as potential biomonitors of environmental change (e.g. Schwoerbel 1959, Young 1969, Smith 1991). Trichoptera show a strong affinity to habitat conditions such as water temperature and food availability. Differences in populations may also be due to elevation, groundwater source, and summer temperatures (Williams 1991b). Monitoring invertebrate species will provide the Forest

Service with the best information about the integrity and quality of the spring and seep habitats (Danks and Williams 1991).

Recommendation VI-4.2.14: We recommend that the Forest Service monitor 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.

These species are of particular interest and information about changes in their abundance and distribution may be potentially useful in managing them and their special habitats. Measuring the populations of these invertebrates provides information about the effectiveness of management systems. Only one of the invertebrates (*Gumaga griseola*) in Table VI-4.2.2 fall into these categories, and, Forest Service personnel should be alert for other species that attain this status.

Recommendation VI-4.2.15: We recommend that the Forest Service monitor nonindigenous invertebrate species.

Many exotic species of arthropods have been introduced into wetland habitats. These species may displace or extirpate important native species. We recommend that the Forest Service monitor non-indigenous species. Exotic species have the potential to disrupt natural systems and their presence is often considered a measure of the condition of the habitat (Danks and Williams 1991).

Recommendation VI-4.2.16: We recommend that the Forest Service monitor other indicator invertebrate populations as research uncovers valid relationships, and as budgets permit.

Invertebrates have been shown to be very useful as indicators of the status of aquatic habitats. Relationships between the presence/absence, or abundance of invertebrate species and habitat conditions have been well-studied for wadeable streams and rivers (Barbour et al. 1999), and for other wetland habitats (see Batzer et al. 1999), however, few studies have focused on invertebrates of spring and seep habitats in the Sierra

Nevada. Information about invertebrate indicator species is preliminary and needs to be developed further. This is a useful goal for Forest Service research and while some information may be collected during monitoring, cause-and-effect relationships can only be studied in controlled experiments.

Only a few studies have been published with information about spring and seep invertebrates in the Sierra Nevada (Erman 1984, 1989). There is a lack of baseline inventory data, and no studies of the relationships between invertebrates of springs and seeps in the Sierra Nevada and ecological condition or conservation status. There is a need for area-wide inventory and monitoring of spring and seep invertebrates to obtain more information on species with respect to potential physiological and ecological adjustments and relationships with other organisms (Danks and Williams 1991).

Table VI-4.2.2. Invertebrates Associated with Spring and Seep Habitats in the Sierra Nevada. A list of invertebrate species associated with spring and seep habitats, the habitats in which they occur, the attribute they may be an indicator for or , and references for information provided. The list contains invertebrate species that appear in the modern literature.

family	genus	species	habitat	indicates	reference
Trichoptera					
Goeridae	Goeracea	oregona	springs		Erman 1989
Lepidostomatidae	Lepidostoma	verodum	springs		Erman 1989
Lepidostomatidae	Lepidostoma	ermanae	springs		Erman 1989
Limnephilidae	Allomyia	cidoipes	springs		Erman 1989
Limnephilidae	Cryptochia	excella	springs		Erman 1989
Limnephilidae	Desmona	bethula	springs		Erman 1989
Limnephilidae	Hesperophylax	designatus	springs, ponds		Erman 1989
Limnephilidae	Homophylax	rentzi	springs		Erman 1989
Limnephilidae	Lenarchus	rilus	springs, ponds		Erman 1989
Limnephilidae	Limnephilus	peltus	springs		Erman 1989
Limnephilidae	Neophylax	splendens	springs		Erman 1989
Limnephilidae	Psychoglypha	ormiae	springs		Erman 1989

Odontoceridae	Parthina	linea	springs, seeps		Erman 1989
Philopotamidae	Wormaldia	occidea	springs		Erman 1989
Phryganeidae	Yphria	californica	springs		Erman 1989
Rhyacophilidae	Rhyacophila	ardala	springs		Erman 1989
Rhyacophilidae	Rhyacophila	brunnea	springs		Erman 1989
Rhyacophilidae	Rhyacophila	grandis	springs		Erman 1989
Rhyacophilidae	Rhyacophila	harmstoni	springs		Erman 1989
Rhyacophilidae	Rhyacophila	oreta	springs		Erman 1989
Rhyacophilidae	Rhyacophila	verrula	springs		Erman 1989
Sericostomatidae	Gumaga	griseola	springs		Erman 1989
Arachnida					
Aranidae	Araniella	displicata	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Aranidae	Cyclosa	conica	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Aranidae	Metapeira	grandiosa	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999

Clubionidae	Clubiona	pacifica	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Dictynidae	Mallos	pallidus	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Micryphantidae			Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Salticidae	Metaphidippus	aeneolus	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Tetragnathidae	Tetragnatha	versicolor	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Theridiidae	Theridion	differens	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999
Thomisidae	Xysticus	locuples	Seeps, bogs	pollinator or associate of Darlingtonia californica	Nyoka & Ferguson 1999

VI-4.3. Ponds

VI-4.3.1. Mapping and Inventory

Recommendation VI-4.3.1: We recommend that Forest Service monitoring of ponds begin with mapping the locations of pond habitats within the management area.

Mapping may involve remote sensing such as satellite or aerial photographs, or ground searching in localities where these habitats are likely to occur. Identifying the locations of the individual ponds will facilitate monitoring design planning, help determine adequate sample size, and allow for randomizations and other sampling selection criteria. It will also help the Forest Service determine the extent of these habitats over the landscape. The maps also provide a base layer for a GIS, upon which all other information will be organized.

Recommendation VI-4.3.2: We recommend that the Forest Service mapping include measurements at each site of the elevation, substrate type, the size (historic extent of inundation) and shape of the habitat, significant landmarks (e.g., large trees, boulders, buildings, etc.), and adjacent vegetation.

Information about these important attributes may help to explain variation of the biota in these habitats. Factors such as elevation and substrate type can influence the flora and fauna that may occur in a pond habitat (Soiseth 1992). In Canadian ponds, perimeter size is positively correlated spawning habitat for Leopard frogs and could be an important factor for frogs and other fauna in the Sierra Nevada (Pope et al. 2000). Knowledge of the surrounding landscape is required to understand species distribution and abundance (Pope et al. 2000).

Recommendation VI-4.3.3: We recommend that the Forest Service photograph the sites upon the first and subsequent visits.

Photographs provide information about the location of major landmarks or features of morphology or orientation, vegetation zones, buildings, etc (Barbour et al. 1999). This information will be useful to those people evaluating and interpreting the monitoring information and can be a good reference record of environmental change.

VI-4.2.2 Basic Explanatory Variables (Condition)

Ecosystems are produced by multiple environmental factors acting simultaneously (Keddy 2000). These "conditions" explain some part of the variation in biotic populations over time, and therefore should be measured. Correlations between changes in environmental factors and changes in biotic populations of interest need to be investigated, and analyzed, to be understood. Knowledge of the nature of these relationships will allow analyses to be "adjusted" for environmental factors, filtering out "noise", so that the impacts from management and disturbance can be distinguished from the natural variability exhibited by the parameters.

Recommendation VI-4.3.4: We recommend that the Forest Service monitor basic environmental factors such as average and minimum/maximum temperatures, rainfall, and humidity.

Biologists have documented the effects of these environmental factors on plants and animals, and their ability to cause great variation in biological assemblages. In the Sierra Nevada, for example, caddisfly larvae presence is largely determined by climate, and timing of collections can influence the assemblage sampled (Erman 1989). It is against these kinds of basic explanatory variables that all other influences will be measured. Low-cost weather stations have made the collection of this kind of information easy and affordable. Data recorders can be used to store weather and climate information for download at convenient intervals.

Recommendation VI-4.3.5: We recommend that the Forest service monitor hydrological factors: water depth, area or extent, and timing of inundation, and water persistence.

Evaluation of habitat quality is essential in any assessment of ecological condition, and should be performed at each site at the time of biological sampling. An important physical attribute that reflects condition is hydrology. Hydrology accounts for more than 50% of the variation found in aquatic plant and animal populations (Keddy 2000). Hydrological factors include water depth, area or extent and timing of inundation, and water persistence, and water discharge rate. All are important factors that influence biotic assemblages found in special aquatic habitats.

Water depth has been shown to influence the populations of invertebrate species in ponds. In Suisun Marsh in Solano County, California, larvae of the midge, *Chironomus stigmatus,* occur in higher abundance in ponds 55 cm deep compared to ponds only 40 cm deep (Batzer and Resh 1992). Water persistence (hydroperiod) has also been shown to impact aquatic species in ponds. In the Emerald Lake watershed in the Sierra Nevada, the size and survival of larval Treefrogs was found to decrease with shorter pond persistence (Soiseth 1992).

Other important physical attributes that have been found important for classifying and evaluating pond status include pond maximum length, breath, surface area, and shoreline length maximum depth and percent relative depth, water permanence, sediment depth (Marcot 1990). Marcot (1990) found water permanence was the best attribute to classify pond habitats.

Recommendation VI-4.3.6: We recommend that the Forest Service monitor water temperature, dissolved oxygen, pH, and TDS.

Water quality and chemistry are other important factors influencing habitat condition and structure of biotic assemblages, and account for about 35% of the variation found in floral and faunal populations (Keddy 2000). Indicators of water quality are temperature, dissolved oxygen, turbidity, pH, conductivity, hardness and alkalinity, salinity, orthophosphate, nitrate, and mineral concentrations (e.g., Calcium and Magnesium per liter). Some of these variables are more important in pond habitats than others.

Water temperature is one of those abiotic attributes that should be considered a basic explanatory variable against which the influence of other attributes can be measured. Water temperature can influence the body size of Treefrog larvae and ultimately impact their survivability. In ponds in South Carolina, Leips et al. (2000) found that higher temperatures led to smaller body size at metamorphosis. These larvae were often more easily preyed upon by predators. We recommend water temperature measurements be included in monitoring of pond habitats in the Sierra Nevada.

Besides temperature, the measurement of conductivity, dissolved oxygen, pH, and turbidity is standard to many aquatic studies and allows some comparison among sites (Barbour et al. 1999). The measurement of these attributes is relatively simple and standardized kits are available. Some attributes are more important than others. For example, episodic acidification in the Sierra Nevada occurs in alpine wetlands during snowmelt and summer rainstorms (Dozier et al. 1987, Melack et al. 1988, Stohlgren and Parsons 1987). Sierra Nevada surface waters are sensitive to acid deposition because of their dilute chemistry (Melack et al. 1988). Larval stages of Treefrogs in the Emerald Lake watershed located in the Sierra Nevada are sensitive to low pH, and may die at pH levels below 5.0 (Soiseth 1992). Therefore, pH is an important physical attribute to measure.

In a study of pond habitats, temperature, dissolved oxygen, pH, conductivity, turbidity were used to classify ponds. These attributes were then used to explain the distribution of pond vegetation (Marcot 1990). The exact relationships between these attributes and vegetation distribution was not discussed in the article, they were considered important attributes. These variables many also impact the condition of Sierra Nevada ponds, and the incorporation of these water quality attributes into analyses will help distinguish signal from noise. We recommend that these attributes be monitored in Sierra Nevada pond habitats.

Dissolved solids (TDS) is also an important factor that influences the quality of pond habitats. In a study of saline ponds in Fresno County, there was a negative correlation between salinity and species richness (Parker and Knight 1992). They concluded that dissolved minerals are most likely the most important factor determining biological characteristics in those kinds of systems. While salinity may not be a big factor in Sierra Nevada ponds, dissolved solids extracted from serpentine substrata may impact species richness. Monitoring TDS may expose close relationships previously unstudied.

Recommendation VI-4.3.7: We recommend that the Forest Service monitor frequency, intensity and extent of disturbances such as fire, grazing, mining, and visitors.

Disturbance can account for up to 20% of the variation in biotic populations (Keddy 2000). We recommend that attributes (frequency, intensity and extent) of disturbances such as grazing, fire, mining, roads, and visitors be measured. Mining activities may also change erosion patterns and the chemical composition of ground water. Fire can change the structure of the forests surrounding peatland habitats, and may potentially influence the conditions in this special aquatic habitat. Road building often alters the physical environment, and soil adjacent to and under the road, soil density, temperature, water content, light levels, dust, surface waters, patterns of runoff, and sedimentation as well as adding heavy metals (especially lead), salts, organic molecules, ozone, and nutrients to roadside environments. Roads also promote the spread of exotic species and the use by humans (Trombulak and Frissell 1999).

Recommendation VI-4.3.8: We recommend that the Forest Service monitor physical attributes using remote sensing techniques wherever practical to avoid unnecessary disturbance by monitoring personnel.

Frequent visits by monitoring personnel can inadvertently change the conditions at sampling sites. Monitors open trails that facilitate access by other visitors who are not aware of the sensitive nature of pond habitats. Trampling and compaction is difficult to avoid, and even the most knowledgeable visitor can disturb sensitive habitats.

VI-4.3.3. Biotic Attributes (Integrity)

Floral Attributes

Plants are important components of all ecosystems, first because they are the primary producers, making energy from the sun readably available to animals and other plants, and second because they can ameliorate conditions so they are more favorable to other biota. We recommend that as many floral attributes be measured that are practical and fit within the monitoring budget. Biological integrity is the presence and abundance of these components and the only way to measure integrity is to measure these components.

Recommendation VI-4.3.9: We recommend that the Forest Service monitor the presence/absence of plant species known to occur in ponds of the Sierra Nevada.

Little information is available about the plants that occur in ponds in the Sierra Nevada. In a recent publication about California vegetation, Sawyer and Keeler-Wolf (1995) offer only sparse information about the plants that occur in pond habitats. We have assembled a list of plants and their associated habitats (Table VI-4.3.1) from available literature. The list is probably incomplete, and general inventories of pond vegetation would expand the list.

Species such as foxtails (*Alopeccurus* spp.), cinquefoils (*Potentilla* spp.), and crowfoots (*Ranunculus* spp.) can be good indicators of stability of pond conditions (Marcot 1990). Foxtails and crowfoot species indicate ephemeral or astatic conditions, while cinquefoils are a sign of pond stability.

Periphytons may be good indicators of mesotrophic and eutrophic conditions. The list in Table 4.3.1 does not include algae, however, studies have shown that some algae species, such as *Aphanizonmenon flosaquae* and *Microcystis aeruginosa*, and epiphytic and tychoplantonic diatoms can reveal provide significant information about the trophic health of ponds and the degree of organic material input (Marcot 1990). Low abundance levels of these algae indicate relatively health habitats. Moderate diversity of the diatoms mentioned can denote mesotrophy or early stages of eutrophy (Marcot 1990).

Recommendation VI-4.3.10: We recommend that the Forest Service monitor all plant species that are listed by the U.S. Fish and Wildlife as Threatened or Endangered, all proposed and candidate species, and all plants listed by the California Department of Fish and Game as rare, threatened, or endangered.

These plant species are of particular interest and information about changes in their abundance and distribution may be potentially useful in managing them and their special habitats. Measuring the populations of these plants provides information about the effectiveness of management systems. None of the plants in Table VI-4.3.1 fall into these categories, however, Forest Service personnel should be alert for species that attain this status.

Recommendation VI-4.3.11: We recommend that the Forest Service monitor nonindigenous plant species.

Invasive, non-indigenous plants are a major concern. They can displace native species and overwhelm a habitat in a short period of time. We recommend that the Forest Service include non-indigenous species as part of their monitoring program.

Recommendation VI-4.3.12: We recommend that the Forest Service monitor other indicator plant populations as budgets permit.

Some plant indicator species react to habitat conditions. Table VI-4.3.1 includes a column "Indicates". This column contains information from modern literature regarding potential conditions represented by the presence of these species. Acronyms are based on the National List of Plant Species that occur in Wetlands: California (Region 0) (Reed 1988).

Table VI-4.3.1. Plants Associated with Sierra Nevada Pond Habitats. A list of plant species associated with pond habitats, their common names, the attribute they may be an indicator for, and references for information provided. The list contains plant species that appear in the modern literature.

genus	species	common name	habitat	indicates	reference
Scirpus	acutus	common tule	freshwater marsh	semipermanent flooding, OBL	Tiner 1999, Guard 1995
Typha	angustifolia	narrowleaf cattail	freshwater marsh	subalkaline water, deeper water, OBL	Tiner 1999, Keddy 2000, Guard 1995
Typha	latifolia	Broadleaf cattail	freshwater marsh	alkaline soil, shallow water, OBL	Tiner 1999, Keddy 2000, Guard 1995
Brasenia	schreberi	Water-shield	marsh	OBL	Sawyer and Keeler-Wolf 1995, Guard 1995
Isoetes	spp.	Quillworts	marsh	OBL	Sawyer and Keeler-Wolf 1995, Guard 1995
Nuphar	luteum	Yellow pond-lily	marsh		Sawyer and Keeler-Wolf 1995
Potamogeton	spp.	Pondweeds	marsh	OBL	Sawyer and Keeler-Wolf 1995, Guard 1995
Sparganium	angustifolium	Narrowleaf bur-reed	marsh		Sawyer and Keeler-Wolf 1995
Sparganium	emersum	Simpleleaf bur-reed	marsh	OBL	Sawyer and Keeler-Wolf 1995, Guard 1995
Sparganium	natans	Small bur-reed	marsh		Sawyer and Keeler-Wolf 1995
Sparganium	spp.	Bur-reeds	marsh		Sawyer and Keeler-Wolf 1995
Torreyochloa	spp.	Torreyochloa moss	marsh		Sawyer and Keeler-Wolf 1995

Typha	spp.	Cattails	marsh		Sawyer and Keeler-Wolf 1995
Carex	utriculata	Beaked sedge	marsh, seep	OBL	Sawyer and Keeler-Wolf 1995, Guard 1995
Scirpus	spp.	Bulrushes	marsh, seep, bog/fen		Sawyer and Keeler-Wolf 1995
Carex	nebrascensis	Nebraska sedge	seep, wet meadow	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Juncus	spp.	Rushes	seep, wet meadow	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Oryzopsis	kingii	Sierra ricegrass	seep, wet meadow		Sawyer and Keeler-Wolf 1995
Achillea	lanulosa	Yarrow	wet meadow		Sawyer and Keeler-Wolf 1995
Agrostis	capillaris	Colonial bent grass	wet meadow	FAC	Sawyer and Keeler-Wolf 1995, Guard 1995
Angelica	tomentosa	Angelica	wet meadow		Sawyer and Keeler-Wolf 1995
Anthoxanthum	odoratum	Vernal grass	wet meadow	FACU	Sawyer and Keeler-Wolf 1995, Guard 1995
Aster	alpigenus	Alpine aster	wet meadow		Sawyer and Keeler-Wolf 1995
Calamagrostis	breweri	Shorthair reedgrass	wet meadow		Sawyer and Keeler-Wolf 1995
Calamagrostis	nutkaensis	Pacific reedgrass	wet meadow		Sawyer and Keeler-Wolf 1995
Cardamine	breweri	Brewer bitter-cress	wet meadow		Sawyer and Keeler-Wolf 1995

Carex	filifolia	Shorthair sedge	wet meadow	pH, dissolved solutes, hydroperiod	Sawyer and Keeler-Wolf 1995, Siegel 1988, Heise and Merenlender 1999
Carex	nigricans	Blackish sedge	wet meadow	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Carex	subnigricans	Mount Dana sedge	wet meadow	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Danthonia	californica	California oatgrass	wet meadow	FACU	Sawyer and Keeler-Wolf 1995, Guard 1995
Deschampsia	cespitosa	Tufted hairgrass	wet meadow	FACW	Sawyer and Keeler-Wolf 1995, Guard 1995
Dodecatheon	jeffreyi	Jeffrey shooting star	wet meadow		Sawyer and Keeler-Wolf 1995
Erigonum	spp.	Buckwheats	wet meadow		Sawyer and Keeler-Wolf 1995
Festuca	arundinacea	Alta grass	wet meadow	FAC-	Sawyer and Keeler-Wolf 1995, Guard 1995
Festuca	rubra	Red fescus	wet meadow	salt tolerant, FAC+	Sawyer and Keeler-Wolf 1995, Tiner 1999, Guard 1995
Holcus	lanatus	Velvet grass	wet meadow	FAC	Sawyer and Keeler-Wolf 1995, Guard 1995
Juncus	mertensianus	Merten rush	wet meadow	hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Kalmia	ploifolia	Alpine-laurel	wet meadow		Sawyer and Keeler-Wolf 1995
Penstemon	heterodoxus	Heretic penstemon	wet meadow		Sawyer and Keeler-Wolf 1995

Phyllodoce	breweri	Brewer heather	wet meadow		Sawyer and Keeler-Wolf 1995
Phyllodoce	empetriformis	Cascade heather	wet meadow		Sawyer and Keeler-Wolf 1995
Phyllodoce	spp.	Mountian heather	wet meadow		Sawyer and Keeler-Wolf 1995
Potentilla	breweri	Brewer cinquefoil	wet meadow	stable environment	Sawyer and Keeler-Wolf 1995, Marcot 1990
Potentilla	drummondii	Drummond cinquefoil	wet meadow	stable environment	Sawyer and Keeler-Wolf 1995, Marcot 1990
Potentilla	spp.	Cinquefoils	wet meadow		Sawyer and Keeler-Wolf 1995
Primula	suffrutescens	Sierra primrose	wet meadow		Sawyer and Keeler-Wolf 1995
Senecio	scorzonella	Coville ragwort	wet meadow		Sawyer and Keeler-Wolf 1995
Sibbaldia	procumbens	Subbaldia	wet meadow		Sawyer and Keeler-Wolf 1995
Solidago	multiradiata	Northern goldenrod	wet meadow		Sawyer and Keeler-Wolf 1995
Trisetum	spicatum	Spike trisetum	wet meadow		Sawyer and Keeler-Wolf 1995
Vaccinium	caespitosum	Bilberry	wet meadow	FACU	Sawyer and Keeler-Wolf 1995, Guard 1995
Eleocharis	palustris	creeping spikerush	wet meadow, seep, vernal marsh	OBL, hydroperiod	Tiner 1999, Guard 1995, Heise and Merenlender 1999

Faunal Attributes

Invertebrates are the most numerous and diverse organisms that occur in wetland habitats, both in number of species and in numbers of individuals, and make up the vast majority of aquatic species in the Sierra Nevada. Their diverse functions as herbivores, predators, omnivores, pollinators, and detritivores make them key components of virtually all food webs. Thus it is important to include information about invertebrate species in aquatic habitat management decisions.

Recommendation VI-4.3.13: We recommend that the Forest Service monitor the presence/absence of invertebrate species known to occur in ponds of the Sierra Nevada.

We recommend that invertebrate species be included in the Forest Service monitoring program of pond habitats. We have assembled a list of invertebrates known to occur in spring and seep habitats in the Sierra Nevada (Table VI-4.3.2). The list is probably incomplete, but substantially represents information available from modern literature. The status of biological integrity is measured by the presence and abundance of these components. Monitoring these invertebrate species will provide the Forest Service with good information about the integrity and quality of the pond habitats.

Recommendation VI-4.2.14: We recommend that the Forest Service monitor 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.

These species are of particular interest and information about changes in their abundance and distribution may be potentially useful in managing them and their special habitats. Measuring the populations of these invertebrates provides information about the effectiveness of management systems. Only one of the invertebrates, the amphipod

Eogammarus confervicolus, in Table VI-4.3.2 fall into these categories. Forest Service personnel should be alert for other species that attain this status.

Recommendation VI-4.3.15: We recommend that the Forest Service monitor nonindigenous invertebrate species.

Many exotic species of arthropods have been introduced into wetland habitats. These species may displace or extirpate important native species. Exotic species have the potential to disrupt natural systems and their presence is often considered a measure of the condition of the habitat (Danks and Williams 1991). Monitoring of exotic species, primarily fish is critical to the integrity of pond habitats. These vertebrates have a predominant influence on the structure and integrity of aquatic habitats (Carpenter et al. 1985, Power 1990, Moyle and Ellison 1991, Knapp and Matthews 2000) and some non-indigenous species may out-compete native fauna. For example, introductions of trout into naturally fishless lakes, or ponds connected to stream networks appears to have negative effects on population size of the mountain yellow-legged frog (Knapp et al. 2000). Lawler et al. (1999) documented adverse effects of introduced mosquitofish and bullfrog tadpoles on red-legged frog tadpoles. We recommend that the Forest Service monitor non-indigenous species.

Note: Only a few studies have been published with information about pond-dwelling invertebrates in the Sierra Nevada (Erman 1989, Batzer & Resh 1992). There is a lack of baseline inventory data, and no studies of the relationships between invertebrates of ponds in the Sierra Nevada and ecological condition or conservation status. There is a need for area-wide inventory and monitoring of pond-dwelling invertebrates to obtain more information on species with respect to potential physiological and ecological adjustments and relationships with other organisms.

Table VI-4.3.2. Invertebrates Associated with Pond Habitats in the Sierra Nevada. A list of invertebrate species associated with pond habitats, the habitats in which they occur, the attribute they may be an indicator for, and references for information provided. The list contains invertebrate species that appear in the modern literature.

family	genus	species	habitat	indicates	reference
Coleoptera					
Hydrophilidae	Berosus	ingeminatus	ponds	plant cover	Batzer & Resh 1992
Diptera					
Syrphidae	Eristalis	tenax	ponds		Batzer & Resh 1992
Ephydridae	Ephydra	millbrae	ponds	plant cover	Batzer & Resh 1992
Culicidae	Culex	tarsalis	ponds	plant cover	Batzer & Resh 1992
Chrinomidae	Cricotopus	sylvestris	ponds	plant cover	Batzer & Resh 1992
Chrinomidae	Chironomus	stigmaterus	ponds	water depth	Batzer & Resh 1992
Heteroptera					
Corixidae	Trichocorixa	verticalis	ponds	plant cover	Batzer & Resh 1992
Trichoptera					
Limnephilidae	Hesperophylax	designatus	springs, ponds		Erman 1989
Limnephilidae	Lenarchus	rilus	springs, ponds		Erman 1989
Limnephilidae	Limnephilus	externus	ponds		Erman 1989

Branchiopoda				
Amphipoda	Eogammarus	confervicolus	ponds	Batzer & Resh 1992

VI-4.4. Vernal Pools

VI-4.4.1. Mapping and Inventory

Recommendation VI-4.4.1: We recommend that Forest Service monitoring of vernal pools begin with mapping the locations of vernal pool habitats within the management area.

Mapping may involve remote sensing such as satellite or aerial photographs, or ground searching in localities where these habitats are likely to occur. Identifying the locations of the individual springs and seeps will facilitate monitoring design planning, help determine adequate sample size, and allow for randomizations and other sampling selection criteria. It will also help the Forest Service determine the extent of these habitats over the landscape. The maps also provide a base layer for a GIS, upon which all other information will be organized. Several authorities have recommended mapping and using a GIS base layer for management of vernal pools (King et al.. 1996, Keeler-Wolf et al. 1998,

Recommendation VI-4.4.2: We recommend that the Forest Service mapping include measurements at each site of the elevation, topographic position (slope and aspect), substrate type, the size (historic extent of inundation) and shape of the habitat, significant landmarks (e.g., large trees, boulders, buildings, etc.).

Information about these important attributes may help to explain variation of the biota in these habitats. Topographic position and geographic location influences vernal pool crustacean and plant assemblages in the Sierra Nevada, and (Cox and Austin 1990, King et al. 1996, Bliss and Zedler 1998, Keeler-Wolf et al 1998, Graham 2001). There can be large variation between sites and measurements of these basic mapping attributes may explain much of that variation, making inferences on the effects of other attributes more powerful and efficient.

Other mapping attributes such as adjacent vegetation can be important to the biota in vernal pools. Heise and Merenlender (1999) found that shade from adjacent vegetation can influence the distribution and abundance of vernal pool vegetation. They found that 31 species of perennial wetland plants did not occur in heavily shaded vernal pools (see Table 3 Heise and Merenlender 1999). Other found that changes in upland vegetation can reduce the viability of vernal pools and their biota (Keeler-Wolf et al. 1998). They concluded that degradation or destruction of upland habitat can change the hydrology, reduce breeding site availability, and limit waterfowl visits that disperse vernal pool plants and invertebrates.

Crustacean assemblage structure varies with elevation (King et al. 1996). Although the exact distribution was not discussed in the article, the authors report that existing geographic, geologic, and floristic-based habitat attributes account for much of the variation in vernal pool crustacean assemblages in the Sierra Nevada. For the reasons discussed above, we recommend that adjacent and nearby vegetation and other site attributes be monitored.

Recommendation VI-4.4.3: We recommend that the Forest Service photograph the sites upon the first and subsequent visits.

Photographs provide information about the location of major landmarks or features of morphology or orientation, vegetation zones, buildings, etc (Barbour et al. 1999). This information will be useful to those people evaluating and interpreting the monitoring information and can be a good reference record of environmental change.

VI-4.2.2 Basic Explanatory Variables (Condition)

Ecosystems are produced by multiple environmental factors acting simultaneously (Keddy 2000). These “conditions” explain some part of the variation in biotic populations over time, and therefore should be measured. Correlations between changes in environmental factors and changes in biotic populations of interest need to be investigated, and analyzed, to be understood. Knowledge of the nature of these relationships will allow analyses to be "adjusted" for environmental factors, filtering out "noise", so that the impacts from management and disturbance can be distinguished from the natural variability exhibited by the parameters.

Recommendation VI-4.4.4: We recommend that the Forest Service monitor basic environmental factors such as average and minimum/maximum temperatures, rainfall, and humidity.

Biologists have documented the effects of these environmental factors on plants and animals, and their ability to cause great variation in biological assemblages. It is against these basic explanatory variables that all other influences will be measured. Low-cost weather stations have made the collection of this kind of information easy and affordable. Data recorders can be used to store weather and climate information for download at convenient intervals.

These attributes often impact vernal pool plants and animals. For example, timing of first inundation can determine which crustaceans will hatch and develop (King et al. 1996). Graham (2001) reports that climatic variability causes temporal and spatial variation in branchiopod populations. They hypothesized that the quality of vernal pool branchiopod habitat is strongly tied to precipitation timing and quantity. Bliss and Zedler (1998) found that changes in timing and amount of rainfall can lead to strong year-to-year differences in the composition of vernal pool plant assemblages, and Purer (1939) found that as rainfall increases, the flowering of vernal pool plants also increases. Other scientists that have studied vernal pools in the Sierra Nevada also recommend monitoring of climate to establish basic relationships between attributes and biota (Keeler-Wolf et al. 1998). We recommend that these kinds of attributes be measured in vernal pool monitoring in the Sierra Nevada.

Recommendation VI-4.4.5: We recommend that the Forest service monitor hydrological factors: water depth, area or extent, and timing of inundation, and water persistence.

Evaluation of habitat quality is essential in any assessment of ecological condition, and should be performed at each site at the time of biological sampling. An important physical attribute that reflects condition is hydrology. Hydrology accounts for more than 50% of the variation found in aquatic plant and animal populations (Keddy 2000). Hydrological factors include water depth, area or extent and timing of inundation, and water persistence, and water discharge rate. All are important factors that influence biotic assemblages found in special aquatic habitats, and we recommend they be measured.

For example, vernal pool crustacean assemblages in the Sierra Nevada are strongly related to habitat hydroperiod (King et al. 1996). At least nine crustaceans were found only in shallow vernal pools with short hydroperiods (King et al. 1996, page 92). Others are found only in pools with longer hydroperiods, apparently because the periods accommodate differences in hatch timing and longer developmental rates.

Vegetation can also be influenced by hydroperiod. The length of hydroperiod is important to germination of vernal pool plants (Bliss and Zedler 1998). Vernal pool specialists such as *Lilaea* and *Pilularia* were absent from "never" inundated pools, and *Myosurus*, germinated only in pools always inundated. Hydroperiod may also impact invasive non-indigenous species (Barry 1995). After studying vernal pools in the Sierra Nevada, Keeler-Wolf et al. (1998) found that the viability of vernal pool plant habitat can be impaired by changes in hydroperiod. Barry (1995) found that as hydroperiod decreased, populations of weedy plants increased. Heise and Merenlender (1999) found similar results. They report that longer hydroperiods lead to increases in native taxa. Black et al. (1997) also found an increase in the number of vernal pool species present with longer hydroperiods.

While pool depth is strongly correlated with log surface area, pool volume, and hydroperiod, researchers recommend measuring both depth and hydroperiod in vernal pool studies (King et al. 1996). Because these measurements are relatively easy and inexpensive to measure, and because they can explain much variation in plant and animal assemblages, we also recommend measuring these attributes.

Recommendation VI-4.4.6: We recommend that the Forest Service monitor water temperature, dissolved oxygen, pH, and TDS.

Water quality and chemistry are other important factors influencing habitat condition and structure of biotic assemblages, and account for about 35% of the variation found in floral and faunal populations (Keddy 2000). Indicators of water quality are temperature, dissolved oxygen, turbidity, pH, conductivity, hardness and alkalinity, salinity, orthophosphate, nitrate, and mineral concentrations (e.g., Calcium and Magnesium per liter).

Water temperature is one of those abiotic attributes that should be considered a basic explanatory variable against which the influence of other attributes can be measured. Water temperature influences the species of plants that appear in vernal pools. Higher temperatures can lead to an increase in non-indigenous plants (Bliss and Zedler 1998). Temperature also impacts branchiopod species. Water temperature controls when species hatch and which will continue to develop (Graham 2001). Species such as the endangered fairy shrimp, *Branchinecta conservatio* is found only in vernal pools with lower temperatures that change slowly throughout the season, while *B. lynchi*, another endangered fairy shrimp, appears to develop only in warmer, more ephemeral vernal pools (Graham 2001).

Besides temperature, the measurement of conductivity, dissolved oxygen, pH, and turbidity is standard to many aquatic studies and allows some comparison among sites

(Barbour et al. 1999). The measurement of these attributes is relatively simple and standardized kits are available. Water chemistry (TDS) is hypothesized to be an important factor in the distribution of vernal pool plants and animals (Gallagher 1996, King et al. 1996). Researchers found that crustacean assemblage structure varied with physical and chemical aspects of vernal pool habitats. TDS is strongly correlated with other water quality attributes such as alkalinity and conductivity and may be a good surrogate variable for these attributes (King et al. 1996).

Recommendation VI-4.4.7: We recommend that the Forest Service monitor frequency, intensity and extent of disturbances such as fire, grazing, mining, and visitors.

Disturbance can account for up to 20% of the variation in biotic populations (Keddy 2000). We recommend that attributes (frequency, intensity and extent) of disturbances such as grazing, fire, mining, and visitors be measured. Also, cattle and off-road vehicles trample vegetation, browse surrounding vegetation, exacerbate erosion and gullying, thereby eliminating potential nesting habitat. Mining activities may also change erosion patterns and the chemical composition of ground water. Fire can change the structure of the forests surrounding vernal pool habitats, and may potentially influence the conditions in these special aquatic habitat.

In studies of vernal pools in San Diego County, California, non-indigenous species responded to burning intensity (Cox and Austin 1990). Populations of weedy species often increase in burned plots, and although most native species may not have been negatively impacted by the burning, some populations declined, including those of *Anagallis minimus, Dowingia cuspidate*, *Pogogyne abramsii*, and *Psilocarphus brevissimus*.

In studies of vernal pool habitats in North Sacramento Valley, grazing intensity was a major factor in native species decline (Barry 1995). Light grazing was found to reduce exotic species and encourage native species, while heavy grazing intensity reduced all vegetation. In the Mayacmas Mountains of southeastern Mendocino County, California, no native plants were found in areas subjected to heavy sheep grazing, but those sites protected from grazing had health bands of native plants surrounding vernal pools (Heise and Merenlender 1999). Keeler-Wolf et al. (1998) call heavy grazing one of the greatest threats to vernal pool habitats. They found light grazing increased native species, by eliminating non-indigenous species, but that heavy grazing destroyed all vegetation.

Recommendation VI-4.4.8: We recommend that the Forest Service monitor physical attributes using remote sensing techniques wherever practical to avoid unnecessary disturbance by monitoring personnel.

Frequent visits by monitoring personnel can inadvertently change the conditions at sampling sites. Monitors open trails that facilitate access by other visitors who are not aware of the sensitive nature of spring and seep habitats. Trampling and compaction is difficult to avoid and even the most knowledgeable visitor can disturb sensitive habitats.

VI-4.4.3. Biotic Attributes (Integrity)

Floral Attributes

Plants are important components of all ecosystems, first because they are the primary producers, making energy from the sun readably available to animals and other plants, and second because they can ameliorate conditions so they are more favorable to other biota. We recommend that as many floral attributes be measured that are practical and fit within the monitoring budget. Biological integrity is the presence and abundance of these components and the only way to measure integrity is to measure these components.

Recommendation VI-4.4.9: We recommend that the Forest Service monitor the presence/absence of plant species known to occur in vernal pools of the Sierra Nevada.

Little information is available about the plants that occur in springs and seeps in the Sierra Nevada. In a recent publication about California vegetation, Sawyer and Keeler-Wolf (1995) offer only sparse information about the plants that occur in spring and seep habitats. We have assembled a list of plants and their associated habitats (Table VI-4.4.1) from available literature. The list is probably incomplete, and general inventories of spring and seep vegetation would expand the list.

Recommendation VI-4.4.10: We recommend that the Forest Service monitor all plant species that are listed by the U.S. Fish and Wildlife as Threatened or Endangered, all proposed and candidate species, and all plants listed by the California Department of Fish and Game as rare, threatened, or endangered.

These plant species are of particular interest and information about changes in their abundance and distribution may be potentially useful in managing them and their special habitats. Measuring the populations of these plants provides information about the effectiveness of management systems. Nineteen federally listed plants appear in Table VI-4.4.1, and many more have candidate of special California threatened and endangered status. Forest Service personnel should be alert for other species that attain this status as well.

Recommendation VI-4.2.11: We recommend that the Forest Service monitor populations of nonindigenous plant species.

Invasive, non-indigenous plants are a major concern. They can displace native species and overwhelm a habitat in a short period of time. Establishment of exotic species usually implies that habitats have been disturbed or are not healthy (Fiedler and Leidy 1987). We recommend that the Forest Service include non-indigenous species as part of their monitoring program.

Barry (1995) found that exotic annuals are capable of reproducing seed, even under the most adverse disturbance and consequently present a formidable obstacle to re-establishment of native plants (Menke 1992).

Recommendation VI-4.4.12: We recommend that the Forest Service monitor other indicator plant populations as budgets permit.

Some plant indicator species react to habitat conditions. Table VI-4.4.1 includes a column "Indicates". This column contains information from modern literature regarding potential conditions represented by the presence of these species. Acronyms are based on the National List of Plant Species that occur in Wetlands: California (Region 0) (Reed 1988).

Table VI-4.4.1. Plants Associated with Sierra Nevada Vernal Pool Habitats. A list of plant species associated with vernal pool habitats, their common names, the attribute they may be an indicator for, and references for information provided. The list contains plant species that appear in the modern literature. Red = Federal Threatened or Endangered, Purple = Federal proposed or candidate species, Green = CA Rare or Threatened.

genus	species	common name	habitat	indicates	reference
Agrostis	hendersonii	Henderson bentgrass	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Artemesia	cana	Silver sagebrush	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Astragalus	tener	Alkali milkvetch	vernal pool	basalt flow pool, claypan pools	Sawyer and Keeler-Wolf 1995
Atriplex	vallicola	Lost Hills crownscale	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Blennosperma	nana	Dwarf blennosperma	vernal pool	claypan pool, volanic mudflow pools	Sawyer and Keeler-Wolf 1995
Castilleja	campestris	Succulent owl's-clover	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Chamaesyce	hooveri	Hoover spurge	vernal pool	claypan pool	Barry 1995, Sawyer and Keeler-Wolf 1995
Crassula	aquatica	Water pygmy	vernal pool	volcanic mudflow pools, OBL, temperature	Sawyer and Keeler-Wolf 1995, Guard 1995, Bliss and Zedler 1998
Distichus	spicata	Saltgrass	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Dowingia	bacigalupii	Bacigalupi dowingia	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Dowingia	bicornuta	Two-crowned dowingia	vernal pool	volcanic mudflow pools	Sawyer and Keeler-Wolf 1995

Dowingia	pusilla	Dwarf dowingia	vernal pool	basalt flow pool, claypan pools, volcanic mudflow pools	Sawyer and Keeler-Wolf 1995
Eryngium	aristulatum	Hoover button-celery	vernal pool	claypan pool, hydroperiod	Sawyer and Keeler-Wolf 1995, Black et al. 1997
Eryngium	castrense	Coyote-thistle	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Eryngium	constancei	Loch Lomond button-celery	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Eryngium	mathiasiae	Mathias button-celery	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Eryngium	spinosepalum	Spiny-sepaled button-celery	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Frankenia	salina	Alkali heath	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Fritillaria	liliacea	Fragrant fritillary	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Gratiola	heterosepala	Boggs Lake hedge-hyssop	vernal pool	basalt flow pool, claypan pools, volcanic mudflow pools	Sawyer and Keeler-Wolf 1995
Hordeum	intercedens	Vernal barley	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Horkelia	bolanderi	Bolander horkelia	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Ivesia	aperta	Sierra Valley Ivesia	vernal pool		Keeler-Wolf et al. 1998
Ivesia	sericoleuca	Plumas Ivesia	vernal pool		Keeler-Wolf et al. 1998
Juncus	leiospermus	Ahart dwarf rush	vernal pool	basalt flow pool, claypan pools, volcanic mudflow pools, hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999
Juncus	leiospermus	Red Bluff dwarf rush	vernal pool	basalt flow pool, claypan pools, volcanic mudflow pools, hydroperiod	Sawyer and Keeler-Wolf 1995, Heise and Merenlender 1999

Lasthenia	burkei	Burke goldfields	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Lasthenia	californica	California goldfields	vernal pool	claypan pool, volanic mudflow pools	Sawyer and Keeler-Wolf 1995
Lasthenia	conjugens	Contra Costa goldfields	vernal pool	basalt flow pool, claypan pools	Sawyer and Keeler-Wolf 1995
Lasthenia	fremontii	Fremont goldfields	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Lasthenia	glabrata	Coulter goldfields	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Layia	fremontia	Fremont tidytips	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Legenere	limosa	Legenere	vernal pool	basalt flow pool, claypan pools, volcanic mudflow pools	Sawyer and Keeler-Wolf 1995
Limnanthes	floccosa	Butte County meadowfoam	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Limnanthes	vinculans	Sebastopol meadowfoam	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Mersilea	oligosperma	Nelson pepperwort	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Mimulus	pygmaeus	Egg Lake monkeyflower	vernal pool	basalt flow pool, volcanic mudflow pools	Sawyer and Keeler-Wolf 1995
Myosurus	minimus	Little mousetail	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Navarretia	leucocephala	Baker navarretia	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Navarretia	leucocephala	Few-flowered navarretia	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Navarretia	leucocephala	Whiteflower navarretia	vernal pool	volcanic mudflow pools	Sawyer and Keeler-Wolf 1995

Navarretia	meyersi	Pincushion navarrietia	vernal pool	basalt flow pool, claypan pools, volcanic mudflow pools	Sawyer and Keeler-Wolf 1995
Navarretia	nigelliformis	Shinning navarretia	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Neostapfia	colusana	Colusa grass	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Orcuttia	inaequalis	San Joaquin Valley Orcutt grass	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Orcuttia	pilosa	Hairy Orcutt grass	vernal pool	basalt flow pool, claypan pools	Barry 1995, Sawyer and Keeler-Wolf 1995
Orcuttia	tenuis	Slender Orcutt grass	vernal pool	basalt flow pool, claypan pools, volcanic mudflow pools	Sawyer and Keeler-Wolf 1995
Orcuttia	viscida	Sacramento Orcutt grass	vernal pool	claypan pool, volanic mudflow pools	Sawyer and Keeler-Wolf 1995
Paronychia	ahartii	Ahart paranychia	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Parvisedum	leiocarpum	Lake County stonecrop	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Phacelia	inundata	Playa Phacelia	vernal pool		Keeler-Wolf et al.. 1998
Plagiobothrys	hystriculus	Bearded popcorn flower	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Plagiobothrys	strictus	Calistoga popcorn flower	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Pogogyne	douglasii	Douglas pogogyne	vernal pool	basalt flow pool	Sawyer and Keeler-Wolf 1995
Pogogyne	floribunda	Profuse-flowered pogogyne	vernal pool	basalt flow pool, volcanic mudflow pools	Sawyer and Keeler-Wolf 1995
Polygonum	polygaloides	Modoc County knotweed	vernal pool	basalt flow pool, volcanic mudflow pools	Sawyer and Keeler-Wolf 1995

Psilocarphus	brevissimus	Round woollyheads	vernal pool	volcanic mudflow pools, fire intensity	Sawyer and Keeler-Wolf 1995, Cox and Austin 1990
Sagittaria	sanfordii	Sanford arrowhead	vernal pool	claypan pool, volanic mudflow pools	Sawyer and Keeler-Wolf 1995
Tuctoria	greenei	Greene's tuctoria	vernal pool	basalt flow pool, claypan pools	Barry 1995, Sawyer and Keeler-Wolf 1995
Tuctoria	mucronata	Crampton tuctoria	vernal pool	claypan pool	Sawyer and Keeler-Wolf 1995
Eleocharis	palustris	creeping spikerush	wet meadow, seep, vernal marsh	OBL, hydroperiod	Tiner 1999, Guard 1995, Heise and Merenlender 1999

Faunal Attributes

Invertebrates are the most numerous and diverse organisms that occur in wetland habitats, both in number of species and in numbers of individuals, and make up the vast majority of aquatic species in the Sierra Nevada. Their diverse functions as herbivores, predators, omnivores, pollinators, and detritivores make them key components of virtually all food webs. Thus it is important to include information about invertebrate species in aquatic habitat management decisions.

Recommendation VI-4.4.13: We recommend that the Forest Service monitor the presence/absence of invertebrate species known to occur in vernal pools of the Sierra Nevada.

We recommend that invertebrate species be included in the Forest Service monitoring program of vernal pool habitats. We have assembled a list of invertebrates known to occur in vernal pool habitats in the Sierra Nevada (Table VI-4.4.2). The list is probably incomplete, but substantially represents information available from modern literature. The status of biological integrity is measured by the presence and abundance of these components. Monitoring these invertebrate species will provide the Forest Service with the best information about the integrity and quality of the vernal pool habitats.

Recommendation VI-4.4.14: We recommend that the Forest Service monitor 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.

These species are of particular interest and information about changes in their abundance and distribution may be potentially useful in managing them and their special habitats. Measuring the populations of these invertebrates provides information about the effectiveness of management systems. At least six species in Table VI-4.4.2 fall into these categories, and, Forest Service personnel should be alert for other species that attain this status.

Recommendation VI-4.4.15: We recommend that the Forest Service monitor nonindigenous invertebrate species.

Many exotic species of arthropods have been introduced into wetland habitats. These species may displace or extirpate important native species. We recommend that the Forest Service monitor non-indigenous species. Exotic species have the potential to disrupt natural systems and their presence is often considered a measure of the condition of the habitat.

Non-indigenous bees can disrupt native pollinators of vernal pool plants (Leong and Thorp 1999), and non-indigenous predators can have a major influence on the population dynamics and community structure of vernal pool crustaceans (Murdoch and Oaten 1975, Zaret 1980, Taylor 1984, Kerfoot and Sih 1987, Sih et al. 1985, King et al. 1996).

Recommendation VI-4.4.16: We recommend that the Forest Service monitor other indicator invertebrate populations as research uncovers valid relationships, and as budgets permit.

Invertebrates have been shown to be very useful as indicators of the status of aquatic habitats. Relationships between the presence/absence, or abundance of invertebrate species and habitat conditions have been well-studied for wadeable streams and rivers (Barbour et al. 1999), and for other wetland habitats (see Batzer et al. 1999), however, few studies have focused on invertebrates of vernal pool habitats in the Sierra Nevada. Information about invertebrate indicator species is preliminary and needs to be developed further. This is a useful goal for Forest Service research and while some information may be collected during monitoring, cause-and-effect relationships can only be studied in controlled experiments.

VI. Recommendations

Only a few studies have been published with information about vernal pool invertebrates in the Sierra Nevada (Gallagher 1996, King et al. 1996, Leong and Thorp 1999, and others). There is a lack of baseline inventory data, and few of these studies had information about the relationships between invertebrates of vernal pools in the Sierra Nevada and ecological condition or conservation status. There is a need for area-wide inventory and monitoring of vernal pool invertebrates to obtain more information on species with respect to potential physiological and ecological adjustments and relationships with other organisms (King et al. 1996, Graham 2001).

Table VI-4.4.2. Invertebrates Associated with Vernal Pool Habitats in the Sierra Nevada. A list of invertebrate species associated with vernal pool habitats, the habitats in which they occur, the attribute they may be an indicator for, and references for information provided. The list contains invertebrate species that appear in the modern literature. Red = Federal Threatened or Endangered, Purple = Federal proposed or candidate species, Green = CA Rare or Threatened.

family	**genus**	**species**	**habitat**	**indicates**	**reference**
Hymenoptera					
Andrenidae	Andrena	limnanthis	vernal pools	Limnanthes douglasii rosea (Limnanthaceae) associate or pollinator	Leong & Thorp 1999
Andrenidae	Andrena	blennospermatis	vernal pools	Blennosperma (Asteraceae) associate or pollinator	Leong & Thorp 1999
Andrenidae	Andrena	cuneilabris	vernal pools	Ranunculus (Ranunuculaceae) associate or pollinator	Leong & Thorp 1999
Andrenidae	Andrena	subchalybea	vernal pools	Ligulate Asteraceae associate or pollinator	Leong & Thorp 1999
Andrenidae	Andrena	submoesta	vernal pools	Lasthenia (Asteraceae) associate or pollinator	Leong & Thorp 1999
Andrenidae	Andrena	cymatilis	vernal pools		Leong & Thorp 1999
Andrenidae	Andrena	microchlora	vernal pools		Leong & Thorp 1999

Andrenidae	Andrena	plana	vernal pools	Trifolium (Fabaceae) associate or pollinator	Leong & Thorp 1999
Andrenidae	Andrena	angustitarsata	vernal pools		Leong & Thorp 1999
Andrenidae	Andrena	orthocarpi	vernal pools		Leong & Thorp 1999
Andrenidae	Andrena	layiae	vernal pools		Leong & Thorp 1999
Apidae	Apis	mellifera	vernal pools		Leong & Thorp 1999
Apidae	Bombus	californicus	vernal pools		Leong & Thorp 1999
Apidae	Bombus	occidentalis	vernal pools		Leong & Thorp 1999
Apidae	Bombus	vosnesenskii	vernal pools		Leong & Thorp 1999
Hylictidae	Halictus	tripartitus	vernal pools		Leong & Thorp 1999
Hylictidae	Lasioglossum	spp.	vernal pools		Leong & Thorp 1999
Hylictidae	Sphecodes	spp.	vernal pools		Leong & Thorp 1999
Megachilidae	Osmia	spp.	vernal pools		Leong & Thorp 1999
Anthophoridae	Nomada	spp.	vernal pools		Leong & Thorp 1999
Anthophoridae	Synhalonia	spp.	vernal pools		Leong & Thorp 1999
Branchiopoda					

Anostraca	Branchinecta	lynchi	vernal pools	pool depth, hydroperiod	Gallagher 1996, King et al. 1996
Anostraca	Branchinecta	conservatio	vernal pools		King et al. 1996
Anostraca	Branchinecta	mesovalliensis	vernal pools		Keeler-Wolf et al. 1998
Anostraca	Branchinecta	coloradensis	vernal pools		Keeler-Wolf et al. 1998
Anostraca	Branchinecta	dissimilis	vernal pools		King et al. 1996
Anostraca	Linderiella	occidentalis	vernal pools	pool depth, hydroperiod	Gallagher 1996, King et al. 1996
Notostraca	Lepidurus	packardi	vernal pools	pool depth, hydroperiod	Gallagher 1996, King et al. 1996
Spinicaudata	Cyzicus	californicus	vernal pools		King et al. 1996
Laevicaudata	Lynceus	brachyurus	vernal pools		King et al. 1996
Cladocera	Alona	davidi	vernal pools		King et al. 1996
Cladocera	Alona	setulosa	vernal pools		King et al. 1996
Cladocera	Alona	spp.	vernal pools		King et al. 1996
Cladocera	Camptocercus	spp.	vernal pools		King et al. 1996
Cladocera	Ceridaphnia	reticulata	vernal pools		King et al. 1996

Cladocera	Chydorus	sphaericus	vernal pools	King et al. 1996
Cladocera	Daphnia	middendorffiana	vernal pools	King et al. 1996
Cladocera	Daphnia	pulex	vernal pools	King et al. 1996
Cladocera	Diaphanosoma	birgei	vernal pools	King et al. 1996
Cladocera	Dunhevedia	crassa	vernal pools	King et al. 1996
Cladocera	Leydigia	leydigi	vernal pools	King et al. 1996
Cladocera	Macrothrix	hirsuticornis	vernal pools	King et al. 1996
Cladocera	Moina	micrura	vernal pools	King et al. 1996
Cladocera	Pleuroxus	aduncus	vernal pools	King et al. 1996
Cladocera	Pleuroxus	spp.	vernal pools	King et al. 1996
Cladocera	Simocephalus	spp.	vernal pools	King et al. 1996
Cladocera	Simocephalus	vetulus	vernal pools	King et al. 1996
Copepoda	Acanthocyclops	carolinianus	vernal pools	King et al. 1996
Copepoda	Acanthocyclops	vernalis	vernal pools	King et al. 1996
Copepoda	Aglaodiaptomus	forbesi	vernal pools	King et al. 1996

Copepoda	Attheyella	sp.	vernal pools	King et al. 1996
Copepoda	Bryocamptus	washingtonensis	vernal pools	King et al. 1996
Copepoda	Canthocamptus	robertcokeri	vernal pools	King et al. 1996
Copepoda	Canthocamptus	sp.	vernal pools	King et al. 1996
Copepoda	Diacyclops	crassicaudis var. brachycercus	vernal pools	King et al. 1996
Copepoda	Diacyclops	navus	vernal pools	King et al. 1996
Copepoda	Diacyclops	sp.	vernal pools	King et al. 1996
Copepoda	Eucyclops	elegans	vernal pools	King et al. 1996
Copepoda	Hesperodiaptomus	caducus	vernal pools	King et al. 1996
Copepoda	Hesperodiaptomus	eiseni	vernal pools	King et al. 1996
Copepoda	Hesperodiaptomus	hirsutus	vernal pools	King et al. 1996
Copepoda	Leptodiaptomus	tyrrelli	vernal pools	King et al. 1996
Copepoda	Microcyclops	rubellus	vernal pools	King et al. 1996
Copepoda	Skistodiaptomus	pallidus	vernal pools	King et al. 1996

Ostracoda	Bradleystrandesia	reticulata	vernal pools	King et al. 1996
Ostracoda	Candona	spp.	vernal pools	King et al. 1996
Ostracoda	Candona	caudata	vernal pools	King et al. 1996
Ostracoda	Candona	stagnalis	vernal pools	King et al. 1996
Ostracoda	Cypridopsis	vidua	vernal pools	King et al. 1996
Ostracoda	Cypris	subglobosa	vernal pools	King et al. 1996
Ostracoda	Eucypris	spp.	vernal pools	King et al. 1996
Ostracoda	Eucypris	virens media	vernal pools	King et al. 1996
Ostracoda	Heterocypris	spp.	vernal pools	King et al. 1996
Ostracoda	Heterocypris	carolinensis	vernal pools	King et al. 1996
Ostracoda	Heterocypris	rotundatus	vernal pools	King et al. 1996
Ostracoda	Heterocypris	incongruens	vernal pools	King et al. 1996
Ostracoda	Limnocythere	spp.	vernal pools	King et al. 1996
Ostracoda	Limnocythere	paraornata	vernal pools	King et al. 1996
Ostracoda	Limnocythere	posterolimba	vernal pools	King et al. 1996

Ostracoda	Limnocythere	sanctipatricii	vernal pools	King et al. 1996
Ostracoda	Megalocypris	sp.	vernal pools	King et al. 1996
Ostracoda	Pelocypris	albpmaculata	vernal pools	King et al. 1996
Ostracoda	Potamocypris	sp.	vernal pools	King et al. 1996

VI-5. List of Recommendations

VI-5.1 Peatlands

Recommendation VI-4.1.1: We recommend that Forest Service monitoring of peatlands begin with mapping the locations of bog and fen habitats within the management area. (page 52)

Recommendation VI-4.1.2: We recommend that the Forest Service mapping include measurements at each site of the elevation, topographic position (slope and aspect), substrate type, the size (historic extent of inundation) and shape of the habitat, significant landmarks (e.g., large trees, boulders, buildings, etc.). (page 52)

Recommendation VI-4.1.3: We recommend that the Forest Service photograph the sites upon the first and subsequent visits. (page 53)

Recommendation VI-4.1.4: We recommend that the Forest Service monitor basic environmental factors such as average and minimum/maximum temperatures, rainfall, and humidity. (page 54)

Recommendation VI-4.1.5: We recommend that the Forest service monitor hydrological factors: water depth, area or extent, and timing of inundation, and water persistence. (page 54)

Recommendation VI-4.1.6: We recommend that the Forest Service monitor peat depth. (page 55)

Recommendation VI-4.1.7: We recommend that the Forest Service monitor water temperature, conductivity, dissolved oxygen, pH, and turbidity. (page 55)

Recommendation VI-4.1.8: We recommend that the Forest Service monitor Calcium concentration of peatland water. (page 56)

Recommendation VI-4.1.9: We recommend that the Forest Service monitor frequency, intensity and extent of disturbances such as fire, grazing, mining, and visitors. (page 57)

Recommendation VI-4.1.10: We recommend that the Forest Service monitor physical attributes using remote sensing techniques wherever practical to avoid unnecessary disturbance by monitoring personnel. (page 57)

Recommendation VI-4.1.11: We recommend that the Forest Service monitor the presence/absence of plant species known to occur in peatlands of the Sierra Nevada. (page 62)

Recommendation VI-4.1.12: We recommend that the Forest Service monitor all plant species that are listed by the U.S. Fish and Wildlife as Threatened or Endangered, all proposed and candidate species, and all plants listed by the California Department of Fish and Game as rare, threatened, or endangered. (page 63)

Recommendation VI-4.1.13: We recommend that the Forest Service monitor *Darlingtonia californica* populations. (page 64)

Recommendation VI-4.1.14: We recommend that the Forest Service monitor nonindigenous plant species' populations. (page 64)

Recommendation VI-4.1.15: We recommend that the Forest Service monitor other indicator plant populations as budgets permit. (page 64)

Recommendation VI-4.1.16: We recommend that the Forest Service monitor the presence/absence of plant species known to occur in peatlands of the Sierra Nevada. (page 74)

Recommendation VI-4.1.17: We recommend that the Forest Service monitor 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. (page 75)

Recommendation VI-4.1.18: We recommend that the Forest Service monitor nonindigenous invertebrate species' populations. (page 75)

Recommendation VI-4.1.19: We recommend that the Forest Service monitor other indicator invertebrate populations as research uncovers valid relationships, and as budgets permit. (page 76)

VI-5.2 Wetland Springs and Seeps

Recommendation VI-4.2.1: We recommend that Forest Service monitoring of springs and seeps begin with mapping the locations of spring and seep habitats within the management area. (Page 81)

Recommendation VI-4.2.2: We recommend that the Forest Service mapping include measurements at each site of the elevation, topographic position (slope and aspect), substrate type, the size (historic extent of inundation) and shape of the habitat, significant landmarks (e.g., large trees, boulders, buildings, etc.). (Page 81)

Recommendation VI-4.2.3: We recommend that the Forest Service photograph the sites upon the first and subsequent visits. (Page 82)

Recommendation VI-4.2.4: We recommend that the Forest Service monitor basic environmental factors such as average and minimum/maximum temperatures, rainfall, and humidity. (Page 83)

Recommendation VI-4.2.5: We recommend that the Forest service monitor hydrological factors: water depth, area or extent, and timing of inundation, and water persistence. (Page 83)

Recommendation VI-4.2.6: We recommend that the Forest Service monitor water temperature, dissolved oxygen, pH, and TDS. (Page 84)

Recommendation VI-4.2.7: We recommend that the Forest Service monitor frequency, intensity and extent of disturbances such as fire, grazing, mining, and visitors. (Page 86)

Recommendation VI-4.2.8: We recommend that the Forest Service monitor physical attributes using remote sensing techniques wherever practical to avoid unnecessary disturbance by monitoring personnel. (Page 86)

Recommendation VI-4.2.9: We recommend that the Forest Service monitor the presence/absence of plant species known to occur in springs and seeps of the Sierra Nevada. (Page 87)

Recommendation VI-4.2.10: We recommend that the Forest Service monitor all plant species that are listed by the U.S. Fish and Wildlife as Threatened or Endangered, all proposed and candidate species, and all plants listed by the California Department of Fish and Game as rare, threatened, or endangered. (Page 87)

Recommendation VI-4.2.11: We recommend that the Forest Service monitor nonindigenous plant species' populations. (Page 87)

Recommendation VI-4.2.12: We recommend that the Forest Service monitor other indicator plant populations as budgets permit. (Page 88)

Recommendation VI-4.2.13: We recommend that the Forest Service monitor the presence/absence of invertebrate species known to occur in springs and seeps of the Sierra Nevada. (Page 90)

Recommendation VI-4.2.14: We recommend that the Forest Service monitor 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. (Page 90)

Recommendation VI-4.2.15: We recommend that the Forest Service monitor nonindigenous invertebrate species. (Page 91)

Recommendation VI-4.2.16: We recommend that the Forest Service monitor other indicator invertebrate populations as research uncovers valid relationships, and as budgets permit. (Page 91)

VI-5.3. Ponds

Recommendation VI-4.3.1: We recommend that Forest Service monitoring of ponds begin with mapping the locations of pond habitats within the management area. (Page 91)

Recommendation VI-4.3.2: We recommend that the Forest Service mapping include measurements at each site of the elevation, substrate type, the size (historic extent of inundation) and shape of the habitat, significant landmarks (e.g., large trees, boulders, buildings, etc.), and adjacent vegetation. (Page 91)

Recommendation VI-4.3.3: We recommend that the Forest Service photograph the sites upon the first and subsequent visits. (Page 91)

Recommendation VI-4.3.4: We recommend that the Forest Service monitor basic environmental factors such as average and minimum/maximum temperatures, rainfall, and humidity. (Page 92)

Recommendation VI-4.3.5: We recommend that the Forest service monitor hydrological factors: water depth, area or extent, and timing of inundation, and water persistence. (Page 92)

Recommendation VI-4.3.6: We recommend that the Forest Service monitor water temperature, dissolved oxygen, pH, and TDS. (Page 93)

Recommendation VI-4.3.7: We recommend that the Forest Service monitor frequency, intensity and extent of disturbances such as fire, grazing, mining, and visitors. (Page 95)

Recommendation VI-4.3.8: We recommend that the Forest Service monitor physical attributes using remote sensing techniques wherever practical to avoid unnecessary disturbance by monitoring personnel. (Page 96)

Recommendation VI-4.3.9: We recommend that the Forest Service monitor the presence/absence of plant species known to occur in ponds of the Sierra Nevada. (Page 96)

Recommendation VI-4.3.10: We recommend that the Forest Service monitor all plant species that are listed by the U.S. Fish and Wildlife as Threatened or Endangered, all proposed and candidate species, and all plants listed by the California Department of Fish and Game as rare, threatened, or endangered. (Page 97)

Recommendation VI-4.3.11: We recommend that the Forest Service monitor nonindigenous plant species. (Page 97)

Recommendation VI-4.3.12: We recommend that the Forest Service monitor other indicator plant populations as budgets permit. (Page 98)

Recommendation VI-4.3.13: We recommend that the Forest Service monitor the presence/absence of invertebrate species known to occur in ponds of the Sierra Nevada. (Page 103)

Recommendation VI-4.2.14: We recommend that the Forest Service monitor 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. (Page 103)

Recommendation VI-4.3.15: We recommend that the Forest Service monitor nonindigenous invertebrate species. (Page 104)

VI-5.4. Vernal Pools

Recommendation VI-4.4.1: We recommend that Forest Service monitoring of vernal pools begin with mapping the locations of vernal pool habitats within the management area. (Page 107)

Recommendation VI-4.4.2: We recommend that the Forest Service mapping include measurements at each site of the elevation, topographic position (slope and aspect), substrate type, the size (historic extent of inundation) and shape of the habitat, significant landmarks (e.g., large trees, boulders, buildings, etc.). (Page 107)

Recommendation VI-4.4.3: We recommend that the Forest Service photograph the sites upon the first and subsequent visits. (Page 108)

Recommendation VI-4.4.4: We recommend that the Forest Service monitor basic environmental factors such as average and minimum/maximum temperatures, rainfall, and humidity. (Page 109)

Recommendation VI-4.4.5: We recommend that the Forest service monitor hydrological factors: water depth, area or extent, and timing of inundation, and water persistence. (Page 110)

Recommendation VI-4.4.6: We recommend that the Forest Service monitor water temperature, dissolved oxygen, pH, and TDS. (Page 111)

Recommendation VI-4.4.7: We recommend that the Forest Service monitor frequency, intensity and extent of disturbances such as fire, grazing, mining, and visitors. (Page 112)

Recommendation VI-4.4.8: We recommend that the Forest Service monitor physical attributes using remote sensing techniques wherever practical to avoid unnecessary disturbance by monitoring personnel. (Page 113)

Recommendation VI-4.4.9: We recommend that the Forest Service monitor the presence/absence of plant species known to occur in vernal pools of the Sierra Nevada. (Page 114)

Recommendation VI-4.4.10: We recommend that the Forest Service monitor all plant species that are listed by the U.S. Fish and Wildlife as Threatened or Endangered, all proposed and candidate species, and all plants listed by the California Department of Fish and Game as rare, threatened, or endangered. (Page 114)

Recommendation VI-4.2.11: We recommend that the Forest Service monitor populations of nonindigenous plant species. (Page 114)

Recommendation VI-4.4.12: We recommend that the Forest Service monitor other indicator plant populations as budgets permit. (Page 115)

Recommendation VI-4.4.13: We recommend that the Forest Service monitor the presence/absence of invertebrate species known to occur in vernal pools of the Sierra Nevada. (Page 121)

Recommendation VI-4.4.14: We recommend that the Forest Service monitor 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. (Page 121)

Recommendation VI-4.4.15: We recommend that the Forest Service monitor nonindigenous invertebrate species. (Page 122)

Recommendation VI-4.4.16: We recommend that the Forest Service monitor other indicator invertebrate populations as research uncovers valid relationships, and as budgets permit. (Page 122)

VI-6. Evaluation of Proposed Monitoring Attributes

A list of proposed attributes was provided by the Forest Service for evaluation. The habitat groups in which some of these attributes would be measured were not identified, therefore we have evaluated these attributes generally and provide suggestions as to which habitat groups the attributes should be used. Monitoring attributes specific for fens and bogs and for lakes and ponds were provided separately. We have evaluated these attributes in separate sections below.

VI-6.1 General Monitoring Attributes

The following list of attributes was provided by the Forest Service for review. After each (*in italics*) attribute is a short evaluation of the appropriateness of the attribute as they related generally to the four groups of special aquatic habitats, and suggestions about which habitat group the attribute should be measured. No justifications for attributes were provided, but can be found for some in the detailed discussions in Sections VI-4.1 through VI-4.4 above.

Forest Service Proposed Special Habitat Explanatory Variables

- Vegetation
  - Seral Stages – *Seral stages are arbitrary and difficult to quantify. We recommend that attributes that relate to seral stage that may be of interest to the Forest Service, such as age-class distribution of vegetation be measured directly.*
  - PH – *pH is not a vegetation attribute, but instead a water quality attribute. We recommend that pH be measured for all habitat groups.*
  - Plant Communities – *Vegetation surrounding special habitat s can have significant and important impacts on the biota of the habitats. We recommend that general conditions of surrounding vegetation be measured (e.g., percent cover over habitat, presence of species, etc.). We also recommend that the presence of plants found in special habitats should recorded with each visit in all special habitats.*
  - Sensitive Plants – *Sensitive plants are of special interest and we recommend that these plants be monitored in all special habitats.*
  - Exotic plant and animal species – *Non-indigenous plants and animals can have dramatic impacts on native species and in special habitats. We*

recommend that non-indigenous plants and animals be monitored in al special habitats.

- Soils
    - Moisture – *The timing and length of inundation is important in all special habitats and can greatly impact species distribution. We recommend that this attribute be monitored in all the special habitats.*
    - Texture – *We found no reference that would support the measurement of this attribute. Instead, geological conditions (e.g., serpentine soils, etc.) are more informative. We recommend that soil texture not be monitored in special habitats.*
    - Rooting Depth – *Typically, plants in aquatic habitats will root down to the extent of inundation. This can be a very difficult attribute to measure and may disturb the habitats. We recommend that this attribute not be measured in special habitats.*
    - Color – *This attribute can give information about the chemical composition of the soils, but has no intrinsic value unless a complete soil evaluation is to be undertaken. We recommend that general aspects of the habitats and the surrounding land be mapped.*
    - Peat depth – *Peat depth is important in peatland habitats. We recommend that this attribute be measured in peatland habitats only.*
- Hydrologic Classes – *These attributes are generally described as topographic attributes. We recommend that these and other important topographic attributes described in Sections VI-4.1 through VI-4.4 above be measured in all special habitats.*
    - Raised Convex
    - Normal
    - Hanging
    - Lotic
    - Xeric
    - Sunken-Concave
- Margin Type - *These attributes are generally described as topographic attributes. We recommend that these and other important topographic attributes described in Sections VI-4.1 through VI-4.4 above be measured in all special habitats.*
    - Basin
    - Slope
    - Stream
    - Flow Regime (perennial, intermittent, ephemeral)
- Disturbance - *These attributes can have significant impacts on the biota of special habitats. We recommend that the type, intensity and timing of these disturbances be monitored in all special habitats.*
    - Fires
    - Timber Harvest

- Grazing (timing and duration)
- Recreation

VI-6.2 Peatland Monitoring Attributes

The following list of attributes was provided by the Forest Service for monitoring in fens and bogs. After each attribute is a short evaluation of the appropriateness of the attribute as they related generally to peatlands. No justifications for attributes were provided, but can be found for some in the detailed discussions in Sections VI-4.1 above.

1. plant species composition on cross section transect. - *Plant species composition is important for measuring the integrity of peatlands. We recommend that species composition (presence/absence) of plants and invertebrates be monitored in peatlands. We do not recommend cross section transects, but instead recommend evaluation of sites as completely as possible. Some rare plants may be missed by transect sampling.*
2. plant community composition on cross section transect – *Plant community composition is essentially the same as 1.*
3. percent bare soil on cross section transect – *This can be a time-consuming activity and we found only sparse reference to the importance of this attribute in the literature. We recommend that more time be spent recording the species composition and the nature (percent cover of habitat) of surrounding vegetation.*
4. water table depths on cross section transect – *Water depth is an important attribute in peatland habitats and we recommend that this attribute be measured.*
5. soil water temperature measured along cross section at two depths-- 20 and 50 cm – *Water temperature is an important water quality attribute and we recommend this attribute be monitored in peatland habitats.*
6. depth of organic/peat layer (cm) along cross section transect – *Peat depth can influence the invertebrate assemblage found in peatlands. We recommend that peat depth be monitored.*
7. margin vegetation – *Vegetation at the margins of peatlands can have significant influence on the vegetation in the habitats. We recommend this attribute be monitored.*
8. soil pH along cross section transect – *We found no reference that supports measurement of soil pH, however, water pH can be an important factor. We recommend that water pH be monitored in peatland habitats.*

VI-6.2 Peatland Monitoring Attributes

The following list of attributes was provided by the Forest Service for monitoring in lakes and ponds. After each attribute is a short evaluation of the appropriateness of the attribute as they related generally to peatlands. No justifications for attributes were provided, but can be found for some in the detailed discussions in Sections VI-4.3 above.

Primary physical/chemical: *These attributes are very specific and address particular questions of interest. We recommend that as budgets allow, these attributes all be measured in pond habitats. However, we have recommended what we consider the appropriate priority for these measurements in Section VI-4.3 above and we recommend that this priority be followed.*

Acid neutralizing capacity
nitrate
sulfate
total & particulate N
total & particulate P
chlorophyll *a*
Secchi depth

Additional physical/chemical attributes for supporting information, but not primary indicators: pH, conductivity, sum of base cations, individual base cations, silica, water temperature. *Some of these attributes are critical to evaluation of habitat condition. We recommend that pH, and water temperature have a higher priority in the physical attributes to be monitored.*

Biological Attributes:

1. diatoms from sediment core - more work/longer history has been done in terms of interpreting results. easy to collect, but expertise for identifying is located in a few universities. Could develop expertise within the FS. Can also look at historical trends from core. – Diatom monitoring requires expertise that does not presently exist at the Forest Service. *While diatoms can provide useful information about the condition of pond habitats, we recommend that the actual physical attributes be measured until sufficient budget and/or expertise exists before monitoring diatoms.*

2. macroinvertebrates - work/longer history has been done in terms of interpreting results, though not specifically for Sierras – *Monitoring invertebrates will provide important information about habitat integrity. Invertebrates taxonomy*

is straightforward and expertise exists in the Forest Service. We recommend that invertebrate species presence/absence be monitored in pond habitats. We further recommend that invertebrate sampling be conducted non-destructively whenever possible.

3. zooplankton - interpretation is less clear, though there are zooplankton that disappear with fish, or with acidification, greater risk that won't be able to use the data – *Unless the Forest Service is confident that taxonomic expertise is available we recommend that zooplankton not be monitored.*

4. amphibians - wouldn't use alone, but useful as part of the community – *Non-destructive monitoring amphibians can provide important information about habitat integrity. We recommend that amphibians be monitored non-destructively.*

5. habitat condition - littoral vegetation (%cover), shoreline disturbance, EMAP has extensive habitat survey. – *We recommend that habitat condition be monitored as described. Use of EMAP protocols is strongly recommended.*

<u>Ranking attributes in terms of importance:</u>

1) fish, water chemistry, habitat condition – *We recommend that mapping also be ranked as a high priority. We recommend that fish monitoring be reduced in ranking to that equal with plants and invertebrates.*

2) macroinvertebrates, - *We recommend that plants also receive equal ranking with invertebrates.*

3) diatoms, - *We recommend reducing the ranking of diatoms to below that of amphibians.*

4) amphibians,

5) zooplankton

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